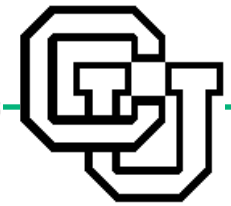

*Cooperative Institute for Research in Environmental Studies*

# CIRES FY 2005 Annual Report

## NOAA Cooperative Agreement #NA17RJ1229

**September 30, 2005**

*Konrad Steffen, Director*
*Paul Sperry, Associate Director of Science*

**University of Colorado**
**National Oceanic and Atmospheric Administration**

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*Acknowledgement*

*The assembly of this report was made possible by the many contributions of Karen Dempsey, Yvonne Garcia, Lisa Ho, Jeff Kosley, Nancy Lathrop, Sunny Lu, Julie McKie, Michael Meshek, Graham Mountain, Jon Rush, and others. And most importantly, recognition goes to the scientists, faculty and Fellows who are the reason we have this report to submit.*

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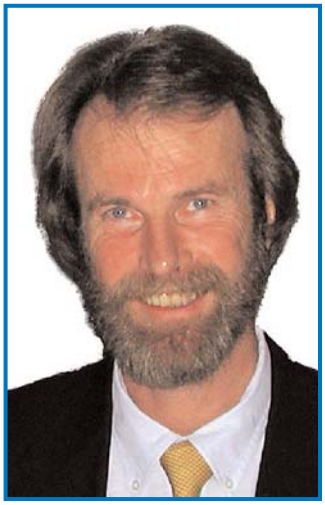
# Letter from the Director



We all bid farewell to Dr. Susan Avery, our CIRES Director from 1994 – 2004. Susan did a tremendous job during her eleven years in office. Under her tenure, CIRES experienced a 27% increase in faculty, a 33% jump in CIRES members, a 10% increase in administrative funding, a 84% increase in research funding, and a 52% increase in science support, including the Distinguished Lecture Series, the Visiting Fellows program, scientific themes, and the SOARS minority assistance program. Further, she started a highly successful outreach program, es-tablished the Western Water Assessment program, created an Innovative Research Program, and was instrumental in the creation of the Center for Science and Technology Policy Research, the Climate Diagnostic Center (on campus), and the Center for Limnology. We wish her good luck as "Ms. Interim" in her various jobs at the University of Colorado as Vice Chancellor for Research, Dean of Graduate School, and Provost.

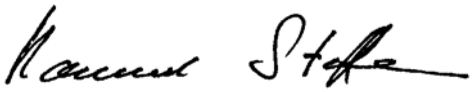
I have been a part of CIRES for a total of sixteen years. I first came to CIRES in 1986 as a Visit-ing Fellow on sabbatical leave from the Swiss Federal Institute of Technology (ETH). Following a successful one-year fellowship, I remained a second year supported by a NASA research grant and by the Swiss Government. In fall 1988 I returned to my former home institution, ETH, and continued my teaching and research commitments at the Institute for Atmospheric and Climate Science. After securing a CIRES faculty position in climatology, I returned to the University of Colorado in January 1991. I had the opportunity to lead CIRES as Interim Director during Susan Avery's sabbatical leave from September 2002 – October 2003, and most currently since September 2004. It's nice to be back!

My general research interest is the study of processes related to climate and cryosphere interac-tion in polar and alpine regions based on in-situ and satellite measurements, and using climate system modeling to study their sensitivity. I am actively involved in the assessment of global sea level change and sensitivity studies of large ice sheets using in situ and modeling results.

As we enter the 21st century, the demands of increasing population, coupled with variability in our natural environment, are placing society and earth's natural resources at greater risk. This is where I foresee the major scientific contributions of CIRES, given the strong disciplinary exper-tise in the physical, chemical, and biological sciences related to environmental processes, and the existing foundation of interdisciplinary research. Further, strong programs in Earth system moni-toring, problem definition and expert interpretation of observational evidence are cornerstones of CIRES research. We have to build on our strengths: the physical sciences related to our environ-ment.

In the past twelve months we were able to hire two new faculty members, one in experimental Lidar application and technology, and the other in carbon cycling. We organized a science retreat with fifty CIRES members and NOAA federal employees to discuss future science directions and interactions. We also discussed the increased need to start our own CIRES graduate education program.

This annual report is a collaborative effort of a number of people in CIRES, researchers as well as administrative staff, and they all deserve credit for what you will find on the following pages. Enjoy your reading!



Konrad Steffen
CIRES Director

# 1.0 Executive Summary and Research Highlights

The following bullets highlight significant accomplishments and research findings that emerged from the CIRES-NOAA-University of Colorado partnership during the previous year. They are grouped by the six CIRES' scientific research themes identified as foci for integrated studies. Further details can be found in sections 3 and 4 of this report.

## Advanced Modeling and Observing Systems

This theme includes the optimization of modeling and observing systems for disciplines such as atmospheric chemistry, physical atmospheric and oceanic processes, cryospheric processes, space weather, nonlinear systems applications, data centers and data management. The space domain links most research fields ranging from local, regional, and global scales. Since the emphasis here is focused upon technology advancement, this theme frequently brings together CIRES scientists from diverse backgrounds to work on topics of common interest to all.

- We designed and built a new cavity ring-down spectrometer (CaRDS) that bounces laser light hundreds of thousands of times between highly reflective mirrors. The first instrument of its kind for detecting nitrogen oxides, it revealed that nocturnal conversions to nitric acid proceed at approximately the same rate at night as it does during the day over the ocean.
- We continued development of a method for determining the speciated composition of organic aerosols by two different paths. One technique utilizes aerosol collection with a multi-sample aerosol impactor, followed by subsequent ex situ analysis of the samples, while the other couples collection to prompt thermal desorption and in situ analysis.
- We designed an ultraviolet spectrometer to measure nitrogen dioxide (NO2) and sulfur dioxide (SO2) simultaneously. The spectrograph was deployed on the NOAA WP-3D aircraft during the New England Air Quality Study/Intercontinental Transport and Chemical Transformation (NEAQS /ITCT).
- CIRES researchers in the Aeronomy and Environmental Technology Labs collaborated on a unique opportunity to present one of the first real-time ensemble O3 and bias-corrected ensemble forecasts that demonstrated the superiority of ensemble O3 forecasts relative to any individual model.
- Researchers developed a radar-only-based method for retrieving liquid water content where sampling reflectivity thresholding can be effectively used to separate between cloud scenes contaminated by drizzle. We also developed a new algorithm to distinguish different habits of ice hydrometeors observed by radar above the bright band using polarimetric scanning radar measurements.
- CIRES and ETL researchers designed a compact, mobile 915-MHz wind profiler that can be rapidly deployed for fire weather applications.
- Researchers designed and implemented a demonstration system that automatically ingests multidimensional NCEP GFS Forecast model output into a relational database and becomes immediately available for comparison with in situ measurements.
- The Boulder ionosonde was completely restored, including updates to the antenna array, implementation of real-time processing into the NGDC Space Physics Interactive Data Resource (SPIDR) system, and physical site improvements.
- We coupled output of the NOAA/SEC Wang-Sheeley-Arge (WSA) and SAIC 3-D MHD coronal models (based on photospheric observations of the solar magnetic field) with an advanced 3-D MHD interplanetary propagation model, then incorporated the

so-called cone model to simulate launching of coronal mass ejections (based on white-line coronagraph observations). Our interplanetary code, ENLIL, was implemented at the NASA Community Coordinated Modeling Center.

- The CIRES Tethered Lifting System (TLS) was deployed to evaluate the surface boundary layer (SBL) in Washington, D.C. in support of Homeland Security. The TLS wind and turbulence profiles provided verification data for Doppler LIDAR-derived profiles predicting the potential for airborne dispersion of pathogens.
- The isotopic composition of water was derived from thermal emission spectra measured by the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) onboard the European ENVISAT satellite.
- Monthly data from GRACE (Gravity Recovery and Climate Experiment) precision mapping of Earth's gravity field revealed that Greenland not only shows a clear annual cycle, but also an apparent linear decrease in mass. After removing model estimates of the contributions from post-glacial-rebound in the solid Earth, we conclude that the Greenland ice sheet lost mass at a rate of 75±26 cubic km per year between the summers of 2002 and 2004.

## Climate System Variability

Climate variability affects virtually all natural systems and human activities. Climate directly impacts such vital areas as agriculture, water quantity and quality, and human health. Understanding, and potentially predicting, climate changes is therefore critical to the public, as well as to a broad array of decision-makers within federal and state government, industry, resources management and hazard mitigation. Indeed, basic issues include determining whether observed changes may be attributable to natural or anthropogenic forcing, and the extent to which natural and human-induced changes may be linked. Prediction problems of vital importance include estimating changes in the likelihood of extreme events, identifying risks for abrupt climate change, and the potential for major societal and ecosystem impacts.

- Our analysis of airborne in situ measurements onboard the NASA WB-57F high-altitude research aircraft revealed a new category of nitric acid-containing particles in the tropical lower stratosphere. These particles were observed in a narrow layer just above the tropopause (18±0.1 km), and over a broad geographic region (>1100 km) south of San José, Costa Rica.
- Scientists measured the UV absorption cross section of CFH2CH2OH, a proposed substitute for CFC's, to ascertain its photolytic lifetime and concluded that no major long-lived or toxic substance would be produced during its atmospheric degradation.
- Temperature and ozone correlations from the POLARIS and SOLVE missions indicate that the tails of the molecular velocity distributions are longer/thicker than those of the canonical Maxwell-Boltzmann distribution upon which the definition of atmospheric temperature depends. The implications for climate could be important, given that human activities have decreased ozone in the lower stratosphere and increased it in the troposphere.
- The long term monitoring of global trends, sources and sinks of ozone-depleting CFC's was expanded to Ushuaia, Argentina and Summit, Greenland. We also added measurements of two potent ozone-depleting Halons and a non-CFC aerosol propellant and foam blowing agent to the existing suite of compounds analyzed in flask samples.
- We developed a new portable cryogenic frost-point hygrometer that for the first time can study processes affecting water vapor in the polar stratosphere as well as in the lower troposphere under almost all atmospheric conditions.
- We developed an algorithm to detect the snow level in the atmosphere from wind profiler measurements.
- We completed quality control on and published Russian weather station data that are currently unavailable to Western researchers and fill both a temporal and spatial gap in

the current record.

- Analyses of GCM simulations conducted in support of the IPCC 4th Assessment Report were performed for the decadal periods of 1991- 2000, 2046-2055 and 2091-2100. Results for the Arctic winter season indicated decreased occurrence of synoptic patterns and an increase in patterns dominated by a North Atlantic storm track extending into the eastern Arctic basin over the 21st century.
- The Western Antarctic Ice Sheet is largely grounded below sea level and therefore more susceptible to rapid advances than its East Antarctic counterpart. Research provided direct evidence that ice streams related to the East Antarctic Ice Sheet were active and responsible for till deposition throughout the western half of the Ross Sea.
- TOPEX/Poseidon and Jason satellite data were used to analyze long-term sea level change, corroborate climate model predictions, and prepare for the socioeconomic impacts of sea level change. Approximately half of the observed 3 mm/year global-averaged sea level rise is apparently caused by the warming of the oceans (thermal expansion). The other half appears caused by the addition of freshwater from the continents, mainly from melting of ice in mountain glaciers, Greenland and Antarctica.

## Geodynamics

The goal of geodynamics is to characterize the internal processes of the planet, including the properties of the core-mantle boundary, convection within the Earth's mantle, and how that convection affects the surface of the planet. The slow changes of flow processes in Earth's deep liquid interior which drive the magnetic field are frequently described using spherical harmonic analysis of the nearly 300 years of surface magnetic observations. Relative velocities in the Earth's mantle of a few cm each year cause plates to drift across the Earth's surface, giving rise to volcanism and seismicity at their margins. Of particular interest to the geodynamics group are the processes of mountain formation, and the dynamics and evolution of surface features through their chemical and mechanical interaction with atmospheric forcing functions.

- Researchers redesigned natural hazard databases and developed software tools to improve quality assurance of the tsunami event. They also enabled ArcIMS display of the data centered on the Atlantic, Pacific Oceans and other ocean basins.
- Researchers produced and distributed a major revision of the POMME-2.5 geomagnetic field model that now includes time varying core fields, crustal fields, ring current fields modulated by the Dst/Est/Ist disturbance indices, time averaged magnetospheric fields, penetration of the horizontal part of the interplanetary magnetic fields (IMF), and the fields induced by Earth rotation in the external fields.
- The first two of five NSF-funded, kilometer-long tiltmeters were installed near Seattle to monitor slip events that occur near the transition between the shallow portion of the plate boundary. The tiltmeters are roughly 1,000 times more sensitive than current GPS monitors and consist of L-shaped horizontal water pipes, each 500 m long, with floats at each end that monitor relative vertical motions >0.2 ìm (1/300 of the thickness of a human hair).

## Integrating Activities

CIRES engages in a wide range of integrating activities in research, education, and outreach that encompass each of the institute's research themes and contribute to the overall mission of the Institute, NOAA, and the University of Colorado. The primary focus is on five overlapping categories that include 1) K-16 Interdisciplinary Education and Outreach, 2) Graduate and Post-Graduate Education, 3) Scientific Assessments, 4) Interdisciplinary Research, and 5) Science and Technology Policy Research. By understanding decision-making processes, the stresses, and the constraints of this community, researchers seek to assess vulnerability to climate variability and develop hydro-climate products that enable better-informed decisions. Collaborations with colleagues

in the local NOAA laboratories have resulted in the transformation of basic research into applied science.

- We evaluated data and informatics needed to support integrated regional ecosystem assessments and improve the empirical basis for ecosystem assessment and communication to policy and decision makers.
- We developed a web-based Climate Services Clearinghouse to assist water resource decision makers find needed information, products, and processes throughout the Intermountain West.
- We launched a lecture series titled "Policy, Politics, and Science in the White House: Conversations with Presidential Science Advisors" to provide useful information that will improve the relationship between societal needs and science and technology policies.
- Researchers developed high-resolution climate data sets on snowpack for the western United States stratified by elevation that include a suite of products from ordinary cooperative climate station records, SNOTEL records, and the 4-km gridded PRISM data set.
- Researchers analyzed and evaluated forest responses to the 2002 drought, found that western Colorado trees produced their smallest tree ring growth in 150 years, and concluded Colorado is now more vulnerable to short-term drought than in the past.
- Researchers developed methods that account for uncertainties in model forcings and parameters plus developed and implemented ensemble data assimilation methods that use snow observations to reduce uncertainties in model simulations of snowpack.
- A new method was developed for reconstructing and forecasting changes in stream metabolism resulting from both human- and climatic-induced hydrologic change and validated with field data of the South Platte River below Denver. This method for predicting metabolic responses to hydrologic manipulation could be used to calculate human influence on stream and river metabolism by reconstructing metabolic changes over long intervals wherever discharge measurements are available.

## Planetary Metabolism

The sustainability of the biosphere during the current period of rapid Earth system change is an issue of prime importance for the environmental sciences. The physical and chemical features of the Earth are intimately tied to organisms and the activities required for their sustenance. The health of the biosphere can usefully be considered using the concept of "planetary metabolism," which refers to the complex web of biochemical and ecological processes and their interaction with the lithosphere, atmosphere and hydrosphere. Both natural and anthropogenic disturbances drive the structure and dynamics of natural systems, and a thorough understanding of these complex processes is essential to protect the biosphere from adverse effects due to pollution, destruction of natural landscapes, and inadvertent alteration of climate.

- We applied a novel approach to explore the release of volatile organic compounds (VOC) by plant roots during biotic stresses to improve our understanding of how the exchange of gases to the atmosphere shapes regional climate and air quality.
- Laboratory studies on drying crops demonstrated that two grass crops release a large variety of oxygenated VOC's that will improve our understanding of global biosphere-atmosphere exchange processes.
- Anthropogenic pollutants persist in the environment in part because microorganisms often lack the enzymes necessary to catalyze their degradation. Novel metabolic pathways for their degradation are being explored by recruiting pre-existing enzymes to serve new functions. This research identified the molecular reasons for the poor functioning of two of the enzymes in the pentachlorophenol pesticide degradation pathway.
- Research on local-to-regional carbon budgets at the remote Niwot Ridge AmeriFlux site (3050 m along the Front Range of the Rocky Mountains) revealed that interannual varia-

tion in the depth of the spring snowpack at this site is correlated with interannual variation in the amount of carbon lost from soils through late-winter soil respiration.

## Regional Processes

Many of the research endeavors within CIRES and NOAA have a regional focus because they address a particular confluence of geography, demographics, weather and climatic regimes, or scientific challenge. This confluence of factors has produced a range of research that is not only rich in its diversity but provides an essential connection between science and its constituents. These human populations range from coastal megalopolises to indigenous peoples on the Arctic Ocean, all of which must coexist with sensitive aquatic and terrestrial ecosystems in a highly variable and evolving climate. Indeed, the impact of short-term climate variability and extremes is often regionally focused, influencing very specific populations, economies, and ecosystems. Research includes the mechanisms of atmospheric transport on climate and air quality, chemical transformation of products of biomass burning, air/sea gas transfer, and ozone pollution.

- Analysis of ICARTT data showed a surprisingly strong coupling between aerosol particle composition and the reactive uptake of dinitrogen pentoxide at night providing evidence for an important and hitherto unrecognized coupling between emissions of the primary gaseous pollutants SO2 and NOx.
- The New England Air Quality Study (NEAQS 2004) study confirmed that power plant emissions of NOx have been significantly reduced during the last few years.
- Findings from the Texas Air Quality Study revealed that routine chemical plant emissions of reactive alkene compounds is the major driving force behind ozone episodes unique to the Houston area. These findings led to a substantial change in the emissions control strategy mandated by the State of Texas that cost-benefit analyses indicate will save 60,000 jobs and $10 billion dollars over the next ten years.
- Soot is a unique species in the atmosphere because it can absorb rather than scatter radiation and can reduce rather than oxidize atmospheric compounds. Researchers thus investigated the interactions of NO2, NO3, N2O5, and HNO3 with soot and concluded that uptake on soot is not a significant HNO3 loss process and that HNO3 does not significantly modify soot.
- Mobile aerosol measurements in Nova Scotia during ICARTT observed differences in aerosol optical properties where interstitial particles—those particles not scavenged by fog or cloud—were more absorbing, smaller and had a higher hygroscopic growth factor than non-fog aerosol.
- We deployed the ETL flux system on the NOAA Ship Ronald H. Brown during the NEAQS 2004 cruise and calculated ozone deposition velocities as a function of location and conditions. The results showed that deposition near the coast was suppressed compared to the open ocean
- Atmospheric mineral aerosol is a potentially important reactive surface. The water uptake by Namontmorillonite is almost as great as that of deliquesced ammonium sulfate, a well known hygroscopic salt found in the Earth's atmosphere. Smectite clays may thus influence Earth's climate by intercepting solar and terrestrial radiation as well as by modifying cloud properties and acting as efficient cloud condensation nuclei.

# 2.0 CIRES in 2004-2005



## 2.1 Advanced Modeling and Observing Systems

The Cooperative Institute for Research in Environmental Sciences (CIRES) is a joint institute established in 1967 between the University of Colorado and the National Oceanic and Atmospheric Administration (NOAA) to create a synergy between studies of the geosphere, biosphere, atmosphere, hydrosphere and cryosphere. CIRES is a unique bridge that provides the mission-oriented NOAA laboratories access to an academic diversity that it does not itself possess. It provides and strengthens the scientific foundation upon which NOAA's many services depend. CIRES' connections with NOAA's Office of Oceanic and Atmospheric Research (OAR) and sister Cooperative Institutes also provide an avenue for coordinated studies on a scale that could not be addressed by academic departments on their own.

Traditional disciplinary research is conducted through a broad range of academic departments and the eight local NOAA laboratories shown in the table on the next page. Interdisciplinary science is fostered through centers that cross traditional boundaries and include the Center for the Study of Earth from Space, the Center for

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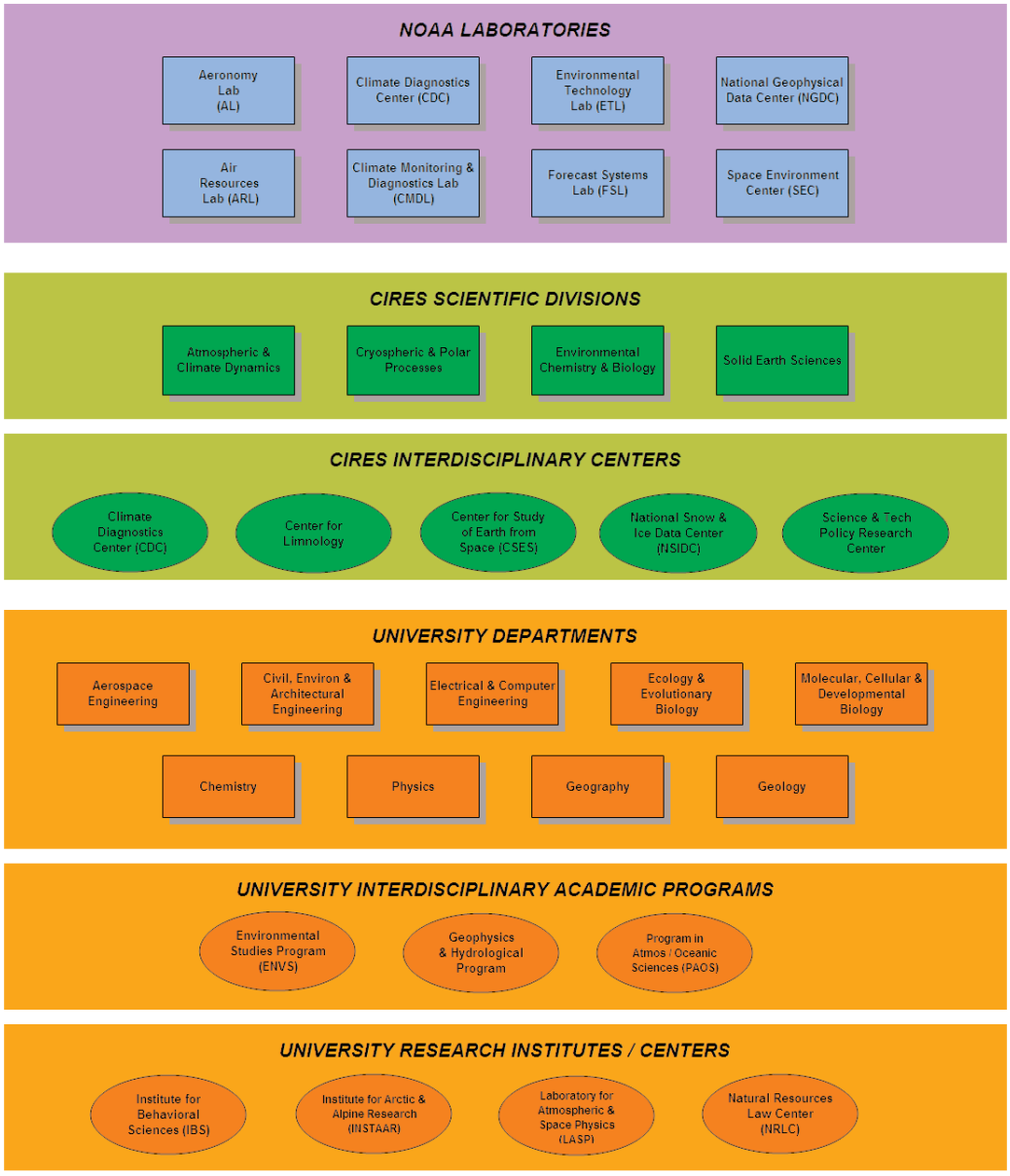
## SCIENTIFIC CONNECTIONS FACILITATED THROUGH CIRES



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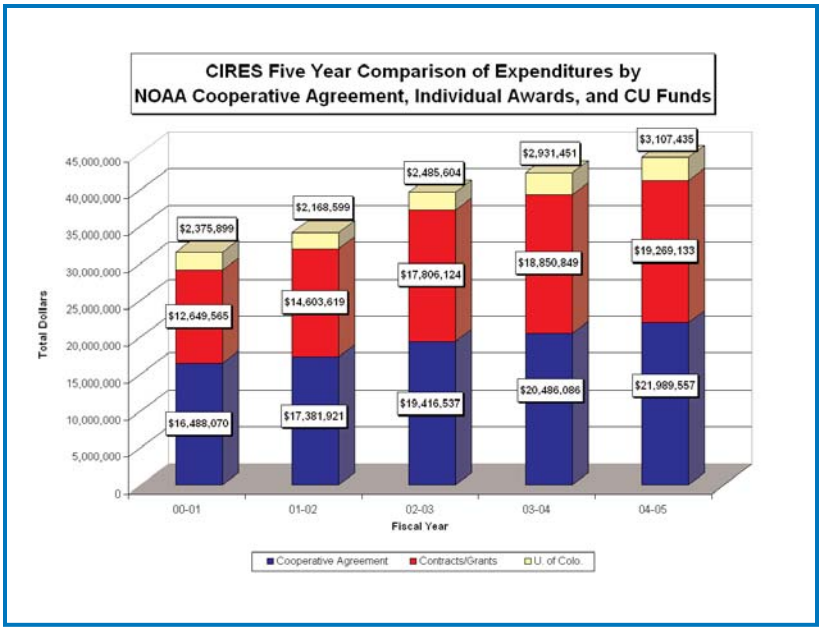
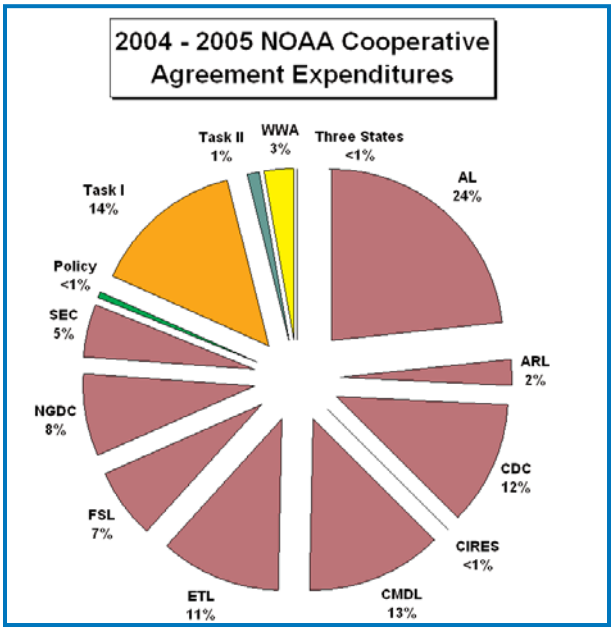



Limnology, the National Snow and Ice Data Center, the Science and Technology Policy Research Center and the campus component of the Climate Diagnostics Center. CIRES' campus affiliation provides NOAA a breadth of connections such as the Natural Resources Law Center that forms a unique component of the Western Water Assessment.

CIRES' direction is provided through its Council of Fellows, an active executive committee, and committees working on focused objectives (such as maintaining computing facility excellence). Communication is facilitated through a members' council, scientific retreats, regular town meetings, and an active outreach effort. Career progression and excellence are promoted through a Career Track and outstanding Employee Recognition Program. A vibrant academic and research environment is fostered through a graduate research fellowship program, a visiting faculty and postdoctoral program, Innovative Research Program, an Distinguished Lecture Series, and research initiative seed funding. Advanced research tools are provided through an instrument design group, machine shop, glassblowing, numerical climate models, and access to various tools such as remote sensing instrumentation.




Vision Statement: CIRES is an internationally recognized leader in innovative Earth Systems Science research, committed to integrating its findings to improve education and public awareness.

Mission Statement: CIRES seeks to create a dynamic and interdisciplinary research environ-

## 3.1 (continued)

ment that can address questions of societal importance, improve our understanding of the earth system, and then communicate its findings in a meaningful context to its scientific peers, society, and the decision-makers who would apply those findings.

CIRES is comprised of more than 500 researchers, faculty, students, and staff housed on the University of Colorado campus and in NOAA's David Skaggs Research Center. At the end of the year, this included 26 professors, 176 research scientists, 216 research associates, 11 post-doctoral fellows, 22 visiting fellows/scientists, 54 graduate students, 29 administrative staff and 62 undergraduate employees.

The two charts shown here provide a summary of CIRES expenditure trends by source and NOAA laboratory. The NOAA cooperative agreement includes research and base funds, the contracts and grants bars derive from supplemental federal agency sources, and university support includes faculty salaries, indirect cost recovery, and non-research general funds.

In the pie chart shown here, Task I is identified in orange, Task II in green, and Task III in purple.

## 2.2 Contributions to NOAA's Strategic Vision

As one of the research partners referenced in Research in NOAA (January 2005), CIRES is directly contributing to NOAA's vision of "An informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions." The CIRES scientists working with their federal counterparts are developing an integrated Earth observing system, regional observational networks, and conducting research that promotes understanding of global catastrophes such as hurricanes and tsunamis.

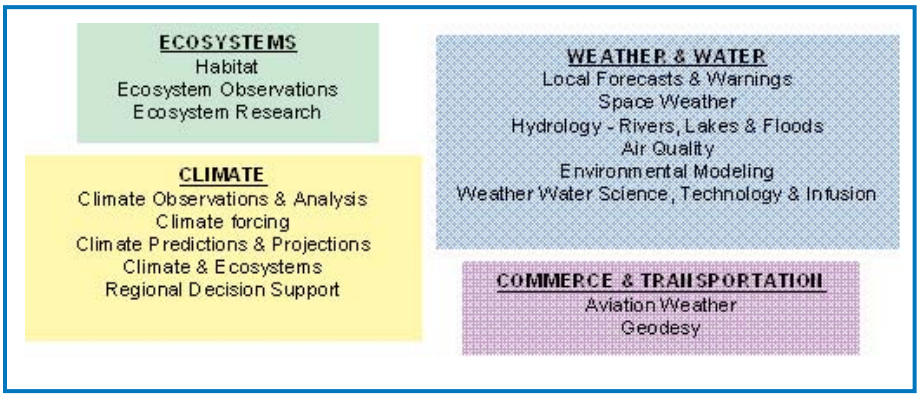
NOAA's partnership with CIRES facilitates academic connections to the University of Colorado that constitute a critical resource to NOAA. Examples of current research collaborations providing depth to NOAA's operational mission include our Center for Science and Technology Policy Research (social responses to hurricanes), the Natural Resources Law Center (water law and drought mitigation), university biology departments (land use impacts on CO2 budgets), the Earth Sciences Department (earthquake-tsunami coupling), the Chemistry Department (aerosols and air quality) and our National Snow and Ice Data Center (thinning of polar ice and melting of glaciers/ice sheets).

CIRES is contributing to over half of the 28 scientific mission goals within NOAA's Strategic Vision. The following are examples where CIRES' research is supporting NOAA's cross-cutting priorities.

1. Protect, restore and manage use of coastal and ocean resources through ecosystem management approaches. CIRES is contributing to the second Ecosystems objective to "protect, restore, and manage species habitats listed under the Endangered Species Act" by documenting riparian habitat impacts in Rocky Mountain watersheds. CIRES is also studying forest ecosystems to understand their ability to recover from stresses including drought, wildfire and land use change.

2. Understand climate variability and change to enhance society's ability to plan and respond. CIRES contributions to long-term remote observations and air quality respond to "build an end-to-end system of integrated global observations of key atmospheric, oceanic, and terrestrial variables." Ensemble data assimilation of pre-radiosonde era surface observations and tree-ring studies serve to "enhance scientific understanding of past climate variations." Studies to assess predictability from deterministic as well as probabilistic perspectives is helping achieve an "improved understanding and create more reliable climate predictions on all time scales."

3. Serve society's needs for weather and water information. RISA (Regional Integrated Sciences and Assessments) studies conducted within CIRES' Western Water Assessment (WWA) serve to "respond to user needs with the most recent, reliable information possible." Monitoring solar disturbances and modeling Earth's upper atmosphere promise to "improve the performance of our suite of weather and water, air quality, and space-weather prediction capabilities."




4. Support the Nation's commerce with information for safe and efficient transportation. The design and evaluation of new verification approaches and tools is providing information about the quality of aviation forecasts and their value to aviation decision makers.

## 2.3 Defining New Directions

This year marked a milestone with the selection of Dr. Konrad Steffen as CIRES' fifth Director. "Koni" immediately assumed the helm with a review of CIRES' structure, resources, strengths and scientific directions.

He convened a scientific retreat where nearly 60 Fellows, faculty, NOAA colleagues and leaders considered the following agenda:

- Future CIRES Focus and Research Directions CIRES Scientific Themes: Review and Redefine
- The Future of Biology at CIRES
- Future Directions for CIRES' Education & Outreach
- Planning for Future Infrastructure Support
- Collaboration between NOAA and CIRES Scientists

Recommendations are now under consideration and will be implemented in the following months. Some of the major recommendations include an emphasis in the biological sciences, the implementation of focus groups within existing scientific themes to promote more effective collaboration, devising new mechanisms to foster faculty collaborations with NOAA researchers, and establishing an infrastructure than encourages teaching opportunities for NOAA colleagues.

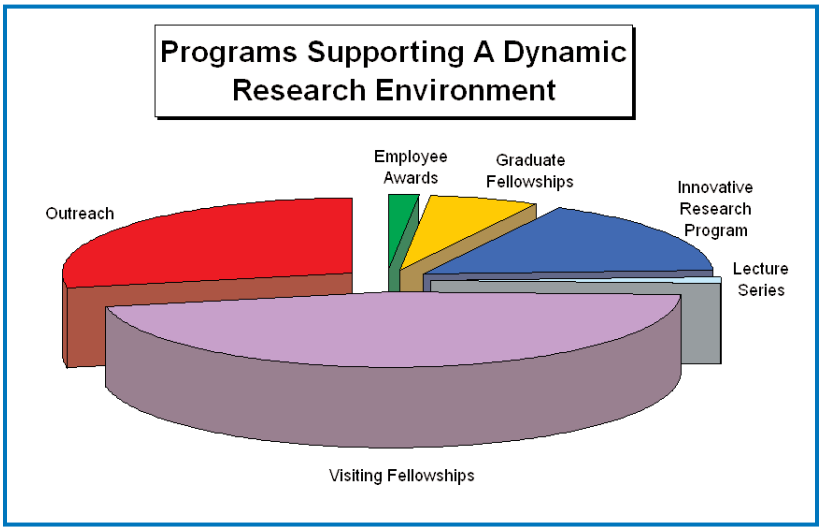
Another recommendation was for CIRES to improve its support of and contributions to the collaborative research effort in NOAA's David Skaggs Research Center. An office was subsequently provided to facilitate integrated research planning and reporting, improve administrative support, and provide a location for personnel management.

CIRES is also being consulted in the planning and implementation of mandated restructuring of the Boulder NOAA laboratories. The inclusion of CIRES on their Science & Technology Council will further assist in achieving a new level of integration that complements the research foundation for NOAA's operational mission.2

# 2.4 Creating a Dynamic Research Environment

CIRES has created a number of programs and initiatives to stimulate interdisciplinary collaborations between CIRES, NOAA and University Departments. The pie chart at right illustrates the relative funding CIRES invests in creating this environment for the benefit of all members.

The following paragraphs summarize our main programs that together annually constitute a million dollar investment. Detailed descriptions and specific research outcomes can be found in Section 4 of this report.




## Employee Recognition Program

CIRES annually convenes a team to review and recommend awards for outstanding professional achievement. Three awards of $2,500 each are given to each individual or research team at our annual town meetings and subsequent receptions. This year CIRES recognized Jason Wolfe, Dorothy Quincy and the Texas Air Quality Team consisting of Wayne Angevine, Charles Brock, Greg Frost, John Holloway, Gerd Hübler, Jon Neuman & Donna Sueper.

CIRES this year expanded its recognition of employee accomplishments by providing matching funding for the Department of Commerce Silver Medal for outstanding research contributions. Six of the 31 authors from CIRES (listed above) shared equal cash prizes for the "Effect of Petrochemical Industrial Emissions of Reactive Alkenes and NOx on Tropospheric Ozone Formation in Houston, Texas" (Journal of Geophysical Research, Vol. 108, No. D8, 4249, doi:10.1029/2002JD003070, 2003).

## Visiting Fellows Program (VF)

CIRES annually conducts a competitive visiting fellowship program that promotes collaborative research at the forefront of scientific knowledge. One-year fellowships are made to Ph.D.-level scholars and university faculty planning sabbatical leave. Post-doctoral fellowships are awarded for one or two years. Selections are based in part on the likelihood of stimulating academic interactions and the degree to which both parties will benefit from the exchange of new ideas. To further this goal, priority is given to candidates with research experience at institutions outside the Boulder scientific community. The program is open to scientists from all countries, and appointments can begin at any time during the year.

Approximately six fellowships are offered to scientists with research interests in the areas of:

- physics, chemistry, and dynamics of the Earth system (atmosphere, biosphere, hydrosphere, lithosphere, cryosphere)
- global and regional environmental change
- climate system monitoring, diagnostics, and modeling
- remote sensing and in-situ measurement techniques for the Earth system
- interdisciplinary research themes

# 2.4 (continued)

## Graduate Research Fellowship Program (GRFP)

CIRES has long supported a competitive Graduate Research Fellowship program. The program was reviewed and redesigned last year to provide more opportunities for current or prospective outstanding Ph.D. students. Support can range from salary and travel for summer research to out-of-state tuition for a full year. This program is being used to 1) attract new candidates to give them a boost in their early years, and 2) support graduating students who can then place a greater emphasis upon completing and publishing their research projects. Selections are based on the promise of candidates to contribute to environmental science, on the basis of their applications to the University of Colorado and their accomplishments thus far. Independence, a passion for science, and ability to communicate are qualifications characteristic of successful candidates.

## Innovative Research Program (IRP)

CIRES-wide competitions are conducted each year to foster an innovative research environment where risk-taking is allowed and even encouraged. The Innovative Research Program (IRP) is designed to stimulate a creative research environment and encourage synergy between disciplines and research colleagues. The intent is to provide an uncomplicated mechanism for supporting small research efforts that can quickly provide concept viability or rule out further consideration. The program encourages novel, unconventional or fundamental research that might otherwise be difficult to fund. Funded projects are inventive, sometimes opportunistic, and do not necessarily have an immediate practical application or guarantee of success. This program supports pilot or exploratory studies where results can be quickly acquired. Activities can range from instrument development, lab testing, and field observations to model advancement.

## Education and Outreach (EO)

The CIRES Education and Outreach program provides science education opportunities for educators, students and scientists. Their work emphasizes scientific inquiry, links with research scientists and current research, and uses of place-based and field-based teaching methods. The impact and scope of the program is increased through strategic partnerships with other geoscience organizations. Examples of programs for educators include Earthworks, a weeklong Earth System Science retreat for Secondary Science Teachers, and Front Range Math and Science Partnerships. Programs designed for students include the National Ocean Sciences Bowl (NOSB) and the GK-12 Graduate Student Fellows Program which places graduate students into middle and high school science classes. Programs supporting scientists include the Ocean Interactions/Teacher at Sea Experience program, Resources for Scientists in Partnerships with Education (ReSciPE) and collaboration with proposing scientists to include educational components within geoscience research projects. Further examples include professional development workshops at national meetings and leadership within the Digital Library for Earth System Education (DLESE) program.

## Western Water Assessment (WWA)

The Western Water Assessment is CIRES' signature integrating activity that involves personnel from the Climate Diagnostics Center, Center for Science and Technology Policy Research, Center for Limnology, National Climatic Data Center, Natural Resources Law Center, Institute for Behavioral Studies, and the Institute for Arctic and Alpine Research. Its mission is to identify and characterize regional vulnerabilities to climate variability and change and to develop information, products and processes to assist water-resource decision makers throughout the Intermountain West. WWA is responsive to NOAA's mission, strategic goals, and cross-cutting priorities, as well as other congressional NOAA mandates including

# 2.4 (continued)

the U.S. Global Change Research Act and the Climate Change Strategic Program. WWA is funded by the NOAA Office of Global Programs as part of their Regional Integrated Sciences and Assessments (RISA) program.

## Distinguished Lecture Series (DLS)

CIRES promotes global perspectives by sponsoring noted speakers whose work crosses disciplinary boundaries. The Distinguished Lecture Series invites outstanding scientists, science policy makers, science journalists and academicians who take imaginative positions on environmental issues and can establish enduring connections after their departure.

The Lecture Series is conducted each academic year. The 2004-2005 series covered topics ranging from climate change and alternative energy sources to the risks of disaster prediction and a historian's perspective on "patenting life." Specific authorities and their titles last year included:

Wallace Broecker, Lamont-Doherty Earth Observatory, Columbia University on "Sea Ice and Global Climate"

Jeff Severinghaus, Scripps Institution of Oceanography, University of California on "How air bubbles trapped in glacial ice have changed our view of abrupt climate change"

Paul Gipe, Ontario Sustainable Energy Association on "An Overview of Worldwide Wind Energy Development"

Dianne Dumanoski, Former writer for the Boston Globe and Author of Our Stolen Future on "Understanding the Planetary Emergency as a Human Crisis"

Bernard Hallet, Director, Quaternary Research Center, University of Washington on "Self-Organization in Landscapes"

James C. Zachos, University of California on "A Rapid Rise in Greenhouse Gas Concentrations 55 Million Years Ago: Lessons for the Future"

Lucile M. Jones, Scientist-in-charge for Southern California Earthquake Hazards Team, United States Geological Survey on "The Politics of Earthquake Prediction"

Policy, Politics, and Science in the White House:

Conversations with Presidential Science Advisors

John H. Marburger III: Science Advisor to President Bush

Robert Palmer: Democratic Staff Director of the Committee on Science, U.S. House of Representatives

John H. Gibbons: Science Advisor to President Clinton

Workshops and Symposia

Summer Institutes for Front Range Teachers: June 26-August 6, 2004

Symposium: "A Chronicle of Distinction: From the Arctic to the Andes": August 2004

Innovative Research Program Poster Session: September 2004

Rocky Mountain Hydrologic Research Center: November 2004

National Weather Service Corporate Board Meeting: November 2004

NOAA/GCOS Workshop to Define Climate Requirements for Upper Air Observations: February 2005

4th Annual NAVDAT Workshop: February 2005

Science, Technology, and Decision Making Symposium: February 2005

Inquiry workshops for Scientists, ASLO (American Society of Limnology and Oceanography) Meeting: February 20 2005

National Ocean Sciences Bowl (NOSB) Regional Competition: February 26, 2005

CIRES Scientific Retreat: March 2005

ICARTT (Int'l Consortium for Atmospheric

## 2.4 (continued)

Research on Transport & Transformation) Workshop: April, 2005

Climate Change Science Program Seminar: April 2005

AGU Geophysical Information for Teachers on "Severe Storms and Hurricanes", New Orleans: May 24-25, 2005

K-12 Educational Workshop: June 2 2005

Earthworks Teacher Training: June 24-July 1 2005

International Polar Year (IPY) Outreach Workshop: July 2005

## 2.5 Scholarly Publications

CIRES scientists and faculty published 355 peer-reviewed and 175 non-peer-reviewed papers during the preceding year. The following table tabulates these by affiliation of first author and their peer review status. We recognize that publication count alone is only one measure of institute impact, but it is the simplest to tabulate and compare. A better grasp of how CIRES research is extending the boundaries of scientific knowledge will be found in the Executive Summary and following detailed sections.

| | CIRES Lead Author | | | | NOAA Lead Author | | | | Other Lead Author | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2001-2002 | 2002-2003 | 2003-2004 | 2004-2005 | 2001-2002 | 2002-2003 | 2003-2004 | 2004-2005 | 2001-2002 | 2002-2003 | 2003-2004 | 2004-2005 |
| Peer Reviewed | 164 | 112 | 177 | 165 | 43 | 60 | 31 | 56 | 127 | 110 | 183 | 134 |
| Non-Peer Reviewed | Incl. above | Incl. above | 100 | 110 | Incl. above | Incl. above | 10 | 43 | Incl. above | Incl. above | 24 | 55 |

# 3.0 NOAA-CIRES Accomplishments by Scientific Theme

CIRES has increasingly aligned its research along scientific themes rather than organizational structures to foster a more interdisciplinary approach. We are addressing scientific questions of societal relevance and seeking to present results in a meaningful context. These themes are designed to reflect changing priorities and can adapt to a dynamic world as needs evolve.



## 3.1 Advanced Modeling and Observing Systems

The goal of the Advanced Modeling and Observing Systems (AMOS) theme is to effectively characterize and predict the state of the Earth system on all scales using direct observations and techniques for projecting outcomes mathematically. Benefits of this theme include improved understandings of relationships between physical properties and of processes that affect air quality, weather, and climate forcings; development of new techniques and instrumentation; improved observational capabilities; and validation of climate models. Our ability to represent the environment and accurately forecast climate depends on our ability to measure Earth systems processes. Observations serve to both validate models and provide the data necessary to parameterize modeled processes.

Space observing techniques, ranging from local, regional, and global scales, link most research fields, including atmospheric chemistry processes, atmosphere and ocean physical processes, cryospheric processes, remote sensing of terrestrial applications, nonlinear systems applications, and data centers and data management. Modeling efforts deal with data assimilation applied to space weather forecasting, forecasts of the geomagnetic environment, and turbulent processes, among others. Researchers have developed instrumentation for more rapid and accurate real-time sampling of the atmosphere in order to better study the environment, and to understand the complex processes affecting it. Because this theme emphasizes technology rather than subject, it frequently stimulates the cooperative, interdisciplinary work among scientists of disparate backgrounds that CIRES was created to promote.

## Project 3.1.1 Instrumentation for Atmospheric Observation and Analysis (AL01)

**Goal: Design and evaluate new approaches and instrumentation to make atmospheric observations of hard-to-measure species that are important players in the chemistry of the troposphere and stratosphere.**

### *Milestone 3.1.1.a*

Continue evaluation of the optical characterization of single aerosol particles by cavity ringdown spectroscopy, as well as collection and analysis of the organic content of atmospheric aerosols.

**Accomplishments**

Aerosol optical properties are of central importance in the determination of radiative forcings by aerosols in the atmosphere. The direct radiative forcing effect of aerosols can be studied by the measurement of scattering and absorption of light by these aerosol particles. The quantity of interest is the single scattering albedo, which is defined as the ratio of scattering to extinction (scattering + absorption). Accurate measurement of this quantity is critically important in climate forcing calculations for aerosols, because albedo values contribute a great deal of uncertainty to the calculations. Black carbon aerosols are the initial focus of these measurements, because their sources are anthropogenic in nature and the pure black carbon aerosols absorb solar radiation leading to a positive (warming) forcing.

Currently, CIRES researchers are developing a laboratory-based spectroscopy instrument for the measurement of single-scattering albedos of aerosols. The system consists of a diode laser locked to an equilateral triangle laser cavity. The aerosol particles are introduced into a scattering cell located at the midpoint of one side of the triangle that collects scattered light over a nearly $4\pi$ solid angle. The forward and backscattered light can also be individually resolved from the total scattering signal. The forward scattering can be used in the sizing of the particles and the back scattering can be used for lidar-type studies. The extinction by aerosol particles is measured by monitoring the decay of light in the laser cavity with the particles present and comparing this to the ringdown times from the empty cavity. The suitably scaled ratio of the scattering to extinction is the single-scattering albedo. The laboratory instrument is currently being tested using pure scattering polystyrene latex spheres of known diameters. This method has allowed for determination of the signal to noise levels, as well as reproducibility and spread in the measured scattering signals and ringdown times from aerosol samples of known sizes and scattering properties. Researchers have also achieved robust locking of the diode laser to the ringdown cavity, which is crucial for an eventual field instrument.

Researchers plan to conduct laboratory studies on other types of particles with various optical properties to determine the response of the instrument to particles of interest that will be encountered in the atmospheric field studies. The instrument will also provide a bright laser source with a narrow line width for numerous other scattering and absorption studies in the future.

Collection and analysis of aerosol content is also an important goal. The organic compounds that make up the organic fraction of atmospheric aerosol have the potential to affect the radiative and microphysical properties of the aerosol, with concomitant impacts on the role of the aerosol in climate forcing through direct and indirect effects. The speciated measurement of aerosol organic compounds poses a significant experimental challenge due to the complexity and large number of organic species, and the low concentration at which individual species are present.

During the past year, our efforts to develop a method for determining the speciated composition of organic aerosol have continued to follow two different paths. One technique utilizes aerosol collection with a multi-sample aerosol impactor, followed by subsequent ex situ analysis of the samples, while the other couples collection to prompt thermal desorption and in situ analysis.

We used two analysis methods with the aerosol impactor: the first, which has proven more robust, and will be our focus going forward, involves collections made onto metal plates for MALDI-TOF (matrix-assisted laser desorption and ionization,

## Project 3.1.1 (continued)

time-of-flight) mass spectrometric analysis. The second approach, onto-quartz fiber-filter punches for ESI (electrospray ionization) mass spectrometric analysis, may ultimately be complementary.

The second path has led to the design and construction of an aerosol impaction/thermal desorption/chemical ionization mass spectrometer. This instrument has an aerosol inlet to direct particles onto a target stage for a variable collection time. The stage is then rapidly heated to volatilize the aerosol organic compounds into a carrier gas flow. This flow then passes through an ion drift tube where the organic compounds are detected by proton transfer ionization coupled to an ion trap mass spectrometer. The prototype instrument has demonstrated the capability to measure representative organic compounds in laboratory-generated aerosols, and appears suitable for use in laboratory studies such as secondary organic aerosol formation. Current efforts include evaluation of a second-generation aerosol collection/desorption module and determination of performance limits for further development as a field-deployable instrument.

### *Milestone 3.1.1.b*

Employ a new UV spectrometer to measure scattered sunlight during the summer 2004 New England Air Quality Study/Intercontinental Transport and Chemical Transformation (NEAQS/ITCT) campaign.

**Accomplishments**

Nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$) emissions are regulated under the National Ambient Air Quality Standards (NAAQS) as criteria pollutants due to their roles in the formation of acid rain. However, both $NO_2$ and $SO_2$ also contribute to other atmospheric chemistry processes. Nitrogen dioxide is a precursor in the formation of tropospheric ozone ($O_3$) and sulfur dioxide is involved in the formation of sulfur containing particles that play a critical role in climate change.

Therefore, we designed an ultraviolet spectrometer to measure nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$) simultaneously. The spectrograph was deployed to Portsmouth, New Hampshire, during the summer of 2004 for the New England Air Quality Study/Intercontinental Transport and Chemical Transformation (NEAQS /ITCT). The spectrometer was aboard the NOAA WP-3D aircraft. The aircraft flew through point and regional air pollution plumes.

### *Milestone 3.1.1.c*

Field two cavity ringdown spectrometers, one aboard NOAA WP-3 aircraft and another aboard NOAA Ship *Ronald H. Brown*, to evaluate the role of nighttime chemistry in regional air quality and climate.

**Accomplishments**

Nitrogen oxides are common atmospheric pollutants that are by-products of fossil fuel combustion. During the day in the lower atmosphere, they participate in a catalytic cycle in the presence of hydrocarbons that produces ozone, the principal component of smog. At night, nitrogen oxides enter into a different set of chemical reactions to form the nitrate radical $NO_3$ and dinitrogen pentoxid, $N_2O_5$ (Figure 3.1.1 (1)); they oxidize hydrocarbons and efficiently convert nitrogen oxides to nitric acid, which is soluble and can be removed by rainout. Thus, the "dark" reactions remove the two key ingredients for daytime ozone production without producing any ozone at all. Understanding the dark reactions is therefore important to understanding ozone production and air quality.

Relatively little is known about the efficiency of the dark reactions, largely because the tools needed to measure the abundances of the nocturnal nitrogen oxides have not been available. We designed and built a new instrument, a cavity ringdown spectrometer (CaRDS), to detect these compounds sensitively and quantitatively. In this instrument a pulse of laser light passes back and forth tens to hundreds of thousands of times between a pair of very highly reflective mirrors, making it easy to detect even a very small amount of light absorption by the compound of interest. The CaRDS instrument is the first of its kind for detection of nocturnal nitrogen oxides, and two such instruments have been deployed during recent field campaigns on different platforms, including the NOAA Ship *Ronald H. Brown* in

## Project 3.1.1 (continued)

2002 and 2004 and the NOAA P-3 aircraft in 2004.

This measurement capability has yielded new insights into processes important to air quality and climate. For example, we have quantified the nocturnal oxidation of hydrocarbons of biogenic origin (emitted either from vegetation over land or from phytoplankton over water) in a marine environment off the coast of New England. We have further shown that nocturnal conversion of nitrogen oxides to nitric acid proceeds at approximately the same rate at night as it does during the day over the ocean. Measurements from the aircraft show a different facet of the dark reactions aloft. Here, there is considerable variability in the efficiency of the removal of nitrogen oxides at night, and this variability is related to the emission of other compounds, such as sulfur dioxide from coal-fired power plants. The latter result indicates that ozone production and air quality issues may depend on a very complex set of factors not previously recognized, and it has implications for ozone control strategies.

The research showed the role played by nighttime chemistry in both regional air quality and climate.

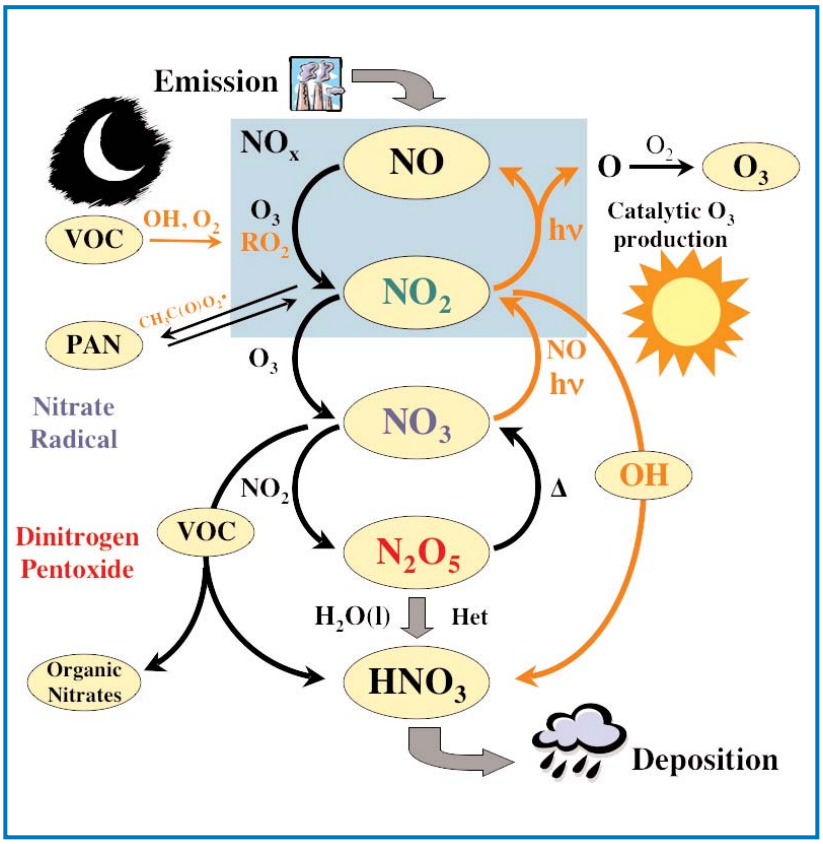



*Figure 3.1.1 (1). Nitrogen oxide cycle in the lower atmosphere, showing "dark reactions."*

## Project 3.1.2 Chemical Transport Model Research (AL02)

**Goal: Undertake research that contributes to the ability to forecast regional air quality and the intercontinental transport of pollution.**

### *Milestone 3.1.2.a*

Use measurements of ozone, aerosols, and their precursors made during the 2004 New England Air Quality Study to evaluate the forecast capability of the current tracer and chemical forecast models.

**Accomplishments**

Air quality forecasts designed for predicting surface ozone levels in populated regions of the Eastern U.S. and Southern Canada are currently operational through a number of forecast offices and research centers. The focus of this research is on using data collected during the ICARTT/NEAQS-2K4 field campaign and from the dense surface networks of $O_3$ and PM2.5 aerosol to validate existing air quality forecast models.

During the 2004 field study, the NOAA Aeronomy Laboratory collected detailed air quality and meteorological forecast results from nine forecast models in real-time. These forecasts were from two NOAA agencies (NWS/NCEP, and FSL); the Meteorological Services of Canada; a private corporation (Baron Advanced Meteorological Services, Inc.); and one university (University of Iowa). We posted the real-time comparisons of these forecasts with observations from thirteen $O_3$ surface monitors, several upper-air wind profiler sites, and ship data from the NOAA Ship *Ronald H. Brown* at the ICARTT regional model verification web page (http://www.etl.noaa.gov/programs/2004/neaqs/verification/). The cooperative efforts of the forecast groups and the NOAA Aeronomy and Environmental Technology Labs allowed a unique opportunity to present one of the first-ever, real-time ensemble $O_3$ forecasts and bias-corrected ensemble forecasts, also posted in real-time on the verification web site. We have since statistically evaluated the real-time model results, using observations from 342 AIRNow $O_3$ surface monitors in the Northeast U.S. and Southeast Canada, resulting in two publications outlining numerical techniques and the superiority of the ensemble $O_3$ forecasts relative to any individual model forecast (Pagowski et al., 2005; McKeen et al., 2005). Six forecast models also predicted PM2.5 concentrations, which we have also statistically evaluated using 118 AIRNow PM2.5 monitors within the domain of model overlap. The results of this analysis are contained within an internal report that we distributed to the model forecast centers in February of 2005. Surprisingly, five of the six models showed more skill and lower relative bias for PM2.5 forecasts compared to analogous forecasts of $O_3$. The statistical superiority of the ensemble PM2.5 forecast (derived from a geometric mean of the six

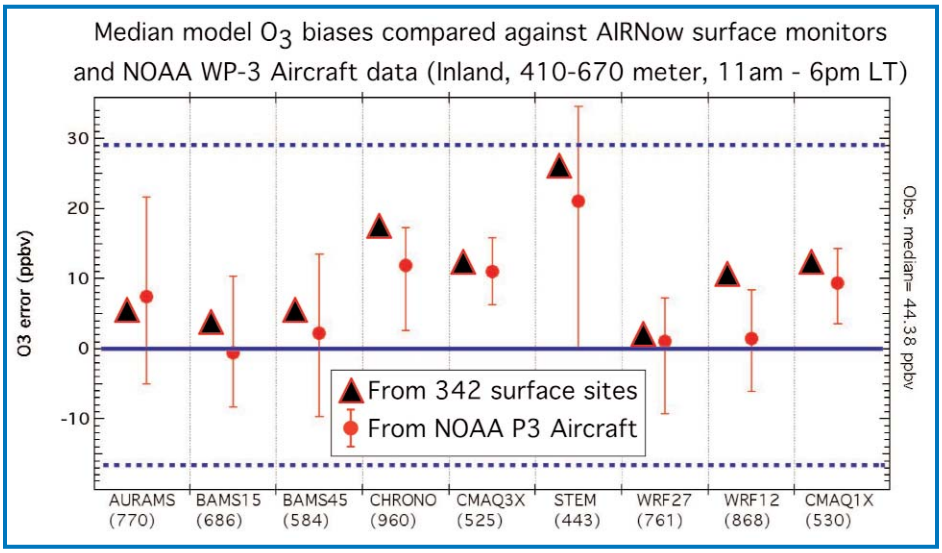



*Figure 3.1.2 (1). Median model $O_3$ error (red circles) and central 2/3 of sorted error distribution (red lines) for nine air quality forecast models compared to a subset of the NOAA P3 aircraft data. Blue dashed lines show the central 2/3 data limits of the sorted distribution of observed $O_3$ relative to the median value printed on the right-hand scale. $O_3$ median errors compared to the EPA-sponsored AIRNow surface network are shown in black diamonds.*

## Project 3.1.2 (continued)

individual forecasts) is another significant finding of the analysis.

The comparison of the forecast model results with the detailed observations from the NOAA WP-3 aircraft and the NOAA Ship *Ronald H. Brown* are important for testing the underlying components and assumptions of the models, leading to improvements in forecast ability, and insuring that the forecasts get the right answer for the right reasons. We created a project web site, displaying the comparison of dozens of gas-phase, aerosol, meteorological, and radiation variables from nine of the forecast models with these NOAA observing platforms. Figure 3.1.2 (1) shows an example of a particular summary statistic, median $O_3$ bias, with a subset of the aircraft data (daytime, low elevation, inland window), and also shows the same statistic derived from comparisons with the AIRNow surface $O_3$ network presented in the McKeen et al. (2005) reference. The close correspondence between $O_3$ biases derived from aircraft and the surface observations confirms that detailed comparisons with aircraft observations of $O_3$ precursors, meteorological and radiation variables contained within this Web site are useful for diagnosing each model's biases and ability to forecast surface $O_3$. Additional comparisons between a few of the forecast models and data collected from the NOAA ETL DC-3 ozone lidar are posted on the ICARTT regional model verification web page. Figure 3.1.2 (2) shows an example for the flight on July 21, 2004, when plumes of high $O_3$ originating from the New York City area were intercepted downwind. The figure also illustrates the comparison with simultaneous $O_3$ columns from the NOAA FLS WRF/Chem model (12 km horizontal resolution case), which predicted the vertical extent and mixing of the plumes quite well compared to the other models for this particular flight.

### *Milestone 3.1.2.b*

Use the forecast capability of current chemical transport models for the planning of the deployment of the NOAA Ship *Ronald H. Brown* and the WP-3D and other aircraft during the summer 2004 experiment of the Intercontinental Transport and Chemical Transformation (ITCT 2K4) pro-

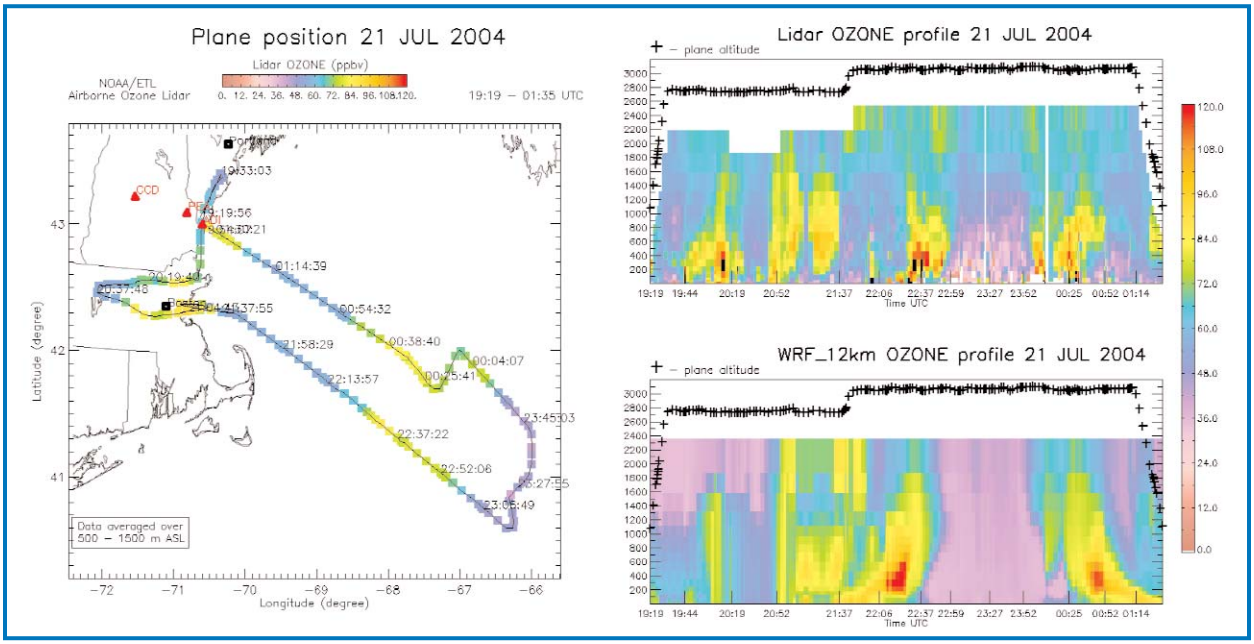



*Figure 3.1.2 (2). Location of the NOAA DC-3 flight-track on July 21, 2004 (left) colored according to the 500-1500 meter observed $O_3$ average mixing ratio. The right panels show observed (top) and model forecast (bottom) $O_3$ columns along the flight track. The model in this case is the NOAA FSL WRF/Chem (12 km resolution) model.*

## Project 3.1.2 (continued)

gram.

**Accomplishments**
The 2004 International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) experiment, which included the Intercontinental Transport and Chemical Transformation 2004 study (ITCT 2k4), was the largest air quality study ever undertaken, involving multiple aircraft and ground stations, a research vessel, and participants from the USA, Canada, and the EU. In addition to state-of-the-art chemical and radiation measurements collected during the study, a key component of the experiment was the accurate forecasting of North American pollution plumes that could be targeted by research platforms over North America, the Atlantic, and Europe.

The primary forecast tool used by NOAA mission coordinators was the FLEXPART particle dispersion model. During the experiment, we ran the model at the NOAA Aeronomy Laboratory, updated four times per day using the NOAA NCEP Global Forecast System 1°x1° wind fields, with forecasts extending out 120 hours. Passive tracers of anthropogenic CO, $SO_2$, $NO_x$ and biomass burning CO were output in operational graphical format at three-hour forecast intervals, depicting tracer locations in plan and cross-section views above the northeast USA, North America, the North Atlantic, and western Europe. Flight planners in New Hampshire, the Azores, and France accessed these products through the World Wide Web and created custom plots of the forecast products using an interactive web tool.

The high resolution output of the FLEXPART tracers (.25° x .33°) allowed the planning of flight tracks through relatively small features like the New York City plume that are poorly resolved by coarser resolution chemical transport models. Flights were typically planned 24 hours in advance although the frequent forecast updates allowed for fine-tuning of the flight track just a few hours before takeoff. During this stage, we verified the position of the FLEXPART tracers with tracer overlays on near real-time GOES satellite imagery (Figure 3.1.a) obtained through the UNIDATA data stream that flows into the NOAA Aeronomy Laboratory. Furthermore, the high temporal and spatial resolution GOES 1 km visible imagery showed the exact location of the Alaskan/Canadian biomass burning smoke plumes over land and water as well as anthropogenic haze features over the Atlantic. This combination of forecast tracer products and satellite imagery allowed the most detailed and accurate flight-track planning of any NOAA field mission and has set the standard for all future experiments.

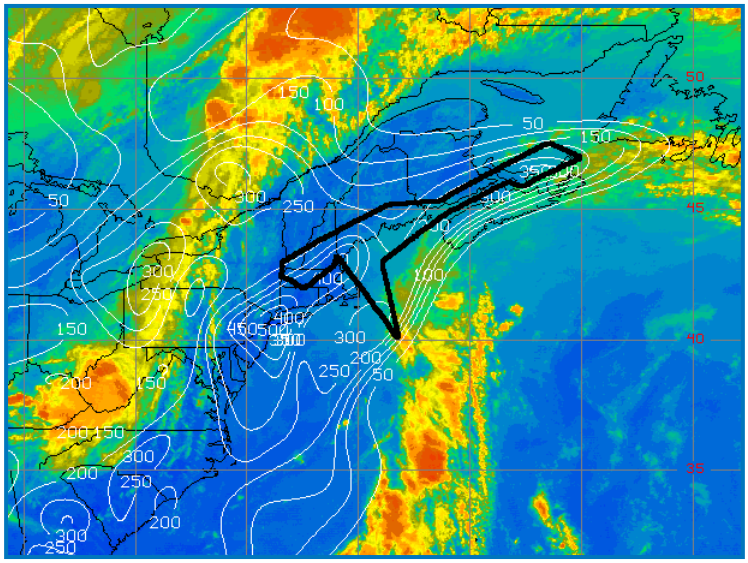


*Figure 3.1.2 (3). GOES-EAST infrared image at 15:15 UTC, July 22, 2004, showing high-altitude clouds (yellow and red), low-level clouds (green) and the Earth's surface (blue). The FLEXPART column CO tracer in the lower troposhere (white contours, mg/m2) shows the New York City plume extending across Nova Scotia, chased and intercepted by the NOAA WP-3D (flight track in black).*

## Project 3.1.3 Central Ultraviolet Calibration Facility (ARL01)

**Goal: Provide a central facility for the calibration and characterization of solar ultraviolet broadband and spectral measurement systems to improve the long-term stability and comparison of measurements across national and international networks.**

### *Milestone 3.1.3.a*

Write two papers related to the evaluation of the performance of the international suite of instruments involved in the June 2003 comparison of spectral radiometers at Table Mountain, Colorado.

**Accomplishments**

Researchers drafted a document on the analysis of the scanning spectoradiometers and spectrograph during the June 2003 intercomparison. A second paper on the filter radiometers is in progress. We completed two presentations related to this project: one poster presentation and one oral presentation.

### *Milestone 3.1.3.b*

The Central UV Calibration Center (CUCF) is the basis for solar UV calibrations in the Americas. The European counterpart is the European reference Center for Ultraviolet radiation measurements (ECUV) laboratory at the Joint Research Center in Ispra, Italy. The CUCF will intercompare its standards of spectral irradiance with the ECUF laboratory to establish a baseline reference between the regional calibration centers.

**Accomplishments**

Researchers traveled to Italy in May to compare the CUCF lamp irradiance scale with the lamp irradiance scale as determined by the European reference Center for Ultraviolet Radiation, and completed an internal report describing the results.

### *Milestone 3.1.3.c*

Intercompare the CUCF's vertical and horizontal irradiance scale with the National Institute of Standards and Technology's vertical irradiance scale as part of the interagency project between the CUCF and NIST to intercompare U.S. national standards. Calibrate and characterize broadband and filter radiometers in existing UV networks.

**Accomplishments**

This project was delayed due to a conflict of projects at NIST and has been postponed for 2005.

**Additional Accomplishments**

Researchers worked with Dr. Kimlim from the EPA National UV Monitoring Center, comparing erythema from the EPA Brewer Network with erythema from the USDA UVB Monitoring and Research Programs. CUCF staff provided the calibrations for both networks. This comparison resulted in an uncertainty assessment, included in the paper completed by CUCF staff.

## Project 3.1.4 Surface Radiation Network (ARL02)

**Goal: Collect long-term research-quality upwelling and downwelling broadband solar and infrared radiation data at seven U.S. sites. Collect long-term, broadband ultraviolet radiation data to evaluate variations in the erythemal doses. Collect long-term, spectral filter data to measure column aerosol optical depth and cloud optical depth. Collect cloud cover data to assess the effect of clouds on the surface radiation budget.**

### *Milestone 3.1.4.a*

Contrast and compare cloud fraction retrievals from the total sky images in SURFRAD with those from trained observers. Develop and evaluate automated calibration and analysis techniques for the optical depth of all aerosol channels. Develop an aerosol optical depth product for SURFRAD. Investigate the retrieval of cloud optical depth. Analyze the data in the current database for trends. Provide data to the Baseline Surface Radiation Network (BSRN) archive to enable CIRES research on a wider scale.

**Accomplishments**

In collaboration with Susanne Benze, a long-term visiting student from Germany, we carried out a comprehensive study on the one-year cloud fraction data set that was collected at Eglin Air Force base. That data included automated cloud fractions retrieved by the Yankee Environmental Systems TSI-880 sky imager and trained observers. We completed a report on the results of the cloud fraction comparison, but we have not yet submitted the manuscript to a scientific journal. We submitted radiation data to the Baseline Surface Radiation Network archive for four DOE Atmospheric Radiation Measurement (ARM) stations and the seven stations of the U.S. SURFRAD surface radiation budget network. Irradiance data from the DOE-ARM Southern Great Plains site was analyzed for trends in the context of global dimming. We presented a paper on these results, which was published in the proceedings of the Fourteenth ARM Science Team Meeting: "Searching for global dimming evidence at SGP, and update of ARM submissions to BSRN." The aerosol and cloud optical depth studies were put on hold in favor of more pressing projects.

*Figure 3.1.a. Altocumulus lenticularis over Boulder, Colorado*

## Project 3.1.5 Sensor and Technique Development (ETL01)

**Goal: Design and develop prototypical remote sensing systems for use from surface, airborne, and satellite platforms to measure critical atmospheric, surface, and oceanic parameters and address emerging observational priorities.**

### *Milestone 3.1.5.a*

Validate quantitative precipitation estimation (QPE) algorithms with data collected from the X-POL radar during the 2003 Pacific Landfalling Jets (PACJET) and 2004 Hydrometeorological Testbed (HMT) field campaigns conducted in the Russian River basin of northern California. Compare these QPE results with those obtained by using nearby WSR-88D radars that tend to overshoot most precipitation in the region. Assess techniques for X-band attenuation correction. Use the X-POL dataset in combination with vertically pointing S-band radar data and raindrop disdrometer data to explore the relationship between warm rain processes and surface raindrop size distributions. CIRES investigators will submit papers on all of these topics.

**Accomplishments**

We applied the attenuation correction algorithms to X-band radar data collected during the PACJET-03 and HMT-04 field experiments. We performed the validation of these algorithms using the ground clutter approach and the in situ raindrop size distribution measurements. We applied the simplified version of the correction algorithms to the radar data in real time. This study demonstrated that the quantitative rain estimates from the X-band transportable polarimetric radar deployed near the mouth of the Russian river are in good agreement with the ground rain gauge observations while the nearby WSR-88D radar due to overshooting shallow precipitation underestimates total rainfall amounts by as much as a factor of five.

We also analyzed disdrometer measurements of raindrop size distributions at two HMT surface sites have in conjunction with collocated S-band profiler data for the winter season of 2003-2004. The measurements show that winter rainfall during periods without a melting-layer radar bright band have larger concentrations of small drops (diameter < 1 mm) and much smaller concentrations of large drops (> 3 mm) than when a bright band is present aloft. These new results confirm earlier findings from PACJET/CALJET studies, which inferred greatly different drop size distributions in the two kinds of rain by remote sensing, without the benefit of direct measurements of drop sizes. In addition to signifying a fundamentally different cloud-microphysical precipitation formation process, the unusual drop size distribution in non-brightband conditions has an important consequence for conventional radar-based estimates of rainfall. If the standard WSR-88D radar (NEXRAD) relation between radar reflectivity factor and rainfall intensity is applied to non-brightband conditions, it results in substantial underestimates of winter season rainfall accumulations at the study locations in northern California.

### *Milestone 3.1.5.b*

Evaluate the incorporation methodology and impact of QuikScat and TRMM/GPM satellite measurements on the numerical simulations of two high-impact Pacific landfalling extratropical cyclones.

**Accomplishments**

We obtained an excellent simulation of the Feb. 19, 2001, case using the Penn State/NCAR MM5 model. The model used nests with grid spacing of 45, 15, 5, and 1.7 km. The simulation produced a narrow cold-frontal rainband with precipitation cores and gap regions, similar to that observed. The frontal convection and the slantwise kinematic and thermodynamic structure of the main frontal cloud shield were validated with analyses of in situ and Doppler radar data. The precipitation structure observed from the TRMM satellite is currently being compared to the simulated and aircraft-observed precipitation structure. We are presently writing two conference papers using the simulation and observations from this case.

## Project 3.1.5 (continued)

### *Milestone 3.1.5.c*

Lead planning for an icebreaker-based international field program to the Arctic Ocean during the International Polar Year 2007-2008.

**Accomplishments**

We submitted an Expression of Intent to the International Polar Year (IPY) international committee to conduct the Interdisciplinary Studies of the Annual Pack Ice Environment (ISAPIE) project. We made contact with the OASIS group to collaborate using the icebreaker *Antarctica*, for which both groups are currently seeking funds. Our participation in the NSF-sponsored workshop on the Sea Ice Mass Budget of the Arctic (SIMBA) led to substantial contributions to the workshop report delivered to NSF. Our contributions to the NOAA SEARCH workshop resulted in the prioritization of pack ice surface energy budget measurements for future SEARCH objectives, as described in the resulting report. Our contributions to these documents emphasized the need for improved and accurate surface energy budget measurements over the pack ice in order to understand the reasons for the observed changes in the pack ice extent and mass. If funding is found for the icebreaker, we will submit coordinated proposals in response to the anticipated NSF call for papers in Fall 2005 for the IPY.

### *Milestone 3.1.5.d*

Conduct a test with a mobile fire wind profiler at a controlled burn, modify design and operating procedures as needed, and publish results.

**Accomplishments**

CIRES and ETL staff have designed a compact, mobile 915-MHz wind profiler that can deployed for fire weather applications. The wind profiler antenna and associated hardware sit on a small boat-sized trailer that can be towed by standard automobile or SUV. A personal computer is used to control the radar and to provide real-time displays of the data. We were hoping to field test the instrument in a controlled burn situation in 2004, but we have not secured funding for the project.

### *Milestone 3.1.5.e*

Develop a compact ultraviolet lidar for measuring profiles of ozone and aerosol from aircraft using the DIAL (Differential Absorption of Light) method.

**Accomplishments**

The transmitter of the new, compact, airborne ozone lidar is currently being built by a commercial company and is scheduled to be delivered in December 2005. The transmitter is based on a solid-state laser which emits tunable ultraviolet light. The tunability aspect represents a significant improvement over previous, fixed-wavelength ozone lidars, as it allows the operator to choose wavelengths that optimize system performance for a wide range of atmospheric ozone concentrations. The designs of the lidar receiver and aircraft mounts will be completed in the next several months. The new lidar system will be assembled and tested on a NOAA Twin Otter aircraft in the spring of 2006. Its first deployment will occur during the TexAQS II air quality study in the Houston, Texas, area in August-September 2006.

### *Milestone 3.1.5.f*

Complete a series of radar experiments in conjunction with Vaisala Inc. and analyze the resulting data in order to validate and assess the impact of using the newly emerging range imaging technology operationally on wind profilers for studies of the boundary layer and lower free troposphere. Present the results in the form of a journal publication.

**Accomplishments**

We conducted a series of tests to establish the viability of a new range imaging technique to improve the vertical resolution of wind profiling radars. The range imaging work was covered under the Cooperative Research and Development Agreement (CRADA) between NOAA and Vaisala, Inc. The very encouraging results from the benchmark testing have convinced Vaisala to pursue commercial development of this tool. Because the bandwidth of 449-MHz radar transmissions is limited by the FCC, range imaging will be critical in helping NOAA management determine the best

## Project 3.1.5 (continued)

approach for implementing wind profiling radar technology in the operational observing system.

### *Milestone 3.1.5.g*

Submit a research paper addressing the accuracy of low frequency acoustic techniques for studying the ocean interior.

**Accomplishments**

We submitted a paper on the following topic to IEEE Journal of Oceanic Engineering; publication is pending in Volume 30, No. 2 (2005). Meso- and smaller-scale processes in the ocean obscure global trends and limit accuracy of assessments of inter-annual variability and climate change. On the other hand, temporal variations in spatially-averaged intensity of internal gravity waves in the ocean arguably reflect climate change and events like ENSO, PDO, and NAO. In modeling of 3-D and 4-D acoustic effects due to internal gravity waves in the ocean, we found that the magnitude of the effects is sensitive to a choice between forms of the Garrett-Munk spectrum of the internal waves which are traditionally viewed as equivalent. This finding has far-reaching implications for acoustic characterization of internal waves and internal-wave induced errors in acoustic thermometry of the ocean. It indicates both feasibility and need for developing acoustic techniques for remote sensing of the internal waves in the ocean.

### *Milestone 3.1.5.h*

Prepare plans for a roving calibration standard for ship flux measurements.

**Accomplishments**

We have developed a plan: the system will be a based on conversion of one of the existing ETL flux systems with new wireless modem data acquisition. Measurement enhancements will include precision pressure, motion-stabilized downward solar and IR radiative fluxes, and a new motion measurement system.

### *Milestone 3.1.5.i*

Develop capability for ship-based ozone flux measurements.

**Accomplishments**

A new ozone sensor has been built at INSTAAR. The sensor is now being tested for sensitivity, frequency response, and noise.

### *Milestone 3.1.5.j*

Analyze the multi-channel radiometric data taken by the Ground-based Scanning Radiometer during the 2004 North Slope of Alaska Arctic Winter Radiometric Experiment

**Accomplishments**

We have carefully calibrated and quality controlled the multi-channel radiometer data taken at the 2004 North Slope of Alaska Arctic Winter Radiometric Experiment. We compared the data with data from other remote sensors, including the Global Positioning System, the Microwave Radiometer, and the Microwave Radiometer Profiler. In addition, we compared the data with brightness temperature calculations based on radiosondes. We presented several of these results at the Atmospheric Radiation Measurement Program Science Team meetings.

*Photo courtesy of Koni Steffen*

## Project 3.1.6 Environmental Monitoring and Prediction (ETL02)

**Goal: Improve numerical model performance through development of new data streams that directly impact forecast ability and through focused observational campaigns supporting geophysical process studies.**

### *Milestones 3.1.6.a*

Improve the prototype of a new blended (infrared and microwave) sea surface temperature (SST) algorithm for a selected one-year period.

**Accomplishments**

Researchers applied bias corrections to one infrared and one microwave satellite-based sea surface temperature (SST) product and developed optimal interpolation method to blend these two SST products into grid data with daily temporal resolution and 0.25 degree spatial resolution. A two-year (1999-2000) daily 0.25 degree blended SST product is available at the ETL Satellite Remote Sensing web site (http://www.etl.noaa.gov/et6/satres/blended_sst.html). This new blended data set optimizes the high accuracy from infrared observations and the greater spatial coverage from the microwave observations. An accurate, high-resolution SST product can ultimately benefit climate and weather model predictions by improving understanding of the effects of heat exchange between atmosphere and ocean.

**Additional Accomplishments**

We implemented a method to create a 22-year global data set of total and high cloud observations from High Resolution Infrared Radiation Sounder (HIRS) observations using the $CO_2$ slicing method. The method was applied to all HIRS swath-level observations, and cloud statistics of cloud height, effective emissivity, and cloud-top temperature were archived. We found no statistically significant change in total cloud cover; however, we did find a small statistically significant increase in cirrus cloud cover over the tropics during the 22-year period. This result contrasts with ISCCP (International Satellite Cloud Climatology Project) cloud products that indicate decreasing trends in total and cirrus cloud cover over the same period.

## Project 3.1.7 Cloud and Aerosol Processes (ETL03)

**Goal: Make observations of clouds, aerosols, and water vapor over a variety of ice, land, and sea surfaces using a multi-sensor, multi-platform approach to improve retrieval techniques useful for satellite validation studies.**

### *Milestone 3.1.7.a*

Develop ground-based cloud, aerosol, radiative, and surface meteorological instruments for use in Arctic observations with an emphasis on regions with strong connections to the Arctic oscillation.

**Accomplishments**

Scientists from NOAA/ETL, University of Colorado/CIRES, University of Wisconsin, and University of Toronto have collaborated to establish a Study of Environmental Arctic Change (SEARCH) atmospheric observatory in Eureka, Canada (80 degrees north). The initial site deployment included shelter for the instruments, power, a satellite communications link, networking, a data archival system, a millimeter wavelength cloud radar, and a high spectral resolution lidar. Additional radiation, meteorological, and aerosol measuring systems will be installed in the future. Initial radar and lidar measurements from Eureka signify the beginning of long-term Arctic climate monitoring activities. Data and images from the Arctic High Spectral Resolution Lidar that is deployed at the Eureka SEARCH site can be found at our project site (http://lidar.ssec.wisc.edu/syst/ahsrl/ahsrl_data.htm). Data images from the Millimeter Cloud Radar that is deployed at the Eureka SEARCH site can be found at the ETL site (http://www.etl.noaa.gov/arctic).

### *Milestone 3.1.7.b*

Diagnose the detailed time and space scales of the Arctic mixed-phase, low-level clouds from the surface data, remote sensors, and aircraft observations available for the SHEBA Experiment during the entire annual cycle.

## Project 3.1.7 (continued)

**Accomplishments**
We submitted a proposal to the National Science Foundation to augment this ongoing research, but it was not funded.

### *Milestone 3.1.7.c*

Participate in Pan-American Climate Studies (PACS) research cruises and deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary layer parameters, and low cloud macrophysical, microphysical, and radiative properties.

**Accomplishments**
Researchers deployed cloud radar, microwave radiometer, and flux systems on the NOAA Ship *Ronald H. Brown* for three weeks in December 2004 in support of the Pan-American Climate Studies program. All systems obtained data in a variety of conditions during the cruise. Data products from the 2004 PACS cruise are available at the ETL FTP site for this project (ftp://ftp.etl.noaa.gov/user/cfairall/EPIC/stratus04).

### *Milestone 3.1.7.d*

Develop new algorithms for microphysical retrievals of cloud parameters (cloud water/ice content, particle/drop size distribution, and cloud optical thickness).

**Accomplishments**
Researchers tested a radar-only-based method for retrieving liquid water content using the marine stratocumulus data set. This test showed that sampling reflectivity thresholding can be effectively used to separate between cloud scenes contaminated by drizzle and clouds scenes for which sensible retrievals using only radar reflectivity can be achieved. Results also suggested different thresholding levels for the ground-based and spaceborne cloud radars. We also developed a new algorithm to distinguish different habits of ice hydrometeors observed by radar above the bright band using polarimetric scanning radar measurements. Accounting for ice particle habit improves the retrieval of ice cloud parameters.

In addition, researchers developed a method to derive both cloud liquid and ice parameters in mixed-phase clouds from radar Doppler spectrum measurements. We tested and validated the method using observations from multiple instruments at the NASA Crystal-Face experiment.

### *Milestone 3.1.7.e*

Based on multisensor data taken by the Ground-based Scanning Radiometer and the Millimeter Wavelength Cloud Radar during the 2004 North Slope of Alaska Arctic Winter Radiometric Experiment, determine the relative sensitivities of microwave and millimeter radiometers to liquid, ice, and mixed-phase arctic clouds.

**Accomplishments**
During 2005, researchers calibrated and analyzed for radiometric sensitivity to water vapor and clouds the data set collected using the NOAA/ETL Ground-based Scanning Radiometer, along with several other instruments at the NSA site during March 2004. Using ancillary data from a millimeter wavelength cloud radar, a dual-channel microwave radiometer, and a cloud lidar, we found the microwave sensitivity to ice clouds, in particular, to be relatively strong at a frequency of 340 GHz. The data suggest a potential for using a wideband passive microwave-only data set for simultaneous measurement of arctic temperature and moisture profiles (especially in the boundary layer) along with both liquid and ice water path.

## Project 3.1.8 Water Cycle (ETL05)

**Goal: Improve weather and climate predictions through an increased knowledge of regional and global water cycle processes.**

### *Milestone 3.1.8.a*

Plan and execute the 2005 HMT (Hydrometeorology Testbed) field campaign in the northern California American River basin, located in the Sierra Nevada mountains west of Lake Tahoe and east of Sacramento. This effort will involve deployment of several instrument systems utilized in earlier HMT's conducted in the Russian River basin of northern California but will yield critical new understanding of orographic influences on airflow and precipitation growth over the Sierra Nevada mountains, a barrier that is substantially wider and taller than the coastal mountains. CIRES investigators will be key participants and contributors to this activity.

**Accomplishments**

Due to budget constraints, we executed a limited field campaign for HMT 2005. The focus was on instrumenting the Blue Canyon site, located just above 5000 feet in the North Fork of the American River Basin. Observing systems at this site included surface meteorology, a heated tipping bucket precipitation gauge, a snow-depth sensor and soil moisture sensors buried at two different depths. The data collection effort yielded unprecedented information about the response of soil moisture and snowpack for rain-on-snow precipitation events, a key scenario for hydrologic applications. Data are available at the project web site (http://www.etl.noaa.gov/programs/2005/hmt/).

### *Milestone 3.1.8.b*

Contribute to a paper describing the site-to-site and interannual variability of orographic precipitation processes observed along the U.S. West Coast, specifically the frequency of occurrence of a shallow, wintertime, non-bright-band (NBB) rain process and the synoptic environment that favors its formation. The shallow cloud tops associated with the NBB rains that are capable of producing flooding often lie beneath the coverage of the operational WSR-88D radars.

**Accomplishments**

CIRES investigators made substantial contributions to a NOAA-led paper describing the site-to-site and interannual variability of orographic precipitation processes observed along the U.S. West Coast, specifically the frequency of occurrence of a shallow, wintertime, non-bright-band (NBB) rain process and the synoptic environment that favors its formation. The results of the paper can be applied in practical terms by weather and river forecasters whose primary responsibilities include closely monitoring significant wintertime precipitation events affecting the western U.S. and warning the public of the potential adverse impacts of these events on personal safety, property, commerce, and transportation. The paper builds on an earlier publication led by a CIRES investigator.

### *Milestone 3.1.8.c*

Study the boundary-layer processes and precipitation microphysics associated with the North American Monsoon using measurements collected during the summer of 2004 at the boundary-layer and microphysics super site in Mexico.

**Accomplishments**

CIRES investigators and NOAA colleagues collected a precipitation microphysics dataset during the North American Monsoon Experiment (NAME, summer 2004). During the past year, CIRES investigators invested a substantial effort in assembling and processing a variety of different remote sensing and in situ data sets collected at the boundary-layer and precipitation microphysics supersite at Estacion Obispo, Mexico. This work included calibrating the different radars that were deployed and determining whether the 449-MHz profiler was able to distinguish between clear air and precipitation vertical motions present in the convective storms of the monsoon. This capability is critical in order for the radar data sets to be used to infer drop-size distributions of the precipitation. CIRES lead investigators submitted a progress report to the sponsor in February 2005. The project PI presented a talk during the NAME Data Workshop held in Mexico City in March 2005. Funding for the third year of the project,

## Project 3.1.8 (continued)

which would have involved more detailed analysis of the observations, was cut by the sponsor. Nonetheless, the processed and calibrated data sets will serve as a legacy for future numerical modeling studies of the monsoon. Data are available at the ETL and JOSS Web sites (http://www.etl.noaa.gov/programs/2004/name/ and http://www.joss.ucar.edu/name/dm/archive/).

### *Milestone 3.1.8.d*

CIRES investigators will use the MM5/WRF modeling systems and the FLEXPART trajectory modeling system to explore the relationship between the observed interannual variability in the global water cycle and the interannual variability of the cloud microphysical characteristics associated with the precipitation on the U.S. west coast.

**Accomplishments**

Due to NOAA budget constraints, only a limited effort on this milestone was possible. We performed trajectory analysis using a weather prediction model for five cases to interpret the formation of enhanced bands of vertically integrated water vapor (IWV) in the central and eastern Pacific that are frequently seen in satellite images from the Special Sensor Microwave/Imager (SSM/I). We also examined the connection of these enhanced bands with poleward watervapor transport from the tropics. These results from the trajectory analysis indicate that the direct poleward transport of tropical moisture within an enhanced IWV band in the eastern Pacific is most possible in the neutral El Niño Southern Oscillation (ENSO) phase and is least possible in the El Niño phase.

## Project 3.1.9 Energy (ETL08)

**Goal: Improve the performance of temperature forecasts provided by operational numerical models to allow better prediction of energy loads for the power generation and distribution industry.**

### *Milestone 3.1.9.a*

Perform a preliminary analysis of data sets of the boundary-layer supersite, which includes a vertically pointing S-band radar for cloud mapping as well as spectrally-resolved radiation measurements including aerosol optical depth.

**Accomplishments**

CIRES investigators contributed to preliminary analysis of data sets collected at the boundary-layer supersite. This year's work focused on comparing the surface energy budget in a mesoscale numerical model with observations of the surface energy budget over a forest canopy and over a grassland area within the supersite domain. Preliminary results show that the differences in the terms of the budget between the two different land-use sites are smaller than the differences between the observations and the model, indicating that the model has serious issues in dealing not only with different land surfaces, but with the surface energy budget in general.

### *Milestone 3.1.9.b*

Evaluate several PBL parameterization schemes using data taken at the New England boundary-layer, including 1-D versions of the NCEP GFS model and ETA PBL schemes and a new PBL scheme that CIRES investigators have helped to develop along with colleagues at NOAA/ETL. A paper describing and evaluating this new PBL scheme will be submitted for publication.

**Accomplishments**

The New England High Resolution Temperature Program was supported by a Senate earmark for energy security. The research in this milestone was tied directly to this funding. Unfortunately, the earmark was cut from the 2005 budget. As such, no work on this milestone was completed.

## Project 3.1.10 Regional Numerical Weather Prediction (FSL01)

**Goal: Design and evaluate new approaches for improving regional-scale numerical weather forecasts, including forecasts of severe weather events.**

### *Milestone 3.1.10.a*

Design a procedure for weighting ensemble members in the Grell-Devenyi convective parameterization scheme.

**Accomplishments**

The original version of the Grell-Devenyi convective parameterization scheme consists of more than 100 types and variants of cumulus parameterization and in most of the implementations the ensemble average is taken. Even in this simple formulation, the ensemble average has been shown to perform better than any individual member. In 2004, we started research to find out the best weighting based on different training data sets. As a first result, it became clear that standard linear regression methods traditionally used in ensemble forecasting do not work in the highly non-linear case of convective parameterization and precipitation relationship. We devised a shortcut by empirically reducing the weight of some ensemble members. In addition to the empirical approach, we started investigation to develop a Kalman-Levy filter based optimal weighting scheme. Using this method, we expect to avoid the two main restrictions applied in traditional Kalman filtering: 1) that the system is assumed to be linear, and 2) that error terms follow Gaussian distribution. Some preliminary results demonstrate the advantage of the Kalman-Levy filter. To date, we have implemented the Grell-Devenyi convective parameterization scheme in the 20 km version of the Rapid Update Cycle (RUC). As of April 2004, the Grell-Devenyi convective parameterization scheme has been implemented in the experimental 13-km version of the Rapid Update cycle, and the the Grell-Devenyi convective parameterization scheme became part of the Weather Research and Forecast Model (WRF) Version 2.0 in 2004.

### *Milestone 3.1.10.b*

Explore the use of Level II high-resolution (1 km in the horizontal, 15 levels in the vertical), three-dimensional, high-frequency National Weather Service WSR-88D radar data in the initialization of cloud and precipitation hydrometeors.

**Accomplishments**

The original version of the Rapid Update Cycle (RUC) cloud/hydrometeor analysis scheme is based on the RUC 1-h predicted hydrometeor mixing ratio background fields modified using GOES sounder-based cloud-top pressure data and METAR information. Because of the limitations of the technique, additional assimilation of radar reflectivity data is considered. In the first experiments, we used the Weather Services International (WSI) reflectivity data at 10-km resolution. We extended the same method to explore the use of Level II high-resolution (1 km in the horizontal, 15 levels in the vertical), three-dimensional, high-frequency National Weather Service (NWS) WSR-88D radar data in the initialization of cloud and precipitation hydrometeors. In the first step, researchers developed data collection and mapping to RUC CONUS grid algorithms. We also developed a data quality control method, using a simple observation operator to convert background mixing ratio values into radar reflectivity for comparison with measured radar reflectivity. Development of a general method for vertical adjustment of hydrometeor fields using GOES, METAR, and radar data is underway.

## Project 3.1.11 Verification Techniques for Evaluation of Aviation Weather Forecasts (FSL03)

**Goal: Design and evaluate new verification approaches and tools that will provide information about the quality of aviation forecasts and their value to aviation decision makers.**

### *Milestone 3.1.11.a*

Enhance the design and functionality of the Real-Time Verification System (RTVS) for the verification of aviation-related forecasts, such as forecasts of convection and turbulence.

**Accomplishments**

In support of enhancements to the Real-Time Verification System (RTVS), CIRES researchers have greatly improved online documentation (http://www-ad.fsl.noaa.gov/fvb/rtvs/manual_index.html) throughout the web-based verification system to help users more fully access the wealth of statistical information that is available. We also implemented verification for the Aviation Weather Center Collaborative Convective Forecast Product (Fig. 3.1.b), the Convective SIGMET forecasts, and the RUC model Convective Probability forecasts. These RUC forecasts are evaluated against a Convective Constrained Area (CCA) verification field. The CCA is an operationally relevant verification developed with contributions from CIRES researchers that is specifically utilized for the evaluation of aviation forecasts. Additionally, researchers designed and coded software in support of the 2004 NOAA/FAA Convective Exercise, including enhancements to the data acquisition mechanism, and to graphical presentations on the RTVS web site. We also designed and implemented an insightful measure of forecast consistency that is accessed by RTVS users in real-time over the Internet. A fifth product involved deployment of a precipitation verification system for the State of Iowa's Maintenance Decision Support System, for wintertime weather. This enhanced tool is available on the RTVS web site. In support of retrospective forecast studies, and real-time winter forecast experiments conducted this past winter, we developed an online verification system for the Weather Research and Forecasting Model (WRF) Developmental Testbed Center. Finally, we established mechanisms for evaluating the latest generation of the FAA Graphical Turbulence Guidance product for aviation forecasts. Statistical results from an analysis of these turbulence guidance products are now part of the RTVS web site.

In an effort to develop new methods of weather forecast evaluation, our researchers have explored the usefulness of Aircraft Situational Display data for evaluating convective weather forecasts. We also participated in research on the relationship

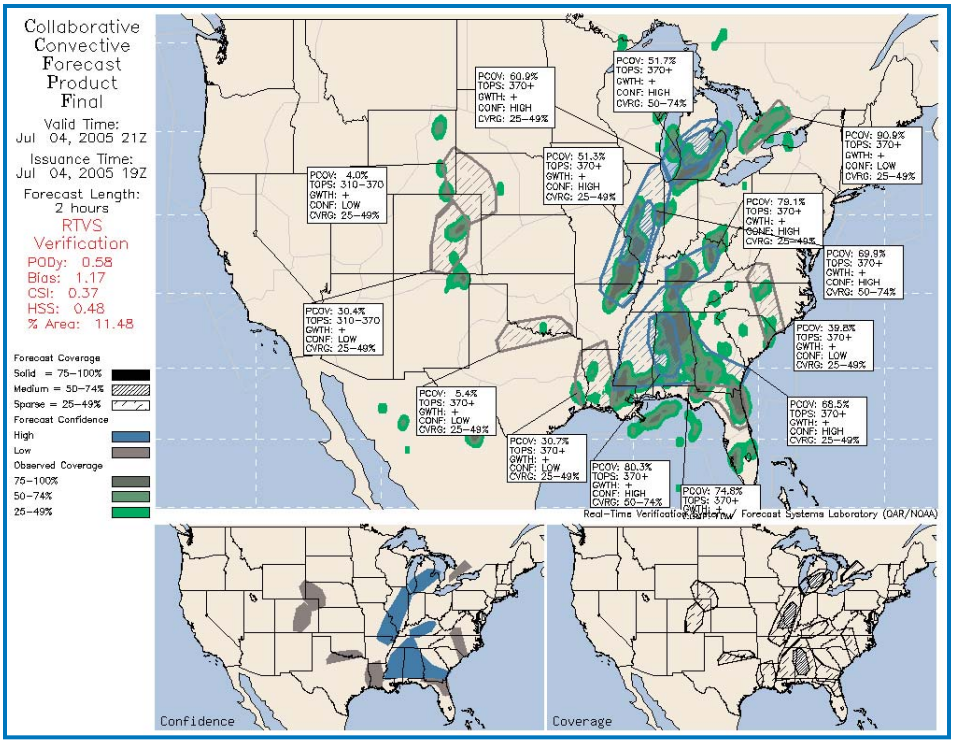



*Figure 3.1.b Collaborative Convective Forecast Real-Time Verification System.*

## Project 3.1.11 (continued)

between forecast verification and scale of convective weather elements. In particular, we sought to quantitatively determine the effect of model grid resolution on verification of convective precipitation. In collaboration with visiting scientists from Iowa State University, we participated in research related to Quantitative Precipitation Forecast (QPF) verification as a function of convective system morphology.

### *Milestone 3.1.11.b*

Investigate and develop new verification techniques for evaluating oceanic cloud-top height forecasts.

**Accomplishments**

In support of the effort to develop a verification technique for cloud-top height forecasts, CIRES researchers made a presentation at the NASA Advanced Satellite Aviation-weather Product (ASAP) meeting on the evaluation of a next-generation cloud-top height product being developed by the FAA Oceanic Weather Product Development Team.

## Project 3.1.12 Geospatial Technology for Global Integrated Observing and Data Management Systems (NGDC01)

**Goal: Develop methods and processes for integrating multiple types of observations (gridded satellite products, in situ measurements) using new Geographic Information System (GIS) data management and access tools; develop methods and processes for partnering with scientists to facilitate interoperability by producing metadata for scientific observations that are compliant with national Federal Geographic Data Committee (FGDC) and international International Standards Organization (ISO) standards; and create tools that allow the mining of vast environmental archives for the purpose of knowledge extraction, data quality control, and trend detection.**

### *Milestone 3.1.12.a*

Design and validate quality control on a geospatial database system for integrating gridded observations and model results with in situ measurements.

**Accomplishments**

Researchers designed and implemented a demonstration system that automatically ingests multidimensional NCEP GFS Forecast model output into a relational database. These data are then made available for comparison with in situ measurements.

### *Milestone 3.1.12.b*

Design and implement a web interface for scientists to use, create, and manage metadata for in-situ observations.

**Accomplishments**

Researchers developed the NOAA Metadata Manager and Repository (NMMR) to provide a web interface for metadata managers to create, use, and manage metadata for in situ observations. The data model is defined by FGDC.

### *Milestone 3.1.12.c*

Build version 5.0 of the Environmental Scenario Generator (ESG) and publish the ESG framework in the Data Science Journal.

**Accomplishments**

We designed and implemented a series of mapping components to integrate on-demand ESG data with existing spatial reference data housed in geospatial databases. The output of this integration can be incorporated into standard Geographic Information System (GIS) tools using the Open GIS Consortium (OGC) Web Map Server (WMS) specifications.

## Project 3.1.13 Marine Geophysics Data Stewardship (NGDC02)

**Goal: Contribute to a streamlined, more fully automated, accessible, and web-based management and stewardship process for Marine Geophysical data in support of seafloor research at CIRES and throughout the environmental science community.**

### *Milestone 3.1.13.a*

Complete a pilot development of Relational Database Management System (RDBMS) data storage and GIS-based web access to inventories, metadata, and primary data.

**Accomplishments**

In collaborating with other NOAA personnel, CIRES researchers developed a RDBMS and GIS-based web access to several databases of marine geophysical data, including Great Lakes bathymetry, multibeam bathymetric data, and, most recently, NOS hydrographic data. These databases have been populated and continue to be updated with data from both national and international sources. In the case of the multibeam bathymetric data and the NOS hydrographic data, product users have several choices of formats to download the data. We are currently working on a common and inclusive database structure for the majority of data in the Marine Geology and Geophysics Division.

### *Milestone 3.1.13.b*

Web delivery of customizable, GIS-based, derivative data by means of the adaptation of acquired systems and the integration and evolution of current systems to the web environment.

**Accomplishments**

Building on the RDBMS for multibeam bathymetry developed earlier, we created an online tool to allow the user to search the database using an ArcIMS interface and to download the original data in its native format, as well as to generate a grid and map. The map-making tool provides the user with a set of calculated default values or allows the user to enter their own custom values, thereby enabling the creation of a custom map product. This system removes the need for a user to have special software to work the native formatted data.

We also developed a scale-dependent display and search system for the Great Lakes bathymetric contour data. The density of the data displayed is a function of the map scale, making it easier to view the data when looking at the big picture. The more the user zooms into an area, the more data that are displayed until the underlying database is completely represented. The data are available for downloading as shape files. One interesting offshoot of making these data available online is an increased interest in and use of the data, and in particular in the generation of custom products. One example is the images of the Great Lakes regional topography/bathymetry that were made available for several publications, including a children's book, *The Day The Great Lakes Drained Away*, by Charles Barker.

## Project 3.1.14 Space Weather (NGDC03)

**Goal: Assess the current state of the space environment from the surface of the sun to the upper atmosphere; use data-driven physical models to construct a realistic and authoritative gridded database of the space environment; and place that description into its long-term climatological perspective.**

### *Milestones 3.1.14.a*

Construct an 11-year gridded database of results from an assimilation model, Assimilated Model of Ionospheric Electrodynamics, a coupled ionosphere-thermosphere model, Global Ionosphere-Thermosphere Model, and an inner magnetosphere model, Inner Magnetosphere Model.

**Accomplishments**

Researchers completed a near-Earth retrospective database for the thirteen years 1990-2002, using three models: NCAR Mapping of Ionospheric Electrodynamics (AMIE), the Global Ionosphere-Thermosphere Model (GITM), and the Inner

## Project 3.1.14 (continued)

Magnetosphere Model (SIMM). This retrospective analysis (over 10 terabytes of data) is available for public use through the NGDC Space Weather Research (SWR) Web site and data from it has been included in many publications. As a first of its kind product, it has lead to new discoveries of how the Earth's ionosphere changes over the solar cycle.

### *Milestones 3.1.14.b*

Present initial results at scientific meetings and submit them for publication in scientific journals.

**Accomplishments**

This project generated three papers this year; one is published, a second is in press, and a third is submitted:

Ridley, A. J., and E. A. Kihn. 2004. Polar cap index comparisons with AMIE cross polar cap potential, electric field, and polar cap area. *Geophys. Res. Lett.*, 31, L07801. doi:10.1029/2003GL019113.

Kihn, E. A., and A. J. Ridley. 2005. A statistical analysis of the AMIE auroral specification. *J. Geophys.Res.* In press.

Kihn, E. A., R. Redmon, and A.J. Ridley. 2005. A statistical comparison of the AMIE derived and DMSPSSIES observed high-latitude ionospheric electric field, *J. Geophys. Res.*, Submitted.

### *Milestones 3.1.14.c*

Assess the quality of and long-term trends in Medium Energy Proton and Electron Detector (MEPED) and Total Energy Detector data recorded on NOAA Polar-Orbiting Operational Environmental Satellite program satellites and the Magnetometer data on Defense Meteorological Satellite Program satellites. Impact: This will be used to make the data useable and accessible to Internet users through our Space Physics Interactive Data Resource.

**Accomplishments**

Researchers successfully developed new algorithms for cleaning, analysis, and update of the NOAA-MEPED data. These algorithms were transitioned to routine operations at the NGDC and the user community has benefited by having a new, more reliable data source and understanding of that data. As a direct result, this project enabled several scientific works. Scientists used the MEPED electron measurements to understand how radiation belt electrons are rapidly lost from the magnetosphere. In addition, researchers used the MEPED data to understand how proton distributions are redistributed from equatorial to off-equatorial regions where they will interact with the atmosphere and produce red auroral arcs. A third study used the data to compare balloon observations to precipitating electron observations to understand how radiation belt electrons are lost. Researchers also used the MEPED precipitating electron measurements to understand the cause of precipitation bands, and correlated medium energy electron precipitation with the formation of $NO_x$ in the atmosphere.

### *Milestones 3.1.14.d*

Assess, upgrade, and operate the Boulder ionosonde observatory.

**Accomplishments**

The Boulder ionosonde was completely restored, including updates to the antenna array, implementation of real-time processing into the NGDC Space Physics Interactive Data Resource (SPIDR) system, and physical site improvements. Additionally, the CIRES team installed the Scion system; coordinated cutting of underground trenches; completed cabling routing; completed construction and rough alignment of eight antennas; performed transmit antenna characterization; and completed transmit antenna repair and replacement assessment. These improvements make the Boulder ionosonde one of the premier ionospheric data sources in the world.

## Project 3.1.15 Solar Disturbances in the Geospace Environment (SEC01)

**Goal: Improve the prediction of traveling solar disturbances that impact the geospace environment. Such disturbances, which are associated with both coronal holes and coronal mass ejections (CMEs) from the sun, can cause substantial geomagnetic effects leading to the crippling of satellites, disruption of radio communications, and damage to electric power grids. Assess the impact of disturbances at Earth through comparisons with GOES magnetometer data.**

### *Milestone 3.1.15.a*

Synoptic maps: Use recently developed methods for preparing uniformly generated synoptic maps of the solar photospheric magnetic field to build an archive of daily updated and full Carrington maps spanning the last solar cycle.

**Accomplishments**

Validation of solar coronal models in a quantitative and objective way is crucial to evaluate the quality of the different coronal models used as input to empirical and numerical solar wind models within the CISM (Center for Integrated Space Weather Modeling) community and the solar and heliospheric community at large. The aim of this project is to provide a metric to validate solar coronal models against observations. This includes validation of coronal holes and white light coronal streamers. The coronal hole metric is fully developed and the validation is underway. We have compared data and models for fourteen solar rotations at different levels of solar activity during the current solar cycle 23. We compare modeled coronal holes, defined as the foot-points of magnetically open field lines, with the observed coronal holes. To identify coronal hole regions we have developed an automatic scheme that uses a combination of solar images taken at different wavelengths and magnetograms. Because it is possible to have open field lines that are not rooted in coronal holes and the observational definition of coronal holes is not unique, we limit the comparison only to the sub-regions of the observed coronal holes that we can identify with high confidence. The metric is given by the percent of the observed coronal holes modeled as open field regions. We use two different coronal models: the WSA model based on a Potential Field Source Surface (PFSS) model and the Magnetohydrodynamic (MHD) SAIC coronal model, and run the computations using the same magnetic field data at the photospheric boundary.

### *Milestone 3.1.15.b*

Rocket data: Construct parametric forward models of GOES solar X-ray instrumentation.

**Accomplishments**

Parametric forward models of GOES solar X-ray

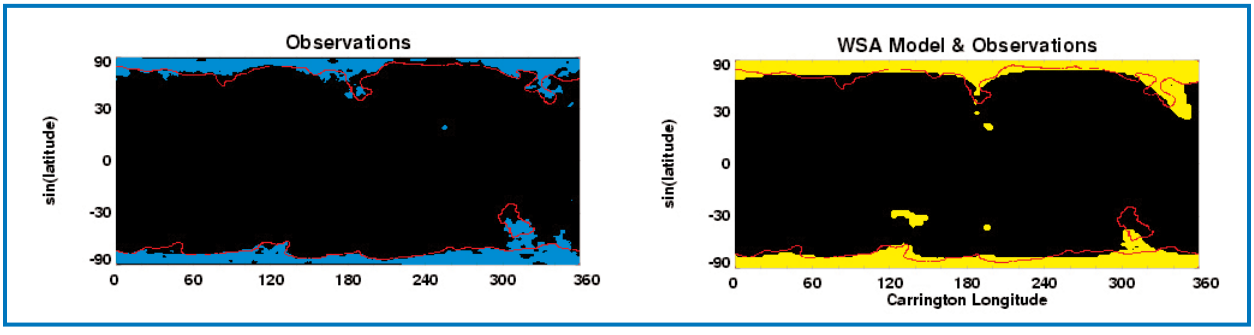



*Fig. 3.1.c and d. Coronal Hole Synoptic Maps.*
*Left: Comparison of coronal holes as determined by our computer code (blue) and by the NSO drawings (red contours). The code finds only the regions of the coronal holes that are visible at several wavelengths. Note that holes that appear separate in the drawings (bottom-right) are found to consist of a single coronal hole by the automatic code.*
*Right: Comparison between magnetically open field lines (yellow) as determined by the Wang-Sheeley-Arge (WSA) model and the observed coronal holes (red contours) for low solar activity, during May 1997. The model is in very good agreement with the observations and identifies 86% of the observed coronal holes.*

## Project 3.1.15 (continued)

instrumentation will improve knowledge of Solar X-ray Imager (SXI) and disk-integrated X-ray Sensor (XRS) instrument response. The National Oceanic and Atmospheric Administration (NOAA) has made X-ray measurements of the sun for over 30 years, beginning with the Synchronous Meteorology Satellites (SMS 1 and 2) and continuing through the many spacecraft of the Geostationary Operational Environmental Satellites (GOES) series. The SXI and disk-integrated XRS instruments currently flying are undergoing a sounding rocket 'underflight' calibration with the Avalanche X-ray Spectrometer (AXS), which made solar observations simultaneously with the GOES instruments. The AXS measurements provide the reference or 'solar truth,' which will be compared to the response functions of the GOES instruments. As a first step, we have worked to understand the instrument measurements during the rocket flight. Figures 3.1.e shows the SXI response during the first (left) and second (right) rocket flights. The signal during the first flight was very low, but we selected a few bright regions to minimize the signal to noise. During the second rocket flight the signal was higher, and the selection of a few bright regions greatly improved our signal-to-noise. Next we will obtain the AXS solar spectrum and propagate it through computer models of SXI and XRS performance. If our initial calibration estimate is correct and no significant degradations have occurred, the modeled SXI and XRS outputs should match fairly closely the actual outputs. Then, we will look more closely at noise, contaminating signals, and secondary effects like vignetting. Along with this effort, we will parameterize our instrument models and adjust those parameters to obtain the best fit to the observations. Applying these models will improve knowledge of SXI and XRS instrument response and the improved measurements will be beneficial to space weather forecasting.

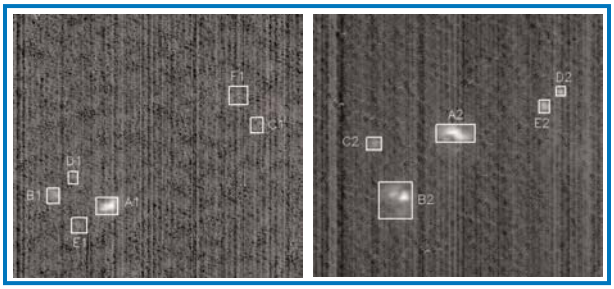



*Figure 3.1.e and f. SXI response during first and second rocket flights.*

### *Milestone 3.1.15.c*

EIT waves and dimmings: Catalog EUV dimmings and EIT waves from data coincident with observations of the corresponding eruptions. Compare the mass loss distribution in cataloged EUV dimmings with the corresponding eruption total masses.
W&S operational model: Bring the latest prototype of the CIRES-NOAA/SEC Wang-Sheeley-Arge (WSA) global solar wind fully and officially into operations at SEC.

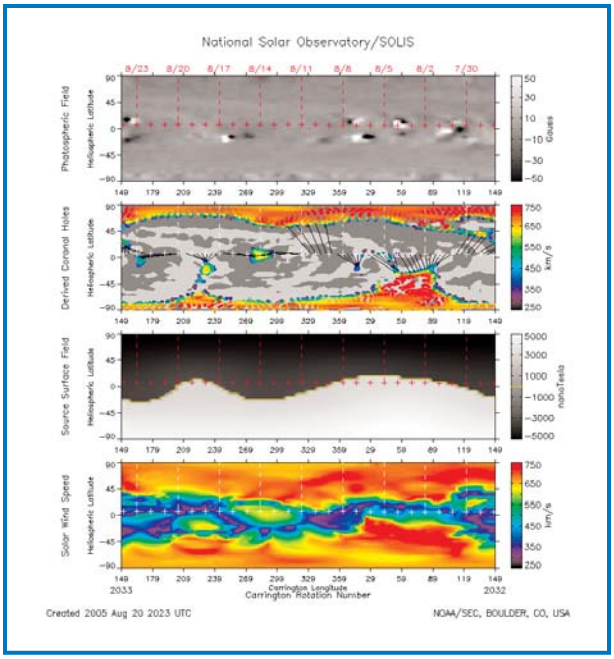



*Figure 3.1.q. Plots of output from newly improved and streamlined Wang-Sheeley-Arge model.*

**Accomplishments**
We reworked the CIRES-NOAA/SEC Wang-Sheeley-Arge (WSA) model to run more efficiently and to provide output in Flexible Image Transport System (FITS). The FITS format is a portable and self-describing format, which has been endorsed by NASA and the International Astronomical Union

## Project 3.1.15 (continued)

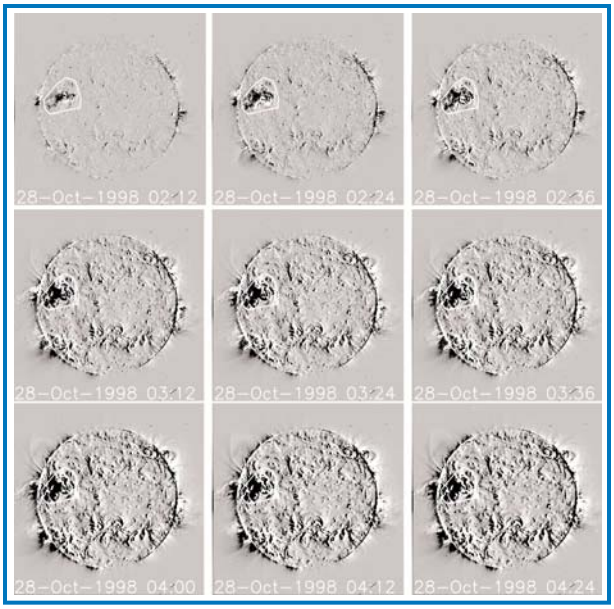



*Figure 3.1.g. EUV dimming (upper left quadrant) associated with solar eruption.*

for transfer of astronomical data. Figure 3.1.q shows an example of improved model output.

Investigation of the mass loss distribution in extreme-ultraviolet (EUV) dimming associated with the corresponding solar eruption will facilitate further research on the space weather forecasting. Coronal dimmings are a phenomenon frequently associated with CMEs (coronal mass ejections). Dimmings can vary in size, shape and intensity, with observations suggesting a relationship between the mass loss from the dimming region and the mass contained within the CME. We are conducting a statistical analysis of CME-associated dimming regions observed with the Extreme-Ultraviolet Imaging Telescope (EIT) on board the Solar and Heliospheric Observatory (SOHO) spacecraft. In this analysis we first determine the relative dimming of each event compared to a pre-event image. These dimmings are then compared with the CME mass as determined by Large Angle and Spectometric Coronagraph (SOHO/LASCO) observations to determine if a consistent relationship can be found. In figure 3.1.g, a dimming region in the upper left quadrant can be seen to develop over time. A region of interest (in white) is chosen which contains the dimming region and the dim pixels are summed over time for comparison with the LASCO mass. In the future, we will extend this analysis and compare EIT waves with CME-related characteristics. The results from this study are expected to provide insight into CME origins and

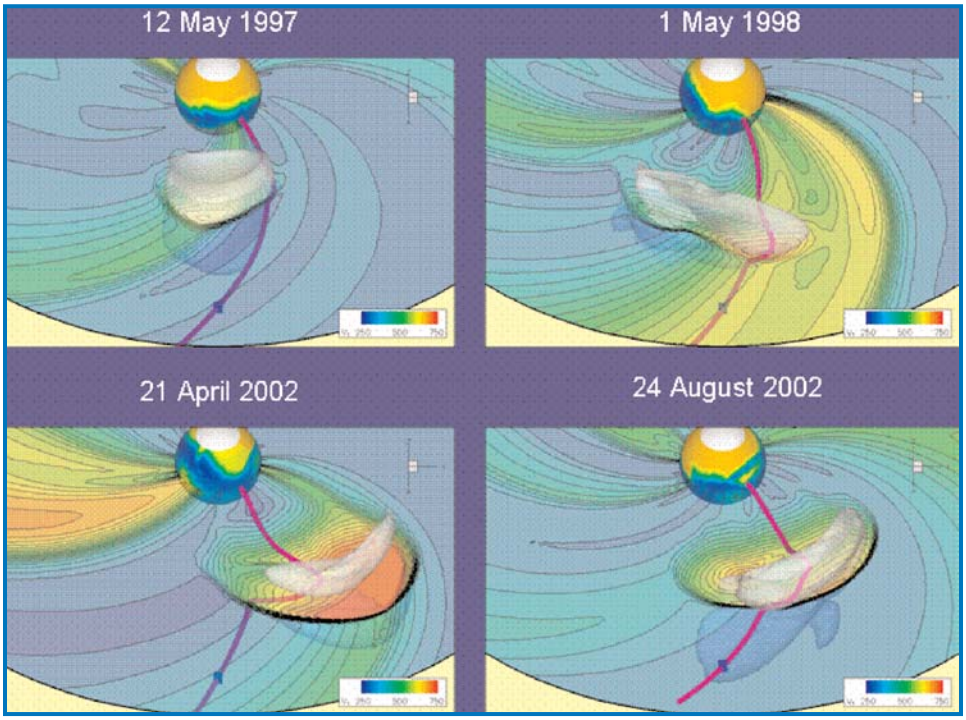



*Figure 3.1.h. Heliospheric disturbances during four solar events.*

## Project 3.1.15 (continued)

may help improve predictions of CME-related parameters.

### *Milestone 3.1.15.d*

3D MHD interplanetary propagation model: Incorporate a modern 3D magnetohydrodynamic (MHD) model into the WSA model to propagate the near-sun global solar wind outflow to Earth and beyond.

**Accomplishments**

The geospace environment is immersed in solar wind, and its state is significantly affected by various quasi-steady and transient phenomena of solar origin. We have continued the development of numerical codes and their space weather applications. In particular, we have (1) coupled the slowly evolving output of the NOAA/SEC Wang-Sheeley-Arge (WSA) and the SAIC 3-D MHD coronal models (based on photospheric observations of the solar magnetic field) with an advanced 3-D MHD interplanetary propagation model; and (2) incorporated the so-called cone model to simulate launching of coronal mass ejections (based on white-line coronagraph observations). Our interplanetary code, ENLIL, was implemented at the Community Coordinated Modeling Center (NASA/CCMC).

Figure 3.1.h shows heliospheric disturbances during four campaign events selected by the solar, heliospheric, and interplanetary environment (SHINE) community. The solar wind flow velocity is indicated by color scale on the coronal boundary at 30 solar radii and on the translucent equatorial plane. The injected cloud is shown as white translucent iso-surface. Earth position is marked by the blue box. The interplanetary magnetic field line passing through geospace is shown in pink.

### *Milestone 3.1.15.e*

Magnetospheric Response: Assess the response of the magnetosphere to solar disturbances by implementing already available magnetic field models and making long-term and detailed comparisons to observed data to assess data quality.

**Accomplishments**

Solar disturbances that impact the magnetosphere have a significant impact on magnetospheric current systems including the magnetopause current, the tail current, the ring current and field-aligned currents. Each of these current systems produces a magnetic field response observed by geosynchronous spacecraft such as GOES, and therefore observations of the magnetic field by GOES are extremely valuable for understanding solar-terrestrial interactions. To quantitatively understand various aspects of the interaction, it is important to have well-calibrated GOES magnetometer observations. This task is difficult because the recent GOES satellites are three-axis stabilized and spinning spacecraft are needed for determining magnetometer offsets. During the past year the GOES data has been prepared for long-term comparisons between models and data to better calibrate and intercalibrate GOES measurements. Therefore, we are deferring the major part of the comparison between the data and models to next year.

## Project 3.1.16 Modeling the Upper Atmosphere (SEC02)

**Goal: Understand responses of the upper atmosphere to solar, magnetospheric, and lower atmosphere forcing, and the coupling between the neighboring domains. Since many of the space weather effects occur in the ionosphere and neutral upper atmosphere it is important to develop an understanding of the system to the point were accurate specification and forecasts can be achieved.**

### *Milestone 3.1.16.a*

Complete the validations of algorithms to quantify the impact of solar protons on the ionosphere, and design a web-based interface to the data and model.

**Accomplishments**

Specification of the propagation characteristics of radio waves through the ionosphere is of high value to the development and maintenance of reliable communication and navigation systems. Application of the near-real-time GOES energetic particle data to the timely estimate of the ionospheric absorption of HF/VHF radio waves during energetic particle events constitutes an important part of that specification. CIRES, the National Geophysical Data Center, and the Space Environment Center have cooperatively developed a system for the near-real-time estimate and display of ionospheric HF/VHF radio-wave absorption during solar energetic particle events.

The GOES-7 and earlier satellites of this series had a spin axis approximately parallel to the Earth's rotation axis. The SEM particle detectors had rather large viewing apertures that looked out perpendicular to the spin axis. Because of this, and the fact that the accumulation time of the various detectors was long with respect to the spin period, the detectors exhibited a nominally omnidirectional response. Beginning with GOES-8 in 1996, the GOES satellites have been 3-axis stabilized and therefore the detectors now "stare" in a given direction. The question arose as to whether this circumstance would compromise the ability to reliably establish event start times and magnitudes.

In 2003, we had performed a study for the FAA in order to address this question as well as others. Examination of the 15 larger events of the period 1996 – 2003, for which data were available from two or more of the GOES satellites, indicated that there was no significant discrepancy (< +/- 5 min) in the determination of event onset time. While differences in reported fluxes as large as 20% were sometimes observed higher energies (>350 MeV) during the early onset period, lower energies showed decreasing discrepancy with energy. By the time the estimated dose at flight altitudes had maximized, the differences were much fewer. Further at the lower energies of consequence to the estimate of D-Region ionospheric absorption, the discrepancies were found to be only a few percent, which is insignificant relative the other uncertainties in such an estimate. It is noted, however, that the local time spanned by the then-available data platforms was only four hours. The subsequent move of the GOES-9 satellite to approximately 205 degrees west in 2003 increased the local time span coverage to more than eight hours, allowing a more stringent test.

Researchers therefore examined these data in light of GOES more definitive coverage. While the GOES-9 data are not routinely processed, we made data available for the three Energetic Particle Events of the "Halloween Storm" period of 28 Oct – 4 Nov 2003. Analysis of these data confirmed that there appears to be no difference of consequence in the estimates of enhanced D-Region ionospheric absorption and aircraft radiation exposure due to the longitude of the GOES satellite providing the data source.

### *Milestone 3.1.16.b*

Validate the total electron content (TEC) prediction from the US-TEC assimilative model by comparing with available ionospheric observations, including the altimeter data from the JASON satellite.

**Accomplishments**

In conjunction with the United States National Geodetic Survey and the Los Alamos National Laboratory, validation of the United States Total Electron Content (USTEC) nowcast system has been under way. USTEC is currently under installation for operational use at the Space Environment Center in Boulder, Colorado, and will provide real-time maps of the electron content in the ionosphere. Researchers have compared results from

## Project 3.1.16 (continued)

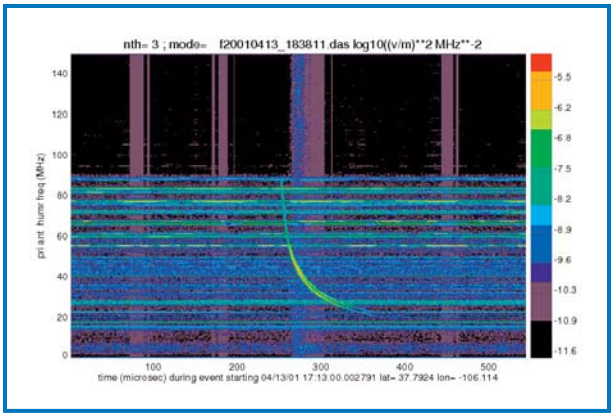



*Figure 3.1.j. A pulse recording by the FORTE satellite.*

MAGIC, the analysis version of USTEC, against total electron content data from the Fast Onboard Recording of Transient Events (FORTE) satellite to evaluate the combined error level of the two systems. The FORTE satellite, able to detect lightning, observes the frequency versus the arrival time, as shown in Figure 3.1.j, for a broadband (pulse) VHF signal transmitter at Los Alamos National Laboratory, New Mexico. The resulting group-delay measurements can be used to estimate the TEC along the raypath. The same raypath from the MAGIC map can be calculated if the geographic coordinates for Los Alamos and the FORTE satellite position are provided. The FORTE raypath and MAGIC map solutions are compared to estimate the combined accuracy for both systems.

An example of the comparisons between the FORTE and MAGIC solutions can be seen in Figure 3.1.k, for a single FORTE pass over Los Alamos. A statistical analysis over many satellite passes provides an estimate of the expected uncertainty in both the FORTE and MAGIC systems. Using the operational 60-station list for USTEC, comparisons of MAGIC to FORTE indicate an error of 1.659 TECU. Increasing the station list to 133 in USTEC decreased the errors further to 1.148 TECU.

Currently, the largest error source for the Global Position System (GPS) comes from not knowing the real-time ionospheric conditions to accurate levels. TEC estimates from USTEC at the low error levels, as indicated in this study, shows that our knowledge of the real-time ionospheric conditions has indeed increased. The improved specification of the ionosphere, through USTEC, will decrease GPS errors due to ionospheric effects.

### *Milestone 3.1.16.c*

Perform comprehensive analysis of the numerical simulations of the storm response to magnetospheric penetration and disturbance dynamo electric fields, utilizing a coupled model of the thermosphere-ionosphere-plasmasphere-electrodynamic system. In particular, quantify the response to each of the sources and the feedback between them.

**Accomplishments**

The direct penetration of the high-latitude electric field to lower latitudes, and the disturbance dynamo, both play a significant role in restructuring the storm-time equatorial ionosphere and thermosphere. Although the fundamental mechanisms generating each component of the disturbance electric field are well understood, it is difficult to identify the contribution from each source in a particular observation. In order to investigate the relative contributions of the two processes, their interactions, and their impact on the equatorial ionosphere and thermosphere, researchers modeled the response to the March 31, 2001, storm, using the Rice Convection Model (RCM) and the Coupled Thermosphere-Ionosphere-Plasmasphere-Electrodynamics (CTIPe) model. The mid- and low-latitude electric fields from RCM have been imposed as a driver of CTIPe, in addition to the high latitude magnetospheric sources of ion con-

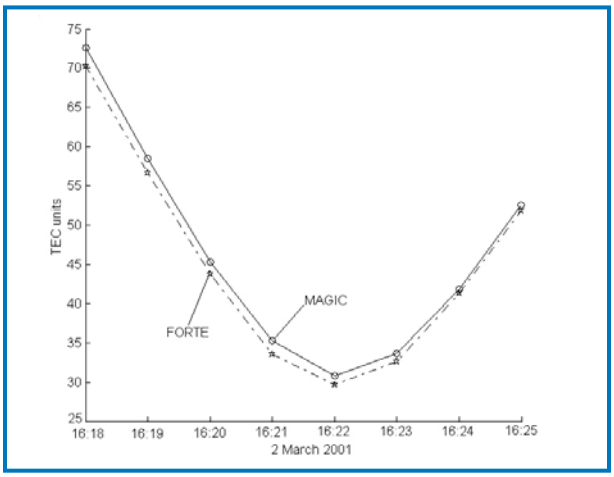



*Figure 3.1.k. TEC values from FORTE and MAGIC.*

## Project 3.1.16 (continued)

vection and auroral precipitation. The high-latitude sources force the global storm-time wind fields, which act as the driver of the disturbance dynamo electric fields. We compared the magnitudes of the two sources of storm-time equatorial electric field for the March 2001 storm period (Figure 3.1.L). During daytime, and at the early stage of the storm, the penetration electric field is dominant; at night, the penetration and disturbance dynamo effects are comparable. Both sources are sufficient to cause significant restructuring of the low-latitude ionosphere. Our results also demonstrate that the mid- and low-latitude conductivity and neutral wind changes initiated by the direct penetration electric field preferentially at night are sufficient to alter the subsequent development of the disturbance dynamo.

**Additional Accomplishments**

Researchers assembled an ionospheric F2 critical-frequency database to determine the variability of the F-region as a function of local time, latitude, season, and geomagnetic activity. The database comprises observations from 75 ionosonde stations covering a range of geomagnetic latitude, and includes 43 storm intervals. The database was previously used to develop an empirical storm-time ionospheric correction model (STORM). We evaluated the mean and standard deviation by sorting the data by local time, season (5 intervals centered on equinox, solstice, and intermediate intervals), latitude (four regions, each 20° wide in geomagnetic latitude), and up to eight levels of the geomagnetic activity index, which was based on a

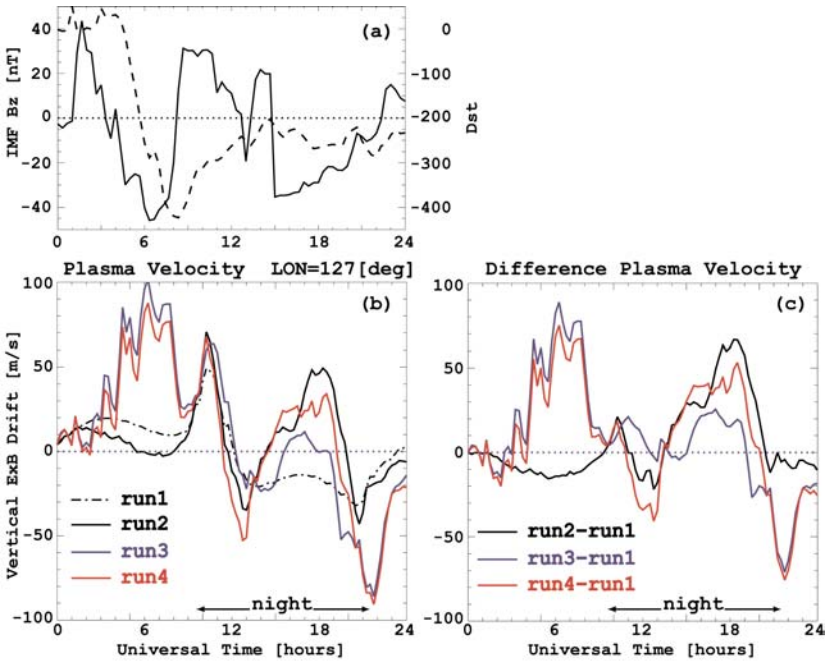



*Figure 3.1.L. (a) GSM z-component of the interplanetary magnetic field (IMF) measured by SWEPAM and MAG instruments on board the ACE spacecraft (time-shifted to the sub-solar magnetopause location) shown by solid line, and the Dst (SYM-H) index plotted by dash line, for March 31, 2001. (b) An example of the vertical ExB drifts at the magnetic equator obtained from CTIPe , at 127 degree longitude. At this longitude sector, 00 UT corresponds to 8.47 LT. Four different CTIPe simulations are shown. The black dash line is the quiet time reference (run1). The black solid line is the simulation with DD effect only (run2). The blue solid line is the simulation with the DP electric field only (run3). The red solid line is the simulation including both effects of the DD and DP electric fields (run4). (c) Same as (b), but the changes in the drifts from the quiet time (run1).*

## Project 3.1.16 (continued)

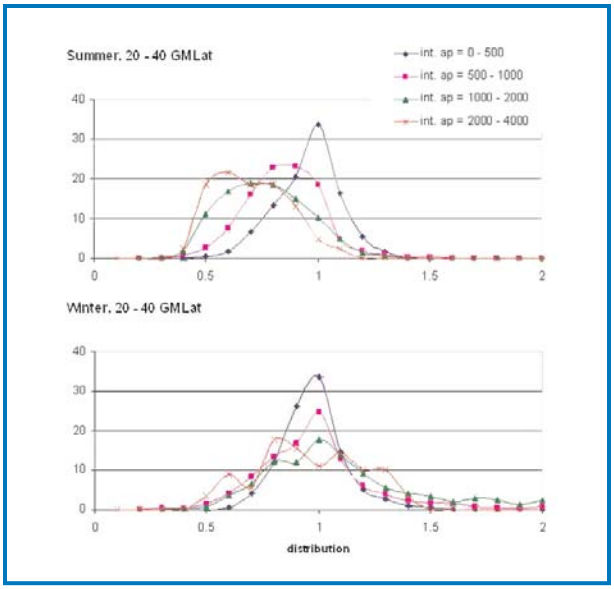



*Figure 3.1.m. Illustration of the near Gaussian distribution of ionospheric variability at mid latitude in both summer and winter.*

weighted integral of the previous 33 hours of $a_p$. The database covers a full solar cycle, but insufficient information was available to sort by solar activity without compromising the estimates of variability on the other sorting parameters. About half the data were contained in the first level of geomagnetic activity, between 0 and 500 units of filtered $a_p$ corresponding to $K_p$ less-than-or-equal-to 2, and half above that level. When local time dependence was included in the binning, sufficient data were available to sort into two levels of geomagnetic activity, quiet ($K_p$ less-than-or-equal-to 2+) and disturbed ($K_p$ greater-than 3). For all latitudes and levels of geomagnetic activity, the lowest variability was typically found in summer (10-15%), the largest variability occurred in winter (15-40%), with equinox (10-30%) lying between the solstice extremes. The exception was low-latitudes at equinox, which had surprising low variability (10%), possibly due to the weak interhemispheric flow at this time of year. At mid- and low latitudes, the variability tended to increase with geomagnetic activity in winter and equinox, but remained fairly constant in summer. The most surprising result was that at high latitudes, in all seasons, but in winter in particular, the variability tended to decrease, probably due to the increased upwelling of neutral molecular species and stronger chemical control of the ionosphere. The data has also been used to build a table of estimated variability suitable for inclusion in the International Reference Ionosphere.

In addition, we have utilized the extensive network of ground-based, dual-frequency Global Positioning System (GPS) to obtain measurements of the ionospheric Total Electron Content (TEC). The TEC has been extracted from the GPS observations using either a regional or global Kalman filter, in order to separate the TEC from the receiver biases. To build the database, we used three different packages and a neural network approach: Win TEC Project (CIRES/University of Colorado and SEC/NOAA), GAIM (Utah State University), MAGIC (SEC-NOAA and NGS-NOAA). More than twenty 10-day storm periods have been processed and the results analyzed. We extracted the storm response of TEC from the data as a ratio to the quiet periods preceding the storms, and sorted as a function of latitude and a storm index defined as the integral, or filtered, $a_p$ over the previous 33 hours. When studying the 10-day periods, a consistent shape of the storm response appears for the mid-latitudes; a clearly-defined positive phase (Figure 3.1.m) early in the storm is seen under certain UT conditions, followed by a long negative phase. These features are more clearly identified by separating the data between the "driven" phase of the storm, when the integral of $a_p$ is rising, and the "recovery" to the storm, when the integral of $a_p$ is declining. The "driven" phase shows a positive phase for the mid-latitude region when CONUS is in the right local time sector, while the "recovery" shows a negative phase. The existence of the positive phase over CONUS at the beginning of the storm period seems to be related to the timing of the peak of the perturbation; a positive phase will be observed when the peak of the perturbation occurs near midnight UT.

In other related research, we began development of a data assimilation system for improving the thermospheric drivers, based upon the Kalman filter.

## Project 3.1.16 (continued)

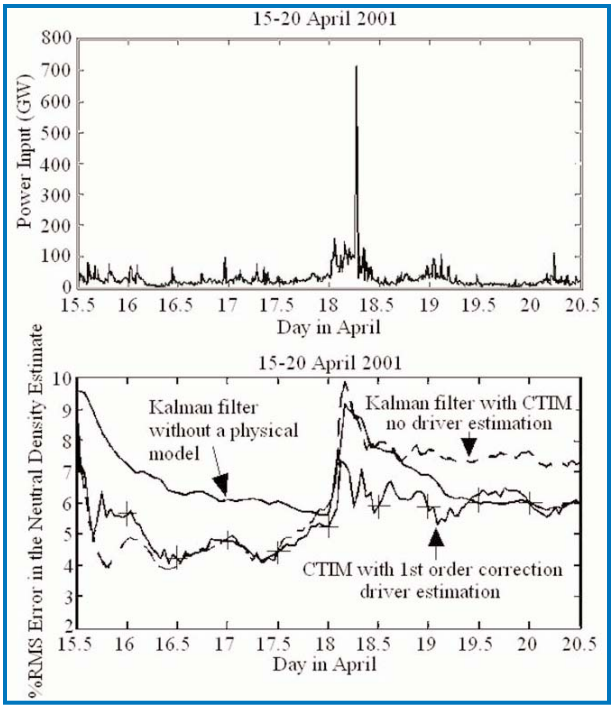



*Figure 3.1.o. A comparison of solutions with no model, model without drivers, and a first-order correction to the drivers.*

This system takes in multiple data types from various remote sensing and in situ sources to estimate the state of the thermosphere as well as the upper atmospheric drivers. Because the thermosphere is strongly driven by external processes, the thrust of research over the last year has shifted toward improving the specification of these drivers, as opposed to estimating the density parameters alone. Drivers can be indirectly observed through the thermospheric response to storms using the physical model, the Coupled Thermosphere-Ionosphere Model (CTIM) (Fuller-Rowell et al., 1996), which has proved to be a substantial advantage since global, direct measurements of the drivers are difficult to obtain in real time.

Results show that improved driver specification can greatly improve accuracy during geomagnetic storms, as illustrated in Figure 3.1.o, showing the simulation of an actual geomagnetic storm during 15-20 April 2001. The power input, in gigawatts, of this storm is shown in the top panel of the figure. In the bottom panel, three data assimilation systems are shown: no model (solid line), model without drivers (dashed line), and model with drivers (solid line with crosses). In all cases, the %RMS error increases during the geomagtic storm between 18 and 18.5 hours. The "no driver" results are similar to having no model since the state is "pushed" away by the incorrectly driven model. When including the drivers and model in the Kalman filter, the errors are greatly reduced, particularly during the storm period between hours 18 and 18.5. The results from this research have quantified the importance of driver specification in data assimilation systems. It has also provided the upper atmospheric data assimilation community with insight, understanding, and new solution methods for specifying the driver/thermosphere system.

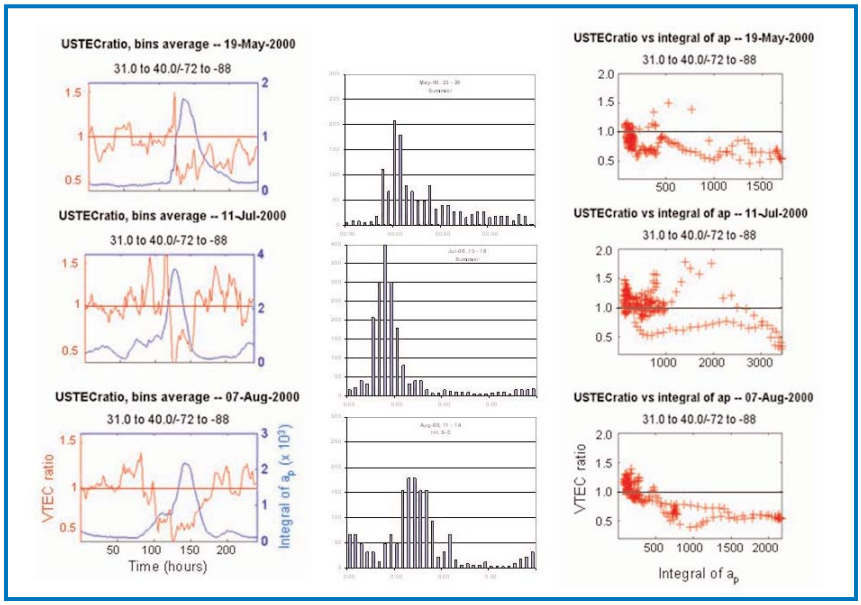



*Figure 3.1.n*

## Project 3.1.17 Information Technology and Data Systems (SEC03)

**Goal: Determine the necessary data systems and infrastructure required for the successful implementation of empirical and physical models of the space environment, together with fast and efficient access to appropriate data sources.**

### *Milestone 3.1.17.a*

Define and deploy next generation ingest and processing systems for three to five space weather data streams. Upgrade legacy IT applications to utilize new shared system services and new data stores. Complete "GetData" client to provide a common application interface for accessing SEC data and metadata.

**Accomplishments**

Addressing the need for high-availability data-ingest-processing-dissemination architecture, researchers deployed the XML-based GetData Data Bridge server, and deployed the SEC messaging service. We also instrumented logging to the SEC logging service from multiple SEC applications, and deployed operational and development web interfaces to the SEC logging service. Researchers further developed Data Bridge clients for Java, RSI-IDL and C++, and researched and evaluated Application Servers as a scalable middle-tier technology. During the year, we performed testing and deployment of the SEC Track+ issue tracking tool, and evaluated Status Monitor applications for implementing an SEC monitoring and recovery service.

Researchers completed several legacy systems upgrades, including completing design and analysis for porting RGON pre-processor to the new Linux platform; re-designing the SXI-processor to eliminate a custom C-interface to RSI/IDL software, by introducing capability to directly access the RSI/IDL DLL, and the introduction of the SEC (Spread) Messages Service to support new deployment of RTIS clients. In addition, we upgraded to the COMM system to acquire data from additional data sources.

We developed several new applications to improve systems. We designed, implemented, and deployed the SEC Product Subscription service, and released FIDS, an FTP ingest and dissemination system for SEC data. We completed design of software for making USGS "near-real-time" and for making magnetometer data available to the SEC.

### *Milestone 3.1.17.b*

Assist in maturing and integrating Space Weather Models into SEC production IT infrastructure. Perform analysis to understand model operational concepts, data input/output requirements and programmatic interfaces. Develop interface software needed for reliable model operations within SEC.

**Accomplishments**

The enhancement of radiation at aircraft altitudes due to the presence of both galactic cosmic rays (GCR), which are always present, as well as radiation due to the sporadic occurrence of Solar Energetic Particle (SEP), are events that have been recognized for many years. The FAA has developed computer code (currently CARI-6) by which radiation exposures due to GCR may be calculated for a given location or flight path and date. No corresponding code had yet been available to estimate the occasional contribution to the total aircraft dose due to the sporadic occurrence of SEPs. This solar contribution may far exceed that due to inescapable GCRs, and result in total accumulated dose levels in excess of those permitted.

Aircraft passengers and crew are constantly exposed to ionizing radiation at higher dose rates than those received by the general population. Galactic Cosmic Rays provide for a continual although solar-cycle varying source of that radiation. Occasionally, a disturbance on the sun leads to the presence of a large flux of solar protons with sufficient energy to penetrate the earth's magnetic field and atmosphere and increase the ionizing radiation levels at aircraft flight altitudes.

Researchers developed software for the continuous evaluation of the estimated radiation enhancement at aircraft altitudes during such energetic solar particle events, based on the measurement of the geostationary particle environment provided by the NOAA GOES series of satellites. We defined procedures and developed a system for the processing of the GOES observations and the subsequent distribution of the results, which have been implemented by the FAA with the cooperation of NOAA. Results are described in the recent

## Project 3.1.17 (continued)

publication, *Solar Radiation Alert System*. Schematically, results are illustrated in Figure 3.1.p. (1) Occasionally, a disturbance in the sun (solar flare, coronal mass ejection) leads to a large flux of high-energy particles in the vicinity of the Earth. (2) Instruments on a GOES satellite continuously measure the radiation and the information is transmitted to NOAA. (3) From there it is sent to the Civil Aerospace Medical Institute (CAMI). A computer at CAMI analyzes the measurements. (4) If the measurements indicate the likelihood of a substantial elevation of ionizing-radiation levels at aircraft flight altitudes, a Solar Radiation Alert is issued to the NOAA Weather Wire Service within 10 minutes. (5) NOAA Weather Wire Service subscribers are provided estimated effective dose rates for 30,000, 40,000, 50,000, 60,000, and 70,000 feet. This information is updated at five-minute intervals for the duration of the alert.

### *Milestone 3.1.17.c*

Complete development of the GOES N ground data systems IT infrastructure needed for post launch test. Provide analysis and technical support to algorithm development, instrument checkout and data verification.

**Accomplishments**

Researchers undertook several tasks related to GOES-N preparation and development. We designed the initial GOES-N Data Bridge left hand side C++ shared object to retrieve SXI and PCM data from the SOCC provided MRS&S server and provide it to the LabView right hand side. In conjunction, we developed a new Detailed User Requirements document format for use on the GOES-N Preprocessor project (PP-N) and mentored five scientists through the requirements development process. As part of this process, we developed two prototype PP-N preprocessors, capable of subscribing to telemetry sources and ingesting high bandwidth SXI telemetry into its component values. In preparation for the data, we developed a system to validate data quality and to write the received telemetry values into a distributed database at over fifty times the expected data rate. And finally, we designed and developed the GOES-N SXI data processing prototype software.

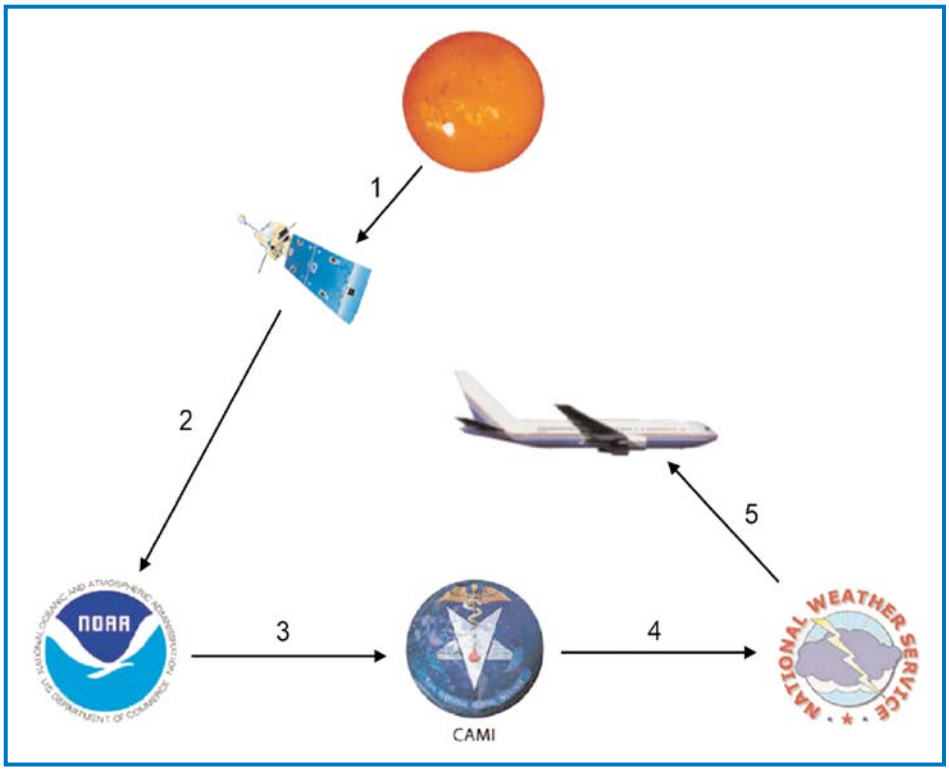



*Figure 3.1.p. Solar radiation alert system.*

# 3.2 Climate System Variability

Climate variability affects virtually all natural systems and human activities. Climate directly impacts such vital areas as agriculture, water quantity and quality, ecosystems, and human health. Understanding and potentially predicting climate changes are therefore critical to the public, as well as to a broad array of decision-makers within federal and state governments, industry, resources management, and hazard mitigation programs. Indeed, basic issues include determining whether observed changes may be attributable to either natural or anthropogenic forcing and the extent to which natural and human-induced changes may be linked. Prediction problems of vital importance include estimating changes in the likelihood of extreme events and identifying risks for abrupt climate change, because of the potential for and likelihood of major societal and ecological impacts resulting from such events. The major research partners in this theme include the Climate Diagnostics Center (CDC), the Aeronomy Laboratory (AL), the Climate Monitoring and Diagnostics Laboratory (CMDL), the National Snow and Ice Data Center (NSIDC) and the Program in Atmospheric and Oceanic Sciences (PAOS). Research done under this theme is especially useful to CIRES Center for Science and Technology Policy Research, as results are often relevant to risk forecasting, management, and mitigation.



## Project 3.2.1 Chemistry, Radiative Forcing, and Climate (AL03)

**Goal: (i) Observe and model the radiative forcing due to stratospheric ozone changes and tropospheric radiatively active gases. (ii) Carry out upper-troposphere airborne experiments and diagnostic analyses that characterize the dynamical and chemical processes that influence the radiative balance in the global atmosphere. (iii) Quantify the chemical and optical properties that determine the lifetimes, abundances, and trends of greenhouse gases.**

### *Milestone 3.2.1.a*

Build on the newly-acquired understanding of the interactions of ozone, water, and nitric acid in the upper tropical troposphere to better characterize transport and cirrus cloud formation there.

**Accomplishments**

The nucleation and growth of ice and other solid-phase particles in the upper troposphere and lower stratosphere affect chemical composition and climate forcing. For example, ice formation in the tropopause region regulates stratospheric humidity through particle sedimentation and controls the radiative properties of high clouds. In addition, polar stratospheric clouds, when composed of nitric acid trihydrate (NAT), sediment and denitrify the lower stratosphere in winter and thereby enhance photochemical ozone destruction. Theoretical efforts have had limited success in identifying and quantifying atmospheric nucleation processes, in part, because of incomplete knowledge of aerosol composition and its affect on

## Project 3.2.1 (continued)

nucleation. This in turn limits our current understanding of how global change might alter future cloudiness, stratospheric dehydration, and ozone concentration.

Our analysis of airborne in situ measurements onboard the NASA WB-57F high-altitude research aircraft revealed a new category of nitric acid-containing particles in the tropical lower stratosphere. These particles are most likely composed of NAT, which is the most stable solid phase of nitric acid in the upper atmosphere. These particles were observed in a narrow layer just above the tropopause (18±0.1 km), and over a broad geographic region (>1100 km) south of San José, Costa Rica. Balloon-borne in situ measurements in the deep tropics from Ecuador and Suriname indicate that a narrow (~4 km) layer near the tropopause is favorable for the existence of these particles (Fig. 3.2.a). Results suggest that these particles could routinely form near the tropical tropopause.

Several important implications follow from the observations of tropical NAT particles and inferred formation conditions. First, it seems reasonable to speculate that the tropical and polar NAT particles nucleate with a common process, because low NAT particle concentrations are observed in both regions. Definitive identification of the tropical NAT particle nucleation process is likely to further our understanding of particle nucleation processes in the polar regions. Second, ice particles might form via a similar nucleation process and with the same nuclei as tropical NAT particles. A dilute population of ice particles could grow, sediment near the tropical tropopause, and, thereby, represent a new contributing pathway to stratospheric dehydration. Third, at the particle concentrations and sizes observed, these NAT particles will not be observable from space-based remote instruments. These results showcase the value of high-quality in situ measurements in the upper troposphere and lower stratosphere.

### *Milestone 3.2.1.b*

Carry out and analyze field observations to improve remote observations of cloud properties and solar radiation.

**Accomplishments**

The role that aerosols play in changing the radiative properties of clouds is uncertain, and even the sign of the forcing is undetermined. The need for remotely sensing clouds is becoming more apparent as the desire to achieve a global estimate of the radiative forcing due to changes in clouds to improve predictive climate models grows. A network of ground-based or satellite measurements is the most likely approach for providing the high temporal and spatial resolution required to reduce

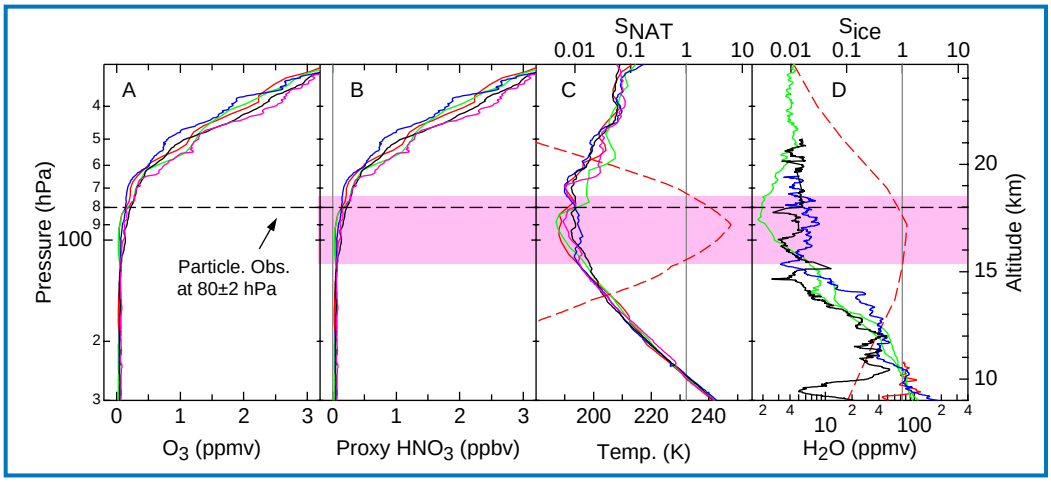



*Figure 3.2.a. Vertical profiles of ozone (A), proxy nitric acid (B), temperature (C), and water vapor (D) from balloon-sonde measurements in the deep tropics. The purple region represents the altitude range favorable for the growth of NAT particles (SNAT>1), calculated using the median values of nitric acid, temperature and water vapor.*

## Project 3.2.1 (continued)

some of the uncertainty that currently exists for global cloud properties. The measurement of atmospheric clouds by spectroscopic observations is an inexpensive means of assessing these properties.

Researchers made airplane-based spectroscopic observations of clouds as part of the New England Air Quality Study from 3 July to 15 August 2004. Additionally, we conducted an intensive ground-based measurement campaign at the Aerosol and Radiation Measurement site in Barrow, Alaska from 12 September to 21 October 2004. We made spectral measurements in the near-infrared wavelength region between 900 nm and 1700 nm and measured solar radiances at 500 nm and 780 nm.

Collaboration between CIRES and the NOAA Aeronomy Laboratory has led to the development of a new technique for deriving the path integrated liquid water path (PLWP) and ice water path (PIWP), both climatically important parameters, from the spectral measurements. The solar flux measurements are combined with the PLWP values to provide an estimate of the effective radius of the cloud particles and liquid water path (LWP). Auxiliary measurements conducted during the Barrow campaign with microwave and radar instruments can also be combined with these data products to obtain the effective radius, leading to an improvement in remote sensing capabilities of cloud information.

### *Milestone 3.2.1.c*

Evaluate the climate friendliness of fluoroethanol, a substitute for the now-banned chlorofluorocarbons (CFCs), by measuring the rate coefficient for its reaction with hydroxyl radicals and calculating its atmospheric lifetime.

**Accomplishments**

2-fluoroethanol ($CFH_2CH_2OH$) is proposed as a possible substitute for the CFCs, which are phased out because of the Montreal Protocol on stratospheric ozone depleting substances. This molecule is expected to be removed from the atmosphere mostly via its reactions with the OH radical. Therefore, the rate coefficients for the reaction, $OH + CFH_2CH_2OH \rightarrow$ products ($k_1$), were measured, using the pulsed laser photolysis-laser induced fluorescence (PLP-LIF) technique between 238 K and 355 K to be $(5.15 \pm 0.88) \times 10^{-12} \exp[-(330 \pm 45)/T]$ $cm^3 \times molecule^{-1} \times s^{-1}$; $k_1(298\ K) = 1.70 \times 10^{-12}$ $cm^3 \times molecule^{-1} \times s^{-1}$. The UV absorption cross sections of $CFH_2CH_2OH$ was also measured to ascertain its photolytic lifetime. We used these data, combined with the infrared absorption cross section for $CFH_2CH_2OH$ measured here, to calculate the global warming potentials (GWP) for $CFH_2CH_2OH$ of 8, 2, and 1, respectively, for the 20-, 100- and 500-year horizons. Researchers sketched out the atmospheric degradation of $CFH_2CH_2OH$ and concluded that no major long-lived or toxic substance would be produced during the atmospheric degradation of $CFH_2CH_2OH$.

The calculated GWP for $CFH_2CH_2OH$ is very small, and the atmospheric degradation of $CFH_2CH_2OH$ will not lead to the formation of any long-lived greenhouse gases or the formation of a persistent toxic substance. Therefore, from an environmental point of view, it appears that $CFH_2CH_2OH$ would be an acceptable substitute for CFCs. Thus, a molecule that is proposed by industry is shown to be acceptable for the environment, and the phase out CFCs can be carried out with minimal impact on society. This research helps to define the potential climatic implications of a CFC substitute, information that is needed by decision makers in industry and government who seeking CFC substitutes that are both climate friendly and ozone friendly.

## Project 3.2.2 Tropospheric and Stratospheric Transport and Chemical Transformation (AL04a)

**Goal: (i) Improve theoretical capabilities to predict the natural and human influences on the stratospheric ozone layer. (ii) Characterize the photochemical reactions relating to the human-induced loss of ozone in the stratosphere. (iii) Carry out in situ studies of the photochemical and dynamical processes that influence the stratospheric ozone layer.**

### *Milestone 3.2.2.a*

Investigate the roles of dynamics and chemistry in the maintenance of the ozone distribution in the upper troposphere and lower stratosphere, with particular reference to the eastern tropical and central subtropical Pacific.

**Accomplishments**

The Winter Storms 2005 campaign once again provided a wealth of in situ ozone measurements within the upper troposphere and lower stratosphere over the central subtropical Pacific from the Gulfstream IV aircraft. Measurements near the subtropical jet stream were of particular importance since this is a region of interaction between the stratosphere and troposphere. Distributions of ozone near the subtropical jet provide a means of determining how much air has been exchanged between the stratosphere and troposphere, and where and when the exchange took place.

Our measurements from the Winter Storms 2005 campaign confirmed findings from previous years, primarily that the exchange of ozone between the stratosphere and troposphere is quite limited in regions of a zonally oriented jet stream during winter and early spring. In regions of jet stream deceleration, called jet exit regions, exchange of ozone between the stratosphere and troposphere is much more common and results in the presence of relatively high ozone mixing ratios in the upper troposphere and low ozone mixing ratios in the lower stratosphere downstream from these regions.

The high-resolution, in situ measurements reveal many regions of very large ozone gradients within small spatial distances in the lower stratosphere. These large gradients result from the dynamical stirring and mixing of air across the subtropical jet stream. The implication of these gradients is that very different chemical reactions can occur within small distances in the lower stratosphere. Since computing power limits the resolution of climate models, these small distances cannot be resolved, which makes the simulation of ozone and other trace gases in this region quite challenging.

### *Milestone 3.2.2.b*

Measure the rate coefficients for the reactions of hydroxyl radicals (OH) with dichlorine monoxide ($Cl_2O$) and hypochlorous acid (HOCl) to fully elucidate the halogen chemistry in the lower stratosphere.

**Accomplishments**

Cl and ClO, the active chlorine species (that is, those that take part in radical chain reactions) catalytically destroy stratospheric ozone. Only a small fraction of the total available chlorine is in this form in the stratosphere. To quantify this, one needs to consider all the possible reactions involving chlorine-containing molecules. Hypochlorous acid (HOCl) is one such stratospheric molecule for which reactions need quantification. Specifically, the rate coefficient for the reaction of HOCl with OH is one of the last remaining major uncertainties in calculating the fraction of active chlorine in the stratosphere and the magnitude of chlorine catalyzed ozone destruction cycles.

HOCl is a very labile compound and it is difficult to produce it in the laboratory in the absence of $Cl_2O$, with which it is often in equilibrium. Also, $Cl_2O$ reacts more rapidly with OH than HOCl. Therefore, to study the reactions of HOCl, one needs accurate values for the rate coefficients for the reaction of $Cl_2O$ with OH. To this end, we measured the rate coefficient for the OH + $Cl_2O$ reaction in the laboratory to be $k = (4.0 \pm 2.0) \times 10^{-12} \exp[(175 \pm 70)/T]$ $cm^3 \times molecule^{-1} \times s^{-1}$. These results are useful not only for elucidating the HOCl reactivity, but also for understanding the trend in OH reactivity with chlorinated species.

Using the rate coefficient for the reaction of OH with $Cl_2O$ measured here, we determined the rate coefficient for the reaction of OH with HOCl to be $(8 \pm 2) \times 10^{-13}$ $cm^3$ $molecule^{-1}$ $s^{-1}$, by subtracting the contribution of the OH with $Cl_2O$. The rate

## Project 3.2.2 (continued)

coefficient is not as accurate as one would have wished, but the current uncertainty of a factor of three has been reduced to roughly a factor of 1.5; this is sufficient to quantify the role of the OH + HOCl reaction in the stratosphere.

The reaction of OH with HOCl is one of the major remaining uncertainties in the halogen chemistry of the atmosphere. Better quantification of the reaction rate helps to improve the understanding of the chemistry associated with depletion of the protective stratospheric ozone layer.

## Project 3.2.3 Climate Dynamics (AL05)

**Goal: Conduct research to improve understanding of (i) tropical Pacific Ocean dynamical processes related to the subseasonal atmospheric variability, (ii) the dynamics and the microphysics of precipitating cloud systems, and (iii) atmospheric circulation, convection, and moisture and heat budgets associated with the El Niño phenomenon.**

### *Milestone 3.2.3.a*

Determine whether oceanic Kelvin modes, which appear to propagate very rapidly eastward, are "breaking" waves, resulting in irreversible changes in sea surface temperature which then lead to air-sea interactions that cause El Niño.

**Accomplishments**

Researchers developed a statistical model relating oceanic Kelvin waves and the atmospheric disturbances that force them, to discern how relationships between these processes change with the basic state and the El Niño/Southern Oscillation (ENSO) cycle. The model suggests that when the waves break or produce positive sea surface temperatures in some other manner, they can affect atmospheric convection and winds. The model shows that during periods of trend toward El Niño conditions, the downwelling Kelvin waves couple to atmospheric convection in a manner that allows the waves to strengthen the westerly winds that lay west of the wave crests, allowing the waves to continue to amplify. The waves then result in the incremental changes in East Pacific sea surface temperature (SST) that dominate periods of transition toward El Niño conditions. The model also suggests that during periods when conditions are trending away from El Niño, this coupling either does not occur or it is limited to the far western basin, and the initial development of Kelvin waves is followed by abrupt transition to enhanced trade winds, which cause the waves to deteriorate. These results together suggest that the ultimate impact of Kelvin waves on East Pacific SST depends largely on the duration of westerly anomalies in the western basin and the timing of basin-wide easterly trade surges with respect to developing Kelvin waves. The implied importance of intraseasonal atmospheric forcing to ENSO suggests that seasonal forecasting of ENSO, based on the current state of intraseasonal variability, is reasonable, but any apparent skill in forecasts of month-to-month variability beyond a season is likely to be artificial.

### *Milestone 3.2.3.b*

Participate in the North American Monsoon Experiment (NAME) field campaign by deploying multiple Doppler radar profilers on the West coast of Mexico to estimate the vertical air motion and raindrop size distributions of the monsoon rain.

**Accomplishments**

During the 2004 North American Monsoon Experiment (NAME 2004), researchers deployed five vertically pointing Doppler radar profilers to measure the profile of horizontal wind and the vertical structure of the precipitating cloud systems that advected over the radar sites. Four radar profilers were located along the west coast of Mexico along the Gulf of California between Mazatlan and Puerto Penasco. The fifth radar profiler was located on a ship that maintained a fixed location on the Tropic of Cancer in the Gulf of California. Three profiler sites were deployed by the National Center for Atmospheric Research (NCAR), and two profiler sites were deployed by

## Project 3.2.3 (continued)

NOAA Environmental Technology Laboratory (NOAA/ETL). The radar profilers supply measurements of the vertical structure of the precipitating cloud systems as well as the time evolution of the precipitation. Analysis of these observations will provide a better understanding of the physical precipitation formation processes, which will lead to improved model parameterizations.

One of the profiler sites deployed by NOAA/ETL had two profilers, with one system operating at 2875 MHz and the other at 449 MHz. The 2875-MHz profiler observed the Doppler motion of liquid raindrops, while the 449-MHz profiler observed the vertical air motion during the precipitating events. Analysis of these observations yields vertical profiles of the raindrop size distributions as the rain events passed over the profiler site. Analysis of the retrieved raindrop size distributions from the 23 observed rain events will provide better understanding of the microphysics and dynamics of the precipitation processes, leading to better parameterizations of warm-shallow convective rain (no ice processes), deep convective rain (with ice processes), and stratiform rain.

### *Milestone 3.2.3.c*

Analyze the microphysical features and orographic precipitation mechanisms in storm clouds over the coastal mountains observed using multiple Doppler radar profilers deployed in Northern California during the Hydrometeorological Testbed (HMT-2004) campaign (December 2003-March 2004).

**Accomplishments**

During a typical winter, the precipitation along the mountain ranges of the western United States is dominated by the orographic lifting of moist air coming on-shore from the Pacific Ocean. Even the modest California coastal mountains, which only extend to about 500 m to 1500 m MSL, can generate orographically induced precipitation. The runoff from these orographically induced storms accumulates in the coastal valleys, occasionally producing floods that have caused millions of dollars in property damage and even a few fatalities. These floods have motivated a series of winter-time experiments in northern California since 1997. The California Land–Falling Jets Experiment (CALJET) was conducted in 1997-1998, the Pacific Land-Falling Jets Experiment (PACJET) was conducted during the winters of 2000-2003, and the Hydrometeorological Testbed (HMT-2004) campaign was conducted in 2003-2004.

During the HMT-2004 campaign, researchers instrumented four sites with profilers and surface disdrometers in the coastal mountains and valleys north of San Francisco. Our analysis of these data sets is focusing on identifying and quantifying the contributions of the two main mechanisms of orographic precipitation: the growth of hydrometeors in low-level clouds from precipitation falling from higher-level clouds (called the "seeder-feeder" process) or the development of convective precipitation as moist air parcels are orographically lifted to their level of free convection.

### *Milestone 3.2.3.d*

Document the daily cycle of lower-tropospheric winds over San Cristóbal Island in the Galápagos during the 1990s, as well as seasonal and interannual variability of the cycle.

**Accomplishments**

Although the daily cycle of near-surface winds over the equatorial east Pacific has been studied in some detail, little is known about the daily cycle above the surface layer. Furthermore, the causes of the observed near-surface daily cycle are not well-understood. A better understanding of the structure and forcing mechanisms at work on the lower-tropospheric winds over this region may increase our appreciation for the varying importance of local and remote atmospheric and oceanic processes.

Researchers have computed longterm-mean daily cycles of lower-tropospheric winds over San Cristóbal in the Galápagos Islands from four years of half-hourly soundings collected during the late 1990s by the NOAA/AL wind profiler. Mean daily cycles have also been computed for months during El Niño/warm events; for months during La

## Project 3.2.3 (continued)

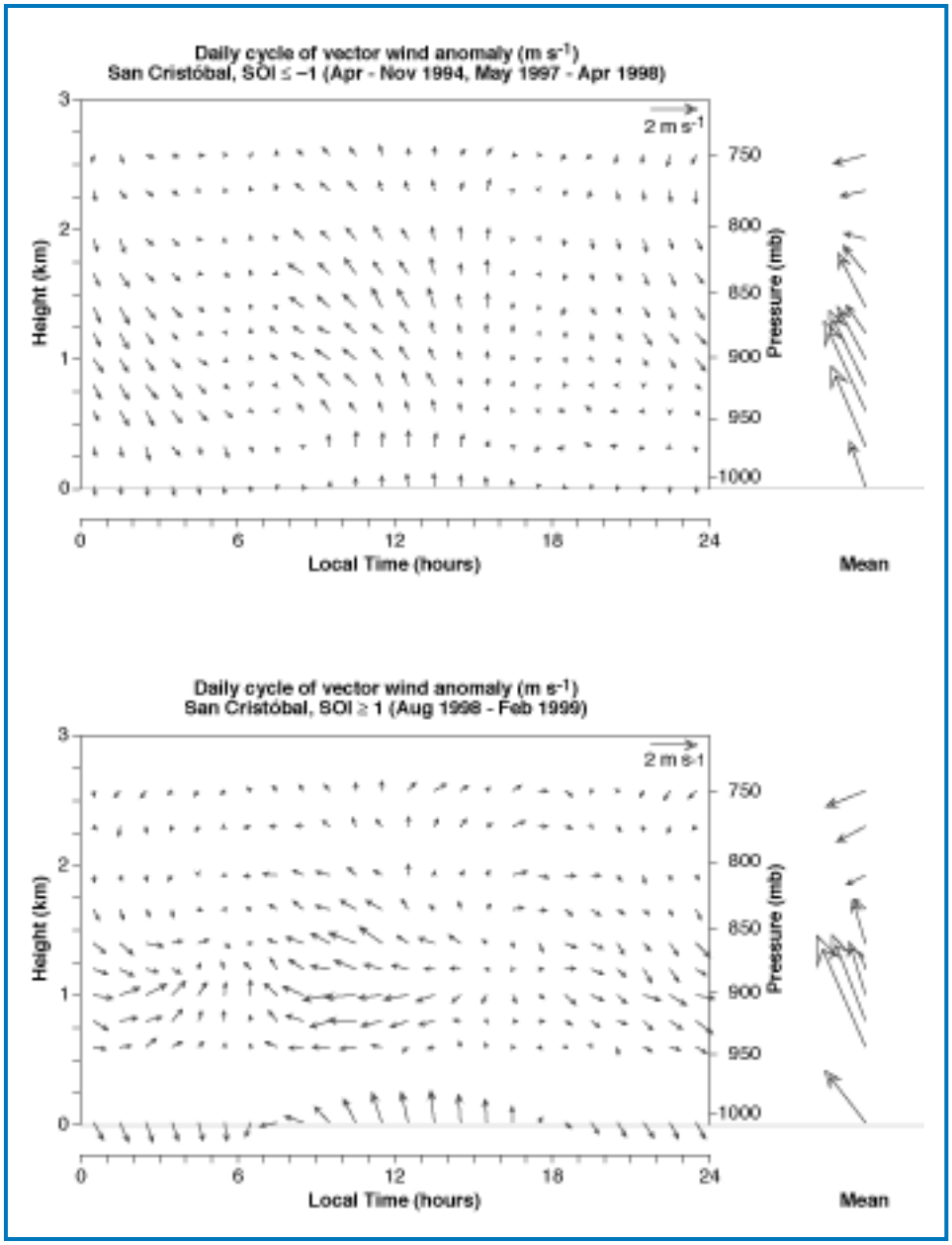



*Figure 3.2.b: The daily cycle of lower-tropospheric winds over San Cristóbal Island during El Niño/warm events (top) and La Niña/cold events (bottom). The profile on the right is the average of the mean daily cycle, which was used to obtain the vector wind anomalies plotted on the left. The timeseries at any height are only plotted if at least 40% of the possible observations were present at each half hour. For the sake of clarity, only alternate half hours are plotted. Arrow sizes are proportional to speed; a 2 m/s reference vector is shown in the upper-right-hand corner of the daily cycle plot.*

## Project 3.2.3 (continued)

Niña/cold events; and for individual warm and cold seasons. The data reveal a strong daily cycle (Fig. 3.2.b) during all averaging periods, and the well-known zonal (east-west) semidiurnal (12-hour) tide is evident in the results. During El Niño/warm events, warm seasons, and the 1997 cold season, the daily cycle projects predominantly onto meridional (north-south) anomalies and is fairly consistent with height. During La Niña/cold events and the 1998 and 1999 cold seasons, it projects onto zonal anomalies above 500 m and meridional anomalies below that. The decoupling of the low-level flow during these periods is presumably caused by the enhanced stability of the lowest levels of the atmosphere caused by the very cold underlying sea surface temperatures (SSTs). During periods with coupled flow, SSTs recorded by the NOAA/PMEL Tropical Atmosphere-Ocean (TAO) buoys at (0°S, 95°W) and (2°S, 95°W) were greater than 24°C, while during periods with decoupled flow SSTs were less than 23°C. The 1997 cold season behaved differently than the other cold seasons, lacking the decoupling of the near-surface flow from that aloft and therefore having a deep meridional anomaly pattern. We attribute this to the strong sea-surface warming accompanying the 1997 El Niño episode. The decoupling, which is not evident in longterm mean profiles that effectively filter the daily cycle, may inhibit the vertical mixing of momentum and the vertical propagation of tidal or wave signatures over the region. For instance, it appears to lead to a higher-amplitude semidiurnal tide at low levels, although further work on the forcing of that tide in the lower troposphere is necessary to confirm that.

Statistical analysis shows that the daily cycle over San Cristóbal is dominated by the meridional diurnal (24-hour) mode. During six of the seven seasons studied, more than half of the observations showed the zonal component of the diurnal cycle leading the meridional component by ten to fourteen hours. This results in a typical diurnal cycle of northwesterly anomalies in the middle of the night and southeasterly anomalies in the middle of the day. This diurnal cycle is inconsistent with simple theories relating the near-surface flow to convergence into convection in the Intertropical Convergence Zone (ITCZ), but may be consistent with convergence into an upsidence wave propagating away from convection over the South American mountains.

This research has documented the structure and variability of the daily cycle of winds over the East Pacific and explained some of the observed variability. The results provide a possible explanation of other aspects of lower-tropospheric dynamical variability seen within the region, such as the changing presence/absence of mixed Rossby-Gravity waves at low levels. Furthermore, it suggests that the cause of the fundamental daily cycle may lie farther afield than previously thought.

## Project 3.2.4 Turbulent Meteorological Motions (AL06)

**Goal: Understand the mechanisms and effects by which turbulence influences atmospheric chemistry, composition, radiation, and transport on all scales, from that of molecular diffusion to that of the globe, some nine orders of magnitude.**

### *Milestone 3.2.4.a*

Use the multifractal intermittency of temperature to explore links between molecular scale and fluid mechanical processes, with special reference to ozone chemistry and infrared absorption.

**Accomplishments**

Researchers analyzed 5 Hz temperature data and 1 Hz ozone data from the lower stratosphere, as measured by instruments aboard the ER-2 during the Photochemistry of Ozone Loss in Arctic Regions in Summer (POLARIS) mission in 1997, and during the SAGE 2 Ozone Loss and Validation Experiment (SOLVE) in 2000. The POLARIS flights spanned the occurrence of the Arctic summer anticyclone with flights between late April and mid September, while SOLVE examined the winter vortex from late January to mid March.

For temperature we computed the intermittency, C1(T), which is a measure of the tendency of the fluid to concentrate its dissipative energy in localized regions in space and time. For ozone we computed the photodissociation rate $J[O_3]$. We found a positive correlation between these two quantities, as shown in the accompanying figure. That is, we have related a molecular scale process, ozone photodissociation, to a macroscopic fluid property, the intermittency of temperature. A plausible mechanism for this correlation is offered by molecular dynamics literature simulations showing interactive generation of vortices ("ring currents") by fast molecules on time scales of 10 s to 12 s and space scales of 10 m to 8 m.

The most fundamental implication of this correlation is that the tails of the molecular velocity distributions are longer/thicker than those of the canonical Maxwell-Boltzmann distribution, upon which the definition of atmospheric temperature depends. The photodissociation of ozone is the primary mechanism by which solar photons are absorbed in the atmosphere, and their energy is transformed directly to translational velocity of air molecules. Longer/thicker velocity distribution tails imply a larger reservoir of translationally hot atoms and molecules than heretofore assumed, with manifold consequences affecting, among other things, the infrared absorption properties of water vapor and carbon dioxide and even our understanding of atmospheric temperature itself. Turbulence, at least at smaller scales, may be the result of a cascade of energy upscale. The implications for climate and change could be important, given that human activities have decreased ozone in the lower stratosphere and increased it in the troposphere; temperature as measured by thermometers may not be the same quantity now as it was in the early twentieth century.

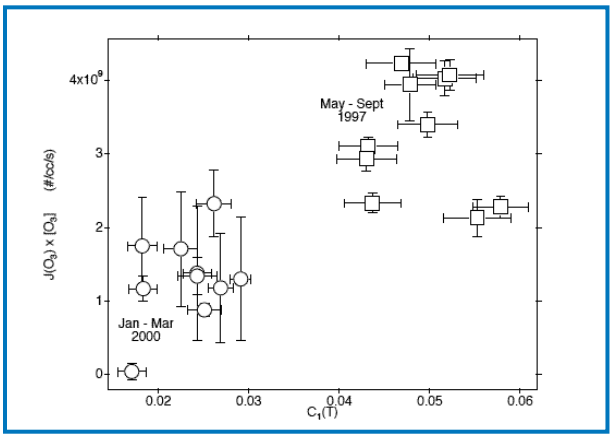



*Figure 3.2.c. Scatter plot showing the correlation between photodissociation of ozone and intermittency of temperature in the lower stratosphere. The data are from the POLARIS and SOLVE campaigns.*

## Project 3.2.5 Climate Trend Analysis (ARL03)

**Goal: Interpret operational data (ozone column, ozone profile, aerosol extinction, broadband spectral radiation, and other environmental parameters) collected by NOAA ground-based instruments. Assess data for long-term quality. Evaluate stability and inter-annual variability in the ground-based data sets. Provide the scientific community with information relevant to climate research and evaluate the usefulness of data for validation of other independent measurements, including satellite observations.**

### *Milestone 3.2.5.a*

Assess the newly updated ozone-profile database for trends and changes in trends. Develop and evaluate total ozone and profile retrieval from traditional Dobson and Brewer radiometric measurements, as well as photo-actinic flux hyper-spectral measurements at high-latitude winter conditions. Provide data to OMI/AURA satellite validation campaigns.

**Accomplishments**

Researchers developed an algorithm that allows deriving a partial ozone column from actinic flux measurements. Highly resolved UV and visible actinic flux measurements were taken by the NCAR CAFS (CCD Actinic Flux Spectroradiometer) instrument as part of the AVE (Aircraft Validation Experiment) Texas campaign in 2004 and 2005 and as part of the PAVE (Polar AVE) 2005 campaign. The CAFS ozone column data are used to validate ozone products retrieved from the OMI (Ozone Monitoring Instrument) and MLS (Microwave Limb Sounder) on board of the Aura satellite. All CAFS ozone data are deposited to the NASA archive (http://espoarchive.nasa.gov). We presented the results of CAFS analysis and Aura comparisons at the Aura Science Team meeting in Pasadena, California, 2005. We developed the new algorithm to derive Dobson Umkehr ozone profile data optimized for climatological studies. We presented this new algorithm and inter-comparisons with SBUV/2 satellite data at the Ozone Quadrennial Symposium (Greece, 2004), Fall AGU (San Francisco, 2005), and published them in Geophysical Research Letters, 2005. The algorithm and limited set of processed data are available on the project web site (http://www.srrb.noaa.gov/research/umkehr).

## Project 3.2.6 Modeling of Seasonal to Interannual Variability (CDC01)

**Goal: Understand how much predictability, especially outside the tropics, exists on seasonal-to-interannual timescales beyond that associated with simple linear El Niño-Southern Oscillation (ENSO) signals, and what additional useful predictive information can be extracted by making large ensembles of nonlinear General Circulation Model (GCM) integrations.**

### *Milestone 3.2.6.a*

Investigate the predictability of extratropical weather statistics (also known as "storm tracks") averaged over seasons to decades.

**Accomplishments**

In a comprehensive study published in the Journal of Climate, we used very large sets of AGCM model runs made at NCAR and NCEP with prescribed observed evolving sea surface temperature (SSTs) during the past 50 years to isolate the SST-forced part of the extratropical storm track variations. We found that a significant SST-forced storm track signal exists in many winters, but its strength and pattern can vary substantially from winter to winter. The correlation of the SST-forced and observed storm track variations over the 50 winters was found to be high enough in the Pacific-North American (PNA) sector to suggest useful predictability. We also showed that most of the predictable storm track signal is associated with tropical Pacific SST forcing. Variations from winter to winter of the pattern correlation of the observed and SST-forced storm track anomaly fields were generally consistent with variations of the signal strength, and to that extent should be identifiable a priori from tropical SST variations. The long-term trend of the Pacific storm track in the fifty-year record was also consistent with the

## Project 3.2.6 (continued)

stronger ENSO SST forcing in the second half of the record.

### *Milestone 3.2.6.b*

Implement a newly developed numerical stochastic integration scheme in numerical weather and climate models and test it for accuracy.

**Accomplishments**

Researchers completed a numerical experiment with the NCEP medium range forecast model, in which we compared sets of two-week forecasts, with stochastic perturbations of the model diabatic tendencies at each model time step, with similar forecasts without such perturbations. The stochastic perturbations increased the spread of the ensemble forecasts, as desired, but not everywhere. The effect was also shown to emanate mainly from the tropics, again highlighting the need to improve parameterizations of tropical convection in numerical weather prediction (NWP) and climate models.

### *Milestone 3.2.6.c*

Evaluate the impact of the most recent El Niño on short-term climate forecasts (6-10 days and Week Two) in real-time during the Northern Hemisphere winter.

**Accomplishments**

CDC scientists continued to provide experimental seasonal forecasts for North America based on multi-GCM ensemble responses to observed historical patterns of anomalous sea surface temperature (SST) forcing. These near real-time experimental predictions contributed to the routine monthly dialogue between CDC and NWS operations. Our seasonal forecast tool is available online to researchers and forecasters. We also continued to provide a monthly discussion of the state of ENSO and its expression in the Multivariate ENSO Index (MEI). As well, we provided related input to the monthly ENSO Advisory issued from the Climate Prediction Center (CPC).

To generate useful short- to medium-range outlooks over western Colorado, we utilized the bias-corrected CDC MRF model forecasts to downscale the near-surface temperature forecasts .

### *Milestone 3.2.6.d*

Develop a prototype ensemble data assimilation system for assimilation of surface-only observations in the pre-radiosonde era.

**Accomplishments**

In a recently completed study, we examined the feasibility of reanalyzing this early record using an ensemble square-root filter (EnSRF). Researchers used real surface pressure observations for 2001, sub-sampled to resemble observation densities in 1895, 1905, 1915, and 1935. We defined analysis errors relative to a three-dimensional variational (3DVar) analysis performed using current observation densities. Results obtained with an improved EnSRF algorithm led us to conclude that a tropospheric northern hemisphere reanalysis of the 20th century is feasible even using only surface pressure observations. The expected analysis errors at 850 mb and 300 mb of geopotential heights and zonal and meridional winds would be similar to current one to two day forecast errors, and two to three day forecast errors, respectively, at those levels.

### *Milestone 3.2.56.e*

Implement the latest versions of NCAR and GFDL atmospheric GCMs on CIRES/NOAA computing platforms and develop hierarchies of new coupled atmosphere-ocean models for climate analysis, prediction, and assessment research.

**Accomplishments**

CDC scientists have successfully ported and can now run the NCAR atmosphere, ocean, and coupled climate system models, as well as the GFDL AM2 model, in addition to the older versions of these models, on in-house computing platforms as well as on the NOAA/FSL JET cluster.

## Project 3.2.7 Understanding and Predicting Subseasonal Variations and their Implications for Longer Term Climate Variability (CDC02)

**Goal: Investigate the variability and predictability of the weekly averages of the atmospheric circulation through modeling and diagnosis of the observed statistics, and also through detailed analysis of numerical weather forecast ensembles for Week Two.**

### *Milestone 3.2.7.a*

Conduct predictability analyses of subseasonal variations in all seasons of the year. Assess predictability from deterministic as well as probabilistic perspectives, particularly in regard to the case-by-case and "regime"-dependent variations of predictability.

**Accomplishments**

We further developed our linear inverse model (LIM) of northern hemisphere weekly and longer-term variations to include stratospheric influences. A study comparing and contrasting tropical and stratospheric influences on extratropical variability and predictability is nearing completion. Perhaps the most important result is that stratospheric influences are important in the Atlantic sector, whereas tropical influences dominate in the Pacific sector.

### *Milestone 3.2.6.b*

Develop an empirical-dynamical coupled atmosphere-ocean model of tropical subseasonal variations.

**Accomplishments**

Researchers spent most of the first year of this project constructing the coupled Linear Inverse Model (LIM) from various observational atmospheric and oceanic data sets and conducting robustness, significance, and error-sensitivity tests to arrive at the best possible model of this type, since this would affect all of our subsequent work. The primary task was to decide on what variables to include in the model's state vector, at what vertical levels, and at what EOF truncation. This work is now nearly complete.

## Project 3.2.8 Empirical and Process Studies (CDC03)

**Goal: Improve understanding of basic physical processes that contribute to climate variability across a broad spectrum of scales, with emphasis on (i) moist atmospheric convection, (ii) radiative transfer in cloudy areas, and (iii) air-sea interaction.**

### *Milestone 3.2.8.a*

Continue research into dynamically coupled atmospheric single-column models to diagnose the interaction between different physical processes within atmospheric columns. Investigate ways of stochastically forcing such models to enable them to be run for extended periods while maintaining realistic variability.

**Accomplishments**

CIRES scientists recently published two studies in the Journal of Climate investigating the viability of using atmospheric single column models (SCMs) to diagnose observed and GCM-simulated climate variations. A fundamental weakness of SCMs stems from their decoupling of adiabatic and diabatic tendencies, which often leads to explosive spurious instabilities. To correct this weakness, a simple coupling scheme was developed that effectively stabilizes the SCM. This helps it maintain a realistic climate in long integrations, reduces error growth in short integrations, and reduces growth of ensemble spread in ensemble integrations. Because the coupled SCM is stable, it provides the foundation for extending its diagnostic utility, by including additional corrective and stochastic forcings, for example. The forcings can be specified in such a way as to reproduce either the observed or a GCM climate variability at any gridpoint of interest. Such a flexible diagnostic tool clearly has wide applications. CIRES scientists recently constructed and tested a prototype based on the NCAR SCM (CCM3.6 and CAM2.0) physics on temperature and humidity fluctuations observed during TOGA COARE. The results were encouraging: the stochastically forced SCM maintained a stable climate in long (1,000 day) runs and produced temperature and humidity variations with realistic amplitude and vertical structure.

## Project 3.2.8 (continued)

### *Milestone 3.2.8.b*

Publish studies clarifying the role of various aspects of diabatic physics in the MJO, including total heating, cloud-radiative heating, latent heating in convective and stratiform precipitation, and subgrid momentum tendencies. Publish studies clarifying the influence of the MJO on South American rainfall, particularly on the timing of the tropical South American rainy season.

**Accomplishments**

CDC scientists were exceptionally active in this area in 2004, publishing at least five papers directly on this topic and several others on related issues. They demonstrated the top-heaviness of the diabatic heating profile associated with relatively strong stratiform precipitation during MJO episodes and showed that the column-integrated radiative heating variations are nearly in phase with the precipitation variations during such episodes. They investigated the impact of vertical wind shear on radiatively important cloud properties. Finally, they explored the sensitivity of tropical intraseasonal variability to the parameterization of deep convection in a simplified "aqua-planet" GCM.

### *Milestone 3.2.8.c*

Investigate improved methods of representing sub-grid-scale variability in clouds and radiative transfer in weather and climate models, conceptually as a series of sub-columns within a GCM large-scale column. Explore connections with more traditional single-column parameterizations, as well as "super-parameterizations" being developed by other researchers.

**Accomplishments**

The fine structure of cloud properties is currently accounted for in large-scale models in terms of assumed probabilities and overlapped properties of the sub-grid scale clouds. CDC scientists are rigorously testing such assumptions, and recently used a month-long cloud-resolving model simulation of continental convection to develop more realistic overlap assumptions. They also explored ways of improving the coupling of statistical cloud schemes with atmospheric convection schemes, specifically mass-flux schemes. In related studies, they explored ways of verifying model cloud fields with cloud radar observations based on interpreting the modeled quantity as a probabilistic forecast at the observation point. Researchers published three papers on these topics.

## Project 3.2.9 Decadal Climate and Global Change Research (CDC04)

**Goal: i) Improve understanding of long-term climate variations through analysis of observations and hierarchies of GCM experiments. (ii) Seek dynamical explanations of oceanic variability and changes through observational analyses and GCM experiments. (iii) Provide attribution for long-term regional climate changes.**

### *Milestone 3.2.9.a*

Conduct studies assessing the significance of the observed warming of the tropical oceans over the last fifty years, with emphasis on determining to what extent it is related or unrelated to changes in ENSO.

**Accomplishments**

Distinguishing natural from anthropogenic climate variations is a central theme in global change assessments. There is growing evidence that much of the global response to anthropogenic climate perturbations will be mediated through changes of tropical SST. A fifty-year trend in tropical SSTs is already evident; the question is to what extent it could be "natural," that is, possible even without greenhouse gas changes. Attempts using dynamical-coupled climate models to address this issue are hampered by the inability of the models to properly represent the mean tropical climate and ENSO variability. CDC scientists have taken an alternative approach, using a linear inverse model (LIM) trained on the short-term (four-month) lag-correlation statistics of the SST observations. The probability distribution of "natural" fifty-year trends was estimated from a very long 100,000-year run of this model. The observed trends were found to be at the extreme ends of this distribution at most tropical locations, and therefore unlikely to be a result of "natural" variations.

### *Milestone 3.2.9.b*

Publish a study assessing to what extent the recent prolonged four-year drought of 1998-2002 in many areas of the Northern Hemisphere was a result of a lingering La Niña event or a regional manifestation of global warming.

**Accomplishments**

Researchers completed a study demonstrating that the precipitation deficits during the four-year drought were almost entirely due to the La Niña event, but longer-term "global warming" also contributed significantly to the anomalous surface warmth in the drought-afflicted areas. Consistent with this, the patterns of northern hemispheric precipitation deficits in the two years following the four-year drought were dramatically different from those during it, but the patterns of the anomalous surface warmth remained substantially similar. A journal article is currently in preparation.

### *Milestone 3.2.9.c*

Publish studies of the different sensitivities of the global climatic response to warming and cooling in different parts of the world ocean.

**Accomplishments**

Researchers are nearing completion of a comprehensive investigation of the sensitivity of the global atmospheric response to SST changes in different parts of the tropical oceans using the NCAR CCM3.10 AGCM. An array of 43 localized SST anomaly patches was specified, and the atmospheric responses were summarized as "Fuzzy Green's Function" sensitivity maps. We have confirmed and extended the results of an earlier study conducted using the NCEP AGCM for four distinct ways: 1) the sensitivities have now been established with a different AGCM and in all seasons of the year; 2) the opposite sensitivity of many aspects of the global response to SSTs in the tropical Indian and Pacific oceans has been confirmed; 3) the counter-intuitive result that warm SSTs in large areas of the tropics lead to global-mean surface cooling and drying has also been confirmed; and 4) the significant modification of the remote atmospheric response to tropical SST anomalies through coupled interactions with the underlying sea surface has been demonstrated. Several substantial journal articles describing these results are in various stages of preparation.

### *Milestone 3.2.9.d*

Publish studies elucidating the mechanisms through which decadal SST variations can occur in the tropical Pacific ocean, such as (i) slowing variations of coupled air-sea interactions within the tropical Pacific basin, and (ii) forcing of slow

## Project 3.2.9 (continued)

equatorial upwelling variations by slow variations of subtropical surface wind stresses and heat fluxes, that may themselves be partly associated with slow variations in higher latitudes.

**Accomplishments**
CIRES scientists are pursuing these studies in a conceptual framework, in which the tropics affect the extratropics through the atmosphere, and the extratropics feed back on the tropics through the oceanic subtropical cells (STCs). We have developed a suite of diagnostics to investigate these interactions in observations and models. Using these diagnostics, along with careful GCM experiments, we demonstrated a link between the excessive simulated Southern Pacific Convergence Zone (SPCZ) precipitation in the NCAR-CCSM3 model and its cold and fresh bias at the equator through the equatorial upwelling of the excessively cold and fresh subducted subtropical water. We also showed that the Atlantic equatorial undercurrent is maintained mostly by subducted South Atlantic water. We submitted two manuscripts describing these results to *JGR-Oceans*. We also published a separate study demonstrating the impact of off-equatorial warm pool SST anomalies on ENSO cycles in *Journal of Climate*.

Shinoda, T., H. H. Hendon, and M. A. Alexander. 2004. Surface and subsurface dipole variability in the Indian Ocean and its relation with ENSO. *Deep Sea Res.* 51, 619-635.

Solomon, A., and F. F. Jin. 2004. A study of the impact of off-equatorial warm pool SST anomalies on ENSO cycles. *Journal of Climate* (in press).

Sun, D. Z., T. Zhang, and S. I. Shin. 2004. The effect of subtropical cooling on the amplitude of ENSO: A numerical study. *Journal of Climate*, 3786-3798.

### *Milestone 3.2.9.e*

Complete the translation of the International Comprehensive Ocean-Atmosphere Data Set (I-COADS) Release 2.0 (1784-1997) data into a new International Maritime Meteorological Archive (IMMA).

**Accomplishments**
Researchers completed the release of this data set. Spanning more than two centuries (1784-2002), it is the largest available set of quality-controlled marine observations. A journal article accompanying the data set release and co-authored by CDC staff was published in the *International Journal of Climatology*.

## Project 3.2.10 Experimental Regional Climate Services (CDC05a)

**Goal: Couple enhanced observations and research in regions of strong climate variability and societal impact with analysis of past data and improved modeling. Determine factors influencing the occurrence of extreme events. Improve the diagnosis, modeling, and prediction of the regional consequences of climate change and variability on timescales of days to decades on hydrological variables of relevance to society.**

### *Milestone 3.2.10.a*

Monitor daily, seasonal, and longer-term precipitation variability over the western U.S. Explore ways to reclassify U.S. "climate divisions" based on coherent precipitation variability. Downscale NCEP Week Two ensemble forecasts for water resource managers in Colorado. Continue developing seasonal forecast guidance tools for the western U.S. based on the predictability of tropical SSTs several seasons in advance, training these tools on the atmospheric responses to different types of anomalous tropical SSTs in large new sets of seasonal integrations made with the NCAR, GFDL, and NCEP GCMs.

**Accomplishments**
CDC scientists continued to provide input to the weekly production of the U.S. Drought Monitor. We monitored current climate conditions, especially in the western U.S., and translated that information into the drought categories used in this product. To generate useful short- to medium-

## Project 3.2.10 (continued)

range outlooks. we utilized the bias-corrected CDC MRF forecasts in the downscaling of temperature forecasts over western Colorado and developed a web page to make these user-friendly forecasts available to water resource managers at the Bureau of Reclamation and other agencies. We continued producing experimental seasonal forecasts based on tropical SSTs every month and created a web page to display forecasts made using six different forecasts of the SSTs. On the state level, we regularly provided input to and made briefings at meetings of the Colorado Water Availability Task Force and other stakeholders on the recent and projected evolution of ENSO and its implications for the southwestern U.S. Some experimental CDC forecasts are used by regional wildfire managers. CDC scientists made progress in creating a first-generation set of new regional climate divisions for the entire continental U.S., based on both regular climate station and automated SNOTEL data to optimize the signal-to-noise ratio for interannual climate variability.

### *Milestone 3.2.10.b*

Publish studies of recent climate change in the hydroclimatology of the western U.S., partly resulting from changes in tropical teleconnections with emphasis on changes in streamflow and watershed health.

**Accomplishments**

CDC scientists discovered an emerging long-term trend toward increasing year-to-year variance (decreasing reliability) of streamflow across the major river basins in western North America: Fraser, Columbia, Sacramento-San Joaquin, and Upper Colorado. They also demonstrated that a concurrent increase in the incidence of synchronous flows (simultaneous high or low flows across all four river basins) has resulted in expansive water-resources stress. The observed trends are associated with trends in the wintertime atmospheric circulation and ocean temperatures, raising new questions on the detection, attribution, and projection of regional hydrologic change induced by climate. We submitted a paper to the *Journal of Climate*.

### *Milestone 3.2.10.c*

Continue developing the CIRES/NOAA Web site dedicated to real-time predictions of tropical convection variations associated with the Madden–Julian Oscillation (MJO) and their remote impacts. Display various experimental and operational ensemble predictions in a uniform format to enable intercomparisons and skill evaluation.

**Accomplishments**

Improved MJO predictions offer the possibility of increasing tropical and extratropical forecast skill at lead times of one to four weeks. Unfortunately, current GCMs have difficulties in representing the MJO and its associated multi-scale interactions of convection and circulation. Acting on recommendations from two recent NASA/NOAA workshops on subseasonal variability, CDC agreed to host a Web site where real-time and experimental MJO forecasts could be objectively evaluated, and feedback provided to the forecasters. A preliminary version of the Web site became operational in November 2003. We have since implemented substantial additions to the site. Forecast contributions now number five statistical models, two GCM ensembles and a coupled ocean-atmosphere model, with more contributions pending. Forecasts of five different variables are displayed in a common graphical format for easy comparison. Week One and Week Two forecasts are being emphasized at this stage, but eventually will be extended to Week Three and Week Four if feasible (for example, the ECMWF 51-ensemble member forecast out to 30 days is available weekly). Forecasts are being verified in real time using spatial anomaly correlations. Results confirm that both the statistical and numerical prediction models have only marginal skill at Week Two, even for planetary scale variables like 200 mb velocity potential. The forecast skill of tropical precipitation is poor for all the available GCMs.

## Project 3.2.11 Experimental Climate Data and Web Services (CDC05b)

**Goal: Improve public access to climate information and forecast products to facilitate research, to inform public planning and policy decisions, and to assist any interested parties impacted by climate.**

### *Milestone 3.2.11.a*

Continue updating the publicly accessible climate data holdings on the CIRES/CDC Web site. Develop and install on local platforms a netCDF version the forty-year daily ECMWF ERA-40 reanalysis data set of the global atmospheric circulation. Acquire new precipitation and soil moisture data sets.

**Accomplishments**

CDC continues to serve as a primary redistribution point for the NCEP Reanalysis data set, providing netCDF versions of the reanalysis fields via the web or (for larger requests) via tape to users throughout the world. CDC is a core NOAA partner, with NCEP, NCDC, GFDL, and PMEL, in the NOAA Operational Model Archive and Distribution System (NOMADS) being developed to provide seamless access to geographically distributed climate model outputs. CDC recently created a NetCDF version of the gridded ECMWF Reanalysis-40 (ERA-40) data set that conforms to the CF metadata standard. A new soil moisture data set was also added to the archive.

### *Milestone 3.2.11.b*

Develop new web pages on the CIRES/CDC Web site explaining basic and applied CIRES/CDC climate research in layman's terms.

**Accomplishments**

The CDC web site (http://www.cdc.noaa.gov) contains links to many experimental and applied climate products developed at CDC and information on how to use them. Examples of available products include prototype global risk assessments; climate probability distributions; interactive pages for calculating and displaying composite fields and correlations from NCEP Reanalysis data; operational analyses, U.S. climate division data; ENSO climate risk pages; and a climate products information page that includes a broad range of operational and experimental climate products, particularly those developed by NOAA and its partners.

### *Milestone 3.2.11.c*

Continue research into assessments of climatic impacts and programmatic development of climate, weather, and water services. Conduct a study of adaptive management strategies to cope with warm-season floods in the Grand Canyon. Take a lead in preparing the U.N. Millennium Ecosystem Assessment chapter on Extremes and Natural hazards and the IPCC Working Group II (Adaptation and Vulnerability) chapter on Assessing Adaptation Practices in response to global change.

**Accomplishments**

CDC continues to provide scientific support to the OGP-funded regional assessment on the effects of climate variability on water resources in the Interior West (Western Water Assessment, or WWA). CDC scientists continue their frequent interactions with other federal and state agencies such as the Department of the Interior, including the Bureau of Reclamation and the Fish and Wildlife Service, and other user groups, such as the Denver Water Board, Colorado River Water Conservation District, and Colorado Drought Task Force. An important objective of this research is to learn how to better incorporate climate information and forecasts into water resource decisions in this highly water-sensitive region. A CDC scientist was involved in preparing first-order drafts as an IPCC Lead Author for Working Group-2 on "Impacts Vulnerability and Adaptation" and as a lead author of a chapter on natural hazards in the U.N. Millenium Ecosystem Assessment.

## Project 3.2.12 Climate Forcing (CMDL01)

**Goal: (i) Greenhouse gases: Conduct research to better understand the interactions of the atmosphere with the land and ocean. (ii) Aerosols: Characterize the means, variabilities, and trends of climate-forcing properties for different types of aerosols, and understand the factors that control these properties. (iii) Radiation: Research into broadband irradiance to improve benchmarks for climatic processes.**

### *Milestone 3.2.12.a*

Build upon climate-related observations at observatories and cooperative sampling sites.

**Accomplishments**

Understanding long-term change through careful observation is critical to climate change research, and CIRES researchers make large contributions to these records of aerosols, trace gases, and radiation through instrument development, logistics, and data analysis. We have recently established new observation sites, especially in the continental U.S., with an expansion of tall (> 400 m) tower and airborne observations. Additionally, we have begun new measurements of gases like carbonyl sulfide (COS) and carbon-14 of $CO_2$, that will allow us to better understand biological and fossil fuel carbon fluxes, respectively.

### *Milestone 3.2.12.b*

Establish a carbon-observing network over North America.

**Accomplishments**

CIRES researchers play a major role in the development of a North American carbon-observing network. Increased sampling density in space and time is the key to improving our ability to quantify regional carbon fluxes, and CIRES researchers have developed, tested, and implemented automated air-sampling units for deployment on light aircraft at sites throughout the continent. Instrumentation has also been developed for the measurement of carbon dioxide, methane, other greenhouse gases, and the transport tracer Radon-222, at three tall tower sites. We rely on inverse models and data assimilation to interpret our observations as fluxes, and significant progress has been made on developing state-of-the-art models that can ingest the huge amounts of data we expect in the coming years.

### *Milestone 3.2.12.c*

Continue conducting measurements from ships and expand measurements to ocean buoys to obtain a better understanding of carbon gases and oceanic gas fluxes.

**Accomplishments**

CIRES researchers continue to assist in the expansion of CMDL oceanic greenhouse gas measurements through logistical support, sample analysis, and instrument development. The data gathered through these measurements are used in global inverse models of $CO_2$ and $N_2O$ to help better determine global scale ocean trace gas fluxes.

### *Milestone 3.2.12.d*

Add perfluorocarbons (PFCs), including $CF_4$ and $C_2F_6$, to the observing system.

**Accomplishments**

Perfluorocarbons (PFCs) exist in the atmosphere at parts-per-trillion (ppt) levels, but have extremely high global warming potentials (GWPs) and long atmospheric lifetimes. This class of compound was included as one of six compounds in the Kyoto Protocol to the United Nations Framework Convention on Climate Change. NOAA/CMDL has started to make ambient standards of the two most abundant PFCs, carbon tetrafluoride ($CF_4$) and perfluoroethane ($C_2F_6$). Mass spectrometers coupled to gas chromatographs are in the final construction phase to measure these compounds in flasks, ground and airborne, and in real time at selected NOAA/CMDL stations.

### *Milestone 3.2.12.e*

Maintain and improve the accuracy and representativeness of radiation data, expand the ancillary data collection, and extend the analysis of existing and newly acquired data.

**Accomplishments**

During August 2004, CIRES personnel joined in partnership with NOAA/CMDL and Environment Canada to upgrade an existing Global Atmosphere Watch (GAW) facility at Alert (82.5N, 62.3W).

## Project 3.2.12 (continued)

Enhancements included a suite of radiometers to measure the surface radiation balance and atmospheric opacity using spectral radiometers plus ancillary meteorological instruments. Project support came from the interagency Study of Environmental Arctic Change (SEARCH)—NOAA Arctic Research Office. The complement of instruments at Alert will permit long-term monitoring of many important climate variables needed to improve our understanding of the Arctic climate system, to validate satellite retrievals and to verify model results. Alert is the northernmost land station in a planned circum-Arctic network, a subset of observatories that will comprise the Global Climate Observing System (GCOS) of the WMO. It is the third Baseline Surface Radiation Network (BSRN) site to operate in the Arctic. GAW and BSRN activities are being coordinated to monitor climates representative of the Central Arctic. Aerosol and cloud effects are of particular interest because there are large uncertainties associated with simulating their climate impacts.

## Project 3.2.13 Ozone Depletion (CMDL02)

**Goal: (i) Stratospheric Ozone Measurements: Measure ozone declines during the past two decades at northern hemispheric midlatitudes and the tropics to characterize dramatic ozone depletions over Antarctica. (ii) Ozone-Depleting Gases: Conduct research in the troposphere, stratosphere, oceans, polar snowpack, and terrestrial ecosystems in an effort to understand and predict the atmospheric behavior of these gases. (iii) Stratospheric Aerosols: Conduct experiments and measurements on aerosols to determine their impacts on solar insolation. (iv) Stratospheric Water Vapor: Conduct measurements to determine the change in water vapor and its coupling with aerosols.**

### *Milestone 3.2.13.a*

Continue monitoring the distributions and trends of gases involved in stratospheric ozone depletion.

**Accomplishments**

During 2004-2005 we continued regular measurements at sites across the globe of ozone-depleting gases including chlorofluorocarbons (3), hydrochlorofluorocarbons (5), hydrofluorocarbons (2), chlorinated solvents (5), methyl halides (3), brominated methanes (2), and halons (3). Flask samples were collected for the first time from Ushuaia, Argentina and Summit, Greenland, enhancing our ability to characterize global trends, sources, and sinks of ozone-depleting gases. We also added measurements of two potent ozone-depleting halons (Halon-1301, Halon-2402) and HFC-152a, a non-CFC aerosol propellant and foam blowing agent, to the existing suite of compounds analyzed in flask samples. Data for selected gases have been updated through early 2005 on the CMDL/NOAA Web site. The updated results show that the effective equivalent chlorine (EECl) burden of the atmosphere has decreased by 9% since peak EECl levels were observed ten years ago. These data will appear in the UNEP/WMO Technology and Economic Assessment Panel Special Report on Ozone and Climate.

We also participated in studies striving to better understand continental sources and sinks of ozone-depleting and other trace gases. These studies utilized mobile measurement platforms including trains, light aircraft, and the Altair uninhabited aerial vehicle (UAV). In situ measurements and flask samples were collected from a train that traveled back and forth across Russia (TROICA-8) in March-April 2004. We now regularly use light aircraft to collect flask samples in and above the continental boundary layer at nine sites across the USA. Several ozone-depleting gases were measured in situ between the surface and lower stratosphere aboard Altair during the April-May 2005 NOAA UAV demo in Palmdale, CA. Results from these studies will allow us to identify and quantify the continental sources and sinks of ozone-depleting halocarbons.

## Project 3.2.13 (continued)

### *Milestone 3.2.13.b*

Continue measurements of the oceanic and terrestrial fluxes of methyl halides and short-lived halocarbons.

**Accomplishments**

In association with colleagues from NOAA/CMDL, University of Texas, and University of California, Irvine, in July 2005 CIRES scientists completed the seventh NOAA/CMDL research cruise, addressing the oceanic fluxes of methyl halides and short-lived halocarbons, located this time in the central Pacific Ocean. These data have been complied with those of other expeditions, showing concentrations of numerous short-lived halocarbons in the air and surface water. Data for all seven cruises, spanning from 1994 through 2005, were updated to the recent NOAA calibration scales for five principal gases – methyl bromide, methyl chloride, methyl iodide, dibromomethane, bromoform – allowing them to be examined for the first time on consistent, accurate calibration scales. The ocean is by far the dominant contributor of the latter three of these gases to the atmosphere and its contribution may help explain the excess of bromine, a major ozone-depleting element, in the lower stratosphere. These data were presented in a number of posters and presentations at the fall meeting of the American Geophysical Union and the annual meeting of the European Geosciences Union. One publication of results from the sixth research cruise, located in the Southern Ocean, appeared in print this fiscal year, and two others are currently in preparation. Data from all the cruises are now on the web for public use and likely will contribute to the next WMO/UNEP Scientific Assessment of Ozone Depletion, a quadrennial assessment advising an international protocol, due out in 2006.

### *Milestone 3.2.13.c*

Improve water vapor instrumentation and expand the measurement program.

**Accomplishments**

The University of Colorado Cryogenic Frostpoint Hygrometer (CFH) is rapidly becoming the de facto standard for balloon-borne water vapor observations between the surface and about 28 km altitude. This instrument has been developed in cooperation with the CIRES Instrument Integration and Design Facility (IIDF). It is capable of accurately measuring water vapor under most atmospheric conditions and is being used to study processes affecting the concentration and distribution of water vapor in the atmosphere as well as in the validation of other instruments measuring water vapor. This instrument has its roots in the NOAA/CMDL frost point hygrometer, and implements fully digital electronics and advanced technologies, allowing a weight savings of a factor of six, which is enormously critical in small balloon-borne applications.

This instrument is becoming the backbone of a network of water vapor observations, including Sodankylä, Finland; Hilo, HI; San Cristóbal, Galapagos; La Reunion, France; and Alajuela, Costa Rica. At various other field sites, this instrument has been used on campaign basis. It will soon replace the old NOAA/CMDL frost point hygrometer at Boulder, Colorado, where frost point observations have taken place for over 25 years. The significance of this instrument is that for the first time one instrument can study processes affecting water vapor in the tropical tropopause region, in the polar stratosphere as well as in the lower troposphere under almost all atmospheric conditions.

### *Milestone 3.2.13.d*

Continue monitoring UV radiation and stratospheric aerosols.

**Accomplishments**

Researchers continue to conduct Spectral UV measurements to study the relationship between UV and ozone and to determine long-term trends. The CMDL Spectral UV program has UV Spectroradiometers located at the CMDL Mauna Loa Observatory and at the David Skaggs Research Center (DSRC) in Boulder. The Mauna Loa instrument was installed as part of the Network for Detection of Stratospheric Change (NDSC) in 1995. The DSRC instrument was installed in 1998 and has recently been accepted as a

## Project 3.2.13 (continued)

Complementary Measurement Site to the NDSC. A working relationship with the NOAA Central UV Calibration Facility has been established to annually calibrate both instruments as well as allowing their use of the DSRC instrument to test new procedures and calibration equipment. A CIRES scientist is working on improving the ozone retrieval from the data collected at both sites as well as collaborating with scientists from around the world to publish the results from the 2003 Table Mountain UV Intercalibration. Work is continuing to be done on upgrading both instruments to facilitate the automation of their calibrations.

## Project 3.2.14 Surface Processes (ETL04)

**Goal: Develop and/or improve physical representations of atmosphere-surface interactions.**

### *Milestone 3.2.14.a*

Incorporate new ice/snow scheme into MM5 and evaluate improvements in winter and summer Arctic simulations.

**Accomplishments**

Researchers tested the impact of surface-flux heterogeneity on GCM-scale fluxes using a new technique that combined a one-dimensional snow and ice model, synthetic aperture radar (SAR) observations of first-year ice distributions, and surface-based precipitation observations. The results show that previously estimated differences between the turbulent flux measurements on multi-year ice and the GCM-scale fluxes is too large by about a factor of two due to sampling biases in the previous studies. Furthermore, the results suggest that the application of local stability characteristics in the estimation of the heat transfer coefficients is inappropriate. The next step is to include this snow and ice model in the Penn State/NCAR MM5 in order to estimate the contribution of mesoscale fluxes resulting from the observed and modeled mesoscale surface temperature variations. A conference paper was written and a journal article is currently in progress.

### *Milestone 3.2.14.a*

Investigate the climatology of the snow-level in the atmosphere using profiler measurements collected along the U.S. West Coast to see if there is any correlation between recent warming in the West (measured at the surface) and the observed snow-level.

**Accomplishments**

CIRES investigators have developed an algorithm to detect the snow level in the atmosphere from wind profiler measurements. We have begun comparing profiler-deduced snow level observations to operational snow pack measurements and surface meteorological parameters collected in the northern Sierra Mountains. This work will be expanded to the Southern Sierra, where snow pack observations at a wide range of altitudes exists. In the meantime, the snow level project has taken on a different twist. The University of Colorado Technology Transfer Office has licensed the snow level product to Vaisala, Inc., for commercial development and implementation. CIRES investigators are working together with an outside contractor on implementing a snow level module in the Vaisala commercial LAPXM software that is used to control data acquisition from wind profilers. Once this work has been completed, CIRES investigators will run historical wind profiler data sets through LAPXM to produce a recent climatology of snow level in the Western U.S. Real-time snow level observations are available during the winter season from wind profilers deployed by the NOAA Environmental Technology Laboratory (http://www.etl.noaa.gov/et7/data/).

### *Milestone 3.2.14.b*

Study the spatial correlations of cloud and surface energy budget terms at past, current, and planned Arctic "supersites" to be used for monitoring

## Project 3.2.14 (continued)

Arctic climate change. Prepare ground-based turbulent flux instrumentation for later deployment.

**Accomplishments**
Researchers planned for the long-term deployment of turbulent flux instrumentation to Alert and Eureka (both on Ellesmere Island). CMDL deployed a baseline surface radiation network (BSRN) to Alert in August 2004, to which we are adding measurements of the turbulent sensible heat and momentum fluxes. The University of Toronto will deploy a BSRN site to Eureka, to which we will add the turbulent flux measurements, tower profile measurements, and basic surface measurements necessary for surface energy budget considerations. The measurement strategy and instrumentation needs have been determined, much of the equipment has been purchased, and pre-deployment testing has begun. The Alert instrumentation will be deployed in Fall 2005. The Eureka deployment in summer 2006 requires further negotiations on the placement of the instrumentation and numerous logistical considerations. A summer student has begun analyzing existing sounding, surface, and model output data from these sites. We have made contact with Oregon State University to use their two years of MM5 model output near Ellesmere Island for understanding local and regional variability near the Alert and Eureka sites.

### *Milestone 3.2.14.c*
Use the MM5 mesoscale model to help interpret the evolution of enhanced satellite integrated water-vapor bands and moisture transport over the Pacific Ocean. The impact of ENSO on the integrated water-vapor bands and moisture transport along the U.S. west coast will be analyzed using simulated cases from years within different phases of ENSO. A paper presenting these results will be submitted for publication.

**Accomplishments**
Researchers performed trajectory analysis using a weather prediction model for five cases, to interpret the formation of enhanced bands of vertically integrated water vapor (IWV) in the central and eastern Pacific that are frequently seen in satellite images from the special sensor microwave/imager (SSM/I). We also examined the connection of these enhanced bands with poleward water-vapor transport from the tropics.

### *Milestone 3.2.14.a*
Publish results from the development of new stable surface-layer similarity functions valid for all ranges of stability.

**Accomplishments**
Researchers used measurements of the atmospheric turbulence made in the Surface Heat Budget of the Arctic Ocean Experiment (SHEBA) to examine the stability profile functions in the stably stratified boundary layer over the Arctic pack ice. We continuously measured turbulent fluxes and mean meteorological data at five levels on a twenty-meter main tower during eleven months that cover different surface conditions and a wide range of the stability conditions. The comprehensive data set collected during SHEBA allows studying the stability-profile functions behavior in detail, including the very stable case. We proposed new parameterizations for the stability-profile functions in stable conditions to describe the SHEBA data. The floe around the main SHEBA tower went from compact and totally snow-covered in winter, to bare ice with melt ponds and leads in the height of summer. In this study, we also considered the effect of the surface heterogeneity on the wind and temperature profiles during different polar seasons. These new functions will improve representation of surface fluxes in operational forecast and climate models. We published one new article on this research in 2005.

## Project 3.2.15 Paleoclimatology: Understanding Decadal- to Millennial-Scale Climate Variability (NGDC04)

**Goal: Improve our understanding of observed long-term climate variations through compilation and analysis of data from the pre-instrumental record, and provide access to both data and information from the paleoclimatic record.**

### *Milestone 3.2.15.a*

Develop new community-driven data sets and continue to improve existing ones. A particular focus in FY05 is the continued development of the new paleofire database in collaboration with academic, NOAA and U.S. Forest Service researchers.

**Accomplishments**

The International Multiproxy Paleofire Database (IMPD) significantly expanded the size and breadth of its holdings. The database incorporated a new proxy of tree stand establishment with the existing tree scar and charcoal in sediment data. We received submissions from researchers from a variety of academic institutions, as well as the USDA Forest Service. IMPD-funded student grants and on-site visits by the program data manager resulted in the acquisition of the data holdings from several prominent paleofire laboratories. The database currently contains fire histories from 439 sites from North, Central, and South America, and new advisory board members from Switzerland and Denmark have been added to help encourage submissions from the European paleofire community. Other data sets that were significantly improved include the climate reconstructions, paleoceanography, and speleothem data. The acquisition of these data, and their presentation on the Internet, contribute to the CIRES research theme to understand climate and environmental change over a broad range of time scales. For example, a data set we published in the Feb. 10 issue of *Nature*, and contributed to the NOAA Paleoclimatology Program, shows a time-series reconstruction of temperature change over the last 2,000 years (Fig.3.2.e). These data expand the archive of climate reconstructions distributed by NOAA, and reveal the unusual amplitude of warming observed in the instrumental record. This reconstruction utilized a new wavelet method also pioneered by CIRES.

### *Milestone 3.2.15.b*

Develop and evaluate new systems for the archive and access of a wide spectrum of paleoclimatic data resulting in a multi-proxy paleoclimatic database system, with new systems for the sharing, visualizing and analyzing gridded paleoclimatic data.

**Accomplishments**

The paleoceanography database on which we began devleopment last year is now online. We have continued to expand its holdings, so there are now 1,685 paleoceanography data sets available for easy online search and access. The database has become the back end of a fully functional search tool to allow for data searches based upon site/core name, location, date, water depth, and investigator. The search engine also allows the user to pick out subsets of variables from the database. Available data subsets include carbonate, isotope, sea surface temperature, and magnetic susceptibility data. The user also has the option to select out marine protozoan assemblages from the Climate, Long Range Investigation, Mapping, and Prediction (CLIMAP) experiment. We also modified the database of the paleoclimate modeling results so that they can be viewed by GrADS DODS and OPeNDAP enabled servers. This new method of distributing data makes the climate modeling results available to a broader range of users, including those in the meteorological community.

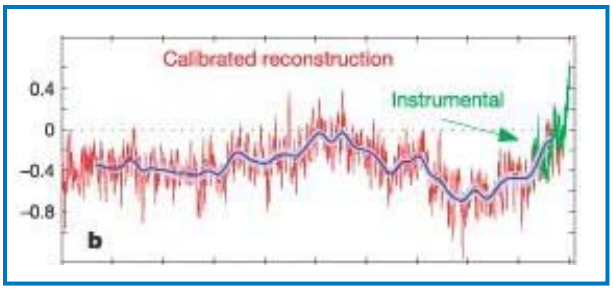



*Figure 3.2.e. Time-series reconstruction of temperature change over the last 2,000 years.*

## Project 3.2.15 (continued)

### *Milestone 3.2.15.c*

Research new approaches for communicating paleoclimatic information to resource managers and decision-makers. Particular plans for FY05 include collaborations with water resource managers and land management agencies.

**Accomplishments**

We have made almost all of our data available via ArcIMS, which has a map interface for browsing data by location. Using map layers, a user can find paleoclimate data in a region of interest or near a site of interest. For example, a user is now able to overlay the paleoclimate sites on top of the U.S. Federal Land Management Units as a great tool to check the availability of proxy data within management areas. ArcIMS map data are downloadable as shapefiles (a digital vector storage format for storing geometric location and associated attribute information), which can be used by a wide variety of GIS software. This makes it quite easy for GIS users to delve further into our data on their own computers. Researchers built a map interface for Dr. Edward Cook's reconstruction of drought in the western United States. It allows the user-clickable selection and plotting of reconstructed Palmer Drought Severity Index (PDSI) values in the United States, Western Canada, and Northern Mexico. Time series can be plotted for one location, or a cluster of grid cells can be selected, and a time series of the averaged PDSI values from these cells is produced. The statistical information and the number of tree-ring chronologies used in the reconstruction are also displayed in the generated plots.

## Project 3.2.16 Meteorological Data from Russian Arctic Stations: Completing the Historical Record (NSIDC01)

**Goal: Complete quality control on and publish Russian weather station data that are currently unavailable to Western researchers. These data will fill both a temporal and spatial gap in the current record.**

### *Milestone 3.2.16.a*

Complete quality control and documentation of daily precipitation data for thirty Russian coastal stations north of 60º between 1940 and 1990, and publish the data on-line.

**Accomplishments**

Researchers carried out preparation of this data set in partnership with investigators at the Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia. Precipitation data originally recorded in log books at 65 coastal and island meteorological stations were digitized under the direction of Vladimir Radionov. Long precipitation data records in digital form with daily frequency are rare, but are necessary for efforts such as reanalysis projects. These data join Meteorological Data from the Russian Arctic, 1961-2000, published and reported as last year's milestone. Although this later data set of fifty stations is monthly rather than daily data, it too contributes to a more complete historical record of meteorological observations across northern Russia. Data are disseminated on our Web site. We released the following data sets this reporting year:

- Daily Precipitation Sums at Coastal and Island Russian Arctic Stations, 1940-1990 (http://nsidc.org/data/g02164.html)
- Meteorological Data from the Russian Arctic, 1961-2000 (http://nsidc.org/data/g02141.html)

## Project 3.2.17 Observations for SEARCH: Data Integration for Arctic Reanalysis and Change Detection (NSIDC02)

**Goal: Unaami, the changes in the Arctic that are the subject of the Study of Environmental Arctic Change (SEARCH) program, became apparent to researchers in the context of long-term and pan-Arctic observations. This work will assess what data are relevant to SEARCH reanalysis and change detection activities, collect these data from a wide variety of sources, and facilitate the SEARCH research community's access to the data. Note that this work is funded through Task III, rather than Task II.**

### *Milestone 3.2.17.a*

Extend the Sea Ice Index Web site and data set back to the beginning of the satellite data record. Develop a prototype "onset of melt date" data product. Investigate Normalized Difference Vegetation Index data streams for SEARCH. Provide progress reports to change detection and reanalysis teams.

**Accomplishments**

The Sea Ice Index data record now begins in 1979, the beginning of the usable passive microwave satellite data record. We conducted extensive testing and revision of data handling procedures to ensure that the data record remained consistent across the change in instrumentation that took place in 1988. In addition to tracking sea ice concentration, anomalies, and trends, the site offers interactive animations of ice concentration parameters, an archive of data files and images, and a Web Image Spreadsheet Tool for easily comparing conditions between different months and years.

The Web site has become an important resource for scientists at NSIDC and elsewhere who are monitoring the response of ice to climate change. Arctic sea ice extent was at a new record low in June 2005, continuing a trend that saw record low extents for December 2004 through April 2005. The record wintertime lows are significant, because in the past it has been the norm for sea ice extent to "bounce back" in winter even after hitting record lows at the end of summer. The Sea Ice Index allows the general public as well to follow changes in polar ice cover. The site receives over 20,000 hits per month, and the majority of these are from servers that are not in the .edu or .gov domain, suggesting that it is reaching non-scientific users. Images from the Sea Ice Index have been provided in response to numerous press inquiries on loss of arctic ice, and NOAA NCDC has asked for regular updates on ice conditions for inclusion in its Monthly Climate Summary. A similar site for Normalized Difference Vegetation Index (or "greenness") and soil temperature has been developed. A melt onset site is under development. The SEARCH work supports the NOAA Cross-Cutting Priority of Environmental Literacy, Outreach, and Education, in addition to NOAA Mission Goals.

## Project 3.2.18 World Data Center for Glaciology, Boulder: Current Programs (NSIDC03)

**Goal: Improve our understanding of recent and unexpected changes in polar regions including lower sea-level atmospheric pressure, increased air temperature over most of the Arctic, lower temperatures over eastern North America and Greenland, reduced sea ice cover, thawing permafrost and changes in precipitation patterns.**

### *Milestone 3.2.18.a*

Maintain, update and improve existing research data sets (such as Former Soviet Union Hydrological Snow Surveys; The World Glacier Inventory). Publish new data sets (such as AWI Moored ULS Data, Greenland Sea and Fram Strait; ORA Interactive Multisensor Snow and Ice Mapping System data).

**Accomplishments**

NSIDC published three new data compilations, and we extensively updated eight existing compilations. Two of the releases represent important new collaborations with NOAA operational offices. These are the Interactive Multisensor Snow and Ice Mapping System data from the NOAA NESDIS

## Project 3.2.18 (continued)

Office of Satellite Data Processing and Distribution, and the Snow Data Assimilation System (SNODAS) Data Products, from the National Weather Service National Operational Hydrologic Remote Sensing Center (NOHRSC). The SNODAS data from NSIDC have proven useful to the Colorado Water Conservation Board and the Bureau of Reclamation, who are exploring the potential for SNODAS output to provide better snowpack and streamflow values than SNOTEL-based maps. NSIDC is committed to serving research users of these operational products.

New data compilations published:

- Morphometric Characteristics of Ice and Snow in the Arctic Basin: Aircraft Landing Observations from the Former Soviet Union, 1928-1989 (http://nsidc.org/data/g02140.html)
- Snow Data Assimilation System (SNODAS) Data Products at NSIDC (http://nsidc.org/data/g02158.html)
- IMS Daily Northern Hemisphere Snow and Ice Analysis at 4 km and 24 km Resolution (http://nsidc.org/data/g02156.html)

Significantly updated data compilations:

- Glacier Photograph Collection digital subset (http://nsidc.org/data/g00472.html)
- Airborne Surface Profiling of Alaskan Glaciers (http://nsidc.org/data/g01378.html)
- Former Soviet Union Hydrological Snow Surveys, 1966-1996 (http://nsidc.org/data/g01170.html)
- Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics (http://nsidc.org/data/g01360.html)
- Arctic and Southern Ocean Sea Ice Concentrations (http://nsidc.org/data/g00799.html)
- West Greenland Glacier Inventory (http://nsidc.org/data/g01375.html)
- Environmental Working Group Joint U.S.-Russian Arctic Sea Ice Atlas (http://nsidc.org/data/g01962.html)
- Central Asian Snow Cover from Hydrometeorological Surveys (http://nsidc.org/data/g01171.html)
- Great Lakes Ice Charts (http://nsidc.org/data/g00486.html)

### *Milestone 3.2.18.b*

Digitize sea ice charts of the Beaufort Sea from the historic Dehn collection.

**Accomplishments**

We shipped the entire collection of 7,182 paper ice charts of Alaska, the western Canadian Arctic and Bering Sea covering the years 1953-1986, to scanning contractor Lason in 2005. Images on DVDs of the scanned charts are being loaded into the NSIDC data distribution system. Information on ice edge position in the charts may shed light on the recent summertime retreat of the ice edge north of Alaska.

### *Milestone 3.2.18.c*

Make research information available through the NSIDC Information Center, acquire and catalog cryospheric materials in the NSIDC library, and maintain NSIDC analog data sets.

**Accomplishments**

In 2004, staff turnover resulted in an opportunity to hire two new professional librarians in 3Q05, one with archival training. The fourth quarter was a period of assessment and laid the foundations for new collaborations and major improvements to be undertaken in 2005. The new librarians completed a review of library procedures and worked off a large backlog of check-in and cataloging. In addition, the archivist began a review of historic analog holdings and identified needs for improving storage and preservation of fragile items. From these activities, the librarians identified a number of initiatives to make materials more accessible and useful to patrons.

During the last quarter of the year, library staff processed over 500 periodical issues, books, and other items, added 273 new items to the catalog, and began the processes needed for future funding, budgets, and growth. Library personnel shipped the first batch of 200 historically valuable Dehn Ice charts for digitization and set up the procedures for future shipments. Also during the last three months of the year, the staff opened up channels of communication with their patrons

## Project 3.2.18 (continued)

and personnel with other similar institutions and libraries in the region.

The Library acquires and catalogs both published and unpublished analog materials on snow cover, land and sea ice, cold climates and permafrost, as well as digital data such as CD-ROMs and web resources. It contains over 44,000 monographs, serials, journal articles, reprints, videos, maps, atlases, and CD-ROMs. We currently receive over 100 periodicals and newsletters relating to the cryosphere and to remote sensing of ice and snow. The Center's collection also includes many hard-to-locate international journals dating back well into the mid-20th century, as well as many foreign-language materials. The Library is funded by the NOAA@NSIDC project and by the NASA-supported DAAC.

# 3.3 Geodynamics

Processes deep within the liquid interior of the earth can cause dramatic effects on the surface of the Earth, such as earthquakes, volcanic activity, climate influences, and the formation of mountain ranges. The goal of geodynamics is to better understand the internal processes of the planet, including the properties of the core-mantle (CM) boundary, convection within the Earth's mantle, and how that convection affects the surface of the planet. Convective motion within the mantle, a few centimeters per year, causes oceans to open and close, continental plates to drift, and the Earth's crust to buckle and deform, creating mountain ranges and other structural features. These convective displacements are the underlying source of earthquakes and volcanic activity. As well, convective motion plays a fundamental role in determining climate, through its influence on surface topography. These processes drive Earth's magnetic field, and are frequently described using spherical harmonic analysis, using nearly 300 years of surface magnetic observations.



In order to advance understanding of these geodynamic processes, our goals are to 1) increase knowledge of the fundamental processes that drive the mantle and core-mantle boundary; 2) use spherical harmonic analysis to model Earth's magnetic field; 3) use new experimental methods to detect and monitor internal motions of the mantle, the presence of layering, the movements of continents and the transfer of mass between atmosphere, continent and ocean; 4) examine the chemistry and physics of near-surface rock processes; and 5) investigate links between geophysical processes and human responses. Partners in geodynamics include the National Geophysical Data Center and National Ocean Service at NOAA and the Physics and Geological Sciences departments of the University.

## Project 3.3.1 Improved Integration and Modeling of Geophysical Data (NGDC05)

**Goal:** Improve integration and modeling of geophysical data, advance research into core-mantle processes, improve representation of magnetic fields at or near the Earth's surface, and improve understanding of past hazardous events and potential future impacts.

### *Milestone 3.3.1a*

Apply new automated analysis and scientific review methods to the global geomagnetic database to speed ingest, identify statistical outliers, and improve integration.

**Accomplishments**

Researchers produced two models of the main magnetic field: the World Magnetic Model (WMM) and the International Geomagnetic Reference Field (IGRF). The WMM is the standard navigational model for the U.S. Department of Defense, the U.S. civilian nautical and aeronautical navigation (NOAA and the FAA), the U.K. Department of Defence, and the North American Treaty Organization (NATO). The IGRF is the standard scientific model for the International Association of Geomagnetism and Aeronomy (IAGA), and is widely distributed for use in numerous scientific, research, and commercial applications.

In addition, we joined (by invitation) the Mission Advisory Group (MAG) for the European Space Agency (ESA) Swarm magnetic satellite, representing NOAA and DOD interests on the MAG. Presently, we are developing a Memorandum of Understanding between NOAA and ESA regarding Swarm. We also serve as advisors to the National Geospatial-Intelligence Agency on future U.S. magnetic satellite missions.

Researchers also established and distributed a new magnetic disturbance index (available at http://www.ngdc.noaa.gov/seg/geomag/est_ist.shtml). Further separating the magnetospheric disturbance magnetic field into external and induced contributions provides the Est index for the external source field

## Project 3.3.1 (continued)

and the Ist index for the internal induced field. This index helps refine monitoring of the magnetic disturbance field by the global network of magnetic observatories.

### *Milestone 3.1.1.b*

Apply new automated analysis and scientific review methods to the significant hazards database (including earthquakes and tsunamis) to speed ingest, identify statistical outliers, and improve integration.

**Accomplishments**

Researchers redesigned the Natural Hazards databases, developing software tools to improve quality assurance of the tsunami event and run-up databases. We also enabled ArcIMS display of the data centered on the Atlantic or the Pacific Oceans, and developed displays for all other ocean basins.

### *Milestone 3.1.1.c*

Improved modeling of Earth's main magnetic field.

**Accomplishments**

Researchers produced and distributed a major revision of a scientific geomagnetic field model (POMME-2.5). POMME-2.5 includes the time varying core field, crustal field, the ring current field modulated by the Dst/Est/Ist disturbance indices, a time averaged magnetospheric field, the penetration of the horizontal part of the interplanetary magnetic field (IMF), and the fields induced by Earth rotation in the external fields.

# 3.4 Integrating Activities

CIRES engages in a wide range of integrating activities in research, education, and outreach that encompass each of the institute's research themes and contribute to the overall mission of the Institute, NOAA, and the University of Colorado. The primary focus is on five overlapping categories that include 1) K-16 Interdisciplinary Education and Outreach, 2) Graduate and Post-Graduate Education, 3) Scientific Assessments, 4) Interdisciplinary Research, and 5) Science and Technology Policy Research. For example, one team is focused on the decision-making processes of the individuals, groups, and organizations in the Interior West that have responsibility for managing, using, treating, and protecting water resources. By understanding decision-making processes, the stresses, and the constraints of this community, researchers seek to assess vulnerability to climate variability and develop hydro-climate products that enable better-informed decisions. Such scientific assessments bring together the expertise of CIRES people across a range of fields, including policy research and technology transfer, in collaboration with experts and end users who partner from outside the Institute. Collaborations with colleagues in the local NOAA laboratories have resulted in the transformation of basic research into applied science.



## Project 3.4.1 Scientific Assessments for Decision Makers (AL10)

**Goal: Plan, lead, prepare, and disseminate assessments for the decision-making communities associated with ozone-layer depletion, greenhouse warming, and regional air quality.**

### *Milestones 3.4.1.a*

Carry out the early planning and drafting stages of the WMO/UNEP 2006 scientific state-of-understanding assessment of the ozone layer.

**Accomplishments**

Researchers have completed the earliest planning and drafting stages of the forthcoming (2006) international scientific assessment regarding the ozone layer. CIRES scientists are serving as co-authors, reviewers, and coordinating editor of the report. The report will describe the current status of our understanding regarding ozone-depleting substances in the atmosphere, polar and global ozone observations, climate-ozone connections, expectations for future halocarbon levels and the ozone layer, and observed/future surface ultraviolet radiation.

Major work entailed the drafting of the chapter structure and contents of the assessment, and the circulation of that draft to the international scientific community for comment. A revised chapter structure and plan was then used by the co-chairs to develop a team of lead authors for the eight resulting chapters of the assessment. Those lead authors have drafted a chapter outline and enlisted their chapter co-author teams.

In FY05, much work also went into planning the first meeting of those lead authors (July 2005) and subsequent meetings for the review of the chapter first drafts (November 2005) and third drafts (June 2006). The team will complete the report August 2006, and printing is planned for early 2007.

## Project 3.4.2 Integrated Science and Ecosystem Informatics (NGDC06)

**Goal: Evaluate data and informatics needs to support integrated regional ecosystem assessments and improve the empirical basis for ecosystem assessment and communication to policy and decision makers.**

### *Milestone 3.4.2.a*

Assess informatics needs for "integrated science" and regional ecosystem assessment and build partnerships for related developments and program support.

**Accomplishments**

We evaluated needs were evaluated in two contexts: (a) the development of a coastal component of the Global Terrestrial Observing System (C-GTOS) and (b) the establishment of a Pacific Regional Integrated Data Enterprise (PRIDE). In the first case, we implemented recommendations for establishing a "World Deltas Network" (http://cires.colorado.edu/science/pro/wdn). In the second case, a partnership was formed between PRIDE and the NBII Pacific Basin Information Node (PBIN) to test a model that will use environmental data to predict vulnerability and suitability for various ecological phenomena. The initial test is on an invasive species problem in Hawaii.

### *Milestone 3.4.2.b*

Design and demonstrate innovative data and information support capabilities for regional integrated science and assessments.

**Accomplishments**

We established the World Deltas Network as a distributed web site in collaboration with the White Water to Blue Water Program and the GTOS. We provided demonstration products through this portal, including (1) a comprehensive global deltas database, (2) delineations of delta areas of influence and the delta itself using GIS methods, and (3) sample Landsat mosaics of deltas. Figure 3.4.a provides a sample image from this database.

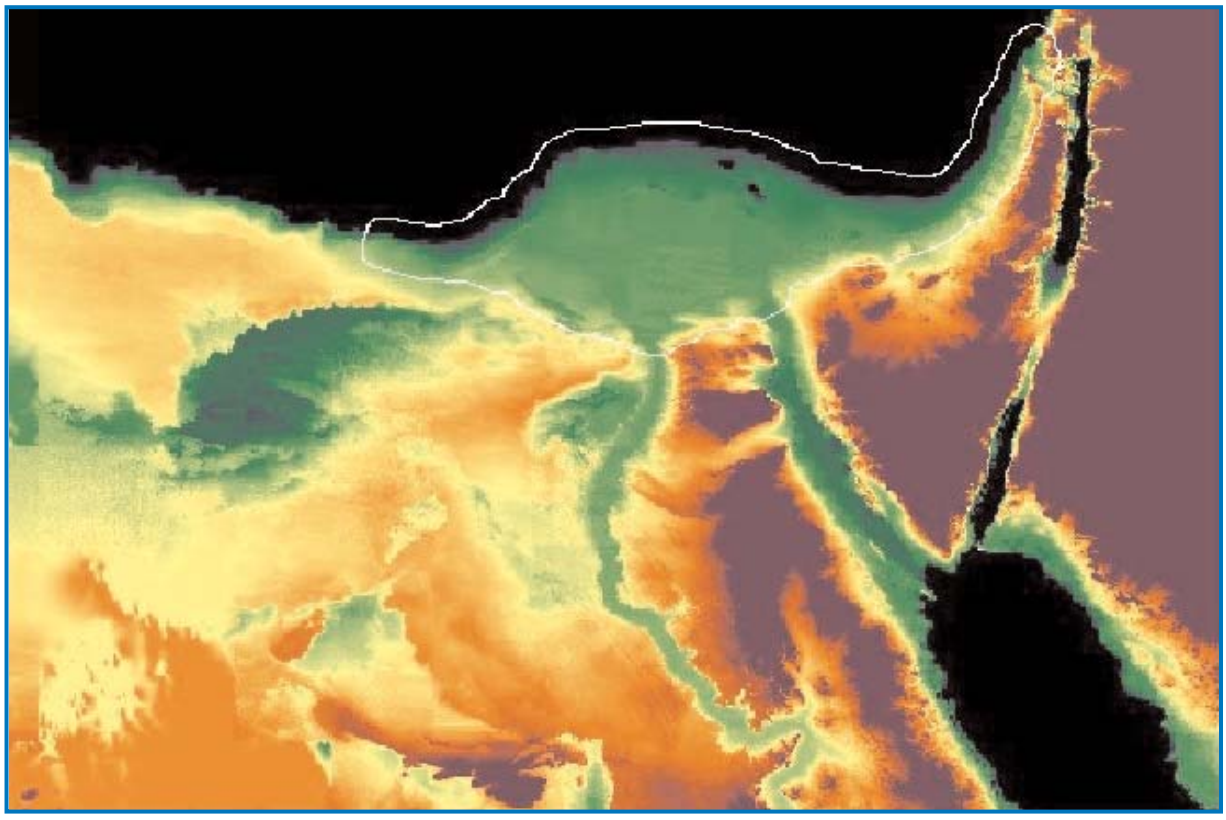


*Figure 3.4.a Landsat image of the Nile delta.*

## Project 3.4.2 (continued)

We also developed and demonstrated an innovative modeling approach to defining geographic areas of vulnerability to invasive marine algae in Hawaii. Work continues to acquire appropriate data from various sources within the PRIDE system, and algal research biologists, to use the model to produce vulnerability maps (Fig. 3.4.b) that can help anticipate future hotspots of invasion, and to help inform management plans.

### *Milestone 3.4.2.c*

Plan and conduct workshops, seminars, and symposia, including planning for GIS/EM5, the fifth in the series of international symposia on integrating GIS with environmental modeling.

**Accomplishments**

A workshop of the World Deltas Network Steering Committee has been postponed to fall 2005. It will precede and help inform another workshop being organized by NOAA International Affairs, to consider integrated science of the Mississippi River system.

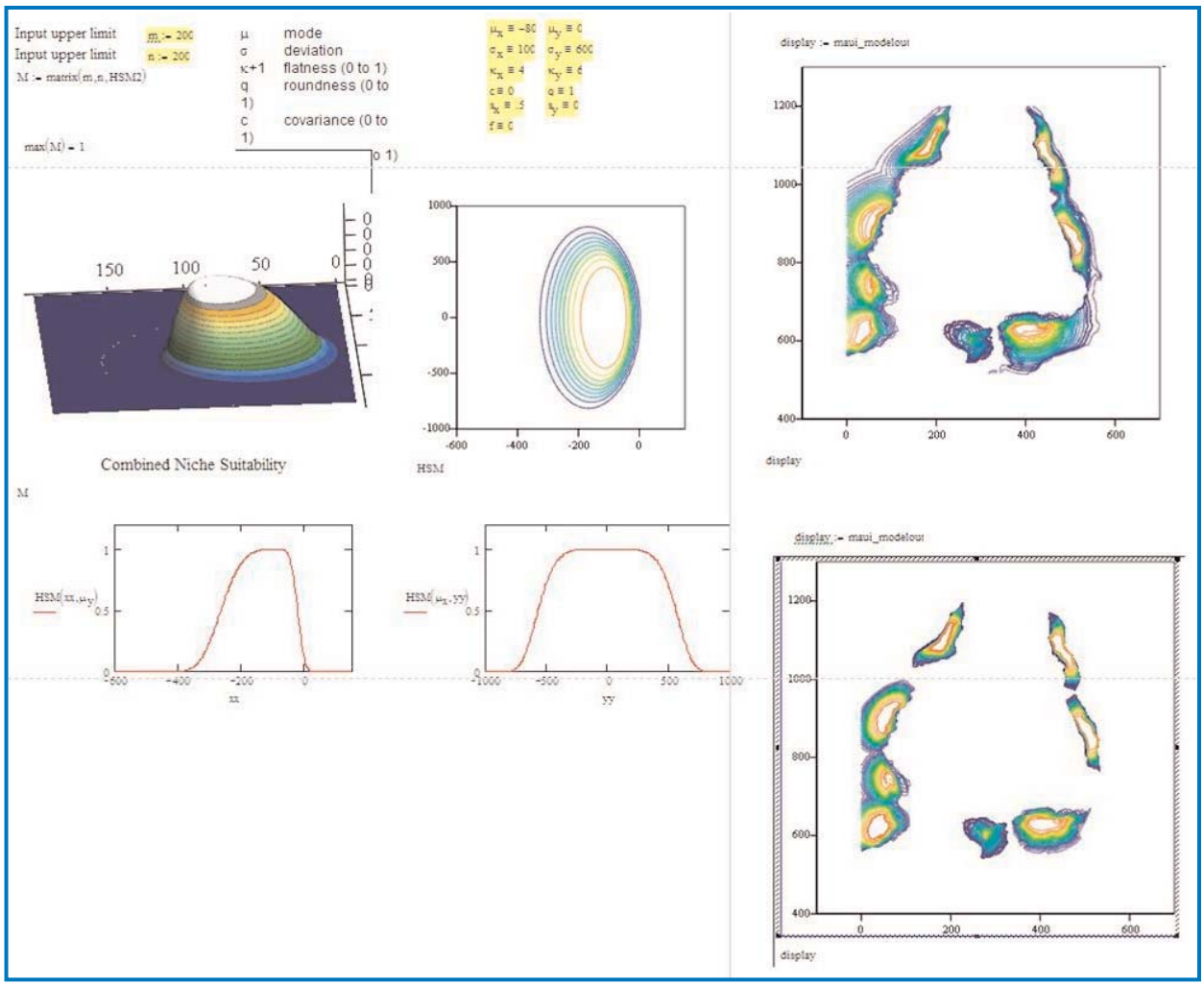



*Figure 3.4.b This sample vulnerability map shows areas potentially vulnerable to invasive marine algae on the island of Maui.*

## Project 3.4.3 Science Policy Lecture Series (Policy01)

**Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.**

### *Milestone 3.4.3.a*

Secure funding for the series. Locate speakers and issue invitations. Develop schedule and make logistical arrangements. Begin series.

**Accomplishments**

In 2005, we launched a lecture series titled "Policy, Politics, and Science in the White House: Conversations with Presidential Science Advisors." We secured commitments from six current and former science advisors to the United States president to visit Boulder, Colorado, for two days to meet with students, faculty, and local scientists, and to participate in a public forum focusing on science policy. We raised approximately 80% of our budget and are continuing efforts to secure funding. Dr. John Marburger, science advisor to President George W. Bush, visited Boulder in February and spoke to an audience of approximately 400 people. Dr. John Gibbons, science advisor to President Bill Clinton, visited in April and spoke to an audience of approximately 75 people. Both advisors also met informally with numerous graduate students, faculty, local scientists, and community members. This fall and winter, we will host Dr. Edward David, science advisor to President Richard Nixon; Dr. Neal Lane, science advisor to President Bill Clinton; Dr. Donald Hornig, science advisor to President Lyndon Johnson; and Dr. George Keyworth, science advisor to President Ronald Reagan. Judging from the number of people in the community who have participated in these events, as well as the local press coverage, we feel the series is having its desired impact.

## Project 3.4.4 Outreach to Decision Makers through the Internet (Policy02)

**Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.**

### *Milestone 3.4.4.a*

Continue to expand our Web presence by adding new content to the Center for Science and Technology Policy site. Complete a system that will allow center members to create and update more of their own content to accelerate content production. Improve the system that drives the center's publications section, the Climate Services Clearinghouse, and other sections of the site. Improve accessibility and usability of all center sites by meeting Section 508 guidelines and by allowing users to set their visual preferences such as font sizes. Implement more extensive link checking and management to keep content current.

**Accomplishments**

In the past year we have added substantial new content to our Web site. We created Web pages for several new projects:

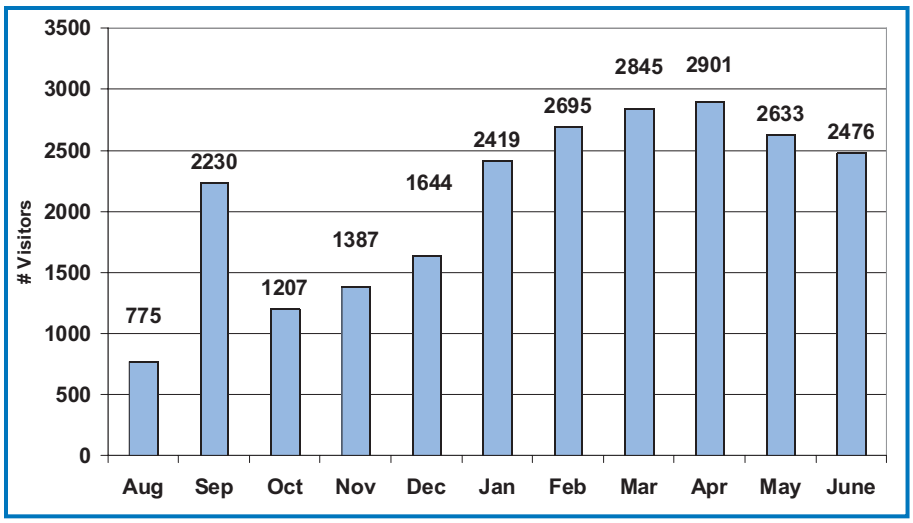



*Figure 3.4.c Daily average number of visitors to the Science and Technology Policy Web site, August 2004 – June 2005.*

## Project 3.4.4 (continued)

- Science Policy Assessment and Research on Climate (SPARC) project (http://sciencepolicy.colorado.edu/sparc/)
- Presidential Science Advisor lecture series (http://sciencepolicy.colorado.edu/scienceadvisors/)
- "Our Science, Their Science" project (http://sciencepolicy.colorado.edu/our_science_their_science/)
- "Scales of Decision Making" project (http://sciencepolicy.colorado.edu/homepages/lisa_dilling/ccycledecisions/)
- Prometheus science policy weblog (http://sciencepolicy.colorado.edu/prometheus/).

We continue to develop and improve our system that allows center staff to update their own content on the web site rather than having to rely on the webmaster to do it for them. We also continue to improve the publications system. We have developed a database that includes all center students, staff, affiliates, visitors, and collaborators to improve content management. We believe that these improvements have greatly increased site visits, as illustrated by Figure 3.4.c.

## Project 3.4.5 Outreach to Decision Makers through Newsletters (Policy03)

**Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.**

### *Milestone 3.4.5.a*

Increase publication of the Center for Science and Technology Policy newsletter, *Ogmius*, from three to four times a year. Resume publication of *Weatherzine* newsletter three times a year.

**Accomplishments**

We increased publication of *Ogmius* from three to four times a year beginning in 2005. Although we did not resume publication of *Weatherzine*, discussions are underway about transferring *Weatherzine* to another institution to resume publication.

## Project 3.4.6 Scientific Assessments (WWA01)

**Goal: Identify and characterize regional vulnerabilities to climate variability and change for use by Intermountain water-resource decision-makers**

### *Milestone 3.4.6.a*

Investigate elevational characteristics of snowpack over the last fifty years.

**Accomplishments**

Researchers have developed high-resolution climate data sets on snowpack for the western United States, stratified by elevation. These data sets include a suite of products from ordinary coop climate station records, SNOTEL, and the 4-km gridded PRISM set. We are also underway on a water balance analysis using the PRISM data. Using this data set, the area-weighted total supply of water from precipitation amounts to 88 MACF for the Upper Colorado River Basin. We are testing different techniques to estimate the other components of the water balance. We have established a collaboration with Greg McCabe of the USGS in this regard.

We also examined climatic changes in the Upper Colorado River Basin (UCRB) in the second half of the 20th century, using the PRISM data set (Fig.3.4.c). We focused on changes in surface temperature and precipitation as a function of elevation for the past 55 years (1950-2004), and over the past 25 years (1980-2004) for which the high-elevation SNOTEL data set is available.

### *Milestone 3.4.6.b*

Evaluate Front Range water needs to the year 2040.

**Accomplishments**

WWA team members have continued to work towards the completion of a useful model of the South Platte River basin to study Front Range

## Project 3.4.6 (continued)

water needs to 2040. This effort has included calibrating and validating the model, completing model documentation, and generating model output. This work has involved truly integrated research (economists, climatologists, water planners, and others) geared towards developing a regional assessment tool capable of integrating climate into long-term water resource planning.

During the past year, WWA has established several working relationships with user groups within the South Platte. Collaboration with these groups has allowed us to identify information needs and to better focus our modeling efforts on research currently relevant to decision makers. This process has helped establish new areas of study within the WWA. Examples include progress towards incorporating tree-ring generated climate scenarios into the SPRAT model, developing a means of modeling the impacts of water transfers on the basin, and updating model inputs.

We have also met with several water managers and planning personnel in an attempt to obtain a better understanding of the role of water transfers in the South Platte (such as why they occur, how they occur, and where they might occur in the future). This work has resulted in a better understanding of how water managers target future sources of supply, including the role that climate variability and change play throughout planning.

Four papers are in process: an introduction to the South Platte Regional Assessment Tool (SPRAT) including model results and forecasts of future water shortages and stress points; a comparison of the effectiveness of various water management alternatives (such as conservation, water transfers, reservoir development, and others); a probabilistic analysis of the effects of increased climate variability on the effectiveness of various management alternatives and the ability for water managers within the South Platte River basin to meet future demands; and a summary of the SPRAT process, including lessons learned regarding the development of a large regional model and interactions with user groups.

WWA team members made SPRAT presentations to user groups, including the Northern Colorado Water Conservancy District and other members of the WWA team; the 2005 Universities Council on Water Resources (UCOWR) conference on River and Lake Restoration; the State Water Supply Initiative consultants and program managers, leading to a short-term research partnership; Colorado Water Workshop; and the American Water Resources Association. We also completed SPRAT model documentation for distribution with SPRAT.

### *Milestone 3.4.6.c*

Evaluate the 2002 drought response.

**Accomplishments**

Researchers completed an article for publication analyzing and evaluating the 2002 drought response. In this paper, we reported our investigation of the 2002 Colorado drought through the lenses of climatologists, hydrologists, and paleoclimatologists. For the state as a whole, 2002 was unlikely to have been the driest on record; however, for some parts of the state, such as the southern Front Range, it was the driest single year onrecord. With regard to snowpack, 1977 was comparable to 2002 until May 1, when dry and warm conditions made 2002 worse. Streamflows in the state were the smallest or near the smallest in the instrumental record. In the context of treerings, 2002 in western Colorado produced the smallest growth in 150 years. Precipitation deficits were not exceptional in all areas of the state; however, high evaporation, hot temperatures, and high water demand made 2002 stand out as a very serious year. This magnification of impacts with respect to the actual precipitation deficit indicates that Colorado is now more vulnerable to short-term drought than in the past.

### *Milestone 3.4.6.d*

Investigate the climate products and vulnerabilities of large water providers.

**Accomplishments**

Researchers began the user study of large Front Range water providers. We hired a research assistant; developed an interview protocol and prepared for required human subjects review; and held initial meetings with water managers. The project is being coordinated with WWA drought activities and will continue into the coming year.

## Project 3.4.6 (continued)

**Additional accomplishments**
WWA continues to focus on drought. In the last year, we began a small survey of the economic impacts of drought. WWA personnel were part of the National Integrated Drought Information System steering committee, and made major contributions to the National Integrated Drought Information System vision document. WWA maintains close contacts with the Denver-based Western Governor's Association lead, Shaun McGrath. WWA team members also provided important chapters for the newly released *Drought And Water Crises: Science, Technology, and Management Issues* (Donald A. Wilhite, editor).

WWA-funded individuals spent much time attending meetings with key personnel from major water entities in the state. The ultimate goal of these meetings is to understand stakeholder needs so that research can be properly directed. In the course of the year, we met with Colorado Foundation for Water Education, Colorado Water Conservation Board, Northern Colorado Water Conservancy, Denver Water (multiple times), City of Boulder Water staff, Colorado River Water Conservation District staff, Water Education Foundation staff, Western Governor's Association staff, USGS staff, CSU faculty, Environmental Defense, Nature Conservancy, Trout Unlimited, Pacific Institute, Colorado Legislature staff, Colorado Water Availability Task Force, NWS Colorado Basin River Forecast Center staff, NWS Climate Focal Points from Kansas City and Salt Lake City, NWS Climate Prediction Center personnel, and NWS Climate Services Division personnel. WWA also hosted or sponsored several important events during the last year: a Wildfire Conference; the NOAA Colorado River Briefing; and the Colorado River Compact Conference.

## Project 3.4.7 Climate Products (WWA02)

**Goal: Develop information, products, and processes to assist water resource decision makers throughout the Intermountain West.**

### *Milestone 3.4.7.a*

Establish and improve a Climate Services Clearinghouse (CSC) Web site.

**Accomplishments**
We have launched, and continue to develop, the clearinghouse Web site (http://sciencepolicy.colorado.edu/climateservices/). We are using the WWA community as an initial test bed to develop, implement and evaluate the CSC as a resource for both the climate services community (research and operations) and, once it approaches maturity, for end users. We have identified two distinct sets of decision makers as the focus of the CSC. First are those who make decisions about climate science, climate services and the connections of science and services. Once it reaches maturity, the CSC has great potential to serve as a resource for end users. We seek to catalogue all contemporary, operational climate services. The Climate Prediction Center (CPC) has agreed to transition the Climate Services Clearinghouse (CSC) to their office for continued implementation once it has reached maturity.

### *Milestone 3.4.7.b*

Improve NWS Colorado Basin River Forecast Center streamflow forecasts at various time scales.

**Accomplishments**
Research has progressed along two paths. First, we have worked on methods to downscale and disaggregate weather and climate forecasts into a form appropriate for use in operational streamflow forecasting models. The research methods used here are a conglomeration of methods of Model Output Statistics used in the meteorological community, and methods of stochastic hydrology used in the hydrological community. Use of these methods in operational forecasting systems is fairly straight-

## Project 3.4.7 (continued)

forward (all that is required is to switch model inputs), and these methods have been implemented at the Colorado Basin River Forecast Center.

Our second research focus has been on developing a probabilistic approach to streamflow simulation. This research is based on a critique of the current operational streamflow forecasting system. The standard streamflow forecasting approach involves running a hydrologic model up to the start of the forecast period to estimate basin initial conditions (such as snowpack and soil moisture), and then running the model into the future, with an ensemble of meteorological forecasts, to produce probabilistic forecasts of streamflow. This approach permits a probabilistic treatment of meteorological forecasts, but all other components of the system are entirely deterministic. For example, the approach assumes there is no uncertainty in model estimates of the basin snowpack. Since the predictability of streamflow in the Intermountain West is intimately tied to knowledge of the snowpack, it is extremely important to account for the uncertainties in snowpack estimation.

Researchers have developed methods that account for both uncertainty in model forcings and uncertainties in model parameters. Further, we have developed and implemented ensemble data assimilation methods that use snow observations to reduce uncertainties in model simulations of snowpack. Operational use of these new forecasting methods is more difficult as their implementation requires an overhaul of the operational streamflow forecasting system; however, we are actively working on these methods with the ensemble group at the NWS Office of Hydrologic Development.

### *Milestone 3.4.7.c*

Provide Web-based seasonal climate forecasts for Colorado Drought Task Force.

**Accomplishments**

The WWA provides bi-monthly briefings to the Colorado Water Availability Task Force. These briefings are based on a monthly updated Web page (http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/index.html) that covers the recent and projected evolution of the El Niño—Southern Oscillation (ENSO) phenomenon, discusses the most recent CPC climate forecast, and examines in detail our experimental forecasts for the full interior southwestern United States, with special emphasis on Colorado. As was confirmed in a survey in early 2005, these forecasts have become a regularly consulted tool for Water Managers in the Front Range region, in particular for the Denver Water and Northern Colorado Water Conservancy districts. During the task force briefings, we educate the audience about climate variability in Colorado, ENSO phenomena, and climate forecasts (including their probabilistic nature). In return, WWA learns about the impacts of the current drought on the management of various public sectors (water resources, wildfire mitigation, agriculture, tourism, etc.). On a national scale, these experimental climate forecasts are now used by wildfire managers in the Western United States, and by CPC, both for the seasonal climate forecasts and the U.S. Drought Monitor Outlook.

Specifically, in 2004 we evaluated the performance of the experimental seasonal climate forecasts during the last five years of independent forecasts, and confirmed improvement in the quality of these forecasts compared to CPC and simple climatology forecasts. Also, we created statistically-based "climate divisions" for the Colorado River Basin that were based on both regular climate station and automated SNOTEL data to create a parsimonious history of the instrumental record back to the 19th century. We then used these data to create composite typical El Niño associations across the basin.

### *Milestone 3.4.7.d*

Provide Web-based dendrohydrological data sets with 400+ years of streamflow data.

**Accomplishments**

Over the course of the project, WWA team members have generated streamflow reconstructions for seven gages in the Upper Colorado River basin, four gages in the Gunnison River basin, and eight in the South Platte River basin. WWA has developed a Web site, TreeFlow (http://www.ngdc.noaa.gov/paleo/streamflow/), that is directed at water

## Project 3.4.7 (continued)

resource managers. The site contains the reconstructions and gage data, as well as background information on how the reconstructions were generated, how to interpret reconstruction statistics and evaluate reconstruction quality, and a case study on the Blue River reconstruction. We have developed a new reconstruction technique based on an ensemble methodology to address critical questions regarding the description and quantification of uncertainty in the annual flow reconstructions that were raised by the water managers when introducing tree-ring reconstructions into the decision process. We were also funded by Denver Water in 2003 to recollect samples and update tree-ring chronologies at twelve western Colorado sites to 2002, and from them, update their three upper Colorado basin gages to 2002.

In the past year, we have provided updated reconstructions for four Northern Colorado Water Conservancy District South Platte gages, and the Denver Water South Platte at South Platte gage. The initial reconstructions ended in 1987 due to length of the available tree-ring chronologies. Fieldwork to update and collect new sites has resulted in reconstructions that start earlier (with variable start dates) and end in 1999 or later.

In June, we contracted with Denver Water to develop methods to better replicate the extreme low flows in the gage record and to reconstruct a water demand index. The contract also involved the updated South Platte reconstruction mentioned above, and the fieldwork needed to accomplish this. In addition, earlywood and latewood chronologies were developed in an attempt to improve the reconstruction of water demand.

Other going work involves users in the Rio Grande Water Conservation District (RGWCD) in the San Luis Valley concerned with upper Rio Grande streamflow. We recently developed preliminary reconstructions of flow for four gages of particular interest to the RGWCD. We are also working with Ben Harding (Hydrosphere Resource Consultants) to develop techniques to use tree-ring chronologies and/or flow reconstructions for the Upper Colorado River to run a water supply model for this basis. This work takes advantage of an unfunded project with co-investigators Dave Meko (UAZ) and Steve Gray (USGS) to update the upper Colorado streamflow reconstructions of Stockton and Jacoby (1976).

Finally, we were recently funded by Center for Community Development and Design (CCDD) to organize and hold a workshop to unite paleoscientists and water resource managers concerned with water supplies in the entire Colorado River basin. This goal of this workshop was to build on the work done with Colorado resource managers, and to develop new partnerships and plans for future work, expanded to the full Colorado River basin. This workshop was held in May 2005.

**Additional Accomplishments**

The Intermountain Climate Summary (ICS) is a new WWA project. The ICS was designed to provide water managers with a one-stop source of climate information from a variety of information providers, including NWS, NRCS, RCCs, Colorado Climate Center and CDC. We produced an initial user survey to get feedback on the tool and more are planned. WWA has coordinated with all entities providing data. It is also anticipated that future WWA user studies will be based on this tool. WWA team members also contributed articles. This product will be distributed eight times annually via e-mail notification containing a Web link.

# 3.5 Planetary Metabolism

The sustainability of the biosphere during the current period of rapid changes in the Earth system is an issue of prime importance for the environmental sciences. The physical and chemical features of the Earth are intimately tied to organisms and the activities required for their sustenance. The health of the biosphere can be fruitfully considered using the concept of "planetary metabolism," a concept referring to the complex web of biochemical and ecological processes that occur within the biosphere, and the interaction of these processes with the lithosphere, atmosphere and hydrosphere. Both natural and anthropogenic disturbances drive the structure and dynamics of natural systems, and a thorough understanding of these complex processes is essential to protect the biosphere from adverse effects due to pollution, destruction of natural landscapes, and alteration of climate. The overarching goals of the Planetary Metabolism theme are to 1) increase our knowledge of the fundamental processes that drive the biosphere; 2) use experimental tools to accurately measure indicators of change; 3) enhance the sophistication of prognostic models capable of forecasting the response of ecosystems and the global biosphere to future environmental changes; 4) carry out research that will develop science and technology to help restore and protect the health of the biosphere. Major collaborations and parallel activities include the Aeronomy Laboratory (AL); the National Geophysical Data Center (NGDC); the Molecular, Cellular and Developmental Biology (MCDB) department; and the Ecology and Evolutionary Biology (EEB) department.



## Project 3.5.1 Biosphere-Atmosphere Exchange (AL07)

**Goal: Gain an improved understanding of the role that the exchange of gases between the surface and the atmosphere plays in shaping regional climate and air quality.**

### *Milestone 3.5.1.a*

Identify and/or quantify processes that involve biosphere-atmosphere exchange of gases that are important in atmospheric chemistry, through research on i) the release of volatile organic compounds (VOCs), an important ozone precursor from plant roots; and ii) the effects of ethylene on the emissions of biogenic VOCs.

**Accomplishments**

In collaboration with plant physiologists from Colorado State University in Fort Collins, we used a novel approach to explore the release of VOCs by plant roots and their induction by biotic stresses. The VOC formation of Arabidopsis thaliana roots was analyzed using proton-transfer-reaction mass spectrometry (PTR-MS), a technology that allows rapid and real-time analysis of most biogenic VOCs without pre-concentration or chromatography. Our studies revealed that the major VOCs released and identified by both PTR-MS and GC-MS were either simple metabolites, ethanol, acetaldehyde, acetic acid, ethyl acetate, 2-butanone, 2,3-butanedione, and acetone, or the monoterpene, 1,8-cineole. Some VOCs were found to be produced regardless of the treatment; other VOCs were induced specifically as a result of different compatible and non-compatible interactions between microbes/insects and Arabidopsis roots. Compatible interactions of Pseudomonas syringae DC3000 and Diuraphis noxia with Arabidopsis roots resulted in the rapid release of 1,8-cineole, a monoterpene that has not been previously reported in Arabidopsis. Mechanical injuries to

## Project 3.5.1 (continued)

Arabidopsis roots did not produce 1,8-cineole, nor any $C_6$ wound-VOCs. Compatible interactions between Arabidopsis roots and Diuraphis noxia did not produce any wound compounds. This suggests that Arabidopsis roots respond to wounding differently from plant organs above the ground. Trials with incompatible interactions did not reveal a set of compounds that was significantly different compared to the non-infected roots.

In this project we exposed a number of plants to enhanced ethylene concentrations, and monitored the VOCs released by the plant using a newly developed proton-transfer ion-trap mass spectrometry (PIT-MS) instrument. Of all plant species studied (tomato, potato, bell pepper, and carnation) only tomato plants emitted significant VOCs when damaged by ethylene. The experiments with tomato plants showed markedly different behavior in light and dark conditions. In the light, when exposed to 10 ppmv ethylene, the plants only produced monoterpenes; in the dark, strong signals for several VOCs: methanol, hexenals, and monoterpenes were observed. In light or dark, 10 ppmv ethylene killed the plants over the course of the experiments: the leaves started to wilt and died over the course of one day. Interestingly, the other plant species tested did suffer the same level of damage from the ethylene exposure as tomato plants, but did not alter their VOC emissions.

As a side project, we compared the performance of a photoacoustic laser absorption instrument for the detection of ethylene with that of a gas chromatography instrument, which has been used in our laboratory for many years. Laser Photo-Acoustic Spectroscopy (LPAS) is highly suitable for the detection of ethene in air due to the overlap between its strongest absorption lines and the wavelengths accessible by high-powered $CO_2$ lasers. We tested the ability of LPAS to measure ethene in ambient air by comparing the measurements in urban air with those from a gas chromatography flame-ionization detection (GC-FID) instrument. Over the course of several days we obtained quantitative agreement between the two measurements. Over this period the LPAS instrument had a positive offset of 330±140 pptv (parts-per-trillion by volume) relative to the GC-FID instrument, possibly caused by interference from other species. The detection limit of the LPAS instrument is currently estimated around 1 ppbv and is limited by this offset and the statistical noise in the data. We conclude that LPAS has the potential to provide fast-response measurements of ethene in the atmosphere, with significant advantages over existing techniques when measuring from moving platforms and in the vicinity of emission sources.

**Additional Accomplishments**

In addition to the plants root and ethylene fumigation experiments above, we continued our work on the release of reactive VOCs by drying crops. Grass crop species, rice, and sorghum that are widely grown in the southeastern Texas region were analyzed for release of biogenic VOCs in simulated leaf drying/senescence experiments. VOC release was measured by both on-line PTR-MS and PIT-MS methods, and demonstrated that these two grass crops release a large variety of oxygenated VOCs upon drying under laboratory conditions, primarily from leaves, not stems. VOC release from paddy rice varieties was much greater than for sorghum, and major VOCs, identified by gas chromatography-PTR-MS, included methanol, acetaldehyde, acetone, n-pentanal, methyl propanal, hexenol, hexanal, cis-3-hexenal and trans-2-hexenal. The latter four VOCs, all $C_6$ compounds known to be formed in wounded leaves, were the major volatiles released from drying rice leaves, and smaller but substantial amounts of acetaldehyde were observed in all drying experiments. On-line detection of VOCs using PIT-MS gave results comparable to those obtained

## Project 3.5.1 (continued)

with PTR-MS, and use of PIT-MS with collision-induced dissociation (CID) of trapped ions allowed unambiguous determination of the ratios of cis- and trans-hexenals during different phases of drying. As rice is one of the largest harvested crops on a global scale, it is conceivable that during rice senescence, releases of biogenic VOCs, especially the reactive $C_6$ wound VOCs, may contribute to an imbalance in regional atmospheric oxidant formation during peak summer/fall ozone formation periods. A county-by-county estimate of the emission rates of reactive biogenic VOCs from sorghum and rice production in Texas suggests that these releases are orders of magnitude lower than anthropogenic VOCs in urban areas, but that VOC emission rates from rice in south-eastern coastal Texas may need to be included in regional air quality assessments during periods of extensive harvesting.

Finally, work continued on the development of PIT-MS, a technique developed in our laboratory which allows the on-line quantification and identification of VOCs. Two papers were published which compared the performance of the instrument versus a PTR-MS and a GC-MS, respectively, with generally favorable results.

## Project 3.5.2 Anthropogenic Remote Sensing (NGDC07)

**Goal: Provide spatial and temporal depictions of human activities based on satellite detection and mapping of population centers, fires, gas flares, and heavily-lit fishing boats.**

### *Milestone 3.5.2.a*

Produce the first global nighttime light change analysis spanning a ten-year time period from 1992-1993 to 2003.

**Accomplishments**

Researchers completed the ten-year time series, including ten annual composites. However, the change analysis has not been completed.

# 3.6 Regional Processes

Many of the research endeavors within CIRES and NOAA have a regional focus because they address a particular confluence of geography, demographics, weather and climatic regimes, or scientific challenge. This confluence of factors has produced a range of research within CIRES and NOAA that is not only rich in its diversity but provides an essential connection between science and its constituents. These constituents include human populations ranging from coastal megalopolises to communities of indigenous peoples on the margin of the Arctic Ocean, all of which must coexist with sensitive aquatic and terrestrial ecosystems in a highly variable and evolving climate. Indeed, the impact of short-term climate variability and extremes is often regionally focused, influencing very specific populations, economies, and ecosystems. CIRES scientists in the Aeronomy Laboratory (AL), the Climate Monitoring and Diagnostics Laboratory (CMDL), the Climate Diagnostic Center (CDC) and the Environmental Technology Laboratory (ETL) work on such projects as the mechanisms of atmospheric transport on climate and air quality, chemical transformation of products of biomass burning, air/sea gas transfer, and ozone pollution. This research contributes substantially to CIRES Center for Science and Technology Policy Research and the Western Water Assessment Program. The latter is of particular value because of its broad focus that includes social scientists in the areas of economics, geography and behavioral sciences, in addition to CIRES physical science experts.



## Project 3.6.1 Tropospheric and Stratospheric Transport and Chemical Transformation (AL04b)

**Goal: Carry out modeling studies and airborne and surface measurements of chemical species in order to elucidate the processes involved in the intercontinental transport of photochemical pollution.**

### *Milestone 3.6.1.a*

Investigate the formation and transformation of particulate material in air that is transported from the East Coast of North America to the North Atlantic.

**Accomplishments**

Researchers made airborne measurements of particle size distributions and composition, gas-phase particle precursors, and tracer species in the plumes transported over the North Atlantic downwind from a variety of these industrial and urban sources, as well as in the smokes from remote forest fires in western Canada and Alaska. Our analysis of the results indicates that photochemical oxidation of volatile organic compounds (VOCs) from urban sources leads to rapid formation of modest quantities of particulate organic matter. However, the oxidation of sulfur dioxide ($SO_2$) from industrial point sources forms sulfate that dominates particulate mass during high-pollution events in well-aged plumes from the East Coast and Ohio River Valley regions (Figure 3.6.a). Because many climate and health effects are related to the total particulate mass loading, this finding indicates that emissions from $SO_2$ point sources are especially important for these issues, even downwind of the heavily urbanized, VOC-rich, East Coast cities.

Forest fire smokes were found to be major sources of carbon monoxide and particulate matter in the free troposphere in air transported from the North American continent. The removal of smoke particles in some plumes was documented and attributed to cloud processing during transport. These studies should improve understanding of the source strength and removal processes for these particles in the atmosphere, leading to more quan-

## Project 3.6.1 (continued)

titative evaluations of their importance to climate, air quality, and global atmospheric chemistry.

### *Milestone 3.6.1.b*

Report the findings from the Intercontinental Transport and Chemical Transformation of 2002 (ITCT 2K2) field mission off the West Coast of the United States.

**Accomplishments**

Researchers investigated the sources and characteristics of Asian emissions sampled during the ITCT 2k2, using trace gas and aerosol measurements made at the Trinidad Head, California ground site and along the west coast of the United States aboard the NOAA P-3 aircraft. The study separated episodic plumes from background air (the continual mixing of emissions into the background atmosphere) using measurements of carbon monoxide (CO). Using the observed hydrocarbon composition and the presence of burning tracers, such as acetonitrile, we identified these plumes as primarily fossil fuel or biomass burning emissions. Additional back-trajectory analysis showed that the fossil fuel emissions originated from Japan and the Korean peninsula, whereas the biomass burning emissions mostly originated in China and Southeast Asia.

We also used correlations between 1-s observations of CO and $O_3$ and total reactive nitrogen ($NO_y$) to characterize the plumes. The $O_3$/CO ratio varied among the plumes and was affected by the mixing of anthropogenic and stratospheric influences. The $NO_y$/CO ratios were similar in each plume and significantly lower than those derived from estimated Asian emission ratios indicating substantial removal of soluble $NO_y$ species during transport. $NO_y$ was primarily in the form of peroxyacetyl nitrate (PAN) in plumes that were transported in cold high latitude and high altitude

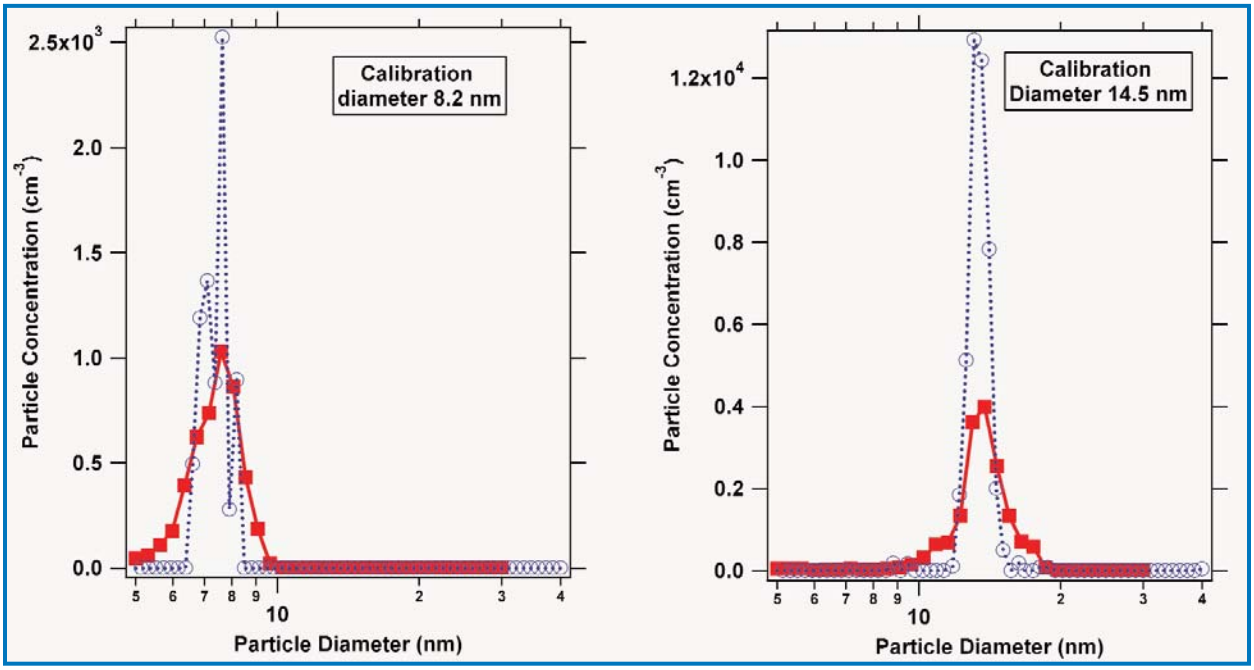



*Figure 3.6.a Relationship between inorganic (y-axis) and total inorganic and organic (x-axis) aerosol mass loading measured downwind of the East Coast of the United States in July 2004. The data are color-coded by the simultaneously measured trace gases acetonitrile, which is produced by biomass burning, and $SO_2$, which is emitted by industrial sources. High concentrations of particle mass were associated with one of these two sources, indicating that they dominate the aerosol mass budget in aged North American plumes.*

## Project 3.6.1 (continued)

regions, whereas in plumes transported in warmer lower latitude and altitude regions $NO_y$ was mainly nitric acid ($HNO_3$). Additional gas-phase species enhanced in these plumes include sulfuric acid, methanol, acetone, propane, and ethane.

Though a focus of the study, unambiguously identifiable plumes accounted for less than 10% of the data, suggesting that the constant mixing of emissions into the background atmosphere may influence background concentrations more than episodic plumes, especially over long time scales. Although plumes were not observed at Trinidad Head, model simulations suggest that 33% of the observed CO was due to Asian emissions. The ITCT 2k2 data set was used in conjunction with previous data sets to show that average $O_3$ levels over the eastern mid-latitude Pacific have systematically increased by ~10 ppbv over the last two decades, likely due to the increased Asian $NO_x$ emissions over that time.

The ITCT 2k2 results showed that the long-range transport of Asian emissions has influenced background levels of CO and $O_3$ on the United States west coast. Asian emission plumes originated from two sources, fossil fuel and biomass burning emissions, and both are likely to increase with the industrialization of Southeast Asia. Observations of PAN in high-altitude and high-latitude plumes represents the transport of an important $NO_x$ reservoir species. The subsequent decomposition of PAN is the main source of $O_3$ enhancement in Asian emission plumes, though the effect at ground level is likely reduced due to dilution during entrainment in to the boundary layer.

**Additional Accomplishments**

Our analysis of the ICARTT 2004 data set has shown a surprisingly strong coupling between aerosol particle composition and the reactive uptake of dinitrogen pentoxide at night. Dinitrogen pentoxide is a primary constituent of atmospheric nitrogen compounds at night, and its uptake on aerosol particles can greatly reduce the amount of reactive nitrogen available the following day for photochemical production of ozone. The ICARTT data indicate that acidic aerosol particles, such as those formed in sulfur-rich plumes downwind of power plants, may not be effective sites for reactive uptake of dinitrogen pentoxide. This provides evidence for an important and hitherto unrecognized coupling between emissions of the primary gaseous pollutants $SO_2$ and $NO_x$.

## Project 3.6.2 Regional Air Quality (AL08)

**Goal: Carry out laboratory measurements, atmospheric observations, and diagnostic analyses that characterize the chemical and meteorological processes involved in the formation of pollutant ozone and fine particles. Undertake research that contributes to the enhancement of air quality prediction and forecasting capabilities.**

### *Milestone 3.6.2.a*

Investigate the sources and meteorological and chemical processes that determine air quality in New England.

**Accomplishments**

Degradation of New England air quality is due to both emissions from major urban areas within the region, and to transport of plumes of emissions from more distant sources (both urban areas and power plants) into the region. The primary focus of the New England Air Quality Study (NEAQS 2004), conducted during July and August 2004, was the chemical transformation and transport of the plumes of emissions moving out of urban centers (primarily Boston and New York City) and downwind from power plants (primarily in the Ohio River Valley). These studies employed comprehensive suites of chemical measurements on the NOAA WP-3D research aircraft and the *Ronald H. Brown* research vessel, remote column measurements of ozone and meteorological variables from the NOAA lidar aircraft, and a wide array of air quality models to provide a comprehensive integration of the measurement results.

The research program was designed to provide improved understanding of the air quality issues in New England needed by decision makers to find better approaches to the management of air quality in this region of the United States. We organized the research around five research areas:

- Emissions verification: How well do current inventories represent actual emissions for: cities, point sources, ships, and vegetation?
- Transport and mixing: What are the relative amounts of pollution imported to New England and emitted there?
- Chemical transformation: How do gaseous and aerosol emissions evolve chemically and physically as they are transported into the region and within the region?
- Aerosol properties: What are the chemical, physical, and optical properties of the regional aerosol and how do these properties affect regional haze and aerosol loading in urban areas?
- Forecast models: What is the current skill of air quality forecast models on local, regional, and global scales and what improvements can be made to enhance the accuracy and extend the periods of these forecasts?

Our early analyses of study measurements have yielded significant findings. First, we found that during the last few years, power plant emissions of $NO_x$ have been significantly reduced. This reduction is clearly observable in aircraft transects of the power plant emission plumes. Model simulations indicate that the changes in emissions have significantly altered regional ozone concentrations. Secondly, it is apparent that the oxidation of $NO_x$ to the terminal, much less reactive species, $HNO_3$, proceeds at night through $NO_3$ and $N_2O_5$. Aircraft observations of these species demonstrate that the conversion to $HNO_3$ is particularly efficient in regions with high acidic sulfate loadings (Fig. 3.6.b).

### *Milestone 3.6.2.b*

Report the findings from the Texas Air Quality Study in 2000, identifying the unexpectedly large role of petrochemical industrial emissions on ozone formation in Houston, Texas.

**Accomplishments**

This CIRES research showed that routine emission of reactive alkene compounds from these chemical plants is the major driving force behind rapid and efficient ozone formation episodes, currently unique to Houston in the continental U.S. in the present day.

Researchers made airborne measurements of ozone, its precursor chemicals, and other species that serve as fingerprints for photochemically produced ozone, immediately over and downwind of the Houston urban center, a large electric utility power plant, and in the plumes of large petro-

## Project 3.6.2 (continued)

chemical industrial facilities in the area. Our analysis of these data showed that petrochemical sources dominated the other biogenic and anthropogenic sources in every extreme ozone pollution episode sampled by the aircraft.

These analyses demonstrated the petrochemical emissions to be sufficiently reactive so that unhealthy ozone concentrations were observed even under meteorological conditions that led to rapid dilution. The earlier understanding had been that a recirculation of already-polluted air back over the petrochemical source regions during a "sea-breeze reversal" was needed to generate such high levels. In contrast, analysis of the airborne data from the 2000 study showed that extremely high ozone levels could be formed under nearly any meteorological condition. Further, these data showed the surface ozone observational network in Houston had missed nearly half of the highest-ozone plumes, which had been transported away from the existing ground-based measurement sites.

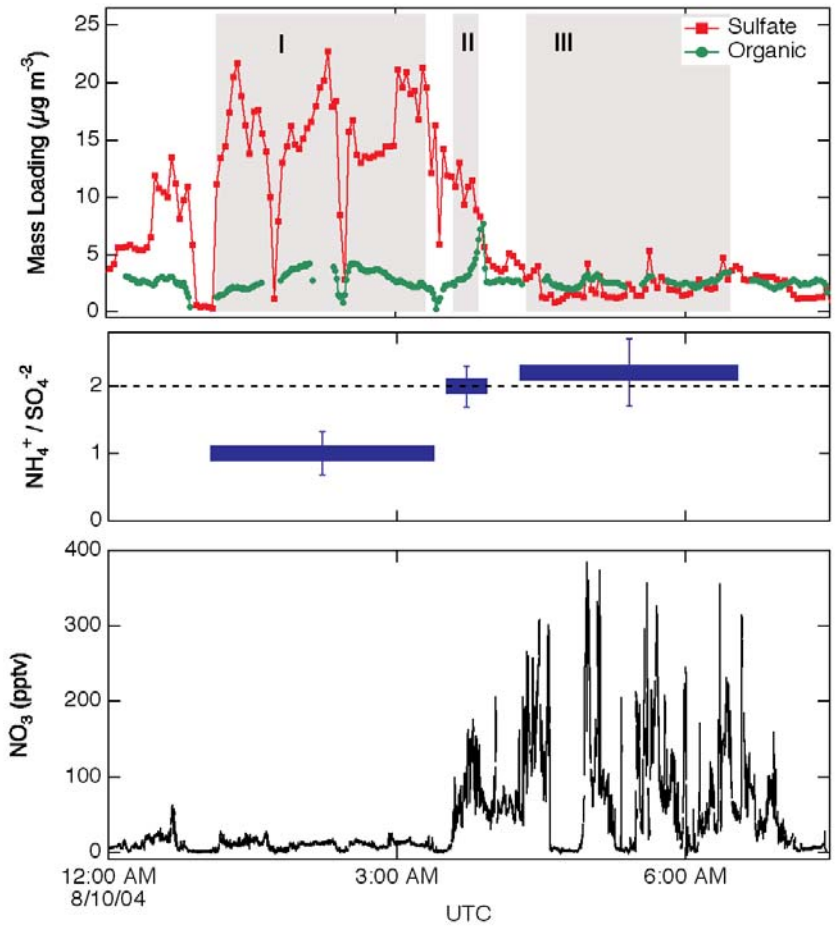



*Figure 3.2.X. Airborne measurements on four days characterized by substantially different meteorological conditions show the ability of petrochemical alkene emissions to routinely form extremely unhealthy amounts of ozone. Flight tracks are shown colored and sized by ozone. High ozone levels are only found downwind of the petrochemical source regions; in contrast, emissions from the urban center and the isolated power plant do not form nearly as much ozone.*

## Project 3.6.2 (continued)

These findings have led to a substantial change in the emissions control strategy mandated by the State of Texas to minimize ozone formation. A cost-benefit analysis estimated that improved scientific guidance on controlling ozone in Houston from this study will save over 60,000 jobs and $10 billion dollars over the next ten years. Finally, a follow-on study planned for 2006 in Houston will feature a redesigned ground sampling network to better characterize the full range of meteorological transport conditions shown to produce unhealthy levels of ozone.

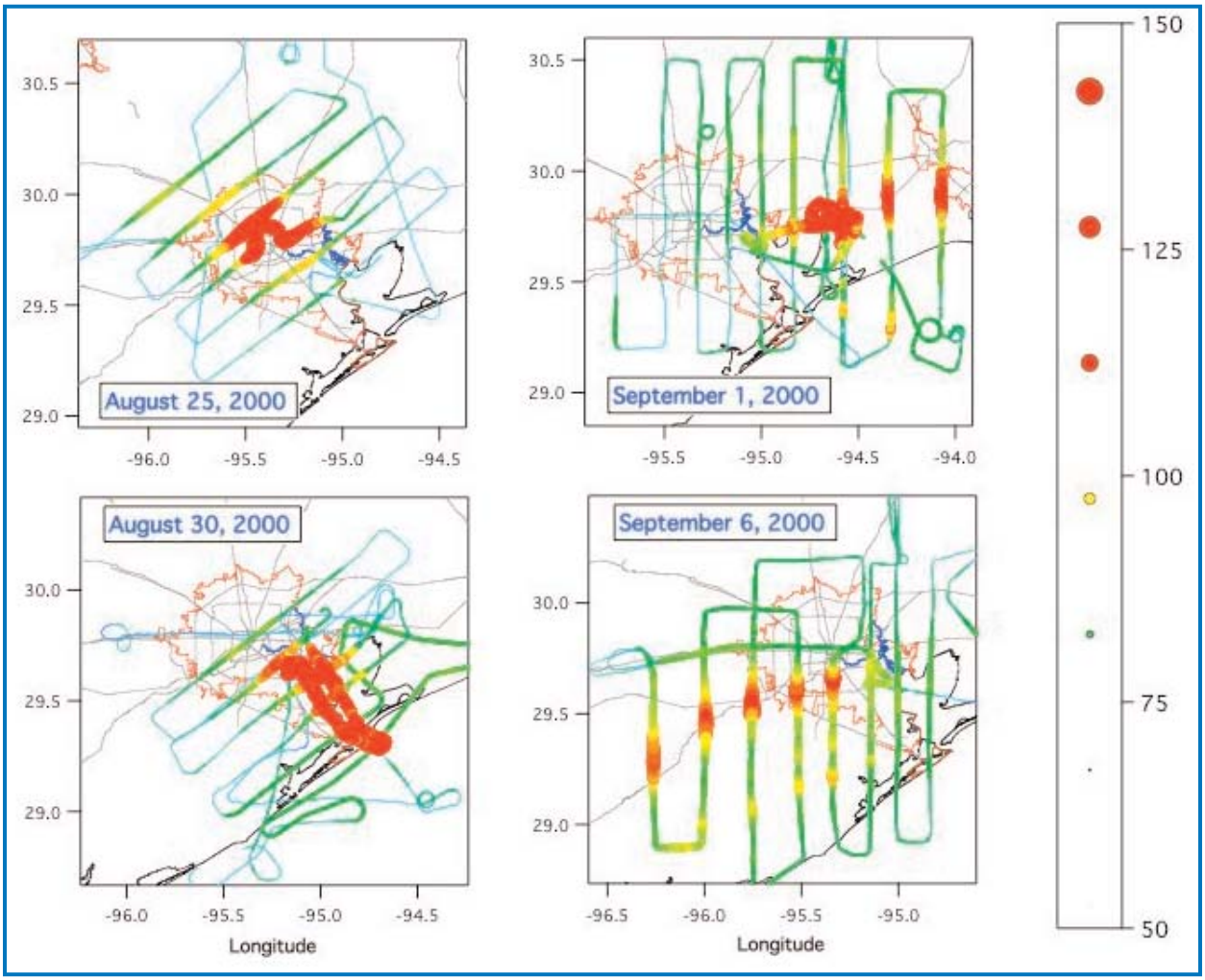



*Figure 3.2.X. Airborne measurements on four days characterized by substantially different meteorological conditions show the ability of petrochemical alkene emissions to routinely form extremely unhealthy amounts of ozone. Flight tracks are shown colored and sized by ozone. High ozone levels are only found downwind of the petrochemical source regions; in contrast, emissions from the urban center and the isolated power plant do not form nearly as much ozone.*

## Project 3.6.3 Aerosol Formation, Chemical Composition, and Radiative Properties (AL09)

**Goal: Carry out airborne and ground-based experiments that characterize the chemical composition of radiatively important aerosols in the upper troposphere and at the Earth's surface.**

### *Milestone 3.6.3.a*

Field a multi-wavelength cavity ringdown spectrometer aboard NOAA Ship *Ronald H. Brown* during the summer of 2004 to measure aerosol extinction and analyze the data to provide climate and air-quality related information for calculating radiative forcing by aerosols.

**Accomplishments**

Scattering and absorption of light and atmospheric particles (aerosols) is an important factor in establishing radiative balance of the Earth. The short atmospheric lifetime of aerosols leads to large local and regional variations and large uncertainties in models. Development and validation of a multi-wavelength cavity ringdown aerosol extinction spectrometer allows direct validated measurements of aerosol extinction. Researchers used the new aerosol spectrometer during the summer of 2004 off the coast of New England aboard NOAA Ship *Ronald H. Brown* to investigate the relative humidity dependence of aerosol mass-scattering efficiency and aerosol single-scattering albedo.

The ratio of inorganic salts (such as ammonium sulfate) to organics (such as dicarboxylic acids) has a significant correlation with water uptake and associated optical properties. Generalization of the dependence of optical properties with composition, size, and relative humidity allows for simplified modeling of the radiative properties of anthropogenic particles in the atmosphere. The parameterization of the relative humidity dependence of the mass scattering efficiency with respect to chemical composition allows simplification of direct radiative forcing calculations and improved accuracy of climate forcing by anthropogenic particles.

Our closure analysis of the single-scattering albedo (ratio of light scattering to light extinction) using traditional in situ techniques and new capabilities with the cavity ringdown aerosol extinction instrument indicates the need to further decrease uncertainties of measured parameters; such a decrease is possible with the cavity ringdown system and continued development of complementary measurements.

This research will advance scientific understanding regarding atmospheric aerosols and the role they play in both climate and air quality. The information will aid decision makers in New England, who are seeking ways to improve air quality for citizens in that region.

### *Milestone 3.6.3.b*

Study how soot modifies nitrogen oxides species ($NO_2$, $NO_3$, $N_2O_5$, and $HNO_3$) in the troposphere and, in turn, how soot is modified by exposure to these atmospheric chemicals.

**Accomplishments**

Soot is a unique species in the atmosphere because it can absorb radiation, in contrast to other aerosols that mostly scatter radiation, and it can reduce oxidized compounds, in contrast to most reactive atmospheric species that oxidize reduced species. Therefore, the impact of soot on the atmosphere and the impact of atmosphere on soot are of great interest. Specifically, there have been many speculations on conversion of $HNO_3$ to $NO_x$ by soot and alterations of soot's properties upon exposure to the atmosphere. Therefore, researchers investigated the interactions of $NO_2$, $NO_3$, $N_2O_5$, and $HNO_3$ with soot.

We found uptake of nitric acid, $HNO_3$, by soot to be mostly reversible and to not produce gas phase products such as $NO_2$, HONO, $N_2O_5$ or $NO_3$. Further, we found that organic nitrates were not formed on the surface of the soot. If soot was exposed to $H_2SO_4$, as it would in the atmosphere, the uptake of $HNO_3$ was reduced; again, gas phase reactive nitrogen oxide species were not produced. We also found that changes in relative humidity have only a minor influence on the uptake. Based on these findings, we concluded that the uptake of $HNO_3$ on soot is not a significant loss process for $HNO_3$ and that $HNO_3$ does not significantly modify soot. We found that $NO_3$ is efficiently converted to $NO_2$ and $HNO_3$ with small amounts of HONO and NO; furthermore, it leaves behind organic nitrates on the surface. In addition, $N_2O_5$ produces gas phase $NO_2$ and an organic nitrate on

## Project 3.6.3 (continued)

the soot surface. In contrast to $N_2O_5$ and $NO_3$, $NO_2$ uptake is very inefficient and, when it occurs, leads to HONO. These results provide information needed to understand and model modifications to atmospheric composition by emission of soot and to better quantify the role of soot in the climate system.

### *Milestone 3.6.3.c*

Analyze results of the spring 2004 Storm Peak Experiment, undertaken to characterize the chemical composition of aerosols that are effective seed particles for the formation of cloud-ice particles.

**Accomplishments**

One of the largest remaining uncertainties in our current understanding of atmospheric science is the process by which atmospheric aerosols nucleate cloud particles. The extent to which anthropogenic aerosols could alter cloud formation and thereby impact the indirect aerosol radiative effect is largely unknown, but potentially significant. Ice clouds are of particular interest, since it has previously been very difficult to measure or estimate the composition or origin of ice-nucleating aerosols. The INSPECT2 field campaign of late 2003/early 2004, a collaboration between CIRES, the NOAA Aeronomy Lab, and Colorado State University, was designed to help answer these critical questions. This collaboration combined instruments and expertise from a number of groups to develop a unique technique that allowed the direct measurement of the composition of ice-nucleating particles.

Over the last year, researchers further analyzed data from this study to improve our understanding of this process. Much of the recent progress in this regard has been in understanding various instrumentation effects, allowing for greater certainty in our interpretation of the data. As shown in Figure 3.6.d, the INSPECT2 experiment involved the coupling of several state-of-the-art instruments into a unique system. Issues affecting the operation of any of these instruments could affect the quality of the data. Analysis of instrument operation has allowed for the validation of the data, so that further conclusions can be drawn with confidence.

At this point in time, the data continue to support the conclusions that the particles most likely to form ice nuclei have the composition of mineral dust and fly-ash, which are a small fraction of the total ambient particles and are distinct from the more common sulfate aerosols. In addition, it appears that organic-containing particles are poor ice nuclei. The importance of these conclusions to global climate models is significant, since a much smaller anthropogenic influence would be required

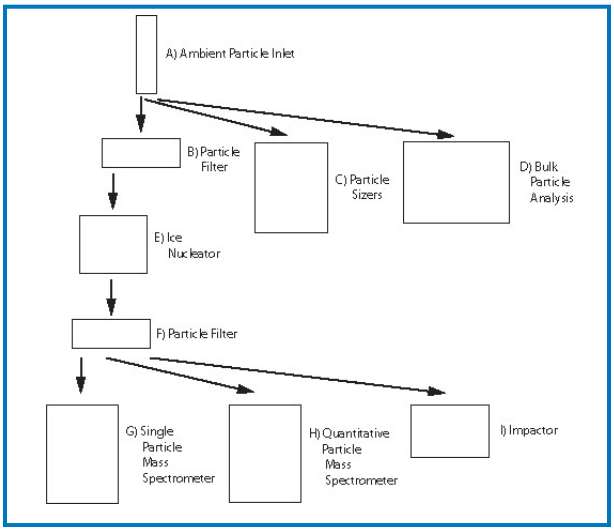



*Figure 3.6.d. Schematic diagram of the experimental apparatus used in the INSPECT2 study. Particles are sampled through the inlet system (A) followed by a filter that removes any large (supermicron) particles so that large ambient particles will not be confused with nucleated ice particles. Commercial particle sizing instruments (C) and bulk particle samplers (D) are used to put the measurements in context with previous data sets. The Continuous Flow Diffusion Chamber (CFDC, item E) nucleates ice particles on a fraction of the ambient aerosols, depending on operating conditions. The Laboratory Counterflow Virtual Impactor (LCVI, item F) acts as another particle filter, removing all the un-nucleated small particles, allowing analysis of just those particles that nucleated ice. Analysis of the ice nuclei is performed in real time with the Particle Analysis by Laser Mass Spectrometry (PALMS) instrument (G) and the Aerosol Mass Spectrometer (AMS, item H). Collection on an impactor (item I) allows ice nuclei to also be analyzed later using standard laboratory methods.*

## Project 3.6.4 Air Quality (CMDL03)

**Goal: Study intercontinental transport events to improve our understanding of their importance in affecting overall air quality and its impacts on public health.**

### *Milestone 3.6.4.a*

Initiate measurements of aerosol optical depth at the West Coast Observatory.

**Accomplishments**

The CMDL Aerosol Group has recently developed a retrieval algorithm for the aerosol asymmetry parameter (g), which is a measure of the angular distribution of light scattered by particles. Calculations of the aerosol direct radiative forcing are highly sensitive to this parameter, with nearly a two-fold change in radiative forcing for a given change in g. Researchers compared this retrieval algorithm with other retrieval methods, using a large suite of measurements during the 2003 Aerosol Intensive Operations Period at the Southern Great Plains, Atmospheric Radiation Monitoring (ARM) test site in Oklahoma. We made comparisons between in situ ground and aircraft measurements as well as lidar column measurements. In this study, we found that size was the most sensitive parameter in determining g, with aerosol composition being less influential.

Use of regionally averaged rather than measured aerosol properties results in an inherent error in radiative transfer calculations of aerosol radiative forcing. Often the standard aerosol models derived from climatology differ significantly from the aerosol properties that exist at any one place or time. The CMDL Aerosol Group used measurements at two Department of Energy ARM sites to assess the error in radiative flux calculations when standard models are used rather than the instantaneous, measured properties or models derived from these site specific data. We undertook a sensitivity study that indicates which properties play the greatest role in the accuracy of the flux calculations along with consideration of the actual measurement accuracy of each property. This information advises the community to which measurements and which aspects of the model are most critical for improvement.

In addition, the CMDL radiation group continued measurements of aerosol optical depth (AOD) at a West coast observatory in Northern California. The measurements probe the long-range transport of aerosols across the Pacific Ocean from East Asia.

### *Milestone 3.6.4.b*

Initiate measurements of hydrocarbons, Peroxyacetyl Nitrate (PAN), CO, $H_2$, and other species involved in air quality issues at the West Coast Observatory.

**Accomplishment**

The instrument planned for Trinidad Head has to date been in use at other sites, so this specific task is on indefinite hold. We installed an automated flask sampler for these and other gases at ground level and managed to sample most planned gases with the exception of PAN. We also initiated vertical profiles of CO and $H_2$ in weekly aircraft profiles.

### *Milestone 3.6.4.c*

Conduct operations with a movable aerosol sampling system.

**Accomplishments**

In July of 2004, the NOAA/CMDL Aerosol Group deployed their mobile aerosol measurement facility to Chebogue Point, Nova Scotia as part of ICARTT. The major goal of this multi-agency, international field campaign is to study regional air quality and intercontinental transport of pollutants across the Atlantic Ocean. The role of the CMDL Aerosol Group in this study is to quantify the aerosol optical properties downwind from a source region under various meteorological and transport conditions. Our direct measurements of the aerosol hygroscopic growth, scattering, backscattering, and absorption will be compared to calculations of the same parameters made with independently, measured aerosol size distribution and chemistry to determine any differences between the two modes of observation. We took advantage of the foggy climate in Nova Scotia to study the role of clouds in modifying aerosol optical properties and the subsequent impact on aerosol indirect radiative forcing. We were able to observe differences in the aerosol optical properties

## Project 3.6.4 (continued)

between non-foggy conditions and interstitial fog particles. The interstitial particles—those particles not scavenged by the fog or cloud—were more absorbing, were smaller and had a higher hygroscopic growth factor than non-fog aerosol. Having also taken also measurements of cloud condensation nuclei at various supersaturations, we are able to look at the relationship between aerosol hygroscopic growth and cloud droplet formation.

## Project 3.6.5 Air-Sea Interaction (ETL06)

**Goal: Perform cutting-edge micrometeorological and climatological research over the open ocean aboard research vessels, sea-based towers, and buoys.**

### *Milestone 3.6.5.a*

Process Eastern Pacific Investigations of Climate (EPIC) and Pan-American Climate Study (PACS) data sets, provide a detailed analysis of these air-sea interaction data products, and make the final data set publicly available. Deployment on new excursions within the PACS and EPIC regions are imminent, as are cruises in the North American Monsoon Experiment (NAME) and New England Air Quality Studies (NEAQS) regions.

**Accomplishments**

Researchers deployed and successfully operated ETL systems in the NAME and NEAQS cruises in July and August 2004. Data are archived at the project sites (ftp://ftp.etl.noaa.gov/user/cfairall/NAME/ and ftp://ftp.etl.noaa.gov/user/cfairall/neaqs_04/). This research will lead to a better understanding of the climatology of the PACS region in the context of the El Niño cycle and a description of the boundary layer structure in the Intertropical Convergence Zone (ITCZ) and predominant stratocumulus region in the Eastern Pacific.

### *Milestone 3.6.5.b*

Continue measurements of sea spray part of the Coupled Boundary Layers Air-Sea Transfer (CBLAST) experiment.

**Accomplishments**

Provide much-needed droplet spectra measurements for characterization of the sea spray source function, which is critically important in the forecasting of hurricanes and other high wind storm systems. The latest version of the ETL spray parameterization was adapted for use in operational models. It was implemented in the GFDL and WRF models and several sensitivity tests were run on past hurricanes (Isabel and Ivan).

Researchers developed an alternative approach to determining the thermal feed back strength in the NOAA/ETL parameterization scheme of the sea-spray mediated thermal fluxes. This new approach is not only physically based, but also consistent with the results from the simulations using the one-dimensional explicit spray model. Simulations using a three-dimensional community mesoscale model have been carried out to evaluate the impact of the feedback strength determined using this new approach on hurricane simulations.

### *Milestone 3.6.5.c*

Further quantify the air-sea transfer of gases and use a detailed physical analysis of data obtained from the Post-GasEx surface processes experiments to evaluate and improve gas transfer parameterizations.

**Accomplishments**

This research will provide an improved capability to accurately predict the sequestration of carbon dioxide from the atmosphere into the ocean. We extended the NOAA COARE air-sea gas transfer model to include the case of reactive gases such as ozone. Matlab and F90 versions were made publicly available. GASEX-01 results and measurements of DMS flux made from the NOAA Ship *Ronald H. Brown* have been published.

## Project 3.6.6 Air Quality (ETL07)

**Goal: Gather and analyze atmospheric observations to characterize meteorological processes that contribute to high-pollution episodes. Compare these measurements with air quality forecasting model predictions to assess and improve research model performance.**

### *Milestone 3.6.6.a*

Document meteorological processes that contributed to high-ozone episodes in the Houston, Texas, and New England areas using data from the Texas 2000, as well as the New England 2002 and 2004 air quality studies. Compare model predictions of meteorological variables and ozone concentrations with observations from these air-quality studies.

**Accomplishments**

Air pollution events in northern New England are primarily caused by transport of pollutants originating from the big East Coast cities. These pollution plumes frequently pass over the Gulf of Maine, where they interact with stable marine air, strongly modifying plume structure and transport patterns. Lidar data gathered during the New England Air Quality Studies (NEAQS) in 2002 and 2004 show that ozone pollution plumes over the Gulf of Maine tend to be detached form the surface and are often transported in distinct vertical layers. The data also show evidence of vertical mixing events that bring pollutants aloft down to the surface where they adversely affect air quality.

Researchers compared airborne lidar ozone measurements collected during NEAQS 2004 with predictions of the Eta-CMAQ and WRF air quality forecasting models. Both models reproduce fairly well the large-scale features in the geographical distribution of ozone observed with the lidar. However, we found significant differences in the vertical distribution of ozone between the models and observations. These differences tend to be more pronounced for the 27-km resolution model data and less so for the 12-km resolution model runs.

### *Milestone 3.6.6.b*

Publish a paper describing the development and application of a Web-based trajectory tool that uses measurements from a regional wind profiler network.

**Accomplishments**

Researchers developed and released an interactive, Web-based trajectory tool for air quality applications. The tool uses data from wind profiler and surface sensor networks to calculate forward or backward particle trajectories. This tool has been used by CIRES investigators and their colleagues in post-experiment analysis to identify sources of pollution plumes and thus aid in the interpretation of multi-dimensional air quality data sets. We have also produced a catalog of hourly back trajectories from several ground-based air quality measurement sites in the Northeast United States and Southeast Canada for the period. Beginning with the Texas Air Quality Study (TEXAQS-II) in 2005/2006, the trajectory tool will also be run in near real-time to support mission planning activities and NWS forecast operations.

### *Milestone 3.6.6.c*

Complete MM5 model runs for the Central California Ozone Study (CCOS). Seasonal model runs with comparisons to observations will be used to assess the skill of the model over the entire summer season. Publication of the seasonal modeling work will be started.

**Accomplishments**

To help California state agencies better meet their need to improve meteorological modeling in their state implementation plans for air quality mandate, researchers compared simulations using both MM5 and WRF for a State Implementation Plan (SIP) case with the observations taken during the 2000 CCOS field experiment. The purpose of this comparison was to compare MM5 and WRF for air quality applications in California. Such a meteorological model appraisal effort is intended to (1) provide a baseline upon which future meteorological model improvements for the California SIPs can be documented and evaluated, and (2) to assess the skill of WRF in reproducing locally forced meteorological conditions for the researchers who rely on numerical model simulations to provide new knowledge about the meteo-

## Project 3.6.6 (continued)

rological processes that influence air quality.

### *Milestone 3.6.6.d*

CIRES scientists will contribute to the 2004 NEAQS by i) deploying a network of integrated boundary-layer wind profiler observing stations and by ii) deploying several lidars on an aircraft and a research ship.

**Accomplishments**

Researchers successfully deployed three lidar systems and a network of eleven wind profilers during the 2004 NEAQS. We used two ozone lidar systems (one was flown on a DC-3 aircraft and the other one was deployed on the NOAA Ship *Ronald H. Brown*) to document the three-dimensional distribution of ozone and aerosols over New England and the Gulf of Maine. A Doppler lidar on theNOAA Ship *Ronald H. Brown* provided high-resolution profiles of wind speed and direction. The primary objective of the Doppler lidar deployment was to characterize the complex structure of the wind field in the marine layer over the Gulf of Maine. The wind profiler network consisted of ten land-based profilers, distributed over an area extending from Pennsylvania and New Jersey to Nova Scotia, and a wind profiler on theNOAA Ship *Ronald H. Brown*. We used the wind profiler data to compute air parcel back trajectories, which were crucial in identifying sources of ozone pollution plumes detected with the lidars and other reserach and operational air-chemistry observing platforms deployed during the study.

### *Milestone 3.6.6.e*

Acquire measurements of air-sea fluxes and gas transfer in the New England experiment on the NOAA Ship *Ronald H. Brown* in August 2004.

**Accomplishments**

We deployed the ETL flux system on the NOAA Ship *Ronald H. Brown* during the NEAQS 2004 cruise, and obtained a full set of fluxes. We used the new ozone parameterization and a new implementation of aerosol deposition to calculate ozone deposition velocities as a function of location and conditions. The results showed that deposition near the coast was suppressed compared to the open ocean.

## Project 3.6.7 Regional Air Quality Prediction (FSL02)

**Goal: Design and evaluate new approaches for improving air quality prediction.**

### *Milestone 3.6.7.a*

Evaluate forecast accuracy and relative efficiency of off-line air quality models (chemistry predicted using output from non-interactive previously run atmospheric forecast) versus on-line air quality models (full coupling between standard atmospheric and chemical processes in a single model).

**Accomplishments**

Researchers completed a version of WRF/Chem that can be run in an off-line mode. A test-bed data set has been selected from the NEAQS2004 summer field experiment to verify and evaluate the different model simulations (on-line versus off-line versus observations). This version of the model is now also used by a group in India in a collaborative effort to further develop an off-line version of the model.

### *Milestone 3.6.7.b*

Use data from real-time air quality forecasts during field experiment (NEAQS 2004) for further evaluation of a coupled model with a focus on aerosols (particulate matter), and interaction of aerosols and radiation.

**Accomplishments**

Researchers used three different versions of WRF/Chem during the NEAQS 2004 field experiment to produce real-time forecasts of air quality and weather. We have begun evaluation of all WRF/Chem versions and comparison to other available air quality modeling systems, using a test-bed data set from NEAQS 2004. We tested the model in forecast mode in real-time as well as in retrospective mode. Further model development included an update to the newest meteorological version of WRF, as well as improvements in the aerosol module and its coupling to the atmospheric radiation. The development of this model has led to many national and international (Europe, South-America, and Asia) invitations, and we now have more than eighty registered users worldwide.

# 4.0 Complementary Research by Program

In this section, we acknowledge the accomplishments of our Fellows as well as those researchers working in our program areas. CIRES supports several programs to foster and promote interdisciplinary research through the Visiting Fellows Program, the Innovative Research Program, and in part the Graduate Research Fellowship Program. Further, our Outreach group is active not only in K-12 Education, but also in coordination and organizing the public outreach for a number of scientific projects. CIRES researchers are involved in several hundred environmental research projects around the globe, and close to home in the semi-desert regions of the southwest or in the alpine regions of the Rocky Mountains.



## 4.1 Campus Fellows Research

CIRES Fellows are primarily University faculty, research associates or Government scientists who form the core and develop the direction of the interdisciplinary research conducted at CIRES. These individuals have an outstanding record of achievement and ability in diverse areas of environmental sciences.

### Understanding the Dynamics of the Nighttime Stable Boundary Layer

**Ben Balsley, Rod Frehlich, Michael Jensen, Yannick Meillier**

Funding: U. S. Army Research Office; National Science Foundation, Defense Advanced Research Projects Agency (DARPA)

The upper limit of the nighttime stable boundary layer (SBL) is a fundamental parameter in a variety of lower atmospheric disciplines. The SBL is important in characterizing the structure of the lower atmosphere in terms of pollution monitoring and low-level weather forecasting. The SBL acts as a barrier to the free atmosphere, through which all near-surface atmospheric constituents—including pollution, heat and momentum fluxes, and humidity—must pass to reach the free atmosphere. The SBL is also the barrier that free tropospheric constituents must pass through to reach the surface. Understanding of the top of the SBL is important in estimating closure schemes for boundary-layer turbulence and pollution models, as well as for numerical weather and climate modeling.

#### *Accomplishments*

Based on more than fifty high-resolution profiles of wind speed, temperature, and turbulence obtained using the CIRES Tethered Lifting System (TLS), we have examined the entire SBL from the surface to the overlying residual layer. These vertical profiles were obtained during a variety of different conditions during the CASES-99 campaign in east-central Kansas in October 1999. Our primary focus was to define the top of the SBL in terms of

## Understanding the Dynamics of the Nighttime Stable Boundary Layer (continued)

wind, temperature, and turbulence profiles. The results of the study showed that the best indicator of SBL height appears to be an extremely sharp turbulence decrease with height that is normally, but not always, associated with appreciable changes in the temperature and wind-speed profiles (Figure 4.1.X). In some important instances, it appears that these results will provide a significant challenge for existing modeling approaches.

### *Significance*

The ability of the in situ TLS measurements to define extremely sharp height variations, as described above, provides a new tool for future boundary-layer research. This is particularly important because there has been no single technique that could simultaneously measure these quantities with the one-meter vertical resolution of the TLS. The method was valuable in a recent campaign to study the SBL in Washington, DC, in support of Homeland Security. The TLS wind and turbulence profiles provided verification data for operational Doppler LIDAR-derived profiles. Future campaigns, such as the Terrain-induced Rotor Experiment (T-REX), are underway to use this technique to study the boundary layer evolution of terrain-induced "rotors" that are hazardous to aircraft. We are also proposing the same technology for wind-energy research and the study of the stable nighttime boundary layer in winter.

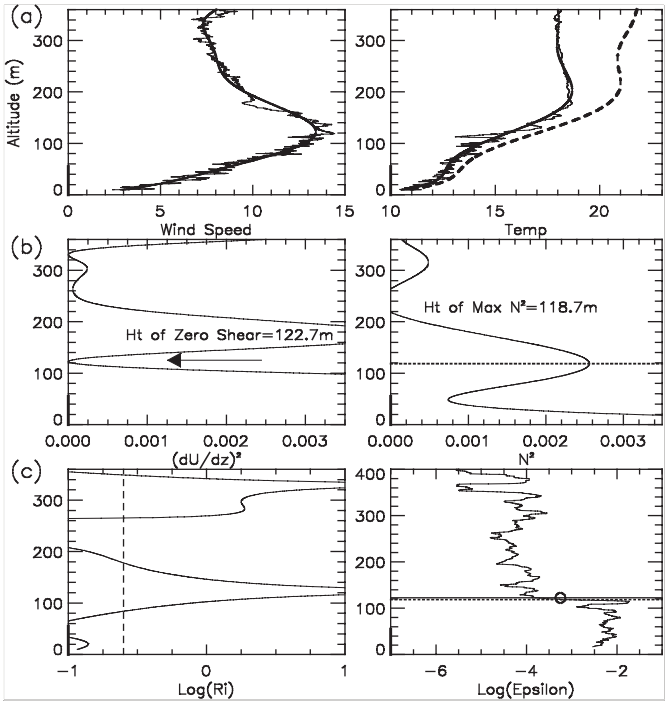



*Figure 4.1.X.*
*(a) Raw and fitted profiles of wind speed and temperature, as well as potential temperature (fitted; dashed line) obtained during a single TLS descent.*

*(b) Corresponding profiles of square of wind shear $(dU/dz)^2$ and square of Brunt Vaisala frequency, $N^2$.*

*(c) Log($R_i$) and Log(Epsilon) profiles for the same period, where $R_i$ is the gradient Richardson number and epsilon is the turbulence energy dissipation rate. The top of the SBL is indicated in the final panel by a solid line (zero wind shear), a dotted line (maximum $N^2$, and a "o" (steep turbulence decrease). Units for wind speed, temperature, $N^2$, and epsilon are, respectively, m $s^{-1}$, $^oC$, $sec^{-2}$, and $m^2$ $s^{-3}$.*

## Deformation Processes in the Earth's Crust

**Roger Bilham**

Funding: NSF and US Geological Survey

The earth deforms prior to and during earthquakes, both at plate boundaries and within the earth's plates. From surface deformation measurements, we may infer the mechanics and rates of the processes involved and from these develop scenarios for future earthquakes. We use space-based tools (GPS and InSAR) and newly devised tiltmeters and creep-meters to monitor epicentral processes. We monitor earthquake processes in India, Pakistan, Nepal and Bhutan, California, the Cascadia region, and parts of New Zealand, Mexico, and Venezuela.

### *Accomplishments*

Slow earthquakes occur at 30-50 km depth in nearly every subduction zone where continuous GPS monitoring has been installed. They manifest as one- to eight-week slip episodes that represent the release of 3-30 cm of slip on the plate boundary. These slip events occur near the transition between the shallow portion of the plate boundary that experiences great earthquakes, and the deeper region that slips steadily into the Earth's mantle. In the Seattle region, 3-5 cm events occur every fourteen months and are accompanied by a long period (6s) seismic tremor that has been ascribed to subsurface fluid movements. As an incremental change in stress, it is possible that a future slow earthquake will be sufficient to trigger a major shallow earthquake.

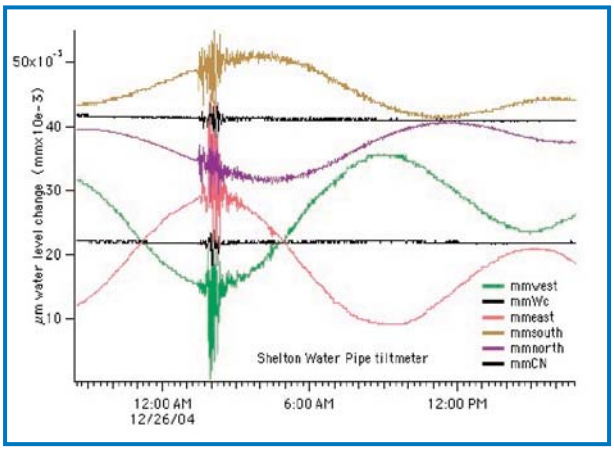



*Figure 4.1.x The 26 Dec 2004 Sumatra earthquake recorded by a new CIRES 1-km-long tiltmeter. Height changes exceeded 50 μm at 20m minute periods.*

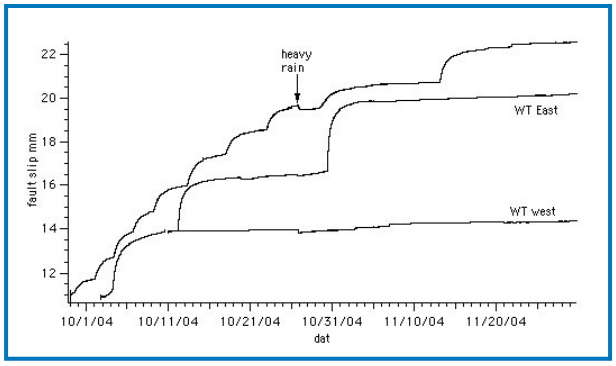



*Figure 4.1.y Surface afterslip near the Parkfield epicenter, as recorded by creep meters.*

To monitor these processes more precisely, we have installed the first two of five NSF-funded, kilometer-long tiltmeters near Seattle. The tiltmeters are roughly 1,000 times more sensitive than current GPS monitors, and consist of L-shaped horizontal water pipes, each 500 m long, with floats at each end that monitor relative vertical motions >0.2 μm (1/300 of the thickness of a human hair). Early results suggest easterly tilt on the order of 0.3 μradian/yr. It monitored the Mw=9.3 Sumatra earthquake (Fig.4.1.x). The next slow earthquake near Seattle is expected September 2005. We also maintain a network of a dozen creep-meters, funded by USGS, along the San Andreas fault system to monitor surface slip of the shallow faults in the Bay area, in central California, and in the Coachella Valley. We redesigned our creep-meters this year to reduce thermal sensitivity, to improve battery life, and for waterproofing.

### *Significance*

The most notable event of 2004 in California was the Parkfield Mw=6.0 earthquake. The creep-meter record of the earthquake data (Figure 4.1.y) showed that although surface strain was instantaneous, no surface slip (such as cracks in roads and broken pipes) developed for at least two days after the mainshock. This finding was disappointing because we had hoped that surface slip might precede shallow strike-slip earthquakes and thus be a definitive indicator.

## Detection and Attribution of Changes in the Hydrologic Regimes of the Mackenzie, the Kuparuk and the Lena River Basins

**John Cassano**

Funding: National Science Foundation Office of Polar Programs

This project is an international, multi-institution, five-year project funded by the National Science Foundation as part of the Arctic System Science Freshwater Initiative and is a contribution to the Study of Environmental Arctic Change (SEARCH). The overarching goal of this project is to understand how the Arctic hydrologic cycle has changed over the past century and how it may change in the coming century.

### *Accomplishments*

One aspect of this project has focused on the analysis of global climate model (GCM) simulations conducted in support of the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report. We have applied an artificial neural network algorithm, known as self-organizing maps (SOMs), to daily sea-level pressure data from ten GCMs for the decades of 1991-2000, 2046-2055, and 2091-2100. This process helped us objectively identify the dominant synoptic atmospheric circulation patterns that this ensemble of GCM simulations depicted (Figure 4.1.X). We applied the same method to two global atmospheric reanalysis datasets for the decade of 1991-2000. The SOM methodology was useful for diagnosing differences between individual ensemble members, the entire ten-model ensemble, and the reanalysis data. The methodology helped us assess predicted changes in the Arctic circulation during the 21st century and allow us to relate these changes to spatial patterns in anomalies of surface temperature and precipitation.

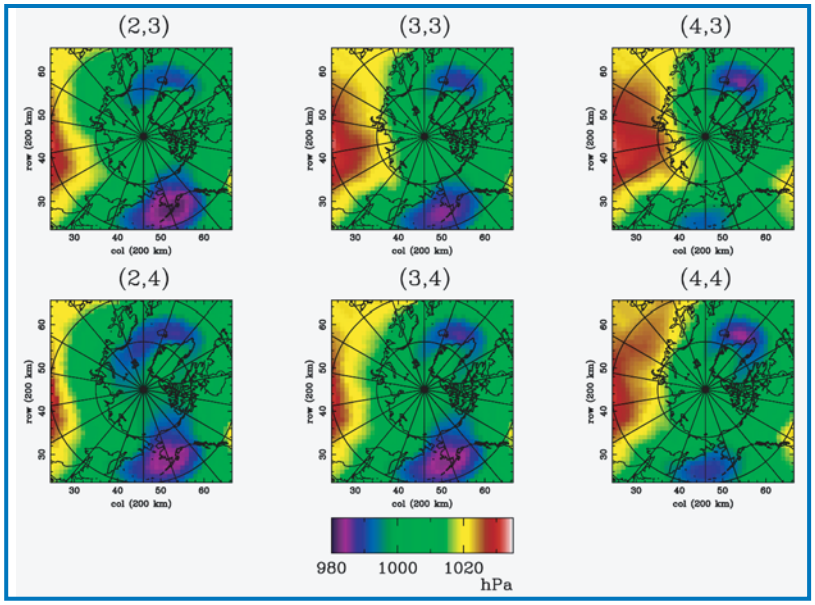



*Figure 4.1.X. Six of the 35 synoptic weather patterns identified using the SOM algorithm. Color shading indicates sea level pressure.*

### *Significance*

The SOM methodology used in this analysis is relatively new to climate research. It has significant potential to improve our analysis and interpretation of large climate-model data sets by providing an objective method to identify synoptic patterns in these datasets. This method also provides a unique way to evaluate GCM simulations of synoptic circulation regimes. Results from this analysis for the Arctic winter season indicated decreased occurrence of synoptic patterns dominated by strong Arctic high-pressure patterns and an increase in patterns dominated by a North Atlantic storm track extending into the eastern Arctic basin over the 21st century. These changes in the atmospheric circulation patterns correspond to warm temperature anomalies in Eurasia and western North America, and positive precipitation anomalies along the east coast of Greenland, from the North Atlantic extending into Scandinavia, and along the western coast of North America.

# Molecular analysis of the function of enzymes in the newly evolving pathway for degradation of pentachlorophenol

**Shelley D. Copley**

Anthropogenic compounds can pose environmental problems because they have been present in the environment for only a short time, and microorganisms often lack the enzymes necessary to catalyze their degradation. We are studying degradation of the anthropogenic pesticide pentachlorophenol (PCP) pathway in the soil bacterium Sphingobium chlorophenolicum. S. chlorophenolicum has assembled a new metabolic pathway for degradation of this xenobiotic compound by patching together enzymes recruited from two or three pre-existing pathways. Our studies address issues such as the origin of enzymes that are serving new functions, and how well they are performing in their new roles in the PCP degradation pathway.

## *Accomplishments*

Our investigation found that PCP hydroxylase catalyzes the initial step in the pathway (Fig.4.1.x), which converts PCP to tetrachlorobenzoquinone (TCBQ). The enzyme is unusually ineffective – its turnover number is three to four orders of magnitude lower than that of most enzymes that catalyze this type of reaction. However, an even bigger problem is posed by the toxicity of the product, TCBQ, which damages proteins and DNA. Indeed, TCBQ damages PCP hydroxylase itself. Incubation of the enzyme with TCBQ results in inactivation of the enzyme, concomitant with formation of a covalent adduct between TCBQ and the flavin cofactor that is required for catalysis. This scenario suggests that the production of TCBQ is an accidental result of a promiscuous activity of an enzyme that evolved to serve a different function and that the enzyme has not yet evolved an active site capable of controlling the highly reactive TCBQ product.

A second "molecular accident" occurs during the conversion of tetrachlorohydroquinone (TCHQ) to trichlorohydroquinone (TriCHQ) and 2,6-dichlorohydroquinone (DCHQ). The enzyme that catalyzes this reaction appears to have evolved from an enzyme that catalyzes a very different reaction–the glutathione-dependent isomerization of a double bond from cis to trans. The active site does not seem to be well suited for catalyzing the new reaction. The aromatic substrates TCHQ and TriCHQ tend to bind to the active site part way through the catalytic cycle, and when this happens, the chemistry required to complete the cycle comes to a halt. This is an unusual example of very severe inhibition of a reaction by the substrate of the reaction.

## *Significance*

The evolution of novel metabolic pathways for degradation of pollutants requires recruitment of pre-existing enzymes to serve new functions. These enzymes would initially be expected to be rather poor catalysts for the newly needed reactions. We have identified the molecular reasons for the poor functioning of two of the enzymes in the PCP degradation pathway. This work provides new insights into the evolution of new enzymatic activities and sets the stage for efforts to evolve more effective enzymes.

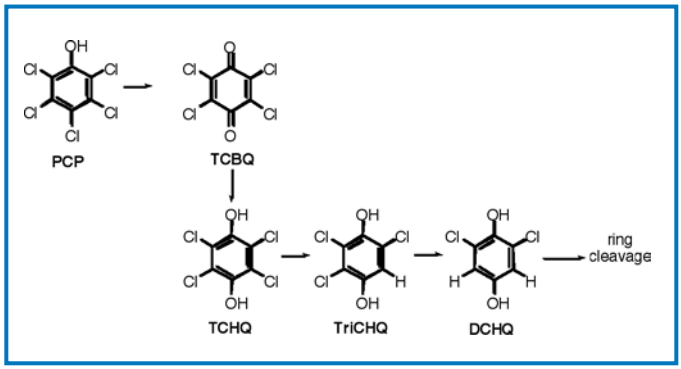



Figure 4.1.x. PCP degradation pathway.

## Using Provenance of Glacial Tills to Investigate Dynamics of Antarctic Ice Sheets

**G. Lang Farmer**

Funding: NSF Office of Polar Programs

The past behavior of the Antarctic ice sheets is critical to assessing their future evolution, particularly the potential for future rapid deglaciation events. Dr. Farmer's group has been using radiogenic-isotope (Nd, Sr and Pb) and trace-element analyses of fine-grained glacial sediment deposited within and along the margin of the Ross Sea to assess the relative roles of the East and West Antarctic Ice Sheets in ice advances during the last glacial maximum (LGM; ~ 20 thousand years ago). The intent is to determine if the West Antarctic Ice Sheet, which is largely grounded below sea level, is more susceptible to rapid advances than its East Antarctic counterpart.

### *Accomplishments*

The major trace elements, as well as $\varepsilon_{Nd,}$ Sr, and Pb isotopic compositions, were determined for the <63mm sediment fraction of thirteen onshore tills and twenty-one marine tills in the Ross Sea and surrounding areas in Antarctica. Onshore tills exposed around the margins of the embayment associated with specific icestreams (and alpine glaciers) have $\varepsilon_{Nd}$ and Pb compositions that vary regularly with geographic position, reflecting the changes in age and isotopic compositions of basement rocks along the margins of the Ross Sea.

In general, till $\varepsilon_{Nd}$ values are –5.6 to –9.9 for both the West Antarctic ice streams and the southern Transantarctic Mountains. In the central portions of the mountain range, till $\varepsilon_{Nd}$ values are –11.9 to –14.9, while the uranogenic Pb becomes less radiogenic in the same direction.

Marine tills from the Ross Sea also vary with geographic progression, with tills from both the western and eastern Ross Sea having high $\varepsilon_{Nd}$ values (–5.8 to –7.5 and –3.8 to –6.9, respectively) compared to the <63mm till in the central Ross Sea (–7.1 to –12.5). Tills in the eastern Ross Sea (most proximal to West Antarctic) have isotopic and chemical compositions identical to onshore till from West Antarctica and the southern Transantarctic Mountains and were most likely derived from these areas. Tills in the western Ross Sea with the highest $\varepsilon_{Nd}$ values have low wt % $SiO_2$ (46%), and high Ni, Nb, Ta and Sr contents. This would require a large component of material eroded from extrusive igneous rocks from the adjacent Late Cenozoic McMurdo Volcanic Field. In contrast, tills in the central Ross Sea were most likely related to icestreams emanating from the central Transantarctic Mountains and flowing north down the Ross Embayment to the continental shelf margin.

### *Significance*

The data produced by Dr. Farmer's group provide direct evidence that ice streams related to the East Antarctic Ice Sheet were active and responsible for till deposition throughout the western half of the Ross Sea (Figure 4.1.x). As a result, models for the past and future dynamics of the Antarctic Ice sheets must account for potential instabilities in both the East and West Antarctic Ice Sheets.

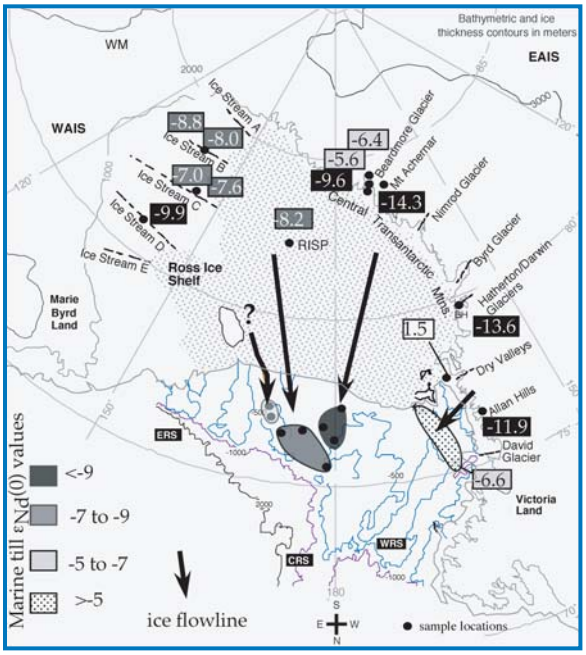



*Figure 4.1.X. The Nd isotopic compositions of onshore till (boxes) reveal that the East Antarctic ice sheet was a major source of ice delivered to the Ross Sea during the LGM.*

## A Spectroscopic Method for Optical Characterization of Swelling Soils

**Alexander F. H. Goetz**

Funding: USGS

Our team is in the final stages of a five-year project to develop a spectroscopic method for characterizing swelling soils by optical means. Swelling soils are a menace to construction within 5 km of the mountain front along the Front Range from Fort Collins to Canon City. Here, the Pierre Shale Formation contains claystones interbedded with bentonite, the result of volcanic ash deposits laid down in the North American Seaway approximately 65 million years ago. Bentonite is a smectite, a 1:2 clay with the cations Na, K or Ca in the interlayers. The resulting charge imbalance attracts water into the mineral structure that can cause the clay to expand by a factor of four going from dry to wet. In addition, the Pierre Shale is tilted nearly vertical by forces that started with the Laramide orogeny 65 million years ago. A vertical test drill hole may not intersect the bentonite layers, and it is too expensive and time consuming to drill hundreds of holes. Foundations can be broken or offset when the moisture regime changes, for instance by watering a lawn.

### *Accomplishments:*

Our swelling soils project was a joint endeavor between CU, Colorado School of Mines, the Colorado Geological Survey and the USGS. We opened three 5 m deep trenches near Roxbury Village East, south of Denver and north of Golden off route 93. Reflectance spectroscopy was carried out at 5 cm intervals along the trench walls that were exposed below the overburden, using a field spectrometer to collect approximately 30,000 spectra in the 400-2500 nm region in each of the trenches. Images in 2150 spectral bands were created with each measurement of a pixel, allowing us to process the data with hyperspectral imaging algorithms available in the ENVI imaging software. These images helped us identify mineral constituents and helped guide the core sampling.

We also collected 500 samples for geotechnical testing that produced values, among others, for swell potential and Atterberg limits. We were then able to develop regression models that linked reflectance spectra to engineering parameters with r2 values ranging from 0.5-0.8. Using this technique, a field spectrometer can then be loaded with the prediction model that will allow a variety of soil engineering parameters to be displayed simultaneously within seconds after a one–second spectrum collect. Thus, researchers can collect field measurements over a large area in a short period of time. While this technique will not replace American Society for Testing of Minerals (ASTM) standard techniques, which takes days to perform, it can augment them and vastly increase the spatial coverage and reduce the potential for post-construction remediation.

### *Signnificance*

Hyperspectral images taken from space and airborne platforms provide information about surface cover composition that is used in a host of applications including mineral and petroleum exploration, agriculture, forest and grassland ecology, water quality and intelligence gathering to name a few. University of Colorado, CIRES and CSES have provided an ideal environment to nurture these developments and to provide for the students who carry these developments into the real world.

Figure 4.1.x. Field collection of spectrometry data at the South Trench near Roxbury Village East.

## Tests of spatial scale invariant statistics in floods and riparian evapotranspiration and their biophysical bases on the 1100 sq. km. Whitewater Basin, Kansas

**Vijay K. Gupta**

Funding: NSF, DOE

Our project is part of a broad, multidisciplinary Hydro-Kansas (H-K) program involving several academic institutions and federal agencies. It is designed to test two integrative scientific hypotheses. The short-term goal is to validate the existence of fundamental, statistical scale-invariant relationships for floods and riparian vegetation evapotranspiration (ET), which can be tested from coupled biophysical processes involving water, energy, terrain and vegetation on time scales of individual rainfall-runoff events. The long-term goal is to extend this research to seasonal, annual and inter-annual time scales.

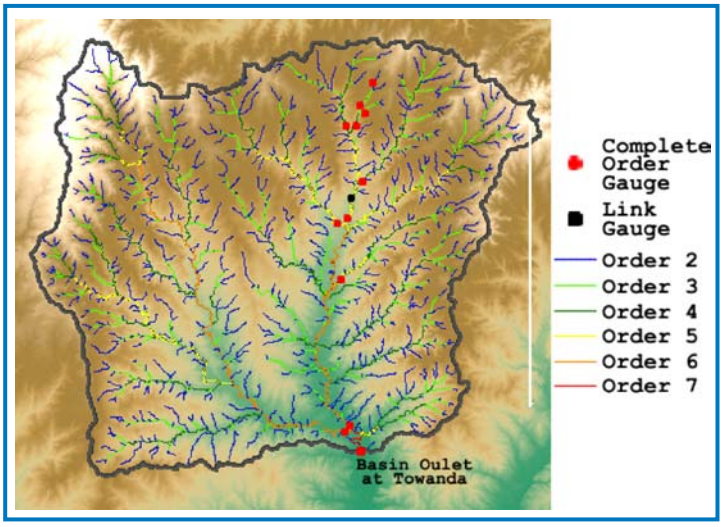



*Figure 4.1.x. Locations of the planned stream flow gauges.*

### *Accomplishments*

H-K is an example of the research proposed in the Water, Earth, Biota (WEB) report to NSF (http://cires.colorado.edu/hydrology), involving specific hypotheses and observations in the Whitewater Basin, Kansas. In the first phase of the H-K project (2001-present), we developed a digital watershed environment for numerical modeling that is being used for testing the biophysical basis of statistical scaling hypotheses, and for data archiving. Initial results illustrate the signatures of channel network geomorphology and temporal rainfall variability in flood-scaling parameters. Diagnostic testing of the flood-scaling hypothesis requires a large number of gauging stations at the end of complete Horton-Strahler streams; obtaining a high-density set of stream flow hydrographs from the existing USGS gauging technology is difficult and cost-prohibitive. Thus, we developed and tested a new stream-gauging methodology on the Whitewater during the second phase of the project (2003-2004). Initial results are promising and comparable to or better than the well-established, century-old USGS methodology. The third phase (2005-06) includes plans to install 12 stream flow gauges at the end of complete Horton-Strahler streams (Figure 4.1.x). In addition, 14 rainfall-gauging sites in Whitewater Basin are being installed in the third phase and will be used in tandem with NEXRAD at Wichita for estimating space-time variable rainfall. A network for automated data acquisition and transmission to a central facility is being designed and implemented by the H-K collaborating institutions. NSF and the DOE Atmospheric Radiation Measurement (ARM) climate research facility (ACRF) in the Southern Great Plains (SGP) are supporting the H-K research.

### *Significance*

The H-K project illustrates first steps towards developing a new unified network-based theory that couples hydrologic science and engineering, hydrometeorology, landscape geomorphology with statistical variability in floods across multiple scales of a river basin. The Riparian ET scaling hypothesis will bring boundary-layer meteorology and landscape ecology into the H-K program. Development of an integrative observational and theoretical core-research H-K program has the potential to incorporate stream ecology, biogeochemistry, climate variability and anthropogenic impacts in a mesoscale river basin.

# Tectonics of Foundering Lithosphere, Sierra Nevada, California

**Craig H. Jones**

Funding: NSF EarthScope Program

In contrast with ocean tectonics, continental tectonics are diffuse and occur in places and with styles not easily anticipated from plate kinematics. One potential cause is the antibuoyant mantle lithosphere under continents and the potential that it could detach and sink into the mantle. The Sierra Nevada of California might overlie lithosphere that foundered in the past 10 million years; Dr. Jones and colleagues at two other universities are conducting a new seismological experiment to understand the dynamics of this process.

## Accomplishments

The present grant represents the very first deployment of the FlexArray facility being constructed by IRIS PASSCAL as part of the US Array component of the NSF ~$200M MRE (Major Research Equipment) EarthScope program. In just over six months from award, we have placed a network of forty field stations in two states, four national forests, and two national parks. Four CU students, as well as a hosted IRIS intern from Georgia Tech, have gained considerable field experience. Although the full analysis awaits completion of this first phase of the experiment, an early examination of P-wave travel times indicates sufficient data to fully image the foundering mantle lithosphere under the Sierran foothills. Surprisingly, the material seems to be plunging to the southeast. Early analysis suggests that the anomaly is about 250-300 km deep, and the top might well extend to the crust just northeast of Fresno, California.

*Fig. 4.1.x. CIRES students complete final checks on seismometer.*

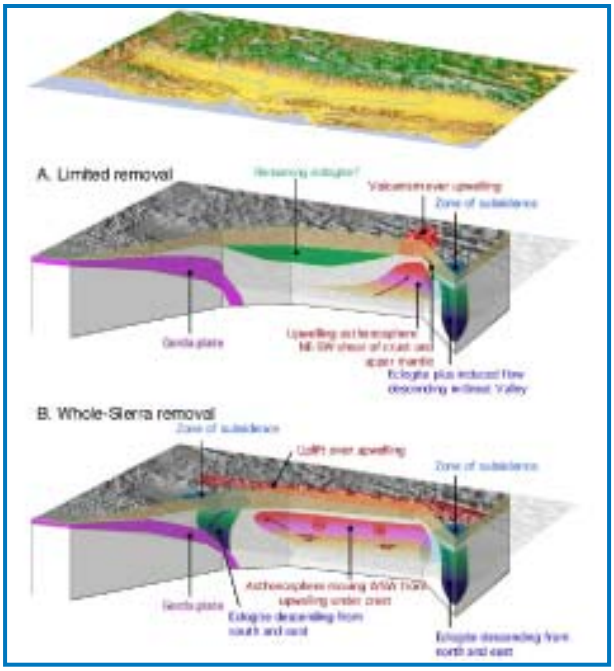



*Fig. 4.1.y. Competing explanations in the Sierra: localized lithospheric foundering with minimal implications (center) and widespread foundering with widespread consequences (bottom).*

## Significance

The removal of mantle lithosphere has long been proposed as a means of driving enigmatic deformation in continents, but hypotheses for the impacts of such an event were largely based on theory. Recognizing that the Sierra overlies freshly-removed lithosphere provides the chance to understand this process from observations. Previously, Dr. Jones and his colleagues (including CIRES Fellow G. Lang Farmer) had proposed that the foundering of sub-Sierran lithosphere had led to widespread uplift of the Sierra and western Great Basin, extensional faulting in the western Great Basin, contraction across the California Coast Ranges, and a shift in Pacific-North America plate motion from the western towards the eastern side of the Sierra (Figure 4.1.y, bottom panel). Work by Jones and CIRES Fellow Peter Molnar had shown that the descent of this lithosphere was consistent with Rayleigh-Taylor instabilities and laboratory experiments on rock rheology provided that high-stress limits on power law rheologies were honored, indicating that such high-stress limits on rock strength are probably real. The constraint of the new experiment on the base of the descending body is critical in providing bounds on descent of this kind of material. Furthermore, the unusual geometry of the descending body, not predicted by experiments to date, poses new challenges for understanding this process and suggests unforeseen factors at play.

## Reconstructing and forecasting the effects of humans and climate on river metabolism

**William Lewis**

Funding: NOAA OAR

Hydrologic manipulation is a constant feature of human activities throughout the world. Irrigation, power production, or domestic and industrial supply can radically alter natural annual and interannual discharge patterns. Obvious effects include impeded movement for aquatic organisms, change in water quality and temperature, and reduced restorative overbank flow. More subtle effects may be equally important but are more difficult to study. Impacts on ecosystem metabolism—rates of photosynthesis and respiration—have been little studied.

### *Accomplishments*

We have developed a new method for reconstructing and forecasting changes in stream metabolism resulting from both human- and climatic-induced hydrologic change. This model is based on the Shields stress, using quantitative linkages between river discharge, channel and bed characteristics, bed movement, and river metabolism. The Shields stress, a ratio of gravitational forces to stress on the particles that make up the bed, is expressed as a threshold value, above which the bed moves. This threshold can be estimated by calculation, and validated in the field for a given site. Data on the physical characteristics of a specific channel, its discharge pattern, and its response to and recovery from disturbance, enable reconstruction or forecast of metabolic changes associated with hydrologic regime changes. Streambed or riverbed movement disrupts the biofilms controlling its metabolism and thus its metabolic processes, which then return to a characteristic, stable metabolic state over time.

We demonstrated this method with field study of the South Platte River below Denver. Crossing the Shields threshold, photosynthesis is virtually eliminated, whereas respiration is only slightly altered. Recovery of photosynthesis occurs in about two weeks at a negative exponential rate. When these relationships were used to reconstruct South Platte metabolism over the 70-year period of daily discharge records, they revealed that the photosynthetic potential of the river has declined by two-thirds. Hydrologic manipulation has increased flow during dry weather, thus bringing the base flow closer to the Shields stress threshold, so that virtually every thunderstorm causes bed movement.

### *Significance*

This method for predicting metabolic responses to hydrologic manipulation could be used to calculate human influence on stream and river metabolism, by reconstructing metabolic changes over long intervals wherever discharge measurements are available. In addition, we could project the effects of hydrologic manipulations that result from increased water development, or that are designed to make rivers function more naturally. Experts could also use the method to predict climate-change scenarios that are either natural or human-induced.

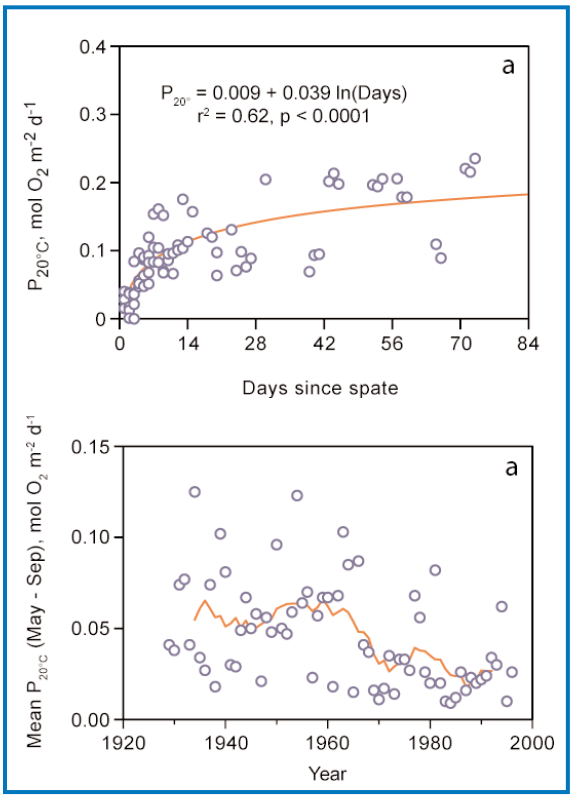



*Figure 4.1.x. Recovery (top) and 70-year reconstruction (bottom) of photosynthesis in the South Platte River approximately 30 km below Denver, Colorado. Rates of photosynthesis are corrected to a common temperature of 20 deg C.*

## Understanding Erosion Mechanics and Climate Influences

**Peter Molnar**

Much of Peter Molnar's effort in the past year has been focused on understanding erosion of the landscape, particularly of high terrain. How does climate, and especially climate change, affect erosion? Answering such a question requires an understanding of how erosion occurs. Most erosion occurs first when particles, including boulders, are dislodged, and then continues when rivers transport them as sediment. The underlying assumption in the two studies described below is that rivers are transport agents rather than erosive agents. The first study addresses the creation of sediment that rivers transport; the second explores how climate change might also, independently, affect erosion.

### *Accomplishments*

Molnar [2004a] first analyzed deviatoric stress in the earth caused by gravity acting on topography. Obviously, if rock lacked strength, it would flow away; hence, rock must be able to sustain stress. Analytic solutions for the state of stress in the crust caused by valley topography allow a simple assessment of how deviatoric stresses depend both on valley shape and on elastic constants. Like most solids, rock can fail by static fatigue; water within cracks can attack crack tips and weaken them so that cracks grow, and this growth can become unstable. The rate of crack growth depends on the magnitude of stress difference at crack tips. Where valleys are steep and deep, such stresses can be large, and thus they can cause failure by static fatigue in periods of time that are short compared with the time needed for erosion to occur. Thus, positive feedback is possible: erosion creates relief, which increases stress differences that in turn cause rock to fracture, making it easier for rivers to transport. Unfortunately, applying these results in the field is risky, but we can ask whether such feedback is likely to occur and what kinds of incision rates we might expect from rivers. The answer is that this static fatigue could play a key role, particularly in steep terrain that erodes quickly.

In a second study, Molnar [2004b] synthesized data on sediment accumulation around the world to show a widespread increase beginning three to four million years ago, when climate changed from warm and stable to cooler and more unstable. Beginning at this time, ice became more widespread, making glaciers more important as erosive agents, but glaciation cannot account for all of the increased sediment. Also at this time, sea level dropped and rose frequently, making erosion of continental shelves possible. However, many regions of increased sedimentation lie inland, far from the sea. Most erosion occurs in major floods; the increased amplitude and frequency of climate variability beginning approximately three to four million years ago offers an explanation for how climate change affected erosion.

### *Significance*

Molnar's first study shows how bedrock might be converted into sediment, at least in steep terrain; he gives a mechanism—static fatigue—for setting the time scale. The second study explains how climate change may have forged a signature on the landscape that has been misunderstood as a rapid recent rise of mountain ranges all around the globe. Both take steps toward understanding how erosion occurs.

# Carbon Budgets in Subalpine Forest Ecosystems

**Russell Monson**

Funding sources: Department of Energy and the National Science Foundation

## *Accomplishments*

Research continues on local-to-regional carbon budgets at the remote Niwot Ridge AmeriFlux site located at 3050 m along the Front Range of the Rocky Mountains. This past year we uncovered two fundamental discoveries that were submitted for publication.

In the first, we discovered that interannual variation in the depth of the spring snowpack at this site is correlated with interannual variation in the amount of carbon lost from soils through late-winter soil respiration (beneath the snowpack). Years with lower snowpack and therefore less thermal insulation produce colder soils and lower rates of carbon loss. Thus, changes in the snowpack due to climate change will have significant ramifications for the potential for forest ecosystems to sequester carbon dioxide from the atmosphere. In this case, lower snowpacks will increase the potential for forests to sequester carbon during the winter.

Unfortunately, our second major discovery tends to mitigate any advantage in terms of long-term carbon sequestration in these ecosystems. We discovered that in years with low snowpacks, and earlier spring thaws, this Front Range subalpine forest ecosystem exhibits lower rates of summertime photosynthesis. This is due to water stress that develops during the early-summer period. Thus, even though there is less carbon lost during the winter (due to colder soils), there is also less carbon gained during the summer (due to limited soil moisture).

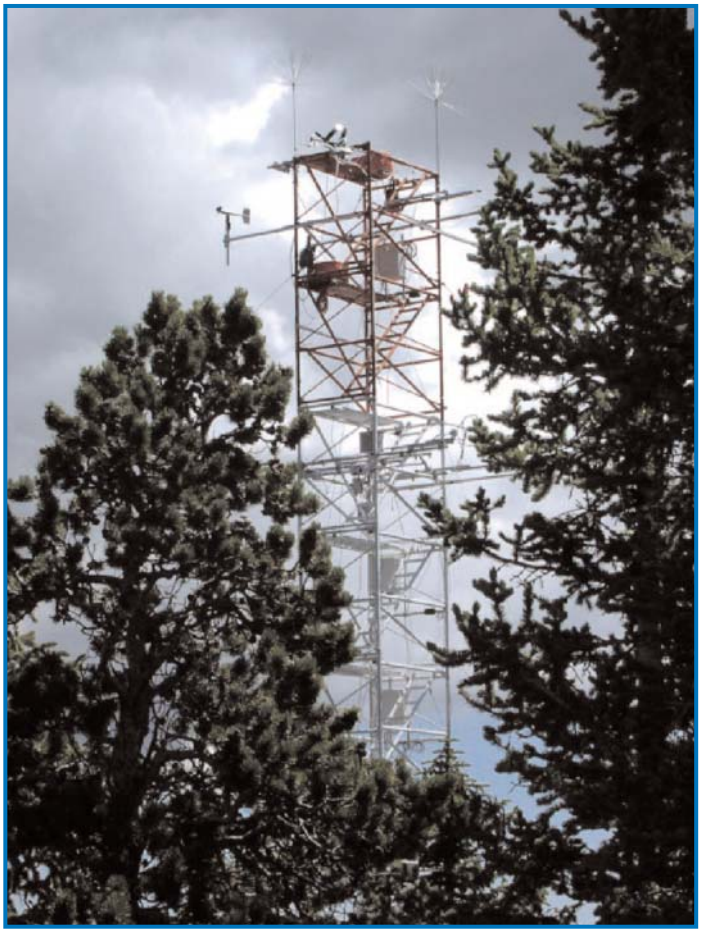


Figure 4.1.x. Instrument tower at the Niwot Ridge AmeriFlux site in the Rocky Mountains, Colorado.

## *Significance*

These findings will be very important to elucidating factors that impact the overall global carbon budget. We are currently working with advanced modeling approaches involving model-data fusion techniques, to determine how these two contrasting responses to the same climatic anomaly sum to give a single annual response.

## Development of 4-D Variational Data-Assimilation Platforms and a Generalized Stability-Analysis Tool-Kit for the Regional Ocean Modeling System (ROMS)

**Andrew Moore**

Funding: Office of Naval Research and the National Science Foundation

The Regional Ocean Modeling System (ROMS) is a community ocean general circulation model using generalized, orthogonal curvilinear terrain-following coordinates. ROMS employs a state-of-the-art numerical scheme and is ideally suited for modeling both basin-scale and coastal ocean regions.

### *Accomplishments*

Building on the experience of operational numerical weather prediction, a sophisticated state-of-the-art analysis and prediction system has been developed for the ocean using ROMS. This consists of (i) a series of 4-Dimensional VARiational (4DVAR) data-assimilation platforms, and (ii) a generalized stability-analysis tool-kit.

The 4DVAR data assimilation tools come in two flavors: a strong constraint (S4DVAR) system in which the model dynamics are imposed as a strong constraint on resulting ocean analyses, and a weak constraint (W4DVAR) in which errors are admitted in the dynamics. The S4DVAR system is also implemented using the so-called incremental formulation (IS4DVAR) as used operationally at ECMWF for operational weather forecasting. To implement the S4DVAR, IS4DVAR, and W4DVAR systems practically, four separate versions of the ROMS are required. These are the nonlinear model (NLROMS), the so-called perturbation tangent linear model (TLROMS), the adjoint model (ADROMS), and the representer tangent linear model (RPROMS). TLROMS, ADROMS, and RPROMS have all been developed by Dr. Moore and project collaborators at Rutgers University and the Scripps Institute of Oceanography.

The ROMS generalized stability tool-kit also utilizes TLROMS and ADROMS and can be used to perform a series of sophisticated eigenvector and singular-value decomposition calculations on complex ocean circulations. These calculations not only provide information about the dynamics of the circulation, but can also be used for ensemble generation in much the same way as they are used operationally at various numerical weather prediction centers.

### *Significance*

The ROMS 4DVAR and generalized stability-analysis tool-kits are unique within the regional ocean-modeling community, and provide the community with sophisticated ocean-analysis and prediction tools that were, until recently, only available in meteorology. Dr. Moore is using these tools to explore the dynamics and predictability of various regions of the world's oceans, including the Southern California Bight and the Intra-Americas Sea.

## A Multidisciplinary Investigation of Present-Day Sea Level Change

**R. Steven Nerem**

Observations of long-term sea level change can corroborate climate variations predicted by models, and can also help us prepare for the socioeconomic impacts of sea level change. The TOPEX/Poseidon and Jason satellites have observed a mean rate of sea level rise of 3 mm/year since 1993 (Figure 4.1.x). Dr. Nerem's research focuses on determining the causes of this change and relating the satellite record of sea level change to the longer-term record from tide gauges.

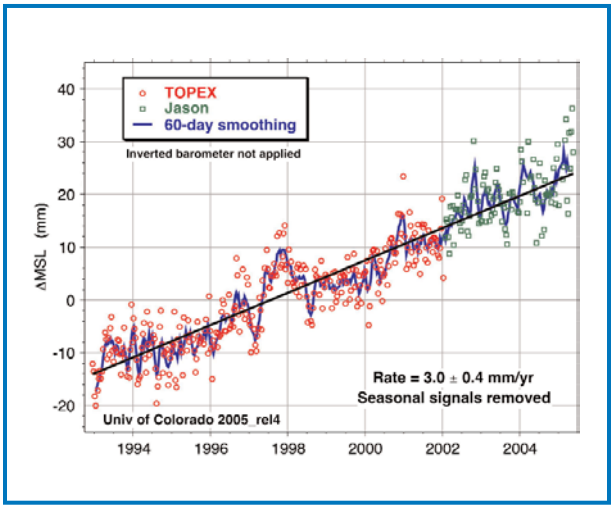
### *Accomplishments*

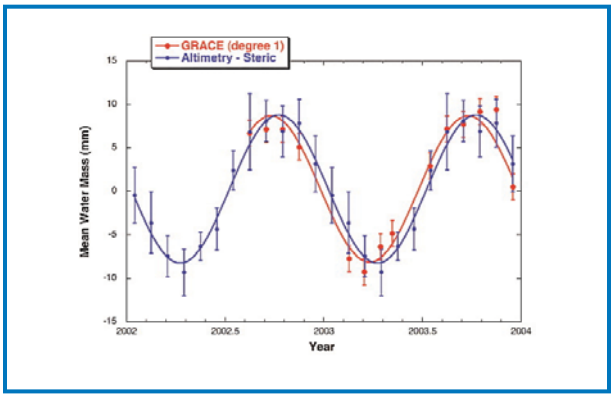
Over the past year, we have learned much about the causes of sea level changes that have been observed by satellites. Approximately half of the observed 3 mm/year global-averaged sea level rise is apparently caused by the warming of the oceans (thermal expansion); and the other half, by the addition of freshwater from the continents, mainly a result of the melting of ice in mountain glaciers, Greenland, and Antarctica. The total rise is significantly greater than has been observed over the last 75 years from tide gauges (~1.8 mm/year), and agrees with in situ observations of in ocean temperature and the melting of continental ice.

Dr. Nerem helped develop a new technique that allows direct measurement of continental water contributions from space. The GRACE satellite mission has precisely measured temporal variations in the Earth's gravitational field since 2002. As ocean water mass increases as a result of normal runoff, melting in mountain glaciers and melting of ice sheets, this research demonstrated that GRACE can directly measure the changes. GRACE can also determine the relative contributions of different areas on the continents. At seasonal frequencies, GRACE ocean mass estimates compare closely with estimates from satellite altimetry corrected for thermal expansion using shipboard measurements (Figure 4.1.y). Because seasonal variations in ocean water mass are caused by seasonal exchange of water with the continents, GRACE measurements will be of greatest use in studies of the global water cycle.

### *Significance*

Satellite altimeter and gravity measurements are significant for the next Intergovernmental Panel on Climate Change (IPCC) climate assessment. Satellite altimetry has conclusively shown that sea level rise has been higher over the last twelve years than during the last century; however, we need a longer time series to rule out decadal variability in the Earth system as a cause. The GRACE record, while too short to detect climate signals, has demonstrated the ability to measure changes in the mass of the oceans, and thus will play an equally important role in diagnosing the causes and magnitude of sea level change.



## Evaluating the hydrology of the stratosphere with water isotopes

**David Noone**

Funding: Royal Meteorological Society

Variation in the water vapor content of the stratosphere has important implications for stratospheric ozone chemistry, the radiation balance of the upper troposphere and lower stratosphere, and climate. Although it is broadly accepted that air and water enter the stratosphere in the tropics in association with deep convection, details about the controls on the rate at which water crosses the tropopause are poorly understood. The isotopic composition of water vapor reflects water temperature and condensation history. As such, measurements of the isotopic composition contribute valuable information on the mechanisms that drive stratospheric hydrology.

### *Accomplishments*

In collaboration with V. Payne of the University of Oxford, Noone's group derived the isotopic composition of water from thermal emission spectra measured by the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) onboard the European ENVISAT satellite. Spectra were available from March 2002 until March 2004, from which concentrations of $H_2O$, HDO $H_2{}^{18}O$, $H_2{}^{17}O$, $CH_4$, $CH_3D$ and $O_3$ were derived. This data set is the first to characterize the global distribution and seasonal variability of water isotopes, and has the potential for unprecedented elucidation of upper tropospheric and stratospheric hydrologic processes.

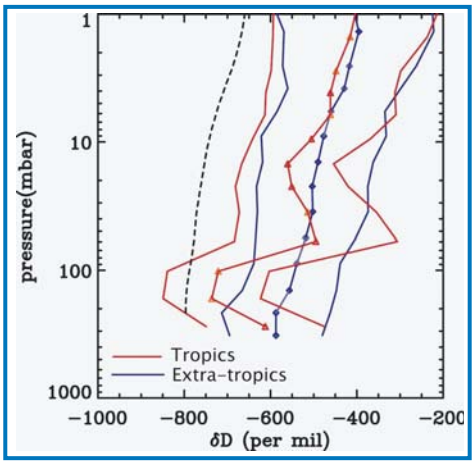



*Figure 4.1.X. Vertical profile of HDO in tropics (red) and extratropics (blue). The range indicated by additional curves represents variability/measurement error.*

Focusing on HDO, Noone's group showed evidence of the transport pathways that comprise the hydrologic cycle in the stratosphere. Contrasting the isotopic profiles in the tropics with other regions revealed the interaction of slow vertical motions with high-frequency convective events that influence the rate of water exchange across the tropical tropopause (Figure 4.1.X). The group's analysis revealed that large-scale horizontal mixing in the extratropics provides a recirculation of water, which is partially responsible for the remarkably constant isotopic depletions in the lower stratosphere. Similarly, the existence of this mixing acts to separate the largely quiescent stratospheric hydrology from the active cloud processes in the troposphere.

In combination with measurements of methane, the source of stratospheric water was partitioned into a fraction originating directly in the troposphere and a fraction resulting from oxidation of methane (Figure 4.1.X). The different isotopic signatures of these two water sources make the separation possible, and highlight the intrinsic utility of the isotopic methods that Noone's group employs.

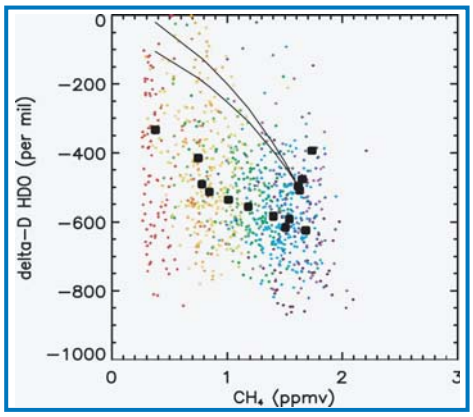



*Figure 4.1.X. Variation in HDO with methane shows the fraction of water coming from methane oxidation. The scatter is indicative of adiabatic mixing processes. Colors indicate altitude from blue near the tropopause to red in the mesosphere. Black curves are theoretical upper bounds on isotopic change in the absence of mixing.*

### *Significance*

A new understanding of cycling and transport of water in the stratosphere helps improve models of climate that perform poorly in this region of the atmosphere. Specifically, the new data allows testing of the way convective clouds are represented and behave in climate models.

## Mass Extinction at the Cretaceous-Tertiary Boundary

**Doug Robertson**

Dr. Robertson developed a model that sheds new light on the environmental catastrophe of the mass extinction at the Cretaceous-Tertiary (K-T) boundary. This mass extinction, 65 million years ago, is best known for marking the end of the dinosaurs. But dinosaurs were only a part of the extinction: between 70 and 80% of all species went extinct in a very brief time interval, perhaps as short as a few hours. In 1980 Luis and Walter Alvarez discovered evidence that the impact of a 10-kilometer asteroid was involved in the extinction. It was known that such an impact would release a quantity of energy approaching a billion megatons of TNT, but the exact effects of such an impact on the global ecosystem were not clear.

### *Accomplishments*

Our model shows that for several hours following the asteroid impact, the entire Earth was bathed with intense infrared radiation from ballistically reentering ejecta. The global heat pulse would have killed unsheltered organisms directly and ignited fires at places where adequate fuel was available. Our model establishes a prima facie case for significantly higher probability of survival for terrestrial vertebrates that dwelt in soils, used burrows, or bathed or swam in water. Sheltering underground, within natural cavities, or in water would have been a necessary but not always sufficient condition for survival. Survival through sheltering from an initial thermal pulse is not adequately considered in literature about Cretaceous-Tertiary non-marine extinctions.

### *Significance*

The thermal-sheltering hypothesis provides a simple explanation that reasonably accounts for much of the pattern of non-marine differential survival observed at the K-T boundary. Despite the various inherent biases in documentation of the biotic record across the K-T boundary, the observed patterns of differential survival do match this increased survival probability. None of the previously advanced extinction hypotheses (for example, acid rain, global cooling, global warming, poisoning, or tsunamis) explains so well these patterns of survival in the non-marine realm.

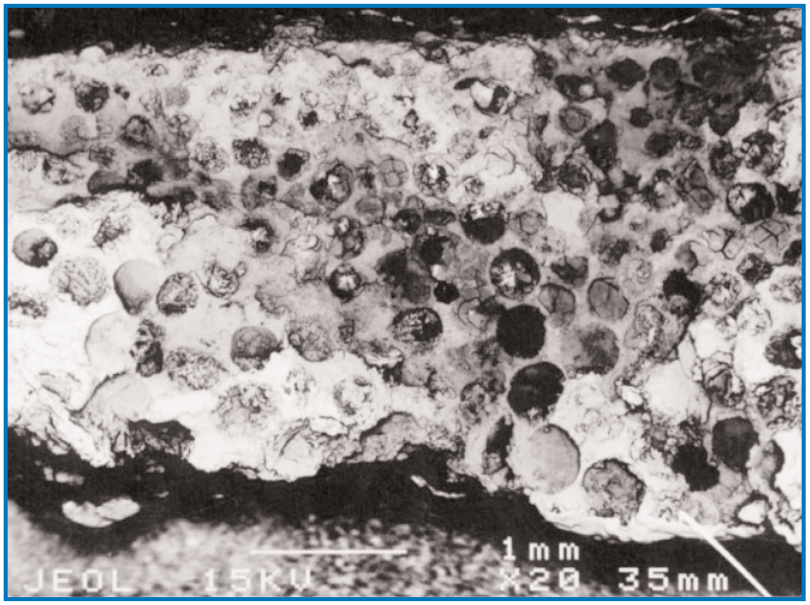



*Figure 4.1.x. Silicate spherules condensed from the vaporized rock of the Chicxulub impact found near Tbilisi, Georgia on the far side of the planet. Similar deposits discovered worldwide have thus far been uniformly distributed in a 3 mm layer coincident with the iridium K-T boundary. This is evidence of an impact that impacted the entire planet in a single event. (Photo from Smit, J., 1999, Ann. Rev. of Earth and Plan. Sci. 27, p. 83.)*

## Aspen Seismic Station for Improved Colorado Earthquake data

**Anne Sheehan**

Funding: NSF, USGS

A new seismic station near Aspen, Colorado, was installed in June 2005 by the Sheehan research group at CIRES in collaboration with scientists at the National Earthquake Information Center of the U.S. Geological Survey in Golden, Colorado.

### *Accomplishments*

The Snowmass station, a new seismic station installed June 30, 2005, is part of the U.S. Advanced National Seismic System and uses a satellite link to continuously relay data to the National Earthquake Information Center in Golden, Colorado. The seismic station is broadband with a high dynamic range, meaning that it can record a large frequency and amplitude range, making it possible to record both local earthquakes and distant earthquakes at a large range of magnitudes. Data from the station can be used to determine the seismicity and seismic hazards in the northern Rio Grande Rift and southern Rocky Mountains, and can be used for tomographic and other types of seismic imaging. Seismicity in the southern Rockies is poorly characterized because of a lack of seismograph station coverage. The data are scanned by computer and by human analysts to locate earthquakes from Colorado and the surrounding region. In its first few weeks of operation, the station recorded a magnitude 2.8 mining-induced earthquake that caused damage at an underground coal mine near Paonia, Colorado. Located high in the Snowmass ski area, the station consists of a seismometer, a digitizer, and a satellite dish to send information to the National Earthquake Information Center. The station is powered by car batteries that are recharged by solar panels. The Snowmass station is the first Advanced National Seismic System station to be run by cooperation between University of Colorado, Boulder, and the U.S. Geological Survey.

*CU graduate students Gaspar Monsalve and Tom de la Torre, together with Colgate undergraduate Christina Viviano, at newly installed Snowmass seismic station near Aspen, Colorado, June 2005.*

### *Significance*

The new Snowmass seismic station enhances the monitoring of earthquakes in the southern Rocky Mountain region. The data from the station will be used for tomographic imaging of the Rocky Mountains and the North American continent. The station is also an important teaching tool for geology and geophysics classes at the University of Colorado.

## Variability and Forcing of Climate Parameters on the Greenland Ice Sheet: Greenland Climate Network (GC-Net)

**Konrad Steffen**

Funding: NASA Cryospheric Sciences

### *Purpose and Objectives*

The GC-Net was established in spring 1995 with the intention of monitoring climatological and glaciological parameters at various locations on the ice sheet over a fifteen-year time period. Currently, the GC-Net consists of eighteen automatic weather stations (AWS) distributed over the entire Greenland ice sheet (Figure 4.1.X). Our objectives are to 1) measure daily, annual, and interannual variability in accumulation rate, surface climatology, and surface-energy balance at selected locations on the ice sheet; and 2) measure near-surface snow density at the AWS locations for the assessment of snow densification, accumulation, and metamorphosis.

### *Accomplishments*

The mean annual temperature at Swiss Camp is -11.9° C over the fourteen-year time period 1991 to 2004. The coldest monthly mean temperatures are found in February, with values as low as -30.4° C. The warmest summer month is generally July, with values slightly above freezing (Figure 4.1.X). Summer months with above-freezing mean temperatures occurred in 1995 and from 1997 to 2004. The statistical analysis of the Swiss Camp temperature record reveals large interannual variability in all seasons, with increasing temperatures throughout the recording period. The annual mean temperature increased from -14.7° C (1991) to -10.8° (2003), mean spring temperatures increased from -17.2° C to -13.6° C, and fall temperatures show a similar trend from -13.8° C to -10.3° C for the 1991 to 2004 records. The largest increase of 6° C was observed for mean winter temperatures, ranging from -25.3° C (1991) to -19.3° C (2003).


*Figure 4.1.X. Greenland Climate Network (GC-Net) automatic weather stations as of summer 2004.*

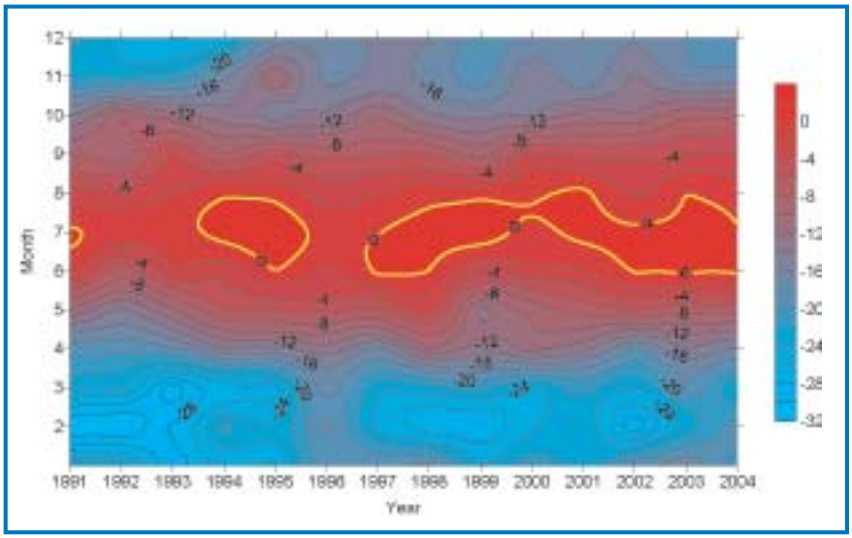



*Figure 4.1.X. Interannual variability of monthly mean air temperatures (1993 – 2004) at the Swiss Camp ETH/CU, located at the equilibrium line altitude on the western slope of the Greenland ice sheet.*

## Reactivity of Atmospheric Mineral Dust

**Margaret Tolbert**

Funding Source: National Science Foundation

### *Abstract*

Atmospheric mineral aerosol is a potentially important reactive surface that may provide a heterogeneous sink for gas phase species such as nitric acid (HNO3). A large fraction of mineral aerosol is composed of clays, including kaolinite, illite and smectite clay minerals. Smectites are known to expand upon addition of water, and thus their properties in the Earth's atmosphere may vary strongly with relative humidity. Over the past few years, research in Professor Tolbert's group has focused on investigating reactive properties of smectite clays in the atmosphere.

### *Accomplishments*

Mineral aerosol is emitted into the Earth's atmosphere from arid and semi-arid regions of the world and can be transported globally. Thus, during transport, desert dust particles encounter increasing humidity as well as local pollution events as they move further from the source region. We have probed the water uptake of Na-montmorillonite, a smectite clay, under conditions representative of the Earth's troposphere. We used a vacuum chamber equipped with transmission Fourier transform infrared spectroscopy to probe adsorption of water to the clay. Although water adsorption to Na-montmorillonite depends strongly on RH, there does not seem to be a strong dependence on absolute temperature. We found that Na-montmorillonite contains 10% water by mass at temperatures from 212 to 231 K at 50% relative humidity (RH) with respect to liquid water. We have also studied the uptake of HNO3 on Na-montmorillonite, a swelling clay mineral, at low temperatures as a function of relative humidity (RH) and HNO3 pressure. We find that below 16% RH, there is no measurable uptake of HNO3 on Na-montmorillonite. However, as RH is increased and the clay swells, it can take up significant amounts of HNO3. Surprisingly, at 44% RH, Na-montmorillonite can contain approximately 20% water and 30% HNO3 by weight. The results of this study suggest that swelling clays can impact the partitioning of gas phase HNO3 in the troposphere when sufficient water vapor is available.

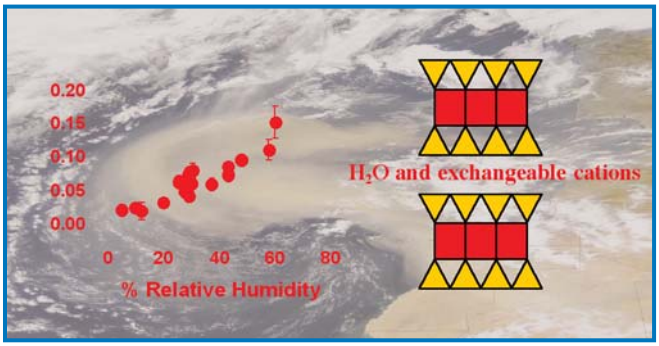



*Figure 4.1.X. Schematic of montmorillonite clay and water content of clay vs. RH overlaid on a photo of atmospheric dust off of the African coast.*

### *Significance*

Montmorillonite clay, due to its swelling abilities, can hold a surprisingly large amount of water depending on the RH. The water uptake by Na-montmorillonite is almost as great as that of deliquesced ammonium sulfate, a well known hygroscopic salt found in the Earth's atmosphere. As a result, smectite clays may influence the Earth's climate by intercepting solar and terrestrial radiation as well as by modifying cloud properties and acting as efficient cloud condensation nuclei. In addition, the presence of water vapor can significantly influence the heterogeneous interactions of HNO3 on mineral aerosol particles and should be considered in atmospheric chemical models. This study emphasizes that the swelling properties of smectite clays can significantly influence the heterogeneous chemistry and hygroscopic behavior of mineral aerosol in the atmosphere.

# Natural Experiments in Landscape Evolution: the Central Apennines, Italy

**Greg Tucker**

Funding:

## Overview

Mountains form via a feedback between solid-earth tectonic processes and climate-driven weathering and erosion. A key player in the sculpting of mountain landscapes is erosion by river networks. Several competing theories exist that describe the rate and pattern of river network development as a function of climate, topography, and other variables. Testing and refining these models requires "natural experiments," or case studies in which topography has grown under known forcing conditions. By developing quantitative models and testing them using natural experiments, Greg Tucker and his students and colleagues seek a better understanding of the physics behind landscape evolution.

A unique natural experiment can be found in the central Apennines of Italy. The Apennines form the spine of the Italian peninsula, and for the past three million years the mountains have been in a state of crustal extension. As in most extensional settings, the crust underlying central Italy is split into a series of fault blocks that move relative to one another, at rates between 0.2 and 2 meters per thousand years. In most extensional settings, information on rates of fault motion is sparse to nonexistent, but in the Apennines—thanks to a fortuitous combination of circumstances—rates of fault motion since the last glacial maximum are well known. Many of the faults have slip-rate estimates at different locations, making it possible to understand how rates vary from one end of the fault to the other. The lithology and climate are both relatively uniform across the region, which reduces the number of variables that need to be considered. Furthermore, we know that several of the faults sped up considerably during the middle Pleistocene. Thus, the region provides a natural laboratory for studying the processes responsible for carving valleys in the mountain ranges that form on uplifted sides of fault blocks.

Field measurements are providing new information about the processes responsible for carving the many mountain valleys of the Apennines, and they are also yielding new data for testing models.

These field data are complemented by digital terrain data, or digital maps of topography. Compared to ground surveys, the digital maps allow quicker measurement of key terrain properties, such as valley gradient, over vastly larger areas.

## Accomplishments

Analysis of data collected to date has revealed topographical features that appear to be "fingerprints" of both the tectonic background and the physics of valley incision. As shown in Figure 4.1.X, stream channels crossing faults that sped up in the mid Pleistocene tend to have steep gorges beginning above the fault and extending a few kilometers upstream. Such features are either absent or much more subtle on channels that cross faults on which slip has remained steady or decelerated. This suggests that the steep gorges formed as a result of accelerated fault motion. By comparing the morphology of these gorges with the predictions of mathematical models, we are working toward testing the models to determine which one best accounts for observed topography.

## Significance

Our research has implications for seismic hazard studies. In many parts of the world, lack of significant modern seismicity and/or long-term seismic records makes it difficult to assess earthquake risk. However, recent work has shown that the topography itself provides useful clues to fault activity that can complement existing methods of seismic hazard assessment. To realize the potential for using topography in this way, it is important to understand the physics of stream incision and related processes. These processes can be viewed as a filter that helps us understand how repeated earthquakes lead to the topography we observe. So that we can read tectonics from topography, it is essential to know how this filter works.

*Figure 4.1.X. Shaded-relief image of the 16-km-wide Fiamignano drainage basin, central Italy.*

## Time-Variable Gravity From GRACE

**John Wahr, Sean Swenson, Isabella Velicogna**

Funding Agencies: NASA, JPL, NSF

NASA, in partnership with the German Space Agency DLR, launched the twin GRACE (Gravity Recovery and Climate Experiment) satellites in March 2002. The nine-year mission of GRACE is to map the Earth's gravity field with spectacular accuracy every month. These monthly maps reveal time-variations in gravity; because mass causes gravity, this time-variability can be used to estimate month-to-month changes in the Earth's mass distribution.

### *Accomplishments*

Before GRACE there was no way to measure the total water storage over regional to global scales. We have been using these data to look at geophysical signals, particularly those involving water storage (including snow and ice) on continents and polar ice sheets. Figure 4.1.X, for example, compares annual water-storage cycle estimates from GRACE (in cm of water thickness), with predictions from three water storage models: Land Dynamics Model (LaD, Milly and Shmakin, 2002), Climate Prediction Center (CPC, Fan and van den Dool, 2004), and Global Land Data Assimilation Systems (GLDAS, Rodell, et al., 2004). All results represent the sum of water on the surface, in the soil, and beneath the soil layers. GRACE results were also validated against predictions from the three models for monthly water storage variations averaged over the Mississippi River basin and Greenland (Figure 4.1.X). Model results for the Mississippi basin lie within the GRACE error bars for most months, showing that the models do a reasonable job of capturing the true water storage variability in this basin. This model assessment has been extended to drainage basins all around the globe. Greenland data show not only a clear annual cycle, but also an apparent linear decrease in mass, as noted by the dashed line. After removing model estimates of the contributions from post-glacial-rebound in the solid Earth, we have concluded that the Greenland ice sheet lost mass at a rate of 75 +- 26 cubic km per year between the summers of 2002 and 2004. This result is consistent with Greenland mass loss estimates obtained using completely different observational techniques (for example, laser altimetry, surface flux measurements). The conclusion that the Greenland ice sheet is losing mass at a significant rate seems inescapable.

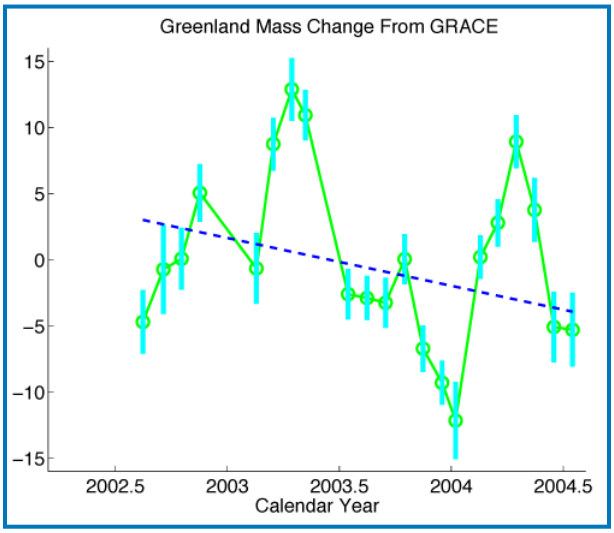



*Figure 4.1.x. Comparative data from four models depicting annual water storage estimates.*

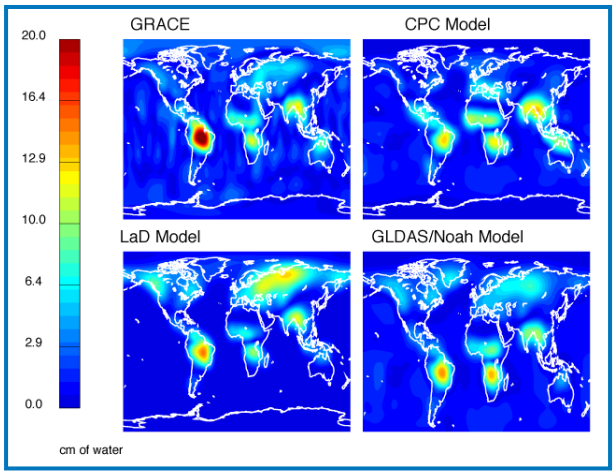



*Figure 4.1.y. GRACE monthly water storage variations compared against three predictive models.*

# 4.2 Education and Outreach Program

## Description

The CIRES Education and Outreach (EO) program provides science education opportunities for educators, students, and scientists. Their work emphasizes scientific inquiry, links with research scientists and current research, and uses of place-based and field-based teaching methods. The impact and scope of the program is increased through strategic partnerships with other geoscience organizations.

## Accomplishments

### *Opportunities for Educators*

**Earthworks: Earth System Science for Secondary Science Teachers**

The annual CIRES Earthworks workshop for secondary science teachers served twenty-three educators from thirteen states. Earthworks participants design and conduct a field-based study in order to be better able to teach science as an inquiry-based process rather than as a collection of facts.

Teachers are chosen on the basis of their can-do attitude, the goals they intend to accomplish, and their ability to serve disadvantaged or under-represented groups. Many of the teachers are new in the classroom and/or teach special-needs or English Language Learner students.

*Figure 4.2.2. Sixth-grade teacher Mike Monroe and high school teacher Christy Strickler do an experiment to understand the growth of crystals in igneous rocks.*

New teachers benefit especially from the example of the experienced teachers. From a new teacher in New York City: "I became really inspired by the positive attitude of the group (especially from teachers who have been doing this for a while—and want nothing but to keep doing it better)…It helped me think about what I want to do with my students and the type of teacher I want to become."

**Front Range Math and Science Partnerships**

CIRES partners with several local school districts to provide professional development and curriculum support. Twenty middle and high school teachers from three local school districts participated in an institute on Earth and space science led by outreach scientist Sandra Laursen. The teachers engaged in inquiry-based activities, lab work, field trips, and discussions during the intensive three-week session. During fall follow-up sessions, teachers are doing additional field and class work and conduct a collaborative "lesson study" project on their own classroom practice and student learning. The institute is offered by a Math/Science Partnership funded by the Colorado Department of Education.

The professional development workshops CIRES provides are not possible without the robust volunteer support of CIRES, NOAA, and other area scientists. Scientists from around the Front Range volunteer to mentor Earthworks teacher groups, to lead activities during workshops, and to partner with CIRES Outreach as part of their own active research grants. This year, Earthworks featured a visit to the CU Mountain Research Station in connection with research being conducted by Russ Monson of CIRES and Dave Schimel of NCAR.

### *Opportunities for Students*

**The GK-12 Graduate Student Fellows Program**

The CIRES Outreach program participates in the GK-12 Fellows Program at CU-Boulder (http://www.colorado.edu/chemistry/GK12/), which places graduate student fellows from the STEM (science, technology, engineering, math) disci-

## Education and Outreach Program (continued)

plines into middle and high school science classes. Partner schools have a significant Hispanic population, and many of the students are in English as a Second Language programs. This past year, ten graduate fellows provided content expertise and classroom support in five Boulder Valley School District schools. Two CIRES graduate students were supported by this grant, and one of these students (http://www.colorado.edu/chemistry/GK12/) helped to develop the next phase of the Sombrero Marsh Science Education curriculum, which is aimed at the 7th grade level.

**National Ocean Sciences Bowl**
For the seventh consecutive year, CIRES Outreach hosted a regional competition of the National Ocean Sciences Bowl (NOSB), which the team from Poudre High School in Fort Collins, Colorado, won for the fourth consecutive year. The winning team went on to compete in the final competition in Biloxi, Mississippi. The CIRES NOSB competition is one of the largest in the country, drawing teams from Colorado, Utah and Kansas. As the only competition site within a land-locked state, the CIRES competition is well-placed to further the NOSB mission to stimulate interest in the ocean sciences, encourage oceanography studies in high school, and demonstrate the importance of the oceans in our daily lives. This competition would not be possible without the generous support of volunteers from NOAA, CIRES, CU, and other Front Range institutions. Numerous prize donors and financial support from the Consortium for Oceanographic Research and Education (CORE) is also important to the competition's success.

**Ocean Interactions/Teacher at Sea Experience**
As part of the NOAA ETL participation in the Rain in Cumulus Over the Ocean (RICO) program, CIRES Outreach implemented a project which included pre-research-cruise classroom visits with the project scientists, student-scientist communications during the cruise, and a research experience on the cruise for a K-12 teacher. Ms. Judy Malley, a middle school teacher from Ann Arbor, Michigan, participated in a leg of the Caribbean cruise and helped the scientist answer questions from thirty-one schools around the country. Students had questions about the science on the cruise, life at sea, and the career path to being an ocean science researcher. Ms. Malley has implemented lessons in the classroom based upon her experiences and says one of the most positive results of the experience was "being able to see what a large-scale, coordinated scientific research mission was like. I had NO idea that scientists worked on the scale of this kind. It was a huge, joint effort, not just one experiment, but many."

### *Opportunities for Scientists*

**Resources for Scientists in Partnerships with Education (ReSciPE)**
ReSciPE is an NSF-funded project designed to assist scientists who are engaged with K-12 education. The project includes professional development workshops for scientists about how to work effectively within K-12 education, makes digital resources available, provides consultation help, and includes a social sciences research study to identify how best to support scientists in these endeavors. A slate of traveling half- to full-day workshops on "Scientific Inquiry in the K-12 Classroom" is being provided for groups of working scientists and their education collaborators, including two at NOAA sites in Boulder, Colorado, and Asheville, North Carolina. To learn more or to discuss a workshop for your group see our Web site (http://cires.colorado.edu/education/k12/rescipe/).

*Figure 4.2.1. Sixth-grade teacher Mike Hack examines a fossil fish as part of a geology field trip.*

## Education and Outreach Program (continued)

To read a CIRES study on this topic published in the Journal of Geoscience Education, click "Research/Evaluation" on that page.

**Support for Research Proposals**
As part of the service provided by CIRES to researchers, the CIRES Education and Outreach program collaborates with proposing scientists to include educational components within geoscience research projects. This sort of component adds value to proposals for which the funding agency requests or encourages such attention and makes proposals more competitive. This service is provided at no cost to the researcher, and can range from review and ideas for the researcher to do on his or her own, contributions to existing CIRES projects at no cost to the proposed grant, or discrete educational projects which are supported in part or in full by the geoscience research grant. Several past submissions have been funded with NOAA and CU investigators and are now underway or in the beginning stages. See the Ocean Interactions section for one such project.

### *Role of Partnerships*

CIRES Outreach is able to extend our reach through collaborations with other institutions and major projects. As a contribution to the American Geophysical Union (AGU) Spring 2005 Meeting in New Orleans, Lousiana, CIRES Outreach organized a professional development workshop on the topic of "Severe Weather and Hurricanes." With the help of others, including scientists from Louisiana-region NOAA offices, teachers and district administrators learned the latest findings regarding these phenomena in the New Orleans area. Through collaborations with the Digital Library for Earth System Education (DLESE), CIRES Outreach has made connections for others at CIRES to work with DLESE and has applied lessons learned (for example, the interface between geoscience data and education) which have been applied to our other work.

### *Evaluation Support for CIRES*

Our ability to apply evaluation techniques to projects has added value to general CIRES outreach efforts. Working with the CIRES Director's Office, Outreach staff adapted museum exhibit evaluation techniques to evaluate the effectiveness of the CIRES Exhibition Booth at the Fall 2004 AGU Meeting. The findings from the study influenced current exhibition plans in order to derive the greatest value from this activity.

### *Impact*

Much of the pilot work we have done in the past has resulted in mature partnerships and products. Inquiry workshops for scientists, the NOSB competition, local school district partnerships, Earthworks, and student fellowships all have a track record on which to build. Past collaborations on research proposals with CIRES and NOAA investigators have resulted in new funded projects that will integrate education and new research. For more information on these or other Outreach activities, see our Web site (http://cires.colorado.edu/~k12).

# 4.3 CIRES Scientific Centers

CIRES is home to five established centers, which individually focus research and bring together scientists with shared interests. Centers are comprised of researchers within CIRES, as well as those in other academic departments at the University of Colorado and others from outside the University, including those in the government and private sector. The four centers located at University of Colorado report their accomplishments in this section.

## Center for the Study of Earth From Space (CSES)

### *Description*

CSES is an association of five faculty members and their research groups who study and model the Earth using remote sensing and other techniques. The fields of study include landscape ecology, polar and regional climate, theoretical hydrology and surface geology. CSES was founded in 1985 to provide a focus for the development and application of modern remote-sensing techniques used in the research of all aspects of earth sciences at the University of Colorado. Although measurements from space are emphasized, aircraft and field measurements are integral to any remote sensing project. Within CSES the aim is to work on all scales of problems extending from technique development in small test sites to understanding pattern and process on a regional and global scale. Data from the available electromagnetic spectrum extending from the UV to the microwave region are used. CSES facilities were developed with generous support from the W.M. Keck Foundation and matching funds from the University. The laboratories are dedicated to both research and teaching.

### *Accomplishments*

Work during the past year on carbon sequestration in Southwestern rangelands demonstrates that dryland regions are changing mosaics of woody plant classes whose trends through time are logistically difficult to track with traditional ground-based techniques. Fieldwork linked to remote sensing imagery offers the capability to monitor and track changes in aboveground carbon pools over large dryland regions and at frequent intervals. Our data indicate that decadal accumulations of aboveground carbon by woody plants can quickly be lost via natural disturbances and land management practices. This emphasizes the need to develop spatially explicit databases of land-use practices in drylands.

A dissertation on urbanization in the Front Range of Colorado explored the regional effects of urban development on carbon storage in this area and is serving as a basis for future work on urban ecology.

Funding through the CIRES Innovative Research Program supported the establishment of permanent plots in the Routt National Forest field site to study the long-term interactive effects of multiple disturbances to sub-alpine forest biogeochemistry and regeneration. Results show that sub-alpine forests experiencing wind disturbance retain tight biotic control on regeneration processes. However, salvage logging following wind throw is a compound disturbance that disrupts recovery mechanisms, converting a biologically intact ecosystem into a modified state, in which a shift in ecosystem regime is possible.

Pollination may be subject to disruption in the face of disturbance or habitat loss. Currently, one of the major potential threats to pollination systems is habitat fragmentation: theory predicts that smaller fragments will support fewer pollinators, and that surviving populations will face higher risks of local extinction within fragments. CIRES/EBIO student Sarah Hinners is developing a comprehensive picture of the status of pollinator assemblages and pollination in Front Range urbanizing landscapes. Early results suggest that richness at the genus level is predicted by fragment size in small- to medium-sized fragments. However, larger fragments appear to behave more like open prairie, where assemblage diversity is related to local habitat characteristics.

The fifteenth field season was spent on the Greenland ice sheet servicing the twenty automatic weather stations and making surface process studies in the ablation area. The long-term climate record along the western slope (Swiss Camp)

## Center for the Study of Earth From Space (CSES) (continued)

of the ice sheet revealed continued warming in all seasons. The annual mean temperature increased from -14.7º C (1991) to -10.8º (2003), mean spring temperatures increased from -17.2º C to -13.6º C, and fall temperatures show a similar trend from -13.8º C to -10.3º C for the 1991 to 2004 record. The largest increase of 6º C was observed for mean winter temperatures, ranging from -25.3º C (1991) to -19.3º C (2003).

A dissertation on cloud climatology for the Greenland ice sheet demonstrated the large seasonal cycle (cloud types and amount), and the usefulness of satellite data (MODIS) for this analysis. A master study analyzed the cyclone frequency around Greenland and correlated the increase in frequency with the observed increase in melt area on the ice sheet.

Evidence of a temperature regulation mechanism at high latitudes related to sea-surface temperatures was found, which might explain the lower rate of observed arctic warming than predicted by climate models. Researchers also found a strong feedback from biosphere albedo in a simple model of the Earth's climate system. Finally, observed trends in reanalysis products were compared with previous claims of tropospheric warming causing some of the rise in tropopause height in the same data and showed that no warming existed in the data.

Researchers made the land surface parameters in a general circulation model consistent overall with satellite observations, while making individual parameters internally self consistent as well. Making these parameters consistent resulted in large impacts on model climate. We are now examining the effect of Asian land cover change on atmospheric circulation. We are also examining trends and predictive models for a subtropical Northeast Asian monsoon which has not been explored in depth before and relating it to trends in NDVI (Normalized Difference Vegetation Index) assessing the two-way interaction between precipitation and vegetation.

Researchers published a simple, nonlinear climate model study called a Dynamical Area Fraction Model (DAFM), which laid the basic theoretical framework for developing simple nonlinear-coupled dynamic models. The DAFM formulation removes the assumption of perfect local homeostasis through the albedo-dependent local heat transfer equation, resulting in globally similar temperature regulation despite the removal of the assumption of perfect local homeostasis. Two subsequent experiments with this revised model suggested the domination of negative feedback from the hydrologic cycle on the climate regulation: the active hydrological cycle greatly reduced the global climate temperature, despite powerful positive hydrological feedbacks like the ice-albedo and hydrological greenhouse feedbacks. These results contrast with anthropogenic explanations of climate change that rely heavily on assumptions of positive feedbacks from the hydrological cycle.

Data from three trenches dug into the Pierre Shale in the northern Front Range show that reflectance spectroscopy is a viable technique to detect the swell potential of smectitic soils and will provide results in seconds rather than days and at a significantly lower cost than standard methods.

Needs to be edited down by this much

### *Impact*

The nature and range of responses by ecosystems to anthropogenic and natural disturbance will be indicative of the resilience of most ecosystems (including human-dominated ones) to predictable and unpredictable climate change, and may identify ecological thresholds of dramatic change. These types of studies will also aid in understanding ecosystem responses to human management regimes and may help identify systems that are more vulnerable to human activities.

The research into arctic climate regulation by sea surface temperatures, observed changes in vertical temperature structure globally, the ability of climate models to reproduce observed climate trends, and potential climate feedbacks all have strong implications for predicting future climate changes and variability.

The cost of remediation of structures, including roads, associated with swelling soil damage is approximately $2.3 billion per year, on par with flood and storm damage. Spectroscopic tech-

## Center for Science and Technology Policy Research

### *Description*

Since 2001, the Center for Science and Technology Policy Research has sought to contribute to both to the CIRES goal of "promoting science in service to society" and to the University's vision of establishing research and outreach across traditional academic boundaries. The Center's vision is to serve as a resource for people, groups, or institutions that make decisions about science and technology. The Center conducts research, education, and outreach to improve the relationship between societal needs and science and technology policy. It fulfills this mission through research, outreach, and education within the following themes: evaluating the relationship between societal needs and science and technology policies; providing new policy alternatives for science and technology policy decision makers; and developing tools for science and technology policy decision making.

### *Accomplishments*

The Center's Graduate Certificate Program in Science and Technology Policy has grown from its initial cohort of ten graduate students to its current enrollment of twenty graduate students representing the following departments or centers at the University of Colorado: Communication, Chemical Engineering, Computer Science, Electrical Engineering, Environmental Studies, Mechanical Engineering, Optical Engineering, Political Science, Psychology, National Snow and Ice Data Center, and World Data Center for Glaciology. Center staff taught three graduate seminars, and the certificate was awarded to its first two recipients.

A number of our projects made significant progress during the year. In the first year of our five-year NSF-sponsored project, Science Policy Assessment and Research on Climate (SPARC), we developed a Web site and organized two workshops to explore the connection between climate science research priorities and decision makers' information needs. Another Center project, "Carbon Cycle Science: Reconciling Supply and Demand," held a workshop in September with scientists, program managers, decision makers and students to discuss reconciling supply with demand for carbon cycle science. The Center also continued its collaboration on the Swedish research project, "Climate Science and Policy Beyond 2012" (CSP 2012+), which is developing action alternatives to support international climate-change decision making with an explicit focus on the period 2012 and beyond. We also gained three new projects with Lisa Dilling, who joined the Center as a CIRES Visiting Fellow, bringing "Scales of Decision Making and the Carbon Cycle," "State of the Carbon Cycle Report," and "Climate Change: Communicating Urgency/Facilitating Social Change." We also received funding to evaluate the policy processes and outcomes related to the partnership on Level II radar data. The proposed evaluation is intended to contribute useful knowledge to the NWS on its continuing development and implementation of partnerships policies, as well as broader lessons in technology policy to government, academic, and private sectors.

We also conducted numerous workshops and talks during the year. Our most successful were the Presidential Science Adviser visits. The Center hosted visits to Boulder by Dr. John Marburger, the current science advisor to the president, and Dr. John Gibbons, science advisor to President Bill Clinton. More than 500 people attended talks and meetings with Marburger and Gibbons. The Center has lined up an additional four former presidential science advisors to visit over the next six months.

In other events, we co-organized an international workshop on hydrologic ensemble prediction in July, and on related topics had thirteen peer-reviewed articles published, and another five in

## Center for Science and Technology Policy Research (continued)

press. The Center hosted and co-sponsored 13 other talks and visits at the Center or on CU campus, including five visitors from outside the campus. The Center also sponsored an all-day symposium on Science, Technology, and Decision Making to showcase the research and other efforts at the Center and the University of Colorado relating to science, technology, and decision making. Center researchers, students, and affiliates gave sixteen presentations on topics ranging from protecting spectators from lightning in large stadiums to climate-change policy to decision structures for the new nuclear age.

### *Products*

Center staff produced 31 publications. including eighteen peer-reviewed articles, and gave 38 presentations at academic conferences and other events. Center graduate students gave thirteen talks and presentations. Other Center products include a quarterly newsletter, an extensive Web site, a well-regarded science policy weblog that receives more than 1,300 visitors a day, and a symposium on science and decision making. The Center continues to develop its Climate Services Clearinghouse (http://sciencepolicy.colorado.edu/climateservices/), which provides a means for searching hundreds of climate products from NOAA, other government agencies, academia, and the private sector.

### *Impacts*

The Center continues to make gains in reaching decision makers and in growing its credibility as a serious source of analysis and information concerning science and technology decision making. Rad Byerly spoke at a NASA workshop organized to determine what future capabilities will be needed to accomplish President Bush's program for humans to return to the Moon, and for a subsequent trip to Mars. The workshop organizer invited Byerly, a member of the Space Studies Board (SSB) of the National Research Council, to present the results of two other workshops the SSB had conducted. These SSB workshop reports form an important part of the context in which NASA will be carrying out its vision, and were relevant to deciding what capabilities should be developed.

Center staff were quoted or referred to 41 times by media including the UPI, Kansas City Star, Philadelphia Inquirer, Wall Street Journal, Space.com, Financial Post, Pacifica Radio, Pittsburgh Post-Gazette, Naples Daily News, Chronicle of Higher Education, Baltimore Sun, New York Times, Christian Science Monitor, Sarasota Herald Tribune, Greenwire, Associated Press, Swedish Public Radio, as well as local newspapers.

Our graduate students are beginning to penetrate decision-making circles as well. During the summer of 2005 Center-affiliated graduate students interned with the House Science Committee, Office of Management and Budget (OMB), ICAT Managers, and National Academy of Sciences. A Center graduate student serves as Co-chair of the CU Environmental Center Board, and another serves as Vice President for the United Government of Graduate Students (UGGS), the primary advocate for graduate and professional students at the University of Colorado.

## National Snow and Ice Data Center

### *Description*

The goal of the National Snow and Ice Data Center (NSIDC) is to make fundamental contributions to cryospheric science and to excel in managing data and disseminating information to advance understanding of the earth system. It was established by NOAA as a national information and referral center in support of polar and cryospheric research. Additional information is available at our Internet site (http://nsidc.org).

NSIDC serves as one of eight Distributed Active Archive Centers (DAACs) funded by the National Aeronautics and Space Administration (NASA) to archive and distribute data from past and current NASA satellites and field measurement programs. NSIDC also supports the National Science Foundation through the Arctic System Science Data Coordination Center, the Antarctic Data Coordination Center and the Antarctic Glaciological Data Center.

### *Accomplishments*

NSIDC data management activities resulted in more than 100 new data sets being available through the online catalog during 2004-2005. These range from small data sets collected by individual investigators under NSF-supported research, to Earth Observing System satellite data products.

NSIDC researchers authored or contributed to 25 journal articles and numerous conference proceedings and other publications during 2004-2005. Research at NSIDC includes activities related to several cryospheric interests:

Ice sheets and glaciers: Glacier and ice sheet mass balance is critical as an indicator of climate change and as a source of fresh water contribution to the oceans. NSIDC scientists developed a revised map of Antarctica and have been documenting the rates of movement of glaciers and critical parts of the Antarctic ice sheet.

Sea ice: Sea ice is important both as an input to global climate models and as an indicator of climate change. The Sea Ice Index, developed by NSIDC to meet a need for tracking changes in the ice as they occur, has indicated declines in arctic sea ice extent during recent years (Figure 4.3.x).

Permafrost and frozen ground: Changes in the extent of permafrost and frozen ground are an indicator of climate change and have an impact on native communities and terrestrial ecology. The carbon tied up in permafrost and frozen ground could impact the global carbon balance. Scientists at NSIDC are integrating remotely sensed data with in situ data to refine predictions of frozen ground conditions.

Snow cover and snow hydrology: Changes in the freshwater contribution to the northern seas are impacting the dynamics of ocean circulation. NSIDCs scientists are working with sparse data, in conjunction with synthesis and modeling approaches, to understand Arctic hydrologic issues.

Climate change in the cryosphere: Scientists working with near real time monitoring of snow, sea ice, and vegetation under the Study of Environmental Arctic Change (SEARCH) program are making progress toward documenting that change by using approaches such as the sea ice index noted above.

Impacts of changes on Arctic peoples: The impacts of changes on Arctic peoples are being recognized and incorporated into research projects. An NSIDC scientist has been living in a community in northeast Canada and has documented the observations of and impacts on the local people.

The activities of NSIDC scientists and managers are documented in the NSIDC Annual Report (http://nsidc.org/pubs/).

### *Impacts*

**Impacts on the science community**

NASA and local FTP statistics indicate that NSIDC distributed 1,709,655 files with 16,769 GB of digital data during 2004-2005. Users also downloaded data files and images were also downloaded from the Internet, and we distributed additional data sets via CD-ROM. NSIDC products support research into all aspects of the cryosphere and the associated impacts related to climate

## National Snow and Ice Data Center (continued)

change. NSIDC supports the scientific community through participation in projects such as the WCRP Climate and Cryosphere (CliC) Project, Global Land Ice Measurements from Space (GLIMS), and the Study of Environmental Arctic Change (SEARCH).

**Societal impacts**
Researchers using NSIDC data products are assessing and monitoring changes in the cryosphere that may have profound impacts on society. NSIDC scientists are a resource for the news media in articles explaining what is happening and why changes are taking place throughout the cryosphere: permafrost extent is declining, glaciers are retreating, ice shelves on the Antarctic Peninsula have disintegrated, and arctic sea ice extent is shrinking.

### *Products*

NSIDC component data centers provided a wide range of cryospheric data and products during 2004-2005. All NSIDC data may be accessed through a user-friendly Web site that provides tools to permit searching for data by the name of the scientist, the project title, the measured parameter, or keywords (http://nsidc.org/data).

**NOAA at NSIDC and the World Data Center for Glaciology, Boulder**
The NOAA project at NSIDC operates in cooperation with the NOAA National Geophysical Data Center and Arctic Research Office to extend the NOAA National Data Center catalog of cryospheric data and information products, with an emphasis on in situ data, data rescue, and data sets from operational communities. The team also works

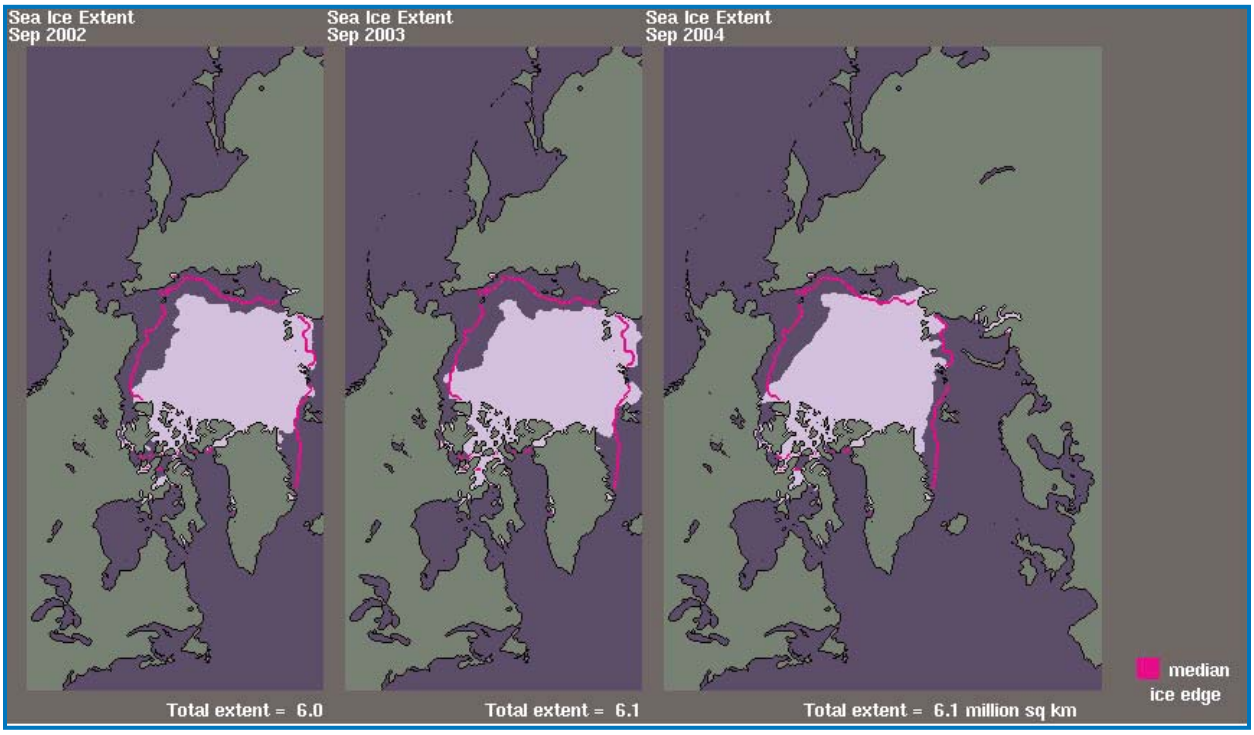



*Figure 4.3.x. A series of sea ice extent images from the Sea Ice Index product web site, showing how the ice extent in September (the month of minimum extent for the arctic) has fallen well inside its median position (marked by the pink line) in 2002, 2003, and 2004.*

## National Snow and Ice Data Center (continued)

with the International Ice Charting Working Group, and WMO Global Digital Sea Ice Data Bank. Recent titles include Snow Data Assimilation System Data Products at NSIDC and Online Glacier Photograph Database.

**The Distributed Active Archive Center (DAAC)**
The NSIDC DAAC provides access to Earth Observing System satellite data, ancillary in situ measurements, base-line data, model results, and algorithms relating to cryospheric and polar processes. The DAAC is an integral part of the multiagency-funded efforts at NSIDC to provide snow and ice data and information management services.

**The Arctic System Science (ARCSS) Data Coordination Center (ADCC)**
NSF has funded the ADCC at NSIDC to house data from Office of Polar Programs Arctic Systems Science funded investigators, and to provide tools for investigators both submitting and looking for data. Examples of new data sets available during 2004-05 include the J-CAD Drifting Buoy Data, and the Russian Historical Soil Temperature Data.

**Antarctic Glaciological Data Center (AGDC)**
The NSF Office of Polar Programs (OPP) funds AGDC to archive and distribute glaciological and cryospheric-system data obtained by the U.S. Antarctic Program. Compiled data include ice velocity, firn temperature, shallow ice core measurements, geochemical composition of ice cores, snow pit data, and satellite images of ice shelves.

**U.S. Antarctic Data Coordination Center (US ADCC)**
OPP funds US ADCC to improve access to U.S. funded Antarctic scientific data by creating descriptions of these data and entering them into the Antarctic Master Directory (AMD), a node of the Global Change Master Directory (CGMD). The AMD is a Web-based, searchable directory of thousands of data descriptions submitted by scientists from over twenty countries.

*Figure 4.3.x. A shovel stands alone at Swiss Camp in Greenland. Photo by John Maurer of NSIDC.*

**The Frozen Ground Data Center (FGDC)**
The FGDC is a collaborative effort between the World Data Center (WDC) for Glaciology, Boulder and the International Arctic Research Center (IARC). FGDC works internationally to collect and distribute data gathered over many decades that are critical for environmental change detection and impact assessment, model validation, and engineering applications.

## Center for Limnology

### *Description*

The Center for Limnology moved to CIRES from the College of Arts and Sciences in 1995. The purpose of the Center is to facilitate research and graduate education relevant to the study of inland waters as ecological systems. Examples of research topics that have figured prominently in the work of the Center over its history include biogeochemistry of key nutrients and carbon; productivity and its natural and anthropogenic regulation in aquatic ecosystems; aquatic foodweb structure and function; and composition of aquatic communities. The Center deals with streams, rivers, lakes, and wetlands. The Center conducts field work in Colorado and in the tropics (Puerto Rico, Venezuela).

### *Accomplishments*

During the last year, the Center for Limnology completed phases of a number of research projects involving post-doctoral associates, graduate students, and external collaborators. These projects span a typical range for the activity of the center in recent years. Under support from NOAA-OAR, the Center for Limnology has taken a leading role studying the ecological significance of changes in river flows caused by climate variability and human influence. One phase of this work has involved relationships between climate, water use, and critical low flows. Critical low flows are those that occur at multi-year intervals. Because the waste assimilation capability of rivers and streams is related to the volume of flow, trends in the frequency or intensity of low flows are directly related to the welfare of aquatic communities. The first phase of our work in this area was related to linkages of critical low flows and changes in water management. During 2004, the Center published the results of a nationwide assessment of influence of climate variability on the estimation of low flows used to protect water quality (*Journal of the American Water Resources Association*, 2004).

*Figure 4.3.X. Center of Limnology affiliates work in the field.*

The Center also completed a study of river metabolism as related to hydrologic changes induced by human activity or by climate change. This work, which has been submitted for publica-

## Center for Limnology (continued)

tion, consists of a new method for reconstructing past or predicting future metabolic changes in streams and rivers that come about as a result of hydrologic changes, which might be either natural or induced by human activity. This method is based on quantitative linkages between river discharge, bed movement, and river metabolism. The South Platte River was used in developing an example for implementation of the method at a specific site. By using the quantitative linkages between discharge, bed movement, and metabolism, it is possible to reconstruct, from the 70-year record of river flows in the South Platte below Denver, the pattern of river metabolism over the last seven decades. It is evident from this reconstruction that human influence, through hydrologic change, has had a drastic effect on river metabolism: the photosynthetic capability of the South Platte River is two-thirds less now than it was for the South Platte prior to hydrologic manipulation. An alteration in the frequency of bed movement explains this shift in river metabolism. The method is offered in published form as a tool for exploring the costs or benefits of hydrologic change that is yet to occur, or for anticipating the influence of climate change.

We published the third in a series of papers on the development of a new method for estimating denitrification rates in streams and rivers based on nitrogen flux through the surface of the water. This method has attracted wide attention because realistic measurements of denitrification, a key process in the nitrogen cycle, have not been possible in the past. The method is based on membrane inlet mass spectrometry and tracer measurements of gas exchange rates over the surface water interface.

We also proposed a new study to the National Science Foundation based on ebullition (bubbling release) of nitrogen from river sediments. This phenomenon, which appears not to have been described previously, may be an important component in the release of nitrogen from aquatic environments to the atmosphere.

The Center completed an extensive study of the role of nutrients in producing algal blooms in Cherry Creek Reservoir. This work was supported by the State of Colorado and by the Cherry Creek Basin Authority. Cherry Creek Reservoir, which is the most often-visited water body in Colorado, has suffered severe algal blooms during summer leading to mass mortality of fish and objections from the public. The Authority has been charged by the Colorado Water Quality Control Commission with eliminating these blooms by control of nutrients. Controls have proven ineffective. The Center for Limnology was asked to determine why. The Center showed that background concentrations of nutrients are so high that it is virtually impossible to intercept sufficient nutrients to affect the growth of algae. The Center recommends instead that the mixing depth of the lake be increased by introduction of an airlift system that will prevent the lake from layering. This approach is being pursued by the Authority, with approval from the state.

During 2004, our Director made a presentation at the National Academy of Science (NAS) Sackler Symposium, which had global water as its theme. The NAS, in an experiment with an alternative to publishing through the Academy Press, put all ten presentations in the symposium on the NAS website. Our Director also spent much of 2004 working for the National Research Council as committee chair for an NAS project dealing with threatened and endangered fishes in the Klamath River Basin. The committee produced a report containing several new kinds of recommendations for action on the Klamath River Basin; it was gratifying to see a substantial new appropriation of federal money to Klamath Basin environmental restoration.

Our graduate students are making important contributions as well. One graduate student study is designed to provide better prediction of the rise and fall of nitrogen-fixing cyanobacteria in lakes and reservoirs. Cyanobacterial blooms have become increasingly disturbing because of their documented association with toxins, many of which pass through standard water treatment. In addition, they are an aesthetic nuisance and can create mass death of fish and other organisms by

## Center for Limnology (continued)

depletion of oxygen as they reach the end of their growth cycle. The Center is particularly interested in relationships between mixing depth, light requirements, and fixation rates for nitrogen for these species.

A second graduate student project has resulted in preparation a series of papers on the interaction between the threatened native cutthroat trout (greenback cutthroat) and the non-native brook trout in Colorado. The graduate student showed, by extensive field studies, that the interaction between these two species does not follow the previously suspected pattern of competition for food or space. Instead, the bottleneck for the native trout lies in winter mortality of very young fish, which is increased by the presence of brook trout. This information can be used in managing populations.

We also finished publishing the last part of its study of the importance of organic nitrogen under natural conditions in Colorado streams. The experiments by a Ph.D. student showed that such organic nitrogen, which has long been considered essentially inert, plays a large role in supporting the metabolism of microbes under nitrogen-limiting conditions. This has practical importance for the natural regulation of microbial populations in streams.

During 2004, the Center for Limnology was pleased to see Claire McGrath, Ph.D. student, graduate with her Ph.D. and find a suitable research position with the state of Iowa. In the same year, Sujay Kaushal, a recent graduate, moved from his post-doctoral position at the Institute for Ecosystem Studies to a tenure-track position at the University of Maryland.

### *Impacts*

Our research to understand the impacts of streamflows, hydrological manipulation, and cyanobacterial blooms on inland water ecological systems, and therefore on productivity and water quality, helps resource managers make better decisions and plan effective actions to steward these natural resources.

*Figure 4.3.X. Center of Limnology affiliates work in a riparian area.*

# 4.4 Innovative Research Program

The Innovative Research Program is designed to stimulate a creative research environment within CIRES and encourage synergy between disciplines and research colleagues. The intent is to provide an uncomplicated mechanism for supporting small research efforts that can quickly provide concept viability or rule out further consideration. The program encourages novel, unconventional or fundamental research that might otherwise be difficult to fund.

## An improved tiltmeter sensor

**Roger Bilham and Naia Suszek**

### *Objective*

Tiltmeters to monitor surface deformation in the epicentral region of future earthquakes require high resolution and stability: 10-9 radian is typical, equivalent to a 1-$\mu$m difference in height between the two ends of a 1-km long water pipe. We have investigated the potential of a new low-inertia float for use as a reference datum.

### *Accomplishments*

The 15-cm-diameter float weighs 42 gm and is formed from a 1/8-inch-thick polypropylene disk (density 0.95 gm/cc). Unlike previous float systems that attempt to minimize the effects of surface tension, 231 six-mm-diameter holes in the new float increase the water-interface length, thereby making surface-tension the dominant force in the system. The effective perimeter length is increased from approximately 46 cm to approximately 460 cm. The angle of contact of polypropylene with water results in an almost horizontal surface in each of the holes so the upper surface of the float is approximately flush with the water surface.

The researchers constructed two float-sensor systems to test their effectiveness in tracking a sinusoidal 0.7-mm water-level oscillation signal from a plunger driven by a stepper motor for a 15-minute period for two days. The differenced data reveal a 2-$\mu$m peak-to-peak signal, mostly caused by the dynamics of the piston/stepper drive system (Figure 4.4.y). Thermal effects are small because the volume coefficients of the float and water are similar near 15°C. The success of the new float is caused by a combination of adhesion tension and surface tension, but its application in a practical water-level sensor is enhanced by the use of sawn-off flower pots lining the inner surface of the measurement reservoir. These earthenware liners raise a damp region to levels 5-mm above the transient water level, eliminating adhesion tension. As a consequence, the float is able to follow water-level changes at the sub-micron level with high fidelity.

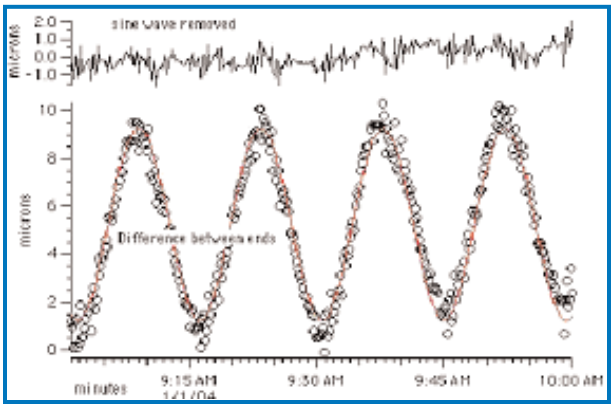



*Figure 4.4.y 2-$\mu$m peak-to-peak signal caused by the dynamics of the piston/stepper drive system*

### *Impact*

The new meniscus float permits a more compact, less fragile tiltmeter sensor that costs only $500 (Figure 4.4.z). The most important aspects of the new meniscus float systems are that four sensors and a recording computer can be carried in suitcase and, together, weigh only 50 pounds. We plan our first field test in a 300-m tiltmeter in the Andaman islands in October 2005, where a half km pipe is currently being installed in an NSF-funded project.

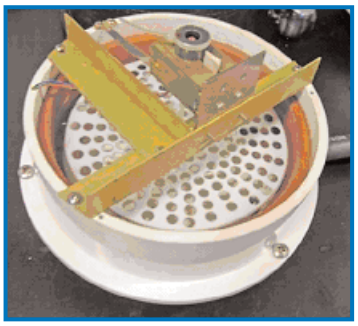


Figure 4.4.z New float and tiltmeter sensor

# Undocumented Nitrogen Fixation in Water by Colonial Blue-Green Algae Embedded in Mucilage

**Mark Bradburn (CIRES/EBIO),**
**William M. Lewis (CIRES/EBIO)**

## *Objective*

Nitrogen often limits the growth of plants in terrestrial and aquatic systems. Aquatic systems limited by nitrogen favor the growth of certain species of cyanobacteria (blue-green algae) that reduce inert atmospheric nitrogen into a biologically relevant form. Consequently, many nitrogen-limited water bodies contain nitrogen-fixing cyanobacteria. However, nitrogen fixation conflicts with photosynthesis. Photosynthesis produces oxygen, while nitrogen fixation is completely inhibited by even low pressures of $O_2$. Known nitrogen-fixing species have overcome this constraint through the spatial separation of photosynthesis and nitrogen fixation. In these species, nitrogen fixation occurs in a specialized cell impermeable to oxygen called a heterocyst (Figure 4.4.a). Thus, nitrogen fixation proceeds uninhibited in the heterocyst, while photosynthesis occurs within the other cells; the products of both processes are then shared among cells. Heterocystous blue-green algae are common in nitrogen-limited environments, where they often form a large proportion of the phytoplankton community. Often, however, non-heterocystous blue-green algae also are present in the same water. These non-heterocystous species have received little attention and are assumed to lack nitrogen fixing capability, but they often thrive in nitrogen limited environments. Here in Colorado, we commonly observe two genera of non-heterocystous blue-green algae, *Aphanothece* (Figure 4.4.a) and *Aphanocapsa*, in water with limiting amounts of nitrogen. Members of both genera are unicells that form aggregates or colonies surrounded by an extracellular polysaccharide mucilage. Using a well-established acetylene-reduction technique, we examined the nitrogen-fixation capabilities of non-heterocystous blue-green algae.

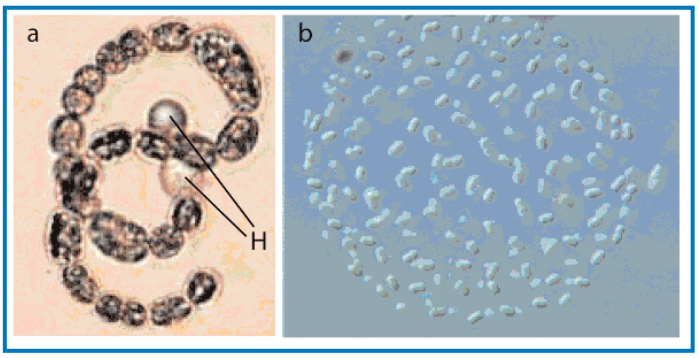



*Figure 4.4.a*
*a) Heterocystous nitrogen fixer* Anabaena circinalis*; note the heterocysts where nitrogen is fixed (H).*
*b) Colony of* Aphanothece *sp., a non-heterocystous blue-green alga.*

## *Accomplishments*

The non-heterocystous blue-green algae *Aphanothece* and *Aphanocapsa* did not demonstrate the ability to fix atmospheric nitrogen. After examination in situ and in conditions established in the laboratory, the non-heterocystous blue-green algae failed to produce a measurable amount of nitrogen fixation. These algae are either incapable of nitrogen fixation or they fix nitrogen in minute quantities beyond the limits of detection for the acetylene-reduction method.

## *Impact*

The non-heterocystous blue-green algae *Aphanothece* and *Aphanocapsa* are cosmopolitan in distribution in freshwater systems, many of which are limited by nitrogen. If these algae are found to possess the capability to fix atmospheric nitrogen, ecosystem measurements of nutrient sources will need to be revised for many freshwater aquatic systems, providing new estimates for biomass production. Thus far, nitrogen fixation in these algae remains undetected. However, the detection limits of the common acetylene-reduction method could obscure nitrogen fixation in non-heterocystous algae if it occurs on a smaller scale. To conclusively confirm nitrogen fixation in non-heterocystous blue-green algae, new tools, including molecular methods and stable isotopes, will be needed.

# Development of a Novel Technique to Measure Ultrafine Particle-Size Distributions for Environmental Science Applications

**Charles A. Brock (CIRES/NOAA Aeronomy), Jose-Luis Jiminez (CIRES/Chemistry)**

## Overview

Recent research indicates that atmospheric aerosol particles <100 nm in diameter, referred to as "ultrafine" particles, are critically important to a variety of environmental issues. For example, studies have shown that increased human mortality and morbidity have a correlation with ultrafine particles in urban environments; ultrafine particles are rich in condensed organic matter including mutagenic polycyclic aromatic hydrocarbons; larger ultrafine particles serve as cloud condensation nuclei, affecting the earth's hydrologic and radiation budgets; and ultrafine soot particles produced from combustion sources absorb solar radiation in climatically significant amounts. In addition to their environmental relevance, ultrafine particles are widely studied and used for a variety of engineering "nanotechnology" applications. However, instruments to measure these ultrafine particles are expensive, complex, and require extensive training for proper use. Researchers developed a new technique, scanning condensation spectrometry, to reduce the cost and difficulty associated with measuring the concentration and size of particles smaller than 30 nm.

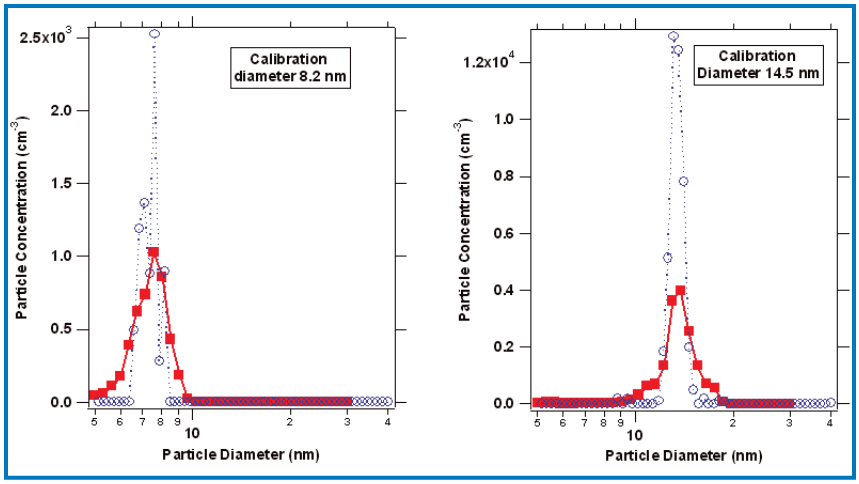



*Figure 4.4.c Comparison of measurements of two monodisperse calibration aerosols measured simultaneously with the SCoPS (closed symbols) and with an existing technique, the scanning mobility particle sizer (open symbols). The SCoPS measured concentration more accurately and was faster, less expensive to construct, and simpler to operate.*

## Findings

The researchers extensively redesigned an existing technique used only to count small particles. The new scanning condensation particle spectrometer (SCoPS) allowed the size of the particles to be determined as they were counted. High-precision, fast-response flow controllers were used to regulate the amount of saturated vapor of a perfluorinated fluid that the particles were exposed to, and custom control and detection circuits and software were used to operate the system and detect the particles. By continuously varying the vapor pressure, the size of the particles that nucleated and grew to detectable sizes could be controlled. Particles ranging in diameter from 5 to 30 nm could be discriminated and counted with good precision. Compared with existing techniques, the SCoPS was comparably precise, less expensive, and produced measurements more quickly (Figure 4.4.c).

## Impact

Findings indicate that the new technique has potential for cost-effective, fast-response measurements of atmospheric and industrial nanoparticles. Improvements in packaging and further testing over a range of environmental conditions will be necessary before the SCoPS can be used for scientific studies or industrial applications. The researchers are discussing licensing for engineering development with an established small business specializing in particle-measuring instruments. A manuscript detailing the design and performance of the SCoPS will be submitted to a particle-technology journal, ensuring that the technique will receive scientific review and broad distribution.

# An Electrochemical Ion Source for Thermal Ionization Mass Spectrometry

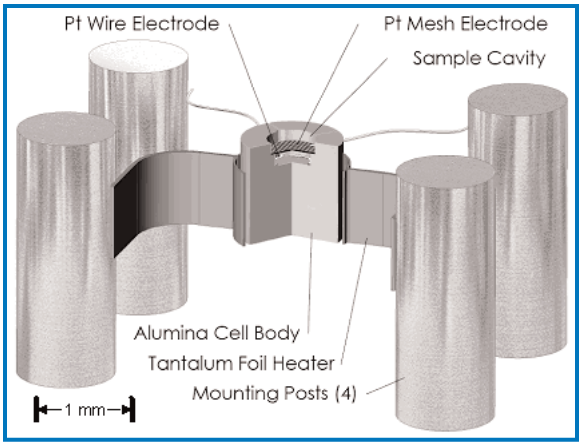
**Lang Farmer (CIRES/Geology), Carl Koval (Chemistry), Mary Beth Cheversia (Geology)**

## *Objective*

Thermal ionization mass spectrometry (TIMS) is the method of choice for high-precision isotope ratio measurements. However, demands for smaller sample sizes (subnanogram) in geochronology and isotope tracer studies are challenging the current capabilities of TIMS instrumentation. We have focused our efforts on improving the thermalized ion source to increase ionization efficiencies of typically analyzed elements, such as Pb. The current state of the thermalized ion emitter is a boro- or phospho- silica gel doped with the element of interest and loaded onto a resistively heated Re or Ta filament. The silica-gel method is favorable because apparently it suppresses the volatility of the element to be analyzed. However, to date, little is known about the actual ion formation mechanism in the silica gel, and typical ionization efficiencies for elements such as Pb, Cr, Ru, and Ag are in the range of 0.05-2%. Other workers have demonstrated that Ag-doped borosilicate glasses heated under high vacuum emitted monatomic metallic species, predominately $Ag^0$ with subordinate $Ag^+$. As suspected, under low $fO_2$ conditions, such as those in the sample chamber of the mass spectrometer, elements exist in their reduced state. We are attempting, therefore, to use modern electrochemical methods to increase the abundance of oxidized metal ions emitted from the molten borosilicate glass ion emitter. By treating the molten borosilicate glass as the electrolyte in the electrochemical cell, and varying the voltage to Pt reference and counter electrodes, we hope to find the potential range in which oxidation metal dopants in the reduced glasses occur, and therefore increase the number of analyzable ions within the mass spectrometer. In this fashion, we should increase the ionization efficiencies and analytical precision of measured isotope ratios.

## *Accomplishments*

We have custom built a high-vacuum test chamber in which to perform preliminary electrochemical experiments. The test chamber consists of a vacuum chamber fitted with an electrical feed through




*Preliminary design for the miniaturized electrochemical cell for use in the TIMS (courtesy of Don David, CIRES). Mounting posts are the filament posts currently used in the mass spectrometer.*

which we vary the voltage to the Pt electrodes. The chamber is attached to a turbomolecular vacuum pump. A Variac and step-down transformer provide high current and low voltage to a heating coil wrapped around an inverted ceramic beaker. The ceramic beaker acts as a chemically inert platform on which to place powdered borosilicate glass between two Pt electrodes. The coil is heated to approximately 1600 °C under vacuum conditions. To date, we have produced a simple cyclic voltammogram that shows that even with the coil heated to 1600 °C, the glass is acting as a resistor, and is not yet completely molten. This condition is essential to mimicking mass-spectrometer conditions and to using the glass as the electrolyte in the electrochemical cell.

## *Impact*

Following further work with the test chamber, including varying the current experimental setup to produce a molten glass, we intend to perform electrochemical experiments, such as determining the potential for oxidizing a doped metal element, such as Pb. Provided we achieve positive results with the test chamber, we will eventually miniaturize our electrochemical cell so that it may function as the ion source within the sample chamber of the mass spectrometer.

# An Opportunity to Develop a State-of-the-Art Tethered Lifting System (TLS)

**Michael Jensen, Rod Frehlich, and Ben Balsley**

## *Overview*

The CIRES Tethered Lifting System (TLS) has been under continuous development and use for more than a decade. The TLS consists of a kite or aerodynamic blimp that lofts a suite of instruments up to 2-3 km and can produce high-resolution profiles of winds, temperatures, humidity, turbulence properties, and trace gases rapidly and accurately. No other technique can obtain such detailed information over a single location and over such a wide altitude range on a relatively continuous basis. As a result, TLS results are becoming well-known throughout the global atmospheric community. Specifically, CIRES researchers have "flown" the TLS widely in the U.S. (Kansas, Oklahoma, Texas, Washington D.C., and Hawaii), Nova Scotia, Newfoundland, Azores, France, the Amazon Basin, Australia, Greenland, and the Arctic Polar Region, as well as aboard a NOAA ship in the Pacific.

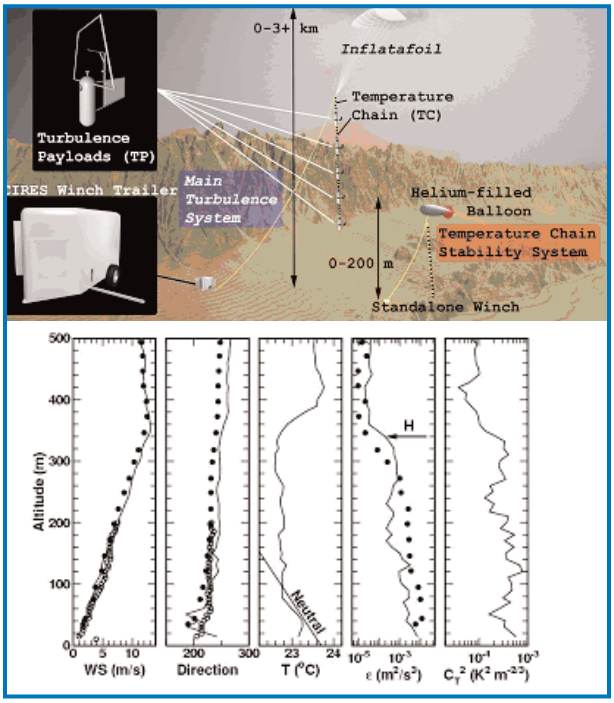



*Figure 4.4.d Top: Diagram of proposed field deployment of the new CIRES TLS during the T-Rex experiment (proposed April—May 2006). Bottom: CIRES TLS in-situ validation of doppler lidar remote-sensing turbulence data over the Pentagon in Washington, D.C. (May 2004). Solid lines represent TLS data, black circles are Lidar profiles, and open circles are sodar data.*

## *Accomplishments*

Using the combined funds from a DoD Defense University Research Instrumentation Program (DURIP) grant (supporting equipment and parts expenses) and the CIRES IRP (supporting salaries for system development and design) we have been able to completely redesign the CIRES TLS, literally from the ground up (Figure 4.4.d).

While we continue to expend DURIP funds to construct and build the improved CIRES TLS, IRP funds have been instrumental in supporting the redesign of all the fundamental components of the system including the winching system, lifting platform, and instruments. Improvements include: (1) design of a new hybrid lifting device, dubbed the Inflatafoil, which combines the best features of our parafoil kites and helium-filled balloons in a single platform; (2) a self-contained state-of-the-art trailer-winch system, allowing for more efficient field operations and profiling capabilities; (3) extension of our fine-wire turbulence sensor instrument capabilities to include continuous sampling at higher data rates and additional support sensors including on-board sonic wind calibration; and (4) the design of a string of temperature sensors (Temperature Chain), which will allow us to make continuous observations of nocturnal boundary-layer stability and boundary-layer height variability, two measurements which were not previously possible.

## *Impact*

The improvements we are making to the CIRES TLS have already generated sufficient interest from the atmospheric research community that we are hopeful for funding to participate in the Turbulence in Rotors Experiment (T-Rex) taking place in California next spring. We have also received genuine interest from the wind-energy community, specifically the nearby National Wind Technology Center (NWTC), part of the National Renewable Energy Laboratory.

# Chemistry of Organic Film on Aqueous Solutions: Model Atmospheric Aerosols

**Teresa Williams and Veronica Vaida, Department of Chemistry and Biochemistry and CIRES**

## *Objective*

Field measurements have recently shown that a significant fraction of the mass of atmospheric aerosols is organic. Dr. Vaida and her collaborators have proposed that organics preferentially partition to water-air interfaces, such as would be found at the ocean surface and on atmospheric aerosols. Organic films at aqueous interfaces can modify the optical and chemical properties of bulk phases with significant consequences for chemistry and climate in Earth's contemporary and prebiotic atmosphere. The objective of this research is to investigate properties of organic films at the water-air interface using conceptual and laboratory methods.

## *Accomplishments*

Our laboratory experiments reflect the conditions of an $NO_X$-free atmosphere, which we tackled as a starting point for understanding the chemistry of hydrocarbon films (Figure 4.4.f). Infrared spectroscopy and GC-MS detect products including oxygenated species, which act as better cloud-condensation nuclei than their precursors.

Particles can be transported vertically as well as horizontally throughout the atmosphere, allowing organic compounds to travel far from their source. As the compounds move, processing of the surfactant layer occurs, releasing volatile products into the atmosphere. Through this mechanism, it is possible for organic compounds to reach the upper troposphere or lower stratosphere. As particles travel to higher altitudes, varying concentrations of oxidants increase the potential for oxidation and drastic alteration of properties.

For unsaturated compounds on atmospheric surfaces, the group's results show that ozone will be a powerful oxidant, not only at night when the concentration of OH drops because of the dependence on light, but also during the day. Ozonolysis reactions are important in the atmosphere because the mechanism involves the shredding of the initial compound, releasing volatile organics that can be further oxidized to produce $HO_X$.

## *Impact*

Aerosols affect the Earth's climate directly by scattering light, both because of the size of the particle and more indirectly because of their ability to act as cloud-condensation nuclei. The nature of the aerosol surface will determine the magnitude of these effects in significant ways relevant to atmospheric chemistry and climate.

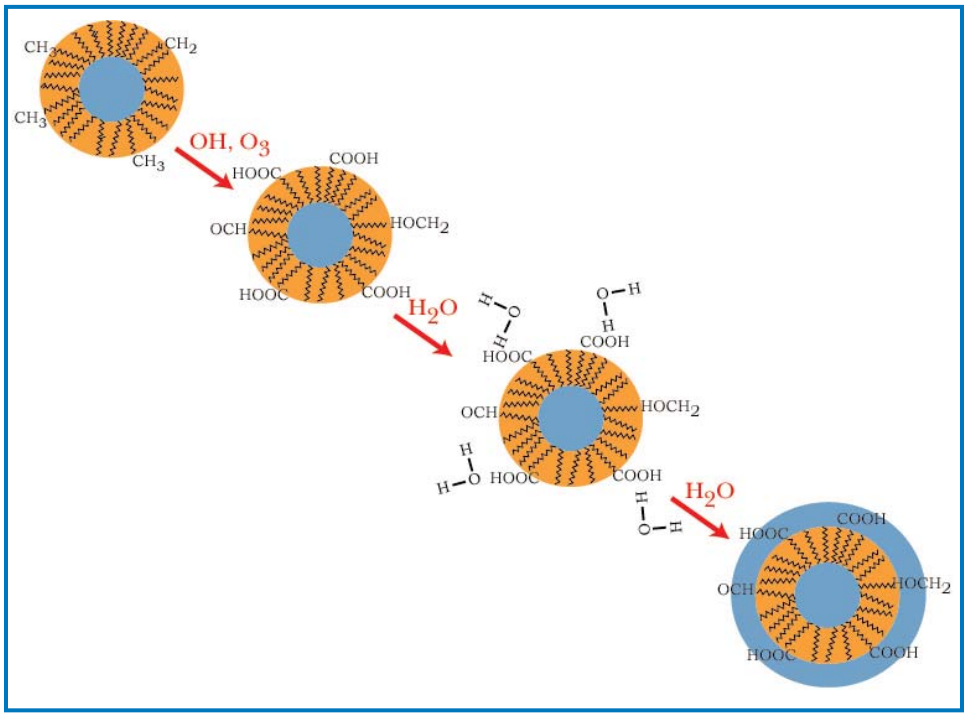



Figure 4.4.f. Release of volatiles into the atmosphere during particle movement through atmosphere.

# 4.5 Visiting Fellows Research

CIRES annually budgets approximately $500,000 to conduct a competitive visiting fellowship program that promotes collaborative research at the forefront of evolving scientific paradigms. One-year fellowships are made to Ph.D.-level scholars and university faculty planning sabbatical leave. Post-doctoral fellowships are awarded for one or two years. Selections are based in part on the likelihood of stimulating academic interactions and the degree to which both parties will benefit from the exchange of new ideas. To further this goal, priority is given to candidates with research experience at institutions outside the Boulder scientific community. The program is open to scientists from all countries, and appointments can begin at any time during the year.

Further information can be found at http://cires.colorado.edu/collaboration/fellowships/.

Approximately six fellowships are offered to scientists with research interests in these areas:

- Physics, chemistry, and dynamics of the Earth system (atmosphere, biosphere, hydrosphere, lithosphere)
- Global and regional environmental change
- Climate system monitoring, diagnostics, and modeling
- Remote sensing and in-situ measurement techniques for the Earth system
- Interdisciplinary research themes.

Table 4.5.1 lists the past year's visiting fellows; the rest of this section details their research.

*Table 4.5.1*

| Name | Affiliation | Research Mentor | Project Title |
|---|---|---|---|
| Domenico Cimini | ETL | Westwater | 1. Micro-millimeter and submillimeter-wave absorption model study 2. Passive estimation of rainfall attenuation 3. Passive measurements in dynamic weather conditions for improving nowcasting |
| Lisa Dilling | Policy | Pielke | Understanding the use and applicability of carbon cycle science in climate policy development and carbon sequestration |
| Masato Furuya | Geology | Bilham | Radar interferometric exploration of ground movements in remote area: southwest Greenland and Kunlun Fault in Tibetan Plateau |
| Jessica Lundquist | CDC | Dole | Summer precipitation in the southwestern United States: linking long-term longitudinal trends to snow and sea surface temperatures |
| Sean Yu McLoughlin | EEB | Copley | The latent enzymatic capabilities of a well-characterised strain of bacteria escherichia coli |
| Noah Molotch | Geology | Steffen | Assessing uncertainty in alpine and sub-alpine snowmelt simulations |
| S.P. Satyabala | Geology | Bilham | Seismology and application of synthetic aperture Rradar interferometry to earthquakes and crustal dynamics |
| Robyn Schofield | AL | Solomon | Retrieval of cloud parameters used in the quantification of the aerosol indirect effect |

## Micro-, millimeter- and submillimeter-wave absorption model study
## Passive estimation of rainfall attenuation
## Passive measurements in dynamic weather conditions for improving nowcasting

**Domenico Cimini**

Ph.D.: University of L'Aquila, Italy
Sponsor: Ed R. Westwater

During the first six months of his visiting fellowship period at CIRES, Dr. Cimini has developed a procedure to calibrate the data collected from a new instrument, the Ground-based Scanning Radiometer (GSR). NOAA-Environmental Technology Laboratory developed the GSR and deployed it for the first time during the Water Vapor Intensive Operating Period 2004 (WVIOP2004). The WVIOP2004 was conducted at the U. S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program's field site near Barrow, Alaska, during 9 March to 9 April 9 2004.

During the WVIOP2004, researchers deployed radiometers over a broad frequency range (22.235 to 400 GHz); radiometers included the GSR, the Microwave Radiometer, and the Radiometric Profiler of ARM (frequencies from 22.235 to 60 GHz). More than six radiosonde observations per day supplemented the radiometric measurements. The major goal was to demonstrate that millimeter wavelength radiometers can substantially improve water vapor and cloud observations during the arctic winter. Secondary goals included forward model studies over a broad frequency range, demonstration of recently developed calibration techniques, and the comparison of several types of in situ water-vapor sensors. Dr. Cimini has implemented a calibration procedure for the GSR for processing data from the entire experiment. In addition, he compared calibrated measurements with the ones from other instruments and with simulations computed using different atmospheric absorption models. He has presented preliminary results to national and international conferences. He has also worked on weighting function analysis for the ARM twelve-channel microwave radiometer, which is capable of atmospheric profiling during dynamic weather conditions.

## Understanding the use and applicability of carbon-cycle science in climate policy development and carbon sequestration

**Lisa Dilling**

Ph.D.: University of California, Santa Barbara
Sponsor: Roger Pielke, Jr.

Dr. Dilling is in the first year of her visiting fellowship at CIRES. Her project focuses on improving science policies to create "usable science." Specifically, Dilling is studying science policies for carbon-cycle science, and understanding how the needs of decision makers outside the scientific community are considered. The visiting fellowship has enabled true integration of her research interests and provided an unparalleled opportunity for collaboration with researchers within CIRES and the broader community. She is co-leading several collaborative projects in this area, specifically the Science Policy Assessment and Research on Climate (SPARC) project (a "Decision Making Under Uncertainty" activity funded by the National Science Foundation), the State of the Carbon Cycle report (a multi-agency-funded project contributing to the Climate Change Science Program), and a project investigating scales of decision making and the carbon cycle.

In this first year, Dilling has focused specifically on two research themes: 1) characterizing the supply of carbon-cycle science, namely the science being conducted, as well as the institutions and processes governing the production of science, and 2) identifying opportunities for carbon-cycle science to become more "usable" to society.

As one of her activities this year, Dr. Dilling convened a workshop at the University of Colorado in June to foster an interested community of researchers and develop a research agenda with the ultimate aim of improving the usefulness of carbon-cycle science for the broader community of decision makers. The workshop was well attended by representatives from the national carbon-cycle science, science policy, and user-interaction communities and proved to be an excellent opportunity for cross-disciplinary dialogue and interaction. The workshop introduced members of the carbon-cycle science community to lessons learned from the seasonal to interannual climate forecasting community concerning the way decision makers utilize scientific information. Attendees also shared information across disciplines about practical options for creating a "usable carbon-cycle science" program component in the future.

This cross-disciplinary fusion of ideas and options will be incorporated into the synthesis and assessment report, "State of the Carbon Cycle." Dilling is co-leading the chapter titled "How can we improve the application of scientific information to decision support for carbon management and climate decision-making?" Other specific action items emerging from the workshop include a workshop report, a presentation at the national Climate Change Science Program workshop, and follow-on work with the carbon cycle community.

Dr. Dilling has also given nine presentations at national and local meetings, supervised a Master's thesis, is writing three papers, is co-editing a book, and is lead for the stakeholder process and co-coordination of the State of the Carbon Cycle report.

# Radar Interferometric Exploration of Ground Movements in Remote Areas: Southwest Greenland and Northwest India

**Masato Furuya**

Ph.D.: University of Tokyo, Japan
Sponsor: John Wahr and Roger Bilham

Dr. Furuya began a twelve-month visiting fellowship at CIRES in August 2004. He proposed to apply an interferometric synthetic aperture radar (InSAR) technique and a novel permanent scatterer InSAR technique to detect and model a variety of dynamic movements of the Earth's surface.

## *Estimating water-level changes around ice-dammed lake in Greenland*

Using European Space Agency SAR data, Dr. Furuya has found a localized deformation signal around an ice-dammed lake in west Greenland, and associated those with draining episodes (*jokulhlaups* in Icelandic) in 1993 and 2003. Based upon an elastic loading model, water-level change in the lake was estimated. For purposes of *jokulhlaups* hazard mitigation, it is indispensable to quantitatively monitor the drainage and refilling of ice-dammed lakes. At many ice-dammed lakes, however, only scattered field observations are available. Dr. Furuya seeks to show that InSAR data can help augment field data.

## *Detection of creep motion along the Chaman fault system, Pakistan*

Dr. Furuya collaborated with Dr. R. Bilham on this project, as well as Dr. S. P. Satyabala, also a Visiting Fellow. Preliminary studies show that the Chaman fault was indeed showing a creep motion with an amplitude of ~1 cm/year. This has implications for future earthquake hazard assessment.

## *Ongoing salt tectonics at Canyonlands National Park, Utah*

Dr. Furuya collaborated on this project with Dr. K. Mueller in Department of Geological Sciences and Dr. J. Wahr.

The Needles District in the Canyonlands National Park, southeastern Utah, is known to have extensional faults formed through sedimentation, erosion, and faulting over the past 300 million years. Whether and how the Needles District is currently undergoing displacements is unclear, because logistical problems have been hampering accurate measurements of the tiny displacements.

According to our preliminary results, the Needles District is currently deforming at a rate of about 2-3 mm per year in the radar line of sight, and the deforming region is almost totally restricted to east of Cataract Canyon (Figure 4.5.2). Several unexpected features should be noted. The displacement amplitude in the southeastern area is larger than that in the northeastern Graben region, where there are well-developed extensional faults on the ground surface. Also, along the river bank, we detected a narrow uplifting region, which presumably represents a salt diapiric rise. The detected displacement amplitude would correspond to the tiniest level of any previously reported ground displacements by InSAR data. However, this result clearly illustrates that SAR data can be used even for slow deformation processes if we use a long-term data set.

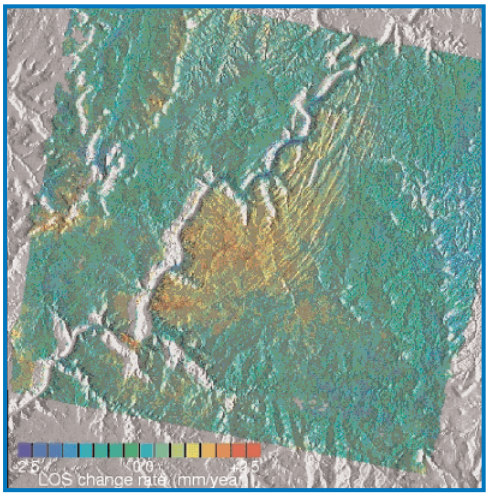



*Figure 4.5.2. The mean yearly displacement rates along the radar line of sight (positive is away from the satellite), obtained by stacking the eleven independent interferograms. Preliminary estimates of measurement error are less than ~1mm/year.*

## Snowmelt and streamflow processes in the Sierra Nevada and Rocky Mountains

**Jessica Lundquist**

Ph.D.: Scripps Institution of Oceanography, University of California, San Diego
Sponsor: Randall Dole

Dr. Lundquist began her two-year visiting fellowship at CIRES in November 2004 with the objective of studying snowmelt and streamflow in the mountains of the western United States. Her research has three main foci:

1) Spatial patterns in snowmelt processes within the Tuolumne and Merced watersheds of Yosemite National Park, California, using case studies to better understand how climatic variability will impact mountain watersheds throughout the western United States
2) Implementing the Hydrometeorological Testbed (HMT) project in the American River basin near Sacramento, California, with a specific focus on rain-on-snow events and flood forecasts, with NOAA's Environmental Technology Laboratory (ETL); see Figure 4.5.3.
3) Measuring temperatures at fine spatial scales in complex terrain, using inexpensive new sensor technology in the Loch Vale Watershed of Rocky Mountain National Park and the Niwot Ridge area of the University of Colorado Mountain Research Station; sponsored by a CIRES Innovative Research Grant and the Western Water Assessment.

Dr. Lundquist's research is integrative across the CIRES Research Themes of Regional Processes, Climate Systems Variability, and Advanced Observing and Modeling Systems. She is also participating in K-14 Education and Outreach through volunteering for the Colorado Ocean Sciences Bowl; involving local high school students in her mountain temperature study; and helping the national park service with interpretive ranger training, alpine inventory planning, and network monitoring.

Dr. Lundquist collaborated with Dr. R. Dole on mountain temperatures and climate; Drs. F. M. Ralph, A. B. White, D. Gottas, and P. Neiman on comparing atmospheric radar measurements with surface snow and precipitation observations; Dr. D. Kingsmill on planning for the HMT project; Dr. R. Zamora on soil moisture; B. Udall on Western Water Assessment; Dr. M. Losleben on mountain temperatures and sensor deployment; Dr. D. Clow on water chemistry and sensor deployment; and Dr. M. Clark on hydrology.

A paper on solar radiation, topographic shading, and the timing of spring snowmelt is in the final stages of review for submission to the Journal of Climate. More than 100 temperature sensors have been deployed in the Rocky Mountains, and six new stream sensors will be deployed in the American River Basin in September.

The results of these studies will help improve snowmelt and streamflow forecasts. These improved forecasts will help water managers make more informed decisions.

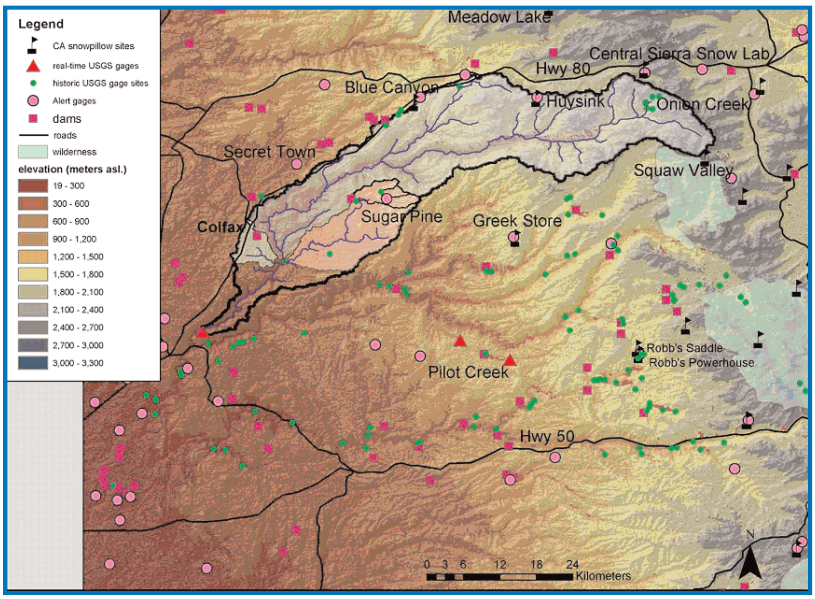



*Figure 4.5.3. Map of American River basin (Focus of the HMT project)*

## Latent enzymatic capabilities of a well-characterized strain of bacteria Escherichia coli

**Sean Yu McLoughlin**

Ph.D.: Australian National University
Sponsor: Shelley Copley

### *Research objective*

Determine how and why new enzymes evolve.

### *Accomplishments*

Dr. McLoughlin's research identified weak shikimate dehydrogenase activity in an E. coli enzyme with unknown physiological function

In addition, his research generated an N-acetylglutamate synthase activity in an E. coli strain in which the main N-acetylglutamate synthase activity had been deleted, as well as an N-acetylglutamylphosphate reductase activity in an E. coli strain in which the main N-acetylglutamylphosphate reductase activity had been deleted.

### *Impact*

These results provide evidence that existing and potential catalytic promiscuity can be identified relatively easily and is more widespread than generally appreciated. Catalytically promiscuous enzymes are thought to be the templates for the evolution of new enzymes, which often evolve in response to environmental toxins such as pesticides and antibiotics.

*Figure 4.5.X. Visiting Fellows chat with Koni Steffen at the Boulder Dushanbe Teahouse near the University of Colorado.*

## Assessing uncertainty in alpine and sub-alpine snowmelt simulations

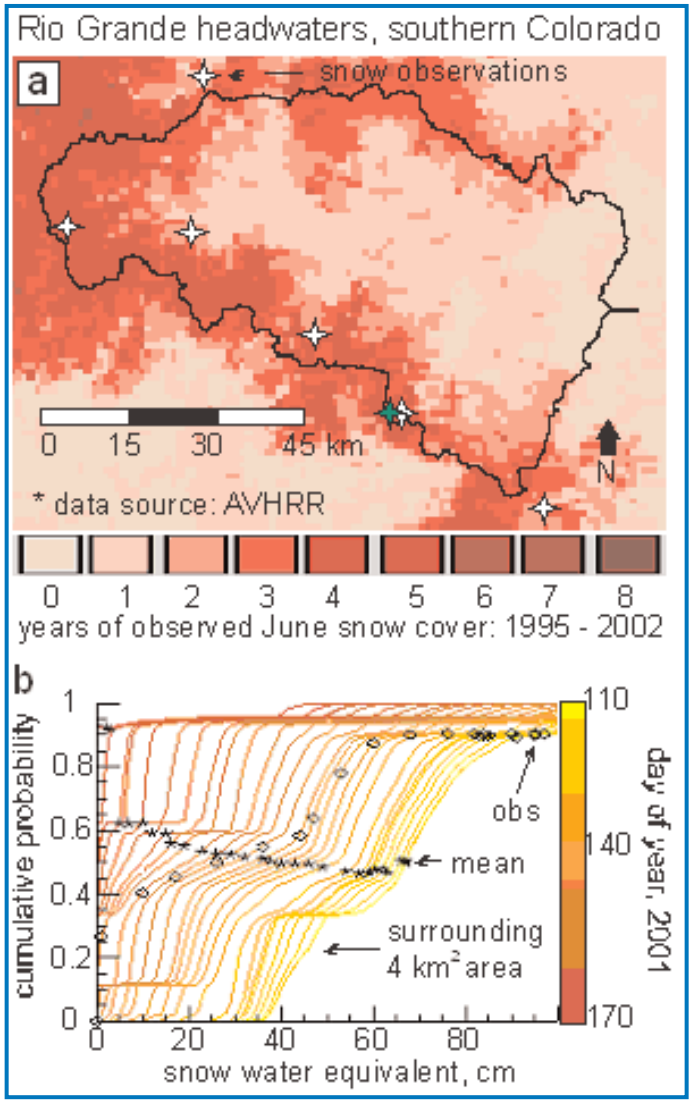
**Dr. Noah Molotch**

Ph.D.: University of Arizona
Sponsor: Konrad Steffen

Dr. Molotch proposed to develop improved techniques for characterizing the spatial distribution of snow water equivalent (SWE) and snowmelt in mountainous watersheds. Since joining CIRES in July 2005, his research program has significantly strengthened the representation of the hydrological sciences within CIRES' "Advanced Modeling and Observing Systems" research theme. His work at the watershed-scale (~10–1000 km$^2$) is complimentary to other CIRES groups studying hydrology and climate at the regional to global scales.

During his time at CIRES, Dr. Molotch has improved understanding of the spatial and temporal dynamics of snow-cover heterogeneity at the watershed scale; improved the ability to scale point observations of snow water equivalent to the grid element; and improved snow-surface albedo estimates within spatially distributed snowmelt models.

In collaboration with E. Small (Geological Sciences), Dr. Molotch has strengthened CIRES capacity for further studies in mountain hydrology by developing infrastructure for the study of hydro-ecological interactions in the Valles Caldera National Preserve, New Mexico. In collaboration with K. Steffen (CIRES) and T. Painter (NSIDC), Dr. Molotch is developing techniques for characterizing the vertical distribution of snow grain size at Swiss Camp, Greenland. Proposals under review with NSF are focused on orographic controls on mountain snow distribution in the Sierra Nevada, California and hydro-biogeochemical feedbacks in the Green Lakes Valley, Colorado (in collaboration with T. Painter of NSIDC an M. Williams of INSTAAR). Dr. Molotch is also PI of a CIRES Innovative Research Program project entitled "Realization of snow/vegetation interactions using field spectroscopy."




*4.5.X Characterizing the spatial distribution of SWE is particularly challenging because ground observations are often located in areas with persistent snow cover (a) and because of considerable sub-grid variability in SWE surrounding point observations (b). The green star in (a) indicates the location of the point observations shown in (b).*

## Application InSAR to earthquakes and estimating the slip rate of the western margin of the Indian plate

**S.P. Satyabala**

Ph.D.: Osmania University, Hyderabad, India
Sponsor: Roger Bilham

Dr. Satyabala worked with Roger Bilham in the CIRES theme of Geodynamics. She focused on the application of Synthetic Aperature Radar Interferometry (InSAR) to earthquakes. Figure 4.5.y shows surface deformation that would result from a large event (thick black lines) of magnitude ~8 on the San Andreas fault system (thin black lines), similar to actual historic events in southern California. The colored fringes are a representation of the deformation field as it would be recorded via Synthetic Aperature Radar Interferometry from a radar satellite. A radar satellite passes over a site three times and uses a double-differencing scheme by taking the difference of the first two, then the difference of the second two, and subtracting the two differences. The resulting set of fringes is a function of wavelength (5.7 cm) that reflects the motion of the ground during those time periods.

Her research also focused on estimating the slip rate of the western margin of the Indian plate. Figure 4.5.x shows the study area in Baluchistan; the Chaman Fault is indicated by the box.

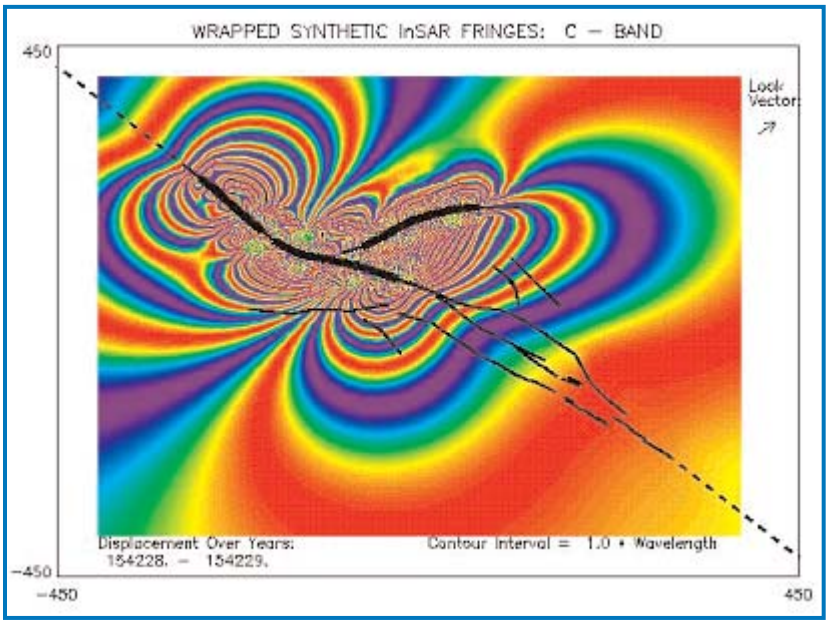



*Figure 4.5.y. Surface deformation as recorded by SAR Interferometry.*

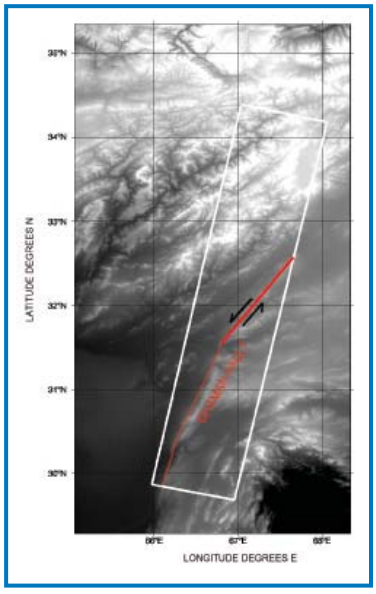



*Figure 4.5.y. A simulated SAR image of the area of study. The area covered by the interferograms is shown by the white box. The Chaman fault is indicated by the red line and the creeping segment by the thick red line. The black arrows indicate the direction of creep on the Chaman fault.*

## Retrieval of Cloud Parameters used in the Quantification of the Aerosol Indirect Effect

**Robyn Schofield**

Ph.D.: University of Auckland
Sponsor: Susan Solomon

Dr. Schofield arrived in May 2004 to begin her two-year CIRES visiting fellowship. She proposed to work with CIRES and NOAA Aeronomy Laboratory staff to examine spectral measurements to provide information on cloud parameters. Specifically, she planned to:

- Participate in making spectral measurements of homogeneous clouds at Barrow, Alaska
- Use an optimal estimation retrieval technique to evaluate the information content of remotely sensed observations to derive cloud parameters of radius and Liquid Water Path (LWP).

The research on cloud parameterization using this novel technique provided a lower-cost alternative to conventional methods of deriving cloud radii, with a complete error analysis. This work will contribute to rigorously assessing the uncertainties that currently exist with respect to the first Aerosol Indirect Effect, thus providing a valuable tool for reducing the uncertainty that currently exists when assessing the impact that aerosols have on cloud properties.

Dr. Schofield's research work addresses the CIRES research themes of Climate Variability, and Advanced Observing and Modeling Systems and Regional Processes. In particular, her work has lead to the development of a novel technique for the evaluation of the effective radius, which, when combined with LWP, provides a means of assessing the first Aerosol Indirect Effect of aerosols on clouds.

Dr. Schofield conducted collaborations with Drs. Solomon, Daniel, Portmann, Miller, and Langford, as well as Ms. Melamed of the Chemistry & Climate Processes group in the NOAA Aeronomy Laboratory. This enabled Dr. Schofield to pursue her interests in model development, particularly radiative transfer in the UV, near-infrared and microwave regions, as well as investigating rotational Raman scattering. She has also had the opportunity to extend her current skill base into trend analyses and investigate the impact of climatic changes upon stratospheric trace gases. Trend investigations have lead to a strengthening of collaboration with the National Institute of Water and Atmospheric Research (NIWA) in Lauder, New Zealand.

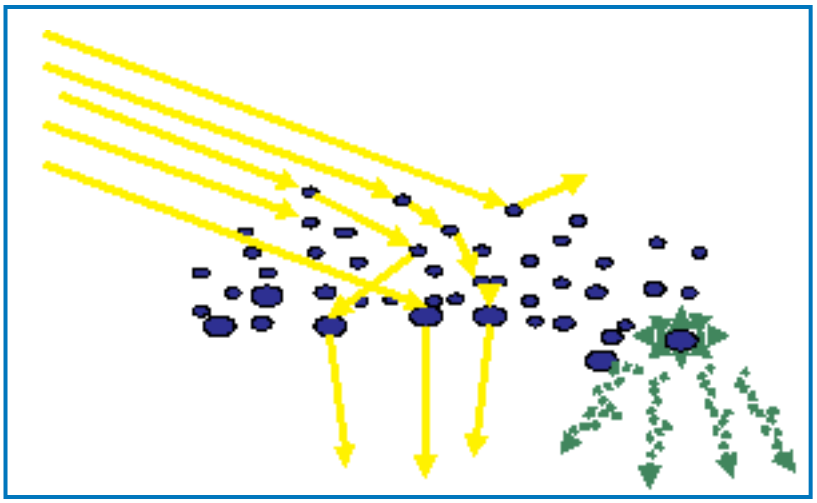


*Figure 4.5.4. Schematic displaying the radiative properties of liquid within a cloud. Yellow lines show the near-infrared absorption photon path, and the green is illustrative of the microwave emission of all of the liquid water molecules. The microwave emission signal is dependent upon the amount of water in the column and essentially independent of size of the particles. The near-infrared absorption signal is dependent upon the amount of water in the column and the photon path length. The photon path length depends on the size of the particles; a higher number of small particles increases the path length.*

# 4.6 Graduate Student Research

Since 1967, CIRES Faculty have supervised the research of hundreds of students who have earned the Ph.D. degree and are now in environmental science and research positions in academia and industry, in the United States and around the world. Table 4.6.1 lists information on our 2004-2005 graduate students and their research projects.

*Table 4.6.1*

| GRA Name | Degree and Major | Area of Research or Thesis Title | Anticipated Graduation | Advisor or PI |
|---|---|---|---|---|
| Aiken, Allison | Ph.D. Analytical Chemistry | Ambient Aerosol Measurement | May 2008 | Jimenez |
| Albert, Todd | Ph.D. | Measuring and modeling changes in glacier mass balance | withdrew | Steffen |
| Beaver, Melinda | Ph.D. Chemistry | Ice nucleation in mixed organic/ sulfuric acid aerosols | May 2008 | Tolbert |
| Benjamin, David | Masters Physics | Geodesy | May 2005 | Wahr |
| Best, Jessica | Ph.D. Analytical Chemistry | Characterization of Device Performance in Inhalable Dry Powder Aerosolo Vaccine Delivery Systems | May 2009 | Sievers |
| Boyd, Oliver | Ph.D. Geophysics | Heterogeneous Upper Mantle: Insights from Seismology | Aug 2004 | Sheehan |
| Bradburn, Mark | Masters E-BIO | Light Response of Nitrogen Fixation in Colorado Lakes | May 2006 | Lewis |
| Brandel,Bryan | Ph.D. E-BIO | Scaling Ecosystem Properties in a Larrea tridentata ecotone:the influence of landscape structure on ecosystem function | May 2007 | Wessman |
| Burger, Jessica | Ph.D. Analytical Chemistry | not available | not available | Sievers |
| Chhak, Kettyah | Ph.D. APAS | Stochastic Forcing of the North Atlantic Wind-Driven Ocean Circulation/ Physical Oceanography | May 2006 | Moore |
| Connelly, Brandon | Ph.D. Chemistry | Acid Catalyzed Reactions as a Mechanism for the Formaton of Secondary Organic Aerosols | May 2009 | Tolbert |
| Curtis, Dan | Ph.D. Chemistry | Cloud formation on Titan | Dec 2004 | Tolbert |

*Table 4.6.1(continued)*

| GRA Name | Degree and Major | Area of Research or Thesis Title | Anticipated Graduation | Advisor or PI |
|---|---|---|---|---|
| Dayem, Katherine (stipend) | Ph.D. Geology | Climate and Tectonics | May 2007 | Molnar |
| de la Pena,Santiago | Ph.D. EEEN | Atmospheric Remote Sensing | May 2007 | Avery |
| de la Torre, Thomas | Ph.D. Geophysics | Seismotectonics of the Himalayas and Southern Tibet | May 2007 | Sheehan |
| DeCarlo,Peter | Ph.D. Chemistry | Advanced Aerosol Measurement and Data Interpretation | May 2007 | Jimenez |
| DeWitt, Langley | Ph.D. Chemistry | Atmospheric Chemistry (astrobiology) | May 2009 | Tolbert |
| Ding, Lihua | Masters Chemistry | Half sites of PCP Hydroxylase | Aug 2004 | Copley |
| Dzepina, Katja | Ph.D. Chemistry | Mexico City aerosol size and composition analysis and aerosol modeling | not available | Jimenez |
| Feldl, Nicole | Masters Geology | | May 2005 | Bilham |
| Finnis,Joel | Ph.D. APAS | Arctic Freshwater Budget | Dec 2007 | Cassano |
| Fox, Jennifer | Masters | Wavelet analysis techniques to look at atmospheric data...examine correlation between El Niño and the Madden-Julien Oscillation | withdrew | Naveau |
| Frinak, Elizabeth | Ph.D. Chemistry | Heterogenous Uptake of atmospheric gases | Dec 2004 | Tolbert |
| Garland, Rebecca | Ph.D. Chemistry | Atmospheric Chemistry | May 2006 | Tolbert |
| Goemans, Christopher | Ph.D. Economics | Three Essays on Water Markets | Dec 2005 | Udall |
| Gregory, Scott | Ph.D. APAS | Atmospheric Dynamics | May 2009 | Noone |
| Hu, Jia | Ph.D. E-BIO | Coupling the water and carbon cycle in a subalpine forest | May 2008 | Monson |
| Huff, Russ | Ph.D. GEOG | Melt anomalies on the Greenland Ice Sheet | May 2006 | Steffen |

*Table 4.6.1(continued)*

| GRA Name | Degree and Major | Area of Research or Thesis Title | Anticipated Graduation | Advisor or PI |
|---|---|---|---|---|
| Huffman, Alex | Ph.D. Chemistry | Characterizing organic species involved in ambient atmospheric particles | May 2008 | Jimenez |
| Kindig,Dave | Ph. D. GEOG | Icelandic Low/Greenland | May 2006 | Chase |
| Knox, Katherine | Masters Geo-chemistry | Evolution of Shallow Magma Systems at Never Summer Mountains, Colorado | not available | Farmer |
| Koch, Linda | Ph.D. Chemistry | Oxidation of naturally occurring sulfur com-pounds | Jan 2005 | Ravisha-nkara |
| Lau, Elias | Ph.D. EEEN | Studies of the Mesoshere/Lower-Thermoshere Region over the south Pole using an all-sky interfermetric meteor radar | May 2005 | Avery |
| Lee, Eungul | Ph.D. GEOG | North East Asian Monsoon | May 2008 | Chase |
| Mantilla, Ricardo | Ph.D. CVEN | Towards a Physical Understanding of Spatial Statistical Scaling of Floods | May 2006 | Gupta |
| Mashburn , Courtney | Ph.D. Analytical Chemistry | The heterogeneous chemistry of atmospheric trace gases with Na-montmorillonite clay: effect of swelling ability on atmospheric chemical processes | May 2007 | Tolbert |
| Maurer, John | M.A. Geography | Accumulation variability derived with ground penetrating radar on the Greenland ice sheet | 2006 | Steffen |
| McAdams , David | Ph.D. Analytical Chemistry | Analytical Chemistry | May 2009 | Sievers |
| McAllister | M.A. Geography | Cyclone occurrence in the Arctic 1963-2002: Impacts on Greenland ice sheet melt cyccles 1979-2002 | 2005 | Steffen |
| McCabe, David | Ph.D. Chemistry | Impacts on Greenland Ice Sheet Melt Cycles 1979-2002 | Dec 2004 | Aerono-my Lab |
| McKim, Eileen | Ph. D. Chemistry | Variability of North American Monsoon Precipitation/Western Water Resources | Dec 2006 | Barry |

*Table 4.6.1(continued)*

| GRA Name | Degree and Major | Area of Research or Thesis Title | Anticipated Graduation | Advisor or PI |
|---|---|---|---|---|
| Meillier, Yannick | Ph. D. APAS | Measurement and study of the fine scale atmospheric turbulence with the CIRES Tethered Lifting System | Dec 2004 | Balsley |
| Melamed, Megan | Ph.D. CVEN | Measuring Reactive Nitrogen and Sulfur Emissions from Point Sources using Visible Spectroscopy | May 2006 | Silver-stein |
| Monsalve, Gaspar | Ph.D. Geophysics | Himalayan Seismotectonics | May 2007 | Sheehan |
| Regonda, Satish | Ph.D. CVEN | Intra-annual to Inter-decadal variability in the Upper Colorado Hydroclimatology: Diagnosis, Forecasting and implication for Water Resources Management | May 2006 | Rajag-opalan |
| Rumbaitis Del-Rio, Christina | Ph.D. | Compound disturbance in a managed land-scape: Ecological effects of catastrophic wind, savage-logging, and fire in a subalpine forest | Dec 2004 | Wessman |
| Seefeldt,Mark | Ph.D. APAS | Antarctic Meteorology | May 2006 | Cassano |
| Shilling,John | Ph.D. Chemistry | Heterogeneous Atmospheric Chemistry | Aug 2005 | Tolbert |
| Starkweathe r, Sandra | Ph.D. Geography | Characteristics of cloud cover and its radia-tive impacts over the high elevations of the Greeland ice sheet | Jul 2004 | Steffen |
| Suszek, Naia | Ph.D. Geology | Tiltmeters in Cascadia | Aug 2008 | Bilham |
| Sutton, Christian | Masters APAS | Perturbation of land surface soil moisture condition and its impact on probable ensem-ble forecasts | May 2005 | Warner |
| Tetreault, Joya | Ph.D. Geology | Paleomatnetics, tectonics, and structural geology | Dec 2005 | C. Jones/ Sheehan |
| Trahan, Ashley | Ph.D Bio-chemistry | Functional Genomics in Sphingobium chlorophenolicum | Aug 2007 | Copley |

*Table 4.6.1(continued)*

| GRA Name | Degree and Major | Area of Research or Thesis Title | Anticipated Graduation | Advisor or PI |
|---|---|---|---|---|
| Vogel, Jason | Ph.D. ENVS | Persistent Policy Problems | Aug 2006 | Maslanik |
| Wallace, Kali | Ph.D. Geology | Crustal deformation of India, Tibet, and Asia | Dec 2005 | Bilham |
| Warner, Joseph | Ph.D. Chemistry | Mechanistic studies of TCHQ dehalogenase | Dec 2005 | Copley |

# 5.0 Appendices



## 5.1 Governance and Management

CIRES is directed and managed through the following structure. Responsibilities for the primary standing committees that assist the Director in evaluating options, making recommendations, ratifying policies and conducting the business of CIRES follow.

### 5.1.1 Direction and Management

#### *CIRES Leadership*

Konrad Steffen – Director
Paul Sperry – Associate Director for Science
Jon Rush – Associate Director for Administration

#### *Division Associate Directors*

Atmospheric and Climate Dynamics: R. Michael Hardesty
Environmental Chemistry and Biology: Fred C. Fehsenfeld
Cryospheric and Polar Processes: Roger Barry
Solid Earth Sciences: Roger Bilham

### 5.1.2 Fellows Committees

#### *Council of Fellows*

CIRES Council of Fellows constitutes the "Board of Directors" and chief governing body of CIRES. It is comprised of individuals with an outstanding record of achievement and ability in diverse areas of environmental sciences. They are primarily university faculty, senior research scientists or government scientists who form the core leadership of the institute. Their responsibilities are to (1) provide leadership at all levels in environmental science, (2) maintain an active scientific research/education program, (3) support the CIRES infrastructure through indirect cost recovery and in-kind contributions, (4) participate in CIRES management, and (5) contribute interdisciplinary expertise and participate in collaborative work. As a group, they personify the concept of collaboration that is the founding principle of the NOAA Cooperative Institutes Program. Ex-officio individuals include representatives of the Members Council and CIRES administration. Fellows meetings are held monthly during the academic year and included:

16-Sep 21-Oct 18-Nov 9-Dec 20-Jan 17-Feb 11-Mar 17-Mar 28-Apr

Susan K. Avery* Interim Provost; Professor, Electrical and Computer Engineering

Ben B. Balsley Research Professor, Electrical and Computer Engineering

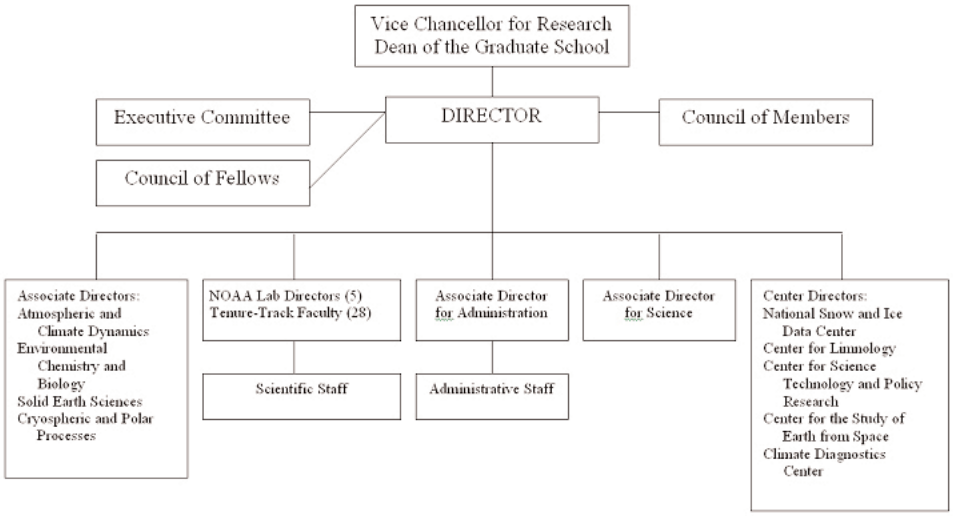
Roger G. Barry* Director, NSIDC; Professor of Geography

Roger Bilham Professor of Geological Sciences

John Cassano* Professor of PAOS

Thomas N. Chase* Professor of Geography

# 5.1 (continued)




Shelley D. Copley* Professor of Molecular, Cellular and Developmental Biology

Randall M. Dole Director, Climate Diagnostics Center

David Fahey Research Physicist, Aeronomy Laboratory

Christopher W. Fairall Supervisory Physicist, Environmental Technology Laboratory

G. Lang Farmer Professor of Geological Sciences

Fred C. Fehsenfeld Senior Scientist, Aeronomy Laboratory

Graham Feingold Scientist, Environmental Technology Laboratory

Timothy J. Fuller-Rowell Senior Research Scientists, CIRES/Space Environment Center

Alexander F.H. Goetz* Director of CSES, Professor of Geological Sciences

Vijay K. Gupta* Professor of Civil, Environmental and Architectural Engineering

Ray E. Habermann Scientist, National Geophysical Data Center

R. Michael Hardesty Chief, Atmospheric Lidar Division, Environmental Technology Laboratory

José-Luis Jiménez* Professor of Chemistry and Biochemistry

Craig Jones Professor of Geological Sciences

William M. Lewis, Jr.* Director, Center for Limnology; Professor of Ecology and Evolutionary Biology

Peter H. Molnar* Professor of Geological Sciences

Russell K. Monson Professor of Ecology and Evolutionary Biology

Andrew M. Moore* Professor of PAOS

William D. Neff Chief, Meteorological Applications and Assessment Division, Environmental Technology Laboratory

Steven Nerem Professor of Aerospace Engineering

David Noone* Professor of PAOS

Roger Pielke, Jr.* Director, Center for Science and Technology Research Policy; Professor of Environmental Sciences

Balaji Rajagopalan Professor of Civil, Environmental and Architectural Engineering

George C. Reid Senior Scientist, Aeronomy Laboratory

Douglas S. Robertson Adjunct Professor, Geological Sciences; Geosciences Laboratory, NOS

Anne F. Sheehan* Professor of Geological Sciences

Robert E. Sievers* Professor of Chemistry and Biochemistry

Susan Solomon Senior Scientist, Aeronomy Laboratory

Konrad Steffen* Professor of Geography, Director of CIRES

# 5.1 (continued)

Margaret A. Tolbert* Professor of Chemistry and Biochemistry

Greg Tucker* Professor of Geological Sciences

Veronica Vaida Professor of Chemistry and Biochemistry

John M. Wahr Professor of Physics

Carol A. Wessman* Professor of Ecology and Evolutionary Biology

* = rostered in CIRES/Graduate School

## *CIRES Affiliates*

Ray Fall – Professor of Chemistry and Biochemistry

Henry Diaz – NOAA Climate Diagnostics Center

Pieter Tans – NOAA Climate Monitoring and Diagnostics Laboratory

## *Executive Committee*

The Executive Committee assists and advises the Director in matters regarding day-to-day management of the institute and makes important decisions and policies affecting CIRES. Members of the Executive Committee include the Associate Directors of the four administrative units for CIRES, two Fellows elected at-large for a two-year term, renewable for one term, and two voting members that are the Members' Council representatives. Staff representatives are ex-officio members of the committee.

## *Career Track Committee*

This committee is charged with consideration of all nominations for promotion within the CIRES career tracks of Research Scientist, Associate Scientist and Administrative Associate. Nominations are made once yearly, and the committee's recommendations are forward to the director for consideration and action. A special committee, organized in early 2005, reviewed and revised the career track descriptions, and clarified the promotion process.

## *Computing Advisory Committee*

The purpose of the CIRES Computing Advisory Committee (CAC) is to provide expert counsel and recommendations on technical issues, user support, resource allocations and the establishment of computing policies. That advice is available to anyone in CIRES; however, the primary CAC advisees are the Director and Council of Fellows and the CIRES Computing Facility (CCF) Manager. CIRES staff or the CCF manager, through CAC members, or via a Web suggestion page to the CAC chairperson for committee consideration, submits questions, issues and recommendations. CAC also serves as the last resort mediator of disputes between users and the CCF. The CAC membership includes people with the diverse expertise that is required to understand and contribute to the CIRES computing decision-making process, as well as people representing the user groups that are supported by the CIRES Computing Facility. The Director of CIRES appoints the Chair of the committee as well as one other Fellow. Additional members are nominated and selected by the CAC. All members serve a three-year term.

## *Distinguished Lectureship Series*

This lecture series was created to bring outstanding scientists and innovative thinkers who have given serious consideration to environmental and earth system science issues. Coordinators are given the task of putting together this program and hosting the scientists'

## *External Awards Committee*

This group identifies and prepares nominations of CIRES employees for awards offered by the university, professional societies, Federal agencies, national academies, and other organizations.

## *Fellows Appointment/Reappointment Committee*

All CIRES Fellows are subject to periodic review. First-term Fellows are reviewed after two years, and continuing-term Fellows generally every five years thereafter. This committee considers the package of reappointment submitted by the Fellow, which includes a cover letter outlining reasons for continuing as a Fellow and a curriculum vita. The

# 5.1 (continued)

committee prepares its recommendations, which are submitted to the full Council of Fellows for consideration and final vote. This committee is also charged with considering the identification and nomination packages of possible new Fellows within the community of scientists at the University of Colorado and NOAA. Nominations for new Fellows are considered once yearly.

### *Graduate Research Fellowship Committee*

Approximately five graduate research fellowships are awarded to CIRES-affiliated graduate students each year through a CIRES competition. This group serves as the review and selection committee for these fellowships.

### *Innovative Research Program Committee*

This program is designed to stimulate a creative research environment within CIRES and encourage synergy between disciplines and research colleagues. The intent is to provide an uncomplicated mechanism for supporting small research efforts that can quickly provide concept viability. The number of awards each year is dependent upon the funds available and funds requested, but averages about six. (http://cires.colorado.edu/science/pro/irp)

### *Space Committee*

A continuing problem for CIRES is the limited office and laboratory space for employees. This committee provides advice on the best use and distribution of existing space, provides ideas on improvement of space through renovation, and develops options for the planning of future space.

### *Visiting Fellows Committee*

This committee is responsible for the review of all applications for CIRES Visiting Fellowships. In the process of this review, the committee makes the decision regarding those best qualified for a fellowship in any given year, and submits that slate to the Fellows Council for final discussion and selection.

### *Bridge Funding and Sabbatical Leave Committee*

This new committee is charged with developing guidelines, procedures and selection criteria for a program through which CIRES Research Scientists may apply for bridge funding for support between funded projects, and sabbatical leave to promote interactions with other research groups, to advance their professional development and build new collaborations.

### *Special Committees*

Additional special committees are appointed as needed by the Director. These include Faculty search committees, CU Program Review Committee, and others. They are created as a need arises, exist to accomplish

## 5.1.3 Member Representation

### *Members' Council*

The Members' Council was created in 1997 to act as an information and policy conduit between CIRES leadership and the Institute members (Associate Scientists, Research Scientists, and Administrative Associates). To accomplish this in the most effective manner, the CIRES membership was divided geographically into six groups of approximately equal size. Each group is represented by two people, preferably from two different classifications in the CIRES Career Track. From this Council of twelve, two representatives to the CIRES Fellows' Council and Executive Committee are elected (one PRA representative and one RA representative). The two representatives to the Fellows' Council/Executive Committee serve as the liaison between the Fellows Council/Executive Committee and the Members' Council. The Members' Council, which meets monthly, then serves as a direct line of communication to the Member population at large. (http://cires.colorado.edu/about/admin/members.html)

## 5.1.4 Administrative Committees

### *Administrative Integration*

Improving communication between diverse CIRES locations, creating smooth transitions for arriving

# 5.1 (continued)

employees, and providing service between offices at CU and NOAA.

### *Annual Report*

Writing the Annual Report on the NOAA Cooperative Agreement each year. This includes creating streamlined input systems for contributors, collecting information from CIRES databases, and editing, proofing and assembling the final product.

### *ASA Database*

Maintaining and improving CIRES interface with its employees for the Annual Summary of Accomplishments, required of all CIRES staff on a yearly basis. Annually entered information becomes part of an increasingly broad and thorough CIRES database for institute information and statistics.

### *Human Resources*

Maintaining resources, including the website, with information, forms, and resources relevant to CIRES employees.

### *Web Communications*

Developing CIRES internet and intranet websites, researching content, and providing communication pathways for internal CIRES information. Presents CIRES face to the public through the external website. Both internal and external websites were completely redesigned in 2004. (http://cires.colorado.edu)

# 5.2 Student Diversity Programs

## Summer Multicultural Access to Research Training (SMART)

The University of Colorado at Boulder offers ten-week summer research internships through the Summer Multicultural Access to Research Training (SMART) program. The internships provide hands-on experience in research and an introduction to graduate education at a leading university. Twenty to twenty-five undergraduates from institutions nationwide take part in this challenging and informative program each summer.

SMART interns conduct research projects in science, math, and engineering fields under the guidance of a faculty mentor (Table 5.2.X). They experience, firsthand, graduate-student life at a major institution. Interns also interact in the social environment of a large university and in a community of underrepresented peers. Program information can be found at http://www.colorado.edu/graduateschool/SMART/SMARTWebsite/index.html.

*Table 5.2.X*

| Name | Affiliation | Research Mentor | Project Title |
|---|---|---|---|
| Luna Rodriguez | CIRES | John Cassano | Evaluation of Antarctic mesoscale prediction system (AMPS) forecasts for different synoptic weather patterns |

## *Significant Opportunities in Atmospheric Research and Science (SOARS) Program*

SOARS is a model learning community and mentoring program for promoting racial and gender equity in the atmospheric and related sciences. Created by and administered through the National Center for Atmospheric Research, CIRES is partnering in this highly successful program while providing NCAR with a wider range of disciplines to place students. It is a multi-summer, four year undergraduate and graduate program for students majoring in an atmospheric science or a related field such as biology, chemistry, computer science, earth science, engineering, environmental science, mathematics, meteorology, oceanography, physics, or social science.

CIRES funds one student, NOAA/OGP funds a second student, and CIRES participates in protégé selection and the identification of appropriate mentors. The students sponsored or mentored through CIRES during the past year are listed below. Further program information can be found at http://www.ucar.edu/soars/.

*Table 5.2.X*

| Name | Affiliation | Research Mentor | Project Title |
|---|---|---|---|
| Nancy Rivera | CIRES | Leslie Hartten | Height corrections of lower tropospheric wind profiles |
| Luna Rodriguez | PAOS | John Cassano | Evaluation of Antarctic mesoscale prediction system (AMPS) forecasts for different synoptic weather patterns |
| Erik Noble | CIRES Policy Center | Roger Pielke<br>Bobbie Klein | Measuring damage from extreme weather |

## Undergraduate Research Opportunities Program (UROP)

The Undergraduate Research Opportunities Program (UROP) creates research partnerships between faculty and undergraduate students. Research in this context is interpreted as any scholarly or creative activity ranging from traditional scientific experimentation to the creation of new artistic works. UROP awards stipends and/or expense allowances to students who undertake an investigative or creative project in collaboration with a faculty member. Although projects are normally designed around some aspect of the faculty sponsor's research, they may also develop from a student's original ideas, which a faculty sponsor has endorsed. Whether the context is scholarly or artistic, UROP projects call for significant input on the part of the faculty sponsor. Program information can be found at http://www.colorado.edu/Research/UROP/.

*Table 5.2.X*

| Name | Affiliation | Research Mentor | Project Title |
|---|---|---|---|
| Jessica Best | Chemistry | Bob Sievers | Improving Aerosolization Performance of Inhalable Dry Powders |
| James Madsen | Chemistry | Bob Sievers | An Improved Miconization Method to Reduce Particle-Size Distribution |
| Thomas Morse | CSES | Thomas Chase | An Analysis of Variance in Combined Major Teleconnections Patterns |
| John Sanderson | EEB | Carol Wessman | The Effects of Urbanization on Forest Health as Assessed by Remote Sensing Techniques |

# 5.3 Personnel Demographics

**Cooperative Institute for Research in Environmental Sciences**
**Personnel Breakdown**
**2004-2005**

| | | | *Supported by NOAA Funding* | | |
|---|---|---|---|---|---|
| *All CIRES* | *Category* | | *B.S.* | *M.S.* | *Ph.D.* |
| 176 | Research Scientist | 99 | | | 99 |
| 22 | Visiting Scientist | 11 | | | 11 |
| 11 | Postdoctoral Fellow | 4 | | | 4 |
| 216 | Associate Scientists | 107 | 54 | 53 | |
| 29 | Administrative | 21 | 16 | 4 | 1 |
| **454** | **Total** ≥ 50% support | **242** | **70** | **57** | **115** |
| 62 | Undergraduate Students | 12 | | | |
| 54 | Graduate Students | 5 | 5 | | |
| | Received less than 50% NOAA support | 35 | 5 | 3 | 27 |
| **570** | **Total** | **294** | **80** | **60** | **142** |

| **Count by OAR Lab** | |
|---|---|
| Aeronomy | 68 |
| ARL | 9 |
| CDC | 44 |
| CMDL | 44 |
| ETL | 32 |
| FSL | 17 |
| **Total OAR** | **214** |
| NWS/SEC | 23 |
| NESDIS/NGDC & NCDC | 25 |
| **Total NOAA** | **262** |

| | |
|---|---|
| Obtained NOAA employment within the last year | 3 |

## 5.4 Refereed Publications


Adachi, A., W. L. Clark, L. M. Hartten, K. S. Gage, T. Kobayashi. 2004. An observational study of a shallow gravity current triggered by katabatic flow. *Ann. Geophys.* 22:3937-3950.

Alexander, M. A., N.-C. Lau, and J. D. Scott. 2004. Broadening the Atmospheric Bridge Paradigm: ENSO Teleconnections to the Tropical West Pacific-Indian Oceans over the Seasonal Cycle and to the North Pacific in Summer. In *Earth's Climate: The Ocean-Atmosphere Interaction*, 85-104. Washington: AGU.

Alexander, M. A., U. S. Bhatt, J. E. Walsh, M. S. Timlin, J. S. Miller, and J. D. Scott. 2004. The atmospheric response to realistic Arctic sea ice anomalies in an AGCM during winter. *J. Clim.* 17:890-905.

Alfarra, M. R., H. Coe, J. D. Allan, K. N. Bower, H. Boudries, M. R. Canagaratna, J. L. Jimenez, J. T. Jayne, A. Garforth, S. M. Li, and D. R. Worsnop. 2004. Characterization of urban and rural organic particulate in the lower Fraser valley using two aerodyne aerosol mass spectrometers. *Atmos. Env.* 38:5745-5758.

Allan, J. D., A. E. Delia, H. Coe, K. N. Bower, M. R. Alfarra, J. L. Jimenez, A. M. Middlebrook, F. Drewnick, T. B. Onasch, M. R. Canagaratna, J. T. Jayne, and D. R. Worsnopf. 2004. A generalised method for the extraction of chemically resolved mass spectra from aerodyne aerosol mass spectrometer data. *J. Aerosol Sci.* 35:909-922.

Anderson, D. N., A. Anghel, J. Chau, O. Veliz. 2004. Daytime, vertical ExB drift velocities inferred from ground-based magnetometer observations at low latitudes. *J. Space Wea* 2, S11001, doi:10.1029/2004SW000095.

Anderson, D. N., B. Reinisch, C. Valladare, J. Chau, and O. Veliz. 2004. Forecasting the occurrence of ionospheric scintillation activity in the equatorial ionosphere on a day-to-day basis. *J. Atmos. Solar-Terr. Phys.* 66:1567-1572.

Anderson-Berry, L., T. Keenan, J. Bally, R. A. Pielke Jr., R. Leigh, and D. King. 2004. The societal, social, and economic impacts of WWRP S2000 FDP. *Wea. and Forecast.* 19:168-178.

Andrews, E., P. J. Sheridan, M. Fiebig, A. McComiskey, J. A. Ogren, W. P. Arnott, D. Covert, R. Elleman, R. Gasparini, D. Collins, H. Jonsson, B. Schmid, J. Wang. 2004. Comparison of methods for deriving aerosol asymmetry parameter. *J. Geophys. Res.* doi:10.1029/2003JD005734.

Angevine, W., M. Zagar, M. Tjernstrom, C. Senff, and A. White. 2004. Transport of urban pollution in coastal New England. *Bull. Am. Met. Soc.* 85:1066-1066.

Angevine, W. M., C. J. Senff, A. B. White, E. J. Williams, J. Koermer, S. T. K. Miller, R. Talbot, P. E. Johnston, S. A. McKeen, T. Downs. 2004. Coastal boundary layer influence on pollutant transport in New England. *Journal of Applied Meteorology* 43:1425-1437.

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# 5.6. Honors and Awards

## Aikin, Kenneth

Web site listing in the Physical Sciences Information Gateway Web site

## Allured, Dave

CDC-CIRES Employee Recognition

## Anderson, Dave M.

Department of Commerce Sustained Superior Performance Award
T. M. Harris Award
Special accomplishment award (CIYA)

## Auerbach, Nancy

2004 NGDC Customer Service Award

## Ballagh, Lisa

Promotion from an Operations Technician II to User Services Representative

## Barry, Roger

Distinguished Professor of Geography

## Bilham, Roger

Miller Distinguished Visiting Professor, University of California, Berkeley

## Cape, Steve

Promotion to CIRES Research Scientist II

## Clifford, Steven F.

Listed in Who's Who in the World
Meritorious Presidential Rank Award winner

## Collins, Julia

CIRES Outstanding Performance Award

## Dichtl, Rudolph

Who's Who Listings in: Strathmore's Who's Who, 2004 Edition
American Registry of Outstanding Professionals
American Men and Women of Science
The Contemporary Who's Who
2004 Edition American Biographical Institute
International Scientist of the Year
International Biographical Centre, England
Man of the Year 2004
American Biographical Institute
Marquis Who's Who in Science and Engineering

## Disterhoft, Patrick

CIRES Outstanding Achievement Award

## Duerr, Ruth

Certificate of Appreciation Board of Directors of the THIC Forum

## Grachev, Andrey

Who's Who in America
Who's Who Nomination for Marquis
Who's Who in America 60th Diamond Edition

## Hurst, Dale

Group Achievement Award NASA

## Jimenez, Jose L.

NSF Young Investigator (CAREER) Award

## Leon, Amanda

Career Track Promotion

## Lewis, William

Outstanding Service Award, Board on Environmental Studies and Toxicology, National Research Council

## Lohaus, Mark

2004 Outstanding Performance Award

## Marquis, Melinda

NASA Group Achievement Award for ICESat Mission Development Team

## McComiskey, Allison

Climate Monitoring and Diagnostics Laboratory, 2004 Annual Meeting: Best Poster

## Michelson, Sara A.

CIRES Career track promotion to Associate Scientist III

## Mondeel, Debra J.

CIRES Employee Service Award

## Monson, Russ

CRCW Faculty Fellowship
Senior Fulbright Fellowship (Germany)

## Moore, Fred

NASA Group Achievement Award to CRYSTAL-FACE Science Team
NASA Group Achievement Award to SOLVE Science Team
CMDL/NOAA Annual Meeting Best Poster
CIRES Members' Council Award of Excellence
NASA Group Achievement Award to POLARIS Project Team

## Nerem, Steven

Pinnacles of Innovation Lifetime Achievement Award, Technology Transfer, University of Colorado

## O'Neill, Michael

NASA Group Achievement Award for the successful September 2003 Balloon Observations of the Stratosphere Team (BOS) campaign

## Ostashev, Vladimir

The Contemporary Who's Who
Who's Who in America

## Osthoff, Hans

Outstanding Presentation, First Annual Postdoctoral Poster Symposium, Boulder Laboratories

## Peckham, Steven

First Place EPA Air Quality Conference, air-quality forecasting contest
CIRES Promotion to Research Scientist II

## Pichugina, Yelena

ETL Environmental Technology Laboratory parking award in December 2004

## Pincus, Robert

CDC-CIRES Employee Recognition Award

## Quincy, Dorothy

CIRES Career Track Promotion to Associate Scientist III

## Raup, Bruce

CIRES Career track promotion to Associate Scientist III

## Sardeshmukh, Prashant

Visiting Scholar, Courant Institute of Mathematical Sciences

## Scott, Michon

Recognition for work at NSIDC: Citation at http://www.sciencemag.org/content/vol306/issue5700/netwatch.shtml

## Smith, Lesley

Superintendent's Honor Roll, Boulder Valley School District

## Steffen, Konrad

Appointed Director of CIRES

## Tolbert, Margaret

Featured in Annual Report of Sponsored Research, 2004
Elected to the National Academy of Sciences

## Tucker, Sara

ETL January Employee of the Month for work done during the NEAQS New England Air Quality Study field campaign on board the NOAA ship *Ronald H. Brown*

## Vaida, Veronica

Faculty Fellowship
Elected American Physical Society Fellow
Elected American Association for theAdvancement of Science Fellow
Guggenheim Foundation Fellowship

## Voemel, Holger

NASA certificate of appreciation in recognition of outstanding contribution to the Southern Hemispheric Additional Ozonesondes (SHADOZ) project and dataset

## Wahr, John

Faculty Fellowship
Vening Meinesz Medal of the European Geosciences Union

## Weil, Jeffrey

NCAR Annual Publication Award

# 5.7 Service

CIRES members serve the scientific communities within the University of Colorado and NOAA, and beyond through participation in professional societies; organization of meetings and special sessions at conferences; review of journal publications and proposals from funding agencies, and service on editorial boards for major journals and committees. Following is a selected list of such memberships and activities, reflecting CIRES employees' service and dedication to their diverse fields of expertise. It is impossible to list all the organizations which benefit from CIRES involvement, but we have tried to include an overview here. For the sake of brevity, service to CIRES, the University of Colorado, and NOAA are not included as we are aiming to illustrate the global reach of CIRES expertise and contributions.

## Professional Memberships

*In addition to society membership, CIRES members served on and chaired a significant number of committees, working groups, and panels associated with these organizations.*

Acoustical Society of America
American Association of State Climatologists
American Association for Aerosol Research
American Association for the Advancement of Science
American Association of Geographers
American Association of Pharmaceutical Scientists
American Chemical Society
American Geophysical Union
American Meteorological Society
American Society of Limnology and Oceanography
American Society for Photogrammetry & Remote Sensing
American Water Resources Association
Association for Women in Science
Association of American Geographers
Chinese Academy of Sciences
Chinese Overseas Association of Scientists and Engineers
China Society of Glaciology and Geocryology
Colorado Earthquake Hazards Mitigation Council
Colorado Lakes and Reservoirs Association
Colorado Water Congress
Consortium of Universities for Advancement of Hydrologic Sciences
Deutsche Gesellscheft fuer Polarforschung
Deutsche Physikalische Gesellschaft
Deutscher Alpenverein
Deutscher Hochschullehrerverband
European Acoustical Association
European Geophysical Society
Geological Society of America
Geoscience and Remote Sensing Society
German Acoustical Society
Hungarian Mathematical Society
Hungarian Meteorological Society
Institute of Electrical and Electronics Engineers
International Association for Mathematical Geology
International Association for Mathematical Physics
International Association for Geomagnetism and Aeronomy
International Astronomical Union
International Glaciological Society
International Institute of Acoustics and Vibration
International Society for Limnology
International Society on General Relativity and Gravitation
International Union of Geodesy and Geophysics
International Union of Radio Science
National Association for Research in Science Teaching
National Weather Association
Optical Society of America
Polar Meteorology and Oceanography Committee
Russian Acoustical Society
Seismological Society of America
Society of American Archivists
Society of Rocky Mountain Archivists
Society of Tibetan Plateau
Society of Vertebrate Paleontology
United States Permafrost Association
Von Humboldt Association of America

## Editorial Service

*Advances in Atmospheric Sciences*
*Applied Optics*
*Atmospheric Environment*
*Bioorganic Chemistry*
*Bulletin of the America Meteorological Society*
*Climate Research*
*Cold Regions Science and Technology*
*Computers & Geosciences*
*Darwin*
*Earth Surface Processes and Landforms*
*Ecological Applications*
*Environmental Science and Policy*
*Geophysical Research Letters*
*Hydrologic Engineering*
*International Encyclopedia of Science, Technology and Ethics*
*IEEE Transactions on Geoscience and Remote Sensing*
*Journal of Atmospheric and Solar-Terrestrial Physics*
*Journal of Geophysical Research*
*Journal of Glaciology*
*Limnology and Oceanography Methods Journal*
*Mathematical Geology*
*Natural Hazards Review*
*Oecologia*
*Physics of the Earth and Planetary Interiors*
*Plant Biology*
*Polar Geography*
*Policy Sciences*
*Society of Geomagnetism and Earth, Planetary and Space Sciences of Japan*
*Stochastic Environmental Research and Risk Assessment*
*Zeitschrift fuer Gletscherkunde und Glazialgeologie*

## Organizer/Convenor

Gordon Research Conference on Enzymes, Coenzymes, and Metabolic Pathways
Special sessions at meetings of the American Geophysical Union, American Meteorological Society, and Association of American Geographers
Ionospheric Effects Symposium
American Geophysical Union Chapman Conference on Corotating Solar Wind Streams and Recurrent Geomagnetic Activity; LWS-CDAW workshop
Fifth Aerodyne Aerosol Mass Spectrometer (AMS) Users Meeting
Workshop on Ecological Aspects of Biogeochemical Cycles
American Meteorological Society 9th Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Ocean, and Land Surface
4th International Symposium of the Tibetan Plateau

## Reviewers

### *Proposals*

AMS
British Antarctic Survey
Canadian Foundation for Climate and Atmospheric Sciences
Council for the Earth and Life Sciences
Department of Energy
Dutch Research Foundation
EAPP
Department of Commerce
Environmental Research & Risk Assessment
European Space Agency
Marine Geodesy
NASA
National Environmental Research Council, United Kingdom
NCERC
NOAA
Norway National Research Council
NSF
Small Business Innovation Research
United Kingdom National Environment Research Council
United States Army Research Office
Water Resources Research Institute

## Reviewers (continued)

### *Journals*

Advances in Space Research
Aerosol Sci. Technol.
American Journal of Science
Applied Optics; Arctic, Antarctic, and Alpine Research
Atmospheric Environment
Bulleting of the American Meteorological Society
BioScience
Books and book chapters
Boundary Layer Meteorology
Bull. Seism. Soc. Amer.
Canadian Journal of Fisheries and Aquatic Sciences
Climate Dynamics
Climatic Change
Cold Regions Science and Technology
Dynamics of Ocean and Atmosphere
Earth Surface Processes and Landforms
Ecological Applications
Ecology
Environmental Science and Technology
Estuarine, Coastal, and Shelf Science
FEBS Letters
Geologische Rundschau
Geology
Geophysical Research Letters
Global and Planetary Change
Global Biogeochemical Cycles
IEEE Journal of Oceanic Engineering
IEEE Transactions on Geoscience and Remote Sensing
International Geophysics Journal
International Journal of Climatology
Journal of Hydrologic Engineering
J. Hydrology
Journal Atmospheric Chemistry & Physics
Journal Environmental Science and Technology
Journal of Atmospheric and Oceanic Technology
Journal of Atmospheric and Solar-Terrestrial Physics
Journal of Climate
Journal of Computational Acoustics
Journal of Environmental Management
Journal of Fluid Mechanics
Journal of Geophysical Research
Journal of Glaciology
Journal of Marine Research
Journal of Physical Oceanography
Journal of Remote Sensing of Environment
Journal of Terrestrial, Atmospheric and Oceanic Sciences
Journal of the Acoustical Society of America
Journal of the Air and Waste Management Association
Journal of the Atmospheric Sciences
Journal of the Meteorological Society of Japan
Journal of Physical Chemistry
Journal of Turbulence
Limnology and Oceanography
Monthly Weather Review
Nature
Philosophical Transactions of the Royal Society
Physics of the Earth and Planetary Interiors
Plant, Cell, Environment
Proceedings of the Royal Society (London)
Protein Science
Quarterly Journal of the Royal Meteorological Society
Radio Science
Science
Spectrochimica Acta A
Tectonophysics
Water Resou. Res.
Weather and Forecasting

## Participants

CIRES Members volunteered with the Department of Commerce Boulder Laboratories 50th Anniversary Science Festival and the National Ocean Science Bowl Regional Competition. These were highly visible community events.

# 5.8 Acronyms

| | |
|---|---|
| 3DVAR | 3 Dimensional Variational Analysis |
| ACD | Atmospheric and Climate Dynamics |
| ADCC | Arctic Data Coordination Center |
| AERI | Atmospheric Emitted Radiance Interferometer |
| AFGL | Air Force Geophysics Laboratory |
| AGCM | Atmospheric Global Circulation Model |
| AGU | American Geophysical Union |
| AIRS | Advanced Infra Red Sounder |
| AL | Aeronomy Laboratory |
| AMS | Aerosol Mass Spectrometer |
| AMIE | Assimilative Mapping of Ionospheric Electrodynamics |
| AMOS | Advanced Modeling and Observing Systems (CIRES scientific theme) |
| AMPS | Antarctic Mesoscale Prediction System |
| AOML | Atlantic Oceanographic and Meteorological Laboratory |
| AQFM | Air Quality Forecast Model |
| ARCSS | Arctic System Science |
| ARCSyM | Arctic Region Climate System Model |
| ARL | Air Resources Laboratory |
| ASLO | American Society for Limnology and Oceanography |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| AUTEC | Atlantic Undersea Test and Evaluation Center |
| AVHRR | Advanced Very High Resolution Radiometer |
| AWI | Alfred Wegener Institute for Polar and Marine Research |
| AWIPS | Advanced Weather Interactive Processing System |
| BP | Before Present |
| BSRN | Baseline Surface Radiation Network |
| BVSD | Boulder Valley School District |
| CAC | Computing Advisory Committee |
| CANDAC | Canadian Network for Detection of Arctic Change |
| CAREERI | Cold and Arid Regions Environment and Engineering Research Institute |
| CBLAST | Coupled Boundary Layers Air-Sea Transfer |
| CCFP | Collaborative Convective Forecast Product |
| CCM | Community Climate Model |
| CCN | Cloud Condensation Nuclei |
| CDAS | Coupled Data Assimilation System |
| CDC | Climate Diagnostics Center |
| CFC | Chlorofluorocarbon |
| CFH | Cryogenic Frost-point Hygrometer |
| $CH_3Br$ | Methyl Bromide |
| $CH_3Cl$ | Methyl Chloride |
| CIMS | Chemical Ionization Mass Spectrometry |
| CIRES | Cooperative Institute for Research in Environmental Sciences |
| $Cl_2O$ | Dichlorine Oxide |
| CliC | Climate and Cryosphere |
| CLIMAS | Climate Assessment Project for the Southwest |
| CLIVAR | CLImate VARiability and Predictability Program |

## Acronyms (continued)

| | |
|---|---|
| CM | Core-Mantle |
| CMDL | Climate Monitoring and Diagnostics Laboratory |
| CME | Coronal Mass Ejection |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| COARE | Coupled Ocean-Atmosphere Response Experiment |
| CONUS | Continental United States |
| CORS | Operating Reference System |
| CRD | Cavity Ring Down spectroscopy |
| CSAP | Colorado Student Assessment Program |
| CSES | Center for the Study of Earth from Space |
| CPP | Cryospheric and Polar Processes |
| CRYSTAL-FACE | Cirrus Regional Study of Tropical Anvils and Cirrus Layers–Florida Area Cirrus Experiment |
| CSP 2012+ | Climate Science and Policy Beyond 2012 |
| CSTPR | Center for Science and Technology Policy Research |
| CSV | Climate System Variability (CIRES scientific theme) |
| CTI | California Technological Institute |
| CU | University of Colorado |
| CUCF | Central UV Calibration Center |
| DAAC | Distributed Active Archive Center |
| DIAL | Differential Absorption of Light |
| DLESE | Digital Library for Earth System Education |
| DMS | Dimethyl-Sulfide |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DSRC | David Skaggs Research Center |
| ECB | Environmental Chemistry and Biology |
| ECMWF | European Center for Medium Range Weather Forecasting |
| ECUV | European reference Center for Ultraviolet radiation measurements |
| EEB | Ecology and Evolutionary Biology |
| EIT | Extreme Ultraviolet Imaging Telescope |
| EM5 | Environmental Model 5 |
| ENSO | El Niño/Southern Oscillation |
| EO | Education and Outreach |
| EPA | Environmental Protection Agency |
| EPIC | Eastern Pacific Investigations of Climate |
| ESA | Endangered Species Act |
| ESS | Earth Systems Science |
| ETA | NCEP model |
| ETL | Environmental Technology Laboratory |
| ETS | Equitable Threat Score |
| EUV | Extreme Ultraviolet |
| FGDC | Federal Geographic Data Committee |
| FGDC | Frozen Ground Data Center |
| FLEXPART | Lagrangian particle dispersion model |
| FSL | Forecast Systems Laboratory |
| FTE | Full Time Equivalent |

## Acronyms (continued)

| | |
|---|---|
| FTP | File Transfer Protocol |
| FYI | First Year Ice |
| GAIM | Global Assimilation of Ionospheric Measurements |
| GAPP | GEWEX Americas Prediction Project |
| GasEx | Gas Exchange Experiment |
| GAW | Global Atmosphere Watch |
| GCM | Global Circulation Model |
| GCMS | Gas Chromatographs with Mass-Selective |
| GDP | Gross Domestic Product |
| GDSIDB | Global Digital Sea Ice Data Bank |
| GEM | Geosynchronous Microwave sounder/imager |
| GEO | Geodynamics (CIRES scientific theme) |
| GFDL | Geophysical Fluid Dynamics Laboratory |
| GFS | NCEP model |
| GIFT | Geophysical Information For Teachers |
| GIS | Geographic Information System |
| GLIMS | Global Land Ice Measurements from Space |
| GOES | Geostationary Operational Environmental Satellite |
| GPM | Global Precipitation Measurement |
| $H_2$ | Hydrogen |
| HATS | Halocarbons and other Atmospheric Trace Species group |
| HCl | Hydrochloric Acid |
| HFC | Hydrofluorocarbons |
| HF/VHF | High Frequency/Very High Frequency |
| HMT | Hydrometeorological Testbed |
| $HNO_3$ | Nitric Acid |
| HOCl | Hypochlorous Acid |
| I-COADS | International Comprehensive Ocean-Atmosphere Data Set |
| IA | Integrating Activities (CIRES scientific theme) |
| IARC | International Arctic Research Center |
| ICARTT | Int'l Consortium for Atmospheric Research on Transport and Transformation |
| IDB | Interface Database |
| IHOP | International H20 Project |
| IMMA | International Maritime Meteorological Archive |
| IMS | Ice Mapping System |
| INSTAAR | Institute of Arctic and Alpine Research |
| IPCC | Intergovernmental Panel on Climate Change |
| IRP | Innovative Research Program |
| ISCCP | International Satellite Cloud Climatology Project |
| ISO | International Standards Organization |
| ITCT | Intercontinental Transport and Chemical Transformation |
| ITCZ | Intertropical Convergence Zone |
| JMA | Japanese Meteorology Agency |
| JPL | Jet Propulsion Laboratory |
| JRC | Joint Research Center |
| KWAJEX | Kwajalein Experiment |
| LACE | Lightweight Airborne Chromatograph Experiment |
| LAI | Leaf Area Index |

## Acronyms (continued)

| | |
|---|---|
| LASP | Laboratory for Atmospheric and Space Physics |
| MALDI | Matrix-Assisted Laser Desorption and Ionization |
| MAQSIP | Multiscale Air Quality Simulation Platform |
| MCDB | Molecular Cellular and Developmental Biology |
| MHD | Magnetohydrodynamic |
| MJO | Madden-Julian Oscillation |
| MM5 | Mesoscale Model 5 |
| MMCR | Millimeter Cloud Radar |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MRF | Median-Range Forecast |
| MYI | Multi-Year Ice |
| $N_2O_5$ | Dinitrogen Pentoxide |
| NACP | North American Carbon Program |
| NAME | North American Monsoon Experiment |
| NAO | North Atlantic Oscillation |
| NARSTO | North American Research Strategy for Tropospheric Ozone |
| NASA | National Aeronautics and Space Administration |
| NBB | Non-Bright-Band |
| NCAR | National Center for Atmospheric Research |
| NCEP | National Centers for Environmental Prediction |
| NDSC | Network for the Detection of Stratospheric Change |
| NDVI | Normalized Deviated Vegetation Index |
| NEAQS | New England Air Quality Study |
| NEHRTP | New England High Resolution Temperature Project |
| NESDIS | National Environmental Satellite, Data, and Information Service |
| NetCDF | Network Common Data Form |
| NGDC | National Geophysical Data Center |
| NGS | National Geodetic Survey |
| NIDIS | National Integrated Drought Information System |
| NIST | National Institute of Standards and Technology |
| NIWA | National Institute of Water and Atmospheric Research |
| NMMR | NOAA Metadata Manager and Repository |
| $NO_2$ | Nitrogen Dioxide |
| $NO_3$ | Nitrate ion |
| NOAA | National Oceanic and Atmospheric Administration |
| NOHRSC | National Operational Hydrologic Remote Sensing Center |
| NOSB | National Ocean Sciences Bowl |
| NPOES | NOAA Polar orbiting Operational Environmental Satellite |
| NRL | Naval Research Laboratory |
| NRLC | Natural Resources Law Center |
| NSDL | National Science Digital Library |
| NSF | National Science Foundation |
| NSIDC | National Snow and Ice Data Center |
| NWP | Numerical Weather Prediction |
| NWS | National Weather Service |
| $O_3$ | Ozone |
| OAR | Oceanic and Atmospheric Research |

## Acronyms (continued)

| | |
|---|---|
| ODP | Ozone Depletion Potentials |
| OGP | Office of Global Programs |
| OI | Optimal Interpolation |
| OMI/AURA | ESS spacecraft |
| OPP | Office of Polar Programs |
| OSDPD | Office of Satellite Data Processing and Distribution |
| ORA | Office of Research Applications |
| PACJET | Pacific Landfalling Jets |
| PACS | Pan-American Climate Study |
| PAN | Peroxyacetyl Nitrate |
| PARCA | Program in Regional Arctic Climate Assessment |
| PAOS | Program in Atmospheric and Oceanic Sciences |
| PBL | Planetary Boundary Layer |
| PCP | Pentachlorophenol |
| PDO | Pacific Decadal Oscillation |
| PFC | Perfluorocarbons |
| PM | Planetary Metabolism (CIRES scientific theme) |
| PITS-MS | Proton Transfer Ion Track Mass Spectrometry |
| PSR | Polarimetric Scanning Radiometer/Sounder |
| PTB | Physikalisch-Technische Bundesanstalt |
| QBO | Quasi-Biennial Oscillation |
| QPE | Quantitative Precipitation Estimates |
| QPF | Quantitative Precipitation Forecasts |
| R/V | Research Vessel |
| RDBMS | Relational Database Management System |
| READ | Regional Ecosystems Assessment Data |
| RICO | Rain In Cumulus Over the Ocean |
| RISA | Regional Integrated Sciences and Assessments |
| RMS | Root-Main-Square |
| ROMS/TOMS | Regional Ocean Modeling System/Terrain-Coordinate Modeling System |
| RP | Regional Processes (CIRES scientific theme) |
| RPC | Rapid Prototyping Center |
| RTVS | Real-Time Verification System |
| RUC | Rapid Update Cycle |
| SAIC | Science Applications International Corporation |
| SAO | Semi-Annual Oscillation |
| SBL | Stable Boundary Layer |
| SCIGN | Southern California Integrated GPS Network |
| SCM | Single Column Models |
| SEARCH | Study of Environmental Arctic Change |
| SEC | Space Environment Center |
| SEM | Space Environment Monitor |
| SEP | Solar Energetic Proton |
| SES | Solid Earth Sciences |
| SGP | Department of Energy Southern Great Plains |
| SHEBA | Surface Heat Budget of the Arctic Ocean |
| SMEX04 | Soil Moisture Experiment |
| $SO_2$ | Sulfur Dioxide |

## Acronyms (continued)

| | |
|---|---|
| SOM | Self-Organizing Maps |
| SPANDEX | Spray Production and Dynamic Experiment |
| SPARC | Science Policy Assessment and Research on Climate |
| SRRB | Solar Radiation Research Branch |
| SST | Sea Surface Temperature |
| STAR | Solar and Thermal Atmospheric Radiation |
| STM | Stormtrack Model |
| STORM | Storm-Time Empirical Ionospheric Correction Model |
| SURFRAD | Surface Radiation |
| SVVSD | Saint Vrain Valley School District |
| SWDS | Space Weather Data Stores |
| SWR | Space Weather Reanalysis |
| SXI | Solar X-ray Imager |
| TAO | Tropical Atmosphere Ocean |
| TEC | Total Electron Count |
| TexAQS | Texas Air Quality Study |
| THREDDS | Themmatic Realtime Environmental Data Distribution System |
| TLS | Tethered Lifting System |
| TOGA-COARE | Tropical Ocean & Global Atmosphere Program's Coupled Ocean-Atmosphere Response Experiment |
| TOPEX | Ocean Topography Experiment |
| TRMM | Tropical Rainfall Measurement Mission |
| TROICA | Trans-Siberian Observations of the Chemistry of the Atmosphere |
| UCAR | University Corporation for Atmospheric Research |
| UNOLS | University-National Oceanographic Laboratory System |
| U.S.A.F | United States Air Force |
| USAP | United States Antarctic Program |
| USC | University of Southern California |
| USGS | United States Geological Survey |
| UV | Ultraviolet |
| VOC | Volatile Organic Carbon |
| VOS | Voluntary Observing Ship |
| WATF | Water Availability Task Force |
| WCRP | World Climate Research Program |
| WGA | Western Governors' Association |
| WDC | World Data Center |
| WMO | World Meteorological Organization |
| WRF | Weather Research and Forecasting |
| WSA | Wang-Sheeley-Arge |
| WSR-88D | Weather Surveillance Radar 88 Doppler |
| WVIOP04 | Water Vapor Intensive Operation Period 2004 |
| WW2BW | White Water to Blue Water |
| WWA | Western Water Assessment |
| WWW | World Wide Web |
| WX | Weather |
| X-POL | Cross-Polar |
| XRS | X-Ray Sensor |