FIRE Phase III: Cirrus Implementation Plan

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Cover Image

Tropical cirrus anvils associated with deep convective clouds acquired at 2315 UTC 31 January 1993 during the TOGA COARE campaign over the Western Tropical Pacific Ocean (13.5˚ S 152˚ W). This image was acquired by the MODIS Airborne Simulator (King et al. 1996, J. Atmos. Oceanic Tech.) onboard the NASA ER-2 high altitude research aircraft. The image, at a visible wavelength of 0.66 µm, covered a total domain size of 37 by 82 km and also showed developing cumulus congestus clouds around the cirrus anvils (provided by S. C. Tsay and M. D. King at NASA Goddard Space Flight Center).

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1.0 EXECUTIVE SUMMARY

The First ISCCP Regional Experiment (FIRE) has conducted basic research on climatically important cloud systems. FIRE was conceived in 1984 as a national US research program responding to the needs of ISCCP (International Satellite Cloud Climatology Project), an international World Meteorological Organization program. Throughout its history, FIRE has been especially interested in the cloud-climate connection. As a result, integrated, interdisciplinary studies involving experimentalists, theoreticians and modelers have been planned and executed by the broad-based community of FIRE scientists. These specialists span the fields of radiation, cloud microphysics and dynamics ranging from cloud scale to the general circulation.

Previous FIRE research has centered on midlatitude cirrus cloud systems and subtropical marine boundary layer cloud systems. It has enhanced our ability to both monitor these systems from satellites and to include their radiative effects in models of various scales. It has significantly increased our understanding of the control of these cloud systems by the large-scale circulation and has greatly enhanced our ability to realistically simulate these systems in Global Circulation models (GCM). Modeling studies and field campaigns have greatly enhanced our understanding of these two climatically important cloud regimes. FIRE GCM research has added to our understanding of the importance of these cloud regimes in the climate system.

There have been two previous phases of FIRE. FIRE-I (1984-1989) focused on midlatitude cirrus clouds in the upper U.S. and marine stratocumulus clouds in the eastern Pacific off the coast of California. FIRE-II (1989-1994) continued to study midlatitude cirrus clouds in the central US and the boundary layer clouds of the eastern Atlantic. The following document outlines the strategies, questions, and programmatic goals of the upper tropospheric component of FIRE-III (1995-).

1.1 PRIMARY COMPONENTS

FIRE Phase III has two primary components:

An upper tropospheric cloud component which consists of continuing investigations of middle latitude cirrus cloud systems with a methodical transition of emphasis to tropical upper-tropospheric cloud systems;

A boundary layer/arctic cloud component which consists of continuing investigations of subtropical marine stratocumulus systems and a new thrust aimed at Arctic cloud systems. A separate document, the Arctic Cloud Implementation Plan, describes this component.

1.2 STRATEGIES:

The FIRE III upper tropospheric cloud component will adopt the following strategies:

1. The continued analysis and simulation of observations obtained during the FIRE Phases I and II field campaigns and the FIRE extended time observations. The FIRE Phase I and II model, theoretical, and field campaign results will be applied to the improvement and evaluation of cloud-system parameterizations employed in cloud resolving models (CRMs) and GCMs. They will also be used to develop and verify improved techniques for the inference of cloud radiative and microphysical properties from satellite and surface based data.

2. Provide a methodical transition from FIRE Phases I and II accomplishments to a coherent research plan for the next generation of research on climatically important cloud systems.

3. Define, design, test and implement new critically needed measurement systems to observe key microphysical and radiative properties of cirrus clouds. The inability to observe these properties is currently a barrier to a better understanding of cirrus cloud systems.

4. The definition and execution of limited but highly-focused observational programs to complement our current understanding of cirrus cloud systems.

5. The assessment of the need for and subsequent definition and execution of a major field campaign focused on tropical upper-tropospheric cloud systems.

1.3 CRITICAL QUESTIONS

Critical questions to be addressed in the upper-tropospheric cloud component are:

What are the distributions and amounts of ice mass and total water in the upper troposphere?

- How can ice mass be determined from remote sensors and how can these measurements be validated?
- How do the concentrations of ice particles, the total water, the ice mass and their distributions depend on large-scale meteorological parameters such as temperature, vertical motion, wind shear, etc.?
- How are the total water mass and ice mass distributions related to detrainment from deep convective cloud systems?
- How do the local and regional evolutions of total water and cloud ice mass distributions and their small-scale variability depend on the ice formation process (e.g. synoptic ascent versus convective detrainment) parameters?

What are the microphysical properties of upper tropospheric clouds?

- How do the particle sizes, shapes and phase depend on the large scale environment?
- How does microphysical composition affect the evolution of the cloud system and the tropospheric water budget (interactions between cloud layers, vertical water transports, precipitation at the surface)?
- What are the microphysics of cirrus formed at extremely low temperatures?
- How do aerosols impact the microphysical development of cirrus clouds?

What are the radiative properties of upper-tropospheric clouds and how do they relate to the ice mass, and the microphysical and macrophysical characteristics of the cloud?

- What are the scattering phase functions, asymmetry parameters, and optical extinction parameters associated with microphysical distributions?
- How can these radiative properties be directly and accurately observed from airborne, satellite and surface-based platforms?
- Can these radiative properties be usefully expressed in terms of an effective particle size that is consistent with cloud ice path and optical depth?
- How do the vertical and horizontal structures of cirrus clouds affect their bulk

radiative properties and how does this impact the remote sensing of cloud microphysical properties?

How representative are midlatitude continental cirrus of upper tropospheric clouds in other regions of the globe?

- Will GCMs be able to use a single universal cirrus parameterization for all latitudinal and regional domains?

- Are tropical cirrus cloud systems sufficiently different from their midlatitude cousins to call for a tropical cirrus field campaign?

1.4 PROGRAMMATIC GOALS

Key programmatic goals that FIRE III must address include serving specific components of our science and technological communities. Among these components are the instrument/measurement technologies and strategies to be used to observe key radiative and microphysical cloud parameters. The term "validation" will be applied in reference to the assessment and improvement of remote sensing of microphysical, radiative and spatial properties of cloud systems; this continues to be a programmatic goal of high priority for FIRE III. Large scale models of the climate potentially represent one of the most powerful tools to explore the role of cloud systems in climate because of their ability to simulate the many feedback processes at work in the earth climate system; however, current model treatments of cloud systems are crude at best. FIRE has a responsibility and a vested interest in working closely with the modeling community to improve the ability of climate models to credibly represent and investigate cloud systems.

1.5 COLLABORATIVE PROGRAMS

In addressing the questions presented above, FIRE-III recognizes a strong common interest with other programs. Those most directly related include the National Aeronautics and Space Administration (NASA) Subsonic Assessment (SASS), Department of Energy (DOE) Atmospheric Radiation Measurements (ARM), National Science Foundation (NSF) Role of Clouds, Energy and Water (ROCEW), and NSF Stratosphere-Troposphere Experiments: Radiation, Aerosols, and Ozone - B (STERAO-B) programs. There is also considerable international activity in the cirrus cloud-climate research arena. Past FIRE collaboration with scientists from Europe and Japan is expected to continue. For example, researchers from the European Clouds and Radiation Experiment (EUCREX) and Japan Cloud Studies (JACCS) communities have expressed interest in possible future participation with FIRE-III. FIRE welcomes the collaboration with other programs and other countries in its quest to better understand the roles of clouds in the Earth's climate system.

2.0 MULTIPLE CRITERIA APPLIED TO SELECTION OF IMPLEMENTATION PLAN GOALS

The development of an implementation plan for FIRE III is especially challenging at this time. Not only must basic scientific goals be met, specific programmatic goals consistent with the needs of multiple constituencies must be addressed and the current fiscal realities faced by sponsoring agencies further constrain the options. The FIRE Research Plan identified the scientific goals for FIRE III. These were restated in the previous section.

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The current fiscal climate is, to say the least, challenging! While all goals in the FIRE III Research Plan have scientific merit, priorities must be set and limited fiscal, logistic and human resources must be focused on the most important elements; furthermore unnecessary duplication and premature execution must be minimized.

The implementation plan that follows represents the best efforts of a group of FIRE Science Team members to provide a plan which fits within these multiple constraints and offers a high probability of successfully achieving the stated goals of the FIRE Research Plan.

Section 3 lists some exciting new advances in both platform and instrument development that are especially relevant and important to future FIRE studies of cirrus clouds. Section 4 describes FIRE research goals and activities that exploit existing FIRE datasets obtained in previous field campaigns (Cirrus Intensive Field Observations (IFO)-I, IFO-II, Extended Time Observations (ETO), Tropical Ocean and Global Atmosphere - Coupled Ocean-Atmosphere Regional Experiment (TOGA-COARE), Central Equatorial Pacific Experiment (CEPEX), etc.) Section 5 outlines research strategies for satellite, airborne, and surface remote sensing investigations that will focus on validation, cloud process studies, and diagnostic analyses. These strategies include continued analyses of previously obtained datasets, theoretical studies, and analyses of future midlatitude and equatorial cirrus field campaigns. Section 6 describes the rationale and measurement requirements for tropical cirrus experiments designed to test the hypothesis that **"radiative properties of cirrus anvils are primarily controlled by the mass flux and vertical velocities in associated cumulus convection."** This hypothesis will provide a direct basis for the development of GCM parameterizations for convective anvils. Section 7 outlines the unique characteristics of tropical cirrus cloud systems, discusses the need for a focused experimental program, and outlines a hierarchy of four experiments of increasing complexity and demand on resources. These experiments include a ground-satellite remote sensing experiment, an in situ radiation-microphysics experiment, a non-precipitating anvil and cirrus layer evolution experiment, and a convection-cirrus system experiment. Section 8 outlines FIRE's collaborative participation in the Subsonic Assessment: Contrail and Cloud Effects Special Study (SUCCESS), conducted in Kansas, April - May, 1996, that will study the impact of contrails and jet engine exhaust products on midlatitude cirrus. In addition to specifying FIRE's contributions to SUCCESS, a number of SUCCESS-funded instruments are identified that may have important roles in future FIRE campaigns. Section 9 outlines FIRE's collaborative participation in the Surface HEat Budget of the Arctic Ocean (SHEBA) field experiment to be conducted in the Arctic ice domain, April 15 - May 30, 1998. The FIRE cirrus component will focus on remote sensing of ice and water clouds. Section 10 identifies additional complementary and collaborative activities that FIRE is currently involved with or is planning towards, such as with DOE ARM, Earth Observing System (EOS) instruments (Moderate-resolution Imaging Spectrometer (MODIS), Multi-angle Imaging Spectro-Radiometer (MISR), and Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER)), NSF Stratosphere-Troposphere Experiments: Radiation, Aerosols and Ozone (STERAO), NASA Land Processes, Brazil Large-Scale Land Processes in the Basin of the Amazon (LBA), EUCREX, and JACCS.

The plan also identifies a number of “Implementation Steps” for each of the research strategies. These are listed at the ends of each section (sections 4-10). The results of a survey soliciting participation from the FIRE researchers in each of these implementation is given in Appendix E.

Appendix A lists the references, B the acronyms, abbreviations, and notations, C the FIRE-III organization and data management, and D the individual research abstracts of the FIRE-III science team members

3.0 NEW PLATFORMS AND INSTRUMENTATION

Since FIRE II, a number of new advances in platform and instrumentation have taken place. This has occurred, in part, through new aircraft progress (e.g. SUCCESS, the ARM Unmanned aerospace vehicle (UAV) program) and new satellite programs. Those relevant to the study of cirrus clouds are summarized below.

3.1 Aircraft

The National Center for Atmospheric Research (NCAR) has recently acquired the WB-57 high altitude aircraft. The ceiling of this aircraft is approximately 20 km and it is able to penetrate most clouds (hard convection excepted). The aircraft is also capable of carrying a payload of about 910 kg. This aircraft clearly holds much promise for study of upper tropospheric clouds; instrumentation packages are now under development, although some of the packages planned for the WB-57 may be "borrowed" from NASA's ER-2 or DC-8 making multiple aircraft missions with common instrumentation somewhat problematic.

UAVs are now being used to study the atmosphere; leading efforts in application of UAV's have come from the DOE ARM UAV program and the UAV program of NASA. While high altitude UAVs have not yet carried science payloads, flight of these aircraft to altitudes similar to the WB-57 is imminent.

Recently the Strato 2C aircraft, designed and manufactured in Germany by Burkhart Grob Lubt- und Raumfahrt Gmbh and Co., flew in some of its early test flights. Although the early test flights were performed at relatively low altitudes, this aircraft has been designed to perform research missions at altitudes as high as 24 km with an endurance of 8 hours and carrying an 800 kg payload. Similarly the Strato 2C has an endurance of 48 hours at 18 km altitude (payload 1000 kg). The pressurized cabin accommodates 2 pilots and 2 mission scientists and has an effective length of 5.5 meters and is 1.88 meters high. The aircraft uses composite materials for a high strength to weight ratio and two reverse mounted, compound engines; the term "compound engine" is used to describe the combined 300 kW piston engine and the gas generator of a 2000 kW turboprop engine which serves as a turbocharger and provides additional thrust. The Strato 2C should be very well suited for tropical upper tropospheric cirrus research.

3.2 Instruments

Instrumentation development has advanced on a number of fronts. Table 3.1 summarizes the airborne instruments under development that have potential application for cirrus cloud studies. Similar instruments are listed for surface operations (table 3.2) and satellites (table 3.3).

Table 3.1 - Potential Airborne Instrumentation (Under Development)

Instrument/ Platform	Parameters	Institution/ Investigators
DIAL ER-2	Cirrus backscatter water vapor profiles	Langley Browell
X-Band Doppler Radar ER-2	Profiles of Z, IWC, Air vertical velocity	NASA Goddard Heymsfield
m-wave Radiometer (325 Ghz) ER-2	water/ice profile	GSFC Wang
MISR Airborne Simulator? ER -2	TOA, cloud, and surface reflectance	GSFC
SSFR DC-8/ER-2	radiation	ARC Pilewskie
94 GHz Radar DC-8	Profiles of Z, IWC	JPL Li
Submillimeter Radiometer DC-8	IWP, Particle size	JPL, GSFC Walks, Chang
m-wave Radiometer (600 Ghz) DC-8	water/ice profile	JPL Walters
Lidar DC-8	cloud structure and profile	NOAA ETL Eberhard
Ice Nuclei Counter DC-8	Number concentration, species	CSU Kreidenweis
p-Nephelometer DC-8	microphysics, scattering phase function	SPEC, Inc. Lawson
CVI DC-8	microphysics, water/ice content	NCAR Twohy
CCN Spectra DC-8	CCN spectra	NCAR Cooper
Diode Laser Hygrometer DC-8	water vapor	LaRC Sachse
Cloudscope DC-8	large particle spectra	DRI Hallett
Gerber Probe (g Meter) DC-8/WB-57	IWC, particle size	Gerber Scientific Gerber
Broad Band Radiometers ER-2/DC-8/WB-57/surface	Broad band fluxes	Scripps Valero
Spectral Polarimeter UAV	Optical depth, particle size, shape index	CSU Stephens
m-Wavelength Radar UAV	Backscatter profiles	LLNL
Advanced AVHRR MPIR UAV	Optical properties	Sandia
FTIR, FTS UAV	Optical properties in IR at 1.4 mm and in A band, in-situ water	Harvard Anderson
A Band Spectrometer UAV/WB-57	Cirrus and aerosol optical properties	CSIRO/CSU O'Brien/Stephens
MODIS /ASTER Airborne Simulator (MASTER)? C-130	Land/surface characteristics	GSFC

Table 3.2 - Potential Surface Instrumentation

Instrument	Parameters	Institution/

		Investigator
MFOV 2	Equivalent size, transmittance	CSU Cox
AERI	Downwelling spectral radiance	U Wisconsin S. Ackerman
35 Ghz radar	Cloud structure and profile	NOAA ETL Eberhard
SPFR	Hemispherical spectral flux	ARC Pilewskie
m -pulse lidar	Cloud structure and profile	GSFC Spinhirne

3.3 Satellites

The latter part of the decade will witness the launch of a number of satellites carrying research payloads. The Tropical Rain Monitoring Mission (TRMM) and EOS AM-1 satellites will carry the Clouds and the Earth's Radiant Energy System (CERES) instrument. The Advanced Earth Observing Satellite (ADEOS) and the AM-1 platform will fly spectral radiometers, the Global Imager (GLI) and MODIS, with channels well suited to the detection of cirrus. ADEOS will also carry the Polarization and Directionality of Earth Reflectances (POLDER) and Interferometric Monitor of Greenhouse Gases (IMG) sensors. The European ERS-1 satellite is flying an advanced version of the Along-Track Scanning Radiometer (ATSR).

Table 3.3 - Potential Satellite Instrumentation

Satellite	Instrumentation	Measurement	Launch Date
ERS-1	ATSR	IR, NIR multi-angular	1994
ADEOS (Japanese)	POLDER, IMG	Solar wavelengths, multi-angular polarization	1996+
ADEOS 2	GLI, POLDER, AMSR	Spectral, high spatial resolution	2000+
TRMM	CERES, LIS, PR, TMI, VIRS	Precipitation water content	1997
EOS AM-1	CERES	Broadband SW, IR	1998
EOS AM-1	MODIS	Spectral, high spatial resolution	1998
EOS AM-1	ASTER	Similar to Landsat with both solar and infrared bands	1998
EOS AM-1	MISR	Multi-angle, multi-spectral, bi-directional reflectance	1998
EOS PM-1	CERES, MODIS	See above	2000
EOS PM-1	MIMR (Microwave Imager)	Water content	2000
EOS PM-1	AIRS (Infrared Spectrometer)	Temperature and moisture soundings	2000
EOS AM-2	EOSP	Spectral, multi-angle, high-precision	2000

		measurements of radiance and polarization	
EOS ALT	GLAS (Lidar)	Cloud top height	2002

4.0 CONTINUED EXPLOITATION OF EXISTING CIRRUS DATA SETS

Funded FIRE-III research projects that address the FIRE-III science objectives on upper tropospheric clouds by utilizing existing observations of cirrus clouds (Cirrus-I, Cirrus-II, FIRE ETO, FIRE/TOGA-COARE, CEPEX, etc.) fall into five basic areas:

- GCM and parameterization evaluation and validation,
- characterization of cloud radiative properties and effects,
- characterization of cloud microphysical properties,
- case studies and modeling of cloud development,
- development, validation and application of satellite remote sensing of cloud properties.

At the present time, the analysis of existing FIRE observations has progressed into the stage where collaborative studies using combined analysis of multiple data sets in comparison with theory/model-based approaches are the rule. To a great extent, analysis and modeling in each basic area supports the efforts in the others resulting in greatly added value.

4.1 GCM and Parameterization Evaluation and Validation

Studies in this area are crucial to the achievement of one of the long-standing central goals of FIRE, i.e., to improve our understanding of the role of cirrus in the global climate system and to improve our capabilities to realistically simulate this system. Two specific approaches are implemented where each makes considerable use of the extensive large-scale observations of atmospheric state obtained during FIRE Cirrus-II, and to a lessor extent during FIRE Cirrus-I and FIRE/TOGA-COARE, as well as the cirrus cloud observations themselves from satellites, ground and airborne remote sensors, and in situ measurements.

First, ISCCP data will be compared with simulations using the Goddard Institute for Space Science (GISS) GCM and Geophysics Fluid Dynamics Laboratory (GFDL) Skyhi models to define regions of GCMs deficiencies in cirrus properties and FIRE data will be used to explore the reasons for the discrepancies. Synoptic conditions giving rise to cirrus formation during FIRE Cirrus-I and FIRE Cirrus-II will be compared to those generating cirrus in the GISS GCMs to understand the GCM's tendency to over predict the altitude of cirrus formation. Simulated radiative properties of midlatitude and tropical cirrus will also be compared and validated against observations from Cirrus-I, Cirrus-II, TOGA-COARE and CEPEX. The distributions of cloud top/base pressure, optical thickness, and particle size will be examined.

Second, diagnostics derived from wind profiler and radiosonde observations, obtained during FIRE Cirrus-II, will be used as input parameters to drive a suite of GCM cloud parameterizations as in Mace et al. (1995). A verification data set, derived from the FIRE Cirrus-II ground-based and satellite observations, is being created for comparison with the parameterization output. An extensive analysis of the relationship between large-scale forcing (meteorological conditions) and cirrus formation and maintenance will be undertaken. To extend the results from midlatitude cirrus to other geographical regions, data collected during TOGA COARE, under the sponsorship of NASA and DOE, will be examined in considerable detail in order to quantify the importance of tropical cirrus to the local radiative energy budgets and identify similarities and differences between tropical cirrus and their midlatitude counterparts.

4.2 Characterization of Cloud Radiative Properties and Effects

One of the key areas of scientific investigation identified in the FIRE-III Research Plan is the characterization of the fundamental radiative properties of cirrus clouds, specifically the scattering phase functions, asymmetry parameters and optical extinction parameters, in relationship to cloud microphysical properties. While a significant effort will be made in FIRE-III to develop and/or refine suitable new instrumentation and to obtain appropriate measurements of these very difficult to observe parameters, continued analysis of the existing measurements will provide improvements in our knowledge of bulk cloud radiative properties, that are useful for characterizing cloud radiative effects, as well as supporting the development of new theories for characterizing the more fundamental radiative properties, and new techniques for retrieving cloud microphysical properties from satellites.

In terms of bulk cloud radiative properties, continued analysis of existing FIRE observations will be used to improve parameterizations of longwave and shortwave radiative effects of cirrus based on probabilities of cloud free lines of sight and the stochastic treatment of cloud optical properties, respectively. In addition, satellite-derived cloud radiative properties will be used to estimate tropospheric heating and cooling caused by radiative processes, including changes in radiative processes associated with the seasonal cycle and with weather systems both in middle latitudes and in the tropics where semi-transparent cirrus clouds are the most numerous and have the largest impact on the heat budget of the Earth.

Analysis of FIRE Cirrus-II observations, both radiative and microphysical, will be used to support development of unified theories for light scattering by realistically-shaped ice crystals using the geometric ray-tracing technique (Takano and Liou, 1995), the new T-matrix method (Mishchenko et al., 1996) and other techniques enabling fast calculations of scattering by non-spherical particles both in the solar and infrared spectral regions over all size parameters in extensive media comprised of gases and particles. Development of such models is integral to the improvement of remote sensing techniques and algorithms. Moreover, the results will be used in sophisticated radiative transfer model calculations, including account of ice scattering and absorption from the visible to the thermal infrared, to assess the effects of cloud inhomogeneities on the results derived from remote sensing algorithms which will then be compared to existing FIRE observations. Effects of cloud inhomogeneity is a key unresolved issue for FIRE-III.

In support of the above line of research, a strong effort will be made to characterize the angular distribution of reflected radiation derived from Tilt Scan Coupled Charge Device (CCD) Camera observations obtained during FIRE Cirrus-II and FIRE/TOGA-COARE. This instrument provides observations of cloud bi-directional reflectance, a critical parameter involved in the reduction of satellite observations and a direct manifestation of the integral effect of the scattering phase function.

4.3 Characterization of Cloud Microphysical Properties

Cirrus cloud microphysical properties provide the physical linkage between, on the one hand, remote sensing and cloud radiative properties and radiative effects, and, on the other hand, cloud formation, water processing and atmospheric dynamics. As such, characterization of cloud microphysical properties is a fundamental requirement for each of the other basic research areas described herein. Further analysis, emphasizing statistical summarization (means and variability) delineated by cloud type and location within the cloud, will be made of the mid-latitude observations obtained during FIRE Cirrus-II and the tropical observations obtained during TOGA-COARE and CEPEX. In addition to directly supporting studies of cloud radiative properties and remote sensing studies, these results will be used to develop and evaluate conceptual models of cirrus cloud formation, to evaluate numerical models (parcel models, LES models and GCM parameterizations) of cirrus clouds, and be incorporated into multi-sensor/multi-parameter analysis of individual observed cases of cirrus cloud development. As such, continued analysis of the microphysical observations is a pivotal element in developing an understanding of how cirrus clouds work, both in mid-latitude and in the tropics.

In terms of remote sensing, the results of analysis of the microphysical observations will be used to advance and improve techniques for remotely inferring cloud microphysical properties, including cloud ice water content using passive high-frequency microwave observations from TOGA-COARE, particle size and ice water content distributions from joint analysis of ground-based short wavelength radar and passive radiometer observations from FIRE Cirrus-II following Matrosov et al. (1992), and techniques using existing satellite observations in the solar and infrared spectral regions (Young et al., 1994 and Minnis et al., 1995).

The analysis of microphysical observations will also be used to further define the observational requirements (in situ and remote sensing instrumentation and observing strategies) for future field experiments and to define the fundamental humidity conditions required for ice nucleation in cirrus, especially with respect to indicating the relative contributions of the homogeneous versus heterogeneous ice nucleation processes. Resolution of the latter issue is central to assessment of the potential global impact of anthropogenic (e.g., aircraft emissions) and volcanic impacts on global climate through aerosol effects on cirrus.

4.4 Case Studies and Modeling of Cloud Development

Integrated multi-sensor/multi-parameter analysis will be made of additional cases from FIRE Cirrus-II and FIRE/TOGA-COARE. These studies combine data spanning a wide range of scales from synoptic rawinsonde observations to mesoscale profiler and aircraft measurements to the very high resolution observations obtained by remote and in situ sensors into a comprehensive description. These studies seek to define the relationship between resolved dynamical processes and cloud physical development and microphysical properties. Cirrus-II cases of particular interest that have not as yet been analyzed in detail include the subtropical jet stream cases and a well-observed case of a large, fairly homogeneous appearing cirrus system. Though not nearly as comprehensive, analysis of TOGA-COARE and CEPEX cases will be used to explore the workings of tropical cirrus systems.

Analysis of high-resolution cloud model simulations will also be used to develop improved understanding of the interaction of dynamical, radiative and microphysical processes in cirrus clouds in both the middle latitudes, as observed during FIRE Cirrus-II, and also for the tropical situations observed during TOGA-COARE and CEPEX. In conjunction with the case study analyses and observations, these studies will provide the understanding needed to further develop improved GCM cirrus cloud parameterizations and to define the issues and strategies for any future tropical observing campaign.

A significant new focus for FIRE-III is the emerging plan for utilization of the extensive and high quality FIRE Cirrus-II data sets and analysis products in the systematic intercomparison of a broad range of cirrus cloud models under the auspices of the GEWEX Cloud System Studies (GCSS) Project Working Group on Cirrus Clouds (WG-2). While this WG-2 activity is presently at the initial planning stage, the plan is to follow the lead of GCSS WG-1 where FIRE Stratus and FIRE Atlantic Stratocumulus Transition Experiment (ASTEX) data sets have played a pivotal role in the organized intercomparison of models of stratus cloud development. To date, the WG-1 intercomparisons have proven very worthwhile to the participants and have resulted in significant gains in understanding model performance, in the context of model content/approach, versus the observations, a very necessary ingredient for the improvement of models. The GCSS working groups are highly international and encompass a much larger community than the FIRE Science Team. The international cirrus modeling community has now developed the sophistication and breadth required for a systematic intercomparison project to be truly fruitful. At the same time, the FIRE Cirrus-II data sets and analysis products, both completed and still in progress, uniquely provide the necessary observational basis for such an effort. It is expected that these activities will constitute a major contribution in advancing understanding of cirrus cloud processes and defining issues and observational requirements during FIRE-III. These activities represent an integral step toward realization of the goal of development and validation of suitable realistic GCM cloud parameterizations.

4.5 Development, Validation, and Application of Satellite Remote Sensing of Cloud Properties

Further analysis of FIRE-II observations will be used to support improvement and validation of techniques for remote sensing of cirrus cloud properties from existing satellite observations, including the ISCCP products. Remote sensing techniques are increasingly incorporating recent and developing theoretical results on the scattering properties of ice crystals (e.g., Minnis et al., 1993). The traditional retrieved cloud properties include cloud optical depth, visible albedo, and infrared emittance as well as cloud altitude. In addition, new experimental retrievals of particle size and type (shape) and ice water path are now being made. FIRE-II observations offer a unique testbed for evaluating these methods. Of particular importance are the "ground truth" measurements of cloud altitude provided by active sensing systems, that have been a cornerstone of FIRE including the ETO observations, as well as the wealth of coincident in situ microphysical observations obtained during FIRE Cirrus-II and to a lessor extent during TOGA-COARE and CEPEX. It is expected that, as the results of theoretical studies (Monte Carlo calculations) and analysis (Landsat) on the effects of cirrus cloud inhomogeneity become available, they will also be incorporated into the algorithms for application to FIRE-II data.

Besides the analysis of the results from the emerging techniques and their integration into each of the other areas described here, such as the case studies, special emphasis will be made on resolving differences between various cloud systems, particularly between mid-latitude and tropical cirrus systems, in terms of the cloud microphysical and radiative properties.

FIRE observations and analysis continue to provide strong support for algorithm development and validation for EOS, especially products to be derived from MODIS, MISR, and EOSP (Earth Observing Scanning Polarimeter). Analysis of FIRE-II observations will also continue to specifically focus on ISCCP validation and application (e.g., Mishchenko et al., 1995), including comparative global and inter-regional studies.

4.6 IMPLEMENTATION STEPS:

In order to assure continued progress in the analysis and application of previously collected FIRE data sets, two FST members will have the responsibility for each of the following topics to coordinate multi-investigator participation and to report on progress.

- GCM and parameterization evaluation and validation,
- characterization of cloud radiative properties and effects,
- characterization of cloud microphysical properties,
- case studies and modeling of cloud development,
- development, validation and application of satellite remote sensing of cloud properties.

The FIRE project office should support the logistics of multi-investigator participation pursing the above goals.

5.0 REMOTE SENSING FOR FIRE III UPPER TROPOSPHERIC CLOUD RESEARCH

Remote sensing plays an important role in quantifying the properties of clouds over small, medium, and large spatial (0.001 - 10 - 1000 km) and temporal scales (1 sec - 15 min - decades). Methods for deriving cloud radiative and physical parameters from radiances -- measured by active and passive sensors on the ground, on aircraft, and on satellites -- are under continual development as new instruments and data sets become available. Past FIRE data have played a critical role in advancing the science of cloud remote sensing (Randall et al., 1995) and the validation and improvement of the ISCCP global cloud products (Rossow et al., 1993). Conversely, the remotely sensed cloud properties from FIRE have been major contributors to better understanding of cloud processes and to the validation and interpretation of meso- and synoptic scale atmospheric circulation models, (Soden and Donner, 1994). This dual role for remote sensing algorithms, as users of FIRE products for validation and development and as providers of datasets for understanding clouds and for model validation and interpretation, will continue during the FIRE III period. The FIRE III scientific objectives will be addressed in the remote sensing realm by implementing the following strategies:

- analysis and development using currently available datasets;
- theoretical sensitivity studies using new models of cloud particle size, shape, and vertical and horizontal distributions;
- the execution of a limited midlatitude experiment focused primarily on contrails and cirrus over land, execution of other limited field experiments;
- and the design and execution of a more extensive tropical upper tropospheric cloud experiment.

Remote sensing investigations during FIRE III focus on several areas, such as validation, cloud process studies, and diagnostic analyses. These endeavors frequently require collaboration with other FIRE investigations.

In the validation area, the heterogeneous characteristics of available and future instrumentation preclude a straightforward comparison of different measurements. Rather a statistical comparison is required to account for different sampling of smaller space and time scales. The primary strategy is to use the in situ, higher resolution aircraft measurements to validate the larger datasets that can be acquired from surface remote sensing instruments. These larger datasets can then be used to validate the satellite retrievals. Thus, a subset of the FIRE team must conduct investigations that integrate a comprehensive collection of coincident observations from aircraft, the surface and satellites, where similar or "identical" quantities are retrieved, to determine how well cloud properties can be determined from satellites alone. Some examples of this type of study are Nakajima et al., (1991), Wielicki et al., (1990), Minnis et al., (1990, 1992, 1993), Wylie (1989), Rossow and Garder (1993a) and Han et al., (1994, 1995c), where statistical comparisons are made between satellite and surface and/or aircraft observations. Cloud process studies and circulation model validations use a variety of remote sensing data for both evaluation and understanding of the phenomena. Close collaboration between the modeling and remote sensing investigators is important to ensure that the data are provided in the most usable format. The collaborative approach were quite successful during earlier FIRE studies (e.g., Wang et al., 1993; Mace et al., 1995; Martin et al., 1995). Joint validation and process efforts such as these will continue during FIRE III.

Measurements of the properties of clouds, surface and atmosphere allow one to infer radiative fluxes, in principle. Several such analyses have been done for the surface radiation (Darnell et al., 1992; Whitlock et al., 1995; Rossow and Zhang, 1995) and for top-of-atmosphere (Rossow and Zhang, 1995), but these calculations are much more detailed than available validating datasets with the exception of top-of-atmosphere fluxes that can be compared with NIMBUS-7 Earth Radiation Budget (ERB) and Earth Radiation Budget Experiment (ERBE) values. These calculations can also be extended to heating/cooling profiles, if enough information about cloud layer structure can be obtained. Aside from continued work on reducing the uncertainties in how ice clouds are to be represented in radiative transfer models, diagnostic studies are possible where measured physical variables are used to calculate flux profiles that are compared with observations of fluxes from the same aircraft or from coordinated aircraft. The most important quantities in terms of uncertainties are ice water content, particle size-shape distributions (shortwave mostly), and small-scale vertical - horizontal structures. Some FIRE III studies will implement improved cloud and surface retrievals and compare the calculated fluxes with available surface and in situ measurements of spectral and broadband fluxes. Such tasks require systematic analyses of the observations from as many instruments over the whole time period as possible, rather than limited case-study analyses.

Other diagnostic efforts for FIRE III include cloud formation/decay processes. Direct diagnosis requires measurements that resolve the relevant space-time scales of atmospheric motions and variations in water, including phase changes and transports from lower altitudes. Such a direct approach may not be entirely feasible at this time, so such studies should be complemented by an indirect approach that examines statistical variations of clouds, water vapor and atmospheric dynamics on larger scales. Modeling studies will apply this approach with information derived from satellite retrievals. Satellites are the best tool for developing larger-scale information, but more diagnostic analyses are needed to obtain information about cloud processes.

5.1. Continued analysis with datasets prior to FIRE III field campaigns

5.1.1 Ground-based and airborne sensors

Datasets taken by ground-based lidars, radars, and radiometers will be analyzed further to examine the vertical and horizontal distributions of ice and liquid water particle sizes and mass content and their radiative effects. These datasets will also be used for satellite algorithm verification and to address the differences between tropical midlatitude cirrus clouds. Table 5.1 lists the FIRE III researchers who will be providing information based on surface remote sensing instruments. Table 5.2 lists the FIRE III researchers who will be providing information based on airborne remote sensing instruments. Table 5.3 delineates the properties that can be derived from these measurements. Table 5.4 identifies satellite remote sensing thrusts.

Table 5.1. Surface remote sensing investigations for pre-FIRE-III

Researchers	Instruments	Data Sets
T. Ackerman	surface radar, lidar, microwave and flux radiometers	FIRE II Cirrus, TOGA/COARE, ARM, PSUCS*
Cox	lidar, IR interferometer, IR radiometer, flux radiometers, wind profiler, rawinsonde	FIRE II, ASTEX
Sassen	surface polarization lidar, flux radiometers, scanning PDL, and 95 GHz polarimetric Doppler radar	FIRE ETO (Utah), FIRE -I, II Cirrus
Uttal	surface radar, lidar, IR radiometer	FIRE-II Cirrus, ASTEX, DOE Pacific Cruise, NOAA Arizona Experiment

* Penn State University Continental Stratus

Table 5.2 Airborne remote sensing investigations for pre-FIRE-III

Researchers	Instruments	Data Sets
Sassen	airborne lidar	TOGA/COARE
Spinhirne	Airborne lidars, Tilt-Scan Camera, microwave and flux radiometers, IR radiometer	FIRE-I and -II Cirrus, TOGA/COARE
Tsay	ER-2 MAS	SCAR-B

These investigators will perform validations of their derived parameters through comparisons with in situ data, other sensors, and satellite data. For example, vertical distributions of cloud phase, particle size, and water content from radar measurements need in situ profiles of similar quantities for verification. Integration of these quantities should match liquid water path retrievals from microwave radiometers. Thus, it is critical that all of the in situ measurements for the experiments in Table 5.1 are analyzed as soon as possible. Initial comparisons between lidar and radar cloud boundaries have already shown some differences between the two types of measurements, apparently due to the different particle size dependencies in the instruments- operating spectral regimes. Airborne lidar and aircraft and satellite thermal radiances provide a check for surface-derived cloud-top altitudes in optically thick clouds. Radar, lidar, and microwave radiometers provide verifications of aircraft-derived phase, particle size, and water path. Sunphotometers and interferometers are used to validate optical depths determined from lidars in thin clouds.

With better quantification of the uncertainties in the surface and air-based remote sensing products, it will be possible to obtain more reliable determinations of the distributions of ice mass in the upper troposphere, of the radiative and microphysical properties of upper tropospheric clouds and how they relate to each other. The measurements taken in most of the experiments in Table 5.2 can be used to develop a very representative statistical base for characterizing mid-latitude clouds. Radar, lidar, and MODIS Airborne Simulator (MAS) data obtained during TOGA-COARE, CEPEX, and the upcoming DOE/NOAA cruise will provide an initial database for characterizing micro physical, radiative properties and spatial variability of tropical cirrus clouds. Because the methods for deriving cloud base and top from radars and lidars are relatively mature, the structural differences between tropical and midlatitude cirrus can be examined in some detail. Although techniques for determining ice mass and ice crystal size distributions are still evolving, it is important to extract as much information as possible on these quantities from the radar and lidar datasets.

Table 5.3. Cloud properties derived from surface and aircraft remote sensing instruments

Cloud Parameter	Instruments
amount	surface radar, lidar; airborne lidar, MAS
top altitude	surface lidar, scanning PDL, and 95 GHz radar; airborne lidar
base altitude	surface lidar, scanning PDL, and 95 GHz radar, ceilometer; airborne lidar
optical depth	surface lidar, sunphotometer; airborne lidar, MAS
phase	surface radar, polarization lidar; airborne lidar, MAS
albedo, reflectance, transmission	surface solar flux radiometers; airborne surface solar flux radiometers, Tilt Scan camera, MAS
emissivity	surface IR radiometer, IR interferometer, flux radiometer; airborne MAS, IR radiometer, IR interferometer
liquid water path	surface radar, microwave radiometer
ice water path	surface radar with IR radiometer or CO_2 lidar
horizontal structure	surface PDL, lidar, radars
vertical structure	surface lidars, radars; airborne lidars

5.1.2 Theoretical studies

The key uncertainties in the representation of clouds in radiative transfer models are three: treatment of ice phase clouds, treatment of small-scale horizontal inhomogeneity, and treatment of cloud vertical structure, particularly phase and particle size changes. Investigations addressing these issues are summarized in Table 5.3. New ice crystal models will be developed for use in satellite retrieval algorithms. Theoretical limitations to retrieval methods will be determined and combinations of remote sensing data and radiative transfer models will be used to develop methods for understanding and accounting for vertical and horizontal inhomogeneities in cloud structure.

The results of the theoretical scattering studies will be tested by some FIRE III laboratory measurements and airborne nephelometer and g-meter measurements as well as by aircraft and satellite multiangle reflectance and polarization data. Studies of new methods for treating vertical and horizontal inhomogeneities will rely on radar, lidar, and satellite radiances and polarization for verification.

Table 5.3. Theoretical studies for remote sensing applications

Researcher	Thrust of Theoretical Research
Han and Welch	Inclusion of effective variance with effective size in particle size retrievals
Liou	Unified theory and methods for computing light scattering properties of ice crystals
Minnis	Sensitivity of effective particle size to vertical distribution of particle size and shape; emittance and reflectance parameterization; angular sensitivity of derived sizes
Mishchenko	T-matrix and ray tracing methods for computing scattering and absorption in ice clouds; test renormalization method for retrieval of cloud inhomogeneities
Wielicki and Cox	Horizontal inhomogeneities in clouds using models and archive data

5.1.3 Satellite analyses

Comparisons of satellite analyses with surface and aircraft measurements taken during FIRE I and II, ASTEX, TOGA/COARE, and CEPEX are being completed to determine the state of the art for satellite cloud remote sensing. Additional studies using these same datasets will the lay the foundation for improved methods that can be tested using measurements taken during FIRE III field programs. The improved methods will be applied to large-area, long-term satellite data to provide climatologies for answering the planning needs of FIRE III and for addressing some of FIRE's main objectives. The FIRE III researchers participating in the analysis of pre-FIRE satellite data for upper tropospheric clouds are given in Table 5.4 with the focus of their research.

Table 5.4. Satellite remote sensing studies for pre-FIRE III datasets

Researcher	Satellite or Instrument Data	Thrust
Han and Welch	AVHRR, ISCCP	climatology, validation
Liou	AVHRR	model validation
Minnis	GOES Imager, AVHRR, SSM/I, SAGE I	climatology, validation,

	and II, GMS, Meteosat, LITE	algorithm development
Mishchenko	ISCCP	model validation
Rossow	ISCCP	climatology, validation
Wielicki	Landsat, LITE	spatial scales, optical properties
Wylie	HIRS, GOES Sounder	climatology

Satellite measurements of temperature and humidity profiles (by NOAA TIROS Operational Vertical Sounder (TOVS) products) and cloud properties (cover, top temperature and height, optical thickness by ISCCP, Rossow and Schiffer, 1991) are routine products, but the accuracy of humidity profiles and cloud properties in the upper troposphere need more work. Results from earlier FIRE observations have already been used to improve the ISCCP retrieval method for ice phase clouds (Minnis et al 1993) and comparisons with Stratospheric Aerosol and Gas Experiment (SAGE) (Liao et al 1995a, 1995b) and HIRS determinations not only quantify the systematic errors in the ISCCP results but also provide, when combined with ISCCP, a good first survey of cirrus occurrence. Methods for retrieval of liquid water cloud, particle sizes (Han et al., 1994, Young et al., 1994) and liquid water path over open water (Greenwald et al., 1993; Liu and Curry, 1994; Lin and Rossow, 1994) are well-developed, but ideas for retrieving the same properties for ice phase clouds (Minnis et al., 1994; Lin and Rossow, 1994) need more thorough testing. Several investigations focus on improving these retrievals and validating them with available pre-FIRE III datasets. A key analysis concept that may improve analyses of upper tropospheric clouds is to analyze observations from many different instruments. In particular, the combination of multi-channel optical and microwave imagers and infrared and microwave profilers has been suggested by some work, e.g. (Baum et al., 1992; Baum et al., 1994) but is not fully developed. Several FIRE III investigations focus on this possibility. Successful developments in this case will provide the first comparisons of the properties of upper-level clouds between polar, midlatitude and tropical regions and an assessment of their seasonal variations. The primary obstacle to progress is lack of complete enough observations for validation of the retrieval methods.

Multi-angle spectral measurements of polarization as well as radiance will be provided by POLDER on ADEOS and EOSP on EOS AM-2. It has been demonstrated that polarimetry is a promising remote sensing technique for retrieving cloud and aerosol characteristics such as optical thickness, cloud top altitude, and particle phase and size (e.g., Goloub et al., 1994; Mishchenko et al., 1996). Additional studies are necessary to further develop and validate polarization retrieval algorithms and to examine the sensitivity of the retrieved characteristics to measurement accuracy.

Validations of the satellite retrievals will use both direct and indirect methods. Direct comparisons with in situ data will be exploited whenever possible using appropriate statistical methods to account for spatial and temporal sampling characteristics. Cloud fraction, top and base altitudes, emissivity, albedo, liquid water path, ice water path, and optical depth will be evaluated through direct comparisons with the results from the measuring instrument in many cases. Other techniques such as multiangle views from various platforms will be used to test limitations and uncertainties in retrievals of several parameters such as cloud amount, effective particle size, and optical depth.

Combined remote sensing datasets will be developed to improve the retrieval of quantities such as ice and water paths, cloud thickness and base, and cloud overlap. Considerable effort will be used to devise new techniques for estimating these parameters and for determining the cloud properties in multilayer and mixed phase conditions.

Datasets consisting of validated retrievals will be developed at time and space resolutions desired by FIRE III modeling investigators for use in diagnostic and cloud process studies. Such datasets will primarily be focused on the field programs, but may include longer time periods. The application of the retrieval algorithms to large time and space datasets will provide some direction for a later tropical cirrus campaign and a large-scale evaluation of differences between tropical and midlatitude cirrus clouds. Other more detailed satellite analyses will provide additional insight in latitudinal cirrus variations.

FIRE III encourages the use of additional satellite instruments to address the FIRE III upper tropospheric cloud issues. The only satellite instruments that have been extensively used to study upper-level cloudiness are the imaging radiometers and infrared sounders on the polar orbiting and geostationary weather satellites. The Along-Track Scanning Radiometer (ATSR) sensor is a different type of imaging radiometer in that it provides multi-angle measurements, but these data have not been released. For many years, several passive microwave instruments have been making measurements that, together with the imagers and sounders, might be analyzed together to increase retrieved information. The microwave instruments may not sense the clouds themselves, but they can help separate upper-level ice clouds from lower-level liquid water clouds and improve cloud-clear discrimination in complicated situations. One or two preliminary studies like this have been done with the Special Sensor Microwave/Imager (SSM/I) (Liu and Curry, 1994; Lin and Rossow, 1994), but SSM/T and the new SSM/T2 have not been used before.

5.2 IMPLEMENTATION STEPS:

- Design and conduct investigations that integrate a comprehensive collection of coincident observations from aircraft, the surface and satellites where similar or "identical" quantities are retrieved.

- Maintain close collaboration between modeling and remote sensing investigators to insure maximum utilization of remote sensing data.

- Seek to establish how ice clouds may be most effectively and efficiently represented in radiative transfer models. Specifically:

    - small scale horizontal inhomogeneity
    - cloud vertical structure
    - phase and particle size/shape changes

- Provide validated retrievals of ice cloud and environmental parameters to FIRE III modeling investigators for use in diagnostic and cloud process studies.

- Explore the application of additional satellite data such as ATSR and passive microwave radiometry to upper tropospheric cloud issues.

- Conduct studies which examine the statistical variability of clouds, water vapor and atmospheric dynamics on larger scales in the tropics.

6.0 GCMS AND FIRE III

Mesoscale anvil clouds are emerging as one of the key unknowns in the assessment of the tropical equilibrium energy budget and its fluctuations on interannual and longer time scales. Unlike optically thin cirrus, cumulus anvils have a substantial shortwave as well as longwave impact, and so the sign of feedbacks due to changes in these clouds is far from obvious. Unlike the deep convective clouds with which they are associated, anvils occupy a sufficiently large area of the tropics to affect the planetary radiation balance. Because of their large physical thickness relative to other cirrus, the vertical structure of their microphysical characteristics and resulting radiative flux profiles may be complex and thus are not easily determined by remote sensing alone.

It has been proposed that tropical sea surface temperatures (SSTs) in the current climate are limited by shortwave reflection from convectively generated anvils (Ramanathan and Collins, 1991), although the importance of this mechanism to seasonal and interannual variations of SST is a subject of controversy (Wallace, 1992; Fu et al., 1992; Hartmann and Michelsen, 1993; Fu et al., 1994; Liu et al., 1994). Idealized climate-change simulations with some general circulation models (GCMs) have further demonstrated that changes in cumulus anvil radiative properties can significantly alter the global climate sensitivity, depending on the nature of the interaction between the convection, the underlying SST, and the tropical general circulation (Del Genio, 1995).

Compared to the relatively thin cirrus observed during the FIRE-I and FIRE-II field campaigns, cumulus anvils have significantly higher ice water contents (Churchill and Houze, 1984) in addition to being physically thicker and are therefore optically thicker. Furthermore, anvils are subject to qualitatively different dynamical forcing than are other cirrus: mesoscale updrafts, driven in part by condensation and radiative heating within the anvil, control their radiative properties, while the midlatitude cirrus of FIRE-I and -II were controlled instead by synoptic-scale dynamical phenomena driven by unrelated energy sources. Finally, unlike their thin cirrus counterparts, cumulus anvils have an important external source of cloud water and ice, in the form of condensate detrained from adjacent or embedded cumulus updrafts (Gamache and Houze, 1983; Heymsfield and Platt, 1984; Churchill and Houze, 1984; Heymsfield and Miloshevitch, 1995). Hence, it is unlikely that the microphysical and radiative properties of cirrus observed by FIRE-I and -II can simply by extrapolated to higher ice water contents to characterize the properties of anvil clouds, and it would be dangerous for cloud parameterizations in numerical models to assume that such extrapolations are sufficient to deal with the problem. Because of these distinctions, we must observe both the anvil microphysical and radiative properties, and the dynamical environment in which they are created and then dissipate, to understand how they differ form other high clouds.

Observational studies (Leary and Houze, 1980), along with cloud-system-resolving models (Sui et al., 1994; Cotton et al., 1995) and new developments in cumulus parameterizations for GCMs (Donner, 1993a), suggest a general hypothesis regarding the radiative properties of anvils. **The hypothesis is: The radiative properties of cirrus anvils are primarily controlled by the mass fluxes and vertical velocities in associated cumulus convection.** This hypothesis is consistent with highly active dynamics in the mesoscale precipitating and non-precipitating cloudiness associated with the convection. While these constitute the primary controls, other factors, such as mesoscale ascending motions slant wise in stratiform anvils, thermal stratification and moisture characteristics in the volume where the anvil forms, also play roles. Since ice can be transported great distances under some circumstances, even cirrus clouds which appear to be detached from convection are likely to require an understanding of the convective anvils treated by this hypothesis, since these anvils are the ultimate source for much of the water vapor and ice for the detached cirrus. However, the large-scale environment, such as humidity and vertical motion, also affect the characteristics of cirrus anvils.

We propose that a FIRE tropical cirrus experiment be designed to test this hypothesis. In the process of doing so, an unprecedented characterization of convective anvils and their sources and sinks will be obtained. This hypothesis provides a direct basis for the development of GCM parameterizations for convective anvils (Donner, 1993b). These anvil parameterizations require both cumulus parameterizations and treatment of ice advection and microphysics as well as vertical velocities. Some basic elements of this hypothesis have been tested in the cumulus parameterization at the European Centre for Medium-Range Weather Forecasts (Christian Jakob, personal communication), and there are plans to use the Donner (1993a, b) parameterization in a GFDL GCM shortly.

The basis for the convection/cirrus hypothesis lies in observational studies which show substantial phase changes and water transport at the scale of both cumulus cells and mesoscale cirrus anvils. These studies also indicate substantial transport of water from the cumulus cells to the anvils. Since this water transport includes both condensate and vapor, in situ condensation within the anvil controlled by vertical motions therein plays a critical role in determining its microphysical and radiative properties. These results have also been obtained with cloud-system-resolving models. The keys to quantifying the water transport from the cumulus cells to the anvils are the mass transport in the cumulus convection and the microphysical characteristics of the water transported in the cumulus cells. The latter can be inferred from microphysical theory, but the vertical velocities at cumulus scale are required to do so. Mesoscale ascending motions play a key role in determining in situ condensation and deposition.

Earlier cumulus parameterizations have been somewhat successful in producing diagnosed large-scale heat sources and moisture sinks (which represent the sum of phase changes and eddy transports) without including mesoscale anvils, but this may have been a result of substituting excessive cell scale activity for the absent mesoscale activity. Although the consequences may have been limited with respect to heat sources and moisture sinks, this is not true for radiative forcing associated with cirrus anvils. Treatment of the latter problem will require parameterizations that treat the transport of water vapor and condensate at the cell scale accurately. This will be true whether the anvils are parameterized as subgrid phenomena in coarse-resolution GCMs or the anvils are calculated using prognostic microphysical equations in very-high-resolution GCMs.

To test the convection/cirrus hypothesis, simultaneous characterization of several statistical properties of deep cells and cirrus properties is required. To characterize deep cumulus cells, information on cell scale mass fluxes, vertical-velocity distributions, liquid and ice contents, turbulent kinetic energy, precipitation fluxes, and particle sizes is required. For the mesoscale anvils, information on mass fluxes, vertical velocities, ice content, particle sizes and habits, phase functions, radiative fluxes, and spatial variability is required. Vertical profiles are desirable. For the convective system as a whole, information on the large-scale apparent heat source and moisture sink is required. Platform and instrument availability will constrain the accuracy and level of detail with which these quantities can be inferred. For many quantities, statistically significant samples are adequate.

The information on deep cumulus cells will permit assessing the portions of the convection/cirrus hypothesis regarding the major water sources for the anvils. Cell scale mass fluxes have long been established as an important control on thermal and moisture interactions between convection and larger scales (Arakawa and Schubert, 1974). Donner (1993a) showed that, by adding vertical velocities at cell scale, microphysics parameterizations can be used to determine the water supply for convective anvils. Information on anvil mass fluxes, vertical velocity, and water content can be used to examine anvil water budgets and their relationships to deep cells (Leary and Houze, 1980). Anvil ice contents, shapes, and sizes can be used to calculate radiative fluxes (Liou et al., 1991; Mitchell and Arnott, 1994). Horizontal variability on scales below those of GCM grids can be important in determining GCM-scale properties due to the nonlinearity in many microphysical and radiative processes. It is important to diagnose large-scale heat sources and moisture sinks because they provide critical closure on the aggregate effects of convective systems (Thompson, 1979).

Since much of the cirrus with strong radiative forcing occurs in the tropics, there is a preference to site the experiment there. Both land and oceanic convection are important (Brazil, western Pacific). However, this may entail great expense for logistical reasons. There is presently no set of experimental data with the simultaneous measurements required to test the convection/cirrus hypothesis. Therefore, a mid-latitude experiment would also provide valuable data, should the tropical location not be feasible.

6.1 IMPLEMENTATION STEPS:

- Reexamine historical cirrus data sets for supporting evidence of the hypothesis: "that the radiative properties of cirrus anvils are primarily controlled by the mass fluxes and vertical velocities in associated cumulus convection." Concurrent satellite-radar data may be helpful.

- Integrate testing of the above hypothesis into the design of a FIRE III cirrus campaign.

- Design a future FIRE Science Team (FST) meeting to specifically address the interface between the modeling and experimental FST constituencies.

7.0 TROPICAL CIRRUS EXPERIMENT

7.1 Background

Tropical cirrus are a ubiquitous feature of the tropical atmosphere. Satellite and shuttle observations suggest that the fractional coverage of cirrus in the tropics is in excess of 60% (Liao et al., 1995a; Wylie, 1994; Winker et al., 1995). Although the formation of cirrus is generally related to deep convection, their lifecycle is complex and poorly understood, being influenced both by local and large scale controls. Our understanding of cirrus lifecycle and properties is limited to a large extent by a lack of observations. The discussion below outlines some of the unique characteristics of tropical cirrus and the need for a focused experimental program.

In order to simplify our discussion, we have adopted the following definitions of cloud types: (a) isolated cirrus: high-level ice clouds isolated in space and time from cumulus convection rooted in the boundary layer; (b) non-precipitating anvil: high-level ice cloud contiguous in space and/or time with cumulus convection rooted in the boundary layer but not precipitating; (c) precipitating anvil: the same as the previous category but precipitating stratiform regions, and possibly including mixed phase microphysics; (d) cells: deep cumulus convection elements rooted in the boundary layer. The generic term "anvil" includes both categories (b) and (c). "Isolated cirrus" can be the debris left by decayed cumulonimbi and mesoscale convective systems or can be cirrus formed in situ (perhaps aided by moisture pumped by active systems days prior) by large-scale vertical motions or radiation/turbulence interactions. The optical thickness of non-precipitating anvil and isolated cirrus may vary considerably from quite thick to tenuous in the case of extensive invisible cirrus' (Prabhakara et al., 1993; Barton, 1993). "Precipitating anvils" are generally associated with dynamically active mesoscale convective systems where the term "precipitating" refers to liquid or ice water substance that actually arrives at the ground. "Attached anvils" are defined as anvils linked at a given time to cells, while "detached anvils" are identifiable anvils produced by earlier cells or MCCs that may have subsequently dissipated.

7.2 Tropical cirrus versus midlatitude cirrus

Tropical cirrus clouds are unique and important in a number of ways:

Tropical cirrus are partly a product clouds directly affect both thermal and solar radiative transfer through their optical properties. (This broad effect is often referred to as cloud-climate radiative forcing.) Unlike mid-latitude cirrus, the large extent of these clouds, as well as their vertical location, imposes large scale radiative effects at the surface and in the atmosphere. Climate model simulations of the tropospheric component of the cloud radiative forcing indicate net heating of the atmosphere. Various studies suggest that the longwave heating of cirrus is a principal component of this net heating and that the amount of this heating is sensitive to the optical properties and altitude of the cirrus (e.g. Ackerman et al., 1988; Stackhouse and Stephens, 1991; Fu and Liou, 1993, Wong et al, 1994). Because of the high altitude and cold temperature of tropical cirrus, the effects of cirrus on the radiative budget of the atmosphere are thought to be more pronounced in the tropics than in midlatitudes.

Tropical cirrus are a product of the transport of water from the tropical boundary layer to the upper troposphere via deep convection. The feedback between the concentration of water vapor in the upper troposphere and other changes in the physical climate system is a crucial issue. Both the effect of clouds on radiation and the effect of clouds on the water budget are controversial issues and our understanding of them is poorly constrained by the existing observational data. Little or no data exist relating tropical cirrus to a regional water budget, whereas results from the recent FIRE I and II experiments, as well as a higher density of conventional observations in midlatitudes, has enhanced our understanding of midlatitude cirrus.

It has been suggested that tropical cirrus clouds produce a particular kind of feedback in the context of climate change. For example, cirrus clouds concentrated over the Pacific warm pool associated with the deep convection are thought to impact significantly the surface energy budget by reducing the amount of solar radiation reaching the ocean surface, thus creating a feedback loop among clouds, radiation, and SST (Ramanathan and Collins, 1991). Also, the atmospheric radiative heating produced by these clouds is thought to feed back onto large scale stability and convection (Fowler and Randall, 1994). Both effects (one in the atmosphere and one at the surface) are central to cloud-climate feedback mechanisms. The low temperatures of tropical cirrus impact cirrus microphysics and, consequently, cloud albedo and the infrared radiative exchange.

7.3 Key issues and questions

- What is the relationship between upper tropospheric cirrus and mesoscale convection? How do we parameterize the lifecycle of cirrus and its impact on large-scale forcing in the context of climate models?

- What is the impact of cirrus on the upper tropospheric water budget? What are the distributions and amounts of ice mass and total water in the upper tropical troposphere?

- What are the relationships between cloud microphysics and radiative properties? To what extent do the radiative properties of these clouds depend on environmental conditions including the extent of the surrounding deep convection? What are the microphysical properties of tropical cirrus and how are these related to their environment?

- What is the impact of cirrus on the tropical radiation budget? Are current model parameterizations an adequate representation of tropical cirrus effects?

- To what extent and with what accuracy can the properties of cirrus be determined by satellite remote sensing? Are there new techniques and instruments that can be applied to the problem?

7.4 Limitations of past experiments

Very limited coincident data on ice microphysics, radiation, and environmental parameters for tropical cirrus exist at this point. Although some microphysical and radiation data are available from GARP Atlantic Tropical Experiment (GATE), TOGA COARE and CEPEX, they are extremely limited. Because of the limited ceiling of the DC-8 (10 - 11 km) and Lear Jet (13 km) which were used in the TOGA-COARE and CEPEX experiments, complete profiles of ice microphysics could not be obtained. The sampling strategies did not address the lifecycle (formation, maintenance, and dissipation) of cirrus. Sampling of the regional environment was not of sufficient density to allow studies of the water budget of the tropical upper troposphere and theoretical interpretation of the radiometric measurements is limited due to the lack of adequate microphysics observations. These experiments were also not closely coordinated with the orbiting meteorological satellites, notably the NOAA series, so that remote sensing validation was highly problematic. Finally, these experiments were primarily focused on an understanding of surface heat fluxes and convection (COARE) and large-scale statistics (CEPEX). Consequently, the volume of data that is directly applicable to the cirrus radiation and microphysics problem is extremely limited. While it is imperative that these data be analyzed, a coordinated and comprehensive experiment focusing on the tropical cirrus is urgently needed in the near future to answer many very fundamental questions.

7.5 Experimental Design

The preceding discussion provides a framework within which we can now outline a hierarchy of tropical cirrus experiments of increasing complexity and demand on resources.

7.5.1 Ground-Satellite Remote Sensing Experiment

The continuing acquisition of coordinated ground based and satellite remotely sensed tropical cirrus data and the analysis of previously acquired data from FIRE II, TOGA-COARE, CEPEX and ARM will provide valuable information on the radiative, microphysical and spatial properties of tropical cirrus cloud systems. The successful analysis of these data sets depends upon an opportunistic selection of cases where cirrus clouds are present over the ground based locations. The ARM deployment in Kavieng is probably the most ideally located site in terms of deep tropical convection and its anvil outflow. However, in summertime, midlatitude locations typically experience episodic "tropical conditions" with high humidities and tropopause heights in excess of sixteen kilometers; these opportunities may be exploited on a case by case basis by individual or small groups of investigators as we build our tropical cirrus database. While ground based systems lack the maneuverability afforded by aircraft, these sites afford a rather complete suite of observations extending over a considerable depth of the atmosphere. The availability of coincident surface based radiation measurements (from solar through microwave wavelengths), lidar measurements, rawinsonde measurements and satellite observations over an extended period of time from multiple locations would represent a powerful set of data. Of course this ground-satellite experiment can be optimized by the addition of in situ aircraft observations of cloud microphysics.

Table 7.1 - Ground Satellite Experiment Measurement Requirements

Minimum	Desirable
Satellite Geostationary imagery	microwave, water vapor imagery infrared temperature, temperature retrievals, radiation budget, multispectral imagery
Surface Lidar, spectral radiation (solar and infrared), fluxes, rawinsonde	cloud radar, profiler, DIAL
In situ	Aircraft with the following: complete microphysics, spectral radiation, water vapor

7.5.2 A Radiation-Microphysics Experiment-An in-situ Experiment

This experiment is aimed at understanding the relationship between the microphysics and the radiative properties of tropical cirrus cloud systems.; in essence, this is an experiment intended to describe the nature of tropical cirrus. The targets of this experiment is isolated and non-precipitating anvil cirrus. The fundamental strategy is the concurrent measurement of cirrus microphysics and radiative properties by aircraft with simultaneous remote sensing by satellite. The experiment is best carried out over the ocean to take advantage of the well-characterized and uniform background of the sea surface.

Resources required for such an experiment are two aircraft, one to serve as a local remote sensing platform, as well as measure the radiative fluxes above cloud, and the second to serve as an in situ platform for microphysics and, alternatively, to measure fluxes below cloud. US scientific aircraft which would fulfill these requirements include the NASA ER-2 and NCAR WB-57. Instrumentation needed for the ER-2 includes active remote sensors such as the Doppler cloud radar and cloud lidar, a scanning imager such as the MAS, and broad-band and narrow-band flux radiometers. The cloud radar, especially 95 Ghz, can be used to address the issue of the water budget by using reflectivity and vertical velocity to map out the ice water content distribution across the entire range of cirrus right into the cell itself. The WB-57 needs instrumentation to measure the complete size distribution of cirrus crystals, ambient meteorology, and broad and narrow-band fluxes. There is also a critical need for turbulence information within the cirrus. Dropsondes capability are under consideration to be included, however a network of rawinsonde stations surrounding the area of flight operations would be preferred. Flight coordination with both geostationary and polar orbiting satellites is also a necessity.

The location of the experiment is relatively flexible as long as it occurs in a region of prevalent deep convection, preferably over open ocean.

Table 7.2 - Radiation-Microphysics Experiment Measurement Requirements

Minimum	Desirable
Satellite Geostationary imagery	Microwave, water vapor imagery infrared temperature, temperature retrievals, radiation budget, multispectral imagery
Surface	Lidar, spectral radiances (solar and infrared), fluxes, rawinsonde, cloud radar, profiler, DIAL
In situ: Aircraft with the following: complete microphysics, spectral radiation, water vapor (DC-8, WB-57) Aircraft with a complement of remote sensing radiation observations (ER-2)	Dropwinsondes

7.5.3 Evolution of Non Precipitating Anvil and Isolated Cirrus Layers

The next experimental step is to investigate the evolution of non-precipitating anvil and isolated cirrus. The goal of this experiment is to understand the lifecycle of tropical cirrus from formation to dissipation. Observation of tropical cirrus, particularly from the vantage point of satellite, shows its longevity, evolution, and formation in the upper troposphere. The mechanism of formation apart from deep convection may be either radiative forcing within an existing cirrus layer or forcing of moist layers by large-scale dynamics. In either case, the long lifetime and formation issues are climatologically important because they exert a strong influence on the overall radiative impact of the cirrus. Required observations include all the microphysics and radiation of the previous experiment, but these observations are now needed in a temporally constrained fashion that follows the evolution and development of cirrus from its initial extrusion from a convective system or in situ formation through its demise. Furthermore, because the environment plays a significant role in this lifecycle, observations of the upper troposphere meteorological properties are needed.

The resources needed for this experiment include both the ER-2 and WB-57 with the instrument complement noted earlier. Another possible alternative is to measure water vapor by DIAL since reliable measurements of upper troposphere relative humidity are a crucial, and difficult, requirement. The incorporation of the NCAR Electra with the Electra Doppler Radar (ELDORA), or possibly one of the NOAA P-3s with Doppler radar, to this experiment is a powerful addition. ELDORA is capable of mapping the dynamics of convection both within cells and precipitating anvil regions. In addition, a first order estimate of ice mass can be made from the reflectivities. This addition permits an investigation of the convective processes leading to the non-precipitating anvil formation and a good estimate of the amount of ice in that anvil. Satellite remote sensing is an integral component of this experiment in order to place the aircraft operations in the context of the cirrus evolution.

The preferred location for such an experiment is again over the ocean because flight operations are generally easier in that environment and remote sensing from above is simplified by the ocean background. Convection also is generally less intense in an oceanic environment, which makes flight operations somewhat safer for the tropospheric aircraft.

Table 7.3 - Evolution Experiment Measurement Requirements

Minimum	Desirable

Satellite Geostationary imagery	Microwave, water vapor imagery infrared temperature, temperature retrievals, radiation budget, multispectral imagery
Surface	Lidar, spectral radiances (solar and infrared), fluxes, rawinsonde network, cloud radar, profiler network (3), DIAL
In situ: Aircraft with the following: complete microphysics, spectral radiation, water vapor (DC-8, WB-57) Aircraft with a complement of remote sensing radiation observations (ER-2)	Aircraft Doppler radar w/lidar (NCAR Electra) Dropwinsondes

7.5.4 Convection-Cirrus System Experiment

The most complete level of characterization of anvils requires certain information about the cells and precipitating anvils in addition to the information described above for non-precipitating anvils and isolated cirrus. The cells comprise the major water source for the anvils. Both vapor and condensed water are important, and the water source may be direct or indirect. ("Direct" refers to the horizontal transport of condensate into an attached anvil; "indirect" refers to condensation of vapor in the active anvil or total water generally in the detached anvil.) Knowledge of the water source is critical for calculating the microphysical and radiative properties of the anvils.

The additional information required for this level of characterization includes information on cell-scale mass fluxes, vertical velocity distributions, liquid and ice contents, and particle sizes. To characterize the convective system as a whole, the large-scale heat source and moisture sink are required. The information required to calculate the large-scale source and sink includes local temperature and moisture tendencies, and temperature and moisture advection averaged over spatial scales of 100-200 km with temporal resolution on the order of a few hours. The heat source and moisture sink are computed as the residuals when these large-scale contributions to the budget are summed and are assumed to represent the aggregate effects of the smaller scale motions on the large scale. In addition, for anvils, information on mass fluxes, vertical velocities, ice content, particle sizes and habits, phase functions, radiative heating profiles, and spatial variability of these quantities is required.

This level of characterization clearly involves cell-scale information and large-scale atmospheric characterization that FIRE by itself is not well-suited to obtain. Collaboration with a large-scale experiment would therefore be necessary to implement the complete experiment as described. But we underscore that this level of characterization does not presently exist from any field experiments that have been conducted to date. (Previous experiments have focused on either convection or cirrus in isolation but have not recognized that anvil cirrus are intrinsically linked to convection and cannot be studied meaningfully in isolation.) Satellite and GCM studies indicate that this is the predominant component of the radiative forcing in the tropics and that the forcing is sensitive to perturbations in this process.

The resources needed for this experiment from the FIRE perspective include the ER-2, WB-57, and Electra discussed above. In addition, a platform, such as possibly the DC-8, is required to make the penetrations of the precipitating anvil and cells required to document the microphysical properties and radiative heating profiles in these regions. Measurement needs include standard microphysical instruments and flux radiometers, but also include precipitation radar and microwave radiometers to assess the hydrologic budget with the cells and precipitating anvils, see Table 7.4.

The location of such an experiment is problematic. In order to characterize the atmosphere at the required detail, this experiment would almost certainly require land-based instrumentation. However, land convection tends to be more intense with stronger updrafts and a propensity for lightning. This in turn makes the aircraft operations more difficult and may preclude penetration of the cells themselves, but not of the precipitating anvil. One possibility is a monsoonal flow environment where the convection may be less intense than in more isolated land convection.

Table 7.4 - Convection Cirrus System Experiment Measurement Requirements

Minimum	Desirable
Satellite Geostationary imagery	microwave, water vapor imagery infrared temperature, temperature retrievals, radiation budget, multispectral imagery
Surface Lidar, spectral radiances (solar and infrared), fluxes, rawinsonde network	cloud radar, profiler network (3), DIAL
In situ: Aircraft with the following: complete microphysics, spectral radiation, water vapor (DC-8, WB-57) Aircraft with a complement of remote sensing radiation observations (ER-2)	dropwinsondes Aircraft Doppler radar w/lidar (NCAR Electra)

7.5.5 Ground-based Remote Sensing

The most appropriate role of ground-based remote sensing in ocean based tropical experiments is difficult to assess. To a very large extent, the utility of ground-based systems will be determined by the specific location and objectives of the proposed experiment. The strengths of ground-based remote sensing are the continuity of the data record, the ability to provide a complete altitude coverage from near ground to the tropopause and the capability of clustering many different types of instrumentation which may not be adaptable to aircraft. The biggest difficulties encountered with ground based observations in maritime tropical field experiments are the expense of site preparation and deployment and the uncertainty of cirrus cloud occurrence over a specific geographic point during the course of the experiment. The latter issue represents a significant problem in the case of limited time and space deployments. Because the location of convection maybe somewhat random in nature and movement of convection can be slow or practically non-existent, one can imagine a situation in which a ground site was largely devoid of thick anvil coverage for the majority of a month-long campaign. When selecting locations for surface based installations, it is critical that a climatology of cirrus clouds, likely constructed from satellite data, be used. While this offers no guarantee of cirrus cloud occurrence in the future, it is probably the best guide to surface site selection. In order to meet the requirement of measuring the regional thermodynamic and dynamic environments, these surface sites should include rawinsonde and 400 or 90 MHz wind profiler observations.

7.5.6 Summary of Four Tropospheric Cirrus Experiments

The importance of upper tropospheric clouds in the understanding and simulation of the Earth's climate demands a focused modeling and observation/analysis research program. This program must satisfy the needs for improvements in capabilities for remote sensing both from space and from the surface, in basic understanding of physical processes contributing to evolution of the clouds, in knowledge of the cloud radiative and microphysical properties and the relationships between, and in the representation of theses clouds in large-scale models used for climate simulation.

A key area where improvements are critically needed is for tropical cirrus clouds. This conclusion arises both from their importance to the global climate system and the lack of adequate observations. In particular, tropical cirrus are highly coupled to deep convective systems which supply copious ice and vapor mass to the upper troposphere. Significant advancement in understanding of the physical processes and in the treatment of tropical cirrus in large-scale models critically depends on the acquisition and analysis of appropriate observations. Specifically, quantitative observations of the convective mass flux in relationship to the ice mass detrainment into the anvil are sorely needed.

Four distinct and graduated observational approaches were defined in this Implementation Plan. They differ in scope and scientific emphasis. While each observational approach offers significant contributions to achieving FIRE III objectives, it is the strongly held position of the FIRE Science Team that a minimum requirement to address the key issue of tropical cirrus clouds is to implement the “cirrus evolution” experimental approach. The “cloud system approach offers additional and substantive advantages such as definition of convective mass flux in relationship to large-scale environmental conditions and integration to the cloud system scale. This is highly desirable for the purpose of parameterization development and even more important for model validation. Ideally, the “cirrus evolution” approach is fully incorporated within the “cloud system” approach in a single coordinated observational/analysis effort.

Conduct of the recommended experimental approach does not preclude the other observational approaches. Theses may be of particular benefit if an early implementation can be achieved. However, the FST emphasizes the importance of conducting the combined evolution/cloud system program because this is the only avenue which affords the opportunity to achieve the FIRE III objectives. Table 7.5 summarizes the objectives addressed by each of the four component observational programs. On a more global scale, the FIRE III science team notes that no other currently proposed research plan within NASA or by other agencies addresses the tropical upper tropospheric cloud issue with sufficient focus to provide the progress required to monitor and to effectively include those clouds in contemporary GCM and climatic models.

Table 7.5 - Experiment Objectives for Four Candidate Experiments

	Remote Sensing	Basic Understanding of Evolution	Radiation and Microphysics	Large-Scale Model Parameterization
Ground Satellite Remote Sensing Experiment	√		/	
A Radiation-Microphysics Experiment - An In-Situ Experiment	√	/	√	/
Evolution of Non-Precipitating Anvil and Isolated Cirrus Layers	√	√	√	/
Convection-Cirrus System Experiment	√	√	√	√

7.5.7 Collaborative Programs

The cost and complexity of tropical deployments makes it almost inevitable that FIRE must develop collaborations with other interested parties. The simplest radiation-microphysics experiment involves a collaboration between NASA and NCAR such as proposed Panama experiment in 1997. Increasing the resource requirements for more complex experiments increases the need for shared resources. In particular, the complete life cycle experiment requires collaboration with a large program such as LBA, which is aimed at understanding surface and meteorological components of the hydrologic cycle. FIRE, because of its developed expertise in clouds and radiation, can contribute a great deal to such efforts. An active component of the planning of any FIRE tropical experiment must be the search for other interested collaborators.

7.6 IMPLEMENTATION STEPS:

- Continue analysis of previously collected data on tropical/subtropical cirrus cloud systems.

- Continue instrumentation and technique development to observe and/or infer radiative and microphysical properties of cirrus clouds.

- Continue collection of radiative and microphysical data on tropical and subtropical cirrus cloud systems on a target of opportunity basis.

- Develop monthly upper tropospheric cloud climatologies from historical satellite data over the region extending from 10°S to 30°N latitude and from 35°W to 135°W longitude.

- Determine collaborative possibilities with other programs such as LBA in order to optimize scope of a FIRE III cirrus campaign.

- Design a modular FIRE III cirrus field experiment capable of addressing the scientific questions outlined in Sections 1 - 6.

- Submit a letter of intent to the NSF OFAP by June 1996 indicating the likelihood of a request to use the WB-57 and the Electra in a 45-day tropical cirrus field campaign in CY 1999.

- Submit a letter of intent to NASA by June 1996 indicating the likelihood of a request to use the ER-2 and DC-8 in a 45 day tropical cirrus field campaign in CY 1999. The NCAR WB-57, NCAR Electra, NASA ER-2, and NASA DC-8 would be part of a Convective Cirrus experiment (section 7.5.4).

8.0 SUCCESS

The Atmospheric Effects of Aviation Program (AEAP) SASS program sponsored by the NASA Office of Aeronautics will conduct the SUCCESS field mission in April 1996 based in Salina, Kansas. FIRE Cirrus and the NASA Radiation Science Program is a full partner in this campaign. In addition, planned flight operations will be focused on the ARM Cloud and Atmospheric Radiation Testbed (CART) site near Lamont, Oklahoma, where the usual ARM ground-based instrumentation will be supplemented by various active remote sensors (95 GHz radar and dual-polarization lidar) and coordinated with a UAV Intensive Observation Period (IOP) focused on cloud radiative properties.

The goals of SASS are to assess the present and future impact of the subsonic aircraft fleet on the Earth's radiation budget and climate. Areas of prime concern for the SUCCESS mission are:

- radiative effects of contrails,

- direct radiative effects of aircraft exhaust (water vapor, soot, etc.),
- indirect radiative effects of aircraft exhaust through modification of cirrus, and
- resultant changes in radiatively active gases such as ozone.

FIRE's interest is primarily in the remote sensing and impact of contrails and in the potential impact of aircraft exhaust on cirrus. Contrails provide a very interesting remote sensing target. Early in their lifetime, they exhibit a very high density of very small particles and relatively large optical depth in contrast to more generic cirrus. These properties evolve in time and persisting (spreading) contrails appear to lose this distinct identity as time goes on. From a remote sensing perspective, they present an extreme cases for detection of high altitude ice cloud properties. Assessment of the global radiative impact relies on satellite-based detection of contrail coverage and radiative properties, which is a significant challenge given their small transverse scale.

Direct contrail modification of ambient cirrus is also an issue of concern. Potentially more significant are the effects of aircraft emissions on the aerosol budget of the upper troposphere and its potential widespread effect on cirrus cloud microphysical and radiative properties by altering the relative importance of the operating nucleation modes (ice nuclei versus homogeneous or heterogeneous nucleation). Such an aerosol effect has been well-documented for stratus clouds during FIRE Stratus and ASTEX and has long been evident in the contrast between continental and maritime clouds in the lower troposphere. Sassen et al. (1995) present results indicating a strong modification of cirrus associated with incorporation of volcanic aerosol into a cirrus cloud during FIRE Cirrus-II. By analogy, aircraft effects on the upper tropospheric aerosol budget, that preliminary assessments indicate is quite significant on a global basis, could have a similar effect. On a more fundamental level, modeling studies using FIRE Cirrus-II data have reached the point where more detailed knowledge of the operating nucleation modes are essential for further progress, i.e., -reasonable assumptions about nucleation mode can significantly impact the results (Jensen et al., 1994) and present data is inadequate to resolve this issue. Thus, SASS presents a good opportunity to advance basic knowledge about this important aspect of cirrus clouds. In addition to potential aircraft effects, assessment of possible global impacts due to volcanic activity also require increased knowledge of cirrus cloud microphysical processes and their relationship to aerosols (Song et al., 1996).

The FIRE contribution to SUCCESS is comprised of the NASA ER-2 platform and associated instruments and investigators, i.e.,

- MAS
- High-spectral resolution Interferometer Spectrometer (HIS)
- Radiation Airborne Measurement System (RAMS)
- Cloud Lidar System (CLS)
- Microwave Imaging Radiometer (MIR)
- Tilt-scan CCD Camera
- RC-10 Camera

This instrument package is nearly identical, with some improvements, to that employed for FIRE Cirrus-II. The MIR is a new addition that was flown during TOGA-COARE but that has now been enhanced through the addition of an additional high frequency (325 GHz) channel for the detection of cirrus ice water content. It is expected that a significant portion of the SUCCESS missions will involve measurements of cirrus in addition to contrail missions. Some remote sensing missions will be flown over the Gulf of Mexico to address specific remote sensing issues for FIRE Cirrus, specifically evaluation of the high frequency microwave observations and observations of cloud bi-directional reflectance using the Tilt-scan CCD Camera in conjunction with the other measurements enabling estimation of cloud optical depth and particle size.

The NASA DC-8 will be the primary in situ observing system and is sponsored by AEAP/SASS. Some FIRE investigators are also sponsored under SASS and will be participating on the DC-8 during SUCCESS. Some of the ground-based instrumentation are also sponsored, at least partially, by SASS. The DC-8 instrumentation includes in situ measurements of:

- standard meteorological parameters (e.g., temperature)
- water vapor (multiple techniques)
- aerosol size distribution and composition, including Cloud Nuclei (CN), Cloud Condensation Nuclei (CCN) and ice nuclei, by a variety of sensors
- ice particle size distributions, including replicators
- cloud ice water content (new NCAR counterflow virtual impactor (CVI) and Gerber probe)
- ice crystal scattering phase function by nephelometer
- a variety of chemical species including NOx, NOy, O3, HNO3, SO2, Odd Hydrogen, PAN, and organics

AEAP/SASS has made a significant investment in the development of some of these instruments. This instrument package represents, by far, the most comprehensive attempt ever made to fully observe upper tropospheric aerosols in conjunction with cloud microphysical properties. FIRE will benefit both through the data obtained during SUCCESS as well as through data obtained in future field missions (e.g., many of these instruments are proposed for integration on the new NCAR WB-57 high altitude aircraft in association with the proposed STERAO missions).

8.1 FIRE Participation

FIRE has already established a collaborative effort to study cirrus and contrails over the central U.S. during Spring 1996. FIRE remote sensing researchers and their participation in SUCCESS are summarized in Table 8.1. FIRE III will provide satellite and meteorological support for SUCCESS in addition to the use of the NASA ER-2. The SUCCESS investigations should improve our understanding of midlatitude cirrus clouds and the effects of aircraft on their optical properties.

Table 8.1 FIRE III Investigations during SUCCESS

Researcher	Instrument	Thrust
T. Ackerman	surface radar, microwave radiometer, flux radiometers	contrail and cirrus radiative properties and structure
S. Ackerman, Tsay	ER-2 MAS, HIS, surface AERI	contrail and cirrus radiative properties, contrail/cirrus dependence on UT water vapor
Eberhard	surface Doppler lidar and cloud radar	contrail and cirrus structure and microphysics
Gerber	DC-8 g-meter (PVM-100A)	contrail and cirrus microphysics
Hallett, Hudson	DC-8 in situ microphysics	contrail and cirrus microphysics
Heymsfield	DC-8 in situ microphysics	contrail and cirrus microphysics
Kreidenweis	ice nuclei	observe ice nuclei concentration, composition and efficiency
Lawson	p-Nephelometer	contrail and cirrus microphysics
Liou	AVHRR	model validation
Minnis	GOES Imager, AVHRR	algorithm validation; cirrus and contrail radiative properties
Mishchenko	ISCCP	model validation
Rossow	ISCCP	climatology, validation

Sassen	surface lidar	cirrus and contrail structure
Stephens, etc.	surface radiometers	contrail and cirrus radiative properties
Spinhirne	ER-2 lidar, IR radiometer, TSC, surface lidar	cirrus bidirectional reflectance; contrail and cirrus structure and optical properties
Toon	airborne radiometers	cirrus and contrail radiative effects
Valero, Pilewskie	Surface, ER-2, and DC-8 radiometers	contrail and cirrus radiative properties

In summary, SUCCESS will advance FIRE Cirrus objectives through evaluation and resulting improvements to remote sensing techniques for cloud ice water content, particle size, and optical properties. The hope is that SUCCESS will result in a major advance in knowledge of upper tropospheric aerosols, their sources and sinks, and their effects of cirrus clouds both locally and, through extrapolation, globally. The present observational data base on upper tropospheric aerosols is paltry at best and SUCCESS should do much to alleviate this situation. Many measurements taken during SUCCESS have never been attempted before in the upper troposphere.

8.2 IMPLEMENTATION STEPS:

- In light of the many related goals of FIRE III and SUCCESS, promote communication of SUCCESS accomplishments to FST scientists. Perhaps common or serial meetings could achieve this.

- A successful FIRE III tropical field campaign will depend upon a number of instrumentation development projects in SUCCESS. As a result, FIRE III management should maintain a close liaison with SUCCESS management on the progress and success of these development programs.

9.0 SHEBA/FIRE III Stratus

Commencing in August 1997 and continuing for approximately one year, SHEBA will mount a field campaign on the pack ice in the Arctic Ocean. In addition the ARM site at Barrow, Alaska should be activated by this time and will provide an additional surface based set of radiation and cloud observations. The SHEBA expedition will consist of an array of surface based instrumentation in place for the duration of the experiment and probably two aircraft expeditions, each with a duration on the order of one month. The two aircraft campaigns are tentatively scheduled for August, 1997 and April 1998. FIRE III scientists plan to participate extensively in the April 1998 aircraft campaign.

Owing to the relatively shallow depths of the troposphere and cold temperatures of the Arctic, there may be relatively little difference between lower and middle tropospheric stratiform clouds and upper tropospheric cirrus. Nonetheless, the dynamics (vertical motions) that contribute to upper tropospheric Arctic cirrus cloud formation may be different from lower tropospheric Arctic stratus resulting in differing cloud properties as well. While the primary focus of the SHEBA experiment is upon the surface and boundary layer, the heat and energy budgets at the surface are dependent upon cloud structures both within and above the boundary layer. Likewise, the ability to observe the surface and lower atmospheric layers from satellite is impaired by clouds at all levels in the arctic atmosphere. It becomes apparent that the FIRE III/SHEBA mutual goals may be best served by including cloud systems at all levels in the arctic atmosphere within the scope of the experiment objectives.

9.1 SHEBA-FIRE Collaboration

The SHEBA-FIRE collaboration will involve several FIRE remote sensing groups (Table 9.1) whose investigations will examine both ice and liquid clouds in the polar regions. The results will provide additional information for the temperature and latitudinal variability of ice clouds and their optical properties. The experiment will also be valuable for validating MODIS and CERES cloud retrievals.

Table 9.1 Remote Sensing Investigators Evaluating Polar Ice Clouds During SHEBA

Researcher	Instrument	Thrust
T. Ackerman	surface radar, microwave radiometer, flux radiometers	contrail and cirrus radiative properties and structure
Fairall	Surface lidar, microwave radiometer, wind profiler	cloud structure, phase
Han and Welch	AVHRR	algorithm validation, cloud mask development, optical properties
Hobbs, King, Tsay	C-130 CAR, lidar, flux radiometers; ER-2 MAS, lidar	algorithm validation, cloud/clear discrimination, optical properties, bidirectional reflectance
Minnis	AVHRR, MODIS	polar ice cloud retrieval algorithm validation, cloud properties, climatology
Rossow	ISCCP, HIS, SSM/T2	polar ice cloud retrieval algorithm development and validation, radiative properties, climatology
Uttal	Surface 35 GHz radar, lidar, IR radiometer	cloud structure, emittance, and microphysical properties, ice mass
Wielicki	Landsat	cloud optical properties, horizontal variability, and validation
Wylie	HIRS	cloud optical depth and height, algorithm validation

It is therefore strongly urged that SHEBA-FIRE III Stratus component include measurements of middle and upper tropospheric cirrus. Aircraft measurements of cirrus microphysics and radiative properties should be made on an occasional basis to compare with their lower tropospheric cousins and mid latitude and tropical counterparts. In addition, when lower tropospheric stratus is absent but cirrus is present, ground-based measurement systems such as lidars, radiometers, millimeter wavelength radars, and sounding systems should be operated to obtain measurements when Arctic cirrus is present.

9.2 IMPLEMENTATION STEPS:

- Maintain active liaison between the FIRE III SHEBA and FIRE III Tropical cirrus components.

- Encourage FIRE III SHEBA principals to include middle and upper tropospheric ice clouds in the Arctic within the experiment's scope.

10.0 COMPLIMENTARY PROGRAMS

FIRE researchers are actively engaged in a number of scientific endeavors, involving other programs, that will advance FIRE Cirrus objectives during FIRE-III. Already described elsewhere in this document are the joint FIRE-AEAP SUCCESS field mission (section 6.0) and FIRE participation in and critical support of the model intercomparison activities of the GCSS WG-2 (section 4.0). Other complimentary programs and opportunities are described below.

In addition to the SUCCESS field mission and associated analysis and modeling, AEAP/SASS will conduct one or more additional field missions during FIRE-III. While these missions are highly focused on heterogeneous chemistry and near-field aircraft wake studies, useful observations of cirrus clouds will also be obtained, especially with respect to resolving the potentially important effect of aerosols on cirrus and fundamental ice particle scattering properties. It is expected that members of the FIRE Science Team will participate in these missions and that FIRE will benefit from the knowledge gained. The continuing AEAP/SASS support of development of critical instrumentation for aerosol and ice physics measurements and cloud radiative properties measurements will also benefit future FIRE missions.

The DOE ARM program is also highly complimentary with FIRE with a number a researchers actively involved in both programs. FIRE and ARM are highly synergistic with FIRE providing the benefits of its efforts to improve satellite-based and ground-based remote sensing techniques for cirrus cloud characterization, studies of cloud development processes and large-scale analysis of cloud data sets; and ARM providing the extended-time collection of cloud and atmospheric observations with enhanced collections during IOPs along with its systematic program of single-column model (as in a single GCM grid cell) and radiative model testing and evaluation using the collected data. ARM has also strongly supported the development and improvement of sophisticated sensors, both ground-based and deployed on UAVs, for application to cloud-radiative research. Airborne observations, involving both UAVs and manned aircraft, are collected during some IOPs. FIRE and ARM are very mutually beneficial with data, results and expertise flowing freely between the programs.

Activities of the Mission To Planet Earth (MTPE) EOS Instrument Teams also constitute a significant opportunity to advance FIRE Cirrus objectives during FIRE-III. Elements of these teams are committed to providing detailed global cloud observations derived from EOS observations. In the near term, the MISR and ASTER teams will develop (expected within 2 years) and collect cloud observations with airborne simulator instruments much the way that the MAS has done during FIRE-II. When developed, the MISR simulator, that will be deployed on the NASA ER-2, will provide a new capability for obtaining observations enabling much improved definition of multi-spectral cloud bi-directional reflectance, models of which are an essential ingredient in satellite-based cloud retrieval algorithms. Though focused on land surface studies, ASTER simulator, that will be deployed on the NASA C-130, will provide a capability to obtain very high spatial resolution multi-spectral cloud scene data of very high quality. Such data sets would be very useful in assessing effects of cloud inhomogeneity and significantly improve the quality of the available data for such studies (presently relying on Landsat observations).

The MAS has provided crucial data to FIRE. Similarly, FIRE data has proven very important to the MODIS team for algorithm development and validation. For example, the incorporation of the 1.3 mm channel on MODIS for cirrus detection resulted from analysis of MAS and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data collected during FIRE Cirrus-II. There is a close relationship between the MODIS-Atmosphere and FIRE teams. Additional MAS data collections are expected during FIRE-III as the MODIS team continues its algorithm development and validation activities in preparation for the AM-1 launch scheduled for 6/98. Where appropriate, FIRE will seek to incorporate those data and results to further understanding of cirrus cloud properties and processes. Similar close relationships should be promoted between the MISR and ASTER teams and the FIRE Cirrus community.

In the longer term, the EOS instrument teams will conduct intensive data validation exercises in the post AM-1 launch era (after 6/98). The teams are presently developing their EOS

Science Data Validation Plans. It will be imperative for FIRE and those teams to seek opportunities for mutually beneficial field deployments and analysis efforts. This will significantly enhance the scientific value of these activities by broadening their scientific purpose beyond the highly focused on remote sensing objectives of the EOS instrument teams.

NSF may support a series of field deployments (NCAR aircraft) focused on the upper troposphere (STERAO). There is an opportunity for FIRE and NSF to join resources to conduct a campaign targeted on tropical cirrus. The NSF program also focuses on upper tropospheric chemistry in addition to its cirrus cloud focus. As with the AEAP program, this may provide opportunities for collection of data on cirrus clouds during FIRE-III. It should be noted that the NSF program strongly benefits from instrument development during FIRE-II and AEAP/SASS. NCAR personnel have also been very instrumental in some of these efforts. NSF's present efforts to deploy a new highly capable resource for upper tropospheric research, the WB-57, will surely have a major positive impact on cirrus cloud research during FIRE-III.

Other possible synergism that will be explored are with the NASA Land Surface Processes Program which is planning a major field campaign, the Large-Scale Land Processes in the Basin of the Amazon (LBA), in Brazil in 1998 or 1999. A joint FIRE mission to this tropical convective environment in conjunction with the substantial planned data collections could prove to be the best possible opportunity to address the issue of coupling between deep convection and upper tropospheric cloudiness which is a major issue confronting the GCM community, as described in section 6.

FIRE will also explore opportunities for useful exchange of data and expertise with the EUCREX community. It is expected that the European community will be highly involved in the GCSS WG-2 activities (section 4.4) and that this may provide the forum for useful interaction between FIRE and EUCREX. Possibilities for joint cooperative field activities will continue to be explored.

10.1 IMPLEMENTATION STEPS

- Explore collaboration with international partners in a tropical upper tropospheric cloud experiment.

- Participate in and provide crucial data sets in support of the cirrus cloud model intercomparison activities of the GCSS WG-2.

- Maintain communication with other international partners performing independent research on upper tropospheric cloud systems and their relationship to climate.

- Explore collaboration with other funded projects in order to provide a more comprehensive field campaign capable of addressing the goals of FIRE III.

APPENDIX A - REFERENCES

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APPENDIX B - ACRONYMS, ABBREVIATIONS and NOTATIONS

2D	two dimensional
2D-C	PMS optical array probe; 25 micron to 1 millimeter
2D-P	PMS optical array probe; 100 micron to 6 millimeter
ACE-1	Atmospheric Chemistry Experiment; first mission
ADEOS	Advanced Earth Observing Satellite (Japan)
AEAP	Atmospheric Effects of Aviation Program
AEM-B	second Application Explorer Mission
AES	Atmospheric Environment Service (Canada)
AIDJEX	Arctic Ice Dynamics Joint Experiment
AIRS	Atmospheric Infrared Sounder
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
ARC	Ames Research Center
ARM	Atmospheric Radiation Program
ARMCAS	Arctic Radiation, Microphysics, Clouds, and Aerosols Study
ASAP	as soon as possible
ASCII	American Standard Code for Information Interchange
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
ASTEX	Atlantic Stratocumulus Transition Experiment
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BASE	Beaufort Arctic Seas Experiment
BRDF	bi-directional reflectance distribution function
Bull. Amer. Meteor. Soc.	Bulletin of the American Meteorological Society
C	cirrus, centigrade
C1	ISCCP hourly cloud analyses
C-130	NCAR airplane
C-131A	University of Washington airplane
CAR	Cloud Absorption Radiometer
CART	Cloud and Atmospheric Radiation Testbed
CARSS	Center for Atmospheric and Remote Sounding Studies
CCD	charged-couple device
CCN	cloud consendation nuclei
CD-ROM	compact disk-read only memory
CEPEX	Central Equatorial Pacific Experiment
CERES	Clouds and the Earth's Radiant Energy System
CFD	continuos flow diffusion
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CIRES	Cooperative Institute for Research in Environmental Sciences
Cirrus-I	Cirrus IFO-I (Wisconsin 1986)
Cirrus-II	Cirrus IFO-II (Kansas 1991)
CLS	Cloud Lidar System
cm	centimeter (10-2)
CN	cloud nuclei
COARE	Coupled Ocean-Atmosphere Regional Experiment
CO2	carbon dioxide
conf	conference
CRM	cloud resolving model
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CSU	Colorado State University
CVI	counterflow virtual impactor
CV-580	University of Washington aircraft
CY	calendar year

DAAC	Distributed Active Archive Center (EOS)
DAT	digital archival tape
DC-8	NASA ARC aircraft
DIAL	Differential Absorption Lidar
DMA	differential mobility analyzer
DMS	daily mission scientist
DMWG	Data Management Working Group
DOD	Department of Defense
DOE	Department of Energy
DRI	Desert Research Institute
ECMWF	European Center for Medium-Range Weather Forecasts
EDX	energy-dispersive x-ray
ELDORA	Electra Doppler Radar
EOS	Earth Observing System
EOS-AM (AM-1)	first launch in NASA EOS series (mid-1998)
EOSDIS	Earth Observing System Data and Information System
EOS-PM	second launch in NASA EOS series (late 2000)
EOSP	Earth Observing Scanning Polarimeter
ERB	Earth Radiation Budget instrument (NIMBUS 6 & 7)
ERBE	Earth Radiation Budget Experiment (ERBS)
ERBS	Earth Radiation Budget Satellite
ER-2	NASA ARC aircraft
ERS-1	European Remote-Sensing Satellite-1
ETL	Environmental Technology Laboratory (NOAA)
ETO	extended time observation
EUCREX	European Cloud Radiation Experiment
FARS	Facility for Atmospheric Research (U. of Utah)
FAX	facsimile
FIRE	First ISCCP Regional Experiment
FIRE Stratus	Marine Stratocumulus IFO (California 1987)
FIRE I	FIRE phase I (1984-1989)
FIRE II	FIRE phase II (1990-1994)
FIRE III	FIRE phase III (1995- ??)
FST	FIRE III Science Team
FTIR	fourier transform interferometer radiometer
ftp	file transfer protocol
FTS	fourier transform spectrometer
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCM	general circulation model; global climate model
GCSS	GEWEX Cloud System Studies
Geophys. Res. Lett.	Geophysical Research Letters
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluids Dynamics Laboratory
GHz	gigahertz (10+9)
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLI	Global Imager
GMS	Global Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
HDF/netCDF	hierarchical data format/net common data format
HIRS	High Resolution Infrared Radiation Sounder
HIS	High-resolution Interferometric Sounder
HNO3	nitric acid
hz	hertz
IFO	intensive field observations
IMG	Interferometric Monitor of Greenhouse Gases
IN	ice nuclei

INDOEX	Indian Ocean Experiment
IOP	intensive observing period
IR	infrared
ISCCP	International Satellite Cloud Climatology Experiment
IWC	ice water content
IWP	ice water path
J. Appl. Meteor.	Journal of Applied Meteorology
J. Atmos. Sci.	Journal of the Atmospheric Sciences
J. Atmos. Oceanic Technol.	Journal of Atmospheric and Oceanic Technology
J. Climate	Journal of Climate
J. Geophy. Res.	Journal of Geophysical Research
JPL	Jet Propulsion Laboratory
kg	kilogram (10+3)
kHz	kilohertz (10+3)
km	kilometer (10+3)
kW	kilowatts (10+3)
l	liter
Landsat	NASA Earth observing satellite series
LaRC	Langley Research Center
LBA	Large-Scale Land Processes in the Basin of the Amazon
LEADEX	Lead Experiment
LES	large eddy simulation
Lidar	light detection and ranging
LIS	Lightning Imaging Sensor
LITE	Lidar In-space Technology Experiment
LLNL	Lawrence Livermore National Laboratory
LWC	liquid water content
m	meter
MAS	MODIS Airborne Simulator
MAST	Monterey Area Ship Track Experiment
MASTER	MODIS/ASTER Airborne Simulator
MCC	Mesoscale Convective Complex
Meteorol. Atmos. Phys.	Meteorological and Atmospheric Physics
Meteosat	geosynchronous meteorology satellite (ESA)
MFOV 2	Multi-Field of View 2 radiometer
Mhz	megahertz (10+6)
MIMR	Multifrequency Imaging Microwave Radiometer
min	minute
MIR	Microwave Imaging Radiometer
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate-resolution Imaging Spectrometer
Mon. Wea. Rev.	Monthly Weather Review
MPIR	Multispectral Pushbroom Imaging Radiometer
mrad	milliradian (10-3)
MSFC	Marshal Space Flight Center
MST	Mission Selection Team
MTPE	Mission To Planet Earth
N	North
NaCl	sodium chloride
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCSA	National Center for Super Computing Applications
NIMBUS	NASA meteorological satellite series (1-7)
NIR	near infrared
nm	nanometer (10-9)
NOAA	National Oceanic and Atmospheric Administration
NOx	nitrogen oxides (NO, NO2, NO3)

NOy	total active nitrogen
NSF	National Science Foundation
N.W.T.	Northwest Territories
OFAP	Observational Facilities Advisory Panel
OGP	Office of Global Programs
ONR	Office of Naval Research
Opt. Lett.	Optics Letters
O3	ozone
P3	NOAA aircraft
P-3B	NASA Wallops aircraft
PAN	peroxyacetyl nitrate
PDL	Polarization Diversity Lidar
Ph. D.	Doctor of Philosophy
PI	principal investigator
PMS	Particle Measurement Systems, Inc., Boulder, CO
PR	Precipitation Radar
Proc	proceedings
PSA	particle surface area
PSU	Penn State University
PSUCS	Penn State University Continental Stratus
POLDER	Polarization and Directionality of Earth Reflectances
PVM	Particulate Volume Monitor
RAMS	Radiation Airborne Measurment System
Rev. Geophys.	Reviews of Geophysics
RH	relative humidity
ROCEW	Role of Clouds, Energy and Water (NSF)
RP	research publication (NASA)
S	stratus, South
s, sec	second
SAGE I & II	Stratospheric Aerosol and Gas Experiment (I-AEM-B; II-ERBS)
SASS	Subsonic Assessment Program (part of AEAP)
SBIR	Small Business Innovative Research
Sc	stratocumulus
SCAR B	Smoke, Clouds And Radiation-Brazil
SCMS	small cumulus microphysical study
SDSMT	South Dakota School of Mines and Technology
SEM	scanning electron microscopy
SHEBA	Surface HEat Budget of the Arctic Ocean
Skyhi	atmospheric model used at GISS
SOCEX I & II	Southern Ocean Cloud Experiments
SO2	sulfur dioxide
SPEC	Stratton Park Engineering Co. Inc.
SPFR	Spectral Flux Radiometer
SSFR	Solar Spectral Flux Radiometer
SSM/I	Special Sensor Microwave/Imager
SSM/T	Special Sensor Microwave/Temperature sounder
SSM/T2	Special Sensor Microwave/Temperature Sounder; version 2
SST	sea surface temperature
Strato 2C	German UAV for atmospheric measurements
STERAO	Stratosphere-Troposphere Experiments: Radiation, Aerosols and Ozone
SW	shortwave
SUCCESS	Subsonic Aircraft: Contrail and Cloud Effects Special Study
TEM	transmission electron microscopy
TIROS	Television Infrared Observation Satellite
TMI	TRMM Microwave Imager
TOGA	Tropical Ocean and Global Atmosphere
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission

TSCC	Tilt-Scan CCD Camera
TWP	Tropical Western Pacific
T-39	NASA Langley aircraft
U, Univ	university
UAV	unmanned aerospace vehicles
UHF	ultra-high frequency
UND	University of North Dakota
URL	Uniform Resource Locator (Internet)
US	United States
UT	upper troposphere
UTC	Universal Time Coordinated
VAS	VISSR Atmospheric Sounder
VCR	video cassette recorder
VIRS	Visible and Infrared Scanner
VISSR	Visible/Infrared Spin-Scan Radiometer
vol	volume
W	West
WB-57F	NCAR aircraft
WCRP	World Climate Research Program
WG	working group of GCSS
WPDN	Wind Profiler Demonstration Network
X-Band	frequency range from 5.2 to 10.9 GHz
Z	altitude

Appendix C: FIRE Scientific Organization and Data Management

TABLE OF CONTENTS

Appendix C: FIRE Scientific Organization and Data Management

1.0 LEAD MANAGEMENT

FIRE has been a multi-agency effort since its inception. The goals of FIRE are not bounded by a single agency's mission; neither is the talent base required to address the complex problems of cloud-climate research. Close interagency cooperation in the past has made possible FIRE's advancements in our understanding of these climatically important cloud systems. It is intention of FIRE's participants to maintain and further refine this spirit of interagency cooperation.

While NASA will continue to serve as the lead agency for FIRE-III, other federal agencies including National Science Foundation (NSF), Office of Naval Research (ONR), Department of Energy (DOE), Department of Defense (DOD), and National Oceanic and Atmospheric Administration (NOAA) will remain strong participants in FIRE-III. The Radiation Sciences Program, Atmospheric Science Branch, NASA Headquarters, will provide overall cognizance of the FIRE project and will represent FIRE to the Working Group on Data Management for WCRP Radiation Projects. Contact points are located at the following offices:

Dr. Robert Curran
Atmospheric Science Branch
NASA Headquarters/YS
Washington, DC 20546

Dr. Robert Abbey, Jr.
Office of Naval Research
Code 1122 MM
800 N. Quincy Street
Arlington, VA 22217

Dr. Michael Ledbetter
Arctic Systems Science Program
Office of Polar Programs
National Science Foundation
2401 Wilson Boulevard
Arlington, VA 22230

Dr. Jay Fein
Atmospheric Sciences
National Science Foundation
1800 G Street, NW
Washington, DC 20550

Dr. Pam Stephens
Atmospheric Sciences
National Science Foundation
1800 G Street, NW
Washington, DC 20550

Dr. Richard Lawford
NOAA/OGP
Mail Stop GP
1100 Wayne Avenue
Silver Spring, MD 20910

Dr. Pat Crowley
Department of Energy
Environmental Sciences Division
Research ER-74
Washington, DC 20585

Dr. Rex Fleming
Director, Climate Observations
NOAA/ERL
3300 Mitchell Lane, Suite 175
Boulder, CO 80301

2.0 PROJECT MANAGEMENT

The FIRE project activities will be managed by the FIRE Project Office at NASA's Langley Research Center. The FIRE project manager will be responsible for the overall management, coordination, and reporting of the project activities. These responsibilities will include interacting with the Radiation, Dynamics, and Hydrology Branch and Physical Climate and Hydrology Branch management at NASA Headquarters, the Meteorology Research Program management at ONR, and the other agency representatives; overall cognizance of project planning, schedules, and field operations; and allocation of approved funding to support the scientific objectives. The project manager will be assisted by a project scientist and a project staff, which will include: an Operations Manager, a Data Manager, and a Project Coordinator.

Project Scientist - The FIRE Project Scientist will be responsible for all scientific aspects of FIRE. The project scientist will (a) act as a scientific advisor to the project manager, (b) represent the members of the science team in their relationship with the project manager, (c) maintain an oversight of the scientific integrity of the project; (d) review and make recommendations of proposed modifications to selected proposals as warranted; and (e) participate in negotiations regarding allocations of specialized project resources among approved investigations.

Operations Manager - The Operations Manager will have overall responsibility for organizing, scheduling, and conducting field operations, preparation of mission plans, establishing mission objectives with the MST Chairman, determining special support requirements, conducting planning and debriefing sessions, and operational procedures. The Operations Manager is also responsible for designing the specific and facilitating operationally feasible flight profiles to meet the scientific objectives and for coordinating the experimental requirements of measurement platforms for resources, testing, and integration for all field measurements. Lastly, the Operations Manager is responsible for the setup, testing, and operation of the mission operations site.

Data Manager - The Data Manager will be responsible for coordinating the types, scope, and quantity of data collected during the intensive field and extended-time activities and its archiving. The Data Manager will serve as the Chairperson for the Data Management Working Group. The Data Manager will ensure that the data is submitted as required to the FIRE Central Archive and eventually released to the scientific community.

Project Coordinator - The Project Coordinator will provide administrative support to the FIRE Project Office, including logistical and reimbursement support in the planning and conducting of FST meetings and field missions as required.

3.0 FIRE-III SCIENCE TEAM

The FIRE-III Science Team (FST) will be comprised of the principal investigators of those agency-approved proposals directly related to FIRE III research. Appointment to the FST will be based on the recommendation of the supporting agency. The term of participation on the team will continue as long as the approved research continues. The team shall determine its own structure and method for interaction. Ex officio members may be appointed to the team, as needed, by the project manager.

The FST will be responsible for implementing the broad scientific objectives of the project in accordance with the selected investigators. Additional responsibilities will be to:

a. Develop implementation plans for FIRE research including:

   1. field experiments.
   2. data management.
   3. research programs.

b. Recommend and perform coordinated research activities, including the interface of modeling and experiments.

c. Conduct individual investigations in accordance with approved proposals.

d. Hold meetings and workshops, as needed, to plan and assess research programs.

e. Designate the makeup and responsibilities of special working group, as needed, to address special task areas.

f. Establish a data protocol that will promote the timely publication and dissemination of scientific results.

Figure 1 shows a schematic of the relationships between the agencies, the agency program managers, the FIRE Project Office, and the FST. Table 1 lists the FST members, their institutions, and working groups in which they will be participating. S refers to both stratus and Arctic cloud systems.

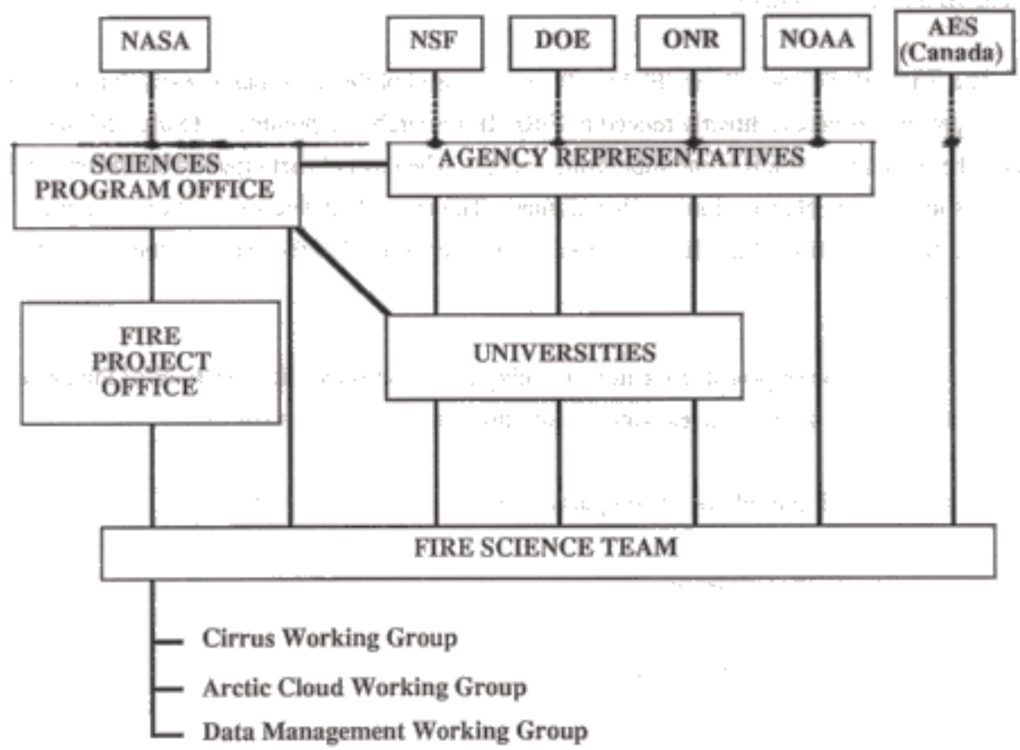

Figure 1 - Schematic of FIRE Organizational Structure

3.1 FIRE Working Groups

FIRE has been designed to address a number of complicated scientific problems. The FIRE strategy is to assemble those members of the scientific community with interests in these problems and to create an environment which encourages them to collectively pursue the solutions to these problems. FIRE working groups representing the themes of cirrus cloud systems, marine stratocumulus and arctic cloud systems, and data management will be constituted from the FST membership as follows:

Table 1 - FIRE-III Science Team: C = Cirrus only; $\underline{C}$,S = Cirrus principal, Stratus secondary; C,S = Cirrus and Stratus equal; C,$\underline{S}$ = Cirrus secondary, Stratus principal; S = Stratus only

Name	Organization	Sponsoring Agency	Research Thrust
Tom Ackerman	PSU	NASA	C
Bruce Albrecht	PSU	ONR	S
Chris Bretherton	U Washington	NASA	S
Kenneth Campana	NCEP	NOAA	C,S
Bill Cotton	CSU	NASA	C,S
Steve Cox	CSU	NASA	$\underline{C}$,S
Judy Curry	U Colorado	NASA	S
Tony Del Genio	GISS	NASA	C,S
Leo Donner	GFDL	NOAA	C
Wynn Eberhard	NOAA-ETL	NOAA	C,$\underline{S}$
Chris Fairall	NOAA-ETL	NOAA	S
Hermann Gerber	Gerber Scientific	NASA	C,S
Jim Hack	NCAR	NSF	$\underline{C}$,S
John Hallett	DRI	NASA	C, S
Mike Hardesty	NOAA-ETL	NOAA	C,$\underline{S}$
Andy Heymsfield	NCAR	NASA	$\underline{C}$, S
Peter Hobbs	U Washington	NASA	S
Jim Hudson	DRI	NASA	C, $\underline{S}$
George Isaac	AES	NASA	S
Mike King	GSFC	NASA	C,$\underline{S}$
Yefim Kogan	U Oklahoma	ONR	S
Sonya Kreidenweis	CSU	NSF	C,S
Bob Kropfli	NOAA-ETL	NOAA	C,$\underline{S}$
Steven Krueger	U Utah	NASA	S
Paul Lawson	SPECinc	NASA	C, S
Don Lenschow	NCAR	NASA	S
Kuo-Nan Liou	U Utah	NASA	C
Pat Minnis	LaRC	NASA	C,S
M. Mishchenko	GISS	NASA	$\underline{C}$,S
Peter Pilewskie	ARC	NASA	C,S

Michael Poellot	U North Dakota	NASA	C
David Randall	CSU	NASA	C,S
Bill Rossow	GISS	NASA	C,S
Ken Sassen	U Utah	NASA	C
Jim Spinhirne	GSFC	NASA	C,S
David Starr	GSFC	NASA	C
Graeme Stephens	CSU	NASA	C,S
Brian Toon	ARC	NASA	C,S
Si-Chee Tsay	GSFC	NASA	C,S
Tanneil Uttal	NOAA-ERL	NASA, NOAA	C,S
Francisco Valero	ARC	NASA	C,S
Shouping Wang	MSFC	ONR, NASA	S
Ron Welch	SDSMT	NASA	C,S
Bruce Wielicki	LaRC	NASA	C,S
Don Wylie	U Wisconsin	NASA	C,S
Qingyun Zhao	NCEP	NOAA	C,S

i. Cirrus Working Group

ii. Arctic Working Group

iii. Data Management Working Group

The Cirrus and Arctic Working Groups will accept the following responsibilities:

i. Define specific goals to be collectively pursued; these include, but are not lin the following:

a. satellite intercomparisons;

b. satellite-*in situ* intercomparisons;

c. case studies;

d. GCM parameterizations.

ii. Identify responsible individuals in each of the collective study areas referred item i and monitor the progress of the collective research.

iii. Define data sources, requirements and schedules essential to working group studies.

iv. Exchange data among PST and working group members.

v. Oversee publication of joint research results from tasks identified in item i.

The Data Management Working Group (DMWG) will be comprised of key members from the Cirrus and Arctic working group, as well as from the FIRE Central Archive. The FIRE Data Manager will chair the DMWG. The responsibilities of the DMWG are:

i. provide interaction and coordinate data management decisions among the FIRE data gathering working group, the FIRE Central Archive, and the principal investigators.

ii. ensure uniform FIRE data characteristics (throughout all working group and FIRE researchers)

iii. define listings of uniform parameter units and conventions for reduced data products.

iv. oversee the plans, progress, and performance of the FIRE Central Archive (see section 4.1.3).

4.0 DATA MANAGEMENT

Data management is an ongoing activity, beginning immediately in the pre-experiment phase and continuing through the end of FIRE-III. Collaboration and data exchange of data among FIRE investigators will be required to produce integrated analyses of multi-platform, multi-scale, and mufti-spectral data sets; these integrated analyses are central to the accomplishment of the FIRE-III science objectives. In addition, the data management activities will seek to ensure the availability of FIRE data and analysis products to the entire science community. To maximize these data management goals, the FST will develop a data management and protocol plan consistent with the supporting agencies' goals for the sharing of the data, the rapid dissemination of results, and documentation of measurements obtained.

At a minimum, the data management activities will disperse most of the data reduction and processing functions to the FIRE investigators engaged in collecting and analyzing the data, but to hold the resultant data sets and analysis products centrally for ready access by all FIRE investigators. The FIRE Central Archive, located at the Langley Research Center EOSDIS Distributed Data Active Archive (DAAC), and the FIRE Project Office will provide a centralized source of information and copies of data which are centrally archived. The FST, composed of the investigators , will coordinate the decentralized data reduction and an analysis activities . In addition , the FIRE Central Archive will transfer, from time to time, certified FIRE data to the scientific community.

Data management activities in FIRE will insure the exchange of data among FIRE investigators that is required to produce the integrated analyses of multi-platform, multi-scale, and mufti-spectral data sets; these integrated analyses are central to the accomplishment of the FIRE science objectives. In addition, the data management activities will insure the availability of FIRE data and analysis products to the entire science community. These activities will be carried out by four organizational components within FIRE:

(1) the Cirrus and Arctic Working Group,
(2) the individual FIRE principal investigators,
(3) the FIRE Central Archive, and
(4) the FIRE Project Office.

The strategy embodied in this organization is to disperse most of the data reduction and processing functions to the FIRE investigators engaged in collecting and analyzing the data, but to hold the resultant data sets and analysis products centrally for ready access by all FIRE investigators. The FIRE Central Archive and the FIRE Project Office will provide a centralized source of information and copies of data which are centrallv archived, whereas the FIRE Working Groups, composed of the investigators, will coordinate the decentralized data reduction and analysis activities. In addition, the FIRE Central Archive will transfer, from time to time, certified FIRE data to EOSDIS and for other organizations for permanent archive and for open access by the scientific community.

4.1 Data Management Responsibilities

4.1.1 Working Groups

There are two data-gathering FIRE working group - a Cirrus Working Group, and an Arctic Working Group. These working group will be composed of FIRE principal investigators pursuing research relevant to that working group. The data management responsibilities of the individual principal investigators, as dispersed elements of the FIRE data processing system, could become onerous if not coordinated properly. Therefore, the FIRE Working Groups must govern these individual activities to insure progress toward the FIRE science objectives. The data management functions of the FIRE Working Groups are:

1. To determine the content and format of all principal investigator data sets to be submitted to the Langley Research Center Distributed Active Archive System (LaRC DAAC). If requested, only FIRE-III researchers will have access to data in the LaRC DAAC during the time period for data certification.

2. To set standards for data quality, documentation of all data sets, and certification criteria for data products that will be released to the at-large scientific community.

3. To assign a data category" (section 8.5) to each data parameter that reflects it's usefulness to subsequent data analysis and whether and when it should be archived.

4. To select case study data sets for special intensive processing (including reformatting) by all relevant principal investigators and to identify other additional processing of data to accomplish FIRE-III objectives.

5. To coordinate data management decisions and ensure uniform FIRE-III data characteristics.

6. To certify, within 6-24 months after acquisition, those data products from the LaRC DAAC that will be released to the scientific community.

4.1.2 Principal Investigators

All data reduction and analysis functions in FIRE-III reside with the scientists carrying out their research as part of the program. To encourage the interactions of these researchers needed to integrate the various observations and models into a more comprehensive understanding of clouds and their effects, FIRE iii investigators will have free and timely access to all data collected during FIRE-III, either by individual principal investigators or collected from satellites. Coordination of data analysis and modeling activities requires all principal investigators to perform certain other tasks as part of the FIRE-iii data management scheme. These functions are:

1. To provide to the LaRC DAAC written information concerning data holdings, including all data collected as part of FIRE-III and other data deemed relevant to FIRE-III research.

2. To save all data collected in unreduced form for five years so that reduction of data can be repeated if necessary.

3. To provide to the LaRC DAAC copies of all category 1, 2, 3 (when practical), and 4 (if desired) observations in a mutually-agreed upon format (see section 7.2 for definition of data category) accompanied by complete instrument, reduction algorithm and data format documentation.

4. To provide, within 9 months after acquisition, to the LaRC DAAC copies of any data analysis products deemed relevant to the accomplishment of FIRE-III objectives, accompanied by appropriate documentation .

5. To provide for archival of all submitted data sets by producing back-up copies of all data and taking other necessary precautions to ensure the preservation of the FIRE-III data.

6. To provide to other FIRE-III investigators or the LaRC DAAC, upon request, copies of other data sets acquired for FIRE-III research, that are relevant to other FIRE-III studies.

7. To provide to other FIRE-III investigators reasonable access to unreduced observations to facilitate

particularly crucial mufti-data analyses.

4.1.3 Langley DAAC

The LaRC DAAC will serve as the FIRE-III Central Archive. The LaRC DAAC is responsible for archiving and distributing NASA science data in the areas of radiation budget, clouds, aerosols, and tropospheric chemistry. It will also archive some of the data sets which result from the EOS program and other elements of Mission to Planet Earth.

The DAAC has developed an on-line computer system which allows the user to logon, search through the DAAC's data inventory, choose desired data sets, and place an order. Data may be received either electronically (via FTP) or on media such as 4 mm tape, 8 mm tape, or CD-ROM (prepackaged datasets only).

Users with an X-Windows terminal (e.g., Motif) or a Sun Open Windows display system with access to Internet, may log onto the system by entering:

xhost + eosdis.larc.nasa.gov
(or: xhost + 192.107.191.17)
telnet eosdis.larc.nasa.gov
login name: ims password: larcims

At the prompts, enter x for the X-Windows interface and then your display name (name of your workstation followed by ": 0" or internet address followed by ": 0").

Users with access to NCSA Mosaic can use the following URL address:

http://eosdis.larc.nasa.gov/

Users without access to a terminal with an X-Windows display system but who have access to Internet may log onto the system by entering:

telnet eosdis.larc.nasa.gov
login name: ims password: larcims

At the prompt, enter c for the character interface and then press return.

Users who cannot access the system or who have questions concerning the Langley DAAC may contact:

Langley DAAC User and Data Services
Mail Stop 157B
NASA Langley Research Center
Hampton, VA 23681-0001

Phone: (804) 864-8656 FAX: (804) 864-8807
email: larc@eos.nasa.gov

For further information on LaRC DAAC contact Ms. Sue Sorlie, Langley Research Center, 804-864-8660, s.e.sorlie@larc.nasa.gov or John Olson at 804-864-8609, olson@magician.larc.nasa.gov.

The LaRC DAAC will provide a centralized data holding and on-line system in order to facilitate easy access to all FIRE-III data by all FIRE-m investigators. Since most of the satellite data are not collected directly by FIRE-m principal investigators, the LaRC DAAC will also be responsible for holding of the satellite data sets required for FIRE-m research from the relevant satellite operating agencies. The specific data management functions of the FIRE-III Data Archive are:

1. To hold all reduced observations and data analysis products submitted by individual principal investigators or group of principal investigators upon the request of the FIRE-III Science Team.

2. To hold all satellite data sets required for FIRE-III as specified by the FIRE-III Science Team.

3. To provide, upon request, copies of any data sets to FIRE-III investigators (et minimal cost to investigators).

4. To produce a data ingest request of the complete FIRE-III data holdings of the archive and the individual principal investigators indicating the current analysis statue of these data. The data ingest request entries should provide information about the location of the data holding, the instrument(s) performing the observations, the temporal and spatial resolution of the data, and the format of the data.

5. To update the data ingest request every year and to make it available to FIRE-III investigators in both hard copy and electronically (on-line dial-up) form.

6. To restrict access to the data products in the LaRC DAAC to only researchers associated with the FIRE-III project, if so requested by the FST. The at-large scientific community will not then have access to these data sets until they are released.

7. To "release", on an annual basis, certified FIRE-III data from the permanent archive for unrestricted access by the at-large scientific community. The "transfer" process removes the access restraints to the at-large scientific community.

8. To provide for archival of the permanent FIRE-III data in the data archive by producing back-up copies of all data and taking other necessary precautions to ensure the preservation of the data.

9. To publish documentation, such as a FIRE-III Data Archive Users Manual that describes the contents of the FIRE-III Data Archive, data formats, data request information, and other pertinent descriptive material.

4.1.4 Project Office

FIRE data management structure vests the primary data processing function with the individual scientific investigators, the information and archival functions with the Central Archive, and the decision-making with the FIRE Working Groups. The Project Office must provide for liaison among these different group. The specific data management functions of the project office are:

1. To provide liaison between the FIRE Working Groups (and individual principal investigators) and the data collecting agencies and agencies operating observing platforms required by FIRE.

2. To provide liaison between the FIRE Central Archive and the satellite and other data collecting group to facilitate the acquisition of the data sets needed for FIRE.

3 .To provide for a close working relationship among the FIRE Working Groups and the Central Archive by including a representative of the Central Archive on the Project Office staff who can attend FIRE Science Team meetings.

4.2 Data Products

There are several types of data products that will be acquired, submitted, and archived at the LaRC DAAC. These products, which will be obtained from a variety of instruments onboard satellite, airborne, or surface-based platforms during the field experiment, are as follows:

1. Guide/Summary--written information about the data holdings of the individual PI's, including location of the data holdings instrument(s) performing the observations; resolution and area coverage of the data; date, time, and location of the observations; format of the data; and analysis statue of these data.

2. Raw data--original observations acquired by the instrument, in instrument units (voltages,

etc.).

3. Reduced data--observations converted to the physical quantity directly sensed by the instrument with quality control inspection and removal of bad data.

4. Value-added products--physical quantifies derived from the observations, including documentation on the analysis algorithm and any auxiliary data sets used in the analysis.

5. Calibration, quality, and navigation information--describes the conversion to physical units, the conditions of observation and the location of the observation.

6. Instrument documentation and data tape format description.

7. Data for special case studies which have been arranged for intercomparison of multi platform observations.

8. Data selected for special processing to facilitate model studies.

9. Status and bibliography of FIRE-III publications.

The data acquired by the individual experimenters will be reduced to final values and forwarded to the LaRC DAAC. The format for the submittal of data to the archive must be in ASCII or HDF/netCDF (see Appendix F). In addition, a written description of the readme file or pertinent remarks should be included in the data file or in a separate file to be submitted with the data. The Langley DAAC will assist data producers putting data into HDF.

Transfer of the final data between the investigators and the LaRC DAAC may be accomplished by electronic data transfer using ftp.

Transfer of the data from the data archive to the investigators will be clone either physically (using DATs, 9-track tapes or floppy disks) or interactively (via electronic transfer) where such systems are available (email or ftp).

4.3 Data Categories

Each of the data products will be assigned a data "category" by the science team which will reflect its usefulness to subsequent data analysis and whether and when it should be archived. Table 2 outlines the definition of the four data categories. The FIRE-III Science Team will be responsible for these assignments, coordinated with the responsible PIs.

Table 2 - Definition of Data "Categories"

Category	Definition	Usefulness	Archive?
1	Fundamental measured parameter	Critical	ASAP or 3-6 months
2	Fundamental measured parameter	"A lot of people will use it"	9-18 months
3	Reduced or value-added parameter	Useful	Welcomed; not required

4.4 Data Protocol and Publications Plan

The FIRE-III data protocol and publication plan has been prepared to encourage an orderly and timely analysis, interpretation, and publication of the data obtained during FIRE-III. It is hoped that the development and distribution of this plan will enhance the science output by promoting cooperation among the investigators and encouraging the early publication of results, thereby enriching the scientific interpretation of the data obtained from single and ensemble of instruments.

The FIRE -III Science Team (FST) is responsible for the certification of data submitted to the permanent FIRE-III data archive located at the Langley Research Center (LaRC) Distributed Active Archive Center (DAAC). The certification process will normally take 6 -24 months after acquisition. During the certification process period, the following set of data protocol and publication ground rules will be agreed upon and abided to by all FST members as a condition of their participation in the FIRE-III project.

4.4.1 Data Protocol

1. FST members will have free and timely access to all FIRE-III data acquired during the project. The normal vehicle for data dissemination will be a transfer of data via the LaRC DAAC; however, direct transfer of data between investigators is also encouraged.

2. Each investigator's data is proprietary until the data appear in publication or, if the data are included in the LaRC DAAC, until this archive is published/released to the scientific community. FST members who collect FIRE-III data are responsible for the reduction, analysis, interpretation and publication of their data and research results.

3. An investigator whose unpublished data are to be used in an investigation has the right to be included among the authors of any resulting publication. The investigator may refuse co authorship but not the use of this data. The investigator must provide information concerning the quality of the data and may require that suitable caveats regarding the data be included in the publication. It is the responsibility of the sponsoring investigator to solicit the participation of the investigator whose data are to be used as early as possible during the formative stages of the investigation.

4. FST members may release their own data to whomever they wish. They may not release the data of other investigators without consent.

5. Selected sets of reduced data obtained by investigators participating in collaborative research will be made available to FST participants within 9 months following acquisition.

6. The FST will normally provide the forum in which collaborative investigations are planned and executed; however, this is not meant to discourage collaborative investigations outside the scope of FIRE-III.

7. Any data sets resulting from collaborative investigations among FST members will be made available to the LaRC DAAC. This includes all collaborative efforts both within and outside the FST.

8. Scientists who are not FST members, co investigators, or associates may participate in investigations using unpublished FIRE-III data provided they are sponsored by a FST member and they make available whatever data they plan to use to the LaRC DAAC at the beginning of the participation. Co-investigators and associates may participate in the investigation of a FST member.

4.4.2 Data Publication

Early publication of results from FIRE-III research is strongly encouraged. Towards this goal, the following minimum publication plan has been developed:

1. An overview synopsis of the FIRE-III program will be prepared by program personnel and key FST researchers for publication in an appropriate journal. The paper will describe the scientific objectives, operational plans, and potential results of the major FIRE-III activities to the scientific community during the early stages of FlRE-III.

2. A synopsis of the key operational activities and possible results from the FIRE-III field experiment will be prepared by project personnel and key FST researchers for publication in an appropriate journal. This paper will be designed to be a "quick look" publication to inform the scientific community at an early stage of the implementation of the mission and possible highlighted observations.

3. Publication of results from the FIRE-III Field experiment may be in a special issue of an appropriate journal. The special issue decision will be made by the FST. The issue will contain (a) an overview paper and (b) science papers.

The overview paper will be co-authored by program personnel and key researchers and will include a statement of the goals of the particular field mission. It will describe the field site, the instrumentation involved in the deployment, flight plans, and other operational activities.

The science papers will be contributions from the FIRE-III investigators. They will be "stand alone" papers that the investigators will prepare summarizing measurements, data interpretation, and data correlations. Collaborative papers between different group are strongly encouraged.

4. A firm timetable for the publication of the special issue papers will be established whereby all of the papers will be submitted for publication prior to a mutually agreed date, usually within a year after the field experiment completion.

5. Oral presentations of selected results by the investigators and the project may be presented together at an appropriate conference.

6. Additional publications or presentations by FIRE-III investigators beyond those identified above are expected and encouraged. Other publications should, however, be in harmony with the data protocol and publication plan contained in this document.

5.0 FIRE MISSION/MEETING MILESTONES

The listing of the key FIRE missions and meetings is given in table 3. An attempt has been made to coordinate the various meetings between the Cirrus and Arctic working group so that those researchers who are participating in both missions can attend. Whenever the two group hold coincident meetings, a full-up FST meeting will also be held so as to integrate the extended time and modeling activities as much as possible. The milestone list reflects a minimum meeting schedule; other meetings may be scheduled (i.e., meetings to plan for/review Tropical Cirrus Mission) as required. Also included are some key cirrus collaborative experiments, such as the Subsonic Aircraft Contrail and Cloud Special Study (SUCCESS) and the Stratospheric Tropospheric Experiment: Radiation, Aerosols, and Ozone (STERAO). Table 4 lists several field experiments and satellite launches that are pertinent to FIRE planning. At a minimum, the entire FST will meet at least once per year.

6.0 NATIONAL AND INTERNATIONAL COLLABORATIONS

FIRE Phase III is a research project to be conducted by U.S. scientists to provide a U.S. national contribution to the ISCCP of the World Climate Research Program. In the sense that the scientific problems addressed by FIRE-m are truly international, it is in the best interests of FIRE III to encourage the free exchange of information with our national and international colleagues. Although resources do not permit direct support of foreign participation in FIRE-III, ways will be sought to allow collaboration, such as full participation and data sharing as members of the FS T. Other forms of collaboration will also be encouraged. Cooperation and coordination with the research projects of other countries will be accomplished through the ISCCP Working Group on Data Management (DMWG), which is responsible for this function under the Joint Scientific

Committee of WMO and International Committee of Scientific Unions. Reports of FIRE-III activities will be made at the annual ISCCP WGDM meetings.

Table 3 - Tentative Schedule of FIRE Activities

Month	1996	1997	1998
January			
February			Arctic Cloud Site Inspection Arctic Cloud Simulated Experiment
March	FIRE-III ST Meeting SUCCESS Simulated Exp.	STERAO-B-I Experiment	
April	SUCCESS Experiment	STERAO-B-I Experiment	Arctic Cloud Experiment
May	SUCCESS Experiment	Arctic Cloud Site Survey-B FIRE-III ST Meeting	Arctic Cloud Experiment
June		STERAO-B-II Site Inspection	
July			
August	Arctic Cloud Site Survey-A	STERAO-B-II Experiment	FIRE-III ST Meeting
September	STERAO-B-II Site Survey	STERAO-B-II Experiment	
October	Arctic Cloud WG Meeting Cirrus WG Meeting SUCCESS Science Workshop	Tropical Cirrus Site Survey-B	
November	Tropical Cirrus Site Survey-A	FIRE-III ST Meeting STERAO-B Science Workshop	
December			

Table 4 - Upcoming Field Experiments/Key Satellite Launches

Field Experiment or Satellite Launch	Date	Location
SUCCESS	April 10 - May 10, 1996	Salina, Kansas
STERAO-B-I (NCAR)	March -April, 1997	Boulder, Colorado
TRMM Launch	June 1997	Global
STERAO-B-II (with NCAR?)	August - September, 1997	Central America?
INDOEX (NSF)	January - March 1998	Indian Ocean
Arctic Cloud (with SHEBA/ARM)	April 15 - May 31, 1998; and August 1998 (if AM-1 is launched successfully)	Alaska
EOS AM-1 Launch	June 1998	Global
Tropical Cirrus (with LBA)?	Fall 1998 or 1999?	Amazon Basin, Brazil

APPENDIX D - FIRE INVESTIGATORS' ABSTRACTS

Arctic Clouds and Marine Stratus Proposals

Coordinated Parameterization Development and Large-Eddy Simulation for Marine and Arctic Cloud-Topped Boundary Layers

C. S. Bretherton
University of Washington

Large-eddy simulations of subtropical and summertime Arctic cloud-topped boundary layers will be carried Out. The subtropical boundary layer simulations will focus On two issues: (1) improving entrainment closures based on in-cloud turbulent kinetic energy and cloud-top Jumps, which are currently quite uncertain, and ascertaining what resolution in the entrainment zone is required for an LES to reliably predict entrainment, and (2) assessing the role of penetrative cumulus entrainment in stratocumulus breakup. We hope to incorporate key findings in both of these areas to improve current GCM parameterizations of the cloud-topped boundary layer. A third area of study will be testing the feasibility of several proposed mechanisms for multiple cloud layering in the Summertime Arctic in an LES and comparing against field data

Application of LES to Understanding and Parameterizing the Arctic Cloudy Boundary Layer

Judith Curry[1] and William Cotton[2]
[1]University of Colorado, [2]Colorado State University

The goal of this research is to improve our understanding of physical processes occurring in the arctic cloudy boundary layer and our ability to parameterize them in climate models. The approach taken here is to use Large-Eddy Simulation (LES) to interpret the interactions among turbulence, cloud microphysics and radiative transfer in the following different arctic cloudy boundary layer types: warm-season layered clouds with decoupled mixed layers; and wintertime ice crystal plumes emanating from leads. The LES results will be compared with observations, and parameterizations suitable for large-scale models will be developed. The results will be evaluated in the context of the forthcoming Arctic FIRE experiment, particularly the optimal measurements to be obtained from aircraft (including flight patterns) and the large-scale measurements required to interpret cloud life-cycles. Specifically, we propose to accomplish the following:

- develop and implement a new subgrid-scale parameterization and other modifications for the LES to accommodate the stable boundary layers that are present in the Arctic;
- introduce new parameterizations into the LES related to the impact of turbulence on droplet spectra and the influence of droplet spectra on the radiation fluxes;
- simulate and interpret the interactions among turbulence, cloud microphysics and radiative transfer in the different arctic cloudy boundary layer types;
- compare the LES output with case studies obtained from the Arctic Stratus Experiment and BASE;
- evaluate the importance of diabatic terms in second-moment equations, and develop a parameterization for these terms for second-order closure models if necessary;
- evaluate the applicability of existing cloud fractional coverage schemes to Arctic stratus and develop a new scheme if necessary; and
- examine scale interactions using the LES nested in a mesoscale model (RAMS).

Boundary-Layer Dynamics and Cloud-radiative Studies in SHEBA: Development of an Atmospheric Lidar and a Wind Profiler

C. W. Fairall, C. Grund, and R. G. Strauch
NOAA Environmental Technology Laboratory

This is an NSF SHEBA Phase-1 project to develop, construct, and test a lidar and wind profiler for future deployment in the main ice camp of the Surface Heat Budget of the Arctic Ocean (SHEBA) program, planned for an 12-month field program beginning in March 1997. These systems will be used in conjunction with other surface-based remote sensors (e.g., Doppler cloud radar, microwave radiometer, Doppler sodar, FTIR radiometers) and in situ sensors for studies of boundary-layer and cloud/aerosol/radiative effects on the ice surface energy budget. The work will be coordinated with the FIRE-III Arctic Cloud research program.

The wind profiler will be a portable, scaled clown version of the NOAA network UHF profilers and be designed to provide wind and temperature profiles continuously to 2.5 km altitude. Through additional data processing, it will also provide information on velocity and scalar turbulence profiles and precipitation. Based on an analysis of LEADEX data, most of the temporal variability in the vertical gradients of temperature, dew point, and (to a lesser extent) winds occurs below this altitude. The lidar will be a derivative of a system being developed for cloud and aerosol monitoring and will measure optical depth and provide cloud ice/water discrimination. It will feature both vertically pointing and zenith angle scan capabilities. The scanning capability is shown to be critical for obtaining information about complex ice crystal habit and structure. Both systems will feature high reliability in Arctic conditions and will operate "unattended" except for occasional changing of storage media or transfer of data. In the first year of the project, the lidar will be designed and constructed. An existing prototype radar (being developed for another program) and the lidar then will be tested in Alaska for one month. In the second year of the project the radar will be constructed following evaluation of the test results . Both systems will be field tested in Alaska a second tune then deployed on the main ice camp for SHEBA.

FIRE III Research

Peter Hobbs
University of Washington

Subject to the availability of funding, the Cloud and Aerosol Research Group at the University of Washington intends to bring" its new twin-engine, turbo-prop, Convair-580 research aircraft to the Arctic to participate in a portion of the 6-week FIRE-m intensive field project. The aircraft will be instrument for state-of-the-art measurements of aerosols, cloud microstructures, and cloud radiative properties, including the NASA-built CAR 13—wavelength radiometer and lidar.

Our proposed research, which will be carried out in collaboration with Drs. Michael King and Si-Chee Tsay, includes the following:

(1) Measurements of cloud-active aerosols and their precursors.

(2) Measurements of the statistical properties of the microphysical structures of arctic stratus and other Clouds.

(3) Direct measurements of the spectral radiative properties of arctic stratus, and comparisons with values derived from simultaneous measurements of cloud structure.

(4) Comparisons of in situ measurements of cloud properties remote sensing measurements from the ER-2 and satellites.

We expect also to carry out a number of measurements concerned with the radiative properties of sea-ice, snow, tundra etc., and the energy balance of the arctic. However, since these are more related to SHEBA, they are not discussed here.

FIRE III Research

James Hudson
Desert Research Institute

I plan to mount both of the DRI instantaneous CCN spectrometers (Hudson 1989) aboard a research aircraft and operate them throughout the project. The most likely aircraft is the NCAR C-130, where they have been in two previous projects—Telford California stratus project (December 1994) and SCMS (July-August 1995). Two spectrometers are desirable in order to efficiently do sample processing upstream of one of the CCN spectrometers. This allows the other instrument to continuously monitor the ambient CCN spectrum. Continuous ambient spectra are vital in aircraft operations where the concentrations change rapidly with position (e.g., there are often vertical differences in concentration and/or spectral slope that are significant for cloud microphysics; also horizontal differences due to scavenging and production). The sample processing mechanisms include:

(1) Volatility—subjecting the sample to various temperatures to indirectly estimate particle composition (Hudson and Da 1995) especially with respect to NaCl, sulfates, and carbon.

(2) Size vs. supersaturation—classifying the sample according to dry particle size with an electrostatic classifier (DMA). This allows an estimate of the relative solubility of the particles. Hudson and Da (1995) showed that CCN from polluted air masses tend to act as though they have more insoluble material internally-mixed with the soluble material that makes them CCN. CCN from cleaner air masses, however, act like pure soluble substances. These two techniques are complementary; when taken together they derive significant information about CCN composition.

(3) Different inlets—The CCN spectra of droplet residue material from the counterflow virtual impactor (CVI) can be used to determine the effects of entrainment on cloud droplet spectra (Twohy and Hudson 1995). If the CVI is not available then a cloud interstitial inlet can also produce similar information about the effects of cloud dynamics on cloud droplet spectra.

When both spectrometers monitor the ambient there is increased confidence in the measurements not to mention the enhanced reliability of two instruments.

In addition to comparing the cloud droplet and CCN concentrations I am keenly interested in comparing the shapes of the two spectra. Martin et al. (1994) suggested that the shape of the cloud droplet spectrum is related to the shape of the CCN spectrum. Indeed Hudson and Li (1995) found significant differences in the shape of the CCN spectra in polluted and clean air masses; this is an additional difference to the well-known difference in number concentration. However this may or may not go the same way in the Arctic. The shape (breadth) of the droplet spectrum is very important for the initiation of drizzle (autoconversion), which has been suggested to be related to CCN concentrations (e.g., Albrecht et al. 1995). Drizzle initiation may also depend on CCN spectral shape, testing this requires measurements at supersaturations longer than the actual cloud supersaturations, which are generally quite low for stratus Clouds anyway (e.g., Hudson and Svensson 1995). Such low supersaturations (<0.1%) are only possible with the DRI spectrometer.

We expect significant variations in CCN concentrations, spectral shape, and composition during FIRE-III. CCN spectral measurements are necessary in order to keep separate the effects on cloud microphysics of differences in cloud dynamics from the differences in the aerosol. Comparisons with identical CCN measurements in several other stratus projects— FIRE, ASTEX, SOCEX-1 and 2, MAST, ACE-1—will be indispensable.

Canadian Participation in FIRE III

George Isaac
Atmospheric Environment Service

Observations collected by the Canadian PIs, together with the other FIRE III data, will be used to understand Arctic cloud formation, development, and their effect on climate change. Special emphasis will be put on the interaction of Clouds with Arctic aerosols, the influence of the aerosol chemistry upon cloud microphysical characteristics, and the general role Clouds play in redistributing, transforming, and transporting Arctic chemical constituents. Using the observations, microphysical, chemical, dynamical and radiative properties, as well as the vertical and horizontal spatial distribution characteristics, of the Clouds studied will be determined. Parameterizations will be developed, describing these properties, that might be used in GCMs. Where possible, these parameterizations will be tested and evaluated in column models, cloud resolving models and full scale GCMs.

It is anticipated that the National Research Council Convair 580 will be involved and would fly out of Inuvik, NWT Some specialized "round instrumentation, such as lidars and radars, might also the used. The possibility of placing instrumentation for measuring chemical constituents on the ice flow and other surface sites will be explored. This research will involve a large number of Canadian scientists and is dependent upon Canadian funding approval. Formal plans for this work, including PIs designated for each task, have yet to be developed.

Remote Sensing and Retrieval of Arctic Stratus Clouds and Surface Characteristics

Michael King and Si-Chee Tsay
NASA Goddard Space Flight Center

This investigation continues studies of the radiative and microphysical properties of Arctic stratus Clouds and snow/sea ice surface. The Moderate Resolution Imaging Spectroradiometer (MODIS), being developed as part of the Earth Observing System (EOS) and scheduled to be launched in 1998 on the EOS AM platform, is a NASA facility instrument designed to meet the scientific needs for satellite remote sensing of Clouds, aerosols, water vapor, and land and ocean surface properties. To support the development of MODIS remote sensing and retrieval algorithms, the MODIS Airborne Simulator (MAS) was developed for NASA's high-altitude ER-2 aircraft. This airborne sensor is capable of providing narrowband spectral coverage similar to MODIS of reflected solar and emitted thermal radiation. Over the past few years, MAS has flown in many field campaigns throughout the world, including recently in Alaska. These diverse data sets provide critical measurements for assessing the scientific capability and usefulness of MODIS charnel s , as well as enabling unique information to be acquired from studies of the Earth's atmosphere and surface. Analyses of various cases obtained during previous FIRE-I and II experiments are an important element of this investigation.

The intent of this investigation is to support our participation in the FIRE-III field campaigns and to analyze data obtained by MAS during previous campaigns. Specifically, we intend to:

(1) participate in flight planning and direction of the NASA ER-2 aircraft over Arctic stratus Clouds off the north slope of Alaska during the 1998 field campaign,

(2) build a well-calibrated and feature-rich data set to improve MODIS cloud masking algorithms,

(3) distinguish Clouds from snow covered tundra and sea ice surfaces,

(4) retrieve stratus cloud properties (i.e., optical thickness and effective particle radius) over highly reflecting surfaces, and

(5) perform statistical analyses of stratus cloud properties by using high spatial resolution MAS data.

Study of midlatitude and Arctic aerosol-cloud-radiation feedbacks based on LES model with explicit ice and liquid phase microphysics

Yefim Kogan[1] and Douglas Lilly[2]
[1]Cooperative Institute for Mesoscale Meteorological Studies, [2]School of Meteorology, University of Oklahoma

The complexity of cloud-radiation problem results in large uncertainties in estimating the cloud forcing in global climate models. Of particular importance are cloud-radiation feedbacks in midlatitude, subtropical, and high-latitude low lever Clouds. Continuing investigation of these cloud systems is a major goal of the FIRE III program.

The proposed work will have two major thrusts:

(1) Continuing the study of marine stratocumulus Clouds using LES simulations based on FIRE I and FIRE II/ASTEX observational data. The data will be used to validate the CIMMS LES model and to improve our understanding of the interaction between the microphysical, radiative, and thermodynamical processes. Validation of the model against observations will result in further refinement and improvement in the model physical and numerical formulation.

(2) Large-eddy simulations of arctic cloud systems, including low lever stratus with liquid and mixed phase microphysics.

The modeling part of the research will be based on the CIMMS 3-D LES model of a stratocumulus cloud layer that includes an explicit formulation of aerosol and cloud drop size-resolving microphysics and radiation. The study of mixed phase Clouds will use the new version of the CIMMS model which includes also explicit formulation of the ice-phase microphysics. Depending on the physics and the scale of the studied phenomena, the model may be also formulated in a 2-D framework with bulk treatment of microphysics.

In accordance with the FIRE m objectives, model simulations and data analysis will aim at the improvement of existing parameterizations of cloud and radiative processes in LES and GCM models. The analysis of ASTEX and FIRE III observational data sets will be made in collaboration with the researchers from British Meteorological Office, University of British Columbia and University of Colorado.

Cloud-Scale Numerical Modeling of the Arctic Boundary Layer

Steven Krueger

Dept. of Meteorology, University of Utah

The interactions between sea ice, open ocean, atmospheric radiation, and clouds over the Arctic Ocean exert a strong influence on global climate. Uncertainties in the formulation of interactive air-sea-ice processes in global climate models (GCMs) result in large differences between the Arctic and global climates simulated by different models. Arctic stratus clouds are not well-simulated by GCMs, yet exert a strong influence on the surface energy budget of the Arctic. Leads (charnels of open water in sea ice) have significant impacts on the large- scale budgets during the Arctic winter, when they contribute about 50 percent of the surface fluxes over the Arctic Ocean, but cover only 1 to 2 percent of its area. Convective plumes generated by wide leads may penetrate the surface inversion and produce condensate that spreads up to 250 km downwind of the lead, and may significantly affect the longwave radiative fluxes at the surface and thereby the sea ice thickness. The effects of leads and boundary layer clouds must be accurately represented in climate models to allow possible feedbacks between them and the sea ice thickness.

The FIRE III Arctic boundary layer clouds field program, in conjunction with the SHEBA ice camp and the ARM North Slope of Alaska and Adjacent Arctic Ocean site, will offer an unprecedented opportunity to greatly improve our ability to parameterize the important effects of leads and boundary layer clouds in GCMs.

We will make extensive use of FIRE III measurements and a high-resolution numerical model, the University of Utah Cloud Resolving Model, to increase our understanding of the physical processes that determine (1) the formation and structure of Arctic stratus clouds and (2) how leads over the Arctic Ocean affect the large- scale budgets of sensible heat, water vapor, and condensate. This is necessary before developing lead and boundary layer cloud parameterizations based on general physical principles. We will:

(1) Determine in detail how large-scale processes, in combination with cloud-scale radiative, microphysical, and dynamical processes, govern the formation and multilayered structure of Arctic stratus clouds.

(2) Quantitatively determine the effects of leads on the large-scale budgets of sensible heat, water vapor, and condensate in a variety of Arctic winter conditions.

Intended FIRE-III Research

D. H. Lenschow and Q. Wang
National Center for Atmospheric Research

Our intended FIRE-III research will utilize previous field observations of Arctic clouds, boundary layer, and ice surface to perform integrated analyses of both the Arctic clouds and boundary layer, and evaluate instrument capabilities for making measurements in the Arctic environment. We plan to use the data set obtained from the Beaufort and Arctic Seas Experiment (BASE) as the primary data source for two important reasons. First, BASE obtained measurements in the Arctic boundary layer during the fall/winter transition sea son which is not well documented Several types of structure were measured during this experiment, including stably-stratified boundary layers, mixed-phase boundary-layer clouds, boundary layers modified by leads and polynyas, and multi-layered cloud structures. Second, a primary platform for BASE was the newly-instrumented NCAR C130 which will likely be deployed in FIRE-III/SHEBA. Evaluation of the capability of the instruments on the C-130 to measure in the Arctic is an essential step in preparing for FIRE-III/SHEBA.

In addition to the BASE data set, we plan to analyze measurements from the Arctic Stratus Experiment and the Arctic Ice Dynamics Joint Experiment (AIDJEX) which measured the summertime Arctic boundary layer, and from the Lead Experiment (LEADEX) which measured the effects of open leads during winter/spring. Although these detests (excluding BASE) have been studied by other researchers, our analyses will focus on addressing problems that were uncovered during and after these experiments with a view towards improving measurements in FIRE-III/SHEBA.

The primary objectives of the proposed research are to:

(1) understand the Arctic cloud and boundary layer structure, especially the interactions among cloud microphysics, turbulence, and radiation using in situ aircraft measurements;

(2) understand the moisture, heat, and momentum exchange between the atmosphere and the Arctic ocean water/ice surface;

(3) assess the instrumentation capability on the newly-deployed NCAR C-130 for making measurements in the Arctic environment and provide a basis for improved measurement capabilities for the FIRE-III/SHEBA field campaign;

(4) optimize the aircraft measurement strategy in the Arctic for FIRE-III/SHEBA;

(5) provide analyses from in situ measurements useful for interpreting and validating satellite remote sensing and retrieval algorithms, and for validating results from numerical modeling of the Arctic clouds and boundary layer (in collaboration with Judith Curry, University of Colorado).

FIRE III Research

Dave Randall
Colorado State University

We propose to investigate the Arctic climate simulated by the current version of the CSU GCM, with particular attention to cloudiness and the surface energy budget. We propose to develop a one-dimensional model of the Arctic atmosphere-sea ice-ocean system, which will exist in two versions, which differ only in their treatment of the atmosphere. The first version will be based on the second-order bulk model developed by Randall et al. (1992), and the second will use a one-dimensional version of the third-order closure developed by Krueger (1988). These one-dimensional models will be tested using the FIRE Arctic data in "single-column model" mode. Following these tests, at least one of the two versions will be transferred to the CSU GCM, and used in simulations of the present climate and of climate change due to increasing CO2.

Radiative Energy Exchanges In The Polar Regions

William Rossow and Barbara Carlson
Institute for Space Studies, Goddard Space Flight Center

Some evaluations of the surface energy balance in the polar regions, that currently maintains a persistent sea and land ice cover, suggest that it may be very sensitive to climate perturbations; however, little change in polar ice/snow cover over the past century has been documented, even though global temperatures have changed somewhat. This situation reflects a generally poor understanding of the polar energy balance and the feedback processes controlling it. There has been recent significant progress in quantitative methods for analysis of satellite measurements of the atmosphere, clouds and surface; however, the paucity of quality in situ observations has prevented verification of these methods under more difficult polar conditions. Very few of these methods have even been applied to study of the polar regions. As one step towards determining the polar energy balance and the key controlling processes, we propose to combine all of the available satellite measurements into a single consistent analysis that measures the key properties of the atmosphere, clouds and surface required to infer the surface and top-of-atmosphere radiation balance and its seasonal variations. Building and improving upon the ISCCP analysis of imaging radiometer data, we will add measurements by infrared and micro-wave sounders to deal with the complex variations of surface and cloud properties. Using energy balance models, together with these observations, we can infer the required energy transports (mostly by the atmosphere) required to balance radiative fluxes and examine the sensitivity of ice and snow cover to variations in these fluxes. If this work is funded as part of a U.S. contribution to the Canadian GEWEX experiment called BASE and a new project called SHEBA, then the value of our combined satellite analysis will be greatly enhanced by comparison with coordinated surface and aircraft observations and more complete atmospheric and sea ice modeling efforts of collaborators.

Studies of the Radiative and Microphysical Properties of Cloud, Aerosol and Surface Bi-Directional Reflectance

Si-Chee Tsay and Michael King
NASA Goddard Space Flight Center

This investigation continues studies of the microphysical, optical and radiative properties of Arctic clouds and aerosols, and characterizes the anisotropy of various types of Arctic surfaces. Tools of this investigation include a multispectral scanning radiometer (CAR; Cloud Absorption Radiometer), which is mounted on the University of Washington's C131A aircraft for the purpose of measuring the angular distribution of scattered radiation deep within a cloud layer, from which the single-scattering albedo of clouds can be determined as a function of wavelength. Recent improvements in the CAR further advance its capability in characterizing the radiative properties of aerosols and surfaces. Over the past few years, the CAR has flown in many national and international field campaigns, providing unique information in studies of cloud, aerosol and surface properties. Analyses of various cases obtained during previous experiments are an important element of this investigation.

The intent of this investigation is to participate in the 1997 FIRE-III and upcoming SCAR-B (Smoke, Cloud And Radiation - Brazil) field campaigns, and to analyze data obtained by the CAR as well as other ancillary and coordinated microphysics/radiation data sets during previous campaigns. Specifically, we intend to:

(1) validate experimentally the relationship between cloud single-scattering albedo and effective particle radius from CAR radiation measurements in the diffusion domain,

(2) determine the radiative properties (i.e., optical thickness, single-scattering albedo and phase function) of aerosol from CAR radiation measurements for use in developing atmospheric corrections, and

(3) characterize the bi-directional reflectance distribution function (BRDF) over Arctic snow and sea ice surfaces, as well as other types of surfaces, to develop physically based surface BRDF models.

FIRE III Research

Tanneil Uttal
NOAA Environmental Technology Laboratory

The National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL) is presently involved in studies of radiatively important cloud properties, utilizing data from the First ISCCP Radiation Experiment (FIRE II) and the Atlantic Stratocumulus Transition Experiment (ASTEX). Important remote sensing techniques based on radar, lidar and IR radiometer measurements have been developed at ETL that remote sensing of profiles of cloud properties such as particle concentrations, sizes , LWC , and IWC from the "round that were not possible even a few years ego. The proposed work includes analysis of FIRE II and ASTEX data sets with an emphasis on comparison of cloud properties between different climatic regimes. In addition, NOAA/ETL has received separate funding for FY96 to conduct a similar measurement campaign in the tropical Western Pacific as part of the DOE/ARM program.

In this proposal we also plan to augment the mid-latitude, sub-tropical and tropical data sets with an arctic data set collected in conjunction with the FIRE III and SHEBA programs in 1997. Deployment of a 35 GHz radar, lidar, and IR radiometer will allow characterization of arctic clouds, haze, and aerosol which will be directly comparable to FIRE III, ASTEX, and TWP results. This will provide the radiation/climate community with an unprecedented data set for four major climatic zones. The emphasis in this study will be on the intercomparison of cloud properties to answer important questions of global variations of upper tropospheric and boundary layer clouds.

A Parameterization Study of Marine Boundary-Layer Clouds

Shouping Wang
NASA Marshall Space Flight Center

The goal of the proposed research is to formulate a new parameterization of marine boundary-layer clouds for a large-scale model. We propose to develop a model based on the buoyancy sorting concept developed by Raymond and Blyth (1986), mass flux-layered model of Wang (1993), and the prognostic cloud scheme developed by Tiedtke (1993). For the application in the marine boundary layer, we need to improve the representation of the cloud-top entrainment, large-scale condensation and evaporation in the cloud scheme. We also emphasize the interaction between the cumulus and stratocumulus clouds in the boundary layer. In the processes, some large-eddy simulation runs will be conducted to study the interaction that is crucial to our new parameterization. We will also implement the new prognostic cloud scheme into a traditional second-order turbulence closure model. Thus, the stratocumulus, trade-wind cumulus regimes and the transition between them can be predicted with a unified cloud scheme. All the one-dimensional models will be tested with ASTEX and FIRE data. Following the tests, we plan to implement the models into a general circulation model.

Tropical Cirrus Proposals

Application of FIRE Phase I and II Results to Model Parameterizations and Extension to other Geographic Locales

T. Ackerman and G. Mace
Pennsylvania State University

The ultimate goal of the proposed research is to improve parameterization of cirrus in large scale models. Our intent is to use the Cirrus II data set to drive a suite of GCM cloud parameterizations using the WPDN wind profiler and radiosonde-diagnostics as input parameters. A verification data set derived from the Cirrus II ground-based and satellite data is being created for comparison with the parameterization output. An extensivanalysis of the relationship between large-scale forcing and cirrus formation and maintenance will also be undertaken. In order to supplement the temporally limited Cirrus II results, we will conducting limited observational campaigns at our Pennsylvania field site taking advantage of our unique suite of instruments, including radar, lidar, microwave radiometer, and flux radiometers. To extend the results from midlatitude cirrus to other geographical regions, data collected during TOGA COARE under the sponsorship of NASA and the U. S. Department of Energy will be examined in considerable detail in order to quantify the importance of tropical cirrus to the local radiative energy budgets and identify similarities and differences between tropical cirrus and their midlatitude counterparts. A recently completed cirrus cloud model that couples ice microphysics, radiative transfer, and cloud-scale dynamics will be used to simulate the COARE data, as well as carry out simulations relevant to proposed tropical cirrus experiments.

FIRE III Research

Leo Donner
NOAA Geophysical Fluid Dynamics Laboratory

My FIRE-III research will focus on cirrus anvils associated with deep convection. I have developed a GCM parameterization for deep convection (Donner, 1993a), which includes a method for determining the ice source for cirrus anvils. The parameterization can be used either diagnostically or in conjunction with a prognostic ice scheme in a GCM. A field experiment to characterize simultaneously the thermodynamic, hydrological, microphysical, and radiative properties of deep convective systems and their associated anvils has not been conducted. Such an experiment is necessary to provide a fundamental understanding of these systems and to permit the validation and further development of parameterizations such as that mentioned. The parameterization provides a number of testable hypotheses regarding deep convective systems and their interactions with larger scales by thermodynamic and radiative mechanisms which can be tested in a convective cirrus experiment of the type under discussion in FIRE III.

Aircraft Cloud Studies: FIRE III

John Hallett
Desert Research Institute

It is proposed to utilize currently available instrumentation and new instrumentation on aircraft participation in the Arctic stratus experiment and also in the proposed high lever tropical cirrus experiment. The purpose is to examine extremes of the particle spectra which are responsible for remote sensing signals, radiative and precipitation properties of such clouds. Such instrumentation is capable of mounting in a PMS pod, and can be readily installed on the NCAR C-130 or University of Washington 580; it can be modified for mounting on WB-57F or (cloudscopes) miniaturized for mounting on a smaller remotely piloted vehicle. The overall purpose is to gain insight into the processes leading to cloud formation and differences in the optical properties of such clouds.

The following instruments and measurements are to be emphasized:

• Continuous Ice Crystals Replicator (few μm to 250 μm)

This provides a continuous record of particles in a plastic formvar film which can consequently be examined by optical microscopy or other techniques. The formvar replicator may be modified to detect sulfate/nitrate containing particles; it is to be used in parallel with 2D-C probe. Sample volume 1 l s^{-1}; spatial resolution a few m. Gives concentration, size, habit, phase of particles (Foster et al. 1995); some automation of analysis is available (Arnott et al. 1995).

• Cloudscope, high resolution (few μm)

This instrument has a sample volume of 100 cm3 s-1 and uses a VCR to record particles impacting on a small (500 ¥ 500 μm) optical flat facing the air stream at stagnation conditions. In cirrus cloud, with many smaller ice particles, it can give size and shape distribution, and together with a mass and density of each particle direct from evaporation time. Spatial resolution ~5 m; maximum particle size ~ 250 μm (Arnott et al. 1995).

It can also be used to show presence of a few large aerosol particles in clear air. Such particles (a few to 10 ~m size) impact on the optical flat and may crystallize at the stagnation relative humidity confirming a hygroscopic component. Visual analysis of real time video gives concentrations of such large aerosol particles. These are important for radiation and cloud physics considerations, they may lead to the presence of large cloud droplets which may precipitate or freeze. Such measurements would be made above the cloud of an Arctic stratus inversion to show their importance in producing large droplets as the overlaying aerosol is clown mixed into the cloud below. This is proposed for ASTEX and would be related to CCN and droplet measurements (as proposed by J. Hudson). The measurements are also important for investigating the structure and origin of high lever, low visibility cirrus; this is proposed for a tropical cirrus experiment. It is anticipated that different composition particles (nitric acid trihydrate compared with ice) will behave differently in evaporation and some estimates of the presence of these components at low temperature could be obtained .

• Cloudscope, low resolution

A similar concept instrument is supposed to seek the presence of low concentration of large particles responsible for radar echoes. The principle is identical to the high resolution instruments, only it uses a forward facing flat of 10 ¥ 10 cm, giving a volume sample rate of several m3 s~ 1. Small particles (10 ~m) will not be collected at all, and large particles (few mm) collected uniformly . Some information on intermediate size particles may be obtained from variation in collected particles from the center to the edge of the collecting flat. This would be used for detecting occasional large ice particles in Arctic stratus or tropical cirrus, to give estimates of radar reflectivity and also an estimate of sizes which dominate mass.

Abstract of Intended FIRE-III Research

A. J. Heymsfield and L. M. Miloshevich
National Center for Atmospheric Research

In summary, our intended F~ m research will include: development of a conceptual and quantitative model of cirrus formation and evolution, based on our FIRE I, II and m studies to date; continued acquisition and analysis of cirrus microphysical measurements from our balloon-borne ice crystal replicators; acquisition and analysis of aircraft measurements for the FIRE experimenters involved in radar operations at the ARM site during SUCCESS; and development of a strategy for a possible FIRE-III tropical cirrus experiment.

Thus Far during FIRE III we have completed reprocessing of the King Air and Sabreliner relative humidity(RH) and 2D probe data. A preliminary look at the RH data seems to confirm the hypothesis put forth in Heymsfield and Miloshevich, 1995, that cirrus clouds can be represented by a three-layer model: a highly ice-supersaturated ice crystal generation zone at cloud top, a mid-level ice-saturated growth zone, and a longer ice-subsaturated zone of ice crystal sublimation. We will use the FIRE II RH, 2D, and replicator data, the aircraft data collected during our pre-FIRE II wave cloud experiment, and the replicator data described below, to define: (1) the fundamental RH condition required for ice nucleation in cirrus, (2) the thickness and representative microphysical and thermodynamic properties of the three distinct regions in cirrus, and (3) insights into the relative contributions of the homogeneous versus heterogeneous ice nucleation processes. We will prepare a publication in the formal literature reporting our results.

We have acquired high-quality data from our ice crystal replicator during the first year of FIRE III. Cases include: two cirrus wave clouds, a stratiform ice cloud, two deep cirrus thunderstorm anvils, two liquid water clouds, two multi-layer cloud cases, and a winter storm case. The first three cases were collected together with high quality RH measurements from a balloon-borne cryogenic hygrometer, making them particularly valuable in assessing the dependence of cirrus formation and evolution on RH. The two liquid water cases provide data on the efficiency with which the replicator collects small particles, an important aspect of the quantitative performance of the replicator. The lest launch was a successful test of an improved prototype instrument. One of us (LMM) is preparing a paper that assesses the qualitative and quantitative performance of the replicator. We will be analyzing these measurements and the FIRE II replicator measurements using efficient image processing techniques we are developing. During the remainder of FIRE III we will attempt to launch one replicator per month on average, focusing on summertime cirrus anvils, about which little is known.

During the NASA SUCCESS program, the DC-8 will be overflying the ARM CART site, with several flights dedicated to remote sensing objectives. A number of FIRE researchers, including Ackerman, Sassen and Minnis, will be using lidar, radar and satellites to study cirrus cloud microphysical properties. One of us (A]H) will be installing a PMS 2D-P probe on the DC-8 for the intercomparison and validation objectives. We will acquire and process the 2D-P data, and make it available to FIRE researchers.

One of us (AJH) is involved in the formulation of a tropical cirrus study under consideration in the vicinity of Panama during the summer of 1997. AJH is also involved in the development of INDOEX, a program that includes a cirrus component being organized by the Scripps Center for Clouds, Chemistry, and Climate, presently planned for winter/spring 1998. We will work toward including FIRE investigators in the Panama experiment or, alternatively, work to conduct a FIRE experiment prior to or after INDOEX.

FIRE III Research

Paul Lawson
SPEC Inc.

Analysis of Existing Data

During the course of SPEC's LaRC SBIR contract, we recorded digital holograms and scattering measurements from thousands of ice crystals in the CSU dynamic cloud chamber. The dynamic cloud chamber performs a predictable adiabatic expansion that produces ice crystals with consistent habits and sizes as the pressure and temperature in the chamber decreases. The crystal habits include stellars, dendrites, plates, columns and a few rosettes (-10 > T > 40 •C) and the size range varied from about 30 to 250 gm. Ice crystals were extracted from the chamber and accelerated through the sample volume of the Pi-Nephelometer. Holograms and scattering measurements of thousand of ice crystals were recorded This data set encompasses more than 100 Mbytes of measurements. Also, in-focus video of the ice crystals is available from video photography of a moving tape that collects crystals as they fall to the bottom of the chamber. The SBIR effort was intended to provide a proof-of-concept demonstration that the Pi-Nephelometer was capable of making digital holography and scattering phase function measurements. This task was accomplished, however, there were no funds to analyze the massive amount of collected data. As a part of our FIRE III effort, we will statistically correlate the scattering measurements with holography images and video photography of crystal size and shape. This effort will include the development of additional software to process, analyze and display the measurements.

Modifications to LaRC Pi-Nephelometer

The optics in the LaRC Pi-Nephelometer will be modified to increase the acceptance angle of the solid-state camera, install a new generation m image intensifier and to provide a separate reference beam. These modifications are intended to improve the capability to reconstruct images of holograms where there is a high percentage of light transmitted through a crystal.

New Measurements in the CSU Cloud Chamber.

We will conduct limited additional tests in the CSU cloud chamber. These tests will focus on crystal types not included in the previous data set (primarily bullet rosettes) and repeats of some other crystal types. The additional tests will be used to supplement the existing data set and to determine the improvement in the ability of the Pi-Nephelometer to record holograms of ice crystals and reconstruct images.

Scattering Phase Function and Radiative Parameters

The cloud chamber and flight measurements of scattering phase function will be used to determine representative phase functions for various habits of crystals typically found in cirrus clouds in the mid-latitudes and the tropics. We plan to work with Dr. Heymsfield and Dr. Liou (available through other FIRE III funding) to integrate our measurements with existing data collected over the lest twenty years by Dr. Heymsfield. Typical phase functions can be estimated for various types of ice crystals.

Radiative Transfer and Satellite Remote Sensing of Cirrus Clouds Using

FIRE-II IFO Data

K. N. Liou
University of Utah

We will use the replicator sonde, atmospheric sounding, and satellite data associated with five cirrus cloud cases (22, 26, 28, and 29 November and 5 December 1991) during FIRE II-IFO to determine and parameterize the radiative properties of cirrus clouds and to validate the satellite retrieval algorithm developed for the mapping of the optical depth and ice crystal size for these clouds based on AVHRR channels.

Specifically, we will carry out the following research:

(1) Analysis of the ice crystal size distribution and shape including small ice crystals from the replicator sonde data obtained in FIRE-II-IFO. Development of the representative ice crystal size distributions and shapes for midlatitude and tropical cirrus for application to radiation/climate modeling.

(2) Development of a light scattering program for aggregate and irregular-shaped crystals based on Monte Carlo/geometric ray-tracing method. Development of a scattering and absorption program for small ice crystals on the basis of a novel hybrid geometric optics method. Use of the "exact" FDTD method to calibrate the efficient modified geometric optics approximation.

(3) Validation of a detection scheme for the identification of clear, cirrus, low cloud, cirrus/low cloud cases in multilayer cloudy conditions using FIRE-II-IFO lidar, radar, and sounding observations. Validation of a satellite AVHRR retrieval algorithm for the mapping of cirrus optical depth, temperature, and mean ice crystal size, employing the FIRE-II-IFO replicator and sounding data for the aforementioned five days during which extensive cirrus occurred.

Physically Based Retrieval of Ice Cloud Properties

Michael Mishchenko, Brian Cairns, and Andreas Macke
Goddard Institute for Space Studies

Previous analyses of the FIRE measurements have been interpreted as indicative of ice particle asymmetry parameters smaller than 0.75 at solar wavelengths. This is consistent with the results obtained by ray tracing calculations for realistic fractal particle shapes. Alternatively , the effect of cloud inhomogeneities can be equivalent to choosing a more isotropic phase function in the standard horizontally homogeneous plane-parallel model. Because of these ambiguities, we are undertaking a broad-minded research effort aimed at improving our understanding of ice clouds and based on self-consistent use of state-of-the-art modeling techniques.

The unique aspect of our approach is the use of ray tracing and T-matrix methods to accurately compute light scattering and absorption by ice crystals with size parameters ranging from zero to infinity. Recent dramatic improvements in the T-matrix method have made it applicable to size parameters as large as 100, thus, potentially, covering the gap between the domain of applicability of the Rayleigh (size parameters less than 1) and geometric optics (size parameters larger than 100) approximations. This result is especially important since the T-matrix method is many orders of magnitude faster than any alternative technique for rigorously computing nonspherical scattering. We are now in the process of examining in detail the convergence of results obtained with the T-matrix and ray tracing methods at size parameters less than 100 for different nonspherical shapes (spheroids and cylinders with varying aspect ratios). This research will result in the complete size-parameter coverage with only two techniques. Both of these techniques are combined with line-by-line and K-distribution techniques to retrieve the properties of physically realistic, vertically extensive, clouds containing a mixture of gas and particles. At thermal infrared wavelengths, light scattering depends primarily on the particles' overall departure from sphericity and is computed using the T-matrix approach. Analysis of infrared spectral measurements permits the retrieval of effective particle size, the vertical distribution of cloud opacity, and cloud temperature. Light scattering at visible wavelengths is very sensitive to particle shape, in particular, to its irregularity, but nearly independent of particle size. In this spectral range the ray tracing technique is an accurate means to retrieve particle shape/phase function information. Both techniques are applicable in the infrared which allows us to transfer the physical parameters retrieved from thermal infrared data to the phase function/shape information retrieved from visible data. We plan to use the results of this work in improving radiative treatment of ice-cloud particles in the GISS GCM and the ISCCP retrieval algorithm.

The ambiguities in the interpretation of FIRE results introduced by cloud inhomogeneities are addressed using a renormalization method. This method allows the effects of cloud inhomogeneities to be included in a standard plane-parallel model, with renormalized single-scatter albedo, phase function and optical depth. These renormalized quantifies depend in a simple way on the single-scattering properties calculated using T-matrix and ray tracing calculations and on the variability in particle density, with the usual single scattering properties being retrieved in the limit of no variability. Comparisons with Monte Carlo calculations indicate that this renormalization method is valid over a wide range of variability. We can therefore readily examine the sensitivity of retrieved microphysical properties to the presence of inhomogeneities and check the consistency of these retrievals with microphysics probe measurements when allowance is made for the presence of cloud inhomogeneities. The renormalization method allows the effect of cloud inhomogeneities to be included in calculations that treat ice scattering and absorption accurately and take proper account of gaseous scattering and absorption from the visible to the thermal infrared.

Analysis of Cirrus Cloud Microphysical Data

Michael Poellot
University of North Dakota

The objectives of the proposed work are to: (1) characterize the cirrus clouds sampled by the University of North Dakota (UND) Citation aircraft during the FIRE Cirrus IFO-II in terms of particle size distributions, crystal habit and ice water content; (2) analyze the spatial variation of cirrus clouds; and (3) participate in limited collaborative case study analysis of IFO data.

(1) Microphysical characterization of cirrus

The method of analysis will follow that of Heymsfield and Platt (1984; hereafter referred to as HP), where pass average values of particle concentrations by size are calculated. Data from the DRI (Desert Research Institute) replicator will be used to determine particle characteristics for the smaller particles and PMS 2~C data for the larger particles. Following HP, the size distributions will be parameterized for each 5 •C temperature range analyzed, and the pass average IWC used to normalize the spectra. Values obtained for the clouds sampled in this study will be compared with those derived by HP. In addition to the stratification by temperature, an effort will be m~ to determine relationships between the microphysical and macrophysical cloud properties such as cloud depth, distance from cloud boundary, and large-scale forcing. It will not be within the scope of this proposal to analyze all of the replicator data; rather, portions of the film from a representative portion of each data leg will be processed. The bulk of the replicator data processing will be performed under subcontract with DRI.

(2) Analysis of the spatial variation of cirrus clouds

It is planned to do a spectral analysis (similar to that of Sassen et al. 1989) of the vertical velocities derived from the UND Citation IFO data for the legs flown in cirrus. This will also be clone for several of the cirrus microphysical parameters (e. g. , ice crystal concentration and size) derived from the 2D-C data. The output of this work will be a description of the variation of these parameters as a function of scale. This will allow us to see if the apparent fluctuations in vertical velocity at the 1 km scale are indicative of fluctuations in cloud microphysical characteristics of the same scale.

(3) Limited collaborative case studies

Not all of the significant observational missions from this IFO have been thoroughly analyzed, including a subtropical cirrus case from November 30 and a multiple-aircraft satellite underpass mission on December 7. It is expected that UND will become involved in one or two such case study analyses.

FARS Cirrus and Anvil Research for FIRE m

Kenneth Sassen
University of Utah

High cloud remote sensing research at the University of Utah Facility for Atmospheric Research (FARS) in support of the Project FIRE Extended Time Observations (ETO) component began in December 1986, and now comprises ~1900 hours of polarization lidar (0.694 ~m wavelength) observations. These measurements are invaluable as "groundtruth" data in statistically defining cloud heights for helping to evaluate and improve the algorithm used in the extensive ISCCP program data set to identify and characterize various clouds from satellite radiance data. Importantly, a strong improvement in the FARS remote sensing capabilities has occurred since 1991, involving initially a comprehensive suite of surface radiation budget radiometers and a narrow-beam midinfrared (9.5 - 11.5 gm) radiometer, and more recently an advanced two-color (0.532 and 1.06 μm) scanning Polarization Diversity Lidar (PDL) and a 95 GHz (3.2 mm) polarimetric Doppler radar. We intend to utilize the entire FARS state-of-the-art remote sensor ensemble to support further ETO high cloud case studies on a selective bias, particularly under optically-dense cirrus and anvil cloud conditions to help assess the effects of optical extinction on our extended dataset. Anvil cirrus clouds will receive particular attention, because previous FARS studies suggest that Great Basin anvils display significant scattering departures from other cirrus in the visible, infrared, and microwave spectral regions, and in recognition of the fact that anvils in other climatic regimes (i.e., the tropics) may differ significantly in their properties. In this regard, we are performing a retrospective polarization lidar data analysis program of western-central Pacific Ocean anvil/cirrus cloud data collected aboard the NASA DC-8 platform during the TOGA/COARE intensive field phase a. D. Spinhirne, NASA co-investigator). This study is yielding statistical information on tropical cirrus cloud physical and scattering properties, as well as providing case studies to delineate the effects on cirrus of the fallout of sulfuric acid aerosol from the June 1991 Pinatubo eruptions. We will also continue to identify for analysis and publication cirrus cloud case studies from our growing FIRE ETO and IFO datasets.

FIRE Cirrus Cloud Studies

David Starr
NASA Goddard Space Flight Center

This research project focuses on the following fundamental questions concerning physical processes in upper tropospheric clouds: What is the role of large-scale, mesoscale and small-scale dynamical processes in determining the physical properties of cirrus clouds? and What is the role of microphysical and radiative processes in determining the physical properties of cirrus clouds and how are they modulated by and how do they interact with dynamical processes at various scales? Improved understanding of the interaction of dynamical, microphysical and radiative processes in determining the net ice water budget and associated vertical transports in cirrus clouds is essential to efforts to develop and corroborate representations of cirrus cloud processes for application in large-scale models used for climate studies. The approach that will be taken is to continue our analysis of the wealth of observations obtained during the 1991 FIRE Cirrus-II field campaign and the FIRE Pilot tropical Cirrus Experiment during TOGA-COARE integrated with renewed efforts to investigate cirrus cloud development using a very high resolution numerical cirrus cloud model. This project will also support proposed FIRE-III field activities (experiment design and execution) and utilize the data obtained. We will continue our active collaboration with and support of other FIRE researchers by providing analysis and data products, as we have in the past. Dr. Starr will contribute substantially to the development of plans for the implementation of FIRE-m and an eventual FIRE tropical cirrus experiment. Dr. Starr is also heavily committed to the planning and execution (mission scientist) of the joint NASA AEAP/FIRE SUCCESS mission scheduled for April 1996 in Kansas/Oklahoma that is concerned with the possible effects of aircraft emissions, including contrails and also possible aerosol effects, on cirrus clouds and global climate.

Our proposed analyses of FIRE Cirrus-II and other observations will define the dynamical and thermodynamic environment and internal structure of observed cirrus cloud systems and characterize the macrophysical and microphysical structure of the clouds. We will investigate the interactions between cloud processes and larger scale atmospheric controls. These results will be used to guide our modeling efforts. A number of significant improvements to our cirrus cloud model are underway including implementation of a new dynamical package, incorporation of an advanced explicit cloud microphysics package enabling explicit consideration of nucleation processes, and improvement in treatment of cloud radiative processes.

We will extend our studies to consider three topics of central importance to FIRE-III: a) anvil cirrus both in the middle latitudes and in the tropics, b) the role of nucleation processes in determining cirrus cloud properties, and c) contrasting cirrus development associated with the subtropical jet stream versus other cirrus situations in the middle latitudes.

Cirrus Cloud Properties from Aircraft

Graeme Stephens
Colorado State University

This proposal describes research aimed at the development of new techniques for both remote sensing of ice cloud properties and for measurement of their shortwave radiative properties. The approach proposes to develop and fly new spectrometers principally in the near infrared region (a high resolution A-band spectrometer and a scanning spectral polarimeter), as well as the use of a new airborne radar and mm microwave radiometer. The aim is to deploy these instruments in a proposed field experiment and carry out analyses of the data and supporting theoretical research.

Theoretical and Experimental Studies of the Interactions between Clouds and Aerosols

Owen Toon, Andrew Ackerman, Joelle Champney, Eric Jensen, Irina Sokolik
NASA Ames Research Center

Our work is aimed at better assessing the indirect effects of aerosols on. We have developed one and two-dimensional models of the interactions between tropospheric aerosols and clouds. Marine stratus clouds have been shown to be sensitive to the abundance of aerosols in the marine boundary layer. Our work has shown that the depth of the boundary layer and the optical thickness of stratus can be controlled by the abundance of aerosols. We have also been able to simulate many of the properties of ship tracks, including the albedo change in the clouds, as well as the liquid water and drizzle rate changes that are induced by adding aerosols to the marine boundary layer from ship exhaust. We have also developed models of cirrus clouds and their sensitivity to ambient nuclei concentrations. We have shown that cirrus clouds are not as sensitive to changes in ambient aerosol concentrations as are stratus. However, even cirrus will respond if aerosols with unusual properties are introduced. At the present time we are working to construct an LES model for both marine boundary layer and cirrus clouds so that more realistic simulations can be conducted.

In addition to theoretical studies we have participated in a number of FIRE sponsored field programs, as well as the NavyÕs MAST program to investigate ship tracks. At the present time the PI is the project scientist for SUCCESS. SUCCESS is a joint program between FIRE and NASA's Atmospheric Effects of Aviation Program. SUCCESS has a number of goals including improving our understanding of the radiative properties of cirrus clouds and of contrails, characterizing the aerosols in the upper troposphere, determining the formation mechanisms of cirrus clouds and determining the role of aircraft exhaust in modifying cirrus. SUCCESS will involve the NASA DC-8, ER-2 and T-39 aircraft in a coordinated field program. The aircraft will be based in Salina, Kansas during April 1996 and concentrate many of their measurements over the DOE ARM site in Oklahoma The SUCCESS program coincides with a DOE intensive operational period in which DOE aircraft equipped with radiometers will also be operating. The ER-2 will be equipped with remote sensing instruments similar to those used in previous FIRE field programs.

The DC-8 and T-39 will be used as in situ sampling platforms to determine cloud optical, microphysical and chemical properties.

Joint Arctic Clouds and Marine Stratus and Tropical Cirrus Proposals

Participation of MAS and HIS in SUCCESS Campaign

Steve Ackerman[1], Paul Menzel[1], Si-Chee Tsay[2], and Steve Platnick [2]
[1]University of Wisconsin, [2]NASA Goddard Space Flight Center

Scientific Goals

(1) Collect a well-calibrated data set of high spectral and spatial resolution radiation measurements to support the objective of SUCCESS and the development of cirrus cloud masking algorithm.

Our major goal is to determine the radiative properties of cirrus contrails, and contras" them with naturally occurring cirrus. To assess the radiative impact of these clouds requires a well-calibrated set of radiation measurements and "ground (or in-situ) truth" observations. We propose to acquire MAS and HIS multispectral observations from the NASA ER-2 aircraft by coordinating over flights of the ER-2 with in situ aircraft and "ground based measurements. Several studies have demonstrated the sensitivity of the MAS and HIS spectral observations to cloud microphysical properties.

The MAS/HIS measurements will address the very important relationship between the cirrus radiative properties and the thermodynamic environment (atmospheric temperature and moisture conditions) wherein cirrus forms and is maintained. The HIS will provide accurate measurements of the atmospheric thermodynamical properties supporting the cirrus life cycle and the MAS will measure the cirrus aerial extent and radiative properties.

Future observations from satellite platforms, such as MODIS and AIRS, are well suited to study these clouds. Participation of MAS and HIS instruments on the ER-2 is a unique opportunity to provide measurements that can be used to develop remote sensing techniques for the future MODIS and AIRS instruments. The HIS spectral region covers the wavelengths of all the current and near future infrared instruments flying in space, and therefore provides a data set for testing any infrared retrieval technique. The MAS has many spectral charnels that are similar to the future MODIS.

Observations made from the MAS and HIS during this experiment will be used to develop techniques to detect the presence of cirrus using multispectral observations. Particular emphasis will be placed on developing and validating methods of detecting tropospheric clouds and defining their aerial extent with infrared (e.g., 13.9 μm) and near infrared (e.g., 1.88 μm) charnels; these are similar to the MODIS charnels and the MAS cirrus detection have relevance to the MODIS cloud mask.

Well calibrated radiances are essential for the development of accurate cloud retrieval algorithm. The calibration of the HIS is such that it serves as a reference for line-by-line radiative transfer models. The MAS infrared charnels are calibrated through two onboard blackbody sources that are viewed once every scan. Calibration of the IR MAS charnels will be augmented through vicarious calibration with the HIS. The MAS solar charnels are calibrated in the field, using an integrating sphere, before and after each ER-2 flight mission.

(2) Perform a statistical characterization of the spectral properties of contrails and naturally occurring cirrus clouds.

Several studies have demonstrated the sensitivity of spectral radiances to cloud particle size and shape distributions. The MAS and HIS instruments provide accurate spectral measurements that can be used to assess differences in the radiative signatures between contrails and naturally occurring cirrus clouds. One difficulty in assessing the impact of the high-altitude subsonic aircraft on cirrus formation/modification is the natural variability of the atmosphere and the potentially small signal of the radiative perturbation. Variations in the atmospheric spectral properties for contrail! and natural cirrus conditions will be assessed with the two ER-2 instruments in conjunction with in situ and ground-based observations.

(3) Participate in the flight planning and direction of the NASA ER-2 aircraft during field campaigns.

One goal of the NASA FIRE and SASS programs is to determine the radiative impact of contrails. Field experiments, such as SUCCESS, which include observations of the radiative characteristics of contrails from a suite of ground-based, aircraft and satellite platforms are crucial to achieving this goal. Such a field program requires the field coordination of a science team. The authors have participated in the execution of a wide variety of national and international field programs, with emphasis on the coordination of the ER-2 flight plans. We will work cooperatively with the science team in the design and execution of the field experiment.

(4) Map the environmental upper tropospheric water vapor distributions around contrails and cirrus.

The HIS was designed to provide accurate, high-spectral resolution observations to support algorithm development that will improve our capabilities of passive remote sensing the temperature and moisture structure of the atmosphere. With appropriate ER-2 flight tracks, the HIS measurements will be used to characterize the upper tropospheric temperature and moisture for environments in which contrails are imbedded.

Improvement of NCEP's Analysis/Forecast System Through Use of FIRE Data Sets

Kenneth Campana, Qingyun Zhao, Yutai Hou
National Centers for Environmental Prediction (NCEP)

We intend to make use of the various FIRE data sets to validate and improve the global and regional model cloud and radiation parameterizations in NCEP's operations. These model's are generally used for routine short-term NWP forecasts, but the global model is used for extended (up to 6 months) forecasts in a coupled ocean/atmosphere environment. We intend to use the data to identify deficiencies in the model's predicted upper-level and boundary-layer cloud. It is expected that improved cloud/radiative processes will result in improved model predictions, especially near the earth's surface.

The current (diagnostic) cloud scheme in NCEP's global model does not attempt to parameterize clouds in the lowest 10 percent of the model atmosphere, except in suspected marine stratus regions, because of large values, and diffuse horizontal gradients, of the relative humidity in the longer layers. Additionally, comparison of upper-level clouds with U.S. Air Force Real-Time Nephanalyses, show this modeled cloud to be excessive; however, we are concerned that the analysis, itself, may not be reliable at these levers. The regional model employs an explicit cloud water parameterization and the global model will soon adopt a similar scheme (currently being tested). Since we have not subjected this parameterization to any rigorous comparison with boundary-layer or 'reliable' upper-level cloud observations, the FIRE data provides us with a unique opportunity to do sot Specifically, we plan to study the cloud water parameterization in the following manner:

1. We will use the FIRE data to regionally validate the model's cloud parameters, e. g. fractional coverage, liquid-water and ice particles, vertical extent, and optical depth. We intend to discern whether the model can successfully simulate these cloud types, and if not, how the parameterization might be improved.

2. We will attempt to isolate the effects of upper-level cirrus cloud on the development of lower-level cloud (via ice-fall 'seeding'), and subsequently on model convective and stratiform precipitation, through a series of sensitivity experiments.

3. We intend to use any FIRE-observed differences in the properties of tropical and midlatitude upper-level clouds to adjust our parameterization of their radiative properties.

4. We will use the SHEBA data to investigate the ability of our models to simulate the Arctic environment (clouds and temperature/moisture structure) in an often-neglected region of the globe.

FIRE III Research

Steve Cox
Colorado State University

A research effort is proposed which transitions the investigation of the radiative characteristics of upper tropospheric cloudiness begun during FIRE I and II into the era of FIRE III. The work is envisioned as both a continuation of the previous efforts and the development of new research strategies which will enhance future studies. The proposed research addresses four major areas. Improved parameterizations of longwave and shortwave radiative effects based respectively on probabilities of cloud free fines of sight and the stochastic treatment of cloud optical properties are proposed. An improved algorithm for inferring the infrared emissivity of cirrus clouds is discussed. New interpretation algorithm for remotely sensing the visible optical thickness and cloud microphysical properties are presented. Hardware efforts are highlighted by the deployment and testing of a near-IR interferometer, completion of a precise and "smart" instrument pointing device and design and construction of a new multiple field of view sun photometer. In addition to a continued attention to data currently archived, activities will include a linkage in data acquisition and analysis leading into future field experiment deployments.

Development and Validation of a GCM Cloud Parameterization Using FIRE and ISCCP Data Sets

Anthony Del Genio
Goddard Institute for Space Studies

We intend to compare ISCCP data to GISS GCM simulations to define regions of GCM deficiencies in cirrus and stratus properties, and use FIRE data to explore the reasons for the discrepancies. For cirrus, we will compare the synoptic conditions giving rise to cirrus during FIRE I and II to those generating cirrus in the GCM to understand the GCM's tendency to overpredict the altitude of cirrus formation. We will compare the simulated radiative properties of midlatitude and tropical cirrus and validate them against observations from FIRE III and-the FIRE Pilot Tropical Cirrus Experiment. We will also explore the factors controlling tropical cumulus anvil ice content and radiative properties in the GCM in order to justify and define the science requirements for a possible FIRE III tropical cirrus field experiment. For stratus clouds, we will explore the sensitivity of marine stratus breakup in the GISS GCM to vertical resolution, forcing a single column version of the model with ASTEX data. We will try to isolate factors controlling optical thickness - temperature correlations, focusing on cloud physical thickness and static/ moist convective stability variations. In the third year of research, we will compare the properties of simulated Arctic clouds to those observed during the FIRE III Arctic Cloud Experiment. We will examine distributions of cloud top/base pressure, optical thickness, and particle size, and for the latter, we will compare ice particle characteristics to those for midlatitude cirrus.

FIRE III Research

Hermann E. Gerber
Gerber Scientific

The planned research consists of two parts: The first part will entail the development of an asymmetry and backscatter meter (!'g meter"). This new optical instrument will be based on the reciprocal nephelometer principle, and will be designed for aircraft deployment. Feasibility, design and breadboarding are efforts of the first year, testing of the g meter under controlled conditions the principal effort the second year, and deployment on the U. of Washington aircraft during the Arctic FIRE III the effort of the third year. The second part of the planned research consists of continued analysis of the ASTEX Sc data base, as well as analysis of the SOCEX I and SOCEX II Sc experiments conducted under Sc baseline conditions south of Australia Cloud-property scaling relationships, 2 kHz microphysical data (LWC, PSA, and effective radius), and entrainment features will be studied. Analysis of optical and microphysical data collected during the FIRE m experiment will follow.

FIRE III Research

Qingyuan Han and Ronald Welch
South Dakota School of Mines and Technology

The proposed investigation is focused upon two main areas. First is the validation of ISCCP cirrus cloud property retrievals using the two cirrus FIRE lFOs over the U.S., the TOGA-COARE and CEPEX results, and the upcoming polar (including SHEBA) observations. Second, it is proposed to use ISCCP data to characterize the cirrus ice crystal particle size retrievals in various regions of the world, including over land and oceans, and especially for the tropical, mid-latitude and polar regions.

This proposal specifically addresses the following critical questions posed by the "First ISCCP Regional Experiment-m Program" Announcement of Opportunity on page A-4:

1) Where are the distributions and amounts of ice mass and total water in the upper troposphere? Specifically, how can ice mass be determined from remote sensors and how can these measurements be validated?

2) What are the microphysical properties of tropospheric clouds? Specifically, how do the particle sizes, shapes and phase depend on the large scale environment?

3) What are the radiative properties of upper-tropospheric clouds and how do they relate to the ice mass, and the microphysical and macrophysical characteristics of the cloud? Specifically, can these radiative properties be usefully expressed in terms of an effective particle size that is consistent with cloud ice path and optical depth?

4) How representative are midlatitude continental cirrus of upper tropospheric clouds in other regions of the globe? Specifically, will GCMs be able to use a single universal cirrus parameterization for all latitude and regional domain, and are tropical cirrus cloud systems sufficiently different from their midlatitude cousins to call for a tropical cirrus field campaign?

A major focus of this proposed investigation is the validation of the ISCCP cloud property retrievals using data acquired during the FIRE field campaigns. Cloud optical thickness and cloud top temperature retrieval algorithm using ISCCP data have been developed by Rossow and Garder (1993a,b) and Rossow et al (1993). Particle size and revised optical thickness algorithm for cirrus and marine stratocumulus have been developed by Han (1992) and Han et al (1991, 1994, 1995a,b). While various efforts have been made to compare satellite retrieved cloud properties with in situ measurements (e.g., Nakajima et al 1991; Minnis et al, 1992; Wielicki et al, 199~, Rawlins and Foot, 1990), there are few direct validations of ISCCP analysis (Rossow and Garder, 1993b, Han et al, 1994, 1995a). The second major focus of this proposed investigation is the retrieval of cirrus ice crystal effective diameters for both land

and ocean regions and for the tropics, mid-latitudes and polar regions. It is expected that there are important regional, seasonal and diurnal differences in the cirrus cloud optical properties which will be important for global climate models and global cloud feedback sensitivity studies.

Some specific questions involve differences between mid-latitude cirrus as observed in the previous FIRE IFOs and tropical anvils and thin polar clouds. What are typical values in each region, and what is the typical variability in properties in each region and season?

The specific objectives of this investigation include:

1) Quantitative validation of ISCCP cirrus cloud retrievals will be made using the FIRE, TOGA-COARE and upcoming polar (FIRE and SHEBA) results.

2) The cirrus cloud algorithm will be extended for retrievals over the continents; this requires the inclusion of seasonal and temporal variations of surface reflectance in the AVHRR charnels 1-3.

3) A special focus of this investigation is the retrieval of cirrus properties over the polar regions; this requires a significant improvement in the polar cloud mask and inclusion of high reflectance surfaces.

4) Cirrus cloud retrievals will include a wide range of new crystal habits and size distributions; in particular, preliminary studies suggest that effective variance of the cirrus size distributions should be included with effective size.

FIRE III Research

Sonia Kreidenweis, Paul DeMott, David Rogers
Colorado State University

Global climate studies have shown that clouds strongly influence the Earth's radiation balance, but many of the factors that are thought to control these influences are not well understood. Ice nuclei (1N) populations are especially important for determining cola cloud microphysical characteristics. Anthropogenic emissions, including aircraft exhaust and long-range transport of pollution, may affect climate through their effects upon ice nuclei abundance and thus upon natural cloud processes. The assessment of the potential for such climate effects is limited by the lack of appropriate measurements that characterize ice nuclei in both relatively unperturbed ("background") air masses, and in air masses strongly influenced by anthropogenic activities.

Our contribution to the cirrus/contrail elements of FIRE III is through our funded participation in the NASA SASS program. The focus of our project is the measurement and characterization of IN in the upper troposphere and longer stratosphere. We are currently finalizing the design of the airborne version of the CSU continuous flow diffusion (CFD) chamber, used to detect IN at controlled temperatures and humidifies. We will use this device in the planned SUCCESS measurement campaigns in Spring 1996, where our contributions will be (1) the measurement of the number concentrations of IN in background air, and in aircraft exhaust regions; (2) the measurement of total number concentrations of particles less than 3 ~m in diameter, to determine the fraction of those particles active as IN; and (3) the separation of the IN and non-IN fractions, and subsequent determination of the elemental composition and morphologies of both fractions. To accomplish item (3), we exploit the rapid growth of activated IN to supermicron-sized ice crystals in the CFD, which permits inertial separation of the activated from the nonactivated particles. Each fraction is then impacted onto appropriate substrates and analyzed using scanning and transmission electron microscopy (SEM and TEM) and energy-dispersive x-ray (EDX) spectrometry. Our results will provide a continuous flight record of IN abundance, which can be used to assess whether IN concentrations have been perturbed in aircraft-influenced air masses.

Ice nuclei probably also play an important role in the formation and properties of boundary layer clouds in the Arctic. The availability and relative abundance of IN could be quite important in determining the water phase in such clouds, which in turn has a significant effect upon their radiative properties. The presence of mixed-phase clouds at only moderately supercooled cloud temperatures in springtime conditions underscores the potential role of IN. In predominantly ice-phase clouds in winter time, the nature of IN may be quite different or profoundly influenced by pollution during episodes of Arctic haze. Continuous measurements of Arctic boundary-layer IN abundance and chemistry, using our CFD system as described above for the SUCCESS campaign, would be a valuable contribution to the stratus/Arctic Cloud component of FIRE III. We are presently pursuing funding for our participation in the Arc tic Cloud Experiment.

Satellite Remote Sensing Studies

Patrick Minnis
NASA Langley Research Center

This proposed research is primarily designed to validate, develop, and apply techniques for the remote sensing of cloud properties to address many of the FIRE m goals as outlined in the FIRE m Research Plan. The research will continue analyses of FIRE-II datasets in the early stages of FIRE-III and will continue theoretical studies supported by additional data analysis. Measurements from other experiments will be examined to address some of the FIRE-III objectives. The proposed research includes participation in the Arctic field program and other field experiments to be developed under FIRE-III.

The basic objectives of this research effort are as follows:

(1) Quantify the uncertainties in satellite-derived cloud and radiation properties:

(a) by comparing derived values to other datasets based on measurements having known uncertainties and accuracies (e.g., in situ, lidar, radar, ceilometer, etc.),

(b) through sensitivity studies using theoretical computations, and

(c) by intercomparing results from various algorithm, especially the ISCCP method, using results having quantified errors arising from (la) above.

(2) Develop and improve techniques to derive cloud amount, phase, effective particle size, optical depth, top and base height, thickness, water path, radiative fluxes, and cloud layering and overlap using multispectral satellite data during both day and night by

(a) using radiative transfer computations to develop parameterizations of reflectance and emittance for various wavelengths and macro and microphysical cloud configurations,

(b) developing empirical-theoretical methods using satellite data combined with measurements from other sources (e.g., radar, microwave radiometers, etc.), and

(c) improving computer-interactive tools for real-time analysis of field experiment satellite data.

(3) Apply improved analysis methods to various geostationary and polar-orbiting satellite datasets to

(a) develop cloud parameter products for understanding the temporal and spatial variability of cloud and radiation fields during field experiments, for validating mesoscale model predictions of cloud properties for specified meteorological conditions, and for validating similar parameters derived from EOS satellites,

(b) address outstanding scientific issues related to the absorption of solar radiation by clouds, the tropospheric ice and liquid water budget, the impact of clouds on the polar radiation budget, and the effects of aerosols on cloud properties, and

(c) provide large-scale, validated cloud parameter datasets to evaluate GCM and ISCCP results.

A Near-Infrared Spectroradiometer for FIRE III

Peter Pilewskie
NASA Ames Research Center

The current lever of understanding of the radiative properties of clouds is incomplete, in part due to the lack of solar spectral data. The near- infrared region of the solar spectrum has proven to be one of the most useful for cloud remote sensing, owing to liquid water and ice absorption that is strong enough to reduce the scattering by cloud particles, yet not to the degree which would make signal detection difficult. Furthermore , the spectral nature of liquid and ice absorption is different enough from water vapor absorption to allow inferences of cloud properties in the vapor transparent near-infrared bands. While numerous remote sensing studies have capitalized on those qualifies, the same spectral absorption properties of liquid, ice, and vapor make the near-infrared the most important spectral region for determining cloud absorption. Our FIRE phase m research effort focuses on developing instruments to match the lever of accuracy achieved by broadband sensors, but with continuous spectral coverage. We have defined the following detector specifications for the Spectral Flux Radiometer (SPFR):

- 0.25 - 2.5 μm spectral range
- hemispheric or narrow field of view (1 mrad)
- 10-20 nm resolution
- 1 Hz spectral sampling rate integrating sphere, standard lamp, standard diffuser calibrated
- surface-based (zenith viewing); aircraft platform (zenith and nadir viewing)

We will obtain the following data products:
- solar spectral radiance or irradiance
- spectral transmission, reflection; bi-directional transmission, reflection
- reduced products: cloud water phase, optical depth, particles size, liquid/ice water path, 1iquid/ice water content

This research includes the design and development of the prototype in our laboratory , calibration, field testing, flight testing, and field deployment. We have successfully deployed, at surface sites, a narrow-field of view prototype. Note that in the characteristics listed above we are also providing for a hemispheric field of view irradiance measurement, requiring a different optical system. The desired optical system will thus depend on the primary scientific objectives: irradiance measurements are more appropriate for cloud energetics, while radiance measurements are better suited for remote sensing.

We have set the following timetable:

Year 1: Complete mechanical and optical design of the SPFR. Procure optical elements and begin work on mechanical components. Integrate optics with housings and mounting components. Refine data control, data transfer, and data storage software.

Year 2: Perform laboratory calibrations and field calibrations (if necessary; remote site, such as the NOAA Observatory on Mauna Loa) for spectral, energy, and angular response. Field test the prototype at surface site during the SUCCESS mission; aircraft testflights in June/July 1995. Develop software for data reduction, processing, and analysis.

Year 3: Prepare instrument for FIRE m field study phase. Calibrate. Refine data analysis routines. Prepare to deploy identical instrument pair on an aircraft platform and surface site. Analyze collected data

A Cloud Observing Experiment: Remote Sensing for the Radiation and Physical Parameters of Clouds

James Spinhirne and James Wang
NASA Goddard Space Flight Center

The proposal is for a continuation existing studies whereby instruments on a high altitude aircraft are applied for the study, application and development of cloud remote sensing. Previous work emphasized the retrieval of important cloud radiation parameters for clouds. The basic direction of the proposed work is to continue to develop and apply remote sensing of radiation parameters and add a strong focus on the retrieval of the cloud physical parameters that relate to cloud radiation. The science objective is improved cloud remote sensing and cloud parameterization for models. The estimate of the cloud ice water content of cirrus clouds from combined passive and active sensing would be specially studied. The proposed work is to involve: (i) the continued analysis of previous observations from FIRE and of extensive observations of tropical clouds from TOGA/COARE, (ii) improvements in instrumentation, and (iii) participation in future field experiments.

An emphasis is the angular distribution of reflected radiation from clouds. Shortwave reflectance functions are a fundamentally important factor for cloud remote sensing and cloud radiation. There are few experimental measurements especially for cirrus clouds. In the previous four years an instrument, the Tilt Scan CCD Camera, was developed and flown on the NASA ER-2 aircraft for observation of the bi-directional reflectance of cloud. Data were acquired in large scale field experiments for mid latitude and tropical cirrus and marine stratus clouds. A principal objective of this proposal is to provide support to continue the analysis and reporting of the existing data.

Limitations in the current instrument have been found. Instrument improvement and participation in a focused cirrus field experiment is proposed.

The combination of high frequency microwave radiometer measurements with multispectral visible and near infrared radiometer measurements and active cloud profiling is to be studied for retrieval of the ice/water content of high clouds and other cloud physical parameters. Data of this type were acquired during observations of tropical clouds in the 1993 TOGA/COARE project and are to be analyzed. Since 1993 the highest frequency of the ER-2 microwave radiometer was increased from 220 to 325 GHz. Study and tests of the 325 GHz charnel for cirrus remote sensing is proposed.

A dedicated and focused cirrus remote sensing and radiation experiment is proposed. Participation in a possible high latitude cloud study is also proposed. In addition, basic field deployment and data processing for the use of the ER-2 cloud lidar and TSCC as support instruments in other cloud and radiation field experiments is covered

Cloud Radiative and Physical Properties Inferred using Landsat

Bruce Wielicki
NASA Langley Research Center

An investigation is proposed to examine both boundary layer and cirrus clouds using high resolution Landsat data. The study addresses issues in three areas critical to FIRE III objectives:

- Satellite Based Cloud Remote Sensing Validation
- Comparison of Landsat results to Cloud Scale Dynamical Models
- Implications of Landsat data for Global Radiative Modeling

Landsat data provide a unique perspective to examine cloud systems across spatial scales from 30 m to 180 km. The high spatial resolution is important for comparisons to cloud scale dynamical models, as well as to the elimination of uncertainties which result from varying amounts of sub-pixel scale cloud in typical meteorological satellite data Landsat spectral coverage also provides a test bed for examining the capabilities of the next generation of space-borne cloud imagers. The proposed studies involve analysis of three types of data:

- Existing FIRE I and FIRE II data sets
- New extended time and space observations to test FIRE I and II conclusions in related cloud regimes (land and polar boundary layer, topical cirrus)
- FIRE III field experiment data (SHEBA and tropical cirrus)

Many of the studies will involve cooperative work with other FIRE investigators. While these collaborations are not explicitly named as Co-Investigators on this proposal, such collaborations are critical to the success of FIRE III and will be pursued as part of this proposal.

Because FIRE III is part of the NASA Mission to Planet Earth program, a major focus of this investigation will be on verification of cloud remote sensing techniques and data/model intercomparisons considered to be examples of the types of global capabilities available with the Earth Observing System (EOS) MODIS imager beginning with the launch of EOS-AM in 1998.

FIRE III Research

Donald Wylie
Space Science and Engineering Center, University of Wisconsin-Madison

Don Wylie intends to participate in FIRE-III in two areas: 1) The SHEBA experiment in the Arctic and 2) global studies of the radiative properties of clouds A cirrus cloud climatology is currently being compiled at the University of Wisconsin-Madison using the mufti-spectral HIRS data from the polar orbiting NOAA satellites. Over six years have been collected. This is an adjunct to the International Satellite Cloud Climatology Project (ISCCP). The SHEBA experiment will help both ISCCP and the Wisconsin Cirrus Climatology by providing an opportunity for in situ data in the Arctic. Polar regions have few good data for improving these cloud climatologies. The cloud and radiation data from SHEBA will be used to refine both satellite cloud climatologies.

Global studies of the radiative properties of cirrus clouds are being clone using the data sets from the Wisconsin Cirrus Climatology and the ISCCP. Both data sets are known for their estimates of the height of the cloud tops. However, both also obtain information on the optical depths of clouds. The Wisconsin Climatology measures optical depths in the infrared 11 μm window region of the spectrum for semi-transparent cirrus clouds while the ISCCP measures optical depths at visible wavelengths. Both data can be used to estimate tropospheric heating and cooling caused by radiative processes. Changes in the radiative processes in the seasonal cycles and weather systems also will be studied. FIRE data from the aircraft flights in the TOGA/COARE experiment will be used to understand the satellite derived radiative quantifies in the tropics, which is where semi-transparent clouds are the most numerous and have the largest impact on the heat budget of the earth.

Miscellaneous Proposals not funded by FIRE III

FIRE III Research

Howard Hanson
CIRES

I'm working with Vern Derr and a couple of other NOAA/CIRES people to 'rescue' the 10plus-year time series of collocated Eppley pyranometer & NOAA microwave radiometer data that was accumulated at Stapleton Airport in Denver. (Some of these data were used in a paper by Derr et al. in J. Atmos. Sci., 47, 2774-2783, 1990.) The instruments have been at Stapleton since about 1983, and have a reasonably good record of calibration by the NOAA labs; also, there's a more recent part of the dataset that includes NOAA profiler data. This constitutes 'rescue' because, with Stapleton being decommissioned, the instruments are going away. This decade-long time series of downward solar radiation at the surface with simultaneous cloud water data is too good to let slip through the cracks. The job involves , essentially , reading some old tapes and finding where other bits and pieces of the dataset are and putting it all into one standard file system.

The actual grunt work is being clone by a student of mine and by one of the NOAA/CIRES guys on the side, since it's all unfunded. Once we get the dataset assembled, my student and I will try some simple time-series analyses of it, just to see if there's anything obvious of interest.

Modeling of Cloud Scale Turbulent Transport

W. S. Lewellen and D. C. Lewellen
West Virginia University

Our long term goals for ONR are to understand the dynamics of cloud motions on scales of 10 kilometers and less in sufficient detail to be able to provide a consistent subgrid scale turbulent closure for mesoscale models, and to be able to utilize simulated variances as a measure of forecast predictability. During FIRE III we expect to first concentrate on the issue of cloud top entrainment. We will be utilizing the ASTEX data set as part of this effort.

The goal of our research for NASA is to gain a better understanding of the role of turbulent mixing on the dispersion and chemistry of the wakes of subsonic aircraft flying in the neighborhood of the tropopause and to provide valid subgrid parameterizations of this effect for the larger scale climate models needed to assess the environmental impact of the projected fleet of subsonic aircraft. We are utilizing numerical Large-Eddy Simulations (LES) of the turbulence to represent mixing during the period from several seconds to almost an hour after wake generation. During FIRE III we expect to make comparisons with the early wake results to be obtained in SUCCESS. Our research will necessarily involve ice microphysics of cirrus as we extend the time covered by our simulation.

APPENDIX E - RESULTS OF CIRRUS IMPLEMENTATION STEPS SURVEY

The following lists are based on responses to a questionnaire that was distributed to the FIRE science community soliciting participation in the implementation steps identified in the Cirrus Implementation Plan. Lead researchers responsible for coordinating the multi-investigator participation and reporting on progress are identified in brackets. The FIRE participants are listed as Participant (P), Liaison (L), or Neither (N)

4.0 CONTINUED EXPLOITATION OF EXISTING CIRRUS DATA SETS

4.6-1 GCM and parameterization evaluation and validation,
(Tony Del Genio, Leo Donner)

P	L	N
Del Genio	Cox	Cairns
M.Miller	McDougal	Gerber
Hallett	Minnis	Liou
G. Mace	Rossow	Pilewskie
G. Stephens	Uttal	Eberhard
	Heymsfield	Hlavka
	S. Kinne	Lawson
	Poellot	A. Macke
	Sassen	Arnott
		Asano

4.6-2 Characterization of cloud radiative properties and effects,
(Peter Pilewskie, Jim Spinhirne)

P	L	N
Cairns	Gerber	Del Genio
Cox	McDougal	Asano
Liou	M. Miller	
Minnis	Rossow	
Pilewskie	Uttal	
Eberhard	Heymsfield	
Hallett	Poellot	
Hlavka	Sassen	
S. Kinne		
Lawson		
G. Mace		
A. Macke		
G. Stephens		
Arnott		

4.6-3 Characterization of cloud microphysical properties,
(Leo Donner, Andy Heymsfield)

P	L	N
Liou	Gerber	Cairns
Minnis	McDougal	Cox
Uttal	M. Miller	Del Genio
Eberhard	Rossow	Pilewskie
Hallett	Hlavka	Asano
Heymsfield	A. Macke	
S. Kinne	Sassen	
Lawson	Starr	
G. Mace		
Poellot		
G. Stephens		
Arnott		

4.6-4 Case studies and modeling of cloud development,

(David Starr, Bill Cotton)

P	L	N
Cairns	Cox	Gerber
Liou	Del Genio	Pilewskie
M. Miller (?)	McDougal	Uttal
Minnis	Rossow	Hlavka
Heymsfield	Eberhard	A. Macke
G. Mace	Hallett	Asano
Sassen	S. Kinne	
Starr	Lawson	
Poellot		
G. Stephens		
Arnott		

4.6-5 Development, validation and application of satellite remote sensing of cloud properties.
(Pat Minnis, Bill Rossow)

P	L	N
Liou	Cairns	Del Genio
Minnis	Cox	Gerber
Rossow	McDougal	Asano
Uttal	M. Miller	
Hallett	Pilewskie	
Heymsfield	Eberhard	
A. Macke	Hlavka	
Sassen	S. Kinne	
G. Stephens	Lawson	
	G. Mace	
	Poellot	
	Arnott	

4.6-6 The FIRE project office should support the logistics of multi-investigator participation pursing the above goals.
(David McDougal)

P	L	N
McDougal	Cairns	Del Genio
Heymsfield	Cox	Gerber
	Minnis	M. Miller (?),
	Rossow	Pilewskie
	Uttal	Liou
	Hallett	Eberhard
	G. Mace	Hlavka
	Poellot	S. Kinne
	G. Stephens	Lawson
		A. Macke
		Arnott
		Asano

5.0 REMOTE SENSING FOR FIRE III UPPER TROPOSPHERIC CLOUD_RESEARCH

5.2-1 Design and conduct investigations that integrate a comprehensive collection of coincident observations from aircraft, the surface and satellites where similar or "identical" quantifies are retrieved.
(Andy Heymsfield, Ken Sassen, Bruce Wielicki)

P	L	N
Liou	Cairns	M. Miller
Minnis	Cox	
Uttal	Del Genio	
Hallett	McDougal	
Heymsfield	Pilewskie	

S. Kinne (?)	Rossow
G. Mace	Gerber
A. Macke	Eberhard
Poellot	Hlavka
Sassen	S. Kinne (?)
G. Stephens	Lawson
	Starr
	Arnott
	Asano

5.2-2 Maintain close collaboration between modeling and remote sensing investigators to in sure maximum utilization of remote sensing data.
(William Rossow, William Cotton)

P	L	N
Minnis	Cox	Cairns
Rossow	Del Genio	Liou
Uttal	McDougal	Pilewskie
G. Mace	M.Miller	Gerber
A. Macke	Hlavka	Eberhard
Sassen	S. Kinne	Hallett
G. Stephens	Starr	Heymsfield
	Arnott	Lawson
		Poellot
		Asano

5.2-3 Seek to establish how ice clouds may be most effectively and efficiently represented in radiative transfer models. Specifically:

- small scale horizontal inhomogeneity
- cloud vertical structure
- phase and particle size/shape changes

(Ron Welch, Si-Chee Tsay)

P	L	N
Cairns	Cox	Del Genio
Liou	McDougal	Pilewskie
Minnis	M. Miller	Gerber
Hallett	Rossow	
Heymsfield	Uttal	
S. Kinne	Eberhard	
Lawson	Hlavka	
A. Macke	G. Mace	
G. Stephens	Poellot	
Arnott	Sassen	
	Asano	

5.2-4 Provide validated retrievals of ice cloud and environmental parameters to FIRE III modeling investigators for use in diagnostic and cloud process studies.
(Leo Donner, Bruce Wielicki, J. Hallett)

P	L	N
Minnis	Cox	Cairns
Rossow	Del Genio	Liou
Uttal	McDougal	Pilewskie
Hallett	M.Miller	Gerber
G. Mace	Eberhard	Heymsfield
Starr	Hlavka	S. Kinne
G. Stephens	Lawson	
Arnott	A. Macke	
	Poellot	
	Sassen	

Asano

5.2-5 Explore the application of additional satellite data such as ATSR and passive microwave radiometry to upper tropospheric cloud issues. (Don Wylie, Graeme Stephens)

P	L	N
Minnis	**Cox**	**Cairns**
G. Stephens	McDougal	Del Genio
	M. Miller	Liou
	Rossow	Pilewskie
	Hallett	Uttal
	Heymsfield	Gerber
	Poellot	Eberhard
		Hlavka
		S. Kinne
		Lawson
		G. Mace
		A. Macke
		Arnott
		Asano

5.2-6 Conduct studies which examine the statistical variability of clouds, water vapor and atmospheric dynamics on larger scales in the tropics. (David Starr, Don Wylie)

P	L	N
Cairns	Cox	Del Genio
Minnis	McDougal	Liou
Rossow	M.Miller	Pilewskie
S. Kinne	Eberhard	Uttal
G. Mace	Hallett	Gerber
Sassen	Heymsfield	Hlavka
Starr	Poellot	Lawson
	G. Stephens	A. Macke
		Arnott
		Asano

6.0 GCMs AND FIRE III

6.1-1 Reexamine historical cirrus data sets for supporting evidence of the hypothesis: **"that the radiative properties of cirrus anvils are primarily controlled by the mass fluxes and vertical velocities in associated cumulus** convection." Concurrent satellite-radar data may be helpful. (Leo Donner, David Starr)

P	L	N
Minnis	Cox	Cairns
Rossow	Del Genio	Liou
Uttal	McDougal	Pilewskie
Lawson	M. Miller	Gerber
Sassen	Hallett	Eberhard
	Heymsfield	Hlavka
	G. Mace	S. Kinne
	Starr	A. Macke
	G. Stephens	Poellot
		Arnott
		Asano

6.1-2 Integrate testing of the above hypothesis into the design of a FIRE- m cirrus campaign.
(Leo Donner, William Cotton)

P	L	N
Cox	Del Genio	Cairns
Lawson	McDougal	Liou
Starr	Minnis	M. Miller
	Rossow	Pilewskie
	Uttal	Gerber
	Eberhard	Hallett
	Heymsfield	Hlavka
	G. Mace	S. Kinne
	Sassen	A. Macke
	G. Stephens	Poellot
		Arnott
		Asano

6.1-3 Design a future FST meeting to specifically address the interface between the modeling and experimental FST constituencies.
(David Starr, Tony Del Genio, Bruce Albrecht)

P	L	N
Del Genio	Cox	Cairns
Uttal	McDougal	Liou
G. Mace	M. Miller	Pilewskie
Starr	Minnis	Rossow
	Hallett	Gerber
	Hlavka	Eberhard
	Lawson	Heymsfield
	Sassen	S. Kinne
	G. Stephens	A. Macke
		Poellot
		Arnott
		Asano

7.0 TROPICAL CIRRUS EXPERIMENT

7.6-1 Continue analysis of previously collected data on tropical/subtropical cirrus cloud systems.
(David Starr)

P	L	N
Cox	Cairns	M. Miller
Liou	Del Genio	Pilewskie
Minnis	McDougal	Uttal
Rossow	Lawson	Gerber
Hallett	A. Macke	Eberhard
Heymsfield	Poellot	Asano
Hlavka		
S. Kinne (?)		
G. Mace		
Sassen		
Starr (HELP)		
G. Stephens		
Arnott		

7.6-2 Continue instrumentation and technique development to observe and/or infer radiative and microphysical properties of cirrus clouds. (Graeme Stephens, Jim Spinhirne)

P	L	N
Cairns	McDougal	Del Genio
Cox	Rossow	Liou
Minnis	Eberhard	M.Miller

Pilewskie	Poellot	S. Kinne
Uttal	Sassen	
Gerber	Asano	
Hallett		
Heymsfield		
Hlavka		
Lawson		
G. Mace		
A. Macke		
G. Stephens		
Arnott		

7.6-3 Continue collection of radiative and microphysical data on tropical and subtropical cirrus cloud systems on a target of opportunity basis.
(Tom Ackerman, Andy Heymsfield)

P	L	N
Cox	McDougal	Cairns
Liou	M. Miller	Del Genio
Minnis	Rossow	Gerber
Pilewskie	Hlavka	
Uttal	A. Macke	
Eberhard	Sassen	
Hallett	Asano	
Heymsfield		
S. Kinne		
Lawson		
G. Mace		
Poellot		
G. Stephens		
Arnott		

7.6-4 Develop monthly upper tropospheric cloud climatologies from historical satellite data over the region extending from 10•S to 30•N latitude and from 35•W to 135•W longitude.
(Tony Del Genio, Pat Minnis)

P	L	N
Minnis	Cox	Cairns
Rossow	Del Genio	Liou
	McDougal	Pilewskie
	M. Miller	Uttal
	G. Stephens	Gerber
		Eberhard
		Hallett
		Heymsfield
		Hlavka
		S. Kinne
		Lawson
		G. Mace
		A. Macke
		Poellot
		Arnott
		Asano

7.6-5 Determine collaborative possibilities with other programs such as LBA in order to optimize scope of a FIRE III cirrus campaign
(David Starr, Steve Cox)

P	L	N
Cox	McDougal	Cairns
Rossow	M. Miller	Del Genio
A. Macke	Minnis	Liou
Starr	Heymsfield	Pilewskie

G. Stephens	Lawson	Uttal
	G. Mace	Gerber
	Poellot	Eberhard
		Hallett
		Hlavka
		S. Kinne
		Arnott
		Asano

7.6-6 Design a modular FIRE III cirrus field experiment capable of addressing the scientific questions outlined in Sections 1 - 6
(Tom Ackerman, Kuo-Nan Liou, David Starr)

P	L	N
Cox	Del Genio	Cairns
Liou	McDougal	M.Miller
Minnis	Pilewskie	Rossow
Heymsfield	Uttal	Gerber
G. Mace	A. Macke	Eberhard
Sassen	Poellot	Hlavka
Starr	Asano	S. Kinne
G. Stephens		Lawson
		Arnott

7.6-7 Submit a letter of intent to the NSF OFAP by June 1996 indicating the likelihood of a request to use the WB-57 and the Electra in a 45 day tropical cirrus field campaign in CY 1999.
(Steve Cox, David McDougal)

P	L	N
Cox	Minnis	Cairns
McDougal	Lawson	Del Genio
Hallett	G.Mace	Liou
Heymsfield		M. Miller
Sassen		Pilewskie
G. Stephens		Rossow
		Uttal
		Gerber
		Eberhard
		Hlavka
		S. Kinne
		A. Macke
		Poellot
		Arnott
		Asano

7.6-8 Submit a letter of intent to NASA by June 1996 indicating the likelihood of a request to use the ER-2 and DC-8 in a 45 day tropical cirrus field campaign in CY 1999. The NCAR WB-57, NCAR Electra, NASA ER-2, and NASA DC-8 would be part of a Convective Cirrus experiment (section 7.5.4).
(Jim Spinhirne, David McDougal)

P	L	N
Cox	Hlavka	Cairns
McDougal	Lawson	Del Genio
Heymsfield	G. Mace	Liou
G. Stephens		M. Miller
		Minnis
		Pilewskie
		Rossow
		Uttal
		Gerber
		Eberhard
		S. Kinne

		A. Macke
		Poellot
		Arnott
		Asano

8.0 SUCCESS

8.2-1 In light of the many related goals of FIRE III and SUCCESS, promote communication of SUCCESS accomplishments to FST scientists. Perhaps common or serial meetings could achieve this.

(Brian Toon, David Starr)

P	L	N
Liou	Cairns	Del Genio
Hallett	Cox	M.Miller
G. Mace	McDougal	Pilewskie
Sassen	Minnis	Rossow
Starr	Gerber	Uttal
	Eberhard	Heymsfield
	Hlavka	A. Macke
	S. Kinne	Poellot
	Lawson	Arnott
	G. Stephens	Asano

8.2-2 A successful FIRE III tropical field campaign will depend upon a number of instrumentation development projects in SUCCESS. As a result, FIRE III management should maintain a close liaison with SUCCESS management on the progress and success of these development programs.

(McDougal)

P	L	N
Hallett	Cairns	Del Genio
Heymsfield	Cox	Liou
	McDougal	M. Miller
	Minnis	Pilewskie
	Hlavka	Rossow
	S. Kinne	Uttal
	Sassen	Gerber
	G. Stephens	Eberhard
		Lawson
		G. Mace
		A. Macke
		Poellot
		Arnott
		Asano

09 . O SHEBA/FIRE III STRATUS

9.2-1 Maintain active liaison between the FIRE m SHEBA and FIRE m Tropical cirrus components.

(Mike King, David Randall)

P	L	N
Rossow	Cox	Cairns
	Del Genio	Liou
	McDougal	Pilewskie
	M. Miller	Gerber
	Minnis	Hallett
	Uttal	Heymsfield
	Eberhard	S. Kinne
	Hlavka	A. Macke
	Lawson	Poellot
	G. Mace	Arnott

G. Stephens
Asano

9.2-2 Encourage FIRE III SHEBA principals to include middle and upper tropospheric ice clouds in the Arctic within the experiment's scope.

(Mike King, Bruce Wielicki)

P	L	N
Minnis	Cox	Cairns
Rossow	McDougal	Del Genio
Uttal	Gerber	Liou
Heymsfield	Eberhard	M. Miller
Arnott	Hallett	Pilewskie
	Hlavka	Hallett
	Lawson	S. Kinne
	G. Mace	Poellot
	G. Stephens	
	Arnott	
	Asano	

10.0 COMPLEMENTARY PROGRAMS

10.1-1 Explore collaboration with international partners in a tropical upper tropospheric cloud experiment.

(David Starr, Steve Cox)

P	L	N
Cox	McDougal	Cairns
Liou	M. Miller	Del Genio
Heymsfield	Minnis	Pilewskie
A. Macke	Rossow	Uttal
Starr	Lawson	Gerber
G. Stephens	G.Mace	Eberhard
	Sassen	Hlavka
	Asano	S. Kinne
		Poellot
		Arnott

10.1-2 Participate in and provide crucial data sets in support of the cirrus cloud model intercomparison activities of the GCSS WG#2.
(David Starr)

P	L	N
Del Genio	Cox	Cairns
Liou	McDougal	Pilewskie
M. Miller	Eberhard	Gerber
Minnis	Heymsfield	A. Macke
Rossow	Hlavka	Arnott
Uttal	Lawson	
G. Mace	Asano	
Sassen		
Starr		
G. Stephens		

10.1-3 Maintain communication with other international partners performing independent research on upper tropospheric cloud systems and their relationship to climate.

(David Starr, Tom Ackerman)

P	L	N
Liou	Cox	Cairns
S. Kinne	McDougal	Del Genio
G. Mace	M.Miller	Minnis
A. Macke	Gerber	Pilewskie
Starr	Heymsfield	Rossow
G. Stephens	Sassen	Uttal
	Asano	Eberhard
		Hlavka
		Lawson
		Poellot
		Arnott

10.1-4 Explore collaboration with other funded projects in order to provide a more comprehensive field campaign capable of addressing the goals of FIRE m.
(Steve Cox, Bob Curran)

P	L	N
Cox	McDougal	Cairns
Hallett	Minnis	Del Genio
Heymsfield	Gerber	Liou
G. Mace	Hlavka	M.Miller
	Lawson	Pilewskie
	G. Stephens	Rossow
	Asano	Uttal
		Eberhard
		S. Kinne
		A. Macke
		Poellot
		Arnott