Progress report for NASA research grant
NAG5-11104

Trans-oceanic measurements for EOS Aqua Validation

Second Year Report

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Submitted to:
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20 February 2004.

Objectives

The objectives of this project are to use state-of-the-art instruments on long, oceanic research cruises to make measurement of the sea-surface skin temperature (SST), boundary-layer meteorology and atmospheric state for the validation of AIRS and AMSR-E geophysical data. In addition to the directly measured SST, surface winds, atmospheric profiles of temperature and humidity, atmospheric columnar water vapor and rainfall, which can be compared to the AIRS and AMSR-E retrievals, measurements of the atmospheric and oceanic state are to be used with an accurate radiative transfer model to derive top-of-atmosphere radiances for comparison with AIRS measurements. The project includes a sub-contract to the University of Wisconsin-Madison for hardware support of the M-AERIs and joint studies of atmospheric infrared radiative transfer studies for the comparison between AIRS and M-AERI measurements of the spectra of atmospheric emission and retrieved atmospheric profiles of temperature and humidity. This project benefits from the leverage of personnel and equipment involved in the MODIS SST algorithm development and validation, in which the PI is involved, and from the data taken during research cruises funded by other agencies, such as the NSF.

Second year activities

The emphasis on during the first year has been on:

1. Maintaining the calibration accuracy of the M-AERIs to ensure that the measurements are accurate and traceable to NIST standards.
2. Testing and deploying a microwave radiometer that measures the atmospheric water vapor and cloud liquid water amounts. This was purchased in the first year of this project.
3. Installing equipment on several ships for validation cruises for the Aqua mission.
4. Interacting with the AIRS Science Team and Validation Team members.
5. Interacting with the AMSR-E Science Team.
6. Interacting with the wider scientific community.

M-AERI Calibration

The Marine-Atmospheric Emitted Radiance Interferometer (M-AERI; Minnett et al. 2001) is a Fourier-Transform Infrared Interferometric spectrometer that operates in the are cooled to ~78°K (i.e. close to the boiling point of liquid nitrogen) by a Stirling cycle mechanical cooler to reduce the noise equivalent temperature difference to levels well below 0.1K. The M-AERI includes two internal black-body cavities for accurate real-time calibration. A scan mirror directs the field of view from the interferometer to either of the black-body calibration targets or to the environment from nadir to zenith. The mirror is programmed to step through a pre-selected range of angles. When the mirror is directed below the horizon the instrument measures the spectra of radiation emitted by the sea-surface, and when it is pointed above the horizon it measures the radiation emitted by the atmosphere. The sea-surface measurement also includes a small component of reflected sky radiance. The interferometer integrates measurements over a pre-selected time interval, usually a few tens of seconds, to obtain a satisfactory signal to noise ratio, and a typical cycle of measurements including two view angles to the atmosphere, one to the ocean, and calibration measurements, takes about five minutes. The M-AERI is equipped with pitch and roll sensors so that the influence of the ship's

motion on the measurements can be determined. The radiometric calibration of the M-AERI is done continuously throughout its use, by using two black-body targets at known temperatures. These provide two reference spectra to determine the gains and offsets of the detectors and associated electronics. The mirror scan sequence includes measurements of the reference cavities before and after each set of spectra from the ocean and atmosphere.

The M-AERIs are some of the primary sensors for the validation of SST's derived from MODIS (both Terra and Aqua), AIRS and AMSR-E, and for spectral radiances measured by AIRS. The MAERI has been installed on several ships for ***Aqua*** validation cruises (Table 1)

Table 1. Research cruises undertaken since the launch of ***Aqua***

Area	**Ship**	**Departure**		**Arrival**		**Days of data**
		Port	**Date**	**Port**	**Date**	
Caribbean Sea	Explorer of the Seas	Miami, FL	Every Saturday	Miami. FL	Every Saturday	Continuous
Canadian Arctic	CCGS Pierre Radisson	Resolute Canada	20020923	Quebec City, Canada	20021018	26
W. Med	R/V Urania	Naples, Italy	20020929	Livorno, Italy	20021008	10
W. Med	R/V Urania	Naples, Italy	20030303	La Spezia, Italy	20030426	49
NE Pacific, Caribbean and NW Atlantic	USCGC Healy	Seattle	20030613	St. John's, Newfound-land, Canada	20030716	33
Southern Ocean, Australian sector.	RV Aurora Australis	Hobart, Tasmania Australia	20030911	Hobart, Tasmania, Australia	20031029	49
Canadian Arctic	CCGS Amundsen	Quebec City	20030921	Coppermine, NWT, Canada	20031013	23
Tropical Atlantic Ocean	NOAA S Ronald H Brown	Charleston, SC	20040212	Charleston, SC	20040414	TBD
South Pacific Ocean	RV Tangaroa	Wellington, New Zealand	20040318	Wellington, New Zealand	20040416	TBD

NB. These cruises were funded from a variety of sources, including NASA, ONR and NSF.

Microwave radiometer

A Radiometrics MWR-1100 was procured through this grant and delivered to RSMAS in mid-summer, 2002. It is a dual-frequency total power radiometer, operating at 23.8 GHz and at 31.4 GHz. These two frequencies allow simultaneous determination of integrated liquid water and integrated water vapor along a selected path. Atmospheric water vapor has an emission line centered at 22.235 GHz, and to reduce the effects of pressure broadening upon the observed brightness, observations are made at the "hinge point" at

23.8 GHz, where the vapor emission does not change 23.8 GHz, where the vapor emission does not change significantly with altitude. The radiometer has been installed on the *Explorer of the Seas* and other ships for at-sea measurements (Figure 1). The individual cruises are described below.

Figure 1. The Radiometrics MWR-100 microwave radiometer installed on the *Explorer of the Seas* (left) and on the USCGC *Healy* (right).

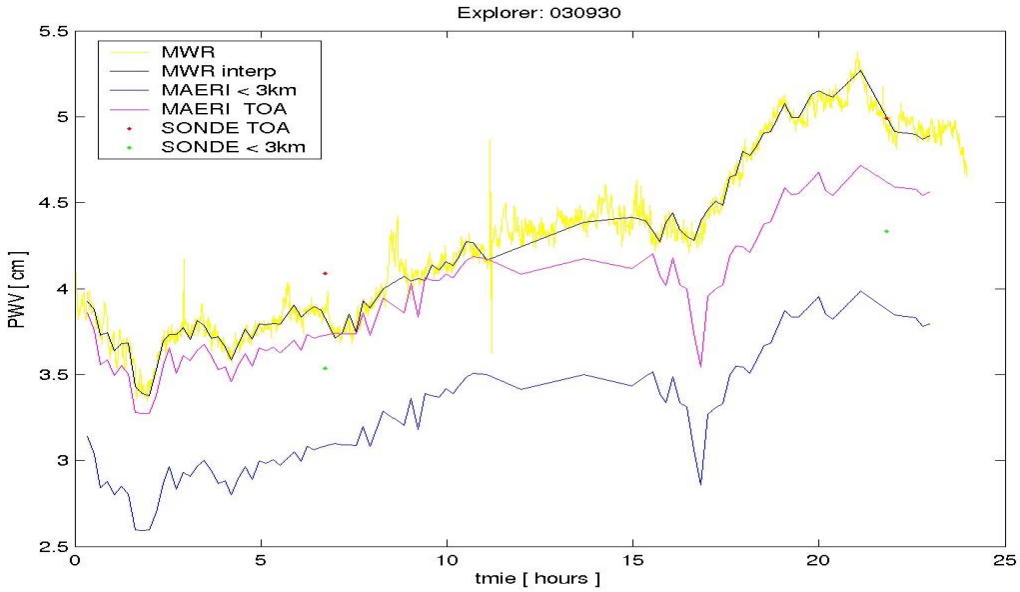

Figure 2. Time series of measurements of precipitable water taken on September 30, 2003, from the *Explorer of the Seas.*

	bias [cm]	rmsd [cm]
Sonde - MWR	0.19	0.30
MWR - M-AERI	0. 23	0.34

Table 2. Comparison of column integrated atmospheric water vapor measured by the microwave radiometer, radiosondes and M-AERI retrievals on the *Explorer of the Seas* 63 radiosondes were launched between July and September 2002, and between August and October 2003.

The usual approach to measure precipitable water, which is required to understand the residual uncertainties in the infrared retrievals of SST from space, as well as provide direct validation for infrared and microwave measurements from AIRS, MODIS and AMSR-E, is to integrate the humidity profile measured by radiosondes. However, radiosonde launches are infrequent, costly over the long term, and of limited accuracy Miloshevich et al. 2001. The MWR measurements are believed to be of higher quality, but are of limited availability as we have only a single sensor. M-AERI measurements of the infrared atmospheric emission can be analyzed to determine temperature and humidity profiles from the surface to 3km height Feltz et al. 2003. Comparisons of collocated column integrated atmospheric water vapor measurements from the microwave radiometer, radiosondes and M-AERI retrievals, PWV measured over a 24h period by MWR, M-AERI and radiosondes on board of the *Explorer of the Seas* are shown in Figure 2. The MWR measurements (yellow line) were interpolated (black line) to M-AERI measurement times. The M-AERI values were derived by retrieving a water vapor profile M-AERI measurements above 3km height were extended by interpolating between radiosonde profiles. MWR and M-AERI estimates follow each other very well. There is a bias between these two instruments that seems to increase with the total PWV loading. This behaviour is typical in many datasets examined in this study. The means and standard deviations of comparisons over two extended periods are shown in Table 2, and compare well with other results in the refereed literature (e.g.Liou et al. 2001). This analysis helps establish the uncertainties in the measurements that are used to validate the satellite retrievals.

Research cruises

The Aqua validation equipment has been installed on four ships in different climatic regimes during the second year of this project: the *Explorer of the Seas* in the Caribbean, the RV *Urania* in the Mediterranean, the USCGC *Healy* in mid-latitudes Pacific and Atlantic Oceans, and the tropical Caribbean Sea, the RV *Aurora Australis* in the Southern Ocean, and the CCGS Amundsen in the Arctic (Table 1). Plans were made to participate the Atlantic cruise of the NOAA S *Ronald H Brown* in spring 2004, under the Saharan Dust Plume, and on the R/V Tangaroa in the South Pacific Ocean off New Zealand.

Explorer of the Seas.

The Explorer of the Seas is a 142,000 ton cruise liner, some 315 m in length, and is the first cruise ship outfitted with a suite of sophisticated oceanographic and atmospheric instrumentation. During construction and outfitting of the Explorer of the Seas, Royal Caribbean International worked with the RSMAS, NOAA-AOML, and the NSF to equip the ship with state-of-the-art instrumentation and install laboratories for oceanography and atmospheric sciences. The ship typically cruises at an average speed of 20 knots on two alternating weekly circuits round the Caribbean (Figure 3). An extensive set of sensors has been installed on the Explorer of the Seas (see http://rsmas.miami.edu/rccl). Of particular relevance to this project for the validation of Aqua instruments are the M-AERI, the Radiometrics MWR and radiosondes. The skin SST and air temperature derived from the M-AERI data for the whole of 2003 are shown in Figure 4.

Figure 3. The weekly cruise tracks of Explorer of the Seas. The ship sails from Miami on Saturday evenings, returning the following Saturday morning. The eastern and western tracks are sailed on alternating weeks.

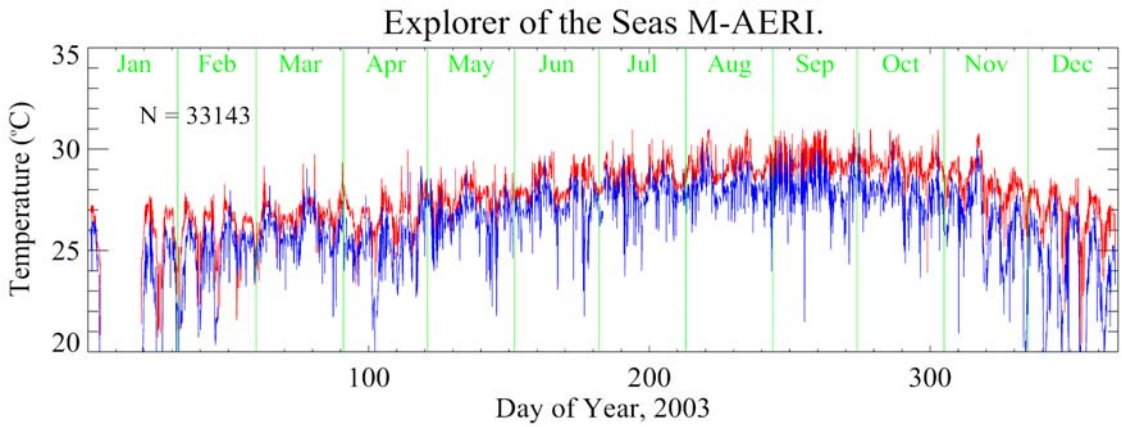

Figure 4. Measurements of skin sea-surface temperature (blue) and air temperature (red) from the M-AERI on *Explorer of the Seas* for 2003. The gap in January was caused by the ship being in dry dock.

Radiosonde launches from the Explorer of the Seas were begun on June 25, 2002, expressly in support of AIRS validation. The launches are scheduled according to the criteria set up by the AIRS Validation Project Office at JPL (Dr E. J. Fetzer). By the end of 2003, 387 radiosonde launches had been completed.

As the *Explorer of the Seas* is in permanent satellite internet contact, it is possible to transmit a subset of the data in real-time to RSMAS. These data include the standard metrological measurements, skin SST and air temperature derived form the M-AERI, and the radiosonde profiles. Some of the data is displayed in near real-time (within less than 15 minutes) on a webpage (see http://www.rsmas.miami.edu/rccl/obs/ex-rt-obs.pl). At the end of each day, the M-AERI temperatures and radiosonde data are written to files in netCDF and placed on an ftp server for transmission to the AIRS Validation Team at JPL.

RV Urania

A berth was offered on the Italian research vessel *Urania* during two cruises in the western Mediterranean Sea led by the Institute of Atmospheric Sciences and Climate (ISAC) in Rome, Italy. This provided an opportunity to gather ***Aqua*** validation data in an

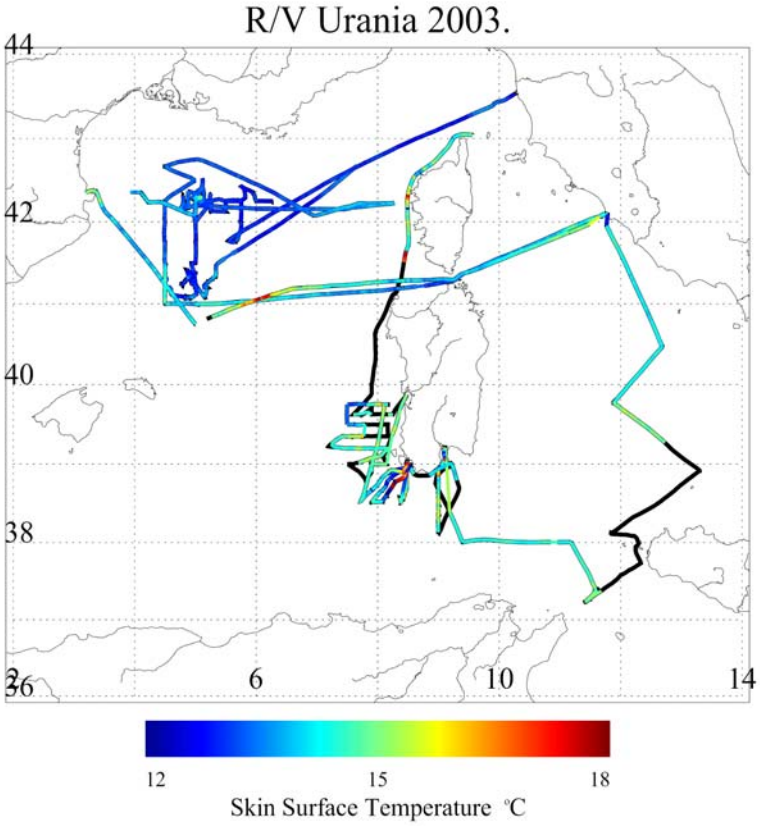

Figure 5. The track of the R/V *Urania*, colored by surface temperature measured by the M-AERI.

area often influenced by aerosol-laden atmospheres. The two cruises were separated by a 3 week interval during which the ship was used by another scientific party. RSMAS equipment was allowed to stay on board and take measurements during this period, but no berth was available for a scientist.

Dr M. Szczodrak of the RSMAS Remote Sensing Group participated in both ISAC cruises. Dr. Szczodrak flew to Naples on Feb 26th to join the ship and setup RSMAS instrumentation on board of Urania. The Urania sailed on March 4th heading west to the study area. Weather conditions were good and validation data were taken almost continuously from March 4th to March 26th with the exception of March 15 when the ship was in port (Livorno) for exchange of the science party. The first cruise ended on March 26th in Civitavecchia. RSMAS instrumentation remained on board *Urania* and was prepared in the best possible way for working without supervision during the interval between the two ISAC cruises (Figure 5)

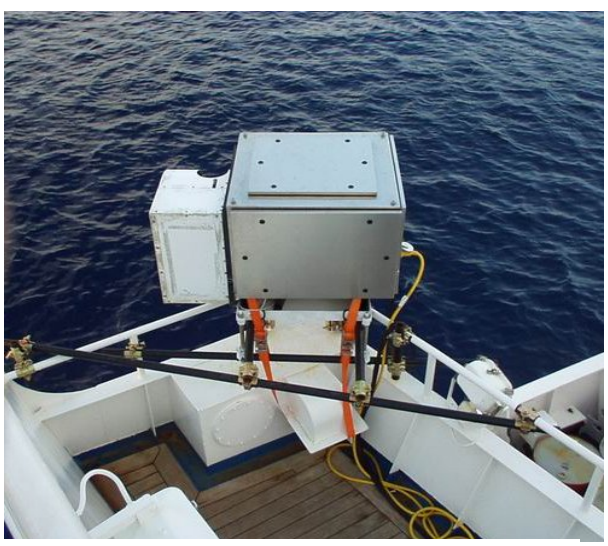

Figure 6. The M-AERI on the R/V *Urania*

The equipment mounted on the ship for *Aqua* validation included M-AERI, a surface float for measuring bulk sea-surface temperature at a depth of ~5cm, an all-sky camera, and a meteorological system, containing sensors to measure wind speed and direction, air humidity and temperature, and incident short- and long-wave radiation. The M-AERI was mounted on the railing of the *Urania* (Figure 6), on the port side so that its field of view was ahead of the bow wave so that the measurements taken of the sea surface at an angle of 55° from

nadir were uncontaminated by the surface disturbance of the ship. The M- AERI operated for ten days and a total of 1026 sets of spectra of the surface at 55° emission angle, of the atmosphere at 55° and at 0° (zenith) were taken. The hard-hat float was deployed at most stations where the ship occupied a fixed position for oceanographic measurements to be taken. Additional sub-surface temperatures are available from the ship's thermosalinograph system, and from the SkinDeEP profiler Ward et al. 2004that was deployed on the last cruise

USCGC Healy

Equipment for the validation of the MODIS, AIRS and AMSR-E measurements, and for determining the environmental conditions under which the measurements are made, was installed on the US Coast Guard Cutter *Healy* prior to its departure from Seattle, en route to the North Atlantic Ocean at the start of a circumnavigation of North America. We were able to secure a berth for Mr. K. Maillet from Seattle to St. John's, Newfoundland. The ship sailed on June 13th and headed south towards the Panama Canal. After crossing the Caribbean Sea, the Healy headed north to Newfoundland. The cruise track is shown in Figure 7, in which the cruise track is colored by the M-AERI measurement of skin SST, indicating a very wide range of values. Radiosondes were launched on 38 occasions (Figure 8) to characterize the state of the atmosphere at the times of the Aqua overpasses. An upward-looking MWR was operated through the cruise, and an all-sky camera system provided images of the sky, for subsequent analysis of cloud type and amount, were run continuously during daylight.

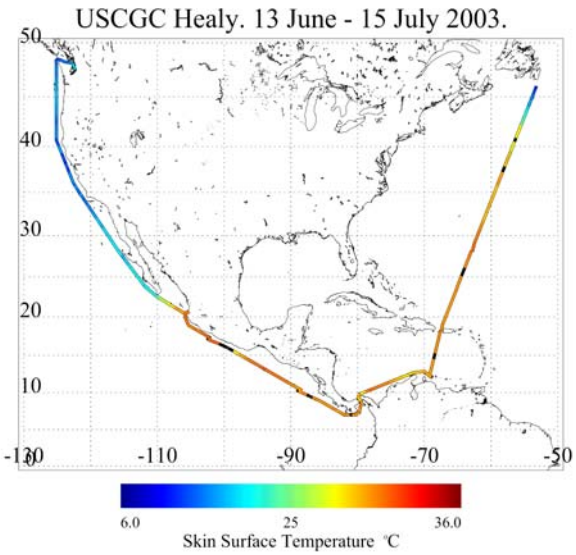

Figure 7. The track of the *Healy* while M-AERI measurements were being taken. Colors indicate the surface temperature derived from the M-AERI data.

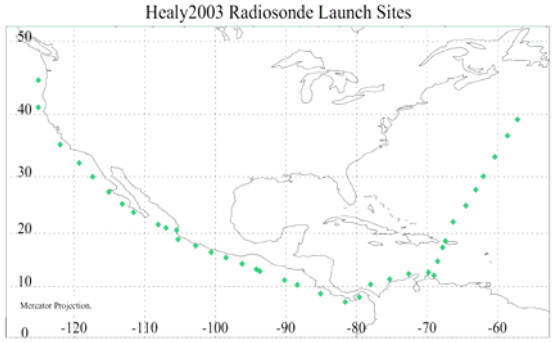

Figure 8. Positions of radiosondes launches during the *Healy* cruise.

RV Aurora Australis

At the invitation of Dr. Robert Massom of the Antarctic Climate Research Centre, Ms. Erica Key flew to Hobart, Tasmania to join the R/V *Aurora Australis* on a Southern Ocean voyage. Over a two month period, the ship transited to an area of open water and pack ice near Casey Station. Validation data for MODIS, AIRS and AMSR-E measurements were collected in the Southern Ocean and Antarctic pack ice, two sparsely-sampled oceanic regimes.

Figure 9. The M-AERI as deployed on the R/V *Aurora Australis*, above the bridge. The field-of-view camera is visible (left) on the railing beneath M-AERI, tilted at a 55° sea-viewing angle.

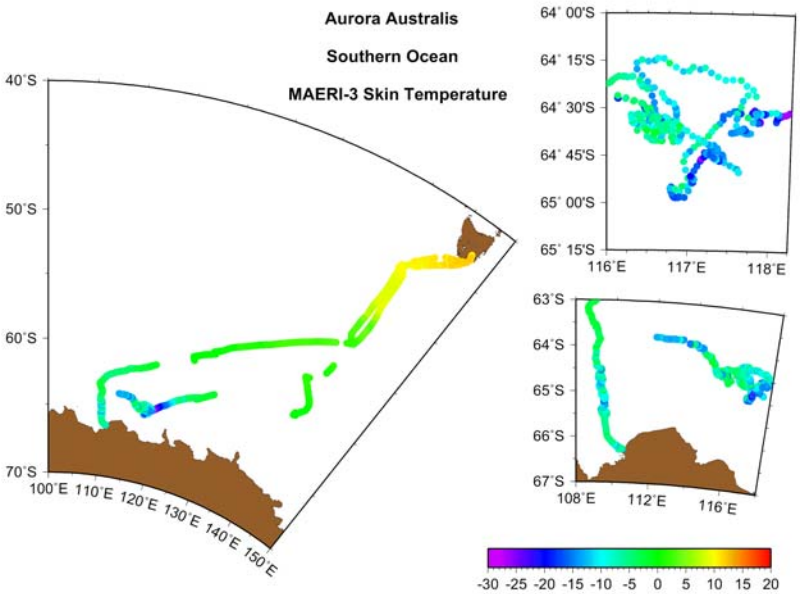

Figure 10. The track of the *Aurora Australis* while M-AERI measurements were being taken. Colors indicate the skin surface temperature derived from the M-AERI measurements.

An M-AERI was secured to the ship on the port railing aft of an observation hut (Figure 9). This position offered the best vantage point for M-AERI – on deck at an easily-accessed height, above the bridge and away from spray, and sheltered from rain by the observation hut. The field of view, though unobstructed by ship superstructure, was at times contaminated by the ship's bow wake. Skin temperature measurements derived from spectra collected at a 55° angle from nadir totaled 5162 over the 49 sampled days. The skin temperature values are shown along the ship's track in Figure 10. During daylight hours underway and twenty-four hours a day in the ice, the M-AERI field of view was recorded at 2-second intervals by a camera mounted beneath the M-AERI and tilted to the 55° sea view.

Hemispheric cloud was also recorded during daylight hours at 17-s intervals for the duration of the cruise. The camera was situated along the forward railing above the bridge deck in an area with as few sky obstructions as possible At times when the ship was hove to in open water or on station in the ice, 10-second averages of bulk sea (or ice) surface temperature were logged by a hard-hat float fitted with a calibrated thermistor.

NGCC Amundsen

RSMAS participation was invited in the Canadian Arctic Shelf Exchange Study (CASES) and a berth was offered on the new Canadian Coast Guard research icebreaker NGCC *Amundsen* for the first stage of the CASES project, a transit from Quebec City through the Northwest Passage to Amundsen Gulf. This provided an opportunity to gather ***Aqua*** validation data in a poorly sampled Arctic region.

Dr. M. Szczodrak of the RSMAS Remote Sensing Group participated in the cruise and flew to Quebec city on September 4th to join the ship. The *Amundsen* sailed on September 13th, four days behind schedule. Severe weather conditions were anticipated (and later indeed encountered) in the Labrador Sea so the setup of all sensitive scientific instruments on open decks, including the external M-AERI unit, was postponed until the *Amundsen* reached the more sheltered waters of Davis Strait. Validation data were taken from September 20th to October 14th. On October 15th the *Amundsen* anchored within few miles of Kugluktuk, NWT and RSMAS equipment was helicoptered from the ship to Kugluktuk Airport. Dr. Szczodrak flew with the equipment to Kugluktuk and made arrangements for storage of the equipment at the airport and shipment back to Miami. She returned to Miami on October 18th.

Figure 11. The M-AERI mounted on the NGCC Amundsen. The video camera housing forward of the M-AERI is used to record the conditions of the sea surface in the field of view, so that cases where ice is present, as is the case shown here, can be identified.

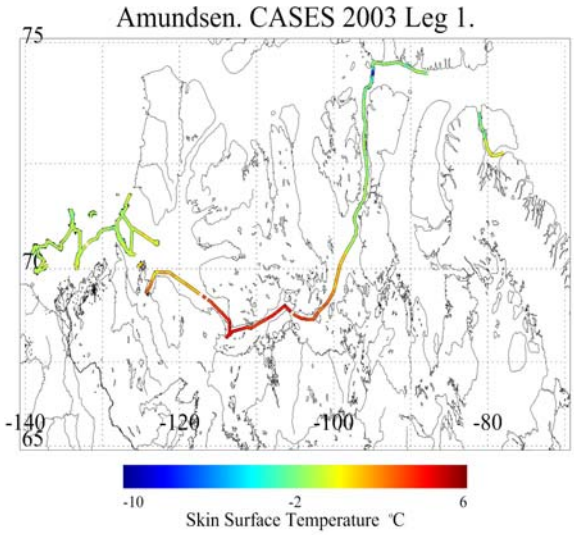

Figure 12. The track of the *Amundsen* while M-AERI measurements were being taken. Colors indicate the surface temperature derived from the M-AERI data.

The equipment mounted on the *Amundsen* for ***Aqua*** validation included an M -AERI, a surface float for measuring bulk sea-surface temperature at a depth of ~5cm, an all-sky camera and a radiosonde system. Colleagues from the University of Manitoba installed a meteorological mast for the measurement of routine surface meteorological variables, including wind speed and direction, air temperature and humidity, and incident short- and long-wave radiation.

An M-AERI was mounted on the foredeck of the *Amundsen* on an instrument mount welded to the ship (Figure 11). It was positioned, on the starboard side so that its field of view

was ahead of the bow wave, and where it was easily accessible for routine maintenance. The measurements taken of the sea surface at an angle of 55° from nadir were uncontaminated by the surface disturbance of the ship. The spectra are processed in real-time to determine the skin sea-surface temperature and the air temperature at the height of the sensor, several meters away from the ship. The M- AERI operated for ten days and a total of 1026 sets of spectra of the surface at 55° emission angle, of the atmosphere at 55° and at 0° were taken. Figure 12 shows the track of the ship while M-AERI data were being taken.

Interaction with AIRS Science and Validation Teams

The PI attended the AIRS Science Team Meeting, Camp Springs, 25–27 February 2003 and the Aqua Science Working Group Meeting, NASA Goddard Space Flight Center, Greenbelt, MD, May 28, 2003. He has also participated in the bi-weekly telephone conference calls organized by the JPL AIRS validation team. The PI has continued the collaboration with Drs D. Hagan and H.H. Auman of the AIRS Team on the radiometric validation of AIRS using comparisons between skin sea-surface temperatures measured at night by AIRS in the 'super-window' at $2126cm^{-1}$ and the RSMAS-derived ***Aqua*** MODIS 11µm 4µm sea-surface temperatures, which have been validated using M-AERI and drifting buoys. These results are shown graphically on Figure 13. The PI has also continued the collaboration with Dr W.W. MacMillan of the University of Maryland, Baltimore County, for AIRS validation over the Chesapeake Bay Light Tower. Dr Elena Lobl, of University of Alabama, Huntsville, was instrumental in setting up the collaboration with Dr Massom that resulted in the Aurora Australis cruise, which is of prime interest to the AMSR-E team. Collaboration with the AMSR-E Team is further facilitated by the close links between RSMAS and Remote Sensing Systems Inc., as Chelle Gentemann, a researcher at RSS is also studying for a PhD at RSMAS under the supervision of the PI.

Interacting with the wider scientific community

The cruise opportunities on foreign ships have arisen out of long-standing collaborations between the PI and Professor David Barber at the University of Manitoba, Canada, for the *Amundsen*, Dr Rosalia Santoleri of the CNR Institute for Atmospheric Sciences and Climate, Rome, Italy, for the *Urania*, and Dr. Robert Massom of the Antarctic Climate Research Centre, for the *Aurora Australis*. It is anticipated that these collaborations will continue and result in additional cruise opportunities in 2004.

The M-AERI data from the Explorer of the Seas have also been made available to the Validation Team for the Advanced Along-Track Scanning Radiometer (AATSR), flying on the European *Envisat* satellite. The AATSR project is led by Professor D. Llewellyn-Jones at the University of Leicester in the U.K.

Dr C. Rocken, of UCAR, Boulder, is refining techniques for measurements of atmospheric water vapor using GPS signals, and is collaborating with the PI by making comparative measurements on the *Explorer of the Seas*.

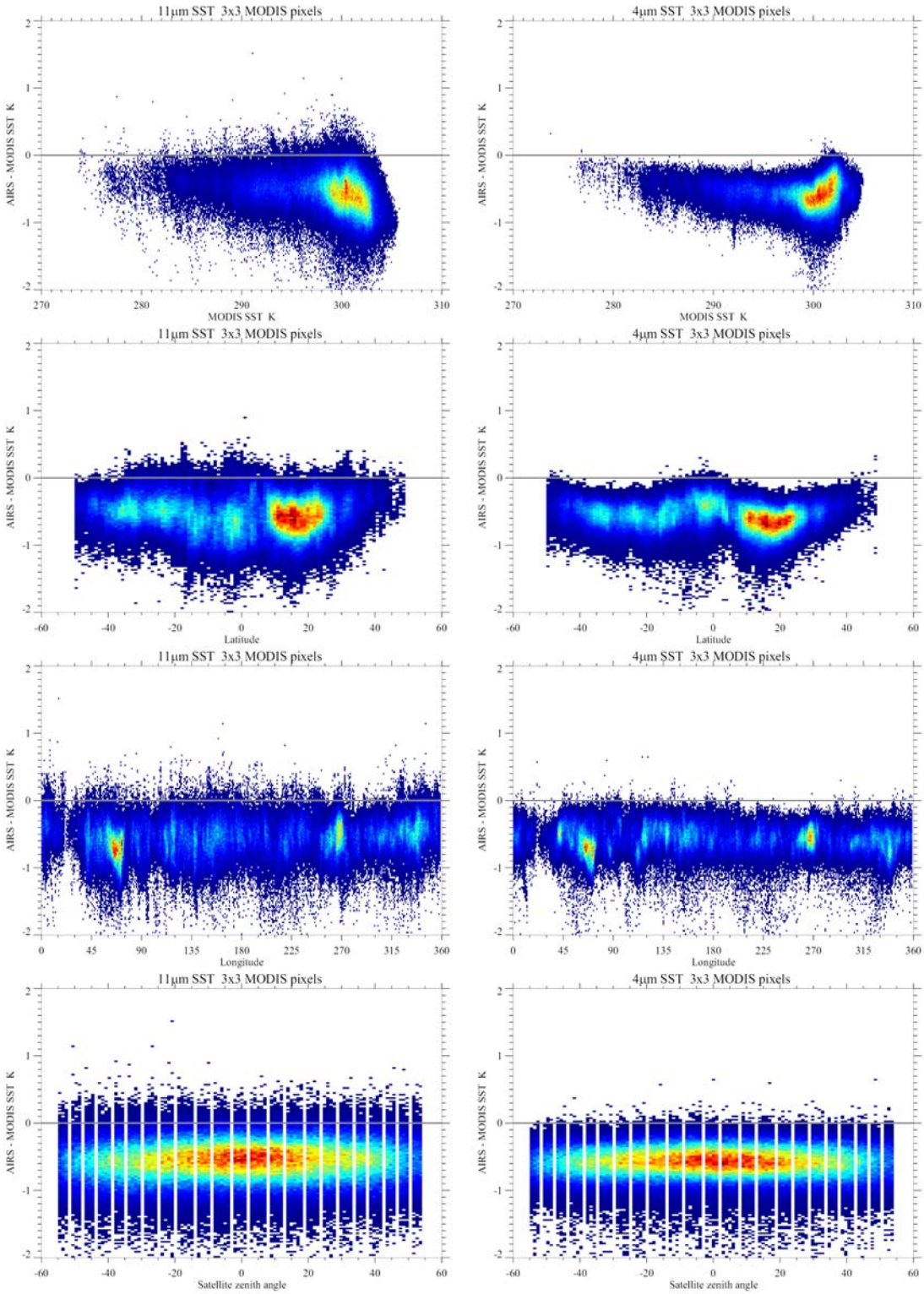

Figure 13. Continued on next page.

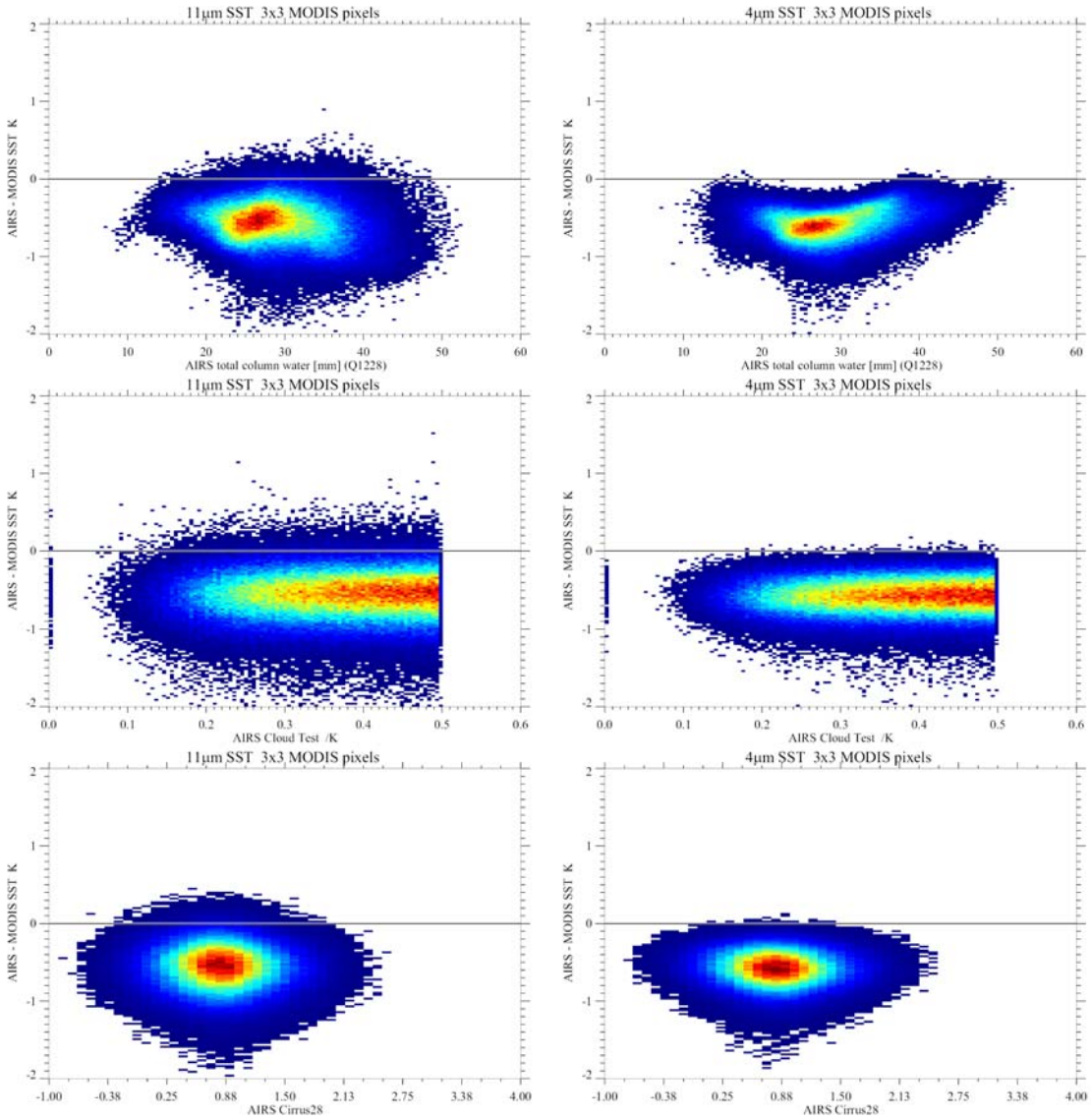

Figure 13. Probability density functions of the differences between AIRS skin SST, derived at 2126 cm^{-1} and ***Aqua*** MODIS skin SSTs for the month of December 2002. Warm colors indicate high probabilities. Differences with respect to MODIS SSTs retrieved using 11µm measurements are in the left column and using 4µm measurements are in the right column. On the previous page, the differences are plotted as functions of MODIS skin SSTs (top), latitude, longitude and satellite zenith angle, and above, as functions of AIRS-derived atmospheric total column water vapor content, an AIRS cloud test code, and the AIRS cirrus cloud test parameter at 2.8 µm. The ~0.5K offset between AIRS and MODIS skin SSTs is very consistent and does not show marked dependency on any of these variables. A corresponding analysis between AMSR-E and ***Aqua*** MODIS SSTs (not shown) does not display this offset; the mode of the differences is at 0.0K.

The PI is a member of the Science Team of the Global Ocean Data Assimilation Experiment (GODAE) High Resolution Sea-Surface Temperature Pilot Project (GHRSST-PP), which aims to facilitate the provision of accurate, high-resolution sea-surface temperature fields to the operational forecasting community and to climate researchers. The PI has been instrumental in bringing the potential of not only MODIS but also AIRS as sources of suitable, well-validated data to the awareness of this project.

Future Plans

The work in the third year will include:

1. Continuing deployment of validation instruments on the *Explorer of the Seas* and other ships as opportunities arise. This leverages other funding and both benefits from and contributes to strengthening international collaborations.
2. Continue to make the validation data sets available to the AIRS and wider community
3. Continued comparisons of AIRS, AMSR-E, MODIS and M-AERI SSTs
4. Begin comparisons of AIRS and M-AERI infrared spectral measurements.
5. Continue collaborations with the AIRS Science and Validation Teams and with the wider scientific community.

Publications

Minnett, P. J., 2003. Radiometric measurements of the sea-surface skin temperature - the competing roles of the diurnal thermocline and the cool skin. *International Journal of Remote Sensing* **24**(24): 5033-5047

Fetzer, E,. McMillin, L.M. Tobin, D. Aumann, H.H. Gunson, M.R., McMillan, W.W., Hagan, D.E., Hofstadter, M.D., Yoe, J., Whiteman, D.N., Barnes, J.E., Bennartz, R., Vomel, H., Walden, V., Newchurch, M., Minnett, P.J., Atlas, R., Schmidlin, F., Olsen, E.T., Goldberg, M.D., Sisong Zhou, HanJung Ding, Smith, W.L., Revercomb, H., 2003. AIRS/AMSU/HSB validation**.** *IEEE Transactions on Geoscience and Remote Sensing*, **41**, 418- 431.

Hagan, D.E. and P.J. Minnett, 2003. AIRS radiance validation over ocean from sea surface temperature measurements, *IEEE Transactions on Geoscience and Remote Sensing*, **41**, 432- 441.

Invited Presentations

Minnett, P.J. Shipboard measurements for AIRS validation. AIRS Science Team Meeting, Camp Springs, 25–27 February 2003.

Gentemann, C. F. Wentz, P.J. Minnett and C. Donlon. Microwave SST validation and microwave/infrared blending status. CEOS Meeting. Tokyo, Japan. March, 2003.

Minnett, P.J., R. H. Evans, E. J. Kearns, K. Kilpatrick, A. Kumar, W. Baringer, O. B. Brown and W. Esaias. AQUA MODIS Sea Surface Temperatures. Aqua Science Working Group Meeting, NASA Goddard Space Flight Center, Greenbelt, MD, May 28, 2003.

Minnett, P.J., R. H. Evans and K. Kilpatrick. MODIS Oceans Cloud Identification. Aqua Science Working Group Meeting, NASA Goddard Space Flight Center, Greenbelt, MD, May 29, 2003.

Minnett, P.J. Remote Sensing of Sea-Surface Temperature: Techniques and Accuracies. 2003 Tyrrhenian International Workshop on Remote Sensing. September 15-18, 2003, Elba, Italy.

Contributed Presentations

Hagan, D.E. and P.J. Minnett, Progress-Report, Surface Marine-L1B Radiance Matchups. AIRS Science Team Net Meeting. Pasadena, CA, January 9, 2003.

Gentemann, C.L., P.J. Minnett, C.J. Donlon and G.A. Wick. Diurnal sea-surface temperature modeling with satellite data. XXIII General Assembly of the International Union of Geodesy and Geophysics, June 30-July 11, 2003, Sapporo, Japan.

Evans, R.H., E.J. Kearns. H.R. Gordon, P.J. Minnett, K. Voss and K. Kilpatrick. MODIS ocean color and SST status, calibration and application. IEEE International Geoscience and Remote Sensing Symposium (IGARSS'03), July 21-25, 2003, Toulouse, France.

Noyes, E., B. Mannerings, G. Corlett, J. Remedios, D. Llewellyn-Jones and P. Minnett. Validation of AATSR SST with ship-based measurements from the M-AERI. MERIS and AATSR Calibration and Geophysical Validation Meeting (MAVT-2003). 20-24 October 2003. Frascati, Italy.

Minnett, P.J., R. H. Evans, E. J. Kearns, K. Kilpatrick, K. A. Maillet, A. Kumar, W. Baringer, S. Walsh, E. L. Key, M. Szczodrak & O. B. Brown. Sea surface temperature measurements from the MODerate- resolution Imaging Spectroradiometer (MODIS) on AQUA. AGU Fall Meeting, San Francisco, CA. December 9, 2003.

Maddy, E, W.W. McMillan, P.J. Minnett and H.H. Aumann. Remote sensing of sea surface temperature from ground and sky. AGU Fall Meeting, San Francisco, CA. December 10, 2003.

Szczodrak, M., P.J. Minnett, K.A. Maillet and R.A. Jones, Comparative Measurements of Atmospheric Water Vapor Over the Oceans. AGU Ocean Sciences, Portland, Oregon, USA, 26-30 January 2004

Minnett, P J., D.T. Llewellyn-Jones, G.K. Corlett and E.J Noyes. Validating the Sea-Surface Temperatures Derived from the Advanced Along-Track Scanning Radiometer on ENVISAT. AGU Ocean Sciences, Portland, Oregon, USA, 26-30 January 2004.

References

Feltz, W. F., W. L. Smith, H. B. Howell, R. O. Knuteson, H. Woolf and H. E. Revercomb (2003). "Near continuous profiling of temperature, moisture, and atmospheric stability using the atmospheric emitted radiance interferometer (AERI)." Journal of Applied Meteorology **42**(5): 584-597.

Liou, Y., Y. Teng, T. Van Hove and J. C. Liljegren (2001). "Comparison of precipitable water observations in the near tropics by GPS, microwave radiometer, and radiosondes." J. Appl. Meteorology. **40**(1): 5-15

Miloshevich, L. M., H. Vömel, A. Paukkunen, A. J. Heymsfield and S. J. Oltmans (2001). "Characterization and correction of relative humidity measurements from Vaisala RS80-A radiosondes at cold temperatures." J. Atmos. Oc. Tech. **18**: 135-156

Minnett, P. J., R. O. Knuteson, F. A. Best, B. J. Osborne, J. A. Hanafin and O. B. Brown (2001). "The Marine-Atmospheric Emitted Radiance Interferometer (M-AERI), a high-accuracy, sea-going infrared spectroradiometer." Journal of Atmospheric and Oceanic Technology **18**(6): 994-1013

Ward, B., R. Wanninkhof, P. J. Minnett and M. J. Head (2004). "SkinDeEP: A Profiling Instrument for Upper Decameter Sea Surface Measurements." Journal of Atmospheric and Oceanic Technology **Accepted**