TECHNICAL REPORT

Contract Title:	Infrared Algorithm Development for Ocean Observations with EOS/MODIS
Contract:	NAS5-31361
Type of Report:	Semi-Annual
Time Period:	January – June 2003
Principal Investigator:	Otis B. Brown RSMAS/MPO University of Miami 4600 Rickenbacker Causeway Miami, Florida 33149-1098

INFRARED ALGORITHM DEVELOPMENT FOR OCEAN OBSERVATIONS WITH EOS/MODIS

Abstract

Efforts continue under this contract to develop and validate algorithms for the computation of sea surface temperature (SST) from MODIS infrared measurements. These include radiative transfer modeling, comparison of *in situ* and satellite observations, development and evaluation of processing and networking methodologies for algorithm computation and data access, evaluation of surface validation approaches for IR radiances, and participation in MODIS (project) related activities. Activities in this contract period have focused on field campaigns, analysis of field data, analysis of MODIS SST retrievals, and preparation of publications and presentations.

A. NEAR TERM OBJECTIVES

MODIS Infrared Algorithm Development and Maintenance

A.1. Algorithmic development efforts based on experimental match-up databases and radiative transfer models and inter-satellite comparisons.

A.2. Interaction with the MODIS Instrument Team through meetings and electronic communications, and provide support for MCST activities.

A.3 Maintain and develop at-sea instrumentation for MODIS SST validation.

A.4 *In situ* validation cruises for the MODIS IR bands.

A.5 Development and population of the MODIS Matchup Data Base.

A.6 Interactions with other EOS groups.

A.7 Interactions with international groups.

MODIS SST – Scientific Research

A.8 Study thermal structure of ocean-atmosphere interface.

A.9 Development of optimal skin-SST validation strategy.

A.10 Compositing MODIS and other SST fields.

A.11 MODIS cloud cover studies.

Overarching Contract Activities

A.12 Provide investigator and staff support for the preceding items.

B. OVERVIEW OF CURRENT PROGRESS

January – June 2003

Activities during the past six months have continued on the previously initiated tasks, including the new measurements from the *Aqua* MODIS. Many of the initial problems found with the *Terra* MODIS are absent, or much reduced, in the measurements of the *Aqua* MODIS. Importantly, the experience gained with *Terra* MODIS has been very beneficial in dealing efficiently with *Aqua* MODIS data. There have been specific efforts in the areas of: (a) deriving an atmospheric correction algorithm for the *Aqua* MODIS; (b) refinement of SST retrieval algorithms for the *Terra* MODIS based on match-ups with M-AERI skin temperature data and buoy sub-surface measurements, and (c) undertake cruises to continue acquisition of M-AERI infrared validation data. Previously initiated activities, such as Team related activities, continue, as have episodic efforts associated with MODIS characterization and response.

Special foci during this six-month period have been:

1) Refine *Terra* and *Aqua* MODIS SST retrieval algorithms based on match-ups with surface data.
2) Continuation of the analysis of measurements from M-AERI research cruises.
3) Continuation of routine data collection on the *Explorer of the Seas*.
4) Preparation and participation in the cruises of the R/V *Urania*.
5) Maintenance of the at-sea hardware. This has involved more effort and sustained higher costs than usual in the repair of two significant M-AERI failures.
6) Continue development of a database for validation cruise data, buoy data and associated satellite measurements.
7) In collaboration with Dr. B. Ward of WHOI, and Dr. M. Donelan of the University of Miami a study of the thermal skin layer with a micro-profiler and the M-AERI, in the University of Miami – Rosenstiel School ASIST facility, is underway (with ONR funding).
8) With new NOPP funding and in collaboration with national and international partners, a new project has begun to develop and deploy autonomous infrared radiometers for use on ships of the Voluntary Observing Fleet.

B.1. Algorithmic development efforts based on experimental match-up databases and radiative transfer models and inter-satellite comparisons.

Activities in this reporting period have focused on the determination of the uncertainties in the Aqua MODIS SST retrievals. The positions of matchups between Aqua MODIS SSTs and *in situ* measurements from M-AERI and drifting and moored buoys are shown in Figure 1. This shows only the highest quality MODIS data, for the Aqua Mission up to early May 2003. Some M-AERI cruise data taken during this time will be included in the next release of the match-up database.

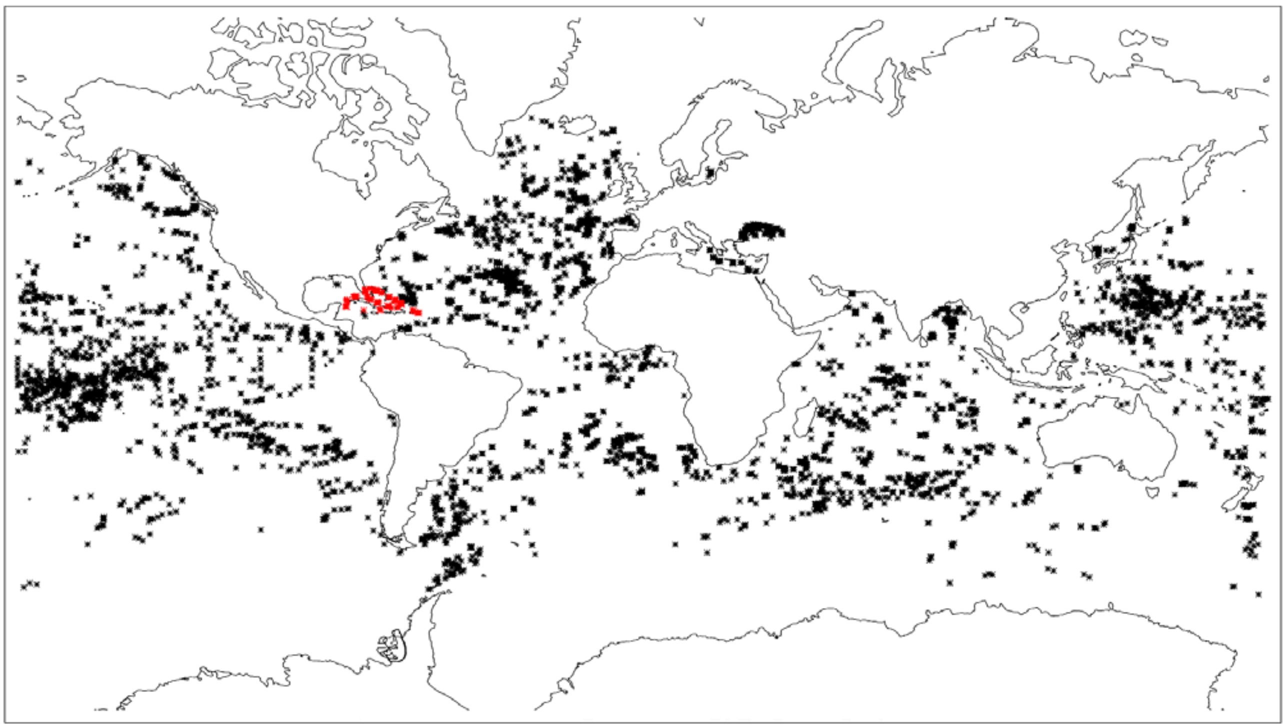


Figure 1. Matchups between Aqua MODIS SSTs and buoys (black) and M-AERI (red), used to generate the statistics shown in Table 1.

	Buoy + M-AERI			**Buoy (bulk)**			**M-AERI (skin)**		
	ΔT	ΔT′	n	ΔT	ΔT′	n	ΔT	ΔT′	n
SST (day +night)	-0.085	0.486	4113	-0.086	0.487	4055	0.019	0.407	58
SST (night)	-0.116	0.440	1845	-0.119	0.441	1813	0.090	0.271	32
SST (day)	-0.059	0.519	2268	-0.059	0.519	2242	-0.069	0.522	26
SST4 (night)	-0.149	0.399	1601	-0.150	0.400	1572	-0.113	0.357	29

Table 1. Statistics of matchups between the *Aqua* MODIS and validation measurements.

The main conclusions to be derived from the statistics are:

- There are few M-AERI SSTs compared to the buoy SSTs
- Biases with respect to buoys more negative than with respect to M-AERI – which is in line with the skin effect
- Scatter at night smaller than during the day – which is in line with diurnal thermocline effects
- Scatter for SST4 smaller than SST, which is in line with the decreased sensitivity of SST4 to atmospheric variability.

<u>B.2. Interaction with the MODIS Instrument Team through meetings and electronic communications, and provide support for MCST activities.</u>

Dr. Peter Minnett attended the Aqua Science Working Group Meeting, NASA Goddard Space Flight Center, Greenbelt, MD, May 28-29, 2003, and gave two presentations, entitled "AQUA MODIS Sea Surface Temperatures" and "MODIS Oceans Cloud Identification." He also gave the presentation entitled "AMSR-E SST Retrieval and Validation" on behalf of Frank Wentz and Chelle Gentemann.

Throughout this reporting period, there has been interaction with Bob Evans (Contract NAS5-31362) and others at RSMAS on a daily basis to address remediation of MODIS instrumental issues; participation in the weekly Ocean PI's teleconference, and numerous telephone discussions with Dr. Wayne Esaias, MODIS Oceans Team Leader on MODIS SST retrievals.

<u>B.3 Maintain and develop at-sea instrumentation for MODIS SST validation.</u>

The maintenance of the M-AERI on the *Explorer of the Seas* has been routine during this reporting period. A second M-AERI was prepared for use on the R/V *Urania* during a two-month series of cruises in the western Mediterranean Sea, with a subsequent deployment on the USCGC *Healy*, which sailed from Seattle on June 13 on a circumnavigation of North America. The M-AERI will be used on the sections from Seattle to Panama to St. John's Newfoundland. The third M-AERI was being repaired during this reporting period.

A new project has recently begun with NOPP (National Oceanographic Partnership Program) funding to develop and deploy autonomous skin-SST radiometers on ships of the Voluntary Observing Fleet. Dr Minnett is leading this project with 12 national and international partners. The radiometer to be deployed is a well-calibrated filter radiometer, called ISAR (Infrared Scanning Autonomous Radiometer). This instrument has proven accuracy and demonstrated ability to function in autonomous deployments. It was developed at the Southampton Oceanography Centre (SOC) in the UK, by Drs Craig Donlon and Ian Robinson, in collaboration with Dr Michael Reynolds of Brookhaven National Laboratory, for the purpose of validating the skin SST measurements form the Advanced Along-Track Scanning Radiometer (AATSR) on the European Space Agency satellite *Envisat.* The skin temperature measurements from the ISAR and other radiometers involved in this project, will contribute to the MODIS SST validation activities.

B.4 *In situ* validation cruises for the MODIS IR bands.

Since November 2000, M-AERI 1 has been permanently installed on the *Explorer of the Seas*, which undertakes alternate weekly cruises in the eastern Caribbean Sea and Bahaman Islands (white track in Figure 2), and through the western Caribbean Sea and Florida Straits (red track in Figure 2). The ship

Figure 2. Weekly tracks of the *Explorer of the Seas.* The ship follows the two tracks on alternate weeks.

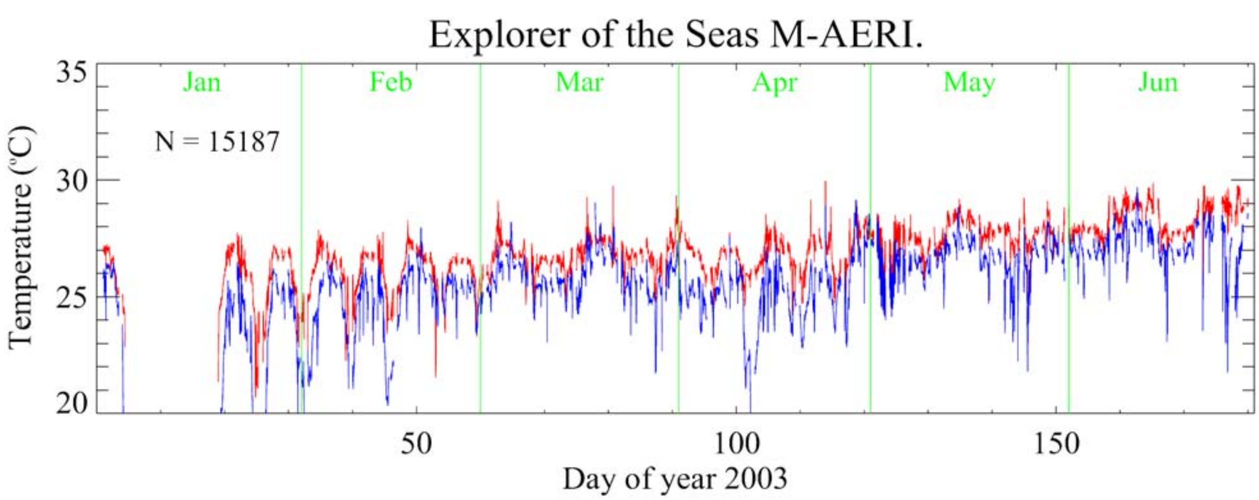


Figure 3. Measurements of skin SST (red) and near-surface air temperature (blue) measured by the M-AERIs on the *Explorer of the Seas* during January to June 2003. The data gap in January is a consequence of a period in dry dock.

returns to Miami each Saturday at which time the data are retrieved and taken to RSMAS. During this reporting period, the track of the eastern Caribbean circuit was changed to include a port call at St Maarten, in place of Labadee, and so both outgoing and return passages are on the eastern side of the Bahamas. The data for this reporting period are shown in Figure 3.

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 MODIS SST validation data in an 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. The track of the Urania during this period is shown in Figure 4. Dr M. Szczodrak of the RSMAS Remote Sensing Group participated in both ISAC cruises. She flew to Naples on Feb 26th to join the ship and setup RSMAS instrumentation on board the *Urania*, which 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. Dr. Szczodrak disembarked on March 27th.

With NASA approval Dr. Szczodrak remained in Italy for the period between the 1st and the 2nd cruises working at the ISAC in Rome. The *Urania* left Civitavecchia on March 29th sailing towards Sardinia and Corsica and returned to the same port on April 16th. The data coverage from this period when RSMAS instrumentation was working unattended is episodic due mostly to weather conditions but also limited by lack of close supervision of the equipment.

Dr. Szczodrak rejoined *Urania* on the morning of April 17th and the ship sailed later that day for the second ISAC cruise. Dr Brian Ward from WHOI also participated in this cruise and took measurements of temperature profiles in the water column from the depth of about 6m to the surface with the SkinDeEP profiler (Ward and Minnett, 2001). RSMAS validation data were taken from April 17th to April 25th with just one gap of 14 hours due to bad weather and two more gaps of few hours due to malfunctioning of the instrumentation. The cruise ended on April 26th in La Spezia.

Mr Kevin Maillet from RSMAS sailed on the USCGC Healy on June 13 to start a M-AERI validation cruise from Seattle to St. John’s, Newfoundland, through the Panama Canal. The ship is scheduled to dock in St. John’s on July 16.

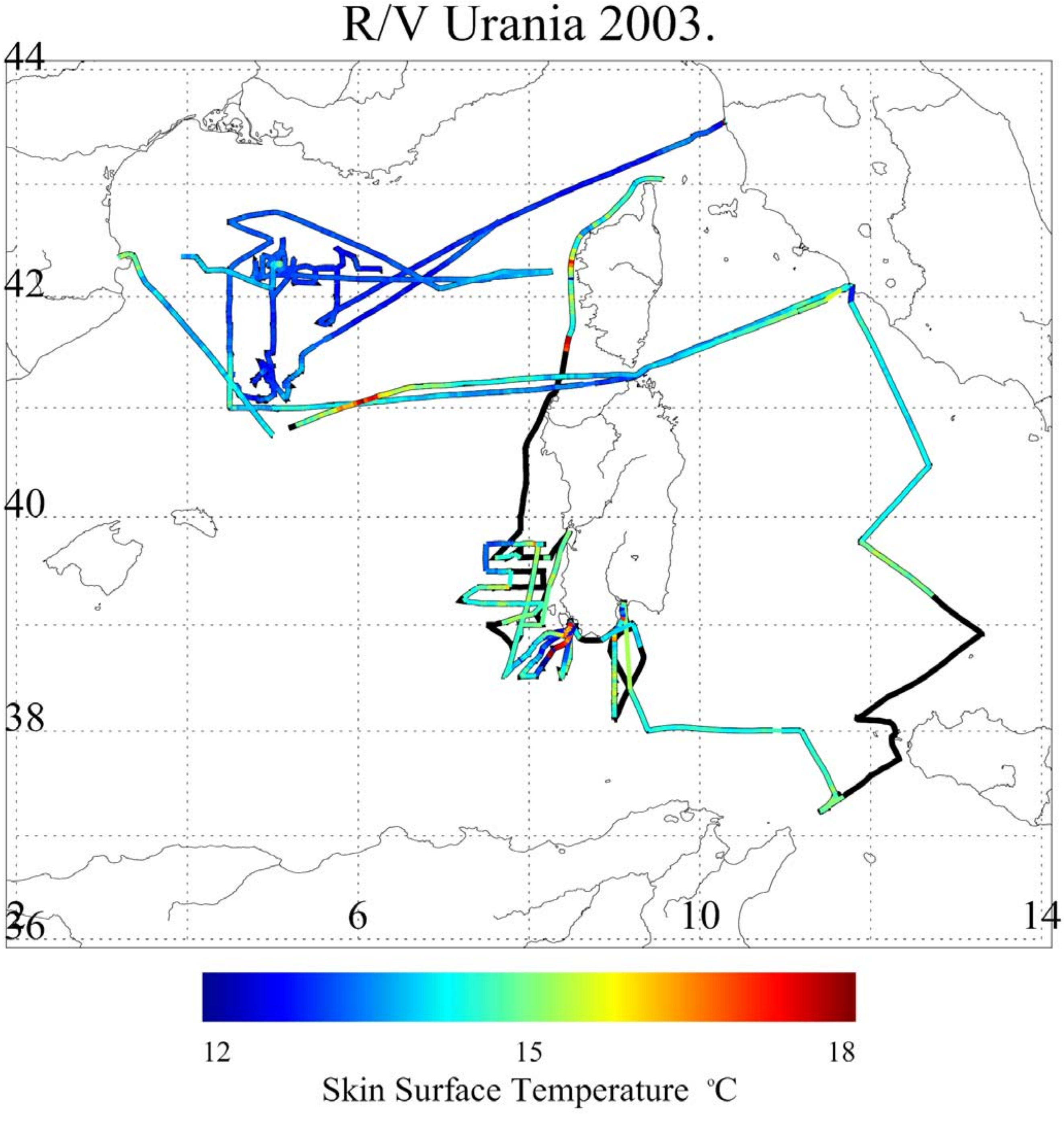


Figure 4. The track of the R/V Urania, colored by surface temperature measured by the M-AERI. Black indicates period when the M-AERI was not taking data.

B.5 Development and population of the MODIS Matchup Data Base

The process of developing a database of matchups between MODIS brightness temperatures, and derived SSTs, and in situ validation measurements from buoys and M-AERIs continues. This is a very time consuming activity as it requires extensive quality control of the buoy measurements, and the processing of all of the oceanic measurements from the two MODIS instruments on *Terra* and *Aqua.* Nevertheless this is a very important activity in providing the information to validate the MODIS SSTs and to provide insight into the behavior of the error characteristics of the SST retrieval algorithms.

A related development is the provision of a web-accessible, on-line database for measurements taken from the *Explorer of the Seas*, which has resulted from ONR funding. This means all M-AERI data, and those from other sensors on board, are accessible to the wider community. At present, the data access is rather obscure to the neophyte, but a user-friendly graphical user interface will be implemented soon to permit efficient searching and downloading of the measurements.

B.6 Interactions with other EOS groups.

Collaborative activities have continued in this reporting period with the AIRS (Atmospheric Infrared Sounder) group at JPL who are using MODIS SSTs to validate the radiometric calibration of the AIRS on *Aqua*. At a wavenumber of 2616 cm^{-1}, the atmosphere is particularly transparent and the residual uncertainties in the AIRS measurements of skin SST are anticipated to be very small. Aqua MODIS SSTS have been sent to the JPL AIRS Team for comparison with the AIRS measurements. These measurements are contemporaneous and share the same emission angle at the surface and path through the atmosphere. The advantages of MODIS over AIRS lies in the higher spatial resolution (~1km *vs* ~15km) that leads, at least in principle, to more reliable identification of measurements contaminated by clouds, and the more established validation of the skin SST retrievals using buoys and M-AERIs. The initial results are very good, with a small bias of ~0.3K (AIRS cooler than MODIS), and standard deviation of 0.14 to 0.21K. The preliminary results are available at ftp://thunder.jpl.nasa.gov/hha/sst/modis-airs-comparions.htm. A two-day workshop was held at Goddard Space Flight Center on 28-29 May to discuss the status of *Aqua* sensors about one year after launch. A lot of emphasis was placed on the measurement of SST from MODIS, AIRS and AMSR-E. Dr Minnett attended the Workshop and gave two MODIS presentations on SST derivation and validation, and on cloud detection. He also gave the presentation on AMSR-E SST measurements on behalf of F. Wentz, C. Gentemann and their colleagues who could not attend the meeting.

B.7 Interactions with international groups.

The M-AERI measurements have been made available to the Advanced Along-Track Scanning Radiometer (AATSR) Team at the University of Leicester for validating the AATSR SST retrievals. The AATSR is the third in the series of dual-view imaging radiometers to fly on European polar orbiting satellites, and is part of the scientific payload of the *ENVISAT* satellite. In return for the M-AERI data, we will receive copies of AATSR data, which will be used in comparative studies with MODIS SSTs. By measuring the same swath of the earth's surface at two view angles, the AATSR provides a direct measurement of the effect of the atmosphere on the infrared signals, thereby permitting an alternative approach to the conventional multi-channel atmospheric correction algorithms used by MODIS. The AATSR has three channels that match quite well bands 20, 31 and 32 of MODIS.

MODIS SST – Scientific Research

B.8 Study thermal structure of ocean-atmosphere interface.

With funding from ONR a study is underway of the thermal skin layer and subsurface temperature structure in the RSMAS ASIST (Air-Sea Interaction Salt Water Tank). ASIST was designed for studies relevant to air-sea interaction including remote sensing, turbulence, gas transfer, wave dynamics, surface chemistry, spray and aerosol generation, and interfacial thermodynamics. The 15 meter long ASIST is equipped with a wind tunnel (0-30 ms^{-1}), programmable wave maker, water temperature control, water current control, turbulence and wave instrumentation. The experiments were made of the behavior of the skin layer under a wide range of air sea heat fluxes and wind speeds. This study is in collaboration with Dr B. Ward, now of the Woods Hole Oceanographic Institution, and Dr. M. Donelan of RSMAS.

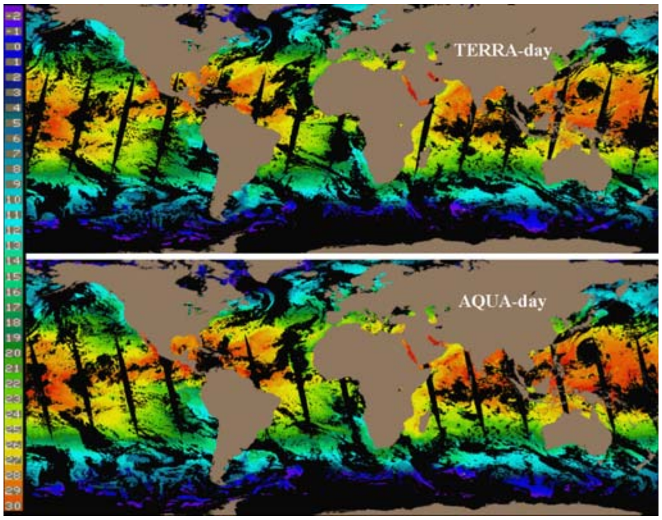
B.9 Development of optimal skin-SST validation strategy.

During the last week of May, 2001 an international workshop for the comparison and calibration of ship-board infrared radiometers that are being used to validate the skin sea-surface temperatures derived from the measurements of imaging radiometers on earth observation satellites, was held at RSMAS. This included laboratory measurements using the newly developed NIST Transfer Radiometer (TXR), and against NIST-certified black-body calibration targets, and an intercomparison of the radiometers on a short cruise on board the R/V F.G. *Walton-Smith* in local waters around Miami. This was funded by NOAA, ESA and EUMETSAT. The results have been prepared for publication and two papers have been submitted to the Journal of Atmospheric and Oceanic Technology (Barton *et al*., Rice *et al*.); these are detailed in F1 below.

B.10 Compositing MODIS and other SST fields.

A significant limitation of the application of MODIS SSTs is the obscuration of the sea-surface by clouds. In many cases, the clouds move and evolve on time scales that are shorter than those of the underlying oceanic features. This permits the compositing of successive images and this has been done in the past using AVHRR and Terra MODIS data. The use of MODIS instruments on Terra and Aqua permits composting images over much shorter time scales, and the use of coarser resolution microwave SSTs from AMSR-E, or TMI in the tropics, can fill in the remaining gaps caused by persistent clouds in the infrared measurements. Studies have begun on the compositing of these data, and initial results are promising, but the correct methods of compositing the data, especially during the day when the effects of diurnal thermoclines can introduce artifacts in combinations of data taken at different times on the same day. Furthermore, the different error characteristics of the microwave and infrared SST retrievals requires careful development of algorithms that do not compromise the inherent accuracies of the component fields in the attempt to provide near-complete cloud-free data

An example of the initial results are shown in Figures 5 and 6 for the data taken on September 29, 2002.



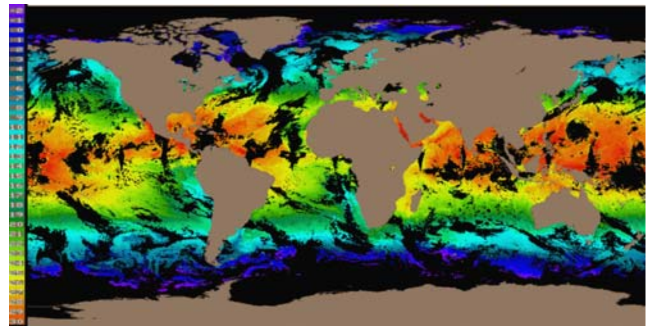
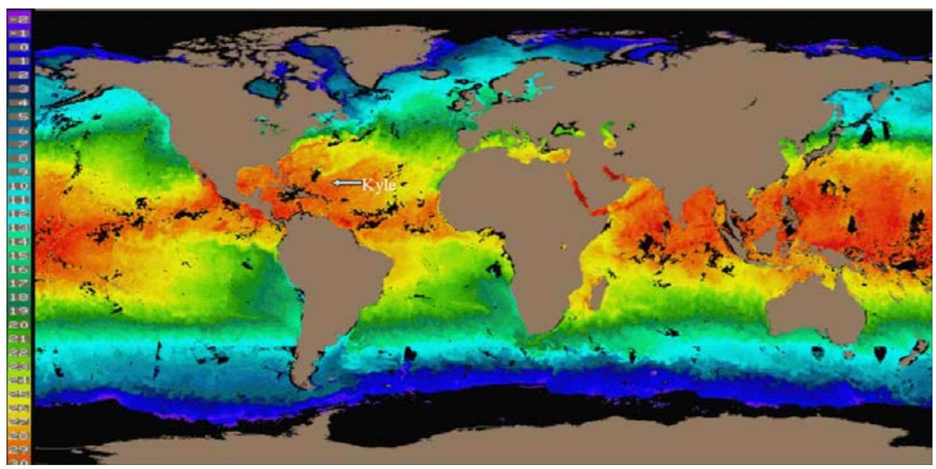


Figure 5. The daytime MODIS infrared SSTs from MODIS on *Terra* and *Aqua* on 29 September 2002 (left) and combined (above). Most of the data gaps (black) between adjacent swaths are filled in, but missing information caused by persistent clouds remains.

Figure 6. Most of the cloud-obscured regions apparent in the composited infrared SSTs (Figure 5) are filled in by using microwave SST retrievals from AMSR-E and TMI.



The compositing of multi-sensor SSTs to produce cloud free fields is the main objective of the GODAE (Global Ocean Data Assimilation Experiment) High Resolution SST Pilot Project (GHRSST-PP). These are to be at a spatial resolution of 10km or better, on a 6-hr time step, and this requires the merging of SST fields from a wide range of satellite sensors operating both in the infrared and the microwave spectral regions. Although the mechanism for full US participation in GHRSST is not yet clear, the potential contribution of MODIS SSTs to this is very significant, and desired by the GHRSST international Science Team.

B.11 MODIS cloud cover studies.

The equipment installed on the *Explorer of the Seas* includes a Total-Sky Imager and Ceilometer to determine the amount and type of cloud cover present at the time of the satellite overpasses. These measurements have multiple applications including the determination of cloud-free conditions when MODIS SSTs are being compared to M-AERI measurements, and as data for validating cloud conditions determined from MODIS. This latter research has been conducted in collaboration with the group at the University of Alabama at Huntsville.

C. INVESTIGATOR SUPPORT

January	W. Baringer	K. Maillet	J. Splain
	O. Brown	Y. Oviedo	M.Szczodrak
	M. Framinan	I. Sanchez	
February	W. Baringer	K. Maillet	J. Splain
	O. Brown	Y. Oviedo	M.Szczodrak
	M. Framinan	M.Szczodrak	
	K. Kilpatrick	I. Sanchez	
March	W. Baringer	K. Kilpatrick	J. Splain
	O. Brown	K. Maillet	M.Szczodrak
	M. Framinan	I. Sanchez	
April	W. Baringer	K. Kilpatrick	J. Splain
	O. Brown	I. Sanchez	M.Szczodrak
	M. Framinan		
May	W. Baringer	A. Kumar	J. Splain
	O. Brown	A. Li	M.Szczodrak
	M. Framinan	I. Sanchez	
	K. Kilpatrick		
June	W. Baringer	K. Kilpatrick	I. Sanchez
	O. Brown	A. Kumar	J. Splain
	M. Framinan	P. Minnett	M.Szczodrak

D. FUTURE ACTIVITIES

D.1 Algorithms

a. Complete repairs of damaged M-AERI, recalibrate and prepare for future validation cruises.
b. Continue to develop and test algorithms on global retrievals.
c. Evaluation of global data assimilation statistics for SST fields.
d. Develop scientifically defensible techniques of merging *Terra* and *Aqua* MODIS data.
e. Develop scientifically defensible techniques of merging infrared and microwave SST fields.
f. Participate in research cruises.
g. Continue radiative transfer modeling to better understand the MODIS SST error characteristics.
h. Continue analysis of research cruise data.
i. Continue to study near-surface temperature structure.
j. Continue planning of validation campaigns.
k. Validation Plan updates (as needed).
l. EOS Science Plan updates (as needed).
m. Continued participation in MODIS Team activities.

D.2 Investigator support

Continue appropriate efforts.

D.3 Presentations and publications.

a. Prepare material for the IGARSS International Symposium in Toulouse in July 2003, IUGG in Sapporo in July 2003, and other symposia as appropriate.
b. Prepare scientific results for publication in the refereed literature.

E. PROBLEMS

One of the two M-AERIs damaged at sea during the last reporting period has been repaired and recalibrated. The damage to M-AERI 2, resulting from a storm that hit the *Polar Sea* in the North Pacific Ocean is being rectified. The interferometer has been refurbished by the manufacturer and returned to RSMAS. Some of the components are being repaired at SSEC and others at RSMAS. It is anticipated that the instrument will be fully repaired and operational by late summer.

F. PUBLICATIONS AND PRESENTATIONS

F.1 Refereed publications:

Barton, I. J., P. J. Minnett, C. J. Donlon, S. J. Hook, A. T. Jessup, K. A. Maillet and T. J. Nightingale. The Miami2001 infrared radiometer calibration and inter-comparison: Ship comparisons. *Journal of Atmospheric and Oceanic Technology*. Accepted.

The second calibration and inter-comparison of infrared radiometers (Miami2001) was held at the University of Miami, Rosenstiel School of Marine and Atmospheric Science (RSMAS) during May-June 2001. The radiometers targeted in these two campaigns (laboratory-based and at-sea measurements) are those used to validate the skin sea-surface temperatures and land surface temperatures derived from the measurements of imaging radiometers on earth observation satellites. These satellite instruments include those on currently operational satellites and others that will be launched within two years following the workshop. The experimental campaigns were completed in one week and included laboratory measurements using black-body calibration targets characterized by the National Institute of Standards and Technology (NIST), and an inter-comparison of the radiometers on a short cruise on board the RV F.G. Walton-Smith in Gulf Stream waters off the eastern coast of Florida. This paper reports on the results obtained from the ship-borne measurements. Seven radiometers were mounted alongside each other on the RV Walton Smith for an inter-comparison under sea-going conditions. The ship results confirm that all radiometers are suitable for the validation of land surface temperature, and the majority are able to provide high quality data for the more difficult validation of satellite-derived sea surface temperature, contributing less than 0.1 K to the error budget of the validation. The measurements provided by two prototype instruments developed for ship-of-opportunity use confirmed their potential to provide regular reliable data for satellite-derived SST validation. Four high quality radiometers showed agreements within 0.05 K confirming that these instruments are suitable for detailed studies of the dynamics of air-sea interaction at the ocean surface as well as providing high quality validation data. The data analysis confirms the importance of including an accurate correction for reflected sky radiance when using infrared radiometers to measure SST. The results presented here also show the value of regular inter-comparisons of ground-based instruments that are to be used for the validation of satellite-derived data products - products that will be an essential component of future assessments of climate change and variability.

Hagan, D. and P.J. Minnett, AIRS Radiance Validation Over Ocean from Sea Surface Temperature Measurements. IEEE Transactions on Geoscience and Remote Sensing, 41, 432- 441.

This paper demonstrates the accuracy of methods and in situ data for early validation of calibrated Earth scene radiances measured by the Atmospheric InfraRed Sounder (AIRS) on the Aqua spacecraft. We describe an approach for validation that relies on comparisons of AIRS radiances with drifting buoy measurements, ship radiometric observations and mapped sea surface temperature products during the first six months after launch. The focus of the validation is on AIRS channel radiances in narrow spectral window regions located between 800-1250 cm-1 and between 2500 and 2700 cm-1. Simulated AIRS brightness temperatures are compared to in situ and satellite-based observations of Sea Surface Temperature (SST) co-located in time and space, to demonstrate accuracies that can be achieved in clear atmospheres. An error budget, derived from single channel, single footprint matchups, indicates AIRS can be validated to better than 1% in absolute radiance (equivalent to 0.5 K in brightness temperature, at 300 K and 938 cm-1) during early mission operations. The eventual goal is to validate instrument radiances close to the demonstrated pre-launch calibration accuracy of about 0.4% (equivalent to 0.2 K in brightness temperature, at 300 K and 938 cm-1).

Kumar, A., P. J. Minnett, G. Podestà, and R. H. Evans. Error characteristics of the atmospheric correction algorithms used in retrieval of sea surface temperatures from infrared satellite measurements; global and regional aspects. Journal of the Atmospheric Sciences, 60, 575-585.

A database of co-temporal and co-located satellite and in situ observation is used to examine the association between brightness temperature differences measured in the thermal infrared channels (T45) of the Advanced Very High Resolution Radiometer (AVHRR) and water vapor (ω) derived form the Special Sensor Microwave Imager (SSM/I). This channel difference is used to estimate the atmospheric correction (due mostly to water vapor absorption) in sea surface temperature (SST) algorithms. The association between T45 and ω is found to be greatest for tropical latitudes; for mid and high latitudes the association is best during summer. However, the association tends to decrease towards mid and higher latitudes during other periods. SST residual errors (satellite – buoy) show a negative mean in the tropics suggesting undercorrection for water vapor in the tropics. The underestimation is explicitly shown for SST in the high water vapor regimes of the Arabian Sea. In mid and high latitudes, the variability of atmospheric water vapor and air-sea temperature difference contribute to the weaker association between T45 and ω, and results in positive mean SST residual errors. A differential form of SST algorithm that incorporates the use of a "first-guess estimate" that correlates with SST is observed to give least residual errors.

Minnett, P.J. Radiometric measurements of the sea-surface skin temperature for the validation of measurements from satellites – the competing roles of the diurnal thermocline and the cool skin. *International Journal of Remote Sensing*. Accepted.

It has long been recognized that satellite-borne infrared radiometers measure radiance that is more closely related to the temperature of the skin of the ocean than the sub-surface bulk temperature, but, historically, atmospheric correction algorithm derivation and validation exercises have been conducted using bulk temperatures measured at a depth of a metre or more. A recent validation of sea-surface temperature (SST) fields derived from the Advanced Very High Resolution Radiometer (AVHRR) with skin temperature measurements of the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) revealed a very low mean bias error, much smaller that was expected given the thermal skin effect which acts to cool the surface with respect to subsurface values by several tenths of a degree. This result does not imply the skin effect is not important – its effect is now well documented in many data sets – but that its effect is being partially compensated by diurnal heating effects. The evidence for this is presented and the consequences in terms of validating satellite-derived SSTs and of merging data from sensors with different satellite overpass times are discussed.

Rice, J.P., J. J. Butler, B. C. Johnson, P. J. Minnett, K. A. Maillet, T. J. Nightingale, S. J. Hook, A. Abtahi, C. J. Donlon and I. J. Barton. The Miami2001 Infrared Radiometer Calibration and Intercomparison: 1. Laboratory Characterization of Blackbody Targets *Journal of Atmospheric and Oceanic Technology*. Submitted.

The second calibration and inter-comparison of infrared radiometers (Miami2001) was held at the University of Miami, Rosenstiel School of Marine and Atmospheric Science (RSMAS) during May-June 2001. The participants were from several groups involved with the validation of skin sea-surface temperatures and land surface temperatures derived from the measurements of imaging radiometers on earth observation satellites. These satellite instruments include those on currently operational satellites and others that will be launched within two years following the workshop. There were two experimental campaigns carried out during the one week workshop: a set of measurements made by a variety of ship-based radiometers on board the research vessel F.G. Walton-Smith in Gulf Stream waters off the eastern coast of Florida, and a set of laboratory measurements of typical external blackbodies used to calibrate these ship-based radiometers. This paper reports on the results obtained from the laboratory characterization of blackbody sources. A companion paper reports on the at-sea measurements.
Five blackbody sources were intercompared by measurements of their brightness temperature using the National Institute of Standards and Technology (NIST) Thermal-infrared Transfer Radiometer (TXR). Four of these sources are used for calibration of sea-surface temperature radiometers. The fifth was a NIST water bath blackbody used for calibration of the TXR. All blackbodies agreed to better than ±0.1 °C at blackbody temperatures near the ambient room temperature. Some of the blackbodies had reduced effective emissivity relative to the NIST water bath blackbody, and hence they began to disagree at blackbody temperatures far enough away from the ambient room temperature. For these, relative effective emissivity values were determined so that corrections can be applied if they are used in conditions of non-laboratory ambient temperatures.

Vogelmann, A.M., P. J. Flatau, M. Szczodrak, K. M. Markowicz, and P. J. Minnett. Observations of large aerosol greenhouse effects at the surface. Geophys. Res. Let. 30(12) 10.1029/2002GL016829. 1655. (Selected by the Editors of Science as Editors' Choice: Highlights of the recent literature - see http://www.sciencemag.org/content/vol301/issue5632/twil.shtml#301/5632/438d)

Studies of aerosol effects on the Earth's energy budget usually consider only the cooling effects at short (solar) wavelengths, but we demonstrate that they also have important warming effects at thermal infrared (IR) wavelengths that have rarely been observed and are commonly ignored in climate models. We use high-resolution spectra to obtain the greenhouse effect (IR radiative forcing) at the surface for aerosols encountered in the outflow from northeastern Asia. The spectra were measured by the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) from the NOAA Ship Ronald H. Brown during the Aerosol Characterization Experiment-Asia (ACE-Asia). We show that the surface greenhouse effects are often a few Wm^{-2} and can reach almost 10 Wm^{-2} for large aerosol loadings. Thus, even the smaller aerosol IR forcings observed here are comparable to or greater than the 1 to 2 Wm^{-2} IR surface enhancement from increases in greenhouse gases. These results highlight the importance of aerosol IR forcings which should be included in climate model simulations.

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

The Skin Depth Experimental Profiler (SkinDeEP) is an autonomous, self–contained, hydrodynamic instrument capable of making repeated, high–resolution profiles of temperature and conductivity within the ocean's upper decameter. Autonomous profiling operation is accomplished through SkinDeEP's ability to change its density: positive buoyancy is achieved by pumping air from inside the body of the profiler into an external, neoprene, inflatable sleeve; the instrument sinks when the sleeve is deflated by returning the air to the interior. The sensors are mounted some distance from the top endcap and data are recorded only during the ascending phase of the profile so as to minimize disruption of a naturally occurring scalar structure within the instrument's footprint. Both temperature and conductivity are measured with resolutions in the submillimeter and millimeter range, respectively. Accurate slower sensors are installed for calibration purposes. These data are used to study exchange processes at the air–sea interface, and the structure of the ocean just below.

F.2 Conference Proceedings and Data Reports:

F.3 Presentations:

Minnett, P.J., Shipboard radiometric measurements of some surface meteorological parameters. Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL, 3-5 March, 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.