TECHNICAL REPORT

Contract Title: Infrared Algorithm Development for Ocean Observations with EOS/MODIS
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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, 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.

MODIS SST – Scientific Research

A.6 Study thermal structure of ocean-atmosphere interface.

A.7 Development of optimal skin-SST validation strategy.

Overarching Contract Activities

A.8 Provide investigator and staff support for the preceding items.

B. OVERVIEW OF CURRENT PROGRESS

July – December 2001

Activities during the past six months have continued on the previously initiated tasks. There have been specific efforts in the areas of: (a) cruises to acquire MODIS infrared validation data and (b) development of an interim SST retrieval algorithm based on match-up with AVHRR Pathfinder data (Evans). In addition, 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 the SST retrieval algorithms.
2) Continuation of the analysis of measurements from M-AERI research cruises (Table 1).
3) Continuation of routine data collection on the *Explorer of the Seas.*
4) Preparation and participation in the cruise of the *R/V Ewing* from Greece to Australia (August – December 2001).
5) Maintenance of the at-sea hardware.
6) Continue development of a purpose-built computer database for validation cruise data and associated satellite measurements.
7) Implementation of various SST data assimilation approaches.
8) In collaboration with Dr. B. Ward of the CIMAS, and Dr. M. Donelan of the University of Miami, a study of the thermal skin layer with his micro-profiler and the M-AERI, in the University of Miami – Rosenstiel School ASIST facility, has begun (with ONR funding).
9) Analyze data from the *2nd International Infrared Intercomparison* at the University of Miami – Rosenstiel School (with funding from NOAA, ESA and EUMETSAT).

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

This reporting period has seen the significant development of validating the MODIS SSTs using both skin temperature measurements from the M-AERI and the potentially much larger data base of measurements from drifting and moored buoys. The provisional atmospheric correction algorithm, based on coefficients derived from near-coincident (collocated but separated by a few hours in time; limited to night-time data where the rapid temperature changes caused by the effects of the diurnal thermocline are much reduced) SST measurements derived from the AVHRR using the Miami Pathfinder algorithm, has produced smaller uncertainties than those associated with the coefficients derived from radiative transfer simulations. The statistics and figures shown here are for the MODIS SSTs derived using the AVHRR-based coefficients. The matchups with M-AERI measurements have a mean discrepancy of 0.20K, with a standard deviation of 0.26K (n = 246). The distributions of the residual errors as functions of surface temperature and time are shown in Figure 1.

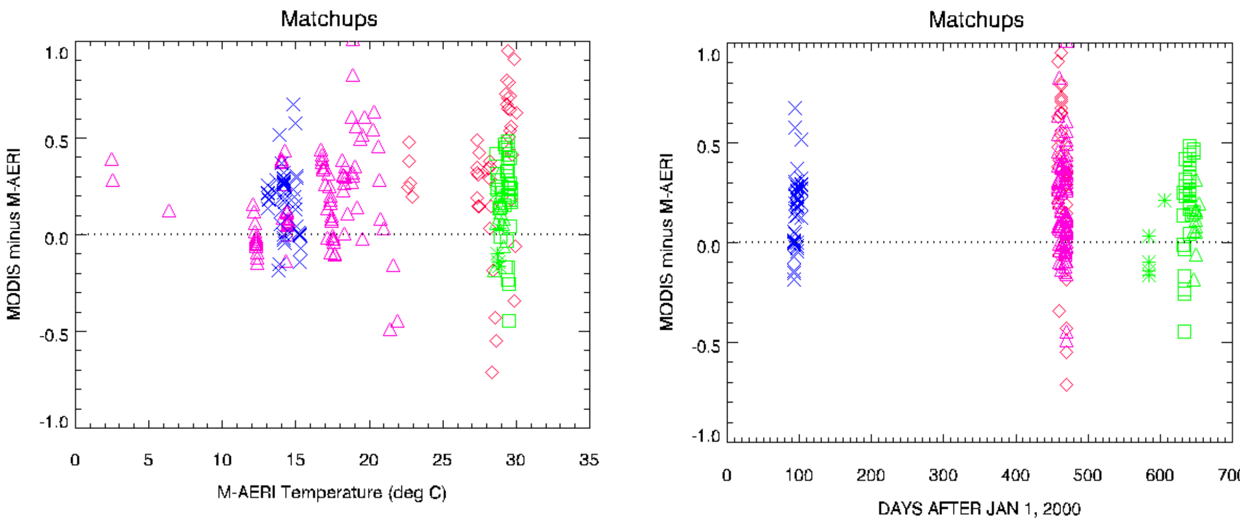

Figure 1. The distributions of the uncertainties in the MODIS SSTs when compared to M-AERI measurements, as functions of surface temperature (left) and time (right). Blue points represent measurements taken in the Mediterranean Sea in April 2000 from the *R/V Urania*; red in the Pacific Ocean between Australia and Seattle in March and April 2001 from the *USCGC Polar Sea*; pink in the northern Pacific Ocean between Hawaii, Japan and Alaska in March and April 2001 from the *NOAA S Ronald H. Brown*; green from the *Explorer of the Seas* in the Caribbean area (see B.4) in August to October, 2001.

The matchups with buoys have the potential to span wider ranges of environmental variability and a more-or-less constant rate of sampling in time. However, the quality of the measurements is poorer than those of the M-AERI and this is reflected in the scatter of the MODIS-buoy comparison: mean -0.04K, standard deviation 0.552K (n=177). These are derived from nine days between November 2000 and June 2001 (November 1 and 2, December 4, January 2, February 2 and 3, March 6, April 8 and June 10) and are illustrated in Figure 2.

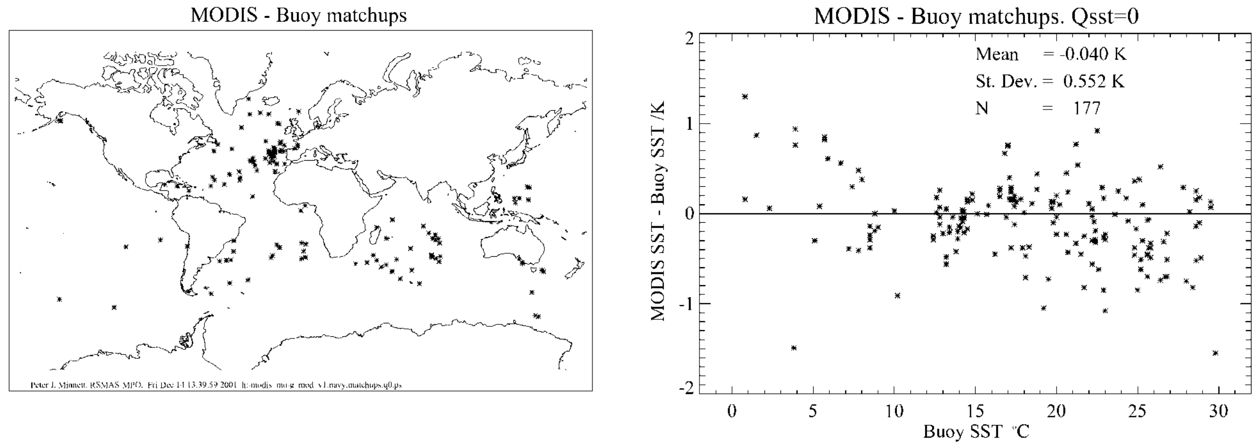

Figure 2. Geographical distribution of buoys for cloud-free coincident measurements of the *Terra* MODIS for nine days between November 2000 and June 2001 (left). The distribution of MODIS SST errors as function of buoy-measured SST (right).

These results indicate that MODIS is working well in producing good SST values. Although these statistics may degrade as more matchups are processed and more of the environmental parameter space is sampled. It is anticipated that improvements in our understanding of the behavior of the sensors will improve, and with time our estimates of the residual SST uncertainties will improve.

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

Throughout this reporting period there has been continuing interaction with Dr R. Evans (Contract NAS5-31362) and others at RSMAS on a daily basis to discuss the remediation of MODIS instrumental issues; improvements to atmospheric correction algorithms, and numerous telephone discussions with Wayne Esaias, MODIS Oceans Team Leader, on MODIS SST retrievals.

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

The MAERI-1, now installed on the *Explorer of the Seas*, has worked without problem during the reporting period. There have been no further problems with the cables. The stainless-steel weather-proof enclosure has worked well on the *Explorer of the Seas*, and additional units have been ordered for M-AERI 2 and M-AERI 3.

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

MAERI-1 is permanently installed on the *Explorer of the Seas*, which undertakes weekly cruises in the eastern Caribbean Sea and Bahaman Islands (Figure 3). The ship returns to Miami each Saturday when the data are retrieved and taken to RSMAS. The data return has been very good (Figure 4).

MAERI-3 was installed on the *R/V Maurice Ewing* at the beginning of August, 2001, in Pireus, Greece, at the start of a multi-part cruise scheduled to finish in Freemantle, Australia in early December. The cruise track is shown in Figure 5. The ship's schedule was disrupted by the events of September 11, and the ship abandoned work in the Gulf of Aden and headed south to the Seychelles, where she remained for about two weeks while scientists, crew and supplies, caught up in the disruption of commercial air traffic, were re-grouped. The M-AERI and ancillary instruments worked very well throughout the cruises, which encompassed a wide range of environmental conditions for MODIS validation.

Figure 3. Weekly track of the *Explorer of the Seas*

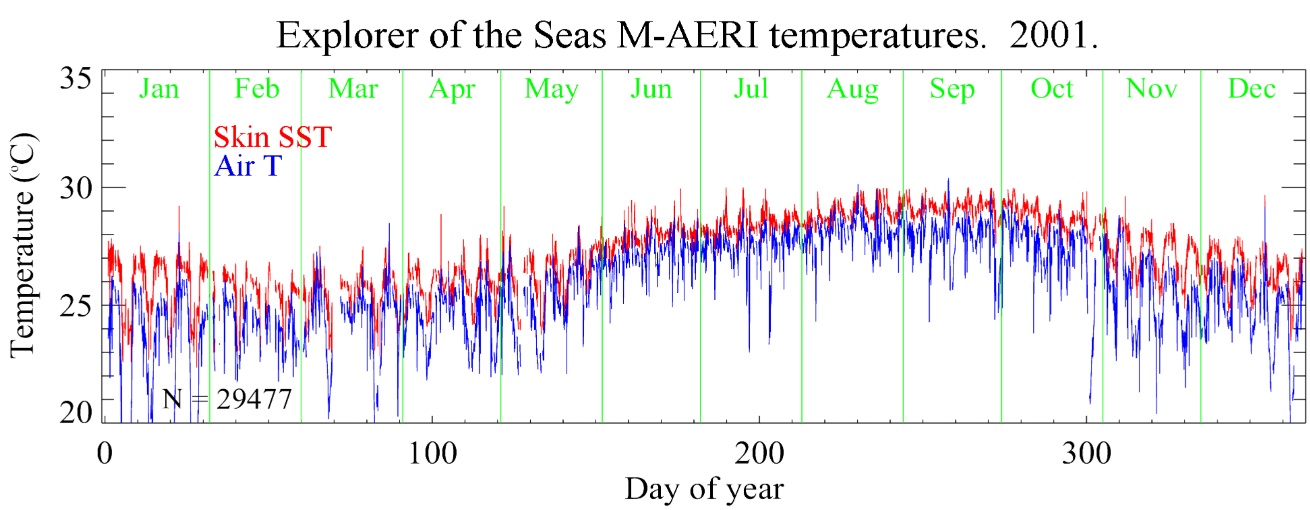

Figure 4. Skin SST and near-surface air temperatures measured by MAERI-1 on the *Explorer of the Seas*, during 2001.

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

The development of a data base of matchups between MODIS brightness temperatures, and derived SSTs, and in situ validation measurements from buoys and M-AERIs continues. This has already been used to determine the errors in the MODIS SST retrievals in the 11µm atmospheric window (see B.1 above) although the samples do not yet sample adequately the full range of atmospheric variability. The data base is modeled on the successful Miami Pathfinder AVHRR Matchup Database that has been widely used in the community.

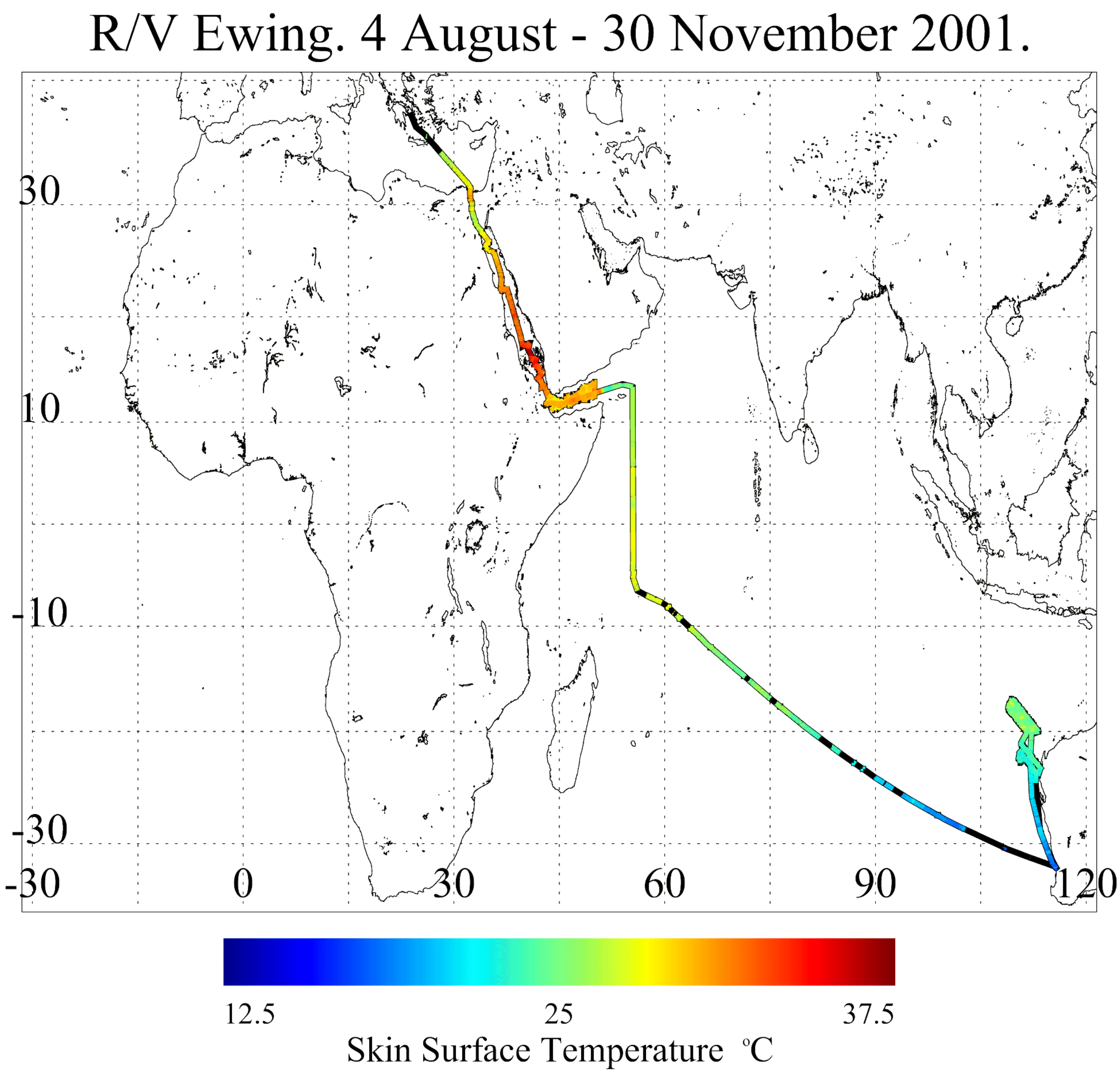

Figure 5. Track of the *Ewing* from Pireus, Greece, to Freemantle, Australia. The track is colored by the M-AERI measurements of skin SST; black indicates missing data, resulting from the instrument being covered during periods of heavy rain.

MODIS SST – Scientific Research

B.6 Study thermal structure of ocean-atmosphere interface.

With funding from ONR a study has begun 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 wavemaker, water temperature control, water current control, turbulence and wave instrumentation. This is in collaboration with Dr. B. Ward of the CIMAS, and Dr. M. Donelan of RSMAS.

A set of ASIST experiments were done over a two week period in December 2001 in which fresh water was used and the wind tunnel was in the open mode to allow steady state fluxes to be established. The experiment covered air-sea temperature differences from -15K to +15K, and wind speeds from 0 to 10ms^{-1} (Table 1). All of the parameters that influence the thermal skin layer were measured directly in the ASIST with uncertainties <5%.

The skin temperature was measured using the M-AERI looking down into flume, and two infrared imagers were mounted above the flume; one was operated by Dr. G. Smith of NRL, as part of collaborative research, and the other was a new sensor at RSMAS funded through this contract.

The *in situ* gradients were measured by a new microthermometer (µT), an accurate thermistor (FP07) and a microconductivity (µC) sensor (to determine the surface). These were mounted on a vertical mast which was attached to a linear servo motor. Measurements were made from a depth of 13 cm to the surface at an ascent velocity of precisely 0.5 ms^{-1}, and at a repetition period of about 5 seconds. The sensors were mounted into J-shaped supports, shown in Figure 6. Profiling action was accomplished by mounting the sensors on the linear motor. Synchronization with other measurements was accomplished with a slow saw-tooth voltage, which was acquired on one of the A/D channels.

Table 1. A matrix of the experimental runs with wind speeds in the range of 0 to 10 ms^{-1} and air-water temperature differences of ±15K.

Wind	T_{air} - T_{water} (K)						
V (ms^{-1})	-15	-10	-5	0	5	10	15
0	x	x	x	x	x	x	x
1		x				x	
2	x	x	x	x	x	x	x
3	x	x	x		x	x	x
4	x	x	x	x	x	x	x
5	x		x		x	x	x
7	x	x	x	x	x	x	x
9	x					x	x
10	x	x	x	x	x	x	x

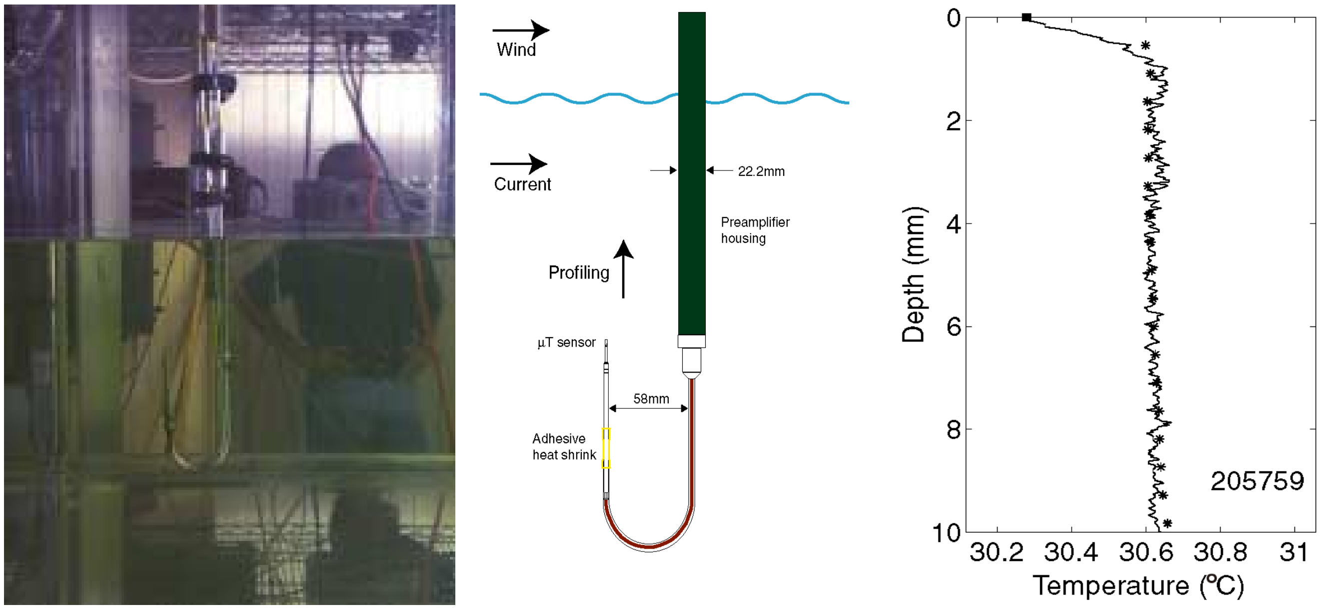

Figure 6. The thermometers used to profile the temperature in the ASIST. Left a photograph with the sensors at the deepest excursions; center is a schematic of the profiling rig; right is an example of the temperature profile measured by the microthemometer (solid), and a high-accuracy thermometer, at a lower vertical resolution (stars). The square symbol at zero depth represents the radiometric skin temperature measured by the M-AERI.

Infrared and visible video, laser systems and hot-film velocimetry were used to determine the flow fields below the interface.

Turbulent velocity fluctuations in the air were made with hot x-film anemometry and these were calibrated against pitot tubes over the full range of wind speeds used. Calibrations were done with the instruments *in situ* by ramping the fan speed up and down over 30 minutes. The momentum flux across the surface was estimated from direct eddy correlation measurements of these velocities recorded at 200 Hz. The hot films were kept in the turbulent boundary layer close to the surface and corrections for the stress gradient in the tank were made.

Temperature fluctuations were made with a fine ('cold') wire TSI constant current anemometer and these enabled direct eddy correlation measurements of the sensible heat flux. The humidity fluctuations were measured with a Li-Cor closed path non-dispersive infra-red analyzer into which air was drawn at 12 litres/min through a 6mm diameter tube that sampled the air 5.3cm behind the x-films. The Li-Cor samples at 10Hz (5Hz Nyquist). The eddy correlation analysis of these data accounts for the time delay and dispersion in the sampling tube leading to the analyzer and also for the loss of flux carrying fluctuations between 5Hz and 100Hz. The latter is done by matching the measured latent heat fluxes in the measured range of 0-5Hz with universal curves (checked with the sensible heat flux measurements) and adjusting the measured flux to account for the missing self-similar high frequency part. In this carefully controlled laboratory environment the fluxes of momentum, heat and moisture are expected to be accurate within 5%.

Wave heights, slopes and wavenumber (directional) spectra were determined using Laser Elevation Gauges (LEGs) and a 2-D Imaging Slope Gauge (ISG) so that wave propagation was not disturbed by intrusive measurement techniques. In the LEG system a line-scan CCD camera observes the vertical displacement of a laser generated bright spot on the water surface. This technique can resolve vertical displacements as small as 0.02 cm at up to a rate of 250 Hz. Three LEGs arranged in an equilateral triangle of side 1 cm will be used to determine elevations, slopes and wavenumber spectra. Spectra having wavelengths as small as 2 cm are resolved.

The principal tool for observing the turbulence structure was Digital Particle Image Velocimetry (DPIV). The measurements were made with a DPIV system manufactured by Dantec. In this Lagrangian flow measurement technique the flow is "seeded" with 10 micron neutrally buoyant spheres and a double flash laser system illuminates the flow at 15 Hz with about 1 ms between the members of the pairs of flashes. These image pairs are captured on a CCD camera and cross-correlated in sub-areas of the 10^6 pixel matrix yielding a "map" of velocity vectors in a 62 x 62 matrix at 15 Hz. In this 2-D system only the projections of the vectors in a vertical plane parallel to the tank's long axis are obtained, although other choices are possible. The area selected was 75.5 mm x 75.5 mm and so the vectors were obtained at a spacing of 1.22 mm. This is an order of magnitude larger than the expected Kolmogorov microscale, but two orders of magnitude smaller than the breaking waves, which are believed to be the principal source of turbulent energy in the "wave zone". This wide range between assumed input scales and those responsible for dissipation to heat augurs well for a defined inertial sub range (ISR), in which the structure function increases as the 2/3 power of the separation distance between velocity pairs according to the Kolmogorov similarity law.

Preliminary analysis of the radiometric measurements has focused on the radiometric and thermometric calibration of the M-AERI and the derivation of the distribution of skin temperature within the field of view of the infrared imager. The M-AERI data have been processed to the production of average skin temperature during selected periods of each run. The analysis of the imager data has revealed a wind speed dependence on the skewness of the skin temperature which increases from a zero value at low winds to a value that appears to saturate at moderate winds. The sign of the skewness is determined by the air-sea temperature difference. The skewness of the distribution is related to the surface renewal time scales, and these data indicate a possibility of experimental testing of models of the thermal skin-layer.

An example of data acquired by the µT is shown in Figure 6 (right), demonstrating that the µT does indeed resolve the temperature structure within the surface viscous boundary layer.

B.7 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) (Figure 7), 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 (Figure 8) . This was funded by NOAA, ESA and EUMETSAT.

Figure 7. The EOS-TXR characterizing the RSMAS Water-Bath Black-Body Calibrator (left), and the DAR-011 radiometer being calibrated by the RSMAS Water-Bath Black-Body Calibrator (right).

Figure 8. The infrared radiometers mounted on the upper deck of the *R/V F.G. Walton Smith* (top left and right). From the left these are SISTeR, ISAR, CIRIMS, M-AERI, DAR011, and the hand-held TASCO. The line-up of radiometers viewed from above (left). An additional radiometer, the JPL Near-Nulling radiometer, was mounted on the fore-deck and viewed the sea between the two hulls of the *Walton Smith* and so is not visible in these photographs. A surface float, measuring the sub-surface SST at a depth of about 5cm is visible ahead of the bow (top left).

C. INVESTIGATOR SUPPORT

July	W. Baringer O. Brown M. Framinan K. Kilpatrick	R. Kolaczynski R. Kovach A. Li	K. Maillet J. Splain M. Szczodrak
August	W. Baringer O. Brown M. Framinan	R. Kolaczynski R. Kovach A. Li	K. Maillet J. Splain M. Szczodrak
September	W. Baringer O. Brown M. Framinan	R. Kolaczynski A. Li K. Maillet	J. Splain M. Szczodrak
October	O. Brown M. Framinan	R. Kolaczynski K. Maillet	M. Szczodrak
November	W. Baringer O. Brown M. Framinan K. Kilpatrick	R. Kolaczynski A. Kumar	K. Maillet M. Szczodrak
December	W. Baringer O. Brown M. Framinan	R. Kolaczynski	

D. FUTURE ACTIVITIES

D.1 Algorithms

- a. Continue to develop and test algorithms on global retrievals
- b. Evaluation of global data assimilation statistics for SST fields
- c. Participate in research cruises
- d. Continue radiative transfer modeling
- e. Continue analysis of research cruise data
- f. Continue to study near-surface temperature gradients
- g. Continue planning of post-launch validation campaigns
- h. Validation Plan updates (as needed)
- i. EOS Science Plan updates (as needed)
- j. 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 Toronto in June, 2002.
- b. Prepare scientific results for publication in the refereed literature.

E. PROBLEMS

None of note.

F. PUBLICATIONS AND PRESENTATIONS

F.1 Refereed publications:

Donlon, C. J., P. J. Minnett, C. Gentemann, T. J Nightingale, I. J. Barton, B. Ward and J. Murray. Towards improved validation of satellite sea surface skin temperature measurements for climate research. *J. Climate*. Accepted.

A poor validation strategy will compromise the quality of satellite-derived sea-surface temperature (SST) products because confidence limits cannot be quantified. This paper addresses the question of how to provide the best operational strategy to validate satellite-derived skin sea-surface temperature (SST_{skin}) measurements. High quality in situ observations obtained using different state-of-the-art infrared radiometer systems are used to characterize the relationship between the SST_{skin}, the subsurface SST at depth (SST_{depth}) and the surface wind speed. Data are presented for different oceans and seasons. These data indicate that above a wind speed of approximately 6 ms^{-1} the relationship between the SST_{skin} and SST_{depth}, is well characterized for both day and night time conditions by a cool bias of 0.17 ±0.07 rms. K. At lower wind speeds, stratification of the upper *ocean layers during the day may complicate the relationship while at night a cooler skin is normally observed. Based on these observations, a long-term global satellite SST_{skin} validation strategy is proposed. Emphasis is placed on the use of autonomous, ship of opportunity radiometer systems for areas in areas characterized by prevailing low wind speed conditions. For areas characterized by higher wind speed regimes, well calibrated, quality controlled, ship and buoy SST_{depth} observations, corrected for a cool skin bias should also be used. It is foreseen that SST_{depth} data will provide the majority of in situ validation data required for operational satellite SST validation. We test the strategy using SST_{skin} observations from the Along Track Scanning Radiometer, that are shown to be accurate to ~0.2 K in the tropical Pacific Ocean, and using measurements from the Advanced Very High Resolution Radiometer. We note that this strategy provides for robust retrospective calibration and validation of satellite SST data and a means to compare and compile in a meaningful and consistent fashion similar data sets. A better understanding of the spatial and temporal variability of thermal stratification of the upper ocean layers during low wind speed conditions is fundamental to improvements in SST validation and development of multi-sensor satellite SST products.*

Hanafin, J. A. and P. J. Minnett, 2001. Profiling temperature in the sea surface skin layer using FTIR measurements. *Gas Transfer at Water Surfaces,* edited by M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof. *American Geophysical Union Monograph 127.* 161-166.

Sea surface spectral emissivity and the depth of the thermal skin boundary layer were determined using high spectral resolution measurements of the sea surface and the atmosphere taken in the field measurements by the Marine-Atmosphere Emitted Radiance Interferometer. In order to determine the sea surface emissivity, the effective incidence angle was found by minimizing the variance in the brightness temperature spectrum retrieved from the corrected upwelling radiance spectrum. Certain wavelength regions have different absorption characteristics, allowing the temperature at different levels to be retrieved from different spectral regions. In this way, the temperature gradient of the thermal boundary layer was determined. The depth of the skin layer was then calculated by determining the depth at which the thermometrically measured bulk temperature intersects this gradient. At low wind speeds, the skin layer can be up to 0.2mm deep, getting shallower with increased wind speed and becoming very shallow (0.01-0.07mm) above wind speeds of $8ms^{-1}$. These results are encouraging for application of this method to determine air-sea heat and gas fluxes in the field.

Minnett, P.J., 2001, Satellite Remote Sensing: Sea Surface Temperatures. *Encyclopedia of Ocean Sciences*, J. Steele, S. Thorpe, K. Turekian (eds). Academic Press, London, UK. 2552-2563.

The ocean surface is the interface between the two dominant, fluid components of the earth's climate system: the oceans and atmosphere. The heat moved around the planet by the oceans and atmosphere helps make much of the earth's surface habitable, and the interactions between the two, that take place through the interface, are important in shaping the climate system. The exchange between the ocean and atmosphere of heat, moisture and gases (such as CO_2) are determined, at least in part, by the sea surface temperature (SST). Unlike many other critical variables of the climate system, such as cloud cover, temperature is a well-defined physical variable that can be measured with relative ease. It can also be measured to useful accuracy by instruments on earth-observation satellites.

The major advantage of satellite remote sensing of SST is the high-resolution global coverage provided by a single sensor, or suite of sensors on similar satellites, that produces a consistent data set. By the use of on board calibration, the accuracy of the time series of measurements can be maintained over years, even decades, to provide data sets of relevance to research into the global climate system. The rapid processing of satellite data permits the use of the global-scale SST fields in applications where the immediacy of the data is of prime importance, such as weather forecasting, with the prediction of the intensification of tropical storms and hurricanes a particular example.

Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces*, edited by M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof. *American Geophysical Union Monograph 127.* 167 - 172.

This paper describes the profiling instrument SkinDeEP (*Skin Depth Experimental Profiler), which measures the temperature of the water column from a depth of about 6 meters to the surface with high resolution thermometers. The instrument operates in an autonomous mode as it has the capability to change buoyancy by inflating a neoprene bladder attached to the body of the profiler. Measurements are recorded only during the ascending phase of the profile so as to minimize disturbances at the surface. Results from deployment of the profiler show strong temperature gradients within the bulk waters under conditions of high insolation. These data were compared to the skin temperatures as measured by the M-AERI, a high accuracy interferometric infrared spectroradiometer. The corresponding bulk-skin temperature differences (ΔT) were shown to have strong dependence on the depth of the bulk measurement during the daytime with low wind speeds, but at higher wind speeds, the depth dependence vanishes. One set of profiles under nighttime conditions is also presented, showing the presence of overturning and thus a heterogeneous temperature structure within the bulk.*

F.2 Conference Proceedings and Data Reports:

Peltola,E., K. Lee, R. Wanninkhof, R. Feely, M. Roberts, D. Greely, M. Baringer, G. Johnson, J. Bullister, C. Mordy, J-Z. Zhang, P. Quay, F. Millero, D. Hansell and P. Minnett. Chemical and Hydrographic Measurements on a Climate and Global Change Cruise along 24^{o}N in the Atlantic Ocean WOCE Section A5R(epeat) during January-February 1998. NOAA Data Report OAR AOML-41. NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, FL. 200pp.

Barton I.J., and P.J. Minnett, 2001. The Second International Infrared Radiometer Calibration and Intercomparison. Report to the 15th CEOS Plenary Kyoto, Japan, November 6-7, 2001. 16pp.

F.3 Presentations:

Hanafin J.A. and P.J. Minnett. Determination of Sea Surface Emissivity and Thermal Skin Layer Depth using Infrared Interferometry. IEEE International Geosciences and Remote Sensing Symposium. Sydney, Australia. July 9-13, 2001. Selected as First Prize Student's paper.

Minnett, P.J. Measurements of the Ocean Surface Skin Temperature from the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI). *IEEE International Geosciences and Remote Sensing Symposium*. Sydney, Australia. July 9-13, 2001.

Evans R.H., P.J. Minnett, O.B. Brown, I.L. Barton, E.J. Kearns, K. Kilpatrick, R.J. Sikorski, A. Kumar and A.M. Zavody. Measurements of the Ocean Surface Temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS). IEEE International Geosciences and Remote Sensing Symposium. Sydney, Australia. July 9-13, 2001.

Esaias, W., R.H. Evans, H. R. Gordon, P.J. Minnett, M. Abbott, O.B. Brown, K. Carder, D. Clark, J. Campbell, K. Voss, W. Balch,, K. Kilpatrick, R. Letelier, R. Chen, F. Hoge, E. J. Kearns, R.J. Sikorski, R. Vogel, K. Turpie, K. S. Walsh and J. Brown. MODIS Ocean Product Quality Improvement over the First 16 Months. IEEE International Geosciences and Remote Sensing Symposium. Sydney, Australia. July 9-13, 2001.

Minnett, P.J. Plans for at-sea *Aqua* validation. AMSR Validation Meeting. GSFC, August 3, 2001.

Minnett, P.J. At-sea validation of AIRS radiances. AIRS Science Team Meeting. Pasadena, CA. 6-8 November 2001.

Vogelmann, A.M., P. J. Flatau, P. J. Minnett, M. Szczodrak, K. Markowicz and J. Jafolla. Spectral Radiative Forcing of the ACE-Asia Aerosol Observed During the NOAA Ship R. H. Brown Cruise. Fall Meeting of the AGU, San Francisco, CA, 10-14 December 2001.

Brown O. B., P. J. Minnett, R. H. Evans and E. J. Kearns. Sea Surface Temperature. *MODIS Ocean Team Meeting*. Baltimore, 17 December, 2001.

Brown, O. B., P. J. Minnett, R. H. Evans, E. J. Kearns, V. Banzon, W. Baringer, J. Brown, J. Hanafin, E. Key, K. Kilpatrick, A. Kumar, K. Maillet, M. Szczodrak and S. Walsh. Sea Surface Temperature - MOD 28 Status. *MODIS Science Team Meeting*, Baltimore, 18 December, 2001.