TECHNICAL REPORT

Contract Title:	Infrared Algorithm Development for Ocean Observations with EOS/MODIS
Contract:	NAS5-31361
Type of Report:	Quarterly
Time Period:	July-September 1996
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INFRARED ALGORITHM DEVELOPMENT FOR OCEAN OBSERVATIONS WITH EOS/MODIS

Abstract

Efforts continue under this contract to develop algorithms for the computation of sea surface temperature (SST) from MODIS infrared retrievals. This effort includes radiative transfer modeling, comparison of *in situ* and satellite observations, development and evaluation of processing and networking methodologies for algorithm computation and data accession, evaluation of surface validation approaches for IR radiances, and participation in MODIS (project) related activities. Efforts in this contract period have focused on radiative transfer modeling, evaluation of atmospheric correction methodologies, analysis of field data, production and evaluation of new computer networking strategies, objective analysis approaches, and participation in MODIS meetings.

MODIS INFRARED ALGORITHM DEVELOPMENT

A. Near Term Objectives

A.1. Continue algorithmic development efforts based on experimental match-up databases and radiative transfer models.

A.2. Continue interaction with the MODIS Instrument Team through meetings and electronic communications, and provide support for MCST pre-launch calibration activities.

A.3 Continue evaluation of different approaches for global SST data assimilation and work on statistically based objective analysis approaches.

A.4 Continue evaluation of high-speed network interconnection technologies.

A.5 Continue evaluation of various *in situ* validation approaches for the MODIS IR bands.

A.6 Provide investigator and staff support for the preceding items.

B. Overview of Current Progress

B.1 July-September 1996

Activities during the past three months have continued on the previously initiated tasks. There have been specific continuing efforts in the areas of (a) radiative transfer modeling, (b) generation of model based retrieval algorithms, (c) continued work on IR calibration/validation as part of the MODIS Ocean Science Team cruise effort, d) analysis of consequences of imperfect pre-launch characterization of the MODIS infrared channels, and (e) work on test and evaluation of an experimental wide area network based on ATM technology. Previously initiated activities such as team related activities are ongoing.

Special foci during this three month period have been:

1) continue exploring sources of radiosondes to compile a global marine data set that correctly represents the distributions of conditions in the atmosphere,
2) AVHRR *in situ* comparison data base studies.
3) analysis of measurements from the DOE/NOAA/NASA ARM Combined Sensor Project cruise in the Tropical Western Pacific in the spring of 1996.
4) Construction of a marine FTIR instrument for cal/val applications by UWSSEC via subcontract .

B.1.1 Radiative Transfer Modeling

Dr. Richard Sikorski has been modeling emitted and reflected infrared radiation at the top of the atmosphere, for the simulation of the brightness detected by satellite instruments with various spectral sensitivities.

As the MODIS instrument has been tested and calibrated, several generations of thermal IR band spectral response profiles have become available. Uncertainties in the pre-launch characterization of the spectral sensitivity of these bands will translate into onboard errors that will be difficult and time-consuming to resolve after launch. The RAL radiance model has been used with each generation of spectral responses to determine whether these filter functions allow the achievement of the level one goals of MODIS for SST. The RAL model was modified to allow substitution and comparison of filters. Radiance-to-temperature lookup tables were generated for alternate filter sensitivities. Also a method to simulate on-board blackbody calibration was developed. Five diverse atmospheric profiles were selected to represent a range of conditions: high latitude-low moisture, low latitude-high moisture, and mid-latitude with prominent features in the vapor profile at low, mid-level, or high altitudes. These atmospheres, calibrations, and filters were run for five zenith angles. This approach permitted the magnitude of error between measured and theoretical filter response functions to be studied *versus* atmosphere type, vapor load, and zenith angle. Modeling of the most recent filter response functions (Hughes - Sept 1996) suggest that the entire error budget of the MODIS thermal IR bands is consumed by uncertainties in the filter response functions. The errors are most severe at high moisture loads, at high zenith angles, and in overall Band 31 response.

We have initiated the conversion of radiosonde profiles to full atmospheric datasets in HDF format. This would speed up modeling and allow a broader use of the atmospheric data.

We have obtained additional atmospheric spectra for the RAL model, to allow simulation of additional MODIS bands in addition to the traditional thermal bands. These simulations will include study of spectral sensitivity to cirrus ice.

B.1.2 Algorithm Development Efforts Based on Experimental Match-up Data bases

During this period we have continued the compilation of *in situ* sea surface temperature

(SST) data from moored and drifting buoys in order to build a co-temporal, co-located set of *in situ* and AVHRR data. The "matchups" are being used to estimate SST algorithm coefficients and to characterize algorithm performance.

We have experimented with numerous alternative formulations for an AVHRR SST algorithm. In close collaboration with the SST Science Working Group, we have defined a consensus algorithm. The algorithm is based on the non-linear SST formulation (NLSST) originally proposed by C. Walton (NOAA-NESDIS). In order to minimize temporal trends detected in the residuals (defined as *in situ* minus satellite SST), the algorithm coefficients are estimated on a monthly basis, using matchups for a 5-month window centered on the month for which coefficients are being estimated. The performance of the algorithm is being assessed in relation to reference fields such as the Reynolds Optimally Interpolated (OI) fields. Results suggest that, in some regions, there may be errors in the retrievals associated with atmospheric aerosols. Examples of this are the eastern tropical Atlantic and the northern Indian Ocean.

B.1.3 The Combined Sensor Cruise of the NOAA ship Discoverer

As reported in the last semi-annual report, Dr. Peter Minnett participated in the Combined Sensor Cruise of the NOAA Ship Discoverer in the Tropical Western Pacific from mid-March to mid-April, 1996.

One of the objectives of this cruise was to test the use of the prototype Marine-Atmosphere Emitted Radiance Interferometer (M-AERI), which will be a key instrument in the post-launch validation of the infrared channels of MODIS, and of the derived Sea-Surface temperature (SST) corrected for the effects of the intervening atmosphere. The area of the cruise included the "warm-pool" of the tropical Pacific where both the SST and the atmospheric water-vapor loading exhibit global maxima. Thus the cruise conditions are at a climatological extreme. The high air temperatures and strong insolation also meant that the instruments were being stressed towards their upper operating temperatures.

Analysis of the M-AERI skin temperature measurements has revealed significant, but anticipated, differences with respect to the *in situ* bulk temperatures (see previous report). Examining these as a function of local sun time reveals the skin temperature oscillating about the bulk temperature with a diurnal cycle, being colder at night and warmer during the day. Even though there is considerable variability along the Equatorial Section (Figure 1) from day to day, as meteorological conditions evolve, and within a day, as a result of spatial as well as temporal changes, the mean temperature discrepancies behave in a physically reasonable manner (Figure 2). During the day, when windspeeds are low, the absorption of the sun's energy in the upper several meters of the ocean generates a vertical temperature gradient that causes the bulk temperature just below the ocean surface to be higher than at the 5m depth where the *in situ* measurements in these figures were made. The heat loss from the oceans to the atmosphere, caused primarily by evaporation, results in a temperature difference across the molecular conducting layer with the skin temperature being cooler than the subsurface *in situ* temperature. Nevertheless the skin temperature difference is smaller than the bulk gradients resulting in the skin temperature being warmer than the 5m bulk temperature.

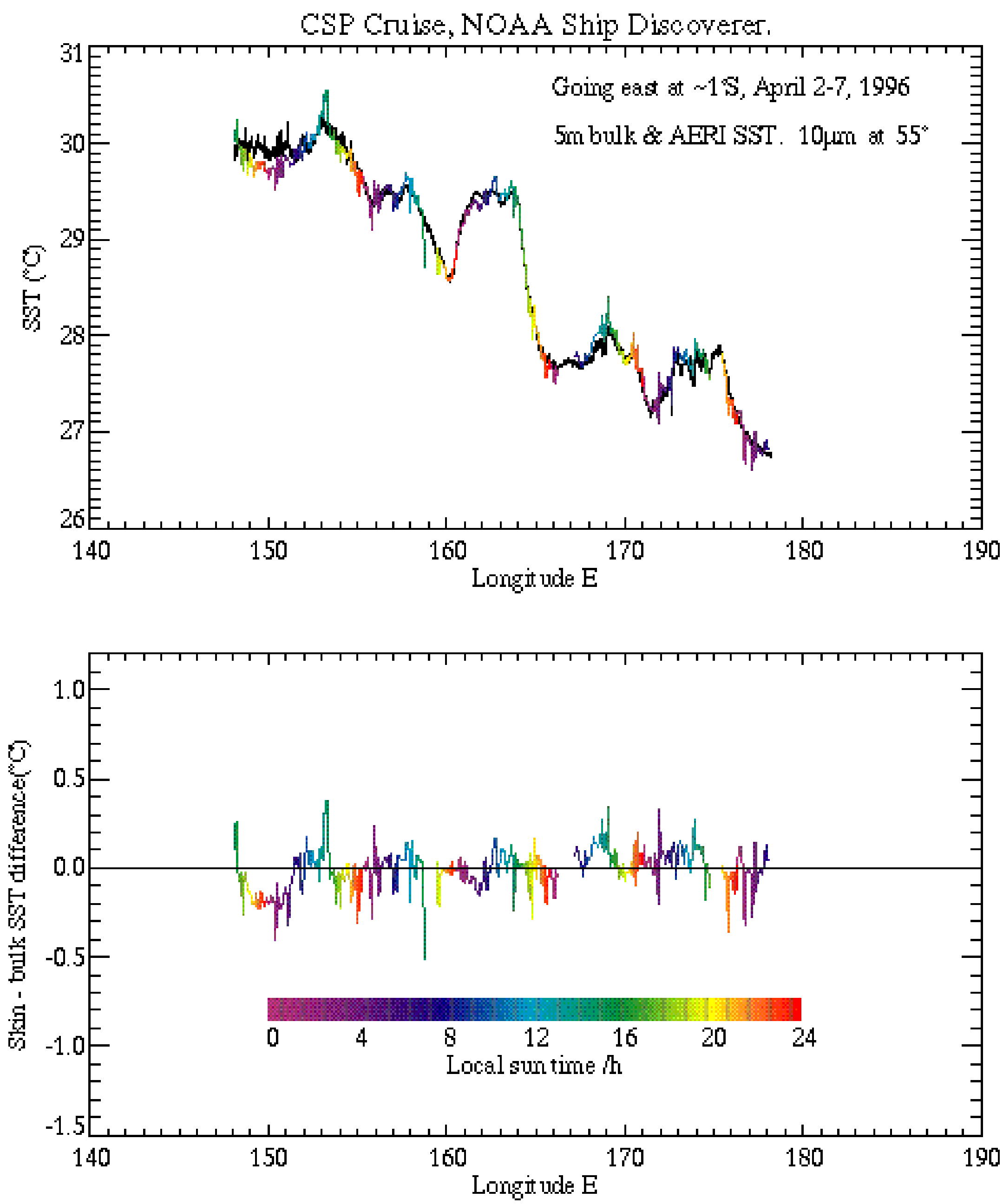

Figure 1. Skin and bulk temperature measurements made along a section at 1°S in the Tropical Western Pacific Ocean. The ship started in the “Warm Pool” off Papua New Guinea and traveled eastward towards the Date Line. The skin temperature measurements, corrected for reflected sky radiation were made at a narrow wavelength interval centered at ~10m, with an emission angle of 55°. In the bottom panel the skin-bulk SST differences are shown. The colors are allocated as the local sun time. In general the largest, positive differences occur during the late afternoon, and the largest negative differences during the night.

During the night, heat loss to the atmosphere causes convective mixing which erodes the thermally induced stratification built up during daylight and results in an isothermal surface mixed layer. The skin temperature difference then causes the skin to be colder than the 5m bulk temperature. The vertical lines in Figure 2 mark the overpass times of the MODIS on the AM-1 platform (10:30 and 22:30) and, for comparison, the AVHRR on the afternoon satellite of the NOAA series. It can be seen from these data that the diurnal and skin temperature effects, in the mean, are not very different between the MODIS and AVHRR overpass times, with typical differences between the skin and bulk temperatures of ~±0.15K. The scatter of the individual measurements is somewhat greater in the afternoon.

The MODIS SST retrievals will be of the skin temperature, since this is what gives rise to the signal detected in space. For users requiring bulk temperature estimates, these discrepancies are a significant component of the bulk temperature retrieval error budget.

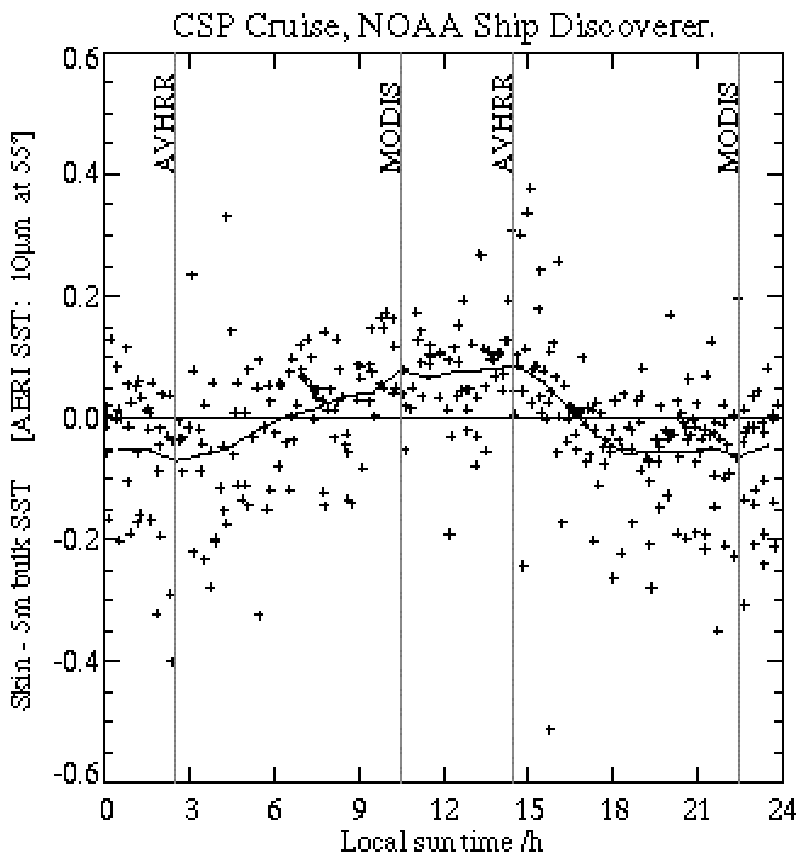

Figure 2. The measurements of Figure 1 are shown as a scatter plot of skin-bulk temperature differences as a function of local sun time. The thick line is the hourly average, smoothed over 3 hours, which reveals clearly the diurnal cycle of the skin-bulk temperature difference. The vertical lines show the overpass times of the MODIS on the EOS AM-1 satellite and of the AVHRR on the afternoon NOAA satellite.

B.1.4 Analyses in support of MODIS infrared channels pre-launch calibration and characterization

In addition to the radiative transfer modeling to simulate the consequences of uncertainties in the spectral characterization of the MODIS infrared channels (see B.1.1), analyses have been conducted to quantify the effects of uncertainties in the instrument properties. Amongst these is the dependence of the scan mirror reflectivity, and infrared emissivity, on angle, wavelength and polarization. An analysis has shown that uncertainties in the scan mirror reflectivity of 0.1% can lead to worst case errors in retrieved SST of 0.6k. This is twice the total target uncertainty in SST. Similarly, uncertainties in the scan mirror temperature of >1K would lead to unacceptable errors in the derived SST.

B.1.5 Wide Area Networking

Two Digital Equipment Corp. 4100s have been added to the ATM networks since the last report. The ATM networks are functioning well.Additional enhancements are in process and should be implemented by the end of the next quarter. The current network includes FORE, Digital and SGI hardware, which is all interoperating.

B.1.6 Documentation

A revised version of the Algorithm Technical Basis Document, ATBD-26, "MODIS Infrared Sea Surface Temperatures" by O.B. Brown and P.J. Minnett has been submitted for review. This document will be presented to the peer review group in mid-November. The revision provides an upgraded algorithm form (NLSST) for the at-launch version of the infrared atmospheric correction algorithm and includes an expanded section on CAL/VAL.

C. Investigator Support

July	W. Baringer O. Brown P. Evans	V. Halliwell P. Minnett
August	W. Baringer O. Brown	V. Halliwell P. Minnett
September	W. Baringer O. Brown P. Evans	V. Halliwell J. Hanafin P. Minnett

D. Future Activities

D.1 Current:

D.1.1 Algorithms

- a. Continue to develop and test algorithms on global retrievals
- b. Evaluation of global data assimilation statistics for SST fields
- c. Continue radiative transfer modeling using RAL code
- d. Continue analysis of Combined Sensor Cruise, data
- e. Continue to study near-surface temperature gradients
- f. Attend ATBD panel review, and revise ATBD-26 as necessary
- g. Validation Plan updates (as needed)
- h. EOS Science Plan updates (as needed)

i. Define and implement an extended ATM based network test bed
j. Evaluate and analyze results of calibration/validation experiment
k. Continued integration of new workstations into algorithm development environment
l. Continued participation in MODIS Team activities and calibration working group.

D.1.2 Investigator support

Continue current efforts

E. Problems

No new problems to report.

F. Publications

Knuteson, R.O., F.A. Best, H.B. Howell, P. Minnett, H.E. Revercomb, and W.L. Smith. High Spectral Resolution Infrared Observations at the Ocean-Atmosphere Interface in the Tropical Western Pacific using a Marine Atmospheric Emitted Radiance Interferometer (MAERI): Applications to SST Validation and Atmospheric Spectroscopy. Accepted for presentation at the Ninth Conference on Atmospheric Radiation, 2-7 February 1997, Long Beach, CA.