TECHNICAL REPORT

Contract Title: Infrared Algorithm Development for Ocean Observations with EOS/MODIS
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MODIS INFRARED ALGORITHM DEVELOPMENT

A. Near Term Objectives

A.1. Continue interaction with the MODIS Instrument Team through meetings and electronic communications.

A.2 Continue algorithmic development efforts based on experimental match-up databases and radiative transfer models.

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 Provide investigator and staff support for the preceding items.

B. Overview of Current Progress

B.1 January-June 1994

Activities during the past six months have continued on the previously initiated tasks. New work is going on in the areas of radiative transfer modeling, studies to understand the impact of temperature inversions on retrieved surface temperatures and generation of model based retrieval algorithms; continuing discussions on IR calibration/validation as part of the MODIS Ocean Science Team cruise effort; and work on implementation of a design and implementation for a wide area network based on ATM technology. Previously initiated activities, such as additional definition of the ATBD data flows and other team related activities, are ongoing.

B.1.1 Radiative Transfer Modeling

Preliminary evaluation of LOWTRAN (Selby *et al*., 1978) and Rutherford Appleton Laboratory (RAL) radiative transfer models was initiated (Llewellyn-Jones *et al*., 1984). A. Zavody (RAC) furnished us with a version of the radiative transfer code which was validated against an atmospheric profile supplied by P. Minnett (Brookhaven National Laboratory). We find that the RAL code is much easier to use and provides more accurate simulations due to the pressure-dependent band absorption models employed. Thus, our MODIS radiative transfer modeling effort will utilize the RAL codes for current and future work. Recent correspondence with A. Zavody has concerned the role of emissivity corrections and skin-bulk temperature differences associated with MODIS's SST retrieval (see below). Fig. 1 schematizes the problem.

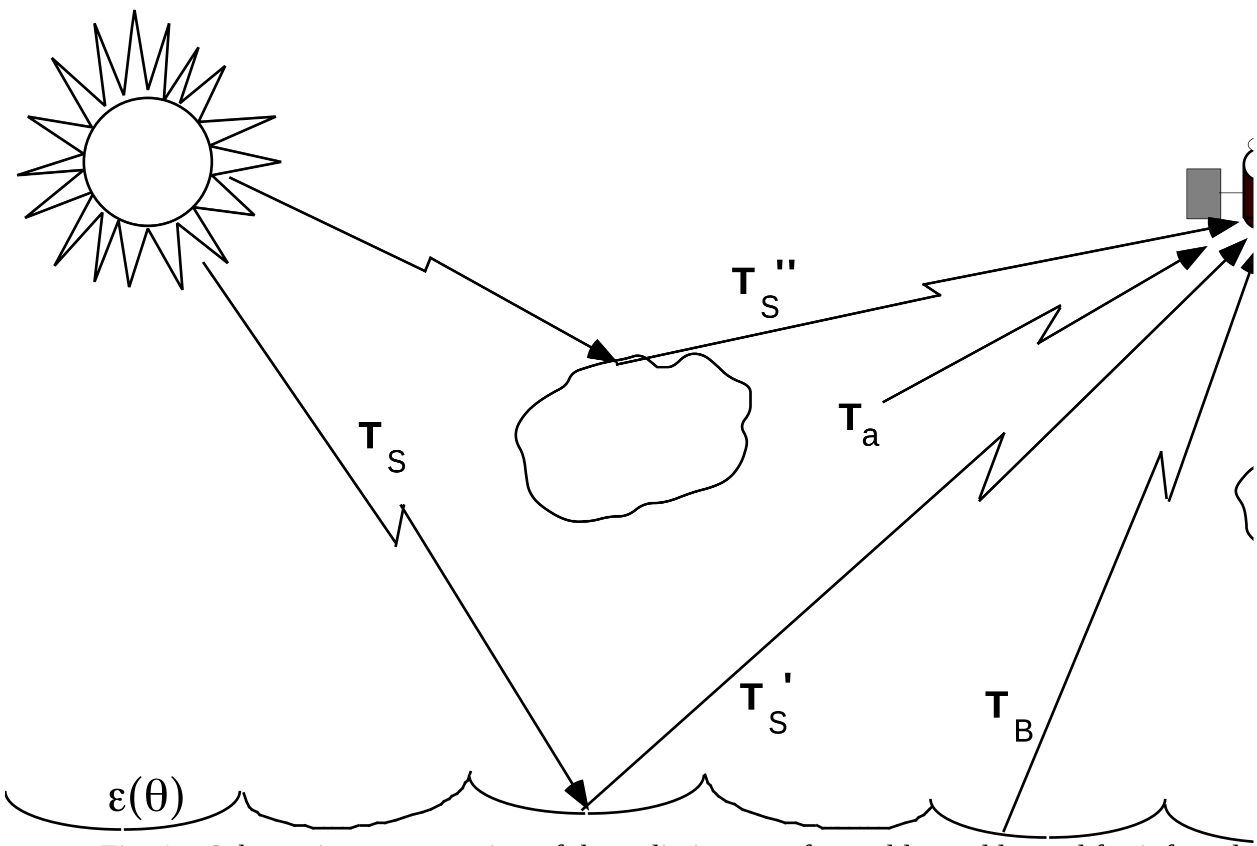

Fig. 1. Schematic representation of the radiative transfer problem addressed for infrared remote sensing.

A necessary prerequisite to developing a representative global ensemble of retrieval cases is to have a quality-controlled set of radiosonde observations with large areal extent and full annual cycle coverage. We have obtained a set of 1200 profiles from RAL, which was originally put together by NOAA/NESDIS, that provides such coverage (Fig. 2). As can be seen, there is reasonable coverage for tropical mid-latitude and polar regions with a reasonable balance between open ocean and coastal regimes.

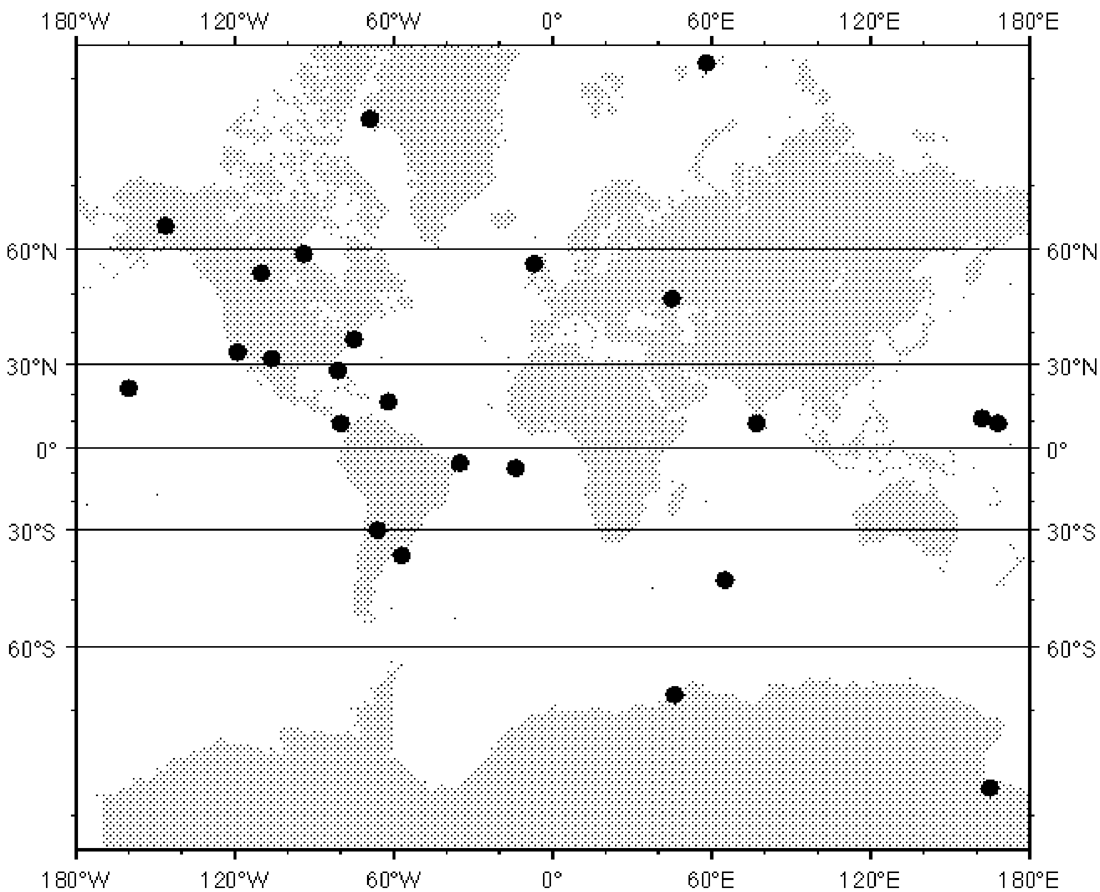

Fig. 2. Radiosonde sites in NOAA/NESDIS profile database. 1200 profiles are available from the 24 sites. The location in the Southern Indian Ocean is only an indicator for a number of ascents taken from an FSU research vessel at various locations in this region.

Examples of profiles at four sites are shown in Fig. 3 (a,b) for January. The profile taken at (77°N, 69°W) on the Greenland coast illustrates a problematic aspect of doing atmospheric corrections in polar latitudes, or more generally with low level inversions. Such low level inversions diminish the brightness temperature difference between the 10µ -11µ and 11µ -12µ bands, and can even cause it to become negative.

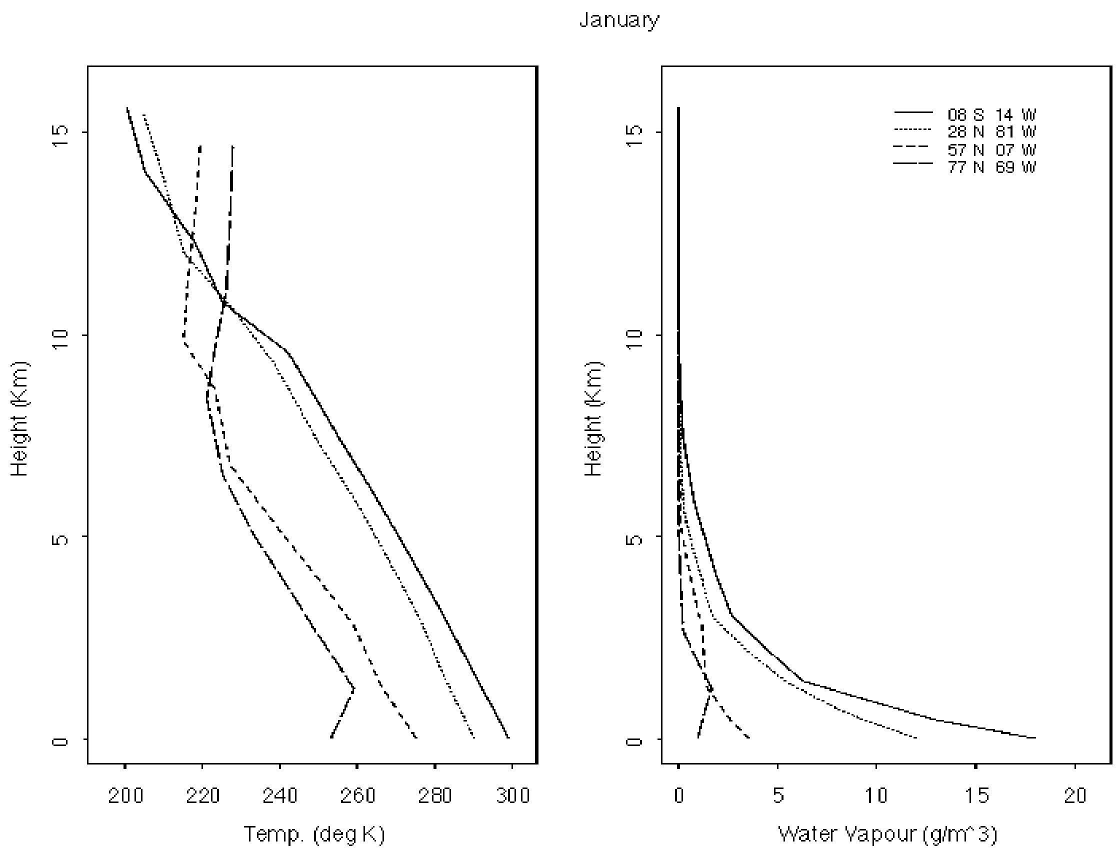

Fig. 3a,b. Temperature and humidity profiles for January at selected sites from the NOAA/NESDIS Radiosonde Profile data set. The four sites are located at: (8°S, 14°W); (28°N, 81°W); (57°N, 7°W); and (77°N, 69°W), respectively.

Retrieval equations using combinations of brightness temperatures have been developed using model (RTE) results based on regressions over the ensemble of radiosonde ascents. Preliminary comparisons of model and retrieved results from the matchup database indicate good agreement with the *in-situ* comparison database for band-temperature differences as a function of surface temperature and water vapor concentration. Fig. 4 illustrates the general trends for band differences as a function of water vapor concentration derived from modeling results.

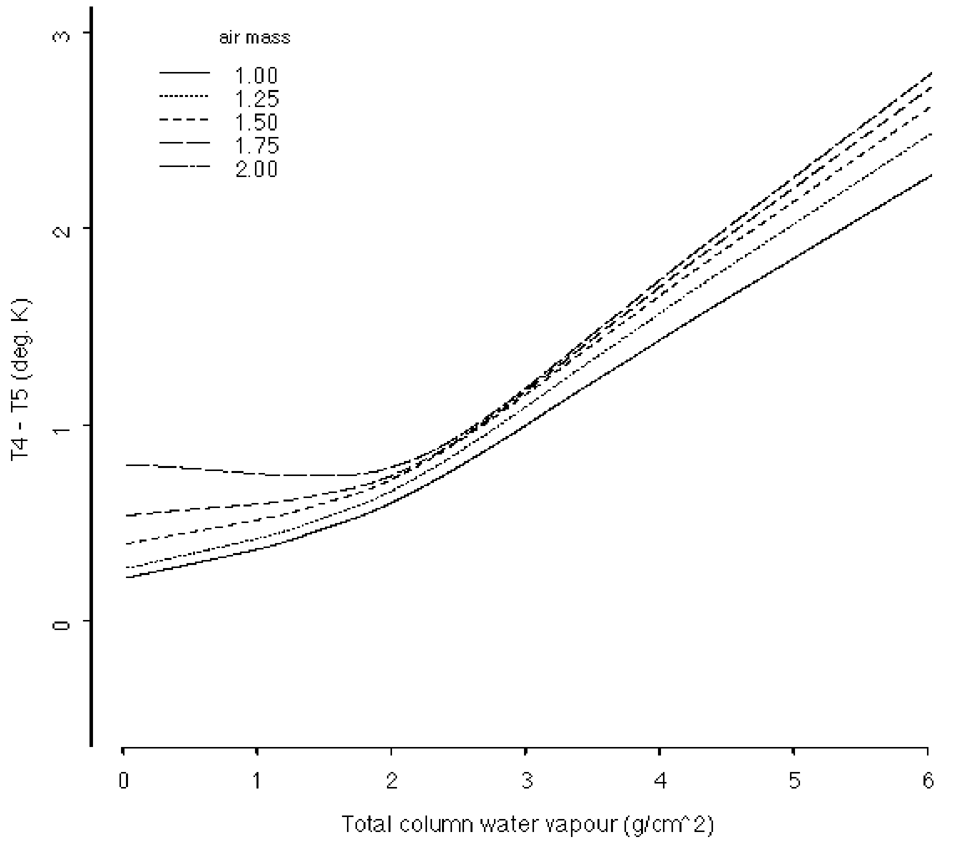

Fig. 4. Radiative transfer modeling results from the RAL model. Differences between AVHRR bands 4 and 5 (10-11 µ, 11-12 µ) were determined for 5 scan angles and the ensemble of near-ocean radiosonde sites (from the NOAA/NESDIS profile set). A robust estimation was used to provide regressions of band temperature differences *vs.* column water vapor concentration.

Notice that there is little correlation between band temperature difference and water vapor at cumulative water vapor concentrations below 2 gm cm^{-2}. Above 2 gm cm^{-2} water vapor concentrations, there exists a strong relationship with band temperature difference. This suggests that atmospheric correction in polar and/or dry mid-latitude regimes is not straightforwardly parameterizable in terms of a simple band difference. It also suggests that simple linear relationships between water vapor and band temperature differences, as used by some workers, are incorrect.

Comparison of *in situ* brightness temperature differences from the NOAA/AVHRR with SSMI based estimates of total column water vapor is illustrated in Fig. 5. While there is a larger scatter than shown in the model calculations (Fig. 4), a similar general trend is found.

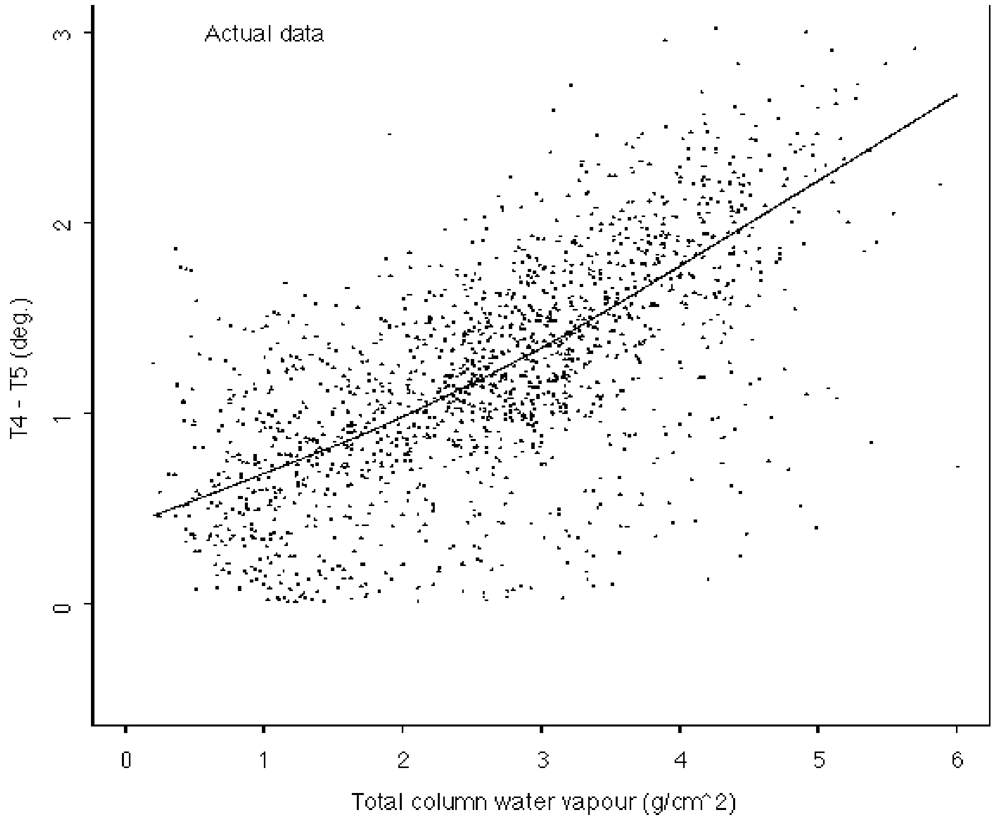

Fig. 5. NOAA AVHRR channel 4,5 brightness temperature differences *vs.* DMSP/SSMI total column water vapor estimates. A *loess* fit is used for the trend line. Data are derived from the Pathfinder *in situ* comparison data set.

Further understanding of the behavior illustrated in Figs. 4 and 5 is provided by utilizing a comparison of SSMI total water column vapor observations coupled with the AVHRR temperature, surface temperature data set as a function of latitude (effectively water vapor regime). An ensemble of RTE model simulations are used to determine the linear transfer function between zonally averaged water vapor (10° bands) and surface temperature. Specifically we determine a regression: ΔT_{45} = slope $\cdot$ *WV* + intercept, where T_{45} is the brightness temperature difference for AVHRR channels 4 and 5, and *WV* is total column with vapor estimated by the SSMI. Fig. 6 presents the results from the combined data set.

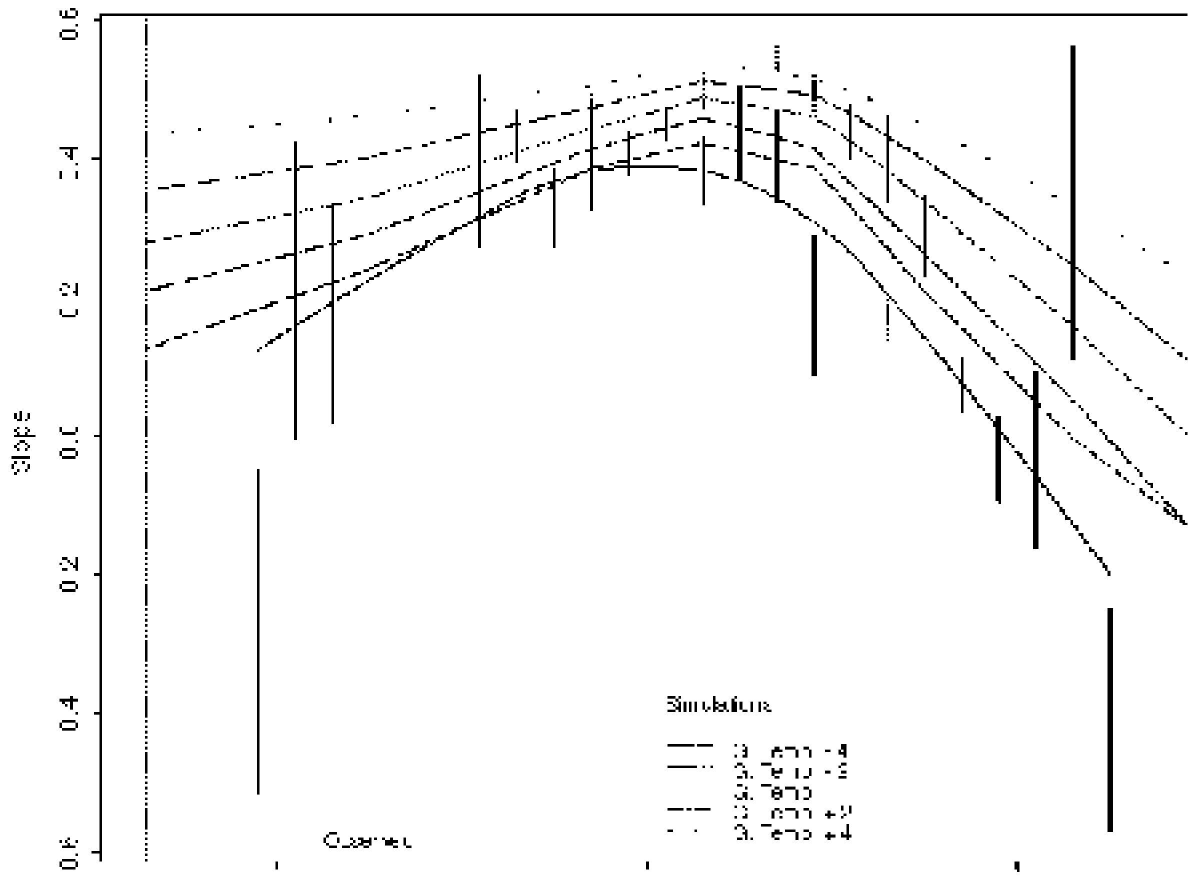

Fig. 6. Radiative transfer modeling results from the RAL model. Differences between AVHRR bands 4 and 5 (10-11 μ, 11-12 μ) were determined for 5 scan angles and the ensemble of near-ocean radiosonde sites (from the NOAA/NESDIS profile set). A robust estimation was used to provide regressions of band temperature differences *vs.* column water vapor concentration. These regressions are compared with regressions based on NOAA/AVHRR brightness temperatures [channel 4 - channel 5 (T_{45})] *vs.* DMSP/SSMI total column water vapor (*WV*) observations. Various surface temperature offsets are explored in the RTE simulations to study the role of differences between skin and bulk temperature on the comparison. Each regression-slope is plotted as a function of latitude (φ).

From Fig. 6 it is apparent that there is minimal dependence on water vapor at high latitudes with a strong dependence at mid- and lower latitudes. There is also a rather striking similarity between the RTE results and the observations. This provides an additional validation of the RTE simulation results, but the spread illustrates two problems: the role of skin/bulk temperature differences and/or the role of surface emissivity.

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

Work has continued and good progress has been made in terms of evaluating a hierarchy of algorithms for atmospheric correction of the infrared retrievals. The lowest order algorithm in the hierarchy is one based on the McClain MCSST formulation. This was taken as a base to test all other implementations. Two implementations have been extensively studied, one based on the work of Walton (NLSST) (1988) and the other a variation on the NLSST approach where a piecewise set was used for correction (Evans/NLSST). A final version of the Evans/NLSST algorithm was selected for processing of the 1988 Pathfinder SST data set. This algorithm gives RMS values of approximately 0.5C based on global monthly composite datasets.

The major limitations in the current AVHRR system involve several issues: (1) instrumental calibration, (2) the NEΔT of the instrument, (3) the impact of water vapor on the opacity of the 10/11 µ windows for tropical atmosphere aerosols, and (4) skin *vs.* bulk temperature differences. MODIS offers significant improvements in the first three of these areas. We still need to evaluate the impact of aerosols and skin *vs.* bulk variances on the overall MODIS retrieval system accuracy.

B.1.3 ATBD

There has been extensive work in the past six months on the ATBD. Efforts have focused on improving the definition of the match-up database characteristics and on defining networking needs for post launch calibration/validation activities. Dr. Robert Evans has integrated our estimates into his ATBD data flow estimates.

A revised ATBD was prepared and submitted. The PI participated in the May ATBD review and presented a summary of the current status on IR/SST retrieval at the meeting. The ATBD presentation focused on the sensitivity of SST to current correction and validation procedures. It was noted that lack of validation opportunities was the major reason for not producing a “skin” temperature product. There is not currently a surface validation product for infrared radiances used for SST retrieval. Reviewers also commented on the need for aerosol corrections: we agree, such work is planned for later in the project.

B.1.4 Wide Area Networking

Efforts continue to establish an experimental wide area high speed network between the University of Miami, Oregon State University and the Naval Research Laboratory. ATM switches have been ordered for each site (through non-EOS funding) and installation was completed in early June. PVCs are currently established through the inter-exchange carrier between Miami, NRL and OSU with SVCs being established over these connections as appropriate. Initial testing indicates ~6 Mbs/socket sustained transports are available at the AAL5 transport layer (IP) with higher rates at AAL0.

Currently the following experiments are planned or are underway:

(1) Engineering demonstration of DS-3 connectivity between the three sites;
(2) Characterization of link performance characteristics over the network;
(3) Engineering demonstration of WAN-ATM connectivity (SVC access) between the three sites;
(4) Provision of near-real time infrared observations derived from AVHRR observations at Miami to Oregon State University for data assimilation using objective analysis codes developed at Miami;

(5) Model visualization and objective analysis at Oregon State University (on the OSU CM-5);
(6) Integration of near-real time buoy and tower data (via NRL) with satellite data (Miami) and model data (OSU); and
(7) Visualization of combined data sets and analysis in near real time of model *vs.* satellite *vs. in situ* observations.

Preliminary results of the early phases of this activity are expected by Fall, 1994.

C. Investigator Support

January	W. Baringer J. Brown O. Brown G. Goni S. Walsh
February	W. Baringer J. Brown G. Goni A. Kroger
March	W. Baringer J. Brown G. Goni G. Halliwell E. Ryan
April	G. Goni G. Halliwell A. Li E. Ryan
May	G. Goni G. Halliwell A. Li E. Ryan
June	W. Barringer J. Brown G. Goni G. Halliwell E. Ryan

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 RT modeling using RAL and AECRL
d. ATBD updates (as needed)
e. Test and utilize ATM based network test bed
f. Continued integration of new 100 Specmark+ workstations into algorithm development environment

D.1.2 Investigator support

Continue current efforts

E. Problems

No new problems to report.

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Llewellyn-Jones, D.T., P.J. Minnett, R. W. Saunders and A.M. Zavody, 1984. Satellite multichannel infrared measurements of sea surface temperature of the N.E. Atlantic Ocean using AVHRR/2. *Quart J.R. Met. Soc*, **110**: 613-631.

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Walton, C. C., 1988. Nonlinear multichannel algorithms for estimating sea surface temperature with AVHRR satellite data. *J. Appl. Meteor*. **27**, 115-124.