IN-48-CR
0 CIT.
42624
P-17

TECHNICAL REPORT

Contract Title:	Infrared Algorithm Development for Ocean Observations with EOS/MODIS
Contract:	NAS5-31361
Type of Report:	Semi-annual
Time Period:	July 1994-December 1994
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 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 and evaluation of atmospheric path radiance efforts on SST estimation, exploration of involvement in ongoing field studies, evaluation of new computer networking strategies, and objective analysis approaches.

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.

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 Initiate planning for evaluation of various *in situ* validation instruments for the MODIS IR bands.

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

(NASA-CR-197851) INFRARED ALGORITHM DEVELOPMENT FOR OCEAN OBSERVATIONS WITH EOS/MODIS Semiannual Report, Jul. - Dec. 1994 (Miami Univ.) 17 p
N95-23212
Unclas
G3/48 0042624

B. Overview of Current Progress

B.1 July-December 1994

Activities during the past six months have continued on the previously initiated tasks. There have been specific continuing efforts in the areas of (a) radiative transfer modeling, (b) studies to understand the impact of atmospheric temperature inversions on retrieved surface temperatures, (c) generation of model based retrieval algorithms, (d) continuing discussions on IR calibration/validation as part of the MODIS Ocean Science Team cruise effort. and (e work on test and evaluation of an experimental wide area network based on ATM technology. Previously initiated activities such as responses to ATBD reviews and additional definition of the ATBD data flows and other team related activities are ongoing.

B.1.1 Radiative Transfer Modeling

Evaluation of LOWTRAN (Kneizys *et al.*, 1980) and Rutherford Appleton Laboratory (RAL) radiative transfer models was completed (Zavody *et al.*, 1994). A. Zavody (RAL) 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 henceforth 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. Figure 1 schematizes the problem. We must resolve the ocean emitted component attenuated by the atmosphere in the presence of atmospheric, cloud and direct effects.

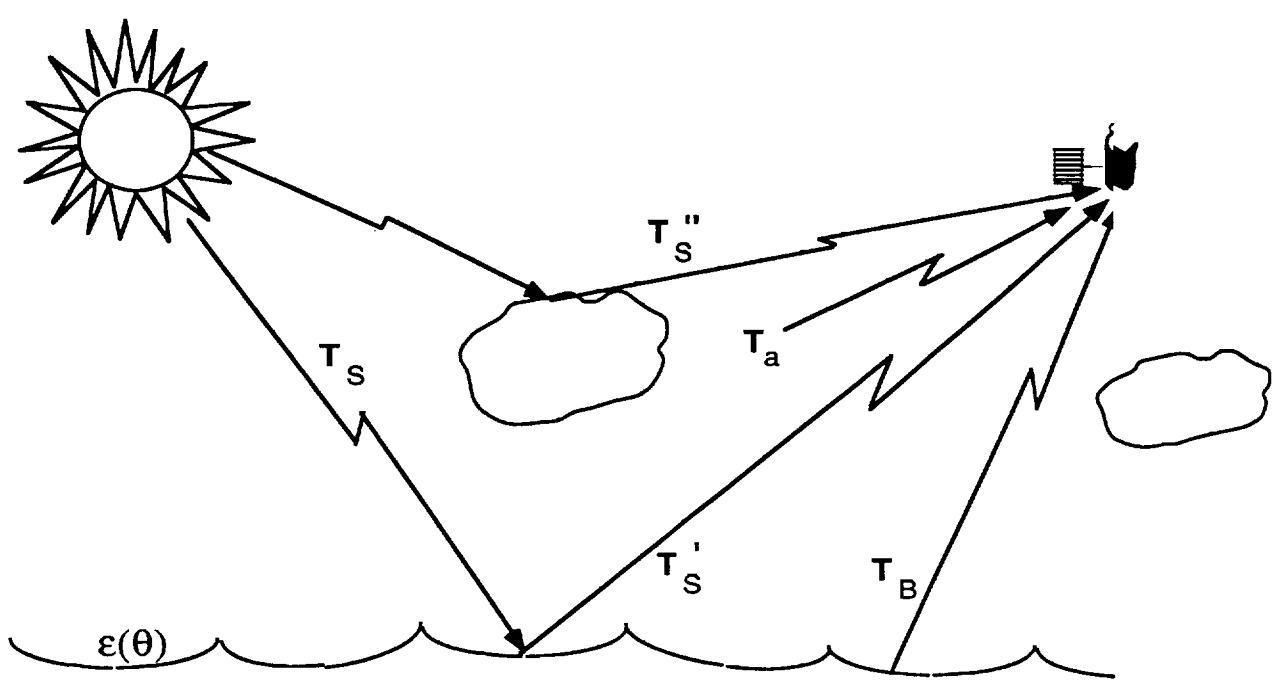

Figure 1. Schematic representation of the radiative transfer problem addressed for infrared remote sensing.

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 obtained a set of 1200 profiles from RAL, which was originally put together by NOAA/NESDIS, that provides such coverage (Figure 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.

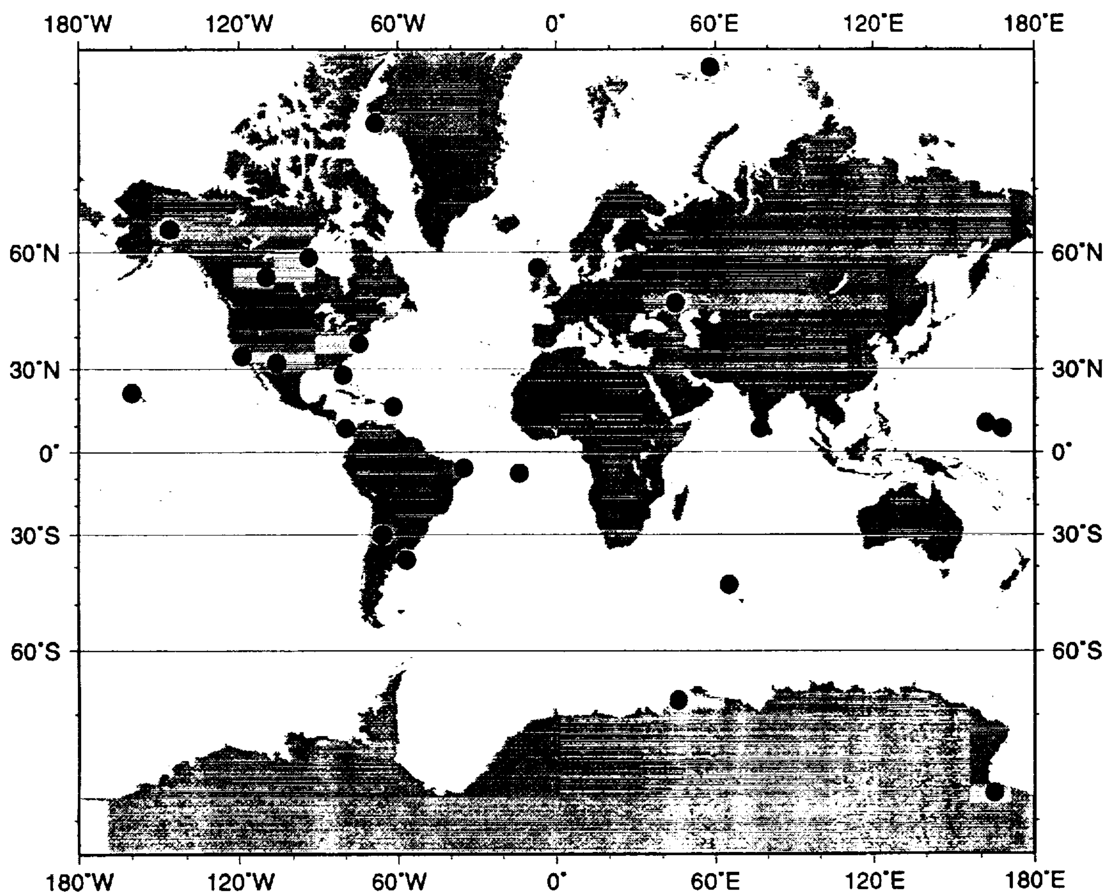

Figure 2. Radiosonde sites in NOAA/NESDIS profile database. 1200 profiles are available from the 24 sites. The location in the Southern Indian Ocean is only an indicator for a number of ascents taken from an FSU research vessel at various locations in this region.

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. Figure 3 illustrates the general trends for band differences as a function of water vapor concentration and viewing geometry derived from modeling results.

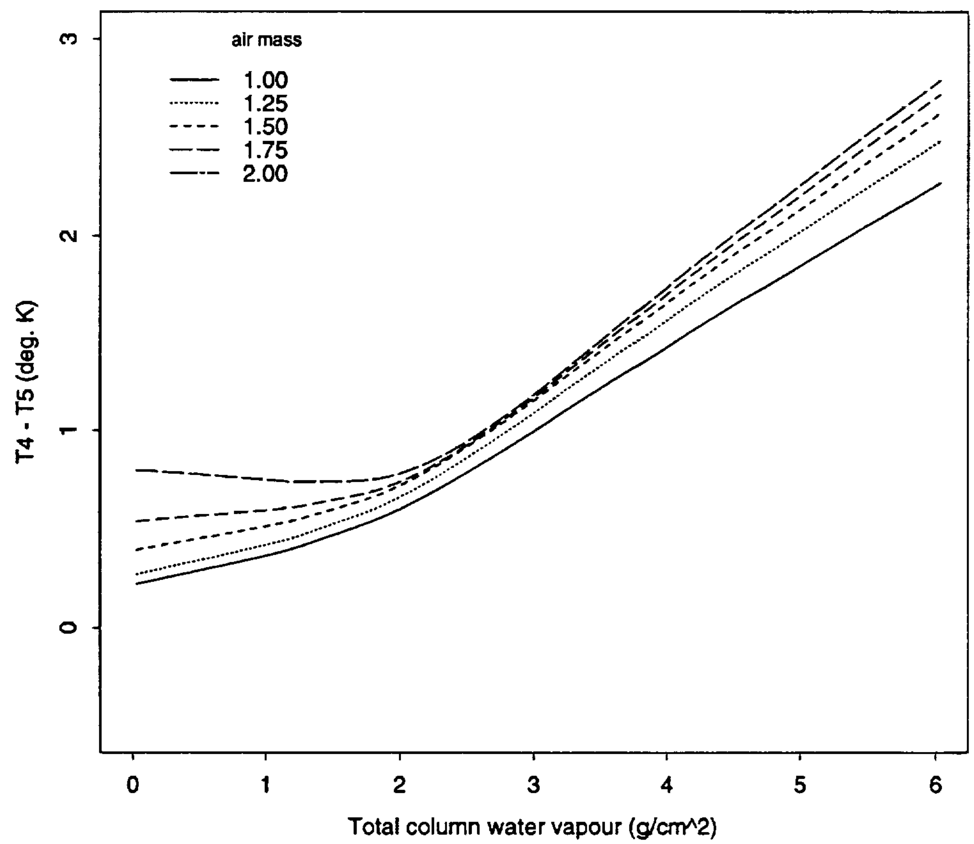

Figure 3. Radiative transfer modeling results from the RAL model. Differences between brightness temperatures for AVHRR bands 4 and 5 (10-11 μ, 11-12 μ; Schwalb, 1978) were determined for 5 scan angles and the ensemble of near-ocean radiosonde sites (from the NOAA/NESDIS profile set). A robust estimation 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 and that the effects of mixed gases at low Wvs may need additional study.

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

In the infrared, water vapor, CO_2, CH_4, NO_2 and aerosols are the major constituents that determine the atmospheric extinction (Minnett, 1990). Among them, absorption due to water vapor accounts for most of the correction (Barton *et al.*, 1989). For this reason, there have been various attempts to incorporate ancillary information on water vapor into the SST estimation. For instance, Schluessel *et al.* (1987) used channels from the High Resolution Infrared Sounder (HIRS) in an algorithm that attempted to incorporate additional information on the atmospheric structure. Steyn-Ross *et al.* (1993) have proposed a dynamic correction for SST estimation that compensates for temporal atmospheric water vapor fluctuations; correction lookup tables are derived from radiosonde data. Recently, Emery *et al.* (1994) proposed an algorithm that explicitly included integrated water vapor estimates derived from the Special Sensor Microwave/Imager (SSM/I), a microwave radiometer (Hollinger *et al.*, 1990).

Despite the importance of atmospheric water vapor in defining the correction needed to estimate accurate SSTs, there have been few successful attempts to document the association between water vapor and AVHRR radiances. Perhaps, the difficulty in obtaining simultaneous atmospheric water vapor and AVHRR measurements prevented such attempts. Since the availability of total column atmospheric water vapor estimates derived from the SSM/I (Wentz, 1989), it is possible to obtain fairly coincident water vapor and AVHRR fields. Both SSM/I and AVHRR instruments are carried by spacecraft in sun-synchronous polar orbits of similar altitudes and have similar pass times over most areas (Emery *et al.*, 1994).

The main objective of our recent work is to explore the associations between atmospheric water vapor content and various AVHRR-derived quantities. Insight gained on the nature of these associations will allow us to better understand the performance of existing SST algorithms, as well as to improve the parameterization of various terms in such algorithms. The difference in brightness temperatures in AVHRR channels 4 and 5 is the quantity most often used as a proxy for atmospheric effects. Therefore, we dedicate considerable attention to exploring the association between this quantity and water vapor, including the effects of AVHRR viewing geometry, geographic location, and season. It has been suggested that the use of ancillary water vapor information such as that provided by the SSM/I may contribute to enhancing SST estimates (Hagan, 1989; Emery *et al.*, 1994). We investigated this possibility using *in situ,* SSM/I and AVHRR data.

In situ SST-AVHRR Matchup database

As part of the NASA/NOAA AVHRR/Oceans Pathfinder program, we have compiled a set of *in situ* sea surface temperature (SST) retrievals and AVHRR observations nearly coincident in space and time. These observations, or "matchups" are being used to develop and test SST algorithms. The matchup database is discussed in detail by Evans *et al.* (in preparation); in this report we give only a brief description. There are two main sources of *in situ* SST retrievals: (i) moored buoys and (ii) drifting buoys. The moored buoys include (a) those deployed by the National Data Buoy Center off the east and west coasts of the US, in the Gulf of Mexico, and around Hawaii, (b) buoys around Japan, operated by the Japanese Meteorological Agency, and (c) the TOGA-TAO array deployed in the equatorial Pacific Ocean. The drifting buoy data were obtained from the archives at NOAA's Atlantic Oceanographic and Meteorological Laboratory and the Canadian Marine Environmental Data Service.

The AVHRR data were collected between January 1989 and December 1990 by the NOAA-11 spacecraft. The data were extracted from the Global Area Coverage (GAC) data set transcribed onto optical disks by collaborators at NASA's Goddard Space Flight Center (GSFC) as part of the Pathfinder program. Data were extracted at locations and times close to those of the *in situ* SST retrievals. The extracted data include, among other things, brightness temperatures for the infrared channels (3, 4 and 5), and geometric information (*e.g.*, satellite zenith angle).

In order to minimize differences between *in situ* and satellite retrievals caused by spatial or temporal separation (Minnett, 1991), a fairly narrow acceptance "window" was used to build the matchup database: both types of retrievals could not be separated by more than ±30 minutes and ±0.1° of latitude and longitude. For the 1989-1990 period, 63,808 matchups were available. A substantial fraction of these matchups, however, corresponded to pixels entirely or partially contaminated by clouds, and for which the brightness temperatures could not be used reliably. Whenever AVHRR quantities were used in this work, we applied a set of empirical rejection criteria to exclude cloud-contaminated matchups. The rejection was based on thresholds for the various channels, spatial homogeneity criteria, and channel-to-channel differences; details on the rejection criteria are given in Evans *et al.* (in preparation). After applying the filters, only 4043 matchups (about 6%) remained. The geographic distribution of the matchups and the relevant atmospheric sounding sites is shown in Figure 4.

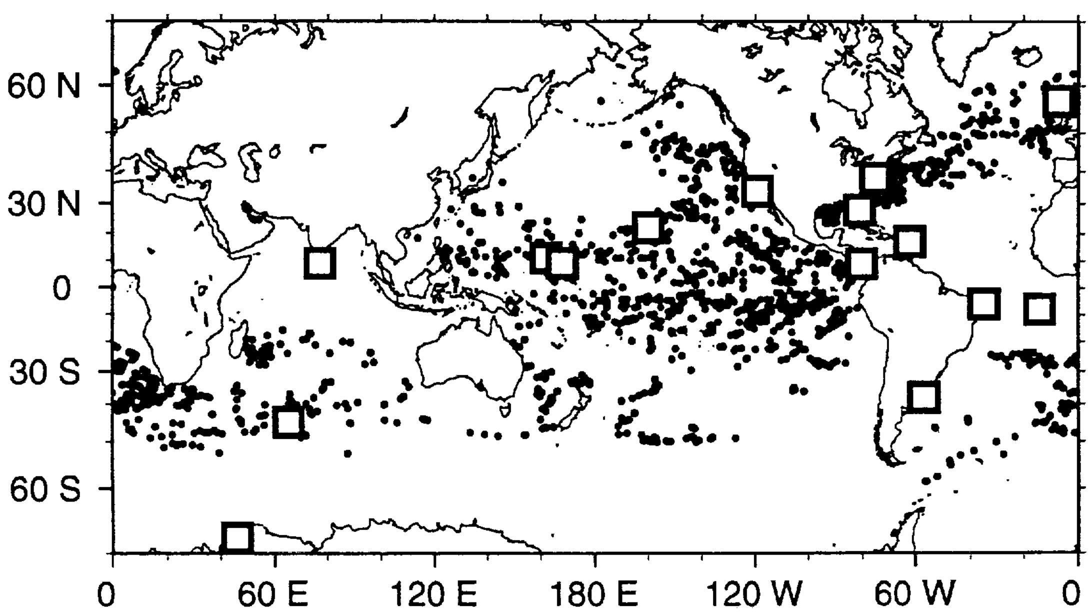

Figure 4. Locations of 1989-1990 matchups of in situ, AVHRR and SSM/I data (dots) and radiosonde profiles (squares).

SSM/I Water Vapor Fields

Estimates of integrated atmospheric columnar water vapor (hereafter WV) were derived from the Special Sensor Microwave/Imager (SSM/I), a microwave radiometer onboard the F-8 spacecraft of the Defense Meteorological Satellite Program (DMSP) series (Hollinger *et al.*, 1990). The WV values were extracted from a set of SSM/I geophysical files produced by Wentz (1989; 1992a) and distributed by NASA's Jet Propulsion Laboratory Physical Oceanography Distributed Active Archive Center (JPL-PODAAC). The WV retrieval algorithm, described in Wentz (1992b), has a stated accuracy of 0.3 g cm^{-2} or better, even in the presence of light rain.

To append WV estimates to the *in situ*- AVHRR matchups, we extracted WV values from global fields built from each SSM/I daily file. To reduce the data volume for each daily file, we combined the WV at ~25 km SSM/I pixels into "super observations" by computing the median of all values within 0.5° boxes. Note that by using all the data in a daily file, in many places the super observations are the composite of data from ascending and descending passes (*i.e.*, separated by about 12 hours). This should not introduce too much variability in the daily composite WV patterns except in areas where rapidly-moving atmospheric fronts are present; examples of these situations are shown by Phoebus and Hawkins (1990). WVs at the locations of the *in situ*-AVHRR matchups were spatially interpolated from the gridded daily WV file. No attempt was made to interpolate the WV extractions in time. That is, if two matchups were available for the same location in a given day, the extracted WVs were the same.

Association between WV and SST Values

A plot of WV as a function of *in situ* SST is shown in Figure 5; a non-parametric trend line (Cleveland *et al.* 1988) is overlaid. WV increases fairly linearly with SST up to about 20-22°C. At this point, the association becomes non-linear, and the slope of the fit increases rapidly. The fast increase in the observed WVs at SSTs above 22°C reflects non-linear changes in WV saturation pressure described by the Clausius-Clapeyron equation (Stephens 1990). The variability of WVs also increases above 22°C: the standard deviation of the residuals from the fit shown in Figure 2 is 0.70 g cm^{-2} below 22°C and 0.78 g cm^{-2} above that temperature.

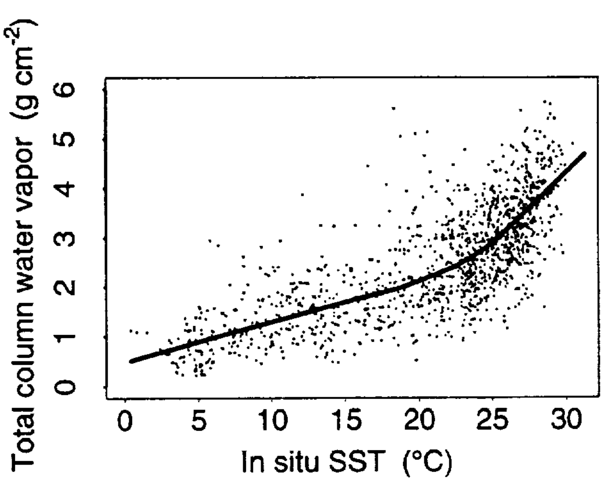

Figure 5 SSM/I-derived integrated water vapor values as a function of *in situ* SST. The line represents a non parametric trend line fitted using loess. Randomly selected one third of the data points are shown to enhance the visualization of trend line.

The close association between SST and WV (including the break at about 20°C) was documented by Stephens (1990) using data from a microwave radiometer (SMMR) and global SST fields. The tightness of this association has led Maul (1985) to speculate that the temperature deficit in an AVHRR channel (*i.e.*, the amount of atmospheric correction needed) is not really a function of the total column atmospheric WV, but instead is really a function of the SST. Maul, then, calls the association between temperature deficit and WV "fortuitous". We will examine the validity of this assertion below.

Association between WV and T45

The difference in brightness temperatures in AVHRR channels 4 and 5 (T45) has been traditionally used in multichannel SST algorithms as a proxy for the amount of atmospheric correction needed (McClain *et al.,* 1985; Walton, 1988; Barton and Cechet, 1989; Emery *et al.,* 1994). For that reason, in this section we will closely examine the association between this quantity and the SSMI-derived WVs. The association between T45 and WV is shown in Figure 6; a non-parametric trend line is overlaid. The trend is almost linear, with a slight increase in the slope at WVs over 3 g cm^{-2}. However, the spread of the T45 values is fairly large, so any trend has to be interpreted with caution. In general, the two quantities seem to be associated throughout the range of observed WVs (0–6 g cm^{-2}). This averts our initial concerns that T45 may become unresponsive at increased WVs as a result of increasingly turbid atmospheres.

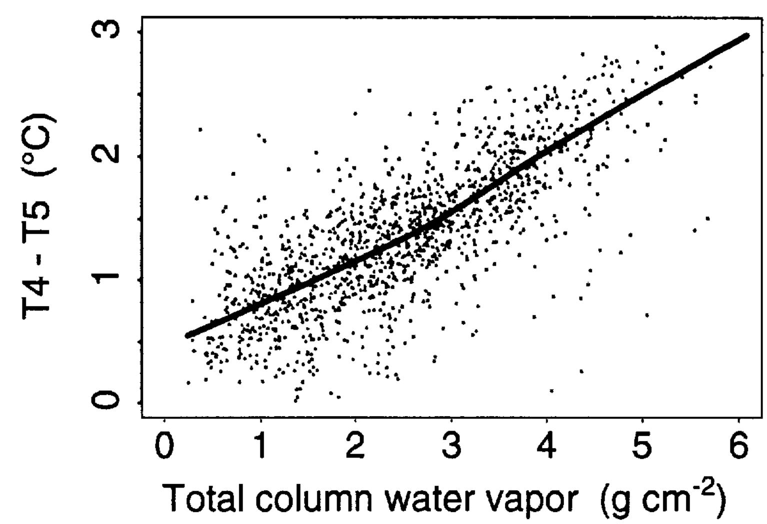

Figure 6. Difference in brightness temperatures in AVHRR channels 4 and 5 as a function of SSM/I-derived integrated water vapor values. The line represents a non parametric trend line fitted using loess. Randomly selected one third of the data points are shown to enhance the visualization of trend line.

Despite the large scatter in the main envelope of points, several outliers clearly stand out. We examined some of these to understand what processes could have caused them. There are two types of obvious outliers: (a) points with high T45 and low WV, and (b) points with low T45 and high WV. The first group of outliers corresponds to matchups with very high (> 65°) satellite zenith angles (SZAs).

The processes that gave rise to the second group of outliers (high WV, low T45) were not easily explainable using only the matchup data set. Hence, we turned to the radiative transfer simulations. We plotted the association between simulated T45 and WV for the radiosonde data set (plot not shown) and detected points with similar characteristics to the outliers in the matchups. The radiosonde profiles corresponding to these outliers showed a common pattern: a temperature inversion in the lower levels of the atmosphere. In some cases, the temperature inversion was accompanied by lower water vapor concentrations in the lower atmosphere. One such inversion is illustrated in Figure 4, which shows temperature and water vapor profiles on 30 July 1966 at 34°N, 119°W (California coast). Both profiles show an inversion at a height of about 1.4 km. The surface temperature (13°C) is 6°C cooler than the temperature at 1.4 km. The integrated water vapor is 5.3 g cm^{-2}. The simulated T45 value for this profile is 0.77°C. This value is significantly lower than expected from the T45 *vs.* WV association: the expected T45 should have been about 1.8°C.

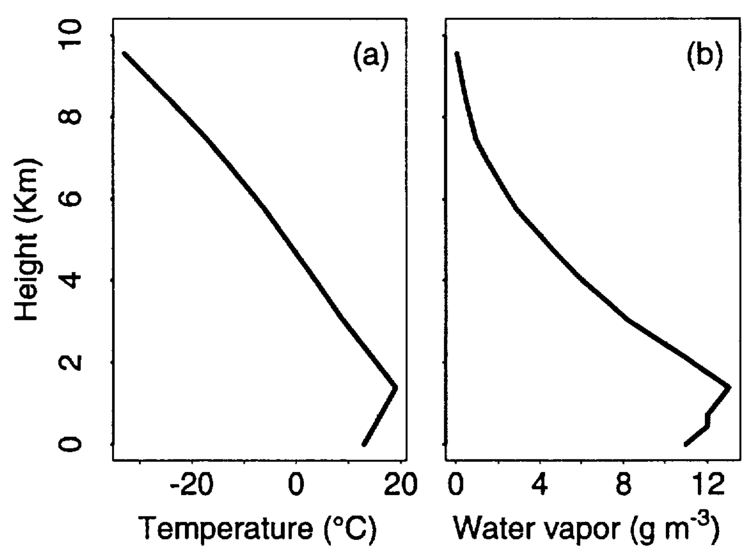

Figure 7 Atmospheric (a) temperature and (b) water vapor profiles at 34°N, 119°W on 30 July 1966.

Why are T45 values lower when a thermal inversion is present? In such cases, the radiance emitted by the cooler ocean surface will be lower than the radiance originating from the warmer atmospheric layer above it. The atmospheric radiance, then, will account for a larger proportion of the total radiance sensed at the satellite. Furthermore, the atmospheric emission will be proportionally higher for channel 5. The end result of these processes is a lower T45. Minnett (1990) also suggests that the usually positive T45 values might even become negative when the atmosphere is warmer than the sea surface.

There are various implications of the effect of temperature inversions. In the first place, it is highly unlikely that SST estimates under these conditions will be correct, mainly due to the anomalously low T45 values. On the other hand, the deviations from the typical association between WV and T45 may be used to identify situations for which reliable SST estimates are impossible. We must note that the empirical quality filters we are using (based only on AVHRR quantities) are unable to identify these cases. The more fundamental implication, however, is that slight changes in the vertical distribution of temperature and moisture in the atmosphere may introduce variability in the AVHRR radiances, and thus in the SST estimates. These changes may be subtle enough so that they cannot be easily identified as the outliers discussed above, and they will contribute to the envelope of unresolved noise in SST measurements.

Zonal Variability in the Association between T45 and WV

We have shown that there is an association between T45 and WV, although the slope of the fitted trend varies according to the WV regime. The range of observed WVs is dependent on latitude, among other parameters, therefore we examined changes in the association between T45 and WV as a function of latitude. Such changes could have implications for the performance of SST algorithms in different regions.

We first divided the matchups into latitudinal bins with a span of 5°. For each bin containing more than 20 matchups, we performed a linear regression of T45 on WV using a robust procedure (Hampel *et al.,* 1986). We then plotted the slopes of the estimated regression lines as a function of latitude (Figure 8). The slope of the association between T45 and WV is highest in the tropics, and decreases towards higher latitudes. Figure 8 shows 90% bootstrapped confidence intervals for the estimated slopes. When the confidence intervals include the zero value, the slope cannot be considered as significantly different from zero, in other words, there is no association between T45 and WV. All the slopes estimated are significant between about 45°N and 45°S. Slopes estimated from model simulations show a similar behavior (figure not shown), giving us confidence in the patterns observed in the matchups. In contrast, Emery *et al.* (1994) detected an association between T45 and WV only between 0° and 20°N using AVHRR and SSM/I data. They did not explain the apparent lack of association above 20°N. Perhaps such an association is obscured because of cloud contamination or other type of bad quality data in their matchups. When we used the matchup database without implementing data quality filters (see above), we also found lower degrees of association.

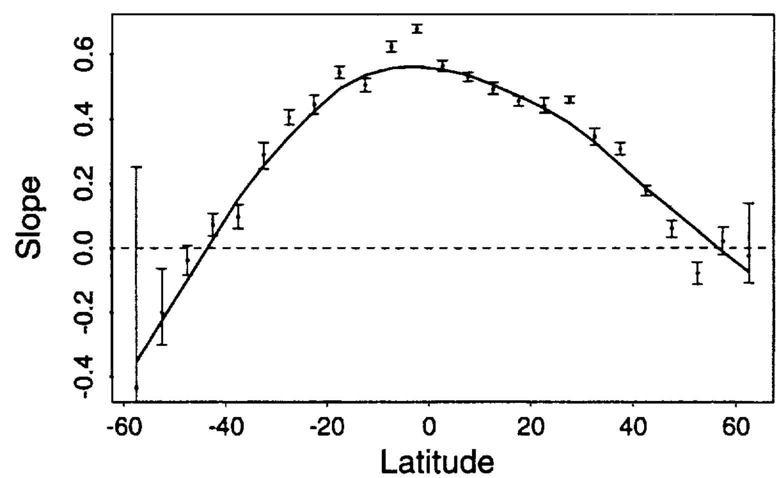

Figure 8. Latitudinal variation in the slope of the association between the difference in brightness temperatures in AVHRR channels 4 and 5 and SSM/I-derived integrated water vapor values. Confidence intervals (90%) for the estimated slopes are shown. The solid line represents a non parametric trend line fitted to the association.

In two high latitude bins (50–55°N and S) the slopes of the T45 vs. WV are significantly different from zero and negative. The reasons for a negative slope are unclear. Examination of model results (see previous section) shows that, at low WVs (typical of high latitudes), the association between T45 and WV could have a slightly negative slope, but only at very high satellite zenith angles (SZA = 60°).

What is the cause for the differences among the slopes of the association between T45 and WV for different latitude bands? We found above that the overall shape of this association seems to be well represented by a piece-wise linear fit with a break in the slope at about 3 g cm^{-2} (Figure 3). To a first order, then, the changes in the slope with latitude could simply reflect variations in the frequency distribution of WV inside each latitude bin. That is, if there is a higher proportion of low WVs in a bin, it is likely that the slope of the association between T45 and WV will be lower. To verify this, we examined histograms of WV for each of the latitude bins. As expected, as one moves from the high latitudes towards the tropical regions, the proportion of high WVs increases. One may speculate that not only there are differences in integrated WV among latitudinal bands, but the vertical distribution of temperature and moisture probably will also differ. Investigating this latter aspect is beyond the scope of the present work and will be undertaken in the future.

Are WV Values Useful for SST Estimation?

One of the questions that motivated this study was whether integrated water vapor values might improve SST estimates. Emery *et al.* (1994) reported that a combination of SSM/I-derived water vapor and infrared radiances from the AVHRR provided considerable improvement over the older cross product (CPSST) and multichannel (MCSST) algorithms. We attempted to confirm this improvement using our AVHRR-SSM/I matchup database. The wider geographic coverage of our matchups should represent a larger spectrum of oceanic and atmospheric conditions than those tested by Emery *et al.* (1994).

We compared three alternative formulations of SST algorithms: (a) the MCSST (McClain *et al.*, 1985), (b) the non-linear SST (NLSST), which is the current operational algorithm used by NOAA (Walton, personal communication), and (c) the water vapor SST (WVSST, Emery *et al.*, 1994). The form of each algorithm is shown in Table 1. The coefficients for all three algorithms were estimated using the matchup database. The NLSST requires a first-guess SST; to supply this value, we used the *in situ* SST to which we added random noise uniformly distributed between -1°C and 1°C. The rms and the mean of the residuals (*in situ* minus predicted SST) are also shown in Table 1.

Algorithm	Form	rms of residuals (°C)	Mean of residuals (°C)
MCSST	SST= -0.02+1.07 T4 + 1.95 T45 + 1.01 (sec(SZA) -1) T45	0.58	0.01
NLSST	SST = 1.42 + 0.96 T4 + 0.07 T45 Tsurf + 1.04 (sec(SZA) -1) T45	0.49	0.00
WVSST	SST = 0.88 + 0.99 T4 + 1.38 T45 + 0.19 WV sec(SZA) T45	0.69	0.01

Table 1. Comparative performance of MCSST, WVSST and NLSST algorithms. The terms in each algorithms have been defined elsewhere in the text, with the exception of Tsurf, a first-guess SST value used in the NLSST.

The NLSST algorithm has the lowest rms and mean of residuals. Surprisingly, the rms value for the MCSST is lower than that of the WVSST. However, conclusions on algorithm performance based only on the examination of rms and mean of residuals can be misleading. For that reason, we also examined the presence of trends in the residuals as a function of *in situ* SSTs and various ranges of SZA. The NLSST shows the least trends at all SZA ranges and, thus, is the best performer. The WVSST, despite its apparently higher rms values, shows a better behavior of the residuals than the MCSST. However, the trends suggest a consistent negative bias in the WVSST residuals for SZAs less than 45°. The differential behavior of the residual trends at different SZA ranges cannot be perceived if the data are plotted all together. Furthermore, trends in different directions may cancel out, leading to an optimistic assessment of performance.

Our comparison of algorithms suggests that the use of ancillary WV values does not appear to significantly enhance SST estimates. One of the reasons Emery *et al.* (1994) cited for the improved performance of their WVSST algorithm was that T45 alone was unable to represent water vapor patterns in mid-latitudes and high latitudes during summer. In this work, however, we have found that the amount of atmospheric correction required (TD) is more closely associated with T45 than with WV. At the same time, we show a significant association between WV and T45 from the tropics to about 45° latitude.

B.1.3 ATBD

There has been extensive work over the past year 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 based on review received during the May ATBD review. My response to the reviewers' comments can be summarized as follows.

<u>General:</u>

The general sense of the written comments and the Panel's comments was that the approach outlined in the ATBD was conservative and might not represent the current state-of-the-art. The P.I. notes in the ATBD and argued at the Review that, while conservative, this approach is the only responsible way to validate SST retrievals with currently available surface truth observations. Further, development of mid wave infrared SST estimators requires calibration/validation observations not currently available - thus the approach developed in the ATBD.

<u>Specifics:</u>

<u>Mid-wave IR Based Algorithms</u>

During the ATBD presentation we argued that the pre-launch MOCEAN cruise efforts can be used to develop improved algorithms for the mid and long wave MODIS band sets. Given that these efforts bear fruition, we are prepared to implement mid-wave infrared algorithms as soon as possible after launch.

<u>"Skin" Temperature Algorithms Development</u>

The other major comment from the reviewers had to do with the development of an SST estimator validated against bulk rather than radiation or "skin" temperatures. We argue in the ATBD that surface validation data is not available with temporal frequency and the spatial diversity required to appropriately develop such an algorithm. We asserted to the Panel that we would try to accelerate the implementation of radiation observations to augment the currently available surface comparison data sets for skin temperature. This could lead to development of a skin temperature product. However, we noted that the probability of the database representing a broad enough range of regimes is not a high probability, thus the likely result at launch will be a bulk-tuned SST algorithm rather than a skin-tuned SST algorithm. It remains our intention to pursue development of a skin algorithm for post launch use at an appropriate time.

As an initial attempt to categorize several of these effects, the investigator, in association with P. Menzel and associates of UW SSEC and their NOAA cooperative institute (CIMMS), is planning a ship/aircraft SST field study in the western Gulf of Mexico during January 1995. The goals of this study include characterization of the angular dependence of emissivity effects, development of a radiation budget closure in the mid- and long-wave infrared between the surface and the top of the atmosphere, validation of a new technical approach for sensing skin temperature using a ship-based infrared radiometer, and comparison of up *vs.* down looking atmospheric sounder data from compatible infrared interferometers.

Aerosols

Although not noted in the panel review, the investigator is also concerned about the influence of aerosols on the various mid- and long-wave infrared retrieval schemes. We stated in the review that we had initial interactions with several of the investigators concerned with atmospheric constituents on the MODIS team, and would vigorously pursue an approach which will address aerosol extinction.

Conclusion:

In summary, we feel the mail and panel reviews validate our approach to this problem and we will continue our development along the lines articulated in the ATBD. Future updates to the ATBD will discuss our evolving strategy for skin temperature algorithm development and methods to approach aerosol extinction in the mid- and long-wave infrared.

B.1.4 Wide Area Networking

Efforts to establish an experimental wide area high speed network between the University of Miami, Oregon State University and the Naval Research Laboratory were successful in July. PVCs were established through the inter-exchange carrier between Miami, NRL and OSU with SVCs being established over these connections as appropriate. Initial testing indicated ~6 Mbs/socket sustained transports are available at the AAL5 transport layer (IP) with higher rates at AAL0.

The following experiments completed:

(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; and,
(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;

It was not possible for us to address:

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

Preliminary results of the ATM WAN evaluation are:

(1) The direct ATM connections demonstrated transfer rates ranging from 30 (Miami<-> NRL) to 80 (Miami<->OSU) times faster than internet connections between these sites;

(2) Buffering and congestion management are quite important in sustaining high rate transfers;

(3) Low level (PVC) interoperability between ATM switches is possible (in our case Digital and FORE switches); and,

(4) There is no viable SVC and/or interoperable NNI standard at this time (we expect the first in early 1995 and the latter in late 1995 or early 1996).

B.1.5 *In Situ* Calibration/Validation of MODIS IR Radiances

Work was initiated during the past six months to evaluate several new approaches to infrared radiance measurements cooperatively with Dr. William Smith of the University of Wisconsin. Specifically we have agreed to participate in a joint study utilizing the NASA ER-2 (MAS and HIS), GOES-8, and two shipboard mounted instruments (AERI and Heimann KT-19). The study is scheduled to occur in early January, 1995 and will be undertaken in the western Gulf of Mexico between frontal passages. Dr. Peter Minnett (Brookhaven National Laboratory) will provide a portable surface meteorology package including long-wave downwelling (Eppley), and a fast response *in situ* temperature probe.

Objectives of the study are to:

(1) Evaluate the AERI as a sea-viewing instrument with particular emphasis on characterizing its integration time *vs.* NEDT, instrumental stability, and comparability with more conventional radiometers;

(2) Examine the emissivity effects (both Fresnel and foam induced) on retrieved radiances; and,

(3) Develop an end-to-end radiation budget in the infrared over the ocean as a test data set.

C. Investigator Support

July	W. Baringer O. Brown G. Goni G. Halliwell
August	W. Baringer O. Brown G. Goni A. Mariano
September	W. Baringer O. Brown G. Goni A. Koger

October	O. Brown W. Baringer G. Goni A. Koger S. Shenoi
November	O. Brown G. Goni W. Baringer A. Li S. Shenoi
December	W. Barringer J. Brown O. Brown P. Evans G. Goni V. Halliwell A. Li D. Li S. Shenoi S. Walsh

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 code
d. ATBD updates (as needed)
e. Define and implement an extended ATM based network test bed
f. Evaluate and analyze results of calibration/validation experiment
g. Continued integration of new workstations into algorithm development environment

D.1.2 Investigator support

Continue current efforts

E. Problems

No new problems to report.

REFERENCES

Barton, I.J. (1992), Satellite-derived sea surface temperatures—A comparison between operational, theoretical and experimental algorithms. *J. Appl. Meteorol.* 31: 433–442.

Barton, I.J., and Cechet, R.P. (1989), Comparison and optimization of AVHRR sea surface temperature algorithms. *J. Atmos. and Ocean. Tech.* 6: 1083–1089.

Barton, I.J., Zavody, A.M., O'Brien, D.M., Cutten, D.R., Saunders, R.W., and Llewellyn-Jones, D.T. (1989), Theoretical algorithms for satellite-derived sea surface temperatures. *J. Geophys. Res.* 94: 3365–3375.

Cleveland, W.S., Devlin, S.J., and Grosse, E. (1988), Regression by local fitting. Methods, properties and computational algorithm. *J. Econometrics* 37: 87–114.

Emery, W.J., Yu, Y., Wick, G.A., Schluessel P., and Reynolds, R.W. (1994), Correcting infrared satellite estimates of sea surface temperature for atmospheric water vapor contamination. *J. Geophys. Res.* 99: 5219–5236.

Hagan, D.E. (1989), A basic limitation of the split window method for SST retrievals when applied to a wide range of water vapour conditions. *Geophys. Res. Lett.* 16:815-817.

Hampel, F.R., Ronchetti, E.M., Rousseeuw, P.J., and Stahel, W.A. (1986), *Robust statistics. The approach based on influence functions.* J. Wiley, New York.

Hollinger, J.P., Peirce, J.L., and Poe, G.A. (1990), SSM/I instrument evaluation. *IEEE Trans. Geosci. Remote Sens.* 28: 781–790.

Kneizys, F.X., Shettle, E.P., Gallery, W.O., Chetwynd, J.H., Abreu, L.W., Selby J.E.A., Fenn, R.W. and McClatchey, R.A. (1980) Atmospheric transmitance/radiance: computer code LOWTRAN 5. Report AFGL-TR-80-0067. Air Force Geophysics Laboratory. Hanscom Air Force Base, Massachussets.

Maul, G.A. (1985), *Introduction to Satellite Oceanography.* Martinus Nijhoff Publishers, Boston, 606 p.

McClain, E.P., Pichel, W.G., and Walton, C.C. (1985) Comparative performance of AVHRR-based multichannel sea surface temperatures. *J. Geophys. Res.* 90: 11,587–11,601.

Minnett, P.J. (1990), The regional optimisation of infrared measurements of sea surface temperature from space. *J. Geophys. Res.* 95: 13,497–13,510.

Minnett, P.J. (1991), Consequences of sea surface temperature variability on the validation and applications of satellite measurements *J. Geophys. Res.* 96: 18,475–18,489.

Phoebus, P.A., and Hawkins, J.D. (1990), The impact of the wet tropospheric correction on the interpretation of altimeter-derived ocean topography in the northeast Pacific. *J. Geophys. Res.* 95: 2939–2952.

Schluessel, P., Shin, H.-Y., Emery, W.J., and Grassl, H. (1987), Comparison of satellite-derived sea surface temperatures with *in situ* skin measurements. *J. Geophys. Res.* 92: 2859–2874.

Schwalb, A. (1978), The TIROS-N/NOAA A-G satellite series. NOAA Tech. Mem. NESS 95. U.S. Government Printing Office. Washington, DC. 75 p.

Stephens, G.L. (1990), On the relationship between water vapor over the oceans and sea surface temperature. *J. Climate* 3: 634–645.

Steyn-Ross, M.L., Steyn-Ross, D.A., Smith, P.J., Shepherd, J.D., Reid, J., and Tildesley, P. (1993), Water vapor correction method for Advanced Very High Resolution Radiometer data. *J. Geophys. Res.* 98: 22,817–22,826.

Walton, C.C. (1988), Nonlinear multichannel algorithm for estimating sea surface temperature with AVHRR satellite data. *J. Appl. Meteorol.* 27: 115–124.

Wentz, F.J. (1989), User's manual, SSM/I geophysical tapes. RSS Technical Report 060989. Remote Sensing Systems. Santa Rosa, California. 16 p. [Available from NASA's JPL PODAAAC].

Wentz, F.J. (1992a), Revision-1 update for SSM/I geophysical tapes user's manual. RSS Tech. Memo. 040792. Remote Sensing Systems, Santa Rosa, California. 8 p. [Available from NASA's JPL PODAAAC].

Wentz, F.J. (1992b), Measurement of oceanic wind vector using satellite microwave radiometers *IEEE Trans. Geosci. Remote Sens.* 30: 960–972.

Zavody, A.M., Mutlow, C.T., and Llewellyn-Jones, D.T. (1994) A radiative transfer model for sea surface temperature retrieval for the along-track scanning radiometer. *J. Geophys. Res.* In press.