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INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

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SEMI-ANNUAL REPORT FOR JULY - DECEMBER 2001

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ABSTRACT

In the last six months, UW continued to adjust the operational algorithms for cloud mask, cloud top properties, and atmospheric profiles to accommodate the characteristics of the MODIS data (striping, noise, and cross-talk) and to account for experiences during validation of the products (better 250 m cloud masks, infrared reflection from land surfaces affecting atmospheric profiles). Significant strides were taken toward validating MOD35, MOD 06, and MOD 07 products. Ten days of polar winds were processed and given to the DAO for impact analyses; initial positive results were found. HIRS global cloud trends were continued and comparison with MODIS global cloud property determinations were undertaken. The International MODIS and AIRS Processing Package version 1.3 with an updated calibration algorithm and look up tables was released 3 December 2001.

TASK OBJECTIVES

<u>MODIS Infrared Calibration</u>

The influence of a possible spectral leak into MODIS Band 26 continues to be assessed with the investigation turning to the development of a detector dependent correction algorithm and influence coefficients that will reduce striping and anomalous surface reflectance in Band 26. Recent efforts suggest a correction algorithm will improve cirrus detection in the MODIS Cloud Mask. Evaluation of the MODIS L1B accuracy continues. MODIS MWIR and LWIR window bands and many atmospheric bands are performing well. Global data sets were started using stable software.

<u>MODIS Cloud Mask (MOD35)</u>

Significant science updates were made to the MODIS cloud mask algorithm during the last half of 2001. The modified code was delivered to SDST on 11/19/01. Shallow inland lakes and rivers are now processed via the "coast" processing path with an NDVI test when appropriate. Cloud mask results from 1-km pixels are used as "ancillary" data input to the 250-m mask process with separate decision trees for land and water. More pixels are now processed when Band 2 is saturated. Band 2 reflectances are considered to be high "valid" values for certain error codes if Band 1 reflectances are also valid. MODIS cloud fractions were compared to those from the CLAVR algorithm.

Clear sky forcing data was computed and analyzed using the cloud mask to discriminate cloudy from clear pixels, work was begun to ascertain the impact of a de-striping algorithm for Band 26, and radiance data were collected and analyzed as a function of clear sky confidence levels.

Cloud detection issues specific to the polar regions continue to be investigated. Modifications to an existing cloud test and the incorporation of a new test are being evaluated. The most significant impact will be on nighttime cloud detection.

MODIS Cloud Top Properties (MOD06)

The reason for the many instances of missing data in the MOD06CT output product has been discovered. A fix will be implemented in the next delivery, no later than mid-February. MOD06CT cloud top pressures from several days in June 2001 were compared to those computed from GOES (GOES Sounder Cloud Product) sounder data over the continental U.S and adjacent waters. The GOES data was also processed using the CO_2-slicing algorithm.

MODIS Infrared Total Precipitable Water Product (TPW)

The operational MODIS Atmospheric Temperature and Moisture Profile Retrieval Algorithm (MOD07) was evaluated and improvements were explored. A solution to the problem of excess moisture retrieved by the total precipitable algorithm over deserts is demonstrated. Other changes were implemented to address the moist bias that exists over mid-latitude land of approximately 5mm. Comparisons between MODIS TPW (operational and new) and other observations at a variety of spatial scales are presented.

Polar Winds

A 10-day case study data set of MODIS polar winds covering both polar regions has been generated. It was made available to the Data Assimilation Office (DAO), the European Centre for Medium Range Weather Forecasting (ECMWF), and the U.S. Navy. The DAO and ECMWF have performed model impact studies and have reported a positive impact on model forecasts.

Global HIRS Cloud Trends

Trends in cloud cover, inferred from monthly averages of the HIRS cloud observation frequencies, indicate that there has been a decrease of more than 10% in the northern mid-latitudes in the winter months since January 1997. In North America and Asia, some regions show 20 to 30% decreases. Possible causes for these decreases in winter clouds mostly below 6 km are being explored.

MODIS Direct Broadcast Software

Version 1.3 of the International MODIS/AIRS Processing Package (IMAPP) was released on 3 December 2001 (v1.3). The calibration algorithm and lookup tables were updated to versions 3.0.0 and 3.0.0.7, respectively. Work commenced on adapting the operational MOD35 (Cloud Mask) and MOD06CT (Cloud Top Properties and Cloud Phase) software to run in Direct Broadcast mode. Prototypes of the algorithms should be ready to run in January 2002.

WORK ACCOMPLISHED

MODIS Infrared Calibration and Evaluation of On-Orbit Performance

MODIS L1B thermal IR band calibration continues to be evaluated using data from ER-2 aircraft underflights of MODIS during the TX-2001 and SAFARI-2000 field campaigns. MODIS radiances are compared with ER-2 based MODIS Airborne Simulator measurements. The recent focus has been on improving the accuracy of the spectral correction (MODIS and MAS spectral bands are not identical) and altitude corrections (MAS radiances must be corrected to account for the altitude differences between the ER-2 and Terra platforms). For both corrections, accurate characterization and forward calculations of the atmosphere are key elements. Seasonal climatology and HALOE (on UARS satellite) upper atmospheric soundings have been appended to radiosonde data to provide a full atmospheric characterization for the PFAAST forward model. After these corrections, the MODIS residuals (see Figure 1) continue to be small and within or very close to specification for MWIR and LWIR window bands.

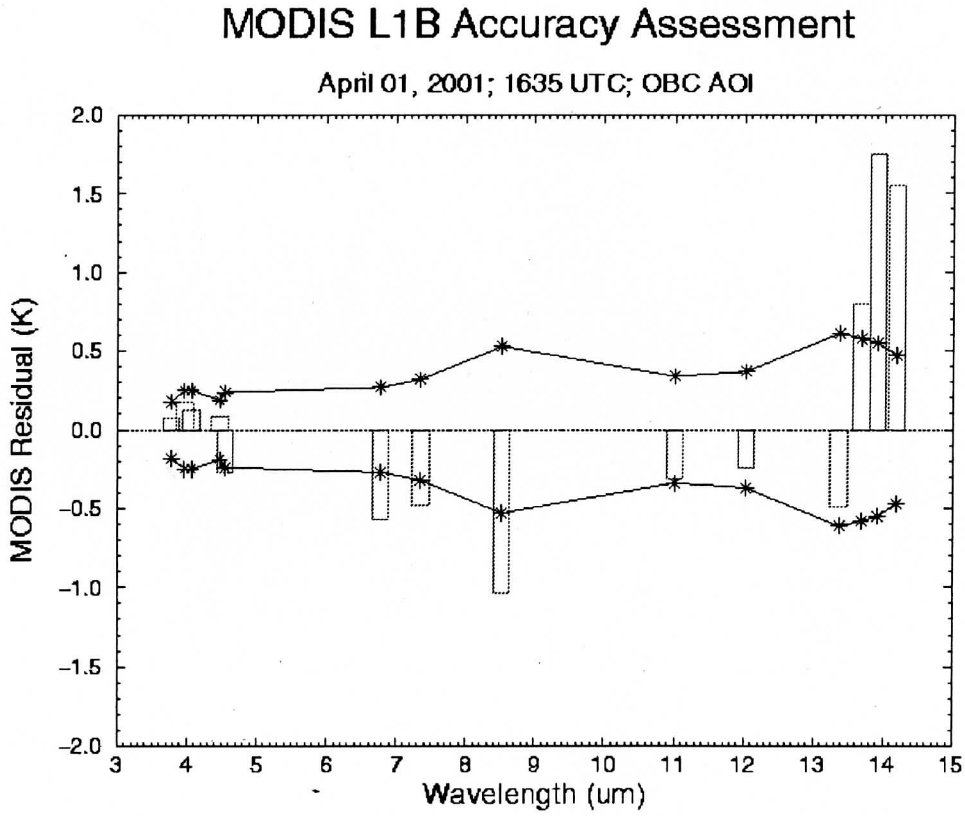


Figure 1. MODIS residuals (open bars) and specification (star symbols) based on comparison to MODIS Airborne Simulator (MAS) for data collected on 1 April 2001 (angle of incidence, AOI=26.3°). The results suggest that MODIS MWIR and LWIR window bands (3.7um, 3.9um, 11um, 12um) are within specification. Slight exceeding of specification in the MODIS water vapor bands (6.7um and 7.2um) is due primarily to striping of a single detector in each band. Upper troposphere CO_2 bands 35 (13.9um) and 36 (14.2um) have residuals exceeding 1°C; however, the large spectral correction of these bands increases the uncertainty of those residuals. The band 29 (8.6um) large residual continues as a point of investigation. Band 30 (9.6um ozone band) not shown due to uncertainly in ozone profile.

Upper tropospheric LWIR CO_2 bands 35 and 36 continue to demonstrate residuals that are larger than specification; however, uncertainty in the upper atmospheric characterization is likely still affecting these results. Water vapor bands 27 (6.7um) and 28 (7.2um) show residuals slightly larger than specification; however, the residuals of these bands are inflated by detector striping. When the effects of detector striping are removed, these bands are near or within specification. Band 29 (8.6um) continues to exceed specification, and remains under investigation.

An effort continues to develop coefficients to correct MODIS Band 26 (1.38 um) earth scene radiances for striping and anomalous earth surface features. Pre-launch testing shows a possible spectral leak into band 26 from a spectral region near band 5 (1.24um). It is thought that this leak imparts earth surface reflectance into band 26 and may also be contributing directly or indirectly to striping in band 26. Using band 26 and band 5 earth scene radiances in moist regions (to isolate the out-of-band signal in band 26 radiance), detector based influence coefficients have been generated and tested on various granules. A simple model has shown promise

$$L_{26,\,i,\,cor} = L_{26,\,i} - A_i * L_{5,i}$$

where $L_{26,i}$ is B26 radiance ('cor' is corrected) for detector i, $L_{5,i}$ is B5 radiance for detector i, and A_i is the influence coefficient for detector i.

The correction effectively softens the striping in band 26 and eliminates most of the earth surface features from the image(see Figure 2); however the influence coefficients are immature until a larger data volume has been sampled (an ongoing activity). Early additional testing suggests that the influence coefficients contribute a 1-2% uncertainty on the corrected band 26 radiances.

Removing striping and anomalous surface features in Band 26 will improve the MODIS Cloud Mask by enabling the 1.38 um cirrus cloud test. Previously, the test threshold was assigned a high reflectance to reduce the impact of striping in MODIS band 26 on the Cloud Mask product. With a lower threshold, it is expected that the Cloud Mask will be able to detect cirrus with optical depths of about 0.01.

MODIS thermal band A0 and A2 calibration coefficients have been reviewed over an extended time series. These coefficients have been periodically updated since launch using onboard blackbody warmup / cooldown exercises. The behavior of these coefficients suggests that external influences are affecting the derived coefficients, especially A0 for the LWIR bands, causing a time series of A0 to exhibit oscillatory behavior since launch. This is particularly important for atmospheric bands 35 (13.9um) and 36 (14.2um) with scene temperatures (220-240 K) much colder than the OBC (~290 K). A comparison using MODIS data processed with two generations of A0 and A2 showed brightness temperature changes of 1.5 K and more in MODIS Band 36. This has been discussed with MCST. A review of MODIS A2 and A0 coefficients from prelaunch data is underway to help identify weaknesses in the OBC warmup / cooldown determinations of A0 and A2 for the PC LWIR bands.

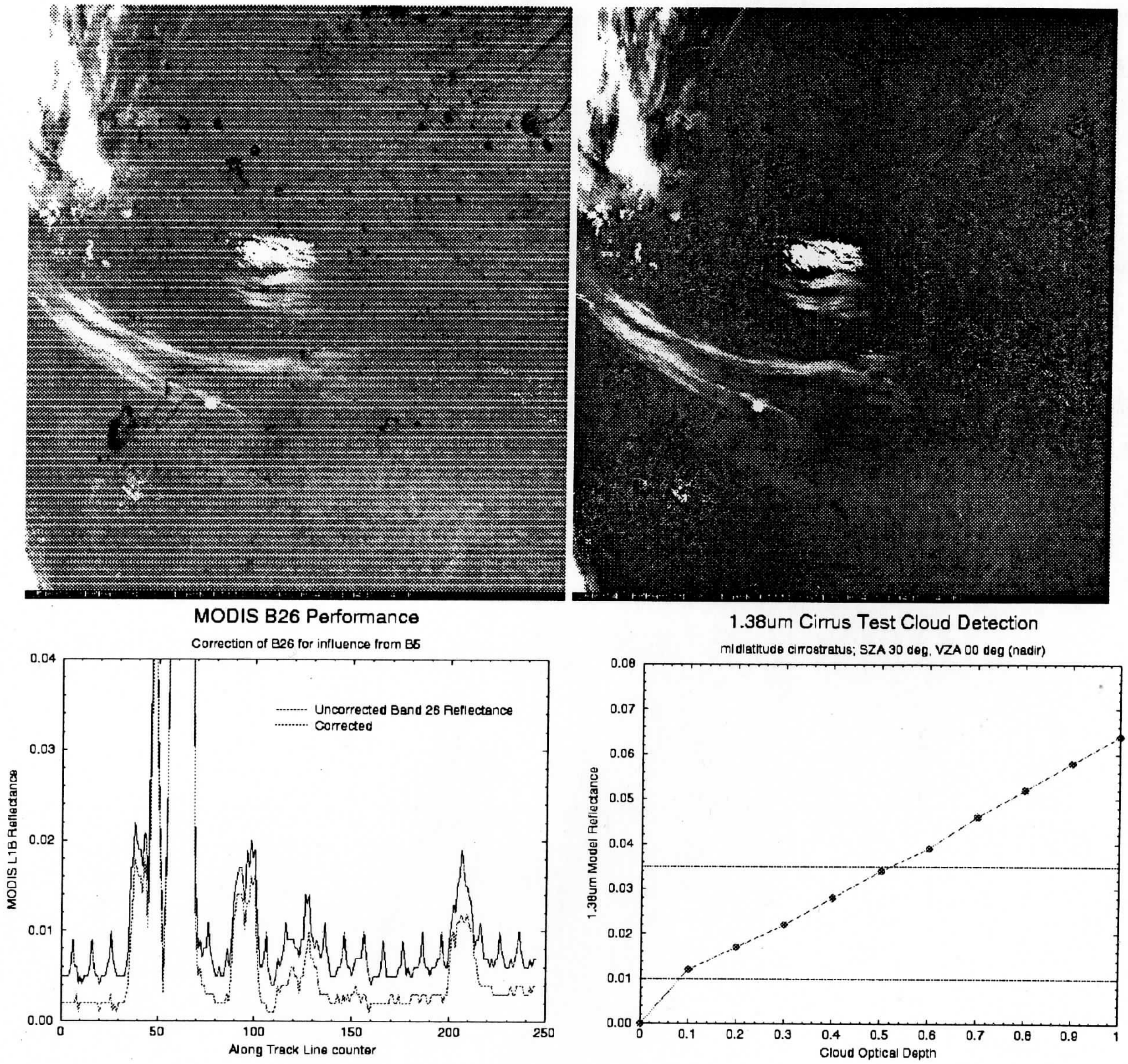


Figure 2. MODIS Band 26 L1B imagery on 21 April 2001 (left) and after correction for influence from spectral leak at Band 5 (right). Striping and surface reflection are much reduced in the corrected image. Along track profile (bottom left) shows diminishing of striping (regular blue spikes are muted in the red trace) and reduction of surface reflectance (elevated average signal of blue trace versus red trace) in the corrected data, effectively increasing the contrast between cirrus cloud features and the background. The reduction of striping and surface reflectance will allow the cirrus cloud threshold to be reduced to near 0.01 reflectance (lower right), allowing cirrus cloud with optical depths as low as 0.01 to be detected.

A one day global data set has been used to investigate MODIS calibrated thermal band radiances for possible residual problems with RVS corrections. The RVS correction used for MODIS is based on an analysis of MODIS data collected viewing the closed Nadir Aperture Door (NAD) in August 2000. An average crosstrack profile for band 36, generated using the global data set of 2 June 2001, is presented in Figure 3. This shows that MODIS end-of-scan radiances are persistently lower than those at begin-of-scan, suggesting a possible residual of uncorrected RVS. A second day (3 June 2001; not shown) revealed similar results. Further testing is required. A similar analysis using MODIS bands 24 and 25, which are not affected by RVS, will be used to eliminate any influence from natural variability. A review of HIRS global data sets (on NOAA series of satellites) will also be undertaken as an independent measure of the natural variability.

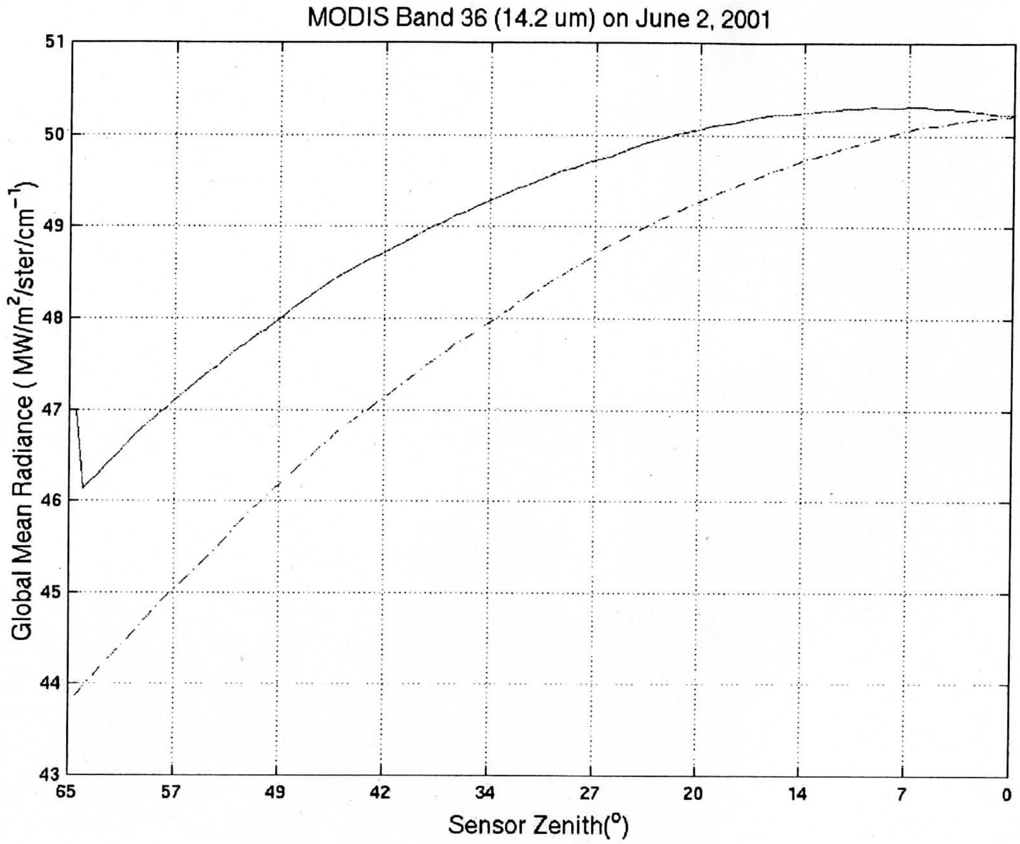


Figure 3. Globally averaged cross track profile of MODIS Band 36 on 2 June 2001 showing that begin-of-scan (solid line) radiances are larger than end-of-scan (dashed line) for same sensor zenith angle. In absence of any scan mirror influence, it is expected that the solid and dashed lines would closely overlay each other for this upper tropospheric band. A similar pattern has been observed in MODIS band 36 data on 3 June 2001 data and in MODIS Band 35 data on both days.

MAS IR Calibration Studies

In November, MAS performance was reviewed at Ames Research Center (ARC). It was agreed that near-term efforts should be focused on reducing Port 3 (MWIR) noise and improving the integrity of FTIR based spectral characterization in the ARC calibration lab. Test data using the Bomem FTIR system was collected and analyzed and a plan of action was designed to completely fill the MAS aperture with the Bomem source. When implemented it will (a) greatly reduce the sensitivity of the FTIR spectral characterization to fixed optical alignment and (b) provide a detailed analysis of MAS spectrometer spectral alignment sensitivity to thermal forcing variation as typically occurs from ground to altitude environment during ER-2 missions. The latter will be tested by deploying MAS in a thermally controlled chamber and collecting FTIR spectral characterization data at several levels of chamber temperature.

Destriping the Infrared Bands

The MODIS infrared bands exhibit a certain amount of variability in the sensor response along track due to detector and mirror side effects. These include (but not limited to):

- the two mirror sides are not identical and are not perfectly characterized,
- each detector is calibrated independently,
- some detectors are "out of family" compared to the majority for a given band.

They have become a major contributor to problems in the Level-2 products. Therefore the striping characteristics of the MODIS infrared bands were analyzed and a prototype correction algorithm was implemented.

A full day of global MODIS data from 4 June 2001 was analyzed. Successive 100 x 100 boxes of 1000 meter pixels at nadir were extracted for bands 20-36 (not including band 26), resulting in about 5760 samples (288 granules per day, and 200 boxes per granule). For each infrared band in each box, the following statistics were computed:

1. overall mean and standard deviation,
2. mean and standard deviation for each mirror side,
3. mean and standard deviation for each detector.

Relatively uniform boxes with low overall standard deviation were identified. For each band, a reference detector was selected that appeared to be performing nominally (low noise, "in family"). For the remaining detectors the ratio of (mean of reference detector) / (mean of detector i) was computed and the adjusted radiances for each remaining detector were computed. This analysis was performed for mirror side corrections also.

IDL code was developed to apply the correction factors to the MODIS infrared bands as follows:

- Bands 24, 25, 27, 28, 29, 30, 33, 34 have detector ratio corrections only,
- Bands 31, 35, and 36 have mirror side corrections only.

The IDL code has been used to destripe global MODIS level-1B datasets in order to assess the impact on CIMSS MODIS Level-2 products. An example of the improvement in Level-1B radiances is shown in Figure 4. Consequently, the MODIS cloud mask (MOD35), where mirror side effects in band 35 and the difference between band 31 and band 29 were causing problems, has been improved appreciably.

However further analysis is required before the correction algorithm can be classified as ready for operational use. Only one day of global data has been analyzed so far, and there is some evidence to suggest that the detector ratio corrections may change over time. In addition, the current detector ratio corrections take no account of the earth scene temperature, and it may be necessary to use different corrections for cold scenes compared to warm scenes. Finally, not all detectors can be corrected, and decisions must be made about whether to mask out these detectors or replace/interpolate the bad values. Analysis is continuing in conjunction with MCST.

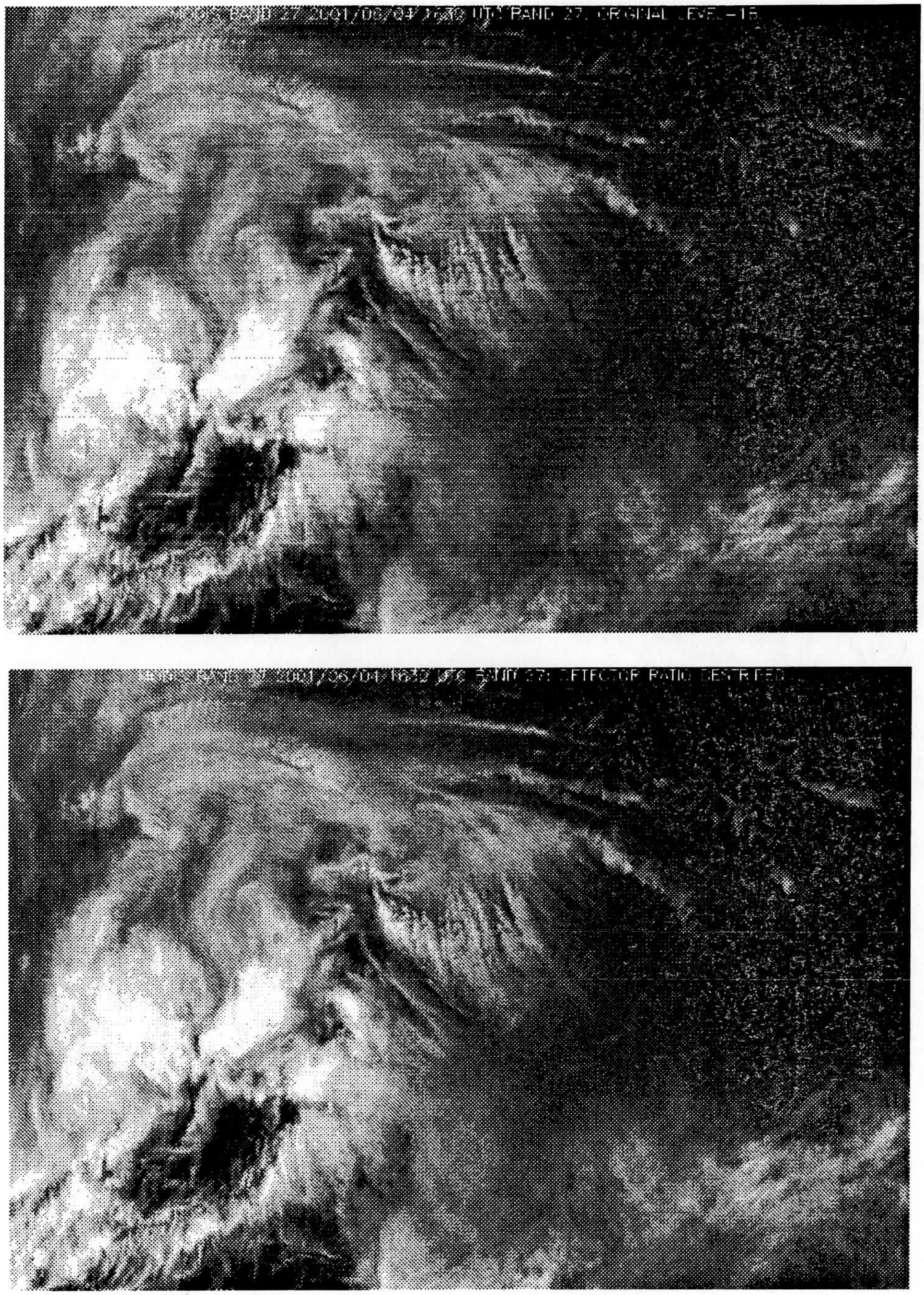


Figure 4. (top) Original Level-1B MODIS Band 27 (6.7 um) from GSFC DAAC (2001/06/04 1630 UTC) and (bottom) destriped MODIS Band 27.

MODIS Cloud Mask (MOD35)

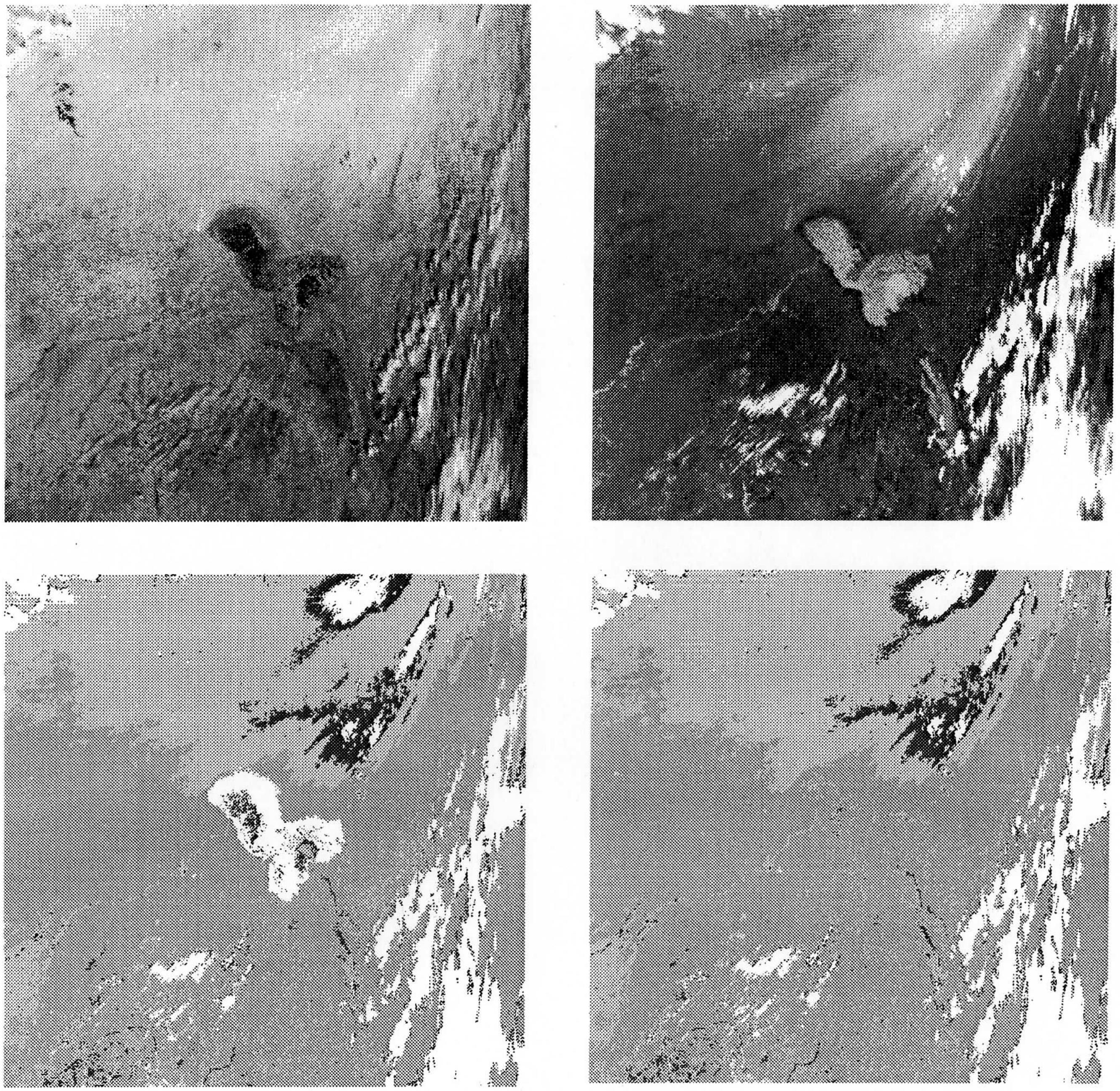
Several significant improvements have been made to the cloud mask processing. First, shallow inland lakes and rivers are now processed via the "coast" processing path. The "water" processing path uses cloud test thresholds more suited to deep, open water rather than the above cases. The coastal path employs tests and thresholds more appropriate for the ambiguous signals sometimes seen in pixels containing combinations of land and water. In addition, an NDVI test is performed for "coast" pixels where either very low (water) or very high (land) values indicate clear skies. This NDVI test is also now employed in shallow ocean regions as suspended sediments in deltas can falsely indicate clouds through simple reflectance tests.

Second, the 250-m cloud mask is significantly upgraded by using the 1-km mask results as ancillary input. The two 250 m bands (one visible and one near-IR) are inadequate for producing a quality cloud mask thus 1-km data are being used where appropriate. A separate decision tree is used for land and water and, in some cases like snow and ice-covered regions, sun-glint, and water pixels with ambiguous reflectances, the 1-km mask is simply copied to the collocated 250-m pixels. For land pixels, when the 1-km mask does not indicate clear skies, the Global Environment Monitoring Index and band 2 reflectances are used for making a final decision.

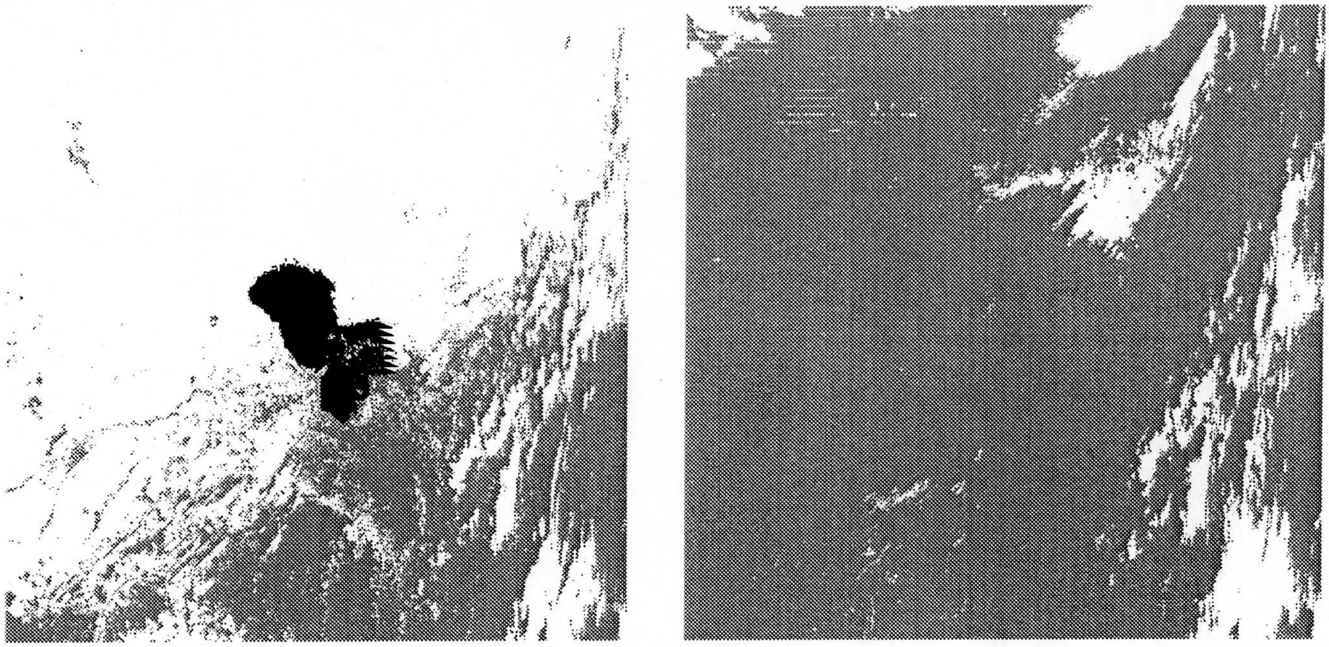
Figures 5 - 10 show examples of the inland water and NDVI improvements noted above. Figures 5 and 6 show Band 2 and Band 31 (.87 and 11 μm) images of the Lake Chad region in north central Africa. Figures 7 and 8 show 1-km cloud mask results from version 3.0 and 3.1, respectively. Green and blue colors represent areas of confident clear and probably clear, red and white represent uncertain and cloudy. The improvement over Lake Chad is obvious as low water depths and sediments were causing open water cloud tests to falsely determine clouds. Figures 9 and 10 show before and after 250-m cloud mask results. Only a binary cloud/no cloud result is provided at 250-m resolution. Again the improvement is significant as bright soils in the region were finding much clear sky to be incorrectly labeled as cloudy.

Third, more pixels containing saturated band 2 data will have valid cloud mask values. Band 2 reflectances will be considered to be high but "valid" if the error code is 65528 (1-km) or 65533 (250-m) and Band 1 reflectances are also valid (no error code). This will decrease the number of invalid cloud mask retrievals in extremely bright cloud situations.

Cloud fraction data from the MODIS cloud mask was compared to that from the CLAVR (Clouds from AVHRR). Figure 11 shows the two data sets with polar regions excluded. There is good agreement on major cloud features throughout most of the domain but differences are seen in areas dominated by partly cloudy skies. MODIS can better resolve the smaller-scale features with more spectral channels and 1-km resolution than can CLAVR which utilizes 2x2 blocks of 4-km GAC (Global Area Coverage) data and only five channels.



Figures 5, 6, 7, and 8. From top left: Band 2 (.87 μm) and Band 31 (11 μm) imagery, v. 3.0 and v. 3.1 cloud mask imagery. Note the improvement in the Lake Chad area. Area of uncertain and cloud in upper right is due to dust storm seen in Band 31 image. Data from 10:05 UTC December 10, 2000.



Figures 9 and 10. Version 3.0 and 3.1 250 meter cloud masks in Lake Chad region. Data is from 10:05 UTC December 10, 2000.

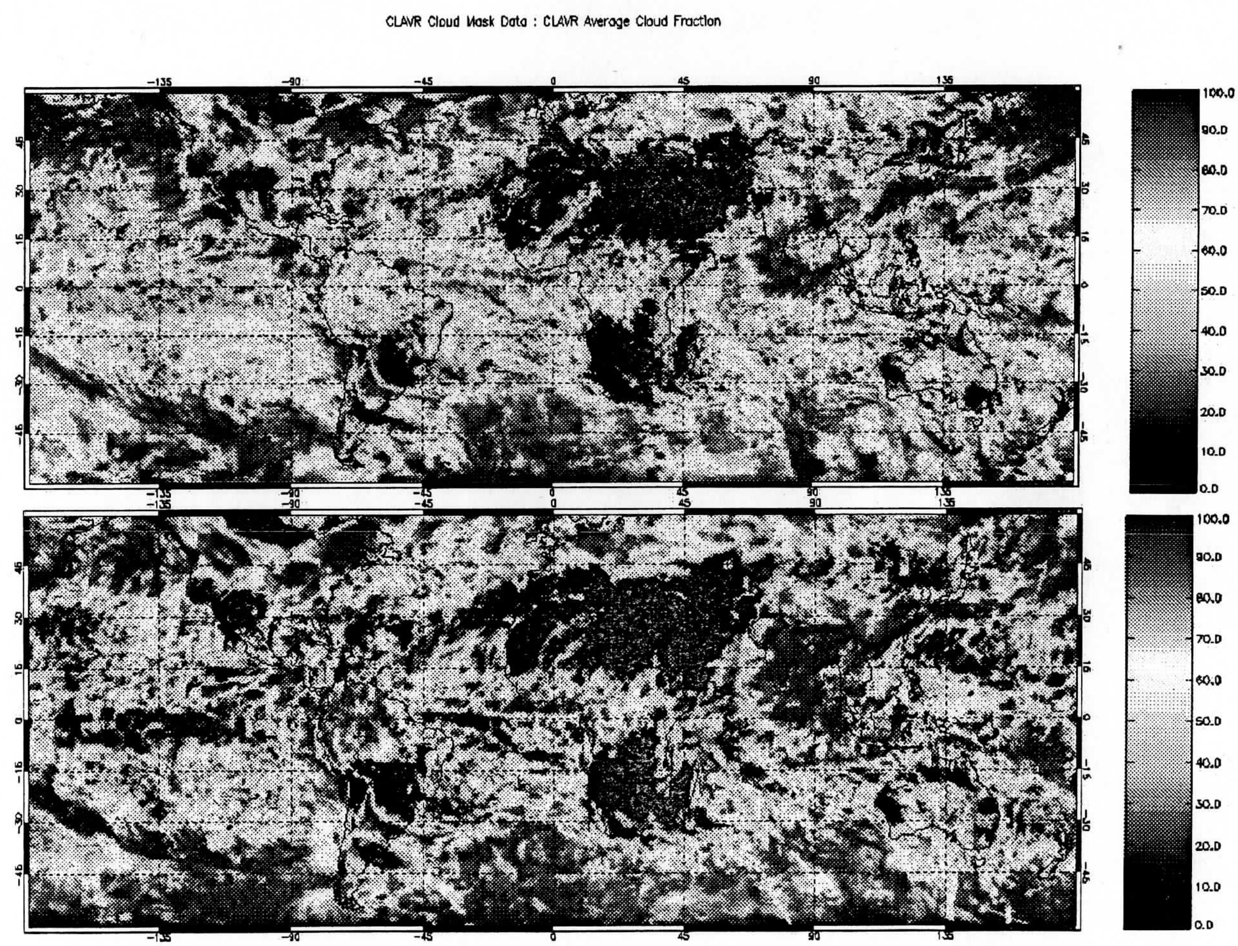
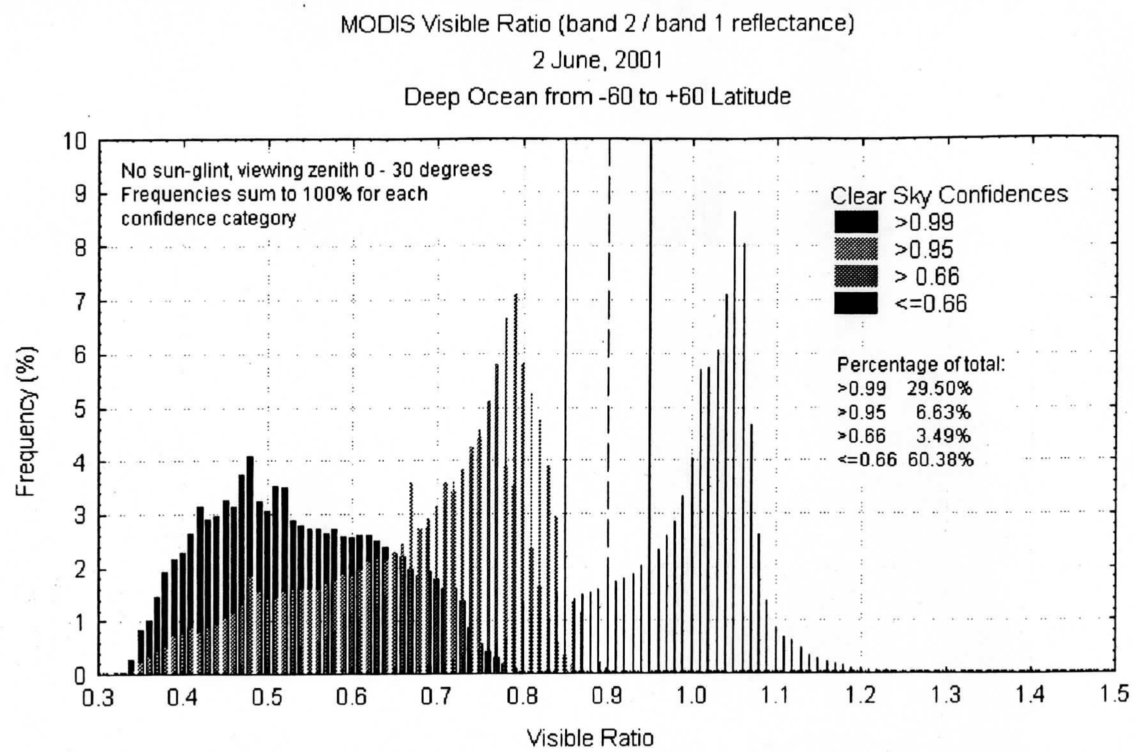


Figure 11. One day global CLAVR 4-km GAC (top) and MODIS (bottom) cloud fraction results.



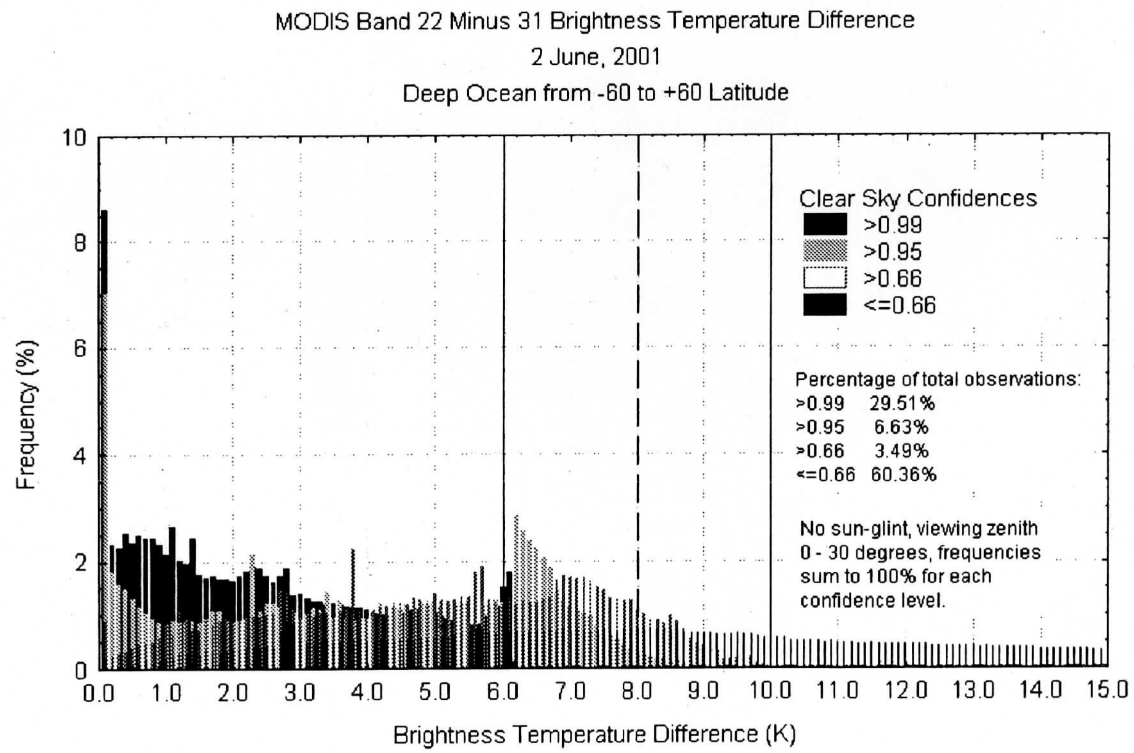


Figure 12 (a and b). Visible Ratio (top) and Band 22 minus Band 31 (bottom) as a function of clear sky confidence.

Clear-sky Spectral Greenhouse Parameter

Frey et al (1995) used collocated HIRS/2 and AVHRR observations in an analysis procedure known as CHAPS (Collocated HIRS and AVHRR Products), to study the spectral greenhouse parameter. They demonstrated that the spectral greenhouse parameter at wavelengths sensitive to middle and upper atmospheric water vapor content is dependent on SST via its connection to large-scale atmospheric circulation patterns. They also showed that the variability of the spectral greenhouse parameter is strongly a function of latitude at these wavelengths, as well as in spectral regions sensitive to lower level water vapor. Standard deviations are largest in the tropics and generally decrease poleward. In contrast, variability in the spectral regions sensitive to upper tropospheric temperature peaks in the middle-latitudes and has its minimum in tropical latitudes. This study was limited by the spatial resolution of the HIRS/2 and the calibration of the two instruments (Frey, R. A., S. A. Ackerman, and B. J. Soden, 1995: Climate parameters from satellite spectral measurements. Part I: Collocated AVHRR and HIRS/2 observations of the spectral greenhouse parameter. (*Jour. Clim.* **9**, 327-344.1995).

Using MODIS-determined cloud free radiances we have computed an initial estimate of the spectral greenhouse parameter, defined:

$$\frac{B_\lambda(SST)}{I_\lambda(MODIS)}.$$

Figure 13 shows the relationship between this parameter and sea surface temperature (SST). The vertical arrows show the limits of the CHAPS study. The higher spatial resolution of MODIS has extended the results from CHAPS and demonstrates two new regions in the relationship between G and SST. The first is due to warmer SST's and results from observations over the Arabian Sea where the SST is very warm but the upper atmosphere is dry due to subsidence. The second regime occurs at colder SST. The reasons for this are still under investigation.

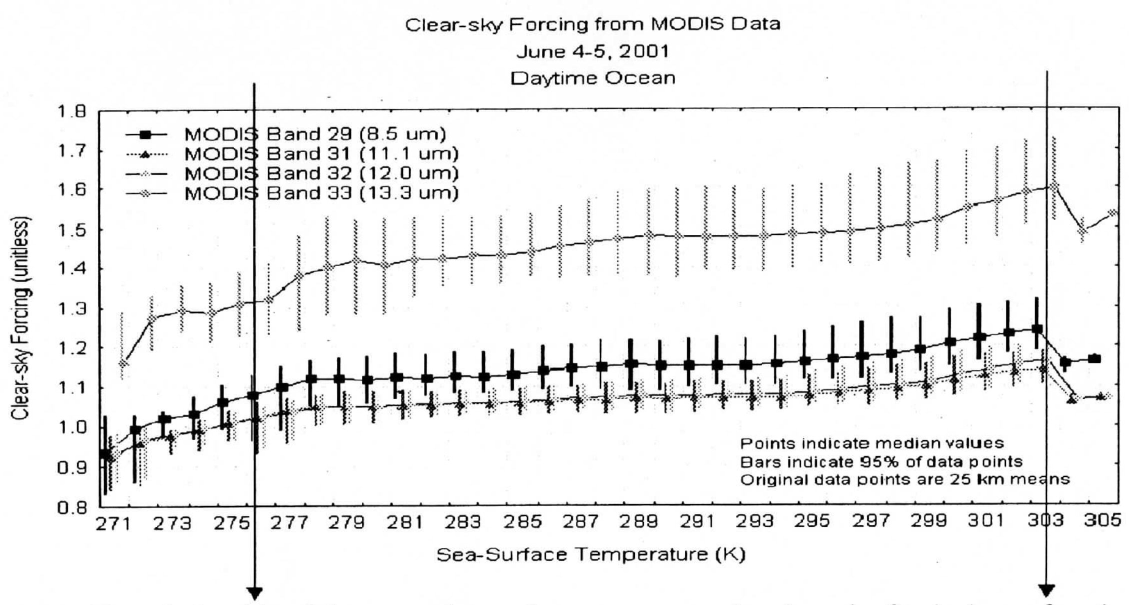
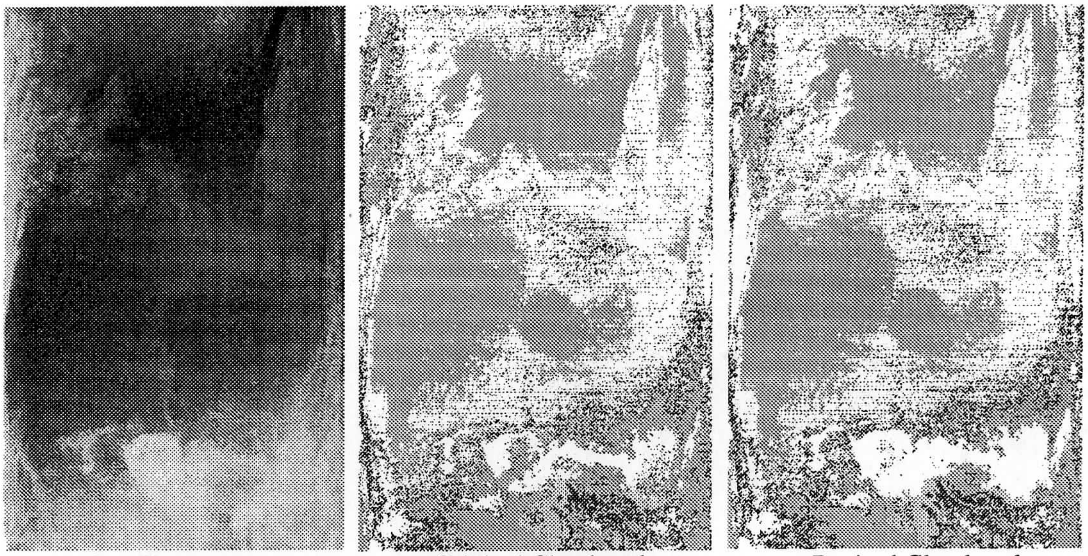


Figure 13. The relationship of the spectral greenhouse parameter (or clear-sky forcing) as a function of SST for 4 MODIS channels. The vertical arrows show the limits of the CHAPS study.

Polar Cloud Detection

Cloud detection issues specific to the polar regions continue to be investigated. While some problems exist in daytime cloud detection, overall the cloud mask performance is good when sunlight is present. Most of our effort has focussed on nighttime cloud detection.

Specifically, the dependence of the 11-4 μm brightness temperature difference test over snow at night has been evaluated, and a temperature dependent threshold is being evaluated. Three temperature ranges are defined, with static thresholds for the coldest and warmest categories and a linear temperature dependent threshold for the middle category (235-265 K). Figure 14 illustrates the effect of the revised test, where some apparently cloudy areas are missed in the original test but correctly detected with the revised test.



Satellite Image Original Cloudmask Revised Cloudmask
green = clear , cyan = probably clear, red = uncertain, white = cloudy

Figure 14. A sample MODIS image (11 μm temperature at left), the current cloud mask (middle), and the cloud mask with a temperature-dependent 11-4 μm cloud test. Data are from 03:35 UTC on May 30, 2001.

The 11-6.7 μm BTD test is useful for detecting deep inversions, particularly over Antarctica. Can shallower inversions be detected with bands that peak closer to the surface? Radiative transfer modeling and data analysis have been performed with the 13.3 μm CO_2 band (band 33) and the 7.2 μm water vapor band (band 28). Both peak lower in the atmosphere than the 6.7 μm band, which peaks near 500 mb. Preliminary results indicate that shallower inversions can be detected with band 33, in both the Arctic and the Antarctic and high and low elevations.

MODIS Cloud Top Properties (MOD06)

From the first days of MODIS data processing, it was noted that many cloud top pressure and effective cloud amount retrievals were missing in the MOD06 output file. The problem was identified and a fix proposed. The CO_2-slicing algorithm uses model output (GDAS) temperature and moisture profiles as inputs. Some simple checks on these input values are performed before use, one of them being that mixing ratios should be non-zero. However reasonable this may be, due to conservation of energy considerations these non-physical values are not removed by the processes that create the GDAS output fields. Since the sensitivity to atmospheric moisture content in the CO_2-slicing algorithm is almost negligible, the check may be discontinued with no ill effects.

A comparison of cloud top pressures via the CO_2-slicing algorithm generated from both MODIS and GOES (GOES Sounder Cloud Product) radiance data was performed. Cloud top pressure retrievals were collected and analyzed for 2-5 June 2001 over the continental United States and adjacent waters. Figure 15 shows a histogram of GOES minus MODIS cloud top pressures. Cloud pressure values from each data set were first averaged over 1-degree bins using the GOES data closest in time to MODIS orbital passes. In general, one sees good agreement between the two, with the peak in the difference distribution falling in the -25 to +25 mb difference class. A small bias can be seen towards higher GOES heights (smaller pressure values). These results must be considered preliminary with a more in-depth analysis to follow.

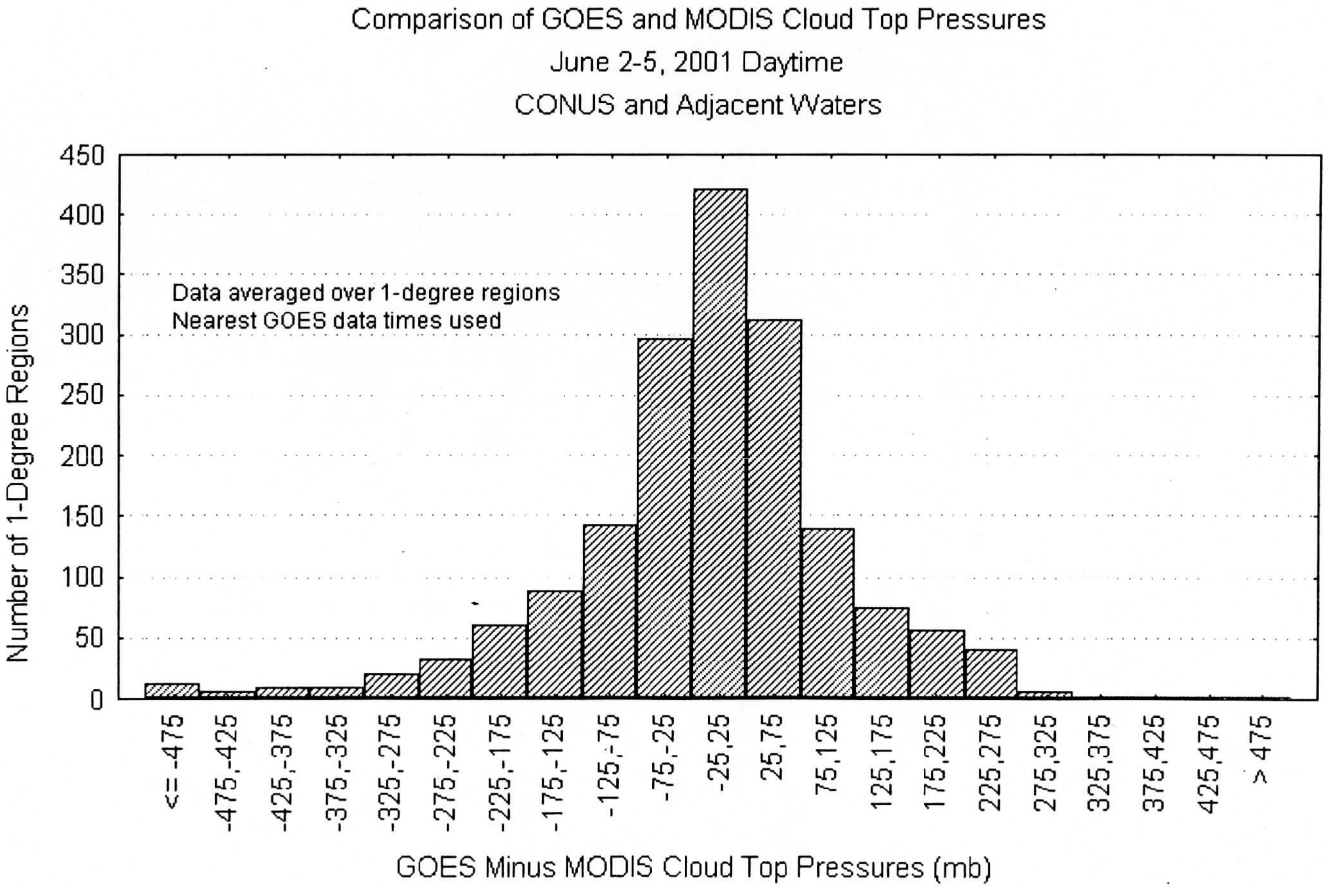


Figure 15. Histogram of GOES minus MODIS cloud top pressures for CONUS regions June 2-5, 2001.

Global Radiances and Cloud Top Pressure Tests

To investigate any possible Cloud Top Pressure (CTP) dependence on MODIS viewing angle, global CTP versus MODIS sensor zenith on 2 June 2001 has been analyzed. Figure 16 illustrates that CTPs between 300 hPa and 500 hPa have more distribution than other CTPs.

The radiances use in the CTP determination was also studied. Global mean radiance versus sensor zenith are shown in Figure 17 for all MODIS CO_2 bands (band 29, 31, 32, 33, 34, 35, and 36) on 2 June 2001. The solid line is for the radiance from the beginning of the scan (BOS) to nadir and the dashed line is the same from nadir to the end of the scan (EOS). The mean radiance from the BOS side is a little bit larger than the EOS side for band 33 (13.3 um) through band 36(14.2 um); the difference is as large as 2 $mw/m^2/ster/cm^{-1}$. For band 29, 31 and 32, the mean radiance from the BOS side is smaller than the other side only when zenith is from nadir to about 35°.

More studies of radiance and CTP dependence on scan angle are underway.

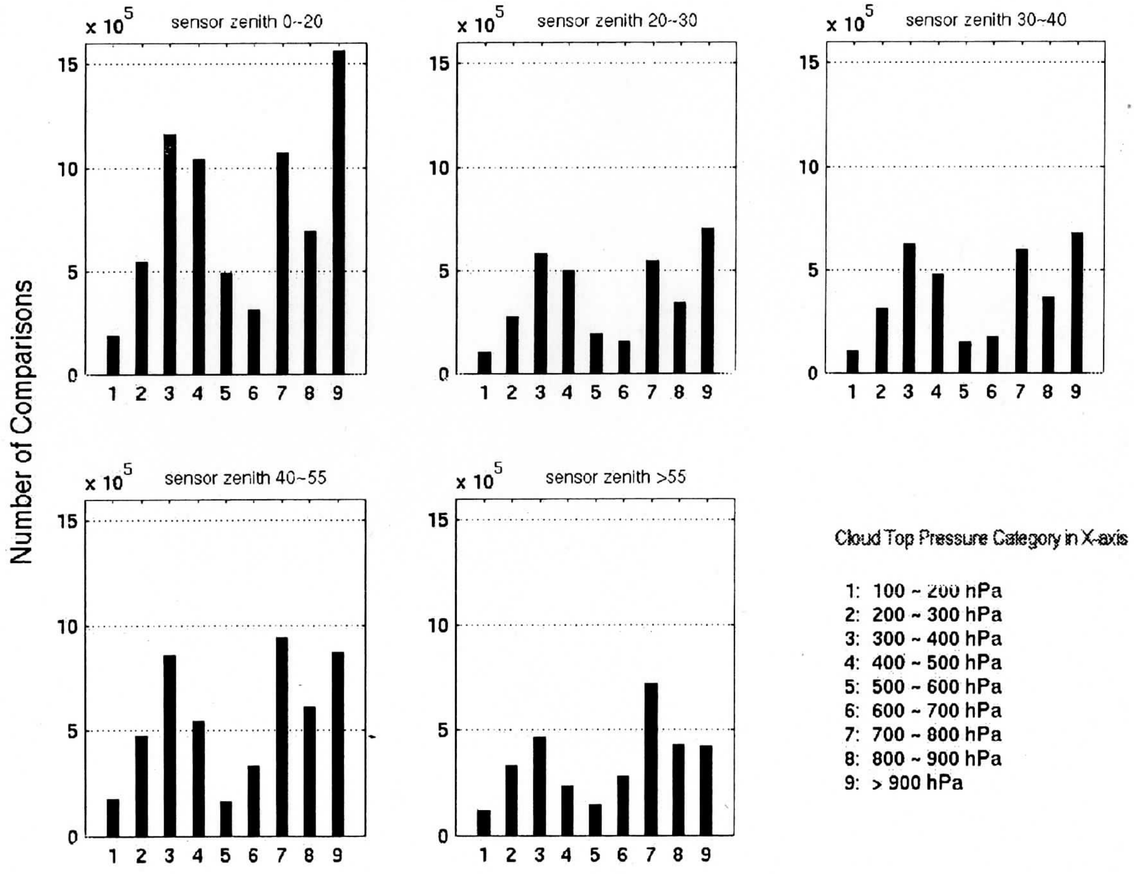


Figure 16. Global CTP separated by sensor zenith.

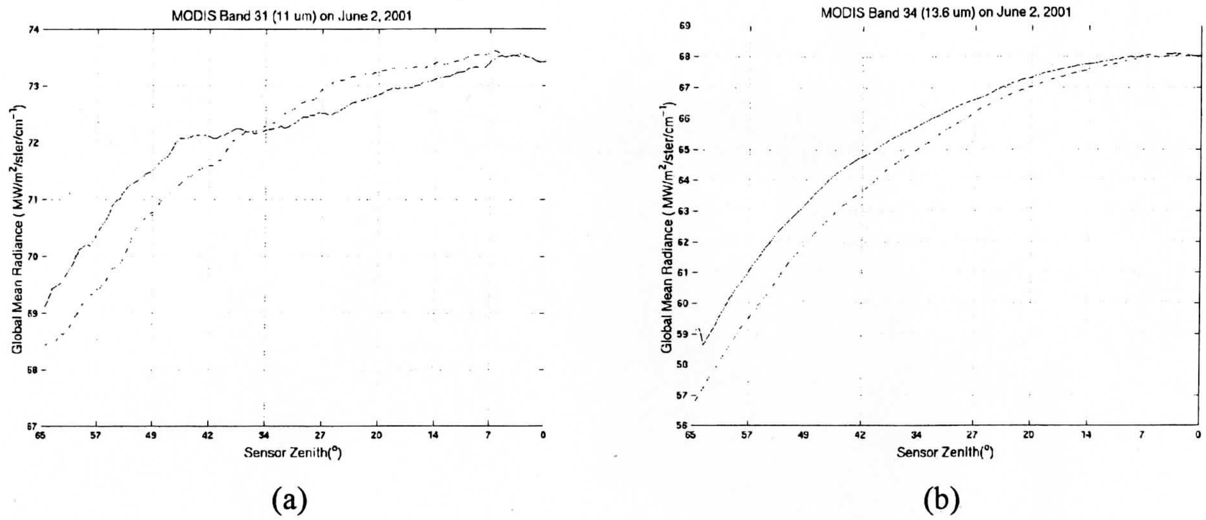


Figure 17. MODIS Global mean radiance vs. sensor zenith on 2 June 2001. The solid line is from the beginning of the scan to nadir and the dashed line is for the reverse side. (a) Window Band 31. (b) Band 34.

<u>MODIS Infrared Total Precipitable Water Product (TPW)</u>

The current operational MODIS Atmospheric Temperature and Moisture Profile Retrieval Algorithm Version 3.0 (MOD07) that was delivered to SDST on 1 April 2001 computes unrealistically moist total precipitable water (TPW) retrievals over desert regions (see Figure 18). In the previous semi-annual report, this problem was attributed to non-blackbody behavior in the shortwave infrared channels in deserts, namely that the surface emissivity of the deserts at 4.5μm is well below the blackbody value predicted by the algorithm. In that report, it was proposed that a solution would involve removing the short wave infrared bands (4.4 and 4.5μm, bands 24 and 25) from the regression algorithm, leaving only the ten infrared bands (6.7-14μm, bands 27-36). Further investigation revealed that this approach helps to avoid excessive moisture in desert areas, but it has the undesired effect of drying out other areas of the globe to unrealistically low values of TPW.

Alternative approaches to the desert problem have been investigated in the past six months, with particular emphasis on the influence of algorithm changes on all areas of the globe. This involves the difficult problem of validating the MODIS TPW in areas where little comparison data is available. Although we have made global comparisons with AMSU and GDAS, our validation has emphasized North America where GOES and the ARM-CART data are available for well-calibrated comparisons. We plan to expand the use of ARM-CART site validation data to include the Barrow, Alaska and Tropical Western Pacific sites in the next few months.

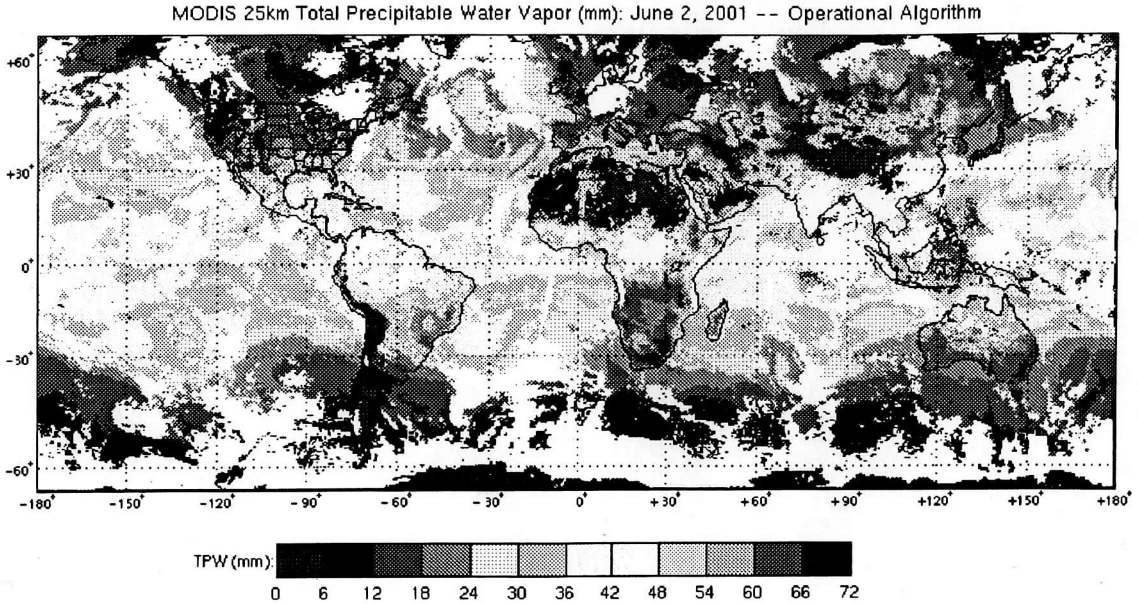


Figure 18. Global image of the operational version of MODIS TPW (mm) for 2 June 2001. This includes both ascending and descending orbits. Desert areas in northern Africa, Saudi Arabia, and the southwestern United States show unreasonably high values of TPW.

From these investigations, significant modifications are being considered for the MOD07 algorithm; delivery of a final version to SDST is pending in February 2002. The changes fall into four categories:

- *Predictors used in statistical regression algorithm*: The original algorithm used the brightness temperatures from individual MODIS bands 24, 25 and 27-36 as predictors for the statistical regression algorithm. Because the surface emissivity was not being properly accounted for in the shortwave infrared channels (24 and 25), this algorithm predicted too much moisture over deserts that have characteristically low emissivity. In the new algorithm, we use the difference between the brightness temperatures of these two bands as one predictor to replace the two individual bands. This removes the surface contribution that is roughly the same for both bands. Because we do not have the problem with surface emissivity over the ocean, we have experimented with using a separate set of predictors over the land (including the brightness temperature difference of bands 24 and 25) than over the ocean (including individual bands 24 and 25).

- *Estimates of instrument noise*: The operational algorithm used pre-launch estimates of NEdT and assumed a constant reference brightness temperature over all bands to convert to NEdR. The new algorithm includes post-launch estimates of instrument noise computed by Chris Moeller and corrects the problem with reference brightness temperature.

- *Training data set*: The existing NOAA-88 training data set includes over 7500 radiosonde profiles and surface data. Figure 19 shows that this data does not include very much information about scenes with very warm surface temperatures (11 μm brightness temperature > 300°K) such as those found in the Sahara Desert. To address this problem, we used new radiosonde data from 2001 in the Sahara Desert region. 900 new radiosondes, spread equally through the twelve months, met the criteria of relative humidity < 90% and physically reasonable behavior up to 100hPa. These radiosondes were included in the new training data set. Further, we have experimented with the training data set by partitioning it into five "zones" of 11 μm brightness temperature calculated by a forward model from the profiles. Each retrieval then uses only that subset of the training data that corresponds to the 11 μm brightness temperature observed by MODIS.

- *Radiance bias correction*: In order to investigate the radiance biases due to transmittance model and instrument errors, time and space co-located MODIS radiances and ground based atmospheric observations at the SGP ARM-CART were collected. The cases are clear-sky scenes when MODIS passed over the SGP-CART site with a viewing zenith angle less than 32 degrees. The brightness temperatures calculated by a forward model using observations at the CART site as input were then compared to the observed MODIS brightness temperatures for all bands to come up with biases. These preliminary biases, based on approximately 20 cases, are shown in Figure 20. Infrared window bands 31 and 32 show the largest biases, with MODIS observed brightness temperature 1.5 and 2.1°K warmer than that calculated by the PFAAST model. Global biases are needed for the final algorithm, and we have begun work computing them using NCEP-GDAS global analysis for the temperature and moisture profile input.

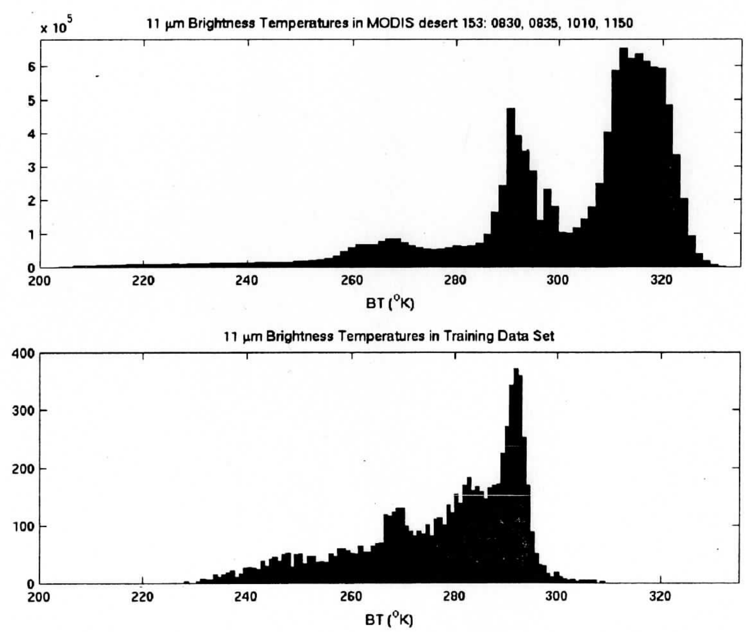


Figure 19. Histogram of actual MODIS 11μm brightness temperature observed in four granules over the Sahara Desert (top), and computed from a forward model calculation using the original NOAA-88 training profiles and surface data as input (bottom).

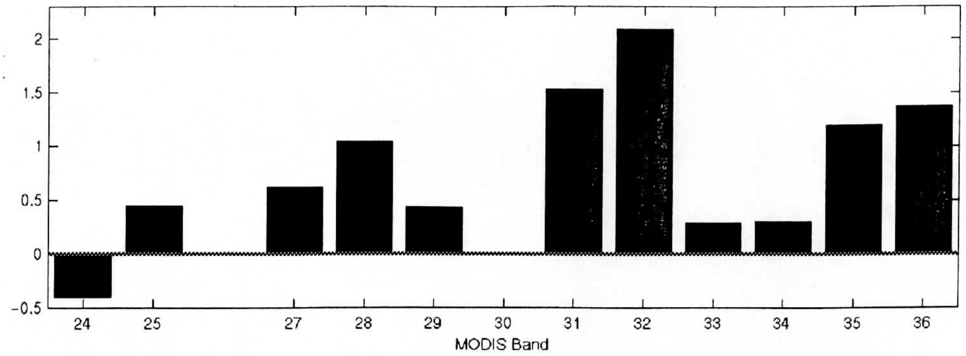


Figure 20. Preliminary bias adjustments (MODIS observed BT – calculated BT, °K) applied to the MOD07 algorithm to account for instrument error and biases introduced by the forward model calculation.

Validation of the MODIS TPW product is being undertaken through comparisons with other observations. These have been performed at three different spatial scales: (a) a single point at the ARM-CART site, (b) the regional scale with GOES, and (c) the global scale with ATOVS. These comparisons are reprocessed frequently as part of the ongoing algorithm development.

Point comparisons at the Southern Great Plains ARM-CART site in Oklahoma were made for 25 cases between 15 March and 1 December 2001 with clear skies at the time of the MODIS overpass. MODIS, GOES-8, and radiosonde TPW were compared to the microwave radiometer (MWR) measurement at the same time. Figure 21a shows the comparison for the operational and new versions of the MODIS TPW algorithm. The operational MODIS TPW is generally moister than the MWR, with an RMS difference of 6.08mm. The new algorithm is still too moist for low TPW, but agrees better with the MWR for higher TPW. The RMS difference for the new algorithm is 3.29mm. Figure 21b shows a comparison for the same cases using the new algorithm, but with the cases separated into day and night. This reveals that the new algorithm still has a consistent moist bias for both day and night cases when TPW is < 15mm. For higher TPW (> 15mm), the new MODIS algorithm shows fairly good agreement with the MWR. At night, however, MODIS is noticeably drier than the MWR for TPW > 15mm. These differences are currently being investigated using various combinations of the algorithm changes outlined in the previous section. We are also exploring the possibility of using a separate set of predictors for the night and day cases. At night, we could include some of the shorter wave infrared bands (22 and 23) that would include too much surface reflection during the day.

Regional Scale comparisons are being made with GOES-8 and GOES-10 over North America for a variety synoptic conditions every month. Figure 22 illustrates that MODIS captures more fine-scale features than GOES on 12 June 2001, especially in the moist tongue extending through Kansas and Oklahoma. For this case, operational MODIS is drier than GOES in Kentucky, Tennessee, and Mississippi but they show good agreement west of the Mississippi River with the exception of western Texas and Mexico. The region in western Texas and Mexico where MODIS shows very high TPW is the Chihuahuan Desert area and has much more reasonable values in the new version of the algorithm. By using the difference between MODIS bands 24 and 25 instead of using the bands individually, the excess moisture in the desert is no longer present in the new version. For 12 June 2001, the new algorithm decreases the TPW throughout

Kansas and Oklahoma, to a level that is too low when compared with GOES. This problem is still being investigated. The noise in the new MODIS image is due to taking the difference of two bands (24 and 25) that each have individual striping noise. We are investigating an approach that would remove this striping. Another case comparison on 19 November 2001 is shown in Figure 23. Here MODIS is generally more moist than GOES west of the front (indicated by the line of clouds) and somewhat drier east of the front through Mississippi and Alabama. The scatter plot comparing MODIS and GOES for this one granule shows a wet bias for MODIS TPW < 15mm and a more even scatter for higher TPW values. Finally Figure 24 shows one example of a comparison over northern Africa, where the operational version previously showed extremely high values of TPW (see Figure 18).

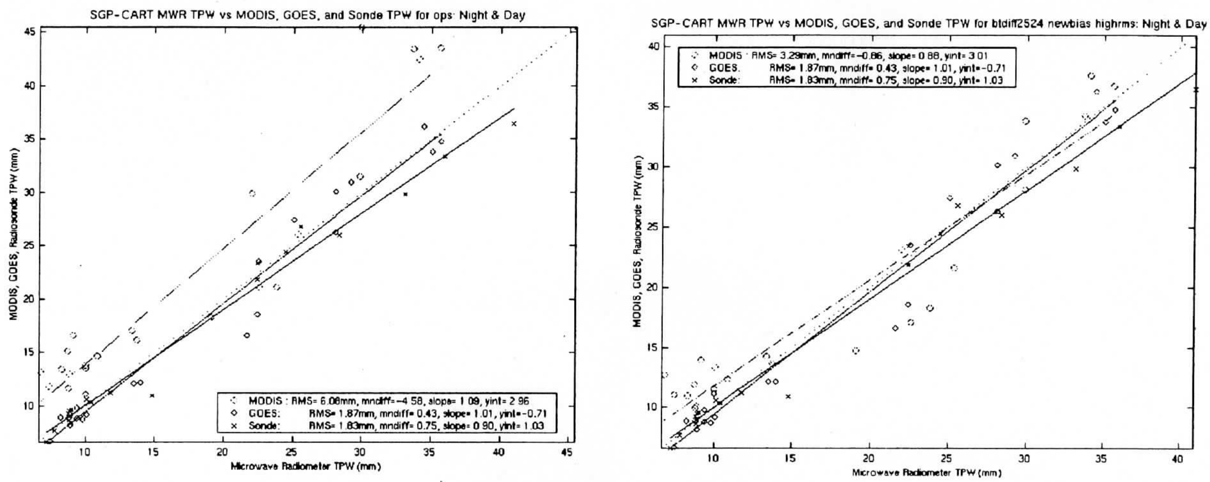


Figure 21a. Comparison of TPW measured by MODIS (red circles), GOES-8 (blue diamonds), and radiosonde (black cross) with microwave radiometer TPW for 25 clear-sky cases at the SGP ARM-CART site for the operational algorithm (left) and a new algorithm (right).

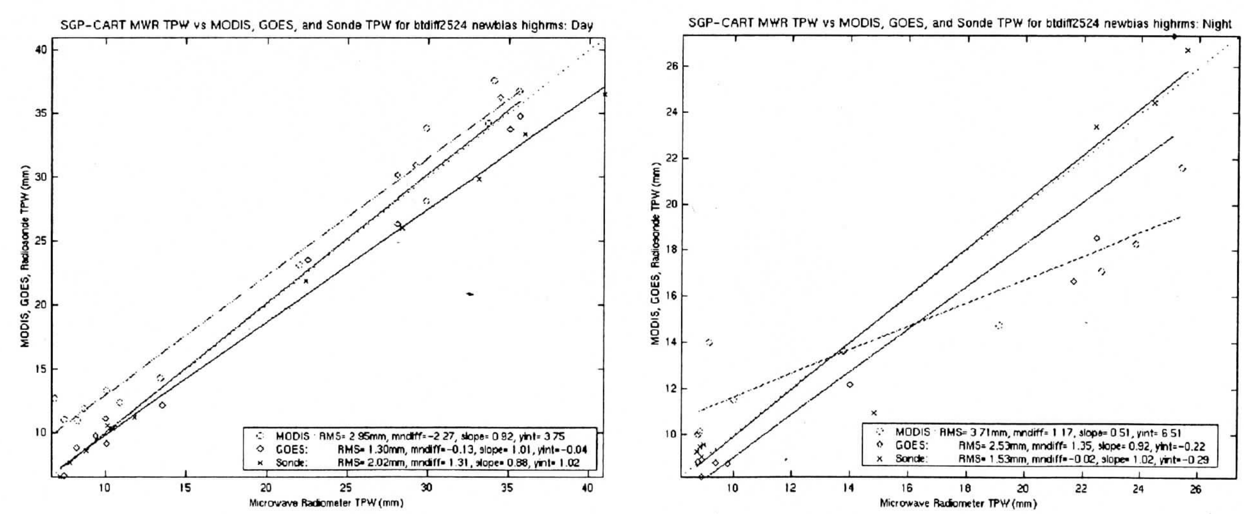


Figure 21b. Similar to 21a except for the new algorithm daytime cases only (left) and nighttime cases only (right).

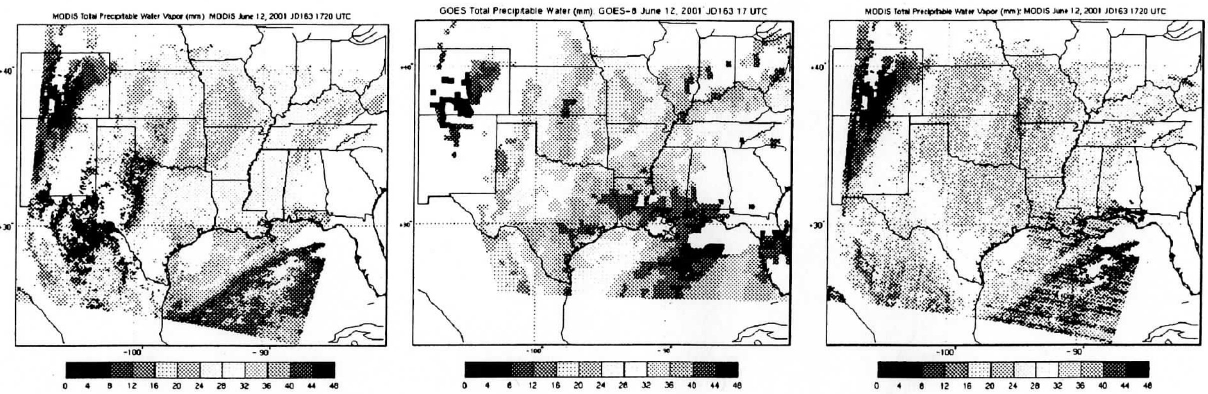


Figure 22. Example of a comparison between the MODIS operational (left) and GOES (center), and MODIS new (right) TPW for 12 June 2001 at 1720 UTC.

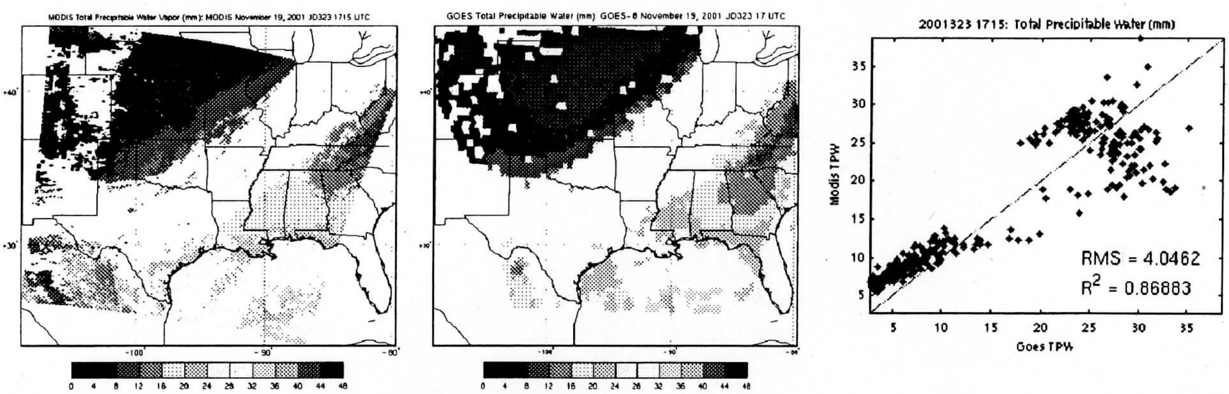


Figure 23. Example of a comparison between the MODIS operational (left) and GOES (center) TPW, for 19 November 2001 at 1745 UTC. The scatter plot (right) was created by first collecting MODIS and GOES onto a 25km equal-area grid then comparing only those grid points where both MODIS and GOES had a value.

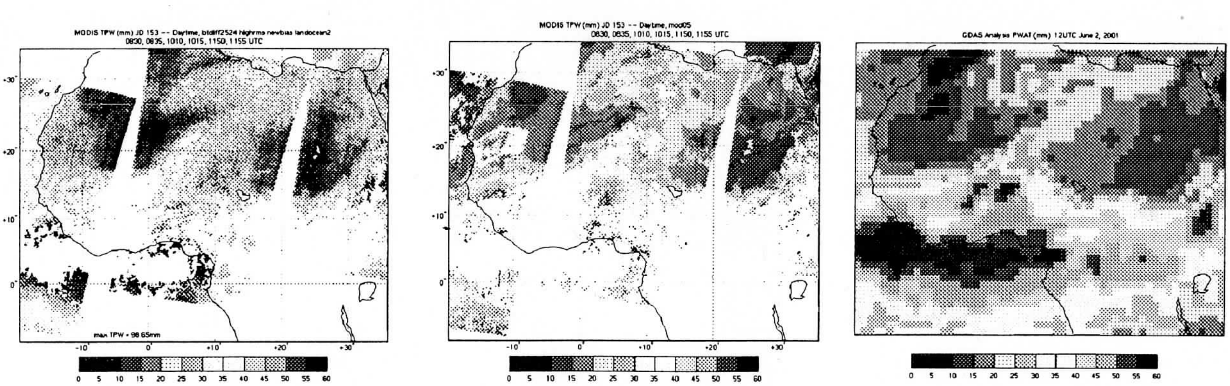


Figure 24. Comparison between TPW from the MODIS MOD07 IR new algorithm (left), MODIS MO05 near-IR daytime-only algorithm (center), and NCEP-GDAS analysis (right) for 2 June 2001 at 0830-1155 UTC. The white areas in the MODIS images correspond to regions where the cloud mask indicated a 95% confidence of clouds and, thus, the clear-sky MOD07 algorithm was not run.

Global scale comparisons are being made with the NOAA-15 Advanced Microwave Sounding Unit (AMSU) and with NCEP-GDAS analysis. Figure 25a shows the global image of TPW generated with a new version of the MOD07 algorithm for 2 June 2001. Comparison with the operational version of MOD07 (Figure 18) reveals that the problem of too much moisture in desert regions has been fixed. The new MODIS TPW shows fairly good agreement with the NCEP-GDAS precipitable water vapor shown in Figure 25b. Global average TPW for the old and new MODIS algorithm compared with NCEP-GDAS shows that on average over latitude bands, the new MODIS TPW agrees fairly well with NCEP-GDAS (see Figure 26).

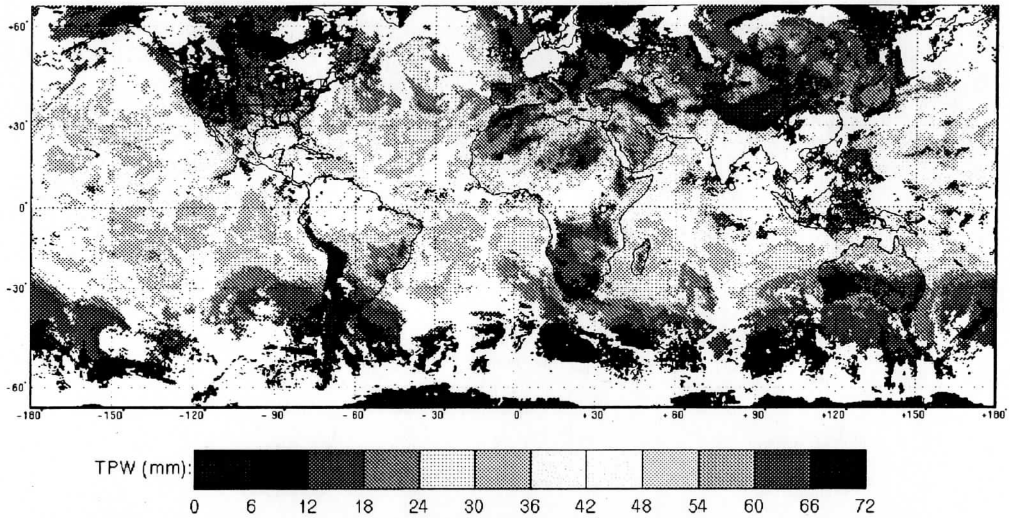


Figure 25a. MODIS new algorithm global TPW (mm) for 2 June 2001. The white areas indicate cloudy regions where this clear-sky algorithm was not run.

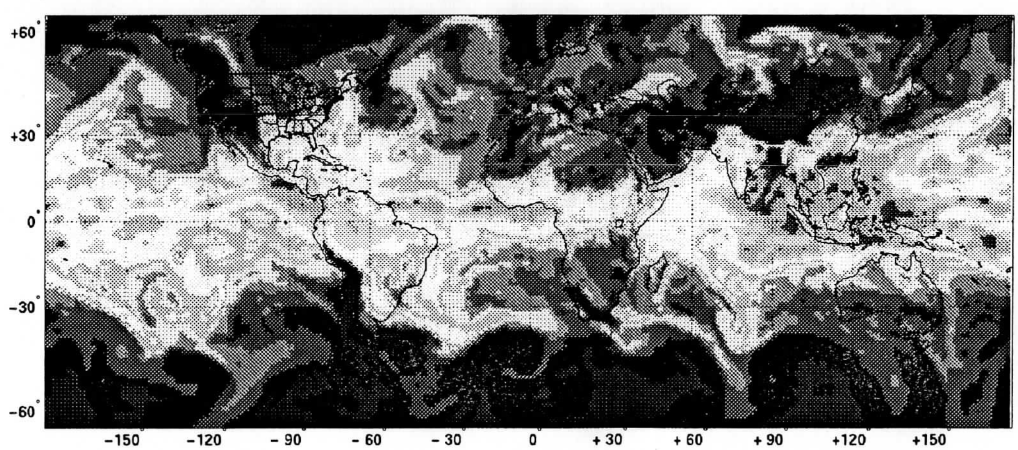


Figure 25b. NCEP-GDAS analysis Precipitable Water Vapor (mm) for 18 UTC 2 June 2001. The color scale is the same as shown in Figure 25a.

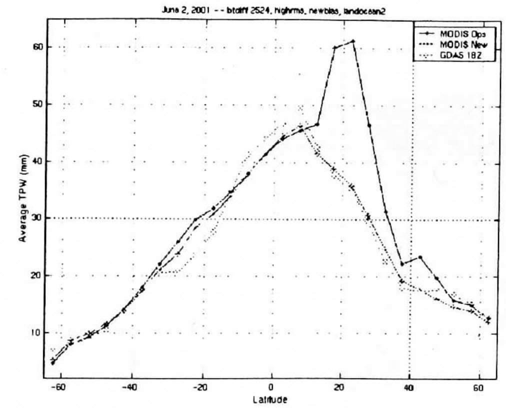


Figure 26. MODIS operational (blue), new MODIS experimental (red), and NCEP-GDAS (green) global average TPW for 2 June 2001:. High TPW values for the operational MODIS around 20° latitude reflect the unrealistically high TPW retrieved over deserts in that algorithm.

The MOD07 product also includes vertical layers of the temperature and moisture. An example of the 850hPa, 500hPa, and 300hPa temperature is shown in Figure 27.

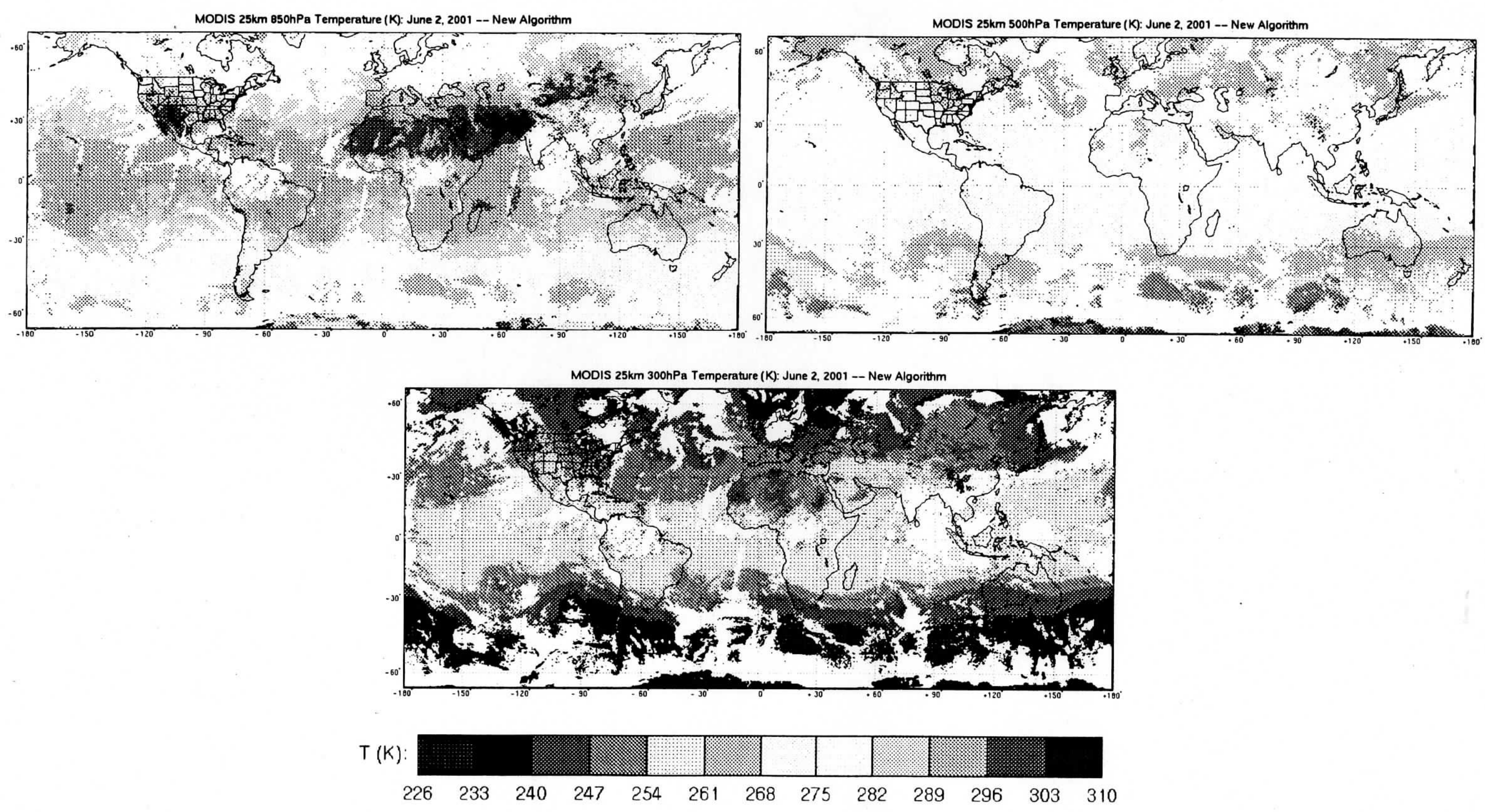


Figure 27. MODIS global atmospheric temperature (°K) on 2 June 2001 from the new algorithm for low (850hPa, top left), middle (500hPa, top right), and high (300hPa, bottom) levels in the troposphere.

Polar Winds

A case study data set of MODIS polar winds from ten consecutive days in March 2001 covering both polar regions has been generated. It was made available to the Data Assimilation Office (DAO), the European Centre for Medium Range Weather Forecasting (ECMWF), and the U.S. Navy. The DAO and ECMWF have performed model impact studies; results from the Navy are pending.

Lars Peter Riishojgaard of the DAO reported that the DAO is seeing a distinct impact of satellite-derived polar winds on model forecasts. Dr. Riishojgaard also stated that the MODIS winds-minus-forecast metric indicates a "fairly dramatic impact", especially for water vapor winds, and especially in the mid-troposphere. N. Bormann of the ECMWF reported that they are "quite happy with the results" of their study with the polar winds and "rather impressed about the quality of the winds". An example of the MODIS winds is given in Figure 28.

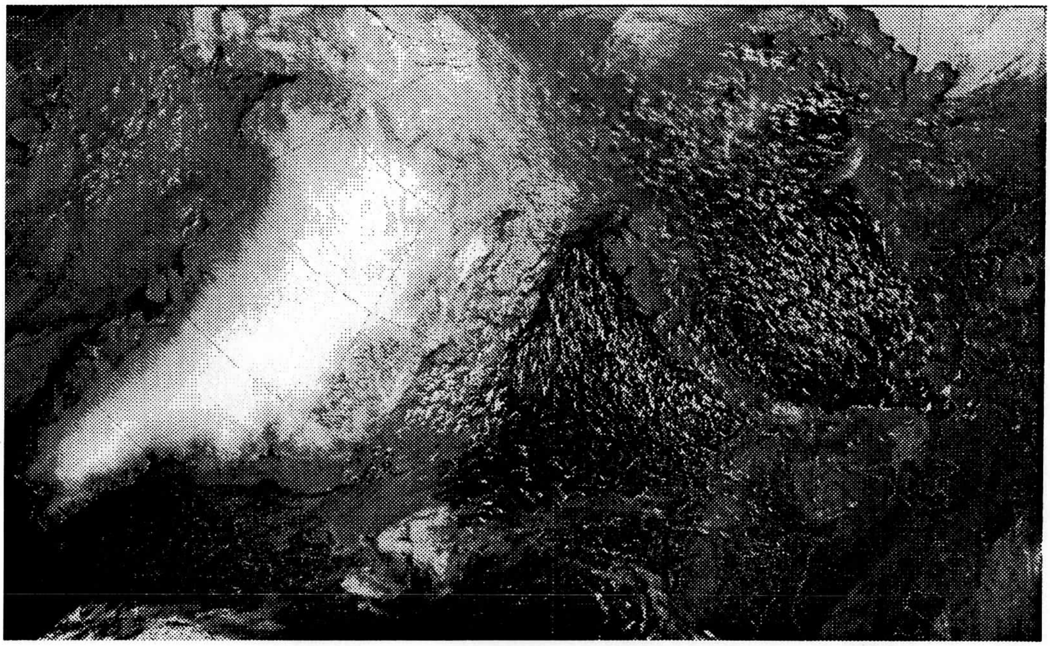


Figure 28. Daily composite of 11 micron MODIS data over half of the Arctic region with derived wind vectors, March 5, 2001. The winds were derived over a period of 12 hours. There are about 4,500 vectors in the image. Vector colors indicate pressure level - yellow: below 700 hPa, cyan: 400-700 hPa, purple: above 400 hPa.

Global Cloud Trends

Seasonal changes in semi-transparent or cirrus global cloud cover have been monitored with multi-spectral observations with the polar orbiting HIRS (High resolution Infrared Radiation Sounder) since June 1989. Trends in cloud cover, inferred from monthly averages of the HIRS cloud observation frequencies, indicate that there has been a decrease of more than 10% in the northern mid-latitudes in the winter months since January 1997. In North America and Asia, some regions show 20 to 30% decreases. Possible causes for these decreases in winter clouds mostly below 6 km are being explored.

Dr. Ehrhard Raschke, emeritus professor from the University of Hamburg, Germany, spent two weeks in October 2001 to help investigate the apparent cloud cover decrease. He asked whether the decrease of cloudiness, as observed in the data during winter, is the result of (a) errors in global model surface temperatures used to discriminate clouds from surface - this was found not to be the case or (b) a change in HIRS instruments – split window measurements for cloud detection did not change. He also noted that the HIRS thin cirrus detection should be greater than that of the International Satellite Cloud Climatology Project – ice clouds are more absorbing at 15 microns than they are reflecting at 0.5 microns.

These studies are continuing as the MODIS global cloud properties are being prepared to continue the HIRS and ISCCP cloud trends.

MODIS Direct Broadcast Software

Version 1.3 of the International MODIS/AIRS Processing Package (IMAPP) was released on 3 December 2001 (v1.3). The calibration algorithm and lookup tables were updated to versions 3.0.0 and 3.0.0.7, respectively. This version includes calibration data for the A-side electronics on MODIS following the outage which occurred from 15 June to 3 July 2001. The calibration algorithm in IMAPP v1.3 is date sensitive, and may be used for all Terra MODIS data back to February 2000. The geolocation algorithm now has improved interpolation/extrapolation of ephemeris and attitude information. This prevents bad latitude and longitude values toward the beginning and ending sections of a pass (originally released as a patch for IMAPP v1.2 on 31 August 2001).

Work commenced on adapting the operational MOD35 (Cloud Mask) and MOD06CT (Cloud Top Properties and Cloud Phase) software to run in Direct Broadcast mode. The goal is to create MODIS algorithms that are easy to install and run on a variety of UNIX platforms, and that require only the HDF4.1 toolkit. Flat-file datasets in ENVI BIL format were created to be used as input to the algorithms. Prototypes of the algorithms should be ready to run in January 2002.

Visualization Software

Prompted by communications with MODIS geolocation developer Robert Woolfe, the coregistration of the MODIS 1000, 500, and 250 meter bands was examined in detail. The goal was to enable the MODIS geolocation data at 1000 meter resolution to be interpolated accurately to 500 and 250 meter resolution. The key point is that the first 1000 meter earth view pixel stored in the L1B output file is co-registered with the first 500 meter earth view pixel on each scan, and also with the first 250 meter earth view pixel. As long as this fact is known, the intermediate geolocation values at 500 meter and 250 meter resolution can be either interpolated (if within the boundaries of the 1000 meter pixel locations) or extrapolated. Code was written in IDL for this purpose.

With the new geolocation interpolation software, it became possible to produce remapped MODIS images at map scales down to 250 meters with bowtie artifacts completely removed. The advantage of this method is that the freely available MODIS Swath to Grid Toolkit (MS2GT at http://nsidc.org/PROJECTS/HDFEOS/MS2GT/) can now be used to accurately resample the MODIS images to map projections. Two examples of such remapped images are shown in Figure 29. The same toolkit can be used (and has been tested) for remapping MAS, GOES, AVHRR without the need for McIDAS. The software that creates the realtime direct broadcast MODIS browse images at SSEC was rewritten to use the new interpolation and remapping algorithm, and the results can be seen at http://eosdb.ssec.wisc.edu/modisdirect/.

A new "resolution merge" algorithm for creating true color MODIS images at 250 m resolution was tested and implemented. The resolution difference between 500 m and 250 m resolution for the MODIS red band is used to create pseudo-250 m versions of the green and blue bands. The algorithm works as follows:

(1) Get the MODIS red, green, and blue bands (1, 4, 3) at 500 m native resolution,
(2) Interpolate the red, green, and blue bands at 500 m resolution to 250 m resolution (IDL code was developed for this purpose),
(3) Get the red band at 250 m native resolution,
(4) Compute the ratio = (red band interpolated to 250 m)/(red band native 250 m)
(5) Create pseudo-250 m versions of green = (green band interpolated to 250 m)/ratio and blue = (blue band interpolated to 250 m)/ratio

The ratio encodes the difference in spatial resolution between the red band at 500 meter and 250 meter resolutions. This information is then applied to the green and blue bands to simulate 250 meter resolution. The images shown in Figure 29 use this technique to create 250 meter green and blue bands.

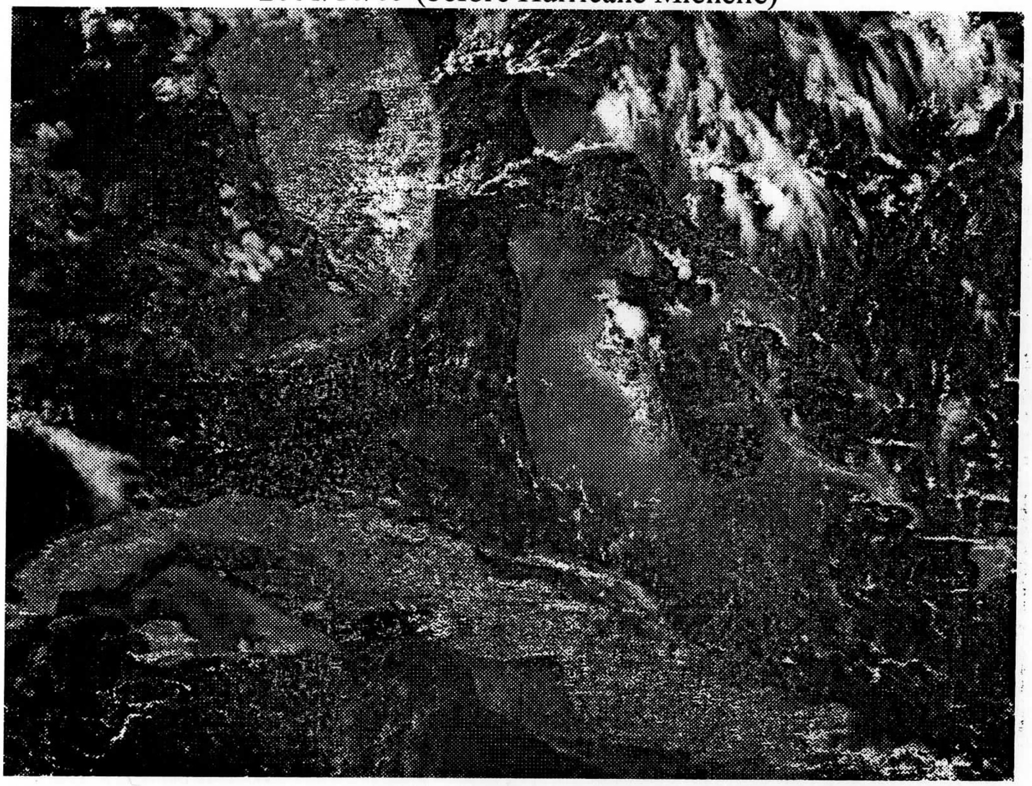
Images created at SSEC featured on NASA Earth Observatory

World Trade Center, 11 September 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=5154

Early Snowstorm in Northern Plains, 24 October 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=5202

Corsica and Sardinia, 7 December 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=6261

2001/10/05 (before Hurricane Michelle)



2001/11/06 (after Hurricane Michelle)

Figure 29. Remapped MODIS images of S. Florida, Bahamas, and Cuba

Scanner's note

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MEETINGS/CONFERENCES

Bryan Baum, Rich Frey, Shaima Nasiri, Liam Gumley, and Paul Menzel presented a paper entitled "Remote sensing of cloud height and cloud thermodynamic phase using MODIS data" at the special MODIS session of the IGARSS meeting in Sydney, Australia, July 9-13, 2001.

Chris Moeller gave a presentation entitled "Radiometric evaluation of MODIS emissive bands through comparison to ER-2 based MAS data" at the EOS VI Conference in San Diego, CA, August 1-3, 2001.

Chris Moeller presented a poster entitled "Evaluation of MODIS emissive band radiometric performance using MAS data collected during TX-2001" at the AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, October 15-18, 2001.

Chris Moeller and Dan LaPorte attended a MAS Instrument meeting at Ames Research Center, San Francisco, CA, November 13-15, 2001.

Chris Moeller gave a presentation on MODIS instrument performance at the MODIS Atmosphere Group and MCST Calibration Meetings in Baltimore, MD, December 17, 2001.

Liam Gumley attended the EOS Direct Broadcast United States user's meeting, Welches, OR, September 4-6, 2001.

Liam Gumley presented a poster entitled "MODIS Direct Broadcast Reception, Processing, and Applications" at the AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, October 15-18, 2001.

Paul Menzel, Steve Ackerman, Chris Moeller, Liam Gumley, Rich Frey, Suzanne Seemann, Hong Zhang, and Dan LaPorte attended the MODIS Science Team Meeting in Baltimore, MD, December 17-19, 2001.

Paul Menzel gave a series of lectures on Remote Sensing at the invitation of the Istituto di Scienze dell'Atmosfera e dell'Oceano - Consiglio Nazionale delle Ricerche (Italian National Council for Research) in Bologna, Italy to twenty students from six different Italian research institutes 4 – 10 September 2001. Many examples of MODIS data were included.

Paul Menzel, Steve Ackerman, Rich Frey, Liam Gumley, Chris Moeller, Jun Li, Suzanne Seemann, Bryan Baum and Hong Zhang attended the AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, October 15-18, 2001.

Rich Frey, Bryan Baum, Shaima Nasiri, Paul Menzel, Steve Ackerman, and Liam Gumley presented a poster entitled "Global Daytime and Nighttime Frequencies of Cloud Thermo-dynamic Phase as a Function of Cloud Temperature Using MODIS Data" at the AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, October 15-18, 2001.

Rich Frey, Steve Ackerman, Paul Menzel, Liam Gumley, Chris Moeller, Kathy Strabala, and Jim Hawkinson presented a poster entitled "MODIS Cloud Mask: An Update and Validation" at the AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, October 15-18, 2001.

Shaima Nasiri, Bryan Baum, David Turner, and G. Mace presented a paper entitled "Comparison of MODIS cloud height and cloud thermodynamic phase to ARM CART site measurements" at the 8th scientific assembly of IAMAS (International Association of Meteorology and Atmospheric Sciences), Innsbruck, Austria, July 10-18, 2001.

Suzanne W. Seemann, Liam E. Gumley, Jun Li, W. Paul Menzel, and Tim J. Schmit presented a poster entitled "MODIS/TERRA Total Precipitable Water Product Evaluation" at the AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, October 15-18, 2001.

PAPERS

Key, J., P. Yang, B. Baum, and S. Nasiri, 2001, Parameterization of shortwave ice cloud optical properties for various particle habits, *J. Geophys. Res.*, accepted (October 2001).

Key, J., D. Santek, C.S. Velden, and W.P. Menzel, 2001, Cloud-drift and water vapor winds in the polar regions from MODIS, Proceedings of the 11th Conference on Satellite Meteorology and Oceanography, American Meteorological Society, Madison, Wisconsin, 15-18 October 2001, 320-323.

Li, J., W. P. Menzel, Z. Yang, R. Frey, and S. Ackerman, 2002: High spectral resolution surface and cloud type classification from MODIS multi-spectral band measurements, submitted to Journal of Applied Meteorology.

Ma, Xia Lin, Z. Wan, C. C. Moeller, W. P. Menzel, L. E. Gumley, and Y. Zhang: Simultaneous retrieval of atmospheric profiles and land-surface temperature/emissivity from Moderate Resolution Imaging Spectroradiometer thermal infrared data: extension of a two-step physical algorithm. Accepted for publication in Applied Optics, March 2002 issue.

Moeller, C. C., D. D. LaPorte, H. E. Revercomb, and W. P. Menzel: "Radiometric evaluation of MODIS emissive bands through comparison to ER-2 based MAS data. Earth Observing Systems VI Conference, SPIE Annual Meeting, San Diego, CA, Aug 1-3, 2001.