INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

SEMI-ANNUAL REPORT FOR JULY – DECEMBER 2002

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Contract NAS5-31367

ABSTRACT

In the last six months, UW characterized the Aqua data with regard to calibration, striping, and noise; a field experiment (TX-2002) was conducted Nov-Dec 2002 to validate clear sky radiances from Aqua and cloudy sky products from Terra. UW made a few adjustments to the operational algorithms for cloud mask, cloud top properties, and atmospheric profiles (MOD35, MOD06, and MOD07) in response to validation data and to accommodate the characteristics of the Aqua MODIS data. Near real time processing of polar winds was started and weather forecast impact studies at the DAO and ECMWF continued. MODIS global cloud top properties were studied for tropical, mid-latitude, and polar regional differences. The International MODIS and AIRS Processing Package incorporated Aqua ingest and processing capabilities for calibrated geo-located radiances, cloud mask, atmospheric profiles; and cloud top properties and started posting products in real time for web access. Aqua MODIS and AIRS data were combined to investigate the cloudiness within an AIRS pixel. The three UW ATBDs (cloud mask, cloud properties, and atmospheric profiles) were updated and posted on the web; the data products handbook was also updated with more current references and product examples. Eight MODIS publications were submitted and accepted with UW authors (lead or supporting).

TASK OBJECTIVES

Documentation and Publications

UW updated the cloud mask, cloud properties, and atmospheric profiles Algorithm Theoretical Basis Documents and participated in writing of seven MODIS articles that were accepted for publication (two in Journal of Applied Meteorology, three in IEEE Transactions on Geoscience and Remote Sensing, two in Journal of Geophysical Research). In addition the EOS Data Products Handbook sections relevant to the three UW product areas were updated with current references and product examples. Four conference papers were given and training sessions were conducted in Italy and Australia.

Shared Source Code Changes

Several changes were made to the UW shared source code. The ancillary data reader was modified so that both formatted and unformatted Reynolds sea-surface temperature files could be opened and read. Also, the GRIB (Gridded Binary) file reader was changed so that any of the GRIB files needed for processing could be accessed independent of the others. These changes were made with advice and assistance from the MODIS SDST (Science Data Support Team).

MODIS Infrared Calibration and Noise Evaluations

Investigations of Aqua MODIS L1B performance have begun with a goal to assess the radiometric accuracy and document the data quality of TIR bands. Early Aqua MODIS performance shows reductions in LWIR CO_2 band striping and NEDT compared to Terra

MODIS; Aqua MODIS water vapor bands also show improved performance. A field experiment (TX-2002) was held to collect ER-2 based data sets (MAS, S-HIS, CPL) for direct comparison to Aqua MODIS observations. Observations of clouds were also collected during TX-2002 for validating Terra MODIS Cloud Mask and Cloud Top Properties products. Correction coefficients for destriping Terra MODIS B26 (1.38μm) are applied in Collect 4 L1B data sets.

MODIS Cloud Mask (MOD35)

The final algorithm modifications were made for Collection 4 processing. Several nighttime land cloud tests were added or modified. Changes were also made to the snow detection algorithm. A switch was added so that MODIS band 7 (2.1 μm) is used in the NDSI (Normalized Difference Snow Index) test when processing Aqua data. Band 6 (1.6 μm) will continue to be used for Terra processing. An additional band 6 divided by band 7 reflectance threshold test was added.

MODIS Cloud Top Properties (MOD06)

A few changes were made to the CO_2-slicing algorithm during the past six months. These included proper specification of moisture profiles taken from the GDAS (Global Data Assimilation System) input data. An output product confidence flag was changed so that its value is always set to "highest quality" to accommodate proper Level 3 processing. The noise (NEDR) thresholds for the CO_2 absorption channels (33-36) were lowered for Aqua processing, to take advantage of the better radiometric quality from Aqua. This allows more frequent use of the complete CO_2-slicing algorithm. The Terra thresholds remain unchanged.

MODIS Infrared Total Precipitable Water Product (MOD07)

Evaluation of the Aqua MODIS MOD07 temperature and moisture products was started through comparisons with Terra MODIS, the GOES sounders, radiosondes, and the microwave radiometer at the ARM SGP-CART site. The Aqua MODIS infrared radiances have significantly less noise from striping, so the image quality of retrieved products such as total precipitable water vapor (TPW) are much improved. Radiance bias calculations have been made using Aqua MODIS data. Improvements have been made in the surface level in the moisture integration routine. These changes are currently being tested for final implementation into the Aqua MODIS MOD07_L2 algorithm and a delivery of an updated version to the GSFC DAAC and UW IMAPP for direct broadcast processing is planned for February 2003.

Polar Winds

Over the last six months UW has completely automated the real-time processing of MODIS data for polar wind retrievals. MODIS level 1b granules for both north and south polar regions are obtained through the NOAA "bent pipe", winds are processed at UW, and polar winds are available for DAO and ECMWF within 3-6 hours after MODIS views any given area. Aqua MODIS data are now being processed in addition to Terra MODIS data. Real-time MODIS wind plots are available on the Web at http://stratus.ssec.wisc.edu/products/rtpolarwinds. ECMWF plans to put the winds into their operational system in January 2003.

Realtime Aqua MODIS Processing

SSEC began receiving raw Aqua MODIS data routinely via direct broadcast on 12 July 2002. Since October, all Level-1 and Level-2 IMAPP products have been created routinely for every Aqua pass, including calibrated radiances and geo-location; cloud mask, atmospheric profiles; and cloud top properties. Real-time Aqua MODIS products from SSEC are already in use by customers including the NASA/MSFC Short-term Prediction and Research Transition Center (see http://www.ghcc.msfc.nasa.gov/sport/sport_featured.html).

WORK ACCOMPLISHED

<u>MODIS Infrared Calibration and Evaluation of On-Orbit Performance</u>

Aqua MODIS performance evaluation was started. Several issues affecting Terra MODIS were reduced or eliminated on Aqua MODIS through pre-launch hardware fixes and better instrument characterization. Early performance assessment indicates that Aqua MODIS TIR bands in general are much improved over those of Terra MODIS.

Aqua MODIS LWIR CO2 bands have reduced striping and reduced NEDT. This is demonstrated for B34 (13.6 μm) in Figure CCM1. The improved LWIR CO2 band performance in the Aqua data restores the utility of these bands for the MODIS Cloud Top Properties product. Influence by a noisy detector 5 (Product Order) of B36 on Aqua has been removed by interpolating this detector. The optical leak from 11 um into bands 32 - 36 on Terra (known as PC crosstalk) has been effectively eliminated on Aqua by a prelaunch hardware fix. This greatly improves the radiometric integrity of these bands on Aqua, making it likely that they meet their respective pre-launch radiometric specification (0.5% for B32; 1.0% for B33-36).

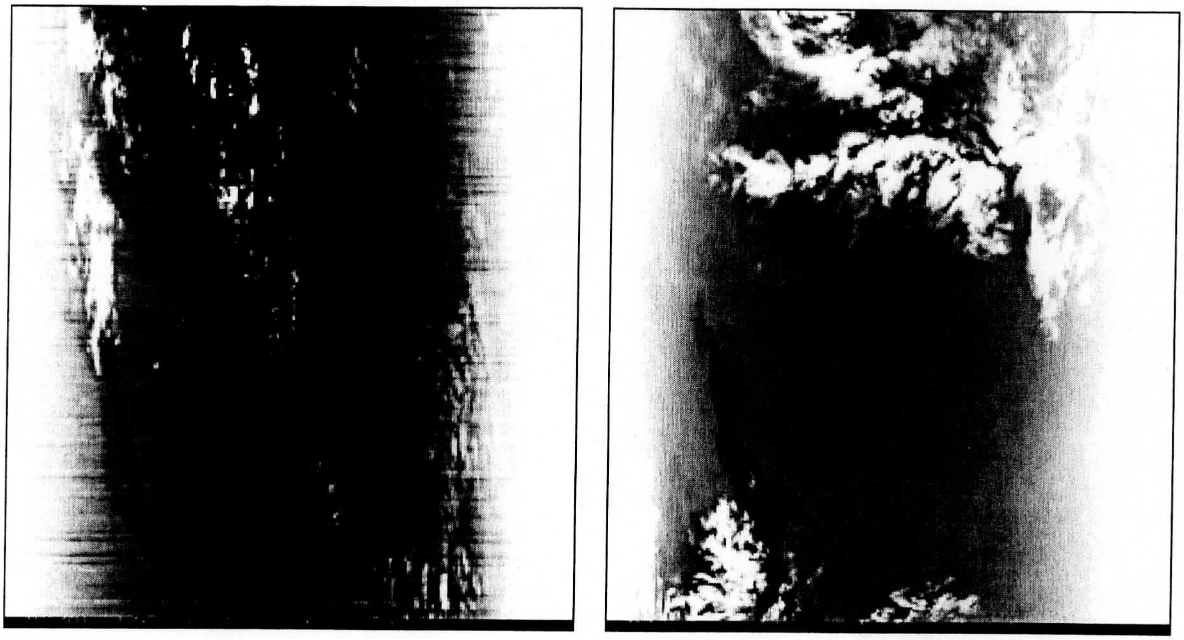


Figure CCM1. Terra (left) and Aqua (right) MODIS B34 (13.6 μm) images on 25 June 2002. Aqua MODIS data quality in the LWIR CO2 bands is much improved over that of Terra.

The influence of the MODIS scan mirror Response versus Scan (RVS) on the LWIR B27 – 36 calibrated signal has also been reduced on Aqua MODIS through excellent pre-launch characterization. This is demonstrated in the left panel of Figure CCM2 for B36 using on-orbit across track brightness temperature profiles. The Terra across track profile (blue) shows warmer (1 to 2 K) temperatures at begin-of-scan (BOS, on the left side of graph) compared to end-of-scan (EOS, right side of graph); Aqua MODIS on the other hand shows a nearly symmetrical across track profile from BOS to EOS. The Terra RVS characterization has been the subject of considerable investigation in the Terra post-launch era; the Aqua RVS correction is based on improved pre-launch characterization of the Aqua MODIS scan mirror and aft optics. The improved RVS characterization on Aqua has effectively removed the influence of the scan mirror reflectance variation across track on LWIR bands and thus largely in Aqua MODIS Level-2 products. This reduces the urgency for post-launch RVS characterization on Aqua MODIS, although scan mirror and optics degradation on-orbit continue to be a consideration. B35 in the right panel of Figure CCM2 shows similar characteristics as B36; Aqua MODIS shows a symmetrical cross track profile. The Terra MODIS on-orbit analysis has been effective at eliminating most but not all of the scan mirror influence in B35 (still some small asymmetry exists from BOS to EOS).

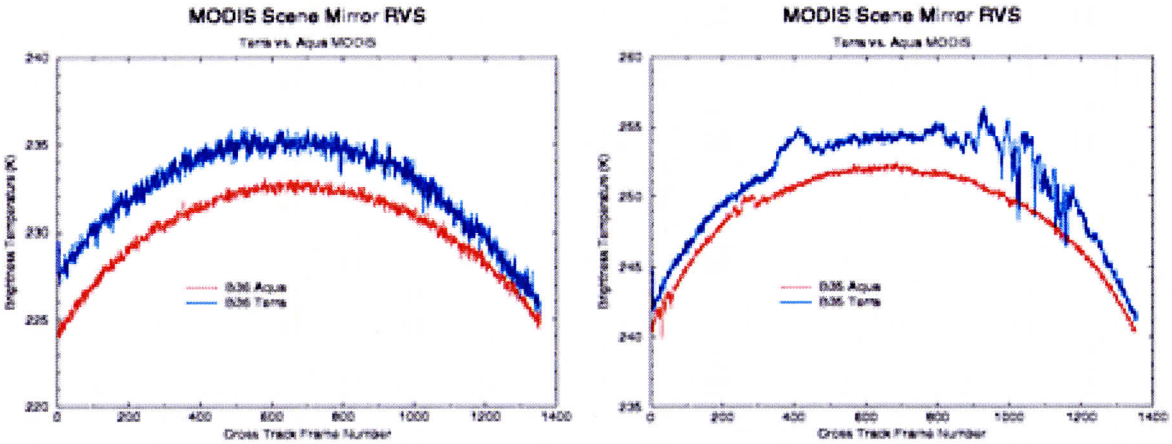


Figure CCM2. Terra (Blue) and Aqua (Red) MODIS cross track brightness temperature profiles for B36 (left) and B35 (right) using on-orbit data sets from 25 June 2002. Spikes in the profiles are caused by data noise (B36) and surface features over Mexico (B35). Cross track profiles collected from data of 25 June 2002 (same data granule as shown in Figure CCM1).

TIR band detector striping prevalent on Terra MODIS has been reduced on Aqua MODIS. This is largely due to the high quality performance of detectors in these bands on Aqua, i.e. noisy detectors contribute significantly to detector striping on Terra. Figure CCM3 demonstrates the significant reduction in striping on Aqua for the mid-tropospheric water vapor sensitive bands 27 and 28. This improvement has greatly reduced undesirable striping influences on the MODIS atmospheric profiles, cloud top properties, and cloud mask level 2 products. Some detector striping continues to be found in B23, B25, B29 and B30 on Aqua.

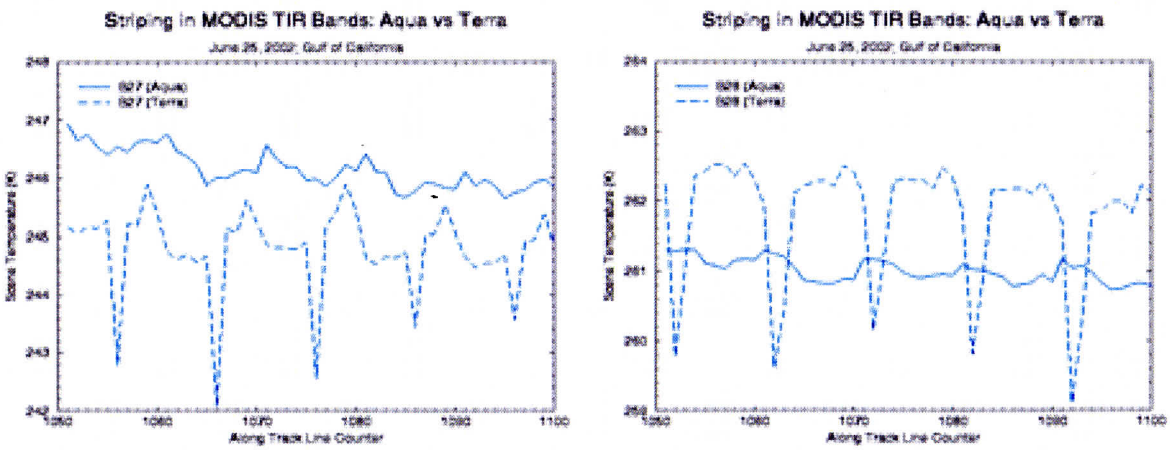


Figure CCM3. MODIS along track brightness temperature profiles for Terra (dashed) and Aqua (solid) MODIS B27 (left) and B28 (right). A significant reduction in detector striping is apparent in Aqua data compared to Terra.

Aqua MODIS data from 21 November 2002 was used to generate NEDT estimates for TIR bands based on clear sky scenes over the Gulf of Mexico. The noise is based upon the Root Mean Square (RMS) for a 35 x 35 element target box; it includes influence from random detector noise, detector and mirror side striping, and any natural variability present in the earth scene. These NEDT estimates are expected to be larger than detector random noise estimates. Figure CCM4 shows the Aqua MODIS TIR band NEDT estimates from 21 November 2002 along with the MODIS single detector random noise specification. The NEDT estimates of November 21 are very close if not within the detector random noise specification for most Aqua MODIS TIR bands. Band 21 NEDT is expected to be large due to truncation error for this low gain fire detection band. MWIR B20 – 23 NEDTs are likely elevated above random noise specification in this case by solar reflection off the water surface, increasing the natural variability in the target region. B23, 25, 29, and 30 NEDTs include some detector striping. B31 and B32 NEDTS exceed the random noise specification; probably due to natural variability in the earth scene (and to a lesser extent for B29 also). LWIR CO2 band 33-36 NEDTs are smaller than random noise specification (in contrast to the Terra MODIS CO2 bands).

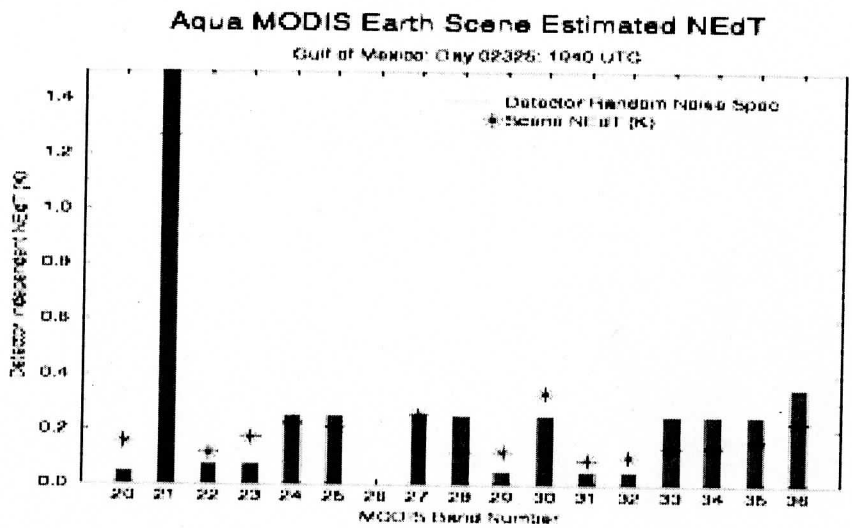


Figure CCM4. Aqua MODIS TIR band NEDT estimates for a clear sky scene over the Gulf of Mexico (21 Nov. 2002, 1940 UTC) using an RMS based technique. NEDT estimates (“star” symbols) include mirror side and detector striping, random noise and any natural variability present in the earth scene. The single detector noise specification (vertical red bars) are matched for many bands. This indicates that detector and mirror side striping influences are small for most Aqua MODIS TIR bands. Note that MWIR B20 – 23 (3.7 μm – 4.0 μm) estimates are inflated by the influence of sunglint in the earth scene.

The performance of Aqua MODIS B26 is nearly the same as that of Terra MODIS B26; it contains significant detector striping and unexpected surface reflectance. Forward model transmittances suggest that reflectance from the earth’s surface should not appear in B26 as long as the total column precipitable water exceeds about 15 mm (Figure CCM5). The cause of this unexpected behavior is not well understood, but may include out-of-band and electronic crosstalk influences. A correction procedure using B5 as a surrogate for contamination in Terra MODIS B26 has been successful at reducing striping and surface reflectance. A similar procedure is planned for Aqua MODIS B26 and expected to be ready for application in the 2nd quarter of 2003.

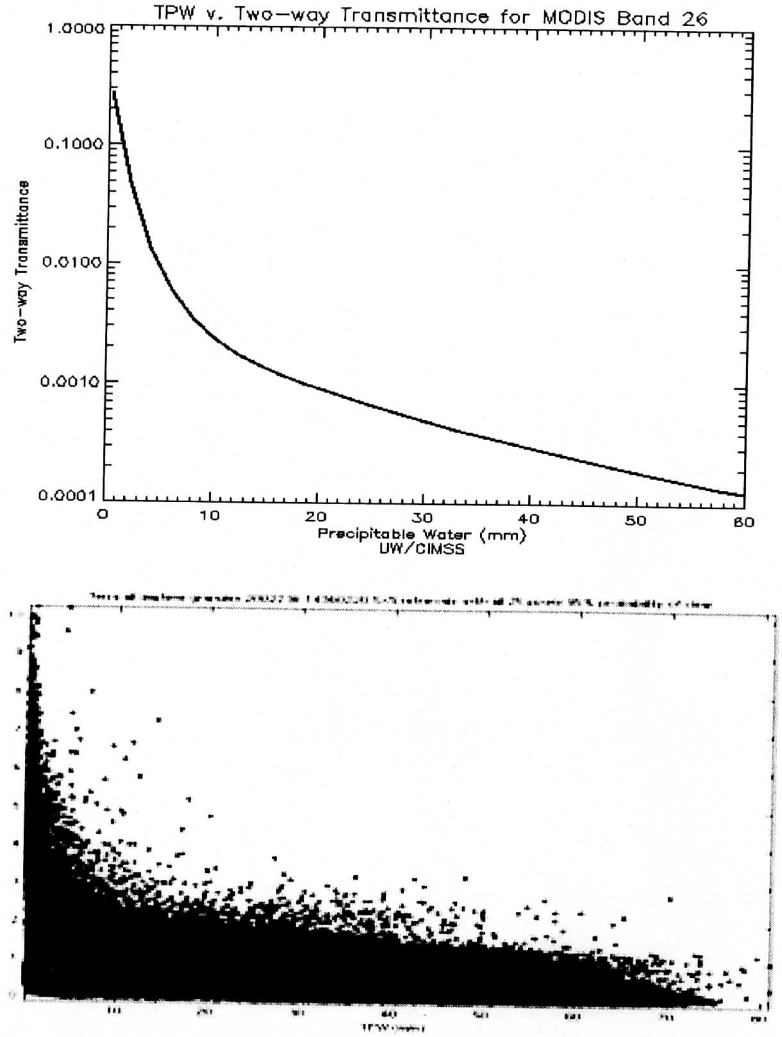


Figure CCM5. MODIS B26 forward model two-way transmittance is shown as a function of atmospheric TPW (top panel). For TPW > 15 mm, the atmosphere effectively becomes opaque to surface reflectance in B26 and MODIS B26 radiance observations are expected to be near zero. B26 earth scene observations (bottom panel) do not exhibit this behavior.

MAS IR Calibration Studies

The MODIS Airborne Simulator (MAS) was flown on a series of missions on the NASA ER-2 during the TX-2002 field experiment in Nov – Dec 2002. MAS performance was good although noise in bands 46 –50 (12.0 um to 14.2 um) was higher than usual (Figure CCM6). MAS responsivity is also lower than expected in these bands. This behavior is under investigation at NASA ARC. Some coherent noise is present intermittently in MAS data scenes though much less than was observed in the MAS CRYSTAL-FACE data. The flights of TX-2002 included S-HIS interferometer data collection. Radiometric comparisons between MAS and S-HIS observations are planned when the data sets become available. Case studies on 21 Nov. 2002 (daytime clear sky over the Gulf of Mexico) and 5-6 Dec 2002 (a night flight over uniform low stratus) will be of particular interest for assessing MAS radiometric performance in the MWIR and LWIR spectral regions.

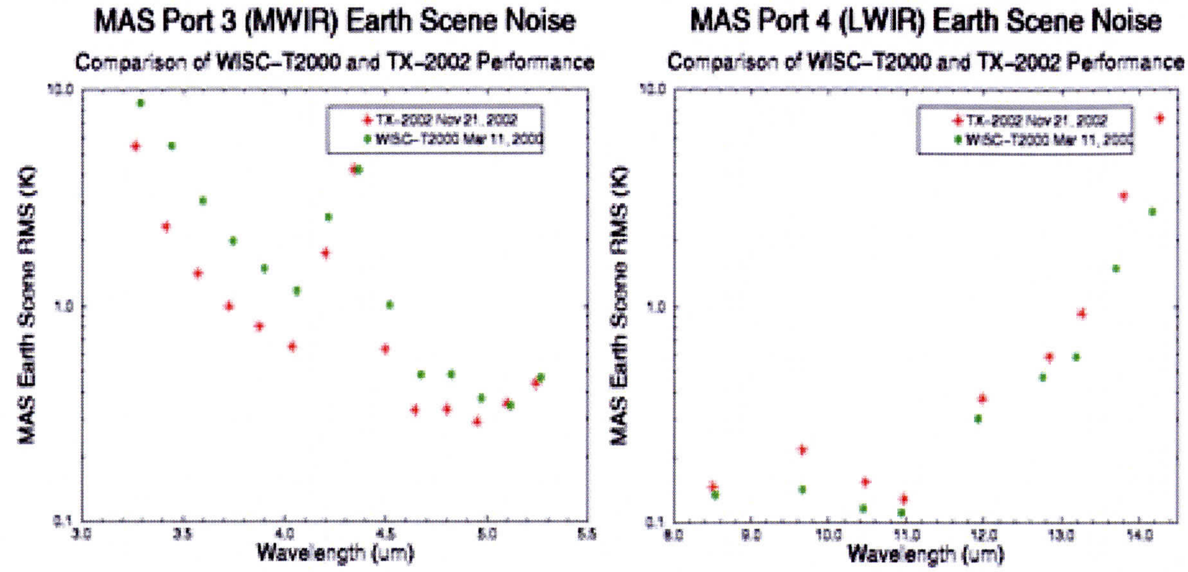


Figure CCM6. MAS NEDT estimates from the recent (Nov. 2002) TX-2002 field experiment compared to those from WISC-T2000 (Spring 2000). TX-2002 MAS performance in Port 3 (MWIR) was good in almost all bands (and improved over WISC-T2000). TX-2002 MAS Port 4 performance was also good in the 8 – 13 µm region; however in the CO2 sensitive 13 - 14 µm region, noise is significantly larger than WISC-T2000.

An effort to model the MAS optics for identifying spectral sensitivity is moving forward. Consultant Richard Cline and ARC have obtained most but not all specifications for MAS lenses and gratings for the model. Once completed the model will be used to identify possible influences on spectral performance of MAS in the MWIR and LWIR regions. The ARC spectral calibration facility is also being modeled to remove spectral sensitivities in the Bomem interferometer-based SRF measurement for spectrally characterizing MAS. These two models will enable an investigation into the spectral performance of MAS in the laboratory versus in flight on the ER-2. The goal is to identify the factors leading to any spectral changes that occur from ground level to nominal ER-2 cruising altitude.

ER-2 MODIS Validation Activities

For the Terra – Aqua eXperiment 2002 (TX-2002), a NASA ER-2 aircraft was deployed to Kelly USA (formerly Kelly AFB) in San Antonio, TX from 19 Nov – 12 Dec 2002 to collect data for validating MODIS and AIRS L1B radiances and cloud products. On each of the ten ER-2 science missions (Table CCM1), the aircraft underflew either Terra or Aqua, collecting high spatial resolution and high spectral resolution radiometric data (MAS and S-HIS) as well as backscatter data (Cloud Physics Lidar, CPL) to characterize clear and cloudy scenes. For the Aqua underflights, the focus was on clear sky L1B validation; for Terra the focus was on cloud science product validation. Single layer cirrus and multi-layer cirrus over water cloud (see Figure CCM7) were observed for direct validation of MODIS cloud height and cloud particle phase products (MOD06). Very thin cirrus data scenes were also collected for validation of thin cirrus detection in the MODIS Cloud Mask (MOD35). A nighttime mission on Dec 5-6 will enable assessment of low cloud detection at night. A clear sky mission on Nov 21 will be used to evaluate MODIS and AIRS L1B calibration. See Figure CCM8 for the ER-2 flight patterns of all TX-2002 flights. The TX-2002 web site (http://cimss.ssec.wisc.edu/tx2002/) provides background and links to instrument quicklook data sets collected during the field campaign.

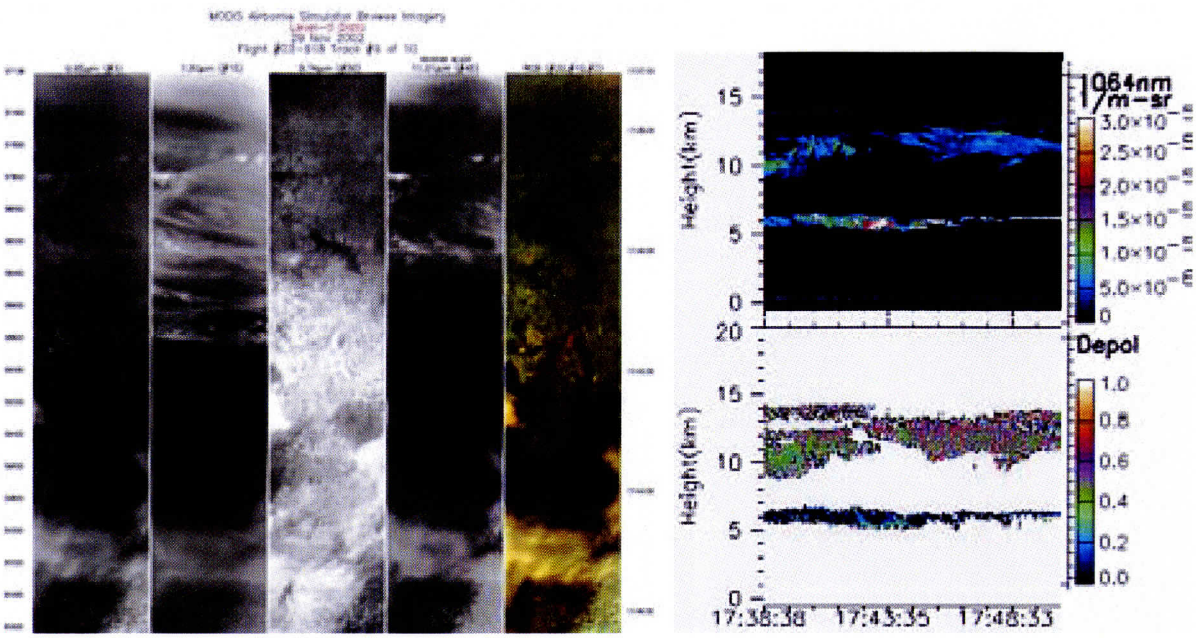


Figure CCM7. Example of MAS quicklook (left) and CPL backscatter and depolarization (right) for the ER-2 flight of 29 Nov 2002. Abundant cirrus over low water cloud is apparent in the CPL data. These data sets will be used to validate Terra MODIS Cloud Top Properties (heights, particle phase).

In complement to the Terra cloud product validation of TX-2002, a TOST (THORpex Observing Systems Test) field activity includes an EOS Validation component to assess the performance of Aqua MODIS and AIRS cloud products. During the TOST a NASA ER-2 and Gulfstream IV aircraft will operate out of Hickham AFB, Honolulu. The ER-2 payload includes MAS, S-HIS, NAST-I, CPL, and the LaRC in situ Ozone Probe. ER-2 underflights of Aqua over the Pacific Ocean will take place from 18 Feb – 12 Mar 2003. The primary EOS validation interest is for tropical cirrus cloud heights in both single and multi-layer conditions, cloud particle phase particularly for super-cooled water clouds, low cloud height definition, and thin cirrus detection. Nighttime data collection is of interest. Clear sky underflights of Aqua will also be sought to add to the MODIS and AIRS L1B assessment effort begun during TX-2002. During a portion of the experiment, a high altitude gondola (65000') will be used to release dropsondes, providing an in situ measurement of atmospheric state. Underflights of IceSAT with GLAS on board will also be sought.

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

Final algorithm modifications were made for Collection 4 processing. Several nighttime land cloud tests were added or modified. They included the following:

- The nighttime land 3.9-11 μm brightness temperature difference (BTD) low cloud test threshold is now a function of total column water vapor through the 11-12 μm BTD. This allows better discrimination between low clouds and clear sky, especially in humid atmospheres.

Table CCM1. TX-2002 Deployments at a glance during Nov - Dec 2002

Date	ER-2 Flt#	Sensors	Data Region	Comments
11/19	9012	M,N,C	DFRC to TX	***Ferry flight***. Clear skies over AZ, NM, TX. Vegetated. Sunny, dry, seasonal day in SAT
11/20				Upload S-HIS on ER-2. Sunny, dry in SAT.
11/21	9013	M,N,C,S	GOM	***S-HIS checkout and Aqua calibration mission***. Clear skies. Aqua at 1940 UTC (nadir).
11/22	9014	M,N,C,S	SGP	***Surface mapping and ER-2 calibration mission w/Terra***. Clear skies and isolated thin cirrus. Terra at 1714 UTC (22° angle).
11/23	9015	M,N,C,S	LA coast	***MODIS Sediment mission*** over Atch. Bay. Light winds post frontal (>48 hrs). LSU in situ. Aqua at 1929 UTC (18° angle). Chenier Plain photo (20 UTC). Continued dry, sunny in SAT.
11/24	9016	M,N,C,S	NE TX	***MODIS Cloud mission***. Expansive single layer thin cirrus over land. Terra at 1703 UTC (23° angle to target). Clouds in SAT.
11/25				No Fly day. Cloudy, cooler in SAT as slow moving front moving through. NAST-I downloaded off the plane.
11/26				Cloud mission canceled due to local winds. Chilly post frontal day in SAT with some rain
11/27	9017	M,S,C	TX	***MODIS Cloud mission*** for single layer cirrus over TX w/Terra at 1733 UTC (nadir). Cool cloudy day in SAT.
11/28				Down day for Tday. Subtropical cirrus over SAT and mild.
11/29	9018	M,S,C	SGP	***MODIS Cloud mission.*** Multiple overpasses of CF for single layer cirrus. Terra at 1720 UTC (10° angle to CF).
11/30				Aqua Clear sky mission canceled by aircraft problem. Seasonal day in SAT with continuing subtropical cirrus.
12/01				Planned Down day. FROPA early through LA coast.
12/02				MODIS Aqua cloud mission canceled due to aircraft problem. Warm day (75°F) in SAT; humidity increasing.
12/03				Down day. Clouds and rain overnight in SAT. Humid day.
12/04				Down day. Tstorms overnight. FROPA in early morning. Windy, chilly in SAT. Skies mostly cloudy.
12/05	9019	M,S,C	GOM	***MODIS Cloud mission*** at night over GOM. Uniform stratus run w/Aqua at 0759 UTC (22° angle). SGP had snow overnight.
12/06				Down Day for recovery from night flight. Winds becoming light, sunny day in SAT.
12/07	9020	M,S,C	SGP	***MODIS Cloud mission*** w/Aqua (1943 UTC; 9° angle) over ARM SGP. Low stratus, multi-layer, single layer thin cirrus, and clear data scenes.
12/08				Planned down day. Cloudy day with increased humidity in SAT. Becoming wet.
12/09				Early morning FROPA in SAT. Rain ending by late morning. No flight due to local weather..
12/10	9021	M,S,C	GOM	***MODIS Cloud mission*** w/Terra (1702 UTC; 12° angle) for thin cirrus, with and without low cloud underneath.
12/11	9022	M,S,C	GOM	***MODIS Cloud mission*** w/Aqua (nadir). Single and multi-layer cloud over GOM and S. LA.
12/12	9023	M,C	TX to DFRC	***Ferry flight*** to DFRC via Utah

Sensor Legend: M = MAS; S = S-HIS; C = CPL; N = NAST-I
GOM = Gulf of Mexico; SGP = Southern Great Plains CART site

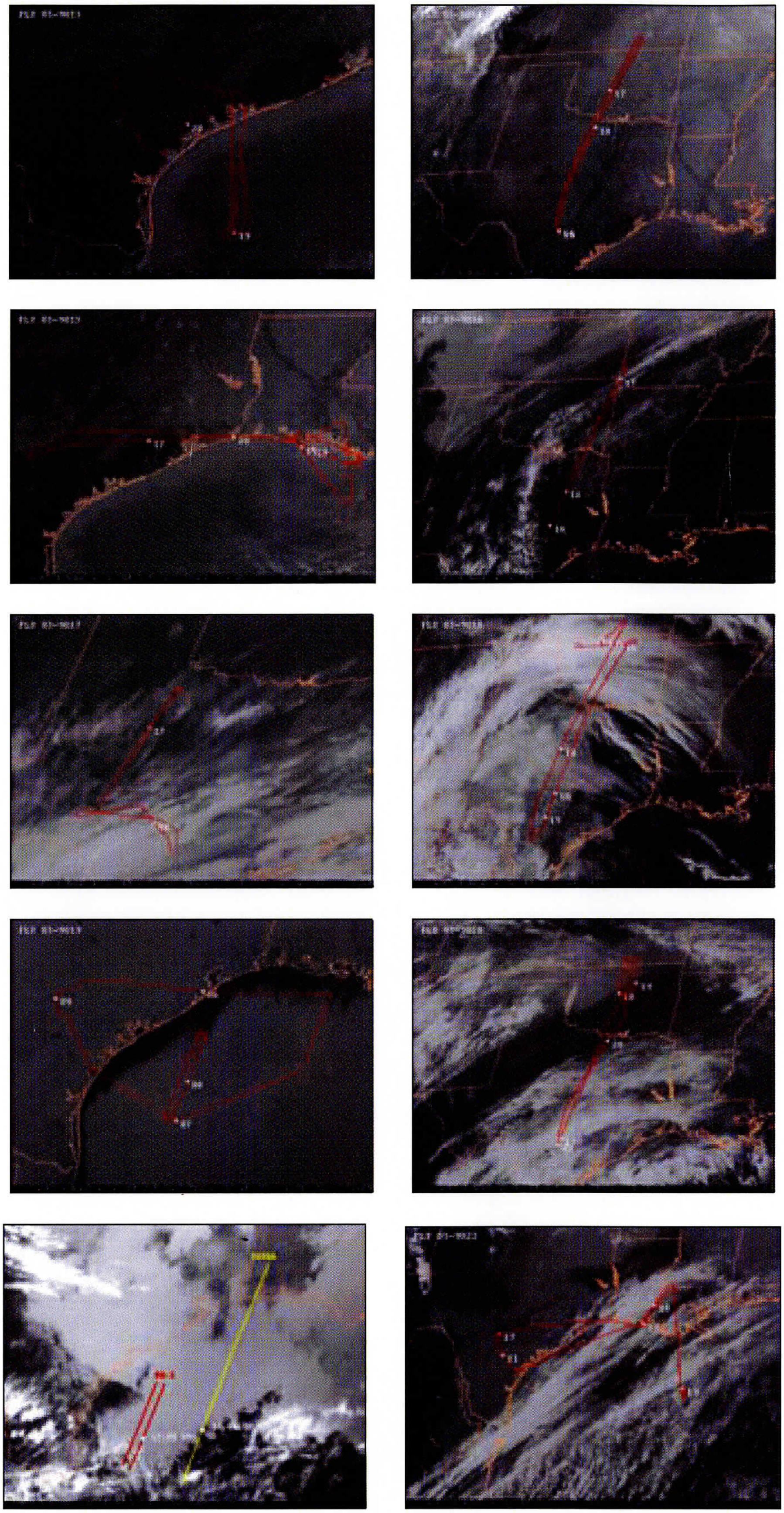


Figure CCM8. ER-2 flight tracks during the TX-2002 field experiment.

- A new 7.3-11 μm BTD test for mid-level clouds has been included for nighttime land scenes. Clouds with temperatures in the 240-260K range are sometimes very difficult to detect without solar illumination.

- The polar night 3.9-11 μm BTD cloud test for snow/ice surfaces will be used for other polar night land surfaces not explicitly listed as snow-covered by ancillary data. This step is taken because many areas near shorelines that are clearly snow-covered are not listed in the ancillary data as such. More low clouds will be identified as a result.

- A nighttime land 11 μm clear-sky restoral test was introduced. It is similar to the daytime 11 μm clear-sky restoral test but uses lower thresholds. It aids in identifying clear-sky pixels.

A switch was added to the snow detection algorithm where band 7 (2.1 μm) is used in place of band 6 (1.6μm) in the NDSI (Normalized Difference Snow Index) snow test, but for Aqua processing only. This was done because of the poor quality of many of the Aqua band 6 detectors. A band 7 threshold of 0.75 is used (the NDSI threshold using band 6 is 0.4). Visual inspection of cloud mask results in snow-covered regions suggests that the modified test is somewhat less sensitive but will not result in markedly changed cloud detection characteristics or statistics. In addition, a band 6/7 (Terra/Aqua) reflectance threshold test was added to aid in discriminating between clouds and snow.

Other changes included defining a small portion of Greenland to be "high elevation" even though it is below the 2000-meter threshold used elsewhere. This prevents the 1.38 μm high cloud test from flagging this region as always cloudy due to the extremely dry atmospheric conditions and bright surface found there. Clear-sky radiance/reflectance files (MODCSR_G files) now contain more bands. All bands are recorded with the exception of ocean color. These granule-based files are small and the change will have little impact on storage space or processing time. Also, daytime land clear sky restoral test thresholds were adjusted for Aqua data.

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 efforts have focused on nighttime cloud detection. The 11-4 μm BTD test has been modified to account for dependence on temperature. A new test with the 13.3 μm CO_2 band has been added. This test is similar to the existing 11-6.7 μm test in that it detects low-level temperature inversions, but the 13.3 μm test performs better when inversions are weak.

Example MODIS images (left) and the corresponding cloud masks (right) from Terra 11:35UTC on 24 Aug. 2002 (Figure HZ1a) and one hour and 40 minutes later from Aqua (Figure HZ1b) are shown below.

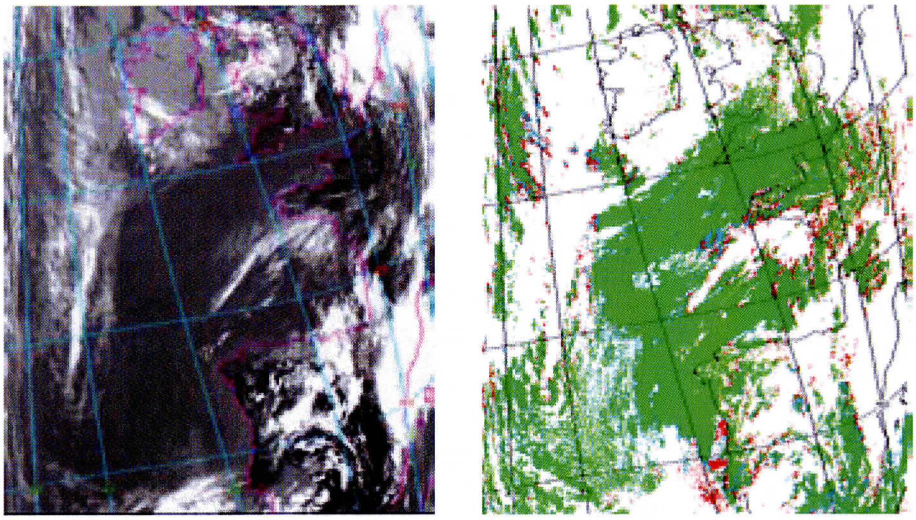


Figure HZ1a. Terra MODIS data over Europe (11μm left, and cloud mask right) on 24 Aug 2002 11:35UTC.

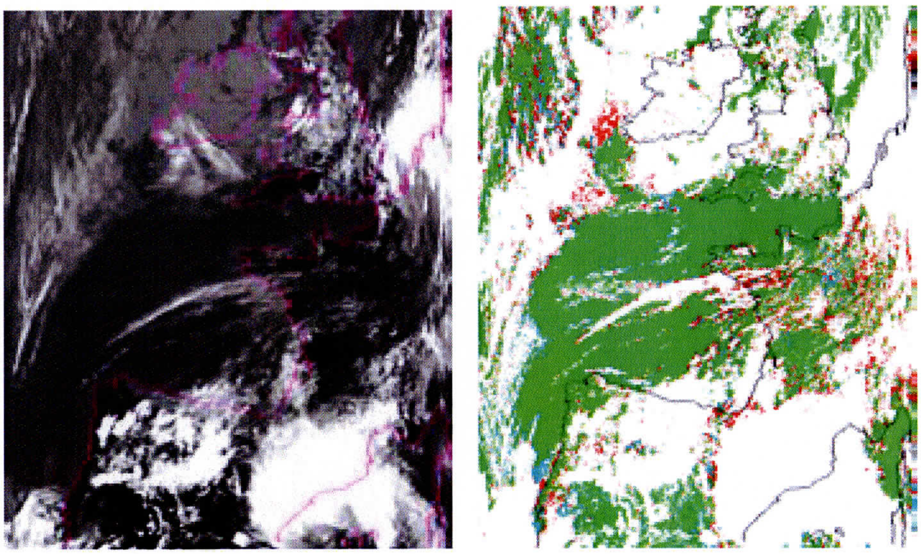


Figure HZ1b. Aqua MODIS data (11μm left, and cloud mask right) on 24 Aug. 2002 13:15UTC. Green is confident clear, cyan probably clear, red uncertain and white is cloudy.

Clear Sky Radiance Processing

Software modules for clear sky daily (MODCSR_D) and weekly (MODCSR_8) composites were developed and delivered to SDST for integration into operational processing. The software composites granule based clear sky files into daily and weekly statistics of clear scene radiances for a given set of MODIS visible and infrared bands. The files will serve a number of purposes, including the generation of radiance biases for more accurate retrievals of cloud top properties and atmospheric profiles. Unfortunately, the increase in the number of bands saved in the daily granule MODCSR_G files from 8 to 27 caused the software to exceed the memory limits of the test machine (600 MB). Options for resolving this issue are being discussed. Some software re-engineering will be required as well as daily and weekly file format changes.

MODIS Cloud Top Properties (MOD06)

Aqua noise (NEDR) thresholds for the CO_2 absorption bands (33-36) were lowered allow more frequent use of the CO_2-slicing algorithm (instead of the default IR window technique). The Terra thresholds are unchanged. There is more influence of NEDR on high and middle clouds since most of low cloud properties were computed by IR window technique. Tropics are more sensitive to NEDR changes, especially high thin clouds.

A change was made to allow the proper specification of moisture profiles from the GDAS (Global Data Assimilation System) input data. An output product confidence flag was modified so that its value is always "highest quality", necessary for proper Level 3 compositing.

Figure HZ2 presents an example of global high cloud distribution from MODIS detection for monthly means in January, April, July, and October 2001.

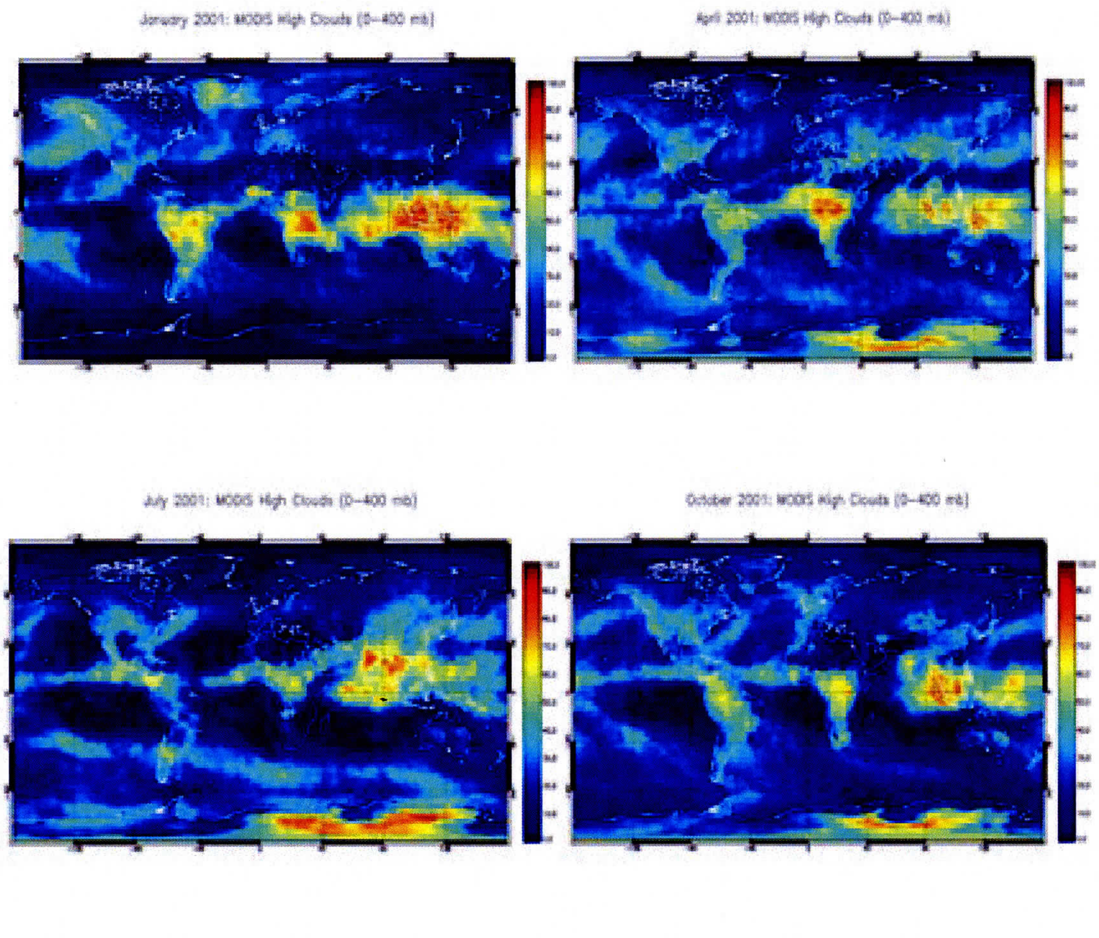


Figure HZ2. Monthly mean global distributions of MODIS detection of high cloud cover in January, (top left) April, (top right), July (bottom left), and October 2001 (bottom right).

The images show that

a) regions of maximum values of high cloud cover are concentrated in the tropics.
b) subtropical highs create cloud minima (e.g. near the Bermuda high in July and the southern Pacific high in January)
c) the Indian monsoon is evident in July
d) Gulf of Mexico moisture intrusion into the central US create high cloud cover in July
e) the Indonesian region has year round high cloud cover (often the global maximum)
f) the high cloud cover follows the Sun – latitudinal moisture bands connecting the continents drift north and south with the seasons
g) high clouds have more distribution over land than over water surface.

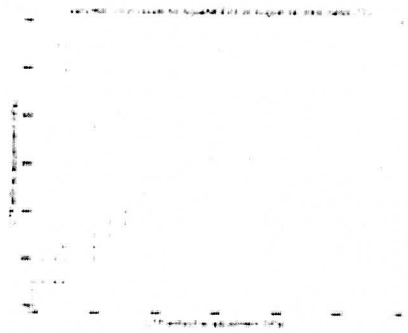
Global cloud and mean cloud top pressure (CTP) distributions for polar, mid-latitude, and tropical regions were tabulated for 24 August 2002 for Aqua MODIS (see Table HZ1). Upper tropospheric clouds are seen in the CO2 slicing results (as distinguished from CO2 slicing and IR window technique which include less reliable lower tropospheric cloud results). From the CO2 slicing results, one sees that the north polar region has the larger cloud cover and lower cloud top pressure while the tropics has the lowest cloud top pressures on average (as one would expect).

Table HZ1. Global cloud distribution detected by Aqua MODIS on 24 August 2002

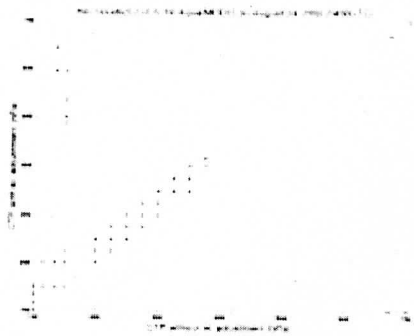
	Cloud cover (%)	Mean CTP (hPa)	Mean CTP from CO_2 slicing only (hPa)
North Polar (60N - 90N)	90.15	654.84	400.56
North Mid. Latitude (20N - 60N)	67.51	642.16	321.24
Tropics (20S - 20N)	78.88	621.75	271.08
South Mid. Latitude (20S – 60S)	87.20	687.77	356.59
South Polar (60S - 90S)	76.84	596.88	385.85

Cloud emissivity adjustment in the MODIS CO_2 slicing algorithm was also investigated. Zhang and Menzel (2002) have shown that adjusting the cloud emissivity ratio (longer wavelength divided by shorter wavelength) to 1.025 in the GOES-8 Sounder CO_2 measurements improves the cloud height product for high thin clouds and produces little change for thick and opaque clouds. Cloud emissivity ratios for MODIS CO_2 bands observing thin high ice clouds (with spherical particle sizes of 10 and 20 um and cloud thicknesses of 0.25 and 0.5 km) were calculated using the Streamer model (Key and Schweiger 1998) wherein longwave ice cloud optical properties are based on Mie calculations. From these calculations for MODIS band pairs 36/35, 35/34, 35/33, 34/33, and 33/31, emissivity ratios of 1.025, 1.01, 1.025, 1.01, and 1.1 were found to be most appropriate respectively.

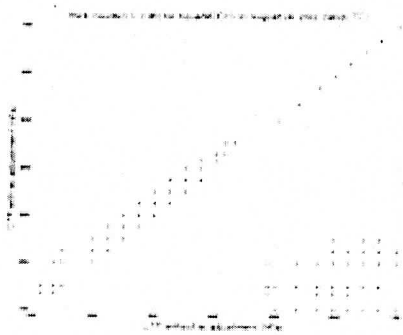
Using a cloud emissivity ratio of 1.025 for all band ratios in one granule of MODIS data from 24 August 2002 (see Figure HZ3) reveals that the emissivity adjusted CO_2 slicing algorithm (a) places very thin clouds somewhat lower in the troposphere and (b) catches more high thick clouds that are misplaced by the IR window technique.



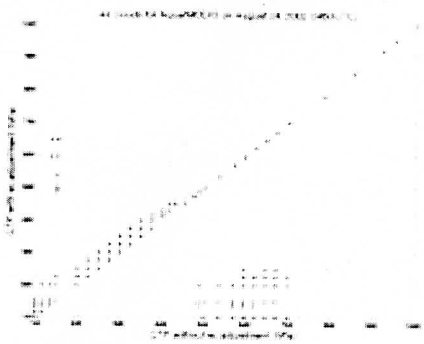
(a) very thin clouds (ECA < 0.2)



(b) thin clouds (0.2<ECA <0.5)



(c) thick clouds (0.5<ECA <0.95)



(d) all clouds

Figure HZ3. The scatter plot of MODIS CTP using emissivity adjusted (y-axis) and original (x-axis) CO_2 slicing algorithms for very thin, thin, thick and all clouds in one granule of data on 24 August 2002.

Cloud Overlap and Phase Determination

Efforts to validate the IR-based cloud phase product continue. UW has been collaborating with Professor Graeme Stephens and colleagues at Colorado State University to compare MODIS and aircraft determinations of cloud phase collected during the Cloud Layered Experiment (CLEX) in 2001. Additionally, we have been working with limited data sets collected from the ARM (Atmospheric Radiation Measurement) CART (Cloud and Radiation Testbed) sites in Oklahoma and Alaska. Comparison of the MODIS cloud phase to surface based products are problematic given the attenuation of radar/lidar signals when clouds approach an optical thickness of about 3. However, during the TX-2002 experiment the Cloud Lidar System (CLS) and the MAS collected some unique data; many flights recorded both single-layered and multi-layered clouds during times of Terra and Aqua overpasses. Since the CLS recorded depolarization data, a CLS-based cloud phase and cloud height product is available with which to compare directly with the MAS and MODIS cloud product. The data sets are now being organized and analyzed at UW.

There has been progress on identification of multi-layered clouds, specifically for the case of optically thin cirrus overlying low-level water clouds. Currently, all cloud properties are obtained under the assumption that only a single cloud layer exists in each MODIS field of view. We have shown in recent publications that biases occur in cloud property retrievals when, in fact, more than one cloud layer exists and the uppermost layer is optically thin. At recent MODIS science team meetings, we have discussed an approach for both daytime and nighttime detection of multi-layered clouds. The daytime approach is based on analysis of data from MODIS bands 6 (1.64 μm) and 31 (11 μm), and also incorporates results from the cloud mask and cloud thermodynamic phase product. A paper is being developed on the daytime multi-layered cloud detection methodology. The software developed for research purposes is based on a COTS product called Matlab, and is not optimal for operational use. A new graduate student (Greg McGarragh) has developed a robust version of the daytime multi-layered cloud detection software entirely in C. Preliminary timing tests indicate that a MODIS granule may be processed more than an order of magnitude faster using the C software than with the Matlab software. The software will soon be implemented into the MODIS direct broadcast processing framework at CIMSS, whereupon the results will be made available to the public on a daily basis. We expect to use the direct broadcast data to help make the method more robust. Once the multilayered cloud detection routine has been through this testing stage, an entire day of MODIS data will be analyzed to explore (a) where multi-layered clouds occur, (b) what sorts of biases occur in the cloud top heights, and (c) possible improvements in the inference of cloud phase when multi-layered clouds are present.

The detection of multi-layered clouds in night-time data is also progressing; a method will be published later this year (Baum et al. 2003). This paper explores the biases inherent in nighttime retrieval of various cloud properties and suggests a method to identify when thin cirrus may be overlying a lower-level cloud. While the daytime approach to multi-layered cloud detection has been developed to the point of being nearly operational, the night-time approach needs further work before attempting to develop and implement an operational algorithm.

Total Column Precipitable Water Vapor (TPW)

Aqua TPW

Aqua and Terra MODIS MOD07 algorithm evaluations were undertaken through routine product comparisons with those from GOES and instrumentation at the SGP ARM-CART in Oklahoma. An example of total precipitable water (TPW) from 20 July 2002 is shown in Figure SWS1. Aqua MODIS TPW is smoother with less noise due to striping than the Terra MODIS TPW. This provides better depiction of gradients and allows full use of the high spatial resolution measurements. Aqua MODIS is generally less moist than Terra MODIS and GOES, as highlighted by the extent of the dry area in Colorado and western Nebraska, as well as the lower TPW values over the Gulf of Mexico. This dry bias is consistent throughout much of the current operational Aqua data.

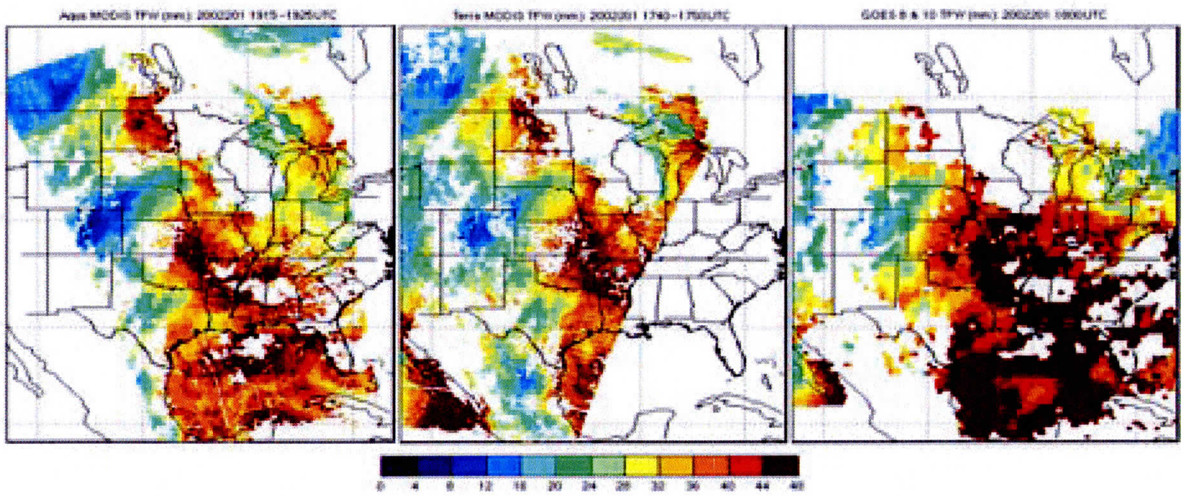


Figure SWS1. TPW (mm) on 20 July 2002 from Aqua MODIS (left), Terra MODIS (center) and GOES 8 & 10 combined (right). Aqua MODIS data was from 1915-1925 UTC, Terra MODIS from 1740-1750 UTC, and GOES 8 & 10 from 18 UTC.

Updates to the MOD07 algorithm

Some of the errors in the Aqua MODIS MOD07 products are related to the use of Terra NEDTs and radiance biases. As Aqua values become available, they are being included in the Aqua MODIS algorithm. A February 2003 delivery of a new MOD07 algorithm to the GSFC DAAC is planned that will include these changes, plus coefficients computed with the new HITRAN 2000 information in the forward model.

Estimates of noise are used in the MOD07 algorithm to apply variability to the brightness temperatures calculated from the training profiles. The noise added to the BT is a randomly generated number from a Gaussian distribution, with standard deviation equal to the NEDT specified for each band and scaled relative to the observed BT. Because the MOD07 retrievals are performed on brightness temperatures averaged from 5x5 FOVs, the noise estimates must include the detector-to-detector and scan mirror variability (striping). New, lower values of NEDT can be used for Aqua because of the much reduced striping in the Aqua MODIS radiances. The estimates used in the new MOD07 algorithm were computed by Chris Moeller using an Aqua MODIS Gulf of Mexico clear sky scene on 21 November 2002 over a 35 x 35 pixel domain (see Figure CCM4).

A small change was made in the way the MOD07 retrieval algorithm handles the surface level when integrating moisture profiles to obtain TPW. Previously, the profile was integrated down to the model level closest to (but most often above[1]) the level of the surface pressure. For situations with high mixing ratio near the surface, this approach underestimated the TPW. The new integration routine accounts for the actual surface pressure by adding or subtracting the TPW increment between the lowest level used previously and the surface pressure. This change typically leads to an increase in TPW values, particularly for situations with high boundary layer moisture. Because we have not yet collected a sufficient number of MODIS Aqua data to study

[1] If the surface pressure is within 5mb less than a model level, then the level below the surface was used; otherwise the lowest model level used for integration is that one above the surface level.

the effects of algorithm changes, results of this change are shown here using MODIS Terra data. For 80 cases from April 2001 to August 2002 at the SGP ARM-CART in Oklahoma, the RMSE between the MODIS TPW and that measured by the microwave radiometer (MWR) decreased from 4.5 to 4.3mm with the new integration (see Figure SWS2). Considering only the 43 cases with MWR TPW greater than 17mm, the RMSE improves from 5.2 mm with the old integration to 4.3mm with the new approach (not shown). One example of a moist case that shows better agreement with GOES-8 TPW with the new integration is shown in Figure SWS3.

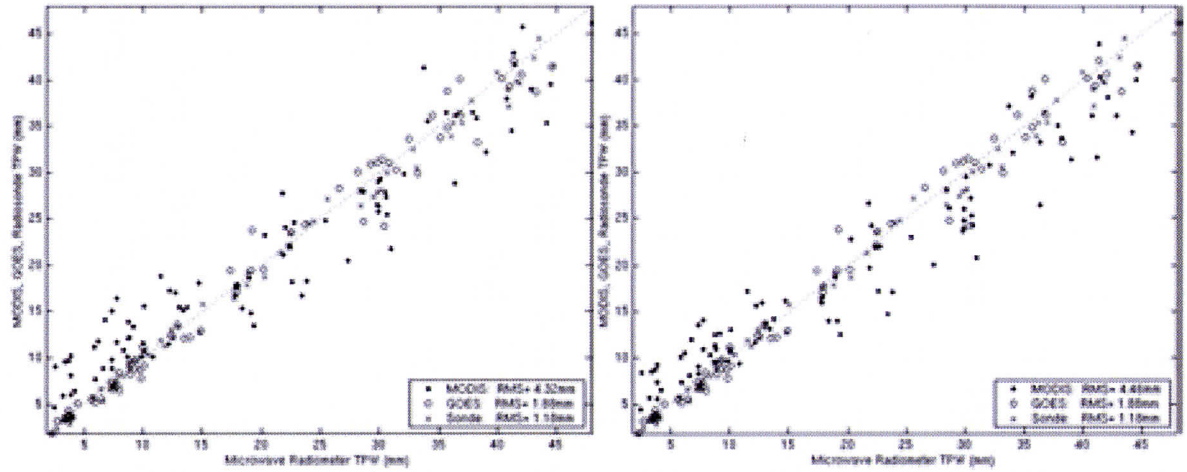


Figure SWS2. Comparison of TPW (mm) from Terra MODIS regression (shaded diamond), GOES-8 (circle), and radiosonde (cross) with the SGP ARM-CART microwave radiometer (MWR). 80 cases from April 2001 to August 2002 are shown in the comparison. The dotted line shows a one-to-one correspondence.

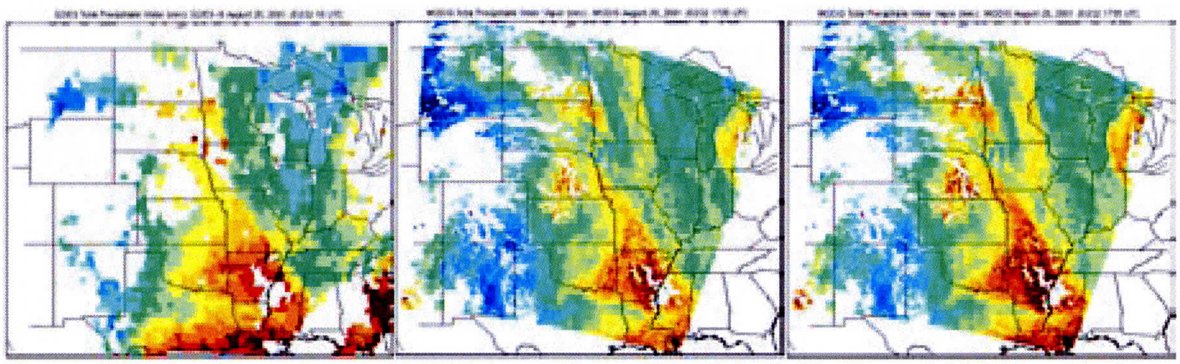


Figure SWS3. Comparison of TPW (mm) from GOES-8 (left), Terra MODIS with the old moisture integration routine (center), and Terra MODIS with the new integration that properly accounts for the surface level.

Previous versions of the MOD07 algorithm included a variable 'Surface Temperature' that was simply a replica of the NCEP-GDAS surface pressure used as input to the regression. A new parameter has been assigned to this variable, regression-based skin temperature. Skin temperature is included as a retrieved variable in the same regression procedure used for atmospheric temperature and moisture. A comparison of MODIS Terra regression-based surface skin temperature with that measured by the infrared thermometer (IRT) at the SGP ARM-CART show that MODIS agrees well with the in-situ measurements (Figure SWS4). The RMSE was 1.75°K for 70 clear-sky cases from April 2001 to August 2002.

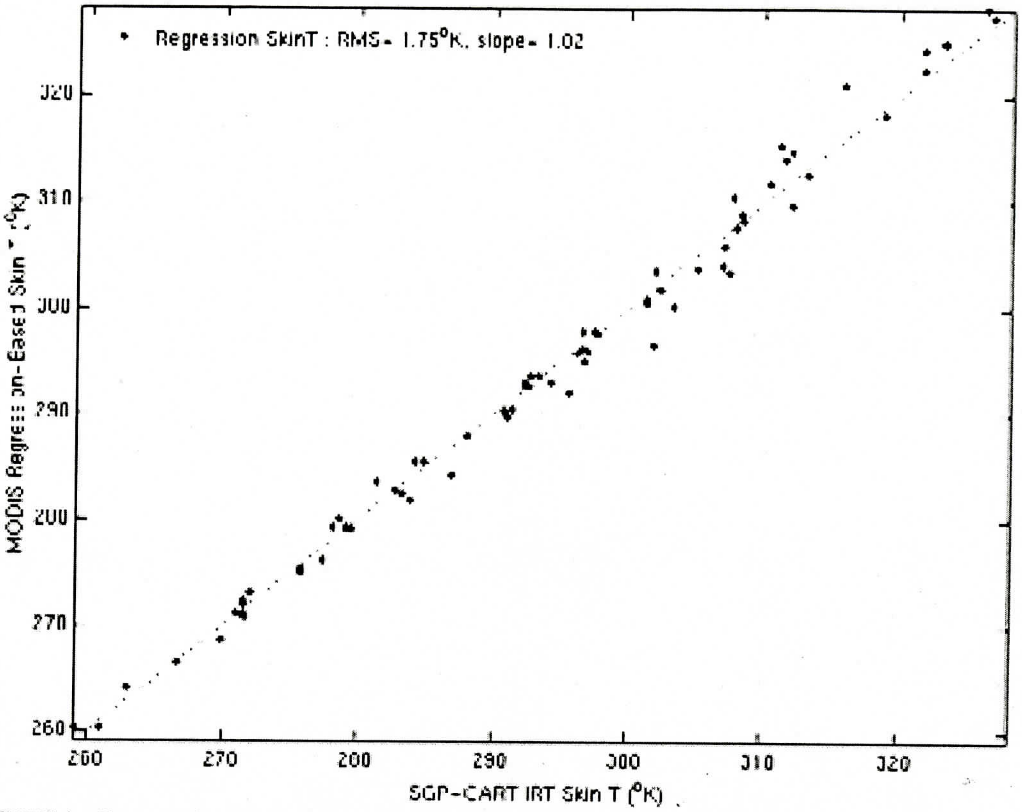


Figure SWS4. Comparison of skin temperature computed by MODIS regression (y-axis) with that observed by the SGP-CART IRT (x-axis) for 70 cases from April 2001 to August 2002. The dotted line shows a 1-to-1 correspondence.

The current operational Aqua MODIS algorithm uses the radiance bias calculations computed for Terra. Because the correction is primarily for forward model error, this was a reasonable first guess. However, now that Aqua data is available we can update the bias corrections based on calculations of Aqua radiances. Observed minus calculated brightness temperatures were computed on a granule basis by first selecting 5x5 FOV areas with zenith angle less than 20° and with all 25 pixels labeled 99% confidence clear by the MOD35 cloud mask. To reduce the computation time, only 10% of the remaining 5x5 FOV areas that meet the clear sky and zenith angle requirements are used. For each of the chosen 5x5 FOV areas, the radiances are averaged and converted to the observed brightness temperature. The calculated BT is found using the PFAAST forward model with the following input: NCEP-GDAS temperature and moisture profiles and surface pressure and MOD07 regression-based skin temperature. The results for one granule from 20 October 2002 are shown in Figures SWS5 and SWS6. Figure SWS5 shows images of the observed minus calculated brightness temperature for selected bands, and Figure SWS6 shows the averages bias for all pixels meeting the zenith angle and clear sky criteria.

The final, global Aqua bias values will be calculated by a similar approach using all granules over a few days. The biases from these granules will be averaged and binned by six latitude bands for land and ocean to come up with the final values. As more data become available, the biases computed from different months or seasons will be compared and the biases will be updated regularly. Global biases computed by this approach will be implemented in the next Aqua MOD07 algorithm; however the variability within a granule in certain bands, particularly band 27, illustrates the need for a more sophisticated bias scheme. Some variability may be due to problems with the input parameters (see for example, the high bias values in the surface-viewing channel 31 in western Texas). Other sources of variability may be real differences in surface and air mass characteristics that lead to different biases. A regression-based bias algorithm is currently being developed to derive the bias of each band as a function of the brightness temperatures from 12 bands, skin temperature, TPW, and sensor zenith angle. The coefficients would be updated seasonally. It is anticipated that this approach will improve upon the current bias calculations.

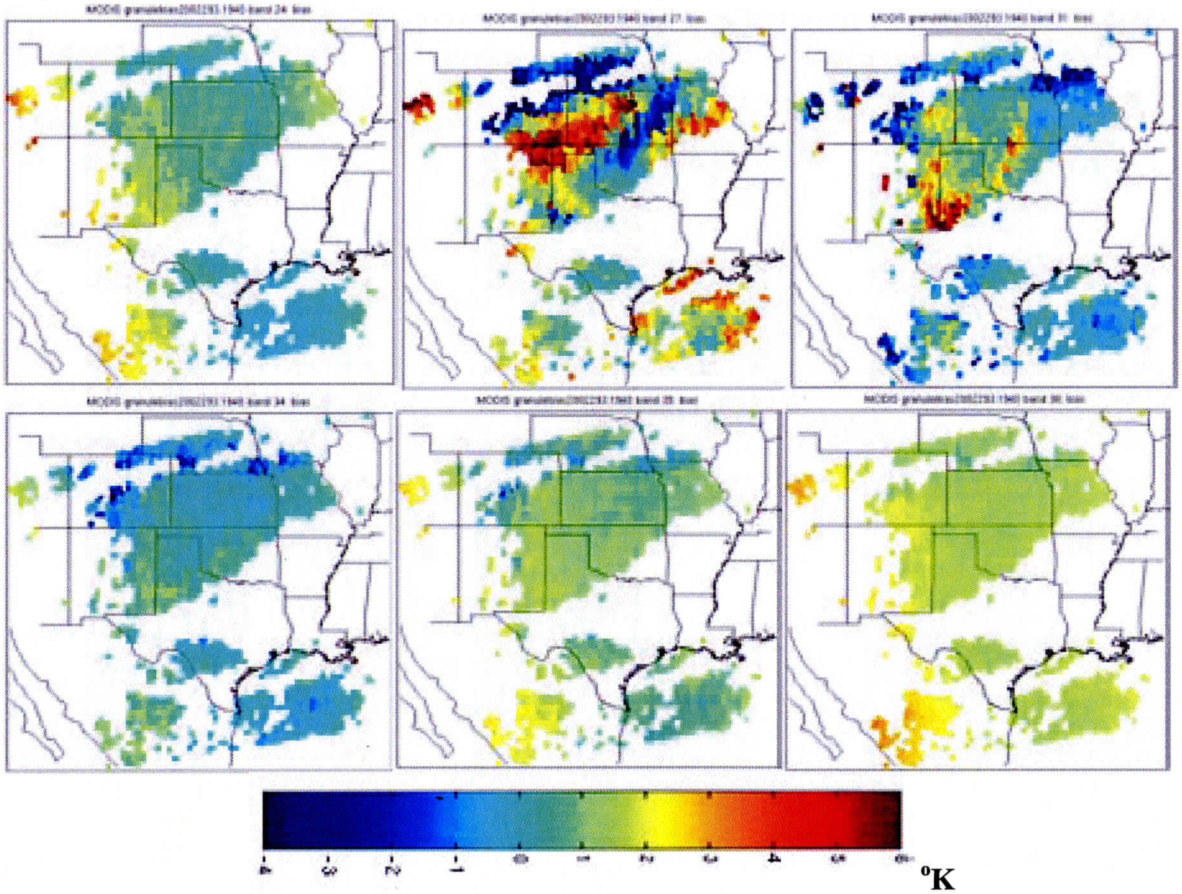


Figure SWS5. Aqua MODIS observed minus calculated brightness temperatures (°K) on 20 October 2002 at 1940 UTC for 5x5 FOV areas that meet the clear sky criteria and with sensor zenith angle less than 20° for MODIS bands 24, 27, 31 (top row) and bands 34, 35, and 36 (bottom row). The colorbar indicates the color scheme used for all bands.

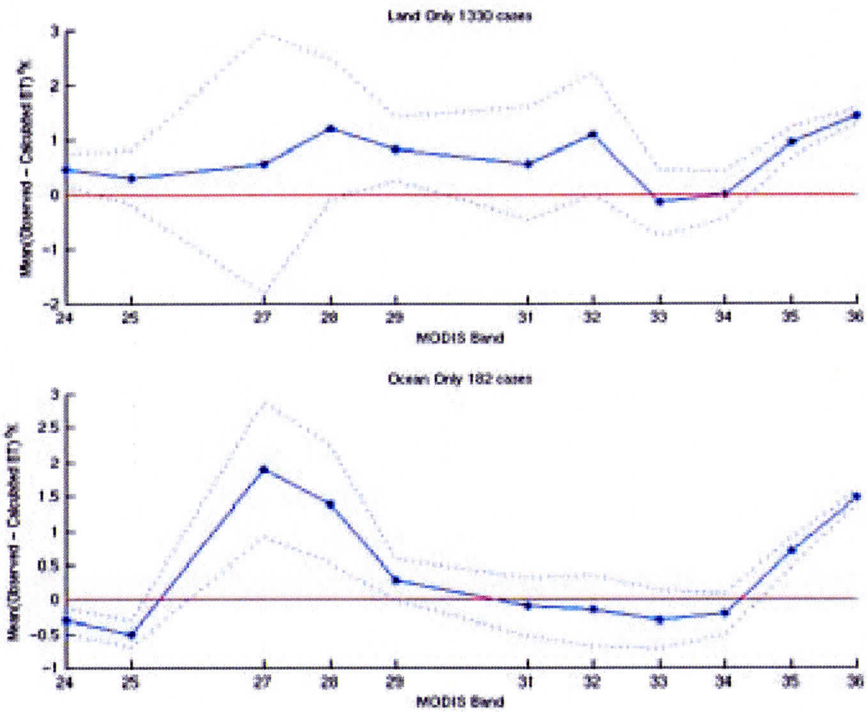


Figure SWS6. Observed minus calculated brightness temperatures (°K) from Aqua MODIS 20 October 2002 at 1940 UTC for 5x5 FOVareas that meet the clear sky criteria and with sensor zenith angle less than 20°. The top panel shows the average (solid) and +/- standard deviation (dotted) for the 1330 and cases. The bottom is the same for 182 ocean cases.

Evaluation of using TIGR-3 profile data for regression training

The TIGR-3 profile database is being investigated for use as MODIS regression training data. The TIGR-3 data may be substituted for or added to the currently used NOAA-88b. The TIGR-3 temperature, mixing ratio, and ozone profiles were interpolated form 40 levels to the 101 levels required for the forward model. Since the TIGR-3 database includes some cloudy profiles, a saturation check was performed from top level down and any profile with mixing ratio equal to 95% or more of the saturated value was removed. Of the 2311 original profiles, 1847 profiles met this condition. Corresponding to the latitude and longitude of each TIGR-3 profile, a percent land, elevation, and an ecosystem value was assigned according to the 18 classifications of the International Geosphere-Biosphere Programme (IGBP). Figure SWS7 shows the location of the TIGR-3 profiles and the ecosystem of each. The total precipitable water of the TIGR-3 profiles is shown as a function of latitude and ecosystem in Figure SWS8, as well as a histogram of the TPW in the data set. There are some profiles with TPW up to 80 mm; however, nearly 600 of the profiles have very low TPW (< 5mm). TPW is distributed as reasonably expected by ecosystem, with the ocean (ecosystem #14) and cropland (ecosystem #12) groups having the highest TPW. These ecosystem values will be used to assign an emissivity and skin temperature to each profile. Ecosystem-dependent emissivity and skin temperature/surface air temperature difference are being investigated for this application.

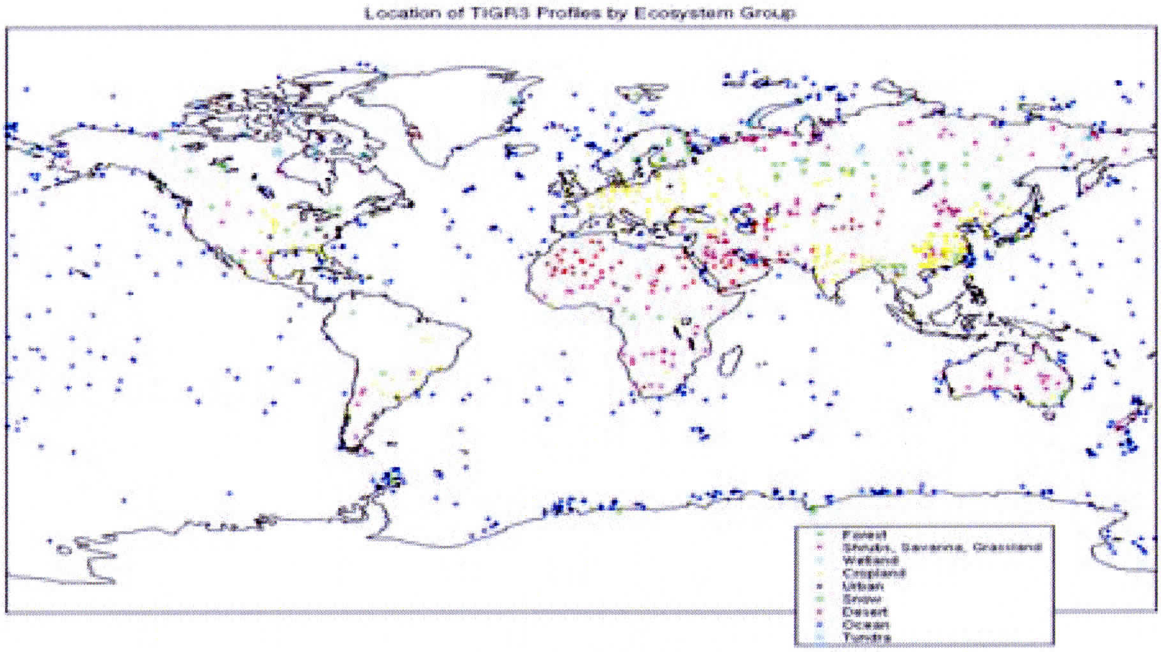


Figure SWS7. Location of TIGR-3 profiles. Color and type of each mark indicates ecosystem group assigned by latitude. Green + is forest, pink +: shrubs, savanna, grassland; light blue +: wetlands; yellow +: cropland; black +: urban areas; green o: snow; red +: desert; dark blue +: ocean; and light blue o: tundra.

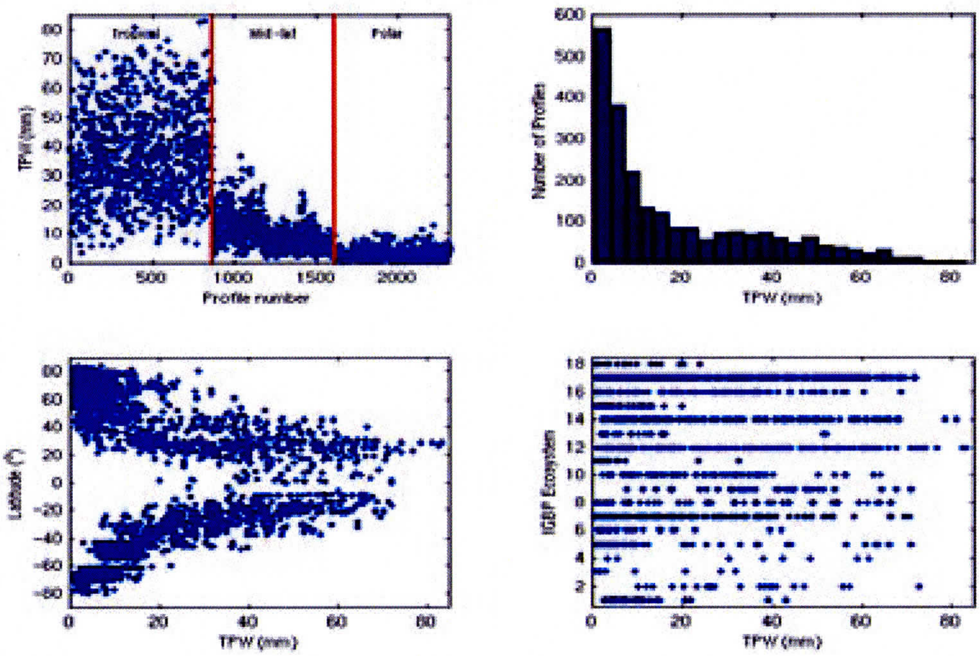


Figure SWS8. Characteristics of TIGR-3 data set. Top left: TPW (mm) by profile number, categorized into the data set specified categories of tropical, mid-latitude, and polar. Top right: histogram of TPW (mm). Bottom left: TPW (mm) as a function of latitude. Bottom right: TPW (mm) separated into IGBP ecosystem classes.

Aqua MODIS Investigation of Cloudiness in AIRS FOV

Aqua MODIS data with 1 km resolution can be used to simulate the IR imager or sounder TPW with various spatial resolutions. Figure JL1 shows full resolution 1 km and reduced resolution 10 km MODIS TPW (note that the resolution of current GOES sounder is 10km) products. It can be seen that the moisture gradients are smoothed when the spatial resolution is decreased from 1km to 10km; also the 10km TPW has much less clear coverage compared with the 1km TPW. Figure JL2 shows the percentage loss of clear sky detection on 1915UTC 20 July 2002 when the resolution is reduced from 1 km IR out to 15 km; if 80% of the 10 km pixel is cloudfree it is considered to be clear is these statistics. It can be seen that 4km IR resolution loses 30% of the clear coverage, while 15km IR resolution loses more than 60%.

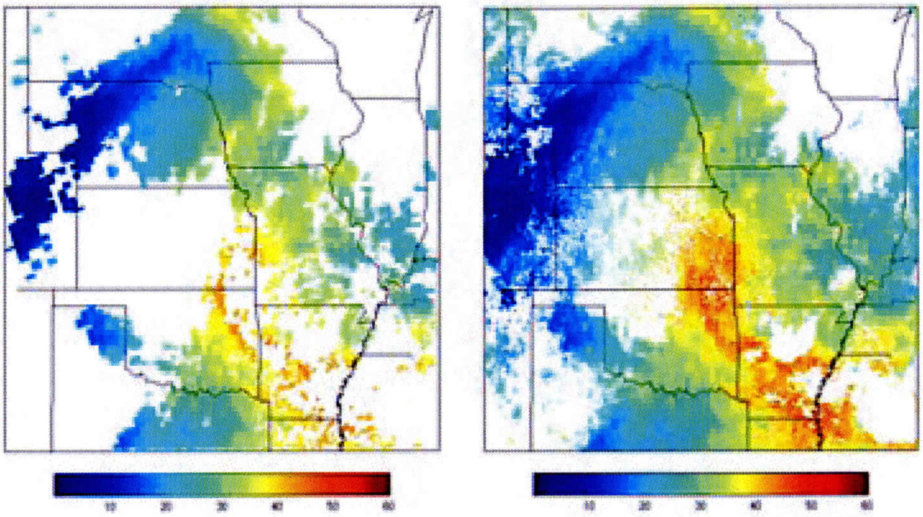


Figure JL1, 1km MODIS TPW (right panel) and simulated 10km TPW (left panel) at 1915UTC on July 20, 2002. MODIS 1km resolution cloud mask are used for the MODIS cloud detection.

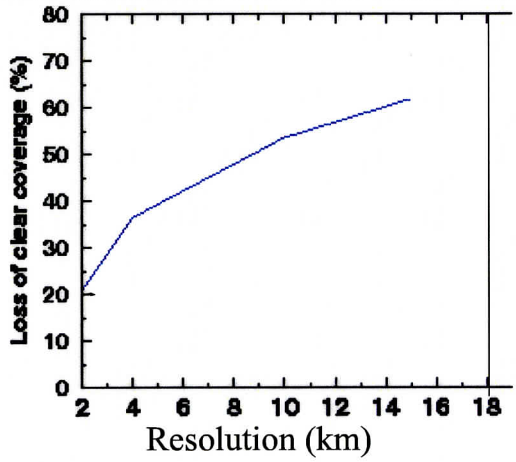


Figure JL2. Loss of clear coverage from 1km MODIS IR data when resolution is reduced. Only boxes with more than 80% clear pixels are counted as clear.

When MODIS pixels are mapped into the AIRS footprint and the MODIS cloud mask is used, the percentage of clear sky AIRS observations (greater than 95% of collocated MODIS pixels clear) can be estimated. Figure JL4 shows that most AIRS granules (90 by 135 AIRS pixels) have less than 20% clear pixels; very few granules have clear pixels larger than 50%. This suggests that MODIS could play a useful role in AIRS clear sky identification and cloud clearing algorithms.

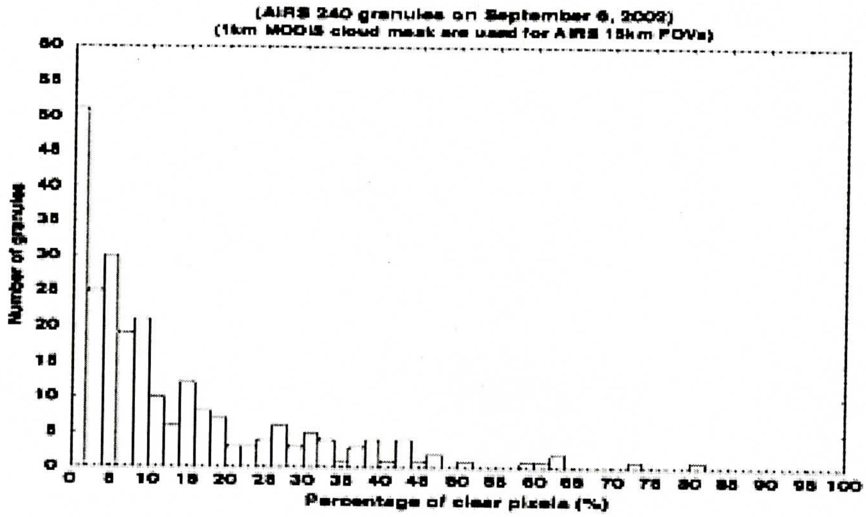


Figure JL4. Number of AIRS granules on 6 Sep 2002 versus percentage of clear AIRS pixels.

<u>Detection of Low-Level Temperature Inversions With MODIS</u>

The near-surface atmosphere of the polar regions is characterized by temperature inversions throughout most of the year, but radiosonde data are sparse and numerical weather prediction models have relatively poor vertical resolution for boundary layer studies. A method was developed for detecting and estimating the characteristics of clear sky, low-level temperature inversions using MODIS. The method is based on an empirical relationship between the inversion strength, defined as the temperature difference across the inversion, or height, defined as the altitude difference, and the difference between brightness temperatures in the 7.2 _m water vapor and 11 _m infrared window bands. Results indicate that inversion strength can be estimated without bias with a root-mean-square error (RMSE) of 2-3 °C. Inversion height can be estimated with a RMSE of 130-250 m. Examples are given in Figures JK1 for inversion strength and inversion height. With MODIS, temperature inversions can be observed at a spatial resolution as high as one square kilometer and a temporal sampling of up to fourteen times per day, providing an opportunity for detailed studies of the spatial distribution and temporal evolution of the high-latitude boundary layer. A journal paper has been submitted describing this work (Liu and Key, 2002).

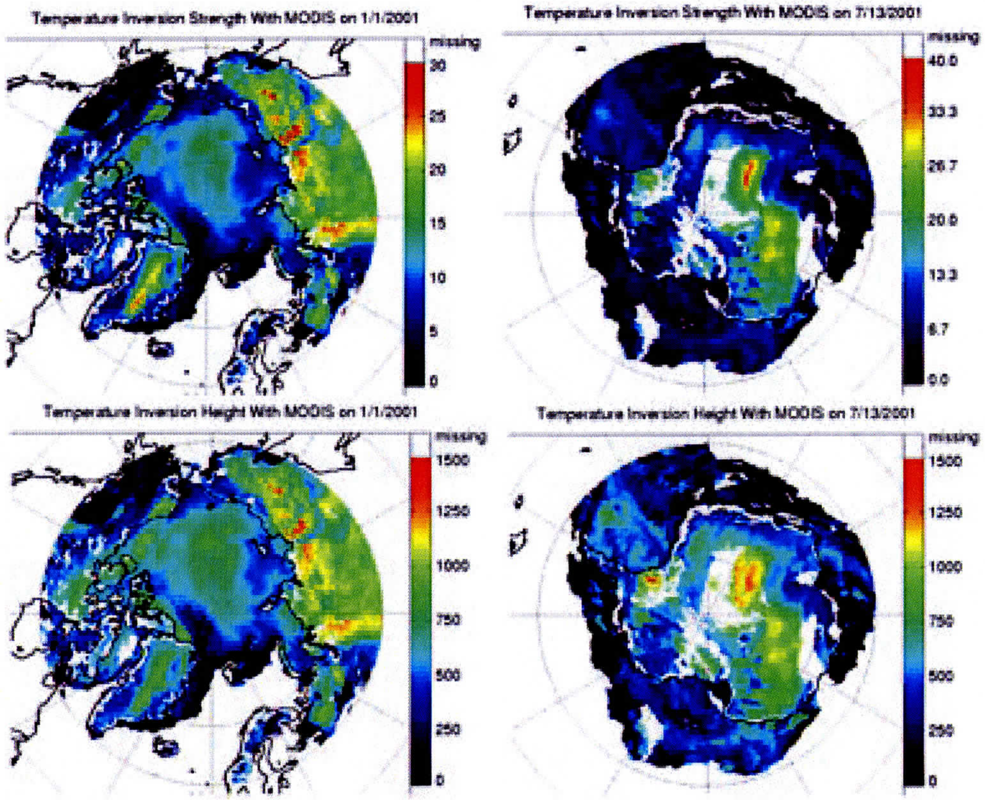


Figure JK1. Temperature inversion strength (top row in deg K) and height (bottom row in meters) estimated from MODIS over the Arctic (left column) and Antarctic (right column) on a single winter day for each hemisphere.

<u>Polar Winds</u>

Over the last six months UW has completely automated the real-time processing of MODIS data for polar winds retrievals. MODIS level 1b granules for both north and south polar regions are obtained through the NOAA "bent pipe". Approximately 100 granules per day are transferred via FTP from a NOAA computer at Goddard Space Flight Center to UW. Wind retrieval procedures are then done locally. Improvements have been made in the data acquisition procedure such that time lags have been reduced from 5-8 hours to 3-6 hours; i.e., MODIS polar winds are available within 3-6 hours after MODIS views any given area. Aqua MODIS data are now being processed in addition to Terra MODIS data.

The real-time winds are being used by the European Centre for Medium Range Weather Forecasting (ECMWF) and the NASA Data Assimilation Office (DAO) in model impact studies and experimental forecasting systems. ECMWF plans to put the winds into their operational system in January 2003. Real-time MODIS wind plots are available on the Web at http://stratus.ssec.wisc.edu/products/rtpolarwinds.

International MODIS/AIRS Processing Package (IMAPP) MODIS Science Products Software

The suite of products available as part of the International MODIS/AIRS Processing Package (IMAPP) continues to expand. During the last half-year, the atmospheric profiles product (MOD07) was added to the IMAPP; it includes vertical profiles of temperature and moisture, total column, low and high water vapor and stability indices. In addition, Aqua compatible science products were developed and tested as part of the UW direct broadcast automated processing scheme in preparation for IMAPP release. Aqua and Terra compatible cloud mask (MOD35), cloud top properties and cloud phase (MOD06CT), as well as atmospheric profiles (MOD07) IMAPP software will be released in 1st quarter 2003.

IMAPP atmospheric profiles product MOD07 software was released in October 2002 and is compatible with DAAC operational version 3.1.0 delivered to the DAAC in May 2002. As stated in previous reports, the IMAPP direct broadcast software differs from DAAC operational software in that it is simplified (no required toolkits other than HDF) and has been ported and tested on a variety of different unix/PC platforms. More information on the current state of IMAPP is available at: http://cimss.ssec.wisc.edu/~gumley/IMAPP/ .

To simplify the direct broadcast version of the atmospheric profiles product, the output file differs from the operational MOD07 output file in that:

1) It is a 4 byte float binary flat file instead of HDF. All parameters (bands) are of type 4 byte float.

2) There are two .img and two .hdr files representing the 83 operational MOD07 HDF Scientific Data Sets (SDS's).

3) There are no geolocation or solar and viewing geometry parameters included as part of the Direct Broadcast product.

4) The output product consists of 83 band interleaved parameters instead of individual HDF file SDS's

5) The output product does not include several operational MOD07 SDS's (most of these operational product arrays are empty). These are:

    Cloud_Mask
    Processing_Flag
    Tropopause_Height
    Guess_Temperature_Profile
    Guess_Moisture_Profile
    Quality_Assurance_Infrared

6) There is no quality assurance array or file included with this release. In operational processing, the quality is always set to good if a retrieval is performed.

In response to user requests for output products in HDF format, IDL routines were included to transform the flat binary output atmospheric profiles product into a simplified HDF file.

An example of the IMAPP MOD07 total precipitable water vapor array produced from both Aqua and Terra data is displayed as part of Figure KIS1.

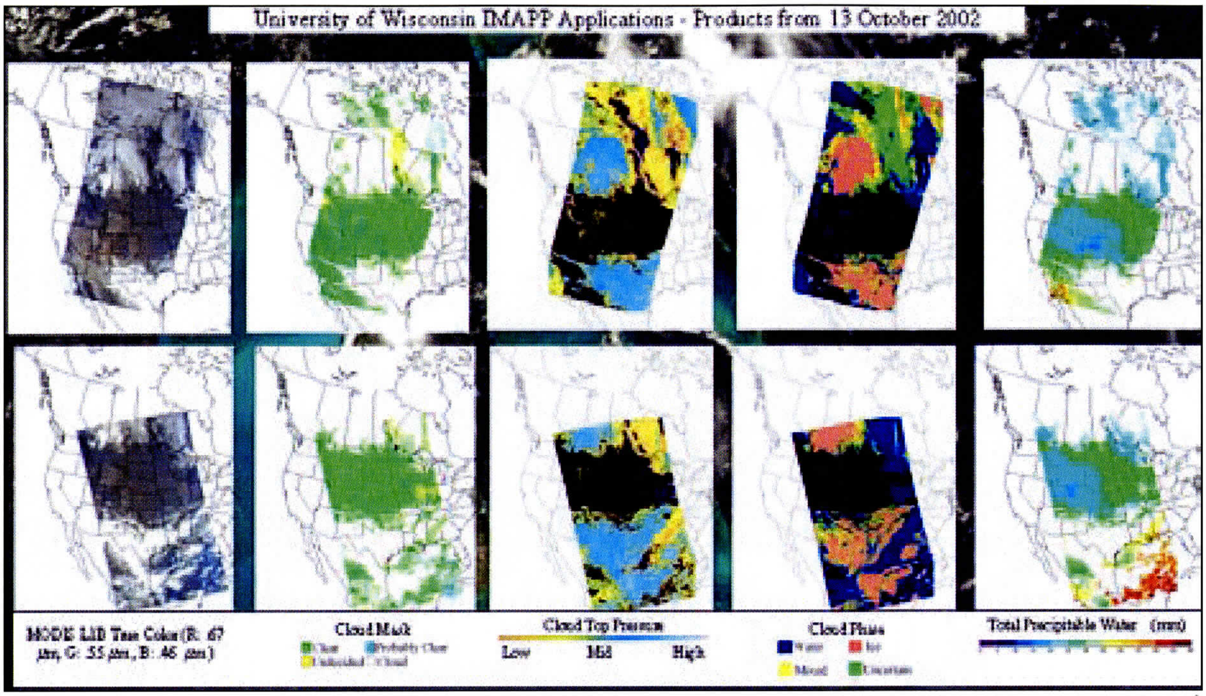


Figure KIS1. Example of Terra (top) and Aqua (bottom) MODIS products generated automatically using the UW IMAPP software on 13 October 2002. The final L1B, Cloud Mask, Cloud Top Properties and Cloud Phase, and Atmospheric Profiles products are all available freely for distribution from the UW ftp server at ftp://terra.ssec.wisc.edu/pub/terra/modis/:

Software producing both Aqua and Terra cloud mask (MOD35), cloud top properties and cloud phase (MOD06CT) as well as atmospheric profiles (MOD07) is being prepared for release in first quarter 2003. Several issues had to be addressed. The dead detectors of MODIS/Aqua band 6 (1.6 micron), used by the cloud mask to differentiate between clouds and snow, necessitated separate Aqua and Terra cloud mask threshold files and snow mask processing routines; these had to be developed, tested, and integrated. Compatibility with the DAAC operational version required a new routine to correct for the striping in band 26 (1.38 micron); without this correction, thin cirrus would not be correctly detected or placed in the thin cirrus bit (bit 9). This was also developed and tested as part of IMAPP.

A de-striping algorithm used to correct for energy from the 1.2 micron region (band 5) leaking into the 1.38 micron detectors (band 26) was developed by Chris Moeller. Terra coefficients have been demonstrated that correct band 26 based upon the amount of band 5 scene radiance for a given detector. It will correct for some of the striping and lower the average radiance in the band 26 scenes. The band 26 scaled integers are corrected and re-written back into the hdf file. In addition, a global attribute "IMAPP_DESTRIPE" is added. The current algorithm applies only to Terra data; coefficients for Aqua data are scheduled to be available in mid-2003.

The IMAPP band 26 de-striping process follows this sequence:

1) Band 26 and Band 5 scaled integer data are read out of the 1 km MODIS IMAPP or DAAC Level 1B HDF file.

2) If Band 5 data is saturated (scaled integer values of 65533 or 65528) the largest possible good data value is used.
3) If the band 5 value is flagged as bad, the band 26 value is replaced as missing.
4) If band 26 value is flagged as bad, it is left as bad.
5) Band 5 and Band 26 data are converted to radiances.
6) The correction is applied to band 26 data using the formula:

$$Rad26cor = Rad26(i) - Rad5(i)*Coef(i)$$

where i is the instrument detector number (1-10).

7) The corrected band 26 radiances are turned back into scaled integers and written back into the file.
8) A global attribute is added to the file to indicate that band 26 has been corrected (IMAPP_DESTRIPE).

Electronics changes (switching from A side to B side) in Terra have caused the correction coefficients to be changed twice since launch. IMAPP users are directed to use the correct coefficient files based upon the date of the data. All coefficient files are available as part of the IMAPP band 26 de-striping software.

IMAPP MODIS Level-1 Software

On 13 September 2002 the first version of IMAPP Level-1 software to support both Terra and Aqua MODIS was released. Several items were noted:

- The Terra MODIS calibration and geolocation algorithm and lookup tables are unchanged from the MODIS Level 1 v1.3 release.
- The Aqua MODIS calibration algorithm and lookup tables are versions 3.0.1 and 3.1.0.2, respectively. These include post-launch calibration data acquired following the Aqua MODIS nadir door opening and will handle all Aqua MODIS data acquired to date.
- The Aqua MODIS geolocation algorithm requires that ephemeris and attitude files, since spacecraft position is not encoded in the Aqua MODIS Level 0 PDS files. For realtime processing, the GBAD data (APID 957) transmitted as part of the X-band downlink may be used in conjunction with the GSFC GBAD processor to produce IMAPP-compatible ephemeris and attitude input files. Experience at UW has been that realtime geolocation using GBAD derived ephemeris and attitude data is accurate to within 500 meters. For non-realtime processing, the definitive Aqua ephemeris and attitude files may be used, providing the same geolocation accuracy as the operational processing at GSFC. The definitive ephemeris and attitude files are usually not available for at least 24 hours.
- The IMAPP MODIS Level 1 processing script (util/imapp.csh) has been updated to handle both Terra and Aqua data. This script combines the functionality of the level1a.csh, geolocate.csh, and calibrate.csh scripts and allows all input files to be specified on the command line. The user is responsible for identifying the satellite (Terra or Aqua).

MODIS Training

From October 24 to December 3 Liam Gumley visited Perth, Western Australia to work with local users of MODIS direct broadcast data. The culmination of the visit was the presentation of a workshop titled "Practical Applications of MODIS data in Australia" at the Leeuwin Centre, Floreat WA. He visited the Leeuwin Center, Department of Land Administration (DOLA), and the Dept. of Applied Physics, Curtin University of Technology.

Three sites in Australia acquire and process Terra and Aqua MODIS direct broadcast data routinely: (a) Perth, operated by WASTAC (http://www.wastac.wa.gov.au); (b) Alice Springs, operated by ACRES (http://acs.auslig.gov.au/modis_data); and (c) Hobart, operated by ACRES (http://www.terss.org.au/). MODIS data from all three stations are regularly processed to Level-1B products, and to a small but growing set of Level-2 products. The purpose of this trip was to work with local users to help them better understand the potential applications of MODIS data and to present a workshop over four days. Both lectures and interactive laboratory sessions helped to introduce the characteristics of MODIS Level-1B data in detail and also to describe the application of MODIS Level-1B data to problems such as cloud masking, atmospheric water vapor retrieval, and fire detection.

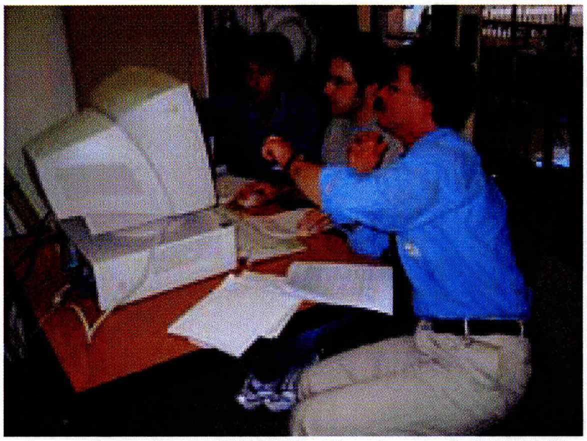
Time was also spent with Curtin University and DOLA personnel discussing MODIS realtime processing and applications by the WASTAC ground station. Assistance was provided to help solve several problems encountered in re-projecting MODIS 250 meter resolution images. Also, discussions with Curtin University staff led to the drafting of a proposal to WASTAC to support a full time employee specifically for MODIS processing; this proposal was subsequently presented at the WASTAC board meeting on Nov. 27th in conjunction with a presentation on MODIS real-time processing.

Lectures for the workshop were made available to attendees at http://www.wastac.wa.gov.au. Laboratory sessions made use of a demo version of ENVI 3.6 for Windows and sample MODIS datasets over the Australian region. Each laboratory was designed to last at least 3 hours, and contained many exercises requiring the attendees to carefully examine the various features of MODIS data. Specially formatted ENVI BIL datasets were used, where conversions to sensor reflectance and brightness temperature had already been done. Many of the attendees had never used ENVI, but all of them were able to work through the laboratory exercises at a good pace without major holdups.

A motivated group of Australians became familiar with some of the challenges and opportunities presented by the new capabilities of MODIS. The workshop participants made very positive comments. (a) "Very well run seminar and labs. The informal nature made them much more enjoyable." (b) "I was told this workshop would get me a long way up the practical MODIS learning curve fairly quickly. I feel that it did. Thanks." (c) "Excellent presentation and exercises." (d) "The practical sessions were well planned and interesting." This suggests repeating such a workshop in locations where direct broadcast MODIS data are acquired and processed. On a related note, many of the attendees expressed their gratitude for the International MODIS/AIRS Processing Package (IMAPP) software, and strongly encouraged continued development and support. IMAPP is now the official processing software for the three operational Australian MODIS ground stations. Several attendees also expressed a high level of interest in future additions to IMAPP including AIRS/AMSU/HSB Level-1 processing, MODIS land products (particularly land surface reflectance), and MODIS ocean products.

Workshop Leader Liam Gumley

Laboratory Session in Progress



Attendees from CSIRO, Curtin, and ACRES

Presenter Stefan Maier

Figure LG1. Photographs from the MODIS Workshop, 26-29 Nov 2002, Perth Western Australia

<u>IMAPP MODIS Product Applications at UW</u>

UW direct broadcast MODIS MOD07 products are now processed for both Aqua and Terra MODIS, and images are automatically generated twice daily and posted to the web site http://cimss.ssec.wisc.edu/modis/mod07. Products displayed for both satellites include TPW, PW high, PW low, lifted index, total ozone, and temperature and mixing ratio at 300, 500, 700, and 850 hPa. Some examples of images created from direct broadcast MOD07 are shown in Figures SWS10 and SWS11. Figure SWS10 shows two isobaric surfaces of temperature (300 and 850 hPa), for each Aqua and Terra MODIS. Good agreement exists between the two, although Aqua MODIS is somewhat cooler than Terra MODIS at both levels. Figure SWS11 compares Aqua MODIS TPW with that from Terra MODIS. Again, the dry bias is evident in Aqua MODIS TPW and the cleaner image makes the gradients in Aqua more discernable, particularly over the Gulf of Mexico

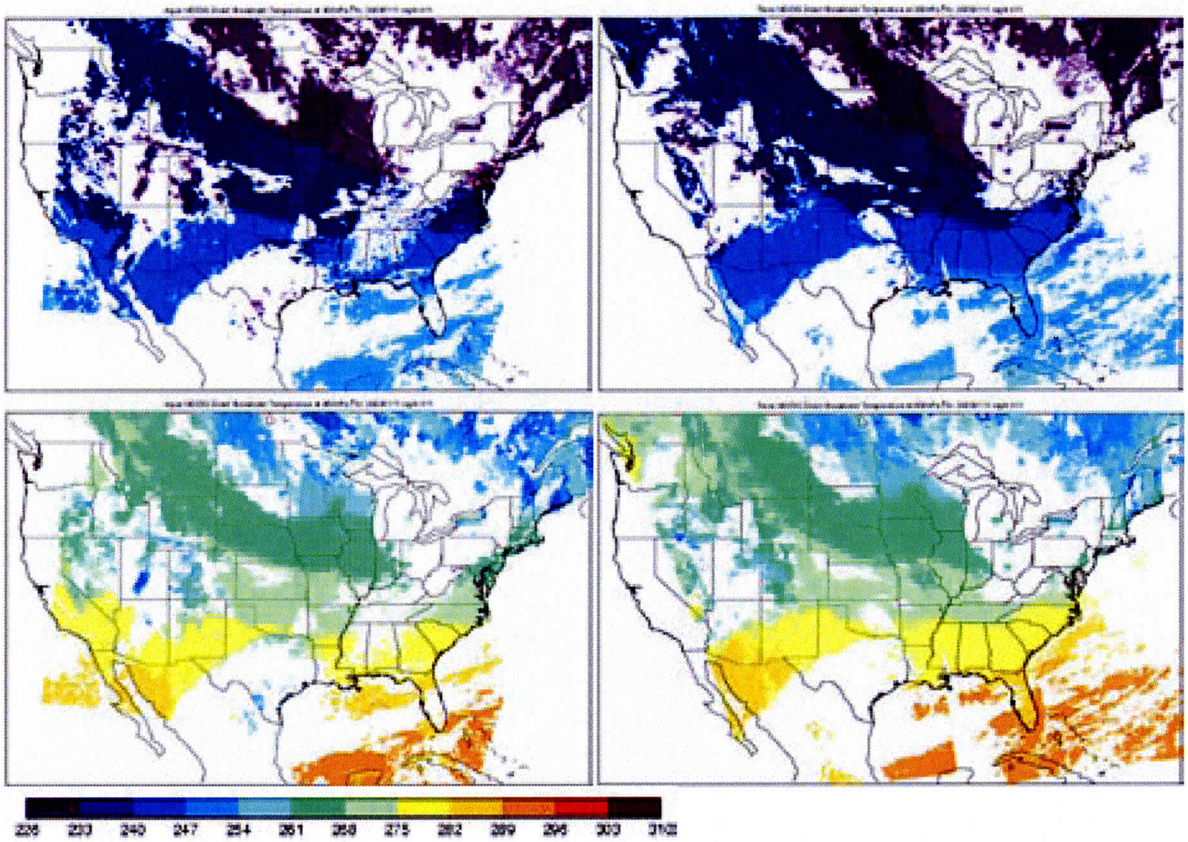


Figure SWS10. Temperature (°K) at 300hPa (top) and 850 hPa (bottom) on 11 January 2003 from Aqua MODIS (left) and Terra MODIS (right) from direct broadcast data processed at UW. All satellite passes that were received and processed during the night (0100-0900 UTC) were combined and displayed on the same image.

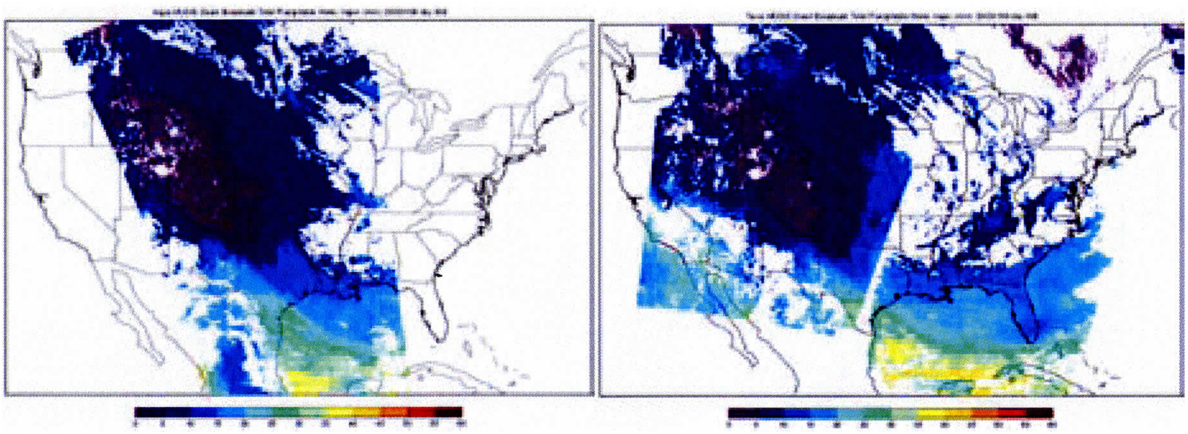


Figure SWS11. TPW (mm) on 8 January 2003 from Aqua MODIS (left) and Terra MODIS (right) from direct broadcast data processed at UW. All satellite passes that were received and processed during the day (1500-2000 UTC) were combined and displayed on the same image.

CIMSS is using IMAPP direct broadcast MODIS products for many purposes. These include validation of MODIS products, testing new MODIS algorithms, and making changes to existing production software. Real-time data collection and processing enable routine sampling of the data covering pre-determined regions and thus facilitating intercomparisons with other instrument measurements and regional applications. For instance, MODIS water vapor retrievals along with MODIS radiances are being processed for all overflights of the Oklahoma Cloud and Radiation Testbed (CART) site and compared with retrievals from other instruments at the site. Data are also being routinely shared with Dr. Simon Hook of NASA's Jet Propulsion Laboratory (JPL) for MODIS calibration and product validation over Lake Tahoe, Nevada, USA. Real-time product files that are staged on the CIMSS direct broadcast ftp site (ftp://terra.ssec.wisc.edu/pub/terra/modis/) are being used by NASA's Short-term Prediction Research and Transition Center (SPORT) to provide real-time high spatial resolution products to meteorologists at the USA National Weather Service (NWS). Figure KIS2 is a screen shot of the SPORT web page found at: http://wwwghcc.msfc.nasa.gov/sport/modis_products.html that is generated and updated automatically displaying MODIS direct broadcast images and products. The Canadian Ice Service has requested routine MODIS quick look images covering Hudson Bay so they can monitor ice cover for shipping concerns. A partial list of current users of the digital MODIS Level-1B data acquired and processed at CIMSS includes:

Environmental Remote Sensing Center, University of Wisconsin-Madison, USA
Naval Research Laboratory, Monterey, California, USA
Short-term Prediction Research and Transition (SPoRT) Center, NASA/MSFC, USA
Satellite Services Division, NOAA/NESDIS, USA
Atmospheric and Environmental Research, Inc, Lexington Massachusetts, USA
Upper Midwest Aerospace Consortium, University of North Dakota, USA
National Center for Environmental Prediction (NCEP), NOAA, USA
MODIS Snow and Sea Ice Global Mapping Project, NASA/GSFC, USA

Other groups are also using IMAPP to generate real-time products. Plymouth Marine Laboratory's Remote Sensing Data Analysis Service (RSDAS) in the UK posts real-time IMAPP MODIS products on their web site for use in the CLOUDMAP2 European program. One of the goals of CLOUDMAP2 is "to produce and exploit value-added remote sensing data products on macroscopic (e.g. cloud-top height) and microscopic (e.g. cloud droplet radius) properties and water vapor distributions to characterize sub-grid scale processes within Numerical Weather Prediction Models (NWP) through validation and data assimilation". The web site is located at http://www.npm.ac.uk/rsdas/projects/cloudmap2/. An example of the IMAPP cloud top temperature product taken from the PML web site is displayed in Figure KIS3. Correspondence from IMAPP users around the world indicates that the software is used in the USA, UK, Germany, Italy, Norway, Japan, China, Russia, S. Korea, Singapore, Thailand, Vietnam, Brazil, South Africa, Australia and Mexico.

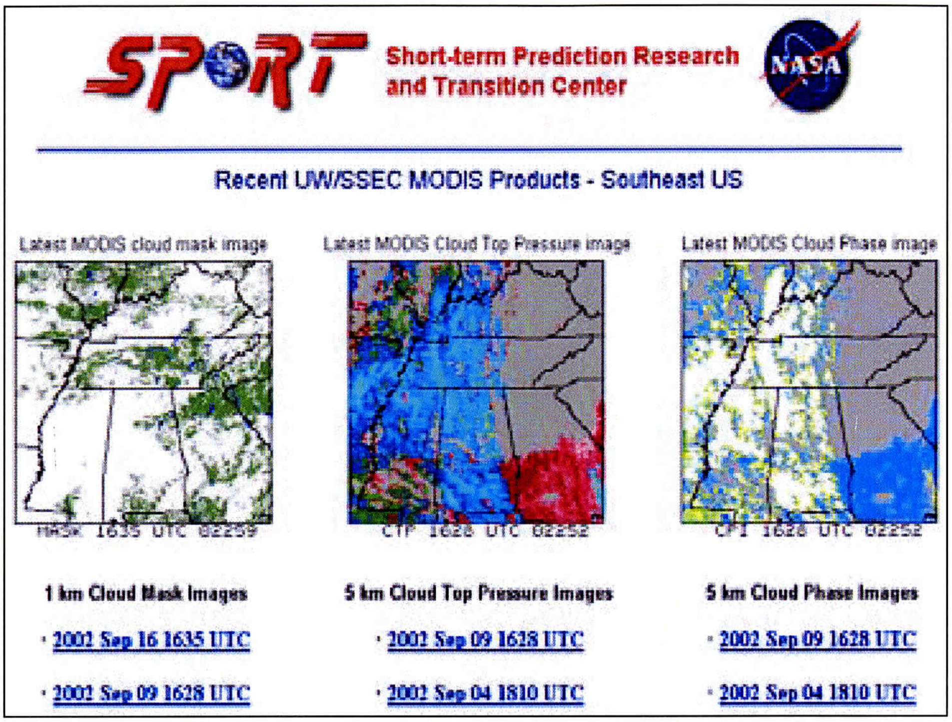


Figure KIS2. Screen shot of the SPORT web page displaying real-time MODIS direct broadcast products for use by the USA National Weather Service forecasters. This particular display is from 16 September 2002.

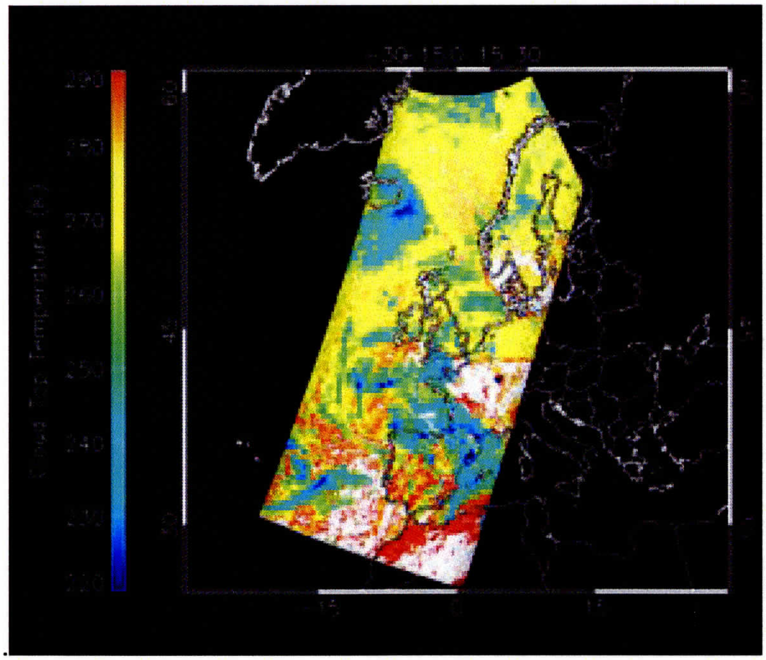


Figure KIS3. IMAPP MOD06 cloud top temperatures from the 18 September 2002 created by the Plymouth Naval Laboratory, UK as part of the CLOUDMAP2.

MEETINGS / CONFERENCES

Bryan Baum, Liam Gumley, Jeff Key, Chris Moeller, Kathy Strabala, and Paul Menzel attended the MODIS Science Team Meeting, 22-24 July 2002. Liam gave a presentation on direct broadcast MODIS atmosphere products at UW in plenary session. Jeff spoke about MODIS polar winds impact in the DAO and ECMWF forecast models in plenary. Chris gave an update on Terra and Aqua MODIS cal/val progress to the atmospheres group and MCST meetings. Bryan spoke about multi-layered clouds and cloud shadows in the atmospheres group meeting and about cloud phase determinations in plenary. Paul spoke about TPW validation in the atmospheres groups and about HIRS and MODIS cloud top property intercomparisons in plenary.

Chris Moeller attended THORpex/TOST planning and science meetings on 17 Sep and 13 Nov 2002 and presented materials on EOS Atmosphere Group validation of MODIS products.

Chris Moeller participated in the TX-2002 ER-2 field campaign from 18 Nov – 12 Dec 2002 to plan and direct ER-2 science missions during the campaign.

Hong Zhang, Suzanne Wetzel-Seemann and Paul Menzel attended the SPIE conference on Remote Sensing of the Atmosphere, Ocean, Environment, and Space on 23-27 Oct 2002 in Hangzhou, China. Each gave a presentation on MODIS science conducted at UW.

Hong Zhang gave a talk on a new CO_2 slicing to detect thin clouds and MODIS cloud mask in Beijing, China from 27 – 31 Oct. 2002 at workshop on environmental satellite and applications at the invitation of National Satellite Meteorology Center, China Meteorology Administration. Paul talked about MODIS products as a precurser of NPOESS capabilities.

Liam Gumley visited Perth, Western Australia from 24 Oct to 3 Dec 2002 to work with local users of MODIS direct broadcast data and to conduct a workshop titled "Practical Applications of MODIS data in Australia" at the Leeuwin Centre, Floreat WA.

Jun Li attended the EOS Investigators' Working Group (IWG) Nov.18 – 20, 2002 in Ellicott City, MD and presented a talk entitled: "Integration of MODIS, HIRS and AMSU Data for Atmospheric Studies."

Paul Menzel gave a lecture on "One Year of Global Atmospheric Total Column Precipitable Water Vapor Retrievals from MODIS Infrared Radiances" in L'Aquila, Italy as part of a series of lectures on "Remote Sensing of the Earth's Environment from Terra" organized by Dr Guido Visconti for the International Summer School on Atmospheric and Oceanic Sciences (ISSAOS 2002) from 25 – 30 August 2002 at the Scuola Superiore Guglielmo Reiss Romoli. Seventy one students attended. Twenty two scientists from the NASA EOS teams presented lectures covering all the Terra instruments and the associated applications areas. A CD of the lectures will be distributed as well as a book presenting the papers.

Paul Menzel gave a paper on "Satellite Observations of High Clouds since 1978" at the EUMETSAT Meteorological Satellite Users Conference held in Dublin, Ireland 2 – 6 September

2002. The paper summarizes 23 years of high cloud trends from the High resolution Infrared Sounder (HIRS), describes impact on the ECMWF 40 year reanalysis project, and introduces the MODIS cloud detection results.

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