INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

SEMI-ANNUAL REPORT FOR JAN - JUN 2000

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ABSTRACT

Following the successful MODIS launch, most of the resources at UW have been focussed on assuring that the data stream logistics are working, the calibration is viable, the pre-processing algorithms are generating good level 1b data, and the science algorithms are generating the expected quality of cloud and atmospheric products. Characterizing and understanding problems with the infrared calibration consumed considerable energy; most of the problems have been corrected or soon will be. UW hosted the WISC-T2000 field campaign that produced many sets of collocated MODIS, MAS, Scanning HIS, and ATOVS data; in addition ground based data from the CART site was also captured in collocation with the space borne instruments. The cloud mask was adjusted to conform with MODIS instrument performance; feedback from the land, ocean, and atmosphere groups using the mask have been positive. The UW cloud and clear sky properties have successfully been compared to those from HIRS and GOES; adjustments to the ozone code is still pending. MODIS direct broadcast hardware installation proceed and initial L1B software was completed: the UW antenna will be installed in early August 2000.

TASK OBJECTIVES

Science Production Software Development

Post-launch adjustments were made to the cloud mask, cloud top properties, and atmospheric profiles production software packages. The changes are being integrated into both the DAAC and MODAPS processing chains. Improvements to the clear radiance files used by both the cloud mask and cloud top properties code were accomplished.

MODIS Infrared Calibration

MODIS performance evaluations at the University of Wisconsin are focused on MODIS scan mirror Response Versus Scan (RVS) behavior, PC LWIR band optical crosstalk mitigation, the SWIR band 5μm leak, electronic cross-talk behavior (especially the impact on the MODIS cirrus band 26 at 1.38μm), and MODIS emissive band calibration validation.

WISC-T2000 Field Experiment

UW hosted the Wisconsin Snow and Cloud experiment – Terra 2000 (WISC-T2000) from 24 February through 13 March. A NASA ER-2 was deployed to Madison, WI to pursue research in snow detection, clear atmosphere profiling, and cloud characterization during MODIS / Terra overpasses.

MODIS Cloud Mask

The first six months of data from Terra were used to perform extensive quality control and "reasonableness" checks on the MODIS cloud mask algorithm. Several coding errors were found and corrected and some thresholds were adjusted. Changes made to the algorithm and implemented on 28 May 2000 included adjustments to the land/snow/sun-glint, the spatial variability test over oceans, the NDSI test processing, and the CO_2 high cloud test.

EOS Direct Broadcast

The first version of the International MODIS/AIRS Processing Package (IMAPP) was released on May 12. The package was rapidly put into operations by the University of Dundee, the University of Hawaii, Kongsberg Spacetec of Norway, SeaSpace Corporation of San Diego, and RD Center Scanex of Moscow, among others. Correct operation of IMAPP was verified by processing Level-0 data samples acquired from Dundee, Hawaii, and NASA GSFC.

WORK ACCOMPLISHED

MODIS Infrared Calibration and On-Orbit Performance

Early MODIS performance evaluations at the UW have primarily focused on MODIS scan mirror Response Versus Scan (RVS) behavior, PC LWIR band optical crosstalk mitigation, the SWIR band 5μm leak, electronic cross-talk behavior (especially the impact on the MODIS cirrus band 26 at 1.38μm), and MODIS emissive band calibration validation.

Cross-track profiles of MODIS LWIR CO_2 band brightness temperature have showed a decided warm bias in clear scenes towards the end of scan compared to the beginning of scan. This asymmetry, approaching 6°C and more, was unexpected given the classical clear scene symmetry displayed by LWIR CO_2 bands of heritage instruments as well as forward model guidance. Also, MODIS band 24, an MWIR CO_2 sensitive band, did not display inordinate asymmetry suggesting that only the LWIR CO_2 band RVS correction was inaccurate. Radiative transfer theory, coupled with these observations and knowledge of MODIS scan mirror thermal characteristics, suggested that unexpectedly large adjustments were necessary to the LWIR band RVS. During the June 2000 MODIS Science Team (MST) meeting, discussions with MCST led to a discovery of an array-indexing error in the L1B processing code. This error was verified by MCST through L1B testing and fixed in short order, with new L1B processing code in place operationally by June 19. Subsequent review of MODIS data since the RVS code fix has demonstrated great improvement in the MODIS CO_2 band symmetry; early MODIS data (i.e. before June 19) must be reprocessed with the new L1B processing code. The discovery and removal of the RVS error has positively impacted MODIS TOA radiometric comparisons, cloud mask, and cloud top properties products at the UW. A plan to evaluate RVS using a large data sample of Antarctica scenes is yet to be implemented but remains under consideration.

Prelaunch testing of the MODIS protoflight model (PFM) demonstrated that MODIS Band 31 is contributing energy through an optical leak to MODIS bands 32-36. Prelaunch correction coefficients were generated using MODIS T/V data sets. It is expected that some adjustment of the prelaunch correction coefficients will be necessary to achieve optimal performance in the PC LWIR bands. MCST has reviewed lunar data sets viewed through the MODIS Space View for evidence of residual band 31 effects on bands 32-36. At the UW, earth scene data sets have been reviewed for similar behavior. Both the UW and MCST independent analyses suggested that the crosstalk correction was too large in bands 34–36. MCST has generated a new set of crosstalk correction coefficients that are about half the original value (i.e. less crosstalk than originally anticipated). The UW has tested these coefficients and corroborated MCST's findings. While the evaluation is not considered definitive, it is believed that the MODIS PC bands 33-36 are performing to an accuracy of about 2%, which still is short of the 1% accuracy requirement in these bands. Additional work on PC band crosstalk mitigation will be undertaken; this will include further evaluation of lunar view data sets as well as earth scene data sets. Earth scenes containing large (> 30°C) surface-based thermal contrast are useful for identifying residual crosstalk effects (the more thermal contrast, the greater the potential to improve PC band accuracy). As the Northern Hemisphere summer season progresses, scenes of high thermal contrast will be evaluated along the Baja coast of CA and other high thermal contrast land/water interfaces.

The MODIS cirrus detection band 26 (1.38 μm) is a low signal reflectance band. It is known to be affected by a leak of 5.0 μm energy and electronic crosstalk among the SWIR and MWIR bands. Corrections are being investigated, including ongoing assessment to optimize instrument bias settings (ITWK/VDET) on-orbit. During nighttime, band 26 should report no signal (assuming lunar reflectance is negligible). This is not the case, as can be seen with the outline of Cuba in Figure 1. Radiative transfer theory indicates that reflectance from the surface of the earth is typically obscured in band 26 by intervening atmospheric water vapor absorption. Thus, the appearance of Cuba in the nighttime imagery is considered anomalous and is likely due to either the 5.0 μm leak or the SWIR/MWIR crosstalk. Using MODIS band 28 (7.1 μm) as a surrogate for the 5.0 μm radiance, it is evident that atmospheric water vapor absorption is sufficient to mask the surface emission of Cuba. Thus the appearance of Cuba in the band 26 nighttime imagery is probably a result of electronic crosstalk. The calibrated radiance in the nighttime band 26 data is negative, which is an observed characteristic of electronic crosstalk; however, overcorrection of the 5um leak could also cause a negative radiance in a low signal scene. Electronic crosstalk is expected to impart surface variability into all (day and night) band 26 imagery. This will challenge the detection of thin cirrus using band 26 at a level that is difficult to characterize; the nighttime band 26 data shows signals (albeit negative) approaching 10% of band 26 Ltyp. In the next several months, the convolved effects of the 5um leak and electronic crosstalk will be further evaluated using nighttime data for all SWIR bands (through a special data set collection). It is not clear that an electronic crosstalk correction algorithm can be effectively designed. As such, it is preferred that the scene dependence of electronic crosstalk be minimized, so that any correction algorithm will be as linear as possible.

With the first ER-2 underflights of Terra (see Table 1), early evaluation of MODIS emissive band radiometric calibration is underway. ER-2 based observations (MAS, SHIS) have been used to estimate top of atmosphere (TOA) radiances / brightness temperatures and compared to collocated (space and time) MODIS radiances / brightness temperatures. It is necessary to remove all viewing geometry (slant path, altitude, spatial effects) and spectral dependencies (bandpass) to perform a viable comparison.

During WISC-T2000, the ER-2 underflew the Terra 1725 UTC overpass on 5 March 2000 in clear skies over Lake Michigan. MODIS fields of view (FOV) were located on the MAS imagery and the MAS 50m spatial resolution data was convolved to the MODIS spatial footprint (as defined by prelaunch OBA test data coupled with idealized blurring by scan mirror motion). The SHIS radiometric calibration was transferred to the MAS instrument to attain a MAS radiometric accuracy of 0.5°C (see section on MAS IR Calibration Studies). Spectral and altitude dependencies between MAS (20 km) and MODIS (705 km) were removed by forward model calculations using the Green Bay, WI 00 UTC (six hours later) radiosonde profile with a surface temperature of 275 K (estimated sea surface temperature of Lake Michigan). Slant path dependence was eliminated by using only MAS FOVs with a slant path between 25° and 35°, similar to that of the MODIS 30° slant path. Solar geometry was also matched between the sensors; this is important for solar reflectance sensitive MWIR bands in the 4 μm region. The March 5 17:25 UTC MODIS granule was reprocessed at GSFC to incorporate the June 2000 RVS indexing code fix; this code fix adjusted MODIS LWIR atmospheric CO_2 band brightness temperatures by several degrees because of the large AOI (~54°) for MODIS scenes of Lake Michigan on March 5.

The comparisons (Figure 2) suggest the radiometric accuracy of MODIS window bands (20, 22, 23, 29, 31, 32) is within 0.5°C, which is the accuracy of the SHIS and MAS radiances. Window bands are easiest to validate since slant path and altitude effects are generally small (~0.1°C). Atmospheric bands (25, 30, 33, 35, 36) show larger residuals. The LWIR CO_2 bands (33, 35, 36) are negatively impacted by perceived overcorrection of PC band crosstalk. This 1-2°C impact will be removed in an anticipated (Aug 2000) L1B processing update by MCST. Band 30 is an ozone sensitive band and is sensitive to the altitude correction. It is likely that the climatological ozone concentration applied in the forward model has not accurately represented the ozone concentration present on March 5, 2000. Bands 25, 33, 35, and 36 are all CO_2 sensitive bands and as such are also sensitive to the upper atmosphere characterization for the altitude correction. Error in temperature knowledge of the upper troposphere and tropopause regions will propagate into the MODIS residuals. Additional investigation and further comparisons are necessary to derive the radiometric accuracy of MODIS atmospheric bands. Figure 2 also shows the MODIS residuals before the RVS indexing code fix was applied. It is clear that the fix has positively impacted almost all bands and is leading to improved understanding of MODIS performance. With additional findings on other MODIS emissive band performance issues (e.g. PC band crosstalk, RVS, detector nonlinearity) it is anticipated that MODIS emissive band accuracy will continue to improve. Further ER-2 underflights will be required to document the improving performance.

WISC-T2000 Field Experiment

The Wisconsin Snow and Cloud experiment – Terra 2000 (WISC-T2000) was conducted from Madison WI from February 24 – March 13, 2000. A NASA ER-2 was deployed from Truax Field. Eight science flights were completed during the experiment (Table 1). The missions were primarily targeted towards MODIS and MISR validation activities, including top of atmosphere (TOA) radiances (Feb 27, March 5 and 11), cloud products (Feb 28, March 1, 3, and 12) and snow characteristics (March 6). During the experiment, the ER-2 flew three missions (March 1, 3, and 12) coordinated with the Spring 2000 Cloud IOP aircraft (Citation II, Learjet, Twin Otter) at the CART SGP site for cirrus and low stratus cloud property studies. During these missions, the ER-2 measured upwelling radiance while the Cloud IOP aircraft below collected in situ and low level radiometric measurements of clouds. All eight science missions flew under the Terra satellite, representing the first science underflights of Terra.

The ER-2 payload included the MAS, SHIS, CLS and Air-MISR instruments. MAS and SHIS data are being used for TOA radiance comparisons with MODIS; CLS data is being combined with MAS to test MODIS cloud top properties and snow detection; Air-MISR data scenes are being used for MISR validation. A large array of ground based instrumentation at the ARM CART SGP site was overflown for independent characterization of clear sky and clouds. Activities using the WISC-T2000 data set are reported in other sections of this report. A plan to make ground based measurements from frozen Lake Mendota in Madison during ER-2 and Terra overpasses had to be scrubbed due to an extended period of near record warm temperatures in late February. The Wisconsin Dept. of Natural Resources issued advisories not to venture out onto thinning lake ice. A WISC-T2000 web page including flight summaries, quicklook data archive, and data examples is located at http://cimss.ssec.wisc.edu/wisct2000/.

ER-2 activities for FY01 are being planned. A flight request for five flights (25 flight hours) in late winter/early spring has been submitted to NASA. An ER-2 deployment to a site in the lower Great Plains or coastal Gulf of Mexico is desired so that both the ARM SGP and the Gulf of Mexico are reachable with the ER-2. Objectives are focused on MODIS cloud product (cloud mask, cloud top properties) and TOA radiance validation. Possible coordination with University of Miami ship based MODIS validation activities is being explored. Additionally, a plan is under development by ARM scientists to deploy a Citation aircraft to the ARM SGP site for cloud in situ measurements in spring 2001. If possible, the ER-2 flights will be coordinated with this ARM activity.

Table 1. WISC-T2000 February 24 – March 13, 2000

Date	Flt#	Sensor	Region	Comments
2/24	062	MAC	CA to WI	***Ferry flight***. Low thick cloud over WI. MSN snowfree.
2/25				Upload SHIS on ER-2. Near record warm temps in WI.
2/26				Short test mission cancelled by lack of interesting data scenes.
2/27	063	MSAC	WI	***MODIS Cal mission***. **TERRA** Underflight (1718 UTC; 0° view). Clear sky over land background. NAV failure.
2/28	064	MSAC	Lake Huron	***MODIS Cloud mission***. **TERRA** Underflight (1623 UTC; 32° view). Low cloud overcast on Lake Huron background.
2/29				Snow mission to NH cancelled in morning. Cirrus over WI.
3/01	065	MSAC	CART	***Cirrus mission*** coordinated with Learjet in situ. **TERRA** underflight (1752 UTC; +20° view) with high cloud over land.
3/02				MODIS cal mission cancelled over L. MI due to low clouds.
3/03	066	MSAC	CART	***MISR Low Cloud mission***. **TERRA** underflight (1739 UTC; 0° view) with low cloud overcast. NAV fail. SHIS fail.
3/04				SHIS off the plane. NAV recorder replaced. CART clear.
3/05	067	MSAC	Lake MI	***MODIS Cal mission***. **TERRA** underflight (1725 UTC; +30° view) with clear sky over Lake MI background. NAV fail.
3/06	068	MSAC	New Hamp.	***MODIS Snow mission***. Crossed **TERRA** (1629 UTC; 0° view) with clear sky over Lake Ontario. **TERRA** also viewed patchy snow scenes (1629 UTC; +30° view) in NH.
3/07				Multilayer over OK with convection; SHIS down.
3/08				Flt cancelled by lack of interesting data scenes.
3/09				Cirrus mission at CF cancelled by local winds (in MSN).
3/10				Thick clouds at CART. Upper level clouds over Great Lakes.
3/11	069	MSAC	Lake MI	***MODIS Cal mission***. **TERRA** underflight (1648 UTC; -23° view); cloudy and clear scenes over Lake Michigan.
3/12	070	MSAC	CART	***Combined MISR/Cirrus mission***. **TERRA** underflight (1734 UTC; -11° view) with clear scenes (some thin cirrus?) over CART Central Facility. Cirrus, alto cumulus scenes later.
3/13	071	MAC	WI to CA	***Ferry flight*** to Calif. Crossed **TERRA** (1816 UTC; TBD view) in partly cloudy skies (wave clouds) over Colorado.

Sensor Legend: M = MAS; S = SHIS; A = AirMISR; C = CLS

MAS IR Calibration Studies

The MAS emissive band radiances have been compared to the SHIS radiances using data from the WISC-T2000 experiment (March 2000). This work supports MODIS emissive band calibration validation, which is based in part on MAS and SHIS radiometric measurements. The NASA ER-2 overflew clear sky scenes of Lake Michigan on March 5 with MAS and SHIS on board. Both the MAS and SHIS collected data on four flight lines over Lake Michigan. SHIS high resolution spectra were convolved with MAS spectral response functions for all emissive bands to remove spectral dependencies. MAS radiances were spatially averaged over the collocated SHIS fields of view to remove spatial resolution dependencies. The comparisons (Figure 3) demonstrate good agreement between MAS and SHIS (over 4000 individual collocations per band). Window bands (30, 31, 36, 37, 42, 44, 45, 46) are within 0.5°C, an excellent result. Historically, MAS has agreed with the HIS (non-scanning) instrument to within about 0.5°C in the LWIR (bands 42, 44, 45, 46) and 1.0°C in the MWIR (bands 30, 31, 36, 37) window regions. Also of importance, MAS CO_2 sensitive LWIR bands (48-50) demonstrate agreement within 1.0°C of SHIS. Historically, these bands have shown departures of 1 - 3°C (MAS too warm). Other atmospheric bands (32, 35, 40, 41) also agree within 1.0°C of SHIS.

These improved results are attributable in part to the production and installation of new MAS onboard blackbodies, with improved emissivity paint coating, in the fall 1999. Direct emissivity measurements of each MAS blackbody at the Jet Propulsion Laboratory facility in CA were made in Jan 2000; close agreement of the emissivity of each MAS blackbody made it acceptable to combine these measurements for use in the MAS calibration algorithm (an approach historically used in MAS calibration). MWIR CO_2 bands (33,34) continue to show large residuals in comparison with SHIS; these bands have been historically difficult to spectrally calibrate in the Ames Calibration laboratory facility due to strong CO_2 absorption in the ambient measurement environment. In order to improve spectral characterization of these bands, MAS must be spectrally calibrated in a vacuum; there are no plans to implement such a procedure due to expense and time constraints. Bands 33 and 34 are not considered mission critical to MAS Science objectives. Also of interest is a large departure of opposite sign for adjacent bands 38 and 39. This behavior is under investigation.

The MAS instrument performed well during the WISC-T2000 field experiment. The use of hard disks for recording inflight data performed flawlessly and facilitated rapid turn-around of MAS data after each ER-2 flight. There were isolated occurrences of blackbody signal convergence in the LWIR bands (Port 4), which have been previously attributed to dewar pressure release. These tended to occur only at the beginning of the ER-2 flights (right after finishing climb-out) and thus had minimal impact on science content of the data sets. Estimates of MAS NEdT (Table 2) were low in Port 4 (very little correlated noise apparent) but larger than normal in Port 3 (e.g. Band 30, 3.75um, NEdT about 2 K).

Dan LaPorte reviewed the ARC spectral calibration laboratory setup and SRF measurement procedure in February. It was suggested to ARC that they modify the spectral calibration setup (add fine angle adjustment to scan mirror position, redesign MAS cradle for a more reproducible placement of MAS) to improve optical alignment repeatability from SRF generation to generation. It was also recommended that ARC perform a full ray trace of the ARC SRF measurement setup to estimate requirements on optical alignment accuracy. LaPorte is also interfacing with ARC on possible MAS blackbody redesign. Eliminating the active coolers on the blackbodies would allow more space in the scan cavity for an improved MAS blackbody geometrical design (with higher emissivity). This will however eliminate the capability to cool the BBs below the ambient temperature.

Table 2. MAS Noise Estimates using March 11, 2000 scenes of L. Michigan.

Band	CWN (cm-1)	CWL (um)	Number of FOVs	Radiance Mean (/..cm-1)	NedL (/..cm-1)	Temp. Mean (K)	NedT at T_{scene} (K)
26	3189.345	3.135	7413	.042	.0251	285.51	10.705
27	3041.629	3.288	9091	.046	.0228	276.61	8.668
28	2906.307	3.441	9988	.080	.0238	276.30	5.464
29	2780.583	3.596	10000	.138	.0218	276.82	3.044
30	2670.775	3.744	10000	.209	.0208	276.28	1.981
31	2564.524	3.899	10000	.298	.0215	274.67	1.477
32	2463.838	4.059	10000	.380	.0213	271.27	1.167
33	2373.057	4.214	10000	.151	.0217	245.95	2.558
34	2291.443	4.364	9999	.086	.0227	229.93	4.237
35	2213.561	4.518	10000	.520	.0256	256.23	1.015
36	2140.961	4.671	10000	1.364	.0274	271.07	.480
37	2074.157	4.821	10000	1.599	.0319	268.62	.483
38	2011.941	4.970	10000	1.972	.0297	267.85	.374
39	1954.017	5.118	10000	2.775	.0367	270.92	.346
40	1899.402	5.265	10000	2.515	.0463	263.01	.466
41	1860.367	5.375	10000	2.688	.1819	260.86	1.721
42	1171.334	8.537	10000	40.784	.1233	273.83	.134
43	1035.318	9.659	10000	40.233	.1293	256.89	.142
44	957.182	10.447	10000	70.947	.1500	275.50	.116
45	914.121	10.939	10000	77.582	.1497	275.56	.111
46	838.543	11.925	10000	88.625	.4321	275.15	.302
47	783.930	12.756	10000	93.282	.6767	272.76	.471
48	758.500	13.184	10000	86.723	.7994	265.56	.586
49	730.174	13.695	10000	67.218	1.7384	247.31	1.484
50	705.989	14.165	10000	50.269	2.6694	229.03	2.710

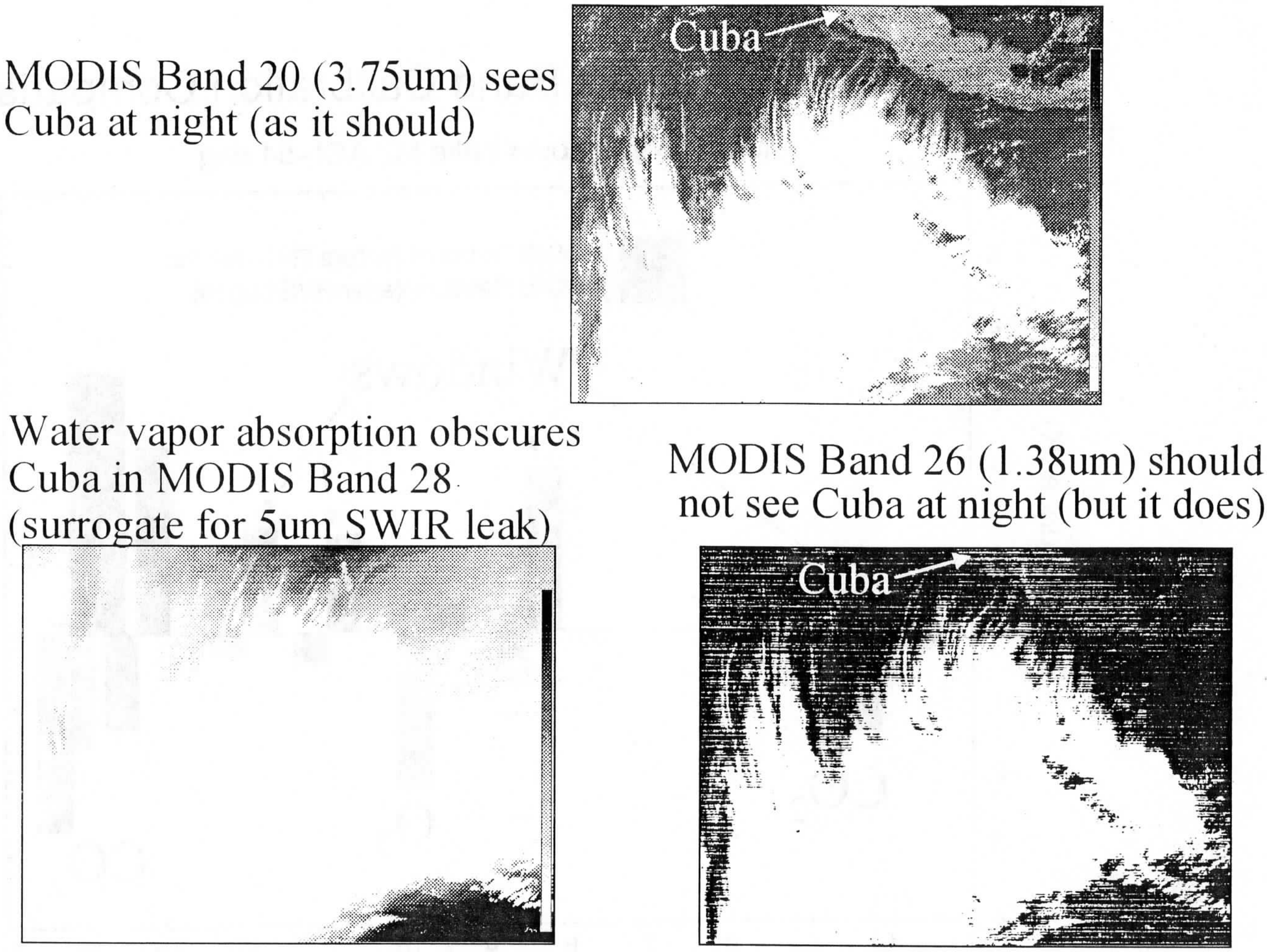

Figure 1. MODIS 3.75μm (upper right), 7.1μm (lower left) and 1.38μm (lower right) nighttime imagery on March 26, 2000 showing Cuba. The 1.38μm inband reflectance signal should be zero at night; however, because of electronic crosstalk and the 5um thermal leak, signatures of cloud and Cuba are clearly present in the lower right imagery. Band 28 serves as a predictor of the 5μm leaked radiance; there is no image of Cuba in Band 28, suggesting that the 5μm leak is not responsible for the image of Cuba in Band 26. Since Band 20 sees Cuba at night, it is plausible that electronic crosstalk between band 20 (or other MWIR bands 21–25) and band 26 is the source of the image of Cuba in band 26.

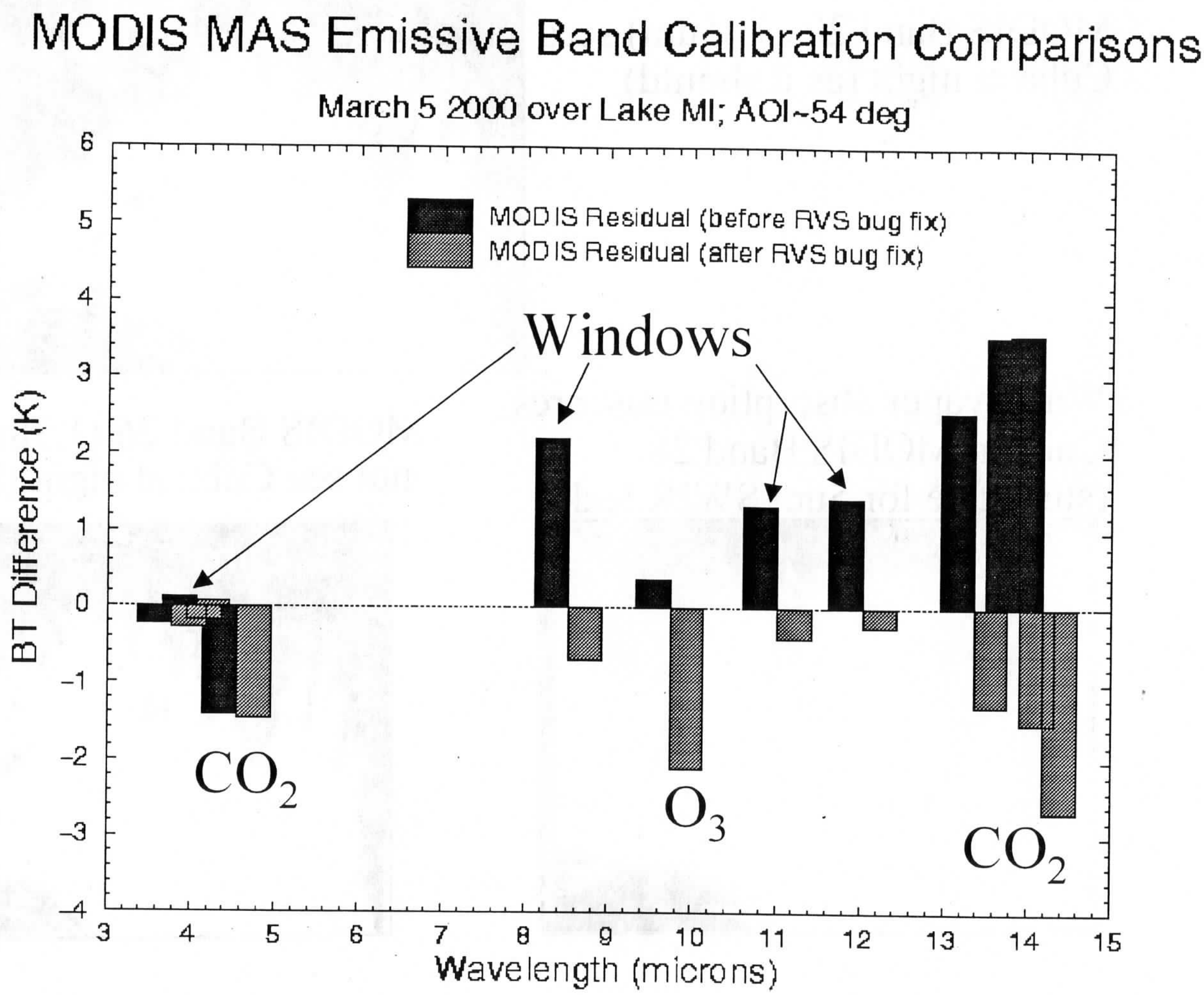

Figure 2. Early MODIS residual for bands 20, 22, 23, 25, 29 – 33, 35,and 36 (left to right) using March 5, 2000 collocations over Lake Michigan. Window band (20, 22, 23, 29, 31, 32) accuracy is within about 0.5°C while atmospheric band (25, 30, 33, 35, 36) residuals are larger, primarily due to uncertainty in PC band crosstalk (bands 33, 35, 36) and upper tropospheric ozone (band 30) and CO_2 absorption (bands 25, 33, 35, 36). The residuals are shown for both before the RVS indexing error was fixed and after. The impact of this code fix is large and beneficial as evidenced by the significant reduction in window band residuals. MODIS accuracy requirements are ~0.3°C for window bands 20, 31 and 32, and about 0.6°C for other emissive bands

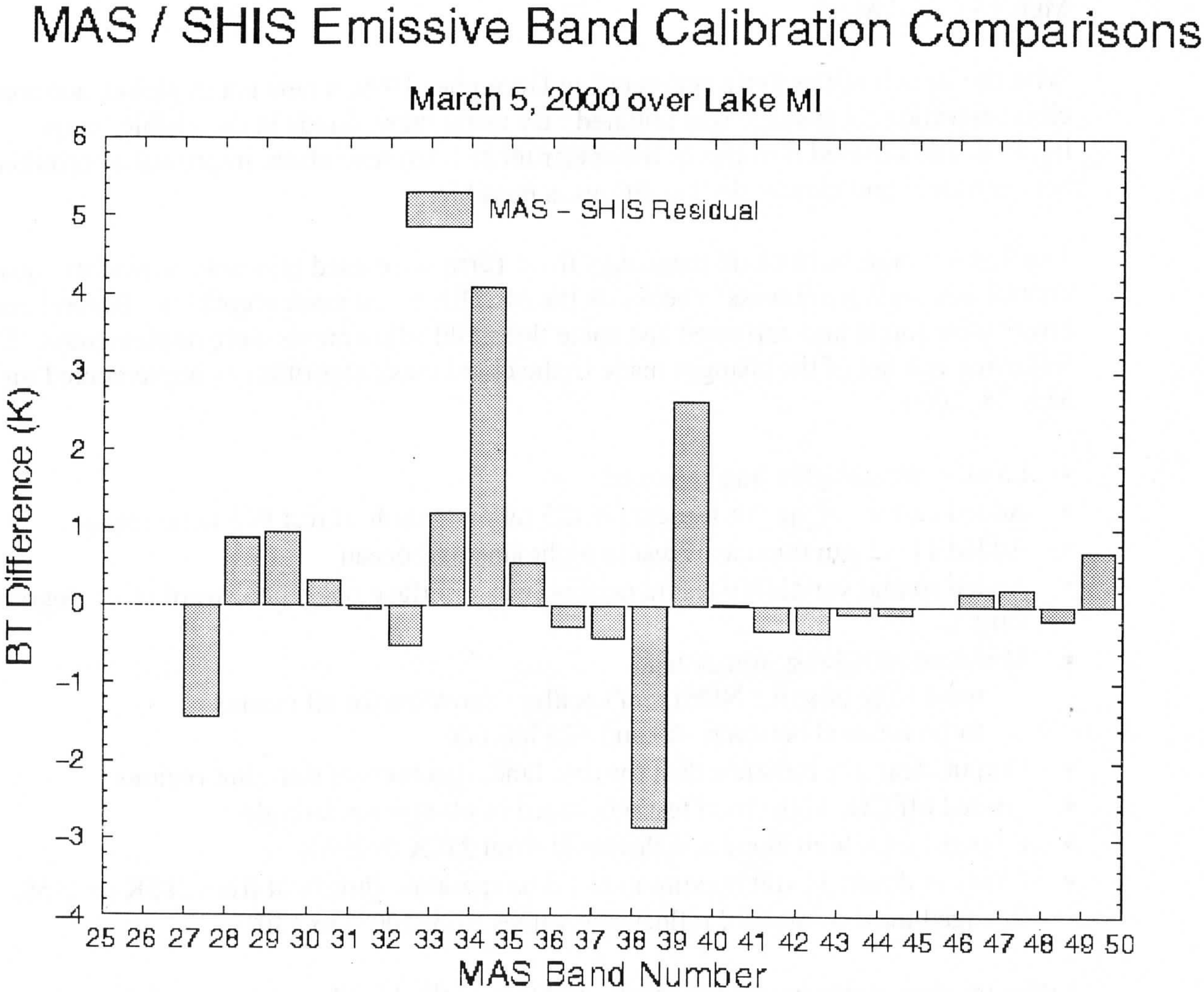

Figure 3. MAS-SHIS emissive band brightness temperature comparisons for Lake Michigan clear sky scenes on March 5, 2000 (WISC-T2000). See Table 2 for spectral position of each MAS band number. Over 4000 SHIS observations were collocated in space and time with MAS to produce the residuals. MAS window bands (30, 31, 36, 37, 42, 44, 45, 46) all show excellent agreement (<0.5°C) with SHIS. LWIR CO_2 (48-50) and water vapor (40, 41, 47) atmospheric bands also show excellent agreement. MAS bands 33 and 34 (MWIR CO_2) have been historically difficult to spectrally calibrate in the ambient laboratory. The apparent reversal of Bands 38 and 39 (5um) is a topic of investigation.

MODIS Cloud Mask

With the launch of the Terra spacecraft in December 1999, a new era in global, automated cloud detection from space was initiated. By using many bands in the visible, near-infrared, and infrared portions of the spectrum at 1-km resolution, improved discrimination between clear and cloudy sky conditions is possible.

The first six months of cloud mask data from Terra were used primarily to perform quality control and "reasonableness" checks on the MODIS cloud mask algorithm. Several coding errors were found and corrected and some threshold adjustments were implemented. The following is a list of the changes made to the cloud mask algorithm as implemented on May 28, 2000:

- Land/snow/sun-glint bug removed
- Added call to set_qa_bit for test bit #25 (allows result of test #25 to be seen)
- Added 11-12 μm thin cirrus test to night land and ocean
- Added spatial variability test to oceans (water surface only) pole-ward of 60 degrees latitude
- Modified NDSI test processing:
  must have positive NDSI *and* ancillary snow/ice for all oceans
  same for land between –60 and +25 latitude
- Output clear-sky radiance data for day, land, (geometric) sun-glint regions
- Turned off CO_2 high cloud test pole-ward of 60 degrees latitude
- Changed CO_2 high cloud test threshold from 236K to 226K
- Changed desert 11 μm maximum cloud temperature threshold from 285K to 295K
- Changed maximum valid reflectance values from 100% to 130%

Major improvements in this list are the addition of the 11-12 μm test at night, changes to the CO_2 high cloud test, and the modification to the NDSI snow and ice tests.

Figure 4 shows a North American scene from 17:10 UTC on April 8, 2000. At left (A) is an image of MODIS band 2 (0.86 μm) while the middle and right panels are, respectively, the MODIS cloud mask results from before (B) and after (C) the above listed changes were implemented. Colors in Figure 4 represent clear-sky confidences. Green is > 99% confidence of clear sky (confident clear), blue is > 95% (probably clear), red is > 66% (uncertain) and white (cloudy) is ≤ 66%. The removal of many uncertain pixels on the left-hand side of Figure 4 is because of changes in the CO_2 high cloud test.

Figures 5 and 6 show global composites of average clear-sky MODIS band 1 (0.66 μm) reflectance and band 31 (11 μm) brightness temperature, respectively, after filtering out cloud scenes with the cloud mask. The images represent average values at 25-km resolution for May 4-7, 2000. Composite images like these have been used extensively in the quality assurance and debugging processes for the cloud mask algorithm.

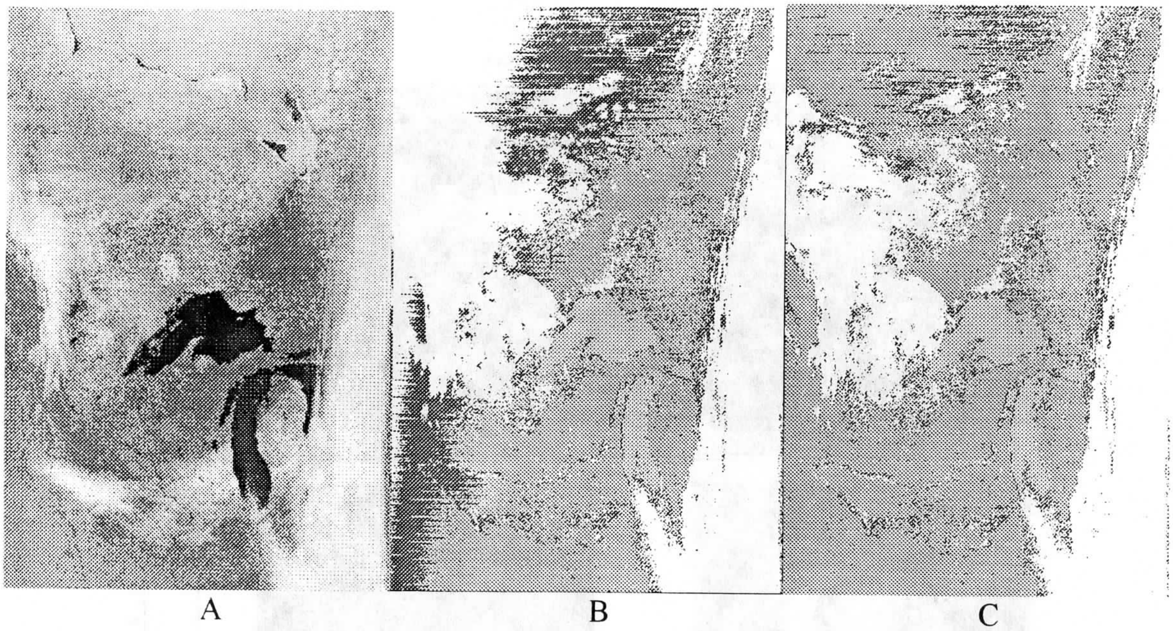

Figure 4. Left panel (A) shows image of MODIS band 2 (0.86 μm). Middle and right panels are the MODIS cloud mask results before (B) and after (C) changes to the cloud mask code were implemented on May 28, 2000. Data from 17:10 UTC April 8, 2000. Green (high confident clear); Cyan (Confident Clear); Red (Uncertain); White (Cloud). Much of the uncertain (red) determinations and some false cloud have been removed by the cloud mask code changes. The bright region extending across the lower portion of the band 2 image towards Lake Michigan is recent snowfall.

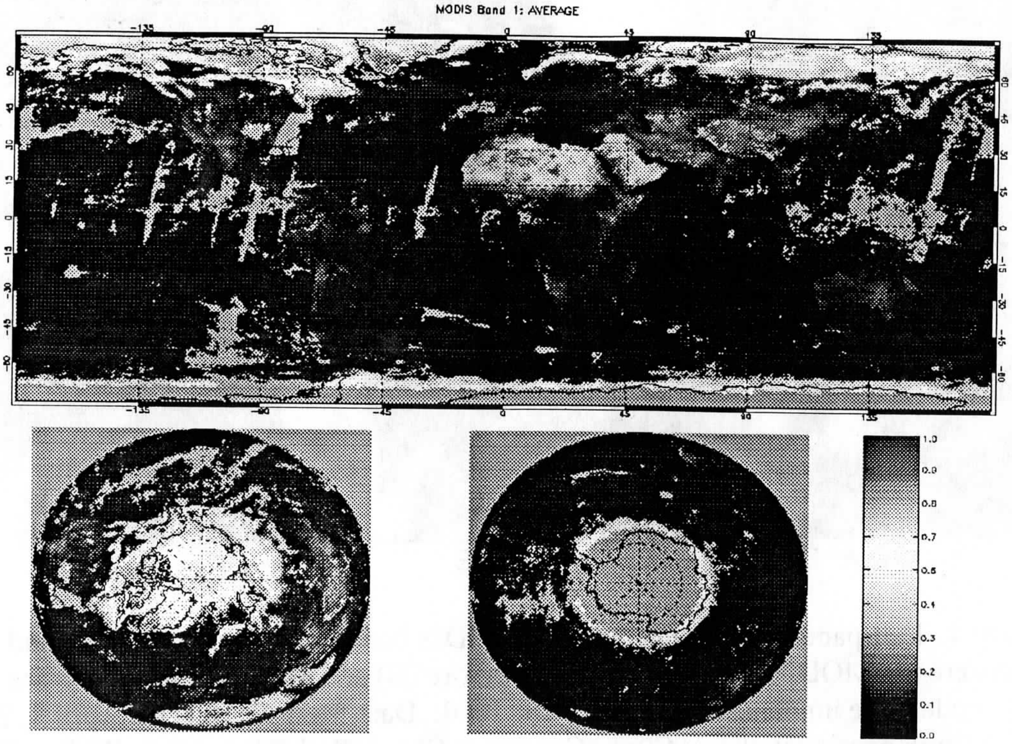

Figure 5. 4-7 May 2000 MODIS band 1 (0.66 μm) clear-sky reflectance.

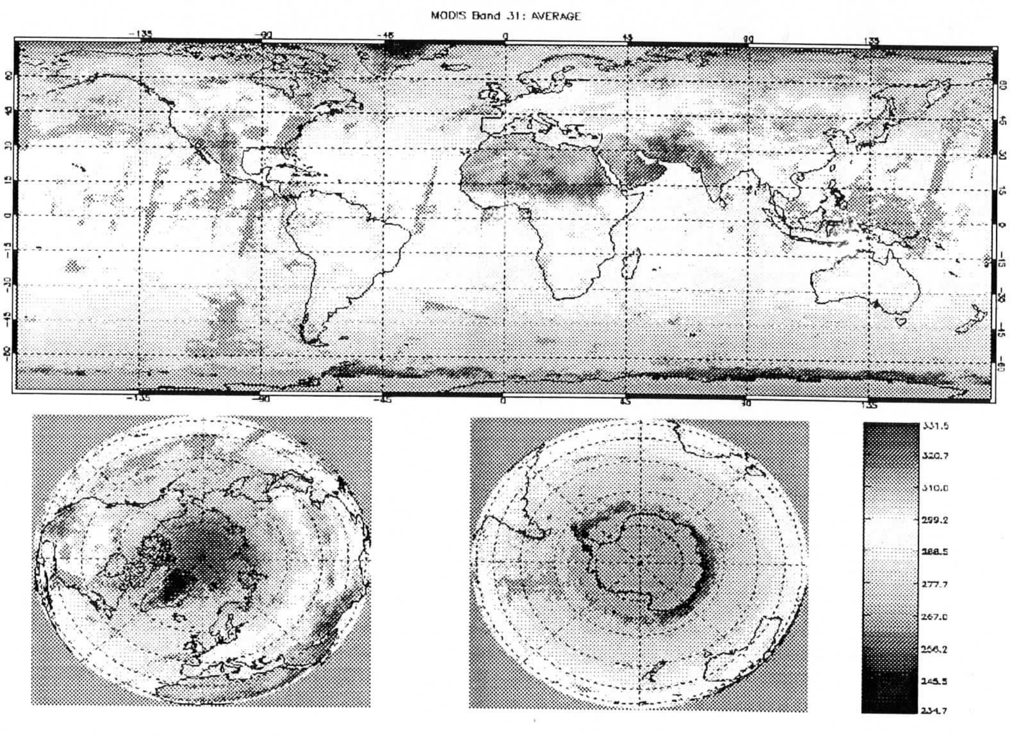

Figure 6. 4-7 May 2000 MODIS band 31 (11 μm) clear-sky brightness temperature.

DATA ANALYSIS

Cloud Top Properties

The MODIS cloud top properties algorithm has been subjected to quality assurance and "reasonableness" checks during the last six months. With the exception of one minor coding error, the algorithm is unchanged from the version that was in operation at launch. It appears that the CO_2-slicing portion of the code (cloud altitude, temperature, and effective emissivity products) has been producing reasonable results, even though the MODIS LWIR CO_2 absorption bands are not yet optimally calibrated. This robustness is attributable in large part to the use of spectral band ratios in the CO_2 slicing technique; ratios are less sensitive to calibration accuracy as long as band to band relative calibration is good.

MODIS cloud top pressures were compared to those calculated from NOAA-14 HIRS data for a region in the U.S. including 90-100 W longitude and 36-40 N latitude on March 12, 2000. Histograms of cloud pressures were computed for both data sets and are shown in Figure 7. Time of the HIRS data was approximately three hours after that of MODIS. The time of the MODIS overpass coincided with an ER-2 aircraft flight over the same region during the WISC-T2000 field experiment. The CLS (Cloud LIDAR System) was in operation, recording cloud top altitudes. A histogram of these values is shown in Figure 8.

In Figure 7 it is easily seen that the frequencies of MODIS cloud top pressure closely follow that of the HIRS, except for the number of clear-sky retrievals. This is not unexpected because of the higher (5 km) spatial resolution of MODIS retrievals compared to that (20 km) of HIRS retrievals. Higher spatial resolution allows MODIS to see clear sky between clouds which HIRS sees only as partly cloudy.

The cloud pressure maximum frequency is 400-499 mb for both MODIS and HIRS. This generally agrees with CLS cloud top determinations (solid bars in Figure 8) from the NASA ER-2. Since the CLS is capable of measuring cloud heights of multiple layers of cloud, "average" CLS cloud heights (open bars) were also included in Figure 8. These suggest slightly lower cloud heights when lower clouds underlay high clouds. Since the CLS instrument does not scan from it's position on the ER-2, its areal coverage is a limited subsample of the broad spatial coverage provided by the MODIS and HIRS cloud top pressure products.

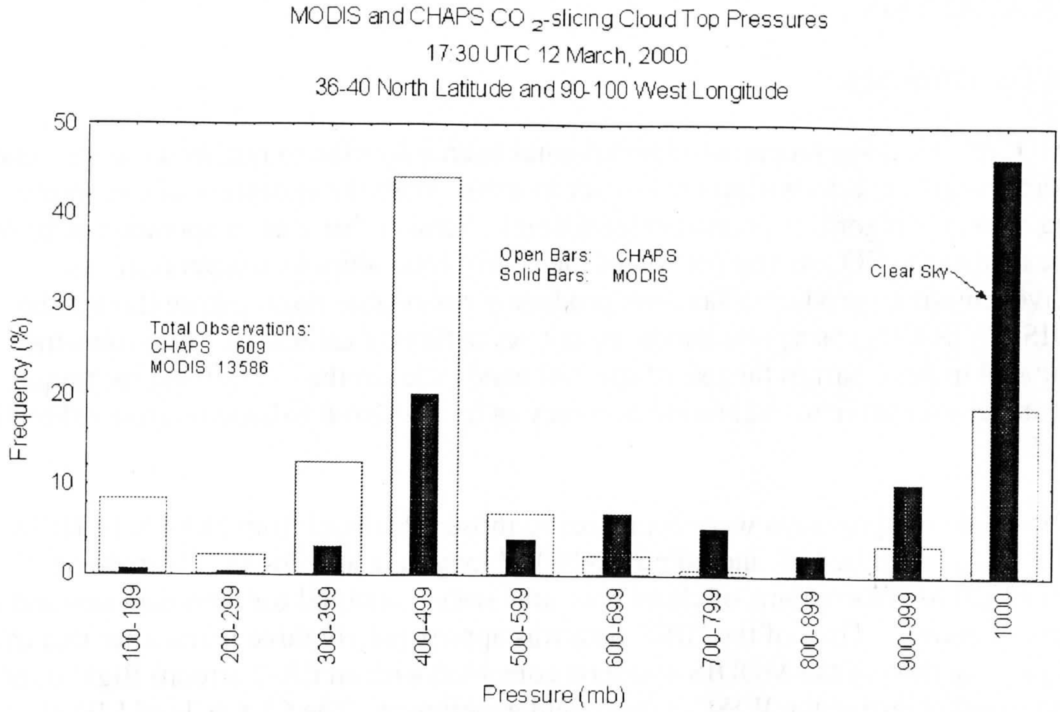

Figure 7. Frequency histograms of MODIS and HIRS CO_2-slicing cloud top pressures from March 12, 2000.

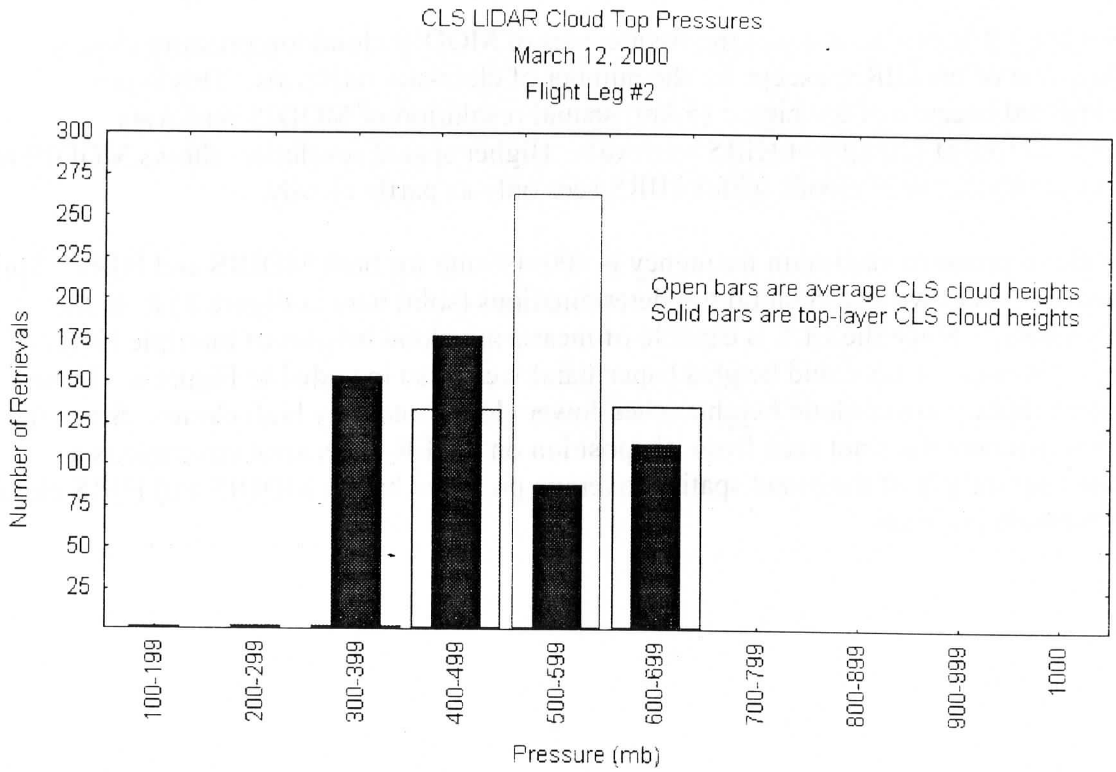

Figure 8. Histograms of cloud top pressures from CLS LIDAR from March 12, 2000. Average values are derived from multiple cloud layers measured in a single time period.

MODIS Cloud thermodynamic phase classification

After testing the cloud thermodynamic phase classification in MOD06, several changes were made. Water and ice cloud banding was eliminated by replacing the statistically based maximum likelihood estimator techniques with a phase classification technique that relies strongly on physically based 8.5 - 11 μm brightness temperature (BT) difference and 11 μm BT thresholds. For simplicity, the cloud thickness (opaque or thin) classification was abandoned. Four cloud phase classifications are possible: ice, water, mixed phase, and unknown phase. Figure 9 contains a recent example of the cloud phase product. Work is underway to tune the thresholds for the algorithm. Future work will incorporate SWIR band tests to reduce the number of unknown pixels during the day.

New MODIS cirrus cloud single scattering property models are being developed based on in situ measurements. These models will be an improvement over the current models described in Baum et al. 2000a. Current models are based on five size bins and a fixed crystal habit distribution for all models; the new cirrus models are based on 27 size bins and crystal habit distributions derived from the in situ data.

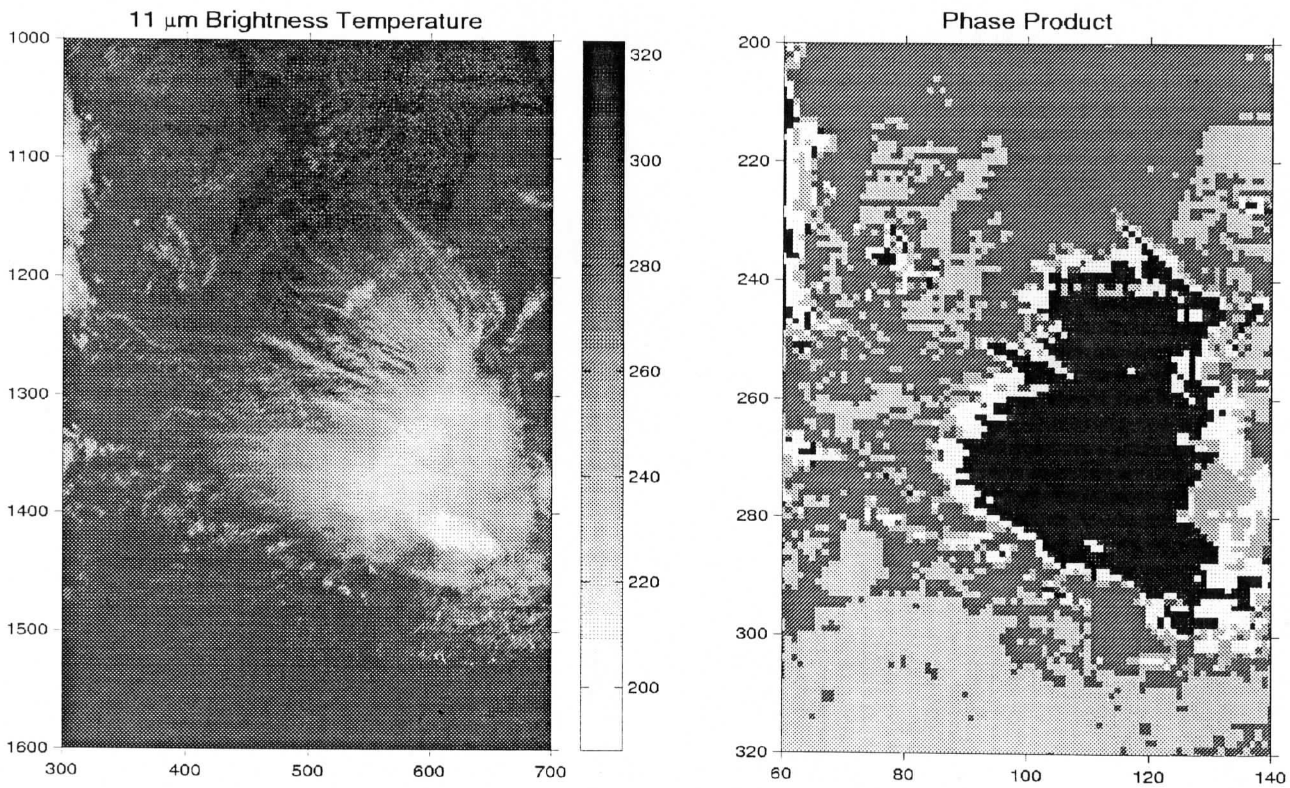

Figure 9. Infrared window image (left) and cloud phase estimates (right) over southern India on 19 April 2000. Blue is ice, red is water, yellow is mixed, and green is uncertain.

Atmospheric Profiles

Early investigation of the results from the MODIS atmospheric profile retrieval algorithm have focused on comparing the MODIS product to other products, particularly to GOES-derived data.

The first case examined was a comparison of the MODIS total precipitable water (TPW) product to the comparable GOES product over the upper US Midwest on 11 May 2000. The MODIS TPW (Figure 10) is regression based and uses only surface temperature and pressure observations. The GOES Sounder TPW (Figure 11) is obtained from a simultaneous physical retrieval of temperature and moisture which uses surface observations and a numerical model to obtain a first guess.

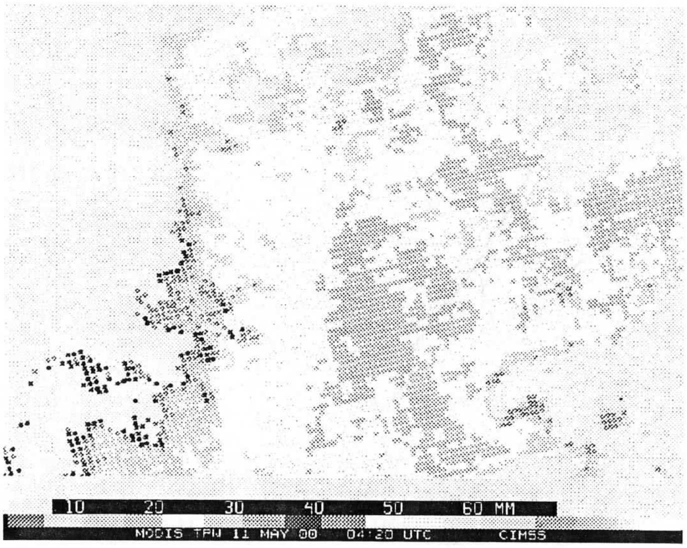

Figure 10. MODIS total precipitable water product, 11 May 2000 0420 UTC

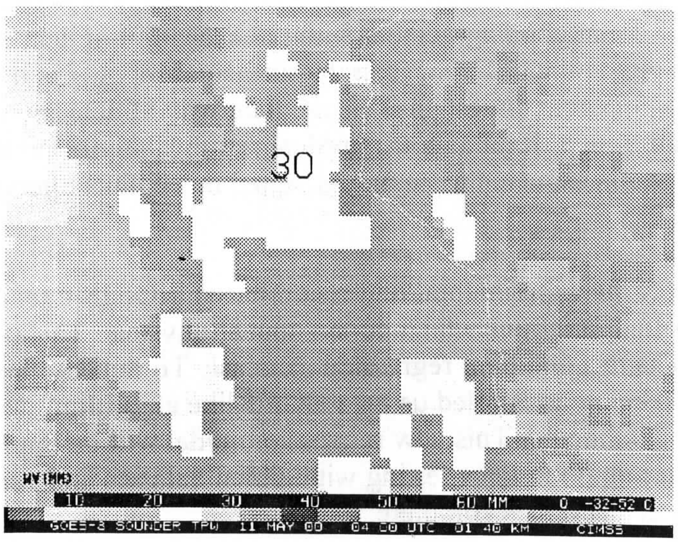

Figure 11. GOES total precipitable water product, 11 May 2000 0400 UTC

The higher spatial resolution of the MODIS product is immediately apparent. The spatial gradients and values are similar, although MODIS shows a moist bias. Both products capture most moist regions in eastern and western Iowa.

The second case examined was a MODIS temperature and moisture profile from 11 May 2000. The closest GOES retrieval was obtained, and the results are shown in Figure 12 (solid line is temperature, dashed line is dewpoint, both in degrees C).

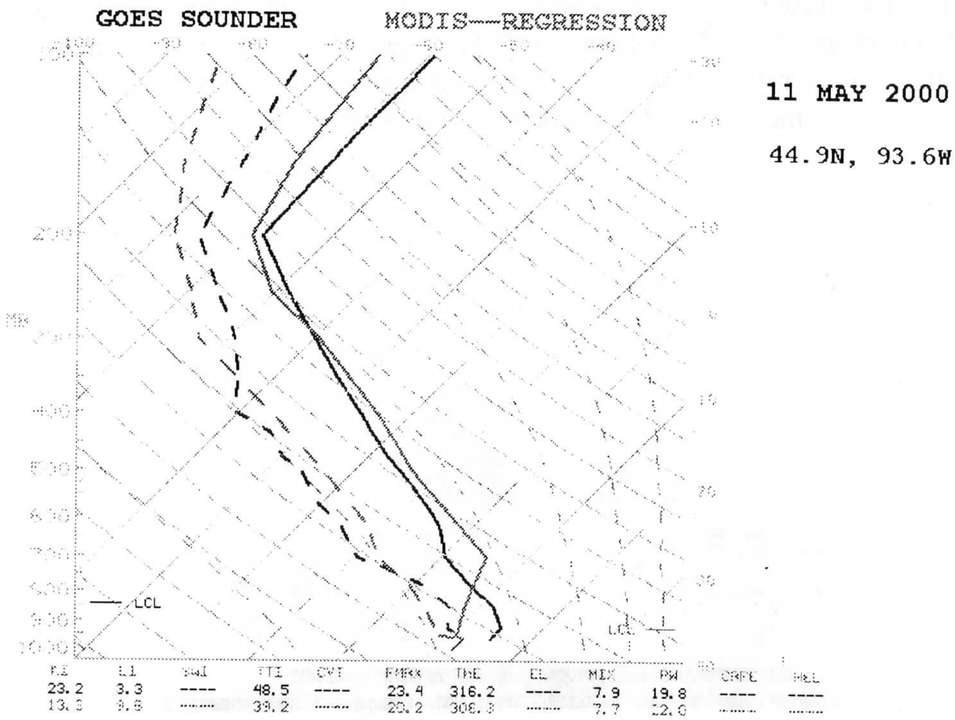

Figure 12. MODIS and GOES profile retrievals on 11 May 2000

Qualitatively, the two are in good agreement with the exception of near-surface levels. This is thought to be due to the differences in the surface observations used by the MODIS and GOES algorithms. Investigations are underway to determine the source of the differences. In addition, a simultaneous physical retrieval algorithm for MODIS is under development, and is expected to be implemented in MODIS operations in fall 2000.

Initial investigations of the experimental regression-based MODIS total ozone product have shown large spatial variations which do not appear physical. The at-launch algorithm appears to have a deficient regression database. To remedy this problem, a new regression database is being assembled using a GOES-like algorithm, which has been extensively tested and validated. This new regression model will be implemented in MODIS operations in fall 2000, once testing with global datasets and verification against other data sources (e.g. TOMS) is complete.

EOS Direct Broadcast

Planning for the UW-SSEC X-band ground station proceeded smoothly, with a target date of August 5 for the antenna installation. During the first half of 2000, UW-SSEC coordinated with SeaSpace (the antenna vendor) to ensure hardware and software interfaces were compatible (http://cimss.ssec.wisc.edu/~gumley/tower/xband.html).

The first version of the International MODIS/AIRS Processing Package (IMAPP) was released on May 12. This version provides Level-1 processing functionality for Terra. The software is distributed under the GNU General Public License, and is available at http://cimss.ssec.wisc.edu/~gumley/IMAPP/IMAPP.html

As a demonstration of IMAPP compatibility, SSEC processed samples of Level-0 data obtained from U-Dundee, NASA GSFC, U-Hawaii, and SeaSpace as shown in Figure 13, which features MODIS Band 31 brightness temperature.

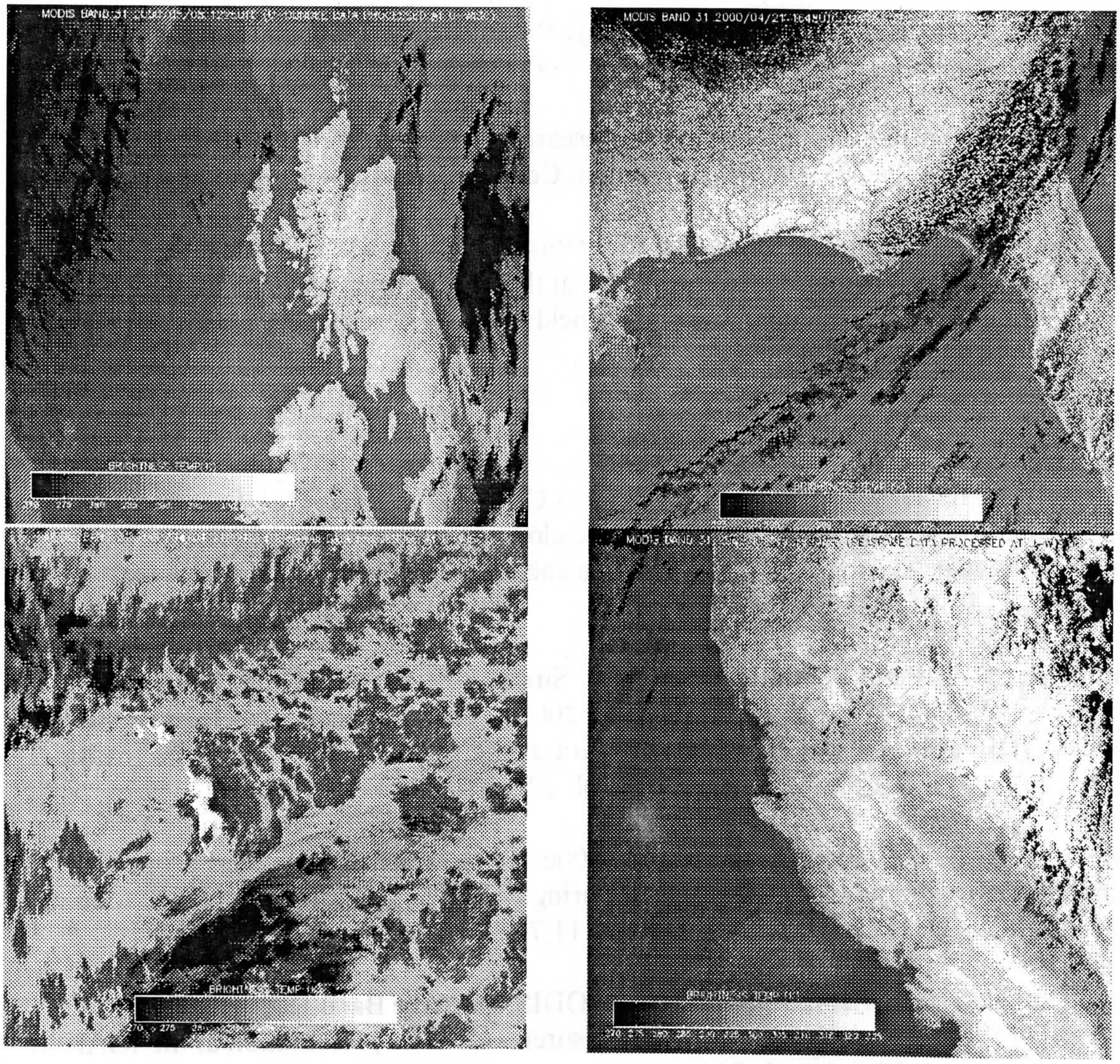

Figure 13. MODIS Level-1B data processed by IMAPP

MEETINGS

Dan LaPorte attended the Bomem Interferometer Workshop held in Quebec City on Feb. 9-10.

Bryan Baum and Shaima Nasiri presented a paper entitled "Daytime Overlapping Cloud Detection in MODIS Data" at the Atmospheric Radiation Measurement (ARM) Science Team Meeting, 13-17 March, 2000, in San Antonio, Texas.

Paul Menzel presented early MODIS results at EUMETSAT in Darmstadt, Germany; the free University of Berlin in Berlin, Germany; MeteoFrance in Lannion, France; and ESA in Nordwiijk, Holland in May 2000

Chris Moeller and Liam Gumley attended the MODIS Calibration Workshop held June 6 in Greenbelt, MD.

Paul Menzel, Steve Ackerman, Liam Gumley, Bryan Baum, and Chris Moeller attended the MODIS Science Team Meeting held Jun 7-9 in Greenbelt, MD.

Shaima Nasiri participated in the Gordon Research Conference on Solar Radiation and Climate held June 24-29, 2000 at Connecticut College, New London, Connecticut.

Liam Gumley and Tom Rink presented the status of the UW-SSEC X-band ground station and MODIS data processing software at the Fourth International Conference on Direct Broadcast of Earth Observation Data held June 27-30 at the University of Dundee, Scotland UK.

PAPERS

Baum, Bryan A., David P. Kratz, Ping Yang, S.C. Ou, Yongxiang Hu, Peter F. Soulen, and Si-Chee Tsay, 2000a: Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS. 1. Data and models. Journal of Geophysical Research, Vol. 105, No. D9, 11,177-11,780.

Baum, Bryan A., Peter F. Soulen, Kathleen I. Strabala, Michael D. King, Steven A. Ackerman, W. Paul Menzel, and Ping Yang, 2000b: Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS. 2. Cloud thermodynamic phase. Journal of Geophysical Research, Vol. 105, No. D9, 11,781-11,792.

Baum, Bryan A. and James D. Spinhirne, 2000c: Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS. 2. Cloud overlap. Journal of Geophysical Research, Vol. 105, No. D9, 11,793-11,804.

Moeller et al. Comparison of Early Terra MODIS Emissive Band Radiances with Collocated ER-2 Based SHIS and MAS Measurements. For presentation at the IGARSS 2000 conference, IEEE, July 2000.

Wylie, D. P. and W. P. Menzel, 2000: Comparison of University of Wisconsin HIRS and ISCCP D2 Cloud Studies. Submitted to the Journal of Geophysical Research.