INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

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ABSTRACT

The last half year found the UW MODIS team preparing for the launch of the instrument, now scheduled for no earlier than August 27. The launch delay has allowed UW to focus the work on production software to robustness and efficiency, culminating in updated software deliveries of MOD35 (cloud mask) and MOD07 (atmospheric profiles). Collaboration with MCST on MODIS instrument characterization continued; a method to assess MODIS RVS post-launch using ground based instruments over Antarctica was proposed. UW hosted a field experiment in Madison, Wisconsin designed in part to evaluate the performance of MODIS cloud and atmospheric retrievals in nighttime and low-light winter conditions. Xia Lin Ma developed an extended physical retrieval algorithm that produces atmospheric profiles, surface emissivity and surface temperature simultaneously, which has been tested using MAS simulated radiances. This new technique should improve the quality of MOD07 and MOD11 (land surface temperature).

MEMORIUM

The CIMSS MODIS team lost a treasured colleague when Dr. Sunggi Chung, a member of the UW Physics department, passed away on June 23. Dr. Chung had been a collaborator on efforts to model the radiative properties of cirrus clouds. He will be greatly missed.

TASK OBJECTIVES

Software Development

Production software refinements continued, focusing on robustness and efficiency. New versions of the cloud mask (MOD35) and atmospheric profiles (MOD07) production packages were delivered and integrated into the DAAC processing environment. Preparations are underway for the delivery of the clear radiance daily and eight day compositors which will be used as input by the cloud mask for temporal consistency checks and cloud top properties code (MOD06) for radiance bias corrections.

MODIS Infrared Calibration

CIMSS personnel continued to work with MCST in characterizing the MODIS blackbody for the PFM instrument, in determining the instrument Response Versus Scan (RVS), calibration uncertainty analyses and crosstalk mitigation. UW has proposed the option of assessing MODIS RVS using Antarctica scenes co-incident with ground based upward and downward looking measurements.

WINTer EXperiment (WINTEX)

CIMSS personnel hosted the WINTEX experiment at Truax field in Madison, Wisconsin from March 15 – April 2. Although the primary objective of WINTEX was to support NPOESS Environmental Data Requirement development, data for the purpose of investigating MODIS cloud and atmospheric retrievals was also collected.

NASA Presence at CIMSS

Dr. Bryan Baum, a NASA employee working at Langley Research Center, has been permanently assigned to work at CIMSS. Dr. Baum has collaborated with MODIS personnel on numerous cloud property research topics and we look forward to working with him in the future.

WORK ACCOMPLISHED

MODIS Production Software Development

Refinements to the production software packages continued, culminating in new versions of the cloud mask and atmospheric profiles production packages which were delivered to the SDST. The main focus of these deliveries was on ensuring software robustness and efficiency.

A list of the updates made to the cloud mask code for delivery V2.1 is provided as an example below.

1). Granule based clear radiance files are now created within the cloud mask production software. Four statistics are saved for each global grid box which is found to have at least one high confidence clear pixel. The four statistics saved are: number of clear pixels found within a grid cell, the sum of the radiance values within a grid cell, the minimum radiance value within a grid cell, and the maximum radiance value for the grid cell. Statistics will be saved for 8 different MODIS bands (2, 26, 6, 31, 33, 34, 35 and 36). Daily composites will be generated from the 288 daily granule files, and finally, a new eight day composite will be made each day. This eight day file will be used as input in the cloud mask processing as a temporal consistency check, and in the MOD06 processing as a bias correction between the observed and calculated clear-sky radiances.

The production and use of these clear radiance files is being tested using AVHRR data at CIMSS, and is discussed later in this document.

2). A new ancillary data reader was written for all UW production packages to use. This version provides a status flag which indicates whether the data was successfully retrieved. The previous version would stop execution when a data set was missing.

3). Threshold files for the cloud mask spectral tests are now stored in a single data file instead of include files. This allows adjustment of the thresholds and execution of the program without having to recompile the source code.

4). The Process Control File (PCF) has an additional 5 runtime parameters which allow definition of sub-granule regions to process. These parameters will be used in coordination with a new output debug layer runtime parameter which defines the level of printable debug statements the user would like to see. Used in coordination, these parameters will make debugging much easier.

5). The National Snow and Ice Data Center (NSIDC) Near Real-Time SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent (NISE) product is now being used as an input to the cloud mask production software. This product will be used to define the snow and ice processing paths at night.

6). A global Olson Index 1 km ecosystem file has replaced the lower resolution 10 minute database used in the original version 2 delivery. There was some concern expressed over the length of time it was taking for the ecosystem value to be extracted from the very large file (695 MB). Liam Gumley resolved this issue by writing a reader that ordered the lat/lon values for a given scan in the order they appeared as records in the binary ecosystem file. This significantly decreased the CPU and wall clock time that it took for the cloud mask to process a granule of data.

7). All MODIS bands are now read in as part of the MOD35 production software. This was done in anticipation of adding new spectral tests post-launch. The Version 2.0 software was hardwired to handle 19 bands in a specified order.

8). The 1 km USGS land/water mask is now read directly out of the MOD03 geolocation file. Previous versions of MOD35 read values from the binary base map file.

9). The UW MODIS group now uses Concurrent Version Systems (CVS) as its' software version control tool.

10). Cloud mask production software was put through a series of rigorous or "torture" tests to make sure it was robust and reliable.

Preparation has been underway for the delivery of a new version of the cloud top properties portion of MOD06. The new code will result in the separation of output parameters into day and night for co-investigations between clouds and aerosols.

Modifications were also made to the MOD06 cloud properties code in order to make use of clear-sky radiance information taken from the MODIS cloud mask. Regional biases between calculated and observed clear-sky radiances (accumulated over an eight day period) will be used to adjust radiative transfer calculations performed during generation of CO_2-slicing cloud heights.

Clear Radiance File Generation and Implementation

After numerous discussions between the UW, SDST and DAAC personnel, the algorithm to produce clear radiance files at the granule and global scales has been decided. All clear radiance production will occur at the DAAC. This simplifies the process considerably by removing the dependency of the global composites on the processing lag time between the DAAC and MODAPS.

Richard Frey has tested the production and utility of clear radiance files using AVHRR data. The results indicate the files are useful in identifying regions where the AVHRR cloud mask has problems; it is expected that the MODIS clear radiance files will serve as a Q/A tool for the cloud mask too. The AVHRR clear radiance files are produced daily and placed on the AHVRR cloud masking home page at http://cimss.ssec.wisc.edu/poes/cldmsk.html. An example of the global 11 micron clear radiance maximum is shown in Figure 1.

MODIS/MAS Visualization

New versions of the SHARP program for visualizing MAS data were released at http://cimss.ssec.wisc.edu/~gumley/sharp/sharp.html. Version 1.39 was released on 15 June 1999 and contained these updates:

1). The IDL command line is now available when SHARP is running (you can run multiple instances of SHARP).
2). Many reliability improvements have been made, including the addition of functional window menus to all dialogs.
3). The IDL command line procedure MAS_FLAT_FILE has been added for extraction of binary image data.
4). Better documentation on how to make SHARP installation more streamlined was added.

Version 1.31 was released on 26 February 1999 and consisted of these updates:
1). The image window title now includes the field experiment name, the time at center pixel, and the flight track number.
2). The image window legend now includes orientation data for the center pixel (latitude, longitude, heading, solar zenith and azimuth, relative azimuth).
3). Input and output dialog boxes are now more intelligent.
4). Pixel data values are now displayed in RGB mode (at the request of Zhengming Wan).

5). The user can now save all 50 bands within the selected plot regions (at the request of Bryan Baum).
6). A program information dialog box is now available at startup.
7). A test has been added at startup to ensure that sufficient colors are available in the current IDL session.
8). There are now SHARP versions available which correspond to IDL 5.0, 5.1, and 5.2.

EOS Direct Broadcast

In February, NASA HQ sent notification that the proposal to install an EOS Direct Broadcast reception system at SSEC had been approved. At that time, SSEC began working with the relevant university, local, and state authorities to gain approval for the installation. As of June 30, all necessary approvals have been obtained. The antenna, which consists of a 3 to 4 meter reflector and radome, will be installed on the roof of SSEC atop a 40 foot tower providing an essentially unobstructed view to the horizon in all directions. SSEC has completed an engineering study of the roof installation site, and a request for bids has been issued for the tower construction. SSEC also drafted a requirements specification for the antenna system and associated data reception and processing electronics, and issued a request for bids. SeaSpace Corporation of San Diego, California submitted the lowest cost bid, and was thus selected to deliver the antenna and processing electronics. Installation and acceptance testing of the system will occur in fourth quarter 1999.

MODIS SCF Facilities

The CIMSS MODIS SCF computing facility, a SGI Origin2000 system, was upgraded to 16 CPU's and 4 GB of RAM. Disk space is currently 270 GB, with another 140 GB to be added soon. Procurement of a robotic tape library is underway.

MODIS Infrared Calibration

Dan LaPorte, Von Walden, and Chris Moeller attended the MODIS IR calibration workshop held in Miami in February. Topics of discussion included MODIS blackbody characterization for PFM instrument, RVS determination (deep space and phenomenological approaches), calibration uncertainty analyses, crosstalk mitigation, and others. Because of electronic crosstalk present in PFM T/V measurements, the MODIS PFM blackbody characterization is being borrowed from the FM-1 T/V data set analyses and modeling results. The electronic crosstalk in PFM T/V data has caused reduced confidence in the PV band nonlinear calibration coefficients estimated from the T/V data. Therefore, a linear calibration is being proposed for PV emissive bands. An assessment of the nonlinear term on-orbit using elevated blackbody temperatures will be undertaken; however, this will be challenging for MWIR bands as the range of attainable blackbody radiances in that spectral region is limited. Von Walden and Chris Moeller presented materials on assessing MODIS Response versus Scan (RVS) using Antarctica data scenes, both with and without co-incident ground based upward and downward looking measurements by an AERI instrument based in Antarctica. An AERI will be deployed to the South Pole station in December 1999; placing a 2^{nd} AERI instrument at the Dome C site (74.5°S, 120°E) in Antarctica is under consideration because of the advantage of MODIS on Terra viewing Dome C at many view angles. Antarctica as a site to assess RVS on-orbit is attractive because of its relatively uniform surface thermal condition, the dry nature of the Antarctic atmosphere, and the numerous observations of the region made by MODIS on each day. An optical crosstalk mitigation algorithm and coefficients for the PC LWIR bands were presented by MCST at the meeting. The coefficients are physically based, relying on matching nonlinear detector performance between PFM and FM-1. FM-1, essentially crosstalk-free in the PC LWIR bands, exhibits the expected behavior of the MODIS LWIR detectors. Analyses show that matching the PFM LWIR nonlinearity to that of FM-1 yields PC band optical crosstalk correction coefficients comparable to previous analyses. These coefficients will be carried to orbit where they will be evaluated using high contrast scenes, large sample data sets, and comparisons to radiosonde-based forward model output. Views of the lunar limb will also be assessed for crosstalk validation. All of the above factors are being compiled into an L1B uncertainty analysis for PFM. At this time, the uncertainty analysis must be considered preliminary as, without high quality T/V data sets, it is difficult to accurately estimate absolute biases of PFM until on-orbit calibration comparisons can be made. Wisconsin is desirous of receiving and implementing the MCST L1B code for product testing. Specifications for running this code were obtained at the workshop. The anticipated date of delivery of at-launch L1B product code is 1 July 1999. Wisconsin will obtain a copy of the code after that date.

Chris Moeller attended the Reflective Solar Band calibration Workshop at GSFC in February. A review of the Solar Diffuser (SD) based and SRCA (lamps) based calibration was presented. There is concern about the SWIR band calibration of the SD, due to uncertainty of spectralon absolute reflectance in this region and lack of SDSM detectors beyond about 950 nm. On-orbit views of the moon may be critical for tracking relative degradation in SWIR bands over the lifetime of PFM. The 5.3um spectral leak into the SWIR bands on PFM will be evaluated on orbit using nighttime MODIS data. NEDL for reflective bands is within specification and thus is only a small contributor to the uncertainty budget. Stray light from adjacent fields of view is a concern for MODIS reflective band earth scenes. Examples demonstrating this effect in SEAWIFS and OCTS were shown. MCST is conducting an exploratory investigation into correcting stray light effects for specified earth scenes on orbit.

ER-2 Activities (WINTEX, CALVEX-M)

The Winter Experiment (WINTEX) data collection phase was conducted from Madison, Wisconsin (Truax Field) from March 15 – April 2, 1999. WINTEX was designed to support NPOESS Environmental Data Requirement development, MODIS cloud and atmospheric retrieval studies, and radiometric calibration assessment. A NASA ER-2 was the primary data collection platform, supplemented with ground based instrumentation. The ER-2 payload included the MODIS Airborne Simulator (MAS) for cloud detection and properties, Scanning High resolution Interferometer Sounder (S-HIS) for absolute radiometry studies and atmospheric properties, NPOESS Atmospheric

Sounder Testbed – Interferometer (NAST-I) for EDR assessment including atmospheric retrievals in partly cloudy conditions, and the NPOESS Atmospheric Sounder Testbed – Microwave (NAST-M) for atmospheric properties. The ER-2 also held a video recorder (VIS) and an RC-10 camera for documenting the scenes overflown by the aircraft. Ground based instrumentation included the uplooking HSRL lidar deployed at the University of Wisconsin for atmospheric aerosol and thin cloud characterization (altitude, optical depth, phase), a mobile AERI instrument, capable of upward and downward viewing for surface and atmospheric characterization (deployed variously at Truax Field and along shore of Lake Michigan), and a classonde balloon launch system to measure local atmospheric conditions during ER-2 overpasses. During the 10 ER-2 missions flown, measurements were collected in clear and cloudy scenes of varying backgrounds (snow, water, bare ground, vegetation). Several missions were flown near 00 UTC in low light conditions to assess MODIS cloud detection at night and to combine NAST observations with the synoptic balloon launch network for atmospheric retrievals.

Date	Flight	Highlights
3/15	99-050	Ferry mission from DFRC to Madison, Wisconsin; snow cover
3/18	99-051	Cloud detection and atmospheric properties; urban Milwaukee in daylight
3/19	99-052	Aborted shortly after takeoff due to aircraft malfunction
3/20	99-053	Atmospheric properties; cloud studies over snow in Southern Canada
3/21	99-054	Atmospheric properties at night; snow showers along Lake Michigan
3/25	99-055	Calibration studies over Lake Superior with NOAA-15
3/26	99-056	Atmospheric properties; moisture gradients; CO detection
3/29	99-057	Calibration studies over Lake Michigan with NOAA-15; urban Milwaukee at night
3/31	99-058	Cirrus properties over HSRL
4/01	99-059	Atmospheric properties; moisture gradients; cloud properties
4/04	99-060	Atmospheric properties; ferry mission to DFRC from Madison

MAS data scenes of particular interest include wave structure in lower tropospheric water vapor bands, thin cirrus at night over a frozen Lake Winnipeg region for nighttime cloud detection, thin cirrus over Madison with HSRL below for cirrus properties, scenes of urban Milwaukee at both day and night to assess urban surface impact on cloud detection, and clear scenes of Lakes Superior and Michigan for calibration studies. The MAS radiances in HDF files are available through the GSFC DAAC by accessing the MAS web page at http://ltpwww.gsfc.nasa.gov/MODIS/MAS/Home.html. A Web page containing information on the science objectives, data collection, and preliminary results of WINTEX is being maintained at http://cimss.ssec.wisc.edu/wintex. The web page includes quicklook imagery from MAS as well as particular scenes of interest from all instruments.

Plans are being formalized for the Calibration/Validation Experiment – MODIS (CALVEX-M) slated for Spring 2000. CALVEX-M is being coordinated with a Spring 2000 Cloud IOP effort at the ARM SGP CART site. A total of 30 ER-2 flight hours have been requested for the deployment. Flight plans will emphasize data collection over SGP CART for atmospheric profile and cloud product validation. The ER-2 payload is currently being developed but likely will include MAS, S-HIS, a cloud lidar, and the AirMISR instrument.

MODIS RVS and Antarctica Feasibility Study

The feasibility of using MODIS data scenes of Antarctica for assessing Response versus Scan (RVS) is under investigation. Antarctica is a useful target to assess RVS on-orbit because of its relatively homogeneous, well known surface type (snow, ice) and minimal atmospheric slant path effect in window bands. Plus, MODIS will view Antarctica on every orbit. A disadvantage is that scene temperatures are typically cold, meaning low signal to noise in the radiometric data (esp. for MWIR bands). Two plans are under consideration, one to combine co-incident MODIS measurements with ground based observations (upward and downward looking) and a second to collect a large data sample of MODIS Antarctica observations over a large region. In each plan radiometric trends as a function of MODIS scan angle will be analyzed. In the former, a 0.1°C absolute radiometric measurement with the AERI instrument would be collected during MODIS overpasses. A tentative plan to deploy an AERI instrument to Dome C is being assessed. The AERI measurement would be used to remove natural variations from the MODIS measurements, so that MODIS radiometric variation due to scan mirror angle would be isolated. The AERI measurement would be supplemented by an array of surface viewing radiometers deployed to scale the AERI point measurement to the spatial scale of MODIS. AERI would view the surface at the same zenith and azimuth angles as MODIS to remove viewing geometry dependence; the high spectral resolution AERI radiances would be convolved with MODIS RSR to remove spectral dependence. In the latter approach, MODIS radiances will be collected for all MODIS views of the snow and ice covered Antarctic Plateau. A key requirement of the approach is that natural variations cancel; an investigation using archived AVHRR data scenes of Antarctica indicates that while much natural variation is removed in the large data sample analysis, some remaining natural variation due to persistent spatial gradients may yet remain (Figure 2). Synergism of co-incident AVHRR and MODIS large data samples will be evaluated as a possible correction mechanism. Another possibility is to reduce the sampling region size to eliminate persistent spatial gradients. These plans and ideas will evolve as logistical issues are worked, especially regarding deployment of an AERI instrument in Antarctica. Another possible AERI deployment site under consideration is Barrow, Alaska, which shares similar surface and atmospheric characteristics with Antarctica and is easily accessible. A goal of making AERI measurements at some polar site in December 1999 is being pursued. Observations to build a large data sample will be collected continuously after MODIS launch.

DATA ANALYSIS

Atmospheric Profiles and Surface Emissivity Studies

Xia Lin Ma, a researcher employed by both Dr. Menzel and Dr. Wan at the University of California - Santa Barbara, has been working on improving the retrievals of atmospheric temperature and moisture profiles, and in turn surface temperature, through the inclusion of surface emissivity in the profiles retrieval algorithm. Remote sensing of atmospheric temperature and water vapor profiles from infrared emission bands usually requires certain assumptions to be made about the behavior of terrestrial materials. To date, it is usually assumed that the surface is a blackbody (emissivity 1.0) or a gray-body (approximately 0.98) for atmospheric sounding. This assumption neglects spectral/spatial variation of the surface emissivity. Accounting for these variations will improve the accuracy of retrieved atmospheric profiles. Alternatively, the land-surface temperature (LST) retrieval requires accurate information of the atmospheric temperature and water vapor distribution for the correction of atmospheric influences. A recently developed physically-based LST retrieval algorithm has demonstrated that the accuracy of the LST retrieval depends largely upon accurate atmospheric information. It indicates that the accuracy of retrieved geophysical parameters from space will be improved by 1) including surface emissivity as a part of the solution of the Radiative Transfer Equation (RTE) and, 2) retrieving atmospheric parameters and surface properties simultaneously.

1) Extended algorithm development.

An extended two-step physics-based algorithm (hereafter referred to as the extended algorithm) that retrieves daytime and nighttime atmospheric temperature and water vapor profiles, surface skin temperature, and seven surface emissivities has been developed. The retrieved emissivities cover MAS bands in the 3-14.5 μm region which are sensitive to variations of temperature, water vapor at the low troposphere and surface properties. The extended algorithm is an extension of the original two-step physical retrieval algorithm (henceforth abbreviated original algorithm) which was developed in 1998.

The major improvements of the extended algorithm over the original algorithm are summarized as follows:

a) Surface emissivity data, consisting of band-averaged emissivities of 80 terrestrial materials, were used as a spectral base map (see Figure 3).
b) A more realistic skin temperature variance (7 K) is used.
c) The reflected solar radiances in the short-wave region were directly calculated from the solar irradiances at the top of atmosphere, solar and local zenith angles, band surface emissivity, and the atmospheric transmission.
d) The retrieved geophysical parameters are produced from a combination of daytime and nighttime observations.

2) Extended algorithm test from simulated data

The physical retrieval is accomplished in two steps: A) The Tikhonov regularization method is employed to generate a regularization solution which updates the initial temperature and water vapor profiles, surface skin temperature and seven surface emissivities obtained by statistical regression analysis based on a collection of radiosondes. Along with the Tikhonov solution, the optimum of the Tikhonov regularization parameter that balances the residual norm and the side constraint norm in the computed solution is also obtained. B) The Tikhonov regularization solution with the optimum regularization parameter is then used as improved guess information in the nonlinear Newtonian iteration algorithm. The test dataset is a collection of 2512 radiosonde samples from the period of March 2 to April 11, 1996 over the central United

States. The radiosondes were divided into dependent (2094 samples) and independent (418 samples) datasets. The forward regression model was used to create MAS simulated brightness temperatures for each radiosonde profile in the dependent and independent datasets. The local zenith angle 0 degree and solar zenith angle 40 degree were assumed in the forward calculation. The dependent dataset of MAS simulation data was utilized to generate regression coefficients and the independent dataset was applied to the extended algorithm to evaluate its performance. The noise of 0.2 K was added into the synthetic MAS data in bands 30-50 in order to simulate the real MAS measurements. The extended algorithm has been tested with the simulated MAS daytime and nighttime radiances and a comprehensive error analysis has been made. Table 1 lists the root mean square (RMS) errors for the retrieved parameters. As can be seen, the layer mean temperatures vary from the dependent mean profile by 4.46-8.23 K in average. The RMS error is reduced to less than 1.98 K for daytime (2.02 K for nighttime). The total precipitable water vapor (TPW) RMS is dramatically reduced from 0.85 to 0.30 cm for daytime (0.26 cm for nighttime). For surface properties, the RMS error of skin temperature is 0.33 K for daytime (0.26 K for nighttime); the RMS errors of seven band emissivities are significantly reduced about 12% for bands 49-50 and 64% for band 31 compared with the regression retrieval results. Table 2 summarizes the retrieved RMS errors from the original algorithm. As shown, the RMS errors of surface emissivities are only reduced 2%-6% from the regression results compared to 12% to 64% in Table 1. Therefore, it demonstrates that the extended algorithm is superior to the original algorithm for the retrieval of surface emissivity. Note that the RMS errors of temperature and surface skin temperature are worse in the extended algorithm than in the original algorithm. The main reason is due to a larger variance of 7 K used in the generation of surface skin temperature data.

Figure 4 shows the MAS bands 30-50 simulated brightness temperature residuals from the extended algorithm. In summary, the test with the simulated daytime and nighttime MAS data illustrates that the extended algorithm is able to retrieve geophysical parameters and improve the retrieval accuracies of both atmospheric temperature and water vapor profiles and surface properties. More tests will be made over wider ranges of the atmospheric and surface skin temperature changes from day to night before real airborne and satellite data are used to evaluate the performance of the extended algorithm.

A paper describing this research is undergoing a second draft review, and will be submitted for publication in third quarter 1999.

<u>AVHRR Cloud Mask</u>

The scope of the prototype MODIS cloud mask (using AVHRR global area coverage data) has been expanded and more functions added. All orbits are now processed every day in order to discover likely problem situations in the future MODIS cloud mask processing. Daily, global clear-sky brightness temperature and cloud coverage maps are produced. Prototype eight-day composite clear-sky brightness temperature maps are also produced every day and displayed on the internet at http://cimss.ssec.wisc.edu/poes/clrsky.html (Figure 1). Experiments are currently underway to determine the best ways to make use of these composites. In addition to using daytime ocean clear-sky maps as a check on nighttime ocean results, it may be desirable to use accumulated clear-sky information for land and daytime ocean situations as well.

Cloud Top Properties

A manuscript was submitted to the Journal of Geophysical Research which describes the results of comparisons between MAS CO_2 slicing derived cloud top heights and CLS lidar heights. In general, comparison were in good agreement.

Paul Menzel is working with Graeme Kelly of the European Center for Medium-range Weather Forecasts (ECMWF) to use the HIRS CO_2 slicing analysis cloud top properties as part of their 20 year re-analysis project.

Cloud Thermodynamic Phase Manuscript

Kathy Strabala has been working with Dr. Bryan Baum on improving the accuracy of the tri-spectral cloud thermodynamic phase retrieval method in regions of multi-layer clouds. Dr. Baum's results are promising when he augments the 8, 11 and 12 micron brightness temperature technique with visible and near-infrared channel observations. A manuscript has been prepared describing the results, and submitted for publication.

Cloud Mask Evolution

MAS cloud masking software now includes the option to produce a binary geolocation file separate to the binary cloud mask output file. Latitude and longitude values are stored in the file in a manner identical to that of the cloud mask binary file. Users can now use this new file as a cloud mask collocation tool instead of having to rely on the much more cumbersome MAS hdf file.

MAS IR Calibration Studies

MAS emissive band calibration is being assessed for the FIRE-ACE and recent WINTEX field programs. Characterization activities include laboratory measurements and analysis of MAS onboard blackbody effective emissivity and system spectral response, and eliminating the effects of background thermal influences on the inflight calibrated data.

The effective emissivity for the MAS blackbodies was estimated from laboratory data sets collected in November and December 1998. Between these data set collections, the MAS blackbody surfaces were stripped and recoated using the same paint (Krylon flat black 1602) as previously used to coat the MAS blackbodies (last recoat pre-1995). The December 1998 effective emissivity estimates are applicable to all MAS data collected since the recoat. As expected, the blackbody emissivity increased from November 1998 to December 1998 for all MAS bands (Figure 5). Degradation of the coating from July

1995 to November 1998 is strongly suggested by the data as well. This degradation suggests that minimally, the MAS blackbody effective emissivity should be monitored semi-annually to track the long term performance and degradation of the MAS blackbody surface coating. Recoating should be considered on a bi-annual basis. The December 1998 MAS effective emissivity drops sharply near the 14 micron region. This indicates that the recoating is optically thin allowing reflection off of the copper plate surface beneath the coating. Low emissivity values increase the complexity of radiometric calibration because they require excellent characterization of background radiance emitted by the MAS scanner hardware and the earth scene below.

In reaction to unexpected absolute radiometric performance of MAS emissive bands during the FIRE-ACE field experiment (May-June 1998), a test was performed to evaluate MAS radiometric performance using the November 1998 effective emissivity estimates rather than the traditional usage of the July 1995 estimates. Logically, the blackbody coating had degraded, as indicated in Figure 5, between July 1995 and June 1998 suggesting that November 1998 effective emissivity estimates would reasonably be more representative of the MAS FIRE-ACE performance than the 1995 estimates. The test recomputed MAS calibrated radiances using November 1998 estimates and then compared those radiances to HIS instrument radiances. Spectral and spatial dependencies of MAS and HIS were removed through spectral convolution and spatial averaging processes. Use of the November 1998 effective emissivity estimates decreased MAS absolute radiometric biases with HIS (Figure 6), bringing them more in line with historical performance. This result promotes MAS November 1998 blackbody effective emissivity estimates as representative of MAS FIRE-ACE performance, corroborating that the MAS blackbody coating degrades over extended periods of time (or flights). This again underscores a need to monitor MAS blackbody effective emissivity on a regular basis.

To establish the absolute calibration accuracy of MAS emissive band data collected during WINTEX, a comparison of MAS and NAST-I inflight calibrated radiances was processed. The MAS data was spectrally calibrated using monochromator measurements made in March 1999 (just before WINTEX). Subsequent SRF measurements using the monochromator in April 1999 (just after WINTEX) showed no change in spectral calibration. Clear sky evening data from the March 25 flight over Lake Superior were used for the comparison. The MAS biases (Figure 7) follow typical MAS historical behavior. Surface viewing bands tend to show negative biases of about 1°C or less; band 30 (3.75um) is out of family with other surface viewing bands. Atmospheric bands (33, 34, 41, 49, 50) tend to show positive biases of varying magnitude, suggesting that the scene temperature may be influencing the MAS calibration. Scene temperature influence on MAS calibration is under investigation. MAS biases were also computed using FTS based SRF measurements collected in April 1999 as part of an ongoing investigation into replacing monochromator based SRF with FTS based SRF. As can be seen in Figure 7, MAS biases are about the same for window bands reflecting the insensitivity of window bands to spectral calibration; atmospheric bands show somewhat larger biases suggesting that the FTS measurements are poorer than the monochromator based. However, thermal effects including scene temperature influence may yet be the cause of a large portion of the bias in atmospheric bands. A paper on this topic of FTS based SRF measurements was presented at the Optical Remote Sensing of the Atmosphere Topical meeting on Fourier Transform Spectroscopy: New Methods and Applications. The FTS based measurements are being promoted to replace the monochromator based measurements because of improved signal to noise, spectral resolution, and data collection time economy. However, it remains for inflight comparisons between MAS and HIS to verify the accuracy of the FTS based approach.

PAPERS

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MEETINGS

Chris Moeller attended the MODIS IR calibration meeting held February 4-5 in Miami, Florida.

Liam Gumley attended the EOS Direct Broadcast Meeting, 4-6 February in Kauai, Hawaii.

Chris Moeller and Dan LaPorte attended the MODIS RSB calibration meeting held 11-12 February in Greenbelt, Maryland.

Paul Menzel, Steve Ackerman, Chris Moeller, Kathy Strabala, Dan LaPorte and Tom Rink attended the MODIS Science Team Meeting held May 4-6 in Greenbelt, Maryland.

Dan LaPorte attended the Optical Remote Sensing of the Atmosphere Topical held 7-11 July in Santa Barbara, California .

Paul Menzel, Steve Ackerman, Kathy Strabala, Chris Moeller and Ma Xia Lin attended the 10^{th} conference on atmospheric radiation held 28 June – 2 July in Madison, Wisconsin.

Table 1 Retrieval RMS Comparisons
(Noise is added, mean = 0 and std = 0.2 K)

A) Day-time

	Dep. Mean	Reg.	Phy.
Layer mean T (K)			
1	4.46	0.90	0.93
2	3.32	1.41	1.41
3	5.62	1.17	1.20
4	6.96	1.23	1.19
5	8.23	2.15	1.98
Ts(K)	11.63	0.48	0.33
TPW(cm)	0.85	0.36	0.30

B) Night-time data

	Dep. Mean	Reg.	Phy.
Layer mean T (K)			
1	4.46	0.90	0.90
2	3.32	1.41	1.39
3	5.62	1.17	1.15
4	6.96	1.23	1.19
5	8.23	2.15	2.02
Ts(K)	11.63	0.48	0.26
TPW(cm)	0.85	0.29	0.26

C) Day and Night-time

ε_1 3.59 μm (band 30).	0.06354	0.01226	0.00479
ε_2 3.74 μm (band 31)	0.06379	0.01309	0.00462
ε_3 3.90-4.67 μm (bands 32-37)	0.05949	0.01250	0.00444
ε_4 4.82-8.60 μm (bands 38-42)	0.05059	0.00925	0.00773
ε_5 9.79-11.02 μm (bands 43-45)	0.02263	0.00793	0.00605
ε_6 11.96-12.88 μm (bands 46-47)	0.01428	0.00847	0.00688
ε_7 13.23-14.17 μm (bands 48-50)	0.01262	0.00863	0.00755

Note:

Layer mean T:

1: 50 - 200 hPa,
2: 200 - 400 hPa,
3: 400 - 600 hPa,
4: 600 - 800 hPa,
5: 800 - 1000 hPa.

Ts: Surface skin temperature. TPW: Total precipitable water vapor.

Table 2, Retrieval RMS Comparisons
(noise is added, mean =0 and std = 0.2 K)

	Dep. Mean	Reg.	Phy.
Layer mean T (K)			
1	4.46	1.03	0.99
2	3.32	1.47	1.46
3	5.62	1.23	1.21
4	6.96	1.17	1.11
5	8.23	1.67	1.60
Ts(K)	10.59	0.32	0.30
TPW(cm)	0.85	0.47	0.36
Sw ε	0.02049	0.01142	0.01113
Lw ε	0.01959	0.00881	0.00820

Note:

Layer mean T:

1: 50 - 200 hPa,
2: 200 - 400 hPa,
3: 400 - 600 hPa,
4: 600 - 800 hPa,
5: 800 - 1000 hPa.

Ts: Surface skin temperature.

TPW: Total precipitable water vapor.

Sw ε Surface emissivity in the short-wave region.

Lw ε Surface emissivity in the long-wave region.

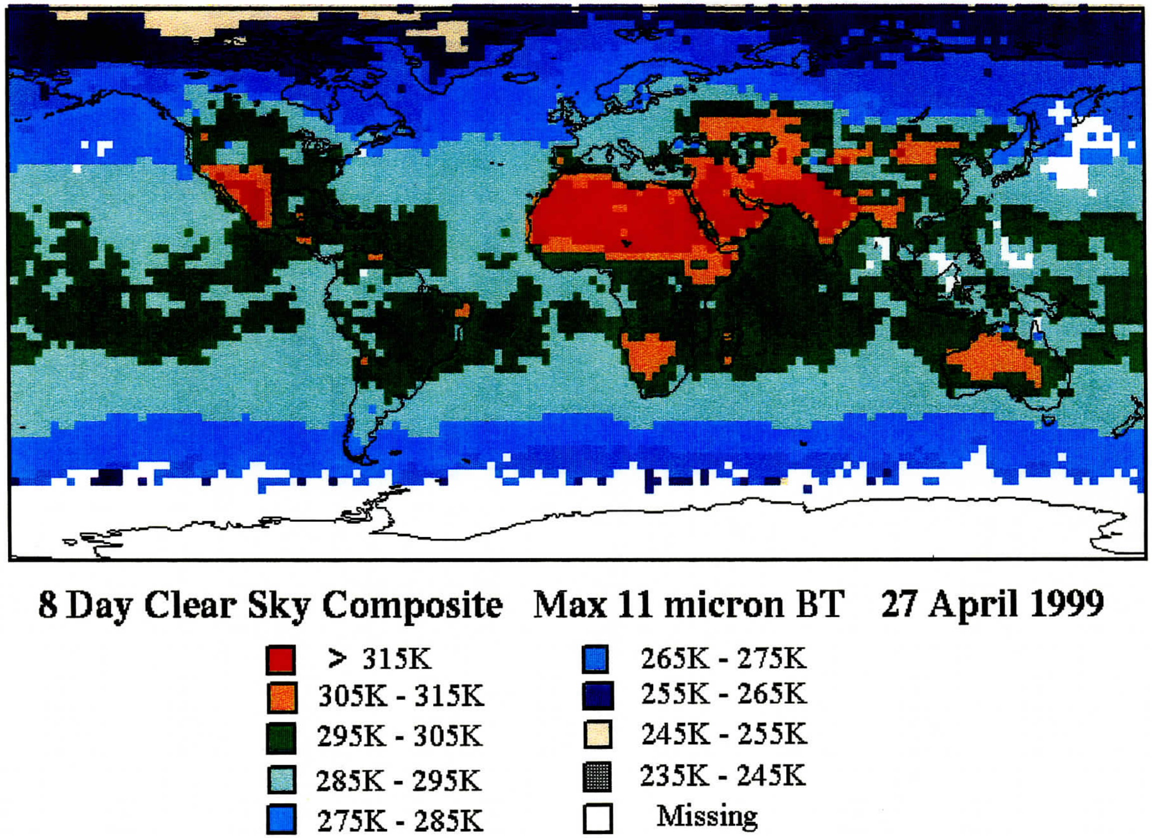


Figure 1. Example of the real-time AVHRR cloud mask processing clear radiance file from 27 April 1999. This file is created by compositing all high confidence clear 11 micron observations within a 25 km equal-area grid cell for eight days. Note the area of missing observations over persistently cloudy regions like the North Atlantic and Indonesia.

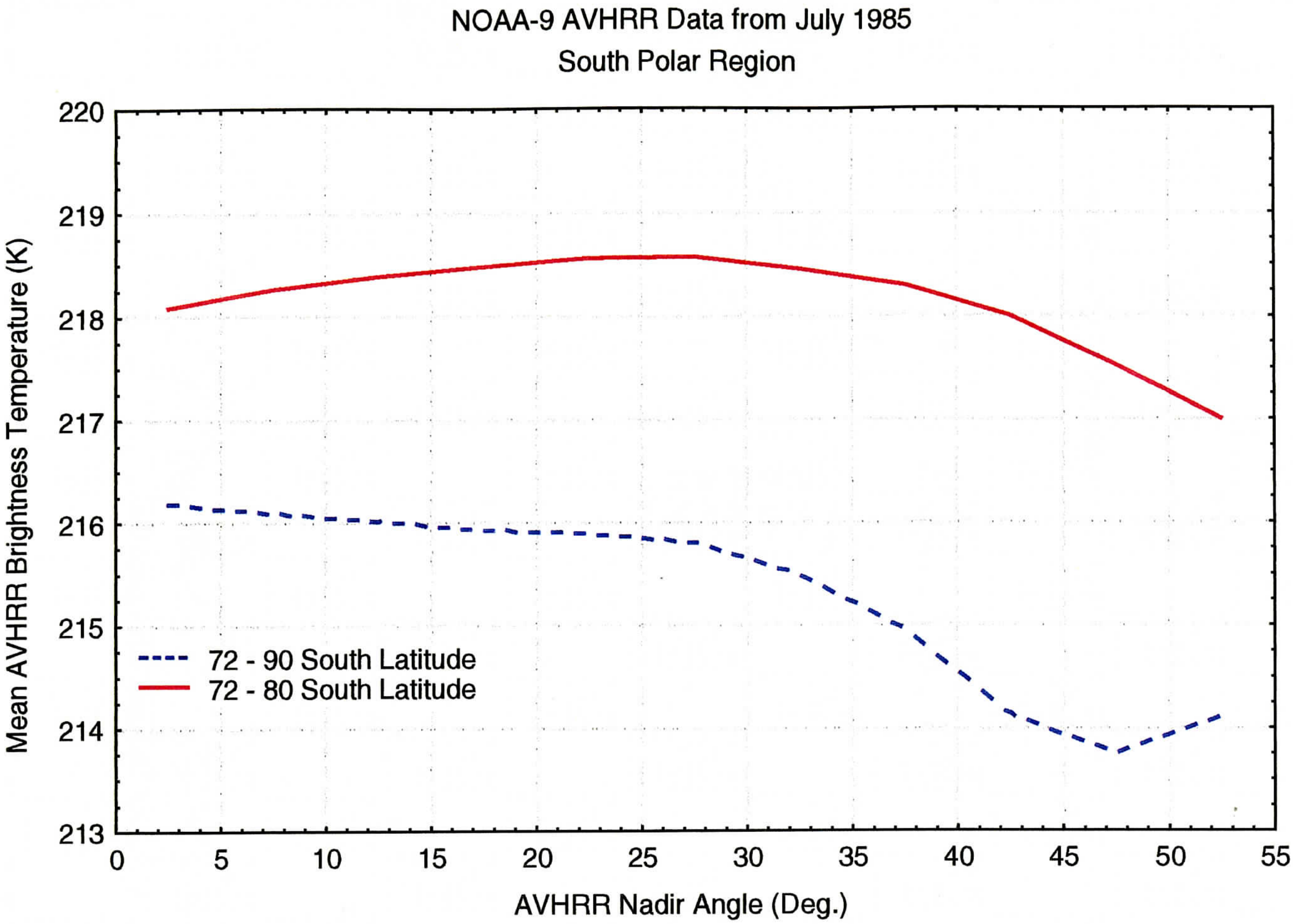


Figure 2. Averaged AVHRR scan angle dependence using a large data sample (>100,000 observations) based on one month of Antarctic observations. Zero scan angle dependence would result in flat lines (no slope); however, the AVHRR data, which is presumed free of scan mirror RVS (response versus scan) effects, demonstrates that natural variability remains in a large data sample and is a function of the selected geographic domain for the data sample. The natural variability may be interpreted as persistent spatial temperature gradients over Antarctica. For MODIS to accurately estimate RVS, natural variability must be minimized in the large data sample. It may be useful to "normalize" the MODIS scan angle dependence with the AVHRR scan angle dependence.

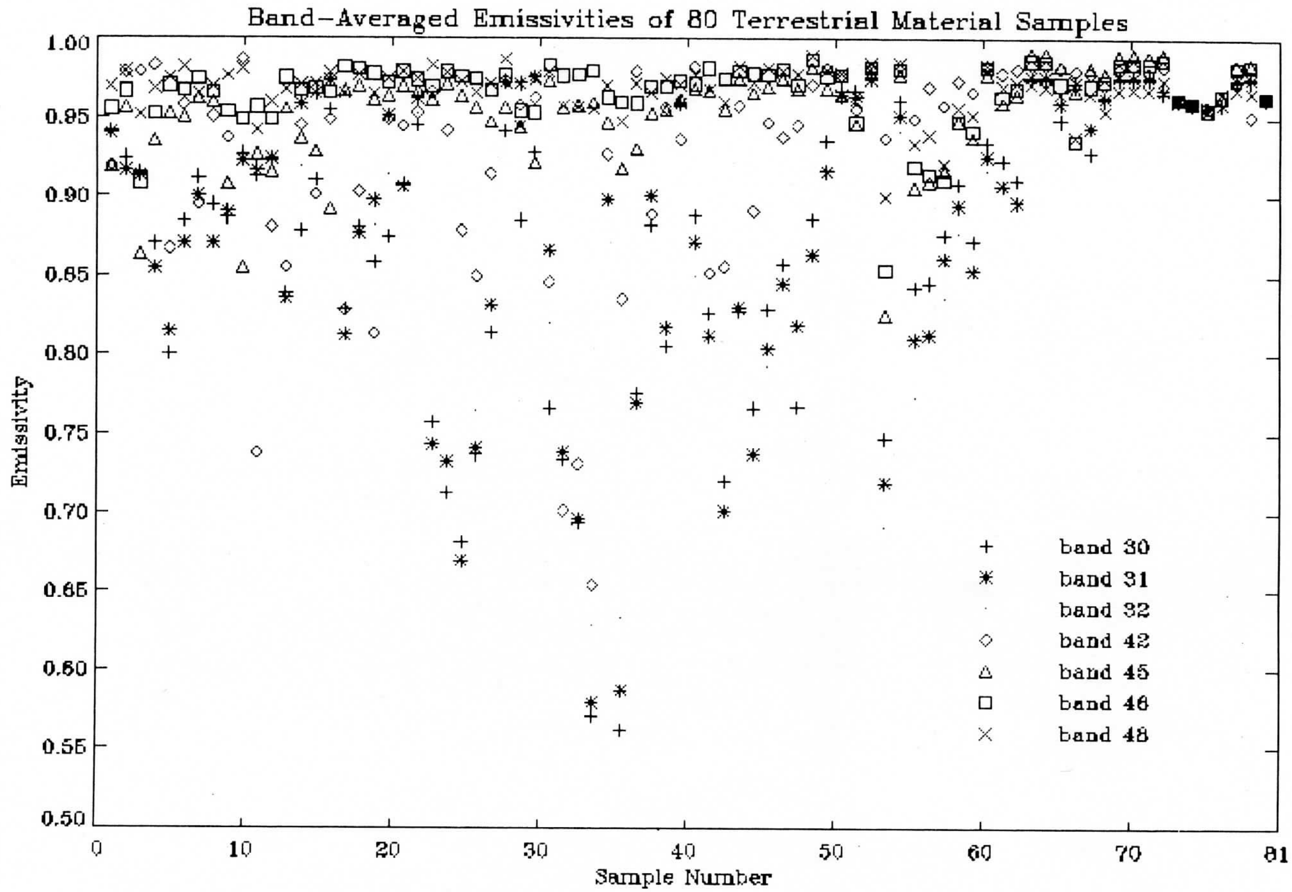


Figure 3. Band-averaged emissivities of 80 terrestrial materials which serve as a spectral base in the new profiles retrieval algorithm.

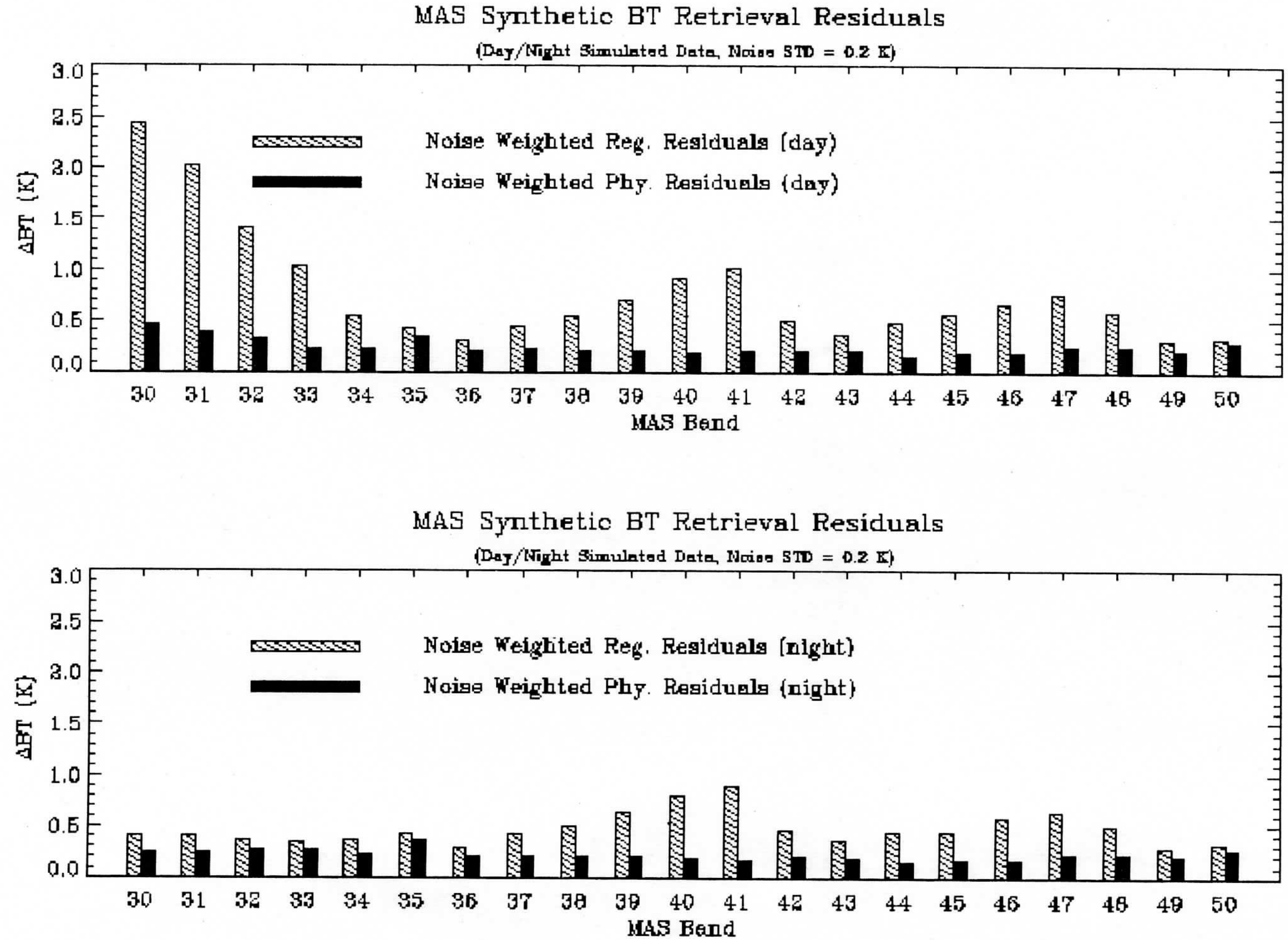


Figure 4. MAS simulated brightness temperature residuals from retrievals using the original algorithm (Reg.) and the new extended algorithm (Phy.) for both day and nighttime data.

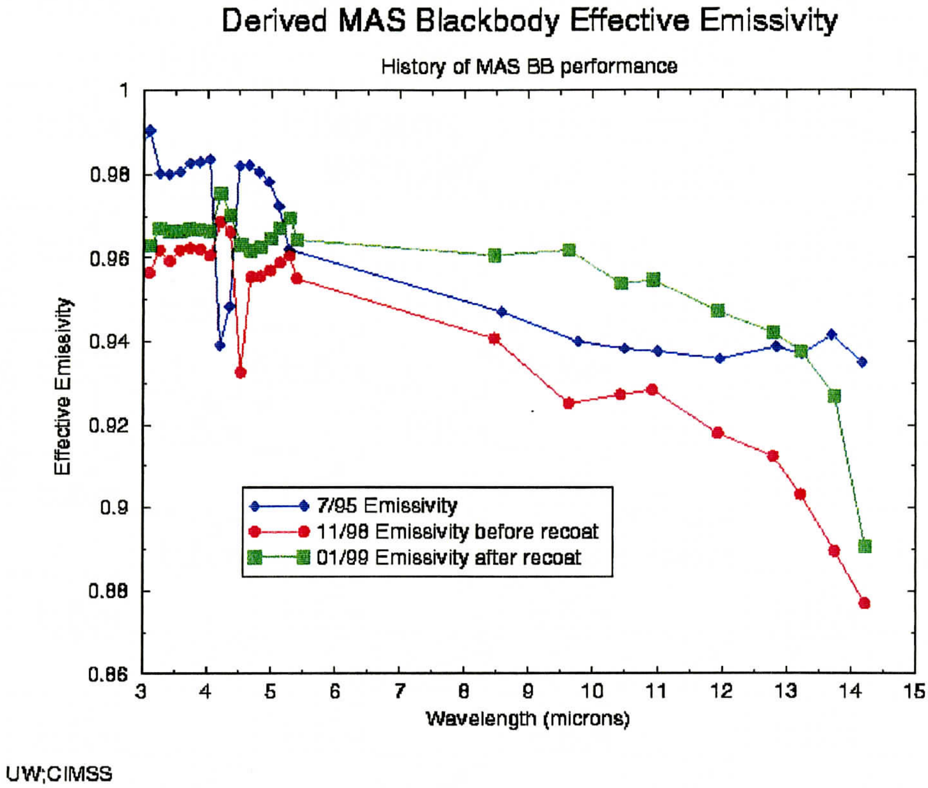


Figure 5. Sampled history of MAS blackbody effective emissivity estimates from laboratory data sets. From July 1995 to November 1998, the coatings on the MAS blackbodies degraded in the difficult aircraft platform environment, effectively changing the MAS emissive band calibration by lowering the emissivity of the two onboard blackbody sources. MAS blackbodies were recoated in early December 1998, raising emissivity at all wavelengths compared to November, 1998. Regular monitoring of the MAS blackbody emissivity is under consideration to reduce calibration uncertainty.

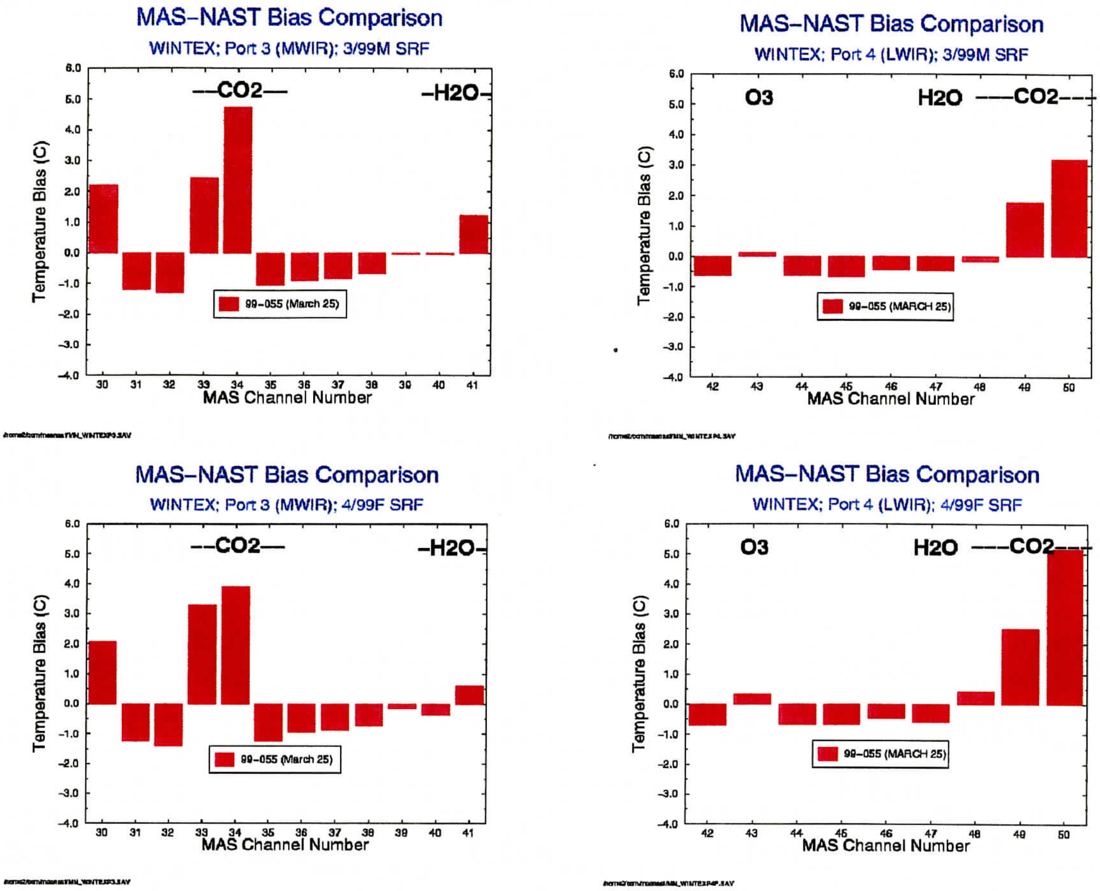
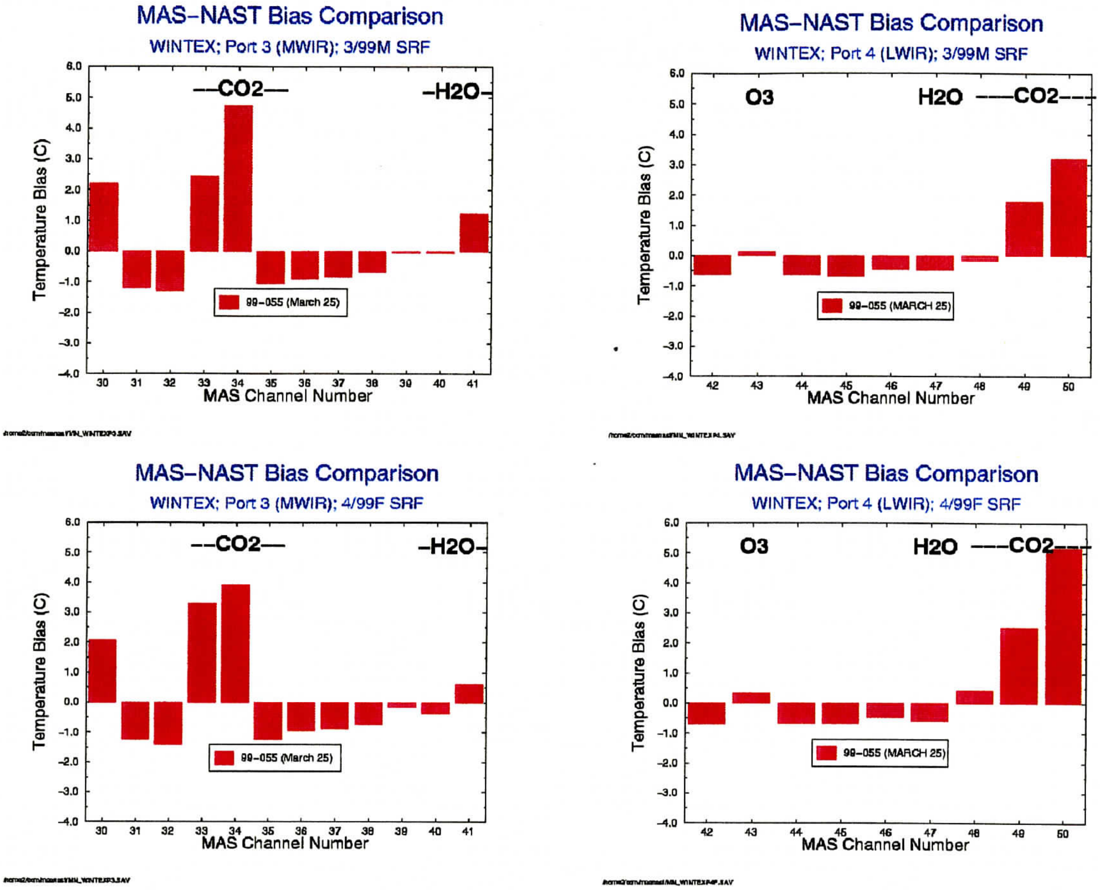


Figure 7. MAS-NAST brightness temperature biases for WINTEX flight 99-055. NAST data assumed to be truth. Data scenes were all clear sky, predominantly of Lake Superior with low or no solar illumination. Upper charts show biases using traditional monochromator based spectral response functions (SRF). Lower charts show same data except using research level FTS based SRF. Biases in atmospheric CO2 bands 33, 49 and 50 increase when using FTS based measurements. Other bands show little change or marginal decrease. Other factors besides spectral calibration affect the MAS biases.



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