INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

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Paul Menzel, Steve Ackerman, Chris Moeller, Liam Gumley, Kathy Strabala,
Richard Frey, Elaine Prins, Dan LaPorte and Walter Wolf
CIMSS at the University of Wisconsin
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ABSTRACT

The UW MODIS group spent the last half-year preparing for the launch of the MODIS instrument. The MODIS Week In the Life Test (WILT) allowed the UW to test the cloud mask and atmospheric profiles software in a production environment. A proposal was submitted to acquire MODIS data via direct broadcast at the UW. Efforts continued for defining methods to characterize the MODIS scan mirror response versus scan on the PFM. Meetings were hosted by the UW to discuss radiation in cirrus clouds and MAS instrument progress. Preparations began for a March ER-2 deployment based in Madison, Wisconsin, that will focus on cloud masking and cloud top property retrieval in transitional atmospheric and surface regimes.

TASK OBJECTIVES

Software Development

The MODIS cloud mask and atmospheric profiles software was run as part of the MODIS Week In the Life Test (WILT). This test consisted of strings of MODIS processes run in sequence, simulating the at-launch processing system. Both algorithms performed as expected; areas where the cloud mask did not perform well were traced to unrealistic synthetic radiances. The WILT identified the importance of communication between the product users and developers. A final at-launch version of the UW MODIS production software packages will be delivered in March and April.

MODIS Infrared Calibration

UW personnel continue to participate in the infrared characterization and calibration of the MODIS instrument. Recent efforts have focused on approaches to correct for the scan mirror response variation versus scan angle on the PFM; multi-angle views of the thermally flat, very dry Antarctic continent offer promise.

Atmosphere Group Meeting

A meeting of atmosphere group members and associates was held at St. Michael's, Maryland in November. Science progress on MODIS products was presented and more detailed validation plans were discussed.

Publications

The MODIS cloud mask paper was published in the December 1998 Journal of Geophysical Research. A paper on HIRS cloud studies will appear in the January 1999 Journal of Climate.

WORK ACCOMPLISHED

MODIS Production Software Development

Efforts to refine the baselined Version 2 UW MODIS production software continued. Changes were made to the MOD06 cloud top properties and cloud phase code due to a change in the production strategy of the MOD06 product suite. Other adjustments came as a result of concern over the performance of the cloud mask as applied to synthetic data during the MODIS Week In the Life Test (WILT). After thorough investigation, it was found that the vast majority of the questionable cloud mask results were due to unrealistic data simulations (see the following paragraphs).

MODIS programmers who use the cloud mask as an input product to their own production software voiced concern over a cloud mask granule of WILT synthetic data located over the ocean. Too much cloud was being found. After obtaining all necessary inputs in the UW SCF, the cloud mask was re-run and examined using UW visualization tools. It was discovered that the cloud mask split window brightness temperature difference test caused most of the granule to be flagged as cloudy. This test relies on the fact that BT11-BT12 values will be larger in clear skies than in thick cloud due to the water vapor absorption that is strongest in the lower atmosphere. In the simulated data, this was not the case (see Figure 1). BT11 is used to infer clear pixels (from warmer temperatures). BT11-BT12 values for cloudy scenes are low (between 0 and 0.1 K), but not unrealistic. BT11-BT12 values for clear scenes are less than zero, down to –1.5 K. As water vapor absorption lines are stronger in the 12 micron region than the 11 micron region, BT11 will be less than BT12 in cases of extreme inversions or extremely cold ice cloud (cumulonimbus cloud). With a minimum clear sky threshold value of BT11-BT12 for low clouds of 0.5 K, the cloud mask ocean processing path flagged almost the entire scene as cloud covered, as experience would suggest.

To enable users who require clear sky to run their algorithms, the BT11-BT12 low cloud test was removed from the cloud mask processing path over ocean scenes. AVHRR global testing had shown that this test was unreliable over certain cold water regions. The results before and after the removal of the BT11-BT12 low cloud test are show in Figure 2.

George Riggs, of the snow algorithm group, also contacted us about his concern that all snow regions in the synthetic data were being flagged as cloud. After re-running a couple of granules at the UW SCF, a problem was found. In the cloud mask algorithm, a quick version of the Normalized Difference Snow Index (NDSI) will be used to determine if the scene has a snow background. Since the regions were not being flagged as snow in the synthetic data, normal land tests and thresholds were being used, causing the region to be identified as cloud (cold and bright). This was fixed and the subroutine was re-delivered to the SDST.

Other areas of concern were also examined. Cigar shaped streaks of cloud were found in some of the cloud mask output granules. The cause was traced to synthetic data depiction of aerosols. The 6.7 micron and 13.9 micron brightness temperature cold cloud tests were finding some cloud in clear regions. This was due to the reversal of clear and cloud brightness temperatures in the synthetic data.

Paul Menzel has agreed to assist the SDST in improving the infrared radiance simulations. The results of our experiences were presented by Steve Ackerman at the MODIS Science Team Meeting in December. In all, we found that:

1). Aside from the snow mask problem, the cloud mask was performing as expected.

2). There needs to be good communication and cooperation between the cloud mask users and developers in order to track down problems and make changes quickly.

3). The UW needs to create a cloud mask users guide that is easily referenced and understandable.

4). The cloud mask output information about whether a cloud mask test was performed is an important diagnostic. This information is stored in the Q/A SDS array.

5). The use of a visualization tool for debugging purposes was invaluable.

6). Data simulations are valuable for testing technical processes and processing strings, but should not be used as a test of the quality of the science.

<u>Visualization Software</u>

A new version of the MAS visualization program SHARP was released on the Web on October 16. It includes the following updates:

1). The correction of an error in the computation of visible/near-IR reflectances (found by Steve Platnick).

2). The correction of an error in the map projection mode.

3). An option to save region data for all 50 bands to an ASCII file (requested by Bryan Baum).

4). The overlay of cloud mask results now includes test run/not-run indicators (requested by UW MODIS group).

Over 75 users of the SHARP program have been confirmed outside of UW. Dr. Zhengming Wan at UCSB sent the following comment via email on 12/20/98: "I want to express my thanks to you for letting me use the SHARP software. It is an excellent tool to visualize the MAS data and cloud-mask". Dr. Wan made several suggestions for improvements which have all been implemented.

UW software for visualizing MODIS data played a critical role in understanding the application of the MODIS cloud mask on simulated data in the Week in the Life Test (WILT). UW visualizations of MODIS data were forwarded to members of the MODIS Land Team.

UW developed an interactive Web based viewer for GOES data during the CAMEX-3 field experiment in September. This viewer allows users to view and loop GOES image data in real-time through a web browser, and view dynamic aircraft flight tracks overlaid on the imagery. This demonstration of Java and IDL components for interactive satellite data display is a prototype of the web based viewing capabilities UW will provide for MODIS data. The viewer is available at http://origin.ssec.wisc.edu/~tomw/camex/. An example of the viewer is shown in Figure 3.

UW continues to investigate strategies for visualizing MODIS data, and remains committed to developing an interactive MODIS visualization capability for the community.

<u>MAS Cloud Mask Software Release</u>

A new version of the MAS cloud mask has been released. This October 1998 version differs from the November 1997 version in that:

1). There are only three required inputs. The MAS hdf file name, the output file name and the specified ecosystem file. The entire flight track will be processed by default; sub-segments can be processed by using optional commands.

2). The MAS spectral configuration is now automatically determined from the date in the input HDF file.

3). The code now meets all F77 ANSI standards.

4). More rigorous bad data checks are now included.

5). Brightness temperatures are now calculated using standardized UW routines. This also means the hdf data set must be using final calibration.

6). APOLLO thin cirrus tests have been added to the nighttime data processing algorithms.

7). Low cloud BT11-BT4 nighttime thresholds have been adjusted after testing with MAS WINCE data sets.

8). The option to use the new global 1 km Olson ecosystem map distributed by the USGS is now available.

This version 2 package has been tested on all 50 channel experiment data sets. The remaining MAS cloud mask efforts will focus on the unused tests (i.e., BT3.7-BT3.9, r0.936, cloud shadow on cloud).

The cloud mask software and ancillary data sets can be picked up via anonymous ftp from: ftp://origin.ssec.wisc.edu/pub/MAS/ .

Direct Broadcast

UW has a long history of developing algorithms and software for processing polar orbiting satellite data. The International TOVS Processing Package (ITPP), developed and distributed by UW, has been widely used throughout the world in the last 15 years by direct broadcast stations to calibrate, navigate, and generate products from TOVS data. Thus, UW has a natural interest in direct broadcast from the EOS AM and PM platforms. Following a visit by Jim Dodge (NASA HQ) in September, UW submitted a proposal to NASA requesting 350K for an EOS direct broadcast ground station. Assuming the funding is forthcoming, UW will install and commission the ground station in the fourth quarter 1999.

In addition to the ground station hardware, UW is committed to developing a MODIS direct broadcast processing software package for the international community. The software package will allow users with a local source of MODIS Level 0 data (i.e. a ground station) to apply calibration and navigation algorithms to produce MODIS Level 1B data. The package will run on commonly available Unix hardware, and will be released and supported by UW in the same manner as ITPP. In addition, UW will include algorithms for generating value-added MODIS products such as a cloud mask, atmospheric temperature and moisture profiles, cloud height and phase, and land products such as NDVI and LST. At the EOS Direct Broadcast Meeting in Canberra, Australia, on 4-6 December, this proposal by UW to provide software for the community was enthusiastically received, and several attendees indicated they will depend on UW for MODIS direct broadcast calibration and navigation. UW will also develop a real-time Web presence for locally received MODIS direct broadcast data focusing on regional products (imagery and land/atmosphere parameters) that will used for science and educational outreach. This new UW task will be managed by Liam Gumley and coordinated closely with existing UW MODIS work.

MODIS PI Processing

UW has played an active role to date in the planning for MODIS PI Processing. UW participated in the review of the MODIS PI Processing proposal, and has actively engaged in regular planning meetings. In the upcoming months, UW expects that other members of the MODIS Atmosphere Group at GSFC will become more involved as they have the advantage of close proximity to MODIS PI Processing daily activities.

Atmosphere Group Meeting

Rich Frey, Paul Menzel, Steve Ackerman, Liam Gumley and Chris Moeller attended the MODIS Atmosphere Group Retreat in St. Michael's, Maryland, on November 4-6. Presentations on MODIS cloud top pressure, cloud microphysics, cloud mask statistics, atmospheric profiles, direct broadcast and MAS IR calibration were made by UW participants. Presentations on MODIS validation were given by MODIS validation scientists, leading to useful discussion and coordination on updating the MODIS Atmosphere's Group validation plan. ER-2 campaigns beginning with FY00 will be coordinated between validation scientists and MODIS science product investigators.

MODIS Infrared Calibration

Dan LaPorte and Chris Moeller attended the MODIS IR calibration meeting held December 14 in Greenbelt, Maryland. This meeting focused on characterization and correction of scan mirror response versus scan angle (RVS) on PFM (AM-1 platform). Approaches for correcting PFM RVS include the deep space maneuver and transfer of MODIS FM-1 optics characterization to PFM. Questions remain about SNR levels during the deep space data collection. However, the deep space maneuver remains attractive because it directly interrogates the MODIS scan mirror RVS. Transferring FM-1 characterization requires that scan mirror witness sample reflectance measurements be highly representative of inflight hardware, consistent aft optics performance between PFM and FM-1, high quality RVS measurements on FM-1, and accurate polarization modeling. Significant progress has been made in these areas with the measurement of FM-1 scan mirror witness samples by NPL, FM-1 RVS from SBRS, and polarization modeling by the MCST. Another approach using on-orbit views of Antarctica to evaluate RVS was offered by UW. Antarctica provides a relatively flat thermal background and minimal slant path effects, especially during the austral winter season. Also, MODIS will view Antarctica during each orbit (14 orbits per day) at various scan angles. This allows rapid accumulation of a large sample data set. Challenges include the cold Antarctica scene temperatures (lower SNR) and cloud clearing the data scenes (may not be necessary). UW will conduct a pilot study using AVHRR data to evaluate the Antarctic natural variability and slant path effects. Further, UW is proposing that synergism between MODIS Antarctica data collection and concurrent ground based radiometric measurements of the Antarctic surface and atmosphere (AERI instrument) at the South Pole will help to substantiate MODIS absolute calibration for RVS characterization.

MAS Instrument Meeting

A meeting to discuss hardware and software status and plans for the MAS instrument was held at UW on 4-5 August. Participants from ARC, DFRC, and GSFC attended. Discussion topics included MAS reflective and emissive band calibration procedures and accuracy, spectral calibration, hardware modifications to MAS, upcoming MAS deployments, pre and post deployment procedures, and MAS L1B data structure. Items of interest from the meeting include:

1). ARC will investigate cost/utility of placing a linear variable filter over MAS Port 3 detectors.

2). There will be a transition to using "raw" ER-2 navigation data in MAS L1B product (instead of regression functions).

3). UW will continue to investigate FTS based SRF measurements from MAS, including comparisons of MAS and HIS inflight data to validate FTS based SRF calibration. A new MAS port 4 dewar will be purchased from EG&G/Judsen.

4). The MAS blackbodies will be recoated and characterized with laboratory data sets at the next convenient interval in FY99.

5). The MAS quicklook image and nadir brightness temperature products will be incorporated into NEWMAS software for field data analysis.

6). Hardware options for evaluating MAS spectral calibration in the field will be researched.

<u>Field Activities</u>

CALibration/Validation EXperiment – NOAA15 (CALVEX-N) was conducted in two phases, one from Wallops Island, Virginia in July (also referred to as "Wallops98") and a second from Dryden Flight Research Center, California in mid December. In July an ER-2 instrumented with the MODIS Airborne Simulator (MAS), High resolution Interferometer Sounder (HIS) and the NPOESS Atmospheric Sounder Testbed-Interferometer (NAST-I) was flown twice (July 11, 14) under NOAA-15 with clear Atlantic ocean background. Because MAS Port 4 (LWIR) was inoperative during these flights, ocean surface thermal variability was provided by MAS Port 3 (MWIR). NAST-I and HIS performed well. In December, the MAS, Scanning HIS (S-HIS) and Microwave Imaging Radiometer (MIR) underflew NOAA-15 on three missions (Dec. 18, 21, and 22). Excellent data was collected on December 21 and 22 over clear coastal Pacific Ocean. Special radiosonde launches during both phases of CALVEX-N will be used to characterize the atmospheric conditions during the NOAA-15 underflights. Upward looking AERI measurements will be used to establish atmospheric properties and absolute calibration of the IR instruments on the ER-2. The ER-2 measurements will be spatially averaged and slant path corrected to match the geometry of the NOAA-15 AMSU-B and HIRS footprints. Of particular interest, the MIR 183 GHz radiances will be compared to the AMSU-B 183 GHz observations to gain insight into AMSU-B absolute calibration and the calibration dependence on scan angle. This exercise is representative of MODIS IR calibration validation activities that will be undertaken after AM-1 launch in July 1999.

Preparations continue for the WINTer EXperiment (WINTEX) to be held in Madison, Wisconsin in March. Plans for an ER-2 instrumented with MAS, S-HIS, NAST-I, NAST-M, and a camera system (RC-10) are in place and ground based instrumentation (uplooking lidar, AERI, radiosondes) deployment logistics are being assessed. During WINTEX, the ER-2 will fly from six to eight missions over snow, bare ground, and vegetated surfaces with and without partial cloud cover. Day and night flights will be conducted. Plans also include collecting cloud microphysical profiles (dropped from aircraft) to supplement the ER-2 measurements of clouds. The ER-2 measurements will be used to continue assessment of the MODIS cloud mask and cloud top properties as well as evaluate absolute calibration of the interferometers (S-HIS, NAST-I); S-HIS and NAST-I will be used to validate MODIS IR calibration after the AM-1 launch in July 1999. WINTEX missions will be flown in southern Canada (winter scenes), over the Great Lakes (snow and bare ground), and around the midwest (spring greening phase) including the SGP CART site (calibration validation).

Cirrus Cloud Meeting

On December 7 several scientists from NASA, NOAA, and the University community met in Madison, Wisconsin to exchange information and opinions on the physical properties of cirrus clouds and how they manifest themselves in remote sensing data.

Andy Heymsfeld from UCAR presented a phlethora of in situ measurements of ice particle sizes and shapes from several NASA field experiments (FIRE, SUCCESS,...). It is evident that the shapes of the ice crystals change with particle size and that no one mean particle profile is representative of most cirrus clouds. Several example replicator profiles suggest that a cirrus cloud can be thought of (modeled) as three layers; the upper 1 km consists of small 10 to 50 micron ice spheres, the next 1 km has large 300 micron columns, and the bottom 2 km reveal medium 150 micron aggregates, bullets, and rosettes.

Steve Ackerman from UW showed that ice clouds separate from water clouds in plots of 8.6 minus 11 versus 11 minus 12 micron brightness temperatures. Calculations with line by line radiative transfer codes and scattering models using ice spheres result in relatively good representations of high spectral resolution measurements of infrared emitted spectra (but introduction of asymmetry is expected to enhance comparisons in some situations). Small particles (less than 10 microns) cause noticeable differences in the absorption/emission of infrared radiation at 11 versus 12 microns (cloud forcing at 12 microns is 20 to 30 C greater than at 11 microns for some clouds producing the "S" shape measured with the HIS).

Paul Menzel from NOAA showed that there is evidence of a preponderance of cirrus cloud around the globe detected in the HIRS CO2 cloud work (more than 40% of the HIRS measurements in the last ten years reveal semitransparent cloud within the field of view). Anticipations are that even more sub-visible cirrus will be revealed in MODIS 1.38 micron images from EOS AM and PM.

Bryan Baum from LaRC summarized theoretical work relating to radiative transfer for different cloud crystal habits. Much work remains, as the broad range of particle sizes and shapes requires a variety of tools for representative calculations. Four habits were suggested for initial work (hollow columns between 10 and 300 microns, aggregate plates greater than 150 microns, rosettes greater than 10 microns, and spheres greater than 10 microns). At least 20 particle sizes were suggested for initial calculations at all MAS and MODIS wavelengths. The code that is developed for these calculations by the group will be shared as facility code for EOS investigators.

Discussion of field experiment data led to a focus of energies on the following days in order to find in situ particle measurements and simultaneous remote sensing data.

22 Nov 91
26 Nov 91
5 Dec 91
16 Apr 96
21 Apr 96 (203117, 202920, 202450 UTC)
26 Apr 96 (1844 UTC)
2 May 96 (1818 UTC)
8 May 96

Several actions resulted from these discussions.

1) UW will pursue two and three layer ice cloud radiative transfer calculations with LBLRTM and DISORT, introducing asymmetric particles (asymmetry parameter as large as five) as well as spheres.

2) UW will investigate available code using the discrete dipolar approximation for radiative calculations for a variety of particle shapes.

3) LaRC/GSFC will suggest calculations for UCLA (Liou) collaborators and coordinate this work through Dr. Michael King.

4) UCAR will put some size spectra data on the Internet.

5) UCAR will review in situ data availability for near top of cloud particle measurements on the focus days.

A meeting will be held in 6 months to measure progress on these actions and to guide day one particle size algorithms. 18 months hence this group hopes to have assembled look up tables containing radiative characteristics of many ice crystal habits for many particle sizes at many wavelengths.

Cloud Thermodynamic Phase Modeling

Kathy Strabala and Dr. Bryan Baum, of NASA LaRC, continue to investigate the strengths and weaknesses of the tri-spectral thermodynamic phase technique and the visible reflection function phase technique through modeled results using discrete ordinates radiative transfer (DISORT) code. The results verify the difficulty that these two techniques have in determining cloud phase for multi-phase multi-layer cloud scenes. Research will continue to focus on improving the performance of the tri-spectral technique through the addition of the BT3.7 – BT8.5 test or through the addition of a multi-layer cloud detection technique.

DATA ANALYSIS

Cloud Properties Algorithm Development and Testing

Work has continued on the prototype MODIS cloud top height algorithm which uses MAS input data. All MAS data from the SUCCESS field experiment has been processed along with some WINCE data. A comparison of cloud top heights derived from CLS lidar data and the MAS CO_2-slicing method was completed and the results reported in a paper submitted to the Journal of Geophysical Research - Atmospheres. Figure 4 shows a histogram of differences between lidar and CO_2-slicing cloud top heights using collocated SUCCESS data.

More than 4700 cloud top heights measured from CLS lidar data and computed from MAS IR radiance data (using the CO_2-slicing method) during the SUCCESS field experiment were compared. This exercise was undertaken to evaluate and adjust the CO_2-slicing algorithm to be used in processing MODIS data. In the course of the study, UW assembled the largest validation data set to date between CO_2-slicing cloud heights and lidar information.

Overall, the algorithm retrieved cloud heights to within ±500 meters in 32% of cases and to within ±1500 meters in 64% of the cases in the ten days of SUCCESS cloud scenes studied. This is an encouraging result when one considers that 66% of all comparisons came from multi-layer cloud situations and that the area of the comparisons was about 0.5 km on a side. One factor to be noted about the SUCCESS data, which is both a benefit and a liability, is that most scenes contained only cirrus and/or underlying boundary-layer clouds. This is a benefit in that cirrus clouds pose the most difficulty when assigning cloud height and therefore require more study, but a liability because very few mid-level clouds are included in the validation. Even in cases of optically thin clouds (of which more than 72% were multi-layer), 30% and 63% of retrieved cloud top heights were within ±500 and ±1500 meters, respectively, of the lidar values.

From a simulation of cloud height errors as a function of various error sources in the CO_2-slicing algorithm, we conclude that observed temperature biases between radiosonde and radiometer data have the most negative influence on the results. Although more comparisons are required (including from diverse locations and measurement systems) to increase confidence, it appears that the problem of multi-layer clouds may be secondary to that of proper specification of clear-sky radiances. No matter how well-defined a particular cloud may be (optically thick and high temperature contrast between cloud and surface), a bias in the input temperature profile leads to biased cloud heights.

Model Calculations and Interferometer Measurements of Ice Cloud Characteristics

The relationship between high-spectral resolution infrared (IR) radiances and the microphysical and macrophysical properties of cirrus clouds was investigated. Using radiosonde measurements of the atmospheric state at the Department of Energy's Atmospheric Radiation Measurement (ARM)-site, high-spectral resolution IR radiances were calculated by combining trace gas absorption optical depths from a line-by-line radiative transfer model with the discrete ordinate radiative transfer (DISORT) model. The sensitivity of the high-spectral resolution IR radiances to particle size, ice-water path, cloud-top location, cloud thickness, and multi-layered cloud conditions was estimated in a multitude of calculations.

DISORT calculations and interferometer measurements of cirrus ice cloud between 700 and 1300 cm^{-1} were compared for three different situations. The measurements were made with the High-spectral resolution Interferometer Sounder (HIS) mounted on NASA ER-2 aircraft flying at 20 km during the SUbsonic aircraft Contrail and Cloud Effects Special Study (SUCCESS).

Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. They are less sensitive to cloud thickness and lower layer clouds. In this study, the ice particles were treated as spheres, and the scattering function was approximated by the Heney-Greenstein function. Model calculations should be improved by using more realistic particle shapes and scattering functions.

The best calculations of effective radius and ice-water path reproduced the observed HIS cloud forcing within 2 K in 800-1000 cm^{-1} and within 4.5 K in 1150-1250 cm^{-1} for both small ($r_{eff} < 10$ μm) and large ($r_{eff} > 10$ μm) particle clouds. Measured HIS spectra were used to infer a range of ice particle sizes between 7.5 and 37.5 μm with ice-water paths between 10 and 600 gm^{-2}. Ice-particle size and ice-water path were estimated with 20-30 % variation in the inferred values. The reasonable reproduction in a rather wide window region shows the reliability of DISORT based algorithm. However, this process becomes less reliable as the opaqueness of clouds increases. Clouds with IWP greater than 50 gm^{-2} (130 gm^{-2}) and small (large) particles of $r_{eff} = 7.5$ μm ($r_{eff} = 30$μm) were found to be opaque.

It was also found that cirrus clouds with small ice particles ($r_{eff} < 10$ μm) exhibit a non-linear *S*-shaped cloud forcing in 800 - 1000 cm^{-1} that gradually disappears as the particle size is increased. This characteristic shape can be utilized to distinguish the large- and small-size particle cirrus clouds – for example effective radius greater or less than 10 μm. For this purpose, the shape may be constructed from the measurements in the infrared window region between 800 to 1000 cm^{-1}, and compared with 'known' (computed) shape, thus making a distinction. Three or four broad bands (spectral resolution around

10 - 20 cm^{-1}) provided by MODIIS can be used for a rough distinction between the large- and small-size particle cirrus as well as IWP estimates. The spectra in 1000 to 1300 cm^{-1} are not as important as their changes are mainly in magnitude with r_{eff} and IWP, but not so much in shape. Suitable applications may include detection and mapping of the global distribution of aircraft contrails as well as cirrus clouds. High spectral resolution sounders in polar orbit will be capable of characterizing both r_{eff} and IWP for ice clouds unambiguously.

A paper on this work has been conditionally accepted by the Journal of Applied Meteorology, pending appropriate revisions.

Cloud Mask Evolution

Cloud mask frequency bit mapping has been performed on several selected MAS flight tracks in order to compare the final cloud mask results with individual test results. The purpose of these comparisons is to assure that no one test is dominating a particular atmospheric or surface condition (that there is a balance of tests for different scenes) and to investigate if there are tests that can be eliminated from certain processing paths. An example of this bit mapping is shown in Figure 5 for a MAS SUCCESS mission flight track.

A comparison of the CLAVR (Clouds from AVHRR) and the MODIS AVHRR cloud masks has begun. Data was collected during a 10-day period in November and December, 1998 and will be processed by both algorithms at the UW. Comparison on one day (14 orbits) has been completed and preliminary results were presented at the MODIS Science Team Meeting in December, 1998. Table 1 summarizes some of these early results.

MAS Performance

MAS data from the FIRE-ACE field campaign (Alaska, May/June 1998) has been compared to well calibrated HIS data to assess MAS IR band performance. These comparisons have been made using data from several field campaigns in an effort to track MAS performance over its lifetime. As the MAS instrument is maintained and modified, the performance has been monitored to assure high quality calibrated radiances for the MAS user community. Flight data from two days (May 27 and June 3) were used to evaluate performance stability during the FIRE-ACE campaign. Spectral characterization used for MAS was provided by the ARC calibration facility. The radiometric comparisons (Figure 6) in the form of temperature biases demonstrate consistent performance for both flight days (the MAS-HIS temperature bias is about –1.4°C for band 45). This consistency demonstrates spectral as well as radiometric calibration stability over time. However, biases are unusually large for LWIR window bands (typically +/- 0.5°C; for FIRE-ACE the biases are close to –1.5°C). The cause of this bias is currently not well understood. Spectral calibration error is not considered to be an important contributor because of the spectral insensitivity of the LWIR window bands. In addition, shifting the entire Port 4 spectral position would not improve the overall bias in Port 4. Another consideration is blackbody effective emissivity error. MAS blackbodies are repeatedly subjected to dust, condensation, freezing, etc., which can cause degradation of the surface material on the blackbodies as well as introduce foreign particulates to the blackbody surface. A bias adjustment of 1.5°C would require a blackbody effective emissivity decrease of about 0.03 at 11um, an unexpectedly large change of emissivity; however, a smaller portion of the bias is likely attributable to blackbody effective emissivity error. Just prior to the FIRE-ACE deployment, MAS was outfitted with a Minco heating element designed to thermally stabilize the MAS spectrometer baseplate inflight. The heating unit may bleed heat towards the blackbodies located about 12 inches below. This may cause a thermal gradient on the MAS blackbodies, especially the ambient blackbody which operated some 25°C cooler than the Minco heating element. It is possible that this has played an important role in the performance change observed when comparing MAS FIRE-ACE biases to historical MAS biases. No direct measurement however is available to verify this line of thought. Future testing including mapping thermal gradients on the MAS blackbodies is being considered. Additionally, in November 1998 an insulating material was placed on the underside of the Minco heating element to reduce thermal bleeding towards the MAS blackbodies. The MAS blackbodies were also recoated in December 1998 to establish a smooth uniform surface on the flat plates. Subsequent to the recoating, a laboratory data set to evaluate MAS blackbody effective emissivity has been collected and is currently under evaluation. Through these concerted efforts, a physical explanation for the change in MAS performance during FIRE-ACE is being actively pursued and the performance characteristics of MAS are being re-established.

GOES Biomass Burning Program

The following work is being funded under separate NASA (NAG5-4751) and NOAA contracts. It has relevance to the MODIS biomass burning investigations.

During the 1998 fire season in South America, CIMSS provided GOES-8 ABBA (version 5.6) diurnal fire products to the Brazilian government and climate change community via the UW-Madison/CIMSS GOES Biomass Burning Monitoring Program web site at http://cimss.ssec.wisc.edu/goes/burn/abba.html. The GOES ABBA results for the 1998 fire season are being compared with 1995, 1996, and 1997 providing a 4-year analysis of burning in Brazil, Bolivia, Chile, Peru, Paraguay, Uruguay, and Northern Argentina. Initial analyses indicate that the peak fire year was 1995. The number of fires detected with the GOES-8 ABBA in 1996 was approximately 25% less than observed in 1995. The number of fires detected in 1997 was nearly 8% less than 1995. Although the beginning of the 1998 fire season showed increased burning due to the dry conditions in South America, the overall number of GOES-8 ABBA fire detections for the whole season was similar to 1997. Figure 7 shows monthly statistics for 1995, 1996 (preliminary), 1997, and 1998 (preliminary). The average number of fires detected per day at 1145, 1445, 1745, and 2045 UTC are presented for each month. The average number of daily unique fires are shown for each month in 1995, 1996, and 1997. The diurnal cycle is clearly evident in all years/months. The average daily unique fire count for each month indicates that roughly 70-80% of the fires observed at a given time period are not observed at the other times.

The GOES-8 Automated Smoke Aerosol Detection Algorithm (ASADA) has been merged with a textural technique. Applications of the merged experimental algorithm on the SCAR-B data set has shown improved smoke/cloud discrimination and the ability to determine scene cloud/smoke fraction. The algorithm is currently being used to investigate the influence of smoke extent and loading on cumulus cloud development in the Amazon Basin.

PAPERS

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MEETINGS

Dan LaPorte attended the MODIS MCST Review at Santa Barbara Remote Sensing on 29-30 July.

UW hosted a MAS instrument meeting in Madison, Wisconsin on 4-5 August.

Liam Gumley attended the HDF-EOS Workshop in Greenbelt Maryland on 22-23 September.

Liam Gumley attended the MODIS PI Processing Meeting at NASA GSFC on 24-25 September.

E. Prins attended the 1998 Wengen Workshop on global Change Research: Biomass Burning and its Inter-Relationship with the Climate System in Wengen, Switzerland on September 28 – October 2, 1998. She chaired a session on "Remote Sensing of Active Fires and Burnt Regions" and presented a paper titled "Using Geostationary Meteorological Satellites to Monitor Trends in Biomass Burning: A Four-Year Case Study in South America."

Paul Menzel, Steve Ackerman, Richard Frey, Liam Gumley and Chris Moeller attended the MODIS Atmosphere Group Retreat at St. Michael's, Maryland on 4-6 November.

Liam Gumley attended the MODIS PI Processing Meeting at NASA GSFC on 20 November.

Liam Gumley attended the EOS Direct Broadcast Meeting in Canberra, Australia on 4-6 December.

UW hosted a meeting to discuss cirrus cloud radiative properties at Madison, Wisconsin on 7 December.

Chris Moeller and Dan LaPorte attended the MODIS Calibration Meeting at GSFC on 14 December.

Paul Menzel, Steve Ackerman, Chris Moeller and Dan LaPorte attended the MODIS Science Team Meeting at the University of Maryland Conference Center in College Park, Maryland on 15-16 December.

MODIS/AVHRR Clear-sky Confidence

CLAVR	>99%	>95%	>66%	≤66%	Totals
Clear	9.6	1.8	1.2	2.8	15.4
Mixed	6.9	3.4	4.4	40.3	55.0
Overcast	0.9	0.3	0.6	27.8	29.6
Totals	17.4	5.5	6.2	70.9	100.0

Table 1. Comparison of cloud mask results between the MODIS/AHVRR cloud mask technique and the CLAVR technique for December 8, 1998. Fourteen orbits were used with data limited to +60 to –60 Latitude. Numbers represent percent of total comparisons.

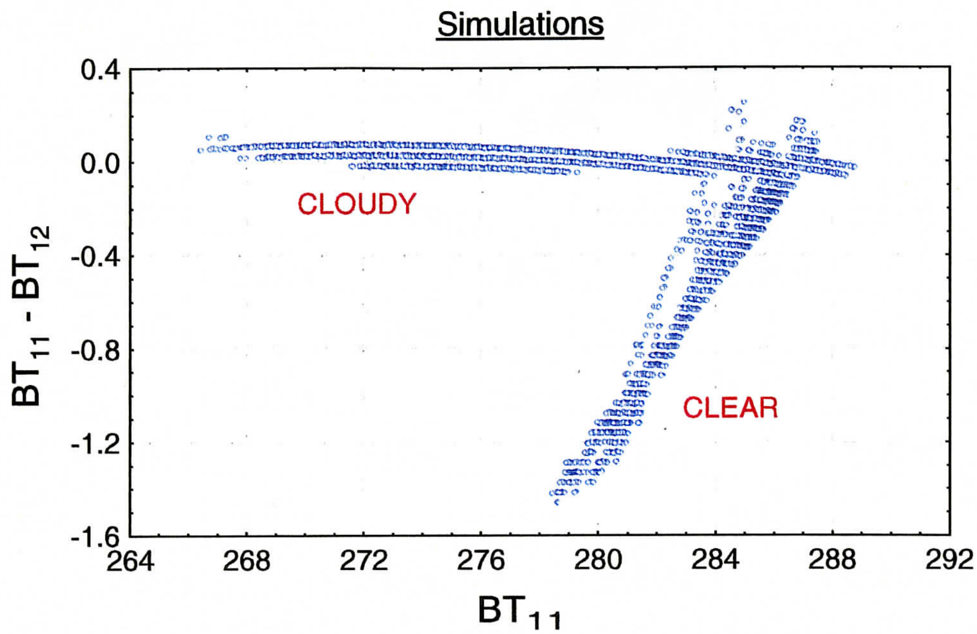


Figure 1. Scatter diagram of brightness temperatures from the MODIS synthetic data granule MOD021KM.A1997212.0225.002.1998294215547.hdf located over ocean. The cloud BT11-BT12 values are consistent with those seen in AVHRR/MAS data sets. However, the negative values of BT11-BT12 found for clear pixels are unrealistic, leading the cloud mask code to flag those scenes as cloud also.

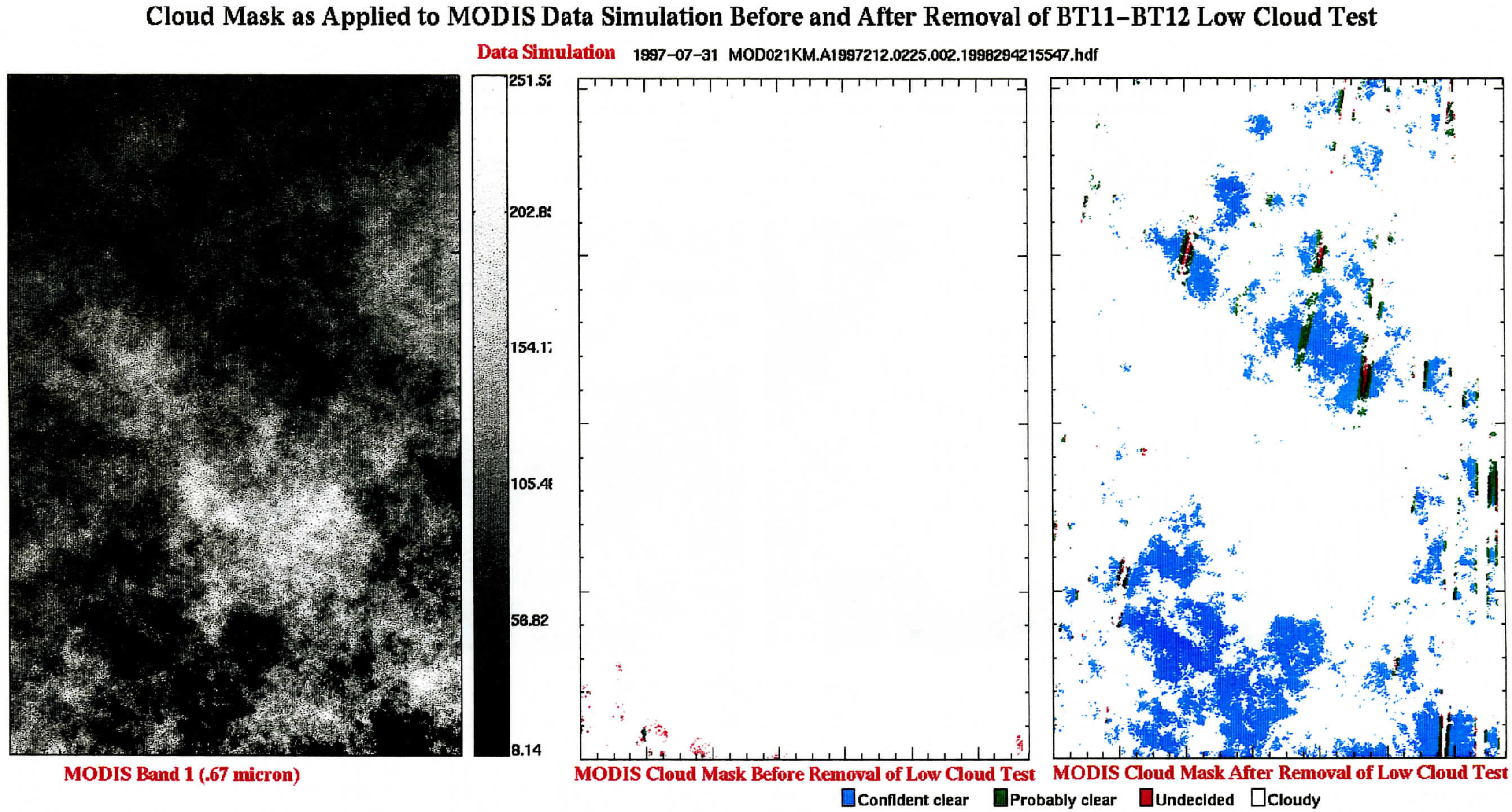


Figure 2. The cloud mask result for the MODIS synthetic data granule of Figure 1, before and after the removal of the BT11-BT12 low cloud test from the ocean processing path. Note the improvement in the cloud mask results when the BT11-BT12 low cloud test is removed. The streaks of lower confidence clear embedded within the confident clear region are due to simulated aerosols in the synthetic data set.

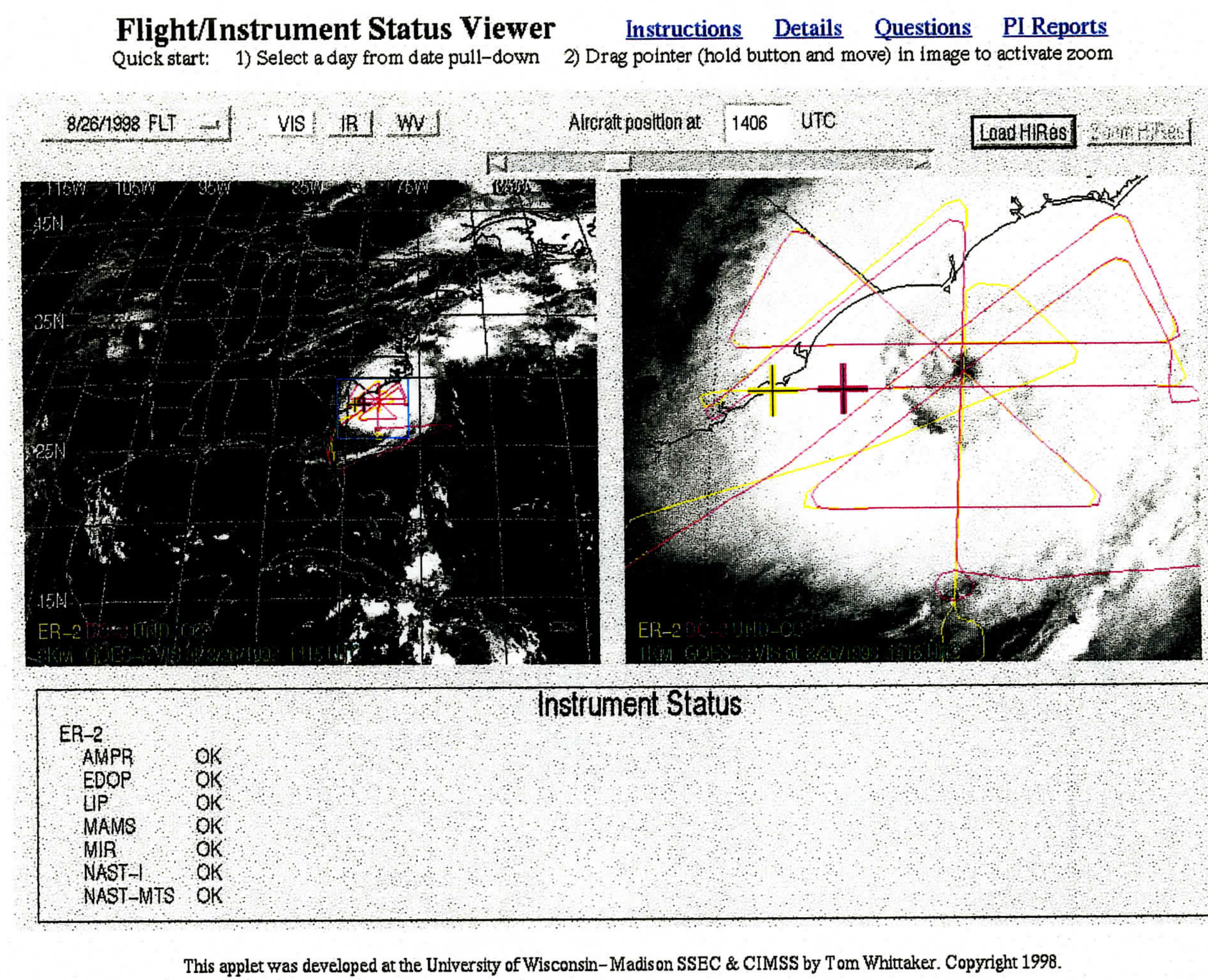


Figure 3. Web based viewer developed at the UW for CAMEX3.

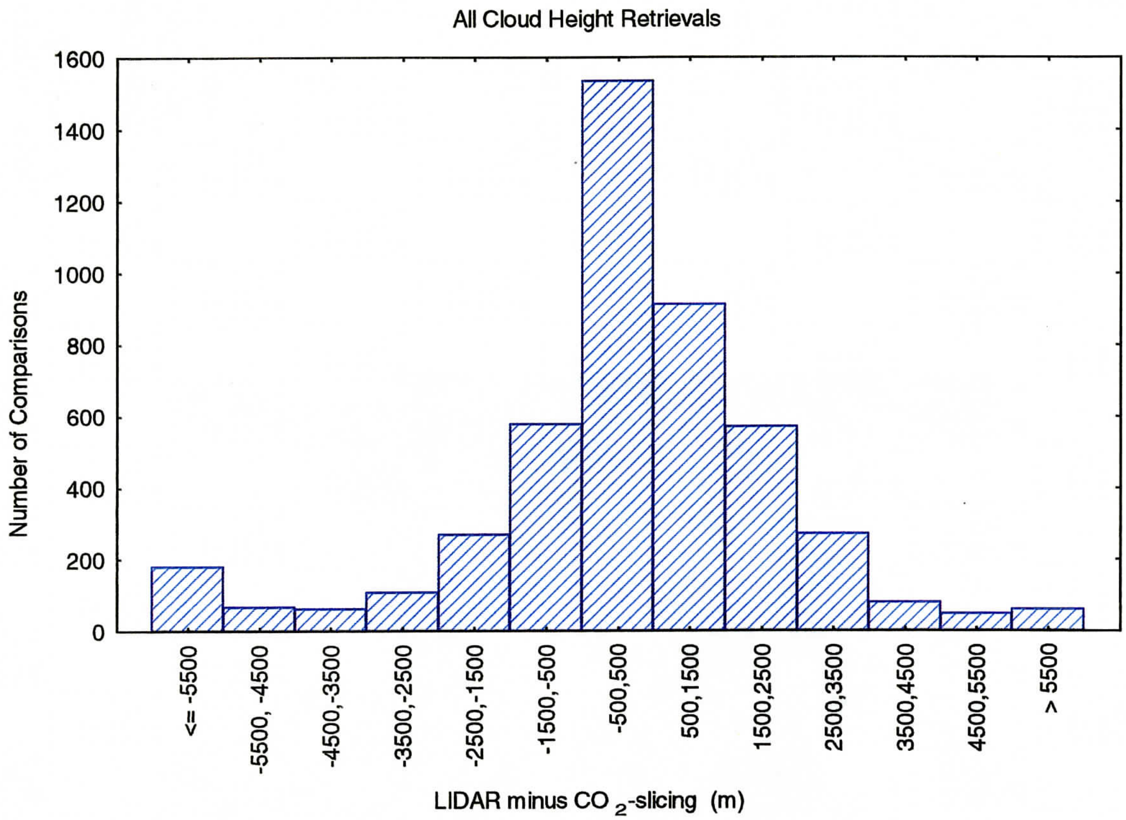
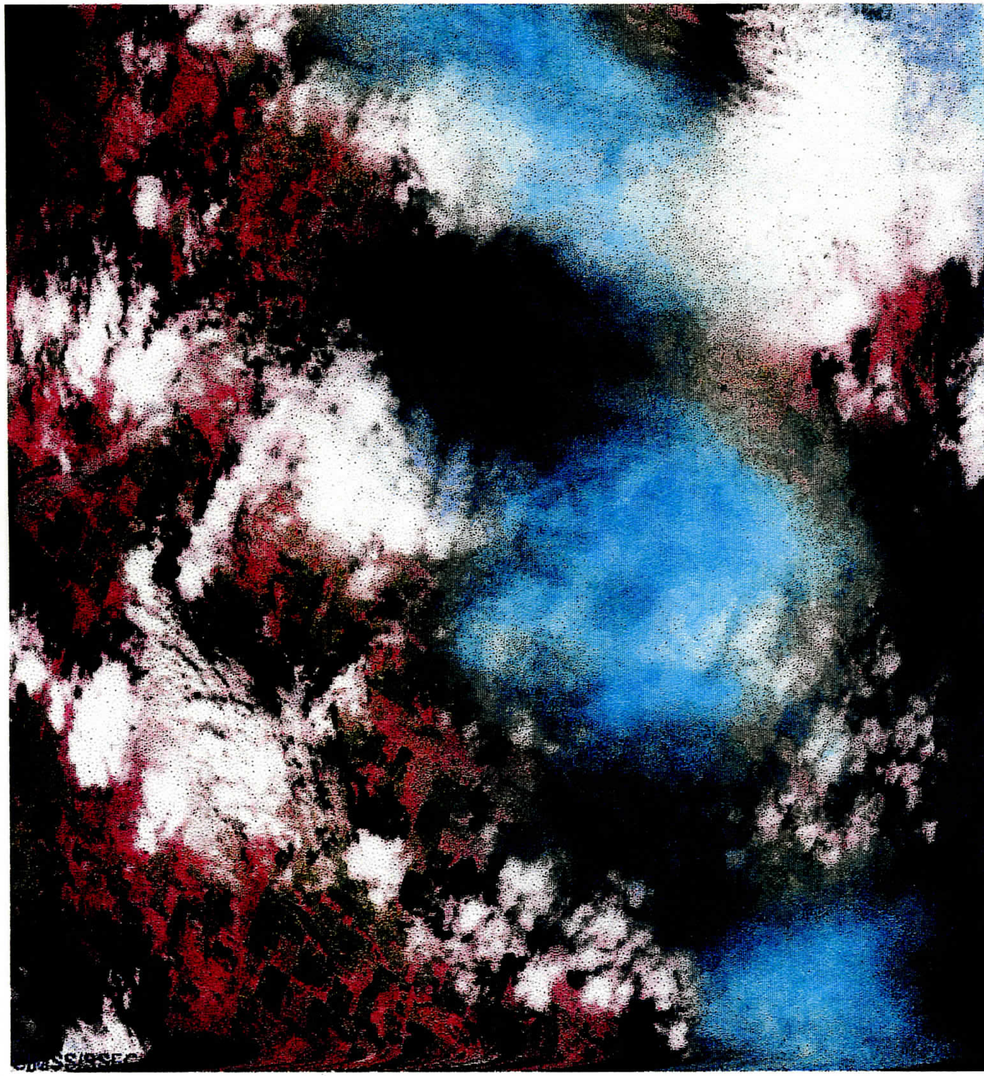


Figure 4. Histogram of differences for all comparisons between CLS lidar and CO_2-slicing cloud heights in meters.



Total Observations in
Entire Flight Leg: 2,465,554

Confident Clear:	27.96
Probably Clear:	2.59
Undecided:	6.94
Cloud:	62.50

Individual Bit Test Results

Test	% of Time Test Applied	% Cloud Found in Segment
BT11 Test:	0.88	0.39
CO2 Test:	100.00	0.00
H20 Test:	0.00	0.00
1.88 Test:	99.26	35.80
BT3.7-12 Test:	0.00	0.00
IR BTDIF Test:	99.94	38.32
BT3.7-11 Test:	100.00	55.95
Vis. Reflectance:	99.94	56.49
Vis. Ratio Test:	92.38	39.92
Near-IR Ratio:	0.00	0.00
Shortwave IR:	0.00	0.00
Temporal Test:	0.00	0.00
Spatial Var.:	3.58	1.23

Figure 5. Three color gun composite of a MAS SUCCESS sub-scene used to perform a bit frequency analysis. The frequency statistics shown on the right are taken from cloud mask results for the entire flight leg. The statistics for this predominately land scene show how each applied test detects cloud a different percentage of the time, indicating each is sensitive to different types of cloud.

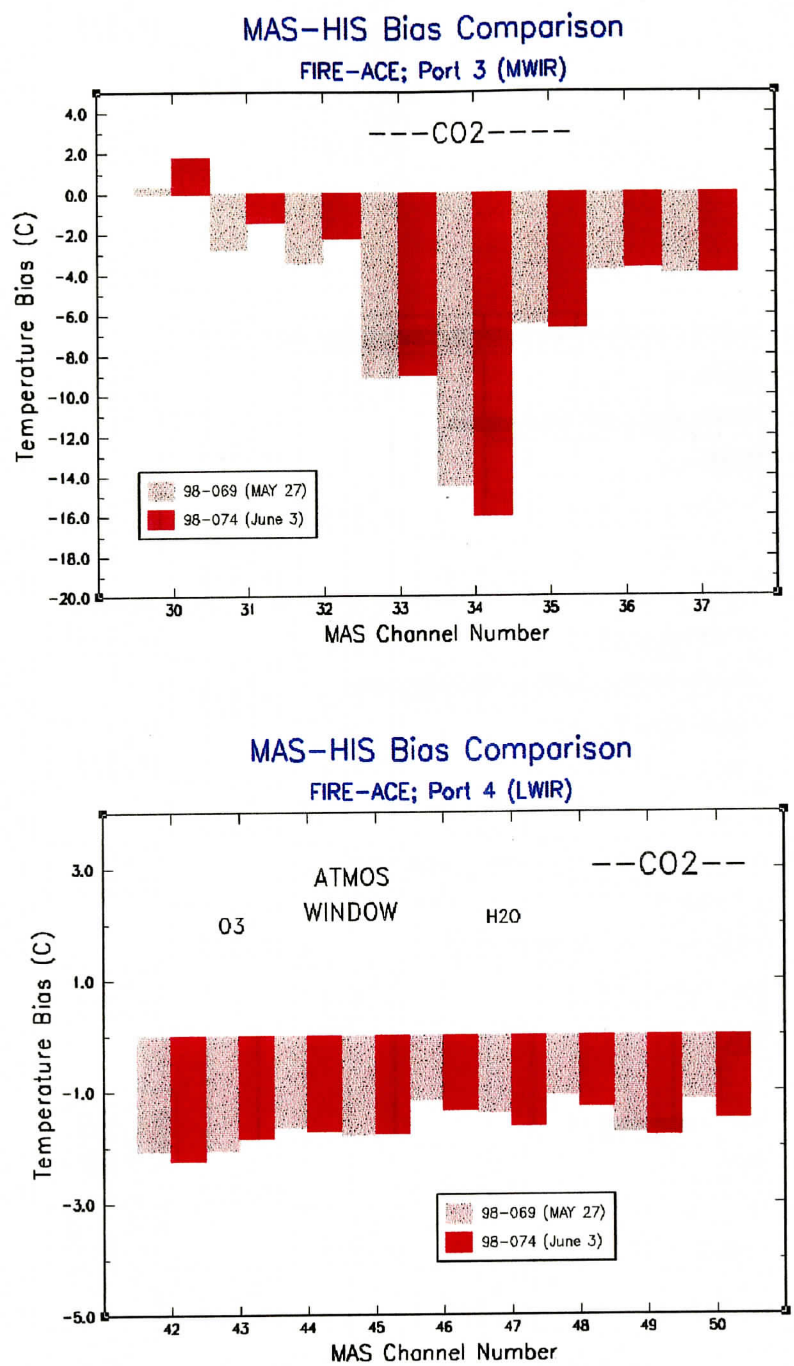


Figure 6. MAS-HIS biases computed using FIRE-ACE data for port 3 (3 – 5um) and port 4 (8 – 14um). Biases are consistent over the two dates shown within each port. Window band (e.g. band 45) biases are larger (> 1°C absolute) than historical levels (< 1°C absolute). This behavior may have been caused by the use of a heat source under the MAS baseplate which may have caused thermal gradients on the MAS blackbodies. There is no obvious indication of spectral calibration error from these comparisons.

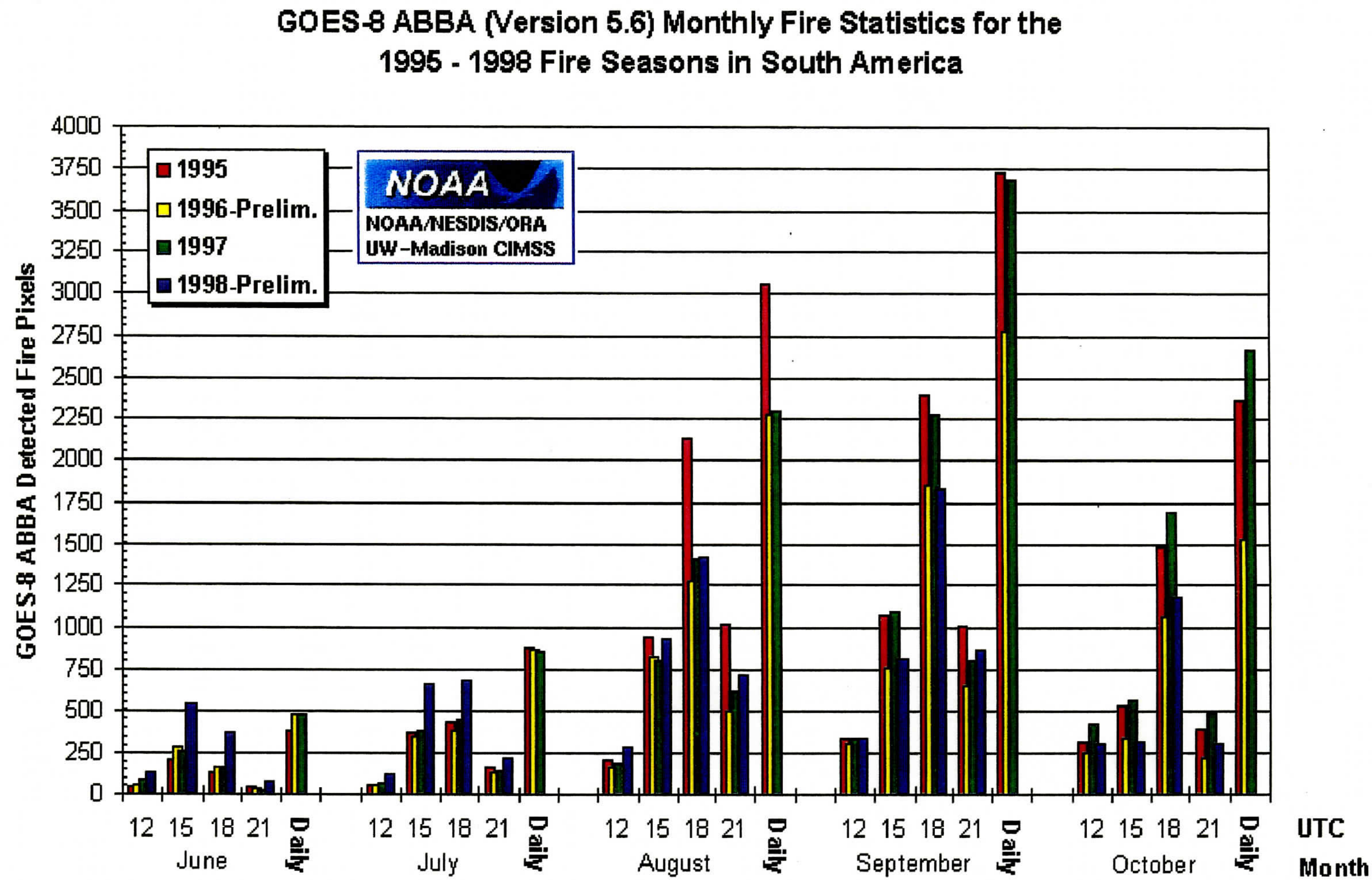


Figure 7. The diurnal GOES ABBA results for the 1995, 1996, 1997 and 1998 fire seasons providing a 4-year analysis of burning.