INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

QUARTERLY REPORT FOR JUL-SEP 1997

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ABSTRACT

The main effort this quarter has been directed toward the evolution of MODIS science production software, to be delivered in the fourth quarter 1997. Most of this work has focused on tasks peripheral to the actual science contained in the code. UW hosted an MODIS infrared calibration workshop in September. Considerable progress has been made by MCST, with help from UW, in refining the calibration algorithm, and in identifying and characterization outstanding problems. Work continues on characterizing the effects of non-blackbody earth surfaces on atmospheric profile retrievals and modeling radiative transfer through cirrus clouds.

MEMORIUM

The UW MODIS team was saddened by the passing of Elvira Mercado Strabala on August 28, 1997. Our thoughts and prayers are with Kathy Strabala and her family in this time of grief and remembering of a mother and wife.

TASK OBJECTIVES

Software Development

Five UW science production software packages (cloud mask, cloud top properties, cloud phase, atmospheric profiles, and ancillary data) are to be delivered in fourth quarter 1997. The science portion of the algorithms have all been written and tested using MAS, AVHRR, HIRS and/or GOES data. Work remains to meet the requirements necessary to run the software in the DAAC production environment. Visualization tools for both MAS and MODIS data and products are being developed for testing and validation purposes.

MODIS Infrared Calibration

UW hosted a meeting of twenty government scientists September 11 and 12 to discuss vacuum test results regarding the MODIS infrared calibration. The two day workshop concluded that the test data characterize the detector non-linearity and the cross-talk adequately so that the infrared calibration will be stable and within specification at launch. A final version of the infrared calibration algorithm will be achieved some months after MODIS launch in July 1998.

Algorithm Theoretical Basis Documents (ATBD's)

The UW ATBD's are being revised and a new version will be completed by the end of fourth quarter 1997.

WORK ACCOMPLISHED

MODIS Software Development

Preparation for fourth quarter delivery of UW science production software continues. Considerable time and energy has been expended in understanding and adhering to the toolkit requirements, coding standards, and metadata implementation. Since each of these are often changing, it has become a very frustrating process.

New routines for reading Level 1B data, geolocation data, and ancillary data have been written to accommodate changing data formats. Wrappers for metadata readers and writers, which were provided by the Science Data Support Team (SDST), have been written and tested. This include ECS Core, Inventory, and Archive metadata. Error handling, messaging and debugging strategies have all been designed and implemented in the Version 2 cloud mask software. All code has been designed to meet MODIS software standards and guidelines and tested using the ftnchk utility.

Walter Wolf continues to assist in the MODIS software development. Over the last quarter he has constructed a common utilities directory which contains all subroutines used by all of the UW production software packages. These include most of the I/O functions and error handling utilities. In addition, he created skeletons of the main routines to be used for each package. Finally, he has worked in collaboration with SDST personnel to develop software which will create an hdf file using the file specification as input.

Visualization Software

An upgraded version of a visualization program for MAS data was released on the World Wide Web at http://cimss.ssec.wisc.edu/~gumley/sharp/sharp.html. It's main purpose, is to aid in the development and testing of the UW MODIS production software packages. The program, developed by Liam Gumley and called SHARP, is a freely available IDL-based viewer for MAS image data that offers a point-and-click interface with the following features:

Selection of any scene (716x716 pixels) in a MAS HDF file,
View any band for a scene (with title and color scale),
Automatic scaling to reflectance or brightness temperature,
Continuous display of data value under cursor,
Image creation via user defined band,

Enhance/stretch image with B&W or color lookup tables,
Scaling of image data into a specified range,
Interactive scatter plots with,
    User selected image regions (rectangle, circle, polygon),
    User selected X and Y axis band formulas,
    User selected X and Y axis limits,
    User selected regions (up to 10 regions with 10 different colors),
RGB image display,
Overlay of cloud mask results,
Overlay of HIS IFOV locations,
Projection onto a map base,
Immediate output to GIF or Postscript.

Figure 1 shows the SHARP display of a MAS image with a cloud mask overlay. This program was demonstrated at the HDF-EOS Developers Meeting, NASA/GSFC, September 8-10. It is expected to play an important role in validation and dissemination of the MAS cloud mask.

Web Based MODIS Visualization Tool

The UW MODIS team has worked in collaboration with UW McIDAS staff to develop visualization tools for MODIS. An initial version enables a modest subset of the McIDAS capabilities to view and investigate MODIS simulated data sets. UW assisted in the definition of the basic functions which would be needed by the MODIS science team. These include visualization of calibrated data, navigation (including maps), data fusion (overlays), and remapping to other satellite projections. These capabilities will be accessible through the web. This effort was funded as part of SDST resources to be used by the entire Science Team.

UW MODIS SCF

Planning for the at-launch UW MODIS Science Computer Facility (SCF) hardware began in earnest. The decision was made to stay with SGI hardware for compatibility with current systems and for compatibility with GSFC. Plans are to purchase an SGI Origin 2000 system with at least 4 processors and a fast disk array with at least 200GB capacity. This hardware will be ordered in October/November 1997 and should arrive in late December 1997. At present it is assumed that our MODIS networking needs will be met by the NSF vBNS upgrade on the UW campus. By the time of MODIS launch there should be a good understanding of whether or not vBNS is capable of fulfilling our MODIS networking needs.

MODIS Infrared Calibration

UW hosted a meeting of twenty government scientists September 11 and 12 to discuss vacuum test results regarding the MODIS infrared calibration. The two day workshop concluded that the test data characterize the detector non-linearity and the cross-talk adequately so that the infrared calibration will be stable and within specification at launch. However, much work remains to correct for the infrared cross-talk of the window channel in to the carbon dioxide sensitive channels (more on this later in this report). It is expected that the inflight spacecraft roll to space will help to detail the scan mirror emissivity as a function of angle of incident radiation; this is necessary to determine the calibration blackbody emissivity. A final version of the infrared calibration algorithm will be achieved some months after MODIS launch in July 1998.

The MCST analysis was reviewed to determine the appropriate range of scene temperatures to be used in the calibration least squares fit; quadratic versus cubic fits were also studied. UW recommended that MCST extend the fitting range to include colder scene temperatures for bands 20-23, 29, 31 and 32. This will improve calibration of cold cloud scenes (temperatures less than 240K). UW also recommended that MCST apply a cubic fit to bands 20-23 in order to improve the fit at cold scene temperatures. However, care must be taken so that the accuracy of the calibration between 0.3 Ltyp and 0.9 Lmax is not be compromised.

<u>MAS Calibration</u>

Monochromator measurements of the MAS IR spectral response functions (SRF) from February 1997 have been atmospherically and spectrally corrected for application to the MAS WINCE data set. Spectral corrections (+1.5nm for Port 3 and +7nm for Port 4) were found to be similar to previous MAS monochromator SRF measurements (within about 1% of MAS channel bandpass); this indicates consistent performance by the monochromator measuring system in the Ames Research Center (ARC) calibration facility. Comparison of February 1997 SRF to June 1996 SRF indicate that Port 3 has shifted about 25nm to shorter wavelengths (15% of typical Port 3 channel bandpass) and Port 4 has shifted about 20nm to shorter wavelengths (5% of typical Port 4 channel bandpass). The corrected SRF for Feb 97 have been provided to ARC for inclusion in final MAS calibration of the WINCE data set. ARC will process MAS Ports 1 and 2 SRF to complete calibration of those ports. SRF atmospheric and spectral correction software as well as forward model transmittance files have been transferred from UW to ARC to facilitate the SRF analysis. A MAS fast transmittance model has also been generated at UW using the Feb 97 SRF; this model is applicable to MAS WINCE data set investigations.

The MAS SUCCESS data set has been calibrated and processed into Level-1B radiances at the GSFC DAAC for distribution. A comparison of MAS radiances produced at UW and at the GSFC DAAC revealed no differences.

MAS data products in the SUCCESS Data Archive are being updated to reflect the improved MAS calibration. Nadir brightness temperatures are being recomputed and quicklook images are being reproduced to match the MAS SUCCESS data available from the GSFC DAAC. All updates will be submitted by mid October for inclusion in a SUCCESS archive CD ROM to be available for distribution later this year.

MAS Participation in CAMEX3

Possible MAS participation in the CAMEX3 field program (to be held in Aug/Sep 1998 from Patrick AFB, FL) has been discussed with NASA organizers. Substituting MAS for MAMS on the ER-2 for one to two weeks near the end of the experiment is being considered. CAMEX3 presents opportunities to monitor clouds (microphysics, heights, detection) in tropical systems with co-incident DC-8 in situ data collection. It also represents the first opportunity for MAS to underfly MODIS in the post-launch A&E phase (clear scenes). The ER-2 will be equipped with a dropsonde capability for characterizing the atmosphere below the aircraft. MAS will contribute quicklook imagery and nadir brightness temperatures for selected bands as well as derived cloud products from case studies of interest to the CAMEX3 archive. A decision on MAS participation is expected by the end of the calendar year.

AVHRR Cloud Mask Validation Activities

In anticipation of future MODIS cloud mask verification efforts, a prototype methodology has been developed using the AVHRR cloud mask product. Three complete Global Area Coverage (GAC) orbits are processed every day, using the previous day's level 1b data as input. Daytime coverage includes the Amazon Basin, Eastern North America, the Saudi Arabian Peninsula and Western Europe.

Hourly surface observations from ten selected sites in North America (manned weather stations) closest in time to the satellite measurements are collected and compared to the cloud mask output. One method compares surface reports to the cloud mask confidences of clear sky for the GAC pixels nearest the station locations. A second method compares the surface reports with cloud mask results from a collection of pixels located within 100 km of the stations. Currently, only results from daytime data are compared, but expansion to nighttime hours and also to other regions of the world is planned for the near future.

Figure 2 shows a frequency scatterplot of the single-pixel comparisons for the month of August, 1997. Weather station reported cloud coverage is plotted on the x-axis and clear sky confidences on the y-axis. The larger circles indicate a higher frequency of occurrence than the smaller ones. One can see that the cloud mask is generally doing a satisfactory job, particularly when clear skies are reported. This is a result of the conservative nature of the cloud mask, where only very high confidence pixels are designated as "clear". Frequencies of confidences associated with the "few", "scattered", "broken", and "overcast" categories change as expected, with the likelihood of having clouds directly overhead increases with increasing cloud cover. Sky coverage for these categories is 1-2/8, 3-4/8, 5-7/8, and 8/8, respectively. A similar plot may be constructed showing the results of the second method, where the "percent of nearby pixels with confidence > 99%"

replaces the "confidence of clear sky" on the y-axis. This plot (not shown) for the month of August 1997 displays a very similar distribution of frequencies.

Effects of Infrared Surface Emissivity

Visiting scientist Dr. Youri Plokhenko continues his investigation of MAS temperature/moisture retrieval sensitivity to surface emissivity. The approach of the study is to use a physical retrieval algorithm to determine atmospheric temperature/moisture and surface emissivity. Surface emissivity patterns determined for the SUCCESS data set have been correlated with NDVI patterns estimated with the MAS data; good correlations are found. This study has been expanded beyond the springtime SUCCESS data set over Oklahoma to include a wintertime WINCE data set over Lake Michigan. Results of that work are expected in the next quarter.

Radiative Transfer Through Cirrus Clouds

Dr. Sunggi Chung has been calculating the cloud forcing expected from various cirrus cloud formations. Using line by line code (LBLRTM) in combination with a discrete ordinate model (DISORT), ice particles of various sizes, water paths, and heights have been inserted into a clear sky atmosphere to investigate the spectral characteristics of the cloud forcing. Figure 3a shows the spectral cloud forcing from a 0.8 km layer of small ice particles (radius of 5 microns); Figure 3b shows the same for larger ice particles (radius of 12.5 microns). The linear versus nonlinear behavior of the cloud forcing in the infrared window between 750 and 1000 wavenumbers is being studied further.

DATA ANALYSIS

MODIS Infrared Calibration

(1) Optical crosstalk from MODIS band 31 into PC bands 32-36 is under investigation. Of interest are the spatial position of the crosstalk, the spectral characteristic of the "leaked" radiance, and the amplitude of the leaked radiance (with respect to band 31 radiance). The goal is to identify a correction algorithm that removes the out of band radiance from MODIS level 1B radiances.

Significant understanding of the spatial and spectral component and the direction of the crosstalk has been gained through the use of IAC data sets; across track or scan direction crosstalk (e.g. channel 5 of band 31 leaking into channel 5 of bands 32-36) is found to be one-way only, originating as a reflection at a position near the edge of the band 31 focal plane. This position is identified as the origin of crosstalk for all affected PC bands. The leaked radiance passes through the band 31 filter before being reflected to the other PC bands. It is difficult to uniquely identify along track crosstalk (e.g. channel 3 band 31 talking to channel 5 bands 32-36) in the IAC data sets. Some evidence that along track crosstalk exists has been found, however this is not conclusive; analysis is still under way to separate the test equipment and instrument contributions. Characterizing the spatial component of the scan direction crosstalk is difficult because the out of band radiance originates from parts of two adjacent band 31 fields of view. Methods to address this in a crosstalk correction algorithm are under review. For a single field of view correction, an average of adjacent band 31 pixels is under consideration. A multiple field of view correction approach is also under consideration; this approach would correct the crosstalk into PC bands over NxN (TBD, 5x5 being considered) fields of view, reducing the sensitivity of the correction to the spatial characteristic.

A radiative transfer based investigation to assess the amplitude of the crosstalk into each PC band is underway. Radiometric data sets (RC-02) collected in T/V are being used. In this investigation, crosstalk is accounted for during the view of each source (SVS, OBC, BCS) and the crosstalk amplitude is formulated as a function of the band 31 inband radiance only. This approach does not depend on the scene radiance of the affected band. A simple linear model is applied:

$$R'_{i,j} = R_{i,j} + R_{31,j} * xtalk_{31,j \rightarrow i,j} * \left(\frac{resp_{i,j}}{resp_{31,j}} \right) \quad (1)$$

where $R'_{i,j}$ is a target's digital count calibrated to a radiance for band i, channel j
$R_{i,j}$ is the measured radiance of a target for band i, channel j
$R_{31,j}$ is the measured radiance of a target for band 31, channel j
$xtalk_{31,j \rightarrow i,j}$ is the crosstalk amplitude from band 31, channel j into band i, channel j
$resp_{i,j}$ are the responsivities (R/dn) of bands i, channel j.

For the analysis, all crosstalk is assumed to be uni-directional across-track only (i.e. channel 5 of band 31 talks to channel 5 of bands 32-36 only); no along track crosstalk is allowed (e.g. channel 3 of band 31 talking to channel 5 of bands 32-36). Because of this assumption, some level of uncertainty exists in the use of the analyzed crosstalk amplitudes in a correction procedure. Adjustments of the BCS, OBC, and SVS radiance for emissivity (based on SBRS/MCST analysis) and scan mirror reflectance (based on Lincoln Lab witness samples) were applied. The UAID1595-1617 series (nominal instrument temperature) and UAID1315-1337 series (cold plateau) data sets have been tested to date. The radiative transfer of the UAID1595 series is more accommodating for the analysis because the OBC, scan mirror and scan cavity are all at ambient temperature, minimizing error due to OBC emissivity and scan mirror reflectance uncertainty in the crosstalk determination. Preliminary results of the analysis using the UAID1595 series (Figure 4) agree with expectations of crosstalk amplitude for bands 32-36. This data shows that band 35 is most affected, with bands 36, 34, 33 and 32 (near 0) showing progressively smaller leaks. However the actual estimates of crosstalk amplitude show sensitivity to small adjustments in the treatment of the RTE. The most reliable assessments of crosstalk amplitude are attained when BCS temperatures are high (> 300K in Figure 4). Radiance crosstalk amounts will be large at warm BCS temperatures, thus making it easier to distinguish from background noise. It is important in the analysis that the crosstalk amplitude be independent of scene temperature (horizontal line for each band in Figure 4). This characteristic is best exhibited by the lower plot in Figure 4. However, to achieve this, an adjustment which assumed that the SVS view contributes zero radiance to the RTE had to be made. This is questionable because of an expected scan mirror emission contribution at the aperture when viewing the SVS. The crosstalk amplitude will continue to be analyzed. It is noteworthy that the more complex radiative transfer of UAID1315 series (cold plateau) does not yield crosstalk amplitude results agreeable with those of UAID1595. Further investigation is required. A near term goal is that the form of a correction algorithm be identified for use by MCST in the Level 1B calibration software. The UAID1595 series results indicate that a simplified linear approach may be suitable.

(2) The wavelength correction of MODIS IR band RSR data has been discussed with and implemented by MCST. An analysis of central wavelength (CWL) as a function of position on the focal plane indicates a characteristic parabolic shape to the adjustment. Some selective editing to remove out of family CWL (especially at each end of the focal plane, i.e. channels 1 and 10) was applied to improve the fit of the model to the data. The average CWL from the parabolic curve will be used to define the wavelength correction for each channel. This procedure will be applied uniformly to all MODIS IR bands. Corrections were typically in the 0 to 10 nm range. The largest corrections (up to 10nm to shorter wavelengths in the LWIR) were made to channels 1 and 10, which reside at each end of the focal plane; channels in the middle of the focal plane (4-7) were corrected typically by 5nm or less to longer wavelengths while channels going towards the end of the focal plane (2,3,8,9) had the smallest corrections. On average, the wavelength corrections in the MWIR were 25 to 50% of those made in the LWIR. A few bands were considerably "out of family" with the parabolic model, most notably band 31. In this case, the parabolic model was applied to a highly subsampled group of CWL. The wavelength corrections translate to calibrated temperature adjustments of ~0.05K (window bands) to ~0.25K (atmospheric bands).

<u>CO_2-Slicing Cloud Height Algorithm Development</u>

The effort to apply the CO_2-slicing cloud height algorithm to MAS data is continuing. Important details concerning the implementation of the algorithm in the MODIS processing environment will be made based on the results of tests conducted with MAS input data. Questions remain relating to channel combination selection, spatial scale of retrievals (number of pixels from which to gather radiance data), surface temperature variations, and emissivity differences between channels, among others.

Figure 5 shows imagery based on data taken from an ER-2 flight segment on April 26, 1996 during the SUCCESS field experiment. The left-most image is of 11 micron brightness temperatures (MAS band 45), while the other two depict cloud height retrievals using the CO_2-slicing method. The IR image shows an area of relatively thick (but still transmissive) cirrus surrounded by somewhat thinner cloud; some of it extremely thin. The rest of the scene is clear. The center image shows the results of the cloud height algorithm where clear-sky radiances have been calculated from nearby temperature and moisture profile measurements. The image on the right is the same except the "clear-sky" radiances are based on a sample of the ten warmest values from within a ten by ten pixel area. In both methods, cloudy radiances are based on a sample of the ten coldest values from the original 100. The magenta color corresponds to cloud heights of 100 mb, blue is 100-200 mb, and yellow is 200-300 mb with other colors representing still lower heights.

There are problems associated with both methods. The calculated clear radiance result is much more consistent over the region, but the cloud height retrievals over the thinnest clouds are too high (100 mb) according to lidar data which indicated clouds near 200 mb. Also, heights increase with distance from the thicker parts of the cloud, counter to most observations of cirrus clouds, and also not consistent with previous experience. On the other hand, the result shown on the right (gradient method) is very noisy, with many cloud height retrievals too low. However, both methods are more accurate than the simple "window" cloud height (not shown) where heights are too low everywhere in the image, except for the very thickest parts of the cloud.

PAPERS

Moeller, C. C., D. D. LaPorte, K. I. Strabala, P. Hajek, and W. P. Menzel, Spectral characterization of MODIS Airborne Simulator (MAS) LWIR bands and application to MODIS science data cloud products. Earth Observing Systems II Conference, July 28-29, 1997, SPIE, pp 235-243.

King, M., S-C Tsay and S. A Ackerman, 1997: MODIS Airborne Simulator: Radiative properties of smoke and clouds during ARMCAS and SCAR-B, Third International Airborne Remote Sensing Conference and Exhibition, 7-10 July, Copenhagen, Denmark.

Strabala, K. I., S. A. Ackerman, C. C. Moeller, L. E. Gumley, R. A. Frey, J. Y. Li and W. P. Menzel, 1996: Cloud Properties Determined from MODIS Airborne Simulator (MAS) SUCCESS Observations. Poster presented at the ERIM Third International Airborne Remote Sensing Conference and Exhibition held in Copenhagen, Denmark July 7-10, 1997.

MEETINGS

Kathy Strabala attended the ERIM Third International Airborne Remote Sensing Conference and Exhibition held in Copenhagen, Denmark July 7-10, 1997.

Chris Moeller presented a paper on MAS spectral calibration stability at the Second EOS conference of the SPIE 97 annual meeting on July 28-29, 1997.

Paul Menzel, Chris Moeller, Dan LaPorte and Steve Ackerman attended the MODIS IR Calibration Workshop held in Madison, WI, on 11-12 Sept.

Liam Gumley attended the HDF-EOS Developers Meeting, NASA/GSFC, September 8-10.

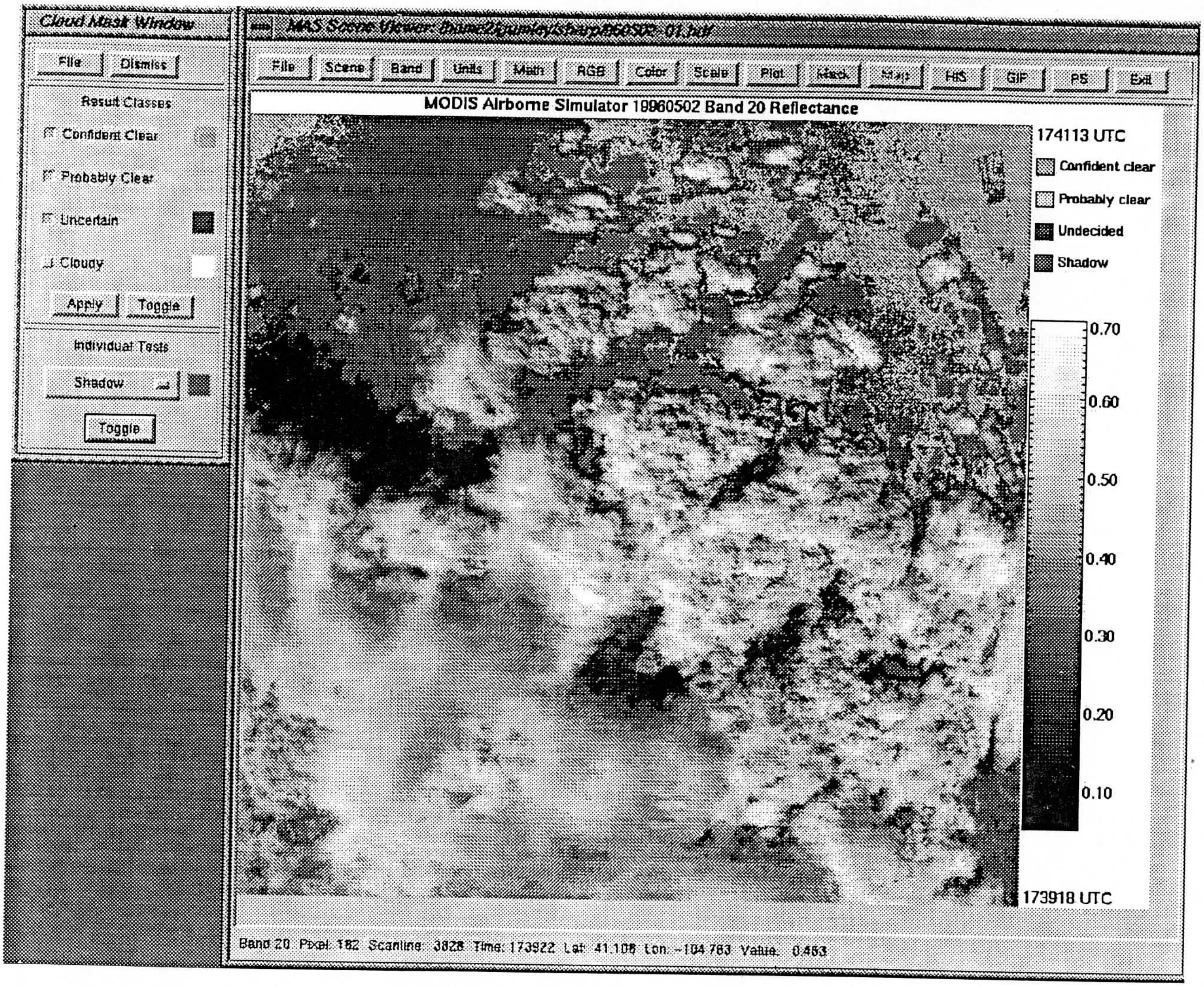


Figure 1. Screenshot from SHARP showing Cloud Mask Overlay.

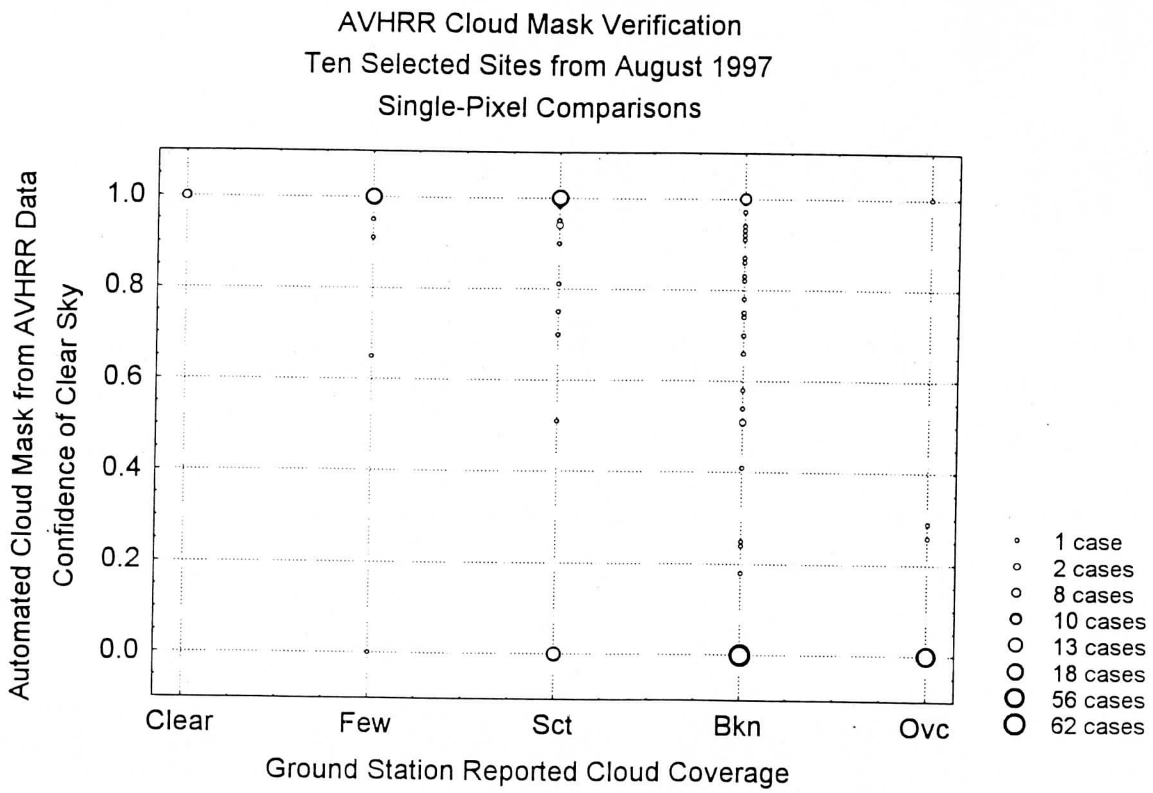


Figure 2. Results of comparison of automated AVHRR LAC cloud mask with ground station observations. Most points occur along the diagonal, which indicates agreement.

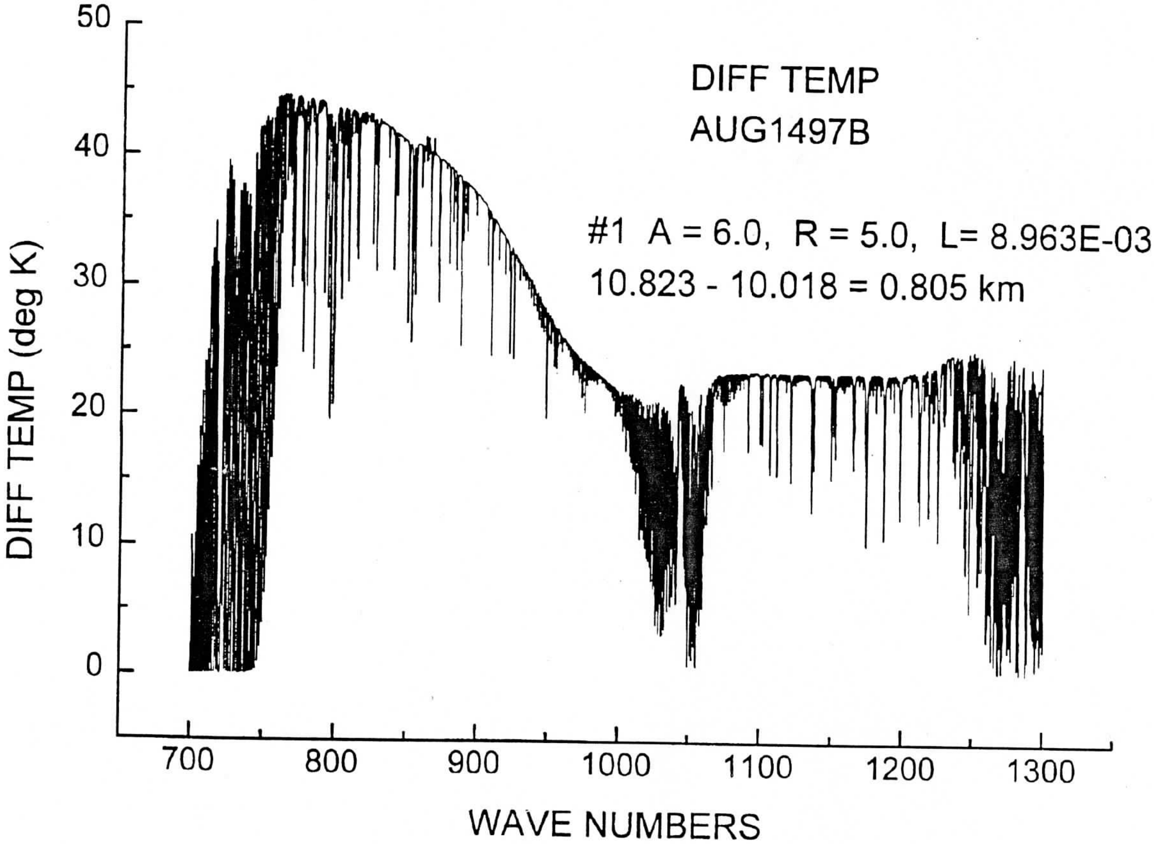


Figure 3a. Spectral Cloud forcing from a 10 km high 0.8 km thick layer of 5 micron ice particles.

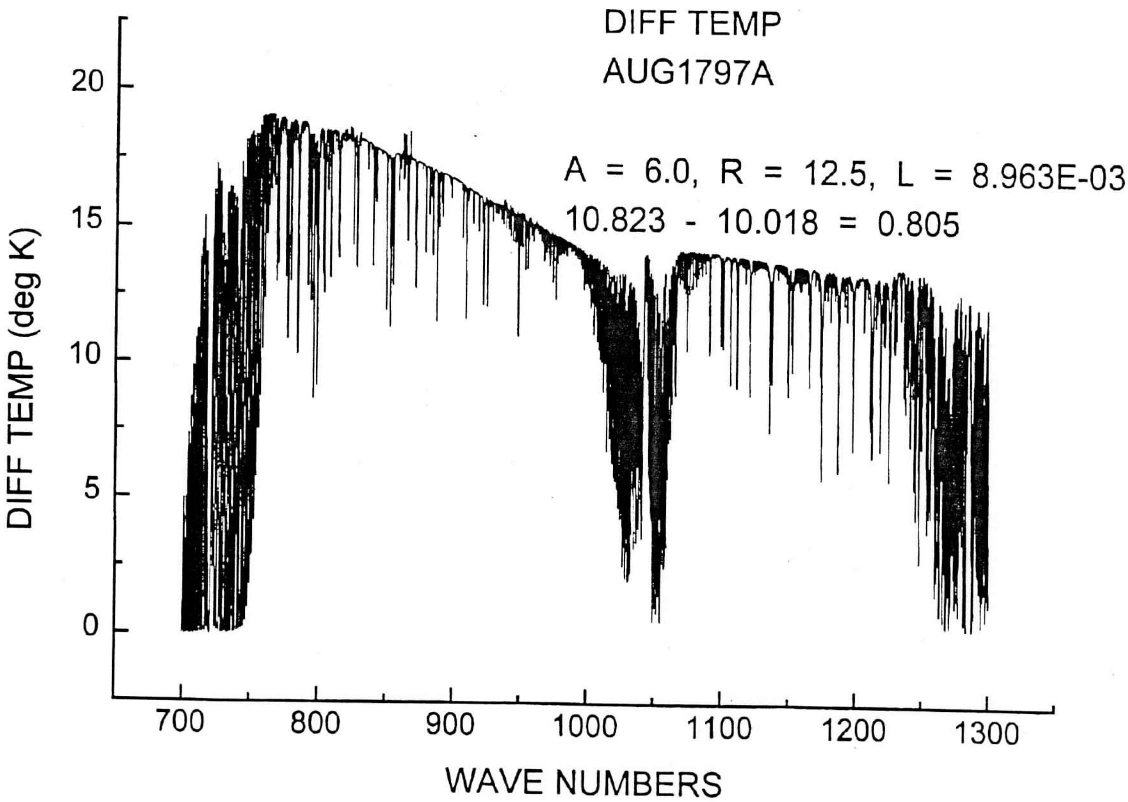


Figure 3b. Spectral Cloud forcing from a 10 km high 0.8 km thick layer of 12. 5 micron ice particles.

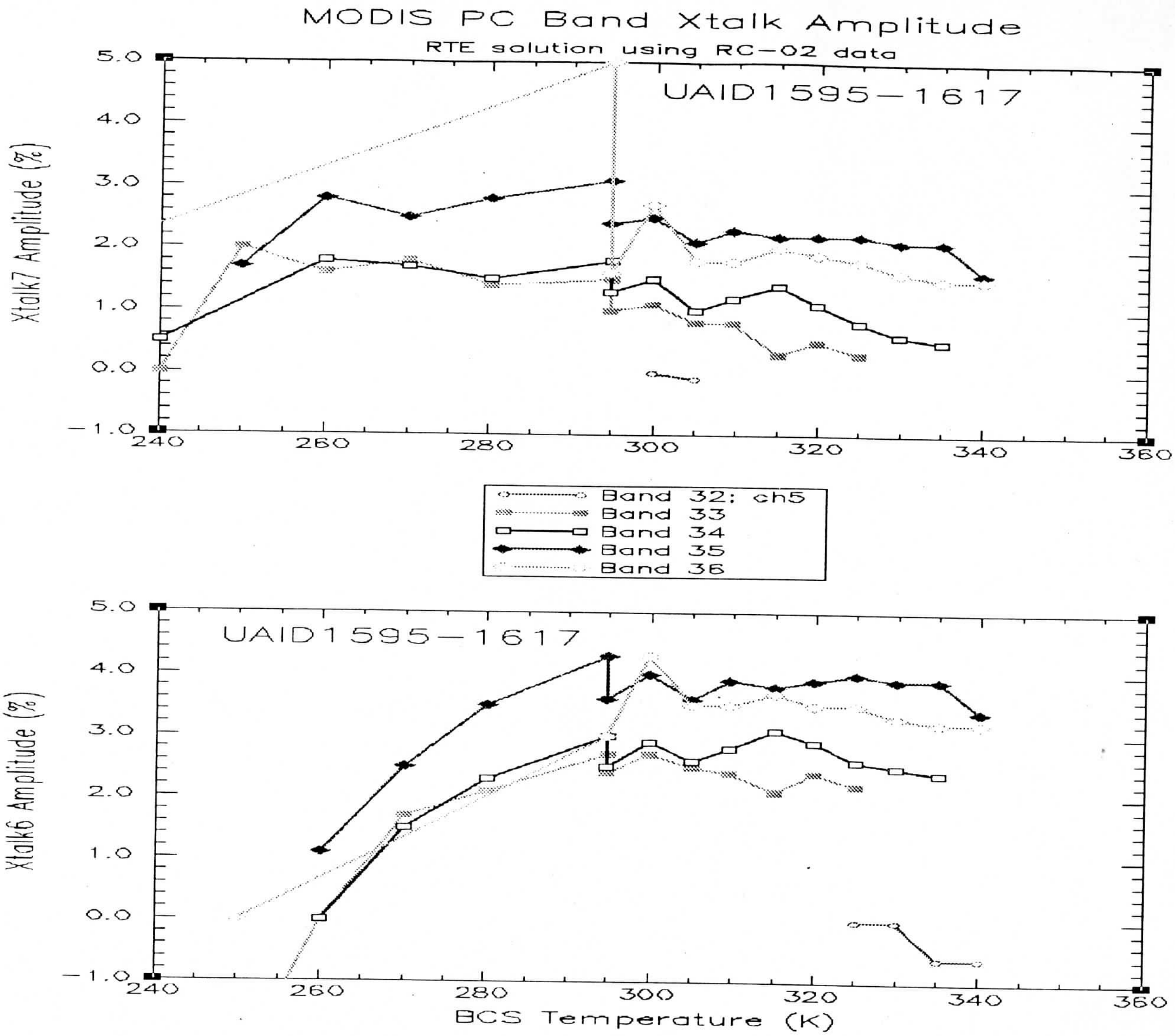
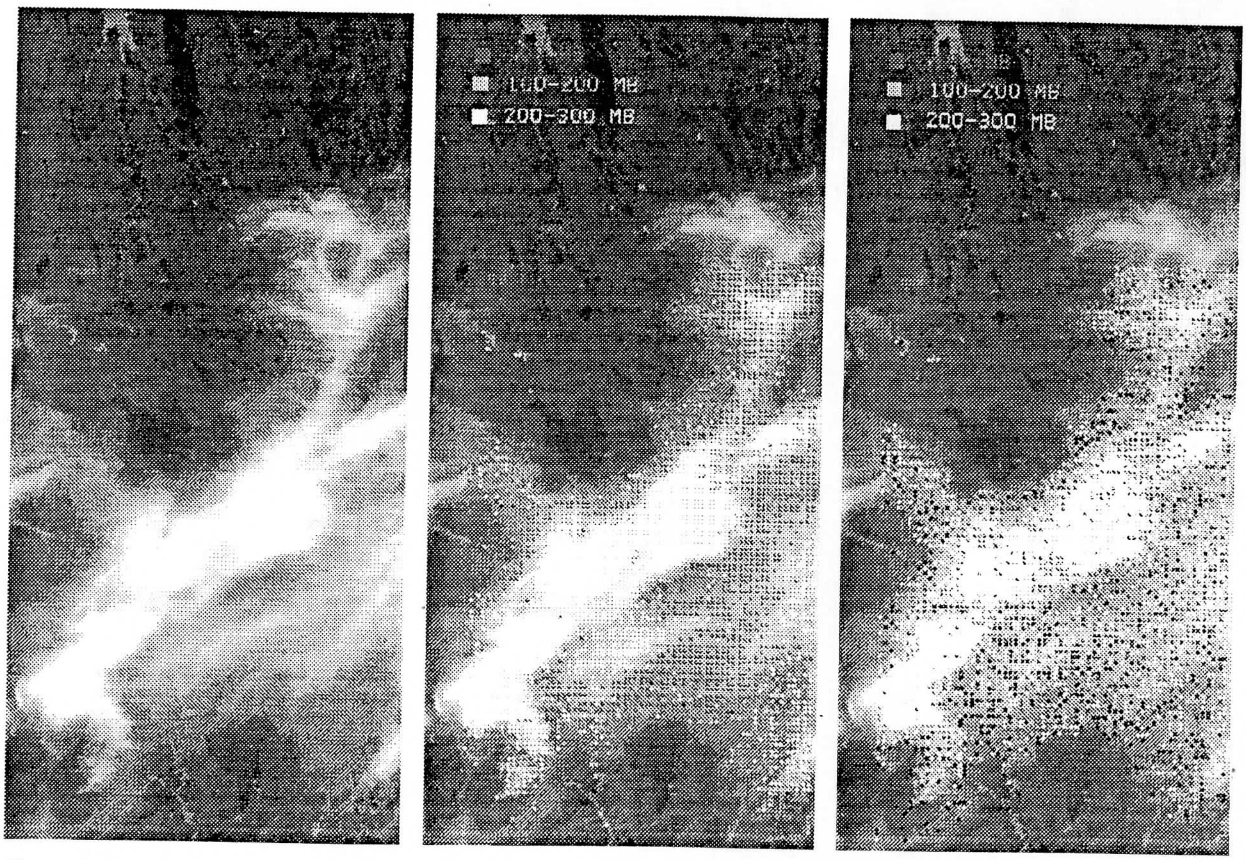


Figure 4. Crosstalk amplitude analysis for MODIS PC bands using UAID1595-1617 (nominal instrument temperature). Results are most meaningful for high BCS temperatures (>300 K). Analyses with (upper) and without SVS contribution (lower) demonstrate sensitivity of analysis to small adjustments in the physics of the crosstalk amplitude retrieval. Results that show crosstalk amplitude is independent of scene temperature (i.e. horizontal trace with BCS temperature) are desired; results show this is best attained when ignoring SVS contribution.



From left to right: MAS band 45, cloud heights using calculated clear radiances, and cloud heights using the gradient method

Figure 5. Results of two versions of the CO2 slicing cloud top height technique applied to a thin cirrus scene from the 26 April 1996 SUCCESS field experiment data set.