INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC STABILITY WITH MODIS

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TASK OBJECTIVES

Preparation for Additional Software Delivery. Transfer of the "Cloud Phase" algorithm has been completed now that the related subroutines from the UNIX version of McIDAS (also called the UW toolkit) have been integrated into the TLCF. The additional cloud algorithms outlined in the ATBD on "Cloud Properties" will be prepared with benchmark data sets (from HIRS and MAS) and delivered to SDST third quarter of 1994. The "Atmospheric Profiles" algorithms will be sent somewhat later.

Revised Cloud Mask ATBD. Based on the peer review of May 1994 and continuing MAS, AVHRR, HIRS, and GOES cloud investigations, the MODIS Cloud Mask ATBD (version 1) will be revised. Infrared threshold and spatial coherence tests are still being tested. The revised ATBD on cloud masking will be redrafted with help from Steve Ackerman, Kathy Strabala, Chris Moeller, Bryan Baum, and Ron Welch. Additional collaboration with the MODLAND group will begin in September.

Algorithm Definition. Processing and testing of the cloud parameter algorithms (mask, temperature, phase, height, and amount) will continue using the MAS (MODIS Airborne Simulator) data gathered during the FIRE (First ISCCP Regional Experiment) in Nov - Dec 1991, TOGA-COARE (Tropical Ocean Global Atmosphere - Coupled Ocean Atmosphere Response Experiment) in Jan - Feb 1993, and SCAR-A (Smoke, Clouds, Aerosol, and Radiation - America) experiment in Jul 1993. Algorithms for atmospheric total column amount (ozone, precipitable water vapor, and stability) and profiles (temperature and moisture) will be developed using the HIRS (High resolution Infrared Radiation Sounder) data from these field experiments and beyond.

MAS TOGA-COARE and SCAR-A Data Evaluation. The MAS (MODIS Airborne Simulator) data gathered during the TOGA-COARE (Tropical Ocean Global Atmosphere - Coupled Ocean Atmosphere Response Experiment) in Townsville 6 Jan to 23 Feb 1993 and during the Smoke, Clouds, Aerosol, and Radiation - America (SCAR-A) experiment in Wallops Island, VA 12 to 28 July 1993 continue to be screened and evaluated. Fifteen successful TOGA missions were flown in varying cloud conditions (including Tropical Cyclone Oliver); seven successful SCAR-A missions were flown in cirrus conditions. Data is being evaluated for instrument performance and meteorological information content.

Global Cloud Study. Pre-MODIS cloud studies will continue via the global cloud census with HIRS data now in its sixth year.

MODIS Infrared Calibration. The approach of validating MODIS radiances using the MAS and HIS (High-resolution Interferometer Sounder) instruments will be tested this December on GOES-8. The calibration of the MODIS infrared channels requires adequate testing before launch to characterize detector non-linear response, stray radiation, and angle dependence of background radiation.

WORK ACCOMPLISHED

Cloud Mask. The first draft of the Algorithm Theoretical Basis Document on "Discriminating Clear Sky from Cloud with MODIS" was finished in April 1994 and peer reviewed in May 1994. It was written in collaboration with members of the CERES Science Team. As defined in the ATBD, the MODIS cloud mask will indicate whether a given field of view has an unobstructed view of the earth surface and additionally whether that clear view is affected by cloud shadows. The cloud mask will be generated at the three resolutions of the MODIS data (250 meter, 500 meter, and 1000 meter). Input to the cloud mask algorithms is assumed to be calibrated and navigated level 1B data; additionally, the MODIS data is assumed to be meeting specification so that no accommodation for striping is being made. The cloud mask will be determined for good data only (ie. fields of view where the data in the cloud mask channels 1, 2, 6, 8, 19, 22, 26, 27, 29, 31, 32, and 35 have radiometric integrity); incomplete or bad data will create holes in the cloud mask.

The MODIS cloud mask algorithm will benefit from previous work to characterize global cloud cover. The International Satellite Cloud Climatology Project (ISCCP) has developed cloud detection schemes using visible and infrared window radiances. The NOAA Cloud Advanced Very High Resolution Radiometer (CLAVR) algorithm uses the five visible and infrared channels of the AVHRR for cloud detection using spectral and spatial variability tests. CO2 Slicing characterizes global high cloud cover, including thin cirrus, using infrared radiances in the carbon dioxide sensitive portion of the spectrum. Additionally, spatial coherence of infrared radiances in cloudy and clear skies has been used successfully in regional cloud studies.

Several case studies have been started with the MAS data of Jan 1993. Tri-spectral infrared detection of cloud has been combined with infrared window spatial coherence tests to suggest an initial automated approach for clear sky estimation. The results are quite promising. Reflectance ratios are also being studied to screen different combinations of cloud and land scenes. These early studies are being used to establish the algorithms; much more work must be done to set thresholds for global application. Even more work and collaboration with the MODLAND group will be necessary for the algorithms to be applicable on the smaller scales in various ecosystems.

The thin cirrus detection with MODIS channel 26 (1.38 micron) is also being tested with MAS data of Jul 1993. Strong atmospheric water vapor absorption in this spectral band effectively obscures the earth's surface while high cloud reflectance is essentially unattenuated because of the paucity of water vapor high in the troposphere. Lowtran calculations verify that over the majority of the earth (exceptions being high latitude dry zones and high terrain regions) the reflectance signal in the 1.38 micron will not be contaminated by surface reflectance. Cloud/no cloud and thin/thick cloud reflectance thresholds are under development in support of this MODIS Cloud Mask test.

Tri-spectral Cloud Phase Algorithm. Testing of the tri-spectral (8, 11 and 12 micron) technique for discerning cloud phase continues; minor adjustments are being made. Processing TOGA-COARE data sets from 18 and 26 January and 23 February 1993 has revealed a few shortcomings. First, better regressions of precipitable water (PW) to brightness temperatures for the infrared windows in clear sky conditions need to be determined for the MAS data. Simulations of TOGA-COARE MAS brightness temperatures from radiosondes versus the integrated PW values differ from regressions currently used with global HIRS/AVHRR data. Reasons for the regression differences are being investigated; direct comparisons will be sought using 12 January 1993 and 23 February 1993 data. Second, identification of mixed phase cloud scenes needs to be improved. The current method is consistently accurate at detecting single phase cloud scenes; however, the unity slope mixed phase envelope in the scatter diagram of the 8-11 versus 11-12 micron brightness temperature difference can encompass obvious single phase scenes. A more complex maximum likelihood estimator may help. Third, the accuracy of the tri-spectral technique still needs to be assessed. This must wait until the processed state parameters and microphysical observations taken from the DC-8 during TOGA-COARE are available. These in situ observations will serve as a verification data set for MAS cloud particle phase determinations .

Discussions have begun with Mike King's group in an effort to combine the infrared tri-spectral technique with the visible reflection function ratio technique to produce a single MODIS cloud phase product. Further discussions are planned.

TOGA/COARE Activities. The NASA TOGA/COARE Science Data Workshop II in March was attended by C. Moeller. Discussions centered on identification of specific data sets for case study, interaction between the radiation and convective science working groups, updates of data processing plans by individual PIs, and a publication plan. A four page summary of the MAS data plan for TOGA/COARE cloud studies was submitted for inclusion in a workshop proceedings document. MAS quick-look imagery of radiation group priority days was used to aid in detailed selection of priority days/times. The following days/times (UTC) were suggested for priority study by the radiation group:

1)	Jan 17-18 (flt 93054)	2330-0015	thin cirrus
2)	Feb 31-01 (flt 93058)	2300-0000	thin cirrus
3)	Feb 20-21 (flt 93065)	2105-2130	microphysics
		2357-0053	thick cirrus
4)	Feb 23-24 (flt 93067)	2244-0030	mixed clouds microphysics profiling
5)	Jan 11-12 (flt 93053)	0245-0345	clear and thin tropopause cirrus
6)	Jan 18-19 (flt 93055)	0230-0400	transit cirrus; microphysics
7)	Feb 08-09 (flt 93062)	late	cirrus

Discussions were held with representatives of other TOGA/COARE data sets, including in situ microphysical data and ER-2 and DC-8 lidar data. These data will be useful in combination with MAS data for studies of cloud particle phase, cloud height and emissivity, and cloud temperature. Specific data sets are still being selected. Interest in MAS radiance data has been expressed by the convective science group for estimating cloud top temperature of convective cells and combining with microwave observations on the ER-2.

MAS cloud parameters. The MAS cloud parameters algorithm continues to be modified. The 11 micron atmospheric correction has been modified to use a T11-T12 brightness temperature difference from MAS clear scene data. MAS-specific coe fficients in this relationship were generated using MAS radiance simulations of TOGA/COARE radiosonde data. A MAS-specific relationship between precipitable water and the T11-T12 difference has also been developed from simulations for cases where the sea surface in the target domain is entirely obscured by cloud. These modifications improve the estimate of the IR cloud/no cloud threshold temperature, enhancing detection of low cloud and thin cirrus (non-unity emissivity) in the IR channel. Other modifications planned are to correct cloud top temperature for emissivity effects, using an emissivity estimate either from visible cloud albedo or from the CO2 technique, and to separate ice and water clouds in relating visible cloud albedo to visible cloud optical depth and IR cloud optical depth. The goal is to explore best use of MAS multispectral data in determining cloud parameters. This algorithm is also being modified to utilize GMS visible and infrared data for use by TRMM investigators in support of rainfall estimation activities.

The CO2 slicing algorithm is being converted for MAS data set processing of cloud heights/effective emissivities. This activity is in support of the beta software delivery to SDST this fall.

The software has been transferred and compiled on the Risc6000 workstation. After final logic tests are completed, the software will be capable of processing full MAS straight line flight track segments in a pseudo operational mode.

RISC6000 Workstation. The IBM RISC6000 model 370 workstation continues to be upgraded with MAS/MODIS data analysis software. This workstation is the primary MAS data processing/analysis/application environment at CIMSS. Upgrades include improved navigation capability and MAS multichannel display. A process to obtain an external 8 mm tape drive has been initiated. This will make it possible to access MAS data without need of the mainframe (IBM 4381), saving on mainframe CPU charges, improving turnaround time, and increasing flexibility in staging MAS data.

MAS FY95 Flights. A flight request has been submitted to NASA for 3 MAS and HIS (High resolution Interferometer Sounder) flights on NASA's high altitude ER-2 aircraft platform in support of MODIS activities. MAS and HIS radiances will be compared with GOES-8 radiances to demonstrate the MODIS calibration approach, cloud properties (height, emissivity, particle size, and thermodynamic phase) will be estimated with the MAS and HIS data, and cirrus detection will tested using the MAS 1.88 micron channel. The requested flights are being combined with carryover flights from fiscal 1994. These carryover flights were originally scheduled for September 1994, but are being delayed into early fiscal 1995 (Nov/Dec) to accomodate MAS instrument upgrades. Fiscal 1995 requested flights are tentatively scheduled for summer 1995.

SCAR Activities. A SCAR-C (California) planning meeting at GSFC was attended by Chris Moeller in May. SCAR-C objectives include forest fire temperature monitoring, smoke characterization, smoke/cloud interaction, background aerosol characterization, and preparation for SCAR-B in Brazil. Coordination between the ER-2, the University of Washington's C-131, and U.S. Forest Service personnel (controlled biomass burns) is required. Approximately 10 forest burns are planned which will be overflown during 3 to 5 MAS flights on the ER-2 aircraft. An operations plan developed at the meeting includes daily weather and data collection support by CIMSS personnel at the University of Wisconsin using the McIDAS system. CIMSS anticipates providing McIDAS support for IOP planning, including daily updates of biomass burning activities associated with natural and prescribed fires and agricultural burning as well as smoke/aerosol transport information in the study regime as observed in GOES-7 and GOES-8 diurnal imagery.

Configuration of MAS for SCAR-C remains an issue. A new 50 channel digitizing system is ready for integration with MAS on the ER-2; however, flight schedules may not leave sufficient time for NASA ARC to perform the integration before SCAR-C. If the new digitizing system is not integrated in time, then a 12 channel configuration is ready as a backup.

Intercomparison studies will be done between GOES-7 and GOES-8 over several of the SCAR-C fires to refine the current GOES VAS Automated Biomass Burning Algorithm (ABBA) and smoke identification software and to assist in GOES-8 fire detection algorithm development. The GOES VAS ABBA software has been ported to a SGI workstation for all future biomass burning analysis activities. For another NASA project, the GOES VAS ABBA software is being modified on the SGI for GOES-8 application as well. During the 1994 biomass burning season in South America Elaine Prins hopes to download 1-2 weeks of GOES-8 diurnal data in real time for GOES-8 fire algorithm development and testing. These data will enable evaluation of the implications of improved geostationary spatial, temporal, and radiometric resolution for monitoring biomass burning in South America. The GOES-8 algorithm is scheduled to be operational for the 1995 biomass burning season in South America in association with the SCAR-B experiment.

Aerosol Detection. The manuscript entitled "Satellite remote sensing of H2SO4 aerosol using the 8-12 micron window region: application to Mount Pinatubo" has been accepted for publication in the Journal of Geophysical Research.

DATA ANALYSIS

Negative 11-12 micron brightness temperature difference investigations. Occurrences of negative 11-12 micron brightness temperature differences (12 micron is warmer than 11 micron) have been found in AVHRR, MAS and VAS data over cold high clouds. Further investigations with High-resolution Interferometer Sounder (HIS) data were presented in June in a poster format at the 7th Conference on Satellite Meteorology and Oceanography held in Monterey, California. Contrary to the AVHRR, MAS and VAS observations, the HIS data (summed over the appropriate spectral rsponse functions for the three instruments) did not show negative differences over cold cloud scenes. However, two clues suggest that negative differences are related to the microphysical properties of clouds. First, forward calculations of MAS radiances using radiosonde observations revealed different results for ice and water cloud (the 11 minus 12 micron differences were not the same) when atmospheric absorption effects were removed. This indicates that the background cloud emission is the source of the negative values, not atmospheric absorption. Second, AHVRR 11-12 micron brightness temperature differences are not negative over very cold clear Antarctica scenes, suggesting that the negativite values are not solely a function of scene temperature, but rather a function of scene type (i.e. clear versus cloud). Figure 1 shows MAS 11 micron imagery where negative differences were found. The image typifies the many negative differences in the MAS TOGA/COARE data set. The negative values correlate very well with the coldest (brightest) clouds. Where the cloud becomes transmissive (thinner), the differences are positive, in agreement with bulk ice properties. MAS differences of -2 to -3 K are not unusual over thick ice clouds. MAS instrument performance cannot account for negative differences of this strength; 11 and 12 micron truncation error is small (about 0.3 K), MAS 11 and 12 micron single sample noise (~1 K for 200 K scene) is also less than the negative differences observed. This investigation will be furthered with the MAS and HIS data set to be collected in December 1994.

HIRS cloud climatology. Upper tropospheric humidity and upper level divergence fields derived using METEOSAT water vapor images were compared with upper level cloud amount averages from the HIRS cloud climatology for January 1992. The results show very strong correlation between areas of high upper level divergence, high upper tropospheric humidity and high upper level cloud amount values. Implications for tracking sources and sinks of atmospheric moisture for climatological studies (eg. GEWEX and pathfinder) are being pursued. The results of these comparisons are being written up for publication.

The HIRS cloud climatology has been updated to include a fifth year of processing. The results indicate that the increase in cirrus cloud observed since the summer of 1991 has leveled off, but has not returned to pre-1991 values. The five years of global cloud statistics were averaged and differences from the mean were taken for each year. The large increase in cirrus cloud which began in 1991, especially over the equatorial Pacific, is very evident. Figure 2 shows the probability of cirrus derived from 5 years of HIRS data.

Cloud Masking. Tri-spectral infrared detection of cloud has been combined with infrared window spatial coherence tests to suggest an initial automated approach for clear sky estimation. Examples from our testing with MAS data are briefly presented. Initially, a cluster analysis is performed on all 10x10 averaged pixels which have a scene uniformity less than .50 mW/m2/ster/cm-1. Figure 3 is an example from a water cloud MAS image from 18 January 1993. Two distinct clusters are apparent. The cluster centers are then compared to brightness temperature difference clear sky thresholds as determined from the relationship of PW to SST described by Stephens (1990)

$$PW = a \exp[\, b\,(T_s - 288)\,]$$

and regressions of PW to clear sky 8-11 micron and 11-12 micron brightness temperature differences as calculated from a global data set of collocated AVHRR GAC 11 and 12 micron and HIRS 8 and 11 micron scenes. Figure 4 is the brightness temperature difference scatter diagram along with the calculated thresholds for the 18 January 1993 image. In this case, only one of the uniform scene centers passes both the clear sky threshold tests (lighter cluster), and is labeled as clear.

Reflectance ratios have also been studied with MAS data of Jan 1993 to screen different combinations of cloud and land scenes. The reflection function ratio test (.87 micron/.66 micron) for clear sky was performed on a TOGA-COARE MAS scene from 26 January 1993 which encompassed a wide variety of surface types and cloud scenes (Figure 5). The tropical island land values clearly separate out with ratios greater than 2.0. The remaining clear scenes can be distinguished from cloud using a threshold of .92, with some ambiguity near sun glint regions and sand bars.

The thin cirrus detection with MODIS channel 26 (1.38 micron) is also being tested with MAS data of Jul 1993. Investigations using MAS 1.88 and 11.0 micron data from the SCAR-A field experiment show that thin cirrus (emissivity estimated 0.2) is separable from clear scenes in the 1.88 micron data (Figure 6). Cloud/no cloud and thin/thick cloud reflectance thresholds will be studied further.

ANTICIPATED FUTURE ACTIONS

First Software Delivery. The remaining portions of the "Cloud Properties" software with benchmark data sets will be delivered to SDST. Cloud phase with MAS data has been delivered. Cloud temperature, height, and amount with HIRS data will be coming in the third quarter of 1994. An initial version of the cloud mask software will be delivered late 1994. Software and data sets for "Atmospheric Profiles" will be forthcoming in early 1995.

MAS/HIS Intercomparisons. The collocated HIS (High resolution Interferometer Sounder) data will be used for intercalibration of several instruments (MAS, GOES, HIRS) and for studying the spectral sensitivity of the cloud parameter algorithms. Three flights are planned for the fourth quarter of 1994.

PROBLEMS

Data Format. Progress has been made in solving the data incompatibility problems which exist between the UW toolkit founded on the McIDAS (Man computer Interactive Data Access System) and the scan cube and HDF file format which are used by the SDST on tyhe TLCF. Initial discussions during the May MODIS Science Team Meeting concluded that SDST would explore the UW Toolkit in order to asses the effort it would take to integrate some or all of it into the TLCF, and to determine if they could benefit from the data assimilation capabilities it already possesses. As part of this agreement, a higher level version of the UW Toolkit developed for NASA Pathfinder data set manipulation, which employs a mouse driven GUI on top, was delivered to the SDST for introductory purposes. This version included a MODIS side car consisting of MAS applications, one of which is the tri-spectral cloud phase technique. Kathy Strabala and Dave Santek gave a demonstration and initial training of the UW Toolkit at GSFC, which included both high level and command line interfaces, to representatives of the SDST. This was followed by more in-depth training at the UW for Rich Hucek and Steve Berrick the following week. Initial reactions are that no insurmoun table hurdles exist to prevent us from delivering our Beta software to the SDST using UW Toolkit data formats and calling sequences, as long as the instrument input and final output are in ECS approved formats.

PUBLICATIONS

Prins, E. M. and W. P. Menzel, 1994: Trends in South American biomass burning detected with the GOES VAS from 1983-1991. Seventh Conference on Satellite Meteorology and Oceanography, Jun 6-10, Monterey, CA, 592-595. AMS publication

Prins, E. P. and W. P. Menzel, 1994: Trends in South American Biomass Burning Detected with the GOES-VAS from 1983-1991. accepted by Jour. Geo. Rev.

Wylie, D. P., W. P. Menzel, H. M. Woolf, and K. I. Strabala, 1994: Four Years of Global Cirrus Cloud Statistics using HIRS. accepted by Jour. Clim.

MEETINGS

Chris Moeller attended the NASA TOGA-COARE Workshop II in Mar 1994 to represent MAS data interests and to continue collaborative efforts with members of the science working groups.

Paul Menzel and Kathy Strabala attended the MODIS Science Team in May 1994. The initial version of the MODIS cloud mask was presented.

Paul Menzel presented the Cloud Mask, Cloud Properties, and Atmospheric Profiles ATBDS at the MODIS ATBD Review in May 1994.

Paul Menzel presented the MODIS Cloud Mask to the SWAMP meeting in May 1994.

Chris Moeller attended a NASA SCAR-C Planning Meeting in May 1994 to represent CIMSS interests in SCAR-C. Materials on the use of the MAS instrument during SCAR-C were presented.

Chris Moeller prepared a poster for presentation at Seventh Conference on Satellite Meteorology and Oceanography, Jun 6-10, Monterey, CA entitled "Negative 11 micron minus 12 micron brightness temperature differences: instrument calibration or reality?" which summarized work by S. A. Ackerman, C. C. Moeller, K.I. Strabala, W. P. Menzel, and W. L. Smith.