INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC STABILITY WITH MODIS

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TASK OBJECTIVES

Preparation for First Software Delivery. The cloud algorithms outlined in the ATBD on "Cloud Properties" will be prepared with benchmark data sets (from HIRS and MAS) and delivered to SDST early 1994. The "Atmospheric Profiles" algorithms will be sent somewhat later. Transfer of all related subroutines from the McIDAS mainframe to the RISC environment will be completed. Hardware capabilities for the MODIS team at the University of Wisconsin have been enhanced to facilitate the software transfer.

Cloud Mask ATBD. Based on MAS, HIRS, and GOES cloud investigations, suggestions for infrared screening for clouds will continue to evolve and be forwarded to the MODIS Calibration Support Team. An ATBD on cloud masking will be drafted in coordination with Ron Welch, Bryan Baum, John Barker, and Liam Gumley.

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 will continue to be 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.

Algorithm Definition. Using the MAS data from FIRE in Nov-Dec 1991, TOGA COARE in Jan-Feb 1993, and SCAR-A in Jun-Jul 1993, the algorithms for specifying cloud parameters (mask, temperature, phase, height, and amount) will continue to be investigated. 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.

Global Cloud Study. Pre-MODIS cloud studies should continue via the global cloud census with HIRS data.

Definition of MODIS Infrared Calibration. The calibration of the MODIS infrared channels continues to demand attention. Adequate testing of the MODIS instrument before launch must be assured so that infrared calibration accounts for detector non-linear response, stray radiation, and angle dependence of background radiation.

MODIS Instrument Review. Tradeoffs between product accuracy and MODIS infrared calibration and spectral selection will continue to demand attention. Simulations of MODIS products with MAS and HIRS data should continue to guide instrument developers.

WORK ACCOMPLISHED

ATBDs Submitted. Two Algorithm Theoretical Basis Documents on Cloud Top Properties and Atmospheric Profiles were submitted in the last half of 1993. The first includes cloud top pressure, emissivity, fractional coverage, and phase to be produced globally at 5 km resolution. The second includes determinations of clear column atmospheric stability, total ozone, and total precipitable water, as well as temperature and moisture profiles also at 5 km resolution.

TOGA/COARE Activities. MAS TOGA/COARE data is being processed and analyzed. MAS TOGA/COARE data sets at CIMSS include Jan 12, 18, 19, 26, Feb 1, 9,and 24. In order to make use of MAS TOGA/COARE data on the University of Wisconsin's (UW) McIDAS, the data sets must be processed into the McIDAS mainframe format. From there, the data sets are transferred to the McIDAS AIX (RISC6000 model 370) environment where data processing is done and products are analyzed. Currently these include cloud particle phase (tri-spectral technique) and a cloud parameter catalogue (low, mid, high, total cloud fraction, albedo, connectivity, multilayering, cloud top height and temperature). Figure 1 shows an example of the MAS derived visible albedo contoured over a .55 um image of a cumulonimbus cloud from 26 January 1993. In the next quarter, cloud height and effective emissivity (CO2 technique) will be added.

In July, C. Moeller attended the NASA TOGA/COARE Science Data Workshop. At the meeting, questions on priority days, data set quality, instrument performance, and scientific collaboration were discussed. A presentation of preliminary MAS TOGA/COARE cloud study results was made. Cloud studies at CIMSS are focusing on the radiation group priority days (Jan 26, Feb 24, Jan 12, Feb 1, Feb 9). To date, selected cases have been processed for cloud particle phase and CO2 cloud height/emissivity studies with the MAS data. Cloud parameters are currently being produced for Jan 26. Lidar data collected simultaneously on the NASA ER-2 platform will be used for verification of MAS CO2 cloud height estimates; microphysical in situ data collected from the NASA DC-8 platform will be used to assist cloud particle phase studies. The workshop also expressed the desire that the complete MAS TOGA/COARE data set (all flight days) be processed by the MODIS Science Data Support Team (SDST) at GSFC and archived for distribution through the EOS Distributed Active Archive Center (DAAC) User Support Office. Processing of MAS TOGA/COARE data at by the SDST has been delayed until spring due to software changes. Attendance at the second TOGA/COARE Workshop, scheduled for mid March, is planned.

SCAR Activities. MAS data collected during the SCAR-A field experiment in July (July 12, 14, 16, 20, 22, 25, 28) has been inspected for data quality at the UW. The data set will be used for cirrus cloud studies (CO2 cloud height/emissivity, cloud particle phase, cirrus detection). Clear scenes from the July 16 MAS SCAR-A data set indicated the following noise performance of the MAS: signal to noise for the visible channels was 85 for .55 um, >100 for .66 um, >100 for .87 um, >100 for .94 um, 20 for 1.88 um, >100 for 2.14 um and noise equivalent temperature error for the infrared channels at 300 K was 0.72 C for 3.7 um, 0.25 C for 8.6 um, 0.26 C for 11.0 um, 1.41 C for 13.2 um, and 0.34 C for 12.0 um. Noise determinations used clear scene signal over water. This noise performance is in line with expectations. An absolute visible calibration during SCAR-A using the Goddard Space Flight Center (GSFC) integrating sphere has been obtained and implemented to calibrate the visible channels. The data of July 14, which includes many multilayer and high cloud scenes is currently being investigated for cirrus cloud studies and being compared with an AVHRR overpass. A 3 channel (vis, near infrared, infrared) cirrus detection algorithm has been tested on the July 14 data set. Further testing and development of the algorithm is planned. Because of a problem with field of view smearing (sampling) in the 12.0 and 13.2 um channels, MAS data must be averaged over 5 X 5 boxes (250m X 250m) for quantitative multispectral applications using these channels.

Elaine Prins attended a MODIS SCAR-A/SCAR-C meeting at GSFC on September 15, 1993 to discuss the status of the data obtained during SCAR-A, preliminary results, data exchange protocol, collaborations on publications of results, and a tentative timetable for publication. She presented GOES satellite imagery with overlays of the flight paths along with examples of various multi-spectral cloud type and cloud height assignment techniques (CO2 slicing, tri-spectral, visible and 1.9 um).

Efforts are focussed on publishing the SCAR-A results in a special issue of a yet unnamed journal, with an emphasis on the concept of the SCAR experiment series and SCAR-A results. The exchange of available data and preliminary results are to be accomplished by March 1994, a first draft of papers by May 1994, and submission for publication by September 1994. UW will write on (1) the meteorological conditions and their relationship to SCAR-A missions and flight paths, the properties of the air mass, aerosol and clouds (Remer, Moeller, Kaufman, King, Hegg, et al.) and (2) remote sensing of cirrus clouds and their properties and structure during SCAR-A (Menzel, Moeller).

Hardware Acquisition. An IBM RISC6000 model 370 workstation has been purchased and implemented at CIMSS. This workstation is being used for science algorithm development, MAS data set processing and analysis, and benchmark software and data set preparation (for transfer to the Science Data Support Team (SDST) at GSFC). Transfer of MAS processing and analysis code to the RISC environment from the McIDAS is continuing. Currently, the workstation supports MAS data sets with navigation and calibration software, data diagnostics including data averaging and instrument noise calculation, data products software including tri-spectral, sea surface temperature, and cloud parameters analysis, and instrument data intercomparison software (AVHRR, VAS, HIS, MAMS).

Cloud Phase Benchmark Data Set Delivered: An interim version of the tri-spectral algorithm (8-11 versus 11-12 um brightness temperature differencing) for discerning cloud phase was completed and the software delivered to the SDST on 5 January 1994. A MAS benchmark data set and resultant phase determinations were also included.

SCAR-C Planning. Examples of aerosol transport associated with biomass burning in South America have been processed in support of SCAR-B Planning. A review of GOES satellite imagery over South America during the dry seasons of 1983, 1988, 1989, and 1991 revealed numerous examples of aerosol transport associated with biomass burning in the selva and cerrado. By looping visible data (and IR data when available) it was possible to isolate the smoke/haze and transport regimes. Hard copy prints were made of those images which showed the best examples of smoke/haze transport during each of those years under different meteorological conditions. Areas of smoke/haze and the prevailing circulation were identified on the prints. The prints include examples of aerosol transport on 6 days (12 images) in 1983, 5 days (10 images) in 1988, 2 days (4 images) in 1989, and 6 days (6 images) in 1991. A copy of the prints and a table summarizing plume activity and aerosol transport for each image were sent to Yoram Kaufman to be used in planning future field experiments in Brazil.

The majority of the images depict anticyclonic flow throughout the Amazon Basin where the easterly winds in the northern portion of the Amazon Basin transport the aerosols westward and the Andes Mountains deflect the smoke to the south-southeast. In 1983 and 1988 there were several examples of anticyclonic flow which resulted in transport out over the Atlantic Ocean near 30 S. This transport regime is often associated with a synoptic disturbance located south of the Amazon Basin which extends out over the ocean and acts as a barrier at the southern extent of the plume. In 1991 there were several instances where the smoke continued southward along the Andes Mountains into Bolivia, Paraguay, and Argentina instead of being channeled to the east toward the Atlantic Ocean. This was the predominant flow pattern in 1991 and was characterized by a lack of synoptic scale activity in the south that might otherwise act to channel the emissions out over the Atlantic Ocean. On at least one occasion the smoke plume extended south along the Andes into the southern half of Argentina (40 to 45 S). A third transport mechanism which was evident in all four years includes flow from the Amazon Basin to the northwest into the selva regions in the northwestern portion of the Brazilian Amazon and extending into Peru and Colombia. This regime is often accompanied by a large scale weather system extending along the front range of the Andes Mountains and into the southern portion of the Amazon Basin. The majority of the other smoke/haze transport mechanisms observed during these four years represent combinations of the above scenarios. Only a few examples of smoke/haze transport were evident in the GOES imagery for 1989. The 1989 burning season was abnormally wet and the region was covered by clouds obscuring burning activities and smoke/haze transport.

Infrared Cloud Mask. An initial set of tests to screen for clouds in the infrared is under investigation. The IR cloud mask is for single field of view (without consistency checks with nearest neighbors) over ocean; it must evolve to more sophisticated algorithms. Six multispectral cloud detection algorithms are suggested; all should be satisfied for clear determination. The first three attempt to correct window channel for moisture contamination, the fourth looks for broken or cirrus cloud, and the last two screen for cirrus. Over land these algorithms need corrections for surface emissivity; which will be addressed later.

Notation indicates wavelength in microns, so that for example T11 is the 11 um brightness temperature. Cloud is present if

1) T11 + a(PW)*(T11-T12) < SST where a is determined from a lookup table as a function of total precipitable water vapor (PW) in the atmosphere; a value of 1 is used in the absence of information about PW.

2) T11 + b(PW)*(T11-T8.6) < SST where b is determined from a lookup table as a function of total precipitable water vapor in the atmosphere; a value of .8 is used in the absence of information about PW.

3) T11 + c(PW) < SST where c is determined from a lookup table as a function of total precipitable water vapor in the atmosphere; PW is estimated from the SST through an exponential relationship PW = k1*exp(k2*(SST-288)).

4) T4 - T11 < 0 or T4 - T11 > 0 where care must be taken to screen out reflected solar contamination in the short wave window channel.

5) T13 < T13(warmest) - 2 where the warmest is selected for an area of roughly 100 km by 100 km

6) R1.38 > threshold value (.3 mW/ster/m2/um)

If any of these tests suspects the presence of cloud the fov is declared not clear. Over land these algorithms need corrections for surface emissivity. Work will proceed on that shortly.

MODIS Infrared Calibration Discussed. An initial set of measurements required to characterize the infrared calibration of the MODIS was presented at the Calibration Team Meeting. The ground testing must provide the following information: (1) spectral response for each IR detector/spectral channel combination, (2) calibration tests with several instrument thermal configurations, (3) stray radiation as a function of view angle, and (4) non linear response and measurement repeatability. This data will be used to calculate R=a+bC+qC2 for each thermal configuration for each detector for each spectral channel. In the process there will be an attempt to characterize changes in the nonlinearity of the calibration equation as a function of instrument temperature (q(T)) and to correlate with foreoptics temperatures. The cal algorithm mean and RMS errors with respect to the external target will also be calculated as a measure of cal performance. With enough data available, half the data will be used to specify the cal algorithm and the other half will be used to determine cal performance.

DATA/ANALYSIS

Cloud Phase Algorithm: Several improvements to the technique have been implemented over the last 6 months. First, a dynamic clear sky discriminator was added. The average brightness temperature for each 10x10 area is corrected for atmospheric moisture and compared to sea surface temperature (SST). The atmospheric correction is derived from the SST through a statistical relationship suggested by Stephens (1990); HIRS global data was used here to establish the relationship of clear sky brightness temperature and precipitable water. An adjustment was made to the relationship to account for the differing spectral bandwidths of the HIRS and MAS instruments. When applied to a variety of cloudy and clear TOGA/COARE scenes, the results are promising. The advantages of this method are (1) it requires no further spectral information beyond the three infrared channels used in the brightness temperature differencing, and (2) the fixed brightness temperature thresholds have been replaced with dynamic ones.

Second, a clustering analysis has been added to assist in opaque cloud scene identification. The analysis is performed only on 10x10 pixels where the standard deviation (SD) of the 8 um radiance is less than .5 mW/ster/m2/cm-1. The analysis uses a SD versus 11 um brightness temperature scatter diagram. This allows scenes with similar characteristics to be categorized together. This method is especially effective for discerning clear sky when used in conjunction with the dynamic thresholding mentioned above. If the center of a cluster exceeds the clear threshold value, then that whole cluster can be identified as being clear.

Third, a maximum likelihood estimator (MLE) has been included to aid in single phase cloud identification in the brightness temperature difference scatter diagram. As described in Strabala et al (1994), single phase clouds tend to cluster in patterns based on phase due to the different microphysical properties of ice and water. Water cloud tend to form in a line with a slope less than one, while thin ice cloud clusters in a slope greater than one. The MLE consists of a least squares straight line fit with errors in both directions. If the fit is good, and the slope is greater than 1, then ice cloud is assumed. If the fit is good, and the slope is less than 1, then water cloud has been detected. A scene with both high and low emissivity ice clouds tend to initially form in a slope greater than one, then curves back toward zero as the cloud becomes opaque. Therefore, the technique is applied only to scenes where the 11 um brightness temperature is greater than 250K. This seems to be where the 8-11 um brightness temperature difference reaches a maximum for ice cloud.

These three additions have greatly improved the accuracy (based on objective observations) and the flexibility of the technique. Figures 2 to 4 show this. Figure 2 contains a MAS water cloud scene from 18 January 1993 overlaid with the tri-spectral cloud detection results; good discrimination of opaque and thin water cloud is noticeable. Figure 3 contains a MAS ice cloud scene from 18 January 1993 overlaid with the tri-spectral cloud detection results; opaque and thin ice cloud are separated reasonably well. Figure 4 shows the tri-spectral brightness temperature difference scatter plot for the water and ice cloud scenes; the different cloud types separate nicely.

<u>Aerosol Detection</u>: Steve Ackerman and Kathy Strabala demonstrated that brightness temperature differences between 8 and 11 um are sensitive to aerosols containing H2S04. A definite decrease is apparent in the 8-11 um brightness temperature differences over low latitude clear sky oceans from the pre-Pinatubo to post-Pinatubo year in the HIRS climatology, which are consistent with observed optical depth measurements. Theoretical simulations suggest that the technique is sensitive to visible optical depths greater than 0.15. Similar investigations using the 11-12 um brightness temperature differences revealed a smaller signal; however, the tri-spectral approach (information from both brightness temperature differences) has the potential to differentiate cirrus and water vapor from H2S04 aerosols, because their spectral signatures are different. Time series analysis was applied to the 8-11 um brightness temperature difference from NOAA-10 (August 1990) and NOAA-12 (August 1991) over a section of the south Pacific. Figure 5 shows the HIRS 8 minus 11 um (top panel) and the corresponding 11 minus 12 um (bottom panel) brightness temperature difference change between August 1990 and August 1991. The coherent decrease in the tropics is apparent in the 8 - 11 but not the 11 -12 um panel. A paper on this work has been submitted for publication.

ANTICIPATED FUTURE ACTIONS

<u>First Software Delivery</u>. Preparations will continue to deliver the remaining portions of the "Cloud Properties" software with benchmark data sets to SDST. Cloud phase with MAS data has been delivered. Cloud temperature, height, and amount with HIRS data will be coming in the first quarter of 1994. Software and data sets for "Atmospheric Profiles" will be forthcoming in the second half of 1994.

<u>Cloud Mask ATBD</u>. Work will continue to refine cloud screening algorithms for different applications and an ATBD will be forthcoming in the second quarter of 1994.

<u>MAS/HIS Intercomparisons</u>. The collocated HIS (High resolution Interferometer Sounder) data will be used for intercalibration of the two instruments (MAS and HIS) and for studying the spectral sensitivity of the cloud parameter algorithms. Flights are planned for the third quarter of 1994.

PROBLEMS

Data Format. After some discussion with SDST and subsequent approval, benchmark data sets have been delivered in the McIDAS (Man computer Interactive Data Access System) file format. Initial indications are that there may have been a mis-communication on this matter. As all of our development is proceeding on McIDAS, we need for this obstacle to be overcome.

PUBLICATIONS

Ackerman, S. A., and K. I. Strabala, 1994: Satellite remote sensing of H2SO4 aerosol using the 8-12 micron window region: application to Mount Pinatubo. submitted to Jour. Geo. Rev.

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

Wylie, D. P., W. P. Menzel, H. M. Woolf, and K. I. Strabala, 1993: Four Years of Global Cirrus Cloud Statistics using HIRS. accepted by Jour. Clim.

Strabala, K. I., S. A. Ackerman, and W. P. Menzel, 1992: Cloud Properties Inferred from 8-12 micron Data. accepted by Jour. Appl. Meteor.

SEMINARS

P. Menzel gave a presentation to the CERES Science Team on "Inferring Cloud Properties from MODIS Observations" in September 1993.

P. Menzel gave a presentation to the MODIS Science Team on "Trends in Global Cirrus Seen in Four Years of HIRS Data" in October 1993.

FIGURE 1

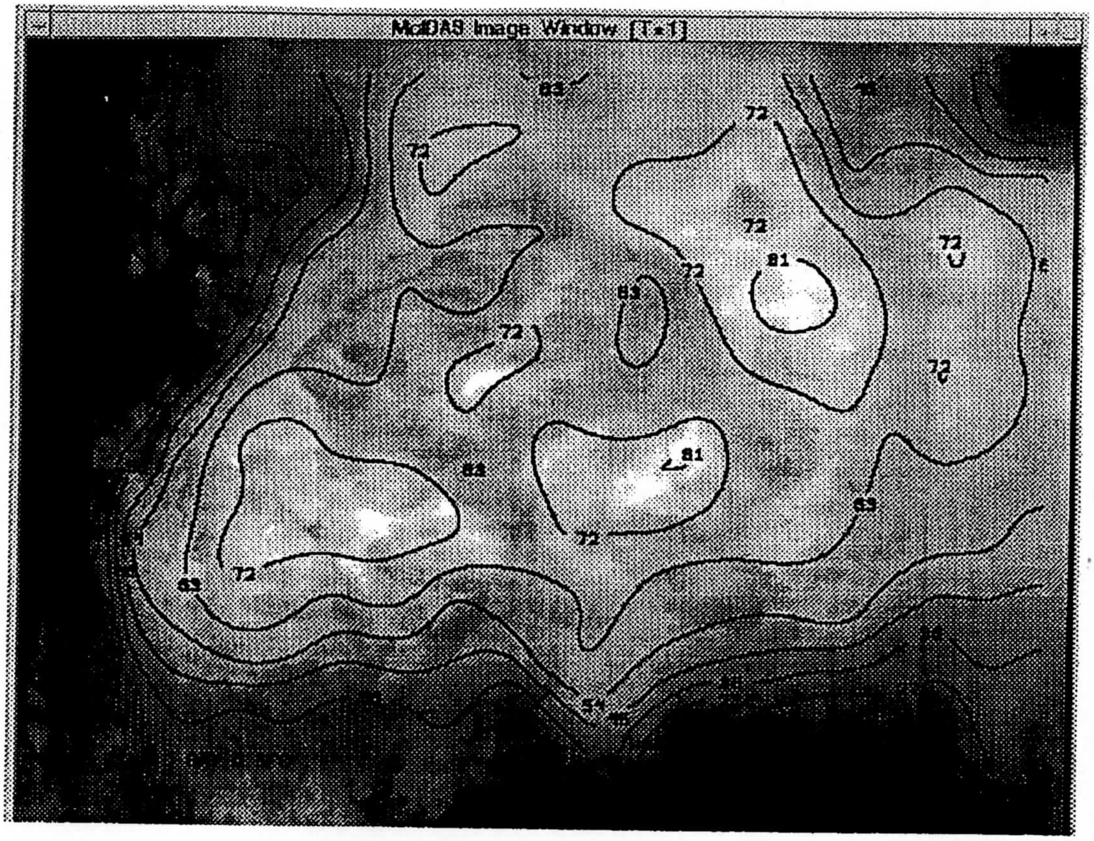
FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5A

FIGURE 5B



McIDAS Image Window [T=1]
63
72
72
72
81
72
72
63
72
72
81
82
63
72
63
72
54

FIGURE 1

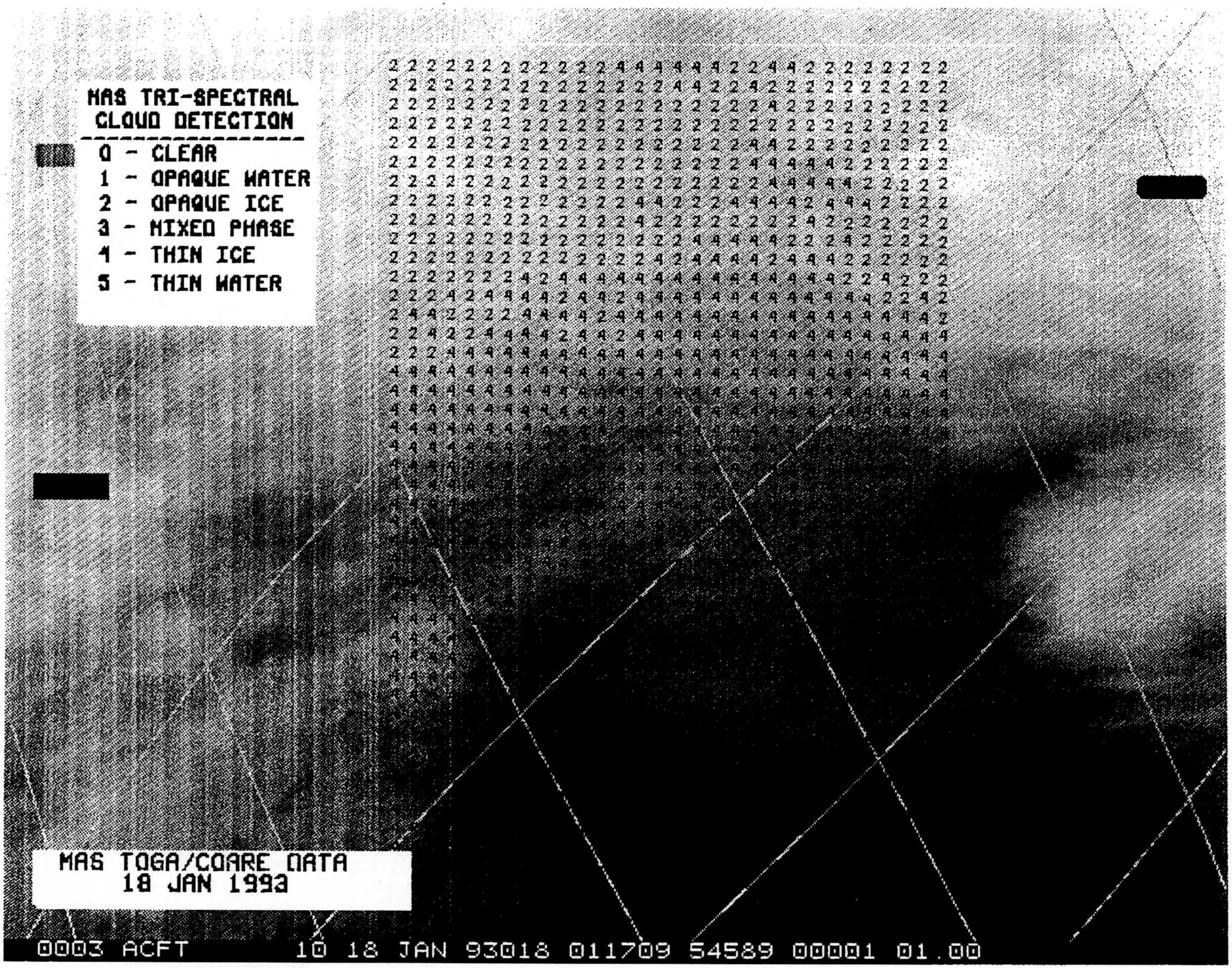

MAS TRI-SPECTRAL
CLOUD DETECTION
0 - CLEAR
1 - OPAQUE WATER
2 - OPAQUE ICE
3 - MIXED PHASE
4 - THIN ICE
5 - THIN WATER
MAS TOGA/COARE DATA
18 JAN 1993
0003 ACFT 10 18 JAN 93018 011709 54589 00001 01.00

FIGURE [illegible]

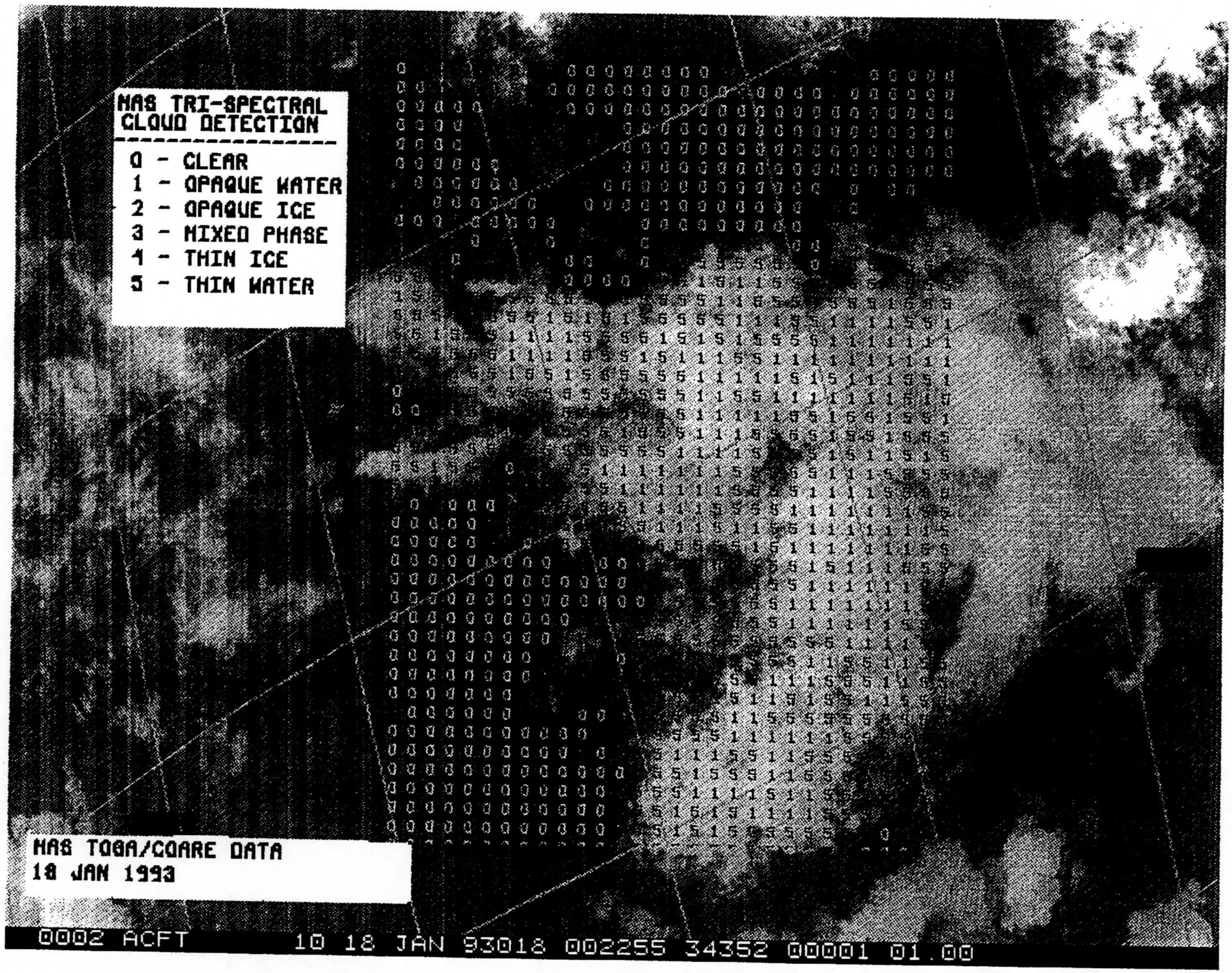

MAS TRI-SPECTRAL
CLOUD DETECTION
0 - CLEAR
1 - OPAQUE WATER
2 - OPAQUE ICE
3 - MIXED PHASE
4 - THIN ICE
5 - THIN WATER
MAS TOGA/COARE DATA
18 JAN 1993
0002 ACFT 10 18 JAN 93018 002255 34352 00001 01.00

FIGURE 3

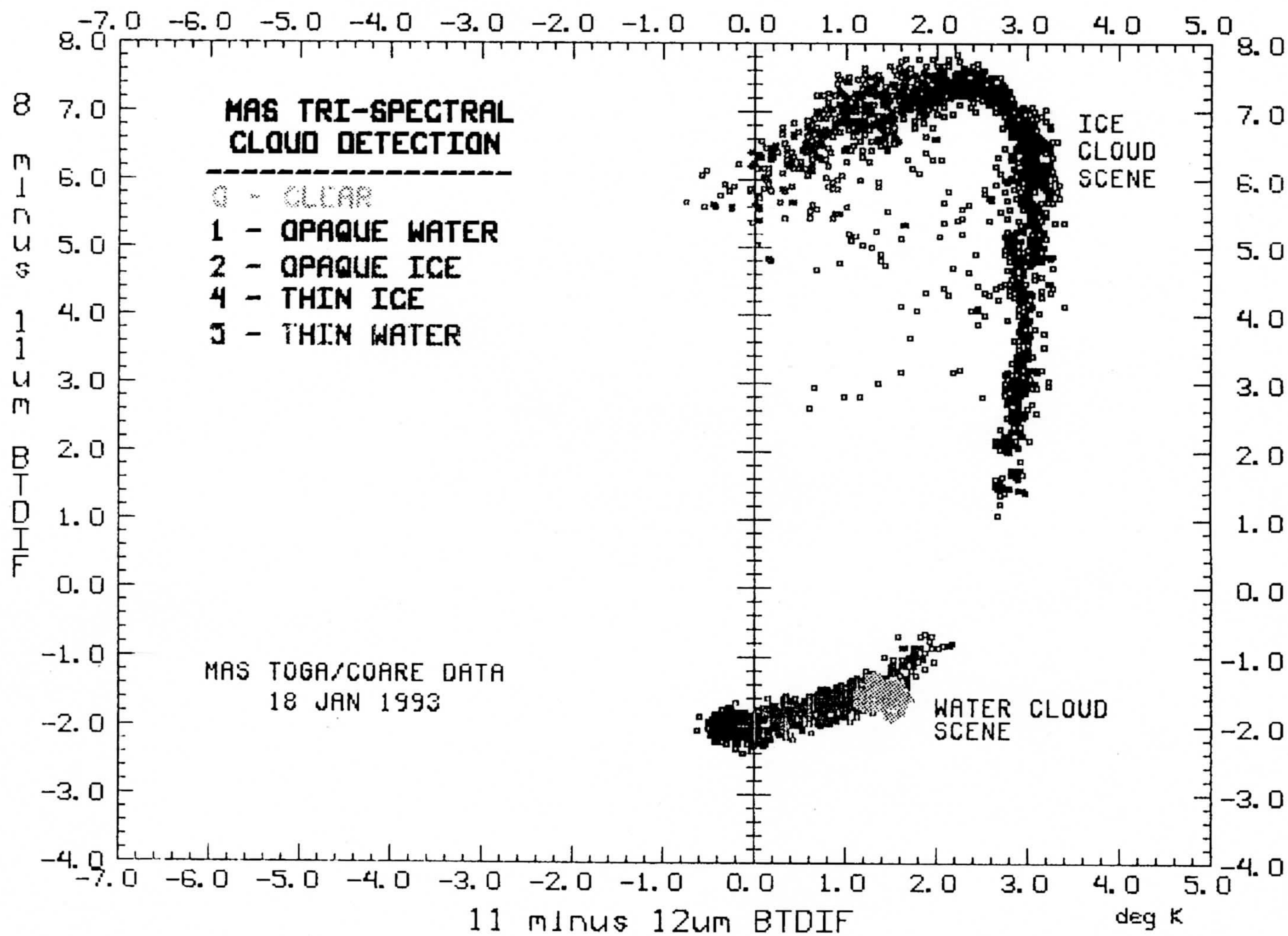

MAS TRI-SPECTRAL
CLOUD DETECTION
0 - CLEAR
1 - OPAQUE WATER
2 - OPAQUE ICE
4 - THIN ICE
5 - THIN WATER
ICE
CLOUD
SCENE
WATER CLOUD
SCENE
MAS TOGA/COARE DATA
18 JAN 1993
8 minus 11um BTDIF
11 minus 12um BTDIF
deg K

FIGURE 4

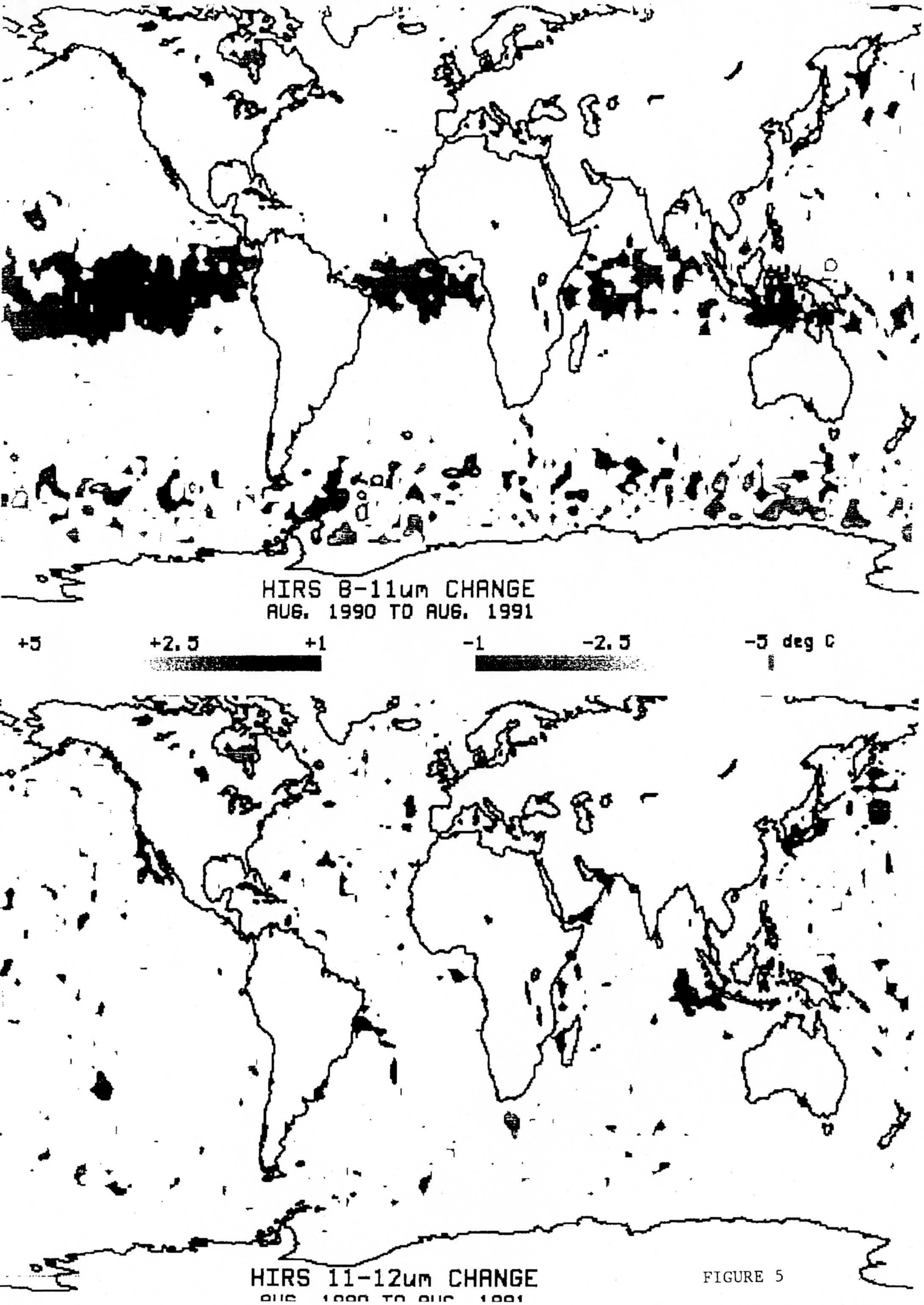

HIRS 8-11um CHANGE
AUG. 1990 TO AUG. 1991
+5
+2.5
+1
-1
-2.5
-5 deg C
HIRS 11-12um CHANGE

FIGURE 5