INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC STABILITY WITH MODIS

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ABSTRACT

In the past six months several milestones were accomplished. Benchmark data and software to test algorithms for four MODIS products were delivered to and successfully implemented by SDST; the benchmark algorithms and data are cloud mask with regional HIRS and AVHRR data, cloud phase with regional MAS data, cloud pressure and emissivity with global HIRS data, and atmospheric profiles with regional HIRS data. ATBDs for the cloud mask, cloud properties, and atmospheric profiles were revised and resubmitted. The cloud mask algorithm was simplified, validation strategies were considered. Software to interface the MODIS scan cube with the Wisconsin tool kit was investigated. Two new members of the UW MODIS team were hired in October, Liam Gumley, who is working on atmospheric profiles, and Dan LaPorte, who is assisting with the infrared calibration.

TASK OBJECTIVES

Software Delivery. With the initial delivery of all four software packages accomplished, focus now turns to evolving those packages from HIRS and MAS data to MODIS data (this will accelerate as information on the MODIS scan cube becomes available). Additionally for the cloud mask, several data sets in different land/ocean and winter/summer regimes will be developed with AVHRR and MAS data. Delivery of a cloud mask over land with AVHRR/HIRS data will be forthcoming in the first quarter of 1995; high resolution cloud masks from January 1995 MAS data will be available in the second half of 1995.

Revised ATBDs. Based on the peer review of May 1994 and continuing MAS, AVHRR, HIRS, and GOES cloud investigations, the MODIS Cloud Mask ATBD (version 1) were revised and resubmitted in December 1994. As work progresses and the algorithms evolve, we expect that another version of the ATBDs will be drafted in late 1995.

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 at UW. 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 field experiments planned with the MAS and the High resolution Interferometer Sounder (HIS) for January 1995.

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 instruments will be tested in January 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

Software Transfer. Beta versions of software and benchmark data sets of four MODIS algorithms were delivered to the SDST and successfully implemented on the TLCF; they are cloud mask with regional HIRS and AVHRR data, cloud phase with regional MAS data, cloud pressure and emissivity with global HIRS data, and atmospheric profiles with regional HIRS data. Related subroutines from the UNIX version of McIDAS (also called the UW toolkit) have been integrated into the TLCF to enable successful beta tests.

Data Issues. A significant effort was put forth in the third and fourth quarter of 1994 in determining ancillary data set requirements and estimating computer processing and data volume requirements for UW MODIS products, in making the input scan cube MODIS data compatible with Wisconsin Toolkit routines and gauging user concerns regarding our MODIS level 2 products. The ancillary data sets were submitted at the MODIS Test Data Workshop at Flathead Lake, Montana. The computer processing and data volume estimates and product abstract descriptions were delivered to the SDST. Dr. Robert Merrill has been examining the structure of the proposed MODIS scan cube data format to assess its' compatibility with the Wisconsin toolkit package. The Wisconsin team relies heavily on the toolkit for MODIS product generation, taking advantage of the reliable handling and integration of ancillary data. In the production environment, it is necessary for Wisconsin toolkit routines to access and integrate the prescribed MODIS format as a standard input. The issue of final user products versus investigator products has been raised. It is likely that an investigator may wish to save supporting product information for research or validation purposes that a user would not need or want. A proposal to create a new file type that would be archived, available only to investigators and include this supporting data has been made to the SDST. The final product file available to the public would include only the MODIS parameters defined in the product abstracts.

Cloud Mask. The Cloud Mask Team met in Madison, WI on August 30 and discussed modifications in response to the peer review. This included the spectral channels, the output format, the algorithms, the ancillary data, and the validation activities. The mask at 500 meter resolution was waived; it was felt that the 250 meter mask would alleviate the need for a 500 meter mask. The spatial coherence tests were placed last in the processing chain of the algorithm; they will be used infrequently due to the large inherent processing load. Validation with ER-2 campaigns, ground campaigns with all sky cameras, and comparison with ASTER were discussed. Quality control was also discussed; monitoring consistency of cloud detection with various tests, performing regional statistics, keeping cloud detection independent of satellite view angle, and correlating with SST and OLR determinations. A revised ATBD was distributed in November.

The CERES team installed the Satellite Image Visualization System (SIVIS) on the UW workstation. This cloud mask tool has been used to generate masked images from MAS and AVHRR data sets using combinations of visible and infrared threshold tests. This tool will be extremely valuable in defining and testing many of the MODIS cloud mask algorithms.

Global Cloud Studies. An automated method of monitoring various climate parameters has been developed. The CHAPS (Collocated HIRS and AVHRR ProductS) algorithm was implemented during the months of July 1993, January 1994, and July 1994. Radiance measurements from the AVHRR and HIRS/2 instruments aboard NOAA-12 were used in conjunction with forecast model output from the National Meteorological Center (NMC) to produce global distributions of cloud altitude and amount, the spectral greenhouse effect of atmospheric water vapor, and spectral cloud radiative forcing. By collocating the high spatial resolution AVHRR (GAC) data within HIRS/2 footprints, scene homogeneity may be assured while preserving the high spectral information of the HIRS/2 instrument. Steve Ackerman and Rich Frey are the leading this effort.

Tri-spectral Cloud Phase Algorithm. Kathy Strabala continued investigation of the effectiveness of the 8-11 micron versus the 11-12 micron brightness temperature difference technique for discerning cloud phase. This effort is now focused on gathering coincident data for validation purposes.

MAS cloud parameters. The CO_2 slicing algorithm is being adapted to MAS data for testing MODIS cloud height and effective emissivity products. The software has been applied to MAS data and the results are under analysis. 5 km by 5 km boxes of MAS data are being used to emulate the application to MODIS data. Tests show that the results are vulnerable to weak 13.3 micron signal to noise. Results were improved by expanding the domain (essentially a spatial average) for the warm and cold temperature determination such that 13.3 micron and 11.0 micron signal to noise were roughly equivalent. However, expansion of the domain has the effect of reducing the natural variability in the data and thus the signal for the CO2 height and emissivity determination as well. When the MAS 50 channel data becomes available in January, the improved signal to noise in the CO2 channels is expected to help the height/emissivity determination; in addition the MAS 13.8 micron data will also be incorporated so that the MAS algorithm will become more like the eventual MODIS algorithm.

SCAR Activities. MAS SCAR-C (California) flights and activities were supported by Chris Moeller, Elaine Prins, and Kathy Strabala from September 21 through October 7, 1994. Satellite imagery interpretation and weather forecast information was provided for all days of the experiment. This included analysis of MAS data collection conditions and wildfire identification (using GOES-8 imager data) in support of mission planning. MAS SCAR-C missions were flown on Sept 21, 22, 27, 30, Oct 5 and 7. The first flight on 21 September included at least 2 fires in Northern California and 3 prescribed fires in Washington. Offshore flow and clear conditions throughout the region provided excellent viewing of the fires and smoke transport. Preliminary comparisons of GOES-7 and GOES-8 data for this flight demonstrate the improved capability of the GOES-8 data to identify isolated small fires which are not detectable in the GOES-7 data. The six days of MAS flights included controlled burns, wildfires, smoke plumes, smoldering and post-burn areas. Several flights were coordinated with the University of Washington C-131A (smoke plume in situ, CAR radiometer, etc.). On MAS flight days, GOES-7 and GOES-8 data were archived at the University of Wisconsin.

Regarding SCAR-B, we provided Yoram Kaufman with some view graphs outlining the anticipated UW-Madison involvement in the SCAR-B field program. He presented these at the planning meeting in Brazil in August. Recent information is that the SCAR-B field experiment will likely occur in August-September 1995. At this time we plan to support the on site people with nowcasting information via McIDAS and real-time access to diurnal GOES-8 imager data for weather forecasting and fire and smoke detection (based on the availability of internet access). The GOES-8 Automated Biomass Burning Algorithm will be operational in real time providing diurnal updates of fire locations and aerosol transport regimes. If internet access is not available, access via the World-Wide Web is possible for supplying daily updates but with limited real-time support.

UW Workstations. The UW RISC6000 workstation for preparing MODIS algorithms was enhanced with the addition of an Exabyte 8505 external tape drive. This drive is being used to read MAS data sets directly into the workstation, making the UW workstation self contained for MAS data processing (in McIDAS format), product generation, and analysis. In addition, a Silicon Graphics Power Indigo^2 workstation has been purchased. This workstation will facilitate using the SIVIS software developed by the CERES team to investigate cloud mapping algorithms. MAS data support software modified for the IBM RISC6000 environment will also be ported to the SGI workstation.

MAS January 1995 Flights. Five to six flights of the MODIS Airborne Simulator (MAS) with the High-resolution Interferometer Sounder (HIS) instrument are scheduled for January 1995 on NASA's ER-2 aircraft. The ER-2 will be deployed from Houston, TX (Ellington Field). In preparation for these flights, MAS has been integrated with a 50 channel 16 bit (12 maximum sensitivity bits recorded) digitizing system, replacing the old 12 channel 8 bit system. This system improves the dynamic range and sensitivity of the MAS instrument data as well as expanding the data collection from 12 channels to 50 channels. The improved electronics is also expected to increase signal to noise in all channels. Flights will cover water (Gulf of Mexico), coastal (Louisiana coast) and land (midwest) background both in clear and cloudy conditions. Atmospheric gradients of moisture and temperature will be overflown. A research vessel (R/V Pelican) will deploy in the deep water Gulf of Mexico during a portion of the experiment, providing in situ radiometric data for SST calibration activities. Balloon launches from ship and shore will provide atmospheric radiometric ground truth. GOES-8 Imager and Sounder, AVHRR, and TOVS data will be collected during ship and aircraft deployment.

Intercomparisons of MAS, HIS, and GOES-8 data from this field effort will demonstrate the MODIS calibration approach and apply techniques in preparation for MODIS post-launch calibration validation activities. Investigations into Cloud properties (height, emissivity, particle size, and thermodynamic phase) and cirrus detection (MAS 1.88 micron channel) will be supported by this data set. This data set will also be used for testing the MODIS Cloud Mask Algorithm.

Aerosol Detection. The manuscript entitled "Satellite remote sensing of H2SO4 aerosol detection using the 8 to 12 micron window region: applications to Mount Pinatubo" by Ackerman and Strabala was published in the September issue of the Journal of Geophysical Research. Original investigations of the 8-11 micron brightness temperature difference aerosol signal were developed using HIRS March through November 1991 data sets. This processing is being expanded to include 2 years of data for comparison with optical depth measurements from analyses of solar beam observations from Mauna Loa, Hawaii by Elsworth Dutton.

Infrared Calibration. A technique to calibrate one sensor with the blackbody from another was successfully tested with GOES and Meteosat data (as part of another program at UW). By matching empirical distribution functions of the raw counts from collocated data, the distribution of Meteosat counts is matched to the distribution of GOES counts (assuming there is sufficient variation in the scene so that as much of the range of possible counts is involved). Then with M-3 counts matching G-7 counts, M-3 counts are correlated with G-7 radiances (via linear fit). G-7 radiances are converted to M-3 radiances by correlating clear sky forward calculations for the given atmospheric state and the respective spectral response functions. Then M-3 radiances calibrated with the G-7 blackbody can be compared with the operationally calibrated radiances. For several different cases, the mean difference for the temperature range was 0.5 C and the standard deviation about that mean was about 0.5 C.

Special attention has been paid this quarter to the problems presented to the data users by the scan mirror induced angle dependency of the polarization and reflectivity in bands 29 and 30. Methods to reduce the problem by new uses of the inflight data are being investigated.

MODIS WWW Page at UW. A MODIS World-Wide Web page has been created which documents the role of the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the UW in the MODIS project through in line text, figures, and movies. The HTML document will be completed and released as a sub-heading under the CIMSS WWW Home Page by the end of January 1995.

DATA ANALYSIS

MODIS Spectral Response Functions

The infrared spectral response functions of the MODIS were compared with the earth-atmosphere emitted spectrum. FASCOD3P was used with a U.S. standard atmosphere to calculate the nadir viewing emission spectrum. Figure 1 shows the comparison.

Investigation of Spectral Greenhouse parameters

An automated method of monitoring various climate parameters using collocated AVHRR (Advanced Very High Resolution Radiometer) and HIRS/2 (High-resolution InfraRed Sounder-2) observations has been developed. The method, referred to as CHAPS (Collocated HIRS/2 and AVHRR ProductS) was implemented during the months of July 1993, January 1994 and July 1994. By combining the spectral resolution of an atmospheric sounder (HIRS/2) with the spatial resolution of an imager (AVHRR), the radiative properties of clear sky regions may be more accurately described.

The radiance data were acquired in near-real time from the Man-computer Interactive Data Access System (McIDAS) at the University of Wisconsin-Madison. Global fields of vertical temperature and moisture profiles were obtained from the National Meteorological Center (NMC) in Camp Springs, MD. Weekly global Reynolds Blended sea-surface temperatures (SSTs) were also received from the NMC. Although the attempt was made to process as much data as possible, HIRS/2 fields of view (FOVs) beyond 30 degrees were eliminated from the collocation in order to minimize problems associated with limb measurements. Also, poleward of 70 degrees latitude only 1 of every 4 FOVs was collocated with AVHRR pixels, due to the oversampling by polar orbiters in these regions. By restricting scan width, the amount of time needed to achieve truly global coverage is lengthened to 2 days, but any given geographical area is observed at least once for 4 consecutive days near the equator and more often nearer the poles. Even with the above restrictions, approximately 20,000 collocated HIRS/AVHRR FOVs were collected per orbit. The collocated measurements (as well as all derived products) were mapped onto an equal-surface-area grid according to the International Satellite Cloud Climatology Project (ISCCP) binning scheme. Each gridbox is approximately 250 km on a side.

Using HIRS/2 spectral measurements and AVHRR GAC collocated pixel data, an attempt was made to determine which of the HIRS/2 FOV locations (if any) were clear within each ISCCP region viewed. Using AVHRR 11 micron radiance measurements, a histogram method was used to develop a clear sky brightness temperature threshold (CST) valid for a given ISCCP region. In each region where a valid CST was found, a series of "clear sky tests" was performed for each FOV. HIRS/2 spectral measurements, means and standard deviations of collocated AVHRR data within each HIRS/2 FOV, and the CST were utilized to eliminate FOVs which were cloud-contaminated. The method is fully described in Frey et al, 1994. Information from individual clear sky FOVs was used to infer certain regional mean clear sky radiative characteristics. Thus far, clear sky determination and derived products have been developed for ocean regions only, though cloud information from the CO_2-slicing algorithm and radiance data has been saved for all locations.

One of the derived clear sky radiative characteristics is a normalized greenhouse parameter defined as

$$g_\lambda = \frac{B_\lambda(T_s) - I_{\lambda,cs}}{B_\lambda(T_s)}$$

where $B_($(T_S) is the Planck function at wavelength (and surface temperature T_S and $I_{(,cs}$ is the satellite observed clear sky radiance. Plotted versus SST, the greenhouse parameter is a demonstration of the atmospheric water vapor feedback to SST variation. The relationship between the spectral greenhouse parameter for wavelengths of 11, 8.3, 7.3 and 6.7 micron and SST are depicted in Figure 2 for January 1994. This figure was generated by averaging the SST and greenhouse parameters over the 2.5 degree ERBE grid. The higher the spectral channels peak in the atmosphere, the colder the temperatures and therefore the larger the value of g. The increase in $g_{8.3}$ and g_{11} with SST is related to the increase in precipitable water with SST. The $g_{7.3}$ and $g_{6.7}$ are correlated to large scale circulation patterns which are also coupled to the SST. For example, tropical convection which transports moisture into the upper troposphere is associated with warm SSTs, while subsidence which dries the upper troposphere is observed over the cool waters associated with persistent stratus regimes. Figure 3 shows g as a function of latitude for HIRS/2 channel 8 (11 micron). Here, values of the spectral greenhouse parameter were averaged over 10 degree latitude bands. The center point represents the mean, the box denotes plus and minus the standard error and the whiskers plus and minus a standard deviation. The solid circles represent January values and the open squares July measurements. Maximum values occur in the tropics where SSTs are the warmest and water vapor concentrations greatest. Commonalities are strong between the summer and winter hemispheres. For example, peak values occur within 10 degrees of the equator in the summer hemisphere. Large variations of water vapor spectral greenhouse parameters occur as a function of latitude as seen in the standard deviations. Variability is larger in the tropics than in the mid-latitudes, though variations do exist there. Latitudinal changes are similar for the winter and summer hemispheres. Similar hemispheric patterns and changes in variability with latitude are seen for the other water vapor channels mentioned above (not shown).

Greenhouse parameter values were also calculated for HIRS/2 channels which are sensitive primarily to temperature rather than atmospheric water vapor content. For example, the 14.2 micron channel has a weighting function which peaks near 250 mb. The greenhouse parameter for this channel is strongly a function of season, particularly poleward of 45 degrees. Unlike the water vapor channels, $g_{14.2}$ shows the greatest variation in the mid-latitudes and only small variability in the tropics. These features are likely related to changes in the height of the tropopause during the progression of mid-latitude cyclones. Of course, this effect is strongest in the winter hemisphere.

The feasibility of collocating imager and sounder data in order to derive a variety of global climate products in near-real time has been demonstrated. The method may be easily modified to an operational procedure or may also be adapted to process historical data sets. Using polar orbiter data, it is possible to build an archive of high quality clear sky parameters over the world ocean.

Cloud Mask Test Data Set

An initial global ocean cloud mask test data set has been generated utilizing the Ackerman/Frey collocated AVHRR/HIRS clear sky technique. Figure 4 details the various tests. The data set consists of input HIRS and AVHRR GAC observations from 6 December 1994 and the resultant output cloud mask in a point source data file. The point source file contains clear or cloudy determinations from the 10 different individual clear sky threshold tests and the final cloud mask product as determined from the tests at the HIRS data resolution. The input and output data sets will be distributed along with MERLIN, a data manipulation toolkit. This is a freeware version of the Wisconsin toolkit with a GUI on top. It allows visualization of both the input and output data sets separately or combined. Figure 5 is an example of the cloud mask product overlaid on the coincident HIRS image.

This test data set has been developed to allow MODIS algorithm developers relying on the operational MODIS cloud mask to decide which individual tests may be most useful for their products, to demonstrate the feasibility of a global MODIS-like cloud mask, and to estimate processing requirements and data volumes. Many of the threshold tests which will be used in the proposed final MODIS cloud mask product are included in this cloud mask; however, the way in which the tests are applied and the proposed resultant bit format are not in final form. The software which produced this test data set has been transferred to the SDST as the cloud mask product beta software delivery.

ANTICIPATED FUTURE ACTIONS

Second Software Delivery. A cloud mask data set over land will be processed using LAC AVHRR and HIRS. This will supplement the ocean only data set already delivered. Benchmark data delivery will occur in the next quarter.

Cloud Properties Algorithm Development. Using the 50 channel MAS data from January, another attempt will be made to process cloud height and emissivity using the improved CO2 channel data.

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. Five flights are planned for the 7 - 21 January 1995.

MEETINGS

UW hosted the cloud mask team meeting in Madison, WI in Aug 1994 attended by scientists from LaRC and South Dakota School of Mines and Technology.

Paul Menzel presented the Cloud Mask ATBD to the assembled MODIS scientists at the meeting in Flathead Lake, MT in Sep 1994.

Paul Menzel presented at the Calibration Team Meeting in October 1994 the technique for intercalibration of satellite sensors mentioned above and also expressed some concerns on vacuum test characterization of background radiation and stray light.

Paul Menzel, Chris Moeller, Kathy Strabala, and Dan LaPorte attended the MODIS Science Team Meeting in October 1994. The initial version of the MODIS cloud mask was presented by Paul Menzel at the plenary. Kathy Strabala presented the tri-spectral cloud phase technique to the Atmospheres Group.

Elaine Prins attended a SCAR meeting at GSFC in November 1994. Early results from SCAR-C were reviewed and plans for SCAR-B in 1995 were discussed.

Dan LaPorte visited SBRC to discuss calibration issues relating to blackbody polarization and angle dependent emissivity of the scan mirror.

PUBLICATIONS

Frey, R. A., S. A. Ackerman and B. J. Soden, 1995: Climate Parameters from Satellite Spectral Measurements Part I: Collocated AVHRR and HIRS/2 Observations of Spectral Greenhouse Parameter. Submitted to Jour. Clim.

Prins, E. P. and W. P. Menzel, 1994: Trends in South American Biomass Burning Detected with the GOES-VAS from 1983-1991. Jour. Geo. Rev., Vol. 99, No. D8, 16719-16735.

Wylie, D. P., W. P. Menzel, H. M. Woolf, and K. I. Strabala, 1994: Four Years of Global Cirrus Cloud Statistics using HIRS. Jour. Clim., Vol. 7, No. 12, 1972-1986.

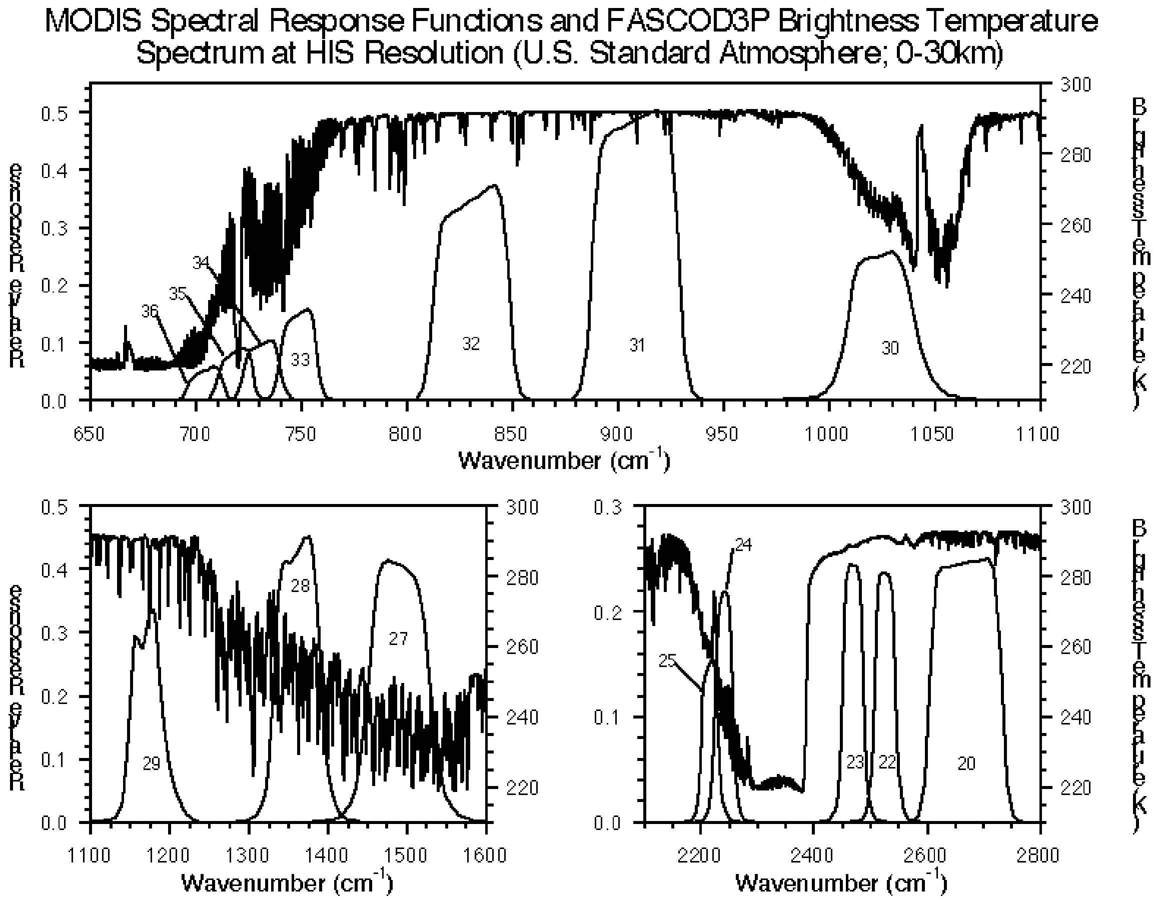

Figure 1: MODIS infrared spectral response superimposed on nadir viewing emission spectrum of U.S. Standard Atmosphere from FASCOD3P.

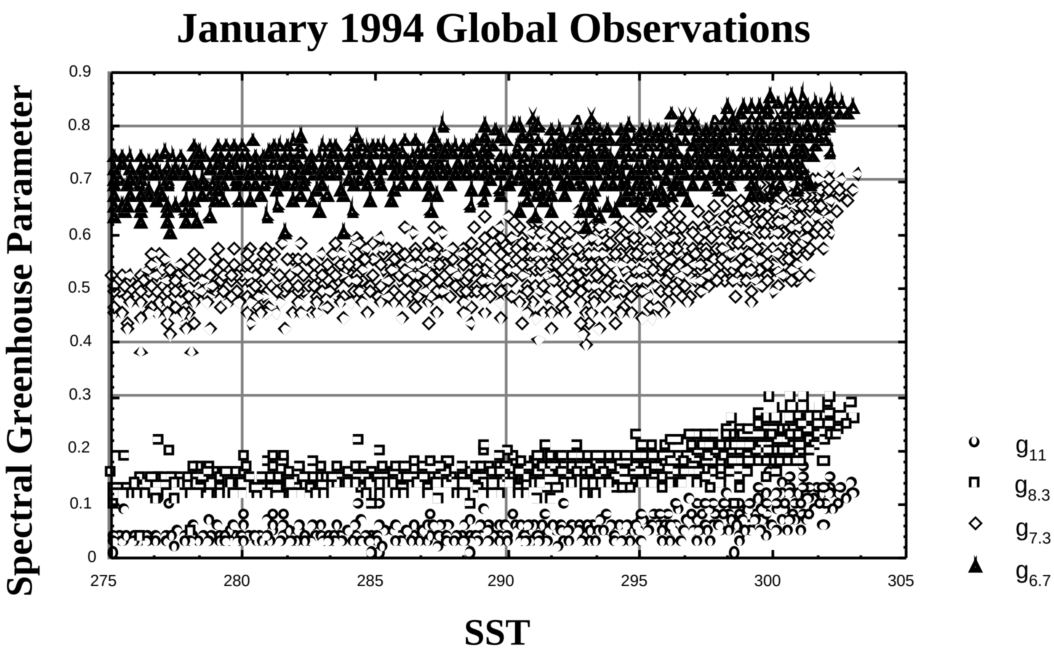

Figure 2. The spectral greenhouse parameter for wavelengths of 11, 8.3, 7.3 and 6.7 micron as a function of SST for January 1994.

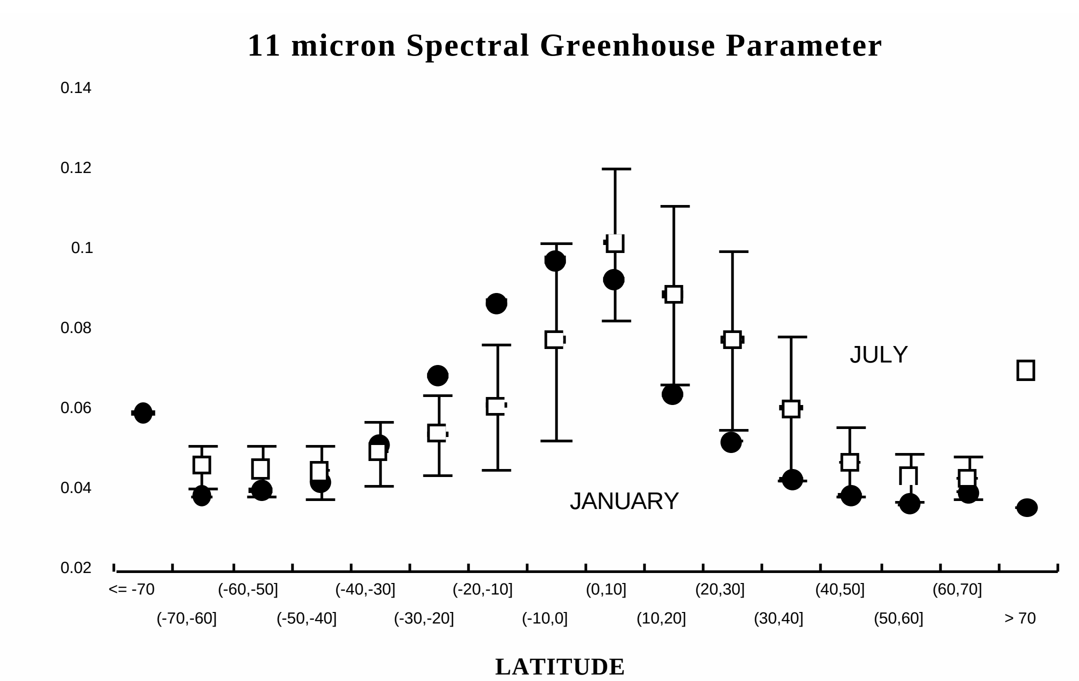

Figure 3. Box whisker diagram of g_{11} as a function of latitude.

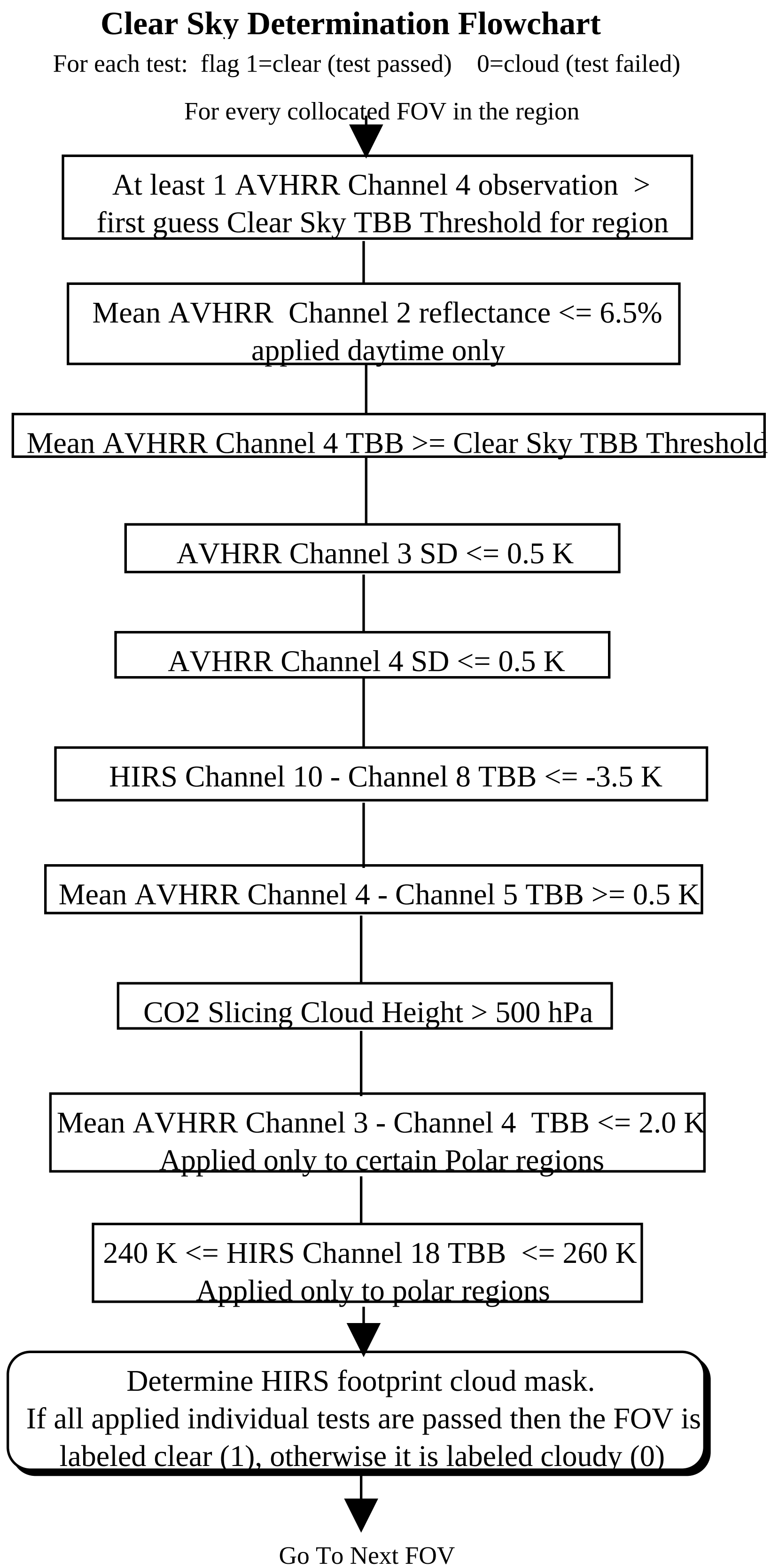

Figure 4. Flowchart showing the initial global ocean MODIS cloud mask test data set determination process for each collocated AVHRR/HIRS FOV.

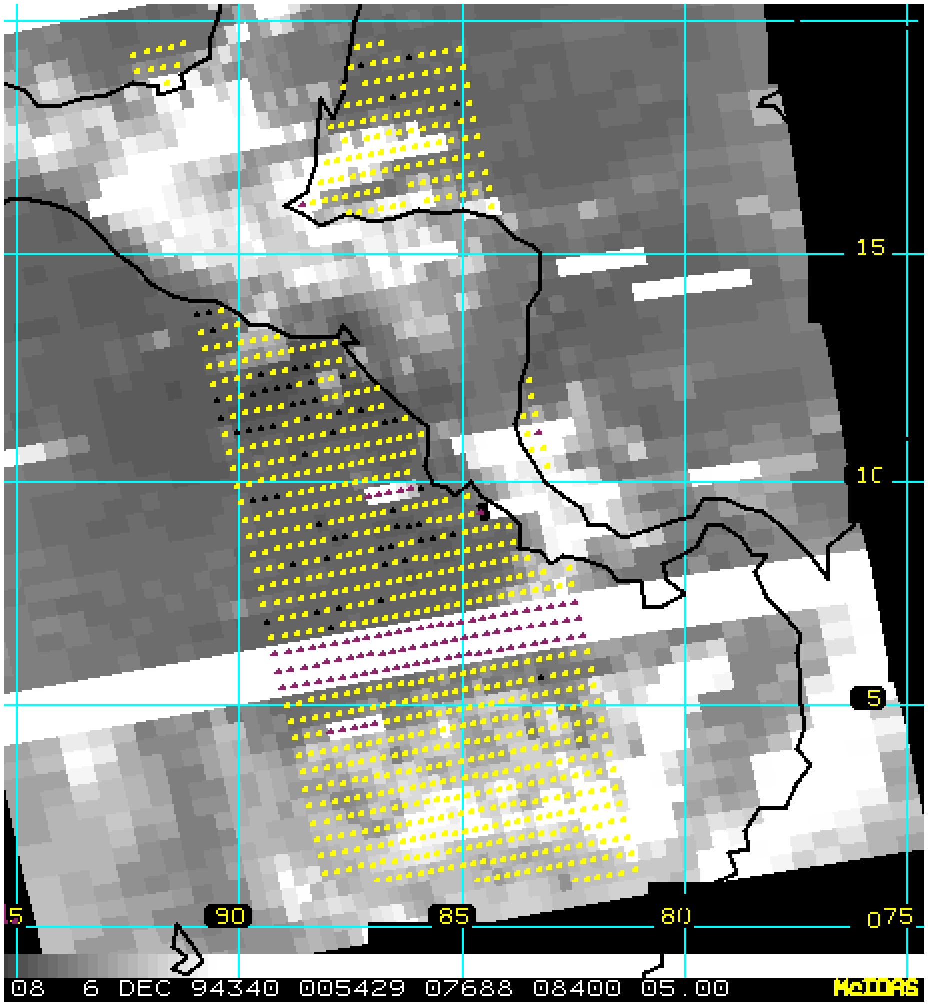

Figure 5. Cloud mask test results from a portion of 6 December 1994 HIRS data. The black dots represent FOVs which passed all applied clear sky threshold tests. The light dots are HIRS pixels which failed at least one test, and the dark triangles are regions where data was missing and the tests could not be applied.