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(This reports covers the MODIS **cirrus characterization and correction** algorithm and part of the MODIS **near-IR water vapor algorithm**)

Main topics addressed in this time period:

1. **MODIS near-IR water vapor algorithm**:

Science algorithm: The combined V2 near-IR water vapor and aerosol algorithm has been revised and delivered to the MODIS Project in May of 1999. Allen Chu has been interacting with MODIS SDST, to make changes so that the delivered software is working on newer operating systems having updated tool kit environment.

The problems present in the aerosol correction module of the near-IR water vapor algorithm and reported previously have been resolved. The module has been re-written (Shen) completely in Fortran90 language with improved interpolation techniques and table-searching procedures. The required computer memory for the execution of the code has been reduced significantly. The processing speed has also been increased dramatically. It now takes less than 3 minutes to make corrections on a pixel-by-pixel basis for a granule of MODIS data set with approximately 1350x2000 pixels. This module is now being integrated into the MODIS toolkit environment and will be delivered to the MODIS Project in a near-future upgrade.

Validation: We plan to use water vapor measurements from microwave radiometers, lidar, radiosondes, GPS network, and AERONET to verify water vapor values retrieved from MODIS near-IR water vapor channels. We also plan to use simulated water vapor image from DAO for the validation. Dr. Rich Ferrare of NASA Langley Research Center, an EOS Validation scientist, will make significant contributions to the validation of MODIS water vapor product using ground-based lidar and microwave radiometer data at the DOE ARMS site in Oklahoma. Gao and Shen have been interacting with DAO on the DAO water vapor product. DAO will likely be able to provide the water vapor simulations at a grid of 1 degree by 1 degree in the near future. We do plan to compare water vapor images derived from MODIS near-IR channels with the water vapor field simulated by DAO.

In order to validate the MODIS products, we must be able to view efficiently our level 2 and level 3 data products, and to find out errors in the products. At present, the viewing of level 3 products does not seem to be a problem. However, the viewing of level 2 products at the granule level still has minor problems. We ported over a software package called HDFLOOK from the MODIS Land Group. This package allows the viewing and dumping of images from huge HDF files. It does not correct for the “bow-tie” effects, which are present in the L1B and L2 data products. The bow-tie effects distort images at large looking angles. Coastal lines may appear zigzagged. An isolated cumulus cloud may appear at several pixels. The bow-tie effects need to be removed in order to obtain nice-looking level-2 images. We have recently copied over another set of softwares developed by the MODIS Land Group for producing the L2G data products. We will soon make minor modifications to the codes to obtain the bow-tie-effect-corrected L2 images.

2. **MODIS thin cirrus and contrail algorithm**:

The science algorithm includes two parts: thin cirrus reflectance and contrail detection. The V2 algorithm was delivered to MODIS SDST in early December of 1997. The algorithm was packed together with other cloud algorithms to form a combined algorithm (MOD_PR06). This combined algorithm has recently been delivered to the MODIS Project.

Since the delivery of our at-launch version of the algorithm, additional progress has also been made in the science algorithm development. The delivered at-launch version of cirrus reflectance algorithm is simple and fully functional. However, the 1.375-μm transmittance factor for water vapor above and within cirrus clouds were estimated based on latitudes and longitudes. The key in our algorithm for retrieving cirrus reflectance in the 0.4 - 1.0 μm spectral region is to accurately estimate the 1.375-μm water vapor transmittance factor. We have developed an operational algorithm to make such estimation from imaging data themselves. The transmittance factor is derived from the scatter diagram of 1.375-μm channel vs 1.24-μm channel for ocean pixels, and from the scatter plot of 1.375-μm vs 0.66-μm channel for land pixels. The algorithm has been further tested and refined during the past six months using spectral imaging data acquired with the NASA JPL AVIRIS instrument. We will incorporate this algorithm to the first “post launch” version of MODIS cirrus reflectance algorithm.

During the past 6 months, Ridgway allocated time to support the cloud top parameters code development (MOD06OD). The cloud optical thickness retrieval code was found to have flaws that resulted in defective product image files. The code flaws proved difficult to diagnose, particularly because the original authors were no longer part of the code development effort. It was finally determined that the flaws were associated with incorrect lookup table references that were done in parallel for liquid and ice phase cloud particles. After the flaws were isolated, the algorithm development team was able to restructure the lookup table procedure, both to eliminate bugs and to greatly enhance performance. Less effort was expended on the contrail detection code during this period as compared to earlier ones. A systematic analysis was done to examine the contrail detection results as scale parameters were adjusted in order to improve sensitivity for various MAS image contrail widths and lengths. Additional visualization tools were developed to display retrieved contrails and statistical measures of contrail coverage. It is likely that additional post-launch tuning will be required when the MODIS 1.375 micron data becomes available.

3. **MODAPS**:

As the Atmosphere Group's PI Processing representative, Ridgway played significant roles in supporting the MODAPS processing. The activity included participation in monthly MODAPS PI processing meetings and weekly MODAPS status meetings that typically included representation by the processing team, Land, and Atmospheres science algorithm developers. Some primary issues included how to prepare for limited (50%) processing and limited (10%) distribution of products during the first 4-5 months post-launch. Of concern to the Atmospheres' team was how to coordinate algorithm development, testing and integration, and code promotion to operational status in order to allow rapid code fixes and science algorithm improvements during the early operational period. To this end, Ridgway worked with the MODAPS team to plan for installation of a replica version of the MODAPS processing environment on the Atmospheres test bed (Windoek).

As an adjunct to MODAPS, the Atmospheres group has planned for the use of a dedicated machine (Windhoek) to perform QA functions, aid in rapid algorithm testing and updates, and to support routine visualization. Ridgway coordinated the hiring of a system manager for the atmospheres QA/visualization processing system. He also worked with the science support team to coordinate L2/L3 Atmospheres visualization strategies. He created prototype global browse images from MODAPS synthetic X-day L3 test products. This included writing prototype shell scripts and IDL programs for processing L2/L3 data products. He met with the Wisconsin team to test and discuss their L1/L2 granule visualization tools, and to coordinate their participation in Windhoek development strategies.

4. **Radiative Transfer Modeling**:

Cirrus clouds, primarily in the upper troposphere and lower stratosphere, have a profound impact on the terrestrial climate system through their radiative effect. The detection of cirrus clouds and retrieval of their optical and microphysical properties are among the key objectives of MODIS project. These clouds are composed of exclusively of nonspherical ice crystals. The absorption and scattering properties of nonspherical ice crystals are fundamental to radiative transfer calculations and remote sensing applications involving cirrus clouds. In the past six months, Yang generated a database of the fundamental scattering and absorption properties of nonspherical ice crystals at 36 MODIS channels using the updated response functions at these channels. In the computation of the bulk optical properties of cirrus clouds, the effect of size distribution of ice crystals must be accounted for. Twelve in-situ observed size distributions typical to mid-latitude cirrus cloud systems in single-scattering computations were used. This database has been delivered to the MODIS Project.

The shapes of ice crystal in cirrus clouds are very diverse, ranging from well defined hexagonal columns and plates to highly irregular aggregates. To understand the impact of ice crystal habits on the radiance observed from satellite in cirrus cloudy condition, we also generate a database of the scattering and absorption properties for various ice crystal habits. In collaborating with our research group, Drs. Bryan Baum and Peter Soulen, are conducting numerical experiments on the sensitivity of the radiance from satellite to the ice crystal shapes. The preliminary results have been presented in a poster displayed in the 10th AMS radiation conference in Madison June 28-July 2, 1999.

Radiative transfer computation is mandatory in generating pre-calculated look-up tables of the cloud reflectance for the development of reliable and accurate retrieval algorithm under cloudy condition. In the case for cirrus clouds, the phase functions of ice crystals normally display a strong forward peak. To account for this strong forward peak in the radiative transfer calculation, thousand terms of Fourier expansion of intensity in terms of azimuth angle are required, leading to a tremendous demand on computer resource. To economize the computational effort, we have developed a novel scheme to truncate the forward peak without losing accuracy in radiative transfer computation. Using this truncation scheme, we are currently developing an efficient radiative transfer model which will be flexible in handling the radiative transfer in cirrus cloudy atmosphere; in particular, this new model will be robust in dealing with the vertical inhomogeneity of optical properties of cirrus clouds.

5. **Meeting**

Ridgway, Yang, and Gao participated the 10^{th} conference on atmospheric radiation organized by American Meteorological Society in Madison, Wisconsin from 28 June to 2 July. Gao had a poster on cirrus detection. Yang had a presentation on the parameterization of scattering and absorption properties for individual ice crystals.

6. **Publications**

Gao, B.-C., A practical method for simulating AVHRR-consistent NDVI data series using narrow MODIS channels in the 0.5 - 1.0 µm spectral range, Submitted to IEEE Transa. Geosci. Remote Sens. in April, 1999.

Gao, B.-C., and R.-R. Li, Quantitative improvement in the estimates of NDVI values from remotely sensed data by correcting thin cirrus scattering effects, accepted for publication by Remote Sens. Env. in June, 1999.

Gao, B.-C., Y. J. Kaufman, R. R. Li, and W. J. Wiscombe, Correction of thin cirrus scattering effects in the 0.4 - 1.0 µm spectral region using the 1.375-µm channel for improved remote sensing of tropospheric aerosols, land surface, and ocean color, in the *Proceedings of the 10th Conference on Atmospheric Radiation*, Madison, Wisconsin, *Vol. 1*, pp 413-415, June 28 - July 2, 1999.

Yang, P., and K. N. Liou, Finite difference time domain method for light scattering by nonspherical particles. Chapter 7 in Light scattering by nonspherical particles: theory, measurements, and geophysical applications, Eds. M. I. Mishchenko, J. W. Hovenier, and L. D. Travis (accepted and in press), 1999.

Yang, P., K. N. Liou, K. Wyser, and D. Mitchell, Parameterization of the scattering and absorption properties of individual ice crystals, J. Geophys. Res. (accepted and in press), 1999.

Wyser, K. and P. Yang, On the uncertainties of the refractive index of ice, Contr. Atmos. Phys./Beitr. Phys. Atmos. (accepted and in press), 1999.

Baum, B. A., D. P. Kratz, P. Yang, S.C. OU, Y. Hu, P. Soulen, and S. C. Tsay, 1999: Remote sensing of cloud properties using MODIS airborne simulator imagery during SUCCESS. I. Data and Models. J. Geophys. Res. (Submitted), 1999.

Liou, K. N., Y. Takano, and P. Yang, Light scattering and radiative transfer by ice crystal clouds: Applications to climate research. Chapter 16 in "Light scattering by nonspherical particles: theory, measurements, and geophysical applications" Eds. M. I. Mishchenko, J. W. Hovenier, and L. D. Travis (accepted and in press),1999.