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TASK OBJECTIVES

Most of this period was focused on the delivery of the Beta code for Level 2 and Level 3 Vegetation Index products. In addition "Interface Control Documents" (ICDs) and quality flags were developed as part of the input and output integration of all MODIS products. Much emphasis was placed on the gridding and compositing aspects of the level 3 VI product. In the area of Validation, a great deal of time and effort was placed on preparation, logistical and science, for the SCAR-B experiment in Brazil. Current efforts now involve validation of the VI products and establishing linkages of the VI with leaf vegetation biophysical parameters, namely leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (FPAR).

WORK ACCOMPLISHED

1. MODLAND Land Cover and SDST Meetings

A land cover meeting was held in Boston in January to assess product dependencies and to determine how the BRDF, surface reflectance, and vegetation index products might be integrated to aid in the development and implementation of the Land Cover Product. Compositing methodologies and gridding schemes were discussed as were data simulation plans.

In early April a MODLAND-SDST meeting was held near Goddard in which all products and dependencies were discussed. A general consensus was reached with respect to the level 3 vegetation index (VI) products. This product is dependent upon the surface reflectance product and the BRDF product. Thus, the fully composited, cloud-free VI product is seen as an atmospherically corrected and BRDF adjusted field which will result in a temporal series of VI images that are adjusted to nadir with minimal atmospheric variations. Angular and atmospheric variations have caused much noise in the composited NDVI product. These noise factors in turn get passed on to the net primary production (NPP), leaf area index (LAI) and absorbed photosynthetically active radiation (APAR) level 4 products.

The most efficient scenario involves using the BRDF and surface reflectance products to produce nadir-adjusted reflectances on a daily basis. With each temporal acquisition the surface reflectances will be composited by eliminating the most cloud contaminated pixels in favor of cloud-free, close to nadir pixels. The close to nadir pixels are preferred since they would require minimal BRDF adjustment. As the choice of pixels deviates from nadir, the BRDF model is used to extend these pixels to nadir. If the BRDF for this period is questionable or is missing, we would revert back to a "maximum value VI" approach with an

appropriate flag.

2. Standard Product Reference Guide

AM-1 MOD 13

Vegetation Indices; the normalized difference vegetation index, NDVI (#2749), and an enhanced, modified vegetation index, MVI (#4334).

Product Description

The MODIS vegetation indices (VIs) will provide consistent, spatial and temporal comparisons of global vegetation conditions which will be used to monitor the Earth's photosynthetic vegetation activity for phenologic, change detection, and biophysical interpretations. The VIs are determined daily and globally for land from MODIS blue, red and near-infrared reflectances (centered at 470 nm, 648 nm, and 858 nm, respectively). Two indices are planned; the normalized difference vegetation index (NDVI) will be a continuity index with the existing NOAA-AVHRR derived NDVI. A modified vegetation index (MVI) utilizes the blue band to remove residual atmospheric contamination due to smoke and sub-pixel/thin clouds; and uses a feedback adjustment to minimize canopy background variations and enhance vegetation sensitivity from sparse to dense vegetation conditions. The VIs utilize atmospherically-corrected (at ~50 km resolution), bidirectional surface reflectances, masked for water, cloud, and cloud shadow. The NDVI and MVI products are archived at 250 m and 500 m pixel resolutions, respectively, along with the sun and view angles of each grid cell.

Research & Applications

Vegetation Indices are utilized for global monitoring of vegetation conditions. The VIs are used as input in the land cover and land cover change products. They also play an important role in the derivation of the FPAR, LAI, and thermal products. The at-launch version will be fully operational.

Data Set Evolution

Although a global validation scheme has been implemented for the modified VI, a thorough evaluation and calibration of this index will be made at launch.

Suggested Reading

Huete, A.R., Justice, C.O., and Liu, H.Q., "MODIS Vegetation Index", Algorithm Theoretical Basis Document (ATBD), 1994.

Huete, A., Justice, C. and Liu, H., 1994, Development of vegetation and soil indices for MODIS-EOS, Remote Sensing Environment 49:224-234.

Liu, H.Q., and Huete, A.R., 1995, A feedback based modification of the NDVI to minimize soil and atmospheric noise, IEEE Trans. Geosc. and Remote Sensing, 33:457-465.

Los, S.O., Justice, C.O., and Tucker, C.J., 1994, A global 1 deg. by 1 deg. NDVI data set for climate studies derived from the GIMMS continental NDVI data, Int. J. Remote Sensing, 15:3493-3518.

Product Information MOD 13

Coverage: Global land surface (level 2) Spatial/Temporal Characteristics: (level 2) daily at 250 m (NDVI) and 500 m (MVI)

Key Science Applications: Global vegetation monitoring; Global biogeochemical and hydrologic modeling; Global and regional climate modeling, land cover characterization.

Key Geophysical Parameters: Vegetation index

Processing Level: 2 Product Type: Standard, at launch

Science Team Contact: Huete and Justice

Processing Team Contact: GSFC (Masuoka) Archive:

AM-1 MOD 34

Gridded Vegetation Indices; the maximum value composited NDVI (#2749a), and the BRDF adjusted MVI (#4334a).

Product Description

The MODIS gridded vegetation indices (VIs) will provide consistent, spatial and temporal comparisons of global vegetation conditions which will be used to monitor the Earth's photosynthetic vegetation activity for phenologic, change detection, and biophysical interpretations. The gridded VIs are 8, 16, and 30 day spatial and temporal, re-sampled products designed to provide cloud-free vegetation maps at nominal resolutions from 250 m to one half-degree. The NDVI composites consist of cloud-free and atmospherically corrected pixels at 250 m resolution and 8 day intervals and are based on the maximum value of NDVI. The MVI composites are calculated from cloud-free and atmospherically corrected, gridded surface reflectances standardized to nadir views through BRDF models at a nominal resolution of 1 km and temporal cycle of 16 days. The VIs are also composited to monthly (30 day) intervals. The 8 day NDVI composites contain 16 bytes for each grid cell, which include maximum NDVI value, red and NIR surface reflectances, solar and sensor zenith angles, relative azimuth, and quality control parameters. The 16 day MVI composites contain 12 bytes per pixel and include nadir-adjusted MVI value, nadir-adjusted red, NIR, and blue surface reflectances, median solar zenith and azimuth angles, and quality control parameters.

Research & Applications

Vegetation Indices are utilized for global monitoring of vegetation conditions. The VIs are used as input in the land

cover and land cover change products. They also play an important role in the derivation of the FPAR, LAI, and thermal products. The at-launch version will be fully operational.

Data Set Evolution

Although a global validation scheme has been implemented for the modified VI, a thorough evaluation and calibration of this index will be made at launch.

Product Information MOD 34

Coverage: Global land surface (level 3)

Spatial/Temporal Characteristics: (level 3) 8, 16, and monthly at 250 m (NDVI) and 1 km (MVI)

Key Science Applications: Global vegetation monitoring; Global biogeochemical and hydrologic modeling; Global and regional climate modeling, land cover characterization.

Key Geophysical Parameters: Vegetation index

Processing Level: 3 Product Type: Standard, at launch

Science Team Contact: Huete and Justice

Processing Team Contact: GSFC (Masuoka) Archive:

3. ICD and Code Delivery

An interface control document was prepared for the level 2 and level 3 VI products. At the level 2 stage, the VI was incorporated into the surface reflectance ICD, produced by Eric Vermote. At the level 3 stage, a compositing procedure required the use of a completely different ICD document.

4. Utah field trip.

Dr. Arnon Karnieli of the Ben Gurion University of the Negev, Israel visited our lab the first two weeks in June for the purpose of conducting field spectral measurements over microphytic surfaces. This is funded through the International Arid Lands Consortium with the objective of investigating the role of microphytic crusts in influencing the vegetation index signal over arid regions. It is hypothesized that the "soil artifact" problem that shows up in AVHRR-NDVI imagery, particularly over the Sahara desert, is due to the chlorophyll-bearing signal of active microphytic crusts and not due to variations in soils. Our goal is to better understand the behavior and activity of microphytic plants and how they could potentially affect the Vegetation Index signal which is meant to detect vascular plant activity only. Our study sites include microphytic plant communities both in southern Arizona as well as in Moab, Utah.

5. SCAR-B Brazil Experiment

The SCAR-B field experiment was officially approved by the Brazilian government with both MAS and AVIRIS included in the

flight plans. The MAS will provide imagery at a +/- 45 degrees scan, providing an opportunity to link the BRDF correction with the VI product generation. The AVIRIS will provide continuous spectra from 0.4 to 2.5 microns, enabling us to simulate MODIS channels, particularly the 'blue', which is needed for the MVI and ARVI equations. Wim van Leeuwen attended the final planning meeting will be held in Brasilia on June 27-30, 1995.

5.1 Brazil SCAR-B Mission Plan:

The primary goal of the SCAR experiment to the land surface group is to obtain simultaneous in-situ and remote measurements of reflected and emitted vegetation signals from Amazonian plant communities under both "clear" and smoke-contaminated atmospheric conditions. Many of the land surface objectives are related to the Earth Observing System (EOS) program, particularly vegetation parameter extraction, land cover and land cover change, vegetation indices, fire mapping/detection, canopy biogeochemistry, and Amazonian rain forest hydrology. The primary EOS beneficiaries will be the MODIS land team and the EOS-IDS Amazon Hydrology Project (UW-Brazil) group. In addition, other geologic, ecologic, and agricultural objectives related to the unique high spectral resolution capabilities of AVIRIS will be addressed by INPE and other Brazilian agencies. The SCAR-B experiment provides an excellent opportunity to study the 'coupled' plant canopy and atmosphere radiative transfer process for improved atmospheric and surface parameter extraction.

Conversion of forests to agriculture and pastures is the major type of land use change in the tropical regions of the world. Fire plays a major role in the process, being used to consume the debris resulting from land clearing of primary and secondary forests as well as in the prevention of subsequent invasion by weeds and shrubs. Undisturbed tropical forests typically have a closed canopy structure that restricts the access of solar radiation to the ground, increasing the relative humidity in the forest understory. Deforestation and the use of fire produce alterations in specific composition, spatial patterns of distribution, and successional pathways of ecological communities. The joint effect of these processes is loss in biodiversity and hence regeneration patterns. Despite large amounts of work already conducted in the tropics, the enormous extent and great heterogeneity of tropical forest ecosystems makes it easy to identify major knowledge gaps and design appropriate remote sensing tools and methodologies to examine these complex and dynamic areas. Thus, new 'remote' methods to study vegetation heterogeneity are required; variability in biomass, burning, and fuel loads need to be better estimated; and the inter-relationships among microclimate, fuels, fire and carbon dynamics need to be better understood.

Remote sensing of tropical vegetation and the effect of deforestation and regrowth are of major importance for regional ecosystems as well as global climate. In the tropics, remote

sensing of these processes is difficult due to smoke, that obscures observation in the visible and near-infrared regions of the spectrum. In SCAR-B it is planned to collect remote sensing data of different surface covers in the tropics, in the presence and absence of smoke, and to compare different remote sensing techniques to parameterize tropical rain forest vegetation.

One of the most important reasons for the SCAR campaign is the recognition that atmosphere cannot be separated nor treated independently from the land. The MODIS land team (MODLAND) has learned the difficulty in development of surface parameter algorithms without incorporation of atmosphere. Current atmospheric correction algorithms make large assumptions with respect to the spectral properties of the land surface (e.g., assumption of dark object reflectances). Furthermore, atmospheric corrections are accomplished at very poor spatial resolutions, which at best involve 100 x 100 km cells, i.e., everything inside this cell is assumed uniform in aerosol distribution. Thus, what makes this campaign so valuable is the joint effort from land and atmospheric scientists in understanding the effects of aerosols and smoke on the vegetation signal and in the development of atmospheric correction of land products. One of the important interfaces between the land and atmosphere communities for joint algorithm development is the "blue" band, which the MODIS Airborne Simulator (MAS) does not yet have, but AVIRIS does. MAS and MODIS compliment each other to produce MODIS products via the angular properties of MAS (wide across-track swaths), the blue and middle-IR channels in AVIRIS, and the calibration strengths of AVIRIS. AVIRIS will compliment MAS and serve as back-up.

AVIRIS flights over Brazil are extremely important to the mission and objectives of the land surface group. It is valuable for MODIS land and atmosphere algorithm development and is valuable to the EOS-IDS teams as well as INPE. The blue band has become one important interface between the land and atmosphere groups. The atmospheric resistant vegetation indices as well as mixture modeling methodologies attempt to minimize aerosol effects on a pixel by pixel basis, based on an understanding of the spectral dynamics of both land and atmosphere. An atmospheric resistance component utilizing the blue band has been incorporated into an improved vegetation index for the MODIS and possibly other EOS sensors. The SPOT4-VEGETATION sensor has also added an "experimental" blue band to their global terrestrial monitoring goals.

Testing of such algorithms on OTTER and BOREAS data have shown smoke plumes and thin (subpixel) clouds to disappear in TM and ASAS imagery. The SCAR campaign will provide a unique opportunity to test such improved algorithms over complex angular, atmospheric, and land surface conditions to ensure that the reduction of atmospheric effects does increase vegetation sensitivity and information content. These are unique in that both land and atmospheric scientists team up to work in so called, noisy (disturbed) areas where there are serious aerosol, smoke,

and other sources of atmospheric contamination. The results of SCAR will answer many of the complex atmospheric issues for land-based algorithms for MODIS and the EOS program.

Aside from land-atmospheric concerns, the Amazon Basin and cerrado provide a diverse and important range of vegetation conditions. There are a variety of rain forest vegetation communities with differences in canopy structure and biomass. Heterogeneity is extreme with various stages of secondary regrowth, clearing (cutting and burning), primary forest, agriculture, and dry-wet grass/shrub cerrado. Vegetation growth, net primary production, and biogeochemistry (organic carbon, nitrogen, etc.) vary widely among the disturbed and natural sites, related to land use type, pressure, and history. The very dynamic and perturbed nature of the SCAR sites offer real world land surface conditions as well as uniform field site conditions. We need to understand these anthropogenic disturbances in order to better interpret perceived climatic changes in the future.

5.2. Objectives

1. Influence of smoke particles, water vapor, trace gases, and clouds on the spectral signatures and vegetation signals from forested, savanna, geologic, and agriculture sites.
2. Measurements of radiative transfer within rain forest vegetation communities, including canopy spectral transmittance; canopy extinction coefficients; canopy reflectance; intercepted and absorbed PAR; soil, litter, and understory reflectance; and 'pure' leaf, soil, litter, and wood spectral signatures.
3. Vegetation index (VI) algorithm development in 'high biomass' conditions.
4. Atmospheric resistance VI modelling under complex and variable atmospheric conditions which include smoke and other spatially varying aerosols.
5. The effects of land use conversion and biomass burning on (1) canopy radiative transfer; (2) canopy and soil biogeochemistry; (3) soil, vegetation, and litter parameters and dynamics; (4) canopy structure and morphology.
6. Remote sensing of fires, fire scars, land cover, and degrees of vegetation disturbance, related to primary and secondary stages of rain forest vegetation.
7. Remote sensing algorithms for the study of biomass burning related to ecological processes, including prediction of fire intensity and spread, burning efficiency, fuel loading, fuel moisture content, and trace gas emissions.
8. The use of high-resolution spectral mixing models to (1) differentiate rain forest vegetation communities; and (2) detect

mineralogic (geologic) deposits.

9. Validation of BRDF, atmospheric, land cover, fire, LAI/FPAR, and VI algorithms planned by the MODIS land team over seasonal and humid tropical rain forest. MAS will provide limited ($\pm 45^\circ$ across swath view angles) data from which angular corrections could be made based on BRDF derivation.

Two priority research study sites:

1. Alta Floresta:
north/south flight from: 56 deg 03' S to 56 deg 08' (LAT)
9 deg 40' W to 10 deg 40' (LONG)
2. Maraba:
north/south flight from: 5 deg 30' S to 6 deg 00' (LAT)
49 deg 05' W to 49 deg 10' (LONG)
6. SPOT-VEGETATION

I attended the first SPOT-VEGETATION team meeting in ISPRA, Italy, June 19-22, 1995 as a member of the IUC (international users committee) and representative of MODIS. The SPOT-VGT sensor will have daily coverage even at the lowest latitudes. This combined with the HRVIR sensor will enable fine and coarse resolution data to be simultaneously measured, a great advantage for multi-resolution studies and ground truth studies/validation of the coarse resolution global data.

SPOT-VGT will provide to data formats -P and -S data with P being the calibrated 'raw' data, and -S being the daily and composited, geophysical products. The data processing segment includes 4 main functions: (1) generate and maintain a Core Archive of all data (including a minimum of ancillary data); (2) generate "enhanced products", (3) maintain and catalogue existing data, and (4) facilitate the use of VGT products and develop enhanced, new products considering both "evolution" of the needs of the community and increased capability to correct raw data and extract new information. Thus there is a provision for maintaining continuity in the data while allowing for evolution of the algorithms and processing of the data.

Malingreau summarized the themes of the SPOT-VGT team; (1) application studies, (2) canopy modeling studies, (3) evaluation of land surface parameters, (4) ecosystem dynamic studies (ecological), (5) development of spectral indices, (6) production in agriculture and forestry, (7) change detection, (8) land cover mapping and (9) drought assessment. The ecosystems and geographical areas covered by the investigators included tropical forest, boreal forest, grasslands, agriculture, savannas, arid lands, and subtropical vegetation. It was felt that arid lands were under-represented and coastal zones missing. The following "supporting actions" were also included in the program; cloud

detection, atmosphere correction, compositing, synergy (high and low resolution, and simulation (AVHRR to VGT).

7. Asian Land Cover Analysis

Jin Hongtao (M.S. student) attended the Geoinformatics '95 Meeting in Hong Kong, May 25-28, 1995 and presented a paper entitled "Asian Land Cover Mapping Using Temporal AVHRR Data", by Jin Hongtao and Alfredo Huete. Jin has been working with AVHRR temporal data (8 km pathfinder) to examine the use of multitemporal NDVI data for land cover discrimination in Asia. His primary area of research concerns transition zones and boundaries. The abstract to his talk is included below:

Abstract:

The high temporal resolution of the Advanced Very High Resolution Radiometer (AVHRR) provides an opportunity to map and update the land cover status of Asia at regional and continental scales. The 10-day composites of the Normalized Difference Vegetation Index (NDVI) of the AVHRR, 8 km Pathfinder data set were used in this study. The approach for land cover mapping is based on a mixture model applied to the temporal NDVI (seasonal) signatures for the different land cover types. The mixture decomposition technique (unmixing) identified the number of unique phenology-based land cover types, improved the determination of boundaries of different land cover types, and enabled effective definition of transition zones in terms of their respective "pure" land cover classes. Sites from the Chinese Ecological Research Network (CERN) were chosen as the locations for extracting signals from the land cover end members ("pure" signatures). The resulting, "fractional" images, delineated the contribution of sub-pixel land cover components to the original signal. Test areas with multiple land cover types were initially used to test the mixture model technique. Comparisons with traditional land classification schemes, including unsupervised classification and principal component analysis, showed the potential improvement that can be attained with the mixture model on temporal AVHRR data.

8. VI-Validation

Various data sets are being used for validation of the VI. These data sets are being used to test the VI under as wide a range of conditions as possible and look for anomalies in the data processing. TM, AVHRR, and ASAS data are the primary data sets being used to test the VIs under different vegetation conditions with angular and atmospheric variations.

8.1 TM-Validation Data Set

Over 20 Landsat TM images have been processed for VI analyses and comparisons. The TM images represent a global set of vegetation conditions in North America, Africa, and Asia and have

been resampled to 250 & 500 m MODIS channels and have been Rayleigh corrected. The data are then converted to the normalized difference vegetation index (NDVI), the soil-adjusted vegetation index (SAVI), the atmospherically resistant vegetation index (ARVI), and the modified NDVI (MVI). There are many appreciable differences in the response of these VIs to the wide range of vegetation conditions. In particular, the saturation problem of the NDVI is greatly reduced with the SAVI and MVI. The on-going analysis includes the use of the dark-object subtraction technique to fully correct the images for atmosphere and the use of a 500 m blue band to produce an enhanced 250 m MVI. There is also an attempt being made to obtain estimates of the LAI and biomass conditions of the dominant vegetation in the selected scenes.

8.2 Chile Validation effort

I attended an ORSTOM-sponsored remote sensing conference at La Serena, Chile from April 24-27, 1995. I was an invited speaker and presented a 45 minute talk entitled "Extension of soil spectra to the satellite: atmosphere, geometric, and sensor considerations". In addition to the conference, I visited and spent much time discussing some of the proposed test sites for the "Global Land Cover Test Site (GLCTS)" initiative with Dr. Fernando Santibanez of the University of Chile, Santiago. Chile's wide range in climatic and vegetation conditions makes it an ideal test area for validation of vegetation products from space.

9. Biophysical Coupling of the VI's

Following suggestions from the ATBD Peer Review Panel, more emphasis is being placed in deriving biophysical products from the VI equations. Leaf area index (LAI), absorbed photosynthetically active radiation (APAR), and %ground cover parameters are being linked to the VI equations in an effort to assess VI linkages and sensitivities. The role of land cover type in controlling the VI-biophysical relationships is also being investigated with both simulated and experimental data sets. It appears quite definite that these relationships are land cover type dependent and will require a set of equations for each land cover type or biome.

The primary direction for MODIS derivation of biophysical parameters has also shifted toward a more direct derivation of these parameters from look-up-tables based on Myneni canopy model simulations. This effort will utilize spectral reflectances as input and is being directed by Dr. Steve Running who will serve as a backup to this effort and will also serve as part of the VI-validation effort.

ANTICIPATED FUTURE ACTIVITIES

1. SCAR-B experiment. The field campaign will run from August 15th through September 15th.
2. Aspen Global Change Institute session. Participant in sixth

annual Aspen Global Change Institute Summer Science Session, Aspen, Colorado, July 9-22, 1995. Session theme was entitled "Changes in Global Vegetation Patterns and Their Relationships to Human Activity". I will present a paper entitled "Soil radiative influences in satellite monitoring of vegetation".

3. Work on Version 1 code for level 2 and level 3 VIs.

4. Trip to GSFC for continued VI-Surface reflectance and BRDF integration into the compositing scheme.

5. Validation and simulation data reports to be completed by December 1995.

PUBLICATIONS

Leeuwen van, W.J.D. and A.R. Huete, 1995. Effects of standing litter on the biophysical interpretation of plant canopies with spectral indices. *Rem. Sens. Environ.* (accepted).

Leeuwen van, W.J.D., A.R. Huete, C.L. Walthall, S.D. Prince, A. Bague and J.L. Roujean, 1994. Deconvolution of remotely sensed spectral mixtures for retrieval of LAI, fAPAR and soil brightness. *J. Hydrology. HAPEX-Sahel special issue* (accepted).

Liu, H., and Huete, A.R., 1995, "A feedback based modification of the NDVI to minimize soil and atmospheric noise", *IEEE Trans. Geoscience and Rem. Sens.* 33:457-465.

Bague, A., Roujean, J.L., Hanan, N.P., Prince, S.D., Thawley, M., Huete, A., and Tanre, D., 1995, "Shortwave radiation budget of Sahelian vegetation during HAPEX-Sahel-1. Techniques of measurement and results", *Agric. & Forest Meteorol.* (accepted).

Epiphonio, J.C.N, and Huete, A.R., "Dependence of NDVI and SAVI on sun/sensor geometry and its effect on fPAR relationships in alfalfa", *Rem. Sens. Environ.* 51:351-360