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ANALYSIS OF TERRESTRIAL CONDITIONS AND DYNAMICS

Progress Report

August 1, 1983 - August 31, 1984

NASA Cooperative Agreement NCC 5-26

Principal Investigator

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CONTENTS

I. INTRODUCTION

The joint research activities between the Department of Geography, University of Maryland and the Earth Resources Branch (Code 623), NASA Goddard Space Flight Center, under NASA Cooperative Agreement NCC 5-26 were extremely active over the twelve month period ending August 31, 1984. As a result the semi-annual report for the period August 1, 1983 to January 31, 1983 was not filed but is contained herein along with report of research activities pursued between February 1, 1984 to August 31, 1984. The general objective of the research is to conduct analysis of land conditions with remotely sensed observations. The specific research pursued of the last twelve months has focussed on;

1. Measurement of land spectral reflectance properties for selected locations, including the Goddard Space Flight Center, the Wallops Flight Facility, a MLA test site in Cambridge, Maryland and an acid rain test site in Burlington, Vermont.
2. Development and implementation of methods to simulate the bidirectional reflectance properties of vegetated landscapes and continued development of a data base for spatial resolution studies.
3. Assessment of North American vegetation patterns observed with the Advanced Very High Resolution Radiometer and compilation of data and methods needed to model large-scale vegetation activity with remotely sensed observations and climate data.

Significant progress has been achieved in each research area which is reflected in the volume of professional presentations and publications that have been prepared during this period. Copies of these documents are provided in the Appendix. Additional publications are under preparation as will be reported in future progress reports.

Dr. Samuel N. Goward, Assistant Research Scholar with the Geography Department, is principal investigator and research director of the activities. Professor Corey, Chairman of the department, and other members of the faculty provide informal guidance and advice. Dr. Donald Petzold, Assistant Professor, was particularly supportive of research this year because he was able to arrange and accompanying Dr. Goward and Mr. Dye on a field study of the vegetation gradient between Maryland and central Quebec. Two graduate students, Mr. Dennis Dye and Ms. Sheila Donovan, are serving as research assistants. Mr. Dye is supporting the ecological modeling studies and is pursuing a Master's thesis on a related topic. Ms. Donovan is supporting the land radiance and scene simulation activities and is proposing to investigate bidirectional reflectance in her thesis work. Dr. Lucy-Ann McFadden a half time research associate on the Cooperative Agreement is supporting of the land spectral radiance studies. She has greatly assisted research activities during this year by carrying on an intensive assessment of new spectrometer instrumentation acquired by the Earth Resources Branch.

The research activities are carried out at the Goddard Space Flight Center (GSFC). The Earth Resources Branch provides work space, data and computer facilities to support the research. The University of Maryland staff interact daily with NASA scientists to carry out the activities. Principal NASA-GSFC contacts are Ms. Elizabeth Middleton, Mr. James Irons and Dr. Compton J. Tucker.

II. RESEARCH ACTIVITIES

A. Land Spectral Radiance Patterns

The need to acquire measurements of land spectral radiance properties in support of Earth Resources Branch studies has increased significantly over the last two years. A major shift and research emphasis has occurred in NASA earth observation objectives, away from applications studies of existing systems, toward more fundamental research concerned with development of new approaches to use of remotely sensed observations and providing knowledge needed to propose innovative new sensors for earth observations. University of Maryland staff supported and/or carried out observations of reflected spectral radiance and related phenomena for MLA science studies, Acid Rain research and large-scale ecological analysis during the last year. In addition Dr. McFadden carried out an intensive examination of the Spectron Engineering SE-590 spectrometer, acquired by the Earth Resources Branch to support the above-mentioned research areas.

SE-590 Evaluation. The primary instrument used for field reflectance measurements is a visible Si-diode array spectroradiometer. Laboratory tests of the performance parameters of this instrument were carried out in the fall. The data have been prepared for analysis. The linear dispersion and resolving power of the instrument have been measured and agree with he specifications within a few percent. Second order diffraction effects are observed, but they may fall on an unusable portion of the detector where silicon response is decreasing rapidly. The wavelength calibration needs to be checked before these parameters can be quantified and an accuracy determined.

During the summer and early fall, hand-held radiometric measurements of natural land covers at Goddard Space Flight Center were obtained using newly acquired SE-590 high resolution Si-diode array spectrometer. Software to process the SE-590 data was implemented on an Apple II computer by Charles Walthall during his summer internship with the University. His programs convert the binary output of the SE-590 microprocessor to ASCII characters, scale the data to 16-bit resolution (to take full advantage of the 12-bit resolution of the instrument), correct for different exposure times, and remove an offset put into the instrument to eliminate negative numbers from the data stream. The data can be uploaded from the Apple to a main-frame but at a presently unacceptably slow rate. We are presently investigating alternatives to speeding up this transfer of data.

Subsequent calibration procedures on an IBM 3081 were implemented by members of the SAR scientific support staff. The calibration involves scaling any calibration standard radiance (BaSO4 or white canvas tarp) to the radiance expected at the time of the target observation. We currently assume that a linear interpolation between two standard measurements is adequate to account for variations due to the path length through the atmosphere and solar elevation. Further computation of variations due to pathlength as a function of time of day and time of year and latitude are needed to quantify the accuracy of this assumption and the range over which it holds. With the standard corrected to the radiance at the time of the target observation, the target radiance is divided by the standard radiance. This eliminates instrumental and solar response.

Helicopter Platform Test. Information on the spectral reflectance properties of forests is sparse. This partly because the observation problem is considerably greater for trees than it is for grasses and agricultural crops. The greatest problem is actually getting the spectrometer instruments above the forest canopy in a platform which is both stable over short periods of time and sufficiently mobil that the variability in canopy forest reflectance may be measured. Discussions between D. Williams and S. Goward in 1983 lead to an experiment carried out on August 24, 1983 at the Wallops Island Flight Facility to evaluate the use of a helicopter as such as platform. Experience gained by NASA investigators during the LACIE-AgRISTARS experiments showed helicopters to be useful in spectral measurements. However the forest problem is considerably more complex, particularly with respect to natural variability of forest canopy cover and species composition. The results of the Wallops Island experiment were presented at the 10th International Symposium on Machine Processing of Remotely Sensed Data, held at Purdue University in June 1984. A reprint of the paper entitled "Collection of Forest Canopy Spectra Using a Helicopter: Discussion of Methodology and Preliminary Results" is provided in the Appendix.

Urban Materials Spectral Reflectances. Measurments of construction materials including brick, concrete, asphalt, gravel and paints were acquired at the Goddard Space Flight Center last year. These measurments were used to assist in analysis of Thematic Mapper observations of the Washington region. Mr. Stephen Wharton is analyzing this TM data in an effort to improve computer-based procedures for information extraction from remotely sensed observations. He approached Dr. Goward concerning possible new means to evaluate the spectral information in TM data. The TM "Tasseled Cap" transformation developed by investigators at the Environmental Research Institute of Michigan, was employed to examine the Washington D.C. scene. A unique distribution of spectral measurements was observed for urban materials. Evaluation of the ground-collected spectra showed that the unique urban spectral patterns originate in the blue part of the spectrum. This absorption difference between soils and urban materials of the region provides a new means to identify urbanization at least for regions such as Washington. The results of this study were presented at the 10th International Symposium of Machine Processing of Remotely Sensed Data held on June 12-14, 1984 at Prudue University. The paper presented is provided in the Appendix under the title, "Use of the TM Tasseled Cap Transform for Interpretation of Spectral Contrasts in an Urban Scene."

Shortwave Infrared Detection of Vegetation. A summary report of studies carried out under the AgRISTARS program to evaluate the value of TM band 5 (1.55-1.75 μm) data in analysis of vegetation was composed for presentation at the 25th Plenary Meeting of COSPAR held in Graz, Austria. This research on use of shortwave infrared measurements for vegetation studies provided empirical and theoretical evidence concerning the utility of SWIR measurements. The findings represent the most up-to-date summary of this knowledge available and thus Dr. Goward was invited to report on this research at the COSPAR workshop on Thematic Mapper and Future Sensors. The paper was well received at the workshop and will be published in its entirety is the next volume of Advances in Space Research. A copy of the draft manuscript is provided in the appendix under the title "Shortwave Infrared Detection of Vegetation."

MLA Field Studies. A Shuttle mission proposed to be flown in the late 1980's (which has since been cancelled) would employ multiple linear array technology in conjunction with a moveable mirror to observe land bidirectional reflectance patterns along the track of the Shuttle orbit. Land surfaces are known to possess anisotropic reflectance characteristics and limited field studies have demonstrated these patterns for a limited range of surface materials. It is hypothesized that anisotropic patterns vary as a function of such vegetation canopy properties as leaf angle distribution, biomass and percentage non-green materials. Current research has shown that nadir-only measurments of spectral reflectance can not be effectively used to estimate canopy LAI or biomass without knowledge of species, species composition and other description information. It is likely that bidirectional measurements will provide the needed additional information.

A field site, outside of Cambridge, Maryland was selected to carry out measurments in support of analysis of land bidirectional properties. The site consisted of an abandoned agricultural field with a natural growth of grasses surrounded by a mixed decidious-confierous forest. Sufficient variability occurs at the site to assess the variation of bidirectional reflectance as a function of selected canopy attributes.

University of Maryland staff supported this field measurements program by collection of leaf angle distributions and leaf optics, for the grasses, during two field experiment days, one in early June and one in Late June. These data are currently being reduced, along with measurments carried out by Dr. Deering's PARABOLA instrument and the LAPR-II aircraft mounted linear array instrument to evaluate the value and physical causes of land anisotropic reflectance.

Subarctic Spectral Measurements. As part of a field study carried out in early August under the ecological modeling portion of these research activities, University of Maryland staff (Dr. Goward, Dr. Petzold and Mr. Dye) carried out spectral measurements of a range of surface covers in the subarctic region near Schefferville, Quebec. These measurements show that lichens possess unique spectral reflectance properties compared to higher order plant forms with green leaves. This difference may be attributed to the complex but little known symbiotic relation between fungi and algae in lichens. The spectral measurements are currently being reduced and analyzed in preparation for a publication devoted to this unique phenomenon. The significance of these measurements vis-a-vis spectral vegetation index measurements and photosynthetic activity will also be examined.

Vermont Acid Rain Measurements. University of Maryland staff (Dr. Goward, Dye, Donovan and Hope) supported helicopter acquisition of spectral reflectance measurements over acid rain damaged forests near Burlington, Vermont during late August. These measurements are in support of research carried out by D. Williams (Code 623) to examine whether spectral measurements may be used to assess forest stress. The Maryland researchers carried coincident measurements of incident solar radiation in the spectral wavelengths observed in the helicopter-mounted instruments. They also assisted in marking field sites with weather balloons so that the pilot could accurately locate test sites on the ground. Problems with cloud cover plagued the operation but at least one half day of observations was sufficiently clear to produce good measurements. Data reduction is currently underway with no results to report as of yet.

B. Scence Simulation

High Spatial Resolution. An analysis of the land cover characteristics at a 2 meter resolution, for the Goddard Space Flight Center, from low altitude aerial photography was finally completed this summer. The region interpreted consists of approximately one square kilometer on the ground which means that at least 250,000 decisions potentially were made. The quality of the photography was poor and thus the interpretation problematic. Much higher quality photography was acquired this year during overflights of the Ames Research Center C-130 aircraft where both stereo pairs of CIR photography and multispectral observations with the NS001 "Thematic Mapper Simulator" (TMS). This new photography has been used to confirm the validity of the original interpretation.

The interpretation is now being digitized on the Laboratory of Terrestrial Physics HP-3000 computer by Ms. Donovan. Progress on the digitization is slow since the entry problem is enormous. Already approximately 6 months of half time effort have been devoted to compiling the file. Hopefully, within another 2 months the task will be completed. The data files may then be used to study the coincident NS001-TMS overflights.

Brian Markham and Dr. Goward tested a scan angle correction algorithm on the HP-3000 to see if it would account for the image distortion observed in the NS001 data. The algorithm was correctly formulated and the rectified image provides a reasonable first order approximate (not accounting for relief displacement) of a planemetric representation of the Goddard region. Further evaluation of the image awaits completion of the digitized photo interpretation. Ultimately the rectified aircraft observations will be subjected to a sensor model developed by Code 725 to simulate Thematic Mapper performance. These results will be compared with actual TM measurements acquired near simultatneously with the aircraft flight to evaluate our ability to simulate spaceborne measurements.

Bidirectional Measurements. A heated discussion occurred last summer between the MLA instrument engineers and members of the MLA science team concerning the need for 10 bits versus 8 bits in the A to D process carried out before the instument observations are recorded. Dr. Goward and B. Markham (Code 623) used principal plane bidirectional reflectance measurements acquired by Dr. Deering with ARABOLA over several vegetated land cover conditions to conduct an analytical experiment to evaluate the 8 bit versus 10 bit question. The Parabola measurements were converted to radiance and convoluted with atmospheric attention, as described by Dave, to simulate at-satellite radiance. Bidirectional measurments at 5^{0} increments from nadir where produced. These measurements were forwarded to Code 725 and subjected to the MLA sensor attributes with 8 and 10 bits A to D. Code 725 staff recently completed this simulation and the resultant data is now being evaluated.

Canopy Models. Several models of vegetation canopy bidirectional reflectance have been developed in recent years. These models are of great value not only in that they may be used to better understand observed land radiance pattern but also that they may be inverted such that radiance measurements may be used to estimate vegetation canopy parameters (which are required to run the model) thus infer vegetation characteristics of interest to earth scientists. For example most models require specification of leaf optics, leaf angle distribution and leaf area index in order to operate. In addition, information on the optics, area and angular distribution of non-green and woody portions of the plant may be needed. However the precision of the inferred parameters is only as accurate as the realism of the model allows. Little research has been completed to evaluate model realism, particularly for a range of view angles and view directions; Thus it is not clear whether bidirectional reflectance measurements may be used to estimate land vegetation properties with analysis techniques premised an inversion of this model.

Two models, one developed by Suits (1972) and an extension of this model developed by Goudrian (1978) called SAIL have been implemented at Goddard Space Flight Center computers. These models are the most likely candidates of inversion techniques because they the simplest to compute and therefore invert. Additional code modifications are needed at this time to permit efficient computation of the full hemisphere of bidirectional reflectance pattern. Comparison of the model results and measurements acquired at the MLA Study site, as described in section A will be used to judge the realism of the models.

C. Ecological Modeling

Observed North American Vegetation Patterns. Remotely sensed spectral vegeation index measurements may provide a major new approach to analysis of large-scale ecological processes. An analysis of North American NOAA-7 Advanced Very High Resolution Radiometer observations, for the 1982 growing season, has shown the spectral vegetation index measurements follow the known seasonality of regional vegetation types and that this temporal variability tracks the climatology of temperature and/or precipitation of selected sites. Research is beginning to show that there is a strong relation between the spectral vegetation indices and intercepted photosynthetically active radiation. Measurements of this type should be related to growing season gross and net photosynthesis. Comparison between the integral of vegetation index measurements over the growing season and available net primary productivity figures shows a strong linear relation. This suggests the value of spectral vegetation index measurements in large-scale ecological analysis. This research has been summarized at submitted for publication in the journal Vegetatio. A copy of the manuscript entitled "North American Vegetation Patterns Observed with NOAA-7 Advanced Very High Resolution Radiometer" is enclosed in the Appendix. Presentation of an earlier version of these results was made at the Annual Meeting of the Association of American Geographers, held on 22-25 April, 1984 in Washington D.C. The abstract of the presentation, which was published in the proceedings of the conference, is also enclosed in the Appendix.

Ecological Modeling Approach. Studies of photosynthesis have shown that there is a strong link between canopy architecture and optical properties, and vegetation canopy photosynthetic activity. Research on canopy spectral reflectance properties have produced equivalent results. It is therefore not unexpected that spectral vegetation index measurements may be employed to study photosynthesis and primary production. Monteith (1965) provides one of the earliest attempts to estimate photosynthesis based on leaf physiology and canopy abosorption of solar radiation. His model takes the form;

$$P = \frac{h}{a} (A (1 - f(n)))$$

where P = Photosynthesis

h = daylength

a = canopy resistance

A = canopy light interception

f(n) = describes the functional variation of leaf photosynthesis canopy resistance and light saturation.

All the terms within the equation may be derived from the research literature or computed approximately from astronomical considerations with the exception of the A (interception) term. However this value may be derived from remotely sensed spectral vegetation index measurements. The resultant calculation produces a measure of potential photosynthesis, without respiration, and under optimum temperature and moisture conditions. Respiration and canopy resistance are empirically related to air (leaf) temperature and may be parameterized approximately in that fashion (Chang, 1968, Terjung et al, 1976). Water stress to first approximation may be assessed by tracking the monthly water budgets of regions (e.g. Thornthwaite, 1948, Linacre, 1981). Thus the full scope of primary productivity processes should be capable of analysis given the spectral vegetation index measurements, and climtological measurements of temperature and precipitation.

Global climate data for 1982 have been acquired from the NOAA Climate Data Center in Ashville, North Carolina. These data are monthly averages of air temperature, total precipitation, mean vapor pressure and air pressure for approximately 3000 stations around the world. The data are on a computer tape which has proven to be quite a task to decode. The station key was not provided with the data and requires manual entry. Corrections to the data are entered as additions in the file and must be incorporated into the data prior to use. Despite these limitations the data will be of great value in producing first order estimates of regional to global rates of photosynthesis and accumulated net primary productivity in collaboration with the satellite observed spectral vegetation index measurements.

Field Observations Along the North American Temperature Ecocline. Analysis of the 1982 AVHRR observations of North America revealed major continental gradients in vegetation index measurements, in an east-west direction coincided with the continental precipitation ecocline and north-south coincident with the continental temperature ecocline. Conversations with Dr. Donald Petzold, Assistant Professor in the Geography Department, revealed that he had spent several summers in the subarctic region of central Quebec while a graduate with McGill University. McGill operates a field research station in Schefferville Quebec (55°N, 66°W) where Dr. Petzold had measured the albedo of various land surfaces. He found that lichens display an unusual pattern of reflectance when compared to other higher order green leaf vegetation. He proposed that one reason we observe such a steep vegetation index gradient in Central Canada is because of the presence of open lichen woodlands in this region. The opportunity to examine this vegetation gradient and conduct spectral measurements in the subarctic (see previous section on lichen spectral reflectance measurements) at a reasonable cost (via the McGill Research Station) was examined and considered worthy of pursuit. Arrangements were made to travel by automobile and train to Schefferville.

Dr. Goward, Dr. Petzold and Mr.Dye traveled by automobile from Maryland to Sept Isles, Quebec. During this traverse stops were made every two hours (aproximately every 100 miles) and vertical fish-eye photographs of the forest canopy, as well as regular photographs of the understory, were collected. These photographs will be analyzed, visual with the regular photographs, and digitally on the vidicon system of the University of Maryland Remote Sensing System Laboratory. This analysis will assess canopy closure and ground cover along the transect. These measurements will be compared to measurements acquired by the AVHRR system. The most significant aspect of the gradient observed was the vegetation shifts slowly from decidious (angiosperm) vegetation species to confierous (gymnosperm) species form Maryland to Sept Isles Quebec. In Sept Isles the predominant tree species are black spruce with poplars and birch present in more favorable microenvironments.

The train trip between Sept Isles and Schefferville (300 miles) revealed the most visually dramatic transition in the vegetation. Within 100 miles of Sept Isles the forest density decreases dramatically, producing an open woodland of predominantly spruce with light-colored lichens dominating the understory. The change in vegetation appearance accompanies the sharp decline in spectral vegetation index measurments observed in the AVHRR spectral vegetation index measurements. One week of field observations, including additional vertical fish eye photography and spectral reflectance measurements, was conducted in Scefferville. These data should provide great insight into the decreases in spectral vegetation index measurements observed with the

Much remains to be accomplished before the full value of the observations is realized. For example, interannual analysis of the data is needed and the effects of atmospheric conditions and sensor configuration on these measurements requires further investigation. However, even at this early stage of investigation, the results suggest that spectral vegetation index measurements provide a consistent and generalized means to conduct global vegetation studies. The AVHRR observations represent a major advance in realization of the promise of remotely sensed spectral observations for vegetation research because they provide the global overview of terrestrial conditions needed in multistage analysis of land conditions. An ability to observe the global distribution and dynamics of vegetation activity opens numerous new avenues of research for geographers, ecologists, climatologists and other earth scientists. Improved understanding of the earth's biosphere should result and at a time when concern is growing about human impact on the biosphere this new source of information is a welcome addition to the limited means available to study global biospheric activity.

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