THE REGIONAL AMAZON MODEL: AN INTERDISCIPLINARY PROJECT OF THE EARTH OBSERVING SYSTEM*

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ABSTRACT

The NASA Earth Observing System (EOS) mission is a large-scale, long-term program dedicated to observing and determining the biophysical basis for human-induced global change. Within the overall structure of EOS, exist a series of so-called interdisciplinary programs, each of which addresses a particular problem of the overall Earth system. The EOSRAM (EOS Regional Amazon Model) project is one of these. The project represents a collaboration between the University of Washington and the Instituto Nacional de Pesquisas Espaciais (INPE). The overall goal of the research to be conducted by the EOSRAM team is to determine, how extensive land use change in the Amazon would modify the routing of water and its chemical load from precipitation, through the drainage system, and back to the atmosphere and to the ocean and to determine how these changes affect the carbon cycle. There are four main research elements of the project; hydrology, phytogeography, biogeochemical cycling, and land use; emphasizing horizontal (across landscape) questions. As such, the research focuses on how the hydrologic cycle and its interactions with biogeochemical cycles function at the land surface on scales of tens to hundreds of kilometers in the last decade of the twentieth century and the first decades of the twenty-first century.

1.0 INTRODUCTION

Amazon region contains nearly half of the remaining tropical rain forest of the world and almost one fifth of the world total fresh water. Since the early seventies it is experiencing a dramatic impact of human occupation for cattle ranching, agriculture, dam building, and intense mining activities. These development activities have been occurring in a very intensive pace and the scientific framework to assess their impact on the Amazon ecosystems has been inadequate. That assessment depends on a better understanding of the links between terrestrial (water, forest, and soil) and atmospheric processes in local, regional, and global scales.

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Research has greatly increased in the last 15 years to address ecological concerns and to help the government formulate policy for the occupation of Amazonia. A remaining question is to determine what changes might occur and to what extent these changes would affect the water cycle and the carbon balance both in the region and globally as a result of the occupancy of Amazonia.

Even though hundreds of scientific papers have been written about Amazonia, difficulties of access, lack of funding and trained personnel, in addition to the diversity of the tropical environment make the representativeness and extrapolation of results very limited. Use of remote sensing may fulfill the basic needs of data and overcome some of the difficulties, especially through the EOS program with its multisensors capability. However, remote sensing in itself is very limited to understand such complex problems as the hydrological cycle and carbon uptake and release in Amazonia. An innovative combination of field, remote sensing, and modeling techniques will be necessary to undertake this task.

The present project originated in 1988 when a group of researchers from the Institute for Space Research (INPE) and University of Sao Paulo submitted a proposal entitled "Long-Term Monitoring of Amazon Ecosystems through the EOS: From Patterns to Processes" (Batista et al., 1988) to NASA Announcement of Opportunity (NASA A. O. OSSA-1-88) to participate in the Earth Observing System (EOS). This proposal after being combined with the proposal submitted by the University of Washington entitled "The Regional Amazon Model: Synoptic Scale Hydrological and Biogeochemical Cycles from EOS" (Richey et al., sdf) became one of the 28 interdisciplinary proposals approved by NASA for the development of EOS (Batista and Richey, 1990).

The Earth Observing System (NASA, 1990) is program coordinated by NASA to develop a comprehensive understanding of the Earth processes within the scenario of global change (IGBP, 1988). It was designed to provide information from low altitude orbiting platforms integrated with geophysical, chemical, and biological information for long term monitoring of Earth. The EOS mission has three major components: The EOS Scientific Research Program; The EOS Data and Information System (EOSDIS); and the EOS Space Measurement System (EOSSMS). This is perhaps one of the first major space programs where science and technology are conducted in coordination since the beginning.

2.0 PROJECT SUMMARY ISSUES

The overall agenda of the EOSRAM project is to contribute to understanding the dynamics of the Amazon system in a natural state, and how it would evolve under possible change scenarios (from instantaneous deforestation to more subtle longer term climatic/chemical changes). Specifically, our overall goal is to determine ***How extensive land use change would modify the routing of water and its chemical load from precipitation, through the drainage system, and back to the atmosphere and to the ocean and to determine how these changes affect the carbon cycle in the Amazon.***

Before any research plan can be implemented to address our overall problem realistically and well, we feel that there is a set of boundary conditions which must be recognized. We must consider logistical realities and access, vast scale, sparseness and location of records. We must recognize the nature of the Amazon, including its heavy vegetation (a 40 m canopy tends to obscure the soil) and frequent heavy cloud cover. We must develop specific capabilities to address issues of land use change; including abilities to detect cutting and regrowth, implied soil degradation, rerouting of drainages and roads, and evolution of reservoirs. We must scale results to what may be unambiguously observed on the ground for calibration and testing. We must represent environmental processes in a realistic way, yet remain comparable in structure to detailed models of the surface hydrology component of (GCMs).

Therefore, our emphasis is on "getting to know" the system through the selection of key "anchor" sites, where extensive field measurements of structure and dynamics can be made and related through detailed process models and image analysis. Then that information can be expanded to regional scales through modeling and remote sensing on first principles, and verified against independently-derived regional data (e.g., large tributary discharge, isotopic composition, or field-campaigns). The approach can be extended further by concentrating on "information-rich" transition zones and time periods. Evidence suggests that "natural" changes occur not only on 100s/1000s of years but on abrupt 1-10s of years events. Given the long-term nature of EOS, this gives us a window to find such transition events, if we are "ready" (e.g., 76/77 high water vs. 83 ENSO, blowdowns, etc.). Ultimately, the structural information and the process information needs to be represented in the form of a series of linked dynamic models of hydrology, biogeochemistry, and community succession.

Achieving our research goal requires the synthesis of a set of research elements addressing a class of interactive questions dealing with horizontal (across landscape) integration of water and chemical cycles into an overall Regional Amazon Model (RAM) . Determining the basic hydrology within the context of vegetation and physical structure of the Amazon basin serves as the framework for a more complete understanding of biogeochemical cycling, ecological processes and changes that accompany agricultural and industrial uses of the land. The degree of geographical variation of land-surface properties in this continental-scale drainage basin and the variety of possible measurements and scientific interests in hydrology requires a set of mathematical models to force some discipline and cooperation on activities. A range of such models will be necessary to handle processes at different scales, and some attention needs to be placed on consistency between the physics and chemistry represented in the hydrological models at various scales.

3.0 RESEARCH QUESTIONS

- ***How do the climatic and surface features of the basin determine the temporal distribution of runoff and the spatial pattern of moisture storage?***

The emphasis of much of the current larger-scale hydrologic modeling is directed toward interfacing with GCMs and is oriented toward SVAT-type vertical modeling, with primary emphasis on the direct biosphere-atmosphere coupling. The emphasis of our group is on the horizontal, with the inclusion of realistic physical processes. To do this, we have been developing a distributed macro-scale hydrological (DMH) model. The model not only simulates the processes that control the vertical moisture fluxes on the land surface (e.g., evaporation and infiltration), but it also explicitly calculates those horizontal processes that effect moisture fluxes across the landscape (hillslope runoff and channel flow). In the model, a basin is divided into a regular grid of Elementary Model Cells (EMC), the size of which defines the spatial resolution of variability of atmospheric forcing and land surface parameters used in the model. The dimension of the cells may be on the order of 1 to 10 km. By representing the basin in such a distributed way, the model allows explicit incorporation of vegetation, soil and geomorphic features of the basin, and space-time rainstorms.

- ***How are the distributions of vegetation communities (phytogeography) influenced by hydrologic, geologic, and ultimately human factors?***

We view phytogeography as one of the main links between the hydrologic modeling, remote sensing measurements, and the distribution of plant communities. We propose to test the hypothesis that each vegetation community has characteristic soil properties and predictable seasonal patterns of site moisture, net radiation and evapotranspiration that can be established by (point) measurements at specific sites, and extended by inference to other similar communities using satellite data. Our strategy is to establish the relationships between satellite observations of vegetation community type and condition and ground measurements of soil properties (including moisture), net radiation, and evapotranspiration at anchor sites. To extend observations at anchor sites to a regional scale it is necessary to establish the spatial distribution of vegetation communities and to understand how they vary seasonally.

To deal with this overall problem set, we are exploring the concept of a "dynamic spectral phytogeography." This rather awkward phrase represents the following. The first issue is to be able to identify characteristic vegetation assemblages over large areas, ultimately with regard to the physical differences between areas. The second issue is to bring these communities "life;" i.e. what are their successional patterns, and then how are they differentially fixing and transforming carbon and related elements? The key to these linked questions is first to characterize species assemblages, and then to identify those spectral properties of these assemblages which are detectable by satellite and can be used to extrapolate to larger regions. A further constraint is imposed by our requirement that these spectral properties carry sufficient information about the vegetation itself that it can (ultimately) be used to calculate or at least infer what the carbon cycling properties are. Hence our emphasis on identifying the spectra corresponding to the relative amounts of leaf, shade, soil, wood, and water and of canopy architecture.

A key "output" will be the definition of vegetation functional groups, where a functional group is defined by attributes which are unifying (similar structure, function, and implicit taxonomy) and which can be determined remotely. Then these groups can be coupled to landscape issues of short-term community succession, such as, Why/how do existing functional groups grade from one type to another? How and at what rate does natural (short-term) succession operate dynamically (e.g. filling gaps, blowdowns, mortality)? The physical attributes of the functional groups include biomass (C, nutrients) and structure (canopy architecture, LAI), which thus provides the bridge to the biogeochemistry.

- ***How does the structure and biological diversity of the Amazon ecosystem control the cycling of water, carbon, and nutrient elements under natural conditions and under different conditions of land use?***

The next major problem is coupling the hydrological cycle and knowledge of the phytogeography to the biogeochemistry of the Amazon basin. Issues include, What is the fixation of C by functional group as a function of insolation, nutrient status, and moisture status? What is the final gross vs. net production? What is carbon and nutrient storage in the soils, and how is some fraction of this matter mobilized through the river systems? To approach these problems, we intend to develop a set of field studies linked to ecosystem/biogeochemical models coupled to the hydrological model. These models will address problems of production and oxidation on land, the linkages between terrestrial and fluvial systems, and finally production and oxidation in aquatic systems (both natural and man-made). In particular, we hope to derive production models based directly on the spectral properties of the canopy, as derived from our end-member mixing model approach (see below).

Then comes the hard question of linkage in how might the biogeochemical dynamics and community structure respond to changes in system state which would occur abruptly (direct clearing or physical intervention) or more subtly (such as changes in ambient environment - moisture, temperature, CO_2) either as propagating edge effects or regionally.

- ***How can the large-scale geologic and topographic frameworks and their associated physical, chemical and biological properties be represented?***

The task of actually combining the multiple data sets in a manner that will allow the above questions to be answered is a challenge in itself. EOS represents the opportunity for a fundamentally different approach to science and the gathering and analysis of remotely-sensed and field data. Taken in its full spirit, EOS requires a concept of imaging and analysis outside of traditional constraints. We must be able to respond to the necessity for processing very large amounts of data rapidly, while the maximum compatibility of image processing and data base software between the UW and INPE, CENA, and INPA is essential.

- ***How can information on the above biophysical perspective of the Amazon ecosystem be used to address issues of biodiversity?***

The perspective taken so far by our group addresses more of the biophysical aspect of the structure of the Amazon ecosystem. In parallel exist important questions concerning how this physical world interacts with the perspective of biodiversity. For example, what subtle change in temperature would affect a particular species assemblage; i.e., its diversity? This is a non-trivial question, given that local landuse change is likely to cause a local change in temperature in an environment where temperature and moisture tolerances are fine."

4.0 REFERENCES

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