CARBON BUDGET AND SUCCESSION DYNAMICS OF CANADIAN VEGETATION

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ABSTRACT

The Northern Biosphere Observation and Modeling Experiment is a research and development effort to obtain an improved understanding of the role of terrestrial vegetation in the total Earth system. The focus is on the vegetation of Canada, and effective use of space observations is stressed. The project is a cooperative effort involving the Canadian Global Change Program led by the Royal Society of Canada, universities, the Canada Centre for Remote Sensing, Forestry Canada, and Agriculture Canada. As a 10-year program NBIOME has established strong links with the international Earth Observing System which accepted the project for the EOS execution phase in January, 1991. This paper emphasizes the linkage by describing the use of remote sensing techniques in the overall NBIOME strategy.

BACKGROUND AND RATIONALE

In response to the Earth Observing System (EOS) Announcement of Opportunity issued by the U.S. National Aeronautics and Space Administration in 1988, a proposal to study the northern biosphere using satellite observations and nested modelling was submitted by scientists from several Canadian organizations, with the Canada Centre for Remote Sensing as the lead sponsoring agency. The principal objective of the project called NBIOME (Northern Biosphere Observations and Modeling Experiment) is to increase our understanding of the role of terrestrial vegetation in the total Earth system and its changes with time in a changing environment. The focus of the project is the vegetation of Canada and its four major biomes: forests, agro-ecosystems, wetlands and tundra.

The project is based on four premises:

1. The knowledge of the distribution, characteristics, and dynamic response of terrestrial vegetation is a necessary pre-requisite to the understanding of the behaviour of the total Earth system, its component parts, and its changes with time--both as a result of natural agents and those caused by the human intervention.

2. Because of the dynamic character of this living system and the broad spatial distribution, satellite observations can serve as a principal measurement technique, supplemented by other methods as appropriate.

3. Models of vegetation behaviour/response are a necessary component of the total approach. This follows from the fact that satellites observe current conditions, but we are also strongly interested in future changes that vegetation may undergo, as well as in the environmental and socio-economic consequences resulting from such vegetation changes. In addition, models are required to infer certain surface parameters from remote sensing data.

4. The present level of knowledge and understanding concerning terrestrial vegetation is inadequate to determine its role in global processes and the potential effect of global climatic change. For example, a study by Tans et al. (1990) suggested that land ecosystems at temperate and northern latitudes must be substantial sinks of atmospheric CO_2 to balance the global budget. Although the exact location of such sinks is unknown at the present, it is likely that a significant portion would exist in the NBIOME study area.

Among the various techniques that might be considered for the assessment and monitoring of vegetation conditions, satellite remote sensing offers a realistic possibility to obtain the requisite data because of the large areal extent, strong spatial and temporal dynamics, and logistical inaccessibility of the vegetation. Although this statement is true globally, it is particularly relevant for vegetation at northern latitudes where population density is extremely low, roads are few, and the growing season is short. However, remote sensing at northern latitudes is hampered by strong cloud cover and low sun angle, including long periods without sunlight. Therefore, the development of accurate and reliable techniques for using satellite data will require substantial research effort.

GOAL AND OBJECTIVE

NBIOME addresses the role of terrestrial vegetation of Canada in the total global ecosystem. Its goal is to obtain an understanding of the behaviour of terrestrial ecosystems of Canada that will allow the forecast of changes in their structure and function resulting from global environmental changes. To achieve this goal, an observation and information system will be developed pertaining to a family of landscape and ecosystem models, backed by process understanding. The observations and process-based models will be used to monitor, evaluate and project the impact of global change on boreal ecosystems including forests, agro-ecosystems, wetlands and tundra.

NBIOME is bounded spatially by the landmass of Canada that is presently vegetated or which could be vegetated within the time horizon of interest. The time horizon is defined as the next 50-100 years, a period over which significant increase in the concentration of radiatively active gases is expected and during which long-term policies may have impact. The specific project objectives are to assess the likely direct and indirect interactive effects of global environmental change on three aspects of Canada's terrestrial ecosystems:

1. Disturbance regimes including fire, harvest, insects, disease, and human intervention;

2. Vegetation change; including growth, regeneration and succession; and

3. The size of carbon pools and the net flux of the important radiatively active gases between the terrestrial ecosystems and the atmosphere.

NBIOME will encompass a variety of investigations ranging from process studies to modeling and remote sensing observations. Modeling will play a key role in various aspects of the project, and it will draw on process understanding obtained in field studies and on information derived through remote sensing. From the remote sensing perspective which is emphasized in this paper, the following aspects will be addressed.

1. Development of a vegetation classification algorithm based on satellite measurements as a principal data source. This algorithm will be used to produce a digital vegetation map of Canada as a baseline for determining future changes as well as for use in growth and succession models.

2. Development of a phytomass model for the vegetation of Canada to produce a map of total phytomass as input into a growth model.

3. Development/adaptation of remote sensing inputs into vegetation growth models. These models should result in digital maps of Canada showing gross primary productivity and net change in carbon storage for different years within the EOS time period.

KEY SCIENCE ISSUES

NBIOME focus has been formulated with reference to the principal cause-effect links and feedbacks through which global environmental change is expected to interact with northern biomes within the time horizon of interest: major impact of climate on changes in the disturbance regime or on the types and rates of ecosystem processes; ecosystem structure and function affected by climate change, directly or through disturbances; carbon fluxes and pools modified as a function of ecosystem characteristics; and feedback to climate from the ecosystem through biophysical and biochemical pathways. The research agenda of NBIOME will thus include the following issues.

1. Physiognomic characteristics of the vegetation of Canada and the spatial distribution of carbon stored in vegetation. To provide reliable answers to basic questions of carbon cycling and vegetation change, we plan to establish a baseline data base showing the distribution of vegetation types and biomass across Canada. Such a data base will initially be established with 1 km resolution, to be increased to about 250 m in the late 1990s.

2. Annual carbon budget of the vegetation of Canada. Because of the large area of Canada and the vast boreal forest biome, Canadian vegetation accounts for a significant fraction of the carbon in the terrestrial biosphere. The carbon budget of Canada has significant uncertainties, particularly at regional and local levels (Apps and Kurz, 1991). Remote sensing technology offers the possibility of contributing to more accurate estimates of above-ground carbon storage by vegetation than those provided by spatially lumped models, and of inferring accumulation and depletion rates.

3. Year-to-year changes in the carbon budget of Canada. Re-measurement over several years is necessary to establish a range of variation of carbon accumulation and depletion. Once this range is established it will be possible to evaluate whether the changes are within the normal range or appear to be abnormal. Changes in disturbance frequency and distribution (e.g., fire), estimated with the help of satellite data, will be one of the key variable components of the annual carbon budget.

4. Relationship of changes in the vegetation composition to ecological changes, using vegetation change as an observable indicator of ecological processes. These effects may occur at the site/landscape, regional, and biome levels. A database of Canadian vegetation based on medium resolution satellite observations will be established to assist in monitoring changes in vegetation distribution, with high resolution satellite and field observations used where required for extra detail. With yearly updates, the observed changes can be compared to expectations based on ecological and successional models to look for abnormalities which may be linked to anthropogenic factors or to climate change. Regional interactions between vegetation development and vegetation change which may be significantly affected by climate change will be of considerable interest. Such mesoscale processes are the critical bridge across the gap between modeling causality at local levels and at continental scales.

METHODOLOGY

Because of the diversity of the vegetation of Canada and the issues addressed in the project, NBIOME will be implemented as a collaborative effort of researchers from various organizations. The strategy for project implementation is to address the overall objectives in the context of each biome (forest, agro-ecosystems including cropland and grassland, and wetlands/ tundra), using a spatial/temporal ecosystem framework. It is postulated that the spatial/ temporal space consists of discontinuous clusters in each dimension, separated by transition regions across which the type or the relative importance of key environmental variables change.

Remote sensing will play an important role in the project. Initial plans call for the development of the following components.

Land Cover module will use medium resolution, daily coverage data (the Advanced Very High Resolution Radiometer (AVHRR) before the launch of EOS, MODerate-Resolution Imaging Spectrometer (MODIS) after the launch), together with ancillary data and Landsat Thematic Mapper (TM) data if necessary, as input into a vegetation classification algorithm. The output of this module will be a vegetation map of Canada with equal-area cell sizes, initially 1km x 1km and decreasing hierarchically to 250m x 250m for MODIS data. An additional output of this module at the end of the growing season will be temporal curves of greenness and brightness.

Phytomass module will be developed to produce a phytomass map of Canada. The vegetation map from the first module will provide part of the basic information from which the phytomass will be determined. The calculations will rely on published and unpublished data to estimate the biomass of cropland, grassland, forest, and tundra communities. For above-ground biomass, satellite data will also be employed where appropriate. In case of forests, the potential of radar data will be thoroughly explored in conjunction with existing inventories. For herbaceous plant communities, the use of medium resolution optical data will be investigated. An important issue is the distribution of below-ground organic matter. This assessment will be based on vegetation cover map and ancillary data, the latter varying with vegetation type (allometric equations, soil analyses, previous field measurements, models).

Annual Organic Matter Budget module will be designed to produce a map of gross primary productivity for Canada. The vegetation map and seasonal growth parameters (greenness, temperature, length of growing season, etc.) derived from satellite data will be employed. After subtracting respiration losses from the gross primary productivity, a net primary productivity will be obtained. Depletions due to fire, harvesting, and insect and disease damage will then be determined using ecological data and models with satellite data, and the resulting distribution will be translated into a carbon budget map for Canada. This module will be the most demanding aspect of NBIOME from the viewpoint of satellite-derived inputs.

Succession module will use several models (for forests, grassland, tundra, and wetlands) to predict changes in the vegetation of Canada resulting from observed or predicted climate changes and from changes in management practices. The vegetation map, together with soil maps and climate data, will be the principal inputs for this module. The most challenging aspect of this portion of the project will be to understand and model the mesoscale interactions which result in regional distribution of vegetation types and their spatio-temporal dynamics.

INFRASTRUCTURE

A key challenge in the NBIOME project is the design of an integrated research program in which generally small teams from numerous geographically dispersed institutions make contributions of the type, comprehensiveness, quality, and with the timing required to achieve successful integration at the national level. Furthermore, it will be necessary to ensure continuity and consistency over a 10-year period or longer and also ensure effective linkages with other elements of the Canadian Global Change Program (CGCP). From the NBIOME team member's perspective, mechanisms and tools must be put in place that will allow (i) easy access to the required data, (ii) access to the results of work by other team members (interim or final); (iii) maximum efficiency and effectiveness of invested time; and (iv) maximum potential for true interdisciplinary teamwork.

To fulfil the above requirements, the NBIOME Information System (NBIS) should have the following functions:

(i) Provide information about, and access to, data and products required by investigators including final products, important raw and intermediate data sets, and models in use by the NBIOME team;

(ii) Support communication among investigators and the conduct of transdisciplinary research in smaller specialty teams. This function can be fulfilled through GCNet (Fisher et al., 1991).

It may be feasible to establish a shared digital database for the project. This database would initially contain data required by all investigators (e.g., soil map of Canada) for their data analysis and modeling research. More specific information would be added later by individual investigators to allow the overall work to proceed efficiently and on schedule. To reduce the impact of inevitable changes in personnel, all inputs will be properly documented and regular updates will be provided.

During its lifetime NBIOME will require a number of field sites. Some will be set up for a specific purpose and a limited time period, others will be monitored on a seasonal and annual basis over the duration of the program. Satellite observations will be recorded regularly for selected sites, while the field measurement program may vary from one site to another. Advantage will be taken of existing sites or other field programs where possible. For example, BOREAS sites and long-term CGCP research observatories, when established, will be included after the NBIOME team actively participates in the definition of such observatories.

PROGRESS TO DATE

Although the first EOS platform will not be launched until late 1990s, research with EOS-like data has already started and will accelerate during the next few years. The principal data of interest for vegetation research are provided by the AVHRR. In addition to remote sensing activities, an accelerated research on the forest -climate interactions has commenced at Forestry Canada. The forestry component of NBIOME will also strongly benefit from the proposed BOREAS project (Sellers et al., 1990; Cihlar et al., 1991). A similar thrust is underway at Agriculture Canada, with emphasis on the role of agro-ecosystems in the budget of radiatively active gases.

A concerted effort is being made to involve the academic community in NBIOME. A coordinated research proposal is currently in preparation, for submission to the Natural Sciences and Engineering Research Council of Canada. It is thus anticipated that the project team will be fully formed in late 1992 and the coordinated research activities will unfold in 1993.

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Note added in proof

The description of the NBIOME project given in this paper is based primarily on the NBIOME Execution Plan submitted to NASA in August, 1990. As part of project planning, two scientific workshops were organized since that time and a science plan has been written by the Science Steering Committee. It is expected that the science plan will be published in early 1993. A proposal for funding university researchers' involvement in NBIOME will be completed in the early 1993 for submission to the Natural Sciences and Engineering Research Council of Canada.

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