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COVER SHEET
FOR TRIP REPORTS SUBMITTED TO THE OFFICE OF ENERGY RESEARCH

Destination(s) and Dates for
Which Trip Report Being Submitted: Laxenburg, Austria, June 3-August 9, 1988

Name of Traveler: W. R. Emanuel

Joint Trip Report ☐ Yes
☒ No

If so, Name of Other Traveler(s): __________

OAK RIDGE NATIONAL LABORATORY

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ORNL
FOREIGN TRIP REPORT

ORNL/FTR-2999

DATE: August 24, 1988

SUBJECT: Report of Foreign Travel of W. R. Emanuel, Research Staff, Environmental Sciences Division

TO: Alexander Zucker

FROM: W. R. Emanuel

PURPOSE: To participate in an extended workshop on the development of global vegetation models at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria.

SITES VISITED: 6/6-8/5/88 International Institute for Applied Systems Analysis, Laxenburg, Austria — A. M. Solomon

ABSTRACT:

The International Institute for Applied Systems Analysis (IIASA) is beginning the development of a global vegetation model. In April 1988, a major international workshop summarized and evaluated available concepts, data, and formalisms. An extended workshop during June and July reviewed findings of the April meeting and other background information. From this review, a framework for analyzing global vegetation dynamics and responses to environmental change was designed. A core plant growth module was derived and implemented.

SUMMARY OF ACTIVITIES

From June 6 through August 5, 1988, the traveler participated in an extended workshop at the International Institute for Applied Systems Analysis (IIASA), located in Laxenburg, Austria. Participants reviewed approaches and developed an initial design for a mathematical model of global vegetation dynamics. The model is intended for use in studies of the impacts of global environmental change.

The workshop was organized within IIASA's project on Ecologically Sustainable Development of the Biosphere, directed by A. M. Solomon. In addition to the traveler, the global vegetation modeling working group consisted of Drs. I. Colin Prentice and Sandra Harrison, University of Uppsala, Uppsala, Sweden; Dr. Thomas Smith, Australian National University, Canberra, Australia; and Dr. Gordon B. Bonan, University of Virginia, Charlottesville, Virginia. Eight graduate students also participated through the institute's Young Scientist Summer Program, and numerous IIASA staff interacted with the group throughout the workshop. Colin Prentice served as overall coordinator.

Work was organized into several broad areas with overlapping objectives: (1) global environmental data assembly, management, and analysis; (2) formulation of a generally applicable model of plant community dynamics; and (3) development of environmental drivers for vegetation models. The traveler participated in each area, emphasizing the first two. The following paragraphs summarize work and accomplishments in each area.

Global Environmental Data

Major global environmental data sets in widespread use were assembled at IIASA for review by the working group. These include

1. two sets of meteorological records containing monthly average temperature and monthly precipitation values for about 7000 stations worldwide,

2. simulated climate from a general circulation model experiment prepared by the British Meteorological Office,

3. world coastlines contained in the World Data Bank II,

4. global topography on a 10′ grid (containing modal, maximum, and minimum elevation for each cell, as well as the number of significant ridges, direction of ridges, extents of water and urban development, and a surface code), and

5. soil characteristics mapped by the Food and Agriculture Organization (FAO) (soil type, texture, slope, and phase are recorded on a 0.5° grid).

The meteorological records are used to calculate climatic indices that enter global vegetation models through functions describing the dependence of plant growth on temperature and moisture. Model solutions are organized on uniform grids, and climatic data and other values available only at arbitrarily located stations must be interpolated to estimate values for each grid cell. A set of FORTRAN routines for bivariate interpolation using a triangle-based method were assembled, and a main program was prepared to control grid value estimation from the meteorological records.

The natural distribution of vegetation is correlated closely with climate. Several schemes that use this correlation to relate vegetation to climate were reviewed. The Holdridge Life-Zone System was used in several previous studies of potential climatic change impacts. Computer programs to map the Holdridge System from the meteorological records and from general circulation model results were prepared and tested. While previous studies analyzed only temperature changes, sensitivity to both temperature and precipitation was considered in these tests.

Possible refinements to the Holdridge System were discussed in detail. The limits of temperature and precipitation intervals defining the Holdridge Life Zones seem too arbitrary. Scrutiny of equilibrium solutions to dynamic vegetation models appears to offer the best approach to refining these definitions.

Currently available geographic information systems are not entirely satisfactory for handling the data sets required by global vegetation models. A unique requirement is the need to manage, review, and analyze results from model experiments.

One user-supported system, the Geographical Resources Analysis Support System (GRASS), was acquired for testing. GRASS is a general-purpose grid-cell system developed within the U.S. Army Corps of Engineers. The overall structure of GRASS meets global vegetation modeling requirements, and because it is distributed with its source code, modifications for managing dynamic model results are feasible.

The main obstacle to installation of GRASS is its association with particular equipment configurations. Display interfaces, storage requirements, and minor variations in UNIX must be contended with when GRASS is installed. By the end of the workshop, GRASS was not successfully installed on IIASA computers.

General Vegetation Model

Greatest emphasis was on the development of a vegetation model capable of simulating transient responses to climatic change and similar continuous perturbations acting on time scales from decades to centuries. Although climatic change affects vegetation on continental scales, important interactions that influence vegetation dynamics over decades and centuries occur on much smaller spatial scales. Models must describe these interactions accurately and account for spatial variability that influences landscape patterns at the scales of interest.

The major components of a plant community model were derived and implemented. The model describes birth, growth, and mortality for a community on a plot that is sufficiently small so that light extinction can be assumed to be horizontally homogeneous. For forests, plot sizes of about 800 m^2 are typical.

Plant size is incremented annually. The annual increment depends on current leaf area and size as well as environmental conditions, including available light, air temperature, and soil moisture. Forest stand models based on this approach have been extensively tested and widely applied. However, whereas those models track the life-cycles of each individual tree on a model stand, the generalized model designed during this workshop accounts only for numbers of individuals of each plant type or species.

Rather than basing growth on a diameter increment as in the individual-based forest models, the generalized model advances individuals through height layers stochastically, based on a mean height increment applied to the population of each type in discrete height layers above the plot.

The generalized model should simulate most aspects of forest dynamics as well as the individual-based models do. The height increment description in the generalized plant community model can be based on the growth equations and associated species-specific parameters used in the individual-based forest stand models, permitting a direct comparison of the performances of the two models for simulating forest dynamics.

The generalized plant community model extends the individual-based forest models in two major ways that are important in making it a suitable core description of plant growth in a global vegetation modeling scheme. First, structural emphasis on height and the assumption of homogeneity within height layers for each plant type or species is conducive to incorporating plant types other than trees for which a growth description based on individuals is unnatural. Second, the computational demands of the generalized model are very much less because the growth of each plant is not individually calculated, nor is the state of each plant maintained. A large number of solutions that sample environmental conditions on a heterogeneous landscape are computationally feasible to generate by using the generalized model.

A test version of the generalized model was implemented and exercised for a plant community comprised of 15 theoretical tree types. The initial tests using broad theoretical types with distinct characteristics reflected by their parameter values permitted rapid assessment of broad model performance without the complications of detailed species-specific responses. The working group concluded its effort by planning the modifications required to make the comparison with the individual-based models feasible.

Although growth equations and approaches to estimating parameter values for plant types other than trees were discussed at some length, work did not progress to the testing of these equations and approaches. A major obstacle to treating some phenomena affecting growth of smaller plants shaded by larger ones arises from the homogeneous shading assumption. For example, a tree does not necessarily shade all grass in a layer beneath it. A model structure with adjustable horizontal subunits was designed to address this point. A second problem arises in treating plants whose growth is reflected more in horizontal dimensions than through height increment. Such plants can be treated within the generalized plant community model by incorporating additional size classes within the appropriate layers.

Large-scale applications will use Monte Carlo solutions of the generalized model with parameter values that sample variance within each landscape unit. This approach has been used successfully in ORNL modeling studies to analyze patterns in the amplitude and phase of the observed annual cycle in atmospheric CO_2 concentration. Management of data sets and setup of the appropriate Monte Carlo solutions for realistic global-scale applications is a major undertaking. Currently available data are sufficient for model experiments planned for the next 1 or 2 years and can be set up on a case-by-case basis. However, practical applications will require a geographic information system that can organize and transfer values to the vegetation model and then display and interpret results.

Environmental Drivers for Vegetation Models

As described by the generalized model discussed in the previous section, plant growth depends on environmental conditions, including available light and climate. A complete system for analyzing global vegetation dynamics requires submodels for calculating indices that relate plant growth to widely measured environmental variables and physical factors such as topography. The most important of these environmental drivers can be adapted from the individual-based forest stand models, another compatibility benefit.

Air temperature affects plant growth in the model through an index called growing degree-day sum, which can be estimated reasonably from monthly average temperatures for a year.

A relatively complex environmental driver is needed to estimate soil moisture. A basic water and energy balance formulation is used to calculate water loss as a result of evapotranspiration. A number of alternate methods for estimating evapotranspiration were reviewed. In addition, a compact description of soil water dynamics is required, so a tentative submodel that can be parameterized from widely available data was designed.

CONCLUSIONS

The workshop was the first attempt to design the major elements of a model suitable for analyzing the global-scale transient responses of vegetation to large-scale environmental changes. One potentially useful approach was worked out in sufficient detail to ensure that a full implementation will be feasible within approximately 6 to 9 months. Interesting model results will be available in approximately a year.

Model performance is expected to be good for near natural forests. The plant growth component can treat nonwoody vegetation in a reasonable way, but there is no prior experience to suggest how well the formulation may eventually work out.

Initially, the most detailed scrutiny of model results will focus on patterns of vegetation distribution when the model is solved from arbitrary initial conditions to equilibrium with climate corresponding to the instrumental records. Tests of the transient behavior of the model will concentrate on a comparison of results with those from individual-based forest stand models.

The traveler wrote the computer programs that implement the general vegetation model, and he will continue developing them after his return to ORNL. The first major model exercises will be carried out at ORNL. These will contribute to DOE- and NSF-sponsored projects on global element cycling and the effects of CO_2-induced climatic change.

An important characteristic of the model strategy adopted by the workshop is to maintain a plot-level description of plant community dynamics at a spatial scale considerably smaller than that of most expected applications. This approach helps ensure that important phenomena, such as gap-phase replacement, can be adequately simulated. As already indicated, compatibility with widely studied forest stand models provides an experience base for application of the new formulation. Of course, alternate models that avoid the scale inconsistency need to be pursued; possibilities will probably be suggested as experience is gained with the plot-level models.

Development of global-scale dynamic vegetation models is just beginning. The task requires a level of effort and organization similar to those that led to success in simulating climate by using general circulation models of the atmosphere. Unprecedented international collaboration is required in global vegetation modeling, and institutes such as IIASA must continue to provide the forum for this interaction. Additional intensive workshops are needed. As model experiments are completed, IIASA and similar organizations will provide coordination between the small groups maintaining and exercising these models and the larger scientific community that will scrutinize results and contribute refinements and interpretation.

APPENDIX A

ITINERARY

June 3	Depart for Laxenburg, Austria
June 4	Arrival in Austria
June 6-August 5	Workshop
August 8	Return to United States

APPENDIX B

PERSONS CONTACTED TO A SIGNIFICANT EXTENT

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Dr. Sandra Harrison, University of Uppsala, Uppsala, Sweden

Dr. Thomas Smith, Australian National University, Canberra, Australia

Dr. Gordon B. Bonan, University of Virginia, Charlottesville, Virginia

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