PEER-REVIEWED ARTICLE

Commentary: Linking Environmental Models with Geographic Information Systems for Global Change Research

Abstract

To effectively analyze the spatial variation inherent in Earth systems, it is essential to integrate the spatial database structures of GIS into the environmental modeling process. This coupling has been attempted using process models in climate, hydrology, biogeochemical, and ecosystem dynamics, but there are a number of technical and theoretical obstacles to overcome before this integration can be fully effective in global change research. This commentary identifies key areas of research involving this integration, and obstacles which limit its success, including data sources, data formats and compatibility, costs, GIS functionality, computing speed, and the level of communication between the modeling and GIS communities. Recommendations for short-term solutions to these problems emphasize improving the transferability of data between existing systems. Long-term solutions suggest changing the way models are designed and how GISs store and process their data.

Introduction

Social and technological activities throughout the world contribute to rapid and potentially stressful changes in the environment. These changes profoundly affect generations to come. Human land-use practices in agriculture, forestry, industry, transportation, and residential development have significantly altered our terrestrial and marine ecosystems. Over the past few decades humans have witnessed a proliferation of pollution and waste, acid precipitation, loss of tropical forests, degradation of soils, and loss of species diversity in both plants and animals. Human activities have also contributed to increasing concentrations of greenhouse gases in the atmosphere and to stratospheric ozone depletion, which may alter our climate.

Global environmental change is an issue of international concern, especially as it affects human habitability. Many less developed nations, where the local environment is severely stressed, are most affected. World organizations, such as the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP), were established to support interdisciplinary research on global environmental issues. In cooperation with the IGBP, WCRP, and other international forums, the U. S. Global Change Research Program (USGCRP) was established by Public Law 101-606 in 1990 (U.S. Congress, 1990). This interagency committee is charged with developing national and international policies related to global and regional environmental issues. The USGCRP addresses this task with four streams of research activities: Earth observation and information management, process research, integrated modeling and prediction, and assessment.

GIS technology is integrated into each of the four USGCRP activities. To effectively analyze the spatial variation inherent in Earth systems, the environmental modeling community is using spatial databases in existing GIS programs. However, this is not a simple operation. The integration of modeling and GIS technology requires transdisciplinary skills, and few organizations have sufficient expertise in both complex process modeling and GIS technology (Nyerges, 1993). Inexperience in coupling process models with GISs could potentially lead to misuse of the technology (Moore *et al.*, 1993). GIS technology provides valuable tools for global change modeling. The spatial overlay capability of a GIS makes it possible to integrate varied sources of data within a single system. These spatially referenced data sets may be manipulated and queried to produce new information that was not previously entered into the system. Resulting data may be displayed in hard copy or soft copy as maps, statistics, or text.

Unfortunately, there are still a number of technical and theoretical obstacles to overcome before the coupling of GIS technology with environmental process models can be considered fully effective in global change research.

U.S. Global Change Research Priorities

The major share of global change research taking place in the United States is funded under the direction of the USGCRP, which budgeted 1.372 billion dollars for these activities in fiscal year 1993 (CEES, 1992a). The USGCRP addresses significant uncertainties in knowledge concerning the natural and human-induced changes occurring in the Earth's life-sustaining environment. To fulfill this goal, the USGCRP focuses on four interconnected scientific objectives:

- *Documenting global change (observations and data and information management)* through the establishment of an integrated, comprehensive, and long-term program of observing and analyzing Earth system change on global scales, including data and information management;
- *Understanding of key processes (process research)* through a program of focused studies to improve knowledge of the physical, chemical, biological, geological, and social processes that influence and govern Earth system behavior and the effects of global changes on natural systems and human health and activities;
- *Predicting global and regional environmental change (integrated modeling and prediction)* through the development and application of integrated conceptual and predictive Earth system models; and

Photogrammetric Engineering & Remote Sensing,
Vol. 59, No. 10, October 1993, pp. 1497–1501.

0099-1112/93/5910–1497$03.00/0
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- *Assessing and synthesizing the state of scientific, technical, and economic knowledge and implications of global change (assessment)* to support national and international policy-making activities that cover the broad spectrum of global and regional environmental issues and to provide guidance for determining research priorities of the USGCRP (CEES, 1992b).

Within these guidelines, seven interdisciplinary science elements provide a framework for proposal reviews and research projects. These elements in order of priority are (1) climate and hydrologic systems, (2) biogeochemical dynamics, (3) ecological systems and dynamics, (4) Earth system history, (5) human interactions, (6) solid Earth processes, and (7) solar influences (CEES, 1992a). Nearly half of the 1993 global change budget was allocated to the first science element (climate and hydrologic systems), which was identified by the international global change community as having the highest priority. Approximately 90 percent of the global change appropriation was divided among the three highest priority elements: climate and hydrologic systems, biogeochemical dynamics, and ecological systems and dynamics.

Another area of the USGCRP relating to the advancement of GIS technology is the development of data and information management systems to support the wide range of data from space and ground-based observations. The USGCRP has a continuing commitment to producing and preserving high-quality, long-term global or regional data sets and data exchange standards; to making data accessible; and to maintaining low cost data for research purposes (CEES, 1992b).

Environmental Process Modeling Activities

Understanding the physical processes that shape our Earth system can help slow the negative effect humans have had on the environment in recent decades. Predictive modeling helps to incorporate descriptions of key processes that modulate the Earth system's behavior with varying degrees of sophistication (Moore *et al.*, 1993). A modeling framework can also provide a basis for evaluating predictive scenarios. This section offers a brief sample of process models relating to the USGCRP's highest priority science elements—climate and hydrologic systems, biogeochemical dynamics, and ecological systems and dynamics. Many of these models were examined at the "First International Conference/Workshop on Integrating GIS and Environmental Models," held in Boulder, Colorado, 15-18 September 1991. Steyaert (1992; 1993) offers a brief overview of the objectives and activities of this conference, and also reviews many environmental simulation modeling activities in progress.

Atmospheric models range from general circulation models, which simulate global climate changes, to small-scale boundary models representing near surface conditions over very small areas. Most atmospheric models consist of a set of differential equations that describe external forcing and the response of the atmosphere to that forcing (Lee *et al.*, 1993). To solve these equations, both initial and boundary conditions must be provided. Accurate characterization of the land surface (albedo, canopy structure, roughness, evapotranspiration, and soil hydrologic properties) is important for correctly initializing these models. Currently, there is no comprehensive global data set providing that land characterization at the required level of detail. Remotely sensed data and interpolated field site data could be incorporated into a GIS to enhance some atmospheric models. The Simple Biosphere model, which simulates the exchange of sensible and latent heat, demonstrates this interaction between vegetation and the atmosphere (Sellers *et al.*, 1986; Xue *et al.*, 1991). This model uses a list of physical and biophysical properties of land cover (bare ground, shrub dominated, grassland, savanna, and forest) that must be described spatially (Schimel, 1993). These models demonstrate that human induced spatial or temporal modifications to the landscape can have a major affect on local climate variations (Lee *et al.*, 1993).

Hydrologic models are defined as mathematical representations of water flow on some part of the land surface or subsurface environment (Maidment, 1993). Because a GIS can provide a representation of the land surface, there is an obvious connection between the two technologies. Hydrologic modeling techniques, however, have developed quite independently of GIS technology, primarily because of the spatially explicit nature of these models. Only recently have attempts been made to integrate GIS data manipulation capabilities into hydrologic models. Previously, a GIS was used mostly as a retrieval system for topographic data. Maidment (1993) presents an excellent review of hydrologic models and the possibility of coupling them with GISs.

Biogeochemical models are often coupled with atmospheric and hydrologic models. An example is the Forest-BGC (biogeochemical cycling) model (Running *et al.*, 1987). The Forest-BGC model uses a leaf area index and, when in mountainous terrain, can incorporate 30-metre digital elevation model data. Models of the Forest-BGC class generally require daily weather data with a low temporal resolution but a high spatial resolution. Another biogeochemical model, named CENTURY, is used in determining net primary production and in tracing carbon and nitrogen cycles while drawing information from a GIS (Schimel, 1993).

Not all ecological models are suitable for GIS applications. Many ecological models are only concerned with the temporal aspects (processes that are independent of adjacent landscape units) of ecological processes (Hunsaker *et al.*, 1993). With the technological tools now available to ecologists, there is an increase in the coupling of terrestrial plant models and freshwater and marine models with GIS technology. Baker (1989) and Hunsaker *et al.* (1993) discuss various ecological models with the potential of incorporating spatial landscape components.

Examples of Linking GIS Technology with Process Modeling

Dangermond (1993) states that, while GIS technology has been used extensively in both the environmental field and in modeling, it has not been used very often for modeling in the environmental field. This is not meant to infer that the many environmental applications that use a GIS cannot be considered as modeling. There are other typologies on the nature of GIS models (Peuquet, 1984; Wheeler, 1988; Tomlin, 1990). Dangermond refers to the direct linking of GIS technology with existing atmospheric or terrestrial process models.

Burrough *et al.* (1988) indicates that, to successfully link models and GIS's for quantitative land resources assessment, the following points need to be considered:

For the Models:

- What are the basic assumptions and methods?
- At what scale or organizational level is the model designed to work?
- What data are needed for control parameters?
- What data are needed to feed the model?
- Under what conditions are certain control parameters or input data more important than others?
- How are errors propagated through the model?

For the GISs:

- Are the right data available at the correct spatial scale and level of generalization?

- Are there sufficient good data to create a finite element substrate when required?
- Are data available for calibrating and validating the model?
- If data are not available, could surrogates be used instead? How should they be transformed?
- How should a user be made aware of the intrinsic quality of the results of modeling?
- Is information available on data quality and errors?
- If the results are not good enough, should the GIS suggest alternative data or alternative models to the user?

One recent effort to integrate GIS technology and hydrologic process modeling links the SWRRB simulation model with a decision support system (Arnold and Sammons, 1989). A library of georeferenced hydrologic, soil, and weather related parameters provides data to fuel the SWRRB model, which simulates water resources of rural catchment basins. Hession *et al.* (1987) and Sharnholtz *et al.* (1990) were successful in linking the FESHM model with digital terrain data using commercial GIS packages. Panuska *et al.* (1991) also were able to integrate terrain data into an agricultural nonpoint source pollution model (AGNPS) at a local scale.

The most widely known example of a regional scale model for assessing vulnerability to ground water pollution is DRASTIC (Aller, 1985), the Environmental Protection Agency's risk assessment and planning tool. The DRASTIC model performs a weighted and summed index of factors influencing ground water contamination, including depth to ground water (D), net recharge rate (R), the aquifer media (A), soil characteristics (S), topography (T), impact of the vadose zone (I), and hydraulic conductivity of the aquifer (C). The simplicity of these weighted parameters makes the DRASTIC model particularly well suited to GIS use, yet its relationships are not based on any explicit physical laws, as is the case with most environmental process models.

Beller *et al.* (1991) and Stutheit (1991) introduced a prototype for a temporal GIS, developed with the cooperation of IBM and Colorado State University, which couples a commercial GIS package with ecological and atmospheric models. This prototype is being used to incorporate multitemporal AVHRR normalized difference vegetation index data from the U.S. Geological Survey's land-cover characteristics database (Loveland *et al.*, 1991; Sturdevant *et al.*, 1991) with existing parameters to determine the strength of relationships between climate and the year-to-year variability of net primary production in grassland areas.

Barriers to Integrating GISs and Process Modeling

GISs were originally designed as a tool to support decision making for land-use planning. The dramatic growth of the GIS industry has generally been spurred by demands for information management capabilities rather than spatial analysis and modeling functions (Goodchild, 1991). The major success of GIS technology is because of its capability for mapping the Earth's surface and for supporting simple queries. Commercial development of GIS software and hardware must, because of financial necessity, support the demands of its majority of users (Dangermond, 1993).

Because of the complex nature of geographic data, GISs rely on more elaborate configurations than do most other information systems or statistical programs. A GIS must support varied graphics oriented hardware peripherals (digitizers, scanners, and plotters) and have a database structure sophisticated enough to handle large volumes of data (including imagery) while referencing each data record to a specific geographic location. Coincidentally, the design and programming of efficient algorithms to perform geographic operations have added to the complexity of GIS programs (Goodchild, 1991). There are many things that a GIS is designed to do — but it cannot do every task at the same level of efficiency as specialized "reduced task" programs (statistical and simulation modeling packages). No current GIS package has both the structural flexibility for handling spatial and temporal data and the algorithmic flexibility to build and test process models internally (Nyerges, 1993).

There are several obstacles that continue to hinder the coupling of GIS technology with environmental process models. These obstacles are in the categories of (1) data sources and formats, (2) GIS functions, and (3) modeling methods.

Data Sources and Formats

- *Accuracy* (locational, categorical, and sampling) of data. The quality of many data sets is unknown, leading to the inability to assess or define uncertainty in models.
- *Availability* of pertinent data. Multitemporal modeling needs time-series data layers (land cover, soils, and field data), which could be nonexistent, costly to produce, or not technically feasible to produce at prescribed levels of detail. There is a lack of coordination for archived digital data, especially at global scales.
- *Scale or resolution* of data. Data are often collected or stored at levels of detail that are inadequate for use as parameters for environmental models.
- *Transferability* of data between programs or systems.

GIS Functions

- *Multitemporal analysis.* Very little has been done to incorporate the dimension of time (an integral part of process modeling) into GIS data structures or operations.
- *Three-dimensional analysis and visualization.* GIS's incorporate point, line, and area cartographic primitives and allow Z-values as attributes (2.5-dimensional), but do not have sufficient volumetric operations to model three-dimensional Earth processes.
- *Interpolation and extrapolation algorithms.* There is a need for greater variety, accuracy, and efficiency in spatial algorithms used in interpolating point samples, especially when many data layers are used in a single model.
- *Mathematical and statistical functions.* GIS programs do not excel at statistical analyses or complex mathematical relations required by most environmental process models.
- *Import and export capabilities.* The spatial data transfer tools found in many GIS packages are inadequate for linking a GIS with analytical and modeling software or other database systems.
- *Speed of computing.* Because of the program overhead required for manipulating data in its spatial form, GISs are slow compared with other statistical or modeling systems. The time needed for running complex models may be prohibitive.
- *User interface.* Modelers are often faced with learning and tolerating an unfamiliar (and potentially unfriendly) system to process their models.

Modeling Methods

- *Failure to incorporate the spatial context* of the natural environment into models, or neglecting the influence of adjacent landscape units upon natural processes.
- *Inadequate calibration* of models or misinterpreting the degree of influence some parameters (especially spatial) might have on model results.
- *Lack of understanding of GIS technology* and its components, its capabilities, and its limitations.
- *Shortage of adequate data* that can be structured into an acceptable format to be processed in a GIS.
- *Resistance to changing* methods to include new technology

or redesign the parameters or functions of the model to match the processing medium.

Recommendations

Integrating GIS technology with process modeling requires finding the common ground between those who believe GIS technology solves all problems and process modelers who view GIS technology as merely a toy. Scientists must be willing to cooperate across disciplinary boundaries to understand the Earth's global environment. Berry (1993) observes that "the GIS community must become familiar with the process modeler's requirements and incorporate more mathematical functionality in their GIS products. On the other front, the modeling community must ... become familiar with the conditions, considerations and capabilities of the technology."

The following suggestions are addressed to those who have a role in "bridging the gaps" between GIS technology and process modeling of the Earth's environment:

For modelers:

- Recognize the spatial pattern of Earth surface phenomena as an important function of process.
- Develop ecological models that incorporate the influence of adjacent landscape units.
- Refine techniques of performing field studies regarding the spatial and temporal variability of landscape processes. Evaluate if existing models produce valid results.
- Investigate ways to scale up from localized process models to more actively use remotely sensed satellite data or other digital data sets already available.
- Increase development of multiresolution or "nested" models to more effectively capture the influence of human-induced spatial and temporal variability on global processes.
- Communicate with GIS vendors to make them aware of modeling needs.

For GIS developers:

- Improve data structures to more efficiently handle multitemporal data, not as simply multiple snapshots of time, but as a seamless transition or trend.
- Improve three-dimensional capabilities with algorithms designed to depict volume (as opposed to 2.5-dimensional surfaces).
- Incorporate faster processing technologies into hardware and software, reducing turnaround time for model results.
- Support realtime interactive manipulation of model data to see how the alteration of model parameters may affect the results.
- Display dynmic modeling with continuous animation.
- Improve methods and algorithms for data interpolation and extrapolation from point samples, image rectification, scale changes, vector-raster conversions, and data transformations.
- Develop natural language expert shell interfaces to assist modelers in using GISs.
- Improve links between different database models (spatial relational and object-oriented).
- Develop easier and more efficient data import and export capabilities by implementing spatial data transfer standards and incorporating expert systems technology, facilitating data input and allowing seamless transfer of data to and from analytical and modeling packages.
- Provide the means for defining accuracy or uncertainty of individual data elements; then make an "audit trail" of those figures through subsequent GIS operations or transformations.
- Improve algorithms for geometrical operations (area calculation, perimeter, shape, and volume) and develop methods for computing relationships between objects based on their geometry.
- Develop data structures with stronger relational associations. Assign new attributes to objects based on both existing attributes and complex mathematical rules (models often use differential equations or other mathematical functions to measure the strength of relationships).
- Support and promote less expensive GIS alternatives (public domain software or CD data storage).

For data producers:

- Implement accepted standards in spatial data format, accuracy, and transferability.
- Improve spatial accuracy of field data by incorporating global positioning satellite technology.
- Provide a statement regarding data accuracy and uncertainty and methods of data collection and compilation with every data set distributed.
- Support various data archives and a directory system to access information about available data sets (i.e., meta data).
- Improve automated methods for converting remotely sensed data into digital land-use and land-cover information.
- Test and enhance existing land characteristic databases.

This is an ambitious list of suggestions for the long-term integration of GIS technology with environmental process models. Some of these goals may appear to be dreams, with little likelihood of reaching fruition. GIS technology may not be able to surmount these technical obstacles within the next few years. However, GIS technology is already capable of performing many functions (storing and retrieving spatially referenced data, doing layer comparisons and neighborhood operations, and supporting simple queries). The strength of simulation modeling programs is their ability to process mathematical functions in an efficient manner. For a short-term solution, it may be appropriate to emphasize the relative strengths of these systems and place the highest priority on developing import and export "hooks" or links to transfer data between components (Goodchild, 1991; Nyerges, 1993). This coupling of GIS with statistical and modeling programs would benefit global change research and encourage the development of further links.

References

Aller, L., 1985. *DRASTIC: A Standard System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*, Report No. EPA/600/2-85/018, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Lab, Ada, Oklahoma.

Arnold, J.G., and N.B. Sammons, 1989. Decision Support System for Selecting Inputs to a Basin Scale Model, *Water Resource Bulletin*, 24(4).

Baker, W.L., 1989. A Review of Models of Landscape Change, *Landscape Ecology*, 2:111-133.

Beller, A., T. Giblin, K.V. Le, S. Litz, T.G.F. Kittel, and D.S. Schimel, 1991. A Temporal GIS Prototype for Global Change Research, *GIS/LIS '91 Proceedings*, Atlanta, Georgia, pp. 752-765.

Berry, J.K., 1993. Seminar on GIS for Modelers, Part II: Treating Maps as Spatial Data and the Analytical Capabilities of GIS, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press (in press).

Burrough, P.A., W. van Deursen, and G. Heuvelink, 1988. Linking Spatial Process Models and GIS: A Marriage of Convenience or a Blossoming Partnership?, *GIS/LIS '88 Proceedings*, San Antonio, Texas, pp. 598-607.

Committee on Earth and Environmental Sciences, 1992a. *Our Changing Planet: The FY 1993 U. S. Global Change Research Program*, CEES, Washington, D.C., 79 p.

———, 1992b. *The U.S. Global Change Data and Information Management Program Plan*, CEES, Washington, D.C., 94 p.

Dangermond, J., 1993. The Role of Software Vendors in Integrating

GIS and Environmental Modeling, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press (in press).

Goodchild, M.F., 1991. Integrating GIS and Environmental Modeling at Global Scales, *GIS/LIS '91 Proceedings*, Atlanta, Georgia, pp. 117-127.

Hession, W.C., V.O. Shanholtz, S. Mostaghimi, and T.A. Dillaha, 1987. *Extensive Evaluation of the Finite Element Storm Hydrograph Model*, ASAE Paper No. 87-2570, American Society of Agricultural Engineers, St Joseph, Michigan, 34 p.

Hunsaker, C.T., R.A. Nisbet, D. Lam, J.A. Browder, M.G. Turner, W.L. Baker, and D.B. Botkin, 1993. Spatial Models of Ecological Systems and Processes: The Role of GIS, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press (in press).

Lee, T.J., R.A. Pielke, T.G.F. Kittel, and J.F. Weaver, 1993. Atmospheric Modeling and its Spatial Representation of Land Surface Characteristics, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press, (in press).

Loveland, T.R., J.W. Merchant, D.O. Ohlen, and J.F. Brown, 1991. Development of a Land-Cover Characteristics Database for the Coterminous U.S., *Photogrammetric Engineering & Remote Sensing*, 57(11):1453-1463.

Maidment, D.R., 1993. GIS and Hydrologic Modeling, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press (in press).

Moore, I.D., A.K. Turner, J.P. Wilson, S.K. Jenson, and L.E. Band, 1993. GIS and Land Surface-Subsurface Process Modeling, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press (in press).

Nyerges, T.L., 1993. GIS for Environmental Modelers: An Overview, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press, (in press).

Panuska, J.C., I.D. Moore, and L.A. Kramer, 1991. Terrain Analysis: Integration into the Agricultural Nonpoint Source (AGNPS) Pollution Model, *Journal of Soil and Water Conservation*, 46(1):59-64.

Peuquet, D.J., 1984. A Conceptual Framework and Comparison of Spatial Data Models, *Cartographica*, 21:66-113.

Running, S.W., R. Nemani, and R.D. Hungerford, 1987. Extrapolation of Synoptic Meteorological Data in Mountainous Terrain and Its Use for Simulating Forest Evapotranspiration and Photosynthesis, *Canadian Journal of Forest Research*, 17:472-483.

Schimel, D.S., 1993. Spatial Interactive Models of Atmosphere-Ecosystem Coupling, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, editors), Oxford University Press, (in press).

Sellers, P.J., Y. Mintz, Y.C. Sud, and A. Dalcher, 1986. A Simple Biosphere Model (SiB) for Use Within General Circulation Models, *Journal of Atmospheric Science*, 43:505-531.

Sharnholtz, V.O., C.J. Deai, N. Zhang, J.W. Kleene, C.D. Metz, and J.M. Flagg, 1990. *Hydrologic/Water Quality Modeling in a GIS Environment*, ASAE Paper No. 90-3033, American Society of Agricultural Engineers, St Joseph, Michigan, 17 p.

Steyaert, L.T., 1992. Integrating Geographic Information Systems and Environmental Simulation Models, *Technical Papers, ASPRS/ACSM/RT 92 Fall Convention*, Washington, D.C., August, 1:233-243.

———, 1993. A Perspective on the State of Environmental Simulation Modeling, *Environmental Modeling with Geographic Information Systems* (M. Goodchild, B. Parks, and L. Steyaert, Oxford University Press (in press).

Sturdevant, J.A., J.C. Eidenshink, and T.R. Loveland, 1991. Organizations Challenged by Global Data base Development, *GIS World*, 4(9):73-79.

Stutheit, J., 1991. Temporal GIS Investigates Global Change, *GIS World*, 4(9):68-72.

Tomlin, C.D., 1990. *Geographic Information Systems and Cartographic Modeling*, Prentice-Hall, Englewood Cliffs, N.J., 249 p.

U.S. Congress, 1990. *Global Change Research Act of 1990*, Public Law 101-606: 101st Congress, Nov. 16, 1990, 104 STAT. 3096-3104.

Wheeler, D.J., 1988. A Look At Model Building with Geographic Information Systems, *GIS/LIS '88 Proceedings*, San Antonio, Texas, pp. 580-589.

Xue, Y., P.J. Sellers, J.L. Kinter, and J. Shukla, 1991. A Simplified Biosphere Model for Global Climate Studies, *Journal of Climate*, 4:345-364.

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Submit nominations to the Executive Director, 5410 Grosvenor Lane, Suite 210, Bethesda, Maryland, 20814-2160 by Wednesday, December 8, 1993 (20 weeks prior to the day of the 1994 Annual Meeting).

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