# The Model Web: A Concept for Ecological Forecasting

Gary N. Geller
NASA Ecological Forecasting Program
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA USA

Woody Turner
NASA Ecological Forecasting Program
NASA
Washington, DC USA

***Abstract*--Ecological forecasting capabilities are constrained by the interoperability of ecological and related models, among other things. This limits the types of questions that can be practically addressed, as well as the range of users that can ask them. We are exploring the concept of an Ecological Model Web, an open-ended system of interoperable computer models and databases, with machine and end-user Internet access via web services. The 5-10 year vision includes a distributed network of interoperating models; that grows organically within a framework of broad goals and standards; with models and datasets maintained, operated, and served independently; and that provides interactive web access to researchers, managers, and the public. Increasing the level of interoperability of these models will increase their collective power and the breadth of questions they can answer.**

***Keywords-model; interoperability; ecological forecasting***

## I. Introduction

Ecological forecasting, like most modeling realms, is constrained by a mixture of factors. One of these is interoperability, including model-model and model-datastore communication barriers, inconsistent terminology, and barriers to model access by other modelers, researchers, natural resource managers, and policy makers. In general, these and other obstacles make the effort required to utilize multiple models very significant, thus limiting the types of questions that can be practically addressed and the range of users that can ask them.

The Ecological Forecasting Program at NASA, with collaborators, is exploring ways to enhance model interoperability. The Model Web, currently just a concept, would be an open-ended system of interoperable computer models and databases, with machine and end-user Internet access via web services. It is not explicitly a fully automated, "plug and play" system of "snap-together" components, though that approach is consistent with the overall concept. Although our focus is ecological, the same concepts can be, and are being, applied to many modeling realms. Also, because ecological forecasting depends upon models from many domains, including climate, hydrology, physiology, and socio-economics, in addition to ecology, the boundaries of a Model Web are not well-defined. A Model Web would utilize data from a variety of sources, including observational data (e.g., meteorological or ecological) and perhaps real-time sensors (e.g., space- or surface-based), so interoperability with these data sources is also important.

## II. Current Situation

While making models interoperable is not a new idea, such interoperability, when it exists, tends to occur in limited clusters; most models or clusters are not interoperable at all. For example, the NASA Terrestrial Observation and Prediction System (TOPS) is a cluster that combines ecosystem, hydrology, and other models to produce about 30 output parameters for hindcasts, nowcasts, and forecasts. But TOPS and its outputs are not yet generically available to other models that could benefit from them, though this being addressed. Practical access to many models is often restricted to the developers and their colleagues, with limited access for other researchers, ecosystem managers, policy makers, or educators. The Model Web would help remove these obstacles. It should be mentioned that it is recognized that similar ideas are being discussed by other groups (both known and probably unknown to us) and we hope that a generalized cooperative approach emerges.

## III. The Model Web Concept

The 5-10 year "vision", which describes what the Model Web might look like in an ideal world, includes:

- Distributed network of interoperating models (and datasets and sensors)

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- Physical, chemical, biological, and ecological processes
- Organic growth within a framework of broad goals and data exchange standards
- Models and datasets maintained, operated, and served independently
- Interactive web access provided to researchers, managers, public
- Voluntary participation, at discretion of each model or dataset owner and sponsor
- Fits with GEOSS; global, interagency, international

Fig. 1 is a simple scenario showing where a Model Web would be useful for ecological forecasting. A park manager wonders whether their park will still provide suitable habitat for a particular rare species in 50 years. If, as the climate changes, the viable range for that species shifts outside of the park, the species would no longer be protected or, perhaps worse, there may not be any suitable habitat outside the park. Knowing this now would allow park management to consider a variety of countermeasures. In this scenario, a global climate model is used with a regional model and TOPS to make predictions about the future environment. These can then be fed into other models, such as a Fire Model and a Landscape Model to predict what the future landscape might look like, such as forest or grassland. Information from many of these models can then be fed into an "Ecological Niche Model" that relates the physical environment to the species' environmental "envelope", i.e., the habitat where it lives. Using the climate predictions the Niche Model can then predict what locations will provide such a habitat in 50 years, thus providing the spatial distribution of the species.

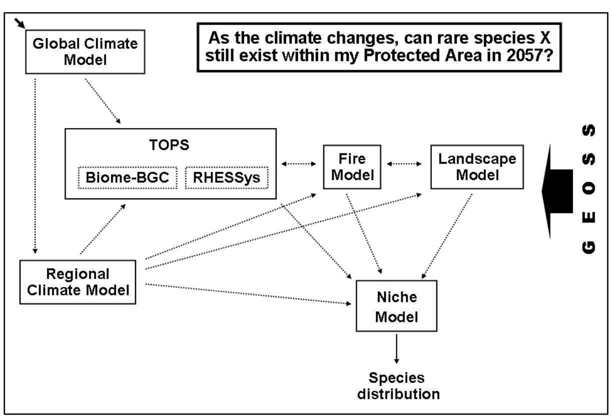


Figure 1. Example scenario where a Model Web would be useful.

## IV. SUPPORTING TECHNOLOGIES

Several emerging technologies could greatly facilitate the convergence upon this vision, though each has limitations. One is Earth Science Markup Language (ESML) which, along with other markup languages such as Geography Markup Language and Ecology Markup Language can act as a translator among data formats. ESML provides a software library that simplifies its use, though some users have reported some problems with that and these may need to be addressed. Another is the "Semantic Web" coupled with the Earth science terminology definitions called SWEET. SWEET and other ontologies can remove ambiguity in the meaning of data elements by providing consistent, shared definitions, ensuring that all models using the data have the same understanding of it, facilitating automation. The ease with which such ontologies can be incorporated into models is not clear, however. Another new technology, the Earth System Modeling Framework, can simplify the interface between ecological models and large, supercomputer-based, gridded, global climate models. Finally, an established technology, web services, could help simplify the approach to transferring information from one model to the next.

It is important to note that universal use of these technologies is not a requirement—the Model Web is specifically intended not to be a monolithic system of rigid protocols and standards. It is guided rather by a "common denominator" that provides a basic framework to facilitate growth towards greater interoperability. As such, a Model Web could include a variety of systems, including commercial and non-commercial models, model systems, and data.

## V. ADDITIONAL CONCEPT FEATURES

Two features of the Model Web concept are worthy of additional discussion. First is the idea of organic growth. Development of a Model Web would not be a project in any traditional sense, rather, it would grow "organically" within a general framework devised by the modeling, datastore, and user communities. Any modeler or data provider could be part of a Model Web, to whatever degree they desired or were able. This leads to the concept of convergence. The Model Web is only a vision, and probably one that will never be completely achieved. However, there would be a gradual convergence towards that vision, and with that convergence would come greater interoperability, greater modeling and forecasting capabilities, and increased access to those capabilities by a broader range of users.

The notion of data universality is also pertinent here. This simply means that, in some sense, the source of a data stream is irrelevant. A model, for example, can be thought of as a virtual sensor that generates data. As long as the uncertainties associated with the data are specified--indeed, those should be part of the data stream itself--it may not much matter whether the source is a model, a sensor, or a data store. In fact, the distinction between these can be blurred, as the output of a sensor often requires processing with software that may be akin to a model.

## VI. Possible Growth Phases

Growth progression of the Model Web might look something like this…It would likely start with a focus on data interoperability, meaning the ability of one model to utilize the output from another model or other data source. It is thought that ESML and other XMLs will play a significant role in resolving that problem. As interoperability increases and new applications are found, gaps in the available data will surface and, often, be filled. Shared terminology for parameters will gradually become important, an issue addressed with the SWEET Earth science and other ontologies. Eventually, as the web of models and data becomes more complete and precisely defined, automation will begin to play a more important role. Increasingly sophisticated portals will provide access to the Model Web, allowing more and more users to extract value from it. Gradually, the Semantic Web vision of Tim Berners-Lee would start to take shape, using, for example, "agents" to help users answer questions.

## VII. Accuracy and Uncertainty

A Model Web can only be as useful as the accuracy of the models permit, though different levels of accuracy and confidence can support different activities. Initially, the Model Web probably would be most useful for research, for example, by facilitating "model experiments". Here, a researcher could explore what happens under a variety of model conditions, swapping out one model for another, and changing input parameters, assumptions, or constraints. Such experiments may reveal how various systems respond to perturbation, for example, even if the results in absolute terms are not suitable for decision makers. However, as model accuracy improves the model results would become increasingly useful to decision makers, gradually becoming an element of the information used in making their decisions. Of course, usefulness to decision makers will vary greatly depending on the models used and their application.

Because uncertainty tends to increase as models are chained together, this can be a problem. It thus becomes more important that each model carries with it the uncertainties associated with the data. This will allow an overall uncertainty to be determined. It should not be assumed that a Model Web will necessarily lead to increased uncertainty, however. Greater interoperability among models and data will make it easier to include additional models or datasets that can act to decrease uncertainty. Also, the ability to more easily swap out one model for another will make it possible for users to see how well different models agree, providing more information about an appropriate level of confidence in the final result.

## VIII. Other Barriers

There are a variety of barriers to model interoperability, both technical and non-technical, and the Model Web concept does not address all of them. Yet these are significant and it is important to recognize them and consider how they might be lowered. Some of these are:

- Model Purpose. Most scientific models were developed to address a specific problem, and interoperability and data sharing are not often part of the original goals.
- Sponsor Goals. Sponsors are typically, and reasonably, focused on addressing problems within their specific programs. However, this tends towards "stovepiped" funding that gets manifested as relatively isolated models.
- Lack of Incentive. What will motivate a model developer to share their model or its outputs? The rewards for doing that may be low or negative, or be perceived as such.
- Cultural Differences. Cultural differences exist between disciplines as well as between modelers and technology developers.
- Lack of Standards. Standards facilitate interoperability; where they are missing they can be both a technical and non-technical barrier.

## IX. Conclusion

The Model Web is just a vision--what really happens will depend on many factors, perhaps especially the acceptance of the concept and a framework by the modeling and datastore communities. Thus, it is important that the concept and its framework be both appealing and practical—if it proves too cumbersome, it won't be used. An organic growth approach will provide some ability to adapt to such issues as they arise.

However it happens, increasing the interoperability of ecological and related models and datastores will increase their collective power and the breadth of questions they can answer. Providing web access to this decentralized system will enhance the benefits that can be extracted from existing models and data, and eventually help people who need answers to "what if" and other questions so they can make appropriate management decisions.

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