The multiscale integrated Earth Systems model (MIMES): the dynamics, modeling and valuation of ecosystem services

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Ecosystem services are defined as those functions of ecosystems that support (directly or indirectly) human welfare. They occur at multiple scales, from climate regulation and carbon sequestration at the global scale, to flood protection, soil formation and nutrient cycling at local and regional scales (Kremen 2005; Table 1).

The MIMES project aims to integrate participatory model building, data collection and valuation, to advance the study of ecosystem services for use in integrated assessments. MIMES builds on the GUMBO model (Boumans *et al*. 2002; Costanza *et al*. 2006) to allow for spatial explicit modeling at various scales. The three major objectives are:

- A suite of dynamic ecological economic computer models specifically aimed at integrating our understanding of ecosystem functioning, ecosystem services and human well-being across a range of spatial scales.
- Development and application of new valuation techniques adapted to the public goods nature of most ecosystem services and integrated with the modeling work.
- Delivery of the integrated models and their results to a broad range of potential users.

The collaborative modeling approach

We used a Web environment (http://www.uvm.edu/giee/mimes/) for collaborative work among interested users and designers to facilitate the three different stages in participatory modeling as outlined by Costanza and Ruth (1998).

We chose SIMILE, a declarative visual modeling environment (http://www.simulistics.com/) for coding models to ensure that they were highly-transparent, easy to modify and easy to use.

Scoping the MIMES

The MIMES outline was constructed after the Millennium Assessment Synthesis report on “Ecosystems and Human Well-being: General Synthesis” (Figure 1). The MIMES at this stage represented a general model scalable in time and space to be applied in global, regional and local models.

Ecosystem services are the interface between the natural spheres and the anthroposphere, where natural amenities are evaluated for their contributions to the economies and well-being of human cultures. When MIMES is used to represent a spatial explicit model (multiple locations), exchanges between locations can be coded to represent not only flows of water, air and people but also the spread of species.

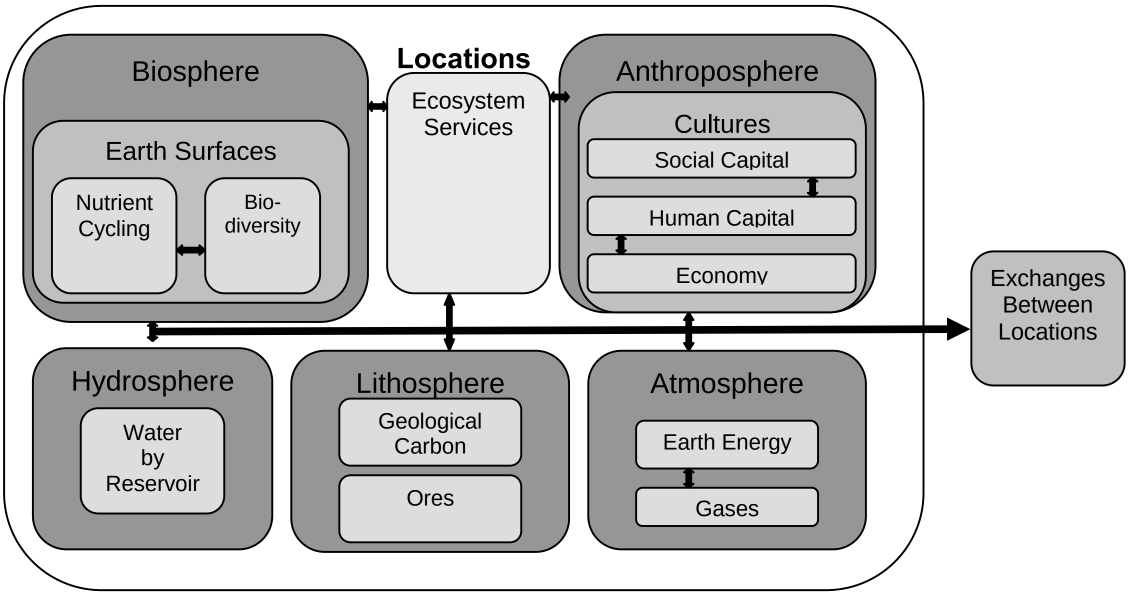
Researching the MIMES framework

Subject-specific models (subject models) relevant within the MIMES outline were studied and translated for representation within the SIMILE declarative modeling language (Figure 2). MIMES development requires an "interaction matrix" to link outputs and inputs among the subject models. This matrix is a dynamic feature within MIMES development for developers of subject models to interact with modelers of other parts in the model (asking for model input and providing model output when asked).

Table 1. *Ecosystem services classified according to spatial characteristics*

Omni-directional, Global (does not depend on proximity)	
	Carbon sequestration
	Carbon storage
	Existence of "nature"
Omni-directional, Local (depends on proximity)	
	Storm protection
	Waste treatment
	Pollination
Directional flow related: flow from point of production to point of use	
	Water supply
	Water regulation/flood protection
	Nutrient regulation
In situ: point of use	
	Sediment regulation
	Rangeland for livestock
	Nitrogen mineralization for agricultural. production
	Soil formation
	Raw materials
	Non-timber forest products
User movement flow related: attraction of people to unique natural features	
	Aesthetic/recreation potential

Figure 1. *General outline of the MIMES model: The multiscale integrated Earth Systems model*



MIMES applications and scenarios

MIMES will be further developed to be applied to case studies (Table 2). Projects are underway to create global implementation (Figure 3), to simulate land-use changes within watersheds in the Amazon, the south of Brazil and the Philippines, and in the United States to investigate salmon issues around Puget Sound, Washington State, to simulate waterflow in the Winooski Watershed, Vermont and to investigate forest deer population dynamics within Alaska.

Figure 2. *Hierarchical representation of the MIMES framework*

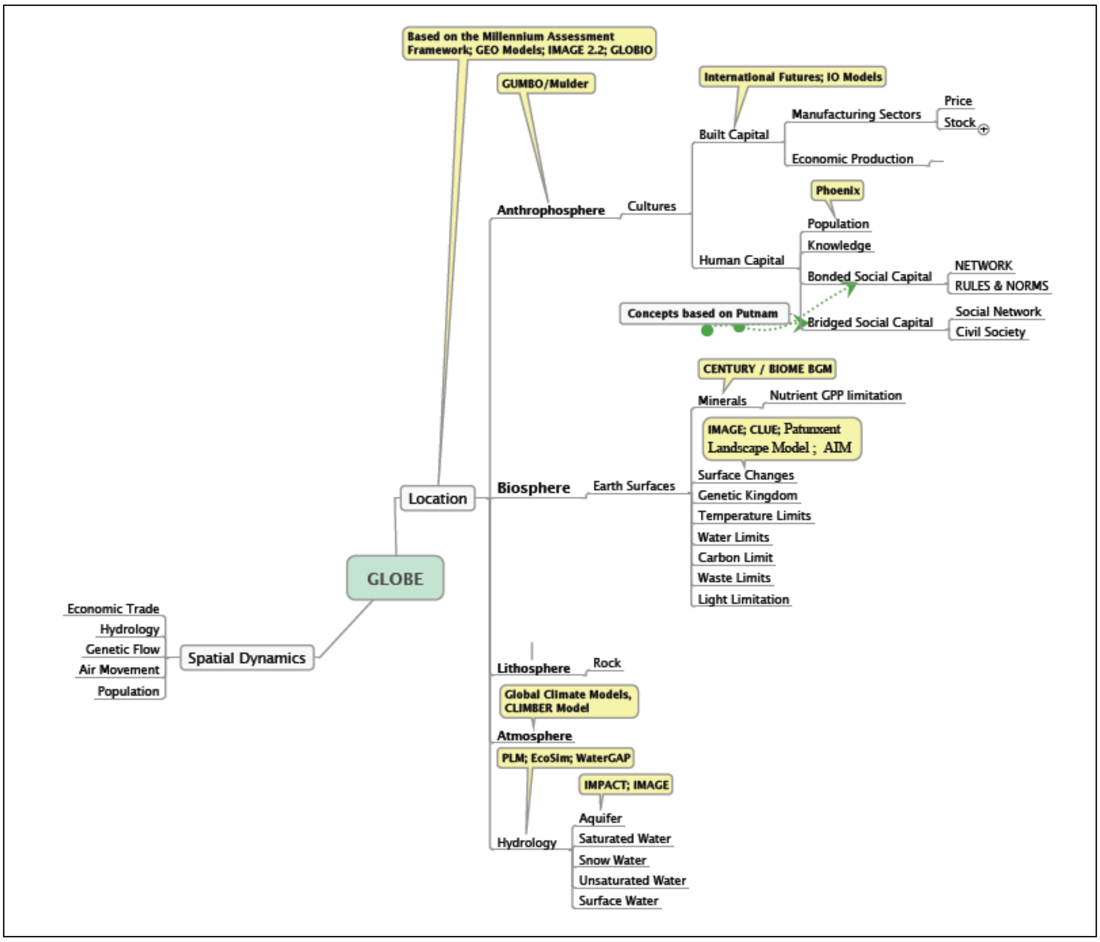


Figure 3. *Atmospheric energy balance generated by the MIMES global implementation model along a 360 x 180 grid matrix representing the globe on a 1 by 1° resolution. Lighter colours represent higher levels of energy*

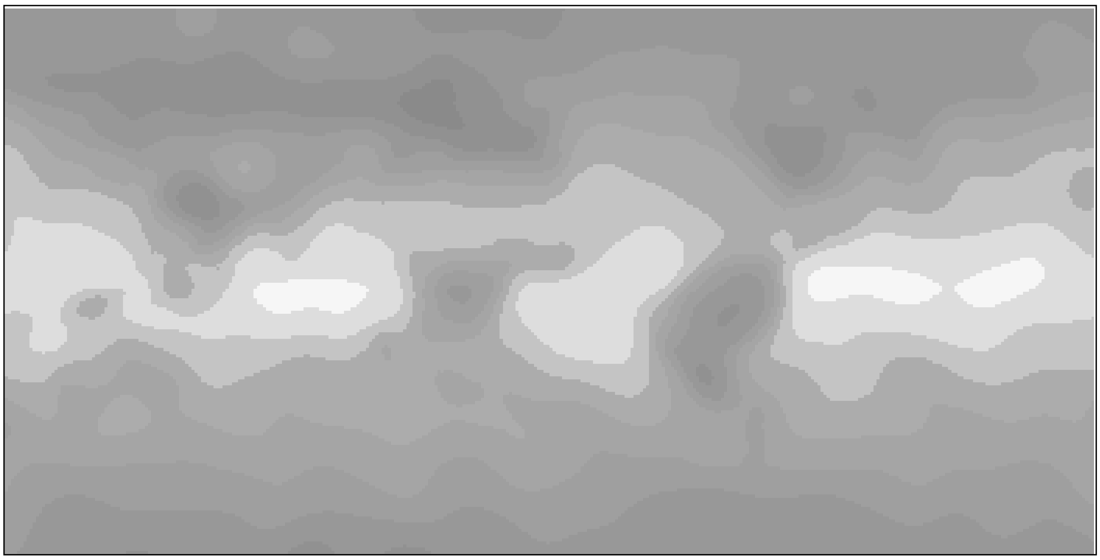


Table 2. *Institutions involved in the development of MIMES*

Universities	
Brazil	University of Sao Paulo, UNICAMP
Germany	Helmholtz CER
Netherlands	Wageningen University
Philippines	Palawan State University
United States	Boston University, Florida Institute of Technology, Kansas University, Michigan State University, Stanford University, University of Denver, University of Vermont
Governmental organizations	
Brazil	Embrapa
United States	National Center for Atmospheric Research, USDA Forest Service
NGOs	
Conservation International	
Conservation Strategy Fund ,Brazil	
Earth Economics	
International Institute for Sustainable Development	
Software developers	
Simulistics	
STELLA Software Systems	

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