Numerical Modeling in Undergraduate Earth and Environmental Science Programs

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Abstract

In recent years computer modeling has gained importance in Earth and Environmental Science research as a means to generate and test hypotheses and to allow simulation of processes in places inaccessible to humans (e.g., outer core fluid dynamics), too slow to permit observation (e.g., erosionally-induced uplift of topography), or too large to facilitate construction of physical models (e.g., faulting on the San Andreas or climate change). Entire fields within the Earth and Environmental sciences now exist in which computer modeling has become the core work of the discipline. Undergraduate programs have been slow to adapt to this change, and computer science curricular offerings often do not meet students' needs.

To address these problems, a course in numerical modeling in the Earth and Environmental Sciences has been developed at Vassar College with support from the NSF CCLI program. The course uses the STELLA iconographical box modeling software developed by Isee Systems, Inc. to teach students the fundamentals of dynamical systems modeling.

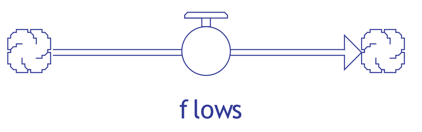
The course has been taught four times and has been received enthusiastically by students, who reported not only that they enjoyed learning the process of modeling, but also that they had a newfound appreciation for the role of mathematics in Earth science and intended to enroll in more math courses in the future.

STELLA

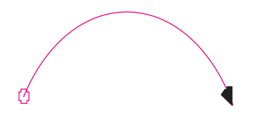
Structural Thinking Experimental Learning Laboratory with Animation - icon-based dynamical systems modeling tool developed by High Performance Systems, Inc.

★ Boxes represent reservoirs

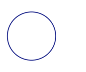
★ Arrows represent flows into and out of reservoirs



★ Dependencies of variables are represented with pink linking arrows



★ Converters, hold values of constants and equations.

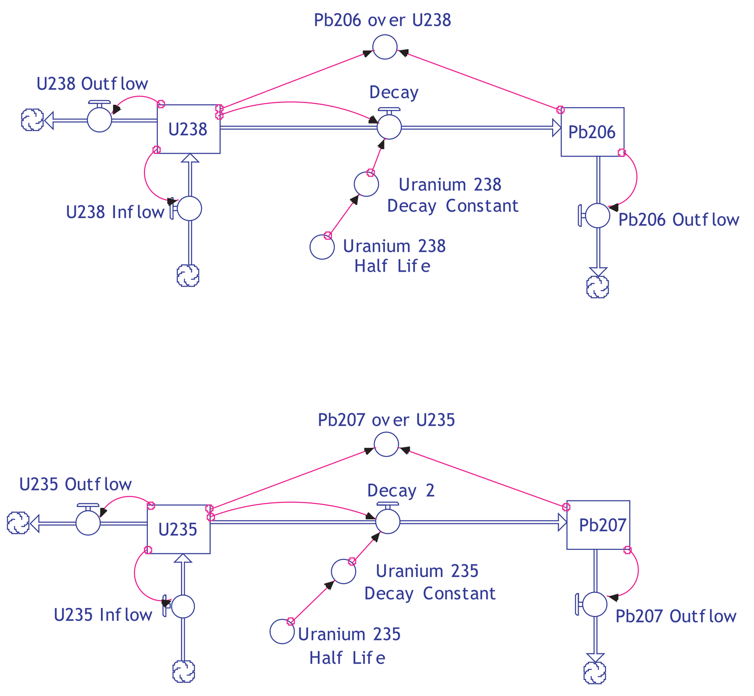


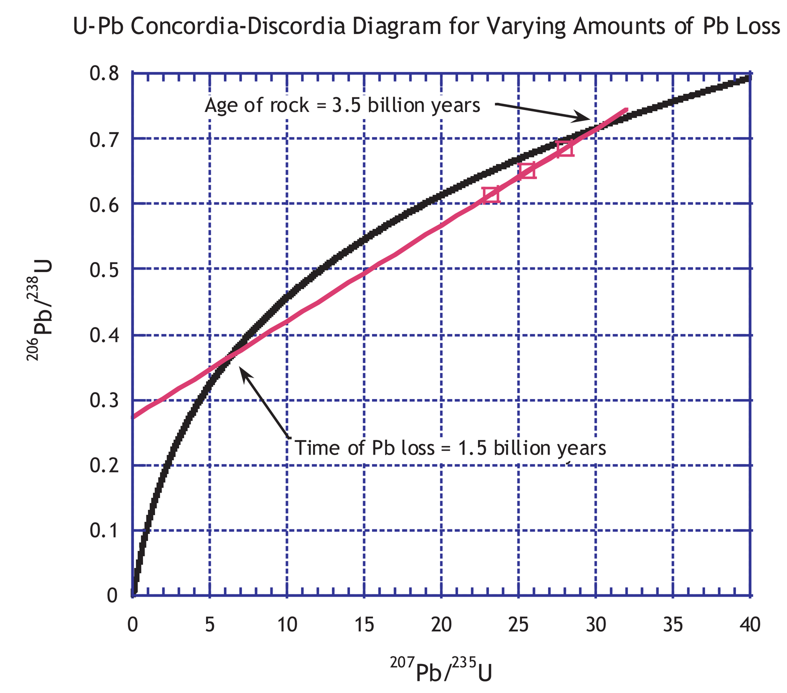
Course Format:

- ★ Meets 1 day a week for 4 hours
- ★ Students present readings from the literature that form the basis of the modeling project for the week
- ★ Students construct models and then run experiments
- ★ Independent projects at the end of the semester allow each student to explore his or her own interests

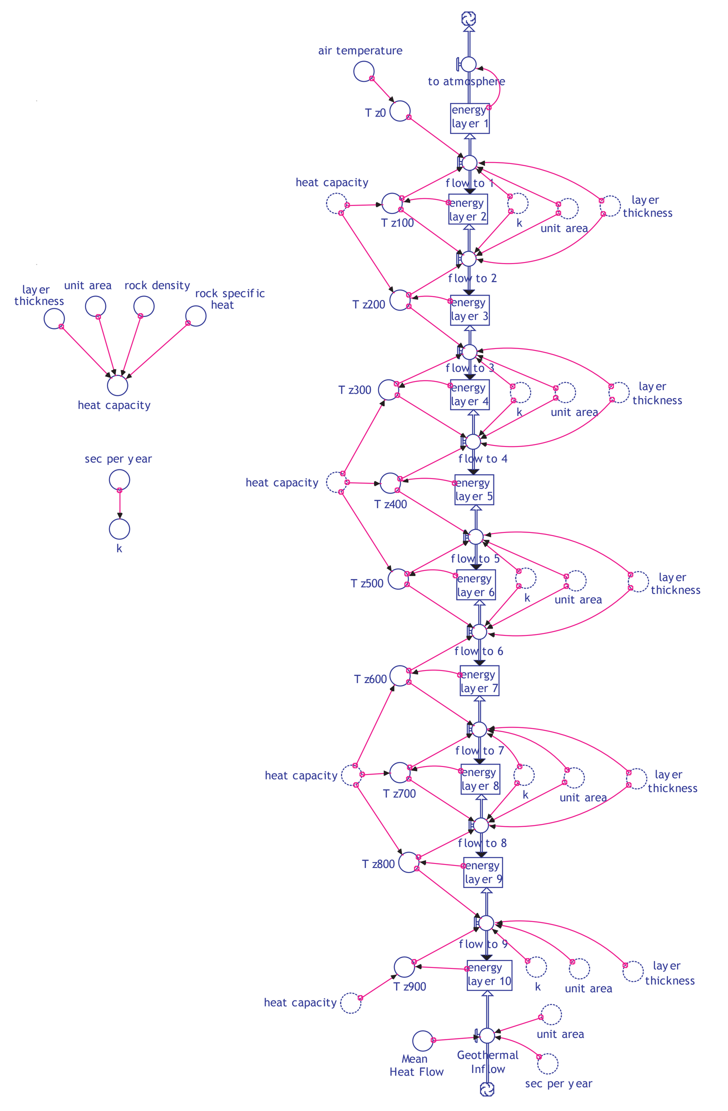
Examples of Modeling Exercises

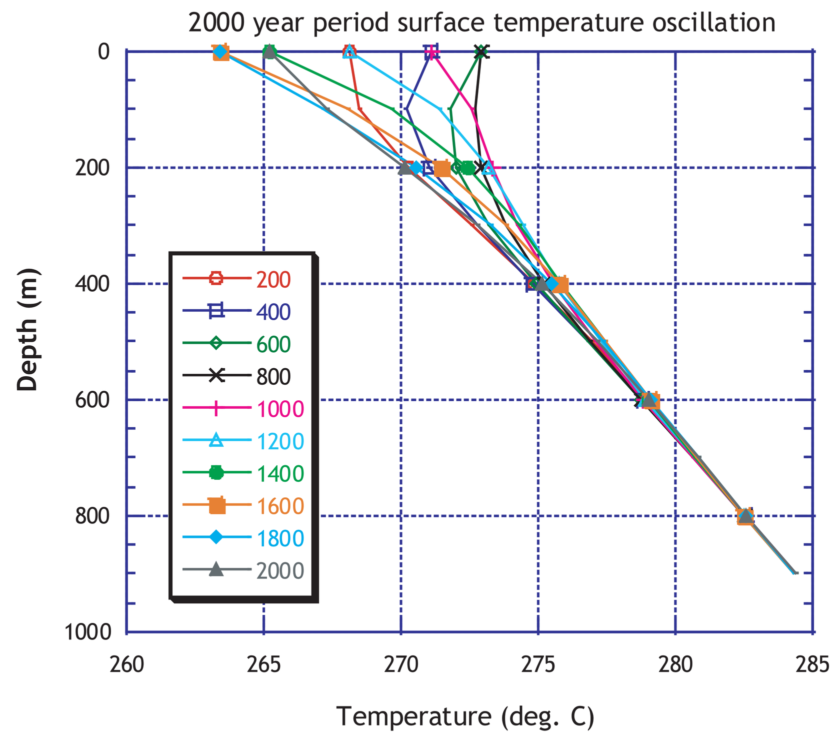
U-Pb Concordia/Discordia Dating Techniques





Heat Flow in Permafrost and the Geothermal Gradient

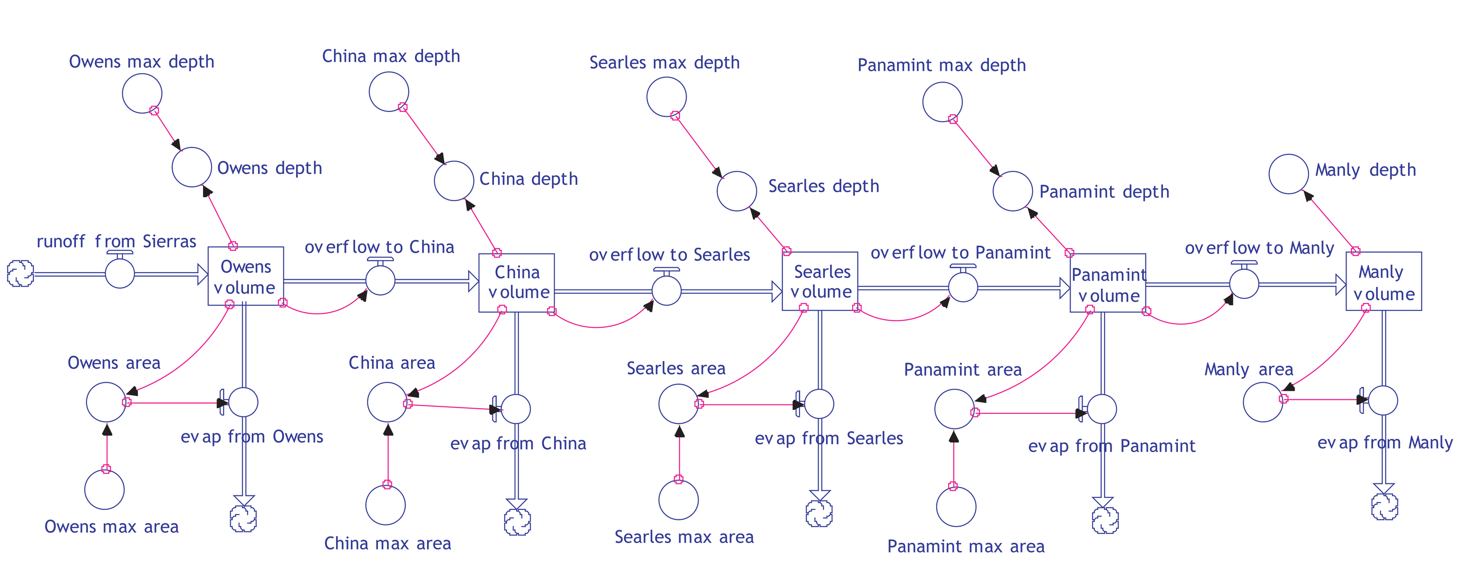


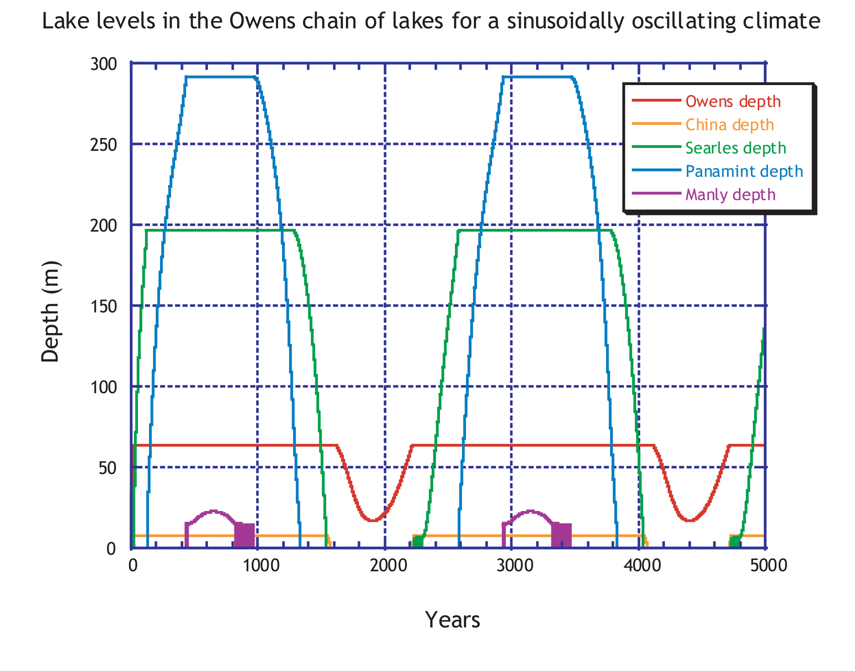


Modeling concepts covered in the course include:

- ★ open vs. closed systems
- ★ initial conditions
- ★ boundary conditions
- ★ positive and negative feedback loops
- ★ if-then-else logical statements
- ★ response time
- ★ residence time
- ★ exponential growth and decay
- ★ oscillatory behavior
- ★ steady state
- ★ how to choose a time step
- ★ different integration methods - Euler, Runge-Kutta

Impact of Climate Change on Lake Levels in Eastern California





Student Responses to the Course

In the end of class questionnaire, students reported that they felt the course was highly effective in teaching the basics of system dynamics and how systems could be modeled, that they found the iconographic structure of STELLA very useful in learning modeling.

Responses to the question 'how would you describe the impact of this course on your general understanding of system dynamics and of how systems can be modeled?' included:

"Before I took this course I had no idea how people knew what they knew about systems with large scales and long timescales. Now I see how useful a computer model can be to understanding this. I also learned that the models can be simple but still give a lot of information. This class has been so useful in making geologic problems realistic."

"This class had a tremendous impact on my general understanding ofmodeling and system dynamics. It has helped me to realize how valuable modeling can be in geology and how to go about modeling a problem."

"Highly effective, I now understand what modeling a system consists of and can think about such relations mathematically much better than I could six months ago."

In response to the question 'Did the course have any impact on your understanding of the usefulness of math in geology?' students said:

"Yes, this is one of the only courses which has done so."

"Yes, it had a huge impact. This class showed me that calculus is very important in the study of geology. Because of this class I'm planning on taking calculus."

"Yea - now I wish I'd taken more math. I may take some next year but haven't had any since freshman year. For the practical applications such as this you have to be able to truly understand it, not just do it."

Available Course Materials

Fully documented and debugged STELLA models along with student exercises and answer keys have been developed for distribution to anyone interested in teaching a course such as this. Exercises available include:

- ★ The global phosphorus cycle
- ★ U-Pb concordia/discordia dating techniques
- ★ Heat flow in permafrost
- ★ Earth's energy balance and temperature
- ★ James Lovelock's Daisyworld
- ★ The impact of climate change on a chain of lakes in eastern California
- ★ Flow of ice in glaciers by plastic deformation
- ★ Scarp diffusion

To access materials, use a web browser to go to:
http://serc.carleton.edu/index.html
and put menking in the search box or contact me directly at kimenking@vassar.edu

Acknowledgments:

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