ENVIRONMENTAL MODELING (AIMS Review Course, Spring 2005 term)

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The course will introduce environmental science and develop tools to model the natural world using mathematics. The emphasis is on understanding complex natural systems by using simplified models. Students will practice order-of-magnitude reasoning to develop intuition for the relative importance of different factors and the scale of natural phenomena. They will translate systems into simple box-and-flow models (for example, to understand the greenhouse effect). They will use real datasets of environmental parameters, such as rainfall and temperature, to evaluate correlations and periodicities. But equally importantly, students will practice statistical techniques to evaluate their own and others' models and analyses. Students should finish the class able to make quantitative models of real-world phenomena and also able to reason critically and spot dubious analyses and misguided assumptions.

Along with the tools described above, the course will introduce environmental and climate studies. Whenever possible the examples will be drawn from African phenomena, so that students learn particular issues they may handle as resource managers or statisticians in their home countries. Modeling will be done in the free-software packages Python and Octave, which will build on the skills taught in the first AIMS semester. Statistical concepts will be introduced with real-world examples and practiced by critically analyzing peer-reviewed publications: there is no shortage of papers from which to learn how *not* to treat data. Data-analysis problems will use publicly available climatologic or satellite datasets so that students learn what parameters in earth science are measured and monitored and how to access and use these data. The emphasis is on concepts, resources, and analysis tools that students can use in science and government careers.

STRUCTURE

Unit 1 (3 days). Estimation and physical intuition. Overview of basic concepts in environment and climate: chemical composition of earth, ocean, and atmosphere; atmosphere and ocean circulation; role of the tropics and Africa in particular.

Unit 2 (6 days). Modeling the physical world and understanding environmental mechanisms. Constructing simplified box models for e.g.: heat transport in oceans and atmosphere; carbon cycling between land, oceans, and atmosphere; precipitation and the water cycle; radiation transfer and greenhouse warming. (These are standard problems for advanced undergraduates or beginning graduate students). Class discussion on model appropriateness and testing. Lectures include a brief description of larger climate and circulation models and information on what models are available for public use.

Unit 3 (6 days including final project). Data analysis and statistical tests. Obtaining and working with environmental datasets. Students review published studies using environmental data and discuss the problems and pitfalls (sparse observations, missing data, aliasing, undersampling, averaging kernels). Students manipulate climatologic or satellite datasets and use them to fit functions and construct models, to investigate correlations between variables and to determine periodicities of variation. Students use statistical techniques for determining significance, including Monte Carlo methods, and critique each other's analyses.

Final Project. Students will complete a final project: a critical review of a published article on African climate, using all the tools at their disposal to evaluate the paper. Papers will be chosen by the instructor to include a mix of solid and problematic studies; students will work in teams to evaluate for themselves the quality of their assigned paper and will present their conclusions to the class.

TEXTBOOKS

Course material will be drawn from several books, annotated below.

Units 1 and 2:

* *Consider a Spherical Cow: a Course in Environmental Problem Solving*, by John Harte. A classic. Introduces order-of-magnitude reasoning in environmental science; progresses to box-and-flux models, equilibrium population calculations, and energy-balance atmospheric models. Covers the basic concepts of environmental modeling: conservation of energy and mass, equilibrium assumptions, aggregating complex systems into simpler subunits.

* *Why Big Fierce Animals are Rare: an Ecologist's Perspective*, by Paul Colinvaux. An eminently readable popular book that offers engaging stories of natural systems; discusses the concerns of natural scientists, such as energy budgets and equilibrium determination; and explains the rules underlying phenomena such as the relative numbers of mice and tigers, the geographical distribution of trees, and competition and coexistence between species. Colinvaux did fieldwork in Africa and often uses African examples. Students will use this book for a modeling homework exercise, choosing one chapter and translating Colinvaux's words and concepts into equations to model the system.

* *The Nature of Mathematical Modeling*, by Neil Gershenfeld. An excellent primer that goes beyond the techniques of *Consider a Spherical Cow* to discuss stochastic processes and numerical modeling techniques. It shows how advanced math skills can be used in modeling. In unit 3 we will draw heavily on its discussion of how to fit observational data.

* *Earth Systems: Processes and Issues*, by W.G. Ernst. Offers a readable, solid foundation on Earth systems science, with chapters on atmospheric motions, biogeochemistry, and the hydrologic cycle. It will provide background material for the modeling lectures.

Unit 3:

Gershenfeld will be the starting point for making a model that fits actual data. The next two textbooks will teach how to test model validity:

* *Statistics for Experimenters: Design, Innovation, and Discovery*, by George E. Box, J. Stuart Hunter, and William E. Hunter. The updated edition of the classic *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, due out in November 2005. We will use it for the introductory discussions of covariance, correlation, and significance testing, and for the new edition's promised chapters on Bayesian methods.

* *Data Analysis: a Bayesian Tutorial*, by D.S. Sivia. This book is a concise primer in Bayesian statistics, treating data fitting and confidence estimation from a probabilistic standpoint.