EOS 995 **Modeling & Analysis of Biogeochemical Cycles** Spring 2001 (3 Credits)

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Office hours: Mon. 9:00-10:00 & Wed. 10:00-11:00

TIME & LOCATION: Tues./Thurs. 2:10 – 3:30, Kingsbury 303 or Hamilton-Smith 3.

**TEXT**: *Modeling the Environment: An Introduction to System Dynamics Modeling of Environmental Systems,* Andrew Ford. Island Press, Washington DC. 1999.
AVAILABLE at DURHAM BOOK EXCHANGE on Main Street.

There will be additional readings from the literature sprinkled throughout the course; 2-3 copies of these articles will be available for you to *borrow* to make your own copies.

**COURSE TOPICS**:

1. **Introduction to modeling** (30%) – Stella modeling, system dynamics, biogeochemistry.
   We will spend ~5 weeks reviewing basic modeling, carbon and nitrogen cycling, and stable and radio-isotope analyses. Readings will include some chapters of the Ford book (*Modeling the Environment*), with additional biogeochemistry readings selected from other sources. This will introduce system dynamics, stocks and flows, modeling with Stella software, and some simple examples from biogeochemistry. One class per week will be held in Hamilton-Smith Room 3, a classroom equipped with ~20 computers and a projection system. This section of the course will have weekly homework assignments.

2. **Data analysis** (15%) – We will spend ~1 week discussing this topic, and you will spend a couple more weeks analyzing a data set of your choice. Each student will select a dataset, take a close and multi-angled look at it, and come up with a model structure related to it. This section will end with brief (10-15 min) presentations by each student on their data set and modeling ideas.

3. **Models and Model evaluation** (15%) – We will spend ~3 weeks on this topic.

   i. We will read several modeling papers on topics of interest to the class, and discuss these in class. Interspersed with this we will read several papers on model evaluation, and use these as a guideline to evaluate modeling papers.

   ii. We will review one modeling paper as a group as if we had been asked by a journal to provide a review. We will discuss this in class.

   iii. You will each do an individual review of a second modeling paper. You will write this as if you had been asked by the journal to review the article: you will need to write a formal review for the author, and, if necessary, a brief letter to the editor outlining your recommendations.

4. **Modeling Project** (40%) – You will spend the final 4-5 weeks of the semester developing a model related to your chosen data set. You can use Stella or any other modeling software, or write a program in C or another language. We may meet intermittently as a class during this time, but most class periods will be used for individual meetings. You will make a final presentation (poster or oral) on the model at the end of the semester. A final written report will be due during the final exam period.

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**Semester Schedule**

| Week | Class Topic | Assignment |
|---|---|---|
| 1. Jan 17 - 19 | Course introduction and outline | Get the textbook. |
| 2. Jan 22 - 26 | Box models, Stella – 1 | Read Ch. 2, 4; HW Exercise #1. |
| 3. Jan 29 - Feb 2 | Global Carbon Cycle | Read Ch. 5; HW Exercise #2. |
| 4. Feb 5 - 9 | Ecosystem Carbon Cycle | Read Ch. 10, 11; HW Exercise #3. |
| 5. Feb 12 - 16 | Ecosystem Carbon Cycle | Read Ch. 10, 11; HW Exercise #3. |
| 6. Feb 19 - 23 | Nitrogen Cycle | Read selected paper(s); HW Exercise #4. |
| 7. Feb 26 – Mar 2 | Stable & Radio-isotopes | Read selected paper(s); HW Exercise #5. |
| 8. Mar 5 - 9 | Data analysis | Locate a data set; start data analysis. |
| Mar 12 - 16 | *NO CLASSES* | Work on your tan. |
| 9. Mar 19 - 23 | Model evaluation – 1 | Readings from the literature; continue data analysis. |
| 10. Mar 26 - 30 | Model evaluation – 2 | Readings from the literature; continue data analysis. |
| 11. Apr 2 - 6 | Data analysis presentations | Informal review; present & hand in data analysis. |
| 12. Apr 9 - 13 | Modeling project – 1 | Written review of a modeling paper. |
| 13. Apr 16 - 20 | Modeling project – 2 | Work on your modeling project. |
| 14. Apr 23 - 27 | Modeling project – 3 | Work on your modeling project. |
| 15. Apr 30 - May 4 | Modeling project presentations –1 | **Thurs. May 3 – oral session.** |
| 16. May 7 – 8 | Modeling project presentations –2 | **Tues. May 8 – poster session.** |
| May 10 – 17 | *FINAL EXAM PERIOD* | **Final project papers due Tues. May 15.** |

## INTRODUCTION TO MODELING

Lassiter, R. 1986. A theoretical basis for modeling element cycling. Pages 341-377 in Hallam TG, Levin SA (eds.) *Mathematical Ecology*. Springer-Verlag, Berlin.

Hilborn R, Mangel M. 1997. *The Ecological Detective: Confronting Models with Data*. Princeton Univ. Press, Princeton, NJ. CHAPTER 2

Schimel DS, Potter C. 1995. Process modelling and spatial extrapolation. Pages 358-383 in Matson PA, Harriss RC (eds.) *Biogenic Trace Gases: Measuring Emissions from Soil and Water*. Blackwell, Oxford.

Thornley JHM, Johnson IR 1990. *Plant and Crop Modelling: A Mathematical Approach to Plant and Crop Physiology*. Clarendon Press, Oxford. CHAPTER 1

## BOX MODELS & NUMERICAL METHODS

Chamiedes WL, P. E. 1997. *Biogeochemical Cycles: A Computer-Interactive Study of Earth System Science and Global Change*. Oxford Univ. Press, New York. CHAPTER 4.

Rodhe, H. 1992. Modeling biogeochemical cycles. In Butcher SS, Charlson RJ, Orians GH, Wolfe GV, eds. *Global Biogeochemical Cycles*. Academic Press, London. pp 55-72

Ferziger, J. 1981. *Numerical Methods for Engineering Application*. John Wiley & Sons, New York. **CHAPTER 3**.

## THE GLOBAL CARBON CYCLE

Holmen, K. 1992. The global carbon cycle. Pages 239-262 in Butcher SS, Charlson RJ, Orians GH, Wolfe GV (eds.) *Global Biogeochemical Cycles*. Academic Press, London.

Schimel, D. 1995. Terrestrial ecosystems and the carbon cycle. *Global Change Biology* 1: 77-91.

Siegenthaler U, Sarmiento JL. 1993. Atmospheric carbon dioxide and the ocean. *Nature* 365: 119-125.

Falkowski P, et al. 2000. The global carbon cycle: a test of our knowledge of the earth as a system. *Science*. 290:291-296.

## ECOSYSTEM CARBON CYCLES

Dai, A., I.Y. Fung, Can climate variability contribute to the "missing" $CO_2$ sink? *Global Biogeochem. Cycles*, *7*, 599-610, 1993.

Pastor J, Post WM. 1993. Linear regressions do not predict the transient responses of eastern North American forests to $CO_2$-induced climate change. *Climatic Change*. 23:111-119.

Pastor J, Post WM. 1986. Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. *Biogeochemistry*. 2: 3-27.

## THE NITROGEN CYCLE

Jaffe, D. 1992. The nitrogen cycle. Pages 263-284. in Butcher SS, Charlson R, Orians GH, Wolfe GV, eds. *Global Biogeochemical Cycles*. Academic Press, London.

Smil, V. 1990. Nitrogen and phosphorus. Pages 423-436 in Turner BL, Clark WC, Kates RW, Richards JF, Mathews JT, Meyers WB, eds. *The Earth as Transformed by Human Action*. Cambridge Univ. Press, Cambridge.

Vitousek, PM. 1992. Perspectives on the nitrogen cycle. Pages 151-163 in Moore M, Schimel DS (eds.) *Trace Gases and the Biosphere*. UCAR/Office of Interdisciplinary Earth Studies, Boulder CO.

Vitousek PM, Howarth RW. 1991. Nitrogen limitation on land and in the sea: how can it occur? *Biogeochemistry*. 13:87-115.

Galloway JN, Schlesinger WH, Levy H, Michaels A, Schnoor JL. 1995. Nitrogen fixation: Anthropogenic enhancement-environmental response. *Global Biogeochemical Cycles*. 9:235-252.

Vitousek PM, Aber JD, Howarth RW, Likens GE, Matson PA, Schindler DW, Schlesinger WH, Tilman DG. 1997. Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications* 7: 737-750.

Aber JD, Nadelhoffer KJ, Steudler P, Melillo JM. 1989. Nitrogen saturation in northern forest ecosystems. *BioScience*. 39:378-386.

Aber JD, McDowell W, Nadelhoffer K, Magill A, Bernston G, Kamakea M, McNulty S, Currie W, Rustad L, Fernandez I. 1998. Nitrogen saturation in temperate forest ecosystems: Hypotheses revisited. *BioScience*. 48:921-934.

Asner GP, Seastedt TR, Townsend AR. 1997. The decoupling of the terrestrial carbon and nitrogen cycles. *BioScience*. 47:226-234.

**TRACERS, STABLE and RADIO-ISOTOPES**

Trumbore S. 1995. Use of isotopes and tracers in the study of emission and consumption of trace gases in terrestrial environments. Pages 291-326 in Matson PA, Harriss RC, eds. *Biogenic Trace Gases: Measuring Emissions from Soil and Water*. Blackwell, Oxford.

Trumbore SE, Chadwick OA, Amundson R. 1996. Rapid exchange between soil carbon and atmospheric carbon dioxide driven by temperature change. *Science*. 272:393-396.

Harrison KG, Post WM, Richter DD. 1995. Soil carbon turnover in a recovering temperate forest. *Global Biogeochemical Cycles*. 9:449-454.

Gregorich EG, Ellert BH, Monreal CM. 1995. Turnover of soil organic matter and storage of corn residue carbon estimated from natural $^{13}C$ abundance. *Can. J. Soil Sci.* 75:161-167.

Schimel, D. 1993. *Theory and Application of Tracers*. Academic Press, San Diego.

Knowles R, Blackburn TH., eds. 1993. *Nitrogen Isotope Techniques*. Academic Press, San Diego, CA. Chapter 1

Ehleringer JR, Rundel PW. 1989. Stable isotopes: history, units, and instrumentation. Pages 1-15 in Ehleringer JR, Rundel PW, Nagy KA, ed. *Stable Isotopes in Ecological Research*. Springer Verlag, New York.

**EVALUATING MODELS**

Aber JD. 1997. Why don't we believe the models? *Bull. Ecological Soc. Am*. 78:232-233.

Oreskes N, Shrader-Frechette K, Belitz K. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. *Science*. 263:641-646.

Rykiel EJ. 1996. Testing ecological models: the meaning of validation. *Ecological Modelling*. 90:229-244.

Costanza R. 1989. Model goodness of fit: a multiple resolution procedure. *Ecological Modelling*. 47:199-215.

Whitmore AP. 1991. A method for assessing the goodness of computer simulation of soil processes. *J. Soil Sci*.. 42:289-299.

Power M. 1993. The predictive validation of ecological and environmental models. *Ecological Modelling*. 68:33-50

Barnes JW. 1994. *Statistical Analysis for Engineers and Scientists*. Ch. 11 & 12: Fitting equations to data, Parts 1 & 2. McGraw Hill. pp. 211-259.

Mitchell PL. 1997. Misuse of regression for empirical validation of models. *Agricultural Systems*, 54:313-326.

Mitchell PL, Sheehy JE. 1997. Comparison of predictions and observations to assess model performance: a method of empirical evaluation. Pages 437-451 in: Kropff MJ, Teng PS, Aggarwal PK, Bouma J, Bouman BAM, Jones JW, Van Laar HH (eds) *Applications of Systems Approaches at the Field Level, Vol. 2.* Kluwer Academic Publ. Dordrecht.

Willmott, C. J., S. G. Ackleson, R. E. Davis, J. J. Feddema, K. M. Klink, D. R. Legates, J. O'Donnell and C. M. Rowe, 1985. Statistics for the evaluation and comparison of models. *Journal of Geophysical Research*, 90:8995-9005.

Willmott, C. J., 1984. On the Evaluation of Model Performance in Physical Geography. In G. L. Gaile and C. J. Willmott (eds.). *Spatial Statistics and Models*. Dordrecht, Holland: D. Reidel, 443-460.

## MODELING AT LARGE SCALES

Cramer W, Fischer A. 1996. Data requirements for global terrestrial ecosystem modelling. Pages 529-565 in Walker B, Steffen W., eds. *Global Change and Terrestrial Ecosystems*. Cambridge Univ. Press, Cambridge.

## SOME GOOD BOOKS

Schlesinger WH. 1997. *Biogeochemistry: an analysis of Global Change*, 2nd Edition. Academic Press, San Diego.

Walker B, Steffen W., eds. 1996. *Global Change and Terrestrial Ecosystems*. Cambridge Univ. Press, Cambridge.

Larcher W. 1993. *Plant Physiological Ecology, 3rd edition*. Springer. Berlin. 505 pp.

Ehleringer JR, Field CB (eds.). 1993. *Scaling Physiological Processes: Leaf to Globe*. Academic Press. San Diego. 388 pp.

Matson PA, Harriss RC (eds.) 1995. *Biogenic Trace Gases: Measuring Emissions from Soil and Water*. Blackwell, Oxford.

Turner BL, Clark WC, Kates RW, Richards JF, Mathews JT, Meyers WB, eds. 1990. *The Earth as Transformed by Human Action*. Cambridge Univ. Press, Cambridge.

Andreae MO, Schimel DS (eds)1989. *Exchange of Trace Gases Between Terrestrial Ecosystems and the Atmosphere*, John Wiley and Sons, NY.

Butcher SS, Charlson RJ, Orians GH, Wolfe GV, eds. 1992. *Global Biogeochemical Cycles*. Academic Press, London.