270.615: Inverse Modeling and Data Assimilation
Fall Semester 2011.

Prof. Thomas Haine
329 Olin Hall, Tel.: 410 516 7048, e-mail: *Thomas.Haine@jhu.edu*

Synopsis

This graduate class will introduce modern inverse modeling and data assimilation techniques. These powerful methods are used in atmospheric science, oceanography, and geophysics and are growing more widespread. Topics will include: least-squares, singular value decomposition, Greens function inversions, variational data assimilation (method of Lagrange multipliers), Kalman filters, and Bayesian methods. The class will include lectures on concepts and theory, and practical experience in the computer laboratory. Applications are mainly drawn from geophysical fluids, especially oceanography.

The class is a follow-on to 270.307 Geoscience Modelling. Fall 2011 is the first time the class is being offered, although I've taught parts of the material in other classes. For this reason, the class will be informal and discoursive: as students, you will help shape and refine the material.

We'll spend about half of our time in the Olin Hall computing classroom working on assignments that illustrate the theoretical ideas. We will use Matlab software which is widely used in science and industry.

Permission of the instructor is required to attend class. Familiarity with linear algebra, statistics, classical physics, fluid dynamics, and calculus (pdes) is assumed at the level of an advanced undergraduate. Familiarity with matlab (or similar scientific programming software) is an advantage. The course may be accessible to you without these requirements, but expect to do some remedial work to catch up.

Class materials will be posted to Blackboard.

Assessment

Six computer assignments will be written up and turned in for credit. There will be no final exam. Attendance at each class is expected, and is essential for good performance. Please inform me ahead of time if you cannot attend class, or as soon as is practicable. We will adhere to the University guidelines on illness: don't worry about catching up with class until you're well again. You will not be academically penalized for following the advice of health professionals! Similarly, religious holidays are valid reasons to be excused from class, but please inform me well in advance.

Ethics

The following guidelines are taken seriously in this class:

Cheating is wrong. Cheating hurts our community by undermining academic integrity, creating mistrust, and fostering unfair competition. The University will punish cheaters with failure on an assignment, failure in a course, permanent transcript notation, suspension, and/or expulsion. Offenses may be reported to medical, law or other professional or graduate schools when a cheater applies.

Violations can include cheating on exams, plagiarism, reuse of assignments without permission, improper use of the Internet and electronic devices, unauthorized collaboration, alteration of graded assignments, forgery and falsification, lying, facilitating academic dishonesty, and unfair competition. Ignorance of these rules is not an excuse.

In this course, collaboration on computer assignments in the classroom is encouraged. The write-ups of the computer assignments must be done individually, however, without any collaboration other than sharing of printouts of your programs and results. If you have questions about this policy, please ask the instructor.

For more information, see the guide on "Academic Ethics for Undergraduates" and the Ethics Board web site (http://ethics.jhu.edu).

Textbooks

There is no required textbook for this class. One day, I hope to write my own text with your help! Relevant recommended texts are:

- *Wunsch* [2006] (ISBN 0521854245, $183, available at the bookstore) which covers almost all the material we'll discuss, and much more besides. It does not cover Bayesian methods, however.
- *Gauch* [2003] has good conceptual coverage of Bayesian methods and is a wonderful introduction to scientific method, including much wisdom on statistics and probability.

Wunsch [1996] is a good alternative to *Wunsch* [2006] with much overlapping material. It's more focussed on oceanographic applications, however.

Topics

- The canonical least-squares inverse problem. Overdetermined case; underdetermined case (tapered-weighted least squares, Gauss-Markov theorem, singular-value decomposition); geometrical interpretation. Application to tomography and/or ocean circulation inverse problem (Hidaka's problem).
- Empirical orthogonal functions: An illuminating basis set. Application to ocean internal waves.
- Green's functions: Another illuminating basis set. Application to ocean transient tracer inverse problem (from *Gray and Haine* [2001]).
- Variational data assimilation: the method of Lagrange multipliers. Application to ocean transient tracer inverse problem and a simple ENSO model.
- Sequential data assimilation: the Kalman filter. Application to ocean transient tracer inverse problem and a simple ENSO model.
- Bayesian methods. Application to ocean water mass analysis.

Schedule

We will meet twice a week for two 80min classes. About half of this time will be spent in Olin 304, and half in the Computer Classroom on the 2nd floor of Olin Hall. Our schedule is: Mondays and Wednesdays at 03:00–04:30. These times are somewhat flexible - please let me know if you'd like to attend class, but have a conflict. You will have access to the Computer Classroom at other times so you have chance to complete your assignments. The tentative schedule is as follows.

- 29 Aug, Week 1: Introduction to the class. Least squares. **Tomography** or **Hidaka's problem.**
- 5 Sept, Week 2: Least Squares continued.
- 12 Sept, Week 3: Least Squares continued. EOFs. **Ocean internal waves.**
- 19 Sept, Week 4: Green's functions. **Ocean tracer inversion.**
- 26 Sept, Week 5: Green's functions continued.
- 3 Oct, Week 6: Variational data assimilation. **ENSO model.** DROP DEADLINE
- 10 Oct, Week 7: Variational data assimilation continued.
- 17 Oct, Week 8: Variational data assimilation continued.
- 24 Oct, Week 9: Sequential data assimilation. **ENSO model redux.**
- 31 Oct, Week 10: Sequential data assimilation continued.
- 7 Nov, Week 11: NO CLASS!!
- 14 Nov, Week 12: Sequential data assimilation continued.
- 21 Nov, Week 13: Bayesian methods. **Ocean water-mass analysis.** THANKSGIVING
- 28 Nov, Week 14: Bayesian methods continued.

Computer assignments are written in **bold** font.

Gauch, H. G. (2003), *Scientific method in practice*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 435 pages.

Gray, S. L., and T. W. N. Haine (2001), Constraining a North Atlantic ocean general circulation model with chlorofluorocarbon observations, *J. Phys. Oceanogr.*, *31*, 1157–1181.

Wunsch, C. (1996), *The ocean circulation inverse problem*, 1st ed., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

Wunsch, C. (2006), *Discrete Inverse and State Estimation Problems*, 1st ed., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 371 pp.