270.615: Inverse Modeling and Data Assimilation
Fall Semester 2016.

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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, Green's 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 2016 is the second time the class is being offered, although I've taught parts of the material several times in other classes. For this reason, the class will be informal: 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. Similarly, 270.307 Geoscience Modelling is an advantage, but not essential. 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 (Bb). I plan to use Panopto to capture lectures and post to Bb.

Assessment

Four or five 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:

The strength of the university depends on academic and personal integrity. In this course, you must be honest and truthful. Ethical violations include cheating on exams, plagiarism, reuse of assignments, improper use of the Internet and electronic devices, unauthorized collaboration, alteration of graded assignments, forgery and falsification, lying, facilitating academic dishonesty, and unfair competition.

In addition, the specific ethics guidelines for this course are: *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.*

Report any violations you witness to the instructor. Please see the web site (`http://e-catalog.jhu.edu/undergrad-students/student-life-policies/#UAEB`) for more information.

For undergraduate students, the policies can be found online here: `http://e-catalog.jhu.edu/undergrad-students/student-life-policies`. The procedures for graduate students are different. The policy can be found here: `http://e-catalog.jhu.edu/grad-students/graduate-specific-policies`.

Textbooks

There is no required textbook for this class. I'm writing a book on this class and 270.307 Geoscience Modeling, however, and will distribute some draft text from it. 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

We will cover four or five of these topics, including 1–4:

1. 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).
2. Empirical orthogonal functions: An illuminating basis set. Application to ocean internal waves.
3. Green's functions: Another illuminating basis set. Application to ocean transient tracer inverse problem (from *Gray and Haine* [2001]).
4. Variational data assimilation: the method of Lagrange multipliers. Application to ocean transient tracer inverse problem and a simple ENSO model.
5. Sequential data assimilation: the Kalman filter. Application to ocean transient tracer inverse problem and a simple ENSO model.
6. Bayesian methods. Application to ocean water mass analysis.

Schedule

We will meet twice a week for two 80 minute classes. About half of this time will be spent in Olin 346, and half in the Computer Classroom on the 2nd floor of Olin Hall. Our schedule is: Tuesdays and Thursdays at 01:30–3:00. These times are somewhat flexible—please let me know if you'd like to attend class, but have a conflict. In addition, I will be absent for weeks 4 and 10. 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:

- 1 Sep, Week 1: Introduction to the class. Least squares. **Tomography**.
- 6 Sept, Week 2: Least Squares continued.
- 13 Sept, Week 3: Least Squares continued.
- 20 Sept, Week 4: Empirical orthogonal functions. **Ocean internal waves.**
- 27 Sept, Week 5: Empirical orthogonal functions continued.
- 4 Oct, Week 6: Empirical orthogonal functions continued.
- 11 Oct, Week 7: Green's functions. **Ocean tracer inversion.**
- 18 Oct, Week 8: Green's functions continued. NO CLASS ON THURSDAY 20th
- 25 Oct, Week 9: Green's functions continued.
- 1 Nov, Week 10: Variational data assimilation. **ENSO model.**
- 8 Nov, Week 11:Variational data assimilation continued.
- 15 Nov, Week 12:Variational data assimilation continued.
- 22 Nov, Week 13: Thanksgiving vacation
- 29 Nov, Week 14: Sequential data assimilation or Bayesian methods. **(Final assignment)**.
- 6 Dec, Week 15: Sequential data assimilation or Bayesian methods continued.

Computer assignments are written in **bold** font. The drop deadline is 16 October.

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.