Syllabus for ATOC 2300: Mathematical and Computational Earth Sciences (a.k.a. HyperGeoMath)

Baylor Fox-Kemper

September 8, 2015

1 Course Description

1.1 GEOL2300 Mathematical and Computational Earth Sciences

Intended for graduate students interested in the quantitative study of the Earth in geological, physical, or engineering sciences. Mathematical topics to be introduced include tensor analysis, asymptotic and perturbation analysis of differential equations, numerical integration of differential equations, basis functions and pattern recognition, fractals and multifractals, and statistics. Applications will vary by offering, but examples include: statistics of turbulence and earthquakes, advection-reaction-diffusion systems, boundary layers, development of shocks and singularities, climate change and carbon sensitivity, and dimensional reduction of geophysical data. Course will feature intensive review of introductory mathematical methods through leading discussions in a lower level class. Pre-requisites: GEOL0250 or GEOL0350 or PHYS0720 or APMA 0340 or equivalent. Earth, fluid, or solid science background recommended.

2 Contacts

The professor for this class is: Baylor Fox-Kemper
baylor@brown.edu, 401-863-3979, Office: GeoChem room 133
`http://fox-kemper.com/teaching`, `http://fox-kemper.com/2300`

Portions of the website are password-protected to ensure that fair use and copyrights are correctly obeyed as I share images from books, etc. You can access these by using:

```
username:  io
password:  ocean
```

3 Getting Help!

I am usually available by email. Office hours will be Monday 1:30-2:30 and Thursday 2-3 or by appointment (see my schedule at `http://fox-kemper.com/contact`). You can also drop into the Math Resource Center (MRC, `http://www.math.brown.edu/mrc/`) or sign up or drop in to a tutoring session (`http://www.brown.edu/academics/college/support/tutor`).

4 Goals

In this class you will:

- Learn how to better quantify some of the physical processes of the Earth System.
- Get practice solving diverse geophysical and geological problems.
- Get practice presenting science topics, conjectures, and solutions in written and spoken form.
- Gain a broader perspective and practice skills for teaching, research, and collaborating by peer reviewing, presenting, and leading discussions.

This class cannot possibly provide a complete understanding of all of the mathematical topics presented, instead the goal is to work through geophysical and geological examples where the mathematical tools are useful, or to review your peers' attempts at the same. A key goal is to introduce the mathematical language and style of thinking, so that students can better choose later mathematics classes and look up mathematical concepts on their own (e.g., using Wolfram Alpha).

4.1 Applications

Geophysical and geological applications touched on in this class may be:

- Waves and Oscillations
- Conservation and Symmetry
- Boundary Layers
- Landscape Evolution
- Rotating and Stratified Flows
  - Oceanic
  - Atmospheric
  - Groundwater
  - Mantle Convection
- Chemical Reactions, Rates, and Equilibria
- Continuum Mechanics
  - of Solids
  - of Fluids
- Curvilinear Coordinates

5 Assignments and (lack of) Exams

The majority of the effort in the class will be toward two self-directed Class Research Projects (CRPs). The weighting of the assignments will be:

- 25% Write-ups of CRPs (1 due mid-semester, 1 due at the end of reading week, each $<$ 12 publication units).
- 25% Presentations related to CRPs (10 minutes + 5 minutes for questions, at least 1 on proposed CRP and 1 on CRP results).
- 25% Discussion/Practicum Leading of GEOL0350 groups, other class presentations.
- 15% Reviews of other students' presented and written Class Research Projects (1-2 per week).
- 10% Attendance and participation.

Bonus points are available for finding typos and errors in my notes! Professor comments and peer reviews will be used to evaluate the write-ups and presentations of CRPs. GEOL0350 student surveys, your self-reflections, and periodic (announced) observations by the professor will be used to evaluate discussion/practicum leading.

5.1 Class Research Projects (CRPs)

You will choose two topics from your research or research interests that require an increase in mathematical or computational sophistication from your present understanding. Examples include: 1) You are working to reproduce a complicated derivation, simulation, or calculation in a paper you need to understand and replicate, or 2) you are developing statistical techniques to analyze your data, or 3) you need to code a computational solution to a problem you have encountered, or 4) you need to develop a mathematical model of a process you are studying. Your CRPs will be the depth-building aspect of the course.

You will present on your CRPs in class. These presentations will include a proposed topic talk and a presentation of results talk (i.e., 4 fifteen-minute presentations during the semester for the 2 CRPs). Depending on the number of students enrolled, additional presentations on technical aspects (e.g., presenting a numerical method from a book chapter or article) may occur by need, interest, and availability.

A written version of the first class project in short article form will be due mid-way through the semester. A written version of the second class project will be due at the end of reading week.

You will review your peers' versions of these same write-ups and presentations. That is, each time you present in class, you will receive feedback from the professor and other students. Your peer reviews of student presentations will be due at the end of each week. Each time you turn in a write-up, you will receive a review from the professor and two reviews from your peers. You will also perform reviews of two other students' write-ups.

All assignments will be turned in through `http://canvas.brown.edu` to facilitate peer reviewing and sharing.

5.2 Peer review

In addition to doing your own CRP write-ups, you will each be performing reviews of two other students' CRP write-ups. We will be using a rubric based on the AGU guidelines for review. A-F for presentation quality and 1-5 for science/math. Such a guide is useful to go by, and when you do reviews of your fellow students, I'll expect to get a A1 or B2 or B1 score, etc. An A1 will count for 100%, and presentation and accuracy will be equally weighted (an F5 will be 20%). There are a few lessons to be learned here, that will help you write your own papers and will help you provide effective and useful reviews in your career.

- Learning to spot unfounded claims
- Learning how to properly support claims
- Learning to distinguish poor writing/presentation from poor thinking/science
- Learning to label equations, graphs, and numerical information understandably
- Learning mathematical problems and techniques that you did not choose for your own projects, or revisiting ones you did choose from a different perspective

You will have each of your homework assignments peer-reviewed by more than one person, and inconsistent results will be rechecked. The assignments for reviewers will rotate (ensuring fairness in grading by randomization). You should feel free to contact me with any concerns about the process or specific issues.

You will also submit short reflections on other students' in-class presentations. Each presentation reflection will include:

- Summary ($<$ 150 words)

- Strengths (on science *and* presentation, < 100 words)
- Weaknesses (on science *and* presentation, < 100 words), and
- Brainstorming and Inspiration (< 150 words)

Each time you present, you will receive feedback from the professor, including a summary of the reflections on your presentation. These peer reviews will be the breadth-building aspect of the course.

6 Meetings and Places

We will meet Mondays and Wednesdays from 4:00 to 5:20PM in GeoChem 150. Office hours will be Monday 1:30-2:30 and Thursday 2-3 or by appointment (see my schedule at `http://fox-kemper.com/contact`) in my office (GeoChem 133) or lab (GeoChem 134). Some weeks, the Monday and Wednesday sessions will be only 4-4:50pm, and you will be asked to lead discussions for one of the GEOL0250 or GEOL0350 course during one of their MTWR 3-3:50pm practical discussion sessions. During course registration you should have chosen one of these sessions as well (although trading sessions may be arranged as need be during the semester).

6.1 Structure of Classtime

Each class will typically have two parts. The first part ($20-35$ minutes) will be a lecture by the professor on a reading assignment (which may include related problems provided by the professor) or a discussion following on a previous lecture, and the second will be one or two student presentations on research (10 minutes, with 5 minutes for questions each). Early in each half of the semester, the student presentations will be general talks about the math encountered in a student's research topic, or class project proposals, but as the due date for project write-ups approaches, these presentations will include the presentations of results in your class research projects.

6.2 Calendar

The main webpage for the class `http://fox-kemper.com/2300` will have the calendar with all assignment deadlines, readings, etc. set up by the first class session. You will complete two projects that will involve a written description and a classroom presentation of a geophysical math or computational problem you have solved. These projects will be peer-reviewed, and you will perform peer reviews of 4 projects. You will lead a one hour discussion/practicum session with groups of students from GEOL0250 or GEOL0350, roughly once every other week. There will be no midterms or exams. Problems assigned to support reading presentations will be self-checked versus an answer key.

7 Canvas and Websites

The primary resource for this class is the webpage: `http://fox-kemper.com/2300`. The class webpage is where all of your assignments will be announced, solution sets posted, links to additional reading will be posted, etc. Assignments should be turned in using canvas. The copiers in GeoChem and elsewhere can be used to scan handwritten assignments (for free).

You will want to familiarize yourself with Wolfram Alpha (`www.wolframalpha.com`), it is a great resource for looking up math definitions. Wikipedia is also handy in a pinch (due to the armies of math & physics grad students who have so very few social commitments that they punch in all the details of their dissertation appendices).

8 Textbooks and Software

We will not have a textbook. However, many references are useful (Boas, 2006; Wilks, 2011; Snieder, 2004; Arfken et al., 2013; Bender and Orszag, 1978; Gottlieb and Orszag, 1981; Fowler, 2011). Many are available electronically through the Brown Library. We will solve problems drawn from many geophysics and geology textbooks (LeBlond and Mysak, 1978; Turcotte, 1997; Schubert et al., 2001; Turcotte and Schubert, 2002; Aki and Richards, 2002; Drazin and Reid, 2004; Holton, 2004; McWilliams, 2006; Vallis, 2006; Marshall and Plumb, 2008; Cushman-Roisin and Beckers, 2010), but these books are not required for the course. If electronic copies of them are available at Brown, I have added an url to the bibliography here and on the website.

Computation may involve Matlab, Mathematica, Python, R, FORTRAN, or many other languages, depending on the problem and your experience. Write-ups in LaTeX are encouraged, and templates are available from the AGU. Write-ups will be in Geophysical Research Letters (GRL) format and length (fewer than 12 publishing units, where publishing units = # of words/500 + # of figures + # of tables).

9 Policies

9.1 Deadlines

Because of the reviewing process, the scheduling of assignments is firm. Thus, I will have to insist that write-ups be turned in on time. If they are late, they will drop a letter grade. If they are really late (so that they mess up the next step in the reviewing process) they will be counted as missed and can not be made up. If you foresee that there are big problems coming up (medical, family, etc.) let me know *before* an assignment is due and we can figure something out.

9.2 Collaboration

I encourage you to work together, and I do not mind at all if you have similar problem sets or share figures or matlab scripts. However, in this case, I want you to list all of your study group on your write-up (so I can avoid you peer-reviewing your group). You are all required to submit a version of each assignment as first author (that is, one that you wrote yourself). You need to be careful to cite your colleagues or the textbooks, websites, or papers you might be working from.

9.3 Miscellany

- Attendance is expected. If you will miss a class, please let me know when and why so I can be sure you'll get any announcements, etc.
- Clothing and behavior (e.g., cell & laptop use) should be appropriate for a learning environment.
- Discrimination and harassment will not be tolerated.
- Please contact me if you have any disabilities that require accommodation.

References

Aki, K. and P. G. Richards, 2002: *Quantitative seismology.* 2d ed., University Science Books, Sausalito, Calif.

Arfken, G. B., H.-J. Weber, and F. E. Harris, 2013: *Mathematical methods for physicists: a comprehensive guide.* 7th ed., Elsevier, Amsterdam, URL `http://bit.ly/1kHZCBQ`.

Bender, C. M. and S. A. Orszag, 1978: *Advanced Mathematical Methods for Scientists and Engineers I: Asymptotic Methods and Perturbation Theory.* McGraw-Hill, New York, NY.

Boas, M. L., 2006: *Mathematical methods in the physical sciences*. 3d ed., Wiley, Hoboken, NJ.

Cushman-Roisin, B. and J. M. Beckers, 2010: *Introduction to geophysical fluid dynamics: Physical and Numerical Aspects*. Academic Press, URL `http://bit.ly/1kMS81x`.

Drazin, P. G. and W. H. Reid, 2004: *Hydrodynamic stability*. 2d ed., Cambridge University Press, Cambridge, UK.

Fowler, A. C., 2011: *Mathematical geoscience*, Interdisciplinary applied mathematics, Vol. 36. Springer, London, URL `http://bit.ly/1xpgSRs`.

Gottlieb, D. and S. A. Orszag, 1981: *Numerical Analysis of Spectral Methods: Theory and Applications*. Society for Industrial and Applied Mathematics, Philadelphia, 170 pp.

Holton, J. R., 2004: *An introduction to dynamic meteorology*, Vol. v. 88. 4th ed., Elsevier Academic Press, Burlington, MA, URL `http://bit.ly/1nrWqtX`.

LeBlond, P. H. and L. A. Mysak, 1978: *Waves in the Ocean*. Elsevier Oceanography Series 20, Elsevier Scientific Publishing Company, New York.

Marshall, J. and R. A. Plumb, 2008: *Atmosphere, ocean, and climate dynamics: an introductory text*, Vol. v. 93. Elsevier Academic Press, Amsterdam, URL `http://bit.ly/1jaqm9B`.

McWilliams, J. C., 2006: *Fundamentals of geophysical fluid dynamics*. Cambridge University Press, Cambridge.

Schubert, G., D. L. Turcotte, and P. Olson, 2001: *Mantle convection in the earth and planets*. Cambridge University Press, Cambridge, URL `http://bit.ly/1pQCS5s`.

Snieder, R., 2004: *A guided tour of mathematical methods for the physical sciences*. 2d ed., Cambridge University Press, Cambridge, UK.

Turcotte, D. L., 1997: *Fractals and chaos in geology and geophysics*. 2d ed., Cambridge University Press, Cambridge, U.K.

Turcotte, D. L. and G. Schubert, 2002: *Geodynamics*. 2d ed., Cambridge University Press, Cambridge.

Vallis, G. K., 2006: *Atmospheric and Oceanic Fluid Dynamics : Fundamentals and Large-Scale Circulation*. Cambridge University Press, Cambridge, URL `http://bit.ly/SDSMSK`.

Wilks, D. S., 2011: *Statistical methods in the atmospheric sciences*, International geophysics series, Vol. v. 100. 3d ed., Elsevier/Academic Press, Amsterdam.