# The Fluid Earth
# GEOL 3820
# Fall Semester 2009

Benson Earth Sciences (BESC), Room 355
Tuesdays and Thursdays 12:30-1:45

**Instructor**
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Office hours: Monday 4-5, Thursday 3-5, or by appointment

**Course Description**
From the atmosphere to the outer core, Earth is a fluid planet. This course looks at how the fundamental laws of fluid motion are expressed in a wide variety of earth systems. We will discover how basic principles of fluid dynamics can help us answer questions such as:

*Why does the Earth's lithosphere sag beneath the load of mountains and ice sheets and rise again when the loads are removed?*
*What controls the speed of a falling raindrop, and how does this relate to rising magma?*
*Why do thunderstorms tend to happen on hot summer afternoons, and what has this got to do with plate tectonics?*
*Why does the mantle convect?*
*Why do mountain ranges make rain shadows?*
*What makes ocean currents like the Gulf Stream move?*
*Why does groundwater sometimes flow uphill?*
*What controls the size and speed of a mountain glacier?*
*What controls the speed and depth of a river?*

We'll discover some surprising similarities in the physics behind these diverse systems. The course will explore these similarities through a mix of lectures, lab demonstrations / experiments, discussion, and readings. A series of examples will illuminate the nature and role of basic fluid properties – such as pressure, density, viscosity – and basic fluid processes – such as buoyancy, convection, and fluid friction – in driving geologic processes. Some background in physics (mechanics), such as high school or first-semester college physics, is helpful but not strictly required.

**Course Goals**
Understanding the physics of fluid motion is a critical skill for a wide range of professionals in the earth and environmental sciences. Fluid dynamics are fundamental to a great variety of environmental systems and fields; these include (to name just a few) water resources, meteorology, air and water pollution, natural hazards, geomorphology, land management, solid-earth geophysics, groundwater, planetary geology, glaciology, climate change, sedimentology/stratigraphy, irrigation, aquatic ecology, oil and gas, and oceanography. This course aims (1) to introduce students to the fundamentals of fluid physics and some of the ways in which those physics are expressed in different kinds of earth system, (2) to help students develop skills in applying fluid mechanics to earth and environmental systems, (3) to improve students' understanding of the mathematics behind fluid motion, and (4) to help students improve their ability to understand technical and scientific literature that relates to fluid behavior. Geological Sciences majors will find connections with many of their other courses, ranging from geophysics (mantle convection, earth's density structure) and volcanology (magma motion) to geomorphology (rivers, glaciers, landslides) and hydrogeology (surface and groundwater flow).

Environmental Studies majors will also discover connections with key topics in their major, such as pollution (flow of wind and water), climate (atmosphere and ocean circulation, glaciers and ice sheets), and water resources (rivers and streams). Students in all majors will, I hope, come to appreciate that earth and environmental systems, however complex they may be, obey basic physical laws – and that these laws lie at the heart of understanding how planets work, whether the aim is to extract drinking water from a well, to decipher the surface of Mars, or to forecast the weather.

**Required Work and Grading**

The work for this course centers on series of weekly readings and problem sets that accompany a series of "geological vignettes." There will be no exams or final projects. Short readings (typically 10-30 pages) will normally be assigned on Tuesdays and should be completed by the following Thursday, when we will discuss them in class. For each reading, you will prepare a summary of the key points together with any questions you may have had about the material. Problem sets will normally be handed out on Thursdays and will be due the following Tuesday. It is crucial that assignments be handed in on time, so that (1) you're prepared to discuss them in class, (2) I can grade them promptly, and (3) you don't fall behind. Therefore, I will not accept assignments more than 24 hours late, and those that are turned in within 24 hours after the due date will receive only partial credit. That said, you may skip one problem set during the semester without a grade penalty (but of course you will learn more if you do them all!). Final grades are based on problem sets (80%) and class participation (20%).

**Books**

There is no text for this course. Rather, readings will be handed out in class and will draw on a variety of sources. A reading list is given below.

**Science Education Initiative**

This course is participating in the CU-Boulder Science Education Initiative (SEI) whose aim is to improve teaching and learning in science courses at CU. During the course of the semester, you may be asked to take a survey, complete questionnaires, or offer your opinions on some aspects of the course content, teaching materials (e.g., homework, clicker questions), and logistics. Your participation would be appreciated as the analyses of those opinions will help Dr. Tucker in his efforts to establish a better learning experience for you. Opinions or input that you give will be anonymous to Dr. Tucker and will have no impact on your grade. Please contact either Dr. Tucker or the SEI liaison (Dr. Mike Vredevoogd, michael.vredevoogd@colorado.edu) if you have any questions or concerns.

**Topics and Schedule**

(Note: this outline will probably change somewhat in response to student interests as the course evolves)

Week 1: Introduction; Floating Mountains, Crustal Roots, and Archimedes' Principle

*Overview of fluid behavior in earth and environmental systems. Definition and basic properties of fluids. Review of Newton's laws of motion. Isostasy. How to construct a static force balance. Hydrostatic pressure. Archimedes' principle. (8/25, 8/27, 9/1)*

Week 2: Post-Glacial Rebound: An Example of Viscous Flow

*Examples of post-glacial rebound. Newton's law of viscosity and definition of a Newtonian fluid. Viscosity of common materials. How to construct a momentum balance. (9/3, 9/8)*

Week 3: Geology in Italy: A Story of Rheology

*Describing earth material deformation in terms of stress, strain, and strain rate. Elastic, plastic (ductile, brittle) and viscous behavior. Examples from the Italian Apennines. (9/10)*

TUESDAY 9/15: NO CLASS

Week 4: Sinking Sediment, Falling Rain, and Rising Magma
*Importance of settling velocity of sediment particles and raindrops. Drag force. Calculating terminal settling velocity. Reynolds numbers. How to do dimensional analysis, and what it can teach you. Why rising magma blobs are like falling raindrops. (9/17, 9/22)*

Week 5: When Dirt Flows (Fast)
*Origin and behavior of debris flows. Examples from Colorado, Italy, and Oregon. Debris-flow rheology and energetics. Debris flows as geomorphic agents. (9/24, 9/29)*

***SATURDAY 9/26: FIELD TRIP TO CHALK CLIFFS DEBRIS-FLOW MONITORING SITE***

Week 6: Mudlumps and Salt Domes: A Tale of Instability
*Density stratification in various geosystems. Mud and salt diapirism. Concept of stability and instability. Experiments in stratification and overturning. Role of salinity in ocean circulation. Example of the Bosporus Strait. Density structure of planet earth. (10/1, 10/6)*

Week 7: Planets, Plates, and Lava Lamps: Heat, Density, and Convection
*Relationship between temperature and density of air, water, and rocks. Examples of thermally driven stability, circulation, and convection. Fourier's law of heat conduction. Rayleigh number and convection. (10/8, 10/13)*

Week 8: The Many Faces of Diffusion
*From random walks to diffusion. Examples of diffusion in contaminant transport, heat conduction, and momentum transfer. Applications of diffusion, from Arctic climate to pollution. (10/15, 10/20)*

Week 9: Thin Air and Rain Shadows: Some Physics of the Atmosphere
*Why is the atmosphere thinner and colder at high altitude? Adiabatic lapse rate. Stability and temperature inversions. Moisture dynamics. Origin and examples of rain shadows, and their possible role in shaping mountains. (10/22)*

TUESDAY 10/27: GROUP WORK ON PROBLEM SETS (GT AT CSDMS MEETING)

Week 10: Big Whorls and Little Whorls: An Introduction to Turbulence
*Definition and examples of turbulence. Osborne Reynolds' experiments and the onset of turbulence. Effect of turbulence on geophysical flows. (10/29, 11/3)*

Week 11: Of Floods and Airplane Wings: The Bernoulli Principle
*Airplane wings and the Bernoulli effect. Energy in free-surface flows. Mass and energy balance for open-channel flow. (11/5-11/10)*

Week 12: What Controls the Depth and Speed of a River?
*Momentum balance for open-channel flows. Sub-critical and super-critical flow. Roughness relations for free-surface flow. (11/12-11/17)*

Week 13: The Dynamics of Frozen Water: Valley Glaciers and Ice Sheets
*Ice as a non-Newtonian fluid. Flowing, sliding, and Glen's flow law. Continuity of mass for a valley glacier. Experiments with valley glacier simulation program. (11/19, 12/1)*

Week 14: Water Underground; Final Wrap-Up
*Fluid motion in porous and fractured media. Darcy's law. Energy and hydraulic head. Simulations. Course review. (12/3, 12/8, 12/10)*

**Reading List**
Readings in the course will draw on these sources (among others):

Allen, J.R.L. (1985) *Principles of Physical Sedimentology*. Blackburn Press.
Coleman, J.M., Walker, H.J., and Grabau, W.E. (1998) Sediment instability in the Mississippi River Delta. *Journal of Coastal Research*, 14(3), 872-881.
Dingman, S.L. (1994) *Physical Hydrology*. Prentice Hall.
Fowler, C.M.R. (1990) *The Solid Earth: An Introduction to Global Geophysics*. Cambridge University Press.
Furbish, D.J. (1997) *Fluid Physics in Geology*. Oxford University Press.
Hancock, P.L., and Skinner, B.J. (2000) *The Oxford Companion to the Earth*. Oxford University Press.
Iverson, R.M. (1997) The physics of debris flows. *Reviews of Geophysics*, v 35, no 3, p 245-296.
Lachenbruch, A.H., and Marshall, B.V. (1986) Changing climate: geothermal evidence from permafrost in the Alaskan Arctic. Science, v 234, p 689-696.
Middleton, G.V., and Southard, J.B. (1984) *Mechanics of Sediment Movement*. SEPM.
Middleton, G.V., and Wilcock, P.R. (1994) *Mechanics in the Earth and Environmental Sciences*. Cambridge University Press.
Montieth, J.L., and Unsworth, M.H. (2008) *Principles of Environmental Physics*, 3rd edition. Academic Press.
Tritton, D.J. (1988) *Physical Fluid Dynamics*, 2nd edition. Oxford University Press.
Turcotte, D.L., and Schubert, G. (2002) *Geodynamics*, 2nd edition. Cambridge University Press.
Watts, A.B. (2001) *Isostasy and Flexure of the Lithosphere*. Cambridge University Press.

## Other Matters

ACADEMIC INTEGRITY: All students of the University of Colorado at Boulder are responsible for knowing and adhering to the academic integrity policy of this institution. Violations of this policy may include: cheating, plagiarism, aid of academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct shall be reported to the Honor Code Council (honor@colorado.edu; 303-725-2273). Students who are found to be in violation of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion). Other information on the Honor Code can be found at http://www.colorado.edu/policies/honor.html and at http://www.colorado.edu/academics/honorcode/

DISABILITIES: If you qualify for accommodations because of a disability, please submit to me a letter from Disability Services in a timely manner so that your needs may be addressed. Disability Services determines accommodations based on documented disabilities. Contact: 303-492-8671, Willard 322, and http://www.Colorado.EDU/disabilityservices

RELIGIOUS OBLIGATIONS: Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly deal with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, students with conflicts between religious observance dates and course exams or assignments must notify the professor via email at least two weeks in advance of the event so that reasonable and appropriate accommodations can be arranged. See full details at http://www.colorado.edu/policies/fac_relig.html

POLICY ON DISCRIMINATION & HARASSMENT: The University of Colorado at Boulder policy on Discrimination and Harassment, the University of Colorado policy on Sexual Harassment and the University of Colorado policy on Amorous Relationships apply to all students, staff and faculty. Any student, staff or faculty member who believes s/he has been the subject of discrimination or harassment based upon race, color, national origin, sex, age, disability, religion, sexual orientation, or veteran status should contact the Office of

Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Judicial Affairs at 303-492-5550. Information about the ODH, the above referenced policies and the campus resources available to assist individuals regarding discrimination or harassment can be obtained at http://www.colorado.edu/odh

CLASSROOM BEHAVIOR POLICY: Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, culture, religion, politics, sexual orientation, gender, gender variance, and nationalities. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. See polices at http://www.colorado.edu/policies/classbehavior.html and at http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code