CERI 8353 Geodynamics

FALL 2023

Instructor: Eunseo Choi

Time and Location: Monday, Wednesday, 10:20 - 11:45 am, House 3 classroom

Contact: echoi2@memphis.edu

Late policy

No late submission will be accepted without prior consultation with the instructor.

Ombudsperson

An Ombudsperson will be elected as early as possible. This person will be the channel for anonymous communication with the instructor. Any concerns and requests can be freely submitted to the Ombudsperson, who will then communicate with the instructor. The Ombudsperson will be responsible for keeping the anonymity of the students who submit concerns and requests.

Plagiarism

Copying someone else's work is prohibited. If any two or more people's submitted works are the same, an investigation will be conducted. If plagiarism is confirmed, all the involved people will receive a zero for the assignment at the first time; and be reported as an academic misconduct to the Office of Student Accountability at the second time.

Writing : Your written work for the assignments or the term project must be your own. You may discuss with your classmates, but you must write your own answers.

Computer code : Your code must be your own. You may discuss with your classmates, but you must write your own code. If someone else's code, open-source or not, is used in your work for this course, you must reveal the source in a verifiable way. When found to have failed to do so, the procedure described above will be followed.

Use of AI

Disclaimer 1/2 The policy reflects only this instructor's personal view to the use of AI in the coursework at CERI. You should NOT assume the same philosophy from other instructors.

Disclaimer 2/2 This policy will be in effect only when all the students have equal access to AI technologies. If not, the use of AI will be prohibited for fairness.

Any form of AI technology is allowed for this course in Fall 2023. The intention of this policy is to assess the potential of AI for more efficient learning and forge consensus on the boundary for reasonable uses. You, professionals in geophysics to be, should be able to do all the work without

AI. However, if there is no way back to the time without AI, it is also important to know how to tap its power and let it assist your work in open and fair ways.

With that said, here is one requirement: Whenever an AI tool is used for your work, you should clearly state so and specify how it assisted your work. For instance, if a large language model-based tool (e.g., chatGPT) is used, you need to submit the entire set of prompts with the generated work itself; if your work includes codes auto-completed by AI tools like GitHub Copilot, specify which part of your code was generated by the tool. You should report a ”block” of codes or more but need not include a single line or variable names that were autocompleted. As stated in the Plagiarism section, spelling and grammar checkers are not considered as AI tools for the purpose of this policy.

If your work is found to include an AI-generated portion (e.g., through changes in a coding or writing style) but you fail to specify it, the procedure given in the “Plagiarism” section will be followed.

Course Description

This course teaches principles in continuum mechanics necessary for understanding plate tectonics and geological phenomena. Major topics include the kinematics and balance laws of continnum, stress and strain in earth’s crust, bending of the elastic part of the Earth, heat transfer in the Earth by conduction and convection, the rheology of rocks, and basic mechanics of faults.

Course Objectives

After taking this course, students will

1. have confident command of the kinematics and balance laws of continuum,
2. understand the governing equations for various geodynamic processes, and
3. be able to tackle complex geophysical problems by finding an approximate model and derive a (semi-)analytic solution to it.

Through a term project, students will

1. build in-depth knowledge in advanced topics in geophysics and related fields and
2. gain scientific communication skills.

Grades

5 homework problem sets and 3 mini-lectures (40 %, equal weight), a written summary and an in-class lecture out of a term project (20 %, equal weight), mid-term and final exams (40 %, equal weight).

Office Hours

Before or after class; or by appointment.

Textbook and Resources

Lecture notes and excerpts from references will be provided.
Main reference book for this course

- Turcotte, D. L. and Schubert, G. (2014). *Geodynamics*. Cambridge University Press, 3rd edition
  - This edition is recommended but the 2nd edition, available in the university library, is okay.

Supplementary books

- Books on geodynamics and continuum mechanics
  - Schubert, G., Turcotte, D. L., and Olson, P. (2001). *Mantle convection in the earth and planets*. Cambridge University Press, Cambridge; New York
  - Holzapfel, G. A. (2000). *Nonlinear solid mechanics : a continuum approach for engineering*. Wiley, Chichester ; New York
  - Malvern, L. E. (1977). *Introduction to the Mechanics of a Continuous Medium*. Prentice-Hall, Upper Saddle River, New Jersey
  - Davies, G. F. (2011). *Mantle convection for geologists*. Cambridge University Press, Cambridge, UK ; New York
  - Watts, A. B. (2001). *Isostasy and Flexure of the Lithosphere*. Cambridge University Press
- Math references
  - Fleisch, D. A. (2012). *Student's Guide to Vectors and Tensors*. Cambridge University Press, New York
  - Green's, Stokes', and the divergence theorems on Khan Academy's Multivariate calculus:
    `https://www.khanacademy.org/math/multivariable-calculus`
  - Kreyszig, E. (2011). *Advanced Engineering Mathematics*. Wiley, 10th edition
  - Arfken, G. B., Weber, H. J., and Harris, F. E. (2005). *Mathematical methods for physicists*. Academic Press, 6th edition
  - Bender, C. M. and Orszag, S. A. (1999). *Advanced mathematical methods for scientists and engineers*. Springer, New York
  - Courant, R. and Hilbert, D. (1989). *Methods of Mathematical Physics, Vol. 1-2*. Wiley-VCH

Useful computing software

- Jupyter notebook on Visual Studio Code (`https://code.visualstudio.com/docs/python/jupyter-support`).

- JupyterLab (`http://jupyter.org/`). A web interface to Python-based scientific computing. Jupyter Notebooks created with JupyterLab will make it easy for you to share documents that contain live code, equations, visualizations and explanatory texts. An excellent alternative to Matlab at least for this course's activities.
- Google Colab (`https://colab.research.google.com`). A free Jupyter notebook environment that requires no setup and runs entirely in the cloud.
- Typesetting equations: LaTeX. LaTeX grammar for math expressions is de facto the universal standard. Even the MS Word equation editor understands it.
- Plotting: GMT and matplotlib (good combination with Jupyter).
- Matlab is prohibited in this course.

Term project

Each student will read about a topic not extensively covered in this course and produce lecture notes on the selected topic. An in-class, one hour-long lecture should be given at the end of the semester. Possible topics include but are not limited to

- Chemical geodynamics: A chapter in Geodynamics by Turcotte and Schubert
- Selected topics in Flows in Porous Media chapter in Geodynamics by Turcotte and Schubert
- "Exotic" rheology: Non-linear elasticity, plasticity and viscoplasticity, odd viscosity and odd elasticity, etc.
- Review of modern observations on oceanic or continental lithosphere: Chapters in Solid Earth by Fowler
- Comprehensive review of classical and advanced solution techniques for ordinary differential equations
- Similarity methods for partial differential equations
- Review of the fundamentals of shock waves

Mini-lectures

- Peer-teaching on selected topics in 3 subjects: elastic bending of plates, heat flow and fluid mechanics.
- A lecture must not exceed 25 min.
- Students choose a presentation style and supporting materials that best serve their lecture topics: e.g., slides, handouts, chalkboard, physical demo, YouTube video, etc.
- Both a presenter and audience students will be evaluated based on the rubrics.
  - Presenters *must* consult the instructor before delivering their lectures to check if they would meet expectations.
  - Audiences should actively participate in the lecture by asking questions or making comments.

Homework requirements

- Most of homework solutions can be hand-written.
- However, all the non-manual calculations must be carried out with Python and plots created with a data visualization library for Python (e.g., matplotlib). Your codes and plotting scripts for a homework must be submitted as a Jupyter Notebook.

Course Schedule

Week 1: **Aug. 28** Introduction to the course, requirements and tools.

Aug. 30 Continuum mechanics: Introduction and kinematics

Week 2: **Sep. 4, 6** Continuum mechanics: Stress and balance laws, constitutive equations, linear elasticity, plane strain/stress, principal stresses.

Week 3: **Sep. 11** No class (Labor Day)

Sep. 13 Elastic bending of plates: Theory and geodynamic applications.

Week 4: **Sep. 18** Elastic bending of plates: Mini-lectures.

Sep. 20 Heat flow: The general form of transport equation, heat conduction and generation. Measuring heat flux, geotherms in mantle and continents.

Week 5: **Sep. 25, 27** Heat flow: Solutions to heat diffusion equation.

Week 6: **Oct. 2, 4** Heat flow mini-lectures: Radiogenic heating and geotherm, periodic heating and skin depth, cooling of oceanic lithosphere, Stefan problem and ocean floor topography, mantle geotherm and subucting slab, McKenzie's crustal stretching model.

Week 7: **Oct. 9, 11** Gravity anomaly and isostasy

Week 8: **Oct. 16** No class (Fall break)

Oct. 18 *Mid-term exam.*

Week 9: **Oct. 23** Fluid mechanics: Description of fluid motion, force balance in fluid and Stoke's equation.

Oct. 25 Fluid mechanics: 1D channel flows. Stream function for 2D flows.

Week 10: **Oct. 30, Nov. 1** Fluid mechanics mini-lectures: Applications of stream function. Post-glacial rebound, angle of subduction, diapirism, folding, Stoke's flow.

Week 11: **Nov. 6, 8** Fluid mechanics: Mantle convection and stability analysis

Week 12: **Nov. 13, 15** Rock rheology: Creep, atomic origin of elasticity and creep

Week 13: **Nov. 20** Rock rheology: Brittle and ductile deformation. Strength envelope.

Nov. 22 No class (Thanksgiving break).

Week 14: **Nov. 27** Rock rheology: Brittle and ductile deformation. Strength envelope (continued).

Nov. 29 Rock rheology: Anderson theory of faulting and critical taper theory.

Week 15: Dec. 4, 6 *Class presentations of term projects.*

Week 16: Dec. 8? *Final exam.*