GEOL 787

Numerical Modeling of Physical and Chemical Processes in Earth Science and Geological Engineering

3 credits, Spring 2025

Wednesday 2:00 - 4:45 Laxalt Mineral Research 275

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Course Description

This course will focus on describing different environmental processes mathematically, and solving those equations numerically to create predictive quantitative models. This course provides a practical, hands-on introduction to numerical modeling, from problem formulation through programming and interpretation.

Course Objectives

Model-building is an essential part of the Earth scientist's/engineer's toolkit. Through a series of bi-weekly computing problems using Python, students will learn:

- How to describe natural systems using mathematics.
- How to write computer codes in Python to compute and plot numerical solutions.

In addition to gaining experience with numerical methods and translating real-life problems into precise mathematical language, students will explore the degree to which the full numerical solution was necessary if first-order predictions could be obtained through dimensional analysis of the governing equations. This type of comparison will be used to evaluate modeling in the literature and to highlight risks and pitfalls associated with excessive model complexity. Finally, data-driven "machine-learning" models are taking the place of physical models for many purposes. We will explore how these models complement traditional physical models and gain some practice building them.

My chief goals are to defuse the fear of computer modeling, to place modeling in the toolkit of all attending students, and to generate a community of users of models that will serve to knit the graduate community together.

Student Learning Outcomes

Students will develop a useful scientific/engineering computing skill set to a level sufficient to write procedural programming scripts to solve equations, complete analysis, plot results, and visualize data across a range of Earth science and engineering problems. Students will be able to discuss the relationship of numerical modeling in the broader context of the field and to their own research interests. Students will demonstrate this proficiency through bi-weekly coding projects.

Course Prerequisites
If students have little to no programming experience, a strong desire to rapidly acquire these skills is a must.

MATH 181 - Calculus I (or equivalent)
PHYS 180 - Physics for Scientists and Engineers I (or equivalent)

Recommended Books/Resources

datacamp.com A collection of online learning resources that we will subscribe to as part of the class.

O'Reilly Publishing, Python for Scientists: A Curated Collection of Chapters from the O'Reilly Data and Programming Library (Free Ebook)

Nagar, S. (2018) Introduction to Python for Engineers and Scientists: Open Source Solutions for Numerical Computation (Free Ebook accessible through UNR library portal)

Downey, A. (2016) Think Python: How to Think Like a Computer Scientist (Free Ebook accessible through UNR library portal)

Downey, A. (2018) Think Complexity (Free Ebook accessible through UNR library portal)

Slingerland, R., and L. Kump, (2011) *Mathematical Modeling of Earth's Dynamical Systems: A Primer*. Princeton University Press.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery (2007) *Numerical Recipes: The Art of Scientific Computing in C++* (Third Edition).

Format
The course centers on a series of modeling assignments. During class meetings, I will present background information for the natural system to be modeled. I will also provide guidance on how to translate the natural system into the language of mathematics, and how to translate the mathematics into computer code. Along the way, we will also learn the basics of scientific programming in Python (no prior experience in programming is assumed). You will then apply this information to derive, design, and create models for the various systems that we will explore during the semester. The examples we work on will be drawn from my experience but will also be tailored to the students' interests and research topics.

Required Work and Grading
No plus/minus grading will be used below a B-.

100%-93% = **A**; 92.9%-90% = **A-**; 89.9%-87% = **B+**; 86.9%-84% = **B**; 83.9%-80% = **B-**; 79.9%-70% = **C**; 69.9%-55% = **D**; 54.9% or below = **F**

Students are expected to participate in discussions and presentation of their own strategies and solutions to the coding problems. At mid-semester, each person will revisit an earlier assignment to polish, add bells and whistles, and hand in. In addition, there will be a final project, presented as a short-format talk with an abstract (~10 minutes), due at the end of the semester. See below for project rubrics. It is expected that students with a large range of programming skills will enroll. Expectations of progress made for each problem will be relative to the level of initial programming experience.

Grades will be based on the midterm project (25%), final project (25%), in class participation (25%), and level of improvement during the semester (25%).

Late work
It is crucial that ALL assignments be handed in on time, so that (1) you're prepared to discuss them in class, (2) we can grade them promptly, and (3) you don't fall behind. Therefore, I will deduct 10% per day that papers are late.

Topics Outline
Topics will vary from week to week. I will tune these according to the interests of participants, but here is a list of problems and methods we might explore (in no particular order, topics in bold are the topics we covered in the last few iterations of this course):

Introduction to Python (three tutorials)
Cosmogenic radionuclide accumulation
Evolution of a cinder cone
Data input/output
Diffusive heat transport
Lake volume (Mono Lake; Great Basin lakes)
Hillslope evolution and soil transport
Evolution of longitudinal river profiles
Landslides
Hazard prediction using machine-learning models
Diffusive contaminate transport
Random walks leading to diffusive behavior
1D Valley glacier dynamics and the influence of climate
Settling of grains in fluids
Hillslope stability
Hortonian overland flow of water on a hillslope
River network development
River discharge prediction
Meander bend development
Flexural loading and unloading
Coral reef evolution on a rising / sinking margin
Sand dune/ripple formation
Fault network growth
Cellular automaton
Examples of deterministic chaos - Lorentz attractor

Fractals

Rubric for Midterm assignment: Polishing code of choice

Code runs and is free of major bugs:	10	_____
Code is clearly commented:	5	_____
Code is organized and easy to follow:	5	_____
Figures produced are clear and high quality:	3	_____
Code moves beyond original assignment (i.e. bells and whistles were added):	2	_____
TOTAL	25	_____

Rubric for Final assignment: Short-presentation with abstract

3 _____ **Abstract**: Clearly and concisely states the topic of the presentation, why it is an important topic, specific problem solved, how problem was solved, important results, and important implications of the results.

1 _____ **Thesis/Hypothesis Statement**: Clearly and concisely states the purpose of the presentation in a single sentence, which is engaging, and thought provoking.

1 _____ **Introduction**: The introduction is engaging, states the main topic and why it is important, concisely reviews needed literature/background.

1 _____ **Methods**: Approach to solving the problem is clear, concise and documented such that others could reproduce the work.

1 _____ **Results**: Results are presented that support the main thesis.

1 _____ **Discussion**: Results are successfully placed in context and interpreted.

1 _____ **Conclusion**: The conclusion is engaging and restates the thesis.

1 _____ **Organization/Structural Development of the Idea**: Writer demonstrates logical sequencing of ideas through well-developed slides.

1 _____ **Mechanics/ Usage**: No errors in punctuation, capitalization and spelling.

1 _____ **Citation**: Work is cited where appropriate.

2 _____ **Figures**: are clear, high quality.

11 _____ Project involved significant coding and/or modeling

TOTAL 25 _____

University Policies

Statement on Academic Dishonesty

The University Academic Standards Policy defines academic dishonesty, and mandates specific sanctions for violations. See the University Academic Standards policy: UAM 6,502.

Consider adding a generative AI statement in the academic integrity section. Clarify what, if any, use of generative AI tools is permitted (for which assignments, for which purposes) and how students will be expected to document and disclose use of generative AI tools. See appendix for sample language.

Statement on Student Compliance with University Policies

In accordance with section 6,502 of the University Administrative Manual, a student may receive academic and disciplinary sanctions for failure to comply with policy, including this syllabus, for failure to comply with the directions of a University Official, for disruptive behavior in the classroom, or any other prohibited action. “Disruptive behavior" is defined in part as behavior, including but not limited to failure to follow course, laboratory or safety rules, or endangering the health of others. A student may be dropped from class at any time for misconduct or disruptive behavior in the classroom upon recommendation of the instructor and with approval of the college dean. A student may also receive disciplinary sanctions through the Office of Student Conduct for misconduct or disruptive behavior, including endangering the health of others, in the classroom. The student shall not receive a refund for course fees or tuition.

Statement of Disability Services

Use either the traditional or online statement, in addition to the last sentence regarding third party materials.

For Traditional and Seated Classrooms:

Any student with a disability needing academic adjustments or accommodations is requested to speak with me or the Disability Resource Center (Pennington Achievement Center Suite 230) as soon as possible to arrange for appropriate accommodations.

For Online Courses:

If you are a student who would normally seek accommodations in a traditional classroom, please contact me as soon as possible. You may also contact the Disability Resource Center for services for online courses by emailing drc@unr.edu or calling 775-784-6000. Academic accommodations for online courses may be different than those for seated classrooms; it is important that you contact us as soon as possible to discuss services. The University of Nevada, Reno supports equal access for students with disabilities. For more information, visit the Disability Resource Center.

This course may leverage 3rd party web/multimedia content, if you experience any issues accessing this content, please notify your instructor.

Statement on Audio and Video Recording

Student-created Recordings

Surreptitious or covert video-taping of class or unauthorized audio recording of class is prohibited by law and by Board of Regents policy. This class may be videotaped, or audio recorded only with the written permission of the instructor. In order to accommodate students with disabilities, some students may have been given permission to record class lectures and discussions. Therefore, students should understand that their comments during class may be recorded.

Instructor-created Recordings

Class sessions may be audio-visually recorded for students in the class to review and for enrolled students who are unable to attend live to view. Students who participate with their camera on or who use a profile image are consenting to have their video or image recorded. If you do not consent to have your profile or video image recorded, keep your camera off and do not use a profile image. Students who un-mute during class and participate orally are consenting to have their voices recorded. If you do not consent to have your voice recorded during class, keep your mute button activated and only communicate by using the "chat" feature, which allows you to type questions and comments live.

Statement on Maintaining a Safe Learning and Work Environment

The University of Nevada, Reno is committed to providing a safe learning and work environment for all. If you believe you have experienced discrimination, sexual harassment, sexual assault, domestic/dating violence, or stalking, whether on or off campus, or need information related to immigration concerns, please contact the University's Center for Civil Rights and Equal Access at 775-784-1547. Resources and interim measures are available to assist you. For more information, please visit the Center for Civil Rights & Equal Access page.

Statement on Campus Closures or Delays

In the event of class cancelations or delays caused by inclement weather conditions, fire/smoke conditions, or other unforeseen emergencies, the safety and well-being of students are the University's top priority. Official notifications will be disseminated through the University website and other official channels with details related to any campus delays or closures.

In the event of a campus closure, you will be informed as to whether the class will be offered remotely or if it will be canceled. If the class is cancelled, you will receive information on how to address any missed course content.

Students facing significant impacts due to these events are encouraged to communicate with their instructor for potential accommodations.

If you are sick, please do not come to class. If you must miss class due to illness, please contact your instructor immediately to make arrangements for any missed work or lecture materials.

Statement for Academic Success Services

Your student fees cover usage of the University Math Center (https://www.unr.edu/university-math-center), (775) 784-4433; University Tutoring Center (https://www.unr.edu/tutoring-center), (775) 784-6801; and University Writing & Speaking Center (https://www.unr.edu/writing-

speaking-center), (775) 784-6030. These centers support your classroom learning; it is your responsibility to take advantage of their services. Keep in mind that seeking help outside of class is the sign of a responsible and successful student.

Mental Health Support Statement

There are times when you may experience difficulties in life, and you may benefit from seeking help. Mental health services are available to you as a student at no additional cost through Counseling Services at the Pennington Student Achievement Center. This includes same-day in-person and tele mental health initial consultations, brief individual counseling, and group counseling sessions. Limited same-day appointments can be scheduled online via Counseling Services or by calling 775-784-4648. Additional brief drop-in "Let's Talk" student consultations are also available in the Counseling Services Annex located at the southwest corner of Great Basin Hall.

Veteran Statement

Veterans, Reservists, National Guard and military connected family members may wish to check the office of Veteran Services for benefits and support. Besides processing VA educational benefits, the department offers a variety of programs year-round to support student academic and personal success while transitioning to higher education and throughout your educational experience. They welcome inquiries regarding VA benefits and assist in navigating resources, the campus, and in the Reno community.

AI Syllabus Language

Generative AI Use is Permitted or Encouraged

In this course you are welcome to use generative artificial intelligence/large language model tools (such as ChatGPT, DALL-E, Gemini, Perplexity, etc.). Using these tools aligns with the course learning outcomes/student goals .

Please be aware that many AI companies collect and store personal information. Please do not enter your confidential information as part of a prompt.

Also, please note that some of these large language models may “make up” or “hallucinate” information. These tools may reflect misconceptions and biases of specific data. Students are responsible for checking facts, finding reliable sources for, and making a critical examination of any work that is submitted.

All use of AI tools or content must be acknowledged or cited. If you do not acknowledge or cite your use of an AI tool, what you submit will be considered a form of cheating, as outlined in UNR Academic Integrity Policy (UAM 6,502).