Inverse Methods in EAS - EAS-6134-A

Spring 2026 (syllabus v1.0)

Updated 12th January 2026

Note: This is the plan we very much hope to follow. Adjustments may be necessary to accommodate the natural pace of the class and in case of unforeseen circumstances.

Course Description

This class deals with geophysical inverse theory, which provides foundational knowledge for making inferences about Earth (or other) systems based on observations that are both finite in number and accuracy. Inverse theory is distinct from simple parameter estimation (the classical statistical problem) since the unknown model requires infinitely many variables for its full description, yet the number of observations available is finite. Thus, in practical inverse problems (those based on real observations as opposed to idealized data) there is always ambiguity in the model. Finding a particular model solution involves a choice from an infinitely large collection of alternative solutions.

Together, we will explore how to use observational data to constrain models of geophysical structure through inversion and, critically, how to assign confidence levels given the inherent non-uniqueness of inverse problems. This course will provide a broad overview of least squares estimation, linear inverse problems, regularization, followed by iterative, non-linear, and stochastic inverse methods.

The initial approach taken in the class is to apply mathematical optimization to select the simplest models (i.e., regularization). Uncertainty quantification is also an important goal. To discover reliable properties of the earth, independent of any particular model, we may need to calculate upper and lower bounds on functionals that represent those properties. The utility of stochastic methods for identifying a range of acceptable models will also be discussed.

Expected Learning Outcomes

- Define a suite of relevant geophysical inverse methods
- Describe the mathematical basis and applicability of these methods
- Determine which inverse method is appropriate for a given problem
- Design and implement a numerical algorithm based on the chosen inverse method to solve the given problem
- Assign a confidence level to the solution (i.e., uncertainty quantification)
- Effectively communicate all the above to others, experts and non-experts alike

Course Topics

- Mathematical precursors, linear algebra and vector spaces

- Over and underdetermined least squares problems
- Linear inverse problems, model construction, and regularization
- Numerical methods, QR and SVD factorizations
- Resolution and inference, model bounds
- Nonlinear inverse problems and linearization
- Iterative optimization: Backus-Gilbert creeping, Occam's method
- Uncertainty quantification
- Stochastic inversion

Instructor: **Dr. Samer Naif** (**snaif@eas.gatech.edu (mailto:snaif@eas.gatech.edu)**)

Lectures: **M/W 12.30 pm – 1.45 am @ Ford ES&T L1116**

The lectures will be in-person. Students are required to attend. Lectures will not be recorded.

Textbook (also see background reading at bottom of page)

Aster, R.C., B. Borchers, & C.H. Thurber, 2013. Parameter Estimation and Inverse Problems, Second Edition.

Electronic version is available at **https://www.sciencedirect.com/book/9780123850485/parameter-estimation-and-inverse-problems (https://www.sciencedirect.com/book/9780123850485/parameter-estimation-and-inverse-problems)**

Supplementary notes from R.L. Parker (**SIO230 Notes.pdf (https://gatech.instructure.com/courses/518738/files/69925731?wrap=1)**)

Office hours

Mondays 2.00 pm – 3.00 pm, and by appointment

Drop-in office hours will be held in ES&T 2234. Email me to request a virtual meeting or to schedule an appointment.

Grading

Homework: 60%

Expect an assignment approximately every 2 weeks, which is due the following week. Many will consist of coding exercises. Homework will be submitted electronically through Canvas and must be clearly organized and presented, points may be deducted for poorly organized and difficult to interpret information.

Term Project: 30%

Project will consist of a written report and in-class presentation of a specific data-driven inverse

problem that may be related to your research. More details will come during the semester.

Participation: 10%

Attending lectures is mandatory. Class engagement is strongly encouraged and essential for your learning.

Letter grade

A ≥ 90%; B = 80–89%; C = 70–79%; D = 60–69%; F <60%

Satisfactory/Unsatisfactory: S ≥ 80%.

Academic Integrity

It is expected that all students are aware of their individual responsibilities under the **Georgia Tech Academic Honor Code**, which **will be strictly adhered to** and is central to the tenets of this course. In particular, improperly obtaining and using written or verbal information in the preparation of an exam or lab exercise will not be tolerated. All assignments must be entirely your own work. If you are caught cheating on exams or labs, you will be turned in to the Dean of Students. The complete text of the Academic Honor Code is found at **http://www.catalog.gatech.edu/policies/honor-code/ (http://www.catalog.gatech.edu/policies/honor-code/)** or **https://catalog.gatech.edu/rules/18/ (https://catalog.gatech.edu/rules/18/)**.

Generative AI: You are welcome, even encouraged, to use large language models and generative AI (e.g., chatGPT) to assist with your learning in this course. Where I draw the line is if you use these tools to complete assignments, write your codes, or write your reports. That is plagiarism, which I take very seriously. Highly recommended, check out this **link (http://forms.office.com/r/f8x9tY3knj?origin=lprLink)** to download the USG Student Guide to GenAI Literacy. If you are not sure whether you are using these tools in an appropriate manner, ask me first! I am happy to discuss.

Student-Faculty Expectations: As members of the Georgia Tech community, we are committed to creating a learning environment in which all students feel safe and included. All members of this class are expected to contribute to a respectful, welcoming and inclusive environment for every other member of the class. Please see this **http://catalog.gatech.edu/rules/22/ (http://catalog.gatech.edu/rules/22/)** for some basic expectations that we should have of each other. We welcome and encourage your constructive feedback and/or suggestions for improvement.

Accommodations for Students with Disabilities

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services at **http://disabilityservices.gatech.edu (http://disabilityservices.gatech.edu/)** or by phone at (404) 894-2563 as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail the instructor as soon as possible to discuss your learning needs.

Student Resources and Well Being

Georgia Tech can be very stressful at times. Fortunately, Georgia Tech has organized resources related to Well Being which can be accessed **here (https://students.gatech.edu/health-wellness-recreation)** . Additional resources are compiled below.

Personal Support

Georgia Tech Resources

- **Office of the Dean of Students (https://studentlife.gatech.edu/about/office-dean-students)** | **404-894-6367**
- **Counseling Center (https://mentalhealth.gatech.edu/)** | **404-894-2575** | Smithgall Student Services Building 2nd floor
  - Services include short-term individual counseling, group counseling, couples counseling, testing and assessment, referral services, and crisis intervention.
  - *Students in crisis may walk in during business hours (8am-5pm, Monday through Friday) or contact the counselor on call after hours at **404-894-2204**.*
- **Stamps Health Services (https://health.gatech.edu/)** | **404-894-1420**
- **OMED Educational Services (http://www.omed.gatech.edu/)** | **404-894-3959**
- **Women's Resource Center (https://womenscenter.gatech.edu/)** | **404-385-0230**
- **LGBTQIA Resource Center (http://lgbtqia.gatech.edu/)** | **404 385 4780**
- **Veteran's Resource Center (http://veterans.gatech.edu/)** | **404-385-2067**
- **Georgia Tech Police (https://police.gatech.edu/)** | **404-894-2500**

National Resources

- The **National Suicide Prevention Lifeline (https://suicidepreventionlifeline.org/)** | **1-800-273-8255**
  - Free and confidential support 24/7 to those in suicidal or emotional distress
- The **Trevor Project (https://www.thetrevorproject.org/)**
  - Crisis intervention and suicide prevention support to members of the LGBTQ+ community and their friends
  - Telephone | **1-866-488-7386** | 24 hours a day, 7 days a week
  - **Online chat (https://www.thetrevorproject.org/get-help-now/)** | 24 hours a day, 7 days a week
  - Text message | Text "START" to **687687** | 24hrs day, 7 days a week

Background Reading

Inverse problems

Bardsley, Johnathan M., 2018. *Computational Uncertainty Quantification for Inverse Problems*.

Society for Industrial and Applied Mathematics, Philadelphia.

Parker, R.L., 1994. *Geophysical Inverse Theory*. Princeton University Press.

- Advanced level inverse theory text that develops the full mathematical foundation using functional analysis (basis of the supplementary notes)

Tarantola, A., 2005. *Inverse Problem Theory and Methods for Model Parameter Estimation*. SIAM.

- Early probabilistic approach to the solution of inverse problems

Menke, W., 2012. *Geophysical Data Analysis: Discrete Inverse Theory*. Elsevier. **https://www.sciencedirect.com/book/monograph/9780123971609/geophysical-data-analysis-discrete-inverse-theory (https://www.sciencedirect.com/book/monograph/9780123971609/geophysical-data-analysis-discrete-inverse-theory)**

- Popular textbook with many geophysics students

Mark Asch, Marc Bocquet and Malle Nodet, 2016. *Data Assimilation: Methods, Algorithms, and Applications*. SIAM, **https://doi.org/10.1137/1.9781611974546 (https://doi.org/10.1137/1.9781611974546)** .

Probability and Statistics

Dekking, F.M., C. Kraaikamp, H.P. Lopuhaä, L.E. Meester, 2005. *A Modern Introduction to Probability and Statistics: Understanding Why and How*. Springer, London.

Jaynes, E.T., 2003. *Probability Theory: The Logic of Science*. Cambridge University Press, New York.

Kay, Stephen, 1993. *Fundamentals of Statistical Signal Processing Volume 1: Estimation Theory*. Prentice Hall.

Mathematical Background

Bishop, C.M., 2006. *Pattern Recognition and Machine Learning*. Springer, New York.

Lancaster, P., & K. Salkauskas, 1986. *Curve and Surface Fitting: An Introduction*. Academic Press.

Mackay, D.J.C., 2003. *Information Theory, Inference, and Learning Algorithms*. Cambridge University Press.

Strang, G., 1980. *Linear Algebra and its Applications*. Academic Press, New York.

Strang, G., 1986. *Introduction to Applied Mathematics*. Wellesley-Cambridge Press, Wellesley, Mass.

On Functional Analysis and Numerical Methods

Korevaar, J., 1968. *Mathematical Methods*. New York, Academic Press.

Lawson, C.L. and R.J. Hanson, 1974. *Solving Least Squares Problems*. Hall.

Englewood Cliffs, N.J., Prentice-Luenberger, D.G., 1968. *Optimization by Vector Space Methods*. New York, John Wiley and Sons.

Course Summary:

Date	Details	Due
Wed Jan 14, 2026	**Homework #1 (https://gatech.instructure.com/courses/518738/assignments/2368462)**	due by 12pm