QUICK REFERENCE: Section 8 contains the calendar of topics and deadlines.

Last compiled: May 2, 2013

1. **Course information.**

GEOS F627	**Inverse Problems and Parameter Estimation**, 3 credits, Spring 2013
Meeting times:	Tuesday and Thursday, 11:30–13:00
Meeting location:	301N Elvey (Geophysical Institute)
Prerequisites:	MATH 202 (Calculus III) and MATH 314 (Linear Algebra); or permission of instructor

2. **Instructor information.**

Instructor:	**Carl Tape**
Office:	413D Elvey (Geophysical Institute)
Email:	`carltape@gi.alaska.edu`
Phone:	(907) 474-5456
Office hours:	Wednesday, 10:00–11:00, or by appointment

3. **Course materials.**

   (a) **Textbooks.** The required (R) and supplemental (S) textbooks are (see "References" at the end of this syllabus) listed in the following table. "Software" lists the software (if any) used in examples within each book. The G.I. Mather library is located in the IARC/Akasofu building.

Textbook	R	S	Software	Availability			
				UAF bookstore	Mather reserve	PDF	UAF e-book
[1] Aster	X		Matlab		X		X
[2] Tarantola	X		none		X	X	
[3] Menke		X	Matlab		X		X
[4] Parker		X	none		X		
[5] Weisberg		X	R				X

   [2] can be downloaded as a pdf from Tarantoa's webpage. However, he writes: "Here are the rules: i) you are invited to download, view, and print the books; ii) if you work in a commercial company, or in a rich institution (like a university in the developed world), and your plan is to use one of the books from time to time, please purchase it (links below)."

   (b) Journal articles (and PDF books) assigned as reading will be available as PDFs through the course website on UAF Blackboard.

   (c) Students will need computers for their homework. General-use computers in UAF labs will be made available to students if needed.

   (d) Matlab will be the primary computational program for the course. Matlab is available via a UAF-wide license.

4. **Course description.**

   An inverse problem is a procedure by which observations or measurements are used with quantitative models to gain inferences about some underlying physical quantity or system. Inverse problems occur in all fields of natural sciences — even something as simple as fitting a line to scattered data is an inverse problem. This course will provide a general framework, as well as general computational algorithms, for approaching inverse problems. The training should benefit all students in natural sciences who are seeking inferences from data.

Catalog description: A forward problem uses a model to make predictions; an inverse problem uses observations to infer properties of an unknown physical model. One example of an inverse problem is how to use seismometer recordings to infer the location of an earthquake. This course covers inverse theory and methods for solving inverse problems, including numerous examples arising in the natural sciences. Topics include linear regression, method of least squares, discrete ill-posed inverse problems, estimation of uncertainties, iterative optimization, and probabilistic (Bayesian) and sampling approaches. Assignments require familiarity with linear algebra and computational tools such as Matlab.

5. **Course goals.**

   We will explore the ubiquitous realm of inverse problems in Earth sciences: how to use observations to make inferences about underlying physical quantities or processes. Our ultimate goal is to be able to recognize the fundamental components of an inverse problem — measurements, model parameters, misfit function, forward model — then to pose an approach to solving the problem, then solve the problem with computational algorithms. Concepts of inverse theory and parameter estimation are fundamental to all observational scientists, which includes most students in the natural sciences. During this course students should acquire both a philosphical and scientific appreciation for inverse methods and problems.

6. **Student learning outcomes.**

   Upon completion of this course, students should be able to:

   (a) Articulate the basic features of forward problems and inverse problems.
   (b) Describe numerous examples of inverse problems and the basic components of each problem.
   (c) Set up and solve an inverse problem using the least squares approach.
   (d) Obtain a linear model from a set of data using multiple linear regression.
   (e) Understand and use data covariances and model covariances within an inverse problem.
   (f) Describe singular value decomposition and its relevance to inverse methods.
   (g) Explain and implement a regularization technique.
   (h) Explain the importance of sampling algorithms for estimating uncertainties of model parameters.
   (i) Pose and answer statistical questions from a particular set of model samples.
   (j) Describe probabilistic approaches to inverse problems.
   (k) Write, improve, and run computational algorithms in Matlab.

7. **Instructional methods.**

   (a) Assignments and grades (along with general course information and handouts) will be posted on Blackboard: `classes.uaf.edu`.
   (b) Lectures will be the primary mode of instruction. Some lectures will be supplemented with computational examples to prepare students for homework problems.

8. **Course calendar (tentative).**

Day	Date	Topic	Reading Due†	Homework Due	Homework Assigned
Thurs	Jan-17	Overview of inverse problems	A1	—	PS-1
Tues	Jan-22	Review of linear algebra	AA		
Thurs	Jan-24	Review of linear algebra	AA		
Tues	Jan-29	Taylor series and least squares (`taylor.pdf`)	notes,T3,AC	PS-1	PS-2
Thurs	Jan-31	LAB: least squares (`lab_linefit.pdf`)	notes,T3,AC		
Tues	Feb-05	Taylor series and least squares	notes,T3,AC	PS-2	PS-3
Thurs	Feb-07	LAB: sampling $\sigma_{\rm M}(\mathbf{m})$ (`lab_epi.pdf`)	T2,T7.1		
Tues	Feb-12	Covariance	notes,AB	PS-3	PS-4
Thurs	Feb-14	LAB (PS-3)			
Tues	Feb-19	Probability density (`tarantola.pdf`)	AB,notes		
Thurs	Feb-21	Generalized least squares (`tarantola.pdf`)	T3,notes	PS-4	PS-5
Tues	Feb-26	LAB: Newton method (`lab_newton.pdf`)	T6.22		
Thurs	Feb-28	LAB: iterative methods (`lab_iter.pdf`)	A6,A9		
Tues	Mar-05	Linear regression	A2	PS-5	PS-6
Thurs	Mar-07	Linear regression	A2		final project
Tues	Mar-12	SPRING BREAK			
Thurs	Mar-14	SPRING BREAK			
Tues	Mar-19	Singular value decomposition	A3	PS-6	PS-7
Thurs	Mar-21	Singular value decomposition	A3		
Tues	Mar-26	LAB: truncated SVD			
Thurs	Mar-28	Singular value decomposition	A3	PS-7	
Tues	Apr-02	InSAR and parameter estimation			PS-8
Thurs	Apr-04	LAB: Mogi source from InSAR			
Tues	Apr-09	Tikhonov regularization	A4	PS-8	final project
Thurs	Apr-11				final project
Tues	Apr-16	Discretizing problems with basis functions	A5		final project
Thurs	Apr-18				final project
Tues	Apr-23	Principal component analysis	handout		final project
Thurs	Apr-25				final project
Tues	Apr-30	final presentations			
Thurs	May-02	final presentations			
Fri	May-03			final report	

†A = Ref. [1], T = Ref. [2]

Some Important Dates:

First class:	Thursday	January 17
Last day to add class:	Friday	January 25
Last day to drop class:	Friday	Feb 1
Last day for student- or faculty-initiated withdraw:	Friday	March 22
Last class:	Thursday	May 2
Final project report:	Friday	May 3
Final project presentation:	Tuesday	April 30
	Thursday	May 2

9. **Course policies.**

   (a) **Attendance**: All students are expected to attend and participate in all classes.

   (b) **Tardiness**: Students are expected to arrive in class prior to the start of each class. If a student does arrive late, they are expected to do so quietly and inform the instructor without disturbing the class.

   (c) **Participation and preparation**: Students are expected to come to class with assigned reading and other assignments completed as noted in the syllabus.

   (d) **Assignments**:

      i. All assignments are due **at the start of class** on the due date.

      ii. Late assignments will be accepted with a 10% penalty per day late, up to five days late; an assignment that is ≥ 5 days late will receive a zero. (An assignment that is "one day late" would be handed in less than 24 hours after the start time of class on the due date.)

      iii. No digital submission of assigments will be accepted (e.g., email or Blackboard).

   Homework Tips: Please type or write neatly, keep the solutions in the order assigned and staple pages together. Include only relevant computer output in your solutions (a good approach is to cut and paste the relevant output for each problem into an editor such as MS Word or Latex). Also clearly circle or highlight important numbers in the output, and label them with the question number. I also suggest that you to include your Matlab code in your answers, both so that you can refer back to it for future assignments and so that I can identify where a mistake may have occurred. Display numerical answers with a reasonable number of significant figures and with *units* if the quantity is not dimensionless.

   Homework scores are based on clarity of work, logical progression toward the solution, completeness of interpretation and summaries, and whether a correct solution was obtained. I encourage you to discuss homework problems with other students, however the work you turn in must be your own.

   (e) **Graded Assignments**: Assignments will be graded for students within seven days of their receipt and returned at the end of the next class.

   (f) **Reporting Grades**: All student grades, transcripts and tuition information are available on line at `www.uaonline.alaska.edu`.

   (g) **Consulting fellow students**: Students are welcome to discuss with each other general strategies for particular homework problems. However, the write-up that is handed in—including any computer codes—must be individual work.

   (h) **Plagiarism:** Students must acknowledge any sources of information—including fellow students—that influenced their homework assignments or final project. Any occurrence of plagiarism will result in forfeiture of all points for the particular homework assignment. If the plagiarism is between two students, then both students will potentially receive the penalty.

   Furthermore, the UAF catalog states: "The university may initiate disciplinary action and impose disciplinary sanctions against any student or student organization found responsible for committing, attempting to commit or intentionally assisting in the commission of ... cheating, plagiarism, or other forms of academic dishonesty..."

   (i) All UA student academics and regulations are adhered to in this course. You may find these in the UAF catalog (section "Academics and Regulations").

10. **Evaluation.**

(a) Grading is based on:

5%	Attendance and participation
70%	Homework Assignments
25%	Individual Final Project

(b) Overall course grades are based on the following criteria:

A	$x \geq 93$	excellent performance:
A–	$90 \leq x < 93$	student demonstrates deep understanding of the subject
B+	$87 \leq x < 90$	strong performance:
B	$83 \leq x < 87$	student demonstrates strong understanding of the subject,
B–	$80 \leq x < 83$	but the work lacks the depth and quality needed for an 'A'
C+	$77 \leq x < 80$	mediocre performance:
C	$73 \leq x < 77$	student demonstrates comprehension of some
C–	$70 \leq x < 73$	essential concepts only
D	$60 \leq x < 70$	poor performance:
		student demonstrates poor comprehension of concepts
F	$x < 60$	Failure to complete work with 60% quality

(c) **Final Project.** The final project will constitute 25% of the course grade. The project will involve independent research into one aspect of seismology. It will require some computation and will be presented in the form of a written report, due on the last lecture class of the semester, and a short in-class presentation during the scheduled final exam. The report will be written in manuscript-submission style and format, using the guidelines for *Geophysical Research Letters*. Additional details, including project suggestions, will be provided by the instructor midway through the course.

11. **Support Services.**

The instructor is available by appointment for additional assistance outside session hours. UAF has many student support programs, including the Math Hotline (1-866-UAF-MATH; 1-866-6284) and the Math and Stat Lab in Chapman building (see `www.uaf.edu/dms/mathlab/` for hours and details).

12. **Disabilities Services.**

The Office of Disability Services implements the Americans with Disabilities Act (ADA), and it ensures that UAF students have equal access to the campus and course materials. The Geophysics Program will work with the Office of Disability Services (208 Whitaker, 474-5655) to provide reasonable accommodation to students with disabilities.

13. **References listed in syllabus.**

[1] R. C. Aster, B. Borchers, and C. H. Thurber, *Parameter Estimation and Inverse Problems.* Waltham, Mass., USA: Elsevier, 2 ed., 2012.

[2] A. Tarantola, *Inverse Problem Theory and Methods for Model Parameter Estimation.* Philadelphia, Penn., USA: SIAM, 2005.

[3] W. Menke, *Geophysical Data Analysis: Discrete Inverse Theory.* Waltham, Mass., USA: Academic Press, 3 ed., 2012.

[4] R. L. Parker, *Geophysical Inverse Theory.* Princeton, New Jersey, USA: Princeton U. Press, 1994.

[5] S. Weisberg, *Applied Linear Regression.* Hoboken, New Jersey: Wiley, 3 ed., 2005.