FORMAT 1

Submit original with signatures + 1 copy + electronic copy to Faculty Senate (Box 7500).

See http://www.uaf.edu/uafgov/faculty-senate/curriculum/course-degree-procedures-/ for a complete description of the rules governing curriculum & course changes.

TRIAL COURSE OR NEW COURSE PROPOSAL

SUBMITTED BY:

Department	Geology and Geophysics	College/School	CNSM
Prepared by	Carl Tape	Phone	907-474-5456
Email Contact	carltape@gi.alaska.edu	Faculty Contact	Carl Tape, x5456

1. ACTION DESIRED (CHECK ONE): Trial Course [ ] New Course [X]

2. COURSE IDENTIFICATION: Dept: GEOS Course #: ~~6XX~~ F626 No. of Credits: 3

Justify upper/lower division status & number of credits: This is a graduate-level science class with GEOS 609 (proposed Foundations of Geophysics) as a prerequisite.

3. PROPOSED COURSE TITLE: Applied Seismology

4. To be CROSS LISTED? YES/NO NO If yes, Dept: Course #:

(Requires approval of both departments and deans involved. Add lines at end of form for such signatures.)

5. To be STACKED? YES/NO NO If yes, Dept. Course #

6. FREQUENCY OF OFFERING: Spring, Even-numbered Years

Fall, Spring, Summer (Every, or Even-numbered Years, or Odd-numbered Years) — or As Demand Warrants

7. SEMESTER & YEAR OF FIRST OFFERING (AY2011-12 if approved by 3/1/2012; otherwise AY2012-13): AY2013-2014 (spring)

RECEIVED OCT - 3 2011 Dean's Office College of Natural Science & Mathematics

8. COURSE FORMAT:

NOTE: Course hours may not be compressed into fewer than three days per credit. Any course compressed into fewer than six weeks must be approved by the college or school's curriculum council. Furthermore, any core course compressed to less than six weeks must be approved by the core review committee.

COURSE FORMAT: (check all that apply)	[ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [X] *6 weeks to full semester*
OTHER FORMAT (specify)	
Mode of delivery (specify lecture, field trips, labs, etc)	Lecture, including in-class computational examples; short in-class discussions

9. CONTACT HOURS PER WEEK: 3 LECTURE hours/weeks 0 LAB hours /week 0 PRACTICUM hours /week

Note: # of credits are based on contact hours. 800 minutes of lecture=1 credit. 2400 minutes of lab in a science course=1 credit. 1600 minutes in non-science lab=1 credit. 2400-4800 minutes of practicum=1 credit. 2400-8000 minutes of internship=1 credit. This must match with the syllabus. See http://www.uaf.edu/uafgov/faculty-senate/curriculum/course-degree-procedures-/guidelines-for-computing-/ for more information on number of credits.

OTHER HOURS (specify type)

10. COMPLETE CATALOG DESCRIPTION including dept., number, title, credits, credit distribution, cross-listings and/or stacking (50 words or less if possible):

GEOS 607 Applied Seismology

3 Credits Offered Spring Even-numbered Years

Presentation of modeling techniques for earthquakes and Earth structure using wave propagation algorithms and real seismic data. Covers several essential theories and algorithms for applications in seismology, as well as the basic tools needed for processing and using recorded seismograms. Topics include the seismic wavefield (body waves and surface waves), earthquake moment tensors, earthquake location, and seismic tomography. Assignments require familiarity with vector calculus, linear algebra, and computational tools such as Matlab. *Prerequisites: GEOS ~~F609~~ XX or permission of instructor.* (3+0) Prerequisites: GEOS F431 or GEOS F631, or permission of instructor.

[Prerequisite is intended to be the new Foundations of Geophysics course. 2/21/2012 JH]

11. ***COURSE CLASSIFICATIONS:*** Undergraduate courses only. Consult with CLA Curriculum Council to apply S or H classification appropriately; otherwise leave fields blank.

H = Humanities		S = Social Sciences	

Will this course be used to fulfill a requirement for the baccalaureate core? **If YES, attach form.**	YES:		NO:	X

IF YES, check which core requirements it could be used to fulfill:

O = Oral Intensive, Format 6		W = Writing Intensive, Format 7		Natural Science, Format 8	

12. ***COURSE REPEATABILITY:***

Is this course repeatable for credit?	YES		NO	X

Justification: Indicate why the course can be repeated (for example, the course follows a different theme each time).	

How many times may the course be repeated for credit?		**TIMES**
If the course can be repeated for credit, what is the maximum number of credit hours that may be earned for this course?		**CREDITS**
If the course can be repeated with <u>variable</u> credit, what is the maximum number of credit hours that may be earned for this course?		**CREDITS**

13. ***GRADING SYSTEM:*** ***Specify only one. Note: Later changing the grading system for a course constitutes a Major Course Change.***

LETTER:	X	PASS/FAIL:	

RESTRICTIONS ON ENROLLMENT (if any)

14. ***PREREQUISITES***	GEOS 609; or permission of instructor

These will be *required* before the student is allowed to enroll in the course.

15. ***SPECIAL RESTRICTIONS, CONDITIONS***	

16. ***PROPOSED COURSE FEES***	none
Has a memo been submitted through your dean to the Provost for fee approval? Yes/No	

17. ***PREVIOUS HISTORY***

Has the course been offered as special topics or trial course previously? Yes/No	Yes

If yes, give semester, year, course #, etc.:	Spring 2012, GEOS F694

18. ESTIMATED IMPACT

WHAT IMPACT, IF ANY, WILL THIS HAVE ON BUDGET, FACILITIES/SPACE, FACULTY, ETC.

This graduate-level will fulfill part of the teaching workload for new Geology & Geophysics faculty member Tape. Anticipated enrollment is 5-10 students; a small classroom in Elvey or Reichardt will be required.

19. LIBRARY COLLECTIONS

Have you contacted the library collection development officer (kljensen@alaska.edu, 474-6695) with regard to the adequacy of library/media collections, equipment, and services available for the proposed course? If so, give date of contact and resolution. If not, explain why not.

No		Yes	x	

20. IMPACTS ON PROGRAMS/DEPTS

What programs/departments will be affected by this proposed action?
Include information on the Programs/Departments contacted (e.g., email, memo)

The Department of Geology and Geophysics will be affected by this proposal action in the sense that Applied Seismology will fulfill credit requirements for M.S. or Ph.D. geophysics students. In the revised geophysics curriculum, Applied Seismology is an elective course.

21. POSITIVE AND NEGATIVE IMPACTS

Please specify positive and negative impacts on other courses, programs and departments resulting from the proposed action.

The course will have a positive impact on the MS/PhD geophysics program (see "Justification" below).

The applied nature of the proposed course will provide valuable research training for students. The computational training would allow students to excel in several other courses with computational applications, such as the STAT 4XX and MATH 6XX courses listed in the proposed revisions to the geophysics curriculum.

The addition of a new graduate-level geophysics course could potentially diminish enrollment in other geophysics courses; however, students tend to take several more courses than the minimum requirements in geophysics MS/PhD. If a student decides to take only one seismology course, then Applied Seismology could diminish enrollment in Intermediate Seismology. C. Tape and D. Christensen have discussed how to make the two seismology courses complementary. We note that neither course is a prerequisite for the other.

JUSTIFICATION FOR ACTION REQUESTED

The purpose of the department and campus-wide curriculum committees is to scrutinize course change and new course applications to make sure that the quality of UAF education is not lowered as a result of the proposed change. Please address this in your response. This section needs to be self-explanatory. Use as much space as needed to fully justify the proposed course.

In the 1980s there were three seismology courses are UAF: Beginning Seismology, Intermediate Seismology, and Advanced Seismology. At present, only Intermediate Seismology is offered (taught by Doug Christensen). C. Tape was hired in 2010 in part to teach an advanced-level, applied seismology course, which is lacking from the current curriculum. The addition of the applied seismology course will strengthen training for seismology graduate students and also strengthen the MS/PhD concentration in Solid Earth Geophysics. Applied Seismology will directly build upon geophysics and computational training that students will receive in the (proposed and) required Foundations of Geophysics (GEOS F609). Furthermore, in spring 2010, geophysics graduate students met multiple times to suggest changes to the MS/PhD geophysics program; an applied seismology course was one of their concrete recommendations.

APPROVALS: ***Add additional signature lines as needed.***

Sarah Fowell	Date	9/8/11
Signature, Chair, Program/Department of:	Geology + Geophysics	
	Date	9/30/11
Signature, Chair, College/School Curriculum Council for:	CNSM	
Paul W. Layer	Date	Oct 5, 2011
Signature, Dean, College/School of:	CNSM	
	Date	
Signature of Provost (if applicable)		

Offerings above the level of approved programs must be approved in advance by the Provost.

ALL SIGNATURES MUST BE OBTAINED PRIOR TO SUBMISSION TO THE GOVERNANCE OFFICE

	Date	

Signature, Chair
Faculty Senate Review Committee: ___Curriculum Review ___GAAC

___Core Review ___SADAC

ADDITIONAL SIGNATURES: ***(As needed for cross-listing and/or stacking)***

	Date	
Signature, Chair, Program/Department of:		
	Date	
Signature, Chair, College/School Curriculum Council for:		
	Date	
Signature, Dean, College/School of:		

ATTACH COMPLETE SYLLABUS (as part of this application). Note: The guidelines are online: http://www.uaf.edu/uafgov/faculty-senate/curriculum/course-degree-procedures-/uaf-syllabus-requirements/
The Faculty Senate curriculum committees will review the syllabus to ensure that each of the it listed below are included. If items are missing or unclear, the proposed course (or changes to may be denied.

SYLLABUS CHECKLIST FOR ALL UAF COURSES
During the first week of class, instructors will distribute a course syllabus. Although modifications may be made throughout the semester, this document will contain the following information (as applicable to the discipline):

1. **Course information:**
   ❑Title, ❑ number, ❑credits, ❑prerequisites, ❑ location, ❑ meeting time (make sure that contact hours are in line with credits).
2. **Instructor (and if applicable, Teaching Assistant) information:**
   ❑ Name, ❑ office location, ❑ office hours, ❑ telephone, ❑ email address.
3. **Course readings/materials:**
   ❑ Course textbook title, ❑ author, ❑ edition/publisher.
   ❑ Supplementary readings (indicate whether ❑ required or ❑ recommended) and
   ❑ any supplies required.
4. **Course description:**
   ❑ Content of the course and how it fits into the broader curriculum;
   ❑ Expected proficiencies required to undertake the course, if applicable.
   ❑ Inclusion of catalog description is *strongly* recommended, and
   ❑ Description in syllabus must be consistent with catalog course description.
5. ❑ **Course Goals (general), and (see #6)**
6. ❑ **Student Learning Outcomes (more specific)**
7. **Instructional methods:**
   ❑ Describe the teaching techniques (eg: lecture, case study, small group discussion, private instruction, studio instruction, values clarification, games, journal writing, use of Blackboard, audio/video conferencing, etc.).
8. **Course calendar:**
   ❑ A schedule of class topics and assignments must be included. Be specific so that it is clear that the instructor has thought this through and will not be making it up on the fly (e.g. it is not adequate to say "lab". Instead, give each lab a title that describes its content). You may call the outline Tentative or Work in Progress to allow for modifications during the semester.
9. **Course policies:**
   ❑ Specify course rules, including your policies on attendance, tardiness, class participation, make-up exams, and plagiarism/academic integrity.
10. **Evaluation:**
   ❑ Specify how students will be evaluated, ❑ what factors will be included, ❑ their relative value, and ❑ how they will be tabulated into grades (on a curve, absolute scores, etc.) ❑ Publicize UAF regulations with regard to the grades of "C" and below as applicable to this course. (Not required in the syllabus, but may be a convenient way to publicize this.) Faculty Senate Meeting #171: http://www.uaf.edu/uafgov/faculty-senate/meetings/2010-2011-meetings/#171
11. **Support Services:**
   ❑ Describe the student support services such as tutoring (local and/or regional) appropriate for the course.
12. **Disabilities Services:**
   The Office of Disability Services implements the Americans with Disabilities Act (ADA), and insures that UAF students have equal access to the campus and course materials.
   ❑ State that you will work with the Office of Disabilities Services (208 WHITAKER BLDG, 474-5655)to provide reasonable accommodation to students with disabilities.

6/30/2011

UNIVERSITY OF ALASKA FAIRBANKS

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

1. **Course information.** Course number is F626 (2/21/2012, JH).

GEOS F607 xx	**Applied Seismology**, 3 credits, Spring 2014
Meeting times:	Tuesday and Thursday, 9:45–11:15
Meeting location:	TBA
Prerequisites:	GEOS F609 xx (Foundations of Geophysics) GEOS F431 or F631, 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.** All textbooks are available at the UAF library. The required textbooks are:

[1]	*An Introduction to Seismology, Earthquakes, and Earth Structure*, Stein and Wysession, 2003
[2]	*Introduction to Seismology*, Peter Shearer, 2nd ed., 2009

   One copy of [1] and [2] will be on reserve in Mather Library (within the IARC building); [1] is also available to be checked out from the UAF library as an e-book.

   I recommend the following textbooks for supplemental and more detailed information:

seismology:	[3, 4, 5, 6],[7] (2009 paperback printing if available)
continuum mechanics:	[8, 5]

   One copy of each of these books is on reserve at Mather library.

   (b) Journal articles 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.**

Seismology combines observational data (seismograms) with numerical modeling methods to obtain powerful inferences about earthquake sources and the three-dimensional structure of Earth's interior. *Applied Seismology* will provide essential training for students' interested in academic, industrial, or governmental careers in seismology.

Catalog description: Presentation of modeling techniques for earthquakes and Earth structure using wave propagation algorithms and real seismic data. Covers several essential theories and algorithms for applications in seismology, as well as the basic tools needed for processing and using recorded seismograms. Topics include the seismic wavefield (body waves and surface waves), earthquake moment tensors, earthquake location, and seismic tomography. Assignments require familiarity with linear algebra and computational tools such as Matlab.

5. **Course goals.**

We will explore the study of earthquakes and Earth's interior structure using seismological theories and algorithms. The underlying physical phenomenon we will examine is the seismic wavefield: the time-dependent, space-dependent elastic waves that originate at an earthquake source (for example, a fault slips) and propagate though the heterogeneous Earth structure, then are finally recorded as time series at seismometers on Earth's surface. Students will examine real seismic data and use computational models to estimate properties about earthquake source and Earth structure. Students will acquire practical, advanced seismological training that will prepare them for seismological investigations in the future, whether in academic, industry, or government jobs.

6. **Student learning outcomes.**

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

   (a) Understand the relevant temporal, spatial, and magnitude scales in the field of seismology.
   (b) Describe the physical quantities that govern seismic wave propagation.
   (c) Describe the seismic phases that arise in a regional or global layered Earth model.
   (d) Describe the seismic moment tensor, the fundamental model of an earthquake source.
   (e) Understand the basic framework of inverse problems within the context of seismology.
   (f) Describe several different seismological tools that can be used to investigate an individual earthquake.
   (g) Understand the connection between earthquakes, continental defortmation, and plate tectonics.
   (h) Understand the distinction between one-dimensional and three-dimensional Earth structure, and how this affects theory and algorithms in seismology.
   (i) Read seismological journal articles and summarize the content efficiently.
   (j) Write, improve, and run simple computational algorithms in Matlab.
   (k) Plot and manipulate recorded seismograms.

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.
   (c) Each student is expected to lead one brief discussion and review of an assigned journal article.

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

	Day	Date	Topic	Reading Due†	Homework Due	Homework Assigned
1	Thurs	Jan-19	Seismology in 1911, 2011, and 2111	SW1	—	PS-1
2	Tues	Jan-24	Seismograms, signal, noise, measurements	S11, SW6.6		
3	Thurs	Jan-26	Basic analysis and processing of seismograms		PS-1	PS-2
4	Tues	Jan-31	Continuum mechanics	DT2.6		
5	Thurs	Feb-02	Equations of motion	DT3, SW2, S2	PS-2	PS-3
6	Tues	Feb-07	Solving the wave equation (3D)	DT2		
7	Thurs	Feb-09	Solving the wave equation (1D and 2D)	SW2, S3	PS-3	PS-4
8	Tues	Feb-14	Normal modes: theory and observations	SW2.9, S8.6, DT10.5		
9	Thurs	Feb-16	Surface waves: theory and observations	SW2.7-2.8, S8	PS-4	PS-5
10	Tues	Feb-21	Body waves, reflection, and transmission	S4, SW3		
11	Thurs	Feb-23	Waveform modeling	SW4.3	PS-5	PS-6
12	Tues	Feb-28	Wavefield modeling	[9, 10, 11]		
13	Thurs	Mar-01	Finite-frequency sensitivity kernels	[12, 13]	PS-6	PS-7
14	Tues	Mar-06	Ambient-noise tomography	[14, 15]		final project
15	Thurs	Mar-08	Preliminary Reference Earth Model	[16], DT8.2	PS-7	PS-8
	Tues	Mar-13	SPRING BREAK			
	Thurs	Mar-15	SPRING BREAK			
16	Tues	Mar-20	Forward problems and inverse problems	[16]		
17	Thurs	Mar-22	Earthquake location	SW4, S9	PS-8	PS-9
18	Tues	Mar-27	Seismic moment tensor	SW4.4, S9		
19	Thurs	Mar-29	Finite source models	S9.8, WS4.5	PS-9	PS-10
20	Tues	Apr-03	Seismic tomography: global	S5, SW7.3		
21	Thurs	Apr-05	Seismic tomography: crustal	SW3.2-3.3	PS-10	PS-11
22	Tues	Apr-10	Anisotropy and attenuation	SW3.6-3.7, S6.6,11.3		
23	Thurs	Apr-12	Adjoint methods in seismology	[17, 18]	PS-11	final project
24	Tues	Apr-17	Finite source inversion	S9.8, SW4.5		final project
25	Thurs	Apr-19	Seismology, geodesy, and deformation	WS5		final project
26	Tues	Apr-24	Seismology of volcanoes	[19]		final project
27	Thurs	Apr-26	Seismology of glaciers	[20, 21]		final project
28	Tues	May-01	Seismology in the oil industry	S7, WS3.3		final project
29	Thurs	May-03	Seismic monitoring for nuclear activity	[22]	REPORT	
		May-XX	FINAL PROJECT PRESENTATION			

†SW = Ref. [1]; S = Ref. [2]; DT = Ref. [5]

Some Important Dates:

First class:	Thursday	January 19
Last day to add class:	Friday	January 27
Last day to drop class:	Friday	Feb 3
Last day for student- or faculty-initiated withdraw:	Friday	March 23
Last class:	Thursday	May 3
Final project report due:	Thursday	May 3
Final project presentation:		TBD (May 7–10)

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 noted in the Syllabus.

      ii. Late assignments will be accepted with a 20% penalty per day late; an assignment that is ≥ 5 days late will receive a zero.

      iii. The lowest homework assignment will be dropped when computing the course grade.

   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 a maximal penalty of forfeiture of all points for the particular homework assignment. If the plagiarism is between two students, then both students will potentially receive the penalty.

   (i) All UA student academics and regulations are adhered to in this course. You may find these in the UAF Catalog.

10. **Evaluation.**

   (a) For students in the M.S. or Ph.D. program, you must receive a C or higher for this course for it to count toward your degree requirements.

   (b) Grading is based on:

10%	Attendance and participation
60%	Homework Assignments
30%	Individual Final Project

(c) 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+	$77 \leq x < 80$	average performance:
C	$73 \leq x < 77$	student comprehends the essential material
C–	$70 \leq x < 73$	as reflected by the average quality of assignments
D	$60 \leq x < 70$	below average performance: student demonstrates comprehension of some concepts
F	$x < 60$	Failure to complete work with 60% quality

(d) **Final Project.** The final project will constitute 30% 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 (203 WHIT, 474-7043) to provide reasonable accommodation to students with disabilities.

13. **References listed in syllabus.**

[1] S. Stein and M. Wysession, *An Introduction to Seismology, Earthquakes, and Earth Structure.* Malden, Mass., USA: Blackwell, 2003.

[2] P. M. Shearer, *Introduction to Seismology.* Cambridge, UK: Cambridge U. Press, 2 ed., 2009.

[3] B. L. N. Kennett, *The Seismic Wavefield: Introduction and Theoretical Development*, vol. 1. Cambridge, UK: Cambridge U. Press, 2001.

[4] B. L. N. Kennett, *The Seismic Wavefield: Interpretation of Seismograms on Regional and Global Scales*, vol. 2. Cambridge, UK: Cambridge U. Press, 2002.

[5] F. A. Dahlen and J. Tromp, *Theoretical Global Seismology.* Princeton, New Jersey, USA: Princeton U. Press, 1998.

[6] T. Lay and T. C. Wallace, *Modern Global Seismology.* San Diego, Calif., USA: Academic Press, 1995.

[7] K. Aki and P. G. Richards, *Quantitative Seismology.* San Francisco, Calif., USA: University Science Books, 2 ed., 2002. 2009 corrected printing.

[8] L. E. Malvern, *Introduction to the Mechanics of a Continuous Medium.* Upper Saddle River, New Jersey, USA: Prentice-Hall, 1969.

[9] T. Nissen-Meyer, A. Fournier, and F. A. Dahlen, "A two-dimensional spectral-element method for computer spherical-earth seismograms – I. Moment-tensor source," *Geophys. J. Int.*, vol. 168, pp. 1067–1092, 2007.

[10] D. Komatitsch and J. Tromp, "Spectral-element simulations of global seismic wave propagation—I. Validation," *Geophys. J. Int.*, vol. 149, pp. 390–412, 2002.

[11] D. Komatitsch and J. Tromp, "Spectral-element simulations of global seismic wave propagation—II. Three-dimensional models, oceans, rotation and self-gravitation," *Geophys. J. Int.*, vol. 150, pp. 308–318, 2002.

[12] F. A. Dahlen, S.-H. Hung, and G. Nolet, "Fréchet kernels for finite-frequency traveltimes—I. Theory," *Geophys. J. Int.*, vol. 141, pp. 157–174, 2000.

[13] S.-H. Hung, F. A. Dahlen, and G. Nolet, "Fréchet kernels for finite-frequency traveltimes—II. Examples," *Geophys. J. Int.*, vol. 141, pp. 175–203, 2000.

[14] N. M. Shapiro, M. Campillo, L. Stehly, and M. H. Ritzwoller, "High-resolution surface-wave tomography from ambient seismic noise," *Science*, vol. 307, pp. 1615–1618, 2005.

[15] J. Tromp, Y. Luo, S. Hanasoge, and D. Peter, "Geophys. J. Int.," *Geophys. J. Int.*, vol. 183, pp. 791–819, 2010.

[16] A. Dziewonski and D. Anderson, "Preliminary reference Earth model," *Phys. Earth Planet. Inter.*, vol. 25, pp. 297–356, 1981.

[17] Q. Liu and J. Tromp, "Finite-frequency kernels based on adjoint methods," *Bull. Seis. Soc. Am.*, vol. 96, no. 6, pp. 2383–2397, 2006.

[18] C. Tape, Q. Liu, and J. Tromp, "Finite-frequency tomography using adjoint methods—Methodology and examples using membrane surface waves," *Geophys. J. Int.*, vol. 168, pp. 1105–1129, 2007.

[19] S. R. McNutt, "Volcanic seismology," *Annu. Rev. Earth Planet. Sci.*, vol. 33, pp. 461–491, 2005.

[20] V. C. Tsai and G. Ekström, "Analysis of glacial earthquakes," *J. Geophys. Res.*, vol. 112, 2007.

[21] M. E. West, C. F. Larsen, M. Truffer, S. O'Neel, and L. LeBlanc, "Glacier microseismicity," *Geology*, vol. 38, no. 4, pp. 319–322, 2010.

[22] D. Bowers and N. D. Selby, "Forensic seismology and the Comprehensive Nuclear-Test-Ban Treaty," *Annu. Rev. Earth Planet. Sci.*, vol. 37, pp. 209–236, 2009.

Example homework

Problem Set 9: Forward problems and inverse problems

GEOS 607: Applied Seismology, Carl Tape

Assigned: March 22, 2012 — Due: March 29, 2012

Problem 1. Forward problem: PREM

The Preliminary Reference Earth Model, established in 1980, is a seminal work in seismology (*Dziewonski and Anderson*, 1981). It is a spherically symmetric model of Earth structure, a type of model described as "one dimensional," since variations are only present in the radial dimension. A PDF of *Dziewonski and Anderson* (1981) is available on the course website on Blackboard.

1. (X points) Read *Dziewonski and Anderson* (1981, Table 1) and the associated text. List and describe the material properties in PREM; list what units PREM assumes for each variable.

   How many geometrical parameters are needed to describe PREM? How many parameters are needed to describe Q_μ? Ignoring anisotropy, how many *additional* parameters are needed to describe $V_S(r)$ in PREM?

2. (X points) Write a Matlab function that inputs a vector of radial (or depth) values and outputs a vector of V_S values. Compute V_S for depths of 1.5 km, 10 km, and 50 km. Do the values seem reasonable?

   Hint: Use the command `polyval` to save some time.

3. (X points) Plot a figure showing $V_S(r)$ for r ranging from the center of Earth to the surface of Earth. Make sure that axes are labeled with units.

Problem 2. Forward problem: Generating an ellipse described by m

In class we discussed the least-squares method and showed how to construct a solution for fitting a line to scattered data, which required a two-parameter model (y-intercept and slope). Here the assignment is to compute a best-fitting ellipse for a set of data.

An equation for an ellipse centered at $(0,0)$ is given by

$$bx^2 + cxy + dy^2 = 1, \tag{1}$$

where b, c, and d are the unknowns that we want to determine by using a least-squares method.

1. (X points) In symbolic form, write down a "forward function" for a model $\mathbf{m} = (b,\, c,\, d)$ that inputs a polar angle θ_i and outputs the point $(x_i,\, y_i)$ on the ellipse described by $\mathbf{m}$ (Eq. 1). This function can be thought of as

$$f(\mathbf{m},\, \theta_i) = (x_i,\, y_i). \tag{2}$$

2. (X points) Now assume an input set of N polar angles, $\boldsymbol{\theta} = (\theta_1, \theta_2, \ldots, \theta_N)$, and you want to determine the corresponding output (x, y)-points describing the ellipse.

Write a function in Matlab `[x,y] = getellipse(m,theta)` that generates the proper output, and plot the result in Matlab for the model $\mathbf{m} = (0.1, 0.3, 0.5)$ using input angles $\boldsymbol{\theta} = (0, \ldots, 2\pi)$.

(Hint: For N linearly spaced angles, use `theta = linspace(0,2*pi,N)'`.)

Problem 3. Inverse problem: Using least squares to fit an ellipse to a set of data

From Problem 2, you should now have a plotting tool for an arbitrary ellipse model $\mathbf{m}$. For this problem, you do not need the parameter θ.

1. (X points) Write down in matrix form the least-squares problem $\mathbf{Gm} = \mathbf{d}$ whose unknown vector is $\mathbf{m} = [b \;\; c \;\; d]^T$, and show the dimensions of each array. Solve for $\mathbf{m}$ in symbolic form.

2. (X points) Using Matlab, implement your result in (a) and solve for $\mathbf{m}$ using the data

$$(x_i,\, y_i) \;:\; (3,3),\; (1,-2),\; (0,3),\; (-1,2),\; (-2,-2),\; (0,-4),\; (-2,0),\; (2,0).$$

   Check that the result is the same as if you simply use the "\" command: `m = G\d`.

   (Hint: The design matrix $\mathbf{G}$ should be 8×3.)

3. (X points) Here are a few lines of code to let you pick points interactively with the mouse. Try it for some data points of your own choosing. (You can copy these lines of code directly from the PDF, then paste them into Matlab.) Then generate a plot containing your points and the best-fitting ellipse.

```
figure;
sd = 3;
hold off, axis equal, axis([-sd sd -sd sd]), axis manual, hold on, grid on
x = []; y = []; button = 1;
disp('Now we get another best-fitting ellipse centered at (0,0).');
disp('Click on your input points using the mouse.');
disp('Hit any key after the final point is entered.');
plot([-sd sd], [0 0], 'k', [0 0], [-sd sd], 'k');
while button==1
    [xx,yy,button] = ginput(1);
    disp(sprintf('    (%.2f, %.2f)',xx,yy));
    x = [x; xx]; y = [y; yy]; plot(xx,yy,'x')
end
```

Problem 4

(0 points) Approximately how many hours did you spend on this problem set? Feel free to suggest improvements here.

References

Dziewonski, A., and D. Anderson (1981), Preliminary reference Earth model, *Phys. Earth Planet. Inter.*, *25*, 297–356.

Problem Set 10: Fault parameters and moment tensors

GEOS 607: Applied Seismology, Carl Tape

Assigned: March 29, 2012 — Due: April 5, 2012

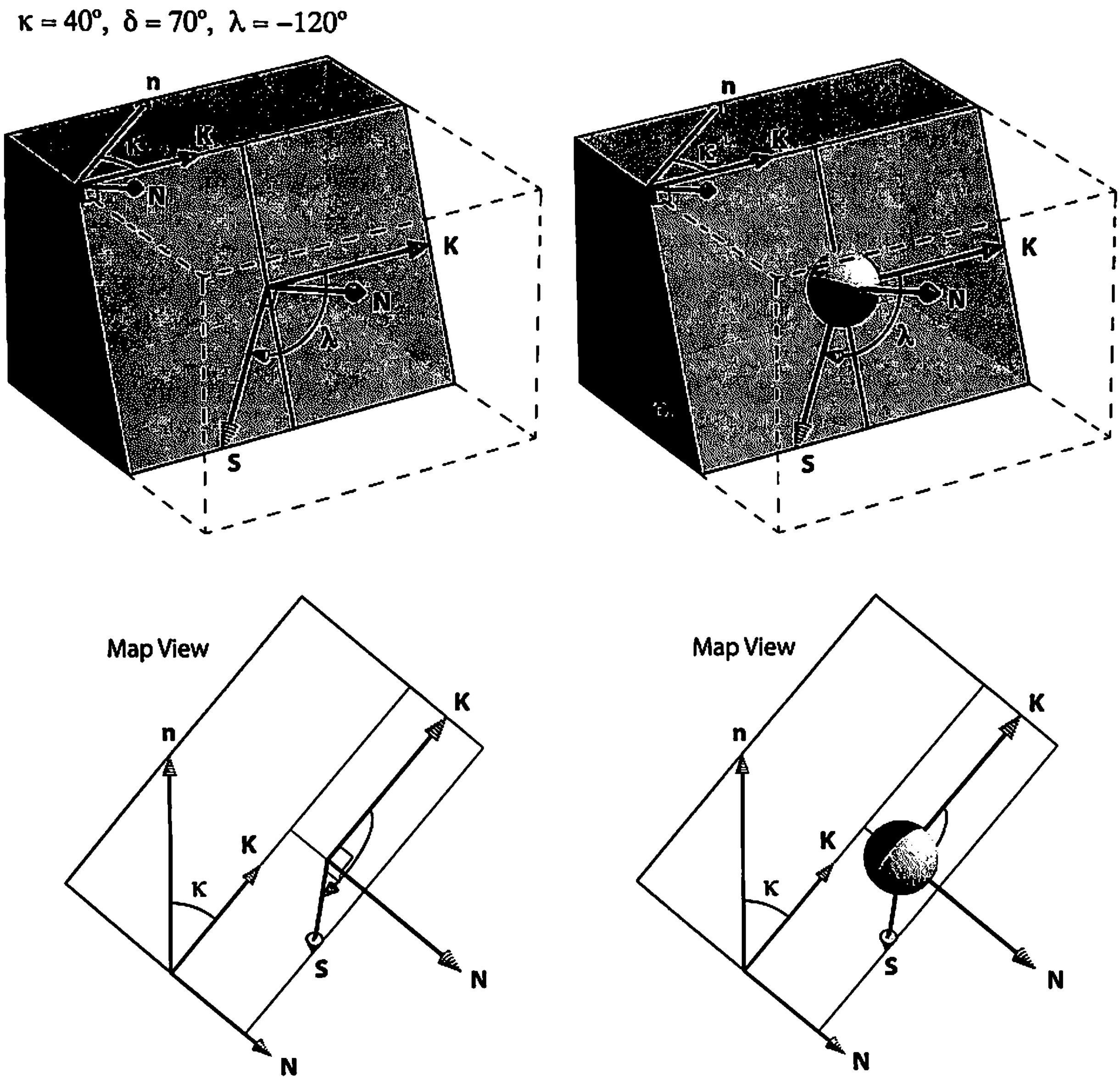

Figure 1: Diagram showing notation for vectors and angles for Problem 2. The strike angle is $\kappa = 40°$, the dip angle is $\delta = 70°$, and the rake angle is $\lambda = -120°$. Note that the map view of the beachballs shows the upper hemisphere, which differs from the seismological convention of plotting the lower hemisphere.

Problem 1. Rotations in 2D and 3D

This problem should prepare you for Problem 2. **Please note:** The full expressions for the equations below are messy, containing dozens of terms of $\cos\alpha$, $\sin\phi$, etc. I am not asking for the full expressions; if you find yourself writing out long, messy equations, please stop!

1. (X points) Write down the 2×2 rotation matrix $\mathbf{R} = \mathbf{R}(\alpha)$ that rotates $\mathbf{r} = (x, y)$ by angle α in the positive (counter-clockwise) direction. What is the relationship between $\mathbf{R}(\alpha)$ and $\mathbf{R}(-\alpha)$? Show that for $\alpha = 90°$ your matrix will rotate $\mathbf{r} = (1, 0)$ to $\mathbf{r}' = (0, 1)$. If $\alpha = 60°$ and $\mathbf{r} = (1, 2)$, compute $\mathbf{r}'$; express your answer in exact (non-decimal) form.

2. (X points) Write down the 3×3 rotation matrix $\mathbf{R}_z = \mathbf{R}_z(\alpha)$ that rotates $\mathbf{r} = (x, y, z)$ by angle α in the positive (counter-clockwise) direction about the z-axis, $\hat{\mathbf{z}} = (0, 0, 1)$. Repeat for $\mathbf{R}_x(\alpha)$ and $\mathbf{R}_y(\alpha)$.

3. (X points) Write a function in Matlab that inputs a rotation angle α and an index for the axis ($k = 1, 2, 3$ for x, y, z), and then outputs the $\mathbf{R}_k(\alpha)$.

4. (X points) Using the matrix functions $\mathbf{R}_x(\alpha)$, $\mathbf{R}_y(\alpha)$, $\mathbf{R}_z(\alpha)$, derive an expression for the matrix, $\mathbf{U}(\mathbf{w}, \gamma)$, that rotates a vector $\mathbf{r}$ about the input vector $\mathbf{w}$ by angle γ. Let θ be the polar angle for $\mathbf{w}$ and ϕ be the azimuthal angle.

   Hint: What operations should be applied to $\mathbf{w}$?

5. (X points) Use your Matlab function for $\mathbf{R}_k(\alpha)$ to compute $\mathbf{U}(\mathbf{w}, \gamma)$ for input values of $\mathbf{w} = (X, X, X)$ and $\gamma = X°$. Check that $\mathbf{U}(-\mathbf{w}, -\gamma)$ gives the same result, and explain why this is the case.

Problem 2. From fault parameters to moment tensors

Figure 1 shows the basics of the problem: given measurements of the angles strike, dip, and slip, compute the 3×3 symmetric moment tensor. This requires a choice of a orthonormal basis for expressing vectors and tensors; we will choose the Global Centroid Moment Tensor (GCMT) convention of up-south-east, or $\hat{\mathbf{r}}$-$\hat{\boldsymbol{\theta}}$-$\hat{\boldsymbol{\phi}}$.

You will utilize the function $\mathbf{U}(\mathbf{w}, \gamma)$ that you obtained in Problem 1. **Please note:** The full expressions for the equations below are messy, containing dozens of terms of $\cos\kappa$, $\sin\lambda$, etc. I am not asking for the full expressions; if you find yourself writing out long, messy equations, please stop!

1. (X points) Referring to Figure 1, write the expression for the strike vector, $\mathbf{K}$, in terms of $\mathbf{U}(\mathbf{w}, \gamma)$. Hint: What should $\mathbf{w}$ and γ be? What angles does $\mathbf{K}$ depend on?

2. (X points) Write the expression for the normal vector, $\mathbf{N}$, in terms of $\mathbf{U}(\mathbf{w}, \gamma)$. Hint: What should $\mathbf{w}$ and γ be? What angles does $\mathbf{N}$ depend on?

3. (X points) Write the expression for the normal vector, $\mathbf{D}$, in terms of $\mathbf{U}(\mathbf{w}, \gamma)$. Hint: What should $\mathbf{w}$ and γ be? What angles does $\mathbf{D}$ depend on?

4. (X points) Using your matlab function for $\mathbf{U}(\mathbf{w}, \gamma)$, compute the vectors $\mathbf{K}$, $\mathbf{N}$, and $\mathbf{D}$ for this example.

5. (X points) There are many choices for computing the eigenvectors associated with a moment tensor. For this example, compute them using the following formulas:

$$
\begin{aligned}
\mathbf{p}_1 &= \frac{\mathbf{D}+\mathbf{N}}{|\mathbf{D}+\mathbf{N}|} \\
\mathbf{p}_3 &= \frac{\mathbf{D}-\mathbf{N}}{|\mathbf{D}-\mathbf{N}|} \\
\mathbf{p}_2 &= -\mathbf{p}_1 \times \mathbf{p}_3
\end{aligned}
$$

   Check that your computed eigenvectors are indeed unit vectors. Sketch the eigenvectors on the upper right diagram.

   The columns of the eigenbasis, $\mathbf{U}$, are $\mathbf{p}_1$, $\mathbf{p}_2$, and $\mathbf{p}_3$. Compute the determinant to check that the eigenbasis is also a rotation matrix.

6. (X points) What are the (unsorted) eigenvalues of any double-couple moment tensor?

7. (X points) Our convention for eigenbasis $\mathbf{U}$ is tied to eigenvalues ordered as $\lambda_1 = 1$, $\lambda_2 = 0$, $\lambda_3 = -1$. Thus, our "base" diagonal moment tensor is $\mathbf{M}'$ with diagonal (1, 0, -1). Write the expression for $\mathbf{M}$, obtained from $\mathbf{M}'$ via transformation by $\mathbf{U}$. Check that the following operations are true for this example:

$$
\begin{aligned}
\mathbf{M}\,\mathbf{p}_1 &= \lambda_1\,\mathbf{p}_1 = \mathbf{p}_1 \\
\mathbf{M}\,\mathbf{p}_2 &= \lambda_2\,\mathbf{p}_2 = 0 \\
\mathbf{M}\,\mathbf{p}_3 &= \lambda_3\,\mathbf{p}_3 = -\mathbf{p}_3
\end{aligned}
$$

   What is the physical meaning of these three operations? (Be careful: The moment tensor is associated with the P-wave motion only.)

8. (X points) Go to `www.globalcmt.org/CMTsearch.html` and enter the following search parameters:

   - Starting Date: 2002/11/03
   - Ending Date: Number of days = 1
   - Moment Magnitude between 7 and 10
   - OUTPUT Type: CMTSOLUTION format

   Compute $\mathbf{M}$ for $\kappa = 296$, $\delta = 71$, $\lambda = 29$; then compute $\mathbf{M}$ for $\kappa = 29$, $\delta = 82$, $\lambda = 19$. Verify that the two moment tensors are the same (to two significant figures or so), and that they match the GCMT solution.

   Discuss one seismic data set for which a point-source model of this earthquake is appropriate. Discuss one seismic data set for which a point-source model of this earthquake is *not* appropriate.

Problem 3

(0 points) Approximately how many hours did you spend on this problem set? Feel free to suggest improvements here.