UNIVERSITY OF CALGARY
FACULTY OF SCIENCE

Department of Geoscience
ES 118
403 220-5841
geoscience@ucalgary.ca

COURSE OUTLINE

1. **Course:** GOPH 671, Inverse Theory & Applications I - Fall 2019

   Lecture 01: WF 09:30 - 10:45 in ST 027A

Instructor	Email	Phone	Office	Hours
Dr Jan Dettmer	jan.dettmer@ucalgary.ca	403 220-4606	ES 212	W 11 am - noon

   An introduction to mathematical and numerical techniques for linear, linearized, and nonlinear inversion. Topics include least squares, singular value decomposition, and Tikhonov regularization, linearization, nonlinear optimization and Bayesian uncertainty quantification. The development of numerical algorithms to solve inverse problems is required for assignments.

   Course Site:

   D2L: GOPH 671 L01-(Fall 2019)-Inverse Theory & Applications I

   Note: Students must use their U of C account for all course correspondence.

   Assignments include questions requiring computer coding, which can be carried out in python, matlab or any other programming language. Students are expected to have access to appropriate computing resources, and to either know or be willing to learn basic computer programming. Some students may find the assignments challenging and I encourage students to come to me with questions while working on the assignments.

   Presentations can consist of either:

   1. A paper review involving one or two significant research papers applying inverse theory to a particular problem.
   2. Applying inversion techniques to a data set of your choice (e.g., related to your thesis research).

   By 13 November students must submit a title and abstract of <=150 words for your presentation to the instructor in printed form. Presentations will be held in class on November 20 and 22 (tentative). Presentations are in class and conference stye and must be 15 minutes long, where 12 minutes are for the presentation and 3 minutes for questions. Going over time will not be accommodated.

   The final exam will be in class on December 6.

   Students are expected to take notes during lecture. However, some notes will also be provided as PDF documents via D2L.

2. **Requisites:**

   See section 3.5.C in the Faculty of Science section of the online Calendar.

   Prerequisite(s):
   Knowledge of linear algebra and vector calculus, and some familiarity with statistics. Also, students should be enrolled in the graduate program in geophysics or receive consent of the instructor.

   Consent of Instructor.

3. **Grading:**

   The University policy on grading and related matters is described in F.1 and F.2 of the online University Calendar. In determining the overall grade in the course the following weights will be used:

Component(s)	Weighting %
Assignments (written & computer)	50
Presentation and abstract	30
Final Examination	15
TopHat	5

Each piece of work (reports, assignments, quizzes, midterm exam(s) or final examination) submitted by the student will be assigned a grade. The student's grade for each component listed above will be combined with the indicated weights to produce an overall percentage for the course, which will be used to determine the course letter grade.

The conversion between a percentage grade and letter grade is as follows.

	A+	A	A-	B+	B	B-	C+	C	C-	D+	D
Minimum % Required	95 %	90 %	85 %	80%	75%	70 %	65 %	60%	56%	53 %	50 %

Scores within 0.5% of the upper boundary of a percent range (e.g., 79.5%) may or may not be rounded up at the discretion of the instructor (a decision will be made based on the student's performance in the course). For percent grades on a boundary, the higher grade will be chosen (e.g., 75% is a B, not a B-).

This course employs TopHat during lectures to conduct quizzes. There will be ~20 questions which provide bonus points when answered correctly. Each correctly answered question counts for 0.25 percent and results are added up to a maximum of 5 percent.

An example final exam will be provided near the end of classes. The final exam will be similar to the example exam with mathematical concepts of some questions being identical. No equation sheet will be allowed.

4. **Missed Components Of Term Work:**

   In the event that a student misses the midterm or any course work due to illness, supporting documentation, such as a medical note or a statutory declaration will be required (see Section M.1; for more information regarding the use of statuary declaration/medical notes, see FAQ). Absences must be reported within 48 hrs.

   The regulations of the Faculty of Science pertaining to this matter are found in the Faculty of Science area of the Calendar in Section 3.6. It is the student's responsibility to familiarize themselves with these regulations. See also Section E.3 of the University Calendar.

5. **Scheduled Out-of-Class Activities:**

   There are no scheduled out of class activities for this course.

6. **Course Materials:**

   Recommended Textbook(s):

   Aster, C. A., B. Borchers and C. H. Thurber,*Parameter Estimation and Inverse Problems*: Elsevier.
   Menke, W., *Geophysical data analysis: Discrete inverse theory (third edition)*: Academic Press.
   Tarantola, A. ,*Inverse Problem Theory and Methods for Model Parameter Estimation*: SIAM.

   The lecture will provide students with self-contained notes. However the listed text-books can be helpful to gain deeper understanding of the topics taught.

   Other materials: Posted on D2L.

7. **Examination Policy:**

   No aids are allowed on tests or examinations.

   Students should also read the Calendar, Section G, on Examinations.

8. **Approved Mandatory And Optional Course Supplemental Fees:**

   There are no mandatory or optional course supplemental fees for this course.

9. **Writing Across The Curriculum Statement:**

   For all components of the course, in any written work, the quality of the student's writing (language, spelling, grammar, presentation etc.) can be a factor in the evaluation of the work. See also Section E.2 of the University Calendar.

10. **Human Studies Statement:**

    Students will not participate as subjects or researchers in human studies.

    See also Section E.5 of the University Calendar.

11. **Reappraisal Of Grades:**

A student wishing a reappraisal, should first attempt to review the graded work with the Course coordinator/instructor or department offering the course. Students with sufficient academic grounds may request a reappraisal. Non-academic grounds are not relevant for grade reappraisals. Students should be aware that the grade being reappraised may be raised, lowered or remain the same. See Section I.3 of the University Calendar.

a. **Term Work:** The student should present their rationale as effectively and as fully as possible to the Course coordinator/instructor within **10 business days** of either being notified about the mark, or of the item's return to the class. If the student is not satisfied with the outcome, the student shall immediately submit the Reappraisal of Graded Term work form to the department in which the course is offered. The department will arrange for a re-assessment of the work if, and only if, the student has sufficient academic grounds. See sections I.1 and I.2 of the University Calendar

b. **Final Exam:**The student shall submit the request to Enrolment Services. See Section I.3 of the University Calendar.

12. **Other Important Information For Students:**

a. **Mental Health** The University of Calgary recognizes the pivotal role that student mental health plays in physical health, social connectedness and academic success, and aspires to create a caring and supportive campus community where individuals can freely talk about mental health and receive supports when needed. We encourage you to explore the mental health resources available throughout the university community, such as counselling, self-help resources, peer support or skills-building available through the SU Wellness Centre (Room 370, MacEwan Student Centre, Mental Health Services Website) and the Campus Mental Health Strategy website (Mental Health).

b. **SU Wellness Center:** The Students Union Wellness Centre provides health and wellness support for students including information and counselling on physical health, mental health and nutrition. For more information, see www.ucalgary.ca/wellnesscentre or call 403-210-9355.

c. **Sexual Violence:** The University of Calgary is committed to fostering a safe, productive learning environment. The Sexual Violence Policy (https://www.ucalgary.ca/policies/files/policies/sexual-violence-policy.pdf) is a fundamental element in creating and sustaining a safer campus environment for all community members. We understand that sexual violence can undermine students' academic success and we encourage students who have experienced some form of sexual misconduct to talk to someone about their experience, so they can get the support they need. The Sexual Violence Support Advocate, Carla Bertsch, can provide confidential support and information regarding sexual violence to all members of the university community. Carla can be reached by email (svsa@ucalgary.ca) or phone at 403-220-2208 .

d. **Misconduct:** Academic misconduct (cheating, plagiarism, or any other form) is a very serious offence that will be dealt with rigorously in all cases. A single offence may lead to disciplinary probation or suspension or expulsion. The Faculty of Science follows a zero tolerance policy regarding dishonesty. Please read the sections of the University Calendar under Section K. Student Misconduct to inform yourself of definitions, processes and penalties. Examples of academic misconduct may include: submitting or presenting work as if it were the student's own work when it is not; submitting or presenting work in one course which has also been submitted in another course without the instructor's permission; collaborating in whole or in part without prior agreement of the instructor; borrowing experimental values from others without the instructor's approval; falsification/ fabrication of experimental values in a report. **These are only examples**.

e. **Assembly Points:** In case of emergency during class time, be sure to FAMILIARIZE YOURSELF with the information on assembly points.

f. **Academic Accommodation Policy:** Students needing an accommodation because of a disability or medical condition should contact Student Accessibility Services in accordance with the procedure for accommodations for students with disabilities available at procedure-for-accommodations-for-students-with-disabilities.pdf.

Students needing an accommodation in relation to their coursework or to fulfill requirements for a graduate degree, based on a protected ground other than disability, should communicate this need, preferably in writing, to the Sr. Instructor of the Department of Geoscience, Dr. Rudi Meyer by email rmeyer@ucalgary.ca or phone 403-210-7848. Religious accommodation requests relating to class, test or exam scheduling or absences must be submitted no later than **14 days** prior to the date in question. See Section E.4 of the University Calendar.

g. **Safewalk:** Campus Security will escort individuals day or night (See the Campus Safewalk website). Call 403-220-5333 for assistance. Use any campus phone, emergency phone or the yellow phones located at most parking lot pay booths.

h. **Freedom of Information and Privacy:** This course is conducted in accordance with the Freedom of Information and Protection of Privacy Act (FOIPP). Students should identify themselves on all written work by placing their name on the front page and their ID number on each subsequent page. For more information, see Legal Services website.

i. **Student Union Information:** VP Academic, Phone: 403-220-3911 Email: suvpaca@ucalgary.ca. SU Faculty Rep., Phone: 403-220-3913 Email: sciencerep@su.ucalgary.ca. Student Ombudsman, Email: ombuds@ucalgary.ca.

j. **Internet and Electronic Device Information:** Unless instructed otherwise, cell phones should be turned off during class. All communication with other individuals via laptop, tablet, smart phone or other device is prohibited during class unless specifically permitted by the instructor. Students that violate this policy may be asked to leave the classroom. Repeated violations may result in a charge of misconduct.

k. **Surveys:** At the University of Calgary, feedback through the Universal Student Ratings of Instruction (USRI) survey and the Faculty of Science Teaching Feedback form provides valuable information to help with evaluating instruction, enhancing learning and teaching, and selecting courses. Your responses make a difference - please participate in these surveys.

l. **Copyright of Course Materials:** All course materials (including those posted on the course D2L site, a course website, or used in any teaching activity such as (but not limited to) examinations, quizzes, assignments, laboratory manuals, lecture slides or lecture materials and other course notes) are protected by law. These materials are for the sole use of students registered in this course and must not be redistributed. Sharing these materials with anyone else would be a breach of the terms and conditions governing student access to D2L, as well as a violation of the copyright in these materials, and may be pursued as a case of student academic or non-academic misconduct, in addition to any other remedies available at law.

Approximate course outline

- Introduction and Fundamentals
  - Data and models; forward and inverse problems
  - Existence, uniqueness, stability
  - Frequentist error statistics, covariance, multi-variate Gaussian distribution
- Linear Inverse Theory
  - Linear and nonlinear inverse problems
  - Continuous/discrete problem
  - Even/over/under/mixed-determined problems
  - Maximum-likelihood/least-squares estimates, vector differentiation
  - chi-square misfit, goodness-of-fit
  - Solution misfit, covariance, resolution, bias
  - Normal (smallest solution), Lagrange multipliers
  - Singular value decomposition and the pseudo-inverse
  - Regularization, minimum-structure (Occam's) inversion
  - Outliers and robust (L1) inversions, iteratively re-weighted least squares
  - Data error estimation, statistical validation
  - Inversion for large problems: steepest descent/conjugate gradient
- Linearized Inversion
  - Newton's method in 1-D: linearization, iteration, convergence
  - Multi-dimensional linearized inversion: creeping and jumping methods
  - Computing Jacobian matrices
  - Comparison to regression/optimization theory; Levenberg-Marquardt algorithm
- Nonlinear inversion and Bayesian Uncertainty Quantification
  - Bates' theorem, posterior probability, prior probability, likelihood function, Bayesian evidence
  - Posterior probability optimization and estimation
  - Analytic solutions for special cases
  - Numerical optimization: simulated annealing
  - Numerical Bayesian sampling: Monte Carlo sampling, importance sampling, Markov-chain Monte Carlo (MCMC) sampling
  - MCMC methods: Metropolis-Hastings algorithm
  - Proposal distributions
  - Bayesian Evidence and Bayesian Information Criterion
  - Model selection and Trans-dimensional models
  - Correlation-based inversion

Department Approval:	Electronically Approved	Date: 2019-09-03 12:13
Associate Dean's Approval for out of regular class-time activity:	Electronically Approved	Date: 2019-09-03 13:37