Course Outline

MATH5231
Prediction and Inverse Modelling in the Ocean and Atmosphere

Faculty of Science
School of Mathematics & Statistics

Term 3, 2021

1. Staff

Position	Name	Email	Consultation times and locations	Contact Details
Lecturer and Course Convenor	Dr Shane Keating	s.keating@unsw.edu.au	Available on Course Moodle site	Contact me via email, Moodle, or during consultation hours

2. Course information

Units of credit: **6**

Pre-requisite(s): 12 units of credit in Level 2 Maths courses including (MATH2011 or MATH2111) and (MATH2120 or MATH2130 or MATH2121 or MATH2221), or (both MATH2019 (DN) and MATH2089), or (both MATH2069 (DN) and MATH2099). Some computing experience (R, Fortran, Maple, Matlab, or Python) is strongly recommended.

Teaching times and locations:

This is a blended learning course, with course materials presented in pre-recorded lecture videos that you will watch in your own time. We will meet once per week for two hours at the times indicated below, alternating between online Python labs and tutorials/discussion sessions, plus group and individual consultations as needed.

Week	Day/time	Activity
Week 1	Wed 12pm-2pm	Lab 1 (Blackboard Collaborate Ultra and Google Colab)
Week 2	Wed 12pm-2pm	Tutorial 1 (Blackboard Collaborate Ultra)
Week 3	Wed 12pm-2pm	Lab 2 (Blackboard Collaborate Ultra and Google Colab)
Week 4	Wed 12pm-2pm	Tutorial 2 (Blackboard Collaborate Ultra)
Week 5	Wed 12pm-2pm	Lab 3 (Blackboard Collaborate Ultra and Google Colab)
Week 6	**n/a**	**Flexibility week – no lectures, labs, or tutorials**
Week 7	Wed 12pm-2pm	Tutorial 3 (Blackboard Collaborate Ultra)
Week 8	Wed 12pm-2pm	Lab 4 (Blackboard Collaborate Ultra and Google Colab)
Week 9	Wed 12pm-2pm	Tutorial 4 (Blackboard Collaborate Ultra)
Week 10	Wed 12pm-2pm	Final group presentations (Blackboard Collaborate Ultra)

2.1 Course summary

This course is a graduate level overview of the mathematical foundations of inverse modelling and prediction and their application to real-world systems, primarily the ocean and atmosphere. The scientific emphasis is on the formal testing of models, formulated as rigorous hypotheses about the errors in all the information: dynamics, initial conditions, boundary conditions and data. Applications in meteorology, oceanography, and climate are presented in detail.

2.2 Course aims

Real-world physical systems, like the ocean and atmosphere, are immensely complicated, and understanding and predicting the future behaviour of these systems is crucial for weather forecasting, marine operations, and climate science. However, our knowledge of the real world sits upon two shaky pillars: imperfect observations on the one hand, and incomplete models (both mathematical and computational) on the other. The mathematical discipline for merging observations and models, plus their relative uncertainties, to form a best-guess estimate for the true state of a system is called *inverse modelling*, also known as data assimilation (in the applied mathematics literature) or filtering (in engineering).

This course aims to provide a graduate-level overview of the mathematical foundations of inverse modelling and prediction and their application to real-world systems, primarily the ocean and the atmosphere. The course introduces the fundamental mathematical underpinnings of forward and inverse modelling in the ocean and the atmosphere. The process of assimilating data into models using the calculus of variations is discussed, and the concept of over-determined and ill-posed problems is introduced. A step-by-step development of maximally efficient inversion algorithms, using ideal models, is complemented by computer codes and comprehensive details for realistic models. Variational tools and statistical concepts are concisely introduced, and applications to contemporary research models, numerical weather prediction, climate forecasting, and observing systems, are examined in detail.

2.3 Course learning outcomes (CLO)

At the successful completion of this course you (the student) should be able to:

1. Demonstrate in-depth knowledge of the fundamental mathematical underpinnings of forward and inverse modelling in the ocean and the atmosphere
2. Implement idealized and realistic computational models of atmosphere/ocean dynamics
3. Apply variational and statistical techniques in inverse modelling and data assimilation to real-world systems including numerical weather prediction and ocean state estimation
4. Communicate discipline specific information in a written form with appropriate referencing

2.4 Relationship between course and program learning outcomes and assessments

Course Learning Outcome (CLO)	LO Statement	Related Tasks & Assessment
CLO 1	Demonstrate in-depth knowledge of the fundamental mathematical underpinnings of forward and inverse modelling in the ocean and the atmosphere	Assignment 1, participation in discussion sessions, final group presentation, final project report
CLO 2	Implement idealized and realistic computational models of atmosphere/ocean dynamics	Assignment 2, participation in discussion sessions, final group presentation, final project report
CLO 3	Apply variational and statistical techniques in inverse modelling and data assimilation to real-world systems including numerical weather prediction and ocean state estimation	Assignment 3, participation in discussion sessions, final group presentation, final project report
CLO 4	Communicate discipline specific information in a written form with appropriate referencing	Assignments 1-3, participation in discussion sessions, final group presentation, final project report

3. Strategies and approaches to learning

3.1 Learning and teaching activities

We believe that effective learning is best supported by a climate of inquiry in which students are actively engaged in the learning process. Hence this course is structured with a strong emphasis on critical analysis and problem solving in discussion sessions and assessments. Students are expected to devote the majority of their study time to such tasks.

There are no formal lectures: new ideas and methods are first encountered from reading the textbook, and then students develop these ideas through active participation in the discussion sessions, and completing the assignments. A short research project will test the ability of students to integrate and apply the facts, concepts, and theory introduced in the discussion sessions.

4. Course schedule and structure

Week [Date/Session]	Topic [Module]	Activity [Learning opportunity]	Related CLO
Week 1-2	Fundamentals of forward and inverse modelling	Lab 1, Tutorial 1, Assignment 1	1,4
Week 2-3	Generalized inverse; Optimal interpolation	Lab 2, Tutorial 2, Assignment 2	2,4
Week 4-5	The Kalman filter	Lab 3, Tutorial 3, Assignment 3	3,4
Week 6	Flexibility week – No lectures	Project group discussions	1,2,3,4
Week 7-8	Applications to ocean-atmosphere-climate science	Lab 4, Tutorial 4, Project group discussions	1,2,3,4
Week 9-10	Final projects	Project group discussions, Final group presentations, Final project report	1,2,3,4

5. Assessment

5.1 Assessment tasks

Throughout the course you will complete three assignments worth 60% of the final mark. The assessment of the assignments is based on the written worked solutions that you submit according to the timetable below.

A final research project will test the ability of students to integrate and apply the facts, concepts, and theory introduced in the discussion sessions. Students will work in small groups and will meet regularly with the course convenor in weeks 7-10 to discuss their project. In Week 10, students will make a group presentation to the rest of the class and will submit an individual project report in Week 11.

Assessment task	Release date	Due date	Weight
Assignment 1	Monday week 2	Monday week 4	20%
Assignment 2	Monday week 4	Monday week 6	20%
Assignment 3	Monday week 7	Monday week 9	20%
Final Project Report	n/a	Thursday week 11	40%

Marks will be awarded for approach, clarity of explanation, and, as required, appropriate referencing, not just the final result. Students will be provided feedback in written form as well as in person during face-to-face consultations.

All assessments must be submitted online via the course Moodle page by 12 noon on the due date. Assessments handed late incur a 10% reduction in the mark per late day. Assessments handed in more than 5 days late will not be marked.

5.2 Final exam

There is no final exam for this course.

Further information

UNSW grading system: https://student.unsw.edu.au/grades

UNSW assessment policy: https://student.unsw.edu.au/assessment

6. Academic integrity, referencing and plagiarism

Referencing is a way of acknowledging the sources of information that you use to research your assignments. You need to provide a reference whenever you draw on someone else's words, ideas or research. Not referencing other people's work can constitute plagiarism.

Further information about referencing styles can be located at https://student.unsw.edu.au/referencing

Academic integrity is fundamental to success at university. Academic integrity can be defined as a commitment to six fundamental values in academic pursuits**:** honesty, trust, fairness, respect, responsibility and courage.[1] At UNSW, this means that your work must be your own, and others' ideas should be appropriately acknowledged. If you don't follow these rules, plagiarism may be detected in your work.

Further information about academic integrity and **plagiarism** can be located at:

- The *Current Students* site https://student.unsw.edu.au/plagiarism**,** and
- The *ELISE* training site http://subjectguides.library.unsw.edu.au/elise/presenting

The *Conduct and Integrity Unit* provides further resources to assist you to understand your conduct obligations as a student: https://student.unsw.edu.au/conduct.

For information about Additional Assessments and other Administrative matters relating to your course please consult the School of Mathematics and Statistics web page at http://www.maths.unsw.edu.au/currentstudents/assessment-policies

[1] International Center for Academic Integrity, 'The Fundamental Values of Academic Integrity', T. Fishman (ed), Clemson University, 2013.

7. Resources

Recommended textbooks

No textbook is required for this course. If a textbook is desired, students are referred to:

- Inverse Modeling of the Ocean and Atmosphere, Andrew Bennett, CUP (2002)
- Discrete Inverse and State Estimation Problems, Carl Wunsch, CUP (2006)

Coding resources

Although not a prerequisite for this course, students are encouraged to familiarize themselves with Python before term begins. Code Academy (https://www.codecademy.com) provides free online tutorials in Python and other programming languages and is an excellent resource for beginners. The labs will run in the Google Colab environment, a free web-based Python notebook server. As such, students do not need to install Python or any other specialist software on their own computers.

Additional support for students

- The Current Students Gateway: https://student.unsw.edu.au/
- Academic Skills and Support: https://student.unsw.edu.au/academic-skills
- Student Wellbeing, Health and Safety: https://student.unsw.edu.au/wellbeing
- Disability Support Services: https://student.unsw.edu.au/disability-services
- UNSW IT Service Centre: https://www.it.unsw.edu.au/students/index.html