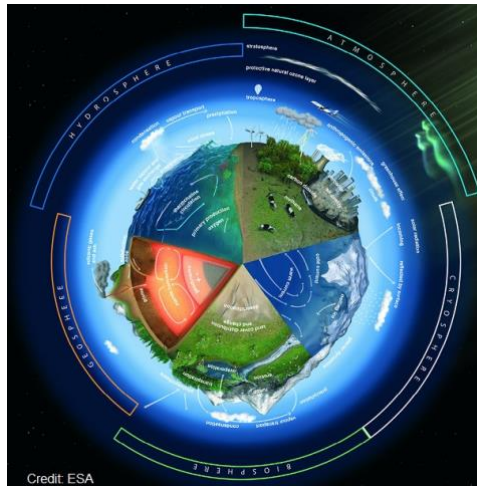


ASEN 6055 Data Assimilation and Inverse Methods for Earth and Geospace Observations

Lecture: M/W 10:40-11:55am, AERO N250
 Office Hours: W 11am-12pm, AERO 467
 Webpage: Canvas (<https://canvas.colorado.edu>)
 Instructor: Prof. Tomoko Matsuo
 E-mail: tomoko.matsuo@colorado.edu



Course Description

Data assimilation and inverse methods play a key role in integrating remote-sensing and in-situ Earth and Geospace observations into a model of the Earth and Geospace system or subsystems, enabling weather prediction and climate projection of high societal relevance. This course covers selected topics in probability theory, spatial statistics, estimation theory, numeric optimization, and geophysical nonlinear dynamics that form the foundation of commonly used data assimilation and inverse methods in the Earth and Space Sciences. The course materials are organized into three sections: (1) Statistical Principles and Background, (2) Building Blocks for Spatial Problems, and (3) Building Blocks for Spatial-Temporal Problems. Hands-on computational homework and projects provide opportunities to apply classroom curricula to realistic examples in the context of data assimilation.

Class Learning Goals

The goal of this course is to provide the fundamental statistical background and context of commonly used data assimilation and inverse methods in the Earth and Space Sciences, and to equip students with the knowledge and skills to construct a data assimilation system on their own. Students will: (1) attain a deeper understanding of the underlying statistical principles of data assimilation and inverse methods; (2) actively apply their own understanding of the fundamentals and tradeoffs of different approaches in critiquing current data assimilation research; and (3) develop the skills, confidence and creativity to design and build a data assimilation system of their own.

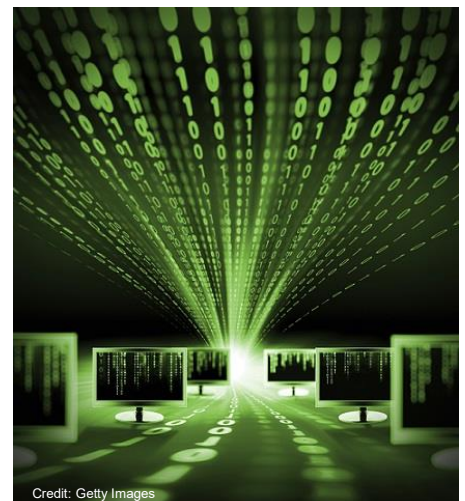
Prerequisites

Some basic understanding of random vectors and matrices, estimation theory, numerical optimization techniques (e.g., ASEN 5044 Statistical Estimation for Dynamical Systems), as well as programming experience with Matlab, Python, C/C++, and/or Fortran are desired.

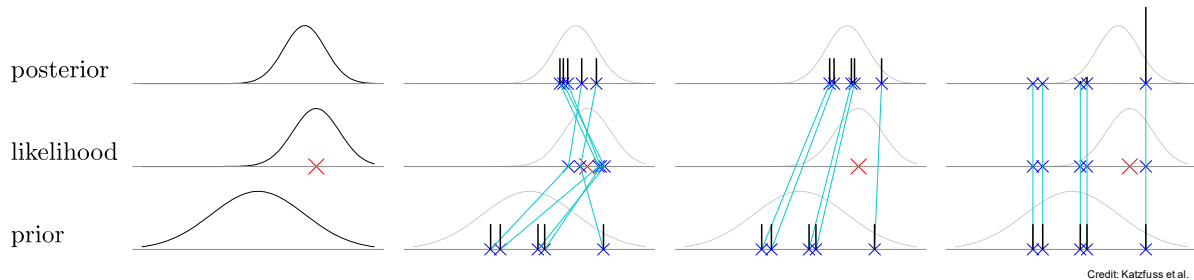
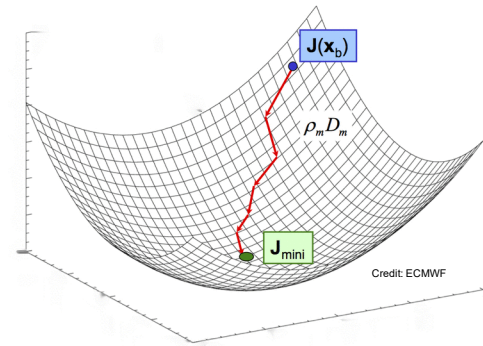
Course Content

The class is broken into a number of sections, as follows:

- **Course introduction and Big picture (Week 1)**
- **Section 1: Statistical principles and background (Week 1-4)**
 - **Reviews**
 - **Random vectors and matrices**
 - **Multivariate normal distribution**
 - **Bayesian statistics**



- Overview of estimators
 - Maximum-likelihood and Bayesian estimators
 - Kalman filters
 - Variational (least-square) estimators
- Optimization problems in data assimilation
 - Quadratic problems
 - Direct and iterative solution methods
- Section 2: Building blocks for spatial problems (Week 4-7)
 - Optimal Interpolation method
 - Stationary and non-stationary covariance models
 - Covariance calibration using Maximum-likelihood
 - 3D Variational method
 - Tangent linear (Jacobian) and adjoint models of nonlinear observation (forward) model
 - Minimization methods for nearly quadratic cost functions
- Section 3: Building blocks for spatial-temporal problems (Week 7-12)
 - Geophysical nonlinear dynamics
 - Low-dimensional Lorenz dynamical models
 - High-dimensional Earth and geospace system models
 - Sequential methods
 - Ensemble square-root filters
 - Covariance inflation and localization
 - 4D Variational methods
 - Tangent linear and adjoint models of nonlinear dynamical forecast model
 - Hybrid methods
 - Verification and validation methods
 - Cross validation
 - Bootstrapping
- Some current research topics and challenges ahead of us (Week 13-15)
- Student final project presentations (Week 15)



Textbooks

All the reading material required for the course will be provided through the Canvas course webpage. Suggested (not required) text books on the topics covered in this course include:

- Statistical methods in the atmospheric sciences, Daniel Wilks (2011) - *eBook at CU library*
- Inverse methods for atmospheric sounding: Theory and Practice, Clive D. Rodgers (2000) - *eBook at CU library*

- Atmospheric modeling, data assimilation and predictability, Eugenia Kalnay (2003) - *CU library*
- Atmospheric data analysis, Roger Daley (1993, 1991) - *CU library*
- Data assimilation: the ensemble Kalman filter, Geir Evensen, (2007, 2009) - *eBook at CU library*
- Inverse problem theory and methods for model parameter estimation, Albert Tarantola (2004) - *eBook at CU library*

Community Data Assimilation Software

Some well-documented community data assimilation software widely used by researchers in the Earth and Space Sciences can be found at:

- NCAR Data Assimilation Research Testbed, <https://dart.ucar.edu/>
- JCSDA JEDI, <https://jointcenterforsatellitedataassimilation-jedi-docs.readthedocs-hosted.com/>
- AWI Parallel Data Assimilation Framework <http://pdaf.awi.de>

Class Format

The course involves weekly lectures and group discussion on the course content outlined above. Distance learning and remote students are asked to participate in discussion via Piazza, and/or Canvas. Homework assignments provide opportunities to apply the statistical principles to realistic examples. Brief feedback about your learning experience and self-assessment will be requested weekly, and any concerns and questions will be discussed in the following class. A midterm take-home exam and project will be given to assess students' understanding on the fundamentals and to apply their knowledge to solve an assigned problem. A final individual project will be required. Final oral and written reports of each student's project will be evaluated in terms of the soundness of the problem formulation, the quality and effort of research and analysis, and the quality and clarity of oral and written presentations. Students will be asked to post a video recording of their presentation on Canvas and participate in peer reviews of the oral presentations as part of the final project evaluation.

Course Grading

5%	Participation (e.g., student's goal statement, weekly feedback and self-assessment)
30%	Homework (3 assignments)
15%	Midterm take-home exam
15%	Midterm project
35%	Final project (5% project outline, 10% oral presentations and 20% written report)
100%	Total

Late work is **not** accepted unless prior arrangements have been made with the instructor at least two weeks before.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the [Honor Code](#). Violations of the Honor Code may include but are not limited to: plagiarism (including use of paper writing services or technology [such as essay bots]), cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. Understanding the course's syllabus is a vital part of adhering to the Honor Code. All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: StudentConduct@colorado.edu. Students found responsible for violating the Honor Code will be assigned resolution outcomes from Student Conduct & Conflict Resolution and will be subject to academic sanctions from the faculty member. Visit [Honor Code](#) for more information on the academic integrity policy.

Accommodation for Disabilities, Temporary Medical Conditions, and Medical Isolation

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the [Disability Services website](#). Contact Disability Services at 303-492-8671 or DSinfo@colorado.edu for further assistance. If you have a temporary medical condition, see [Temporary Medical Conditions](#) on the Disability Services website. If you have a temporary illness, injury or required medical isolation for which you require adjustment, contact the instructor by email as soon as possible. You do not need to state the nature of your illness or provide a doctor's note, but you are required to provide cation in advance. There is no need to notify your absence from lectures.

Accommodation for Religious Obligations

Campus policy requires faculty to provide reasonable accommodations for students who, because of religious obligations, have conflicts with scheduled exams, assignments, or required attendance. Please communicate the need for a religious accommodation in a timely manner. In this class, *please make* prior arrangements, at least two weeks in advance of assignment due dates, with the instructor. See the [campus policy regarding religious observances](#) for full details.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information does not always align with how they identify. If you wish to have your preferred name (rather than your legal name) and/or your preferred pronouns appear on your instructors' class rosters and in Canvas, visit the [Registrar's website](#) for instructions on how to change your personal information in university systems.

Classroom Behavior

Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, marital status, political affiliation, or political philosophy.

Additional classroom behavior information

- [Student Classroom and Course-Related Behavior Policy](#).
- [Student Code of Conduct](#).
- [Office of Institutional Equity and Compliance](#).
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Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits [protected-class](#) discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner abuse (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who have been subjected to misconduct can contact OIEC at 303-492-2127 or email OIEC@colorado.edu. Information about university policies, [reporting options](#), and [OIEC support resources](#) including confidential services can be found on the [OIEC website](#). Please know that faculty and graduate instructors are required to inform OIEC when they are made aware of incidents related to these concerns regardless of when or where something occurred. This is to ensure the person impacted receives outreach from OIEC about resolution options and support resources. To learn more about reporting and support a variety of concerns, visit the [Don't Ignore It page](#).

Mental Health and Wellness

The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact [Counseling and Psychiatric Services \(CAPS\)](#), located in C4C, or call (303) 492-2277, 24/7.

Plagiarism

This course includes a research project and final written report. In constructing the research paper, it is expected that ideas and concepts will come from specific reference material. It must be demonstrated that this material supports the original premise of your research project and is properly referenced. Please examine the following guidelines to avoid committing plagiarism:

[How to avoid Plagiarism](#), Northwestern University

[Plagiarism: What it is and how to recognize and avoid it](#), Indiana University