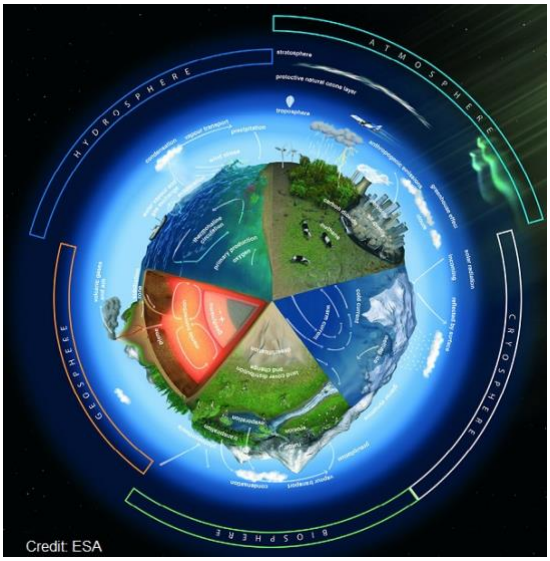
ASEN 6055 Data Assimilation and Inverse Methods for Earth and Geospace Observations

Lecture: T/TH 10:05-11:20am, SEEC N125
Office Hours: TBD
Zoom meeting ID: 915 1676 5637
Webpage: Canvas (https://canvas.colorado.edu)
Instructor: Prof. Tomoko Matsuo
E-mail: tomoko.matsuo@colorado.edu

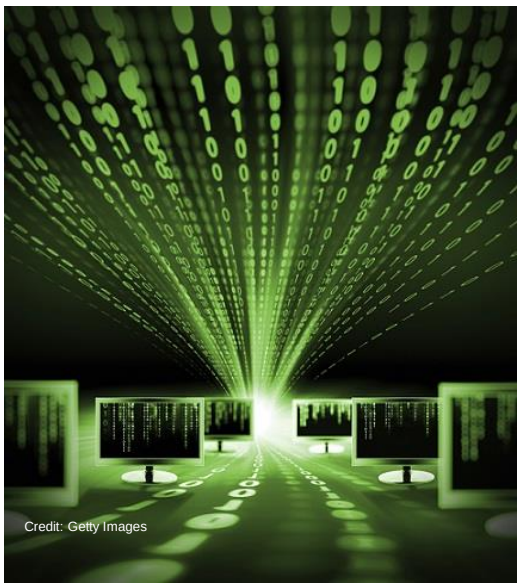


Course Description

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

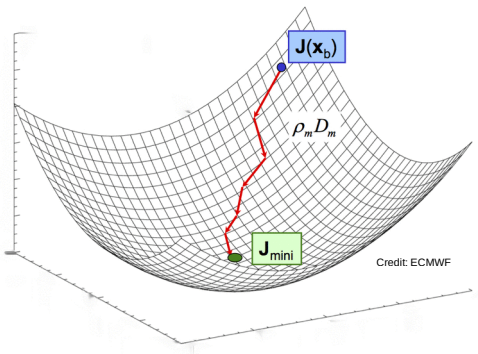
Some basic understanding of random vectors and matrices, estimation theory, numerical optimization techniques (e.g., ASEN 5044 Statistical Estimation for Dynamical Systems), as well as programming experience with Matlab, Python, C and/or Fortran are desired.

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**

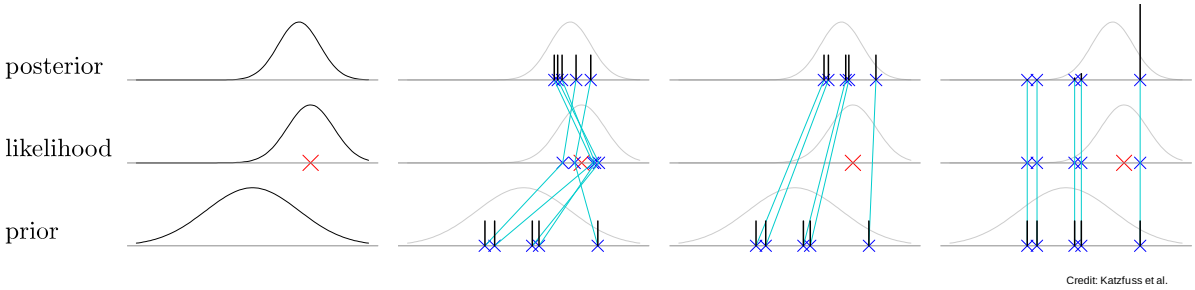


- **Section 2: Building blocks for spatial problems (Week 4-7)**
  - **Optimal Interpolation method**
    - **Stationary and non-stationary covariance models**
    - **Covariance calibration using Maximum-likelihood**
  - **3D Variational method**
    - **Tangent linear (Jacobian) and adjoint models 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)**



Texts

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) - *on reserve in CU library*
- Atmospheric data analysis, Roger Daley (1991) - *on reserve in 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/
- DTC GSI, http://www.dtcenter.org/com-GSI/users/
- Parallel Data Assimilation Framework http://pdaf.awi.de

Class Format

The course will involve weekly lectures and group discussion on the course content outlined above. Distance learning and remote students are asked to participate in discussion via Zoom, Piazza, and/or e-mails. Homework assignments will provide opportunities to apply the statistical principles to realistic examples. Brief feedback about your learning experience and self-assessment will be requested weekly, and will be discussed in the following class. A midterm take-home exam will be given to assess students' understanding on the fundamentals and to apply their knowledge to solve an assigned problem as a small group. 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 are asked to post a video of their presentation on Canvas and to participate in peer reviews of the oral presentations as part of the final project evaluation.

Course Grading

10% Participation (e.g., student's goal statement, weekly feedback, peer-reviews, Piazza discussion)
30% Homework (3-4 assignments)
25% Midterm take-home exam (10% written exam and 15% group project)
35% Final project (15% oral presentations and 20% written report)
100% Total

Late work is **not** accepted. There will be one 'makeup' homework opportunity at the end of semester before final project presentations.

Course Delivery Plan

This course is a three-credit course that includes lectures delivered in a hybrid of **Remote** and **In-Person** mode. All lectures will be recorded and posted on the course Canvas website later. Definitions of difference teaching modes are as follows.

- **In-Person** (Synchronous): activity in person on campus on scheduled days and times.
- **Remote** (Synchronous): activity via Zoom on scheduled days and times; students will need to participate in activity or complete assignment at a specified time.

- **Online** (Asynchronous): activity via lecture capture or other online learning tools available through Canvas course webpage; students can participate when it is convenient for them within a specified time window.

If an **In-Person** mode turns out to be impractical for various reasons including health and safety concerns, the instructor reserves the right to switch ASEN 6055-001 into a **Remote** delivery mode. ASEN 6055-001B is a distance learning section that will be delivered in an **Online** mode as usual. In addition to the scheduled lectures, additional office hours will be offered in a **Remote** mode per guidelines.

Classroom Behavior

Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote or online. Those who fail 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, political affiliation or political philosophy. For more information, see the policies on classroom behavior and the Student Code of Conduct.

Requirements for COVID-19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements, and public health orders in place to reduce the risk of spreading infectious disease. Required safety measures at CU Boulder relevant to the classroom setting include:

- maintain 6-foot distancing when possible,
- wear a face covering in public indoor spaces and outdoors while on campus consistent with state and county health orders,
- clean local work area,
- practice hand hygiene,
- follow public health orders, and
- if sick and you live off campus, do not come onto campus (unless instructed by a CU Healthcare professional), or if you live on-campus, please alert CU Boulder Medical Services.

Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct and Conflict Resolution. For more information, see the policies on COVID-19 Health and Safety and classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please see the "Accommodation for Disabilities" statement on this syllabus. Before returning to campus, all students must complete the COVID-19 Student Health and Expectations Course. Before coming on to campus each day, all students are required to complete a Daily Health Form. Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home and complete the Health Questionnaire and Illness Reporting Form remotely.

Accommodation for Disabilities

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.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

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 policy may include: plagiarism, 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. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu; 303-492-5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

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

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website. Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

Religious Holidays

Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly deal with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, all dates for exams, assignments and presentations are listed in the course schedule. Please review the course schedule and let me know if certain dates conflict with your religious obligations. See the campus policy regarding religious observances for full details.