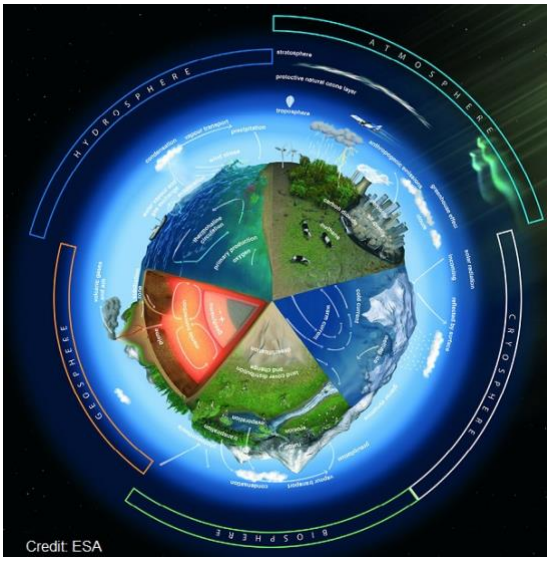
ASEN 6519 Data Assimilation and Inverse Methods for Earth and Geospace Observations

Lecture: T/TH 12:30-1:45pm, ECCR 150
Zoom meeting ID: 682-295-278
Office Hour: T/TH 1:45-2:45pm or by appointment
Webpage: Canvas (https://canvas.colorado.edu)
Instructor: Prof. Tomoko Matsuo
Office: ECOT 614
E-mail: tomoko.matsuo@colorado.edu
(Note that the Canvas Conversations communication tool is not used)

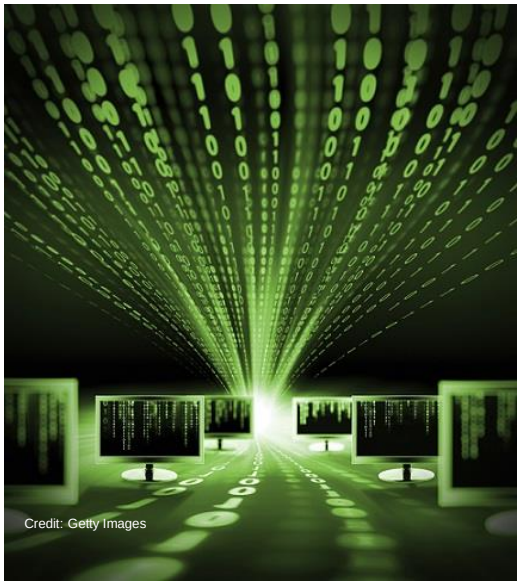


Course Description

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

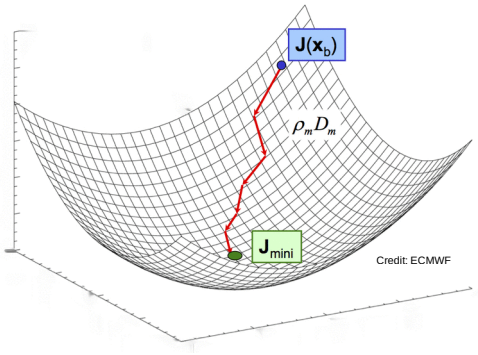
Some basic understanding of random vectors and matrices, estimation theory, numerical optimization techniques (e.g., ASEN 5044 Statistical Estimation for Dynamical Systems), as well as programming experience with Matlab, Python, C and/or Fortran are desired.

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**

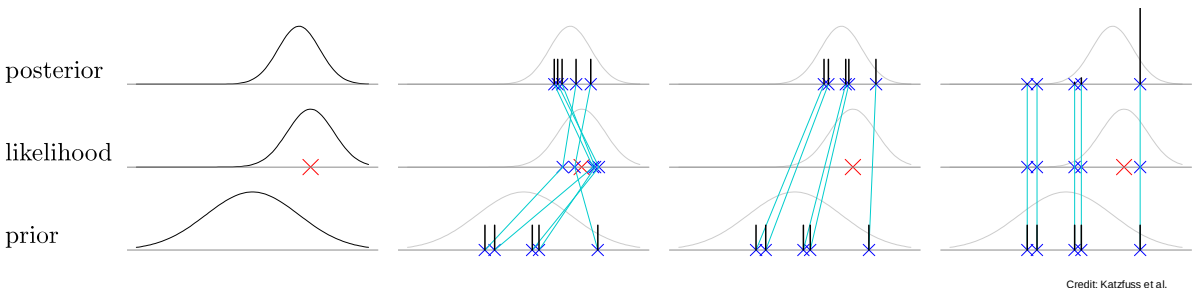


- **Section 2: Building blocks for spatial problems (Week 4-7)**
  - **Optimal Interpolation method**
    - **Stationary and non-stationary covariance models**
    - **Covariance calibration using Maximum-likelihood**
  - **3D Variational method**
    - **Tangent linear (Jacobian) and adjoint models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

You can access these books as eBook from the CU library website or in the CU Gemmill Library of Engineering, Math and Physics.

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 DART, http://www.image.ucar.edu/DAReS/DART/
- DTC GSI, http://www.dtcenter.org/com-GSI/users/
- DTC EnKF, http://www.dtcenter.org/EnKF/users/index.php

Class Format

The course will involve weekly lectures and group discussion on the course content outlined above. Distance learning students are asked to participate in discussion via Canvas discussions, Zoom chat, 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 also asked to participate in peer reviews of the oral presentations as part of the final project evaluation. Distance learning students are asked to send a video of their presentation to be viewed in class.

Course Grading

10% Participation (e.g., student's goal statement, weekly feedback and self-assessment, peer-reviews)
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.

Zoom Meeting Connection Information for Distance Students

- Join via web browser: https://cuboulder.zoom.us/j/682295278
- Join via Zoom app (using meeting ID: 682-295-278)
- Join via iPhone one-tap: US: +16699006833,,682295278# or +16465588656,,682295278#
- Join via telephone: US: +1-669-900-6833 or +1-646-558-8656

This course requires the use of the Zoom conferencing tool, which is currently not accessible to users using assistive technology. **If you use assistive technology to access the course material, please contact me immediately to discuss.** For more information on Zoom, please visit http://www.colorado.edu/oit/services/conferencing-services/web-conferencing-zoom

Disabilities

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to me 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 or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

Classroom Behavior

Students and faculty each have responsibility for maintaining an appropriate learning environment. 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. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the Student Code of Conduct.

Academic 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 who are 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. Violations of the Honor Code include any act of **academic dishonesty** which is defined as follows. Any act in which a student gains, or attempts to gain, an unfair academic advantage over other students. These acts may include, but are not limited to:

I. **Plagiarism:** Portrayal of another's work or ideas as one's own.
II. **Cheating:** Using prohibited notes or study aids, allowing another party to do one's work/exam and turning in that work/exam as one's own, copying another student's course work, and collaborating on course work when prohibited.
III. **Fabrication:** Falsification or creation of data, research, or resources, altering a graded work without the prior consent of the course instructor.
IV. **Lying:** Deliberate falsification with the intent to deceive in written or verbal form as applied to an academic submission.
V. **Bribery:** Providing, offering, or taking rewards in exchange for a grade, or, an assignment, or in the aid of Academic Dishonesty.
VI. **Threat:** An attempt to intimidate a student, staff, or faculty member for the purpose of receiving an unearned grade or in an effort to prevent the reporting of an Honor Code violation, or in connection with any other form of Academic Dishonesty.

VII. **Unauthorized Access:** Gaining unauthorized access to protected academic information including, but not limited to: CU-SIS; a faculty member's computer, files, and/or office; or secure information on an online server.

VIII. **Clicker Fraud:** Using, or having someone else use, clicker technology fraudulently in an effort to receive academic credit.

IX. **Resubmission:** Submitting the same or similar work for credit more than once without permission from all course instructors involved.

X. **Aiding Academic Dishonesty:** Intentionally facilitating any act which may help a student to gain an unfair academic advantage including, but not limited to, any of the aforementioned acts.

Any act of academic dishonesty will result in an F for this course and will become a permanent part of the student's academic record.

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

Misconduct, Discrimination, Harassment and/or Related Retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (including sexual assault, exploitation, harassment, dating or domestic violence, and stalking), discrimination, and 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, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

Other Policies

Please be respectful of others during class time. This includes turning off your cell phone before class and not talking during class unless you have the floor. Details about all of the university policies can be found on the web at http://www.colorado.edu/policies/index.htm

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.