Data Assimilation

ATS 651, Department of Atmospheric Science
11:00 – 12:15 Tuesday and Thursday, 212B ACRC
2025 Spring Term

Instructor Contact Information

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Course Description

This is an introductory graduate level course on fundamentals and applications of data assimilation in the geosciences. The unifying framework of Bayes Theorem is introduced, and the different state-of-the-art data-assimilation methods are derived, and practical issues related to e.g. numerical weather prediction are discussed. We also discuss how machine learning fits into the data-assimilation framework and discuss ways to include machine learning techniques into data assimilation methods and the other way around. Furthermore, we will discuss digital twins. The main teaching method is lectures, with coding assignments and assignments employing the data-assimilation framework JEDI. JEDI is the data-assimilation framework used by NOAA, NASA, and the US NAVY and Airforce. Assignments are designed for students to increase the level of understanding, mainly via basic programming and analyzing results from simplified data-assimilation problems.

Course Goals

Students who complete this course successfully will be able to:

- Describe and explain theoretical principles of data assimilation, focusing on atmospheric and oceanographic applications.
- Reproduce the pro's and con's of the different data-assimilation methods that are presently used in numerical weather and ocean prediction, and understand the present focus of data-assimilation research.
- Apply data-assimilation techniques to real-world problems, including using the JEDI system, and critically evaluate the literature in this subject.

Course materials

Detailed lecture notes will be available on Canvas in due course. The instructor does not use a specific textbook, but closest are informal lecture notes and the new **open access** book:

Evensen, G., F.M. Vossepoel, and P.J. van Leeuwen (2022) Data Assimilation Fundamentals, Springer, **open access**, doi: 10.1007/978-3-030-96709-3

The following recent textbooks provide partly overlapping and further reading material that relate to the course:

Asch, M., Bocquet, M., & Nodet, M. (2016). *Data assimilation: Methods, algorithms, and applications, fundamentals of algorithms.* Philadelphia, SIAM.

Fletcher, S. J. (2017). *Data assimilation for the geosciences: From theory to application*. Amsterdam, Elsevier.

Reich S, Cotter C. 2015. *Probabilistic forecasting and bayesian data assimilation.* Cambridge University Press.

Van Leeuwen P.J., Cheng Y., Reich S. 2015. *Nonlinear data assimilation*. Springer, doi:10,1007/978-3-319-18347-3.

Evensen, G. (2009) *Data Assimilation: The Ensemble Kalman Filter* (2nd ed.) Springer. doi:10.1007/978-3-642-03711-5.

Mathematically oriented students might enjoy

K. Law, A. Stuart, and K. Zygalakis, 2015, *Data Assimilation, A Mathematical Introduction*, Springer, Cham, doi:10.1007/978-3-319-20325-6

Class Participation

Students are expected to attend all classes. Students' participation and engagement are strongly encouraged. All interactions and discussions in the classroom are aimed to provide a supportive and active learning environment for students.

Grading

Grading will be based on assignments, often based on using the JEDI system. Homework will be due at the date and times indicated. No late homework assignments will be accepted without prior approval. Audits are strongly encouraged to do all assignments.

Statement on Academic Integrity

This course will adhere to the CSU Academic Integrity Policy as found in the General Catalog (http://www.catalog.colostate.edu/FrontPDF/1.6POLICIES1112f.pdf) and the Student Conduct Code (http://www.conflictresolution.colostate.edu/conduct-code). At a minimum, violations will result in a grading penalty in this course and a report to the Office of Conflict Resolution and Student Conduct Services.

Disclaimer

The instructor reserves the right to make modifications to this information throughout the semester.

Preliminary Schedule of Topics, Readings (refer to open access book) , and Assignments

Lecture	**Topics**	**Deadlines**
1	• Logistics • **Session 1: Introduction to Data Assimilation –** why we should care about data assimilation; its relevance to predicting weather in atmosphere and ocean, and climate, and for model improvement	
2	• **Session 2: The basics: Bayes Theorem** – what is Bayes Theorem, where does it come from, and why is it important (Chapter 2)	
3	Session 2 (continued)	
4	• **Session 3: Linear DA: the Kalman filter –** an exploration of the Kalman Filter (Chapter 6 and 12)	Assignment #1 due
5	Section 3 (continued)	
6	• **Session 4: Ensemble Kalman Filters –** What they are, and why they are so useful, and their limitations (Parts of chapters 7,8,10, and 13,14)	
7	Session 4 (continued)	
8	• **Session 5: Ensemble Kalman Smoothers –** What they are, and why they are so useful, and their limitations (Parts of chapters 7, 8, 10, and 15)	
9	Session 5 (continued)	Assignment #2 due
10	**Session 6: Iterative Ensemble Kalman Filters and Smoothers –** What they are, and why they are so useful, and their limitations (Parts of chapters 7, 8, 10, and 21, 22)	
11	Session 5 (continued)	
12	• **Session 6: Variational Data Assimilation** – derivation from Bayes Theorem, exploring its features, adjoint coding (Chapter 3, 4, 5, and 16, 17)	
13	Session 6 (continued)	
14	Session 6 (continued)	
15	**Session 7: Hybrid Methods** (Chapter 7,8 and 10)	

Lecture	Topics	Deadlines
16	**Session 8: Nonlinear Data Assimilation–** random numbers and sampling, Markov-Chain Monte-Carlo Methods (e.g. Gibbs Sampler and Metropolis-Hastings) (Chapter 9 and 10)	Assignment #3 due
17	Session 8 (continued)	
18	Section 8 (continued)	
19	**Session 9: Particle Filters** (Chapter 9, 10, and 19)	
20	Session 9 (continued)	Assignment #4 due
21	Session 9 (continued)	
22	**Session 10: Particle Flows** (Chapter 9, 10, and 20)	
23	Session 10 (continued)	
24	**Session 11: Hybrid Methods Revisited** (Chapter 7,8 and 10)	Assignment #5 due
25	**Session 12: Machine learning**	
26	Session 12 (continued)	
27	**Operational weather forecasting**	
28	**Session 13: Putting it all together, and digital twins** (Chapter 11 and 18)	Assignment #6 due