Course Details:

Course Rationale:	Across the broad spectrum of Civil and Environmental Engineering, one commonality is the desire to estimate variables that obey the laws of physics and chemistry. Traditionally, these variables are estimated either from observations or via models. The emerging field of "data assimilation" is a general technique whereby observations and physical models are optimally merged based on weighing uncertainties between both in order to derive the most utility from two disparate data streams. Application-based homework assignments are aimed at providing the student with a hands-on learning experience in order to better understand the underlying theory.
Course Description:	Introduction to basic concepts of classical and Bayesian estimation theory, marginal and conditional probabilities, random vectors, deterministic and open-loop modeling, variational methods, sequential methods, and ensemble methods.
Prerequisites:	Numerical methods using Matlab©; probability and statistics; multivariate calculus;
Course Schedule:	Tuesday and Thursday 4:00-5:15 PM CHE 2110 (Chemical Engineering Building)
Instructor:	Professor Barton Forman 1159 Glenn L. Martin Hall Office Hours: Monday and Wednesday 10:30-11:30 AM (or by appt.) Email: `baforman@umd.edu` Canvas: `https://umd.instructure.com/`
Recommended Reference:	Evensen, *Data Assimilation: The Ensemble Kalman Filter* (available on-line through UMD library system)
Additional References:	Gelb, *Applied Optimal Estimation* Kalnay, *Atmospheric Modeling, Data Assimilation, and Predictability* Wilks, *Statistical Methods in the Atmospheric Sciences*
Grading Basis:	Homework: 65% (undergraduate students) / 50% (graduate students) Reading Assignment: 15% (graduate students only) Final Project: 35% (undergraduate and graduate students) **Homework is due by the start of lecture.**[1]

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[1] unless due to extenuating circumstances

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Honor Pledge:	The university has a nationally recognized Honor Pledge, administered by the Student Honor Council. The Student Honor Council proposed and the university Senate approved an Honor Pledge. The University of Maryland Honor Pledge reads: *"I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination."* This pledge was designed to promote academic integrity by the student body and emphasize the importance of the university academic policies. Additional course-related policies established by the University can be found at `http://www.ugst.umd.edu/courserelatedpolicies.html`.
Class Logistics:	The tentative class schedule, including topics to be covered, is listed below. The course is organized into three parts: 1) lecture-based survey of the basics of probabilistic data assimilation. 2) literature-based survey of the state-of-the-art data assimilation, and 3) a hands-on project to acquire experience with modeling and data assimilation techniques. The background lectures will be the focus of the first part of the course. The remaining class periods will consist of: 1) brief, student-led presentations of application papers from literature, and 2) final project presentations by students at the end of the semester.

Tentative Course Schedule (subject to change):

#	Lecture Date	Topics Covered
1	Tuesday, September 1	Course motivation, basics of a data assimilation framework
2	Thursday, September 3	Basic axioms of probability, independence, univariate probability distributions
3	Tuesday, September 8	Random vectors, joint probability density functions, marginal and conditional densities, expectation
4	Thursday, September 10	Conditional expectation, correlation matrix, covariance matrix, cross-covariance matrix, derived distributions
5	Tuesday, September 15	Gaussian random vectors, Monte Carlo methods, estimation theory
6	Thursday, September 17	Classical versus Bayesian estimation, weighted least squares estimation
7	Tuesday, September 22	Minimum variance linear estimation, Best linear unbiased estimation

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#	Lecture Date	Topics Covered
8	Thursday, September 24	Maximum likelihood estimation
9	Tuesday, September 29	Accuracy analysis
10	Thursday, October 1	Bayesian estimation, prior and posterior estimates, maximum *a posteriori* estimate
11	Tuesday, October 6	Time-dependent models, deterministic and open-loop simulation, temporal aspects of data assimilation (smoothing versus filtering), sequential estimation
12	Thursday, October 8	Kalman filtering (Part 1)
13	Tuesday, October 13	Kalman filtering (Part 2)
14	Thursday, October 15	Controllability and reliability
15	Tuesday, October 20	Observability, Kalman filtering examples in Matlab©
16	Thursday, October 22	Adaptive Kalman filtering
17	Tuesday, October 27	Extended Kalman filtering
18	Thursday, October 29	Ensemble methods, ensemble Kalman filter (Part 1)
19	Tuesday, November 3	Ensemble Kalman filtering (Part 2)
20	Thursday, November 5	Ensemble filtering examples, batch estimation, Kalman smoother (Part 1)
21	Tuesday, November 10	Student-led paper presentations and discussion
22	Thursday, November 12	Kalman smoother (Part 2)
23	Tuesday, November 17	Student-led paper presentations and discussion
24	Thursday, November 19	Ensemble Kalman smoother
25	Tuesday, November 24	Variational assimilation (Part 1)
-	Thursday, November 26	No Lecture (Thanksgiving)
26	Tuesday, December 1	Variational assimilation (Part 2)
27	Thursday, December 3	Student-led project presentations and discussion
28	Tuesday, December 8	Student-led project presentations and discussion
29	Thursday, December 10	Student-led project presentations and discussion

Homework:

Eight (8) homework problem sets will be assigned as shown below. These assignments are designed to reinforce your basic understanding of the theory covered in the lectures so that you can apply them to your data assimilation project. Due to limited lecture time, some concepts and applications may be introduced in the homework assignments. It is your responsibility to know the material covered not only in lectures, but in all assignments. Several of these assignments will contain problems involving numerical computing using Matlab© . Matlab© access is provided through the Virtual Computing Lab (`http://www.eit.umd.edu/vcl`) and is available for remote use. Additionally, Matlab© is found on the

workstations housed in the CEE Design Laboratory located in 1156 Martin Hall.

Assignments:

#	Subject Matter	Assigned Date	Due Date
1	Dynamic modeling (Introduction to Matlab©), probability, expectation, univariate distributions	September 10	September 17
2	Random variables, joints PDFs, Linear Algebra review, Gaussian random vectors	September 17	September 24
3	Monte Carlo methods	September 24	October 1
4	Weighted Least Squares (WLS), Best Linear Unbiased Estimate (BLUE), Maximum Likelihood Estimate (MLE), Bayesian estimation with a static model	October 1	October 8
5	Bayesian estimation with a dynamic model	October 8	October 15
6	Kalman filtering	October 15	October 29
7	Extended Kalman filtering, ensemble Kalman filtering	October 29	November 5
8	Error modeling, ensemble-based parameter estimation, ensemble Kalman filtering	November 5	November 19

Data Assimilation Project:

One of the primary components of this class is a data assimilation project. For this you will choose a dynamic model and then propose a synthetic experiment with measurements of the system using one or more of the assimilation techniques discussed in class. In a synthetic experiment, the model is used to generate "true" states and observations, which are then corrupted with measurement noise. Unlike actual applications where the truth is never known, synthetic experiments can be used to test the feasibility of the method. They also provide a good test-bed for learning the methods. The goal of the project is to have each of you become familiar with the methods by applying them to a specific dynamical model and data assimilation scenario of your design. Synthetic experiments that you design could include parameter estimation, comparison of multiple assimilation techniques, downscaling of observations in space and/or time, temporal sampling strategies, multi-measurement assimilation, estimating unsampled parts of the study domain, etc. **NOTE:** Your model selection and experimental design should be done in consultation with the instructor.

Project Schedule:

Item (% of the total project grade)	Due Date
Model selection and implementation: Select the model you will use for the project. Implement the model and run a deterministic simulation. Turn in a brief description (5 pages or less) of the model and preliminary results (10%).	November 3
Project proposal: Turn in a brief description (5 pages or less) of the proposed set of experiments you will do for your project, including a clear description of the synthetic observations that will be assimilated, what hypotheses you will examine, and what statistical analyses you will conduct (10%).	November 17
In-class project presentation: Present the model background and data assimilation framework used in your experiments. Discuss the major findings of your study, including what worked and what did not. Summarize the experimental results and present (briefly) ideas for future study. Limit the presentation to 15-20 minutes (40%).	December 1 or December 6 or December 8
Written project report: Summarize the material discussed in your in-class project presentation. Limit yourself to 10 pages (excluding the title page and bibliography) using standard margins, single line spacing, and 12-point font. The 10-page limit will force you to focus on the most relevant details of your study, which will require you to succinctly describe the entire project (40%).	December 12

Data Assimilation Literature Reading Assignment:

For the reading assignment you are asked to choose one (1) paper from the literature on a particular aspect/application of data assimilation. Once chosen, everyone in class will read the papers and you will be responsible for presenting the paper and leading the class discussion of it.

Reading Assignment Schedule:

Item	Due Date
Submit paper selection (List of top 3-5 choices)	October 6
Present paper and lead in-class discussion session	November 10 or November 17