THE UNIVERSITY OF ARIZONA
COLLEGE OF SCIENCE
Hydrology & Atmospheric Sciences

ATMO 545 (HWRS 545) Section 001
Spring Semester 2024

Syllabus

Department Website
www.has.arizona.edu

D2L Website
d2l.arizona.edu

Zoom Meeting IDs
889 197 9205 (Student Hours)

Instructor Website
sites.arizona.edu/afarellano

Dates and Deadlines

Last Day of Dropping:
01/23 (UG), 02/06 (G)

Project Deadlines:
Proposal Presentation
(Apr 5-8, 2024)
Project Presentation
(Apr 29-May 1, 2024)
Project Report
(May 9, 2024 5:30pm)

Assignment Deadlines:
Jan 22, 2024
Feb 2, 2024
Feb 16, 2024
Mar 15, 2024
Apr 3, 2024
May 1, 2024

Spring Recess:
Mar 04-10, 2024

Last Day of Classes:
May 01, 2024

Useful Websites
registrar.arizona.edu
deanofstudents.arizona.edu

ATMO/HWRS 545: Introduction to Data Assimilation

Class Hours	09:00 am – 09:50 am Monday, Wednesday, Friday
Class Modality	In-Person, Harshbarger Bldg, Rm 110
Instructor	Assoc. Prof. Avelino F. Arellano, Jr. (Ave) afarellano@arizona.edu Harshbarger 314C, 520-626-3015 Zoom Personal Meeting ID: 889 197 9205 Student Hours, M,F 10:30-12:00 pm or by appt.

Course Description

Data assimilation (DA) involves combining information from observations and "models" of a particular physical system in order to best define and understand the evolving state of the system. It is currently applied across a wide range of Earth sciences, including weather forecasting, oceanography, atmospheric chemistry, hydrology, and climate studies. This course provides an introduction to the theory and applications of DA in atmospheric and related sciences. Topics include common DA methods like optimal interpolation, Kalman filtering and variational schemes within the context of estimation theory. The course is designed as a hands-on approach to key DA concepts that are currently used today.

Textbook

There are no required textbooks for this course. Handouts will be distributed during class (mainly based from notes by Saroja Polavarapu, Environment Canada). See also reference section of this syllabus for recommended materials.

Course Modality

This class will be taught as **In-Person** in Harshbarger 110, MWF 9-950am.

Goals & Objectives

My intent as an instructor is to convey applied concepts of data assimilation such that students will:

a) gain an understanding of basic principles of current DA algorithms
b) think holistically of data and models in the context of associated errors
c) grasp the significance of current DA algorithms in analysis and forecasting research and operations
d) know how to use DA techniques to real world applications (your own research).

Learning Outcomes

By the end of this course, ATMO/HWRS 545 students will be able to:

a) derive and solve the following DA formulations: i. least-squares (LS), ii. optimal interpolation-OI, iii. Kalman filter (KF) and its variants (EKF, EnKF), iv. 3D/4DVar, and v. Bayesian update and inference)
b) conduct simple numerical exercises of toy model and synthetic data experiments using these formulations
c) run OI for a specific 'climatological' 2D analysis problem
d) run KF (and EnKF), 3D-4DVar for a dynamical analysis and parameter estimation problem (advection-diffusion equation)

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On top of the outcomes listed previously, ATMO 545 students will also be able to:

a) apply one of these DA algorithms to existing Earth science problem (or to their own research)
b) present related application in a clear, understandable, and efficient manner.

This class is scheduled to be taught in the in-person course modality. This is designed as an introduction to data assimilation under a mostly hands-on learning environment. The students are encouraged to engage themselves (before, during and after lectures). At the end of the course, they should be able to have a good appreciation of the key DA concepts, which you can apply as tools for your own research. Students who desire more advanced topics (e.g. mathematical/statistical concepts) not included in this course are encouraged to pursue graduate courses in the Department of Mathematics (or consult instructor).

Prerequisites for this class include: a) a strong desire to learn how to combine models and observations, b) a basic understanding of linear algebra & elementary statistics, and c) a basic skill in programming (e.g., Matlab).

Course Assessment

There is **no exam for this course**. Students will be assessed on how they are able to grasp the key concepts through assignments and one individual project. The percentage distribution of your grade will be as follows:

Assignments : 75%
Project : 25%

Letter grades are determined using the following scale:

A : ≥ 90.0 %

B : 80 to 89.9 %

C : 65.0 to 79.9 %

D : 55.0 to 64.9 %

E : below 55.0 %

Unless otherwise noted, **assignments** either follow the demo exercises in class (computer toy models/Matlab) or practice exercises (e.g. derivation, problem solving). Assignments are typically given after a major section has been discussed. A total of 5 major assignments (15% each) and 1 minor pre-proposal assignment. See Course Outline and Dates and Deadlines for details.

A large part of the grade will be through **individual student project,** which will be designed by the students themselves depending on their particular research interest or application of choice.

Projects should be more comprehensive than exercises in class. They can either include but not exclusively: a) use of data and model output (1D to 3D) with a DA algorithm of choice, b) development of new algorithms or modification of algorithms discussed in class, c) critique of a DA paper. The project should be something that can be made as a short paper/report (i.e. includes introduction, methods, theory, implementation, results, discussion, conclusion). The project will be assessed throughout the course (i.e. project proposal-10%, project presentation & report -15%).

You are required to complete these numerical exercises with specific deadlines (see schedule) on your own time to accomplish your assignments and 1 project.

I will accept late assignments with full credit as long as the solutions have not been distributed in class. However, any assignments received after the solutions are distributed will not be accepted for credit.

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Attendance

The UA's policy concerning Class Attendance, Participation, and Administrative Drops is available at: http://catalog.arizona.edu/policy/class-attendance-participation-and-administrative-drop

The UA policy regarding absences for any sincerely held religious belief, observance or practice will be accommodated where reasonable: https://policy.arizona.edu/human-resources/religious-accommodation-policy

Absences pre-approved by the UA Dean of Students (or Dean Designee) will be honored: https://deanofstudents.arizona.edu/absences

University Policies

All university policies related to a syllabus are available at: https://catalog.arizona.edu/syllabus-policies.

Safety on Campus and in the Classroom

For a list of emergency procedures for all types of incidents, please visit the website of the Critical Incident Response Team (CIRT): https://cirt.arizona.edu/case-emergency/overview

Also watch the video available at https://arizona.sabacloud.com/Saba/Web_spf/NA7P1PRD161/common/learningeventdetail/crtfy000000000003560

Student Resources

For more information regarding student resources, please see: http://basicneeds.arizona.edu/index.html

Life, Physical, & Mental-health Challenges

If you are experiencing unexpected barriers to your success in your courses, please note the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office can be reached at (520) 621-2057 or DOS-deanofstudents@email.arizona.edu.

If you are facing physical or mental health challenges this semester, please note that Campus Health provides quality medical and mental health care. For medical appointments, call (520) 621-9202. For After Hours care, call (520) 570-7898. For the Counseling & Psych Services (CAPS) 24/7 hotline, call (520) 621-3334.

Accessibility and Accommodations. At the University of Arizona, we strive to make learning experiences as accessible as possible. If you anticipate or experience barriers based on disability or pregnancy, please contact the Disability Resource Center (520-621-3268, https://drc.arizona.edu) to establish reasonable accommodations."

Academic Integrity

Note that associated with your learning experience are sets of 'rules' to diligently follow. From the University perspective, you are expected to adhere to the University's "Code of Academic Integrity" and "Student Code of Conduct". You are responsible for knowing these codes (and revisions).

Academic Advising

If you have questions about your academic progress this semester, please reach out to your academic advisor (https://advising.arizona.edu/advisors/major) Contact the Advising Resource Center (https://advising.arizona.edu/) for all general advising questions and referral assistance. Call 520-626-8667 or email to advising@.arizona.edu.

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Nondiscrimination & Anti-Harassment

The University of Arizona is committed to creating and maintaining an environment free of discrimination. In support of this commitment, the University prohibits discrimination, including harassment and retaliation, based on a protected classification, including race, color, religion, sex, national origin, age, disability, veteran status, sexual orientation, gender identity, or genetic information. For more information, please see: http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy

Student Responsibilities

As a student, you are responsible in a) actively asking and answering questions during class, b) doing your assignments (including reading materials) after class, and c) responding to d2l class announcements/surveys. As your instructor, I invite you to make use of our student hours if you have some pressing questions. From the University perspective, you are expected to devote a minimum of two (2) hours outside class (for study, reading, homework) for every contact hour (or 50 minutes) in classroom.

Equipment and Software

For this class you will need access to the following hardware: [laptop or web-enabled device; regular access to reliable internet signal; ability to download and run the following software: [Matlab/R/Python, spreadsheet, e.g., MS Excel, web browser to access D2L, PDF reader, text editor -e.g., Microsoft Word, slide presentation -e.g., Powerpoint, Zoom client, and VPN].

For lecture recordings, which are used at the discretion of the instructor, students must access content in D2L only. Students may not modify content or re-use content for any purpose other than personal educational reasons. All recordings are subject to government and university regulations. Therefore, students accessing unauthorized recordings or using them in a manner inconsistent with UArizona values and educational policies (Code of Academic Integrity and the Student Code of

Class Recordings

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Reference Materials

Daley, R. (1991), Atmospheric Data Analysis, Cambridge University Press, Cambridge.

Gelb, A. (ed.) (2001), Applied Optimal Estimation, The MIT Press.

Lewis, J.M., S. Lakshmivarahan and S.K. Dhall (2006), Dynamic Data Assimilation: A Least Squares Approach, Cambridge University Press, Cambridge.

Lahoz, W., B. Khattatov and R. Menard (Eds.) (2010), Data Assimilation: Making Sense of Observations, 1st ed., Springer, New York.

Kalnay, E. (2003), Atmospheric Modeling, Data Assimilation and Predictability, Cambridge University Press, Cambridge.

Final Note

Information contained in the course syllabus, other than the grade and absence policies, may be subject to change with advance notice as deemed appropriate by the instructor. Your comments are welcome and appreciated.

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Introduction to Data Assimilation

Course Outline

Below is our tentative schedule. We may extend/shorten the lecture/discussion of some sections (e.g. special topics) depending on the average progress of the class. Project dates on the other hand are fixed.

Course Syllabus/Introduction

Jan 10

Data Assimilation and Information

Observations & Models of the Earth System

Jan 12, 17

Concept of Least Squares

Jan 19, 22, 26, 29, 31

Introduction to Estimation Theory

Bayes Theorem

Jan 31, 2, 5

Concepts of Probabilistic Estimation

Feb 5, 7

Least Squares Estimation

Feb 9

Common Algorithms

Optimal (Statistical) Interpolation

Feb 12-Mar 1

Kalman Filter

Mar 11-29

4D-Var

Apr 1-5, Apr 12-24

Proposal Presentations

Apr 5-8

Longer View

Reanalysis, OSSEs

Apr 26

Project Presentations

Apr 29-May 1

Project Report Due

No later than May 9, 2024 530pm