School of Meteorology Course
Fall 2023
Computational Fluid Dynamics
METR 5344
Instructor: Prof. Ming Xue
1:00 pm - 2:15pm, Tuesday, Thursday, NWC 5720
Credit: 4 hours

Whom is it for? Graduate students or upper-level undergraduates (with permission) interested in numerical modeling and prediction of fluid motions, weather, air quality, climate, water/hydrology, or engineering. It will provide knowledge and skills for constructing and/or using CFD codes/numerical models for weather and environmental problems, including numerical weather prediction (NWP), climate and air quality modeling and predictions.

General Information: This course teaches the background theories and numerical methods for solving fluid dynamics equations and related problems. It is the foundation of numerical modeling/simulation of fluid (including water and air) flows, numerical weather prediction (NWP) and climate simulations.

Prerequisites: Engineering Math II or equivalent; a course in fluid mechanics/dynamics or atmospheric dynamics, and ability to program in a computer language such as Python, Matlab, C or Fortran.

Objectives and Goals: In this course, you will learn practical issues of high-performance/parallel computing, code optimization on parallel computers and vector CPUs, and learn to understand performance of a large modeling system on a parallel computer (OSCER Schooner). You will learn classification and properties of partial differential equations, including parabolic, hyperbolic, and elliptic equations. You will learn various numerical methods for solving different types of partial differential equations, including finite difference, finite volume, spectral and semi-Lagrangian methods. You will be able to perform stability analyses on numerical schemes to understanding their error characteristics, accuracy, and stability conditions. You will learn how to design and program a numerical model that can produce realistic clouds and convection. We will also do a short survey of numerical methods used in mainstream weather and climate models.

What are involved? There will be ~5 programming exercises that will help you to better understand the properties and behaviors of numerical schemes and to improve your program skills. There will be a term project where you will develop your own numerical model capable of producing realistic moist convection (such as a squall line). Three in-class exams, homework programming exercises, and the project will account for, respectively, 45%, 30% and 25% of the total grade. The 4th credit hour of this course accounts for the extra programming work required by this course.

Prerequisites: Math 3123 (Engineering Math II or equivalent); ENGR 3723 (Numerical Methods or equivalent); a course in fluid mechanics/dynamics (e.g., ENGR 3223, METR 3113 and/or 5113) or their equivalent; ability to program in Fortran and/or another programming language (e.g., C, matlab) but Fortran is strongly preferred; familiarity with the UNIX operating system.

Text: *Computational Fluid Mechanics and Heat Transfer* by R. H. Pletcher, J.C. Tannehill, D. A. Anderson, 3rd Edition, CPC Press, 753pp.

Reference Book: *Numerical Methods for Wave Equations in Geophysical Fluid Dynamics* by Dale R. Durran.

<u>Practical Issues of High-Performance Computing</u>; computer architectures; code design and optimization; parallel and vector constructs; limiting factors and constraints on simulation studies; guidelines for writing maintainable code. Background of numerical weather prediction. (1.5 week)

<u>Theory of Partial Differential Equations</u>; classification; canonical forms; linear vs nonlinear problems; characteristics; well-posed problems (1 week)

<u>Fundamentals of Finite Difference Methods</u> consistency; stability; convergence and order of accuracy; methods for obtaining discretizations (2 weeks)

<u>Classical Problems and Methods</u> implicit and explicit methods for parabolic, hyperbolic, and elliptic problems; directional splitting; dissipation and dispersion errors; practical measures of convergence and accuracy. (5 weeks)

<u>Basic Hydrodynamics</u> Burgers equation and nonlinear steepening; filtering; the shallow water equations; grid staggering, nonlinear instability, conservation constraints. (2 weeks)

<u>Boundary Conditions</u> (BC) for Hyperbolic Problems/Systems - Options of BC, wave-permeable radiation conditions, well-posedness of BC; PE and vorticity/streamfunction formulations. (2 weeks)

Semi-Lagrangian and Spectral/Pseudo Spectral Methods philosophy and formulation; application to 1-D problems; FFT and spectrum transform method. (3 weeks)

Survey of Numerical Methods used in Mainstream Mesoscale Models/New techniques used in NWP Models (time permitting)

Course Grading:	3 In-class Exams	45%
	Homework Computer Problems	30%
	Term Project	25%

Students will be required to write computer programs using high-level languages such as Fortran, C, python, Matlab, including running parallel programs that will use multiple processors. Students will have access to OSCER supercomputer Schooner (see www.oscer.ou.edu).

If you have any question, please contact me at *mxue@ou.edu*.

Any student in this course who has a disability that may prevent him or her from fully demonstrating their potential should contact the School of Meteorology (325-6561) immediately to arrange for appropriate accommodations that will ensure your full participation and facilitate your educational opportunity.

All students are expected to be familiar with and abide by the OU Academic Misconduct Code. Information on this code and other student policies is located at http://studentconduct.ou.edu.