AT745 Syllabus

Earth System Models

2026

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This fall AT745 will deal with “Earth System Models” (ESMs), which include representations of the atmosphere, the ocean, the land surface, sea ice, and continental ice sheets. The nature, scope and history and formulation of ESMs will be covered in general terms. Guest lecturers will cover material that I have little or no clue about.

Each student will “adopt” a current ESM for detailed examination during the semester. Possible choices include the ECMWF models IFS and AIFS, CESM, MPAS, and ICON. Near the midpoint of the semester, each student will give a presentation on the overall structure of their adopted model. Near the end of the semester, each student will give a second presentation, focusing in more detail on a particular aspect of their adopted model.

We will of course also compare the models with each other.

Feel free to contact me if you have questions or suggestions.

1. Introduction

a) Scope of the class

Syllabus

Lots of subjects, so not much detail

100-years paper

b) ESM components

Atmosphere, ocean, sea ice, land surface, ice sheets

c) Physics and dynamics

Atmosphere models

d) Parameterizations in general terms

Atmosphere models

Ocean models

Land surface models

e) Couplers

Atmosphere, ocean, sea ice

f) Synergy with high-performance computing

ENIAC, IBM360/91, vector computing, parallel computing, GPUs

Speed, memory, I/O

g) Some current models

ECMWF, GFS, CESM, EarthWorks, E3SM, GFDL, GISS, ICON, MIROC, NICAM, more…

2. Atmosphere models

a) History

b) Flavors of data

Prognostic variables

Diagnostic variables

Boundary conditions

Initial conditions

c) Dynamical cores

Equation systems and horizontal discretization methods

Grids

Time differencing

Vertical coordinates

d) Physical parameterizations

Turbulence

Cumulus convection

Radiation

Microphysics

Momentum transport by gravity waves

Atmospheric chemistry

Space weather

Coupling the parameterizations with each other

e) Overviews of some current models

Student presentations here

f) Current issues

Stratosphere and beyond

Very high resolution

Scale-aware parameterizations

3. Ocean models

a) History

b) Dynamical cores

Equation systems

Horizontal discretization methods

Grids

Vertical coordinates

Time differencing

c) Physical parameterizations

Mixed layer

Abyssal mixing

Internal gravity waves

Radiation

Marine biology

d) Overview of some current models

e) Current issues

Eddy parameterizations, ocean biology, radiative transfer

4. Land-surface models

a) History

Manabe & Budyko, Sellers & Dickinson

b) Current issues

Photosynthesis, heterogeneity, rivers

5. Sea ice models

a) History

Semtner, Hibler

b) Sea ice dynamics

c) Sea ice physics

d) Current issues

6. Ice sheet models

a) History

b) Ice sheet dynamics

c) Ice sheet physics

d) Current issues

7. Tuning

a) Definition and history

b) Current issues

8. Software engineering

a) Couplers/mediators

b) Workflows

9. Computational performance

a) History

Early machines, vector machines, massively parallel machines

b) Current issues

Precision, machine learning

10. Diagnostics

a) History

b) Current issues

New kinds of grids, and high resolution

11. Sharing models

FANGIO
AMIP
CMIP

Other MIPs

Open source codes

Community models

EPIC

12. Applications to analysis and forecasting

a) *History*

ECMWF

Ensemble forecasting

b) *Data assimilation*

c) *Seasonal and inter-annual forecasting*

13. Applications to climate simulation and climate change prediction

a) *History*

Manabe, Hansen

b) *Current issues*

Forcing, ensembles

14. Including societal processes in ESMs

Integrated Assessment modeling:

Energy management, war and peace, elections, economy, technological change

15. Applications of ESMs to inform policy decisions

a) *History*

Supersonic transports, Charney report,

b) *Current issues*

IPCC and Shared Socioeconomic Pathways (SSPs)