Supporting materials for AOSS 589 received after the meeting.

The committee passed the course approval pending receipt of this supporting information.

Suggested course number: AOSS 589
Suggested title: The Art of Climate Modeling

Suggested number of credit hours: 4
Instructor: Prof. Christiane Jablonowski (AOSS)
Repeatable course: yes
Suggested start: Fall term 2013, taught bi-annually in the Fall

The course was taught once with course number AOSS 605 section 005 (4 credit hours) during the Fall 2010 term. The 2010 class' shared workspace is available under:
https://sites.google.com/site/theartofclimatemodeling/home
The design and schedule of the suggested course is very similar to the previously taught class.

Enrollment in the Fall 2010:

7 (enrolled for credit)
3 (auditors/visitors)

Final class evaluations, Fall 2010 (7/7):

Q1: 5.0
Q2: 4.92

Short catalogue description:

The course introduces the newest climate modeling techniques by surveying the design decisions in atmospheric General Circulation Models (GCMs), the trends in GCM and dynamical core modeling, and how GCMs are coupled. It is built upon hands-on GCM modeling and data projects, journal paper discussions, lectures, shared cyberinfrastructure and computational tools.

Long description:

1) Synopsis:

The course trains graduate students in the newest climate modeling techniques. It surveys the many design decisions in atmospheric General Circulation Models (GCMs), the trends in GCM and dynamical core modeling and how GCMs are coupled to land, ocean and ice components in Earth System Models (ESM). Furthermore, next-generation ESMs will require greater computing capabilities, transparent software designs with exchangeable model components, self-explanatory (metadata) descriptions of data and models, online gateways and portals for data exchanges, and shared online workspaces for both tight and loose science collaborations. Therefore, the course will review and utilize a variety of computational tools that enable students to work effectively with the most modern software infrastructure for the climate and weather sciences.

2) Overarching goals of the course:

After the completion of this course a GCM will no longer be a black box. The students will be enabled to make informed decisions on how to use GCMs in their research and what the limitations of GCMs are. The students will be exposed to real world GCMs, and software practices in atmospheric science, and will have an understanding of the GCM design literature and model documentations.

3) Scientific focus of the course

The main science focus of the course addresses the so-called dynamical cores of GCMs that describe the fluid dynamics component of weather and climate models. The design decisions for building dynamical cores of GCMs incorporate the choice of the equation set, numerical methods, computational grids, grid staggering options, accuracy, conservation properties, diffusion mechanisms and computational efficiency. The course will review the broad range of choices and provide an in-depth look at their pros and cons. In addition, the design decisions for building Earth System Models incorporate much more, such as the coupling strategy between the dynamical core and the subgrid-scale physical parameterizations. The course will review the design of selected physical parameterizations, as well as the coupling strategy to other components of the climate system such as the land, ocean and ice. The course will also discuss computational aspects such as the use of parallel hardware architectures.

Climate models and their individual components are typically compared to other models in international model intercomparsion projects and observations to assess their performance. The latter aspects demand the efficient use of computational tools and shared online workspaces. The course will review and utilize a broad selection of cyberinfrastructure tools.

4) Class format

This hands-on project-driven class is based on lectures, in-class journal paper discussions, GCM modeling projects, model data analyses, and the exploration of software tools in the climate modeling community. No exams are given. Grades are determined based on the GCM modeling projects, journal paper discussions and class participation.

Some of the modeling projects are 'homework-like', e.g. shorter projects or paper reviews that will take 1-2 weeks to finish. In addition, the students will be asked to pick a more comprehensive modeling project as a term project. The latter should ideally be relevant to both the course and the student’s research area (if applicable). There will also be a list of suggested class projects.

The students will utilize the newest version of the Community Atmosphere Model (CAM) developed at the National Center for Atmospheric Research (NCAR) for most of the hands-on projects. The class will get access to NCAR’s most recent high-performance computing platform and the data portal ‘Earth System Grid Federation’.

Some class projects have common themes, such as the intercomparison of the dynamical cores in CAM or the design of test cases for dynamical cores. The class will utilize a shared Wiki-driven online workspace to share and discuss results and create a collaborative spirit.

5) Grading policy

The course grade is based on 7 building blocks:

a) 12.5%: Modeling project 1 (due in week 3), individual
b) 12.5%: Modeling project 2 (due in week 5), individual

c) 12.5%: Modeling project 3 (due in week 7), individual
d) 12.5%: Modeling project 4 (due in week 9), 2-person team
e) 10%: Journal paper discussion, led by individual student
f) 5%: Overall class participation
f) 35%: Term project: individual modeling project with presentation

6) Detailed schedule and overview of the lectures (assuming 3 lectures per week during the Fall term)

Week 1:
1) Overview and logistics of the course: What is a General Circulation Model (GCM), weather model, climate model? Components of the climate system
2) History of weather and climate modeling, journal paper 1 out

Week 2:
3) Overview of the design choices in GCMs and their dynamical cores
4) Strategies for testing and evaluating dynamical cores
5) Journal paper discussion 1. Hands-on introduction to the Community Atmosphere Model (CAM) developed at the National Center for Atmospheric Research (NCAR), shared cyberinfrastructure, visualization aspects, modeling project 1 out

Week 3:
6) Equation sets and prognostic variables in dynamical cores
7) Overview of computational grids and grid staggering
8) In-class discussion of modeling project 1, journal paper 2 out, modeling project 2 out, strategies for selecting term projects

Week 4:
9) Horizontal discretizations I
10) Horizontal discretizations II
11) Journal paper discussion 2. Horizontal discretizations and accuracy

Week 5:
12) Vertical discretizations and mapped coordinates, vertical staggering, inclusion of orography
13) Temporal discretizations
14) In-class discussion of modeling project 2
Journal paper 3 out, modeling project 3 out

Week 6:
15) Diffusion and filtering mechanisms I
16) Diffusion and filtering mechanisms II
17) Journal paper discussion 3. Conservation properties

Week 7:
18) Fixers in dynamical cores
19) In-class discussion of modeling project 3. Journal paper 4 out, modeling project 4 out, discussion of potential term projects

Week 8:
20) Forms of the advection transport equation numerical discretization of advection, physical constraints: positive-definiteness, monotonic, conservation
21) Inclusion of moisture in dynamical cores
22) Journal paper discussion 4. Physics-dynamics coupling techniques

Week 9:
23) Overview of physical parameterizations
24) Selected physical parameterizations: gravity wave drag schemes
25) In-class discussion of modeling project 4. Journal paper 5 out. Finalize term project selection

Week 10: 26) Selected physical parameterizations: planetary boundary layer, turbulence, surface fluxes
27) Selected physical parameterizations: deep convection parameterizations
28) Journal paper discussion 5. Journal paper 6 out. Overview of Earth System Models (ESM)
Week 11: 29) Overview of ocean, ice and land models, and the coupling to the atmosphere
30) Overview of the Earth System Modeling Framework (ESMF), coupling of components
31) Journal paper discussion 6. Journal paper 7 out.
Earth System Grid Federation: data and metadata, standard data formats
Week 12: 32) Earth System Grid Federation: remote data analysis and visualization, visualization tools, reanalyses data
33) Journal paper discussion 7. Journal paper 8 out. Discussion of term projects
Week 13: 34) High-performance and parallel computing concepts, computational aspects, computer architectures, scalability, efficiency, how it impacts science decisions
35) GCM testing and evaluations, uncertainty of dynamical core and GCM simulations
36) Journal paper discussion 8. Ensemble simulations and ensemble spread
Week 14: 37) Trends in GCM modeling: variable-resolution, non-hydrostatic modeling, high-resolution, stochastic approaches
38) Term project presentations
39) Term project presentations
Week 15: 40) Term project presentations, final discussion

7) Student preparation (recommended prerequisites): Graduate standing
The enrolled student should have a basic understanding of

- atmospheric dynamics and the general circulation of the atmosphere
- Unix computing environment
- at least one higher-level programming language (like C/C++ or Fortran (preferred))
- numerical methods
- visualization techniques

There is no strict enforcement of these prerequisites, but knowledge of these areas will be helpful. The course will cover the principles of atmospheric dynamics and numerical methods to a certain degree, but with a strong focus on the practical model design decision in atmospheric General Circulation Models.

8) Class resources:
There is no single textbook that covers all aspects of the course. A variety of online sources will be utilized such as

- Dave Randall, Colorado State University:
  An Introduction to Atmospheric Modeling
  http://kiwi.atmos.colostate.edu/group/dave/at604.html

Free online resource. Very comprehensive discussion about the numerical methods for the dynamical cores of GCMs. Some prior knowledge of numerical methods is helpful. Mostly focuses on finite-difference methods.

- UK Met Office Model Documentation, written by A. Staniforth and A. White and N. Wood and J. Thuburn and M. Zerroukat and E. Cordero and T. Davies and M. Diamantakis:
  Joy of U.M. 6.3 - Model Formulation
  http://research.metoffice.gov.uk/research/nwp/publications/papers/unified_model/
  The very comprehensive and detailed documentation of the UK Met Office dynamical core.
- Springer book by P. Lauritzen, C. Jablonowski, M. Taylor, R, Nair (Eds.)
  Numerical Techniques for Global Atmospheric Models
  The book is available as a free ebook at UM. The most up-to-date review of dynamical core modeling. Lots of practical examples and advice.
- NCAR CAM model documentation:
  http://www.cesm.ucar.edu/models/cesm1.0/cam/
  Official documentation of the NCAR CESM dynamical cores and physical parameterizations.

Other recommended resources are

- Thomas Tomkins Warner
  Numerical Weather and Climate Prediction
  Cambridge University Press, 2011
  The book provides a comprehensive overview of weather and climate prediction, and surveys the strength and weaknesses of atmospheric models.
- David J. Stensrud
  Parameterization Scheme: Keys to Understanding Numerical Weather Prediction Models
  Cambridge University Press, 2007
  The book introduces the design principles of the most commonly used subgrid-scale physical parameterization schemes.
- Dale Durran
  Numerical Methods for Wave Equations in Geophysical Fluid Dynamics
  2nd edition, Springer, 2010
  The book focuses on the numerical techniques for the fluid flow component of climate models. The discussion is broad and comprehensive, most examples are shown for Cartesian geometry.
- Warren M. Washington and Claire L. Parkinson
  An Introduction to Three-Dimensional Climate Modeling
  2nd edition, University Science Books, 2005
  A good textbook at the graduate level, provides an overview of climate modeling. Not very technical.
- Eugenia Kalnay
  Atmospheric modeling, data assimilation and predictability
  Cambridge University Press, 2003

Very nice overview of the numerical techniques in climate models, second half of the book discusses data assimilation.

- David Randall (Ed.)
  General Circulation Model development
  Academic press, 2000
  Collection that reviews the history of GCM modeling and surveys its status in 2000.
- Masaki Satoh
  Atmospheric Circulation Dynamics and General Circulation Models
  Springer (Praxis), 2004
  The book discusses both atmospheric dynamics and GCM modeling with an applied focus. Very thorough and detailed. Great resource for advanced readers.
- Mark Z. Jacobson
  Fundamentals of atmospheric modeling
  2nd Edition, Cambridge University Press, 2005
- Goosse H., P.Y. Barriat, W. Lefebvre, M.F. Loutre and V. Zunz.
  Introduction to Climate Dynamics and Climate Modeling
  Free Online Textbook. Very basic but efficiently fills in gaps.

Reviews of atmospheric dynamics and the general circulation of the atmosphere:

- James Holton and Gregory Hakim
  An introduction to dynamic meteorology
  5th edition, Academic Press, 2012
- B. Cushman-Roisin and J.-M. Beckers
  Introduction to Geophysical Fluid Dynamics: Physical and Numerical Aspects
  2nd edition, Elsevier, 2011
- David Randall, Colorado State University:
  An Introduction to the General Circulation of the Atmosphere
  http://kiwi.atmos.colostate.edu/group/dave/at605.html

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Fall 2010 Final

Instructor with Comments Report

7 students responded out of the total enrolled 7

Instructor: Jablonowski,Christiane

AOSS 605 005

		Responses from your Students**							Other Users of This Item* University Wide			Other Users of This Item* School/College		
		5 SA	4 A	3 N	2 D	1 SD	NA	Your Median	75% Above	50% Above	25% Above	75% Above	50% Above	25% Above
1	Overall, this was an excellent course.	7	0	0	0	0	0	5.00	3.83	4.19	4.60	4.08	4.33	4.68
2	Overall, the instructor was an excellent teacher.	6	1	0	0	0	0	4.92	4.00	4.50	4.80	4.13	4.53	4.79
3	I learned a great deal from this course.	5	2	0	0	0	0	4.80	3.94	4.28	4.67	4.14	4.49	4.71
4	I had a strong desire to take this course.	4	3	0	0	0	0	4.63	3.50	4.06	4.50	4.17	4.42	4.64
140	I deepened my interest in the subject matter of this course.	5	2	0	0	0	0	4.80	3.75	4.13	4.50			
201	The instructor gave clear explanations.	6	1	0	0	0	0	4.92	4.00	4.38	4.73			
203	The instructor stressed important points in lectures/discussions.	6	1	0	0	0	0	4.92	4.10	4.50	4.77			
207	The instructor appeared to have a thorough knowledge of the subject.	6	0	0	0	0	0	5.00	4.40	4.75	4.91			
216	The instructor acknowledged all questions insofar as possible.	6	1	0	0	0	0	4.92	4.20	4.56	4.79			
218	The instructor encouraged constructive criticism.	5	2	0	0	0	0	4.80	4.07	4.50	4.75			
228	The instructor followed an outline closely.	4	3	0	0	0	0	4.63	4.13	4.56	4.79			
229	The instructor used class time well.	4	2	1	0	0	0	4.63	4.00	4.38	4.70			
230	The instructor seemed well prepared for each class.	6	1	0	0	0	0	4.92	4.25	4.63	4.83			
232	Work requirements and grading system were clear from the beginning.	3	3	1	0	0	0	4.33	4.00	4.29	4.60			
239	The amount of work required was appropriate for the credit received.	4	3	0	0	0	0	4.63	3.89	4.13	4.50			
240	The amount of material covered in the course was reasonable.	4	3	0	0	0	0	4.63	4.00	4.20	4.50			
318	Writing assignments seemed carefully chosen.	6	0	0	0	0	1	5.00	3.88	4.15	4.50			
331	The laboratory was a valuable part of this course.	2	0	0	0	0	5	5.00	3.83	4.17	4.67			
332	Laboratory assignments seemed carefully chosen.	2	0	0	0	0	5	5.00	3.63	3.95	4.33			
336	Laboratory assignments required a reasonable amount of time and effort.	2	0	0	0	0	5	5.00	3.75	4.00	4.25			
337	Laboratory assignments were relevant to what was presented in class.	2	0	0	0	0	5	5.00	4.00	4.25	4.59			
340	The textbook made a valuable contribution to the course.	1	0	0	0	0	6	5.00	3.50	4.00	4.34			
356	Examinations covered the important aspects of the course.	1	0	0	0	0	6	5.00	4.00	4.25	4.60			
365	Grades were assigned fairly and impartially.	4	2	0	0	0	1	4.75	4.00	4.24	4.56			
366	The grading system was clearly explained.	3	1	3	0	0	0	4.00	4.00	4.29	4.64			

Written Comments

900 Comment on the quality of instruction in this course.

Student 1
NA

Student 2
I enjoyed the different perspectives given by the guest lecturers. If possible, keep bringing in guests to lecture in the future.

Student 3
I really enjoyed this course. The informal nature of the wiki page for submitting lab results took a lot of competitive pressure off and really contributed to the cooperative environment in the class. It was very cool to develop the class as a group and this was a significant strength of the course.

Instructor with Comments Report

7 students responded out of the total enrolled 7

Instructor: Jablonowski,Christiane

AOSS 605 005

I enjoyed working with other students on the first several projects, and would encourage similar group work for subsequent courses.

The papers we read provided a good and current snapshot of the climate modeling community. The student-led discussions were illuminating and enjoyable for the diversity of the students within the course.

Work with CAM and NCAR's bluefire was a huge benefit to the class, as it provided a practical introduction to the current methods of climate modeling. My only suggestion would be to shorten the discussion of numerical analysis by one or two days to allow more time for a more thorough how-to introduction and user orientation to CAM, NCL, and Bluefire.

Student 4

This was a great course that helped me really get a running start on my research, which was important to me since I am switching fields relative to undergrad. I have a much better understanding of how climate models work, and how advanced yet sometimes "hidden" features to the models can affect experiment design and results.

Student 5

NA

Student 6

Everything is very clearly instructed.

Student 7

NA

* The quartiles are calculated from Fall 2010 data. The university-wide quartiles are based on all UM classes in which an item was used. The school/college quartiles in this report are based on graduate level students in College of Engineering.
** SA - Strongly Agree, A - Agree, N - Neutral, D - Disagree, SD - Strongly Disagree, NA - Not Applicable.