Idealized Models of Climate Processes

EESC 6926

Department of Earth and Environmental Science, Columbia University

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Meeting Times	MW 1-2:15
Office hours	At LDEO, by appointment
Course website	Courseworks
Prerequisites	Previous graduate-level coursework in atmosphere and/or ocean physics and/or chemistry. One year of calculus. GR6901 or equivalent programming experience. Or permission of instructor.
Textbook	There is no textbook. Readings will be posted on Courseworks.

COURSE DESCRIPTION:

This course teaches students to design and apply idealized models to study the fundamental properties of climate system processes and their interactions. Though these models typically have at their core only a handful of interacting differential equations, they can significantly advance process understanding. We cover three topical areas in climate system science: (1) the interpretation and attribution of atmospheric methane trends (2) the role of the ocean in regulating atmospheric carbon dioxide, and (3) the influence of climate system feedbacks on the Earth's energy balance. Throughout the course, emphasis is placed on identifying assumptions underlying conclusions drawn from simple models and the time scales over which different processes operate.

COURSE COMPONENTS:

Lecture: Lecture will be used to introduce basic principles of simple modeling and to introduce each of the three modules.

Lab: Much class time will be devoted to working through modeling exercises relevant to each module. Students will run existing models and modify these models to add new processes.

Discussion: Interspersed with lab sessions, discussions that integrate the models run in class and the peer-reviewed literature will be held.

Final Project: Students will propose a unique final project in which they will further explore an existing model or create their own new model. Students will prepare a presentation and short-format style paper to summarize their work.

GRADING:

1. Labs 50%
2. Final Project 30%
3. Participation 20%

LATE WORK:

Submitting work on time is critical so that you can stay fully engaged with our discussions. Work will receive a 10% reduction in credit for each day late.

ACADEMIC INTEGRITY:

Academic integrity is essential. Please make you are familiar with expectations and consequences as outlined in the Faculty Statement on Academic Integrity and Honor Code established by the students of Columbia College and the School of General Studies. If you have any further questions, please contact the Professors. In this course, all infractions will result in loss of credit for the assignment in question, and will be reported per University policy.

Week	Date	Topic	Reading, ***Assignment Due***
1	4-Sep	Introduction	
2	9-Sep	Principles of mechanistic modeling	Sarmiento and Gruber, Ch 1
	11-Sep	Principles of mechanistic modeling	Jacob Ch3 (through 3.2); Brasseur&Jacob (2017), Ch1 & Ch4.7
3	16-Sep	Introduction to Methane	Kirschke et al., 2013
	18-Sep	Lab 1: Methane (1 & 2 box, OH constant)	Dlugokencky et al., 2003
4	23-Sep	Discussion of Lab 1	Montzka et al., 2011
	25-Sep	Lab 2: Methane (isotopes)	***Lab 1 write up due*** ; Schaefer et al., 2016
5	30-Sep	Discussion of Lab 2	Nisbet et al., 2016
	2-Oct	Paper Discussion	Sections of Prather, 2007 (1,2,4); Naus et al., 2019
6	7-Oct	Final Discussion, Methane	***Lab 2 write up due*** ***Turner et al. 2017; 2019; Prather & Holmes, 2017***
	9-Oct	Introduction to Ocean Carbon	Williams and Follows, Ch 5,6
7	14-Oct	Lab 3: Ocean Carbon (2 box, biotic, no carbon)	Sarmiento and Gruber, Ch 8
	16-Oct	Discussion of Lab 3	Marinov et al. 2006
8	21-Oct	Lab 4: Ocean Carbon (3 box, abiotic with carbon)	**Lab 3 write up due**; Sarmiento and Toggweiler, 1984; Knox and McElroy 1984; Sigenthaler and Wenk, 1984
	23-Oct	Discussion of Lab 4	Broecker et al. 1999
9	28-Oct	Paper Discussion	Sigman et al. 2010
	30-Oct	Final Discussion, Ocean Carbon	***Lab 4 write up due*** Hain et al. 2010, Stephens and Keeling 2000
10	4-Nov	Election day holiday	
	6-Nov	Student Project Proposals	
11	11-Nov	Introduction to Energy Balance Climate Models	Held 2005 BAMS
	13-Nov	Lab 5: Budyko-Sellers EBCM	Sellers 1969, Budyko 1970
12	18-Nov	Discussion Lab 5	
	20-Nov	Paper Discussion	Pierrehumbert et al., 2011
13	25-Nov	Final Discussion, EBCM	***Lab 5 write up due***
	27-Nov	Thanksgiving holiday	
14	2-Dec	Student Presentations	
	4-Dec	Student Presentations	
15	9-Dec	Final Discussion	***Final paper due***

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Preliminary Bibliography

Brasseur, Guy P., and Daniel J. Jacob. 2017. *Modeling of Atmospheric Chemistry*. Cambridge: Cambridge University Press.

Broecker, Wallace, Jean Lynch-Stieglitz, David Archer, Matthias Hofmann, Ernst Maier-Reimer, Olivier Marchal, Thomas Stocker, and Nicolas Gruber. 1999. "How Strong Is the Harvardton-Bear Constraint?" *Global Biogeochemical Cycles* 13 (4): 817–20.

Budyko, M. I. 1970. "Comments on 'A Global Climatic Model Based on the Energy Balance of the Earth-Atmosphere System.'" *Journal of Applied Meteorology* 9 (2): 310–310.

Dlugokencky, E. J. 2003. "Atmospheric Methane Levels off: Temporary Pause or a New Steady-State?" *Geophysical Research Letters* 30 (19): 7993.

Hain, Mathis P., Daniel M. Sigman, and Gerald H. Haug. 2010. "Carbon Dioxide Effects of Antarctic Stratification, North Atlantic Intermediate Water Formation, and Subantarctic Nutrient Drawdown during the Last Ice Age: Diagnosis and Synthesis in a Geochemical Box Model: Atmospheric CO2 during the Last Ice Age." *Global Biogeochemical Cycles* 24 (4). https://doi.org/10.1029/2010GB003790.

Held, Isaac M. 2005. "The Gap between Simulation and Understanding in Climate Modeling." *Bulletin of the American Meteorological Society* 86 (11): 1609–14.

Kirschke, Stefanie, Philippe Bousquet, Philippe Ciais, Marielle Saunois, Josep G. Canadell, Edward J. Dlugokencky, Peter Bergamaschi, et al. 2013. "Three Decades of Global Methane Sources and Sinks." *Nature Geoscience* 6 (10): 813–23.

Knox, Fanny, and Michael B. McElroy. 1984. "Changes in Atmospheric CO 2 : Influence of the Marine Biota at High Latitude." *Journal of Geophysical Research*, Geophys. Monogr, 89 (D3): 4629.

Marinov, I., A. Gnanadesikan, J. R. Toggweiler, and J. L. Sarmiento. 2006. "The Southern Ocean Biogeochemical Divide." *Nature* 441 (7096): 964–67.

Montzka, S. A., E. J. Dlugokencky, and J. H. Butler. 2011. "Non-CO2 Greenhouse Gases and Climate Change." *Nature* 476 (7358): 43–50.

Naus, Stijn, Stephen A. Montzka, Sudhanshu Pandey, Sourish Basu, Ed J. Dlugokencky, and Maarten Krol. 2019. "Constraints and Biases in a Tropospheric Two-Box Model of OH." https://doi.org/10.5194/acp-19-407-2019.

Nisbet, E. G., E. J. Dlugokencky, M. R. Manning, D. Lowry, R. E. Fisher, J. L. France, S. E. Michel, et al. 2016. "Rising Atmospheric Methane: 2007-2014 Growth and Isotopic Shift: Rising Methane 2007-2014." *Global Biogeochemical Cycles* 30 (9): 1356–70.

Prather, Michael J. 2007. "Lifetimes and Time Scales in Atmospheric Chemistry." *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences* 365 (1856): 1705–26.

Prather, Michael J., and Christopher D. Holmes. 2017. "Overexplaining or Underexplaining Methane's Role in Climate Change." *Proceedings of the National Academy of Sciences of the United States of America* 114 (21): 5324–26.

Sarmiento, J. L., and J. R. Toggweiler. 1984. "A New Model for the Role of the Oceans in Determining Atmospheric P CO2." *Nature* 308 (5960): 621–24.

Sarmiento, Jorge Louis, and Nicolas Gruber. 2006. *Ocean Biogeochemical Dynamics*.

Schaefer, Hinrich, Sara E. Mikaloff Fletcher, Cordelia Veidt, Keith R. Lassey, Gordon W. Brailsford, Tony M. Bromley, Edward J. Dlugokencky, et al. 2016. "A 21st-Century Shift from Fossil-Fuel to Biogenic Methane Emissions Indicated by $^{13}CH_4$." *Science* 352 (6281): 80–84.

Sellers, William D. 1969. "A Global Climatic Model Based on the Energy Balance of the Earth-Atmosphere System." *Journal of Applied Meteorology* 8 (3): 392–400.

Siegenthaler, U., and Th Wenk. 1984. "Rapid Atmospheric CO2 Variations and Ocean Circulation." *Nature* 308 (5960): 624–26.

Sigman, Daniel M., Mathis P. Hain, and Gerald H. Haug. 2010. "The Polar Ocean and Glacial Cycles in Atmospheric CO(2) Concentration." *Nature* 466 (7302): 47–55.

Stephens, Britton B., and Ralph F. Keeling. 2000. "The Influence of Antarctic Sea Ice on Glacial–interglacial CO2 Variations." *Nature* 404 (6774): 171–74.

Turner, Alexander J., Christian Frankenberg, Paul O. Wennberg, and Daniel J. Jacob. 2017. "Ambiguity in the Causes for Decadal Trends in Atmospheric Methane and Hydroxyl." *Proceedings of the National Academy of Sciences of the United States of America* 114 (21): 5367–72.

Williams, Richard G., and Michael J. Follows. 2011. *Ocean Dynamics and the Carbon Cycle: Principles and Mechanisms*. Cambridge University Press.