SIO 217C Atmospheric and Climate Sciences III: Climate and Climate Change

Spring 2022

Instructor:	Nick Lutsko	**Time:**	Tu/Th 4:00pm – 5:30pm
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Climate science is inextricably linked to the problem of climate change. In this class we will cover some of the key concepts in dynamics, thermodynamics and radiation required to understand our changing climate, focused through the lens of three motivating questions:

1. What is Earth's climate sensitivity?
2. Why does the atmosphere's circulation expand polewards?
3. How will the hydrologic cycle change in the future?

To answer these questions we will cover topics such as jet dynamics, Hadley Cell theory, models of clear-sky radiation, cloud physics and extreme precipitation. We will also discuss some of the latest research on these questions and explore how theory, models and observations can be combined to better constrain these aspects of the climate system's response to CO_2 forcing.

Grading Policy: Homeworks (75%), class participation (25%).

Lectures: Lectures will be a mixture of in-class derivations, discussions and Jupyter notebook presentations. The notebooks also serve as lecture notes, and the relevant notebook will be made available before each class.

Attendance Expectations: Students are expected to attend all classes in person. Please let me know if you are unable to make a class.

Homeworks: There will be four homeworks, structured as mini-research projects and to be completed in small groups. Each homework will include a literature review component and a calculation component. Groups should decide how they want to divide up the work of each project, before coming together in the end to do the write-up together. Groups are strongly encouraged to submit their write-ups via Github as either Jupyter notebooks or as Latex documents with accompanying code. More instructions will be provided on the problem sets.

Departmental Exam: As well as the homeworks, at the end of each part of the course I will provide a list of sample Departmental questions to test your knowledge. I will not provide answers to these questions, but can talk them over with you if you get stuck.

Office Hours: After class or by appointment.

Background Reading: Please see the attached reading list for references on each part of the course.

Course Schedule:

Part 1: What is Earth's climate sensitivity?
03/29 — Earth's insolation
03/31 — Energy balance models
04/05 — Clear-sky feedbacks 1
04/07 — Clear-sky feedbacks 2
Homework 1 due: 04/11
04/12 — Clear-sky feedbacks 3
04/14 — Clouds
04/19 — Two-box model, the pattern effect and constraining climate sensitivity

Part 2: Why does the circulation expand polewards?
04/21 — Overview of Earth's circulation/angular momentum fluxes
04/26 — Two-layer Phillips model 1
04/28 — Two-layer Phillips model 2
Homework 2 due: 05/02
05/03 — Jet shifts
05/05 — Hadley Cell dynamics 1
05/10 — Hadley Cell dynamics 2
05/12 — Hadley Cell expansion

Part 3: How will precipitation change in the future?
05/17 — Why does it rain?
05/19 — Projected changes in the hydrologic cycle
Homework 3 due: 05/23
05/24 — Radiation and precipitation
05/26 — Extreme precipitation
05/31 — Relative Humidity
06/02 — Monsoons and the ITCZ
Homework 4 due: 06/06

References

Climate Sensitivity

[1] Armour, K. C., C. M. Bitz, and G. H. Roe (2013), Time-Varying Climate Sensitivity from Regional Feedbacks, *Journal of Climate*, *26*(13), 4518–4534. **Time-varying feedbacks/pattern effect**.

[2] Armour, K. C. (2017), Energy Budget Constraints on Climate Sensitivity in Light of Inconstant Climate Feedbacks, *Nature Climate Change*, *7*, 331–335. **Time-varying feedbacks/pattern effect**.

[3] Hartmann., D. 1994: *Global Physical Climatology*. 1st ed., Academic Press (Chapters 2 and 3). **Clear-sky radiation, clouds**.

[4] Held, I. M., and and B. J. Soden, 2000: Water vapor feedback and global warming. *Annual Review of Energy and the Environment*, *25*(1), 441–475. **Clear-sky feedbacks**.

[5] Held, I. M., M. Winton, K. Takahashi, T. Delworth, F. Zeng, and G. K. Vallis (2010), Probing the fast and slow components of global warming by returning abruptly to preindustrial forcing, *Journal of Climate*, *23*(6), 2418–2427. **Two-box model/time-varying feedbacks**.

[6] Jeevanjee, N., D. D. B. Koll, and N. J. Lutsko (2021), "Simpson's Law" and the Spectral Cancellation of Climate Feedbacks, *Geophysical Research Letters*, *48*, e2021GL093699. **A contemporary take on clear-sky feedbacks**.

[7] Sherwood, S. C., M. J. Webb, J. D. Annan, K. C. Armour, P. M. Forster, J. C. Hargreaves, G. Hegerl, S. A. Klein, K. D. Marvel, E. J. Rohling, M. Watanabe, T. Andrews, P. Braconnot, C. S. Bretherton, G. L. Foster, Z. Hausfather, A. S. v. d. Heydt, R. Knutti, T. Mauritsen, J. R. Norris, C. Proistosescu, M. Rugenstein, G. A. Schmidt, K. B. Tokarska, and M. D. Zelinka (2020), An assessment of Earth's climate sensitivity using multiple lines of evidence, *Reviews of Geophysics*, *n/a*(n/a), e2019RG000,678. **Massive recent review of climate sensitivity literature**.

Soden, B. J., A. J. Broccoli, and R. S. Hemler (2004), On the Use of Cloud Forcing to Estimate Cloud Feedback, *Journal of Climate*, *17*(19), 3661–3665. **Cloud feedback**.

Dynamics

[8] Held, I. M., 2000: The general circulation of the atmosphere. *Woods Hole Lecture Notes*. **Background on large-scale atmospheric circulation**.

[9] Schneider, T. 2006: The general circulation of the atmosphere., *Annual Reviews of Earth and Planetary Sciences*, *34*, 655–688. **Background on large-scale atmospheric circulation**.

[10] Shaw, T. A. 2019: Mechanisms of Future Predicted Changes in the Zonal Mean Mid-Latitude Circulation, *Current Climate Change Reports*, *5*(4), 345–357. **Overview of proposed mechanisms for jet shifts**.

[11] Shaw, T. A., J. Lu, K. M. Grise, S. M. Davis, and T. Birner, 2018: Re-examining tropical expansion, *Nature Climate Change*, *8*(9), 768–775. **Overview of proposed mechanisms of tropical expansion**.

[12] Vallis, G. K., 2006: *Atmospheric and Oceanic Fluid Dynamics*. 1st ed., Cambridge University Press, Cambridge, UK. Chapters 6, 10, 12, 14, 15. **Background on large-scale atmospheric circulation**.

Hydrologic Cycle

[13] Boos, W. R., and Z. Kuang, 2010: Dominant control of the South Asian monsoon by orographic insulation versus plateau heating. *Nature*, *463*, 218–222. **Monsoons**.

[14] Byrne, M. P., and P. A. O'Gorman, 2013: Link between land-ocean warming contrast and surface relative humidities in simulations with coupled climate models. *Geophysical Research Letters*, *40*, 5223–5227. **Relative humidity changes over land**.

[15] Chadwick, R., I. Boutle, and G. Martin, 2013: Spatial Patterns of Precipitation Change in CMIP5: Why the Rich Do Not Get Richer in the Tropics. *Journal of Climate*, *26*, (11), 3803–3822. **Spatial patterns of precipitation change**.

[16] Held, I. M., and B. J. Soden, 2006: Robust Responses of the Hydrological Cycle to Global Warming. *Journal of Climate*, *19*(21), 5686–5699. **Overview of expected changes to hydrologic cycle**.

[17] Jeevanjee, N., and D. Romps (2018), Mean Precipitation Change from a Deepening Troposphere, *Proceedings of the National Academy of Science*, *115*, (45) 11465–11470. **Mean precipitation change**.

[18] Lutsko, N. J., and T. W. Cronin, 2018: Increase in Precipitation Efficiency With Surface Warming in Radiative-Convective Equilibrium. *Journal of Advances in Modeling Earth Systems*, *10*, 2992–3010. **Precipitation efficiency**.

[19] Manabe, S., and R. T. Wetherald, 1975: The Effects of Doubling the CO2 Concentration on the climate of a General Circulation Model. *Journal of the Atmospheric Sciences*, *32*, (1), 3–15. **Very early climate change simulations**.

[20] Muller, C. J., P. A. O'Gorman and L. E. Back, 2011: Intensification of Precipitation Extremes with Warming in a Cloud-Resolving Model. *Journal of Climate*, *24*, (11), 2784–2800. **Extreme precipitation**.

[21] P. A. O'Gorman, 2015: Precipitation Extremes Under Climate Change. *Current Climate Change Reports*, *1*, 49–59. **Extreme precipitation**.

[22] Pendergrass, A. M., and D. L. Hartmann, 2014: The Atmospheric Energy Constraint on Global-Mean Precipitation Change. *Journal of Climate*, *27*, (2), 757–768. **Mean precipitation change**.

[23] Pendergrass, A. M., F. Lehner, B. M. Sanderson, and Y. Xu, 2015: Does extreme precipitation intensity depend on the emissions scenario? *Geophysical Research Letters*, *42*, 8767–8774. **Extreme precipitation**.

[24] Privé, N. C., and R. A. Plumb, 2007: Monsoon dynamics with interactive forcing. part i: Axisymmetric studies. *Journal of the Atmospheric Sciences*, *64*, (23), 1417–1430. **Monsoons**.

[25] D. M. Romps, 2014: An analytical model for tropical relative humidity. *Journal of Climate*, *27*, (19), 7432–7449. **Relative Humidity**.

[26] Schneider, T., P. A. O'Gorman, and X. J. Levine (2010), Water Vapor and the Dynamics of Climate Change *Reviews of Geophysics*, *48*, RG3001. **Dynamical changes in hydrological cycle**.

[27] Singh, M. S., and P. A. O'Gorman, 2013: Influence of entrainment on the thermal stratification in simulations of radiative-convective equilibrium *Geophysical Research Letters*, *40*, 4398–4403. **Changes in CAPE**.