Ph.D. Defense Announcement
Luke Davis
May 30, 2023, at 1:00 p.m.

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Ph.D. Defense

Tuesday, May 30, 2023
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Defense
ATS Large Classroom (101 ATS) and Teams

Post Defense Meeting
ATS Community Space Conference Room (116 ATS)

Committee:
David Thompson (Adviser)
Edwin Gerber (New York University)
David Randall
Eric Maloney
Olivier Pinaud (Mathematics)

Links between climate feedbacks and the large-scale circulation across idealized and complex general circulation models

The circulation response to anthropogenic forcing is typically considered in one of two distinct frameworks: One that uses radiative forcings and feedbacks to investigate the thermodynamics of the response, and another that uses circulation feedbacks and thermodynamic constraints to investigate the dynamics of the response. In this thesis, I aim to help bridge the gap between these two frameworks by exploring direct links between climate feedbacks and the atmospheric circulation across ensembles of experiments from idealized and complex general circulation models (GCMs).

I first demonstrate that an existing, widely-used type of idealized GCM — the dynamical core model — has climate feedbacks that are explicitly prescribed and determined by a single parameter: the thermal relaxation timescale. The dynamical core model may thus help to fill gaps in the model hierarchies commonly used to study climate forcings and climate feedbacks. I then perform two experiments: One that explores the influence of prescribed feedbacks on the unperturbed, climatological circulation; and a second that explores the influence of prescribed feedbacks on the circulation response to a horizontally uniform, global warming-like forcing perturbation. The results indicate that shorter relaxation timescales (i.e., more stabilizing climate feedbacks in the context of the model) are associated with 1) a more vigorous climatological circulation, with increased diffusivity and stronger and more poleward storm tracks and eddy-driven jets, and 2) a weaker poleward displacement of the storm tracks and eddy-driven jets in response to the global warming-like forcing. Importantly, since the most commonly-used relaxation timescale field resembles the real-world clear-sky feedback field, the uniform forcing perturbations produce realistic warming patterns, with amplified warming in the tropical upper troposphere and polar lower troposphere. The realistic warming pattern and circulation response disappear when the relaxation timescale field is instead spatially uniform, demonstrating the critical role of spatially-varying climate feedbacks on shaping the response to anthropogenic forcing.

I next explore circulation-feedback relationships in more complex GCMs using results from the most recent Coupled Model Intercomparison Projects (CMIP5 and CMIP6). Here, I estimate climate feedbacks by regressing top-of-atmosphere radiation against surface temperature for both 1) an unperturbed pre-industrial control experiment and 2) a perturbed global warming experiment forced by an abrupt quadrupling of CO2 concentrations. I start by examining the feedback estimates themselves: In particular, I find that across both ensembles, the cloud component of the perturbed climate feedback is closely related to the cloud component of the unperturbed climate feedback. Critically, the relationship is much stronger in CMIP6 than CMIP5, contrasting with many previously proposed constraints on the perturbation response. The relationship also explains the slow part of the CO2 response better than the fast, transient response, consistent with fluctuation-dissipation theory. In general, the strength of the relationship depends on the degree to which the spatial pattern of the response resembles internal variability, with “El Niño-like” East Pacific warming and related tropical cloud changes. I then present an emergent constraint on the future perturbed cloud feedback using a recent observational estimate of the unperturbed cloud feedback. Finally, I relate inter-model differences in the cloud feedback to the large-scale climatological circulation, finding strong but distinct relationships across the CMIP ensembles. In CMIP6, more positive cloud feedbacks are associated with stronger Hadley cells and increased Southern Ocean temperature gradients. In CMIP5, they are associated with reduced Southern Ocean temperature gradients and strongly increased extratropical cloud cover. These results are related to differences in extratropical and tropical cloud processes between the CMIP ensembles.

I conclude by discussing some implications of these results. I consider how the relaxation feedback framework might be further developed and reconciled with traditional climate feedbacks to provide future research opportunities with climate model hierarchies.