ATS 781 Proposal
A potential emergent constraint on climate sensitivity

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Coupled climate model estimates of equilibrium climate sensitivity (ECS) are subject to persistent, considerable uncertainty (e.g., *Zelinka et al.* 2020). So-called *emergent constraints*, defined as statistically significant relationships between model ECS and the unforced model climate, are critical for reducing this uncertainty. Recently, *Davis et al.* (in review) used the dynamical core model to identify links between ECS and the circulation – including possible "candidates" for emergent constraints.

In the dynamical core model, all sources of diabatic heating Q are replaced with the linear damping term $Q \equiv -(T - T^{\mathrm{e}})/\tau$, where T^{e} is the *equilibrium temperature* and τ is the *thermal damping timescale*. Since heating is explicitly linearized about temperature, τ^{-1} is analogous to the *climate feedback parameter* – in other words, the climate feedbacks are explicitly prescribed, and thus ECS is known *a priori* (*Davis et al.* in review). By systematically varying τ^{-1}, *Davis et al.* (in review) identify two unique relationships between ECS and the unforced extratropical circulation of the dynamical core model:

1. ECS and *isentropic slope* (defined as the meridional slope of constant potential temperature surfaces – units m / km).
2. ECS and *thermal diffusivity* (defined as the ratio of the meridional eddy heat transport to the meridional temperature gradient – units m^2 / s).

If these relationships hold in more complex general circulation models (GCMs), then they might be used to construct *emergent constraints* on climate sensitivity. Compared to existing candidates, the above candidates have a number of advantages. First, their physical basis is rooted in well-established theories of baroclinic dynamics (*Schneider* 2004, *Zurita-Gotor* 2008). Second, they are independent of dynamical core equilibrium temperature (*Davis et al.* in review), suggesting resistance to inter-model biases in absolute temperature and radiative-convective equilibria. Third, while previous constraints largely focused on the tropical climate *Bretherton and Caldwell* (e.g., 2020), recent work has highlighted extratropical cloud feedbacks as a critical source of uncertainty in ECS estimates *Zelinka et al.* (e.g., 2020) – and constraints derived from the extratropical climate are more likely to pick up on this uncertainty.

I propose testing the above constraint "candidates" using phases 5 and 6 of the Coupled Model Intercomparison Project (CMIP5 and CMIP6). I will first compile climatologies of the CMIP "pre-industrial control" simulations, computing hemisphere-wide metrics of isentropic slope and thermal diffusivity. I will then compare these metrics against estimates of the ECS obtained by regressing the atmospheric energy imbalance against 1) surface temperature and 2) column-average temperature on both a global and per-hemisphere basis (*Gregory et al.* 2004). If robust statistical relationships are identified, I will compute the same metrics from "observational" data using the ERA-5 and MERRA-2 reanalysis products (*Gelaro et al.* 2017, *Hersbach et al.* 2020) and use these metrics to establish restricted error bounds on ECS for the CMIP5 and CMIP6 ensembles.

This work has the potential to reduce uncertainty in model-derived estimates of equilibrium climate sensitivity. It would also test the utility of the dynamical core framework for instructing us on real-world relationships between the circulation and climate sensitivity.

References

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