Understanding the direct and indirect circulation response to radiative forcings

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Introduction

We study meridional shifts in the general circulation due to specific external forcings using a model-based approach.

We are interested in understanding how shifts in different circulation features relate to each other and whether fundamental scaling laws exist.

Results may yield insight into the mechanisms behind circulation change.

Time slice experiments

We run time slice simulations for 500+ years using an enhanced, high-top version of GFDL AM2.

We prescribe different levels of CO2 and O3 to examine the circulation response to direct radiative forcings, and SSTs to examine the indirect response. CO2 forcings range from \( \frac{1}{2} \) to 4x pre-industrial levels. O3 levels range from pre-industrial to present day. SST distributions come from coupled simulations for years between 1900 and 2100 (from the A1B scenario).

Seasonality north and south

Over the SH during DJFM, we see a 2:1 ratio in the shifts in Ferrel cell and Hadley cell boundaries like that in Kang and Polvani (2010). As in Kang and Polvani, this relationship breaks down during JJAS.

Over the NH, Hadley cell expansion is less definite in all seasons, and we see more scatter and strongly varying relationship between metrics under different forcings during all seasons. For example, O3 changes seem to produce a contraction of the NH Ferrel cell during DJFM.

Relationships between shifts in selected circulation features

Table showing the relationships between shifts in selected circulation features.

Poleward amplification of circulation shift

During DJFM, the entire NH Ferrel cell shifts poleward and, at the same time, expands. This implies a poleward amplification of circulation shifts.

This is also true for the NH Ferrel cell during both seasons.

During JJAS, the SH Ferrel cell (not shown) also shifts poleward, but appears to contract under O3 depletion and SST increases.

Our results are probably not related to the mechanism described in Kidston and Vallis (2010), as the shifts in our study are too small.

Discussion and conclusion

We see a general widening of the zonal mean circulation, independent of hemisphere and season.

In addition, for a given type of forcing (e.g. CO2, O3, or SST) and season, circulation features tend to change in proportion to each other. This is most noticeable over the SH during DJFM. However, these proportionalities depend on the type of forcing. This casts doubt on the existence of a fundamental ratio for shifts in different circulation features. It rather suggests that shifts are due to multiple mechanisms, and that the change in a particular circulation feature depends on the relative strengths of the mechanisms involved. The different forcings considered in this study trigger these mechanisms to varying extents, thus producing the different slopes.

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