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Understanding the varying timescales of the tropospheric circulation response to increasing greenhouse gases

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One common characteristic of Earth system models is that, in response to an increase in greenhouse gas concentrations, the atmospheric circulation expands poleward: that is, the descending branch of the Hadley circulation shifts poleward toward midlatitudes and the midlatitude storm tracks shift toward the poles, particularly in the Southern Hemisphere (SH). It is commonly assumed that these circulation responses are directly linked to warming tropospheric temperatures, either through horizontal temperature gradients at the surface or in the upper troposphere or through vertical temperature gradients (static stability). In this presentation, we examine the timescales of the large-scale atmospheric circulation response to increasing greenhouse gases in CMIP5 models and show that, in contrast to this prevailing thinking, certain key aspects of the tropospheric circulation actually equilibrate substantially faster than tropospheric temperatures.

One interesting example is the poleward shift of the Hadley cell edge and storm track in the SH. In response to an abrupt quadrupling of atmospheric CO_2, the SH Hadley cell edge and storm track shift poleward on the timescale of the increasing global-mean surface temperature during austral summer and fall (as would be expected), but on a much faster timescale during austral winter and spring (which is quite unexpected). This behavior is pervasive across almost all CMIP5 models. To understand this seasonality, we partition the circulation response into the components associated with the direct radiative effects of CO_2 and rising sea surface temperatures (SSTs). The direct radiative effects of CO_2 enhance the meridional temperature gradient in the upper troposphere-lower stratosphere (UTLS) during all seasons, whereas the rising SSTs only substantially enhance the UTLS meridional temperature gradient during summer and fall months. Consequently, the direct radiative effects of the CO_2 forcing have a greater influence on the circulation response during winter and spring months, contributing to its faster timescale. The seasonal timescales of the SH circulation response have direct implications for the seasonality of the cloud-radiative feedbacks that are closely tied to the circulation response.