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Variability of zonal and meridional atmospheric overturning circulation and the connection to ENSO

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The El Niño–Southern Oscillation (ENSO) is the dominant mode of inter-annual climate variability and has been shown to impact the atmosphere in both the tropical regions and, via various teleconnections, the midlatitudes. This has also been shown to affect the transports of mass and energy in both the zonal and meridional directions globally. Studies have found that during an El Niño event, the zonally oriented Walker Circulation weakens while the meridional Hadley Circulation intensifies. To understand the response of the global atmospheric circulation to various ENSO phases, we unify its zonal and meridional components by introducing the hydrothermal stream function. The hydrothermal stream function resides in latent heat vs dry static energy coordinates, thus a purely thermodynamic space. Using ERA-Interim reanalysis data 1979-2010, we find that diabatic motions in the tropical Hadley and Walker Circulations and fluxes by midlatitude eddies both reinforce to form a single thermodynamic cycle. The time-averaged amplitude is 418 Sv (Sv $= 10^9$ kg s^{-1}), of which zonal overturning such as the Walker Circulation accounts for at least 133 Sv. The hydrothermal stream function encapsulates a globally interconnected heat and water cycle comprising moist convection, radiative damping, and injection of heat and moisture to near-surface air.

We use the hydrothermal stream function calculated from ERA-Interim data 1979-2010 and ENSO indicators such as sea level pressure (SLP) and sea surface temperature (SST) in the tropical Pacific Ocean to investigate the effects of different ENSO phases on the global atmospheric circulation. We also decompose the hydrothermal stream function into zonal and meridional components to assess the strength and variability of both the Walker Circulation and the meridional overturning separately.

Moreover, changes to the atmospheric general circulation in the 21st century are investigated by calculating the hydrothermal stream function in both present-day and 21st century simulations from the EC-Earth coupled climate model. Changes on both inter-annual and multi-decadal time scales are investigated. By also decomposing the stream function into zonal and meridional components, we examine future changes to the strength and variability of the Walker Circulation and the meridional overturning.