Simulated Changes in Large-scale Atmospheric Circulation Energetics from Volcanic Aerosol Forcing

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Abstract. Understanding the response of large-scale atmospheric circulation to radiative forcing agents is important for climate prediction. The radiative forcing from volcanic stratospheric aerosol is one of the most important natural climate forcings, with impacts on surface temperature and atmospheric dynamics. In this study, we explore changes in the energetic properties of the Hadley and Ferrel systems under the influence of radiative forcing associated with large volcanic eruptions in multi-model simulations performed as part of the Model Intercomparison Project on the Climatic Response to Volcanic Forcing (VolMIP) within the Coupled Model Intercomparison Project Phase 6 (CMIP6). In the Earth's atmosphere, the Hadley and Ferrel systems are examples of thermally direct (warm air rises and cold air sinks) and indirect (cold air rises and warm air sinks) circulations, respectively. Being the part of Lorenz cycle of energy transformation in the atmosphere, the direct circulation converts zonal-mean available potential energy into zonal-mean kinetic energy. The indirect circulation in the midlatitude, however, converts some of the zonal-mean kinetic energy back into zonal-mean available potential energy. Averaged over the 4 models that provided the required model output from the VolMIP Pinatubo simulations, the mean power associated with the Hadley system in preindustrial simulations is 235.6 TW. The mean decrease of the power in VolMIP simulations of the 1991 Pinatubo eruption is 7.58 TW (3.22%) for the first post-eruption northern-hemisphere (NH) winter and 6.59 TW (2.80%) for the second one. For the Ferrel system, the preindustrial mean DJF power is 326.10 TW, and post-volcanic anomalies are 16.3 TW (5.00%) and 18.3 TW (5.61%) in NH winters 1 and 2, showing a stronger anomaly in the second NH winter than the first one. In additional VolMIP experiments, we also explore the response of the Hadley and Ferrel cells to the relatively strong forcing associated with the 1815 Tambora eruption and find the Hadley system weakening by 15.3 TW (6.48%) and 11.5 TW (4.90%) for the first two NH winters. We explore how post-eruption changes in the meridional atmospheric circulation strength and the cells' location can be explained with simple theoretical models of atmospheric thermodynamics.