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Implications of El Niño-Southern Oscillation on volcanic impacts on Northern Hemisphere winter climates during the Last Millennium

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The viability of using Earth System Model (ESM) simulations of the last millennium to determine aspects of the climate variability generated by strong volcanic eruptions (SVE) is explored by using five all-forcing ESM ECHAM5/MPIOM simulations. This enables us to investigate a large number of historical SVE (35 tropical and 35 high-latitude ones) under different climate conditions. Volcanic effects were determined through ensemble composite analysis on winter values of selected geophysical variables as well as on winter climate indices, mostly referring to the Northern Hemisphere. Specifically, we tested the significance of the difference between average states for the five pre-eruption and the two post-eruption years: The availability of very long simulated time series allows us to put such short-term climate variability generated by major SVE within the context of its background long-term variability.

The simulated influence of El Niño Southern Oscillation (ENSO) on the general atmospheric circulation largely contributes to determine the way volcanic signals propagate in the stratosphere as well as in the lower troposphere. Specifically, large anomalies of ENSO are found to be able to alter the response of the stratospheric polar vortex by both affecting the meridional gradient of temperature and influencing planetary waves activity. Accordingly, neutral (warm) ENSO conditions produce the strongest (the weakest) volcanic impact on the stratospheric polar vortex. The very strong simulated linkage between ENSO and extra-tropical Northern Hemisphere variability as well as a very strong year-by-year simulated variability of ENSO likely contribute to dampen atmospheric responses to volcanic activity in the lower Northern Hemispheric troposphere. Under neutral ENSO conditions the simulations can reproduce the winter surface warming (cooling) over Northern Europe and Siberia (over the Mediterranean region) which is typically observed after SVE. The mechanisms involved in such climate response seems to be associated to a concomitant strengthening of the North Atlantic Oscillation and East Atlantic/Western Russian patterns and to a weakening of the East Atlantic pattern.

We thus demonstrate that very long and realistically forced climate simulations are highly valuable tools for improving our understanding of climate dynamics and model behavior also on short timescales. In particular, they feed the discussion on the statistical relevance of climate responses to SVE and highlight the importance of taking long-term background climate variability into proper consideration, even when assessing short-term climate responses. From our investigations, it emerges the importance of having teleconnection patterns as well as major climate anomalies (such as ENSO) realistically reproduced by global climate models both on their spatial structure and temporal variability in order to improve our capability to assess global as well as regional climate responses to major historical SVE.