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Very large volcanic eruptions: A challenge for Earth system models

C. Timmreck and M.P.I. Super Volcano Group
Max-Planck-Institut für Meteorology, Hamburg, Germany (claudia.timmreck@zmaw.de, +49 40 441173-298)

Very large volcanic eruptions (super eruptions) produce extremely strong radiative forcing, which can affect the Earth system for longer times than the pure atmospheric residence time of the volcanic aerosol. Applying such radiative forcing provides a wide range of possibilities to investigate the complex feedback mechanisms of the Earth System, e.g., which processes will be activated, how stable will the system be, are positive or negative feedback loops dominant. Super eruption simulations with Earth System Models (ESMs) are therefore an ideal test bed for the quality and performance of such models. Here we present and discuss MPI- ESM simulations of a very large Northern Hemisphere mid latitude eruption (Yellowstone) and a very large tropical one (Toba) and eruptions in different seasons and hence different states of the climate system. All simulations show that the climate system is disturbed over more than a decade. A strong cooling signal is found in the first years after the eruption in particular over the Northern Hemisphere mid and high latitude land masses with a maximum cooling of more than –10 K in the annual average. This strong cooling leads to a decrease in precipitation in particular in the tropical region. Tropical precipitation and temperature anomalies are modulated by changes in the tropical ocean dynamics. After 75 years the climate has completely recovered. In the ocean, heat content is reduced after the eruption and the anomalies persist for decades. CO_2 concentrations in the atmosphere shortly increase in the first 3 years after the eruption and decline quite rapidly during the next 3 years before reaching a minimum and starting to increase slowly towards the pre-eruption level. The atmospheric CO_2 signal is explained mainly by changes in land vegetation and ocean cooling in the initial phase, and by changes in the land soil carbon pool in the phase beginning 3 years after the eruption.. During this phase, the ocean compensates for the carbon loss from the atmosphere to the land by increased outgassing. After 150 years the carbon cycle has reached an equilibrium state and atmospheric pCO_2 is similar to pre-eruption levels. The new equilibrium states of the land an ocean carbon pools, however, are slightly different from their pre-eruption state.