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Simulation of the climate impact of Mt. Pinatubo eruption using ECHAM5

Manu Anna Thomas

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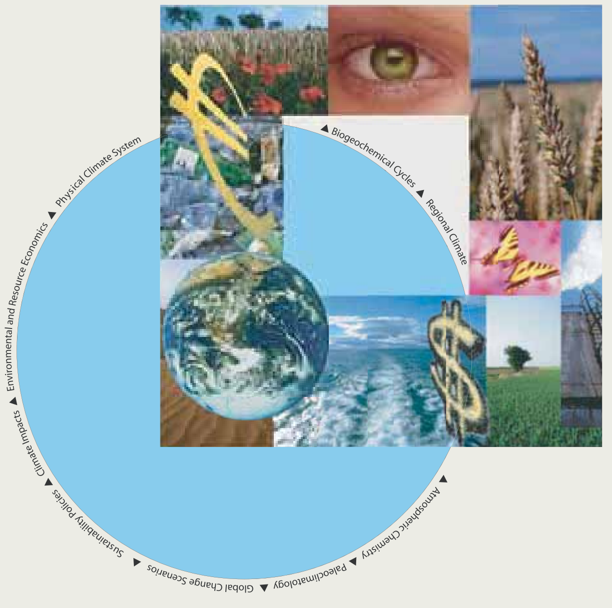

Abstract

Large volcanic eruptions provide an excellent opportunity to study the response of the climate system to a global radiative perturbation and to test the climate models to assess this response. The eruption of Mt. Pinatubo in Philippines in June 1991 was one of the strongest volcanic eruptions in the recent history. In this study, most comprehensive simulations to date of climate impact of Mt. Pinatubo eruption are carried out with prescribed volcanic aerosols including observed SSTs, QBO and volcanically induced ozone anomalies (a) to analyze individual and combined response of these boundary conditions to volcanic forcing and (b) to assess sensitivity of climate response to the change of QBO phase using the middle atmosphere version of ECHAM5. ECHAM5.3 was overestimating the SW heating rate anomalies and hence, the lower stratospheric temperature response in the simulations with Pinatubo aerosols. Hence, few improvements are made in the radiative transfer parameterization scheme of ECHAM5 to include the effects of multiple reflection and the aerosol gas interactions in case of high volcanic aerosol loadings. Both these effects contradict one another and the dominance of either of them depends on the aerosol optical properties and their concentration. In this study, the multiple reflection effect overrides the aerosol-gas interaction effect since the sulfate aerosols are mostly scattering in the solar spectrum.

In order to understand the individual and combined, radiative and dynamical responses of observed SSTs and QBO to volcanic forcing, the climate response of Mt. Pinatubo eruption is evaluated under varying boundary conditions, including one at a time. Among all these experiments, it is seen that the experiment that includes the most realistic set up (with observed SST, QBO and ozone anomalies) with the volcanic forcing simulates the climate impact most realistically. The analysis shows that the pure lower stratospheric tropical aerosol responses are insensitive to the boundary conditions. The pure El Niño-related stratospheric temperature anomalies exhibit tropical cooling and subtropical warming and the pure QBO-related temperature anomalies show a cooling during the easterly QBO and warming during the westerly QBO phase. The pure effects of El Niño and QBO is known from other studies and are realistically simulated in this study too. The QBO-related 30 hPa geopotential height anomalies show a strengthening of the polar vortex during the westerly phase of the QBO and vice versa. The magnitude and pattern of the anomalously strong polar vortex is more or less captured in the second winter in the combined responses of volcanic forcing with QBO and observed SST+QBO. However, the polar vortex is disturbed during the first winters and this is due to the enhanced wave propagation during El Niño winters. The dynamical response manifested as the "volcanic winter pattern" is not simulated in either of the individual or combined mean responses, although 30% of the ensemble members do show the dynamical response. The results also show that the ocean response in the surface temperature anomalies in the two winters are so strong that it masks the effects due to volcanoes in the model. Apart from this, inconsistencies are seen

in the planetary wave propagation characteristics in the model climatology in comparison with ERA40 climatology. The results show that the vertical wave activity flux values of the stationary waves at 200 hPa are 48% less in the model climatology than in the ERA40 climatology.

Further, the climate response to Mt. Pinatubo eruption is investigated, if the eruption had occurred in the opposite phase of the QBO. Mt. Pinatubo erupted during the easterly QBO phase and the phase change occurred 14 months after the eruption. Here, the winds in the model are forced by the opposite QBO phase. The results show that the QBO-related lower stratospheric temperature responses are simulated realistically depending on the QBO phase encountered. The polar vortex is disturbed in the first winter irrespective of the QBO phase due to the increased vertical wave activity during El Niño winters. The simulated "volcanic winter pattern" for the first winter following the eruption is independent of the QBO phase as the El Niño effects modulate the response and override the effects due to the change of phase of QBO. Finally, all these results highlight the degree of efficiency of ECHAM5.4 in simulating such large perturbations, although the simulation of the dynamical response still remains a major challenge.