RADIATIVE FORCING AND CLIMATIC IMPACT OF THE MOUNT PINATUBO VOLCANIC ERUPTION

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The volcanic eruption of Mount Pinatubo in the Philippines, which occurred on 15 June 1991, injected the largest amount of gaseous sulfur dioxide (SO_2) into the stratosphere in this century. Aerosol particles, converted from the gaseous SO_2, spread all over the globe and were suspended in the stratosphere for a few years. They imposed a large impact on the atmospheric radiation, temperature, circulation and chemical constituents. This study is focused on the radiative forcing of the Pinatubo volcanic aerosol and the atmospheric responses to this forcing.

Changes in radiative fluxes and atmospheric heating rates induced by the Pinatubo aerosol were computed for the two years following the eruption by using the UIUC 24–layer Stratosphere/Troposphere General Circulation Model (ST–GCM) and a reconstructed dataset of the Pinatubo aerosol optical properties. The absorption of terrestrial and solar near–infrared radiation by the Pinatubo aerosol radiatively heated the middle and lower stratosphere. The back–scattering of solar UV and visible radiation by the Pinatubo aerosol radiatively cooled the troposphere. Cloudiness exhibited a large influence on the calculated radiative forcing.

Statistical tools were used to detect the signals of the Pinatubo aerosol forcing and ENSO events in the observed surface air–temperature anomalies (ΔT_s) over land. Composite analyses showed that over land the distribution of ΔT_s for the El Niño composite is almost everywhere opposite to that for the La Niña composite, and the patterns of ΔT_s changes from season to season. This feature is more distinct over North America than over the other continents. Over

North America, negative ΔT_S dominates for the El Niño composite in JJA and for the La Niña composite in DJF, and positive ΔT_S dominates for the La Niña composite in JJA and for the El Niño composite in DJF. The volcano composites are different from either the El Niño or the La Niña composites. The Singular Value Decomposition (SVD) analysis showed that ENSO signals were weak over Eurasia but relatively strong over the other continents. The 1991~1992 El Niño event contributed about –0.6°C to the observed cooling of about –1.0°C over North America in JJA 1992. The averaged ΔT_S over Eurasia, North America, South America and Africa reached about –0.5°C in JJA and SON 1992 and SON 1993 with the ENSO signals removed.

Ensemble simulations were performed by using the UIUC 24–layer ST–GCM, with prescribed real–time SST and with climatological SST as boundary conditions, to explore the responses of the atmosphere to the Pinatubo aerosol forcing for the two years following the eruption. Ensemble simulations were also performed to examine the responses of the atmosphere to the observed SST anomalies, with and without the Pinatubo aerosol included. Simulations were compared to observational data analyses. It is found that the simulated temperature anomalies in the troposphere and near the surface (stratosphere) by the Pinatubo aerosol forcing are sensitive (insensitive) to initial conditions and the type of prescribed SST. The signal of SST anomalies is stronger in the troposphere and near the surface than in the stratosphere, while the signal of the Pinatubo aerosol forcing is strongest in the lower stratosphere. Over Eurasia and North America, the model simulates better the observed cooling in JJA 1992 than the observed warming in DJF 1991–1992.

The simulated stratospheric temperature anomalies induced by the Pinatubo aerosol forcing are generally 1°C to 2°C larger than observed in 1992. Empirical data analyses and model simulations showed that this discrepancy is explained in part by the influences of the quasi–biennial oscillation (QBO) and the observed ozone depletion, which the ensemble simulations were unable to resolve.

The influence of the ocean on the simulated climatic responses of the atmosphere to the Pinatubo aerosol forcing was examined by performing ensemble simulations using the coupled UIUC 24–layer atmosphere/18–layer ocean GCM. The coupled GCM simulates better the observed winter warming over Eurasia than the uncoupled ST–GCM. The simulated stratospheric warming is about 0.2°C to 0.3°C smaller than that simulated by the uncoupled ST–GCM. The coupled GCM overestimated the observed tropospheric cooling, and was unable to simulate the observed SST anomalies in the eastern tropical Pacific.

In summary, this study improved our understanding of the radiative forcing of historical volcanic eruptions, in particular the Pinatubo eruption, which is vital for us to understand the observed climate changes in the past centuries. For the first time, the signals of volcanic eruptions and El Niño events in the observed ΔT_s over land have been quantitatively determined by using the SVD analysis, and cross–examined by performing ensemble numerical simulations. The UIUC 24–layer ST–GCM demonstrates a high skill in simulating the ENSO–induced large–scale ΔT_s over land. This study showed that to understand the observed atmospheric temperature changes following volcanic eruptions one must take the QBO and atmospheric ozone chemistry into account in addition to the volcanic aerosol forcing. This study also performed the first simulation using a coupled atmospheric and oceanic GCM to explore the responses of the ocean–atmopsphere system to the Pinatubo aerosol forcing. Through this study we also better understand the strengths and weaknesses of the newly developed UIUC 24–layer ST–GCM in its applications for studying climate and climate changes.