Simulation of the dynamical response after volcanic eruptions – The challenge still remains!

Introduction

Explosive volcanic eruptions are one of the largest natural perturbations to the Earth's system. They can have multiple effects on climate. The sulfate aerosol particles in the stratosphere from strong volcanic eruptions produce significant warming in the lower equatorial stratosphere, thereby increasing the equator to pole temperature gradient in the lower stratosphere and hence force a positive phase of Arctic Oscillation during NH winter. This is manifested at the surface as a winter warming pattern in the NH high latitude continents. This feature is observed for two winters following the eruptions and is typical of tropical explosive eruptions as can be seen from the observed ERA-40 anomalies in fig.1.

Agung - 1963/65 **El Chichon- 1982/84** **Mt. Pinatubo - 1991/993**

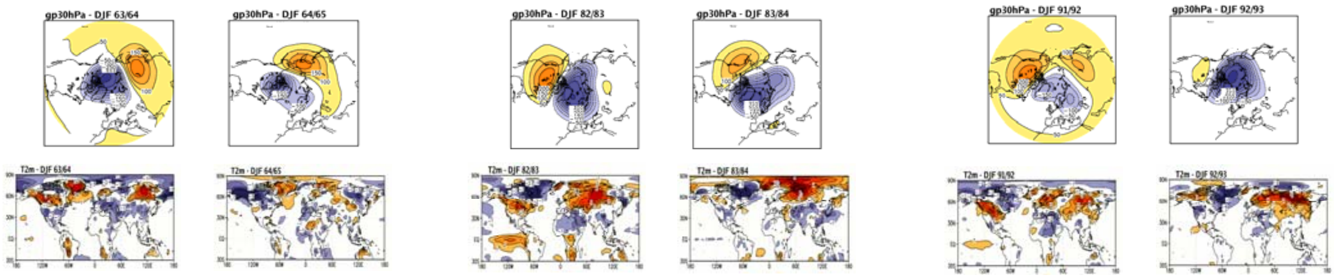


Fig.1: The first row shows the geopotential height anomalies at 30 hPa (m) and the second row shows the 2m temperature anomalies (K) for two winters following the eruptions.

The observed climate evolution after tropical explosive eruptions has significant anomalies compared to the climatology. However, the simulation of these anomalies still remains a challenge. Many of the previous studies considered only one or the other of the forcings in the simulation of impact after explosive eruptions, thus resulting in incomplete interpretation of the results. Here, the climate anomalies after Mt. Pinatubo eruption is evaluated by

(1) including all the known factors such as the observed SST, the observed QBO phase and volcanically induced ozone anomalies
(2) using a higher vertical resolution.

Model and Data sets

Model used: Middle Atmosphere version of ECHAM5
Resolutions: T42L39 and T42L90, top layer at 0.01 hPa
Aerosol forcing: Pinatubo aerosol data (Stenchikov et al.,2002)
Ozone forcing: Volcanically induced ozone anomalies compiled by Stenchikov et al.,2002
QBO in T42L39 resolution: The zonal winds in the tropics are nudged towards the zonal wind observations at Singapore (Giorgetta and Bengtsson, 1999)
QBO in T42L90 resolution: The QBO is internally generated (Giorgetta et al.,2002)

Experimental set up

Boundary conditions: Climatological SST (C), Observed SST (O) and QBO (Q)
Ensemble members: 10
Simulations with T42L39 resolution:
Combined AOQ : OQp – Cu
Ocean alone response: Ou – Cu
Simulations with T42L90 resolution:
Combined AQ response: Qp – Cu

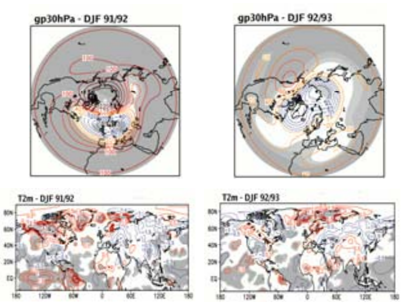
	C	O	Q	OQ
Perturbed run			Q_p	OQ_p
Unperturbed run	C_u	O_u		

Perturbed run includes the aerosol forcing and the volcanically induced ozone anomalies

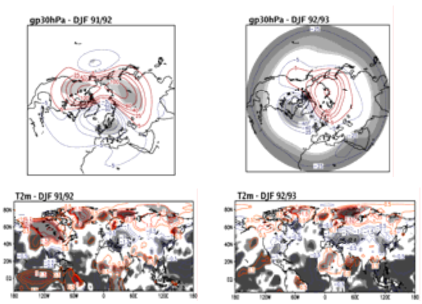
Results – 1: T42L39 resolution

(Thomas et al., 2008)

Combined Aerosol + SST + QBO (AOQ)



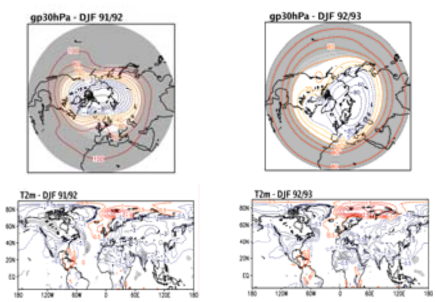
Ocean-alone (O)



Areas of significance with 90%, 95% and 99% levels are shown in the order of increasing shading intensity

Results – 2: T42L90 resolution

Combined Aerosol + QBO (AQ)



Summary and Conclusions

- The model tries to simulate a relatively weaker polar vortex in the second winter, where as the vortex is slightly shifted southwards in the first winter as shown in AOQ.
- Associated surface pattern does not show a 'winter warming pattern' during the first winter, but the pattern is much more shifted towards the north in the second winter as in the observed winter anomalies of DJF 83/84.
- The surface anomalies in the AOQ simulation compares well with the surface anomalies in the ocean-alone simulation, pointing that the ocean signal in the model is so strong that it overrides the effects due to aerosol and QBO.
- The polar vortex is disturbed in both the winters in the ocean-alone experiment, mainly due to the increase in planetary wave propagation from the troposphere to the stratosphere.
- With a higher vertical resolution (L90) model, a well-structured polar vortex, though weaker, is simulated in both the winters after the eruptions in the combined AQ run.
- The surface pattern in the L90 experiment is shifted north as in the observed anomalies of 83/84, whereas the cooling over Greenland, Middle east and Mediterranean is simulated realistically, though the anomalies are not statistically significant.

Detailed analysis is required to understand the inability of our climate models to reproduce the surface winter anomalies after eruptions. This is important as it has implications for simulating the impacts of geo-engineering on our Earth system. One of the reasons that our model does not reproduce the dynamical response could be that our model simulations use zonally averaged volcanic forcing and volcanically induced ozone anomalies. The omission of the zonal asymmetric component of volcanic forcing and ozone forcing may produce differences in the response (Gabriel et al., 2007) or the coupling of stratospheric changes to annular variations at the surface is underestimated by the models.

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