# Changes of the Brewer Dobson Circulation due to major volcanic eruptions in different ECHAM simulations

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## Motivation

Major volcanic eruptions have a significant impact on stratospheric and tropospheric climate, chemical composition and the atmospheric circulation. The climate effects are global if the volcanoes are located in the tropics and subtropics. As the last three major volcanic eruptions (1963 Mt. Agung, 1982 El Chichon and 1991 Mt. Pinatubo) occurred during El Nino events and at different Quasi-Biennial Oscillation (QBO) phases, it is difficult to understand from these three cases alone, what part of the climate anomalies following the eruptions results from the volcanic radiative forcing and what part has to be explained by internal modes of variability of the climate system, including El/Nino-Southern Oscillation, the QBO or extratropical wave mean-flow interaction. Therefore this study is concentrating on model results only.

**Part I:** Based on the coupled chemistry climate model (CCM) MAECHAM4CHEM we investigate the changes of the Brewer Dobson Circulation (BDC) following major volcanic eruptions. The CCM is coupled to an interactive stratospheric chemistry module taking the chemical feedbacks of volcanic aerosols into account. Two transient experiments were run one from 1960 to 1999 and one from 1980 to 1999 forced by prescribed observed sea surface temperatures, QBO phases, solar cycle, volcanic eruptions and greenhouse gas (GHG) scenarios.

**Part II:** To derive a better understanding of the BDC changes of these transient model runs, a set of single forcings with the general circulation model (GCM) ECHAM5 are used to distinguish the effects of the Pinatubo eruption from the ocean, QBO and ozone effects on the BDC. These results are demonstrated in part II of this poster. Deficiencies of the different model set-ups and agreements with observations will be used to derive a better understanding of the important atmospheric processes and for a process-oriented validation.

## ECHAM simulations

### Coupled Chemistry Climate Model (CCM)

**MAECHAM4**
- T31L39, high top model: lid at 0.01 hPa at 80km (Steil et al 2003; Manzini et al. 2003)

**Chemistry: CHEM**
- interactive chemistry model
- chemical reactions: $O_X$, $N_X$, $Cl_X$, $HO_X$ cycles (Steil et al. 1998)

**Experimental setup**
- GHG (IPCC) and CFCs (WMO) scenarios
- observed SST, QBO, solar cycle and volcanic aerosol forcing including 3 major eruptions from 1960-1999
- simplified volcanic forcing: zonal aerosol climatology taken from Sato et al. 1994
- aerosols are interacting with radiation and chemistry
- 2 model runs: one from 1960-1999 (**CCM**) and one from 1980-1999 (**CCM**)

**Anomalies**
- The composite anomalies are calculated for three volcanic eruptions AEP (1xA+2xEC+2xP) during NH winter (DJF).
- For the anomalies the mean of the first post volcano winters are taken from which the ensemble mean is subtracted.

### General Circulation Model (GCM)

**MAECHAM5**
- T31L39; high top model: lid at 0.01 hPa (~ 80km) (Roeckner et al., 2006; Manzini et al., 2006)

**Experimental set up (Thomas et al 2008a/b ACPD, and SPARC poster A-00206)**
- Pinatubo eruption: from June 1991 to May 1993
- 10 ensemble members per forcing
- single forcings using observed, prescribed:
  1.) volcanic aerosol+ozone
  2.) SSTs
  3.) QBO (nudged between 70 and 10 hPa (Giorgetta and Bengtsson, 1999))
  4.) all three forcings together

**Anomalies** are calculated for DJF 1991/92 as:

**Aer1 (A)** $=C_p-C_u$
**Ocean (O)** $=O_u-C_u$
**QBO (Q)** $=OQ_u-O_u$
**AOQ** $=OQ_p-C_u$

$C_p$: clim. SSTs+volcanic aerosol
$C_u$: clim. SSTs
$O_u$: obs. SSTs (Ocean)
$O_p$: obs. SSTs+volcanic aerosol
$OQ_u$: obs. SSTs+QBO
$OQ_p$: obs. SSTs+QBO+volcanic aerosol
p: perturbed
u: unperturbed

## Global temperature anomaly

Lower stratosphere

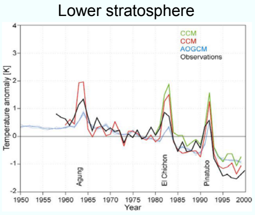



**Fig.1** Warming of the lower stratosphere (50hPa) on a global scale after major volcanic eruptions in observations (black line) and in different ECHAM simulations (CCM: green and red lines; AOGCM; blue lines). Indicated are the last three major volcanic eruptions of Agung (A) March 1963, El Chichon (E) April 1982 and Pinatubo (P) in June 1991.

## Ozone anomaly in the tropics

Ozone at 50 hPa / Observed total ozone

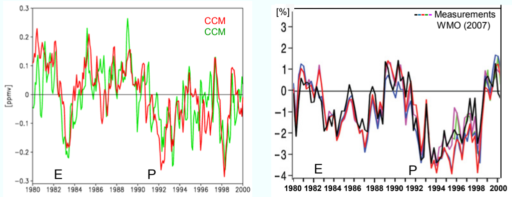



**Fig. 2**: Less tropical ozone is simulated in the lower stratosphere following the volcanic eruptions of El Chichon (E) and Mt. Pinatubo (P), which is in good correspondence with observed total ozone anomalies. This effect is known to be caused by enhanced diabatic ascend (lofting of low ozone values) in the tropics due to direct sulphate aerosol heating and in situ chemical ozone loss (e.g. Robock, 2000).

## Changes of the BDC after major volcanic eruptions

Zonal wind [m/s]

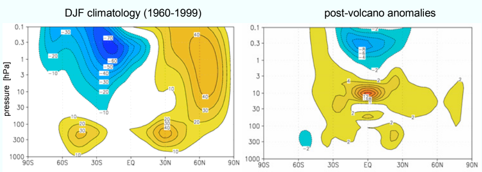



**Fig. 3**: The lower and mid stratosphere shows a weak strengthening of the polar and extratropical Westerlies in the northern winter hemisphere. In the tropics a dominant QBO pattern is apparent with a strong westerly phase in the mid stratosphere.

Divergence of the Eliassen-Palm-Flux [m/s/d]

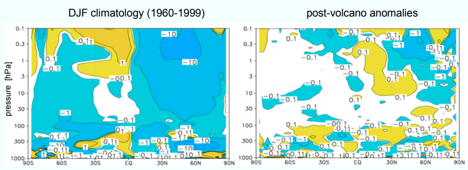



**Fig. 4**: In the model runs enhanced/weakened wave breaking is simulated poleward/equatorward of 50°N (> 30hPa), which is accompanied by enhanced/weakened wave propagation into the stratosphere (not shown).

Mass stream function [$10^9$ kg/s]

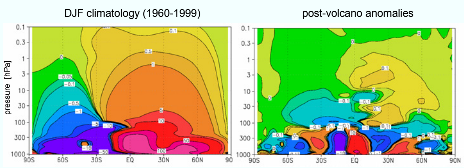



**Fig. 5**: The tropical branch of the BDC shows a detailed pattern: A strengthening poleward of 5°N. This signal is superimposed by the oscillating phase of the QBO, whereby Westerlies/ Easterlies correspond to a weakening/enhanced ascend. The extratropical BDC is accelerated, whereas the polar branch does not show a clear signal.

## Changes of the BDC after the Pinatubo eruption

Zonal wind [m/s]

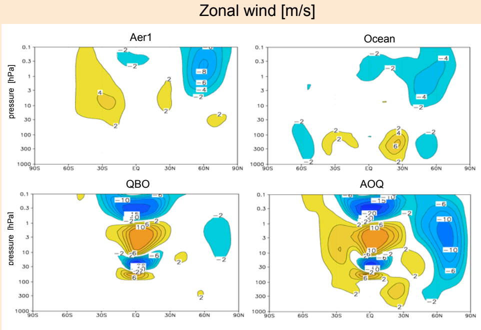



**Fig. 6**: Zonal wind anomalies for the sulphate volcanic aerosol (Aer1), observed SST (Ocean), observed QBO and the combined AOQ effect. Negative/positive values correspond to weakened/enhanced Westerlies on the winter hemisphere.

Divergence of the Eliassen-Palm-Flux [m/s/d]

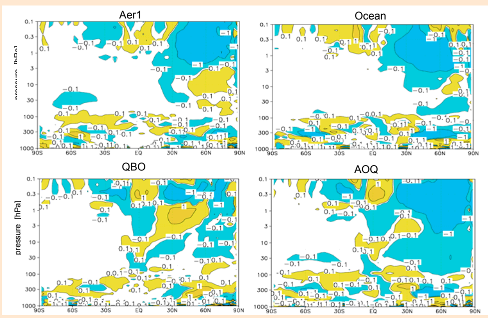



**Fig. 7**: Div F anomalies: negative anomalies correspond to enhanced wave breaking, positive values to weakened wave breaking during NH winter.

Mass stream function [$10^9$ kg/s]

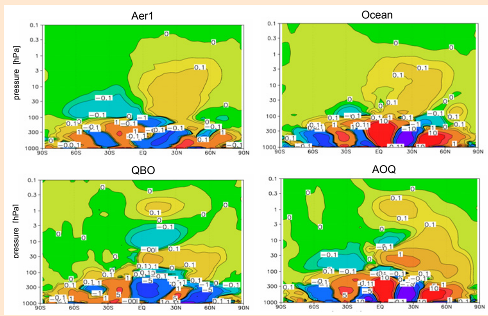


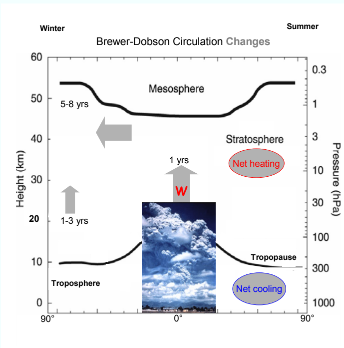

**Fig. 8**: The mass stream function: positive/negative anomalies indicate an accelerated/decelerated BDC on the NH winter side.

## How is the BDC changing?

**Conclusion I**: The CCM results are based on 3 volcanic eruptions (n=5):

- The observed **enhanced ascend in the tropical stratosphere,** due to direct aerosol heating (Robock, 2000), is supported by the model experiments. The model simulates negative tropical ozone anomalies (Fig. 2) and a localized enhanced ascend in the tropics (stream function changes in Fig. 5). Superimposed is a clear QBO signal in the tropical stratosphere, with enhanced/ weakened ascend in the Easterly/Westerly phase of the QBO (Fig. 3 and 5).
- **Weakened descend in the winter lower stratosphere** is simulated over the polar region (Fig. 5), accompanied by a colder and stronger polar vortex (not shown here) and slightly enhanced Westerlies (Fig. 3). In the mid and upper polar stratosphere slight positive changes are visible in the stream function.
- **Stronger meridional transport** from the tropical towards the polar upper stratosphere illustrated by enhanced mass transport in the meridional branch of the stream function (Fig. 5).
- The **planetary wave driving is enhanced** (a) in the extratropical lower stratosphere south of 45°N and (b) in the mid- and upper stratosphere north of 50°N, leading to an accelerated BDC from 5°-10°N up to ~50° to 70°N (Fig. 4).
- The model simulates an **asymmetric response of the BDC** probably due to a) direct radiative effects and b) indirect dynamical effects, as all natural forcing components are included at once. This does not allow to distinguish between single forcings.

More detailed studies with longer time series and single forcings are needed → part II.




**Conclusion II**: The GCM results are based on the Pinatubo eruption (n=10) for DJF 1991/92

**Zonal wind anomalies** for the NH (Fig. 6) show in the:
**US/MS:** a weakening of the PNJ due to all three forcing components (A-O-Q-AOQ), which is in contrast to Fig. 3 (right).
**LS:** a strengthening/ weakening of the PNJ in the A/O-Q-AOQ responses.
**Tropics:** a strong QBO signal, which is visible in the whole stratosphere with compensating Easterly anomalies in the US (Q-AOQ).
**Troposphere**: the El Nino in 1991/92 caused a strengthening and a shift of the subtropical jet streams (O).

**Div F anomalies** in the extratropics (Fig. 7):
**US:** enhanced wave driving in the A-O runs, whereas the QBO-AOQ simulations show a dipole pattern with weakening wave driving equatorward of 60N.
**LS/MS:** enhanced/weakening wave driving in AOQ/Aer1, with a change in the vertical in O-QBO.
**Tropics:** a clear QBO signal with more/less wave breaking below the QBO E/W phase.
**Troposphere:** weakening wave driving in the subtropics (Hadley cell) probably due to the El Nino in 1991/92 (O-AOQ simulations).

**Mass stream function anomalies** (Fig. 8):
**Stratosphere:** accelerated BDC in the extratropics, which shows only in the Aer1 runs a decelerated polar branch of the BDC in the lower stratosphere.
**Tropics:** a clear QBO signal, with acceleration/deceleration of the tropical branch of the BDC due to the QBO E/W phase (Q-AOQ runs).
**Troposphere:** strengthening of the mass stream function in the tropics and extratropics (Hadley and Ferrell cell) in the O-AOQ anomalies.

(US: Upper Stratosphere, MS: Middle Stratosphere, LS: Lower Stratosphere)

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