Reassessment of the Total Ozone Column Variability after Pinatubo using a nudged CCM

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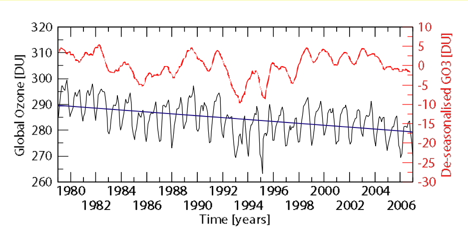
Introduction:

The eruption of Mount Pinatubo volcano in June 1991 resulted in the largest stratospheric aerosol loading in the Twentieth Century. The aerosols affected the atmosphere's dynamics, heating the lower stratosphere and cooling the troposphere. These changes had significant impacts on atmospheric chemistry, producing record lows in the mid-latitude ozone column and affecting the growth rates of methane and CO_2.

We study this period using the UKCA CCM (Morgenstern et al., 2008a). This combines the Met Office's New Dynamics UM with a stratospheric chemistry scheme. We use the nudged version of this model (Telford et al., 2008) to constrain the model using ERA-40 data to reproduce the temperature changes and associated changes in circulation. We then investigate the impacts of these changes on ozone and study the different causes.

Ozone Observations

- Use TOMS/SBUV total ozone column (Bodeker et al., 2005).
- No high latitude TOMS data, global ozone is defined as 60°S-60°N.
- Remove long term trend, annual cycle and apply smoothing.
- The low ozone in 1993 and 1995 can clearly be seen.



Model Set-up

We use the new UKCA CCM (Morgenstern et al., 2008a,b) with a

- Horizontal grid of 3.75°×2.5°
- 60 vertical levels from surface to 84 km
- Dynamical time-step of 30 minutes
- comprehensive stratospheric chemistry (Cl, Br, O3...)

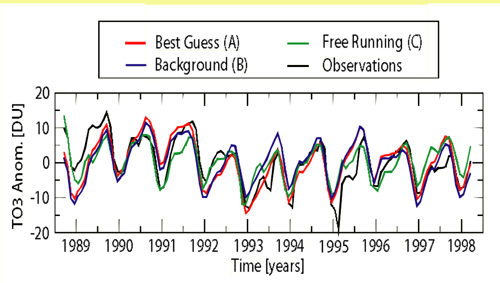
The Pinatubo eruption is introduced into the model by

- Nudging to ERA-40 T(θ),u,v to obtain dynamical response
- Prescribing SAD from NASA, updated from Thomason et al., (1997)
- Prescribing Optical Depth from Sato et al. (1995)

Perform three model runs, compare with observations. Subtract mean to compare anomalies.

Run	Dynamics	SAD
A (Best Guess)	Nudged	Pinatubo
B (Background)	Nudged	Background
C (Free)	Free	Pinatubo

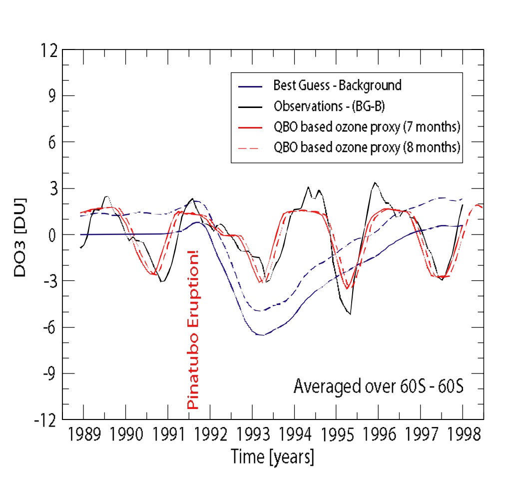
- Either use nudged or free running dynamics
- Either use full time-series of SAD or fix to 1990 (background) levels



- Best Guess (A) gives good agreement after spun-up
- Background (B) underestimates Pinatubo depletion, as expected
- Free running (C) generally good, but poor QBO leads to differences

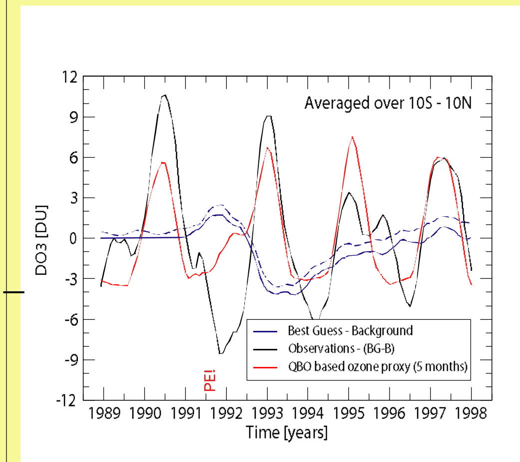
Global Ozone Variability:

- Compare runs with Pinatubo and Background SAD
- Difference in ozone (Run B-A) is attributed to 'chemical effects'
- Subtract this from observed variability and attribute the remaining variability to 'dynamics'



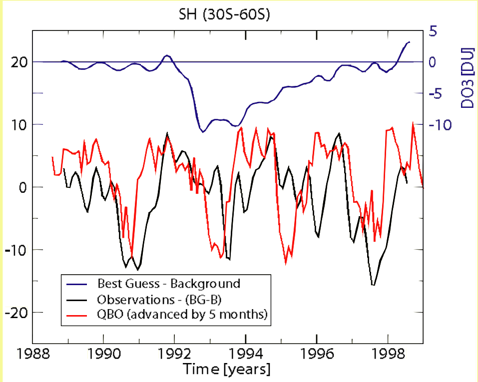
- Observe chemical depletion as sulfate cloud spreads, returning to normal by late 1990s
- Peak effect in early 1993 of 7.2 DU, agrees with observed 6.7 ±1.1 DU (Stolarski et al., 2006)
- No depletion observed in dynamical variation
- Dynamical variability correlates well with QBO proxy (Naujokat, 1986)
- No observable correlation with ENSO index (Wolter & Timlin, 1993)
- In addition to global ozone focus on regional effects in the tropics (10S-10N) and mid-latitudes (30-60 S/N)

Tropical Ozone:

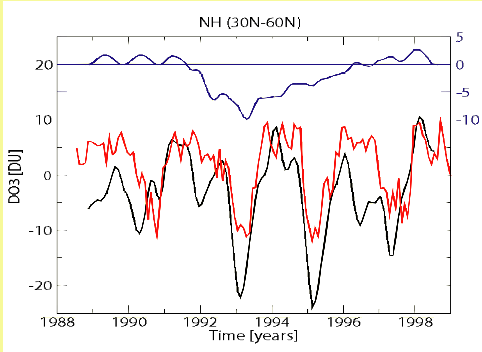


- Magnitude of chemical depletion smaller than, though timing similar to, global ozone
- Residual correlates well with QBO proxy (Note inverted and different lag to global ozone)
- Low ozone at the time of the eruption, BUT see before and after
- Residual correlates well with an ENSO index ('91/'92 El Niño)

Mid-Latitudes Ozone:



- Ozone variations for Southern mid-latitudes (above) & northern mid-latitudes (below)
- Chemical effect (blue) is similar for both, though timing of the minimum is triggered by the annual cycle of temperatures (e.g. dilution of polar air in spring)
- Superimpose QBO proxy (red, note different lag to global)



- Before '91 and after '96 NH and SH ozone look similar, both correlate with QBO proxy with a 7 month lag
- After the eruption, SH ozone no longer correlates with QBO proxy and NH ozone correlates well with a 5 month lag
- NH 'dynamical' depletion in 1993 and 1995
- This dynamical variability is the main cause of the very low ozone in northern mid-latitudes after Pinatubo

Conclusions:

- UKCA CCM reproduces global ozone variability around Pinatubo eruption
- Increased heterogeneous chemistry causes depletion of global ozone, peaking at 7.2 DU in early '93
- No detectable evidence of any other causes of ozone depletion on a global scale
- Main cause of variability at all studied latitudes is QBO
- Some contribution from El Niño in the tropics
- Qualitative difference in variability in northern mid-latitudes after Pinatubo produced low ozone

References:

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Summary: The eruption of Mount Pinatubo produced record low amounts of extra-polar ozone. We diagnose that the depletion of global ozone by heterogeneous chemistry peaked at 7.2 DU in early 1993. On global scales we see the remaining variability is driven by the QBO. In the tropics we observe low ozone related to the '91/'92 El Niño. In mid-latitudes we see a qualitative difference in the relationship between the QBO and ozone after Pinatubo, producing low values of ozone in the Northern hemisphere.