Modelling the effects of a realistic QBO on Antarctic ozone variability

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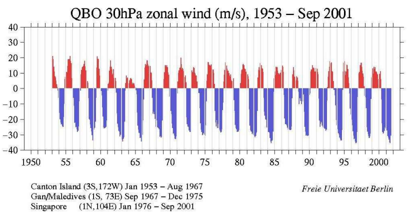
Abstract

The size and intensity of the Antarctic ozone hole is known to be influenced by a number of natural and anthropogenic factors. This large year-to-year variability is due to the heterogeneous chemistry of ozone destruction being extremely sensitive to changes in stratospheric temperature (within the polar vortex). Several recent studies support the hypothesis that the simulation of Antarctic ozone would be significantly improved by the inclusion of an important mode of atmospheric variability known as the Quasi-Biennial Oscillation (QBO).

Recent work using a chemistry-climate model (SOCOL) has investigated the chemical and dynamical variations associated with both the solar cycle and the solar rotation period. The present study will build on this analysis, and incorporate QBO variability into the system. Model resolution and diffusion limits the explicit representation of model waves that help drive the QBO. To overcome this restriction a two-phase investigation is proposed: (1) transient solar-irradiance will be combined with imposed, realistic equatorial-wind profiles. The latter will be achieved by relaxing the model towards typical observed QBO/E and QBO/W values, (2) the Hines gravity wave parameterisation will be incorporated into SOCOL to simulate the action of gravity waves on the mean flow. The Hines parameterisation has recently been shown to produce a realistic QBO signal in the Hadley Centre Unified Model.

The Quasi-Bienniel Oscillation (QBO)

The QBO dominates the variability of the equatorial stratosphere and is characterised by downward propagating easterly and westerly wind regimes, with a variable period averaging 28 months. Although essentially equatorial in nature, many studies have demonstrated a strong relationship between QBO phase and Antarctic ozone loss.



The mechanism is as yet not completely understood, but a likely candidate is that induced-changes in zonal winds and potential vorticity, increases the effectiveness of wave energy propagation to high latitudes in the easterly phase while reducing it in the westerly phase. In turn, temperatures in the Southern Hemisphere stratosphere are increased/reduced respectively (with associated impacts on the nonlinear heterogeneous ozone chemistry).

Image sourced from: http://www.jisao.washington.edu/data_sets/qbo/

SOCOL Model

The chemistry-climate model SOCOL has been developed which couples a middle-atmosphere GCM with a chemical-transport model:

MA-ECHAM4 AGCM

- **T30 truncation (grid spacing of 3.75º)**
- **39 hybrid vertical levels; surface to 0.01hPa**

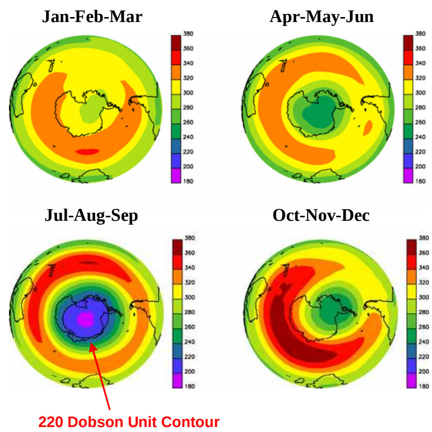
MEZON chemistry model

- **41 chemical species**
- **118 gas-phase reactions**
- **33 photolysis reactions**
- **16 heterogeneous reactions on/in sulphate aerosol and PSC particles**

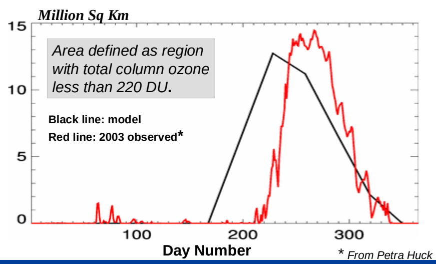
SOCOL Installation

A version of SOCOL has been installed locally, and is now undergoing a series of test runs. An initial analysis is made of the results from a one year integration (pre-anthropogenic CFCs), with specific emphasis on Antarctic ozone variability.

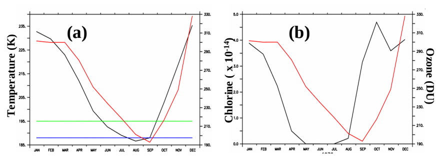
Seasonal Total Column Ozone



Ozone Hole Area



Polar Vortex Chemistry



Black lines and left axis indicate (a) temperature, (b) chlorine concentration. (Average values for stratospheric region 5-125 hPa). Red line on each plot indicates total column ozone. All field averaged over geographical region 78S-pole. In (a) green and blue lines indicate temperature of type I and type II PSC formation respectively.

Model Results*

- **SOCOL looks to have a realistic ozone climatology.**
- **Model shows seasonal development and recovery of Antarctic ozone hole.**
- **But: The ozone hole develops too early (before PSC formation) , and also becomes far too strong (for a pre-CFC scenario).**
- **Ozone destruction seems too closely correlated with vortex temperature, rather than solar irradiance/PSC-formation (possible anomalous Brewer-Dobson circulation: polar diabatic descent too strong).**

** It should be noted that these are very preliminary results from a test run*

The QBO Problem

Several studies have indicated that the QBO has a significant impact on polar stratospheric ozone chemistry. The problem is:

- **The present generation of GCMs are unable to spontaneously produce an atmospheric QBO (SOCOL included).**
- **Although model spatial and temporal resolutions seem adequate for simulating such a large feature, model resolution and diffusion limit the explicit representation of model waves that help drive the QBO.**

The QBO Solution

Inclusion of the QBO may improve the anomalous model Brewer-Dobson circulation. To overcome the present model deficiencies, two courses of action are possible:

1. Data Assimilation

- **The CCM will be run with specified solar irradiance and imposed realistic equatorial wind profiles by relaxing the model towards observed QBO/E and QBO/W values.**
- **With realistic, enforced conditions the resulting stratospheric ozone chemistry will be contrasted with that of a control run without QBO forcing*.**

2. Improved Gravity Wave Parameterisation

- **A Hines gravity wave parameterisation will be incorporated into SOCOL to simulate the action of gravity waves on the mean flow.**
- **It is proposed that the WM scheme is implemented. A source spectrum of upward propagating buoyancy waves will be launched from a quasi-horizontal level near the surface.**
- **A similar scheme has been seen to produce a realistic QBO in another AGCM (see figure 4).**
- **The model analysis will take the same form as per the assimilation scheme above.**

** The there will be an ensemble of control/perturbed integrations*

Modelled QBO using the WM Scheme

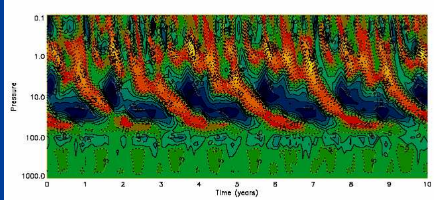


***Figure 4**: Model simulation of zonal winds over the equator for a period of 10 years (MetOffice Unified Model). Plot from Scaife et al., 2000. GRL, Vol. 27, No 1, pp 3481-3484.*

Closing Remarks and Contact Details

The SOCOL model has been installed and initial integrations performed. The successful incorporation of a realistic QBO into the model would be a major boon for research into understanding the annual Antarctic ozone hole onset (and ensuing recovery).

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