Modelling the effects of an active QBO in the SOCOL chemistry-climate-model

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Abstract

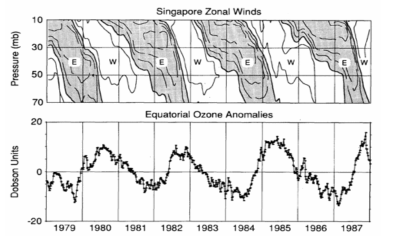
The size and intensity of the Antarctic ozone hole is known to be influenced by a number of natural and anthropogenic factors. This is due to the heterogeneous chemistry of ozone destruction being extremely sensitive to changes in stratospheric temperature within the polar vortex. Defining temperature anomaly mechanisms is crucial if one wishes to understand the austral springtime formation, and interannual variability, of the ozone hole.

Several recent studies have shown the mode of dynamic variability know as the Quasi-Biennial Oscillation (QBO) to be significant in the regulation of Antarctic stratospheric temperatures. Limits in the resolution of present-generation atmosphere models prevent the explicit representation of the QBO: to correctly simulate middle-atmosphere dynamics its characteristics need to be parameterised.

The standard SOCOL Chemistry-Climate-Model fails to exhibit any QBO-like variability. A new non-orographic gravity wave parameterisation is detailed. Results are presented showing the impact of the new scheme on SOCOL middle-atmosphere dynamics.

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.



* *Bowman, JAS, 1989*

The equator-to-pole 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).

SOCOL Model

The chemistry-climate model SOCOL has been developed which couples a middle-atmosphere GCM with a chemical-transport model (see Egorava *et al*, 2005):

MA-ECHAM4 AGCM

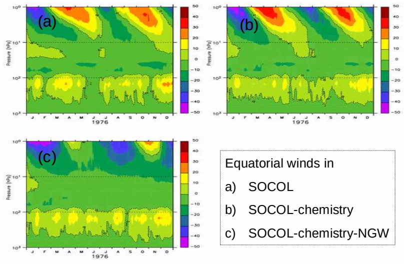
- **T30 truncation (grid spacing of 3.75º)**
- **39 hybrid vertical levels; surface to 0.01hPa**

MEZON chemistry model

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

Non-orographic gravity wave (NGW)

The QBO is believed to be forced by small-scale wave sources (e.g., deep convection, boundary-layer turbulence) which are unresolved in present generation-models: modelled stratospheric winds are, in general, non-oscillating and easterly. NGW paramerisations attempt to correct for this deficiency, and SOCOL includes a Hines NGW scheme.



The parameterisation has an insignificant impact on equatorial-stratospheric winds (compare runs with and without Hines). Vertical momentum transport is evident via an enhancement in the semi-annual oscillation (SAO) wind magnitudes of the mesosphere.

New NGW scheme for SOCOL

The new NGW scheme uses Warner and McIntyre dissipation theory: code based on that of Scinocca.

Unresolved wave sources are simulated by a spectrum of waves launched at a specific height in the model atmosphere. These are azimuthally isotropic and independent of time and location. The dispersion relationship is assumed to be hydrostatic.

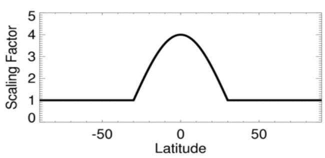
The linear component of the vertically propogation gravity wave spectrum are dispersed by applying critical (velocity) layer filtering. Non-linear dissipation is applied to the remaining spectrum using the saturated momentum flux density in k-ω space:

$$\rho F^{sat}(k,\omega,\phi) = C^{*} B m_{*}^{3} \rho N^{2} m^{-3} \hat{\omega}^{-3/2}$$

which defines the maximum energy absorption at that model level (see McLandress, 2004)

SOCOL Model Specifics

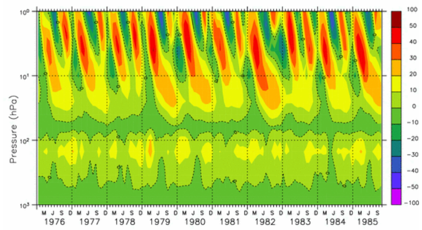
De-coupling the atmosphere from the chemistry model was shown (above) to have an insignificant effect on equatorial wind patterns. NGW paramerisation development has proceeded using a locally decoupled version of MA-ECHAM4 due to model run-time considerations (MEZON is not optimised for supercomputer usage).



The source momentum flux is scaled latitudinally by 1.0 in the extratropics and (1+3cos(3xlatitude)) in the tropics (30S to 30N) with a (scaled) E-P flux of 4.25 x 10^{-4} Pa.

New Stratospheric Winds

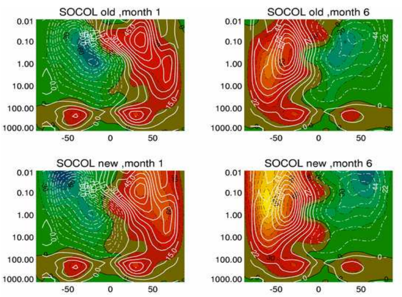
The figure below shows a SOCOL model run of 10-years with the new scheme (spectrum launch level of 125 hPa)



The model now deposits momentum in the equatorial stratosphere, and simulates a weak oscillation in wind direction. The wind direction is now predominantly westerly (a reversal of previous results).

Global Picture

Comparison of SOCOL (old and new) zonal winds with the CIRA standard atmosphere (white contours). Model data are 10-year monthly climatologies (January and June).



The plot shows significant differences between the two models jet structure at the stratopause (with potential impacts on the seasonal development of the Antarctic ozone hole). The polar night jet in the new system is at a more realistic altitude than previously, though is too intense.

Further Work

The results presented here are very much "work-in-progress". The replacement NGW scheme has only recently been implemented, and requires further optimisation. Some of these steps are as follows:

- clarify the E-P flux magnitude and its latitudinal scaling.
- define optimum launch level.
- investigate the model sensitivity to starting conditions.
- investigate westerly bias in new model winds.
- verify the momentum deposition vs. observational data

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