Spatial structure of the quasi-biennial oscillation in zonal wind and ozone simulated with the MRI-CCM

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MRI-CCM (Shibata et al., 2005)

GCM : MRI/JMA98 (Shibata et al., 1999)
Chemistry module : full chemistry and transport process

Chemistry
- 36 long-lived species including 7 families
- 15 short-lived species (which are diagnosed)
- 35 photodissociations and 80 gas phase reactions
- 9 (6+3) heterogeneous reactions on PSCs and sulfate aerosols

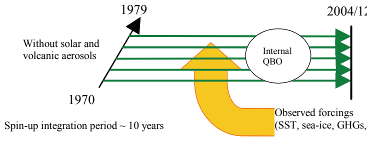
Transport – **hybrid semi-Lagrangian scheme**
- Horizontally, simple semi-Lagrangian scheme (quintic interpolation)
- Vertically, flux-form semi-Lagrangian scheme (piecewise rational method)

Resolution
- 68 layers (thickness = 500 m from 100 to 10 hPa)
- eta-ordinate (Surface to 0.01 hPa)
- T42 (64 x 128 Gaussian Grids: 2.8 deg)

Gravity Wave Drag
- **Hines (1997) parameterization with enhanced source in the tropics**

CCMVal Simulations

Scenario	Core Time Period	GHG (N_2O, CH_4, CO_2)	Halogen (CFCs..)	SSTs	Volcanic & Back-ground Aerosol	Solar Flux	QBO
REF1	1980 - 2004	Observed WMO/UNEP 2002 runs	Observed WMO/UNEP 2002 runs	Observed HadISST1	Observed	Observed	Spontaneously Generated



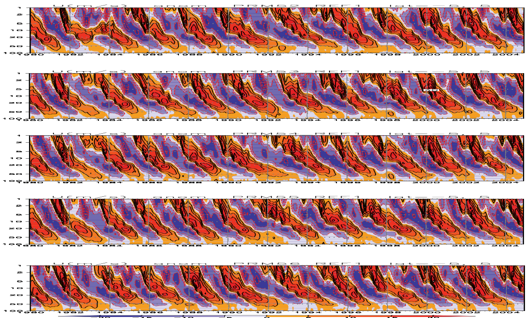


Fig.1. Time evolution of the zonal-mean zonal wind averaged between 10°S and 10°N for the five members.

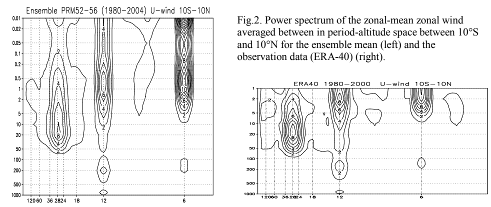


Fig.2. Power spectrum of the zonal-mean zonal wind averaged between in period-altitude space between 10°S and 10°N for the ensemble mean (left) and the observation data (ERA-40) (right).

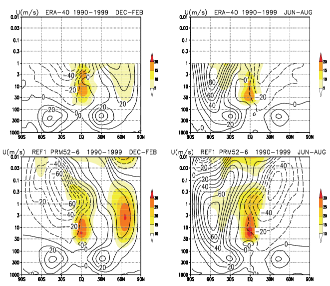


Fig.3. Latitude-pressure cross section of zonal-mean zonal wind (contour, m/sec) and its interannual variations (shading) during Dec.-Feb (left) and Jun-Aug. (right) over 10 years (1990-1999). Upper panel is for ERA-40 and lower one is for the ensemble mean.

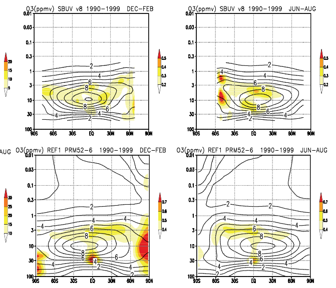


Fig.4. Same as in Fig.3 but for ozone (ppmv).

Multiple Linear Regression Analysis

$$
\begin{aligned}
O_3(t) = {} & A + \\
& B \times t + \\
& C \times QBO\,(50\,hPa)(t) + \\
& D \times QBO\,(20\,hPa)(t) + \\
& E \times Pinatubo\,(t - \alpha) + \qquad (\alpha, \beta < 12) \\
& F \times El\ Chichon\,(t - \beta) + \\
& G \times ENSO\,(t) + \\
& H \times Solar\ Flux\,(t) + \\
& Residual\,(t)
\end{aligned}
$$

To fit seasonal variability, the coefficients A, B, C, …, and H are expanded as

$$A = A0 + A1\cos(\omega t) + A2\sin(\omega t) + A3\cos(2\omega t) + A4\sin(2\omega t) + A5\cos(3\omega t) + A6\sin(3\omega t)$$

$$(\omega = 2\pi/(12\ \text{months}))$$

Fig.5. Formulation of the multiple linear regression model. Reference (explanatory) variables are the mean value, the linear trend, the QBOs at 20 and 50 hPa, volcanic aerosols of El Chichon and Mount Pinatubo, ENSO, and the 11-year solar cycles. Coefficients are expanded by annual, semiannual, and triannual cycles to explain seasonality.

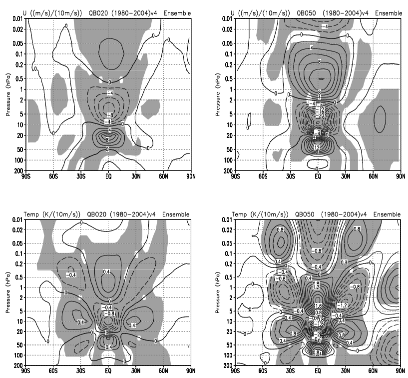


Fig.6. Latitude-pressure cross sections of the annual-average QBO20 (left) and QBO50 (right) signals for zonal winds (upper, (m/s)/(10m/s)) and temperature (lower, K/(10m/s)) from 200 to 0.01 hPa. Contour interval is 2 and shading denotes the 95 % confidence level (t-test).

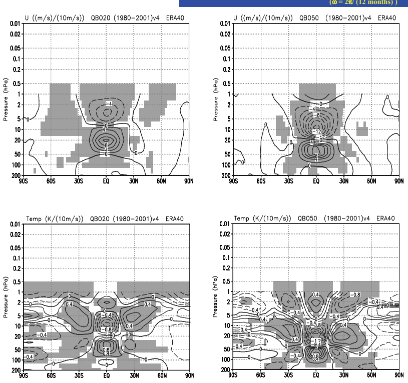


Fig.7. Same as in Figure 6 but for ERA-40.

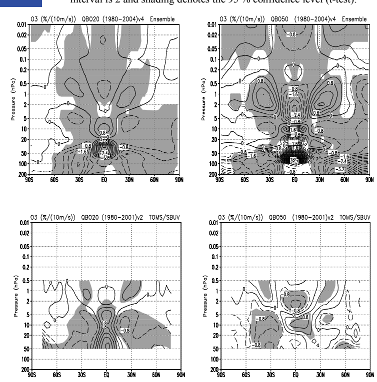


Fig.8. Latitude-pressure cross sections of the annual-average QBO20 (left) and QBO50 (right) signals (%/(10m/s)) for the simulated ozone (upper), and SBUV/TOMS ozone from 200 to 0.01 hPa. Contour interval is 2 and shading denotes the 95 % confidence level (t-test).

Summary

- Ensemble (five members) simulation of the middle atmosphere over the past 25 years (from 1980 to 2004) was performed with the MRI-CCM by imposing observed natural and anthropogenic forcings of SST, sea ice, greenhouse gases, halogens, the 11-year solar cycle, and volcanic aerosols.
- Multiple linear regression analysis was performed for temperature, zonal wind, and ozone to separate the trend, the QBO, the El Chichón and Mount Pinatubo, the 11-year solar cycle, and the ENSO signals. Time lags less than 12 months are incorporated for the two volcanic eruptions.
- The annual average QBO signals of temperature and zonal wind are well reproduced with regard to their meridional structures, which are characterized by two or three cells with alternating signs in the strato-sphere, in spite of the slightly shorter QBO period of 27 months.
- Similarly, the simulated ozone QBO signal also captures the observed meridional structure of vertical multi-cells.
- The seasonality of the mid-latitude total ozone QBO, which extends poleward with opposite sign to the equatorial total ozone QBO in the winter hemisphere, is also quantitatively reproduced in the QBO20 signal, although there is no extension to high latitudes in the spring time.

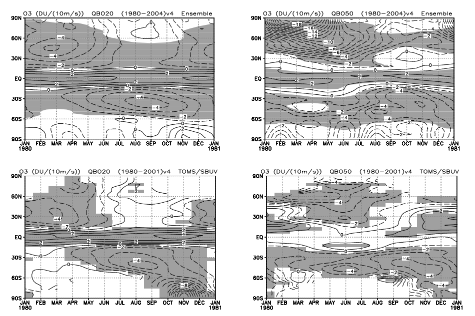


Fig.9. Month-latitude cross sections of the QBO20 (left) and QBO50 (right) total ozone signals (DU/ (10m/s)). The contour interval is 1, and shading denotes the 95 % confidence level (t-test) for the model (upper) and the TOMS (lower).