The study of the non-linear interaction between Quasi-biennial Oscillation and Solar Cycle from THINAIR model

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The THINAIR model is a two and a half dimensional dynamics model as it has zonally averaged dynamics plus three longest planetary waves. It uses isentropic vertical coordinate above 350 K. Below 350 K a hybrid coordinate is used to avoid intersection of the coordinate layers with the ground. The model version used in this study has 29 layers from the ground up to ~100 km for dynamics and 17 layers from ground up to ~60 km for chemistry. The model has 19 horizontal grid points evenly distributed from pole to pole.
The isentropic coordinates provides the natural framework to treat eddy fluxed with only one non-zero element. They also provide conceptual advantages stemming from the relationship between vertical velocity and diabatic heating rate (Kinnersley and Harwood, 1993). The QBO-source term in the momentum equation could choose either wave parameterization (Kinnersley, 1996) from Kelvin Waves and Rossby-Gravity Waves or relaxation to Observed QBO (Singapore, 80-93) Winds (Kinnersley, 1998). QBO data and lower boundary condition for planetary waves has been extended to 2005. Solar cycle was also been added in this model. The 11-year solar cycle input in the model is UARS/SOLSTICE spectral irradiance observation (figure 1). It consists of the solar spectrum in UV 119-400 nm during 1991-2002, with 1-nm resolution. The monthly data has been extended to 1947-2005 using F10.7-cm as a proxy (Jackman, et al. , 1996). Beyond 2005, the solar cycle is estimated by repeated use of previous cycles.

Recent analysis of NCEP data provides strong evidence for the role of the solar cycle in modifying the QBO (Salby and Callaghan 2006). Mayr et al. (2006) linked the solar cycle effect in the lower atmosphere to the QBO of the zonal circulation. They simulated the solar cycle modulation of the QBO and found that the solar cycle influence on the QBO is amplified and transferred to lower altitudes by tapping the momentum from the upward propagating gravity waves. The most likely connection between solar cycle and climate is via ozone. Therefore ozone in stratosphere response to the solar UV variability was study here by analysis the THINAIR model simulation.

(1)

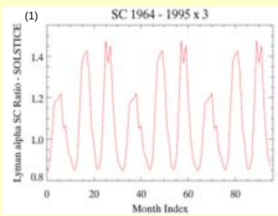

Figure (1) The ratio of change of the photon flux input at the Lyman-alpha line (121.5 nm) of the 96-year input. The first three cycles (corresponding to 32 years) were repeated three times to give the 96-year data set. Ratio = 1 corresponds to the original flux input at the Lyman-alpha line in the THINAIR model.

Camp *et al.* (2003) showed that two leading modes of tropical total ozone variability in the Merged Ozone Data (McPeters, 1996) exhibit structures of the QBO and the solar cycle.

Figure (2) is the cross section of latitude and time series of ozone column in the THINAIR (see above panel for details) model simulation including both QBO and solar cycle. This plot shows only the low-passed solar cycle response. The solar cycle signal of ozone column is well simulated in this case. Of particular interest is the fact that the polar ozone is twice as large as the equatorial ozone (8 DU at the pole vs 4 DU at the equator, Figure 3a) and that both are *in phase* with the solar UV flux. Their correlation coefficient is 0.85 (figure 7). Figure (3 b) below is the power spectrum for the black line (90˚N) in figure (3 a), which shows the frequency of the solar cycle.

(2)

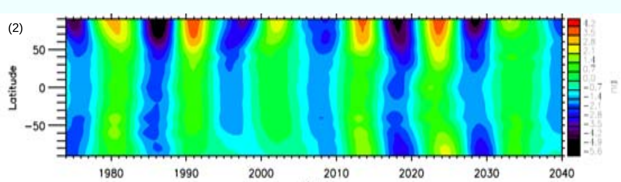

Figure (2) the cross section of latitude and time series of the lowpass filtered ozone column in the simulation case with both solar cycle and QBO.

Abstract

The effect on column ozone by the 11-year solar cycle and the quasi-biennial oscillation (QBO) is studied using the THINAIR (Two and a Half dimensional INterActive Isentropic Research; Kinnersley and Tung 1999) model, an isentropic chemical-dynamical-radiative atmospheric model. Both easterly QBO and solar max create large anomalies at the polar region, clearly due to the effect of transport from the photochemical region in the tropical stratosphere; the anomaly at the polar region is twice (more than twice) as large at the pole compared to that at the equator for solar cycle (QBO) forcing. Of interest is the different phase relationships. For QBO forcing, the polar response is anti-correlated with the equatorial response, as is well known, but for solar cycle forcing, the response is in phase. The difference illustrates the different origins of the anomaly. For the solar cycle phenomenon, there is more UV radiation during solar max and hence more production of ozone in the tropical stratosphere, which is then transported to high latitudes. For the QBO phenomenon, the rising equatorial branch of the QBO circulation reduces column ozone in the equatorial region, but transports photochemically produced ozone to high latitudes, resulting in an anti-correlation.

(3 a) (3 b)

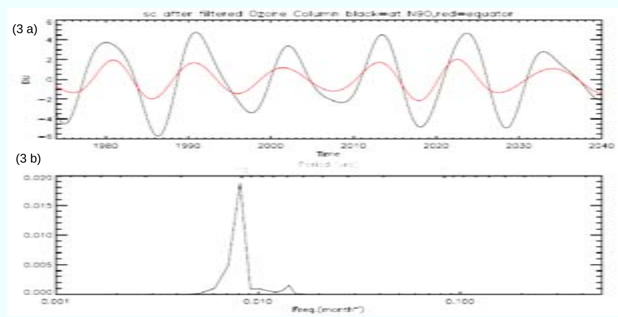

Figure (3a) the black line is the ozone column at 90˚N and the red line is that at equator. Both are lowpass filtered.
Figure (3b) is the power spectra is for that black line in figure (3 a) at 90˚N ozone column.

Two cases from THINAIR model are compared. One case includes QBO only and the other case includes both QBO and solar cycle. Comparing the amplitude of solar cycle signal of column ozone between these two cases after the QBO was lowpass filtered, the case with QBO has a larger amplitude than the case without QBO (figure 4). With the QBO effect, the solar cycle response at the equator is amplified about 5%.

(4)

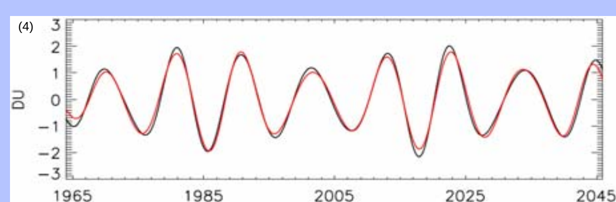

Figure (4) Lowpass filtered ozone column at equator. Black line is the case with solar cycle and QBO signal; red line is the case with solar cycle but no QBO signal.

By studying the case with QBO signal only, the model reproduces the previous observation that QBO signal of column ozone at equator is anti-correlated with that at North pole. The black line and red line in figure (5) correspond to the ozone column at equator and one-year running mean of ozone column at 90˚N for the case with only QBO. The scatter plot (figure 6) between these two lines is shown below. The QBO at equator is anti-correlated with that at 90˚N. The correlation coefficient is -0.50. It was also noticed that the amplitude of QBO signal in column ozone in 90˚N is larger than that at equator. This pattern agrees with the observation. Thus, THINAIR model simulates QBO well.

The solar cycle signal in ozone column at equator is correlated with that at 90˚N with correlation coefficient of 0.85 (figure 7).

(5)

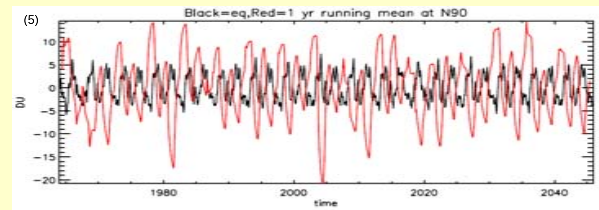

Figure (5) QBO signal in column ozone, black line: at equator, red line: at 90°N

(6)

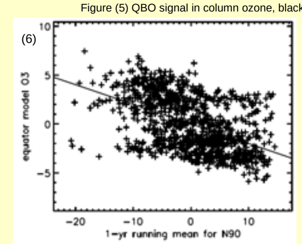

Figure (6) Scatter plot of QBO sigal in column ozone at equator and that at 90˚N. Correlation coefficient is -0.50

(7)

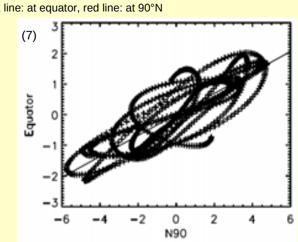

Figure (7) Scatter plot of solar cycle signal in column ozone at equator and that at 90˚N. Correlation coefficient is 0.85.

Conclusion:

Although solar variability variance has little direct effect at high latitudes, the 11 year solar cycle signal has been found in the polar region in both the stratosphere and troposphere. It is suggested that the QBO is the pathway through which the solar cycles affect the polar dynamics. Salby et al (2006) argued that the modulation of QBO frequency by solar cycles magnify the solar signal in the poles. Camp and Tung (2006) suggested that the number of the Stratospheric Sudden Warming (SSW) events preconditioned by the solar max increases, as that by the preconditioning by the easterly QBO. Our model simulations didn't find any difference of QBO frequency in the different solar cycle phases. However, we did find that the SSW occurs more frequently during solar maxima, consistent with the results of Camp and Tung (2006). The reason is that the changes of winter dynamics at high latitudes due to the SSW lead to the larger solar signal at the polar than in the tropics in column ozone and Brewer-Dobson circulation .

The model simulations help us understand the nonlinear interaction of solar cycle and QBO. The solar cycle signal of column ozone is about twice as large at the North pole than at the equator. Solar cycle signal of column ozone is amplified slightly at the equator by QBO. Solar cycle signal of column ozone is well correlated between equator and north pole while this relation of QBO signal is found to be anti-correlated.

Reference:

Camp, C. D. et al. 2003, *J. Geophys. Res*., 108, 4643; Camp, C. D. and K. K. Tung, 2006, *J. Atmos. Sci*. in press; Jackman, C., et al., 1996, *J. Geophys. Res., 101*, 28753-28767. Kinnersley, J. S. et al., 1993, *Q. J. R. M. S.119,*1167-1193; Kinnersley, J. S., 1996, *Q. J. R. M. S. 122*, 219-252; Kinnersley, J. S., 1999, *J. Atmos. Sci*., *56*, 1140—1153; Kinnersley, J. S. et al., 1999, *J. Atmos. Sci*., *56*, 1942—1962; Mayr, G. H. et al. 2006, *Geophys. Res. Lett., 33*, doi: 10.1029/2005GL025650; McPeters, R. et al., 1996, *Bull. Am. Meteor. Soc., 77*: 353-357, http://code916.gsfc.nasa.gov/Public/Analysis/merged/; Salby, M. L. et al.,2006, *J. Geophys. Res.-Atmos, 111*, Art. No. D06110.