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

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Camp *et al.* (2003) illustrated that two leading modes of tropical total ozone variability exhibit structrures of the QBO and the solar cycle.

Figure (2) is the cross section of latitude and time series of ozone column in the model simulation including both QBO and solar cycle signal. This plot is the ozone column after the QBO signal was lowpass filtered. The solar cycle signal of ozone column is well simulated in this case. Analyzing this case which with both solar cycle and QBO signal and comparing its lowpass filtered ozone column at equator and 90°N, it was found that the amplitude of solar cycle signal in column ozone is increased from 4 DU at equator to more than 8 DU at pole (figure 3 a). The solar cycle signal of column ozone is about twice increased at North pole than at equator. It was also noticed that the solar cycle signal of ozone column at 90°N and at equator are well correlated. 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 signal of solar cycle.

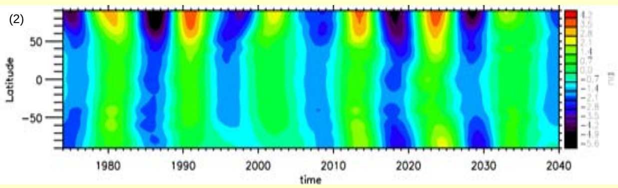


Figure (1) the cross section of latitude and time series of the lowpass filtered ozone column in the simulation case with both solar cycle and QBO.

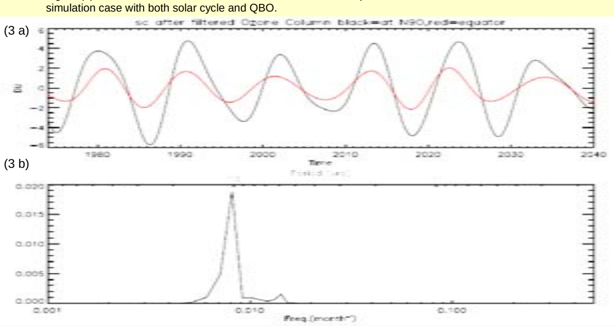


Figure (3 a) the black line is the ozone column at 90°N and the red line is that at equator. Both are lowpass filtered. Figure (3 b) is the power spectra is for that black line in figure (3 a) at 90°N ozone column.

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

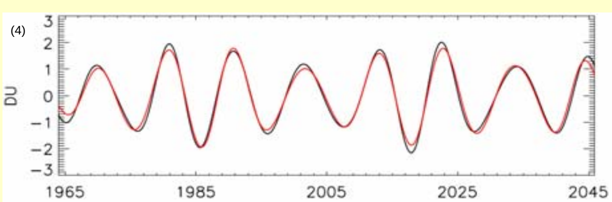


Figure (4) Lowpass filtered ozone column at equator. Black line is the case with solar cycle and QBO signal; red line is the case with solar cycle but no QBO signal.

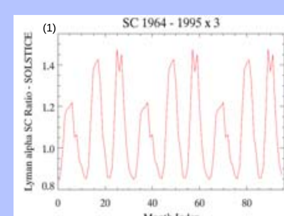
Abstract

The quasi-biennial oscillation (QBO) is considered a potential amplifier of the solar cycle effect in the lower atmosphere (Mayr et al., 2006). We used the THINAIR (Two and a Half dimensional INterActive Isentropic Research; Kinnersley and Tung 1999) model, an isentropic chemical-dynamical-radiative atmospheric model, to investigate this mechanism. This model can simulate the ozone QBO quite well. In the simulation using a non-interactive chemistry transport model, the model O3 column for the solar cycle in the tropics agrees with the scaled solar flux at 10.7 cm, except that the amplitude of model O3 column variability is about half of that from MOD data. In the interactive model, it is found that the amplitudes of the model O3 column of both QBO and solar cycle are larger at the north pole than those at the equator. The amplitude of solar cycle signal of column ozone is also increased by 5% at equator with the influence of the QBO. The results support the recent findings of a non-linear interaction between the QBO and the solar cycle in the stratosphere (Salby and Callaghan, 2006).

The THINAIR model is a two and a half dimensional dynamics model as it has zanally 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, C., et al. , 1996).

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. In order to quantify the solar influence on climate, the most likely connection is via ozone. Therefore ozone in stratosphere response to the solar UV variability was study here by analysis the THINAIR model simulation.



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.

By studying the case with QBO signal only, it reproduced 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) are corresponding 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 -0.5. 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 has a good ability to simulate QBO.

It was found that solar cycle signal in ozone column at equator is correlated with that at 90°N with correlation coefficient of 0.85 (figure 7) while QBO signal in ozone column at equator is anti-correlated with that at 90°N with correlation coefficient of -0.5 (figure 6).

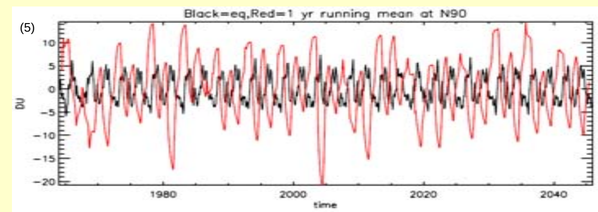


Figure (5) QBO signal in column ozone, black line: at equator, red line: at 90°N

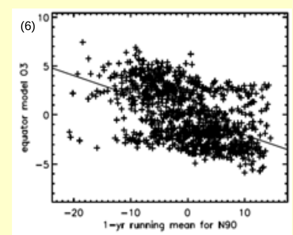


Figure (6) Scatter plot of QBO sigal in column ozone at equator and that at 90°N. Correlation coefficient is -0.5.

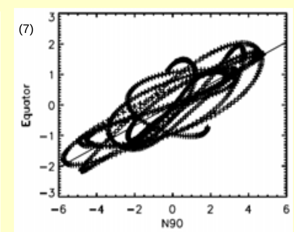


Figure (7) Scatter plot of solar cycle signal in column ozone at equator and that at 90°N. Correlation coefficient is 0.85.

***Conclusion*:**

The model simulation help us to learn the nonlinear interaction of solar cycle and QBO. It was found that solar cycle signal of column ozone is about twice increased at North pole than at equator. Solar cycle signal of column ozone is amplified at equator by effect of 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(D20), 4643; Jackman, C., et al., 1996, *J. Geophys. Res., 101*, D22. 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; Salby, M. L. et al.,2006, *J. Geophys. Res.-Atmos, 111*(D6), Art. No. D06110, MAR 31.