P4.2 THE THREE DIMENSIONAL STRUCTURE AND TIME EVOLUTION OF THE DECADAL VARIABILITY REVEALED IN ECMWF REANALYSES

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1. INTRODUCTION

Earlier studies asserting that the 11-yeas solar cycle has no effects on the Earth's climate emphasize the weak variability of the Sun's luminosity (Gerety *et al*., 1977; Hartmann, 1994), while a few have presented evidence of the effects in the upper atmosphere in general (Labitzke, 2005). Many Studies have stated the probable effects of the solar cycle on the surface weather at individual stations (King, 1973; Currie, 1974; Labitzke and van Loon, 1995).

The increase of the Sun's luminosity in a particular frequency band such as the ultraviolet is associated with solar forcing of atmospheric motions. Especially in the tropical stratosphere the production of ozone is proportional to increases in the ultraviolet radiation over a certain time period, after accounting for the quasi-biennial oscillation (QBO) and ENSO in the stratosphere (Angell, 1989; Zerefos et al., 1997; Hood, 1997; Labitzke, 2005). The solar cycle has a strong effect on the tropical Atlantic decadal oscillation (TADO), which has been documented for the sea surface temperatures and atmospheric variables such as relative humidity (Lim *et al*., 2006; Suh and Lim, 2006). It has been suggested that the zonal-mean zonal wind anomalies formed in the upper stratosphere and stratopause region in early winter can propagate downward into the troposphere through dynamical processes (Kodera *et al*., 1990; Kodera, 1995). Furthermore, It is stated that the solar influence produced in the upper stratosphere and stratopause region is transmitted to the lower stratosphere through modulation of the internal mode of variation in the polar night jet and a change in the Brewer-Dobson circulation (Kodera and Kuroda, 2002).

Our aim is to show that characteristics of phenomenon probably resulting from the 11-year solar cycle effects and its month-to-month variations in the northern winter time.

2. DATA and Methods

The data used to analyze the effects of 11-year solar cycle are monthly means of various meteorological parameters, reproduced from the European Center for Medium Range Weather Forecast (ECMWF) 6-hourly reanalyses for 45 years from September 1957 to August 2002. The data set covers 23 standard levels from 1000hPa up to 1hPa

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and its horizontal resolution is 2.5°×2.5°. Throughout this study, the solar forcing is quantified by the solar 10.7cm radio flux obtained from NGDC/WDC http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarradio.html, which can be regarded as a general proxy, highly and positively correlated with the 11-year solar cycle (Gleisner and Thejll, 2003; Kodera and Shibata, 2006).

We employed simple analysis methods: digital time filtering and composite mean difference. First, after monthly data were deseasonalized by removing the climatology, monthly anomaly data have been corrected for a linear trend and QBO-, ENSO-signals by using the linear detrend and the wavelet filtering procedure. Second, spatial patterns have been obtained by using the difference of the solar-max composite mean and the solar-min composite mean (Camp and Tung, 2007). One variability that the above wavelet filtering may not remove is the volcanic-aerosol effect. We didn't select the cases of volcanic eruptions, particularly El Chichón in March 1982 and Pinatubo in June 1991, coincidentally occurring during solar maxes, which may contaminate the 11-year signal (Fig. 1).

We calculate the monthly mean Eliassen-Palm flux (E-P flux) and the residual circulation ($\bar{v}^*$, $\bar{w}^*$) from 6-hourly ECMWF reanalyses (Eq. 1) (Edmon *et al.* 1980; Andrews *et al.*, 1987).

$$F_\varphi = a\cos\varphi\left(-\overline{u'v'} + \frac{\partial\bar{u}}{\partial z}\frac{\overline{v'\theta'}}{\frac{\partial\bar{\theta}}{\partial z}}\right) \qquad \text{1a}$$

$$F_z = a\cos\varphi\left[\left\{f - \frac{1}{\cos\varphi}\frac{\partial(\bar{u}\cos\varphi)}{\partial\varphi}\right\}\frac{\overline{v'\theta'}}{\frac{\partial\bar{\theta}}{\partial z}} - \overline{u'w'}\right] \qquad \text{1b}$$

$$\frac{\partial\bar{u}}{\partial t} + \bar{v}^*\left[\frac{1}{a\cos\varphi}\frac{\partial(\bar{u}\cos\varphi)}{\partial\varphi} - f\right] + \bar{w}^*\frac{\partial\bar{u}}{\partial z} - \bar{X} = \frac{1}{a\cos\varphi}\nabla\cdot\mathbf{F} \qquad \text{1c}$$

3. Analysis Results

Figure 2 represents the corrected southerly winds averaged over 40°W-20°W, 5S°-5N° varying in concert with the 11-year solar cycle, which is consistent with the reproduced southerly anomalies in Suh and Lim (2006).

Month-to-month variations of wave activity are represented as composite mean differences of the E-P flux and its divergence in Figure 3. E-P flux anomalies in December are directed poleward and downward from the middle and upper stratosphere in the northern hemisphere, while waves in January abruptly change to equatorward and upward directions and converge at upper stratosphere. Considering the wave-mean flow interaction, the zonal-mean zonal wind at high latitude upper stratosphere decelerates as January in Figure 4. Furthermore, E-P flux anomaly diverges and the polar night jet (PNJ) weakens in February (Kuroda and Kodera, 2001; Kodera and Kuroda, 2002; Matthes *et al.*, 2006). This downward penetration of the solar influence can be well reproduced by a general circulation model simulation (Shindell *et al.*, 1999). Another possible downward extension of the solar influence is through changes in meridional circulation.

The Brewer Dobson (BD) circulation (Figure 6) is weakened during solar-max years, which is associated with a strong zonal wind and a reduced wave forcing (Kodera and Kuroda, 2002)

Figure 5 shows composite mean differences of the zonal-mean meridional wind. Southerly winds at equator in the upper troposphere are stronger for solar-max years, while southerly winds at equator near the tropopause weaken (i.e. northerly anomaly). It is suggested that Hadley circulation for solar-max years is enhanced and shallower; two branches of the meridional circulation exist.

4. References

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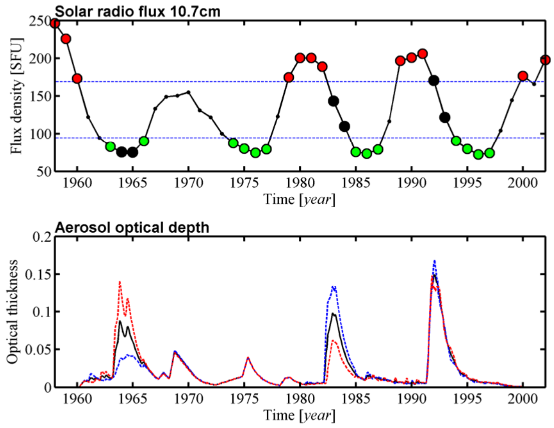

Figure 1. Time series of the annual mean solar 10.7cm radio flux (upper panel), and the monthly aerosol optical depth (lower panel). Criteria for composite are ±75% standard deviation from the mean solar radio flux. Red and Green circles mean solar-max and solar-min cases, respectively.

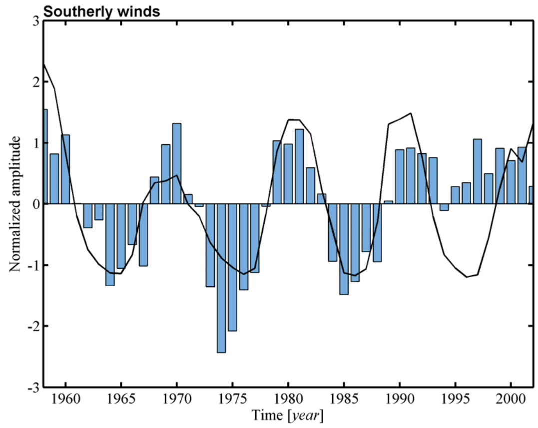

Figure 2. The corrected southerly winds at 1000hPa (averaged over a predefined area 40ºW-20ºW, 5ºS-5ºN) are represented in a bar graph format. The black line is the annual mean of the solar 10.7cm radio flux.

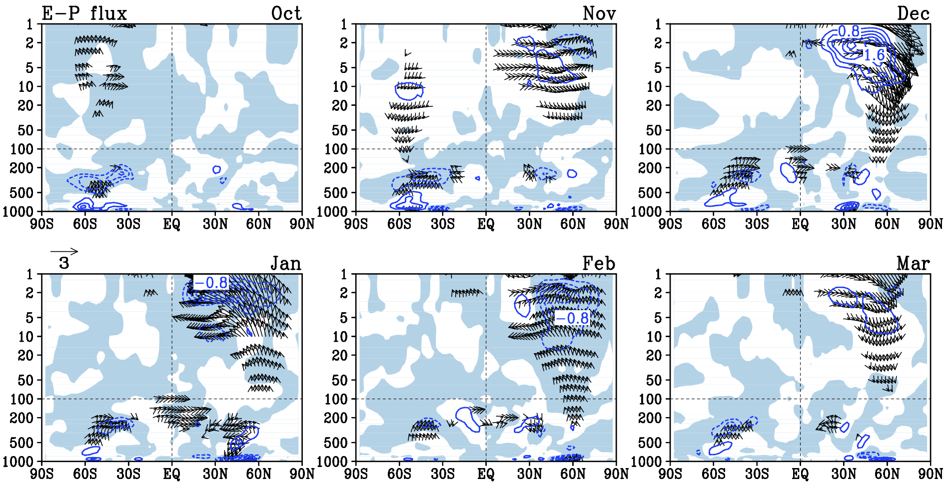

Figure 3. Monthly composite mean difference of E-P flux (black arrows) and its divergence (contour, a converged area is shaded) from October to March. All value are scaled by the inverse of pressure and z-component of the E-P flux is multiplied by two times y-component.

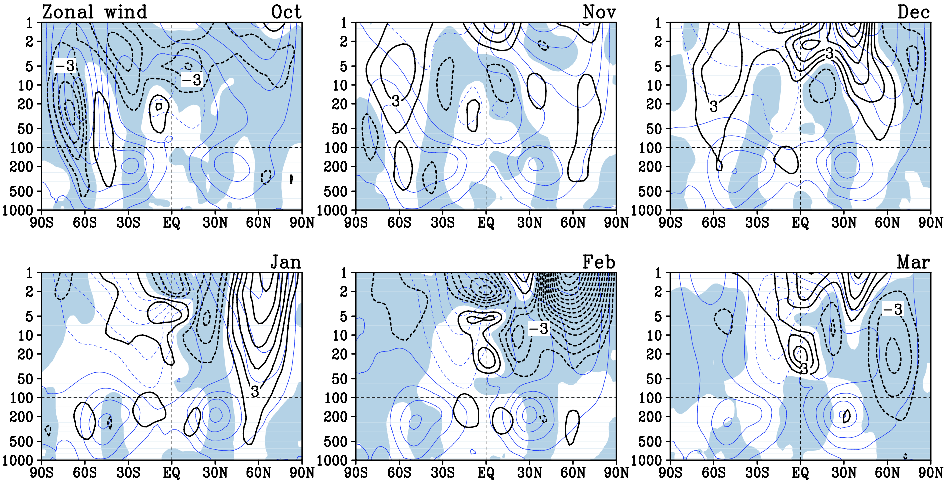

Figure 4. Monthly composite mean differences of zonal-mean zonal wind from October to March.

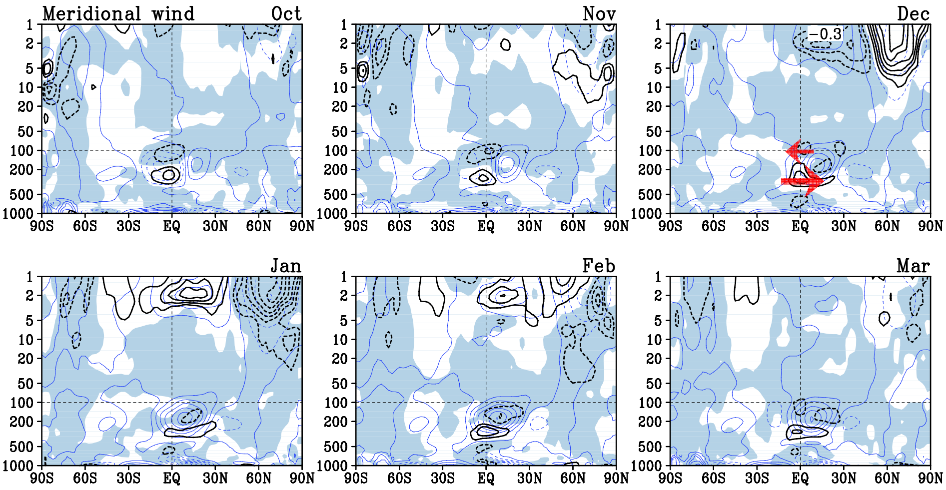

Figure 5. Monthly composite mean differences of zonal-mean meridional wind from October to March.

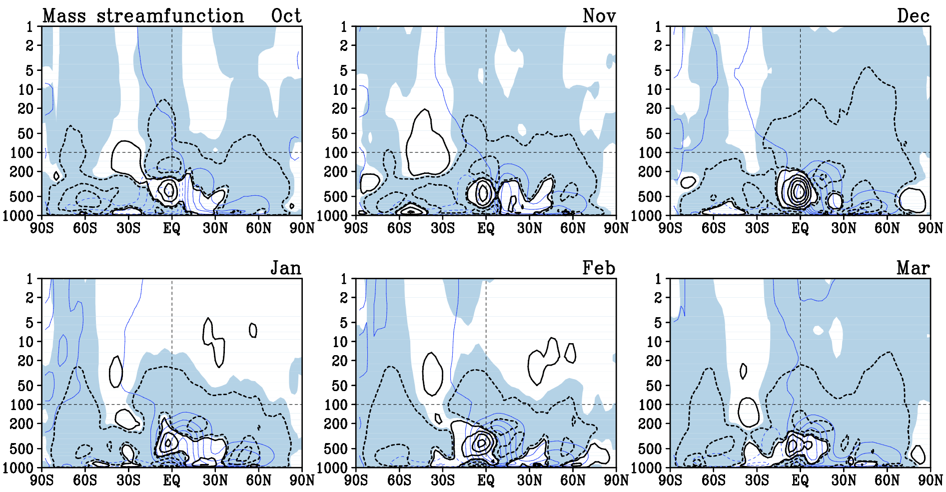

Figure 6. Monthly composite mean differences (black line, a negative value is shaded) of mass streamfunction (residual circulation) from October to March. The blue solid-line represents climatology.