Tropospheric and stratospheric wind contributions to Earth's variable rotation from NCEP/NCAR reanalyses (2000–2005)

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SUMMARY
The individual tropospheric and stratospheric wind contributions to the Earth's variable rotation during the period 2000–2005 are investigated to further our understanding of the role of wind in exciting polar motion and the variation of the Earth's rotational rate (or the length of day, LOD, change). Instead of the previous empirical approach, which simply assumed the tropopause as an equal-pressure level, the present study employs a tropopause, which is space- and time-dependent and is from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP/NCAR) reanalyses. For the axial component, the tropospheric and stratospheric wind effects are essentially additive. For the equatorial components, however, a significant cancellation is found between the tropospheric and stratospheric wind terms, based on the NCEP/NCAR reanalysis model.

Key words: Time series analysis; Earth rotation variations; Global change from geodesy.

1 INTRODUCTION

The rotation of the Earth changes slightly with time. Its axial and equatorial components are associated with the variations of the Earth's rotational rate (or the length of day, LOD, change) and the polar motion, respectively (Munk & MacDonald 1960; Lambeck 1980). The atmosphere is the primary excitation source for the Earth rotation on seasonal and intraseaonal timescales (Barnes *et al.* 1983; Naito *et al.* 1987; Eubanks 1993; Salstein *et al.* 1993; Gross *et al.* 2003, 2004). The atmospheric excitation function (AEF), known also as the atmospheric effective angular momentum function, may be separated into two portions, that is, the 'wind' terms due to the atmospheric motion relative to the crust plus mantle and the 'pressure' terms due to the variations of atmospheric mass distribution, evident through surface pressure changes. At seasonal and intraseasonal timescales, the wind has been shown to be the dominant excitation source to the LOD change, whereas it is comparable to the surface pressure change in exciting the Earth's polar motion (e.g. Chao & Au 1991; Kuehne *et al.* 1993; Salstein 1993; Aoyama & Naito 2000; Naito *et al.* 2000; Zhou *et al.* 2001, 2006).

The wind contribution to the Earth's variable rotation comes predominantly from two layers: the troposphere and stratosphere—the two lower atmospheric layers. The temperature generally decreases with height in the troposphere, but it tends to increase with height in the stratosphere, associated with the heating by ozone there. Because these temperature lapse rates and their horizontal gradients lead to different dynamic effects in the winds, it is important to account for the different winds in the two regions separately. Indeed, proper accounting of the stratosphere and troposphere in deter-

mining temperature trends has been important to issues of global warming as well (Fu *et al.* 2004). The tropopause is defined as the boundary between different signs of temperature lapse rate in the vertical direction. The tropospheric wind field extends to about 6 to 17 km above the Earth's surface, depending upon location, whereas the stratospheric wind field extends from the tropopause to about 50 km above the Earth (Peixoto & Oort 1992). To further our understanding of the role of wind in exciting the LOD change and polar motion, thus, it would be interesting to investigate the contributions to the Earth's variable rotation from the troposphere and stratosphere separately. Aoyama & Naito (2000) obtained the tropospheric wind contribution to the annual polar motion by integrating winds from the Earth surface to 100 hPa and the stratospheric wind contribution by the integration from 100 hPa to the top of the atmospheric model. Their formulation implicitly sets the tropopause to a constant 100 hPa pressure level. This empirical approach was also employed earlier in studying the stratospheric wind contribution to annual and semi-annual fluctuations in atmospheric angular momentum and the length of day because of the limitation of data (for example, atmospheric energetics was calculated only to 100 hPa in some earlier works) (Rosen & Salstein 1985; Salstein & Rosen 1997).

The tropopause pressure, however, varies with location, notably, with latitude. It also changes seasonally. Its long-term variation relates to the changes in atmospheric temperature caused by both natural and anthropogenic factors (Seidel *et al.* 2001; Santer *et al.* 2003). This study employs the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP/NCAR) reanalysis (Kalnay *et al.* 1996) 6-hourly

tropopause, wind and pressure fields to compute the tropospheric and stratospheric wind contributions to the Earth's variable rotation during the period 2000–2005. Note that the total AEF from the NCEP/NCAR reanalysis provided by the Special Bureau for Atmosphere (http://www.aer.com/scienceResearch/diag/sb.html; Salstein *et al.* 1993) of the Global Geophysical Fluids Center of the International Earth Rotation and Reference Systems Service (IERS) is the same set as the sum of the tropospheric and stratospheric wind contributions in this paper. In Section 2, we introduce the basic formulae and data processing of the AEF and the Earth rotation excitation function. In Sections 3 and 4, we show the results of the tropospheric and stratospheric wind contributions to the observed polar motion and LOD change on seasonal and intraseasonal timescales. A discussion and a summary are given in Sections 5 and 6.

2 FORMULATION AND DATA PROCESSING

2.1 Earth rotation excitation function

The rotation of the Earth is governed by the following excitation equations, under the conservation of the Earth's total angular momentum (Barnes *et al.* 1983; Eubanks 1993; Aoyama & Naito 2000; Zhou *et al.* 2006):

$$\mathbf{m} + (i/\sigma_c)\dot{\mathbf{m}} = \boldsymbol{\psi}, \tag{1}$$

$$\dot{m}_3 + \dot{\psi}_3 = 0. \tag{2}$$

In eq. (1), $\mathbf{m} = m_1 - im_2$ is a dimensionless complex-valued small quantity, representing the Earth's polar motion, where subscripts 1 and 2 refer to the x (along the Greenwich Meridian) and y (along the 90°E longitude) coordinates of the terrestrial coordinate frame (the negative sign comes from the left-handed coordinate system in the conventional definition of polar motions m_1 and m_2). $\boldsymbol{\psi} = \psi_1 + i\psi_2$ with ψ_1 and ψ_2 being the x and y components, respectively, of the polar motion excitation function (PMEF), $\sigma_c = 2\pi F_c(1 + i/2Q)$ is the complex Chandler frequency, F_c is about 0.843 cycles per yr and Q is the damping factor of the Chandler oscillation. In eq. (2), $m_3 = -\Delta\Lambda/\Lambda_0$ is a small dimensionless quantity, where Λ_0 and $\Delta\Lambda$ are a standard LOD and its deviation, the subscript 3 refers to the z (along the north pole) coordinate of the terrestrial frame and ψ_3 is the excitation function for the LOD change.

The observed LOD and polar motion time-series are from the Jet Propulsion Laboratory SPACE2005 EOP time-series (Gross 2004), which is sampled at daily interval and covers the period 1976–2005. It is generated through a Kalman filter combination of the Earth orientation measurements from advanced space-geodetic techniques, including lunar and satellite laser ranging, very long baseline interferometry and the global positioning system. The PMEF is calculated using eq. (1) (Wilson 1985), at a discrete set of time periods, with $Q = 179$ (Wilson & Vicente 1990).

2.2 Atmospheric excitation function

Similar to the 3-D Earth rotation vector, the AEF has equatorial and axial components (χ and χ_3). Each component consists of the pressure term ($\boldsymbol{\chi}^P$, χ_3^P) due to air mass redistribution, and the wind term ($\boldsymbol{\chi}^W$, χ_3^W) due to atmospheric relative angular momentum.

They are expressed as follows (Eubanks 1993):

$$\chi^{\mathbf{P}} = \chi_1^P + i\chi_2^P$$
$$= \frac{-1.098R^4}{(C-A)g} \int\int p_s \sin\phi\cos^2\phi e^{i\lambda} d\lambda d\phi, \tag{3}$$

$$\chi^{\mathbf{W}} = \chi_1^W + i\chi_2^W$$
$$= \frac{-1.5913R^3}{\Omega(C-A)g} \int\int\int (u\sin\phi + iv)\cos\phi e^{i\lambda} dp d\lambda d\phi, \tag{4}$$

$$\chi_3^P = \frac{0.753R^4}{C_m g} \int\int p_s \cos^3\phi d\lambda d\phi, \tag{5}$$

$$\chi_3^W = \frac{0.998R^3}{C_m\Omega g} \int\int\int u\cos^2\phi dp d\lambda d\phi, \tag{6}$$

where R and Ω are the Earth's mean radius and angular velocity, $A = 8.0115\times10^{37}$ kg m^2 and $C = 8.0376\times10^{37}$ kg m^2 are the Earth's principal moments of inertia, $C_m = 7.1236\times10^{37}$ kg m^2 is the mantle's principal moment of inertia, g is gravitational acceleration, λ and ϕ are longitude and latitude at a given gridpoint, p_s is surface pressure, u and v are the zonal and meridional wind velocities, respectively.

The AEF is computed on the basis of eqs (3)–(6), using four-times daily (0000, 0600, 1200 and 1800 GMT) wind and pressure fields for years 2000–2005, from the NCEP/NCAR atmospheric reanalysis system (Kalnay *et al.* 1996). The output is on a grid with resolution 2.5° longitude by 2.5° latitude. The wind fields covers 17 pressure levels (1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 hPa). The tropospheric AEF wind term is computed by integrating winds from the Earth surface at the topogrpaphy (Zhou *et al.* 2006) to the tropopause, and the stratospheric AEF wind contribution is computed by the integration from the tropopause to the top (10 hPa) of the atmospheric model. The AEF pressure term is computed on the basis of the inverted barometer (IB) assumption, which assumes that oceans respond to the atmospheric loading isostatically (Munk & MacDonald 1960). To match the temporal resolution of the LOD and PMEF, the 6-hourly AEF is averaged daily by summing five consecutive values using weights of 1/8, 1/4, 1/4, 1/4, 1/8.

Fig. 1 displays a 'snapshot' of the pressure of tropopause (in unit of hPa) at 0 hr, 2000 January 1. It is evident that the tropopause pressure changes notably with latitude, dropping from ∼100 hPa at the belt of 30°N–30°S to as low as ∼400 hPa at part of the regions surrounding 60°N and 60°S. Figs 2 and 3 show, respectively, the axial and equatorial AEF wind terms (χ_3^W, χ_1^W and χ_2^W) of the troposphere and stratosphere during the period 2000–2005, deduced from the empirical study (blue curves), which assumes an equal-pressure-level tropopause of 100 hPa, and this study (red curves), which employs the NCEP/NCAR reanalysis tropopause, which varies with location and time. Whereas a relatively small disparity is seen for the axial tropospheric and stratospheric terms between these two formulations, significant relative differences are seen for the equatorial tropospheric and stratospheric terms. Therefore, it is necessary to consider the fluctuation of the tropopause in evaluating the tropospheric and stratospheric wind contributions to the Earth's polar motion.
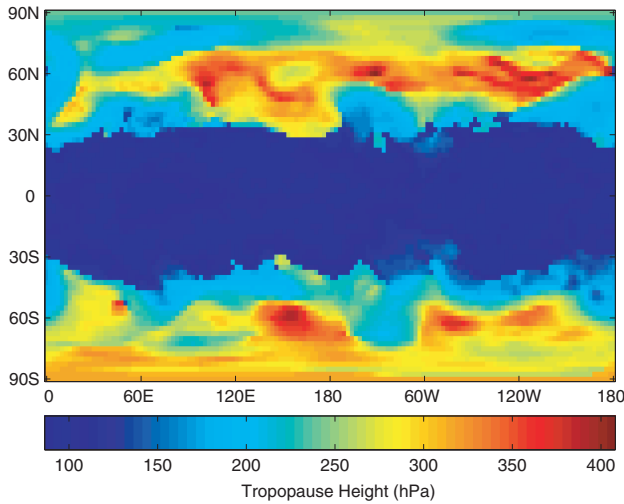
Figure 1. The tropopause pressure (in unit of hPa) at 0 hr, 2000 January 1.

3 TROPOSPHERIC AND STRATOSPHERIC WIND CONTRIBUTIONS TO POLAR MOTION

3.1 Seasonal variations

A linear combination of a trend, annual, semi-annual and terannual terms is fitted in a least-squares sense to the PMEF, the tropospheric and stratospheric AEF wind terms and the AEF pressure term under the IB assumption, respectively. Table 1 lists the results of this fit for the amplitude A and phase α of the prograde (subscript p) and retrograde (subscript r) components of the excitation of annual polar motion defined by (Munk & MacDonald 1960)

$$\chi(t) = A_p e^{i\alpha_p} e^{i\sigma(t-t_0)} + A_r e^{i\alpha_r} e^{-i\sigma(t-t_0)}, \qquad (7)$$

where σ is the annual frequency and the reference date t_0 is 2000 January 1, 0000UT. The amplitude and phase of the semi-annual and terannual excitations are assembled in Table 2.

Information in Tables 1 and 2 for the (a) prograde and (b) retrograde components is graphically represented in the phasor diagrams in Figs 4–6 for the annual, semi-annual and terannual components, respectively. For the annual prograde component, the tropospheric and stratospheric wind terms are about 1/5 in amplitude of the surface pressure term; whereas, for the retrograde component, the tropospheric and stratospheric wind terms are only slightly smaller than the pressure term. Due to the cancellation effect between the tropospheric and stratospheric winds, the surface pressure variation is seen to be dominant over the total winds in the atmospheric excitation of the annual polar motion. The annual cycle in the troposphere and stratosphere winds may be due to the seasonality in the two hemispheres, with winter winds typically stronger than summer winds (Rosen & Salstein 1983).

For the semi-annual component (Fig. 5), the tropospheric and stratospheric wind terms are about half of the surface pressure term for the retrograde component; the tropospheric and stratospheric wind terms reach about 5 times as large as the surface pressure term for the prograde component. Again, due to the significant cancellation effect between the tropospheric and stratospheric winds, the atmospheric excitation of the semi-annual polar motion comes mainly from the surface pressure variation rather than the total winds.

For the terannual component (Fig. 6), the tropospheric and stratospheric wind terms appear larger than the surface pressure term for
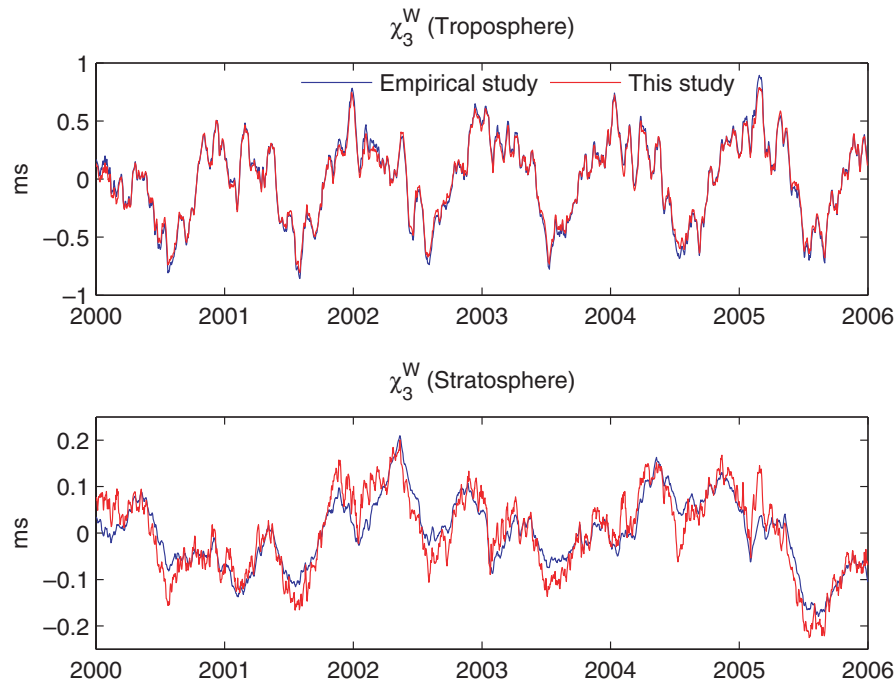

Figure 2. The axial wind terms (χ_3^W) of the atmospheric excitation function (AEF) from the (a) troposphere and (b) stratosphere during the period 2000–2005, deduced from the empirical study (blue curves) which assumes an equal-pressure-level tropopause of 100 hPa and from this study (red curves) which employs the NCEP/NCAR reanalysis tropopause that varies with location and time.
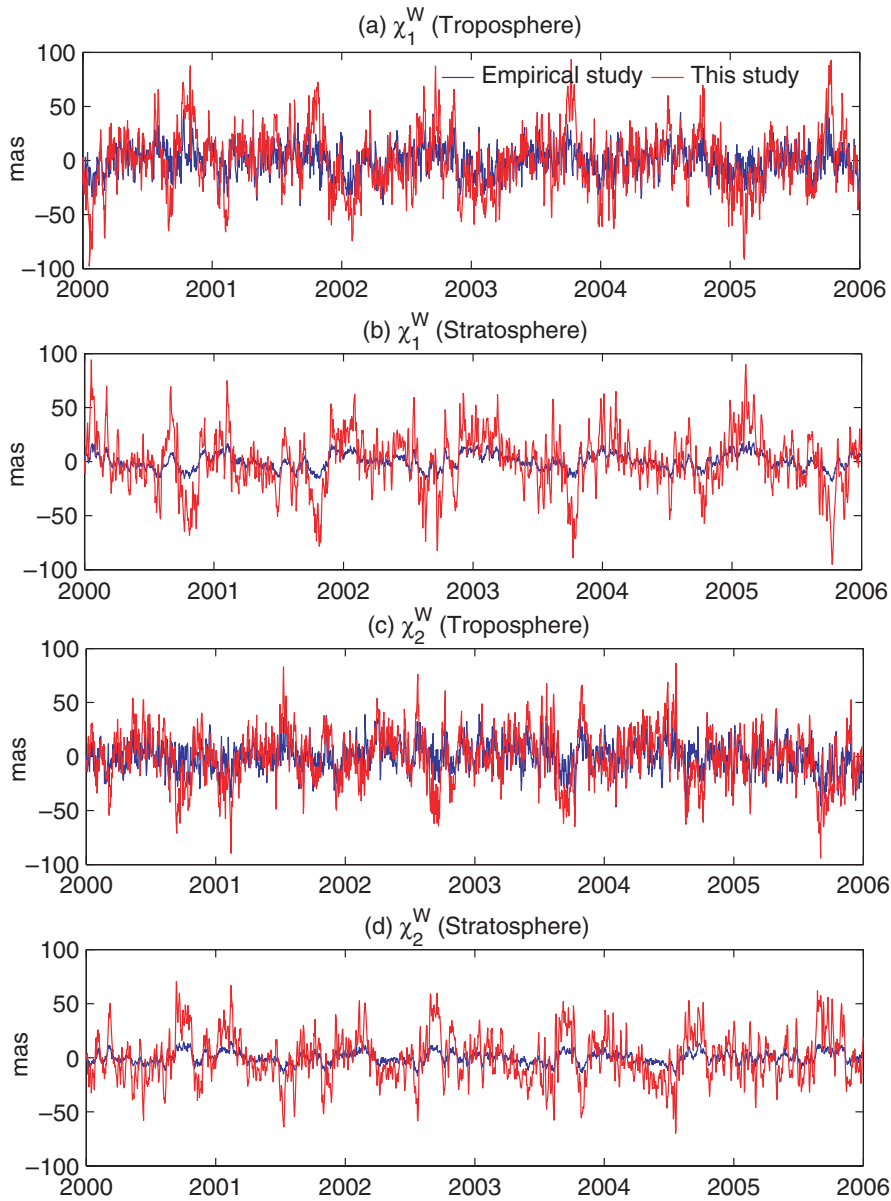
Figure 3. The equatorial AEF wind terms (χ_1^W and χ_2^W) from the troposphere (a, c) and stratosphere (b, d) during the period 2000–2005, deduced from the empirical study (blue curves) and the present investigation (red curves).

Table 1. Amplitude and phase of the prograde and retrograde components of the annual equatorial atmospheric excitation function (AEF) and polar motion excitation function (PMEF).

Excitation function	Annual prograde		Annual retrograde	
	Amplitude, mas	Phase, deg	Amplitude, mas	Phase, deg
OBS	17.30 ± 0.68	−51.4 ± 2.3	10.24 ± 0.68	−135.1 ± 3.8
W(tro)	3.01 ± 0.46	103.2 ± 9.2	13.24 ± 0.46	−134.0 ± 2.0
W(str)	3.17 ± 0.42	−59.2 ± 7.9	12.50 ± 0.42	49.8 ± 1.9
W(tro)+W(str)	0.96 ± 0.27	12.5 ± 16.6	1.13 ± 0.27	178.8 ± 14.0
P	15.37 ± 0.31	−92.5 ± 1.2	15.84 ± 0.31	−114.0 ± 1.1
W(tro)+W(str)+P	15.15 ± 0.46	−89.0 ± 1.7	16.31 ± 0.46	−117.6 ± 1.6

The reference date for phase is 2000 January 1, 0000UT. OBS, the PMEF inferred from SPACE2005 polar motion; W(tro), the AEF wind term from the troposphere; W(str), the AEF wind term from the stratosphere; P, the AEF pressure term under the inverted barometer assumption.

Table 2. As in Table 1 but for the semi-annual and terannual polar motion excitations.

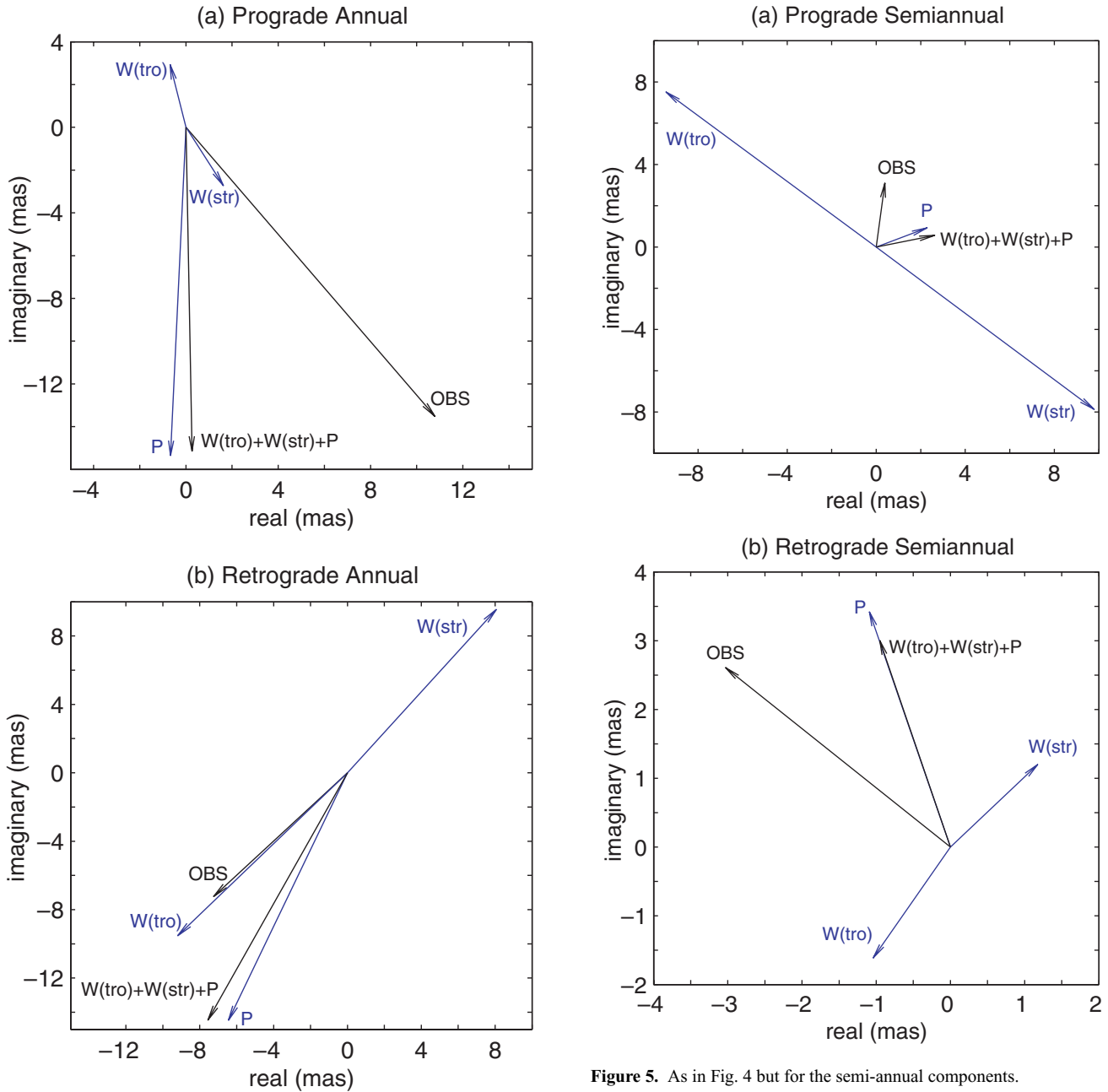| Excitation function	Semiannual prograde		Semiannual retrograde		Terannual prograde		Terannual retrograde	
	Amplitude, mas	Phase, deg	Amplitude, mas	Phase, deg	Amplitude, mas	Phase, deg	Amplitude, mas	Phase, deg
OBS	3.12 ± 0.68	82.8 ± 12.4	4.00 ± 0.68	139.3 ± 9.9	1.65 ± 0.68	70.0 ± 23.5	2.37 ± 0.68	−76.9 ± 16.2
W(tro)	12.07 ± 0.46	141.5 ± 2.2	1.92 ± 0.46	−122.8 ± 14.2	7.37 ± 0.46	−155.5 ± 3.6	2.11 ± 0.46	−88.3 ± 12.8
W(str)	12.56 ± 0.42	−38.8 ± 1.9	1.68 ± 0.42	45.5 ± 14.7	7.08 ± 0.42	24.3 ± 3.4	2.02 ± 0.42	90.7 ± 12.2
W(tro)+W(str)	0.50 ± 0.27	−47.4 ± 31.8	0.44 ± 0.27	−71.8 ± 35.6	0.29 ± 0.27	−151.9 ± 53.1	0.09 ± 0.27	−66.0 ± 162.4
P	2.47 ± 0.31	22.0 ± 7.2	3.59 ± 0.31	107.7 ± 5.0	0.59 ± 0.31	−128.4 ± 29.6	1.37 ± 0.31	−58.7 ± 12.8
W(tro)+W(str)+P	2.69 ± 0.46	12.0 ± 9.9	3.15 ± 0.46	107.6 ± 8.4	0.87 ± 0.46	−136.0 ± 29.9	1.47 ± 0.46	−59.1 ± 17.8

Figure 4. Phasor diagrams of the (a) prograde and (b) retrograde components of annual AEF and polar motion excitation function (PMEF).

Figure 5. As in Fig. 4 but for the semi-annual components.

the retrograde component and much larger for the prograde component. The polar motion excitation still results more from the surface pressure variation than the total winds of the troposphere and stratosphere, which are out of phase in both components.
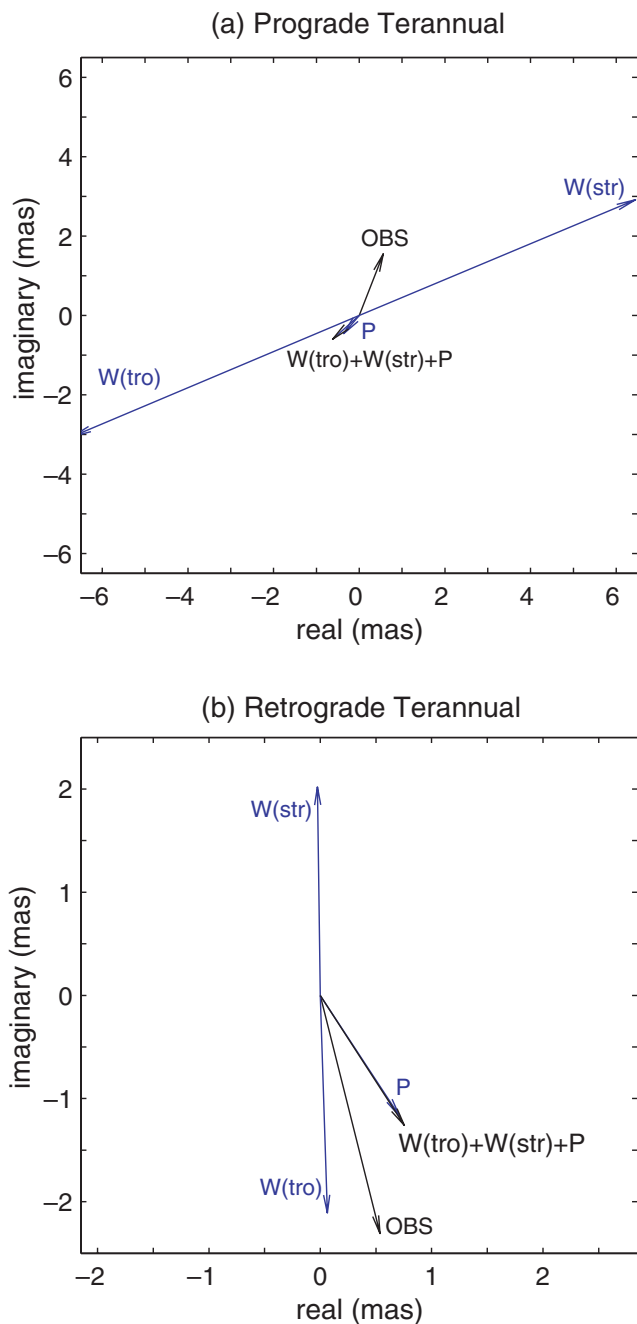
(a) Prograde Terannual

(b) Retrograde Terannual

Figure 6. As in Fig. 4 but for the terannual components.

A common notable feature for the annual, semi-annual and terannual excitations shown in Figs 4–6 is that considerable discrepancies remain between the PMEF and the total AEF wind and pressure terms, which imply the existence of non-atmospheric sources to the polar motion excitation, like global oceans and continental water storage changes (Johnson *et al.* 1999; Ponte & Stammer 1999; Gross *et al.* 2003; Zhong *et al.* 2003; Chen *et al.* 2004; Zhou *et al.* 2004, 2005; Chen & Wilson 2005).

3.2 Intraseasonal variation

We first remove from the AEF and PMEF, a linear combination of a trend, annual, semi-annual and terannual terms that was fitted by the

least-squares method. Then, the residual series is passed through a Butterworth bandpass filter of order 2, in both forward and reverse directions to eliminate any phase distortion (Wiley 1979). The lower and upper cut-off frequencies are 1 and 73 cycle per yr (cpy), respectively. Thus the resulting series, having periods between 5 d and 1 yr, is considered as the intraseasonal variation used in the following cross-correlation and variance analyses.

Figs 7(a) and (b), respectively, shows χ_1 and χ_2 components of the tropospheric (blue curves) and minus stratospheric (red curves) AEF wind terms at the intraseasonal timescale during the period 2000–2005. The vivid similarity therein demonstrates the striking cancellation effect between the tropospheric and stratospheric intraseasonal winds. The correlation coefficients at zero time lag for χ_1 and χ_2 components reach 0.87 and 0.82, respectively, which far exceed the 99 per cent significance level.

Table 3 summarizes the cross-correlation coefficients between the intraseasonal PMEF and AEF and variance reductions (in percentage) when the atmospheric effects are removed from the PMEF. In spite of stronger variations of the tropospheric and stratospheric wind terms than the surface pressure term, owing to the cancellation effect between the troposphere and stratosphere, the total winds contribute less than the surface pressure to the intraseasonal polar motion excitation (28.1 per cent vs. 36.2 per cent). The total atmospheric motion and mass redistribution can explain 54.3 per cent of the intraseasonal polar motion excitation, and they have a correlation coefficient of 0.74 with the observational polar motion during 2000–2005. Gross *et al.* (2003) indicated that the total atmospheric effect accounted for 48.7 per cent of the observed excitation and the correlation coefficient between them amounted to 0.71 during 1993–2000. As can be seen, better agreement between the observed and modelled excitations during the beginning of this century are found, which is presumably due to the improvements in the polar motion observation and both assimilation of observations and modelling of atmospheric processes.

4 TROPOSPHERIC AND STRATOSPHERIC WIND CONTRIBUTIONS TO LOD CHANGE

4.1 Seasonal variations

A linear combination of a trend, annual, semi-annual and terannual terms is fitted to the observed LOD, the tropospheric and stratospheric AEF wind terms and the AEF pressure term, respectively. Table 4 assembles the results of this fit for the amplitude and phase of the annual, semi-annual and terannual components. As can be seen for the annual, semi-annual and terannual variations, the stratospheric wind term is about 1/6, 1/5 and 1/4 as large in amplitude as the tropospheric wind term, and the phase differences between the tropospheric and stratospheric wind terms are 10.9°, 18.6° and 12.9°, respectively. Thus, the tropospheric and stratospheric wind terms are relatively in phase. The total wind term reaches 11, 19 and 5 times, in amplitude, as large as the pressure term for the annual, semi-annual and terannual variations, respectively. Therefore, the wind plays a much more important role than the surface pressure variation in exciting the LOD change. Moreover, the remaining discrepancy between the observed LOD and the total atmospheric excitations can be attributable to the effects of upper atmospheric winds over 10 hPa, the effective top stratospheric level, global oceans and continental water storage changes (Marcus *et al.* 1998; Chen *et al.* 2000; Gross *et al.* 2004; Yan *et al.* 2006). Earlier estimates
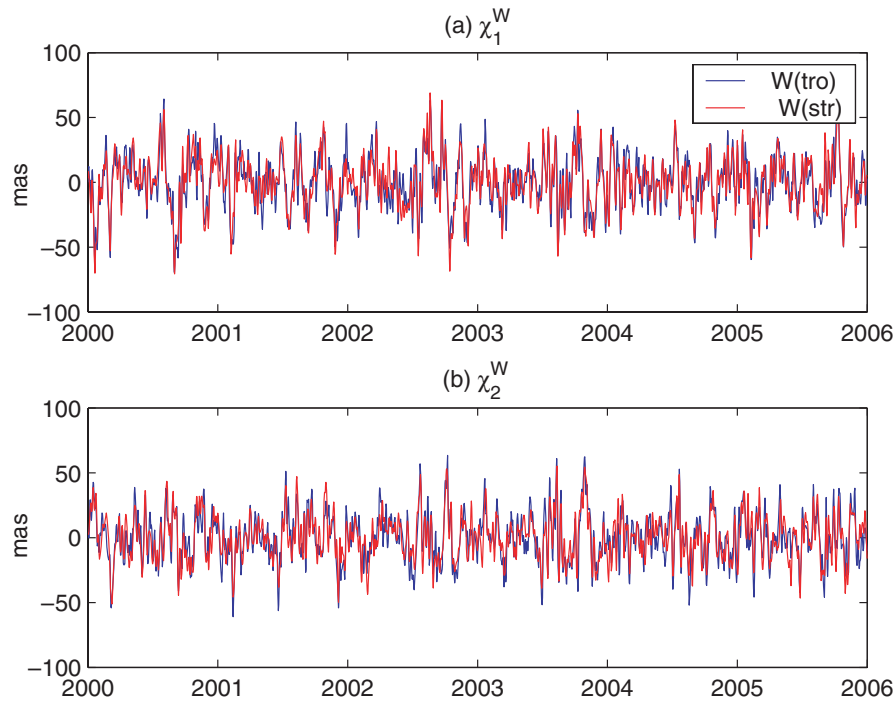
Figure 7. (a) χ_1^W and (b) χ_2^W components of the tropospheric (blue curves) and minus stratospheric (red curves) AEF wind terms at the intraseasonal timescale during the period 2000–2005.

for the winds above 10 hPa, given in research data sets (Rosen & Salstein 1985), indicate amplitudes for the annual signal per hPa of 2–3 times that in the mean stratosphere, though from only about 10 per cent of its mass.

4.2 Intraseasonal variation

We first remove from the observed LOD and axial AEF, a linear combination of a trend and seasonal terms that was fitted by the least-squares method. Then the residual series is passed through a bandpass filter to extract the intraseasonal signal, as we did for the equatorial AEF and PMEF in Section 3.2. Fig. 8 shows the axial wind terms of the intraseasonal AEF from the troposphere (blue curve) and stratosphere (red curve) during the period 2000–2005. The amplitude of the stratospheric wind term is about 1/5 as large as that of the tropospheric wind term. The cross-correlations between the tropospheric and stratospheric wind terms at a distribution of lags are displayed in Fig. 9. A positive correlation peak around

Table 3. Cross-correlation coefficients between the observed intraseasonal polar motion excitation SPACE2005 and atmospheric effects, and variance reductions (in percentage) when the atmospheric excitations are removed from SPACE2005.

AEF	χ_1		χ_2		$\chi_1 + i\chi_2$	
	Correlation coefficient	Reduced variance (%)	Correlation coefficient	Reduced variance (%)	Correlation coefficient	Reduced variance (%)
W(tro)+W(str)	0.57	31.3	0.59	26.7	0.57	28.1
P	0.54	28.2	0.66	39.6	0.62	36.2
W(tro)+W(str)+P	0.73	53.5	0.74	54.6	0.74	54.3

Table 4. Amplitude and phase of the annual, semi-annual and terannual components of the axial AEF and observed length of day (LOD) change, 2000–2005.

Excitation function	χ_3 (annual)		χ_3 (semiannual)		χ_3 (terannual)	
	Amplitude, μs	Phase, deg	Amplitude, μs	Phase, deg	Amplitude, μs	Phase, deg
LOD	355.9 ± 5.7	60.3 ± 0.9	228.6 ± 5.7	-157.7 ± 1.4	39.5 ± 5.7	75.8 ± 8.3
W(tro)	378.5 ± 4.6	60.3 ± 0.7	147.4 ± 4.6	-169.6 ± 1.8	43.1 ± 4.6	60.2 ± 6.2
W(str)	58.3 ± 1.9	49.4 ± 1.9	45.6 ± 1.9	-151.0 ± 2.4	6.9 ± 1.9	73.1 ± 16.3
W(tro)+W(str)	435.9 ± 5.1	58.9 ± 0.7	191.2 ± 5.1	-165.2 ± 1.5	49.8 ± 5.1	62.0 ± 6.0
P	39.8 ± 0.8	-111.7 ± 1.2	12.3 ± 0.8	-21.6 ± 3.9	6.1 ± 0.8	-133.8 ± 8.0
W(tro)+W(str)+P	396.6 ± 5.1	57.9 ± 0.7	181.4 ± 5.1	-162.9 ± 1.6	44 ± 5.1	64.1 ± 6.7

The reference date for phase is 2000 January 1, 0000UT.
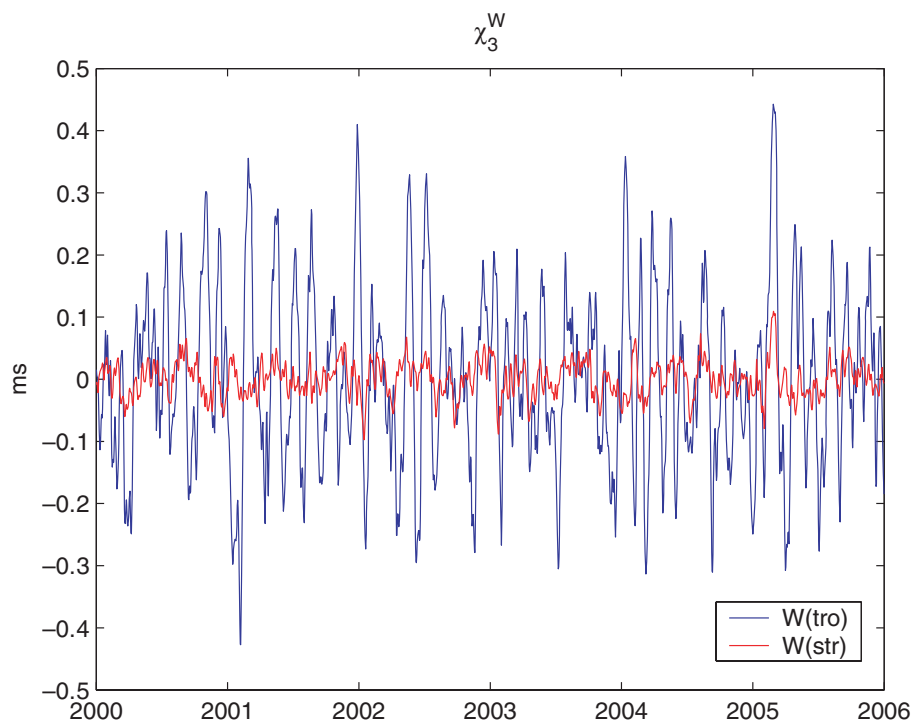
Figure 8. The axial AEF wind terms (χ_3^W) from the troposphere (blue curve) and stratosphere (red curve) during the period 2000–2005.
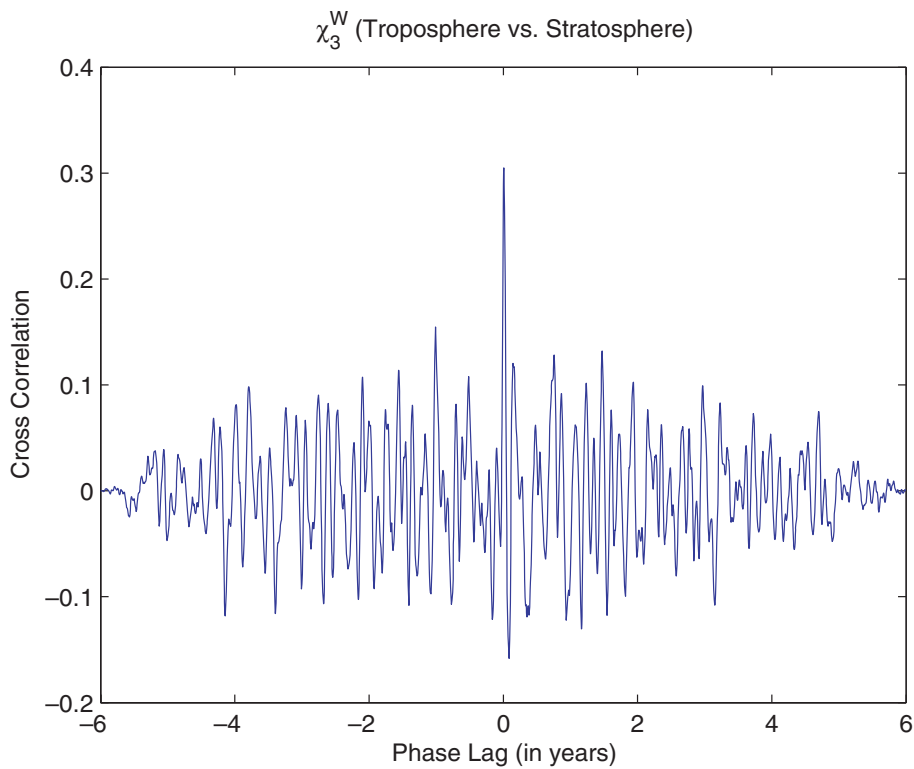

Figure 9. Cross-correlation coefficients between the tropospheric and stratospheric wind terms (χ_3^W) on the intraseasonal timescale.
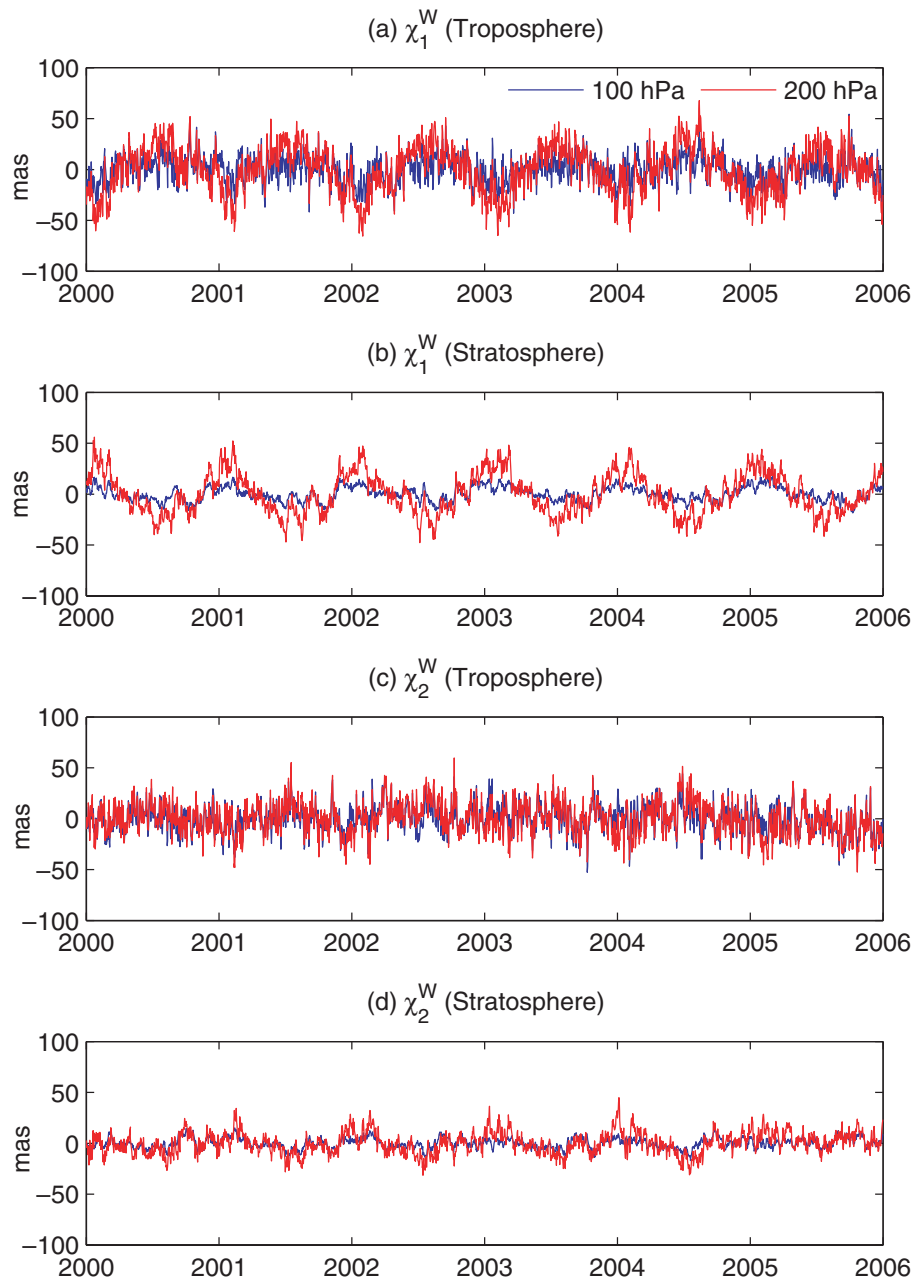
Figure 10. The equatorial AEF wind terms (χ_1^W and χ_2^W) from the troposphere (a, c) and stratosphere (b, d) during the period 2000–2005, deduced from the empirical studies in which the tropopause is set to constant 100 (blue curves) and 200 hPa (red curves) pressure levels.

zero time lag is found, which exceeds the significance level of 99 per cent from the Monte Carlo simulation tests. The result of variance analyses indicates that the total wind effect from the troposphere and stratosphere can account for 86.3 per cent of the observed intraseasonal LOD variation, whereas only 0.9 per cent of the LOD change comes from the surface pressure variation during the period 2000–2005. It further confirms that the wind plays a dominant role in exciting the intraseasonal variation of the Earth's rotational rate (Ponte & Ali 2002; Gross *et al.* 2004).

5 DISCUSSION

The estimate of tropospheric and stratospheric wind contributions to the Earth's polar motion in the empirical study depends signif-

icantly on the selected tropopause pressure level. Fig. 10 shows the equatorial AEF wind terms from the troposphere and stratosphere during the period 2000–2005, deduced from the empirical studies in which the tropopause is set to constant 100 (blue curves) and 200 hPa (red curves) pressure levels. It can be seen that the tropospheric and stratospheric wind contributions differ drastically between these two cases. As the tropopause pressure level varies appreciably from the tropical to extratropical latitudes, the whole tropopause can be represented realistically neither by a constant 100 hPa nor by a constant 200 hPa pressure level.

The present investigation employs the NCEP/NCAR model's tropopause, based on vertical temperature gradients, which varies with location and time, to compute the tropospheric and stratospheric wind contributions to the Earth's polar motion. We found a

significant cancellation between the tropospheric and stratospheric wind terms, which may imply a strong angular momentum exchange between the troposphere and stratosphere. The physical mechanism therein will be studied further in the future through the torque approach.

6 SUMMARY

The individual tropospheric and stratospheric wind contributions to the Earth's variable rotation during the period 2000–2005 are investigated on seasonal and intraseasonal timescales to further our understanding of the role of wind in exciting polar motion and the variation of the Earth's rotational rate. Instead of previous empirical approaches, which simply assumed the tropopause as an equal-pressure level, the present study employs the NCEP/NCAR model's tropopause, which varies with location and time. For the axial component, the tropospheric and stratospheric wind effects are typically additive. For the equatorial components, however, a significant cancellation effect is found between the tropospheric and stratospheric wind terms, based on the NCEP/NCAR reanalysis model.

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