Statistical relation between the quasi-decadal and quasi-biennial variations in the equatorial stratosphere and similar variations in solar activity

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We report statistical investigation of possible relations between the zonal wind velocity, temperature and ozone concentration in the equatorial stratosphere, on the one hand, and the 10.7 cm solar radio flux ($F_{10.7}$), on the other hand, at the quasi-decadal (QD) and quasi-biennial (QB) time scales. Significant coherency was recently found between the equatorial stratospheric wind and the $F_{10.7}$ index at the QB scale (Soukharev and Hood, 2001; Bezverknnii and Gruzdev, 2007). Moreover, Bezverknnii and Gruzdev (2007) found the coherency at the QD time scale.

DATA

Solar radio flux at 10.7 cm wavelength is used as an index of solar activity (index $F_{10.7}$). Fig. 1 shows the $F_{10.7}$ index for the whole period of measurements. The quasi-decadal cycle (called 11-year cycle) dominates superimposed by small-scale variations including variations within period specific for the quasi-biennial oscillation (2-2.5 year; see Gruzdev and Bezverkhny, 2000).

For the analysis, monthly mean data of (1) the equatorial zonal wind velocity at pressure levels from 70 to 10 hPa from the Free University of Berlin (B. Naujokat), for the period 1953-2004, (2) the zonal mean zonal wind velocity and temperature at levels up to 1 hPa from National Meteorological Center (NMC), for the period 1979-1995, and (3) the daily mean zonal mean ozone mixing ratios at pressure levels from 50 to 0.25 hPa from SBUV measurements (version 8), for the period 1979-2003, are used.

Figure 2 shows amplitudes of the quasi-biennial (QBO) and semi-annual oscillations of the wind velocity of the equatorial stratospheric wind derived from NMC data. The QBO dominates in the lower and middle stratosphere while the semiannual cycle dominates in the upper stratosphere and lower mesosphere.

ANALYSIS METHODS

Among analysis methods used are high-resolution cross-spectral analysis (Jones, 1978) and cross-wavelet analysis (Bezverkhnii, 2001).

RESULTS

Figure 3 shows for example high positive values of local coherency between the equatorial wind velocity at 15 hPa and the $F_{10.7}$ index at the QD scale for 1953-1989 and high negative values after 1996. The local coherency at the QB scale is largely negative for 1953-2001 and positive after 2001.

High positive local correlation is observed at the QD scale between the two time series shifted to each other by 12 months (velocity lags solar index) for 1953-2004. At the QB scale, the high positive correlation is noted in the neighborhood and in the first half of the 1960s, 1970s, 1980s, and 1990s and negative correlation in the first half of 2000s, i.e. when the QB variations are exhibited in the solar activity index (see Fig. 1).

Spectral analysis shows significant coherency of the equatorial wind velocity and the $F_{10.7}$ index at the QB and QD time scales (Figures 4 and 5, black, red and pink curves).

Quasi-biennial time scale. According to Fig.4, the QBO in the equatorial wind velocity lags behind the QB variations in the $F_{10.7}$ index by about 1 month at the stratopause level (~50 km), and the lag increases with decreasing altitude with the rate close to the rate of descending of the QBO. The nearly in-phase relationship between the wind and solar QB variations suggests a possible influence of solar activity on the equatorial QBO, probably by radiative effects of solar ultraviolet variations.

One important agent of these effects in the stratopause layer is ozone. Indeed, Fig. 4, blue curve, shows that the QB ozone variations in the neighborhood of the stratopause are approximately in phase (lagging by 0-2 months) with solar QB variations. In the upper stratosphere layer (35-45 km), the QB ozone variations are close to anti-phase relative to solar variations (dashed part of the curve).

The role of the ozone heating effect in the QBO is emphasized by the QB variations in ozone meridional gradient, which in 45-60 km layer are opposite to the solar QB variations, see light blue curve in Fig. 4. Supposing that variations of the ozone gradient may result in similar variations in the meridional heating rate gradient, and probably in the temperature gradient, the associated variations in the zonal wind velocity should have a tendency to be approximately in phase to the QB solar variations (according to thermal wind equation) as just observed.

The QB variations in temperature precede solar QB variations while QB variations of meridional temperature gradient lag solar QB variations by several months (see green and light green curves in Fig. 4).

Quasi-decadal time scale. Three aspects of the 11-year solar cycle effect on the equatorial zonal can be distinguished: (1) the well known modulation of the wind QBO period (see e.g. Baldwin et al., 2001; Gruzdev and Bezverkhny, 2000; Soukharev and Hood, 2001);
(2) modulation of the amplitude of the wind QBO in the middle stratosphere: the amplitude increases with increase in the QBO period (Gruzdev and Bezverkhny, 2000); (3) the influence on the zonal wind velocity described below.

Figure 5, shows that the QD variations of the zonal equatorial wind velocity above and below the 20 hPa level are generally in anti-phase to each other (compare solid and dashed parts of black and red curves). The altitude dependence of the phase lag of the QD wind variations relative to similar variations of the $F_{10.7}$ index is approximately the same as the phase lag dependence for the QB time scale (cf. yellow curve in Fig. 5) taking into account the change of the QD wind variations to opposite phase below the 20 hPa level. The QD wind variations above the 20 hPa level are approximately in phase to the 11-year solar cycle, which means increase in westerly and decrease in easterly wind during periods of high solar activity compared with periods of low solar activity.

The QD variations in ozone concentration above 45 km are approximately in phase with 11-year solar cycle (lag latter by about 3 months), see blue curve in Fig. 5.

Figure 6 shows profiles of amplitudes of the QB and QD variations of the equatorial stratospheric wind velocity as well as a profile of the ratio of the amplitudes. The amplitude the QD variations is about 7% of the amplitude of the QB variations below 30 km and 16% at 15 hPa level.

CONCLUDING REMARKS

It has been shown that the quasi-decadal and quasi-biennial oscillations of zonal wind velocity in the equatorial stratosphere are coherent with similar oscillations in solar activity.

The Lindzen-Holton mechanism of the equatorial wind QBO is believed to act in the middle stratosphere where the semiannual cycle is not important (see Fig. 2). At higher altitudes, the QBO is likely affected by QB variations in solar activity by the agency of variations in ozone heating. An important question is how these mechanisms of the QBO interact.

The QD variations in the equatorial zonal wind velocity look like descending with the QBO (“frozen” in the QBO). It is unclear however, what is the reason of the sharp change of the phase of the QD wind variations by about 180° below 20 hPa level.

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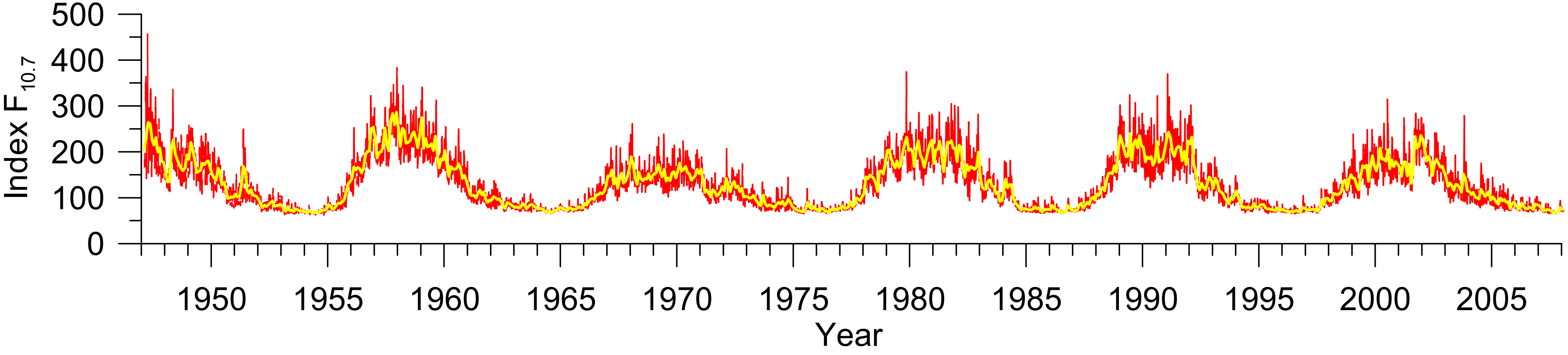

Fig. 1. Daily (red curve) and monthly (yellow curve) mean values of the solar radio flux at 10.7 cm wavelength (index $F_{10.7}$). Units are 10^{-22} Wt·m^{-2}·Hz^{-1}.

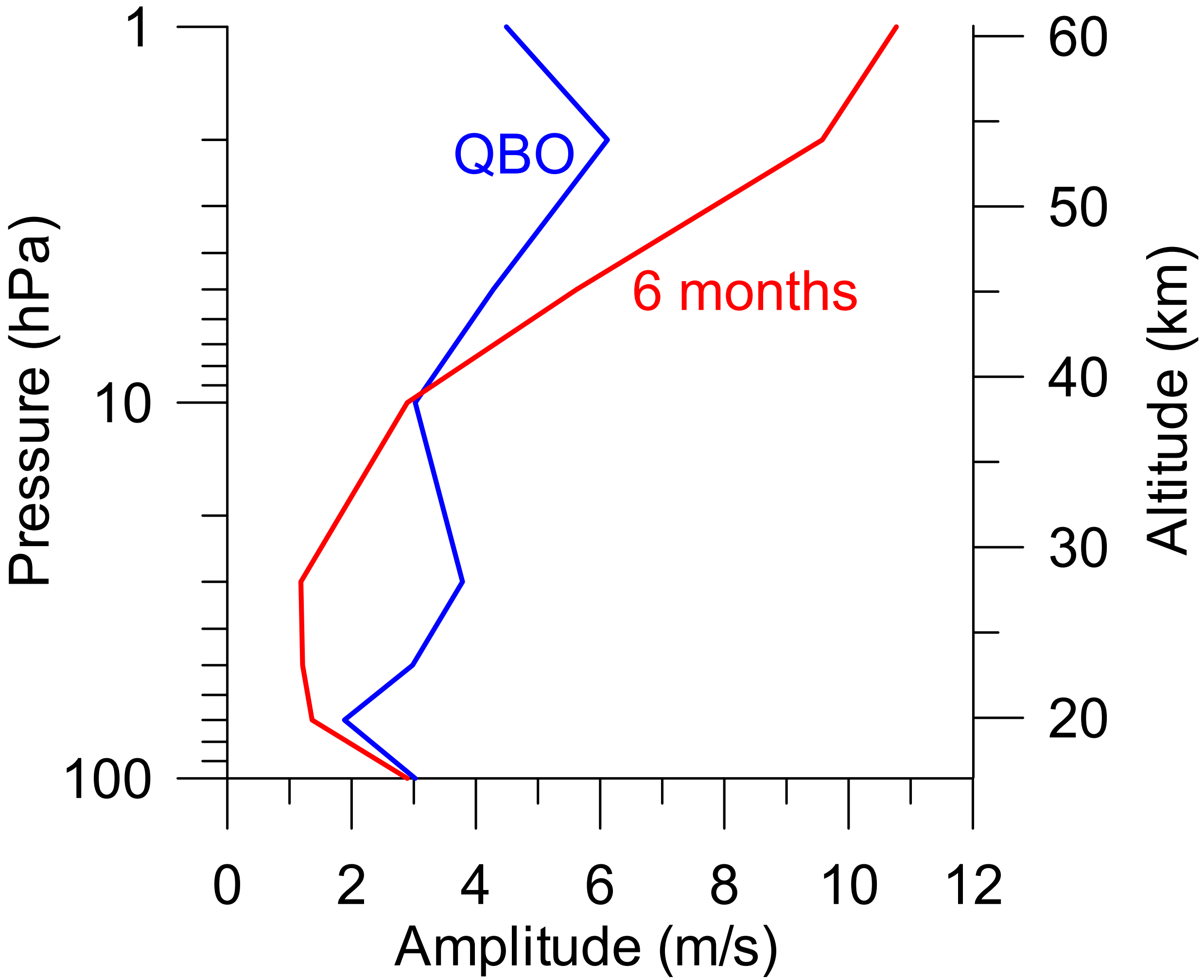

Fig. 2. Amplitudes of the quasi-biennial (blue curve) and semi-annual (red curve) oscillations of the velocity of the equatorial stratospheric wind, according to NMC data.

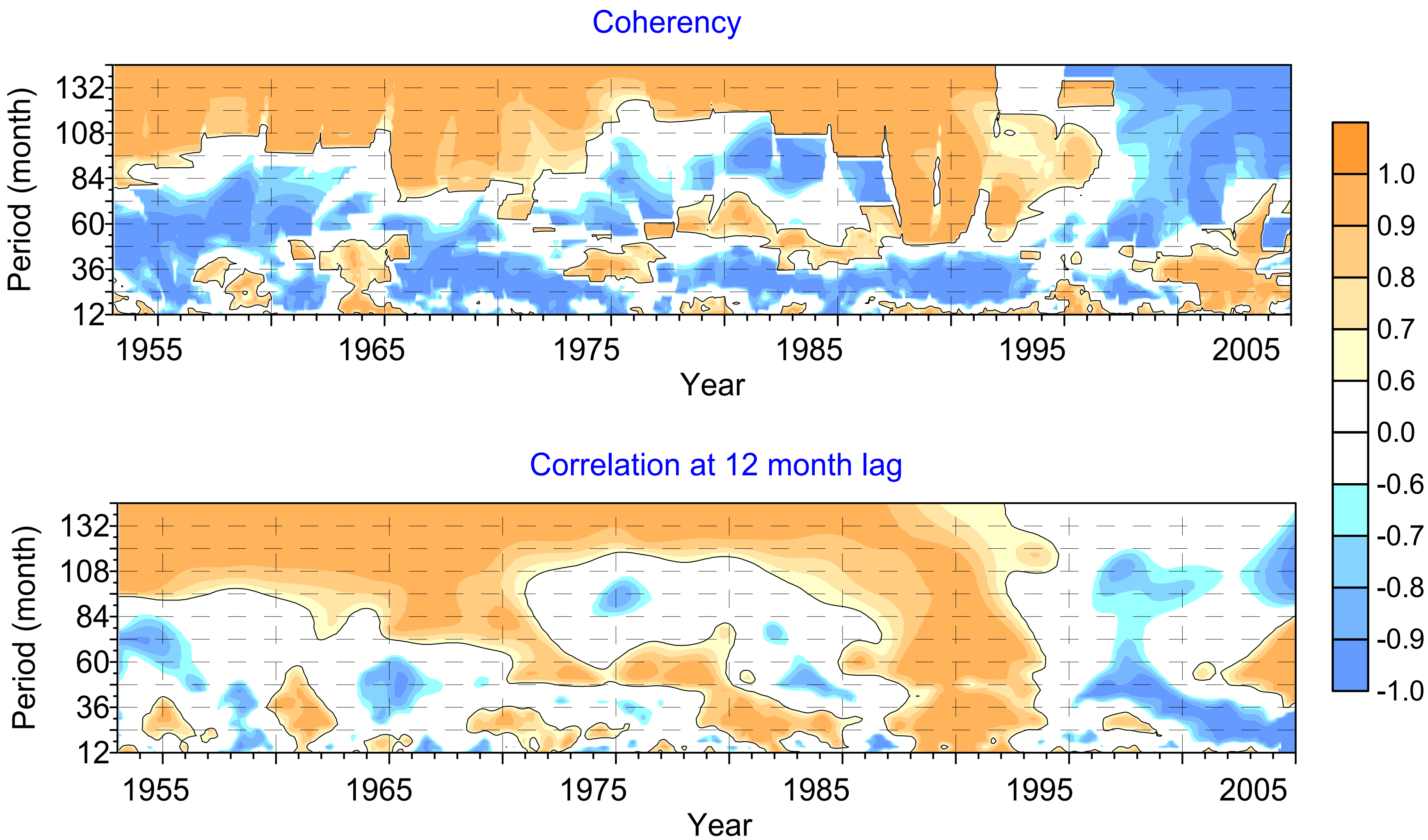

Fig. 3. Local coherency between the equatorial wind velocity at 15 hPa (from Berlin Free University data) and the index of solar activity $F_{10.7}$, and their local correlation at a fixed time lag of 12 months (velocity lags the index).

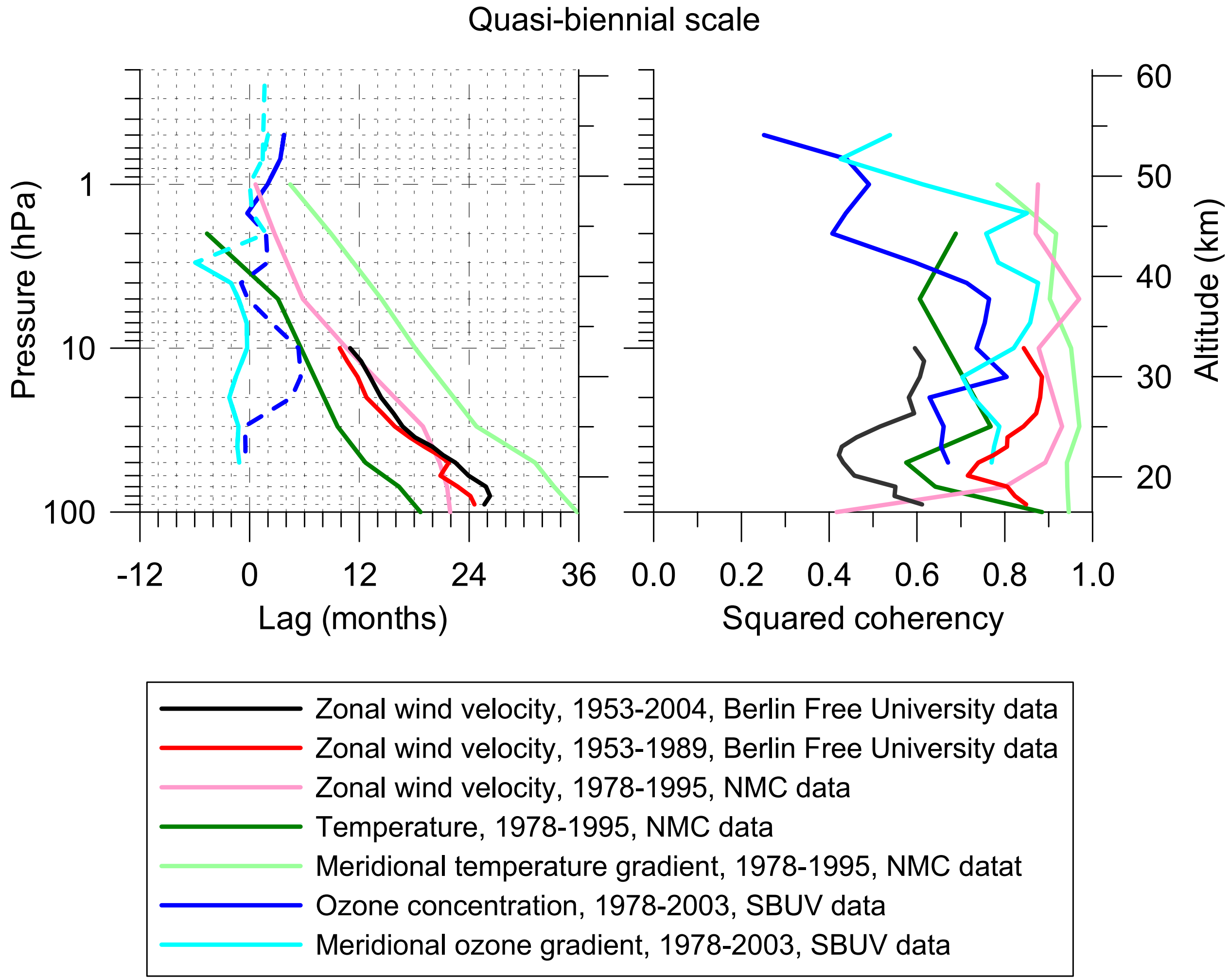

Fig. 4. Phase difference and coherency between the zonal wind velocity, temperature, ozone concentration, and temperature and ozone meridional gradients at the equator, on the one hand, and the $F_{10.7}$ index, on the other hand, at the **quasi-biennial** time scale. Positive lags correspond to solar index advance. Dashed parts of the curves correspond to additional phase shift by half period.

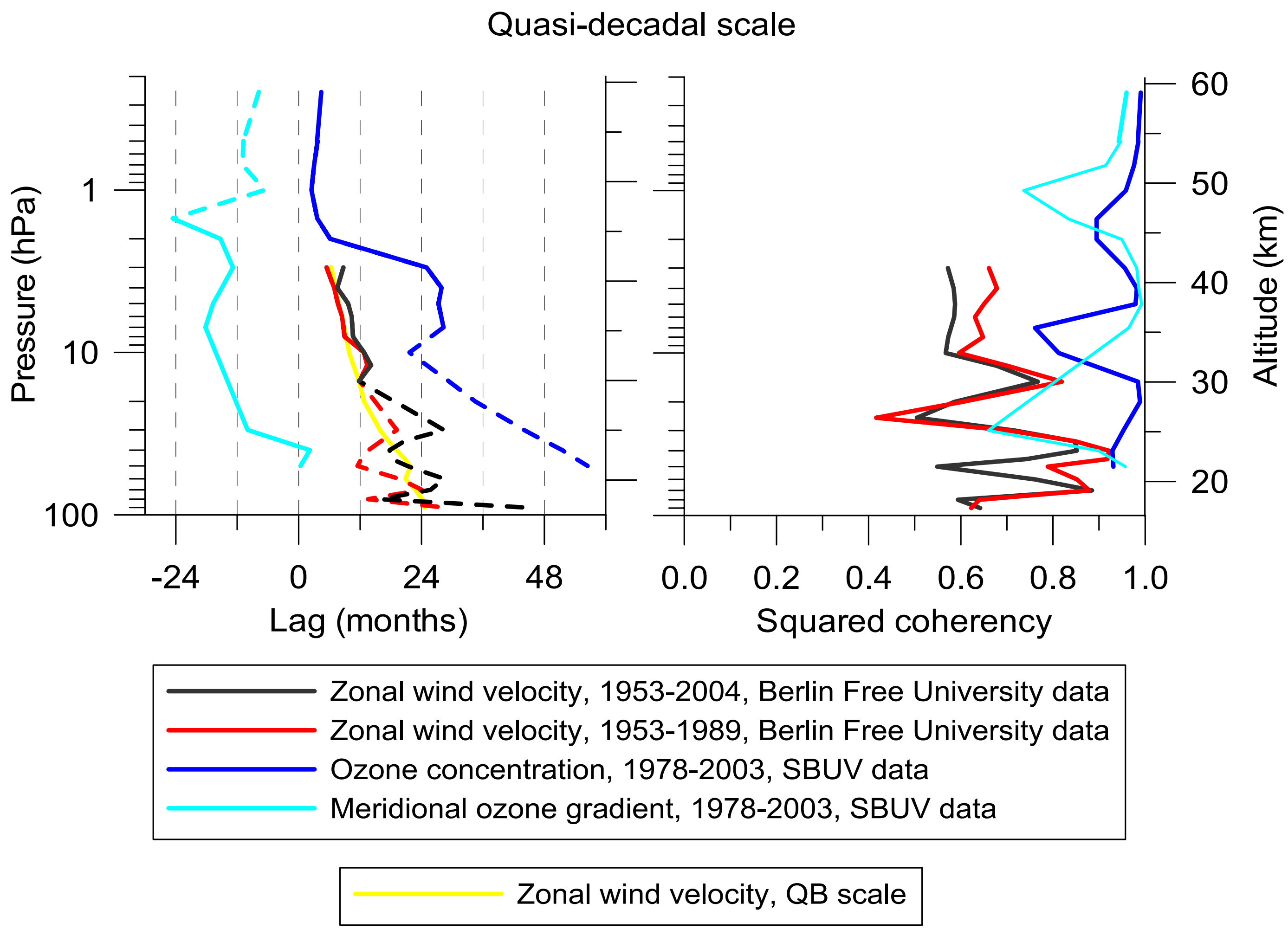

Fig. 5. Phase difference and coherency between the zonal wind velocity, ozone concentration, and ozone meridional gradient at the equator, on the one hand, and the $F_{10.7}$ index, on the other hand, at the **quasi-decadal** time scale. Positive lags correspond to solar index advance. Dashed parts of the curves correspond to additional phase shift by half period. The yellow curve repeats the phase curve for the wind velocity at the **QB** scale (cf. red curve in Fig.3).

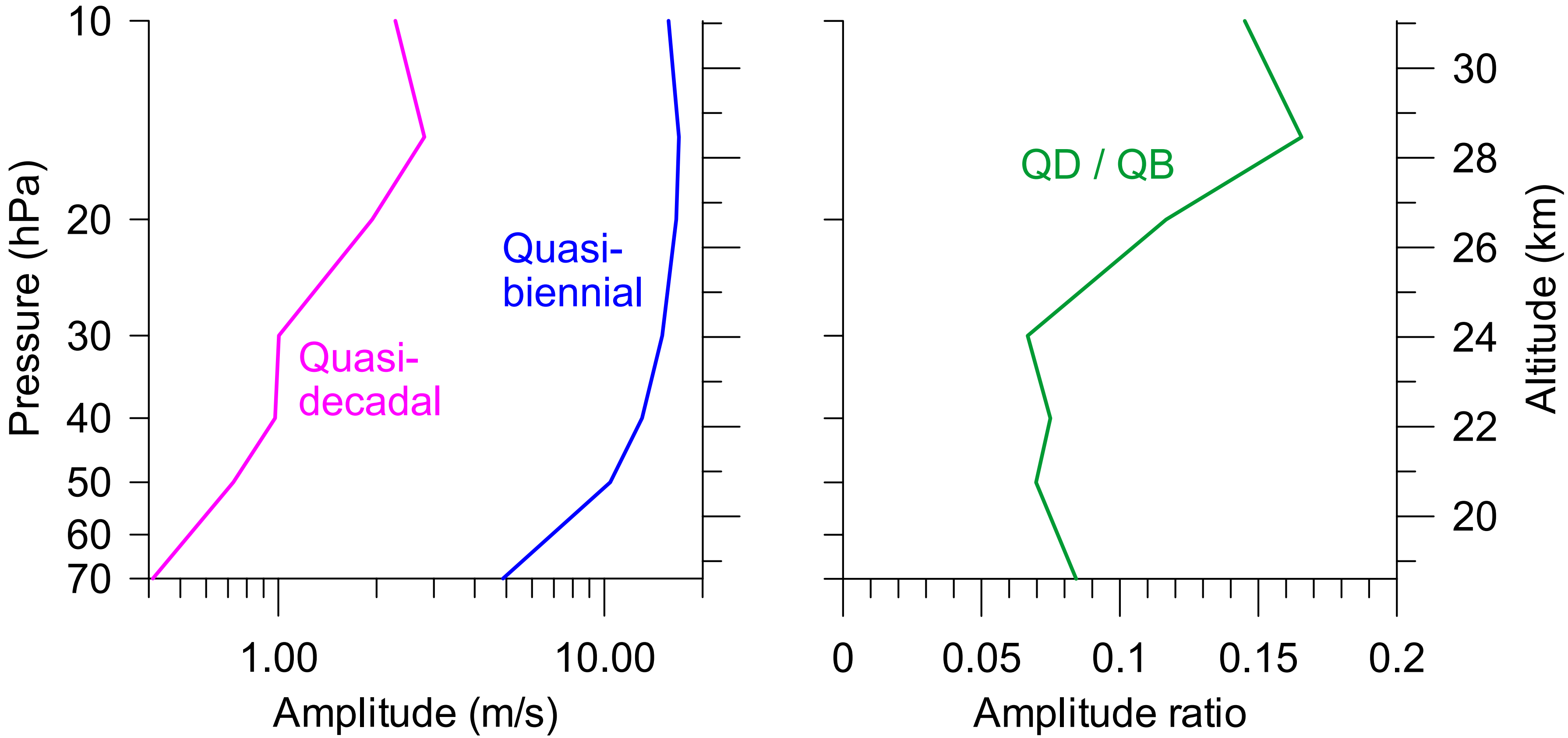

Fig. 6. Amplitudes of the quasi-biennial (pink curve) and quasi-decadal (blue curve) variations of the equatorial zonal wind velocity and ratio of the amplitudes (green curve).