Stratospheric vacillations, QBO, and solar activity

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Summary

The aim of the study is to compare planetary wave characteristics derived from NCEP/NCAR reanalysis data with Collm wind observations and validate solar activity influence. Vacillations of the SPW 1 amplitude and 5-,10-, 16-day atmospheric modes calculated from NCEP/NCAR reanalysis data and wind variations processed from Collm LF mesopause wind measurements since the 1980s are compared. Similarity of decadal variations of the SPW amplitude vacillations and meridional wind from Collm data is visible for the period 1980-1995. Comparison of the 5-,10-, 16-day atmospheric modes with 2-7, 7-12, 12-30 day period Collm wind variation data do not show clear correspondence for period 1980 - 2005. Correlations between vacillation amplitudes with sunspots numbers and the stratospheric QBO of different phases are presented also.

Zusammenfassung

Die Charakteristik planetarer Wellen, analysiert auf der Basis von NCEP/NCAR-Reanalysen, wird mit Windmessungen von der Außenstelle Collm verglichen, und auf den Einfluss solarer Variationen und der stratosphärischen QBO untersucht. Wir verwenden Schwankungen der stationären planetaren Welle 1, sowie Analysen der 5-, 10- und 16-Tage Welle. Die Variabilität der stationären Welle 1 und diejenige der Windvariationen am Collm stimmt auf der dekadischen Zeitskala überein, jedoch spiegelt sich die Variabilität der Normalmoden (5-, 10-, 16-Tage-Welle) nicht in der entsprechenden Variabilität der Collmer Messdaten wider.

Introduction

Many recent studies emphasize the necessity of analyzing the influence of stratospheric dynamics on processes in the troposphere and a possible connection between solar activity and the atmospheric global wave patterns (e.g. Baldwin et. al., 2003; Baldwin and Dunkerton, 2005; Labitzke, 2006). The stratospheric dynamics is sensitive to changes of external parameters such as the solar flux. This highlights the need for stratospheric analyses, with respect to its response to solar forcing but also to its internal variations, with the potential influence on lower atmospheric circulation.

The atmosphere of the Earth is an oscillating system having its own global oscillations (normal atmospheric modes). At the same time, nonlinear interaction of the stationary planetary wave with the mean zonal flow evokes quasiperiodic oscillations of the former and the latter, which are called stratospheric vacillations. This paper is devoted to the consideration of connections between vacillations of the SPW 1 (Stationary Planetary Wave, m=1) amplitudes and 5-,10-, 16-day atmospheric modes with variations of the QBO (quasi-biennial oscillation), mesospheric wind data and solar activity. The vacillations of the zonal flow are not taken into consideration here.

Analyzed data

NCEP/NCAR (National Center for Environmental Prediction - National Center for Atmospheric Research) data have been used to estimate vacillation amplitudes and 5, 10-, 16-day normal atmospheric modes. The data used for analysis are zonal wind and geopotential height distributions in the troposphere and stratosphere for December, January and February during the entire NCEP/NCAR reanalysis time interval, i.e., from 1948 till 2007. During the first decade of the reanalysis some of the basic features like the QBO of the zonal mean flow in the equatorial stratosphere are not reproduced correctly. This is possibly due to the lack of sufficient observed stratospheric data assimilated into the model. Therefore only the NCEP/NCAR data since 1959 have been used here to investigate the long-term changes. NCEP/NCAR data are available on a 2,5 * 2,5 degree grid at a temporal resolution of 6 hours. All data are taken at 8 isobaric surfaces: 1000, 500, 400, 300, 200, 100, 30 and 10 hPa. Calculations include the decomposition of the longitudinal variations of the geopotential height for each time interval and each latitude into a mean zonal value and a superposition of 12 zonal harmonics. Amplitude and phase (longitude of maximum values) are calculated for each harmonic. Then real and imaginary parts of the complex amplitude for each zonal harmonic are calculated at all latitudes and their monthly (January) average values are obtained.

SPW characteristics were calculated as a mean for 2 winter months (from the middle of December till the middle of February after excluding 15 days from both sides) at 62.5 N. This latitude was chosen for consideration according to Kanukhina et al. (2007), who analyzed the statistical significance of the SPW variability from NCEP/NCAR data.

Vacillations of SPW arise as a result of nonlinear interaction between the SPW 1 and the mean zonal flow. The nonlinear interaction becomes apparent as quasi-periodic oscillations of the SPW amplitude and the mean zonal flow (Holton and Mass, 1976). The vacillation amplitudes are characterized by periodic expansions and contractions of the wave patterns with no noticeable change in the phase of the disturbances. Amplitudes of the vacillations **Ãvac** were calculated as follows:

$$\text{If } \mathbf{Aw} \geq \mathbf{Ae} \rightarrow \quad \mathbf{\tilde{A}w = Aw\text{-}Ae,}$$

$$\mathbf{\tilde{A}vac = 2{*}Ae,}$$
$$\mathbf{\tilde{A}e = 0;}$$

$$\text{If } \mathbf{Aw < Ae} \rightarrow \quad \mathbf{\tilde{A}e = Ae\text{-}Aw,}$$

$$\mathbf{\tilde{A}vac = 2{*}Aw,}$$
$$\mathbf{\tilde{A}w = 0,}$$

where **Ãe, Ãw** are recalculated eastward and westward PW amplitudes, **Ãvac** is the recalculated vacillation of the SPW 1 amplitudes, and **Ae, Aw** are wavelet spectra of the eastward and westward PW amplitudes.

At Collm Observatory, LF (low frequency) D1 wind measurements at 80-100 km altitude have been carried out near 52°N; 15°E continuously for several decades. Commercial radio transmitters in the LF range (177 kHz, 225 kHz and 270 kHz) are used, and the similar fade analysis is used for interpretation of the measurements. The reference height has not been measured before September 1982 so that the results from the earlier measurements have been attributed to the mean nighttime height near 90 km. From late 1972 the analysis is performed automatically, and since 1979 half-hourly winds from three measuring paths are constructed.

The measurements are usually investigated by calculating monthly median winds at each time during a day (with a resolution of 30 minutes) of the daily measuring intervals and applying a multiple regression analysis to the monthly medians of the half-hourly mean winds. The method has been described by Jacobi and Kürschner (2006), and references therein. Alternatively, daily mean winds from a regression analysis can be used to analyze their monthly or seasonal mean standard deviation in different period ranges typical for planetary waves (Jacobi et al., 2008). These data will be used here.

Values of the QBO (January) at 30 hPa level are provided by NOAA/NCEP/CPC on http://www.cpc.ncep.noaa.gov/data/indices/. QBO data are available during 1979–2007 as reanalysis data and, thus, are not the Singapore winds used by Freie Universität Berlin but the zonally averaged CDAS Reanalysis data winds at 30 hPa and taken from over the equator. QBO of Freie Universität Berlin are used at the beginning of studied interval from 1959 till 2001. As a proxy for solar activity we use monthly International Sunspot Numbers taken from NOAA National Geophysical Data Center for January.

Results

Variations of the SPW 1 amplitude vacillations of periods of 10-30 days and Collm zonal wind data of long-period waves (7-30 days) show a similarity of the decadal variation during 1980-2005 accompanied by coincidence of some of the amplitude maxima (Fig. 1). However, the zonal mesospheric wind variations differ strongly from NCEP/NCAR vacillations after 1992, especially with respect to the long-term trend and its trend and counter phases of maxima. Usually, vacillations of the SPW 1 are in counter phases with zonal wind amplitudes (Pogoreltsev, 2007) but at Fig. 1 this is observed only during the second part of the considered period. So, zonal wind decadal variations did not show good compatibility with the vacillation variations.

Meridional wind standard deviations of 7-30 day periods temporally changes as the vacillations did from 1980s till the middle 1990s. Opposite phase event of the SPW vacillations and Collm meridional wind speed variations appeared since 1995. After coincidence of minima at 1997 the Collm wind speed extrema are shifted by 2 years later comparing with the SPW vacillations.

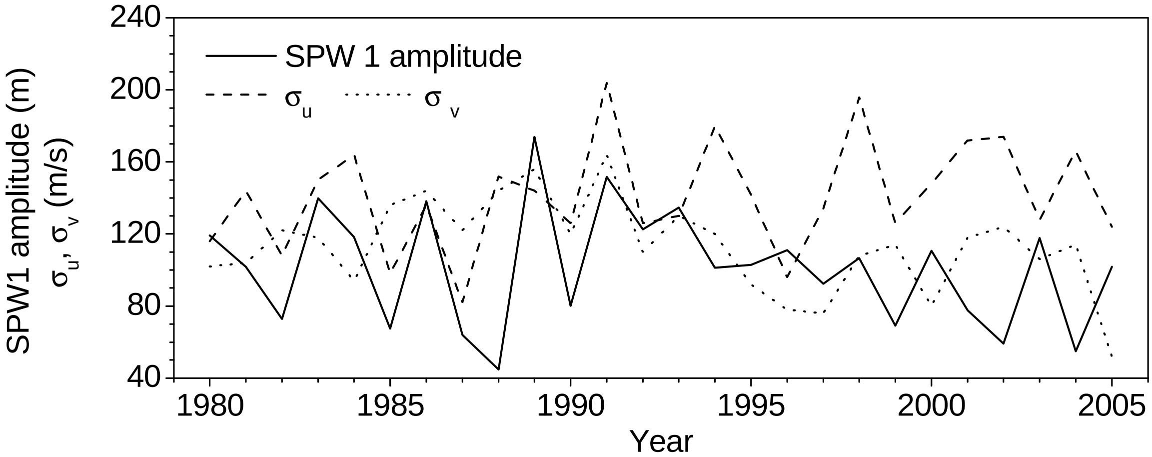

Figure 1. December–February mean amplitudes of SPW1 amplitude vacillations from NCEP/NCAR data (solid line), and Collm zonal (σ_u, dashed line) and meridional (σ_v, dotted line) standard deviations of daily wind speeds in the 7-30 day period range multiplied by 20.

Very similar decadal variations of the Collm meridional wind speed and the SPW vacillations are obvious from Fig. 1. We may suggest that the meridional wind speed has noticeable impact on the formation of the SPW vacillations and vice versa. As discussed at different studies, the mean meridional circulation systems are influenced by the solar cycle (Labitzke, 2006). Also, the following process is recognized as an acting mechanism of the energy transfer: variation of the incoming solar radiation changes the ozone content and the stratosphere temperature field causing thermal gradient disturbances, which affect the wind systems. Redistribution of the lower and middle atmosphere wind pattern affects propagation conditions of the planetary waves and, finally, the atmospheric global circulation. Therefore in the following we consider the vacillation variations in connection with sunspot numbers and QBO.

Composition of the SPW vacillation variations and QBO winds at 30 hPa (Fig. 2) shows only weak coincidence of maximum and minimum phases and tendencies during 1959-2007. Their decadal changes (if there is any) tend to have the same character. The last two decades are remarkable by strong interannual variability of the vacillations. Sharpened and complex decadal variations of the SPW 1 vacillations after the 1980s could be explained by satellite observation included in the NCEP/NCAR reanalysis (Kalnay et al., 1996). There is a tendency of a quasi-biennial oscillation in the SPW vacillations, however, at first glance there is no clear correspondence between the equatorial QBO and the SPW vacillations.

To analyze a possible external influence on a QBO/SPW connection, we examined running correlations between the vacillations of the SPW 1 amplitudes from NCEP/NCAR data, QBO wind values and solar activity (Fig. 3). According to literature, high sunspot numbers (more than 100) and westerly QBO correspond to a strong polar vortex (Labitzke, 1987; Labitzke et al., 2006) and thus to weak SPW vacillations, so that for high sunspot numbers a negative correlation between the vacillations and QBO is expected, while positive correlation is expected for lower sunspot numbers. In Fig. 3 after 1980 a tendency for a coupling of the correlation with the solar cycle is visible, which would support this assumption, however, the large correlation coefficients around 1980 and the low values in the early 1960s do not fit into this picture. Thus, we may only speculate about a solar activity variation influence on the SPW 1 vacillations through QBO intermediation.

Fig. 4 presents different types of linear correlations of the vacillations with QBO, sunspot numbers at west and east phase of QBO. Linear correlation between the vacillations and QBO wind speed is positive, although weak, R=0.3, as seen from Fig. 4a. That means the direct influence of the QBO on the SPW vacillations at 62 N, with stronger vacillations of the SPW 1 amplitude during years with western QBO values, is relatively weak. According to investigations of Holton and Tan (1980) the westerly QBO at 50 hPa is associated with small amplitudes of the SPW 1 during early winter (November – December) but during late winter (January – March) there was very little difference for SPW 1. Influence of the QBO phase on the SPW 2 is stronger especially at late winter when westerly QBO is correlated with strong SPW 2. We consider the vacillations of the SPW 1 amplitude which present a combined parameter dependant on nonlinear interaction of both, SPW 1 and zonal wind amplitudes. Such discordance of the QBO influence on the SPW 1 amplitude and its vacillations could be caused by impact of the counter phase zonal mean wind variations and nonlinearity of the interaction, generating the vacillations.

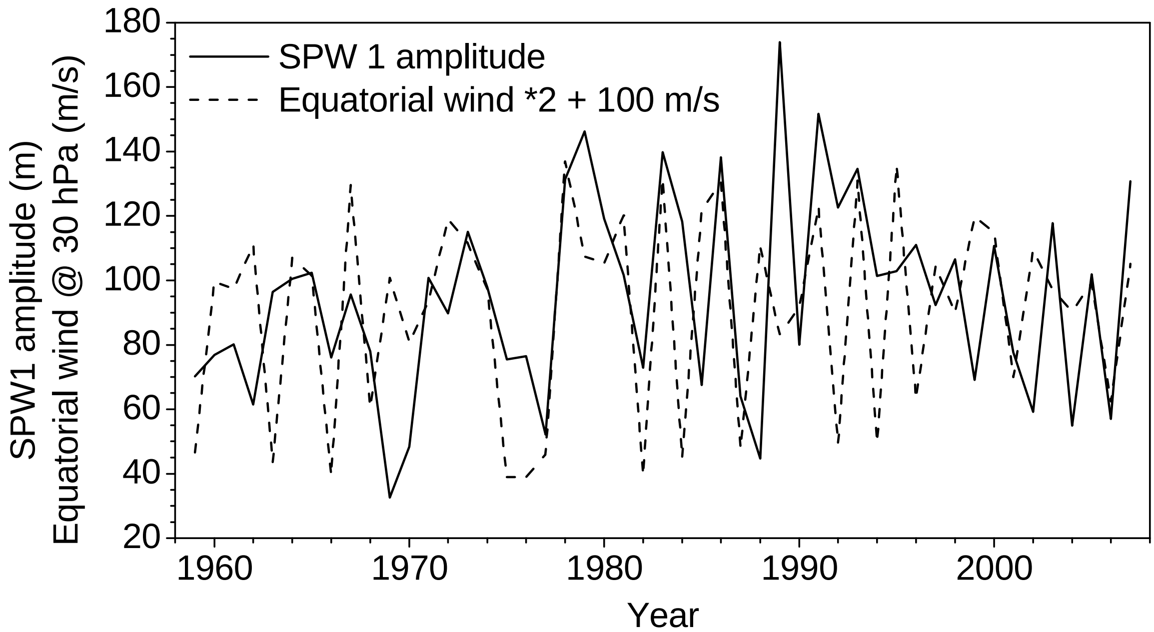

Figure 2. December–February mean amplitudes of SPW1 amplitude vacillations from NCEP/NCAR data (solid line), and 30 hPa QBO wind speeds (January) multiplied by 2 and added 100 m/s.

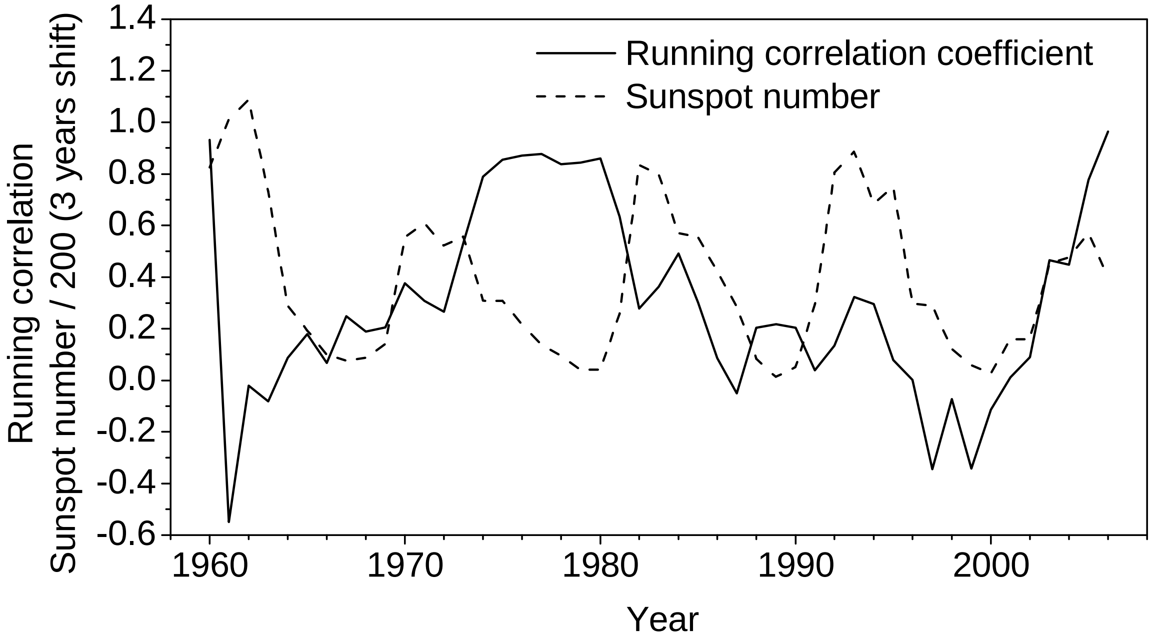

Figure 3. Running correlation coefficients for the vacillations of the SPW amplitudes from NCEP/NCAR (December-February mean at 62N) and QBO values (solid line) and January sunspot numbers divided by 200 and shifted by 3 years (dashed line).

The running correlation coefficient between sunspot number shifted by 3 years and the SPW vacillations is -0.09 (Fig. 4b) and statistical insignificant . To consider in more details we present linear correlation of amplitudes of the vacillations and sunspot numbers (January) shifted by 3 years for the period 1960-2006, during the east and west phase of the QBO separately (Fig. 4c). West phase of the QBO corresponds to low negative correlation r = -0.12 with the vacillations amplitude, while the east phase one has weakly positive correlation r = 0.26. This means the westerly QBO is associated with small negative correlation between solar cycle and the vacillations. Easterly QBO winds correspond to positive correlation of the vacillations and sunspot numbers.

Vacillations of the SPW 1 amplitudes are responsible for generation of the low frequency atmospheric modes in the low and middle atmosphere (Pogoreltsev, 2007). Different numerical experiments showed generation of the 10- or 16-day atmospheric modes, or sudden stratospheric warmings after arising of strong SPW 1 vacillations. We checked the possibility to use observational Collm atmospheric modes for vacillation effect study. Comparisons of the reanalysis 5-,10-, 16-day atmospheric modes with 2-7, 7-12, 12-30 day period Collm wind data is presented in Fig. 5. Normal atmospheric modes and Collm meridional and zonal wind components have quite different decadal variability and the only similar details could be seen with 10-day mode and 7-12 day Collm wind during 1987 – 2000 when linear negative trend could be recognized within the amplitudes (Fig. 5b). But it is difficult to find clear relation between normal modes from reanalysis data and Collm LF mesopause wind measurements. Different latitudes (vacillations at 62N, Collm winds from 52N) of analyzed data could produce the discordance.

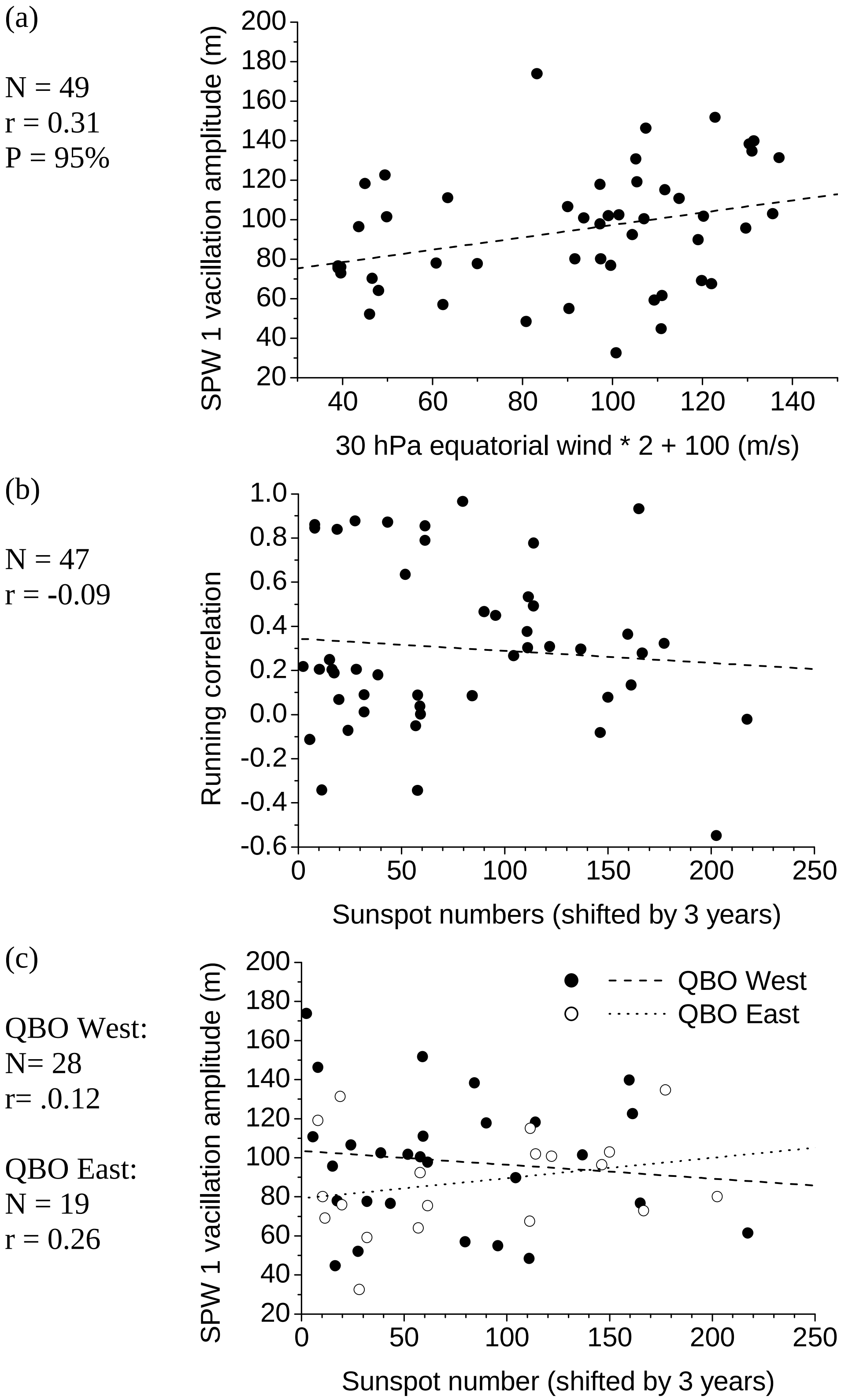

Figure 4. SPW 1 vacillations amplitudes (December-February means at 62N) against QBO wind speeds (a), running correlation coefficient between SPW 1 amplitude vacillations and QBO against sunspot numbers shifted by 3 years (b), and SPW 1 vacillation amplitudes against sunspot numbers shifted by 3 years, for QBO East and West phase separately (c).

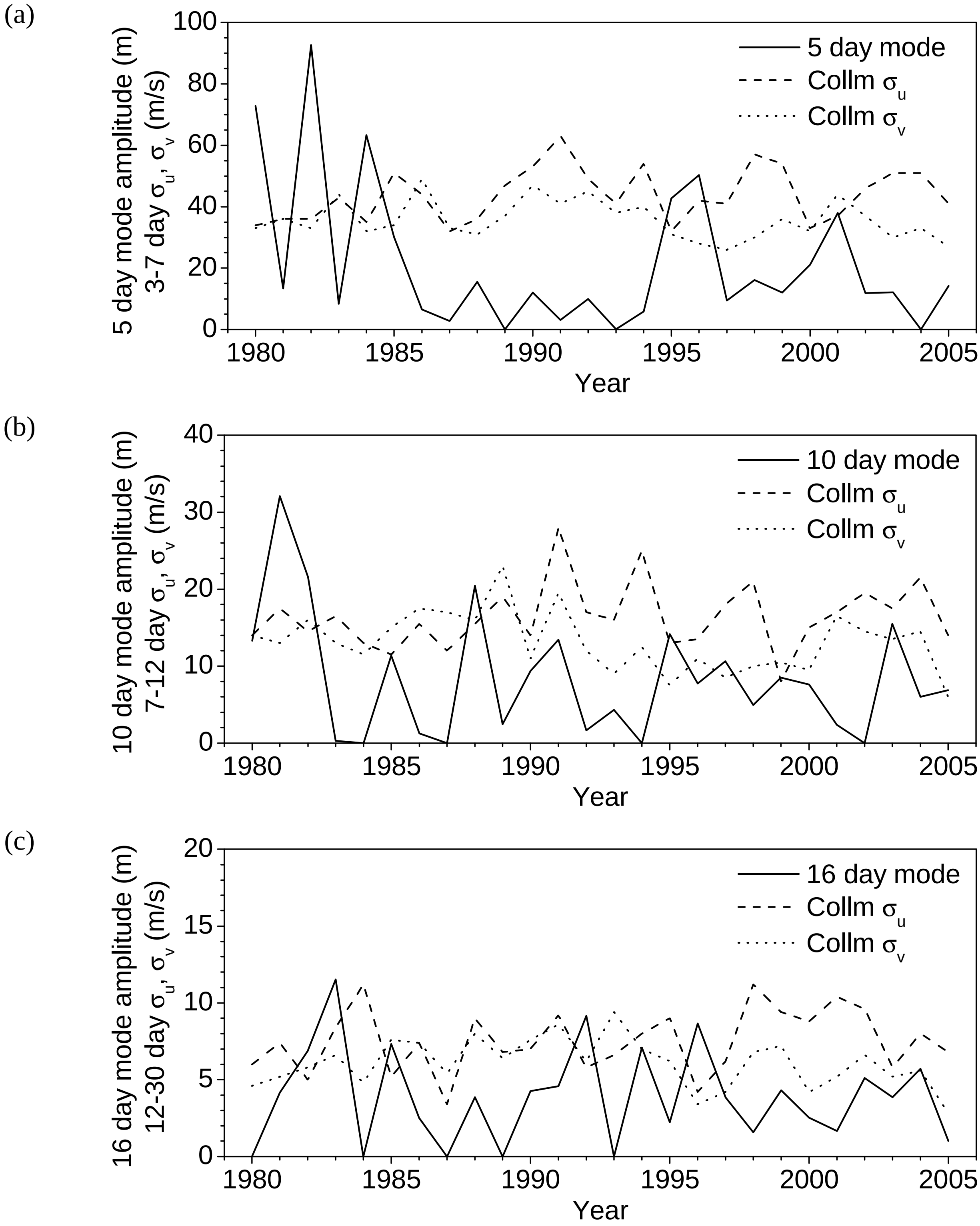

Figure 5. Stratospheric normal modes amplitude (solid), and Collm zonal (dashed) and meridional (dotted) standard deviation data with (a) periods 3-7 days multiplied by 10; (b) periods 7-12 days multiplied by 5; (c) periods 12–30 days multiplied by 5. Collm standard deviation data are taken from Jacobi et al. (2008).

Conclusions

Collm meridional wind speed and the SPW vacillations showed very similar decadal variations during 1980 –2005. Small negative correlation is observed between solar cycle activity and the vacillations at westerly QBO. Easterly QBO winds are associated with positive correlation of the vacillations and sun spot numbers. Estimating correlation coefficients we remind that only 5 available solar cycles are quite a short period and our conclusions have preliminary character. Normal atmospheric modes and Collm meridional and zonal wind components do not show the expected similarity and do not allow to study connections between the SPW 1 vacillations and observational, not reanalysis, atmospheric modes.

Acknowledgements

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