Comparison of quasi-2-day wave amplitudes and phases over Collm (51.3°N, 13.0°E) based on two different analyses

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Summary: Collm meteor radar (MR) winds have been analyzed with respect to quasi 2-day wave (QTDW) amplitudes and phases. Two methods have been considered, one of them taking into account the varying period and the other one assuming a fixed period of 48 h. While the use of a fixed period leads to a slight underestimation of amplitudes, the seasonal cycle, the inter-annual variability, and the distribution of amplitude and phase differences between the zonal and meridional horizontal component are similar for both methods. One may conclude that the use of a fixed period is justified for analyzing QTDW amplitudes and phases as long as only qualitative results are required.

Zusammenfassung: Ergebnisse von Windmessungen des Meteorradars Collm wurden in Bezug auf Amplituden und Phasen der Quasi-zwei-Tage-Welle analysiert. Dabei wurden zwei verschiedene Methoden gewählt: eine berücksichtigt die Variation der Periode, bei der anderen wird eine feste Periode von 48 h angenommen. Zwar führt die Annahme einer festen Periode zu einer leichten Unterschätzung der Amplituden, jedoch zeigen sowohl der Jahresgang und die Jahr-zu-Jahr-Variabilität als auch die Verteilung von Amplituden- und Phasendifferenzen zwischen zonaler und meridionaler Komponente ähnliche Resultate für beide Methoden. Man kann schlussfolgern, dass die Verwendung einer festen Periode so lange gerechtfertigt ist, wie lediglich qualitative Ergebnisse von Interesse sind.

1 Introduction

The quasi 2-day wave (QTDW) is a regular phenomenon of the summer middle atmosphere first reported by Muller (1972). The QTDW usually appears as a series of 1-3 bursts of few days to few weeks duration in every summer. There is a considerable variability of the QTDW from year to year. Regarding the excitation mechanism, Salby (1981) suggested the QTDW to be a manifestation of a Rossby gravity normal mode with zonal wave number 3, while Plumb (1983) and Pfister (1985) came to the conclusion that baroclinic instability could be the excitation mechanism for QTDWs. These theories were later combined by analysing observations of the QTDW and results of a numerical model (Salby and Callaghan, 2001).

The period of the QTDW varies between 43 and 56 h in the northern hemisphere (Pancheva et al., 2004) and is close to 48 h in the southern hemisphere (Wu et al., 1996). Thus, to analyze the QTDW from radar wind time series, different methods have been applied. Meek et al. (1996) fitted a 48 h period to the original data after subtracting oscillations with larger amplitude. Huang et al. (2013) used multiple regression to fit the 48 h period and other periods of interest to wind data from the meteor radar (MR) at Maui. A similar analysis was performed by Lilienthal and Jacobi (2013) using Collm MR winds. Jacobi et al. (1997) determined the period of the QTDW through least-squares fitting of the wave to half-hourly winds and then used a harmonic fitting of the wave and the solar tides using this period to obtain amplitudes and phases. Harris (1994) analyzed wind data filtered in a period range 32-96 h to determine phases and amplitudes. In addition, through demodulation technique he was able to detect the period of the wave.

To summarize, the QTDW exhibits considerable variability concerning its phase, and a variety of different complex analyses has been applied to obtain information about the wave. In some cases, not all the details of the wave are required, for example, Jacobi (1998) analyzed the QTDW inter-annual variability using monthly mean amplitudes based on 48 h fits disregarding the period variations. Therefore, the latter raises the question, whether a pure 48 h fit describes the variability of the QTDW well enough, or whether the period variability must be taken into account in each analysis. To this end, we analyzed MR wind data over Collm (51.3° N, 13.0° E) with and without taking into account QTDW period variability.

2 Measurements and data analysis

The Collm All-Sky Interferometric Meteor Radar (SKiYMET) measures mesopause region winds, temperatures, and meteor parameters since the summer of 2004 (Jacobi, 2012). The principle of the radar is based on the Doppler shift of the reflected very high frequency (VHF) radio wave from ionized meteor trails, which delivers radial wind velocities along the line of sight of the radio wave. Since vertical winds are assumed to be small, a least-squares fit of the horizontal half-hourly wind components has been applied to the individual radial wind in order to deliver half-hourly mean horizontal wind values (Hocking et al., 2001). The transmitting antenna is a 3-element Yagi. The five receiving antennas are

2-element Yagis, arranged in an asymmetric cross. This way, the azimuth and elevation angle can be calculated from the phase comparisons of the individual antenna pairs. Together with the range measurements the meteor trail position can be detected. More details can be found in Hocking et al. (2001). Meteor trail reflection heights vary between 75 and 110 km with a maximum at about 90 km (e.g., Stober et al., 2008). Here, we analyze the data from a height gate centered at 91 km and a width of 3 km, taken between September 2004 and October 2013. To obtain the amplitudes and phases of the QTDW a harmonic analysis was applied to the half-hourly mean winds. It is based on a least-squares fit of the prevailing wind, tidal oscillations of 8 h, 12 h and 24 h and the period of the QTDW. Each individual fit is based on 11 days of half-hourly mean winds and the results are attributed to the center of the respective data window. The window is then shifted by one day. This procedure has been applied to the zonal and meridional wind components. Then, QTDW total amplitudes were calculated as the square-root of the sum of the squared zonal and meridional horizontal wind components.

For periods between 40 h and 60 h these amplitudes were delivered using a normalized Lomb periodogram (after Press et al., 2001) calculated from half-hourly mean values of the meridional wind component in 11-day windows. The period of maximum amplitude for each window has been assumed to be the real period of the QTDW, and it was used for the harmonic analysis described above. Alternatively, the QTDW period was set to 48 h. These latter data have already been presented by Lilienthal and Jacobi (2013).

3 Results

Daily total amplitudes, each based on an analysis of 11 days of data, are shown in Fig. 1. In each part of the figure, the curves of one year are shown which have been calculated by both methods. The QTDW proxy, calculated with fixed period, usually underestimates the amplitudes based on the real periods. A scatter plot, showing the proxy amplitude vs. the real amplitude, is provided in Fig. 2. On an average, the proxy amplitudes underestimate the real ones by a factor of 0.86 with a prediction error of 3.2 m/s which is given by

$$\sigma(\epsilon) = \sqrt{\frac{\sum_i (y_i - y_{fit})^2}{DF}} \quad , \tag{1}$$

where DF denotes the degrees of freedom, y_i the measured proxy period amplitude and y_{fit} the predicted (fitted) proxy period amplitude.

One can see in Fig. 1 that the seasonal cycle in each year is similar. There is a weak winter maximum and a large summer maximum in each year, although there is considerable inter-annual variability. The real and proxy curves show

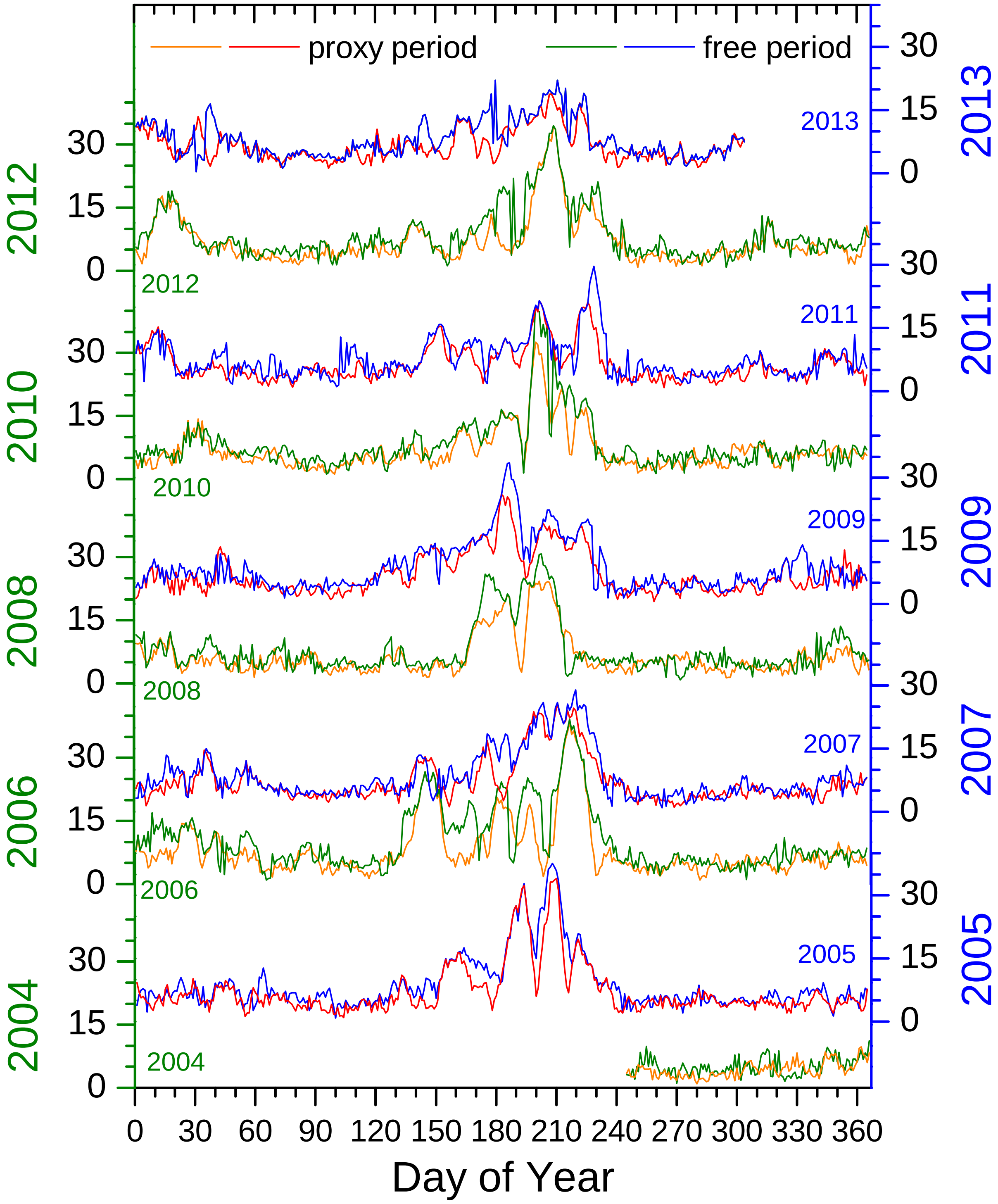

Fig. 1: QTDW total amplitudes (m/s) for each year from September 2004 to October 2013. Red/orange: proxy period of 48 h. Blue/green: real period from periodogram analysis.

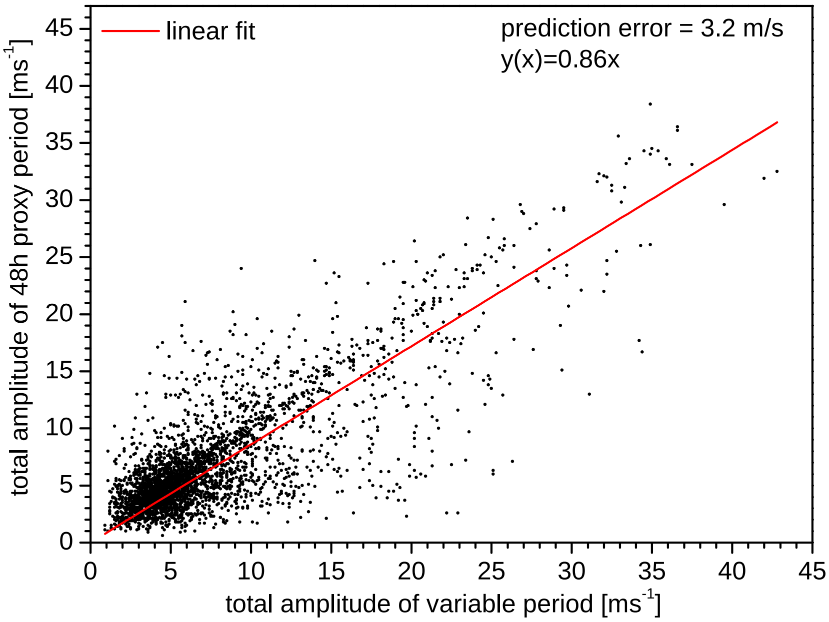

Fig. 2: Scatter plot of total amplitudes of the QTDW with periods retrieved from a periodogram analysis vs. those obtained using a proxy period of 48 *h. A linear fit is added as a red line.*

a similar tendency. This is well visible in the multiple year mean climatology provided in Fig. 3. Apart from the underestimation mentioned before, the proxy amplitude shows the same seasonal cycle like the analyses based on real periods. One may see from Figs. 1 and 3 that there is a sort of "noise floor" at about 5 m/s amplitude, which is due to irregular variations not owing to the QTDW. Therefore, to investigate the properties of the wave, only the cases with sufficiently large amplitudes should be considered. In Fig. 4, the frequency of the phase differences between the zonal and meridional component is shown for total amplitudes of 15 m/s or more. Data are only shown for May through August, however, during the rest of the year the amplitudes are small anyway and there are only very few cases when the amplitude exceeds 15 m/s. The positive values in Fig. 4 refer to the meridional component leading the zonal one, and a phase difference of 90° indicates a circular polarized wave. One can see that for both proxy and real phases the mean/median phase differences are similar (101.6°/103.9° for the proxy and 99.5°/98.9° for the real phases) and also the distribution shows similar width.

The relative amplitude differences are the differences between zonal and meridional amplitudes divided by their mean, where positive values indicate larger zonal than meridional amplitudes. Again, a similar behavior for both methods has been found (Fig. 5). While the shape of the distribution is asymmetric, mean

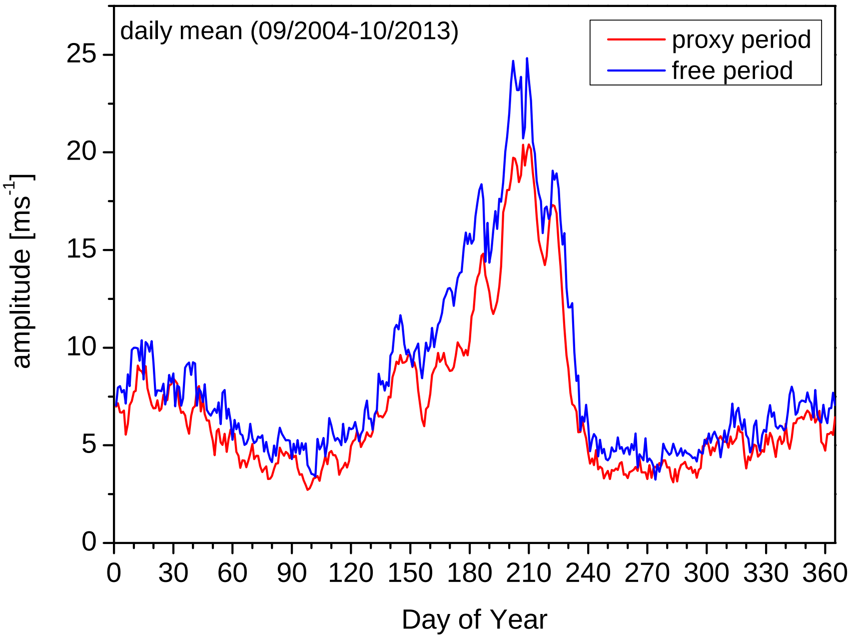

Fig. 3: Mean annual cycle of QTDW total amplitudes. Red: proxy period of 48 *h. Blue: real period from periodogram analysis.*

values and median values are comparable (−44.7%/−34.7% for the proxy and −49.6%/−43.9% for the real amplitudes).

One may see from Fig. 3 that there is considerable inter-annual variability of the QTDW amplitudes. The summer mean amplitudes, simply calculated as the arithmetic means of the daily amplitudes from May to August, are shown in Fig. 6. One can see that the inter-annual variability is qualitatively the same for both methods. In particular, there is a similarity of the year-to year changes with the one of the background wind shear shown in the upper panel of Fig. 6. This indicates a possible forcing mechanism of the QTDW through instability of the mean flow as has been mentioned by Lilienthal and Jacobi (2013). The solar cycle dependence, as has been indicated by the results of Jacobi et al. (1997) is not visible in these data, possibly because of the peculiarities of the deep recent solar minimum.

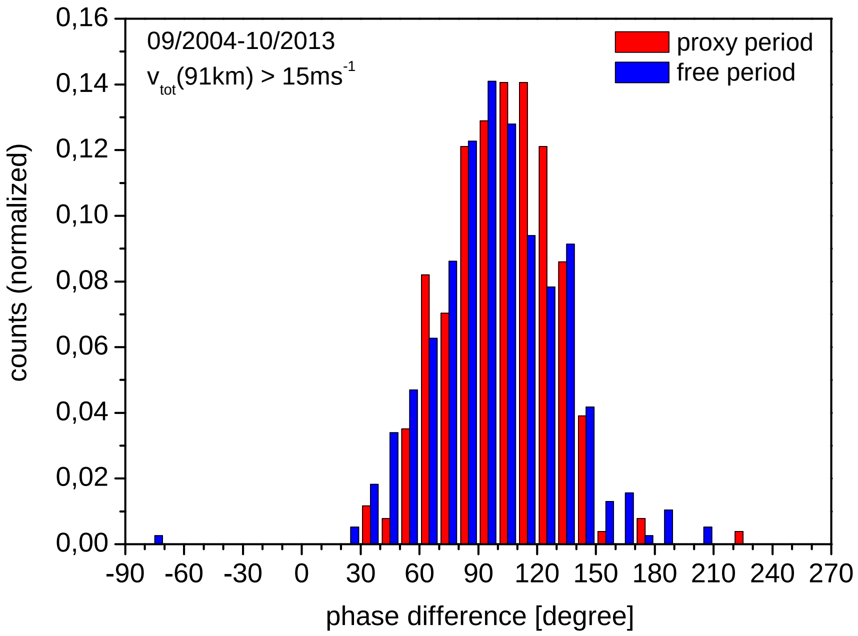

Fig. 4: Histogram of phase differences between the zonal and meridional component of the QTDW at 91 *km altitude. Only data with total amplitudes larger than* 15 *m/s are considered. The bars show the frequency per* 10% *relative difference. The analysis is based on 256 (proxy, red bars) and 383 (variable period, blue bars) data points, respectively.*

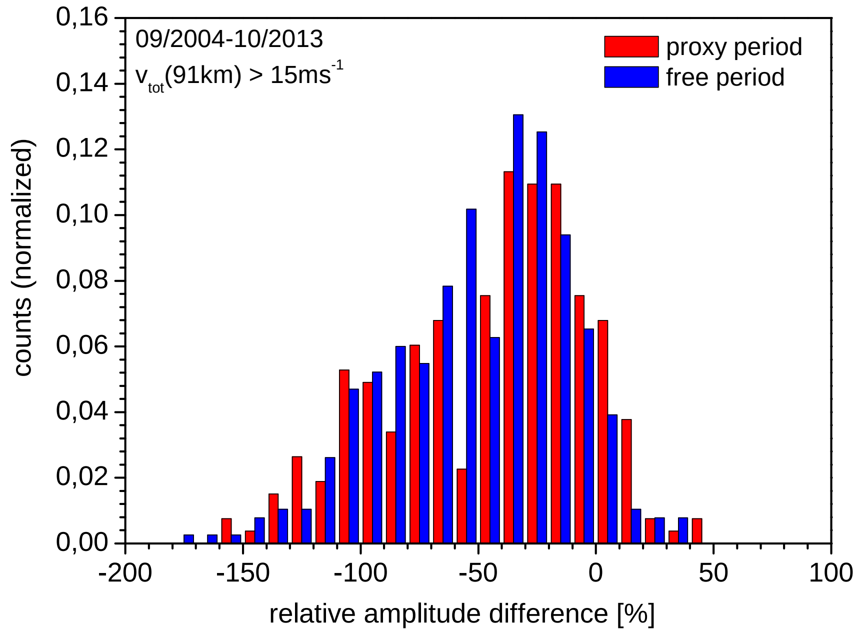

Fig. 5: Relative amplitude differences of the QTDW at 91 *km altitude. Only data with total amplitudes larger than* 15 *m/s are considered. The bars show the frequency per* 10% *relative difference. The analysis is based on 256 (proxy, red bars) and 383 (variable period, blue bars) data points, respectively.*

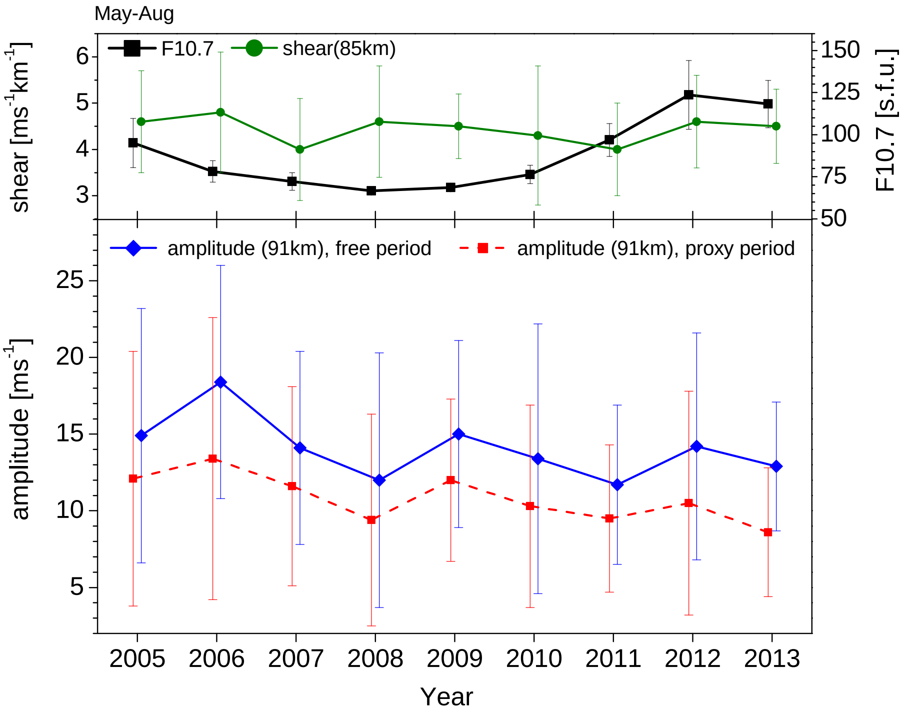

Fig. 6: Inter-annual variability of the QTDW, solar activity and background wind shear. Values for each year refer to means of daily data over the respective summer (May-August). Upper panel: F10.7 solar radio flux (black) and vertical wind shear of the zonal prevailing wind at 82 km *altitude (green). Lower panel: QTDW total amplitudes at* 91 km *altitude for real periods (solid, blue) and proxy period of* 48 h *(dashed, red). Error bars denote standard deviation.*

4 Conclusions

Collm MR winds have been analyzed with respect to QTDW amplitudes using two different methods, one taking into account the varying period and the other one assuming a fixed period of 48 h. Since the former method requires spectral analysis before the harmonic analysis can be performed, the latter method, resulting in a sort of proxy for the QTDW amplitudes and phases, requires less effort.

We have compared the seasonal cycle and found that, on an average, the tendencies are similar, independent of the used method. The use of a fixed period leads to a slight underestimation of the amplitudes by a factor of 0.86 on an average. The distribution of the amplitude and phase differences between the zonal and meridional horizontal components, however, is similar for both methods. The same holds for the inter-annual variability, which shows the same qualitative tendencies for both methods. One may conclude that the use of a fixed period is justified as long as only qualitative results of QTDW analyses are required.

Acknowledgements

F10.7 solar radio flux data have been provided by NGDC through ftp access on `http://ftp.ngdc.noaa.gov/STP/SOLARDATA/`.

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