Interannual variability of the quasi two-day wave over Central Europe (52°N, 15°E)

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Summary

Using the spaced receiver method in the low-frequency (LF) range, lower E-region ionospheric drifts are measured at Collm Observatory, Germany since several decades. These drifts are interpreted as upper mesospheric winds at the reflection height of the used amplitude modulated LF radio waves, the latter being measured since 1983 using travel time differences between the ground wave and the ionospherically reflected sky wave within a small sideband range near 1.8 kHz above and below the carrier frequency. One regular feature of midlatitude upper mesosphere winds is the quasi two-day wave (QTDW), known as a wavenumber 3 or 4 wave in the middle atmosphere, usually occurring as one or more bursts during the summer season at midlatitudes. The OTDW bursts, as measured in LF winds, shows substantial decadal and interannual variability. Comparison with the background winds show that the onset of QDTW bursts is found near maximum values of the vertical wind shear, and maximum QTDW amplitudes are measured, on average, about one week after the maximum wind shear. This supports the theory that the QTDW is forced by instability of the summer mesospheric wind jet.

Zusammenfassung

Am Observatorium Collm werden seit mehreren Jahrzehnten Langwellenwindmessungen in der unteren ionosphärischen E-Schicht durchgeführt. Die zugehörige Reflexionshöhe wird, auf der Basis von Laufzeitdifferenzmessungen zwischen der Raum- und Bodenwelle, seit 1983 ebenfalls registriert. Eines der regelmäßig beobachteten Phänomene ist die quasi 2-Tage-Welle, die als eine planetare Welle der Wellenzahl 3 oder 4 bekannt ist. Diese Welle erscheint in mittleren Breiten in einem oder mehreren Schüben im Sommer. Nach den Messungen am Collm besitzt die Welle eine deutliche Variabilität von Jahr zu Jahr. Vergleiche mit dem zonalen Grundwind zeigen, dass das Auftreten von Maxima der 2-Tage-Welle in vielen Fällen mit erhöhter vertikaler Windscherung in Verbindung steht, so dass im langzeitlichen Mittel maximale Wellenamplituden einige Tage nach dem Auftreten maximaler Windscherung zu finden sind. Dies unterstützt die These, dass die quasi 2-Tage-Welle durch barokline Instabilität des sommerlichen Mesosphärenjets angeregt wird.

Introduction

One of the strongest signals in midlatitude mesosphere/lower thermosphere (MLT) winds is the quasi-two-day wave (QTDW). This wave has been measured both in equatorial and midlatitude regions since the 1970s (Muller, 1972; Babadshanov et al., 1973), and has been identified as a westward propagating wave with wavenumbers 3 or 4 (Muller and Nelson, 1978; Meek et al., 1996). The wave is confined to lower latitudes in the stratosphere and lower mesosphere, but also propagates to the summer hemisphere MLT at midlatitudes (e.g. Fröhlich et al., 2003) so that at middle latitudes the QTDW is known as a summer phenomenon, with a weak secondary wave activity maximum during winter (Muller and Nelson, 1978).

The QTDW broadly has the character of a Rossby normal mode (Salby, 1981), but is believed to be forced by baroclinic instability of the summer wind jet (Plumb, 1983). The possible forcing of the QTDW through instability implicates a connection with the background wind shear (Plumb, 1983), being one factor affecting the meridional gradient of the potential vorticity, and QTDW amplitudes. Merzlyakov and Jacobi (2004) found from numerical calculations that increasing the summer mesospheric wind jet leads to the onset of a QTDW. Strongest vertical wind shear in the midlatitude MLT is found near solstice. Consequently, with decreasing shear the QTDW amplitudes strongly decrease after approximately mid August.

The period of the QTDW is close to 48 hours, but usually differs a bit from this exact value. In particular, a tendency towards shorter periods with increasing amplitude has been found, while towards the end of the QTDW season the periods tend to increase (Jacobi et al., 1997a). Therefore, analysis of the 48 hr oscillation is a good proxy for the QTDW activity. At midlatitudes, the QTDW activity is very variable both from year to year and within one year. Usually the wave appears as burst of about 2 weeks duration. During one summer season, several bursts of wave activity may be found.

In this study we make use of the long-term measurements of MLT winds at Collm to analyse the possible correspondence of QTDW amplitudes and background wind shear.

Data base and analysis

We make use of the low-frequency (LF) wind and reflection height measurements performed at Collm Observatory, which have been carried out since late 1982 (wind measurements without accompanying height estimations date back much longer). Using the spaced receiver method in the LF range, lower E-region ionospheric drifts are measured since the 1960s, which are interpreted as upper mesospheric winds at the reflection height of LF radio waves. The reflection height is measured since September 1982 using travel time differences of the ground wave and the reflected sky wave on a sideband near 1.8 kHz. The measurements are described in detail by Kürschner (1975, 1981), Kürschner and Schminder (1980), and Kürschner et al. (1987). They refer to an ionospheric reflection point at 52°N, 15°E, and a height between 80 and 100 km, depending of season and time of day.

Individual wind values are measured through estimations of time displacements (at a temporal resolution of 0.25 s) between corresponding fading extrema on closely spaced receivers. These wind values are combined to half-hourly means, which again were subjected to harmonic analysis based on multiple regression analyses with quadratically height-dependent coefficients, and using a running 10-day data window while attributing the respective day to the middle of the data window. We included into the analysis the semidiurnal tide and a 48 hr oscillation, the latter taken as a measure of the QTDW. For the semidiurnal tide, but not for the QTDW, circular polarization was assumed. The uncertainty of the wind values amounts to 5 ms^{-1}. (e.g. Jacobi et al., 1997b) The zonal prevailing wind gradient was calculated from the wind difference between 90 and 95 km. Prevailing winds and wave amplitudes were analyzed for a height of 92.5 km. No group retardation correction was applied, therefore these measured heights have to be considered as virtual, and real heights refer to an altitude of about 85 km (Jacobi et. al., 2006). As a further consequence the real zonal prevailing wind gradient may be somewhat stronger. In the following we only regard relative wind gradient changes.

Long-term results

Figure 1 presents 23-year mean values of the zonal prevailing wind gradient, the zonal prevailing wind itself, and the QTDW amplitude. Standard deviations are shown for QTDW amplitudes and vertical zonal prevailing wind gradients, each calculated from the 23 values corresponding to the respective day of the year. While the QTDW activity in winter is small, large amplitudes are found only from March through August. It can be seen that on average the maximum burst of QTDW activity occurs some time after the maximum vertical wind shear is measured. However, the interannual variability, expressed through the standard deviation of QTDW amplitudes, is large. In addition, obviously several bursts of large wind shear and QTDW amplitudes may appear in one year.

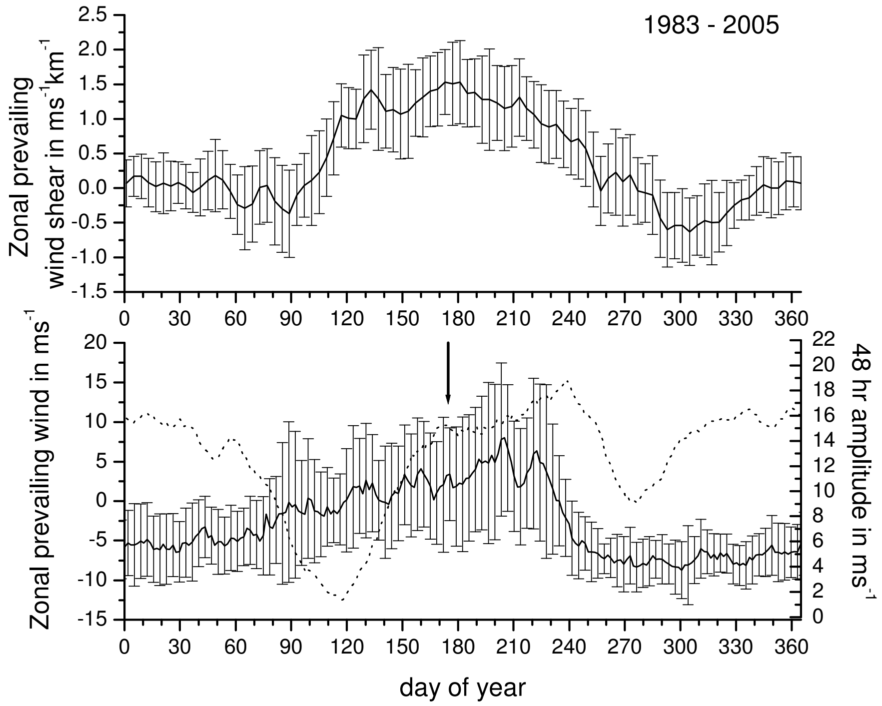

Figure 1: *23-year mean vertical gradient of the zonal prevailing wind at 2.5 km virtual height (upper panel), zonal prevailing wind (lower panel, dotted line, left axis) and QTDW amplitude (lower panel, right axis). Standard deviations are shown for QTDW amplitudes and vertical wind gradients.*

As also seen in Figure 1, there is no simple relation between the zonal prevailing wind and vertical wind gradients. This to a certain degree weakens conclusions of earlier results on the connection between the QTDW and the mean zonal circulation (Jacobi et al., 1997a). There it was found that during the growth of the QTDW activity the zonal westerly wind is slowed down or even reversed (a tendency towards such a behaviour is also visible in July after day #180, marked by the arrow in the lower panel of Figure 1). Including the vertical zonal wind gradient leads to additional insight into the process of QTDW generation.

Two examples that represent different behavior for single years are shown in Figure 2. In 2003, on the upper panel, one clear maximum of wind shear is visible in early July (after day #180, see the arrow in the upper panel of Figure 2), connected with an onset of QTDW activity near that maximum. After that, the wind shear decreases. In 2004, the situation is less clear, there are two large and one smaller burst of QTDW activity. While the wind shear is large more or less throughout the summer, it still may be possible the connect at least the two larger QDTW amplitude maxima with wind shear maxima. However, wind shear and QTDW amplitudes are not well correlated during this summer compared with 2004.

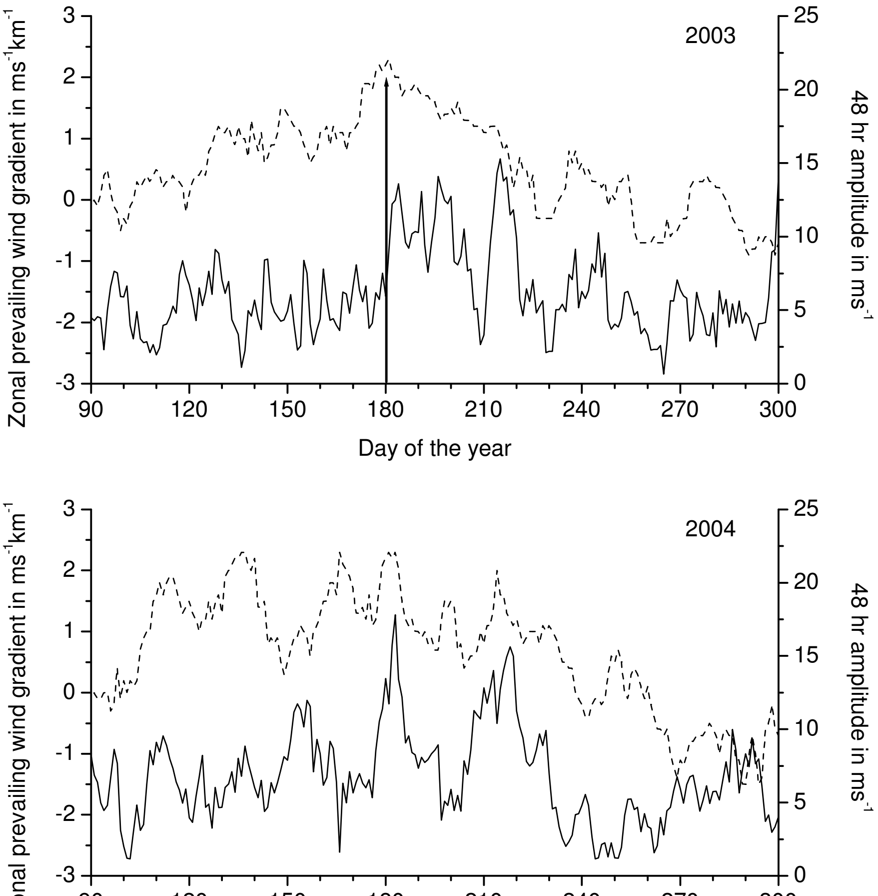

Figure 2: *Examples of QTDW amplitudes (solid) and zonal prevailing wind shear (dotted) in 2003 (upper panel) and 2004 (lower panel).*

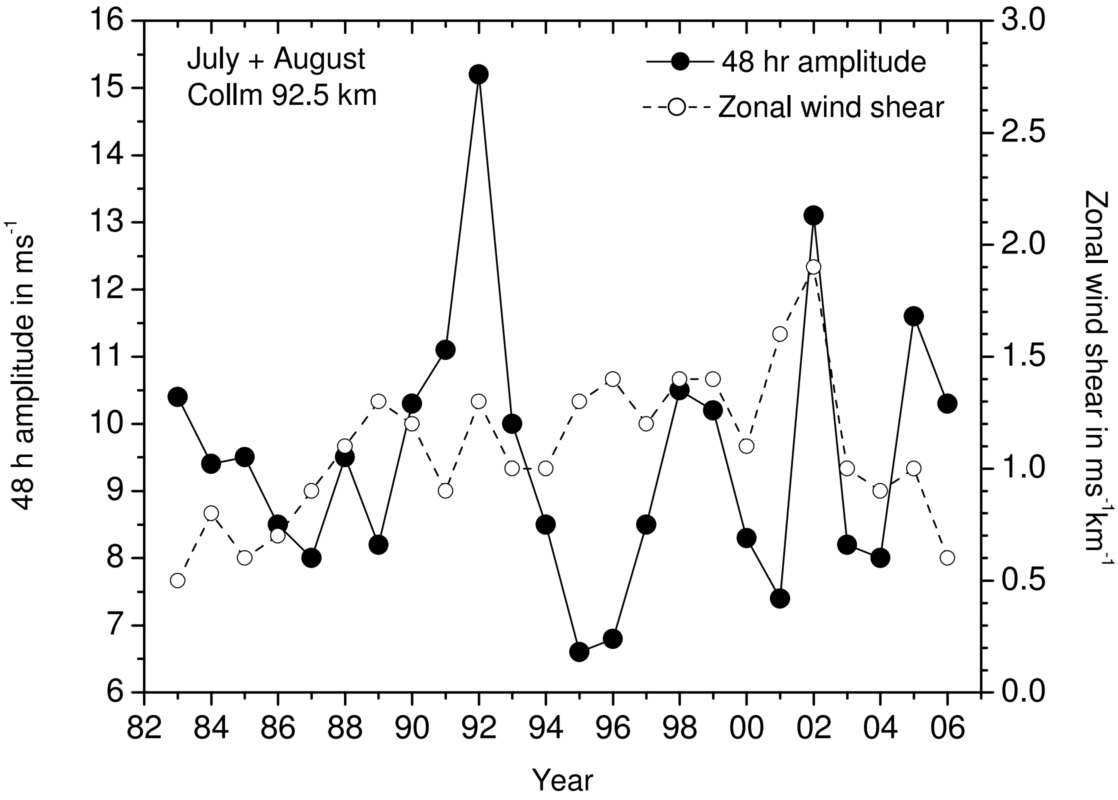

Figure 3: *July+August mean QTDW amplitudes and vertical zonal prevailing wind gradients.*

The apparent connection between QTDW amplitude and wind shear raises the question of their long-term behavior. July/August mean values are shown in Figure 3. While during the last decade of the measurements (roughly after 1996) a good correspondence between the year-to-year variations of QTDW amplitudes and wind shear is found, this is not the case with the earlier measurements. This means that the connection between QTDW and wind shear is more complicated. In particular a time delay between wind shear and maximum wave activity may be assumed. This delay is analysed in the following section.

23 year mean composites

Figure 4 shows a composite of zonal prevailing wind gradients, relative to the day of each year, when the QTDW amplitude (square root of zonal and meridional values squared) first exceeds a value of 15 m/s. 19 years out of the 23 years under consideration have been included in the analysis; during the remaining 4 years the QTDW amplitudes did not reach a value of 15 m/s. The same analysis was done using 10 m/s (all 23 years included) and 20 m/s (11 years included) as threshold (not shown here), resulting in similar behavior. We do not present the corresponding results for possible further QTDW bursts in one single year, because the oscillatory nature of QTDW amplitudes in some years makes it possible that the MLT winds before one burst are already affected by the preceding burst. Figure 4 shows that roughly during the week before the QTDW amplitude reaches large values the wind shear maximizes, but decreases when the QTDW amplitude is large. This is in correspondence with the picture of an instability causing the QTDW, which then tends to remove the source of the instability, i.e. the wind shear (Merzlyakov and Jacobi, 2004). Note that later on the wind shear increases again. This is owing to the fact that in may years more than one burst of QTDW activity is registered, and Figure 4 only refers to the first one of these bursts, so that in many cases the wind shear recovers (see lower panel of Figure 2).

The choice of the reference day in the manner as has been done in Figure 4 is somewhat arbitrary. Therefore in another analysis we used these days of the year as reference day, when the amplitude of the QTDW reached its absolute maximum during the respective year. The composite wind shear is presented on the upper panel of Figure 5. One can see that, on average, the wind shear maximizes several days (typically one week) before the QTDW amplitude reaches its maximum. The interannual variability, for example to be expressed through the standard deviation of the 23 year values from which one of the data points in Figure 5 is calculated, is large and amounts to typically 5 ms^{-1} for the QTDW amplitude and 0.5 $ms^{-1}km^{-1}$ for the wind shear. However, still the decrease of the wind shear during the strongest QTDW burst (approximately -0.5 $ms^{-1}km^{-1}$ from day -5 to day 15) is at least of the order of the standard deviation.

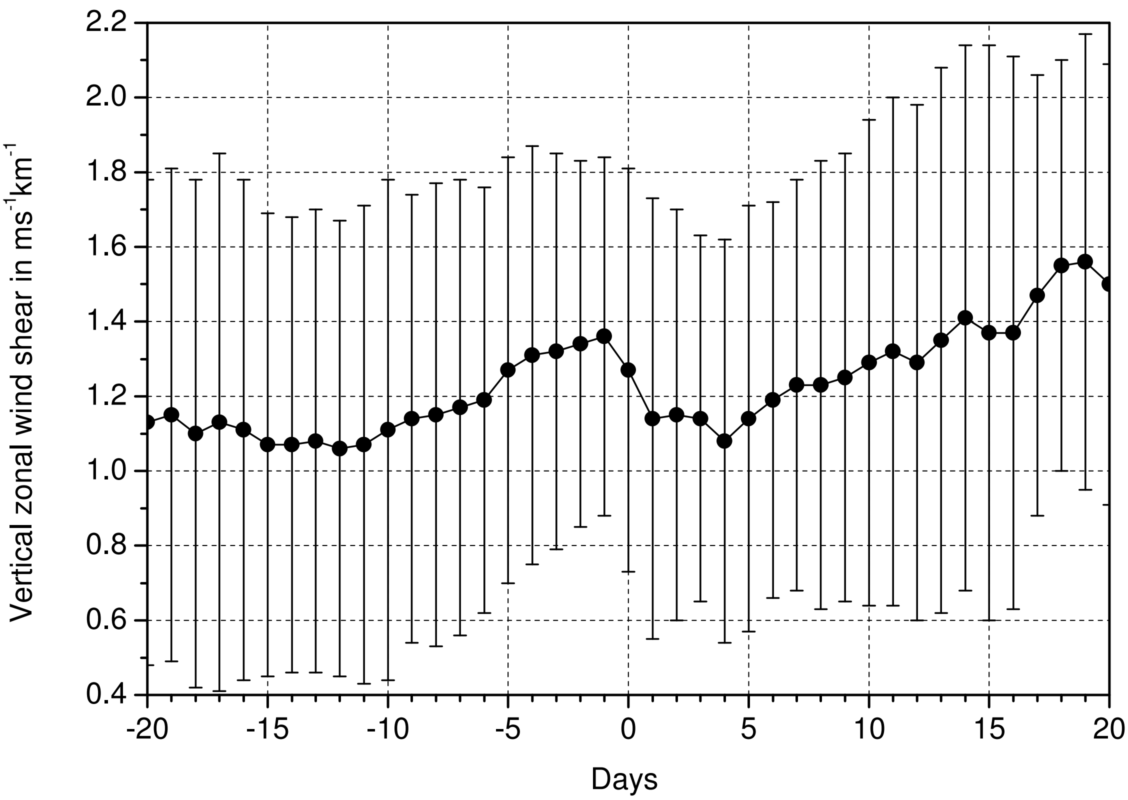

Figure 4: *Composite of 1983-2005 mean zonal prevailing wind gradients, relative to the day of each year, when the QTDW amplitude first exceeds 15 m/s.*

Considering the mean wave amplitudes relative to the day of maximum wind shear the maximum amplitudes are found about one week after the maximum wind shear appears, which corresponds to the picture given in the lower panel of Figure 5. Another maximum of QTDW amplitudes is seen about 2 weeks before the wind shear maximum has happened; this one is connected with earlier QTDW bursts. On average, maximum wind shear is found near solstice, and QTDW bursts may appear after solstice as well as before (although less frequently in the latter case). A similar picture is not visible on the upper panel of Figure 5, because maximum QTDW wave activity more or less tends to mark the end of the QTDW season. Note that the average change of QTDW amplitudes before and after the time of maximum wind shear is smaller than the amplitude standard deviation.

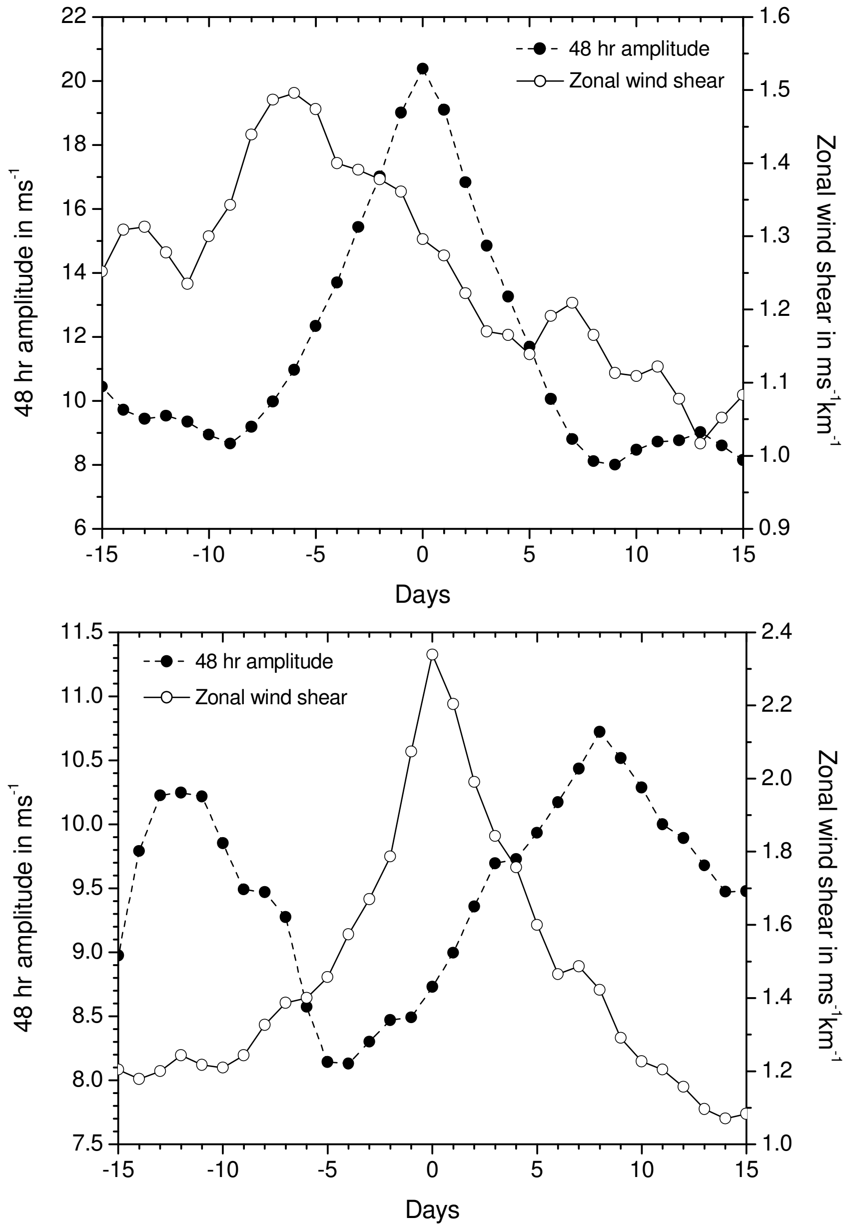

Figure 5: *Composites of 1983-2005 mean QTDW amplitudes (left axes) and zonal wind shear (right axes), relative to that day of each year, when the 48 hr amplitude maximises (upper panel) and that day, when the zonal wind shear maximises (lower panel).*

The long-term average maximum QTDW amplitude reaches 20±5 ms^{-1} (upper panel of Figure 5). This is much more than the 10.7 ms^{-1} that is found after the time of maximum shear. This, as well as the different shapes of the curves for wind shear and wave amplitude in Figure 1 show that the strongest wind shear during the summer is not necessarily connected with the strongest QTDW burst. Instability of the circulation is connected with a negative gradient q_y of zonal mean potential vorticity, and zonal wind shear (or rather its curvature) is only one part which, together with the meridional wind curvature that cannot be observed using one radar, contributes to q_y. This also, besides a time shift between shear and wave activity forced through that shear, explains the weak correspondence of vertical wind shear and mean QTDW amplitude in Figure 3, and is the reason for the relatively small differences of QTDW amplitudes before and after the wind shear maximum relative to the interannual variability (lower panel of Figure 5).

Conclusions

We have analyzed the variability of the QTDW in the course of the summer seasons using LF MLT wind measurements from 1983-2005. The QTDW is generally believed to be forced by baroclinic instability of the summer mesospheric wind jet. A connection between the quasi two-day wave and the mean circulation has been reported from measurements (Craig et al., 1985; Plumb et al., 1987; Poole, 1990), mainly basing on case studies. It was found, that during the growing of the quasi two-day wave pulse the zonal westerly wind is slowed down or even reversed. However, our measurements did not show convincing evidence for a connection of the QTDW with the background mean wind in a statistical sense, but rather a connection between QTDW and vertical wind shear. This connection, however, is not expressed through a direct correlation between wind shear and QTDW amplitude, but through a relationship of their increase and decrease in the course of the summer.

If an instability forces a wave, this wave tends to remove the source of the instability (Merzlyakov and Jacobi, 2004), so that a phase delay between wind shear and wave amplitude can be expected. Such a phase delay was really observed in the Collm winds. On a long-term average, maximum QTDW amplitudes are found approximately one week after maximum wind shear is measured, and there is a tendency for decreasing wind shear during the strongest QTDW event in one summer. This correspondence does not imply a clear correlation between the strength of the wind shear and the amplitude in a particular case: while maximum wind shear on average is found near solstice, the largest QTDW amplitudes are measured in late summer. This is also reflected in the weak correlation of summer mean QTDW amplitudes and wind shear values.

The MLT represents a crucial region of the atmosphere, since there coupling processes between the lower and middle atmosphere and the upper atmosphere take place mainly through wave-wave and wave-mean flow interaction. Knowledge of the degree of coupling will help improving models that cover the middle and upper atmosphere.

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