# Long-period oscillations derived from mesosphere/lower thermosphere meteor radar temperature measurements

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## Abstract

Using measurements, derived from a meteor radar in Collm (51.3°N, 13°E), the mesopause region is analyzed with respect to the temperature distribution at an altitude of 90 km over a period of 10 years. The analyzed period lasts from 2005 till 2013. Based on these measurements, the typical temperature seasonal cycle of the mesopause region can be observed. The temperature reaches its minimum of about 130 K in summer and its maximum of about 220 K in winter. At this altitude, also strong day-to-day-fluctuations of up to 35 K exist, which are probably partly induced by planetary waves. Shorter-period oscillations with a period between 2 and 6 days have maximum amplitudes during summer, while longer-period oscillations with a period between 7 and 20 days maximize during winter. During the measurement period the amplitudes of oscillations with periods between 4 and 6 days, which may be attributed to the quasi-5-day-wave, increase with time.

## Zusammenfassung

Auf der Grundlage von Messungen eines Meteorradars in Collm (51.3°N, 13°E), die in einer Höhe von 90 km erfolgten, was in etwa der Mesopause entspricht, wird die Temperatur hinsichtlich ihres Jahresganges und insbesondere ihrer Variationen in einem Messzeitraum von 10 Jahren analysiert. Der analysierte Zeitraum erstreckt sich von 2005 bis 2013. Anhand der Daten kann man den typischen Jahresgang der Temperatur in der Mesopausenregion erkennen. Die Temperatur erreicht im Sommer das Minimum bei etwa 130 K und im Winter das Maximum bei etwa 220 K. Zudem treten starke Tag-zu-Tag-Fluktuationen auf, die im Maximum 35 K betragen. Diese werden vermutlich durch planetare Wellenaktivität der Atmosphäre hervorgerufen. Hierbei spielen im Sommer die kurzwelligen und im Winter die langwelligen Oszillationen, letztere mit Perioden größer 7 Tage, die wesentliche Rolle. Ferner sind innerhalb des Messzeitraums zunehmende Amplituden von Oszillationen mit Perioden zwischen 4 und 6 Tagen (quasi 5-Tage-Welle) zu erkennen.

## 1. Introduction

At an altitude of 90 km the mesopause temperature shows considerable variability. This variability becomes apparent from day-to-day observations but also from interseasonal observations. The variability is evoked by natural incidents. One of those incidents is the impact of planetary waves (PW). The dimension of the temperature change depends on the altitude, at which the planetary waves are breaking.

There have been frequent attempts to characterize planetary wave activity and their trends in the middle atmosphere. E.g., Pogoreltsev et al. (2009) found a decrease of the winter quasi 5-, 10-, and 16-day waves in the stratosphere since the 1960s from NCEP/NCAR reanalysis. However, interannual and quasi-decadal variability of the waves is large, and the results of linear trend analyses over short time intervals of about one decade may deviate from the long-term trends. For the mesosphere/lower thermosphere (MLT), Jacobi et al. (1998, 2008) found increasing tendencies for PW in meteor radar winds, in particular for the zonal component, while for the meridional component the trends are small or negative, which overall results in only slightly positive wind trends.

To summarize, the degree of interannual variability of PW in the middle atmosphere is still subject to current research, and new data may lead to new insights into long-term tendencies of the middle atmosphere.

Therefore, in this article, temperature oscillations in the period range between 2 and 30 days are analyzed and attributed to the activity of PW in the middle atmosphere. We analyze the seasonal cycle, and the magnitude of the wave activity changes during the period from 2005 through 2013.

## 2. Measurements and data analysis

### 2.1. Calculation of the absolute temperature

The ambipolar diffusion coefficient is needed to receive the absolute values of the temperature at a height of 90 km. The ambipolar diffusion plays a vital role during the decay of the plasma tail of the meteoroids passing the atmosphere. Consequently, the ambipolar diffusion coefficient $D_{amb}$ can be derived from the half-time decay time $\tau_{1/2}$ of the plasma tail. The process concerning the decay of the plasma tail is illustrated in equation:

$$A(t) = A_0 e^{-\frac{16\pi^2 D_{amb} t}{\lambda^2}} = A_0 e^{-ln2\frac{t}{\tau_{1/2}}} . \tag{1}$$

Here $A(t)$ is the radio wave amplitude (of wavelength $\lambda$) at time t, while $A_0$ is a the amplitude at $t = 0$. With the help of equation (1) the half-decay period can be calculated. The half-decay period $\tau_{1/2}$ only depends on the frequency of the meteor radar λ and the ambipolar diffusion coefficient $D_{amb}$, which is given in equation (2):

$$\tau_{1/2} = \frac{\lambda^2 \, ln2}{16\pi^2 D_{amb}} . \tag{2}$$

The ambipolar diffusion coefficient in equation (2) can be replaced by the ratio between the absolute temperature $T$ and the local pressure $p$ [Jones and Jones, 1990]:

$$D_{amb} = k_{amb} \frac{T^2}{p} . \tag{3}$$

The constant $k_{amb}$ is a value, describing the properties of plasma. If the plasma consists out of many metallic ions and $N_2$ molecules, the constant $k_{amb}$ reaches a value of $2.5 \cdot 10^{-4}$ $m^2 s^{-1} V^{-1}$. The pressure $p$ in equation (3) will be replaced by a mean linear temperature gradient [Hocking, 1999]. For this purpose the Boltzmann barometric equation is necessary:

$$p = p_0 e^{-\int_0^z \frac{mg}{kT} dz'} , \tag{4}$$

where $k$ is Boltzmann´s constant, $m$ is mean molecular weight of the gas mixture, $g$ is acceleration due to gravity taken as 8.5 $ms^{-1}$ at 90 km and $T$ is temperature. Using a linear temperature gradient (5) instead of an isothermic atmosphere (6):

$$\alpha = \frac{1}{T_0} \frac{dT}{dz}, \tag{5}$$

$$T = T_0 \left(1 + \alpha z'\right), \tag{6}$$

and inserting this into (3) one obtains:

$$ln D_{amb} = ln k_{amb} + 2 ln T_0 \left(1 + \alpha z\right) - ln\, p_0 + \frac{mg}{kT_0} \int_0^z \frac{1}{1 + \alpha z'} dz' \ . \tag{7}$$

Choosing $z = 0$ at the height of the maximum meteor flux and differentiating with respect to $z$ one obtains:

$$\frac{d}{dz} ln D_{amb} = 2\alpha + \frac{mg}{kT_0} \ . \tag{8}$$

Using the relation:

$$\frac{1}{S_m} = \frac{d}{dz} ln D_{amb}, \tag{9}$$

and substituting equation (9) in equation (8) and solving for $T_0$ results in the following equation:

$$T_0 = S_m \left( 2 \frac{dT}{dz} + \frac{mg}{k} \right). \tag{10}$$

From one day of data, $S_m$ is determined as the slope of a best-fit line. Equation (10) is defined by the height of the maximum meteor flux, which approximately can be found at an altitude of 90 km.

## 2.2. Filtering and determination of standard deviation

For filtering the values of the absolute temperature a Lanczos-filter [Duchon, 1979] is used. The filter is based on sinc functions (also called sigma approximations), which reduce the Gibbs phenomenon. This means that the amplitudes of strong harmonics are dampened. The sinc function is defined by:

$$sinc\ (x) = \frac{sin(\pi x)}{(\pi x)}. \tag{11}$$

For the analysis of the temperature values the number of weights was chosen as 50. The filter was applied as a bandpass filter with 2-3, 4-6, 8-12, 12-20 and 2-30 days cutoff periods, which allows us to investigate the period range of PW.

As a proxy for PW activity, the standard deviation of the daily temperatures was chosen. We calculated the standard deviation of the filtered time series in a running 91 day window, and allocated the respective results to the middle of the time interval. This resulted in a time series of daily standard deviations. Daily climatological values have been calculated by averaging the standard deviations from each day of the year over the years. Additionally, seasonal means were calculated by averaging 91 days of standard deviations.

## 3. Mean seasonal cycle of wave activity

Figure 1 shows the typical temperature cycle in the mesopause region with its minimum in summer and maximum in winter for 2005. In 2005 the minimum temperature in summer is 145.8 K and the maximum temperature in winter is 229.5 K. The summer in 2005 is the warmest of all summers during the measurement period under investigation.

Additionally, strong day-to-day fluctuations can be observed. During the whole measurement period the maximum fluctuation is 35 K. Compared to the difference of the summer and winter extremes, which is nearly 85 K in 2006, the day-to-day fluctuations prove to be a major component of temperature variability. These fluctuations are dominantly caused by PW, which will be demonstrated in the following. Furthermore, measurement uncertainties play a role as well.

Additionally, Figure 1 illustrates the values of the temperature profile, filtered in a range of 2-3, 4-6, 8-12 and 12-20 days. The smaller the range of days is chosen, the stronger is the filtering process. The four ranges were chosen to investigate the amplitudes of PW. Especially, those of the quasi-2-day, quasi-5-day, quasi-10-day and quasi-15-day wave are observed. These filtered values are used to calculate the standard deviations for the different ranges and the averages for each day of the year in the period from 2005 till 2013. Actually, at the beginning and the end of the time interval analyzed, additional data have been used but had been disregarded because they would have been influenced by the filter applied. The results are shown in Figure 2.

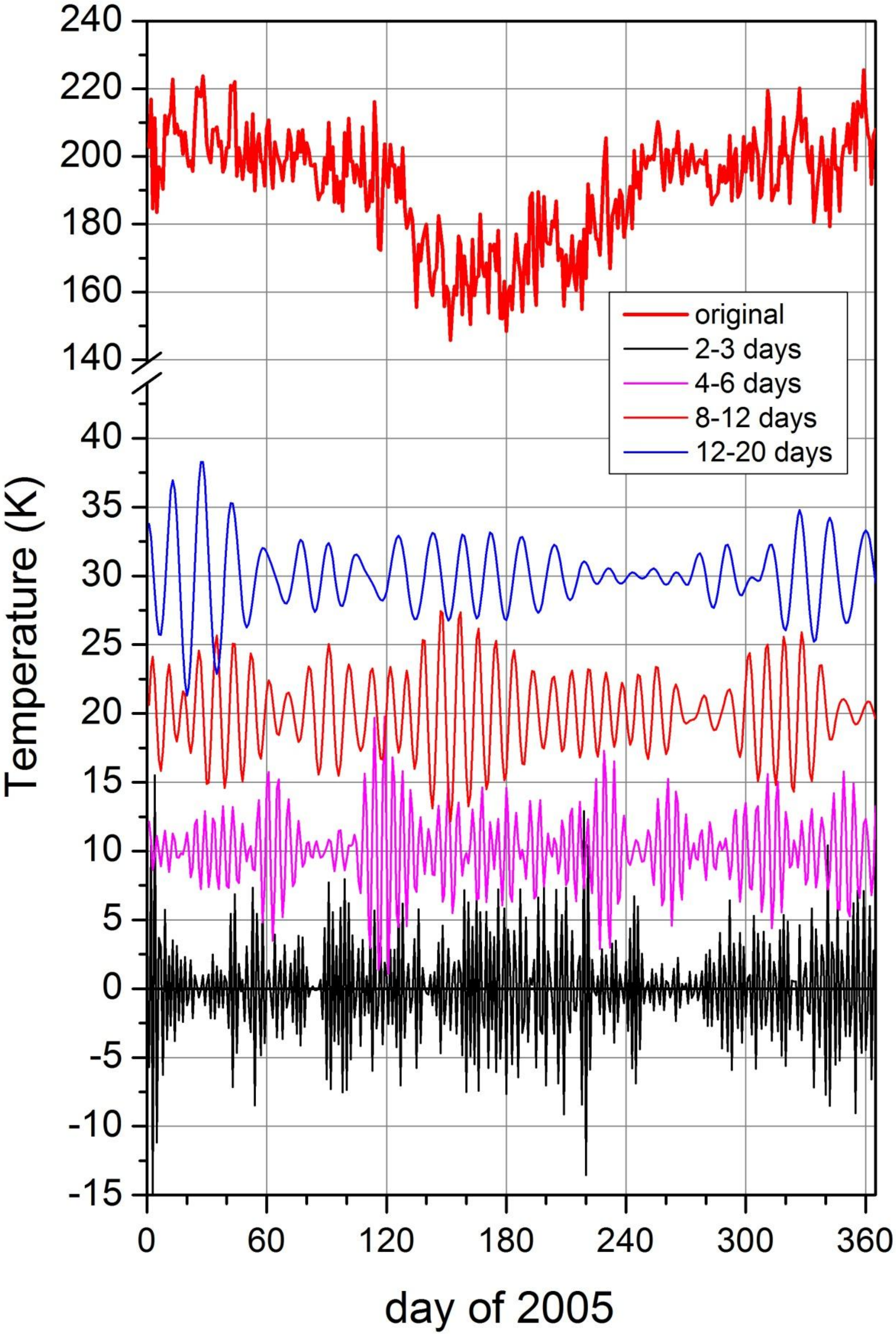

*Figure 1: Example of time series of daily temperatures at 90 km over Collm in 2005. The red line shows the unfiltered data. The other curves show data filtered in the respective period ranges as given in the legend.*

The standard deviation reflects the temperature fluctuation, which is assumed here to be caused by the PW. So the standard deviation is taken as proxy for seasonal PW activity and it also represents the magnitude of the wave amplitude. In general, each range, illustrated in Figure 2(a-e), demonstrates the standard deviation, which is maximal during summer and winter and minimal during the equinoxes. This means the influence of PW is stronger during solstices.

In Figure 2(a) the averaged standard deviation of the filtered data in a range between 2 and 3 days is presented. The standard deviation is larger in summer than in winter. This means that oscillations with a period between 2 and 3 days, which also includes the quasi-2-day wave, have a larger amplitude in summer than in winter. The standard deviation reaches values of about 5 K in summer, which is large in comparison to the other period ranges. The quasi-2-day wave plays an important role concerning the fluctuation of the temperature.

In Figure 2(b) the mean standard deviation of the filtered data in the range between 4 and 6 days is presented. As with the quasi 2-day oscillation shown before, the standard deviation reaches its maximum in summer. However, the maximum reaches approximately only 4 K, so the quasi-5-day wave is less dominant compared to the quasi-2-day wave. In the range between 8 and 12 days the maximum of the mean standard deviation, presented in Figure 2(c), is not reached in summer anymore but rather in winter, and it reaches nearly 3.5 K. Consequently, oscillations with periods smaller than 8 days are dominant in summer and those with periods larger than 8 days are dominant in winter. This is also confirmed by Figure 2(d), which shows the mean standard deviation of the filtered data in a range between 12 and 20 days. The mean standard deviation has its maximum in winter at about 4.25 K.

When comparing the mean standard deviation of Figure 2(c) with Figure 2(d), it can be observed, that oscillations between 12 and 20 days are more dominant in winter. So the quasi-16-day wave causes more temperature fluctuation than the quasi-10-day wave.

In the lowermost panel of Figure 2, all oscillations in a range between 2 and 30 days are taken into account. With this it can be analyzed, for which season the wave activity is strongest. The mean standard deviation reaches its maximum in winter. Consequently, the wave activity in winter is stronger than in summer.
The sum of the mean standard deviation maxima from oscillations with periods between 2 and 6 days corresponds to the maxima of the mean standard deviation of the filtered data in a range between 2 and 30 days. The sum of the mean standard deviation maxima from oscillations with periods between 8 and 20 days is 7.75 K. There are missing 3.5 K to the mean standard deviation maximum of the filtered data in a range between 2 and 30 days. Consequently, in the range between 20 and 30 days are also strong oscillations, which cause strong fluctuations.

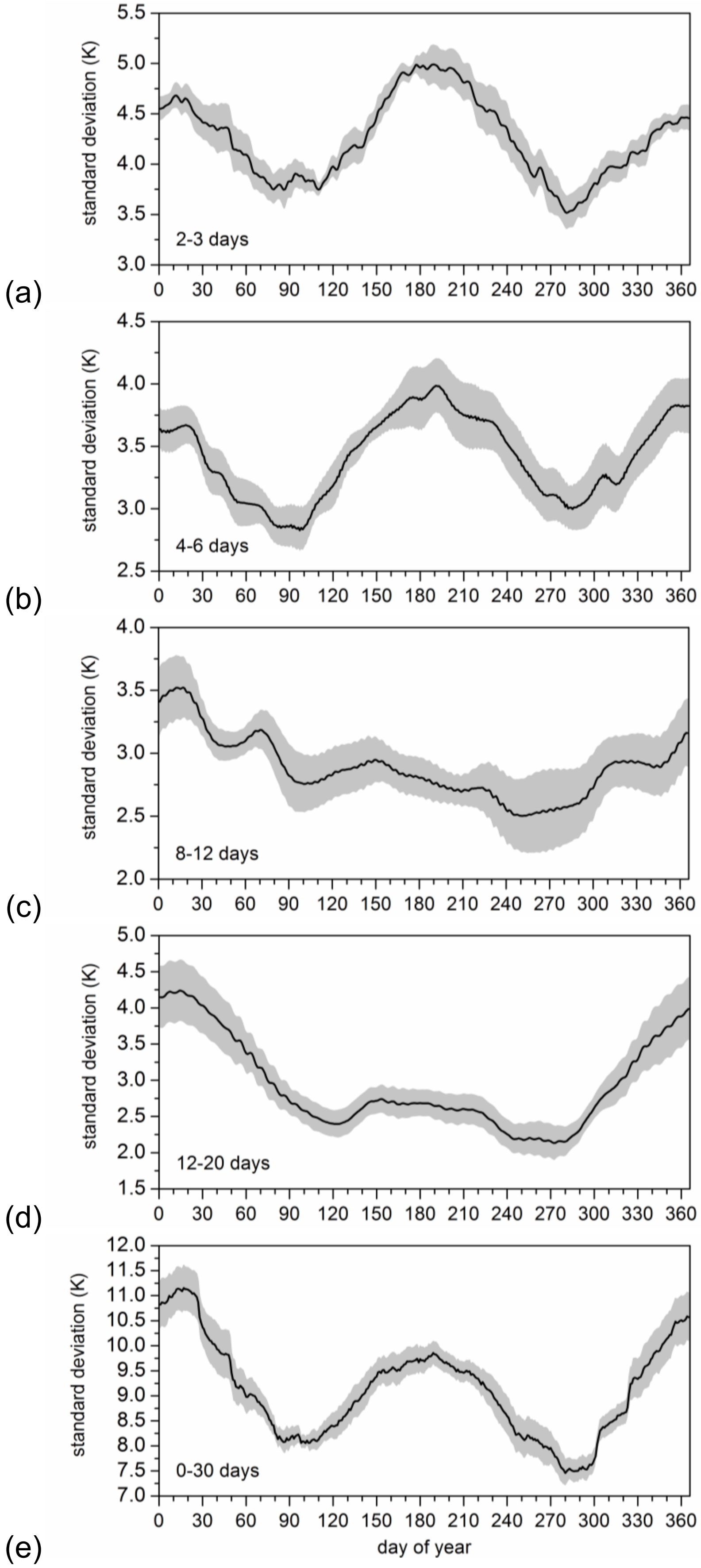

*Figure 2: 2005-2013 mean standard deviation, each based on 91 days of temperatures filtered in the respective period intervals given in the legend. The greyshaded regions indicate the standard errors of the values of each day of the year.*

## 4. Interannual variability

Due to the maximum amplitudes of oscillations during the solstices, we restrict our analysis to the interannual variability in summer and winter. Therefore, the standard deviation of the 15th of January and July of each year in different period ranges are used. These dates are chosen, because they represent the whole summer and the whole winter. As has been mentioned, during the filtering of the absolute temperature values, a time frame of 91 days was chosen. The 15th of January and July are the middle of these time frames. The standard deviation of the 15th of January represents the period from December to February and that of the 15th of July represents the period from June to August.

In Figure 3 one can see that the amplitudes of the different oscillations are different from one year to another. Consequently, the amplitude of the oscillations is not predictable from climatology alone. In contrast to the mean climatology, for some cases the standard deviations of oscillations with periods smaller than 8 days are smaller in summer than in winter. Also in some cases the standard deviations of oscillations with periods larger than 8 days are smaller in winter than in summer.

Figure 3(a) shows the individual standard deviation for a period range from 2 to 3 days. The red line represents summer (JJA – June, July, August) and the blue line represents winter (DJF – December, January, February). No clear pattern or trend can be observed. The standard deviation changes rapidly from year to year. In the period range between 4-6 days (Figure 3(b)) this is different, and a positive trend is visible. The standard deviation increases nearly from year to year, especially in summer. The wave activity in this range shows an increase of 0.2 K/year (+/- 0.05 K/year). In Figure 3(c) oscillations with periods between 8 and 12 days and in Figure 3(d) those with periods between 12 and 20 days are shown. In these cases no trend or clear variability pattern can be found.

In Figure 3(e) the standard deviation of all oscillations with periods between 2 and 30 days is presented. It can be seen that the sum of all standard deviations does not show strong variability. The standard deviation fluctuates in a specific range. One can say that in summer the impact of all oscillations causes mostly a deviation of the mesopause temperature in a range from 9 up to 10.5 K. In winter the deviation is in a range between 9 and 11K. The high value in year 2009 is neglected in this discussion, because there was a strong stratospheric warming in this year, which lead to stronger wave activity [Labitzke and Kunze, 2009; Manney et al., 2009]. This value would falsify the result. So in the end, the fluctuation of mesopause temperature due to the wave activity is nearly constant during summer and winter. During the equinoxes the range of the deviation is much smaller.

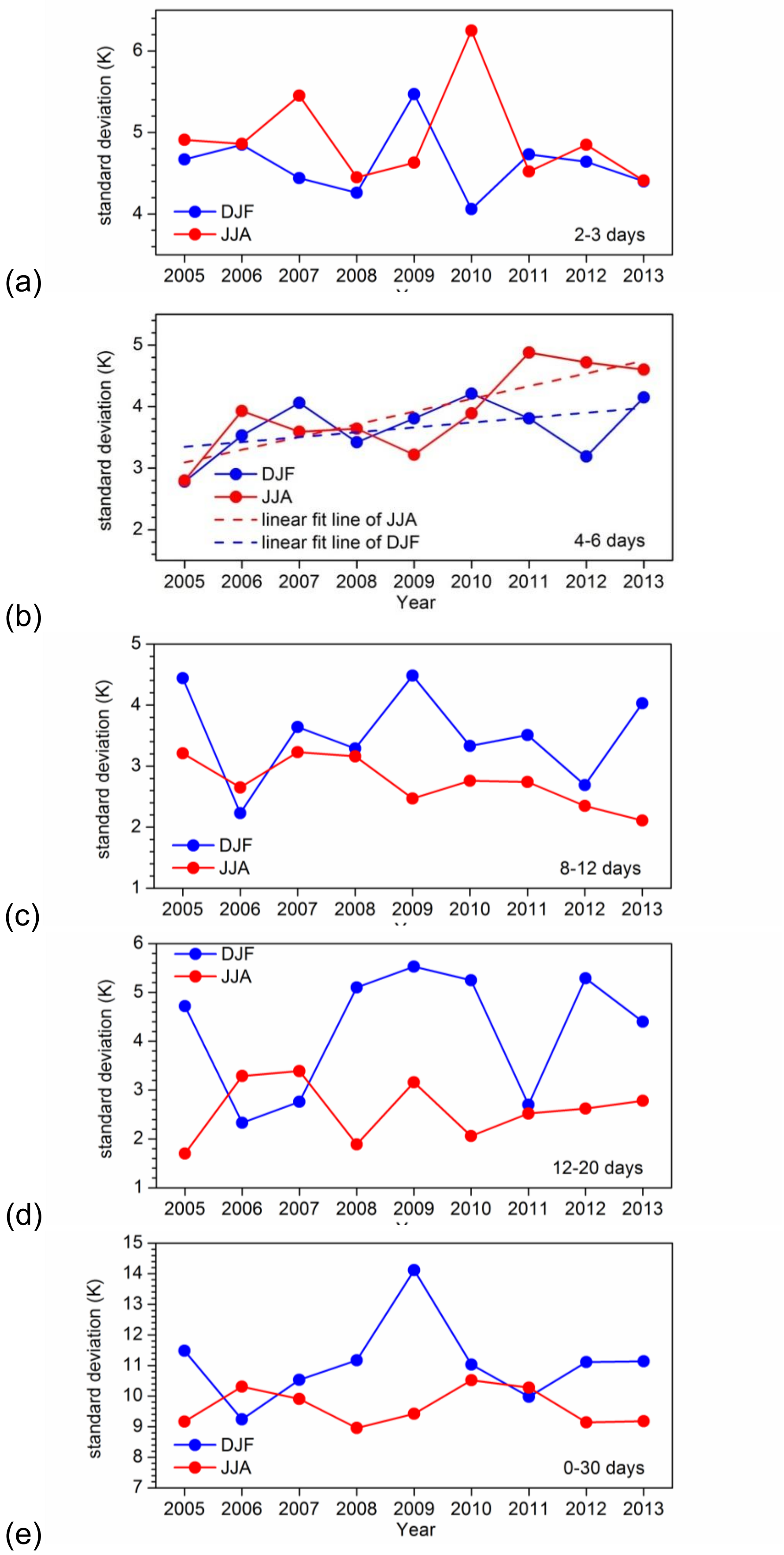

*Figure 3: Seasonal mean standard deviation, each value based on 90 days of data filtered in the respective period intervals given in the legend.*

## 5. Conclusions

On the basis of the temperature measurements one can see strong day-to-day fluctuations which are caused by PW. The amplitudes are stronger during solstices than during equinoxes. In summer (winter) oscillations with periods smaller (larger) than 8 days dominate the day-to-day variability. Except the period range between 4 and 6 days, the overall power of all oscillations was nearly constant during the measurement period. They showed a positive trend of 0.2 K/year (+/-0.05 K/year) during the last 9 years, thus, the wave activity of the quasi-5-day wave is increasing. All oscillations evoke a deviation of the mesopause temperature in a range between 9 and 11K in summer and winter.

## References

Beig, G., 2011: Long-term trends in the temperature of the mesosphere/lower thermosphere region: anthropogenic influences, J. Geophys. Res., 116, doi: 10.1029/2011JA016646

Duchon, C.E., 1979: Lanczos Filtering in One and Two Dimensions, J. Appl. Meteorol., 18, No. 8, 1016–1022, doi: 10.1175/1520-0450

Hocking, W.K., 1999: Temperatures using radar-meteor decay times, Geophys. Res. Lett., 26, No. 21, 3297-3300, doi: 10.1029/1999GL003618

Jacobi, Ch., Schminder, R., and Kürschner, D., 1998: Planetary wave activity obtained from long-term (2-18 days) variations of mesopause region winds over Central Europe (52°N, 15°E), J. Atmos. Sol.-Terr. Phy., 60, 81-93, doi: 10.1016/S1364-6826(97)00117-X

Jacobi, Ch., Hoffmann, P., and Kürschner, D., 2008: Trends in MLT region winds and planetary waves, Collm (52°N, 15°E), Ann. Geophys., 26, 1221-1232, doi: 10.5194/angeo-26-1221-2008

Jones, W., and Jones, J., 1990: Ionic diffusion in meteor trails, J. Atmos. Sol.-Terr. Phy., 52, 185-191, doi: 10.1016/0021-9169(90)90122-4

Labitzke, K., and Kunze, M., 2009: Über die unerwartet warme Stratosphäre im Winter 2008/2009, Beiträge zur Berliner Wetterkarte, 27/09, SO 13/9, 8p

Manney, G.L., Schwartz, M.J., Krueger, K., Santee, M.L., Pawson, S., Lee, J.N., Daffer, W.H., Fuller, R.A., and Livesey N.J., 2009: Aura Microwave Limb Sounder observations of dynamics and transport during the record-breaking 2009 arctic stratospheric major warming, Geophys. Res. Lett., 36, L12815, doi: 10.1029/2009GL038586

Pogoreltsev, A.I., Kanukhina, A.Yu., Suvorova, E.V., and Savenkova, E.N., 2009: Variability of planetary waves as a signature of possible climatic changes, J. Atmos. Sol.-Terr. Phy., 71, 1529–1539, doi: 10.1016/j.jastp.2009.05.011