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Comparison of mesopause region meteor radar winds, medium frequency radar winds and low frequency drifts over Germany

Ch. Jacobi^a, C. Arras^b, D. Kürschner^c, W. Singer^d, P. Hoffmann^d and D. Keuer^d

^a*Institute for Meteorology, University of Leipzig, Stephanstr. 3, 04103 Leipzig, Germany*

^b*GeoForschungsZentrum Potsdam, Department 1, Telegrafenberg, 14473 Potsdam, Germany*

^c*Institute of Geophysics and Geology, University of Leipzig, Collm Observatory, 04779 Wermsdorf, Germany*

^d*Leibniz-Institute of Atmospheric Physics, Schlossstr. 6, 18225 Kühlungsborn, Germany*

Correspondence to: C. Jacobi (jacobi@uni-leipzig.de)

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Abstract

During 2004 and 2005 measurements of mesospheric/lower thermospheric (80–100 km) winds have been carried out in Germany using three different ground-based systems, namely a meteor radar (36.2 MHz) at the Collm Observatory (51.3°N, 13°E), a MF radar (3.18 MHz) at Juliusruh (54.6°N, 13.4°E) and the LF D1 measurements using a transmitter (177 kHz) at Zehlendorf near Berlin and receivers at Collm with the reflection point at 52.1°N, 13.2°E. This provides the possibility of comparing the results of different radar systems in nearly the same measuring volume. Meteor radar winds are generally stronger than the winds observed by MF and especially by LF radars. This difference is small near 80 km but increases with height. The difference between meteor radar and medium frequency radar winds is larger during winter than during summer, which might indicate an indirect influence of gravity waves on spaced antenna measurements.

1. Introduction

Measurements of the dynamics of the mesosphere/lower thermosphere (MLT) region have been continuously performed by ground-based methods, in particular meteor radars (MR) and medium frequency (MF) radars. These radar measurements have widely been used to detect mean winds and tides (Manson, 1992; Manson et al., 1989, 2002), and to get insight into the seasonal, interannual, and long-term behaviour of the MLT circulation including long-term trends (Bremer et al., 1997). In addition, MR and MF radar wind measurements have been combined to analyse properties of planetary waves (Pancheva et al., 2004), and to construct empirical climatologies of MLT wind parameters (Portnyagin and Solovjova, 1998; Portnyagin et al., 2004).

However, during recent years MR and MF wind comparisons have provided hints to systematic differences between the results of the two methods. A detailed study has been performed by Hocking and Thayaparan (1997) who found that there are such systematic differences in some wind parameters. They also reviewed and provided suggestions of possible reasons for these differences, including an effect of gravity waves on spaced antenna measurements, as earlier discussed by Hines et al. (1993). Spaced antenna measurements are usually performed with MF and also LF. Portnyagin et al. (2004) have found a small mean difference of 2 m/s between MR and MF prevailing winds. Manson et al. (2004) used 3 radars in Scandinavia and found that MR winds are larger than MF radar ones by a factor of 1.6 at 97 km, but this factor is close to unity at lower heights. This would mean that the comparatively small prevailing winds even at higher altitudes are not affected as much as the tidal amplitudes and this is thus not in contradiction to Portnyagin et al. (2004). In addition, the ratio of MR/MF winds appeared to be larger in winter than in summer.

Direct comparisons between LF and MR measurements, although both without height finding, have been performed by Lysenko et al. (1972). They concluded that the resulting winds and tides show general agreement on average, but may differ at shorter time scales. However, the LF winds in that era had been calculated by manual data evaluation with large gaps in the diurnal / local time coverage. This process may lead to errors through incomplete decomposition into mean winds and tides. In addition, when data without height finding are used, this leads to values becoming averaged over a

relatively large height interval. This results in an underestimation of tidal amplitudes, particularly when the vertical wavelengths are small, as is typical for winter conditions.

Comparisons of MF and LF winds have been performed by Hoffmann et al. (1990), who found very good correspondence between MF and LF half-hourly winds. This provides the possibility of constructing vertical wind profiles jointly from MF and LF measurements (Schminder et al., 1997). It also becomes possible to extend the MF measuring height interval to altitudes above 94 km using the LF results.

In all cases, results published in the literature indicate that generally winds measured using MF and LF are smaller than MR ones. To analyse these differences we make here use of the fact that all three methods are used in a network over Germany. The LF method, which has been applied at Collm Observatory for more than 30 years is unique, and the results of comparisons are therefore particularly useful to interpret historical data. However, since such an extended time series is available at Collm, this may also be helpful for trend analysis of the MLT region. The MF/MR comparison is certainly of more general interest, e.g. for constructing MLT empirical models, and for analyses of the global dynamics.

2. Data base

For this study we used wind measurements made between September 2004 and August 2005 by a meteor radar at Collm Observatory (51.3°N, 13°E), a MF radar at Juliusruh (54.6°N, 13.4°E) and LF D1 measurements of lower E region drifts using a transmitter (177 kHz) at Zehlendorf near Berlin and receivers at Collm with the reflection point at 52.1°N, 13.2°E.

2.1. Collm meteor radar

The Collm meteor radar is a commercially produced VHF system manufactured under the brand name SKiYMET. The radar operates with a frequency of 32.6 MHz and a peak power of 6 kW. The transmitter produces short pulses (~13 μ s) at a pulse repetition frequency of 2144 Hz in the standard mode of operation. The radar operates in an “all-sky” configuration with the radiated power from a vertically pointing 3-element Yagi antenna. Five individual 2-element receiving antennae with horizontal distance of 2 or 2.5 wavelengths, respectively, are configured to act as an interferometer. The interferometer is situated near the Collm Observatory main building at 51.3°N, 13°E on the slope of the Collm mountain about 230 m amsl, with an interferometer plane slope of 7°. The transmitter and receiver are housed in a small building about three wavelengths away from the transmitting antenna.

The wind measurement principle is the detection of the Doppler shift of the reflected VHF radio waves from ionised meteor trails. This delivers radial wind velocity along the line of sight of the VHF radio wave. The interferometer is used to detect azimuth and elevation angle from phase comparisons of individual receiver antenna pairs. The meteor trail position is detected, together with the range measurements. The raw data collected consist of azimuth and elevation angle, wind velocity along the line of sight, meteor height, and additionally the decay time for each single meteor trail. The data collection procedure is also described in detail by Hocking et al. (2001).

The meteor trail reflection heights vary roughly between 80 and 100 km, with a maximum around 90 km. For this investigation, the data are binned in height gates of 2 km width between 82 and 98 km. Individual wind profiles calculated from the meteors are collected to form hourly mean values using a least squares fit of the horizontal wind components to the raw data of at least 4 meteors, under the assumption that vertical winds are small (Hocking et al., 2001). An outlier rejection is added.

2.2. Collm LF drift measurements

Collm radio drift and reflection height measurements in the LF range use the ionospherically reflected sky wave of a commercial radio transmitter on 177 kHz (distance between transmitter and receivers in the order of 170 km), assuming that in the lower ionosphere neutral winds and ionospheric drift movements are largely equal. The measurements are carried out according to the closely-spaced receiver technique. An algorithmised form of the similar-fade method is used to interpret the drift measurements (Kürschner, 1975; Schminder and Kürschner, 1994). The procedure is based on the

estimation of time differences between corresponding fading extrema in the course of sky wave amplitudes received simultaneously at three measuring points which form a right angled triangle over the ground with small sides of 300 m in direction N and E, respectively. The individual pairs of time differences which are measured at a temporal resolution of 0.25s allow the calculation of individual drift vectors.

The individual data are combined to half-hourly mean drift values, with a mean value being averaged over 30-60 data points. The $1-\sigma$ variation of the half-hourly mean, with σ being the standard deviation, is in the order of 20 ms^{-1} , caused by the real drift variations, the resolution and number of the individual drift measurements, and some statistic uncertainties connected with properties of ionospheric irregularities and additionally turbulent motions.

The virtual reflection height is measured using travel time differences between the ground wave and the sky wave, which are obtained using side-band phase comparisons of both wave components in a selected narrow modulation frequency range near $1.8 \pm 0.1 \text{ kHz}$ on sporadic oscillation bursts (Kürschner et al., 1987). The $1-\sigma$ uncertainty of an individual reflection height measurement determined from a single burst is nearly 2 km. On average, the half-hourly means consist of nearly 6000 individual values. The $1-\sigma$ variation of the half-hourly mean is of the order of 3 km below 95 km and more than 5 km above 100 km height. This is caused by the variability of the reflection heights.

The mean virtual reflection height and the corresponding standard deviation of the virtual heights is $96.6 \pm 7.2 \text{ km}$. Real height estimates are calculated using a semi-empirical 3rd order correction based on radio wave field calculations (Singer, Bremer, pers. comm.) and comparisons of LF and MR mean vertical wind profiles over Collm. Depending on altitude, the real heights are up to 10 km lower than the virtual ones (Figure 1). The new mean height is $89.6 \pm 5.7 \text{ km}$.

2.3. Juliusruh MF radar

At Juliusruh (54.6°N , 13.4°E), the Leibniz-Institute of Atmospheric Physics, Kühlungsborn has operated a MF radar at 3.18 MHz since 1989 (Hoffmann et al., 1990). This radar had been working as a CW radar, and was replaced by a pulse radar at the same frequency in 2003 using a peak power of 64 kW. During summer of 2005, this system was updated through a new modular transmission/receiving system and a Mills Cross Antenna. The radar now operates at a peak/medium power of 128 kW/195 W. The height region covered is 50-95 km at a height resolution of 1000 m. The measured parameters are winds, turbulence, and electron densities. The latter is performed through differential absorption and phase measurements at 70 - 85 km altitude.

The narrow radar beam allows the measuring of winds and spectral widths using the Doppler beam swinging method in addition to the hitherto used spaced receiver method combined with the full correlation analysis (FCA). For our analysis, we use only the FCA results of hourly mean winds, as has been used in previous studies to combine the advantages of both techniques, the LF drifts and the MF winds (Schminder et al, 1997). In contrast to the LF measurements, the MF measured reference height values are assumed to be correct in the height range below 94 km.

3. Results

MR and MF measurements cover a different, but overlapping, height range; while the former, as well as LF measurements, measure winds between about 80-100 km, the latter cover a range between about 50-95 km. For comparison we therefore chose the measuring range between 82-94 km. For the comparison, we used a best fit linear regression of the form

$$V_{\text{MF,LF}} = a + b \cdot V_{\text{MR}} \quad (1)$$

so that negative values of a and values of b smaller than unity denote larger MR wind compared to MF or LF winds. As an example, scatter plots of LF (Figure 2) and MF (Figure 3) zonal and meridional winds at 88 km are plotted against the respective MR winds. We used half-hourly means for a comparison of LF and MR winds. With the LF method, mean winds are measured at one mean height only at a half-hourly measuring time intervals, and this mean height is changing through the day. Especially during the morning hours obtaining hourly means would imply averaging over a large

height interval during a period when the reflection height is decreasing rapidly. The MF and MR winds are compared on the basis of hourly mean winds, which provide a better data coverage.

For both LF and MF, the slope of the regression line is smaller than unity, and in both cases it is smaller for the meridional than for the zonal component. This is to a certain degree in correspondence with results of Hocking and Thayaparan (1997), who noted that mean meridional winds are not as closely correlated as the zonal winds. We tested the hypothesis that this is an effect of the generally smaller meridional mean winds, by subtracting the mean winds and repeating the analysis (not shown here). This did not change the picture given in the figures. The LF zonal winds correlate very well with the MR ones; this is due to the fact that comparisons of LF and MR wind profiles had already been used to estimate the height correction function, and since the zonal wind profile owing to the stronger gradients compared to the meridional wind is more suitable for that purpose, a good correspondence with the MR winds is therefore partly self-evident. The correlation of LF meridional winds with MR is clearly weaker.

The vertical dependence of the correlation between MR and MF/LF winds is shown in Figure 4. The correlation is strongest for LF zonal winds, while LF meridional winds do not correlate very well. For comparison of MR and MF winds, the correlation generally slightly decreases with height, and it is somewhat stronger for the zonal component. From the middle panel of Figure 4 it can be seen that the coefficient a is small for comparison of MF and MR, which means that differences are not due to a systematic bias, but through a pure underestimating of the hourly winds. For LF/MR comparison there is still some bias; however, it is not clear whether this may be due to the height correction, which is possibly not sufficiently precise. Still, also for the LF, the coefficient a is small for most heights. The slope b , as is shown in the right panel of Figure 4, maximizes near 86/90 km for LF meridional/zonal winds. This is again partly an effect of the semi-empirical height correction. For the MF zonal winds, it decreases with height, indicating increasing differences between MF and MR with height. At 82 km the differences are small, while they grow to nearly a factor of 2 at 94 km. For the meridional wind, the differences are even larger. However, the increase of the differences is only clearly expressed above about 88 km.

In Figure 5 the seasonal variation of the parameter b is shown for the MF/MR and LF/MR comparison. In contrast to the scatter plots in Figure 2 and Figure 3 we used here data at 92 km, since we can expect more significant statistical results for that height than for 88 km. We do not present the values for May, since only a small number of wind values (less than 50) are available from the MF measurements. For MR/MF comparison the coefficient is slightly larger for the zonal than for the meridional wind, which is the case for each month of the year. For LF/MR comparison, as has been discussed above, b is close to unity on average. We also note that the coefficient b is smaller for winter than for summer, i.e. the difference is larger for winter, which corresponds to results of Manson et al. (2004). This is the case with both MF and LF compared to MR. In the left panel of Figure 5 we added the monthly means of the MR zonal semidiurnal tidal amplitude, which is the strongest MLT dynamical signal at least in winter and autumn, so that we may expect large absolute hourly mean winds during these seasons. We note that for the winter months, there is a slight tendency to greater differences, when the tides are stronger, i.e. during times of large amplitudes and thus large absolute values of the hourly winds. At such times, the MF winds are especially small with respect to the MR winds. However, for the summer months this correspondence is not seen. There is a tendency for larger values of b in August/September, when tidal amplitudes have a seasonal relative maximum, i.e. this behaviour is different to that of the winter case.

At lower altitudes the seasonal dependence changes. In Figure 6 the slope b of the regression line of MF vs. MR winds is shown for the height gate 81-83 km. LF wind analyses are not shown here, since these measurements are too rare, especially in summer. This is due to D region ionisation and the associated strong absorption of the sky wave. As has been shown in Figure 4, the zonal MF and MR winds correspond quite well in autumn and early winter. However, the MF wind measurements are still lower than the MR winds (b is smaller than unity) in the period from January to June. This may be connected with the smaller tidal amplitudes at lower heights, but it may be partly due to strong prevailing winds in spring/summer (Schminder et al., 1994, 1997). The meridional wind comparison does not show such a clear seasonal course.

4. Conclusions

We have used one year of MR, MF, and also LF winds for a comparison of wind measurements. As has been shown in literature, MF absolute winds are smaller than MR ones. We showed that the LF winds are also weaker than the MR ones, and the differences are sometimes somewhat larger, especially for the meridional component. While the differences are small near 82 km, they increase with height up to a factor of 2 and more. Generally, the meridional MF/LF winds differ more from the respective MR winds than the zonal ones. It is evident that both MF/LF measurements show generally similar differences to MR observations. The reasons for this result are not clear. It may be possible that a fixed orientation of anisotropic structures caused by the earth magnetic field contribute to such an effect in the case of similar fade evaluation in connection with the LF measurements. In contrast, however, the method of FCA used by the evaluation of MF measurements should eliminate this effect of anisotropic structures.

In this analysis we only analysed hourly or half-hourly mean winds, and we abstained from analysing mean wind or tidal amplitude differences in MR and MF/LF winds. Therefore we may exclude possible errors in mean wind and tidal analysis that may arise from the incomplete daily coverage of the LF measurements.

We can confirm, for the upper height gates considered here, the results by Manson et al. (2004) showing that MF/MR differences are larger during winter months. We have seen from comparisons with tidal amplitudes that there is no direct correlation between the differences between MF, LF and MR and the amplitude and the maximum hourly winds during the day. The seasonal dependence may indicate an indirect influence of gravity waves which, according to most climatologies, at 92 km show more activity in winter than in summer. When comparing the results at 92 km with those at 82 km in Figure 6, the seasonal variation of the coefficient b corresponds to a certain degree to that of gravity wave activity. This shows a maximum in summer that with increasing altitudes moves towards the spring equinox. It is replaced by the winter maximum at greater heights (e.g. Gavrilov and Jacobi, 2004). Therefore, it is conceivable that gravity waves acting in different measuring volumes are a source for differences in MF/LF and MR measurements.

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Figure Captions

Figure 1: Distribution of half-hourly LF virtual heights and corrected true height estimates.

Figure 2: Collm LF zonal (left panel) and meridional (right panel) half-hourly mean winds vs. the respective Collm MR winds for the height range 87-89 km. Only each 5th data point is plotted here. Additionally shown are the $x=y$ curve (solid) and the linear best fit line (dashed).

Figure 3: Juliusruh MF zonal (left panel) and meridional (right panel) hourly mean winds vs. the respective Collm MR winds for the height range 87-89 km. Only each 5th data point is plotted here. Additionally shown are the $x=y$ curve (solid) and the linear best fit line (dashed).

Figure 4: Vertical profiles of the correlation coefficient and the coefficients a and b from Eq. (1), for comparisons of MF and LF winds with MR ones.

Figure 5: Coefficient b (slope of the regression line) for comparison of MF vs. MR (left panel) and LF vs. MR (right panel) winds at 92 km altitude, for each month of the year, except for May, when the number of hourly means was low. Also given in the left panel are MR zonal semidiurnal amplitudes.

Figure 6: Coefficient b (slope of the regression line) for comparison of MF vs. MR winds at 82 km altitude, for each month of the year, except for the case when the number of hourly means was low.

MF vs. MR

LF vs. MR