

# Drifts and their short-period perturbations in the lower ionosphere observed at Collm during 1983 – 1999

N. M. Gavrilov, Ch. Jacobi, and D. Kürschner

## Abstract

Estimations of the intensity of short-period perturbations of the horizontal drift velocity at 80 – 110 km altitude are made using data from the regular low-frequency D1 ionospheric reflection observations at Collm, Germany (52° N, 15° E) for the period 1983 – 1999. A simple half-hourly-difference numerical filter is used to extract perturbations with time scales between 0.7 and 3 hours. The results are compared with the mean drift analyses in order to study the interaction between short-period perturbations and the mean circulation. The average monthly variances of short-period perturbations of the zonal velocity near 80 km altitude show a main maximum in summer, a smaller maximum in winter, and minimum values at the equinoxes. At higher altitudes the summer maximum is shifted towards spring, and another maximum of perturbation variances in autumn appears at altitudes near and above 100 km. The seasonal changes of variances of the meridional velocity show maximum values in spring and summer, also some indications for an increase of the summer maximum at altitudes larger than 100 km are found. The observed altitude changes of the seasonal variations of drift perturbation variances are consistent with some numerical calculations of the height structure of a spectrum of internal gravity waves in the middle and upper atmosphere.

## Zusammenfassung

Die Intensität kurzperiodischer Störungen der horizontalen Driftgeschwindigkeit im Höhenbereich zwischen 80 und 110 km wurde anhand der regulären D1 Langwellen-reflexionsmessungen in Collm (52° N, 15° E), bestimmt. Verwendet wurden Daten der Jahre 1983 - 1999. Ein einfache numerische Filter basierend auf den Unterschieden aufeinanderfolgender halbstündiger Windmittelwerte wurde verwendet, um Störungen im Zeitbereich von 0.7 - 3 Stunden zu ermitteln. Die Ergebnisse wurden mit Analysen der mittleren Drift verglichen, um die Wechselwirkungen zwischen kurzperiodischen Störungen und der mittleren Zirkulation zu untersuchen. Die mittlere monatliche Varianz der kurzperiodischen Störungen der Zonalgeschwindigkeit bei etwa 80 km zeigt ein Hauptmaximum im Sommer und ein schwächeres Maximum im Winter, wobei die Minima während der Äquinoktien auftreten. In grösseren Höhen verschiebt sich das Sommermaximum zum Frühjahr hin, und in Höhen über 100 km erscheint im Herbst ein weiteres Maximum. Der Jahresgang der meridionalen Windstörungen zeigt maximale Werte in Frühjahr/Sommer, und es sind auch Hinweise auf eine Verstärkung des Sommermaximums oberhalb von 100 km zu finden. Die gemessenen Höhenänderungen im Jahresgang der kurzperiodischen Driftschwankungen entsprechen numerischen Ergebnissen der Höhenabhängigkeit interner Schwerewellen in der mittleren und oberen Atmosphäre.

## 1. Introduction

At the Collm Observatory of the University of Leipzig, Germany (52° N, 15° E) continuous ionospheric drift velocity measurements have been performed in the altitude range between 80 and 110 km since 1959 using corresponding fadings of low-frequency (LF) radio wave propagating from transmitters at the earth surface through the lower ionosphere to a closely spaced antenna array (D1 method) (Schminder and Kürschner, 1984; Schminder, 1995). At present, fully automatic devices are available for these measurements, which allow average sampling densities of one drift velocity value per minute or more (Kürschner, 1975). Since 1982, also the virtual reflection heights of radio waves have been measured simultaneously (Kürschner et al., 1987).

Multi-year measurements at Collm gave systematic information about the mean winds, parameters of diurnal and semidiurnal tides, and their seasonal and interannual variations (Schminder, 1995; Jacobi et al, 1997a,b). Except for these components, ionospheric drifts reveal strong fluctuations with periods from minutes to hours. This variability may be connected with the propagation of gravity waves in the lower thermosphere. The present paper is devoted to the estimation of the intensity of such short-period drift variations and their seasonal and interannual variations from the Collm data.

## 2. Method of analysis

The similar-fade method is used for determination of horizontal drifts of ionospheric plasma at Collm Observatory, Germany, since the International Geophysical Year, 1959 (see Schminder, 1995). In this method the fading of a radio signal that propagates from a ground-based transmitter and that is reflected from the ionosphere is recorded at three points at the corners of a right-angled triangle separated by distances of the order of one wavelength or less. The velocity of ionospheric drift motion is then determined from the time shifts of the three fading curves relative to each other (so-called similar fade method).

At Collm Observatory the amplitude modulated carrier waves from three commercial broadcasting stations working at frequencies of 177, 225 and 272 kHz and located at distances of 170, 460, and 400 km, respectively, are used. The receivers are placed on the ground at the corners of a right-angle triangle with equal sides along zonal and meridional directions of 300 m, which does not exceed wavelengths of the radio signals.

At Collm, an algorithmized form of the similar-fade method is used to determine the velocity of ionospheric drift motions from the time shifts of the fading curves at three receivers (Kürschner, 1975; Schminder and Kürschner, 1994; Schminder, 1995). The procedure is based on the estimation of time differences between corresponding fading maxima and minima for three points. The individual pairs of time differences for calculation of individual drift velocity vectors are measured at a temporal resolution of 0.25 s. The data are combined to half-hourly zonal and meridional mean drift velocity values on each frequency, with the mean value being averaged over 30 – 60 individual velocity values. Since the absorption of the radio waves in the lower ionosphere (D region) is large during daylight hours, almost no half-hourly means can be obtained during this time, which particularly has an effect on the measurements in summer. This results in a total of about 700 or 1200 half-hourly mean values per month in summer and winter,

respectively.

Since late 1982, the virtual height,  $h$ , is measured on 177 kHz using travel time differences between the ground and sky radio wave (Kürschner et al., 1987). The differences are obtained using side-band phase comparison of both radio waves in the modulation frequency range near 1.8 kHz. The standard deviation of an individual reflection height measurement is about 2 km. Relation of the measured virtual height  $h$  to the real height  $z$  depends on the electron density profile, which is unknown during the measurements. However, we use relations between  $h$  and  $z$  (e.g., Jacobi et al., 1997b) that are based on the wave field calculations performed by Singer (1975), using mean electron density profiles. The relations give residual  $z$  values of the order of 1 – 2 km at 100 km, decreasing at lower altitudes. Standard deviations of half-hourly mean heights (essentially caused by the natural variability of individual reflection heights) are about 3 km below altitude 95 km and about 5 km near 100 km.

Using described procedures, during any day Collm measurements give a series of half-hourly values of zonal,  $u_i$ , and meridional,  $v_i$ , components of drift velocity. In the present study we use only data for the frequency 177 kHz after 1983, for which we have also half-hourly mean values of the reflection heights  $z$ . To estimate the intensity of short-period perturbations of the drift velocity, we use a simple numerical filter calculating differences of mentioned successive half-hourly drift velocities:

$$u'_i = (u_{i+1} - u_i)/2; \quad v'_i = (v_{i+1} - v_i)/2, \quad (1)$$

and taking only pairs with differences of their heights  $(z_{i+1} - z_i) \leq dz = 3$  km to minimize possible apparent wind variations due to height changes in the case of vertical gradients of the mean winds. Calculations show that a decrease of  $dz$  to 2, 1 and 0 km give practically the same values of variances  $\overline{v'^2}$  and  $\overline{v''^2}$  as we have for  $dz = 3$  km. But using  $dz = 3$  km allows to increase the number of drift velocity pairs involved into the analysis and so to improve the statistical reliability of the results. Equation (1) and previous half-hourly averaging of the data are equivalent to a numerical filter with the power transmission function

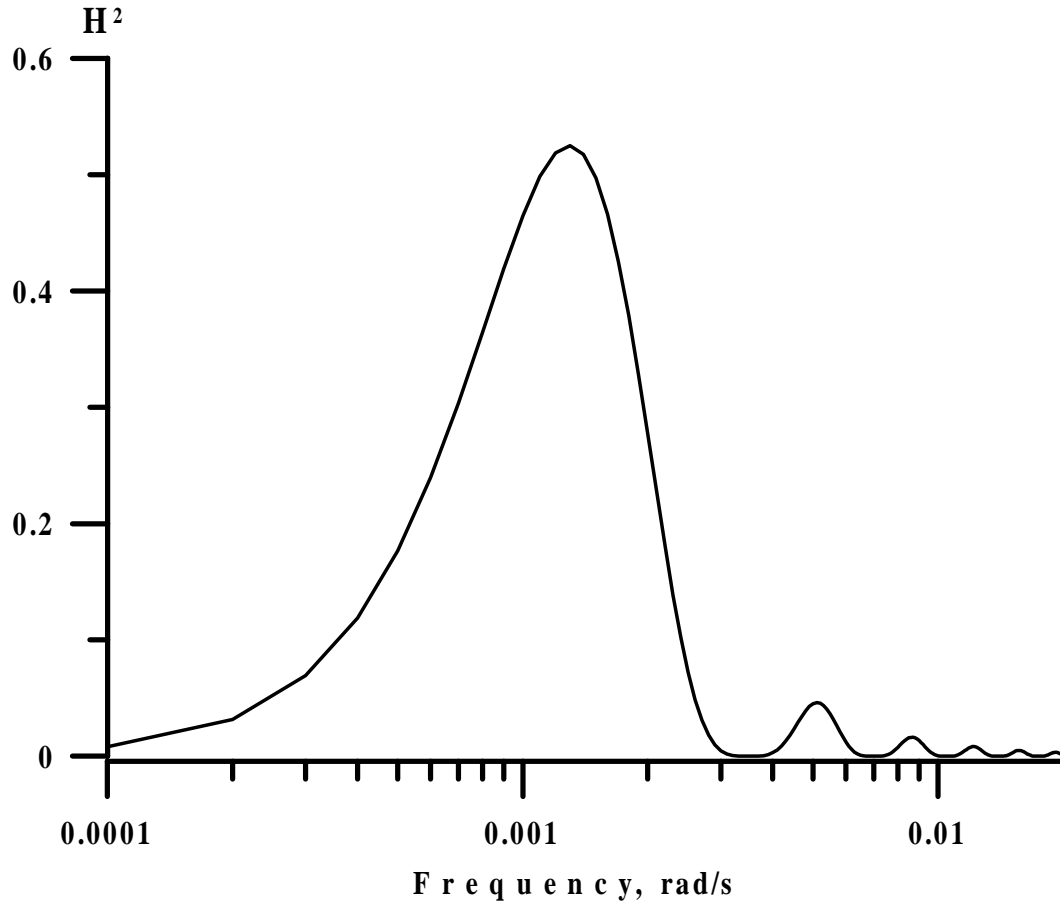
$$H^2 = \frac{\sin^4(\sigma T/2)}{(\sigma T/2)^2}, \quad (2)$$

where  $\sigma$  is the frequency and  $T = t_{i+1} - t_i$  is the time step (30 minutes) of the experimental data. The transmission function (2) is shown in Figure 1. The filter passes harmonics with periods  $\tau \sim 0.7 - 3$  hr with a maximum at  $\tau \simeq 1$  hour. The transmission function (2) is not depended on whether selected pairs of data are consecutive or randomly distributed in time and space. Therefore, it is especially eligible to be used for interpretation of low frequency D1 measurements with substantial height changes during a day.

For each pair of data involved into Eq. (1) we calculate the mean height  $z_{0i} = (z_{i+1} + z_i)/2$ , and the hourly mean drift velocities

$$u_{0i} = (u_{i+1} + u_i)/2; \quad v_{0i} = (v_{i+1} + v_i)/2. \quad (3)$$

After such procedure the results of Eq.(1) and (3) are arranged in height layers of 10 km thickness. We select pairs with  $z_{0i} \in [z_j - \Delta z/2, z_j + \Delta z/2]$ , where  $z_j$  and  $\Delta z =$



**Figure 1** Power transmission function of the difference filter (1), (2).

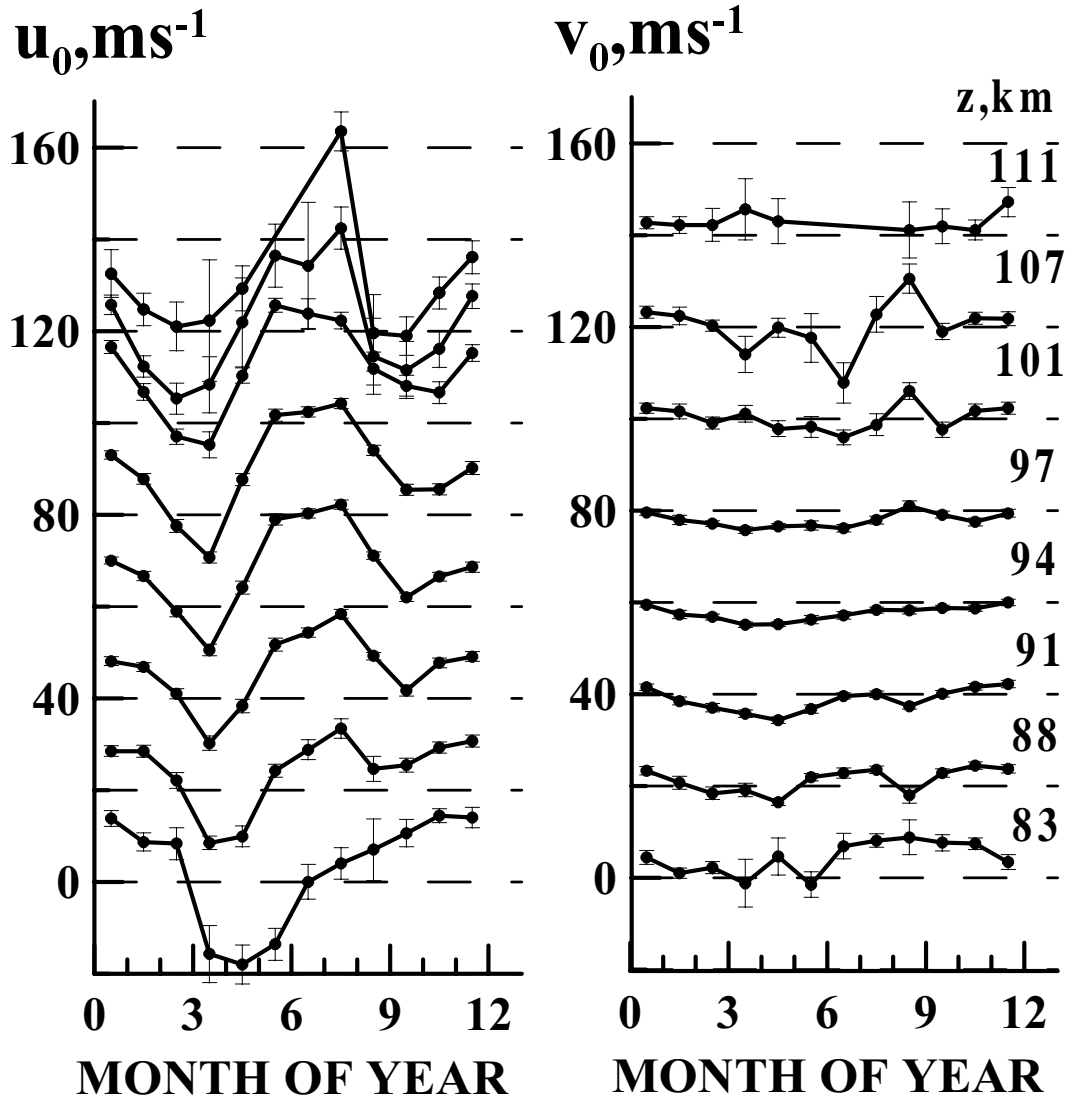
10 km are the nominal center and thickness of the layer, respectively. For each layer we calculate monthly mean values of zonal,  $u_{0j}$ , and meridional,  $v_{0j}$ , drift velocities, and also the respective variances of short-period perturbations,  $\overline{u_j'^2}$  and  $\overline{v_j'^2}$ . In addition, we calculate the mean heights for each layer,  $z_{0j}$ , which can differ from nominal values  $z_j$  due to different real distributions of reflection heights during the experiments. Note also that the mean drift obtained here is not necessarily equal to the prevailing winds published previously (e.g. Jacobi et al., 1997b), because we do not make an extraction of tides here. But calculated in the manner used here, the mean velocities better reflect the true background conditions corresponding to the measured drift velocity variances.

### 3. Results of measurements

Monthly mean values of zonal and meridional drift velocities and and variances with time scales between 0.7 and 3 hours were calculated as described in section 2 for the observation period from 1983 to 1999 at Collm, for which we have measurements of altitude (see section 2).

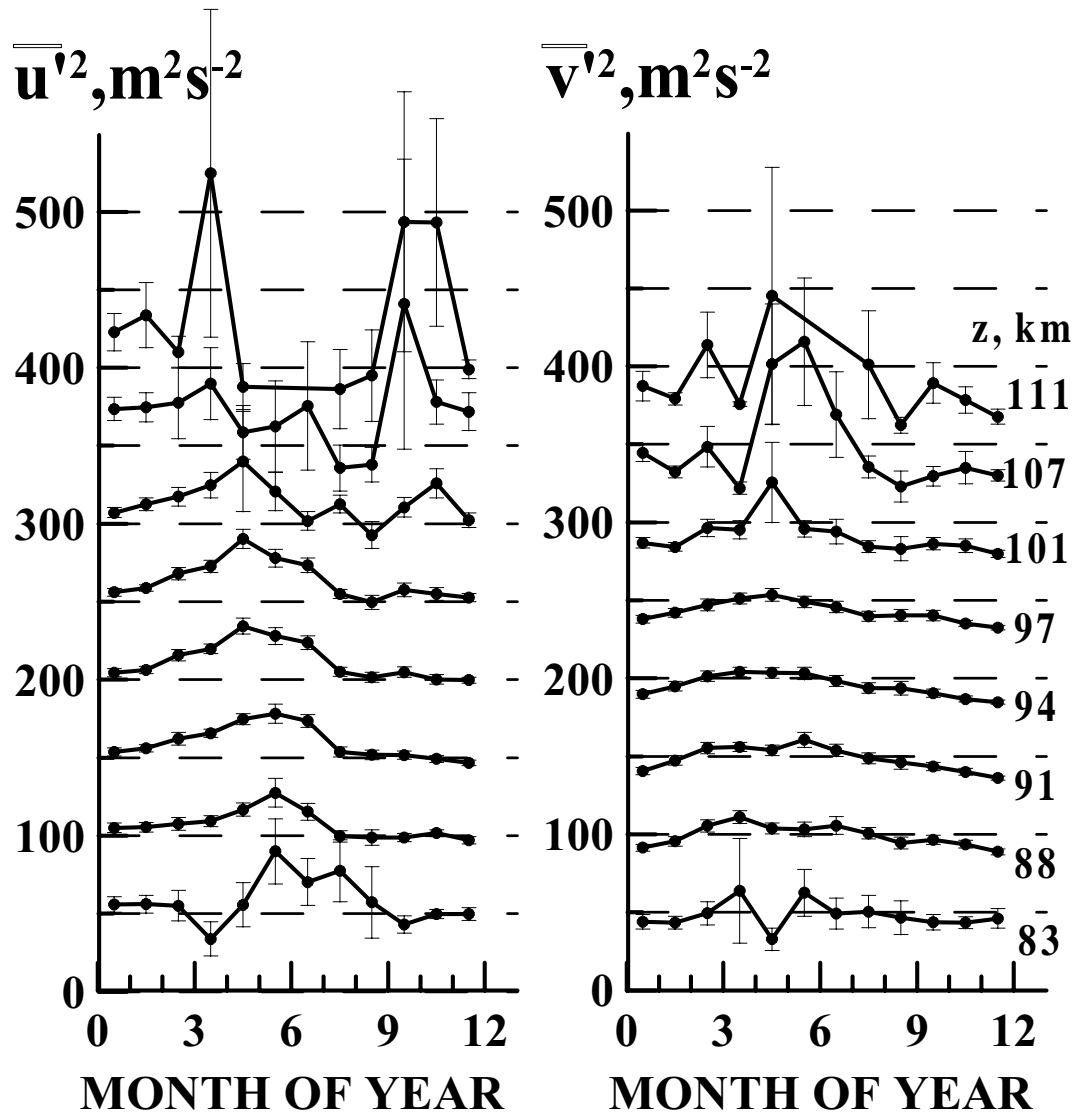
#### 3.1. Average seasonal variations

To study average seasonal variations of the mean drift velocity and its short-period



**Figure 2** Seasonal variations of the mean zonal and meridional drift velocities averaged over 1983 – 1999. Curves for consecutive altitudes are separated by adding  $20 \text{ ms}^{-1}$  to the next curve. Numbers denote the mean reflection heights of the data.

variances we averaged monthly values mentioned above for each respective month over the entire period from 1983 to 1999. The results for zonal and meridional mean drift velocities are presented in Figure 2. Specified are the mean heights calculated for the data belonging to 10-km thick consecutive layers shifted by 5 km nominal heights. In Figure 2 one can see mainly the annual cycle in changes of the mean zonal drift velocity near 83 km, which is eastward in winter and westward in spring and beginning of summer. At higher altitudes the period of westward zonal drifts are shifted towards spring months, and another period of westward velocities appear in autumn. Therefore, in Figure 2 we can see substantial semiannual variations of zonal velocity at altitudes of 100 – 110 km with maxima of eastward drifts in winter and summer, and largest westward drifts in spring and autumn. Variations of the meridional velocity in Figure 2 are smaller. Such behavior of the mean velocity were observed in the Collm data previously (Jacobi et al., 1997b). Also, similar seasonal variations of the mean zonal

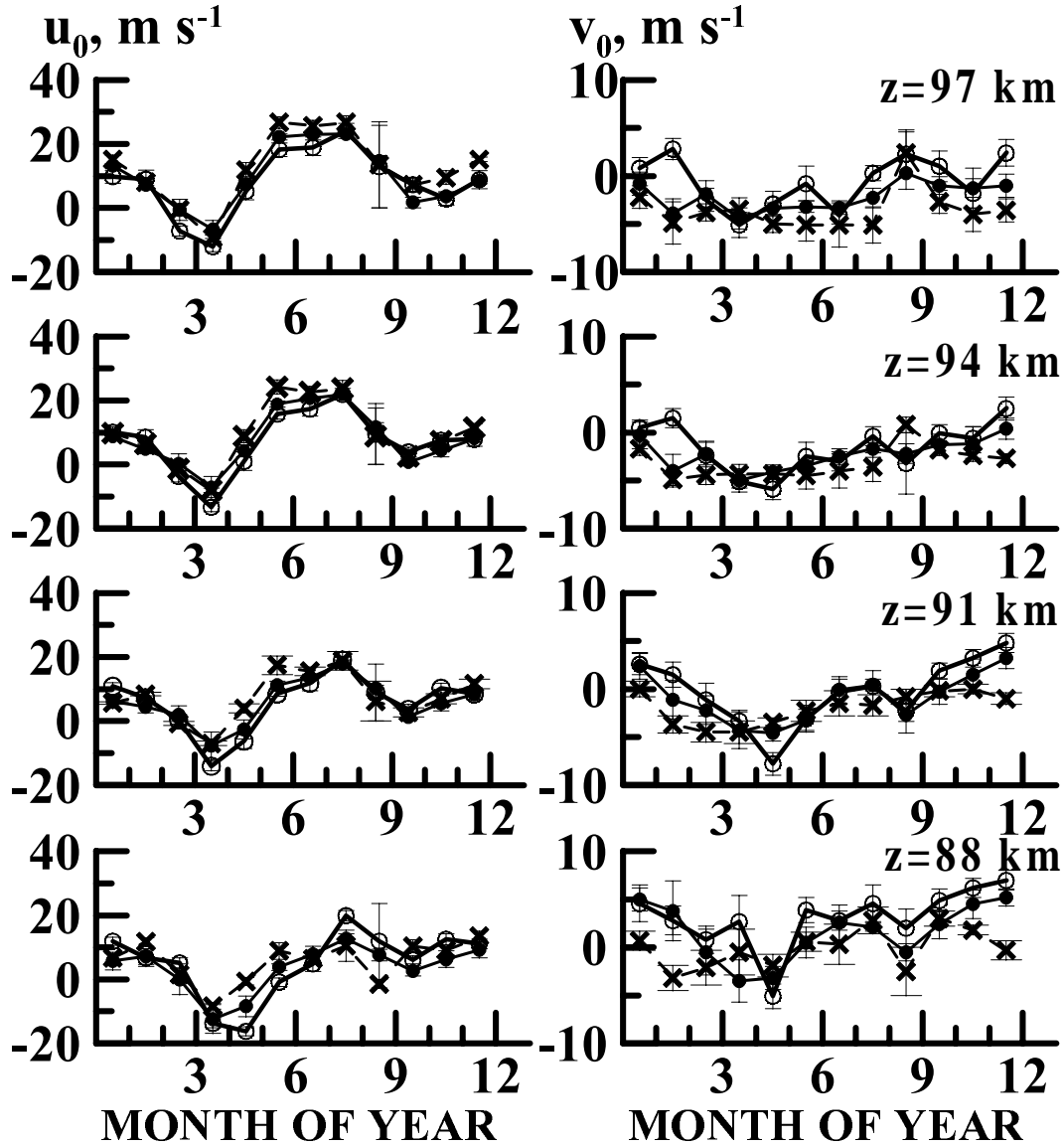


**Figure 3** Same as Figure 2, but for short-period drift velocity variances. Curves are separated by adding  $50 \text{ m}^2\text{s}^{-2}$

wind were observed with meteor and medium frequency (MF) radars (c.f. Kashcheyev and Oleynikov, 1994; Fahrutdinova and Ishmuratov, 1995; Manson et al., 1990; Manson, 1992; Franke and Thorsen, 1993; Fritts and Isler, 1994). The more complicated structure of the seasonal variations of meridional velocity at high altitudes is probably due to lower data density there, and also due to the uneven distribution of the measured values during the day.

Average seasonal variances of perturbations of zonal drift velocity with periods 0.7 – 3 hr are calculated as described in section 2 and shown in Figure 3. At the lowest altitude (83 km) one can see a seasonal variation with the minimum values of  $\overline{u'^2}$  near the equinoxes, the main maximum in summer, and a smaller maximum in winter. This is consistent with the character of seasonal variations of gravity wave activity in the mesosphere, which was observed with the Japanese MU radar and also MF radars (Tsuda et al., 1990; Nakamura et al., 1996; Gavrilov et al., 1995). At larger altitudes in Figure 3 one

can see a shift of the maximum of  $\overline{u'^2}$  towards the spring months, and the formation of another maximum in autumn at altitudes near and above 100 km. Seasonal changes of variances of the meridional drift  $\overline{v'^2}$  in Figure 3 show maximum values in spring and summer, and some indications of an increase of the summer maximum at altitudes above 100 km.



**Figure 4** Seasonal variations of the mean drift velocity averaged for the years 1984-1988 (solid dots), 1989-1993 (open dots), and 1994-1998 (crosses) at different altitudes.

### 3.2. Interannual variability

To study possible changes of the seasonal variations of the mean drift velocities and their variances, we subdivided the entire analyzed period of observations into three 5-year subintervals, namely 1984-1988, 1989-1993, and 1994-1998. The respective seasonal

variations of the mean velocities for altitude layers with reliable numbers of data are shown in Figure 4. Within the variations of the zonal velocity in Figure 4 one can distinguish stronger westward velocities in spring and summer during 1989-1993 at all altitudes. At lower altitudes one can see larger eastward velocities in January and August during this period. However, near 100 km these eastward flows become weaker in these months in 1989-1993 compared to the other time periods. Seasonal variations of the mean meridional drift velocity in Figure 4 show stronger southward velocities in May at 88 and 91 km altitude during 1989-1993, and larger northward velocities in winter, summer and autumn at higher altitudes.

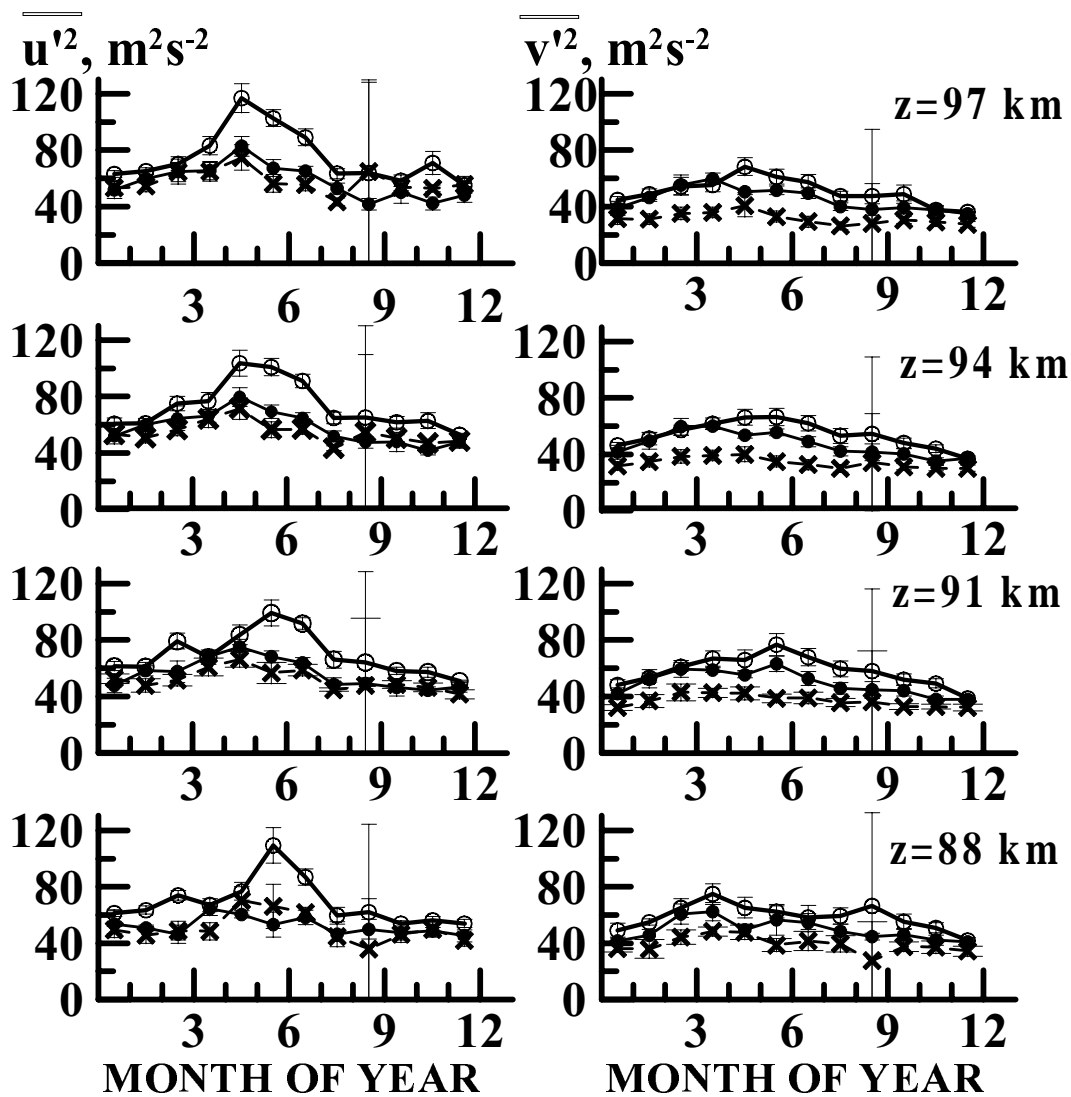
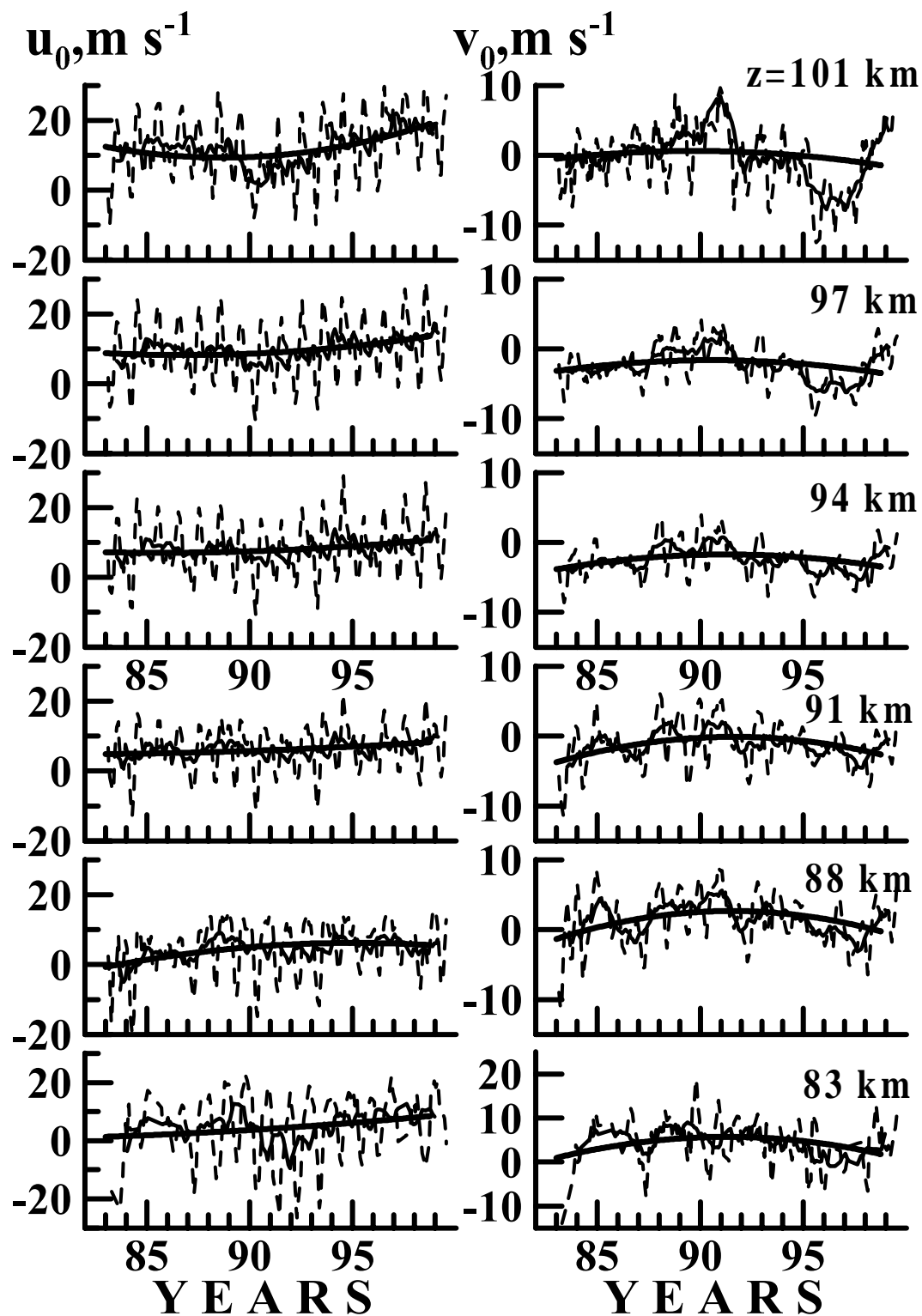


Figure 5 Same as Figure 4, but for short-period drift velocity variances.

The seasonal changes of the variances of short-period perturbations of the drift velocity are presented in Figure 5. One can see generally stronger values of  $\overline{u'^2}$  and  $\overline{v'^2}$  during 1989-1993 compared with the other time periods in Figure 5. This corresponds to previous observations of increased gravity wave intensity in the middle atmosphere in



1990 - 1993 over the Japanese MU radar (Gavrilov et al., 1999) and over Central Europe (Laštovička et al., 1998).



**Figure 6** Interannual variations of the mean drift velocities at different altitudes: 3-month running average (dashed lines), 12-month running average (thin lines), quadratic trend (thick lines).

Figure 6 shows interannual variations of the mean zonal and meridional velocities at different altitudes. One can see substantial interannual variations. Between 1989 and 1993 one can observe a decrease in the values of winter eastward velocities at all altitudes in Figure 6. Similar decrease was observed previously using the MU radar data (Gavrilov et al. 1999). Also, Figure 6 shows stronger summer westward velocities especially at lower altitudes, which corresponds to the changes of season variations in different years presented in Figure 4. Figure 6 also shows the existence of variations of the mean velocity with periods larger than one year. One can see variations with periods of 2 – 4 years, more noticeable in the meridional velocity in Figure 6. Amplitudes of such variations tend to become larger at higher altitudes. Also, we can see longer-period changes, which form, for example, maximum values of northward velocities in 1991-1992 and stronger southward velocities in 1995-1998 more noticeable above altitude 95 km in Figure 6.

Interannual changes of short-period variances of zonal and meridional drift velocities are presented in Figure 7 for different altitudes. We can see that variances of both drift components each have a maximum between 1989 and 1993, which correspond to the results from Figure 5 and previous results by Gavrilov et al. (1999) and Laštovička et al. (1998). Minimum values of the drift velocity variance were observed in 1985-1987 and in 1996-1998. Superimposed to these long-term changes of the drift velocity variances are variations with periods of several years more noticeable in the meridional component and at higher altitudes in Figure 7.

#### 4. Discussion

One factor, which may contribute to short-period perturbations of drift velocity with periods 0.7 – 3 hours are atmospheric internal gravity waves (IGWs). Numerical modeling performed by Gavrilov and Fukao (1999) shows that IGW intensity in the middle and upper atmosphere is controlled by the intensity of wave sources and by the conditions of IGW propagation through the mean fields of wind and temperature. Seasonal variations of the mean wind and temperature in the troposphere-stratosphere-mesosphere-system may cause seasonal variations of IGW intensity in the mesosphere having the maximum values in winter and summer (Gavrilov and Fukao, 1999). Such type of seasonal variations of IGW intensity has been observed with the MU radar and other radars (Tsuda et al., 1990; Gavrilov et al., 1995; Nakamura et al., 1996) in the middle atmosphere. Similar seasonal variations with perturbation intensity peaking in winter and summer we can see in Figure 3 at the altitude 83 km.

Furthermore, numerical modeling by Gavrilov and Fukao (1999) reveals that near 100 km altitude we can expect another type of seasonal variations of IGW intensity with maximum intensity at the equinoxes. Figure 3 shows the height structure of the seasonal variation of drift perturbation intensity with a formation of equinox peaks near and above 100 km. This may indicate that short-period drift velocity perturbations observed at Collm are partly owing to atmospheric IGWs. At the same time, one should keep in mind that vertical profiles of the mean wind used by Gavrilov and Fukao (1999) are different from these observed at Collm. Therefore, further numerical modeling of IGW generation and propagation is needed for better understanding of the contribution of atmospheric waves into drift velocity perturbations.

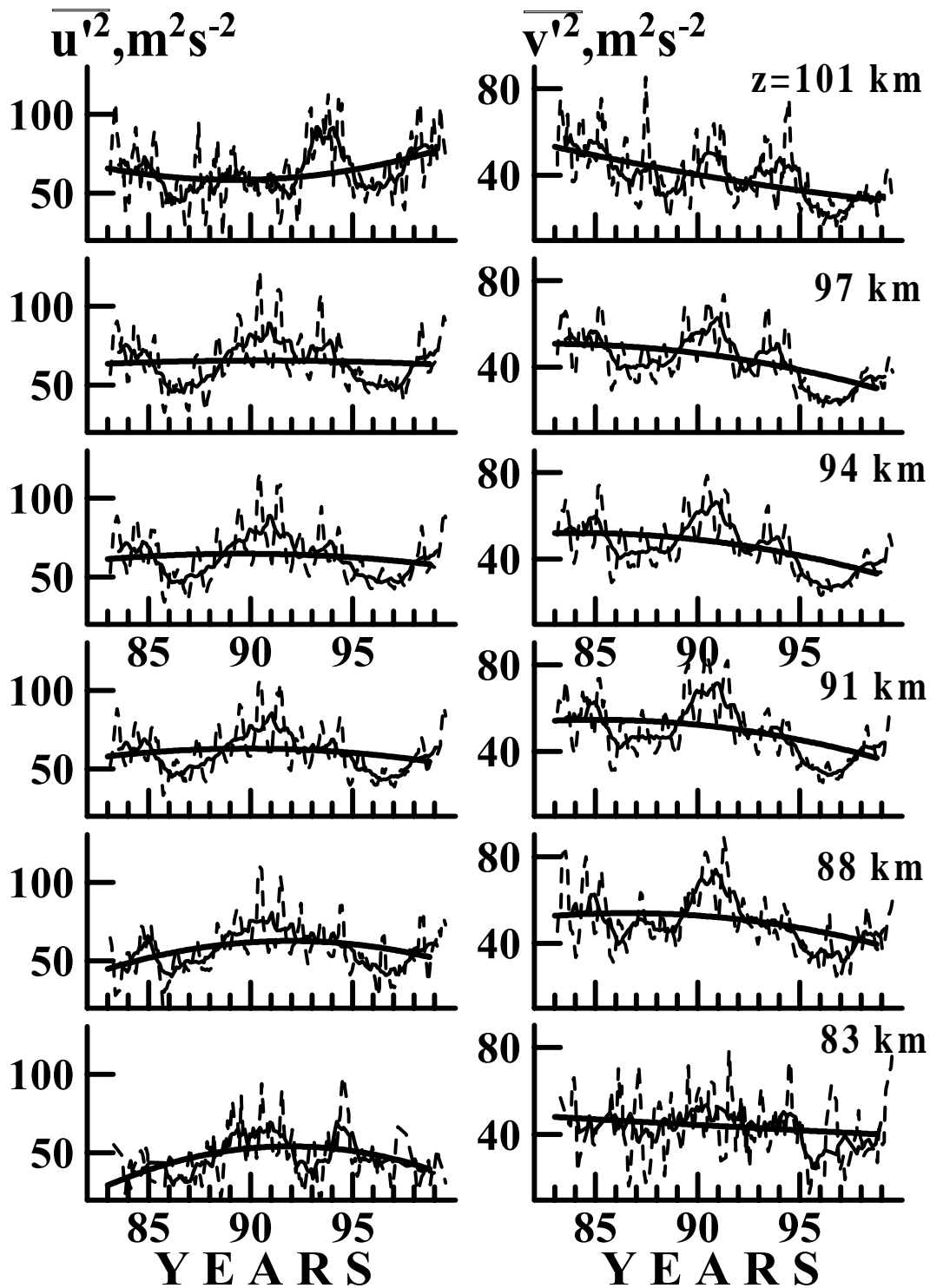


Figure 7 Same as Figure 6, but for short-period drift velocity variances.

It is interesting to compare the Collm interannual variations of drift velocities and intensity of their short-period perturbations presented in section 3 with the data from other sites. Unfortunately, regular multi-year measurements of winds and drifts in the middle and upper atmosphere are made only at a few places. Results of the mean wind observations with the Japanese MU radar at the altitudes 65 – 80 km in 1983 – 1999

show a decrease in the winter eastward velocities in 1992 – 1994 similar to our results shown in Figure 6 (see Gavrilov et al., 1999). The same MU radar measurements show a maximum of short-period wind variances attributed to atmospheric IGWs in 1992 – 1994. The analogous maximum of IGW intensity in 1992 – 1994 was observed using the ionospheric absorption technique (Laštovička et al., 1998).

The authors of the mentioned studies attributed the interannual changes in the wind perturbation intensity to the changes in the strengths of IGW sources in the lower atmosphere and to the conditions of wave propagation into the middle and upper atmosphere. Among the possible reasons for these changes could be solar activity (which had a maximum in 1989 – 1992), the eruption of the Pinatubo volcano in June 1991 and, probably, interannual changes of the temperature of oceans in tropics (El Niño events) on the circulation of the middle and upper atmosphere (Gage et al., 1996; Laštovička et al., 1998; Gavrilov et al., 1999). These events may also influence the mean drift velocities and their short-period perturbations observed in the ionosphere over Collm.

## 5. Conclusion

In this paper, estimations are made of the intensity of short-period perturbations of horizontal drift velocity at the altitudes 80 – 110 km from the data of the regular low-frequency D1 ionospheric reflection observations at Collm, Germany (52° N, 15° E) in 1983 – 1999. A simple half-hourly-difference numerical filter is used to extract perturbations with time scales 0.7 – 3 hour.

The average over 1983 – 1999 seasonal variations of the mean zonal drift velocity show mainly an annual cycle near 83 km altitude with eastward velocities in winter and westward velocities in spring and the beginning of summer. At altitudes between 100 and 110 km a substantial semiannual variation of the mean drift velocity is present with westward flows in spring and autumn. Average monthly variances of short-period perturbations of the zonal velocity near 83 km have the main maximum in summer, a smaller maximum in winter, and the minimum values at the equinoxes. At larger altitudes the summer maximum is shifted towards spring months, and another maximum of perturbation variances in autumn appears at altitudes near and above 100 km. Seasonal changes of variances of meridional velocity show maxima in spring and summer, also some indications of the increase in summer maximum at altitudes larger 100 km.

Interannual variations of the mean zonal velocity show a decrease in the values of winter eastward winds and stronger spring-summer westward velocities in 1989 – 1993. Variations with periods of 2 to 4 years exist and are more noticeable in the meridional component. Perturbation variances for zonal and meridional drift components have a maximum in 1989–1993 and minima in 1985 – 1987 and in 1996 – 1998.

The observed altitude changes of the seasonal variations of drift perturbation variances are consistent with some numerical calculations of the height structure of a spectrum of internal gravity waves in the middle and upper atmosphere. Further experimental studies and numerical modeling are necessary to better understand the contribution of atmospheric waves to the formation of short-period perturbations of drift velocity, and to study the climatology of gravity waves and the peculiarities of wave-mean flow interactions.

## Acknowledgements

This study was partly supported by the International Association for the promotion of cooperation with scientists from the New Independent States (INTAS) and by the German Research Foundation under grant LE 758/11-1.

## References

- Fahrutdinova, A. N., and R. A. Ishmuratov, 1995: Height structure of interannual variations in the circulation of the middle latitude lower atmosphere (in Russian). *Geomagn. Aeronomy*, **35**, 183–189.
- Franke, S. J., and D. Thorsen, 1993: Mean winds and tides in the upper middle atmosphere at Urbana (40°N, 88°W) during 1991–1992. *J. Geophys. Res.*, **98**, 18607–18615.
- Fritts, D. C., and J. R. Isler, 1994: Mean motions and tidal and two-day structure and variability in the mesosphere and lower thermosphere over Hawaii. *J. Atmos. Sci.*, **51**, 2145–2164.
- Gage, K. S., J. R. McAfee, and C. R. Williams, 1996: On the annual variation of tropospheric zonal winds observed above Christmas Island in the central equatorial Pacific. *J. Geophys. Res.*, **101**, 15061–15070.
- Gavrilov, N. M., A. H. Manson, and C. E. Meek, 1995: Climatological monthly characteristics of middle atmosphere gravity waves (10 min–10 hr) during 1979–1993 at Saskatoon. *Ann. Geophys.*, **13**, 285–295.
- Gavrilov, N. M., and S. Fukao, 1999: A comparison of seasonal variations of gravity wave intensity observed by the MU radar with a theoretical model. *J. Atmos. Sci.*, **56**, 3485–3494.
- Gavrilov, N. M., S. Fukao, and T. Nakamura, 1999: Peculiarities of interannual changes in the mean wind and gravity wave characteristics in the mesosphere over Shigaraki, Japan. *Geophys. Res. Lett.*, **26(16)**, 2457–2460.
- Jacobi, Ch., R. Schminder, D. Kürschner, J. Bremer, K. M. Greisiger, P. Hoffmann, and W. Singer, 1997a: Long-term trends in the mesopause wind field obtained from LF D1 wind measurements at Collm, Germany. *Adv. Space Res.*, **20(11)**, 2085–2088.
- Jacobi, Ch., R. Schminder, and D. Kürschner, 1997b: Measurements of mesopause region winds over Central Europe from 1983 through 1995 at Collm, Germany. *Beitr. Phys. Atmosph.*, **70(3)**, 189–200.
- Kashcheyev, B. L., and A. N. Oleynikov, 1994: Dynamic regime of the mesopause – lower thermosphere at midlatitudes of the northern hemisphere by radio meteor observations. *J. Atmos. Terr. Phys.*, **56**, 1197–1207.
- Kürschner, D., 1975: Konzeption und Realisierung eines vollautomatischen Registriersystems zur Durchführung von nach der D1-Methode angelegten Routinebeobachtungen ionosphärischer Driftparameter am Observatorium Collm. *Z. Meteorol.* **25**, 218 - 221.
- Kürschner, D., R. Schminder, W. Singer, and J. Bremer, 1987: Ein neues Verfahren zur Realisierung absoluter Reflexionshöhenmessungen an Raumwellen amplitudenmodulierter Rundfunksender bei Schrägeinfall im Langwellenbereich als Hilfsmittel zur Ableitung von Windprofilen in der oberen Mesopausenregion. *Z. Meteorol.*, **37**, 322–332.
- Laštovička, J., D. Burešová and J. Boška, 1998: Does the QBO and the Mt. Pinatubo

- volcanic eruption affect the gravity wave activity in the lower ionosphere. *Studia Geoph. et Geod.*, **42**, 170–182.
- Manson, A. H., 1992: Dynamics of the mesosphere/lower thermosphere region from radar observations. *Adv. Space Res.*, **12**(10), 67–76.
- Manson, A. H., C. E. Meek, M. Masseur, J. L. Fellows, W. G. Elford, R. A. Vincent, R. L. Craig, A. Phillips, R. G. Roper, G. J. Fraser, M. J. Smith, S. Avery, B. B. Balsley, R. R. Clark, S. Kato, T. Tsuda, R. Schminder, and D. Kürschner, 1990: Description and presentation of reference atmosphere radar winds (80–110). *Adv. Space Res.*, **10**(12), 267–283.
- Nakamura, T., T. Tsuda, S. Fukao, A. H. Manson, C. E. Meek, R. A. Vincent, and I. M. Reid, 1996: Mesospheric gravity waves at Saskatoon (52°N), Kyoto (35°N), and Adelaide (35°S), *J. Geophys. Res.*, **101**, 7005–7012.
- Schminder, R., 1995: Die Entwicklung des Arbeitsgebietes Physik der Hochatmosphäre am Geophysikalischen Observatorium Collm. *Wiss. Mitt. LIM u. IfT, Bd.*, Leipzig, **1**, 1–21.
- Schminder, R., and D. Kürschner, 1984: D1 LF wind measurements in the 90-100 km height range. *Handbook for MAP*, **13**, 248–261.
- Schminder, R., and D. Kürschner, 1994: Permanent monitoring of the upper mesosphere and lower thermosphere wind fields (prevailing and semidiurnal tidal components) obtained from LF D1 measurements in 1991 at the Collm Geophysical Observatory, *J. Atmos. Terr. Phys.*, **56**, 1263–1269.
- Singer, W., 1975: Bestimmung von Elektronenkonzentrationsprofilen der Mesosphäre und unteren Thermosphäre auf Grundlage von Funkwellenausbreitungsdalen, *Doctorate Thesis*, Berlin, 130 pp.
- Tsuda, T., Y. Murayama, M. Yamamoto, S. Kato, and S. Fukao, 1990: Seasonal variations of momentum flux in the mesosphere observed with the MU radar, *Geophys. Res. Lett.*, **17**, 725–728.

#### **Addresses of the authors:**

- Nikolai M. Gavrilov, Saint-Petersburg University, Atmospheric Physics Department, Petrodvorets, 198904, Saint Petersburg, Russia.
- Christoph Jacobi, University of Leipzig, Institute for Meteorology, 3 Stephanstrasse, 04103, Leipzig, Germany.
- Dierk Kürschner, University of Leipzig, Institute for Geophysics and Geology, Collm Observatory, 04779, Wernsdorf, Germany.