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Ionospheric F-region Drift Measurements in Observatory Průhonice, Seasonal Quiet Day Patterns

D. Kouba,[1,2] P. Šauli,[2] J. Boška,[2] O. Santolík[1,2]

[1] Department of Surface and Plasma Science, Faculty of Mathematics and Physics, Charles University,
V Holešovièkách 2, 18000 Prague 8, Czech Republic.

[2] Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic,
Boční II/1401, 141 31 Prague 4, Czech Republic.

Abstract. Measurements of plasma motion brings important information about the state of the ionosphere. In the present study we concentrate on the data measured by the ionospheric station Průhonice (50.0N, 14.6E) in the Central Europe. First, we briefly introduce a new quality control method included in the procedure of evaluation of plasma drifts. The method consists of a three-step selection of skymap points and application of the standard DDA algorithm on the corrected skymaps. This selection method guarantees a better quality of obtained drift velocities and improves further interpretation of plasma motion (Kouba et al., 2006 and Kouba et al., 2007). We demonstrate application of the method on the data set collected in 2006, during a period of exceptionally low geomagnetic and solar activity. Using histograms of horizontal and vertical velocity components we found prevailing directions of plasma motion corresponding to specified ranges of velocities. Our preliminary results show how F-region drift velocities evolve during January - June 2006. Within the analyzed data we found significant decrease of the daily-maximal horizontal component from winter to summer 2006.

Introduction — Drift velocity measurement using Digisonde

State of the ionosphere can be monitored using many radio techniques based on electromagnetic wave reflection and refraction (*Davies, 1990, Kohl et al., 1996*). Each instrument imposes restrictions in its velocity determination. Different techniques and their limitations are discussed by *Cannon et al. (1991)*. Regular ionospheric sounding and monitoring is mainly provided by a wide network of ionosondes. A classical ionosonde usually measures profiles of the electron density *N(h)*. Digisondes also allow us to measure the plasma motion at predefined ionospheric heights employing the Doppler shift measurement of the reflected signal. Principles of the ionospheric drift measurements are described in details by *Reinisch et al. (1998)*. The term “drift velocity” refers to the motion of ionized particles at a particular height and involves effects from both the neutral atmosphere through collisions and particle forcing due to magnetic, electric, and gravity fields and gradients. Special experiments were organised in order to compare drift measurements provided by the Digisondes and incoherent scatter radars (*Scali et al., 1995)*. These comparative studies found a good agreement of different techniques in the determination of the apparent velocities. Experimental study of *Dyson et al. (1998)* reported new findings about height variation of plasma motion. Vertical plasma drift studies using an incoherent scatter radar conducted at the Jicamarca Observatory focused on the plasma drift variability with respect to solar variability. Data indicated that the quiet-time variability of vertical drifts depends on local time, season, and solar activity. This variability is largest in the dawn-noon sector and during March equinox and solar minimum periods. The day-to-day variability of the vertical drifts decreases in the afternoon sector and with the increase of solar activity for all seasons (*Fejer and Scherliess, 2001*). The ionospheric plasma motion reflects many processes in the neutral atmosphere and ionosphere including geomagnetic storms, photoionization and recombination, changes of the electric field, wave propagation, etc. Evidence of the relation between the formation of the midlatitude trough in the dusk sector and the measured F region drift velocities is reported by *Scali and Reinisch (1995).* Data indicate that troughs develop due to an increase in the horizontal westward velocity component.

As the transmitted signal illuminates a large ionospheric area of several hundred kilometres diameter above the sounder, the receiving antenna field observes multiple vertical and oblique echoes arriving from the locations with matching electron density *N* and local density isocontour perpendicular to the wave propagation vector. The oblique echoes occur due to ionospheric irregularities disturbing the density contours. Multiple echoes overlay each other as they arrive at the receiver location and remain inseparable for analysis by conventional ionosondes. The Digisonde, by means of Fourier spectral analysis distinguishes between individual echoes with different Doppler frequency shifts. In a classical situation of a large travelling ionospheric disturbance crossing the sampling space volume, oblique signals from the opposite sides along the line of travel would have opposite Doppler shifts. The multi-element antenna interferometry can determine the source location (incidence angle, azimuth of arrival) for identified echoes.

For practical use, source (reflection) points are graphically interpreted in so called skymap. Identified source locations can also be used to calculate velocity of the bulk drift of the ionospheric structure across the sounder sampling area. Routinely used method for drift velocity computation from skymaps called Digisonde Drift Analysis (DDA) is well documented in *Reinisch et al. (1998)* and need not to be further discussed here. The DDA method is implemented in the interactive analysis software tool “Drift Explorer” (*Reinisch et al., 2005)* commonly used by scientists.

Skymap processing

Since January 2004 new Digisonde with four cross-loop receiving antennas (Digital Portable Sounder 4, DPS4) provides routine measurements of plasma motion in the Prùhonice Observatory. Our experience with manual data control reveals, however, that the DDA method is rarely applicable for routine automatic drift velocity calculations from the raw data due to the presence of irrelevant reflection points. Therefore, careful manual skymap control and further point selection is necessary. The DDA method encounters problems especially when there are multiple-hop Es or F reflections present on ionogram, range of the measured Doppler frequency shifts is too wide, and velocity distribution across the sounding range is non-uniform. Application of the DDA method to the raw skymaps in such conditions can lead to incorrect results. *Kouba et al., 2006* and *Kouba et al., 2007* propose a method of skymap points selection consisting of three steps: (i) robust selection of the height range, (ii) setting limits on the Doppler frequency shift, and (iii) setting limits on the incidence angle. Following section briefly summarizes the proposed procedure.

Height range selection

Reflection points in the ionospheric F-region typically occur above *170 km* and below *1000 km* (*Davies, 1990; Prolls, 2004* among others). However, this height interval can cover not only direct F region reflection points but usually also multiple-hop reflections that travelled the path between the Earth and ionosphere more than once. In the drift mode, Digisonde automatically stores reflection points that correspond to an expected interval of virtual heights. We thus plot the virtual heights of the skymap points as a function of the sounding frequency to eliminate those points that corresponds to multiple-hop reflection according to the preceeding ionogram. Occurrence of the sporadic E echo represents another complication. In case of strong Es echoes, higher ionospheric layers are not well seen or even completely blanketed. In these cases no information about F region plasma motion can be derived from data.

Doppler frequency shift range

Skymaps frequently comprise two populations of reflection points. The first population consists of a cluster located around the central part of the skymap. Representative Doppler frequency shifts of such points typically fall within the more or less narrow interval and form peak around null value on a histogram of Doppler frequency shifts. Furthermore, the space distribution of frequency shifts shows a bipolar pattern. The characteristic range of the Doppler shift values and the bipolar pattern of their distribution for the first population of skymap points remain fairly consistent over a consecutive sequence of skymaps. The first population is of the primary importance in the determination of the ionospheric plasma motion. Therefore we select only those skymap points forming a pronounced separated peak around the zero frequency-shift on the histogram.

Choice of the maximum incidence angle

The DDA method assumes a uniform velocity within the entire region of measurement. In general, plasma velocity can vary in the ionosphere, therefore pattern of clustered points on a skymap is not always strictly bipolar. We argue that, for the purpose of evaluating the drift velocity in the space volume above the Digisonde, the most relevant points are those with the incidence angles close to vertical. However, when we select points with too small incidence angle, sensitivity of horizontal velocity computation rapidly decreases. In cases with non-bipolar skymap pattern it is necessary to think over trade-off between maximal incidence angle and accuracy (sensitivity) of velocity computation. In our analysis we typically use reflection points with the incidence angles smaller than *20°*.

January – June 2006 ionospheric drift measurements

Our database consists of *14 123* corrected F-region drift velocities covering period January – June 2006. Analysed data represent measurements performed during a period of low solar activity. Such period allows us to concentrate on the behaviour of the drift velocity during quiet conditions and derive corresponding seasonal changes of the plasma motion in midlatitudes.

Data used for our analysis were collected exclusively by the Prùhonice Observatory (geographic coordinates: *50.0N, 14.6E*). The routine regime of the Digisonde DPS-4 is as follows: each 15 minutes an ionogram is recorded and the F-region critical frequency (foF2) is automatically detected by an ionogram-autoscaling procedure. The F-region drift measurement then follows with a delay of 5 minutes. According to the determined foF2 frequency, sounding frequencies are automatically selected below the foF2 frequency (autodrift mode). The height resolution is set to 5km and the Doppler shift spectral resolution is *0.195* Hz. Reflection points then undergo automatic DDA velocity calculation and preliminary results are immediately available on a web page (http://digisonda.ufa.cas.cz).

For our analysis we first use automatically pre-processed data displayed in a skymap. From the skymap we choose correct reflection points according to the selection method described above. On the corrected skymap we apply the least square DDA analysis in order to obtain a corrected drift velocity.

Drift velocity distribution

We independently analyse vertical and horizontal velocity components. Positive vertical velocity refers to an upward plasma motion, while negative values correspond to a downward plasma transfer. The horizontal velocity component is always positive and refers to the absolute value of the horizontal plasma motion. We include all drift measurements recorded during January – June 2006 in our analysis of the velocity distribution, no data are excluded. Figure 1 illustrates occurrence histogram of the vertical velocity component with the following parameters; median $m=0.06\ m.s^{-1}$, mean value $\mu=0.12\ m.s^{-1}$, and standard deviation $\sigma=9.24\ m.s^{-1}$. The histogram well follows the normal probability density function, as we show by a Gaussian fit to the obtained values. Figure 2 shows a histogram of the horizontal velocity. Horizontal component reaches values in a wide interval of velocities. The most probable velocity value is around $30\ m.s^{-1}$ but the median and mean values are significantly shifted towards higher velocities ($m=46\ m.s^{-1}$ and $\mu=56\ m.s^{-1}$).

Vertical velocity histogram indicates that at long time scales there is no prevailing vertical direction of the ionospheric plasma motion since the most probable value of the vertical drift velocity component is very close to zero (Figure 1). The vertical drift velocity component reaches rarely values over 20 m/s. Indeed, as seen on the horizontal velocity distribution (Figure 2), most of the time the plasma motion is bounded to the horizontal plane.

Let us analyse the properties of this horizontal plasma motion. In the Figure 3, there are four plots of occurrence histograms of the directions of the drift velocity. Azimuth angle is measured from North (*0°*) clockwise. Four plots in Figure 3 refer to different horizontal velocity ranges: all analysed data (*14 123* cases – Figure 3a), data with velocities exceeding $60\ m.s^{-1}$ (*5 092* cases – Figure 3b), data with velocities exceeding $100\ m.s^{-1}$(*1 813* cases – Figure 3c) and, finally, data with velocities over $170\ m.s^{-1}$ (*277* cases – Figure 3d).

Figure 3a shows two well pronounced peaks located at *180°* (direction to the South) and at *270°* (direction to the West). On the following plots (Figure 3b – Figure 3d), after removing lower velocities, the Southward peak rapidly decreases. On the contrary, the Westward peak remains present at all plots. It is evident that the first peak is mainly formed by slowly moving plasma with velocities below $100\ m.s^{-1}$. To the formation of the second peak, however, fast moving plasma contributes significantly. The second peak is clearly developed even on the histogram containing highest observed velocities.

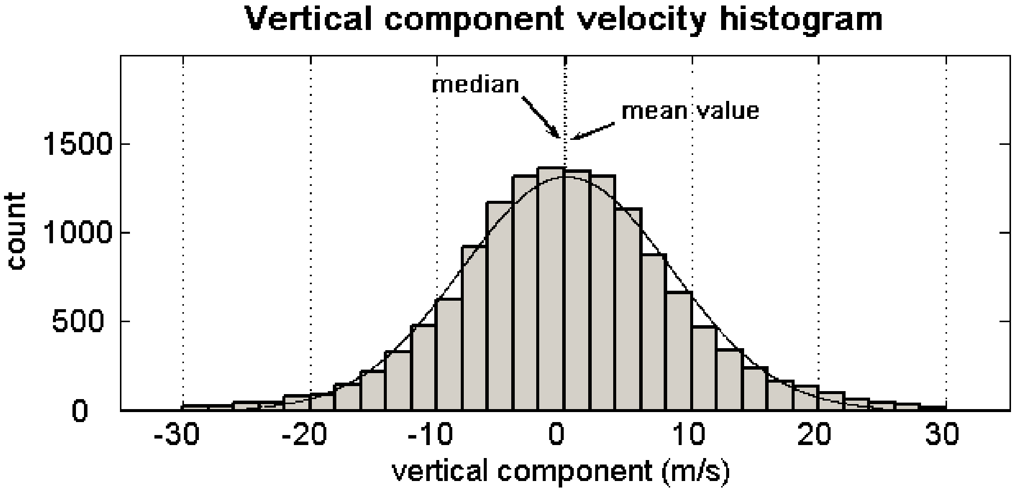

Figure 1. Vertical velocity-component histogram; Gaussian curve with mean value $\mu=0.12\ m.s^{-1}$, standard deviation $\sigma=9.24\ m.s^{-1}$.

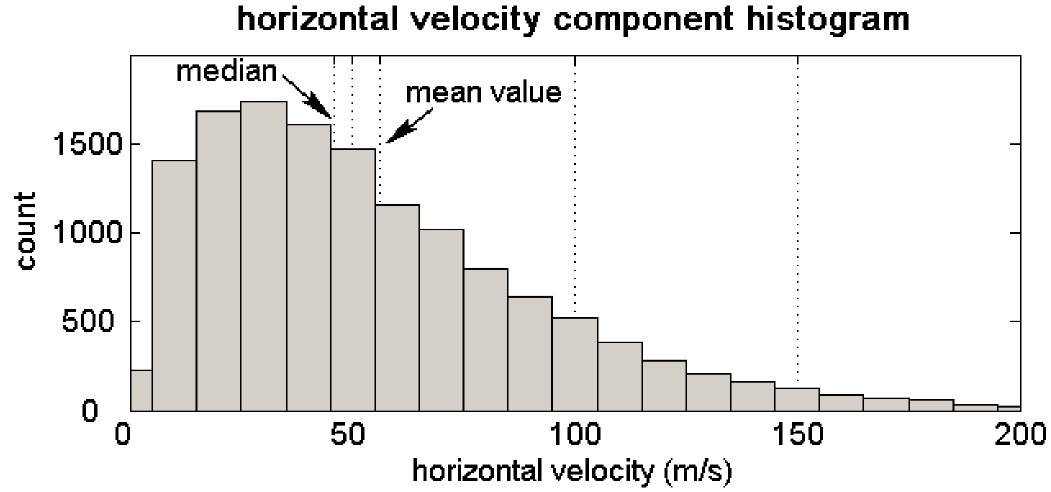

Figure 2. Horizontal velocity-component histogram. Median *m=46 m.s*$^{-1}$ and mean value μ*=56 m.s*$^{-1}$.

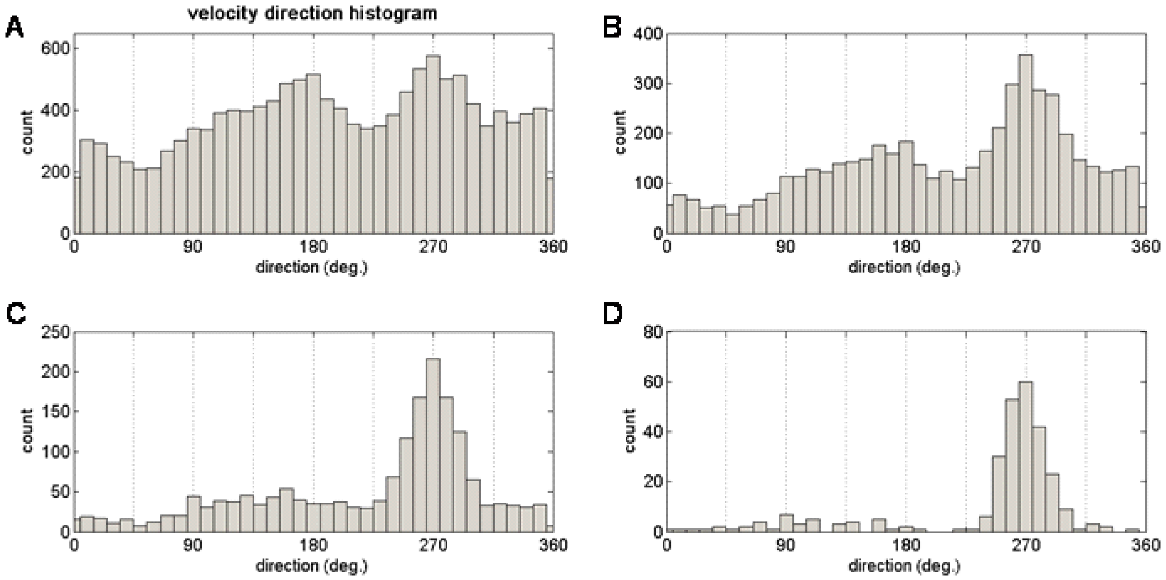

Figure 3. (A) Velocity direction histogram for all 14 123 measurements. Velocity direction histogram for measurements where velocity exceeds (B) *60 m.s*$^{-1}$, (C) *100 m.s*$^{-1}$ and (D) *170 m.s*$^{-1}$.

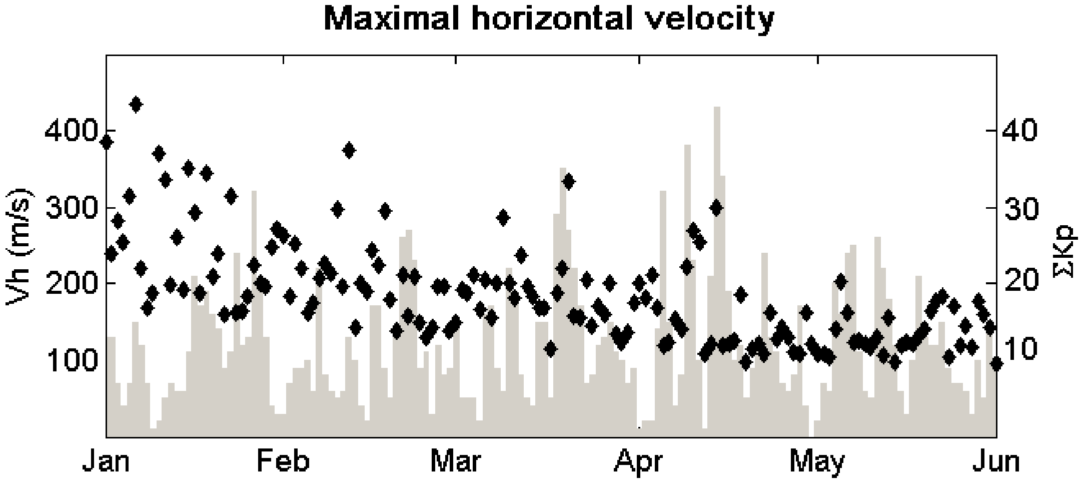

Figure 4. Seasonal change of the daily-maximum horizontal velocity value for the period Jan-Jun 2006. Daily ΣKp indices are shown with grey bars on the background.

Figure 4 shows the seasonal change of the horizontal velocity defined as the maximum value from the daily sets. It is evident that daily-maximum value decreases during January – June. During January, velocity reaches values above $200\ m.s^{-1}$ most of the days. Values of about $250\ m.s^{-1}$ are not rare. The daily horizontal maximum decreases till May and then stays approximately at a constant level in the range $100\text{-}200\ m.s^{-1}$. There are also several irregular points with significantly higher velocities compared to their neighbours. In Figure 4 we also plot ΣKp (data from *the Potsdam Database*) representing geomagnetic situation in order to see possible correspondence of the drift velocity to the geomagnetic activity. During period March – June, irregular points often roughly correspond to the increase of ΣKp to moderately disturbed values (maximum $\Sigma Kp=43$).

Conclusion

We demonstrate application of the skymap points selection method for plasma drift determination on the data measured in period January – June, 2006 at the Prùhonice Observatory. This approach increases reliability of the drift velocity evaluation and further interpretation. We emphasize the importance of skymap point selection for determining the correct values of the drift velocity.

Our analysis performed on the data collected during a period of a low solar activity clearly reveals a pattern of plasma motion during quiet periods. Preferred Southward and mainly Westward plasma motion direction are well developed within the velocity distribution. Further studies are necessary to confirm these trends.

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