Automatic Visualization Method of Height–Time Development of Ionospheric Layers

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Abstract. An automatic method for visualization of variability of ionospheric plasma in terms of ionospheric layers is presented. Here, we use the virtual reflection height for visualization. We directly plot the height–time dependence using original raw digisonde outputs. It gives us an opportunity to promptly visualise the ionospheric digital data and locate events of the interest for further analysis. In this paper, we present a variability in height of E-layer with a special focus on the sporadic E-layer. The proposed method is applicable for any ionospheric region.

Introduction

Ionospheric layer is an area of increased density of ionospheric plasma. The ground-based measurements using ionosonde allow us to observe present ionospheric layers and their time variability. In the paper we concentrate mainly on the time-height development of a Sporadic E-layer (Es). It is a special stratification of very thin layer(s) of high ionization occurring at height of E-layer which is usually formed at height of 90–150 km (for instance Wakai et al., [1986] and others). The sporadic E behavior was reviewed in the paper Whitehead, [1989]. Ionization in a such layer may often exceeds maximum ionization density that is under normal circumstances formed in the F-layer. The Es is formed in lower heights where regular E layer is formed. Es-layer behavior has been studied over many years (e.g., see review by Mathews, [1998], Haldoupis et al., [2004, 2006], Pancheva et al., [2003]). It is believed that vertical wind shears in the neutral velocity play a major role in the formation of Es. Thus this layer is controlled by complex neutral dynamics in the mesosphere and lower thermosphere (Bayru, [2007], Haldoupis et al., [2007]). In midlatitudes it is formed mainly (but not only) during summer season in heights of approximately 90 to 150 km. The Es-layer is composed mainly of the metallic ions of meteoric origin (rocket measurements, e.g., Roddy, [2005]). However, the dynamics and formation conditions need further investigation.

Basic characteristics of Es-layer derived from ionogram are critical frequency foEs and virtual height h'Es. The term critical frequency is equal to maximum plasma frequency of particular layer (the ionosonde registers reflection echoes up to the critical frequency foEs) and virtual height is a height of the layer computed from the time-of-flight of the reflected signal under assumption that its velocity is equal to a velocity of light in free space (real height is lower than virtual because the signal passes through ionized medium). In case of Es-layer the difference between real and virtual height is very small as this highly ionized layer is formed at height of E layer plasma where ionization reaches much smaller values. High ionization within Sporadic E-layer often blankets the above laying ionospheric structures. This fact very often complicates ionospheric monitoring or influences radio communication systems. Hence the Es-layer is subject of many investigation project.

In our paper, we present an automatic visualization method suitable for indication of height-time movements/developments of ionospheric layers using raw digisonde data for the DPS-4 digisonde outputs (Huang and Reinisch, [1996], Reinisch et al., [2005]). Using vertical ionospheric sounding data our method is restricted into vertical direction motion.
Figure 1. Left panel—Original output from the digisonde (RSF binary file). The frequency and height range and other descriptions are defined in the header of the RSF. Right panel—ionogram visualization from standard digisonde software SAO Explorer. Both panels show first and secondary reflection of the F-layer.

Method

We prepared our software for the digital ionosonde (digisonde) DPS–4 (one operates in Pruhonice (50.1N, 14.5E)). After some correction it will be applicable also for new type DPS–4D. The digisonde measures the time-of-flight of the transmitted signal detected after reflection from ionosphere and represents it as an ionogram (time–frequency characteristic of the ionosphere). Left and right panels in Fig. 1 show raw outputs and the standard visualization of the ionogram (using the SAO Explorer software, Conway et al., [2006]), respectively.

From this plot, we can directly read a virtual height, and a critical frequency of the layer. Using standard inversion software (e.g., NHPC Huang and Reinish, [1996], POLAN algorithm Titheridge, [1985], etc.) the true height concentration profile can be derived from virtual height profile. Both virtual and true heights contain information about variability of the ionospheric plasma. We follow the idea of Haldoupis et al., [2006] who used the Canadian Advanced Digital Ionosonde (CADI) raw outputs to study vertical movements of the ionospheric layers. They invented the Ionogram Height–Time Intensity analysis (HTI) and computed the overall intensity of the reflected signal as a function of the height and time. They created HTI plots within a range of heights versus one 24-h day by averaging over a given number of days. It allowed them to study daily vertical movements averaged to a chosen number of days and variability of the Es layer. They used several different frequency ranges, for instance 1.5–3.0 MHz, 2.0–6.00 MHz, 5.0–7.0 MHz etc. in order to describe different aspects of the behaviour of ionospheric plasma with different electron concentration and/or distinguish between layers.

We developed a software which automatically reads the raw digisonde outputs from DPS–4 for similar purpose. During the digisonde sounding, an ionogram is stored in a RSF (Routine Scientific Format) file as a binary map (Fig. 1—left panel and Fig. 2—left panel) representing the amplitude of the reflected signal. Both the resolution and the range depend on the ionosonde setting (Reinisch et al., [2005]). The particular resolution of our digisonde is 5 km and 0.1 MHz for the virtual height and frequency, respectively, in all data described. Time resolution of the ionograms is adjustable as well. Usually, 4 ionogram per hour are recorded.

In the software, we select the frequency–height window for further visualisation. Using both frequency and height of the window we may locate the ionospheric structure of our interest. The frequency range is chosen for the study of developments of ionospheric plasma of selected plasma frequency range and the exact values will remain as a parameter which can be adjusted according to the necessities. It allows us for example compare vertical movements of the plasma with different plasma frequencies. The height window is necessary for the normalization as follows. At first, we subtract the mean value of the amplitudes for each frequency (Fig. 2—right panel) and then normalize signal for each frequency. The mean and maximum values are...
Figure 2. Left panel—Original output from the digisonde. Mention the high noise at the frequencies where no reflection is present and different value of noise at each sounding frequency (the frequency step is 0.1 MHz step). At the frequency where we detect signal reflected by the ionospheric layer we observe a weaker noise. Right panel—first step of normalization after subtracting the mean value for each frequency.

Figure 3. Left panel—Final ionogram after the normalization. The shape of layers are well recognisable. The flat low layer is the Es with the secondary reflection. The curved high layer is the F2 layer. Right thin strip—transformation from the amplitude as a function of height and frequency to the “mean” amplitude as a function of height. The “mean” amplitude is computed from 60 % of the highest amplitudes.

taken from the chosen height interval. Such a treated plot shows distinct reflections from the ionospheric layers with a much lower noise background (Fig. 3—left large panel). The right strip in Fig. 3 represents mean value of the amplitude of received signal for each height step in left ionogram. To increase the signal/noise ratio and to get the image with more distinct layers we only use 60 % of the higher values to compute the mean (see Discussion). Thus, we get the “mean” signal for each height. High values of signal indicate that a significantly high plasma concentration was present in particular height (Fig. 3—strip on the right side). These strips (one strip covers 15 min.) are then used to create the final plot showing changes of height of plasma structure(s) with time. Example of two-days situation represents the upper panel in Fig. 4. For a comparison, the same time visualization using standard digisonde software SAO Explorer can be seen in middle (foEs) and bottom panel (h’Es) in Fig. 4. The SAO Explorer visualization encounters problem when more than one Es layers are present.

Discussion and Results

On the plot (Fig. 4) there is the Es-layer height-time development over two days using standard and above described method. It is evident that present visualisation method is more illustrative. It allows to follow the layer development even when the structure is more complicated and classical method encounters problems. Using this we are able to detect situation when two types of Es layers are visible in one ionogram. The 1–D time–series created by standard
Figure 4. Upper panel–Two days of the Es-layer movements are plotted using 182 (two days of 15 min resolution) “stripes” similar to the 3b. The upper part above 150 km is visualized but the bw scale is suppressed as this height range was not included into computation. Middle and Bottom panels show foEs and h’Es plots from SAO Explorer software. The decreasing of the Es layer during the day is much more distinct and illustrative than using the SAO Explorer outputs.

method only operates with one value of the virtual height in one moment.

As proposed by Haldoupis et al. [2006], the periodicities in Es occurrence and height development may be detected by such visualisation method. Paper of Haldoupis et al., [2004] brought investigation of influence of tidal and planetary waves on the Es. The above mentioned works reported the 24 and 12 hour and 8 hour tidal period as an important feature of the Es-layer. Besides that Sauli and Bourdillon, [2008] analysed the 24 hour tidal component in detail (by mean of Continuous wavelet transform (CWT)) and proposed planetary wave modulation of the tidal oscillation components. Upper panel in Fig. 4 presents that during first day there...
are two descending Es-layers (the 12-hour period is clearly seen from the plot). Second layer is vanishing for about 3 hours, however the the general pattern of the 12-hour descend remains clearly visible. The situation starts to complicate next day and 12-hour tidal component is not evident. Complicated structure demonstrates situation when different types of E-layer develop at the same time. Two types of Es at one moment are present in the plot in Day 1 at about 1600 UT, or in Day 2 in several moments within the interval between approximately 1530 and 1830 UT.

The parameters used during the normalization (e.g., managing the quasi-logarithmic signal, using upper 60 % of signal to compute the resulting “strip” etc.) will probably need to be specified. The height range which is necessary to remove unwanted signal (e.g. secondary reflections or different layers that are out of our interest) will be changed according to our needs and according to the ionospheric situation. The frequency range is more sensitive parameter and need further testing. Large frequency range may especially during studying of Es-layer mix up with the E-layer. Small frequency window may remove important part of the signal. The window 90–150 km and 3–5 MHz (above E-layer critical frequency) was used in the upper panel in Fig. 4. Plot is in good agreement with manual checking of the ionograms.

Conclusion

The visualization method shows possibility how to process the raw ionograms. It allows to study height movements and variability of regions with a plasma density of the interest. Advantage of this method lays in a “Quick look-like” visualization of measured data and choosing time interval of interest which will be afterwards manually scaled and furthermore analysed. We may for example visualize the situation before, during, and after the geomagnetic storm or during similar irregular process affecting the state of the ionosphere (Georgieva et al., [2006]). The possibility of visualization of multiple layering is a point that should be emphasised. In the future, this method will be adapted according our demands for example as a tool for multi-day averaging of the signal.

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References


