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Comparison of Digisonde and CDSS measurement for the monitoring of the existence of the Ionospheric communication channel

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A B S T R A C T

This paper describes systems for detection of the availability of the Ionospheric communication channel. The Digisonde and the Continuous Doppler Sounding System for the detection of the availability are used and are compared by means of here. Their precision, correctness and benefits of these systems are tested at the observatory Pruhonice in Czech Republic. The last part of this paper deals with ambiguities of both systems.

1. Introduction

The ionosphere is a region which significantly affects propagation of radio waves. Bottom border of the ionosphere is located in the upper part of the atmosphere at heights above ≈ 50 km during day-time and above ≈ 90 km during night-time (Fig. 1). The ionosphere is highly variable. The most important factors that affect the ionosphere are related solar and geomagnetic activity (e.g. solar irradiation, solar wind coupling, through the magnetosphere), and neutral atmosphere activity. Ionosphere reflects external forcing in variability on scales from minutes to a solar cycle.

Since the beginning of 20th century, the ionosphere has been intensively studied using ground instruments called ionosondes, by rocket measurement, and satellites. In recent years, GNSS based techniques have been used for global description of the ionosphere.

Total electron concentration (TEC) can be computed from the electron density profile by the equation (1). Range of the heights for the calculation is usually from 80 km to the heights of GNSS satellites (e.g. 20.180 km for GPS).

$$TEC = \int_{h_1}^{h_2} N(h)dh \tag{1}$$

N(h) electron density in the height *h*,

2. Continuous Doppler sounding system (CDSS)

This system is installed in the Czech Republic, South Africa, Argentina and Taiwan. System is composed from the transmitters and receivers. CDSS transmitters in the Czech Republic are placed in the stations Panska Ves, Pruhonice, and Dlouha Louka. Receiver is located at the headquarters of the Institute of Atmospheric Physics, Czech Academy of Sciences in Prague. Frequencies used in the Czech Republic are 3.59 MHz, 4.65 MHz and 7.04 MHz. Frequency channels used in South Africa is 3.59 MHz. Frequency used in Argentina is 4.63 MHz. Frequency used in Taiwan is 6.57 MHz. Multipoint observations in the specific locations are realized by the transmitters with distances approximately 100 km. To distinguish between different transmitters the transmitted frequencies are shifted by 4 Hz. This system is in detail described in the articles (Chum et al., 2014) and (Chum et al., 2011).

FFT spectrum of the received 4.65 MHz signal recorded during one minute is shown in the Fig. 2. Other methods for the creation of the spectra or pseudo spectra are described in (Stoica and Moses, 1997). In the Fig. 2 three peaks are shown. These peaks represent signals received from all three transmitters. Sometimes more peaks can be observed, e.g. by the variability of the ionosphere. Such case is described in (Kouba and Koucka Knizova, 2012).

Spectra can be plotted in the 2D matrix where horizontal axis is time, vertical axis is Doppler shift and color represents power spectral density (Fig. 3). Quasi periodic behavior observed in the 2D matrixes

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(Fig. 4) can be caused by the neutral atmosphere oscillation due to infra sounds, earthquakes and other events.

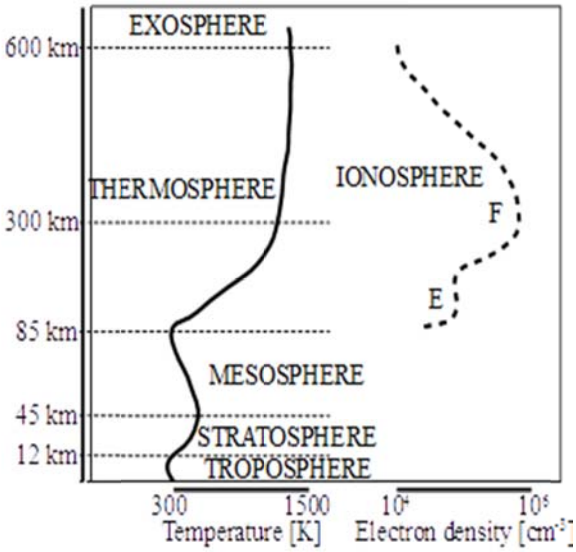

Fig. 1: Classification of the atmospheric regions according to temperature changes (solid line) and Ionospheric layers according to electron density (dashed line) (Prolss, 2004)

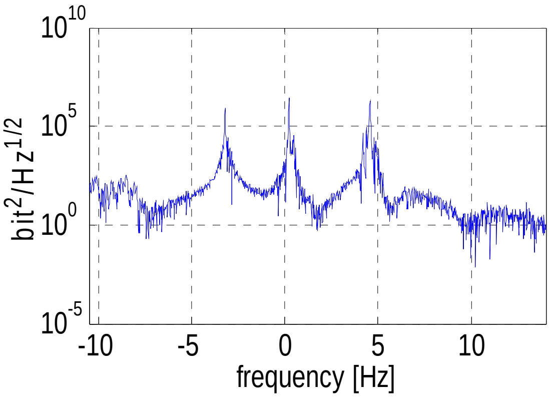

Fig. 2: Spectrum of the received signal measured in 2.11.2013, 7:00 in Prague, Czech Republic

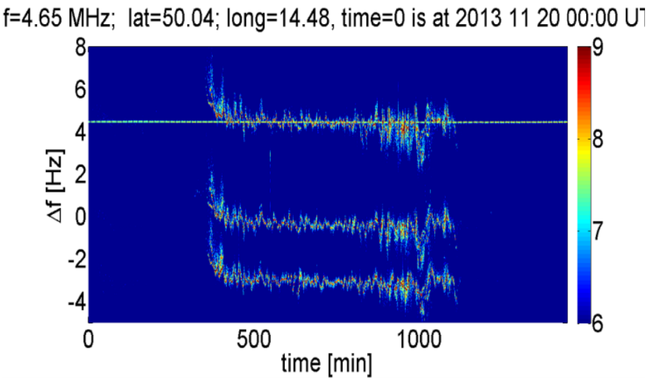

Fig. 3: Doppler shift at frequencies near 4.65 MHz measured by the CDSS at the observatory Prague; 20 November 2013; during whole day after suppression of the low powers. Time in min, 0 min = 0 LT

Existing reflections at given frequency are proofs of the availability of the ionospheric communication channel. For example, Fig. 4 shows available communication channel after time 350 min and no reflections before this value. Periods at which the ionosphere oscillates corresponds to infrasound oscillations. Straight line in the spectrum is caused by the direct ground wave propagation. Split of the spectrum in time ~350-370 min is due to different propagation of the ordinary and extraordinary mode. Spreads of the spectrum are probably caused by the nonplanar geometry of the Ionospheric layer and multiple points of reflections at one time.

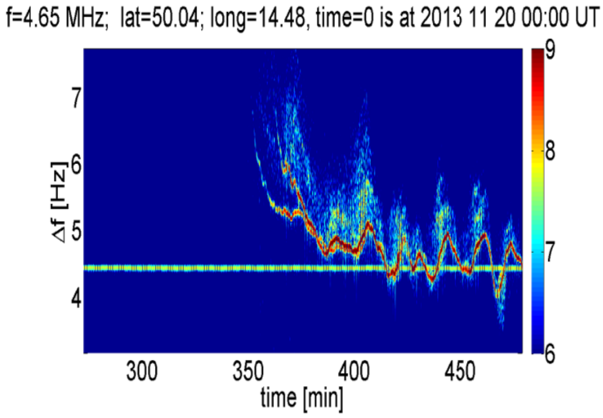

Fig. 4: Signal transmitted from the observatory Pruhonice received at the station Prague 5:00 UT and 8:00 UT

3. Digisonde

A Digisonde is a ground device for the measurement of the Ionospheric parameters. The Digisonde DPS-4D is placed in the observatory Pruhonice (49.5 N, 15 E). In the Fig. 5 receiving antenna (dual loop antenna – left part), transmitting antenna (double delta – middle part) and the Digisonde are shown. Outputs from the Digisonde are Ionograms, sky maps and other records. Four receiving antennas are in the form of a triangle and one receiving antenna is fitted in the middle. The Digisonde is composed from the three parts, the transmitter, the four channel receiver and the control computer. The Digisonde uses coded signals which allows decrease the transmitted power.

Fig. 5: Digisonde DPS-4D located at the observatory Pruhonice. (Left panel shows receiving antenna, middle panel shows transmitting antenna and right panel shows the computer part of the Digisonde) (Beran et al., 2015)

The Ionogram shows time of reflection of the transmitted signal or so called virtual height (vertical axis) vs. frequency of the transmitted signal (horizontal axis). Example of daily Ionogram is shown in the Fig. 6. This Ionogram is composed from four layers E, F1, F2 and Es. During night usually F2 layer is only present; however Es can be observed as well (Whitehead, 1961). The Ionograms from the observatory Pruhonice are measured with 15 min time resolution. Typical ionospheric parameters derived from Ionograms are critical frequencies of the layers, virtual and real heights of the layers, electron density profile and TEC.

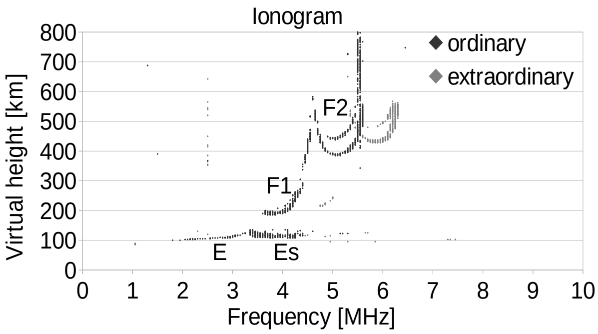

Fig. 6: Ionogram with description of the layers measured at the observatory Pruhonice 13.11.2015 (10:30 UT). Black and grey colors denote ordinary and extraordinary modes of reflection respectively

4. Communication by the using of the ionosphere

Principle of the communication by the using of the ionosphere is shown in the Fig. 7. In this case a quiet ionosphere is considered. The behavior of the ionosphere during geomagnetic storm is described for example in (Kouba and Koucka Knizova, 2012). This communication channel is usually used for the communication on long distances. Communication depends mostly on the critical frequency, (maximum plasma frequency of the layer) which can be derived from the electron concentration using the equation (2) (Chen, 1977). The state of ionosphere and it's parameters as critical frequency are highly variable and depends on the phase of solar cycle, seasons of the year and on local time. However, other irregular behavior is observed due to neutral atmosphere influence, solar activity, geomagnetic activity and other factors. In the practice ground-ionosphere-ground communication is used e.g. for the radio connection between national embassies. This communication is not depended on the satellites.

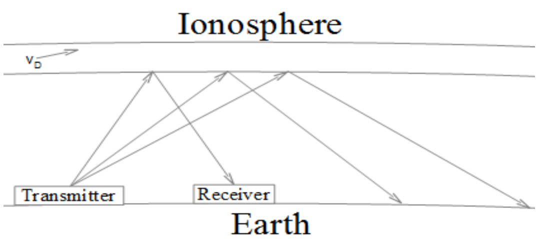

Fig. 7: Principle of the signal propagation in the ionosphere during the total vertical layering of the ionosphere (Kouba and Koucka Knizova, 2012)

$$f_N^2 = \frac{N \cdot e^2}{4\pi^2 \cdot \varepsilon_0 \cdot m} \tag{2}$$

f_N = Plasma frequency,
N = Electron concentration,
e = Electron charge
ε_0 = Permittivity of vacuum
m = Electron mass

Experiment for the detection of the availability of the ionospheric channel is described in the Fig. 8. Left branch shows using of the CDSS and right branch shows using of the Digisonde.

5. Principle of the layer detection

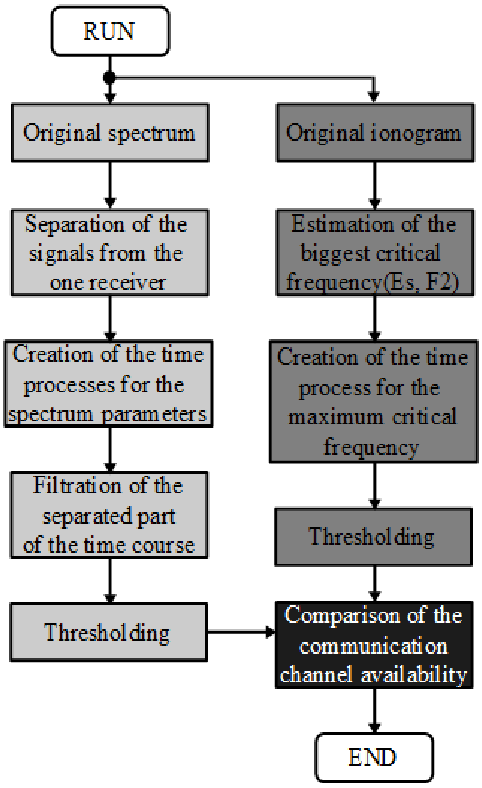

Fig. 8: Algorithm for the detection of the ionospheric communication channel availability by the CDSS and the Digisonde and their comparison

In the later frequencies reserved for one transmitter are separated from the spectra. These parts are connected to the time process. This time signal from the spectra is filtered (see the Fig. 9). In this Fig. gray solid line represents maximum of the spectra after filtration, black points represents maximum of the spectra before filtration, solid black line represents medians of the spectra after filtration and gray points represent medians of the spectra before filtration. In the next step filtered signal is thresholded. Equation for the calculation of the threshold is (3) with the output in dB. Algorithm for the process of the data received from the Digisonde is realized in three steps. First step is estimation of the critical plasma frequency from the Ionogram. Second step is creation of the time process. The third step is thresholding. During the experiment, both CDSS and Digisonde results are compared.

6. Description of the results

Data obtained from the measurements are shown in Table 1. Used data were measured during 10 days with 15 minutes resolution. Right column describes percentage of time when both systems give identical results. From the table is possible to dedicate that results for the both systems are very similar for all days under consideration.

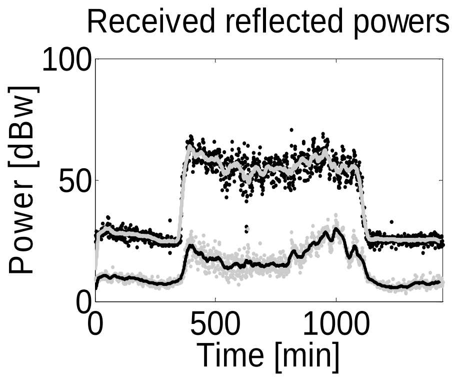

Fig. 9: Maxima and medians of the received power during one day (20.Nov.2013) measured at the observatory Pruhonice at the frequency 4.65 MHz.

$$TV_{24} = \max(median_{24}(FFT(x))) + 3 \qquad (3)$$

TV_{24} = Threshold value calculated from the last 24 hours,

x = Measured data in the time dimension,

Table 1: Availability of the Ionospheric Connection and Comparison of the Systems at the Frequency 4.65 MHz.

Date	Channel Availability		Mutual
Mm/Dd/Yy	Digisonde	Cdss	Coincidence
11/11/13	77%	76%	97%
11/12/13	51%	55%	96%
11/13/13	53%	54%	97%
11/14/13	58%	56%	98%
11/15/13	56%	55%	99%
11/16/13	65%	75%	88%
11/17/13	57%	57%	98%
11/18/13	59%	56%	95%
11/19/13	52%	51%	99%
11/20/13	52%	53%	97%
Average	58%	59%	96%
Median	57%	56%	97%
Minimum	51%	51%	88%
Maximum	77%	76%	99%

The differences between both systems are following: CDSS works with higher repeated frequency. Digisonde makes more complex outputs. Disadvantage of the CDSS is very small frequency resolution. In the Czech Republic the system operates only with three frequencies 3.59 MHz, 4.65 MHz and 7.04 MHz. Main disadvantage of the Digisonde for described purpose is that automatic estimation of critical frequency may fail at times (see Fig. 10) and thus the maximum frequency for the communication is estimated wrongly (Rejfek et al., 2015). Second important disadvantage of the Digisonde is very slow sampling frequency of the measurements, typically between 5 and 15 minutes. Advantage of the CDSS is much affordable price compared to the Digisonde.

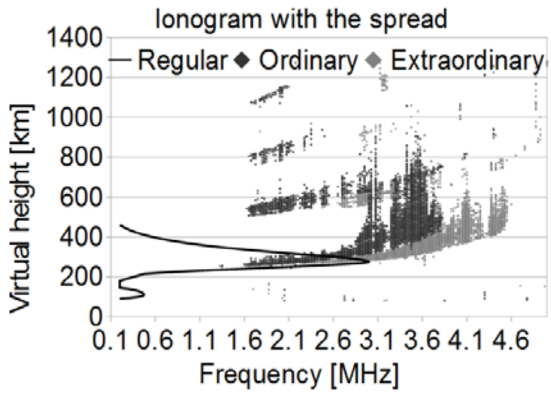

Fig. 10: Ionogram with ambiguous boundaries of the critical frequency of the layer F2 for the ordinary mode

This Ionogram was measured at the observatory Pruhonice 19.11.2013 CET 2:15. Ordinary and extraordinary reflections are plotted by black and grey color, respectively. The electron content (black solid line) is computed using the automatically scaling and the critical frequency foF2 is under estimated by ~ 1 MHz.

Communication channel is limited from the higher frequencies and from the lower frequencies. In the Fig. 11 spectra for the low frequency are shown. In this Fig. it is possible to see that the communication channel is available more or less only during the night time. Comparison of maximum values and medians of the spectra from the Fig. 11 (3.59 MHz) are shown in the Fig. 12. During day time the power is low and below usable value. Using CDSS for the detection of the communication channel availability at last two frequencies must be used.

The Digisonde can serve to estimate the lower range (lowest usable frequency, Fig. 13). From the comparison of the Ionograms it is possible to see, that minimal reflected frequency is changing in time.

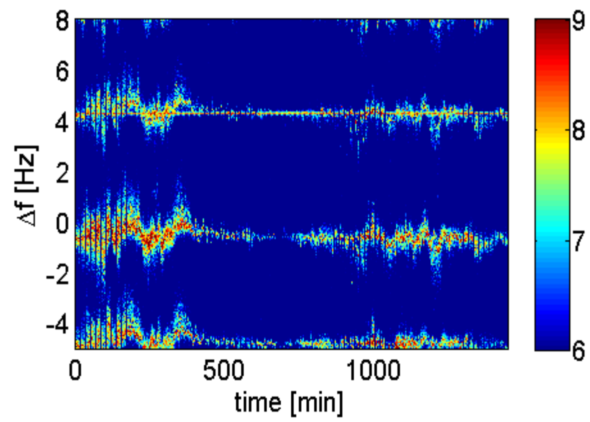

Fig. 11: Doppler shift at the frequencies near the 3.59 MHz measured by the CDSS at the observatory Roztyly (Prague) 11.Nov.2013 during whole day after background suppression. Time in min, 0 min = 0 LT

7. Conclusion

In present paper principle of the detection of the frequency range measured by the CDSS and the Digisonde is described. Both methods can be used for measurement of frequency range for the communication. While the Digisonde gives better resolution for the range estimation the CDSS works with better time resolution. Uncertainty of the frequency range estimated by the using of the Digisonde is lower than resolution by the using of CDSS.

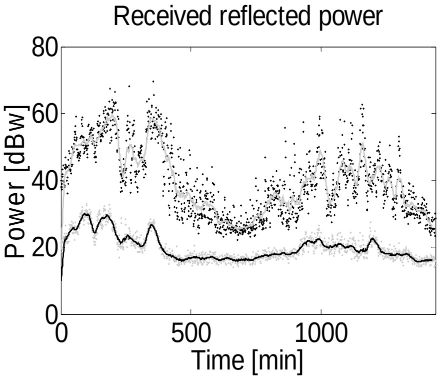

Fig. 12: Maxim and medians of the powers during one day (11.11.2013) measured at the observatory Pruhonice at frequency 3.59 MHz

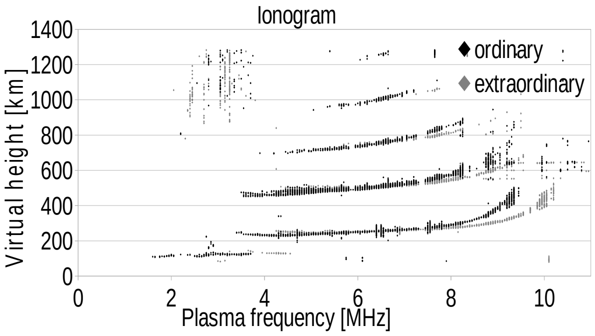

Fig. 13: Ionogram without interception of the low frequencies measured at the observatory Pruhonice 11.11.2013 (8:45 UT)

Both systems give very similar results by detection of the communication channel. From the results it is possible conclude that communication channel is available more than in 50% from the monitored time.

Better function of the CDSS can be realized by the use of additional frequencies. On the other hand, frequencies used for monitoring of the availability of the channel prevent from using these frequencies for communication and thus reduction of available communication band.

Acknowledgment

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