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IONOSPHERIC D-REGION INFLUENCE ON SAR SIGNAL PROPAGATION

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Abstract. Many studies have suggested that the signals used for satellite observations can be interrupted by the influence of a certain part of the ionosphere. In the course of our research we observed the perturbed D-region and its influence on the Synthetic Aperture Radar (SAR) signal delay that occurred as a consequence of the perturbation induced by a solar X-ray flare. To model the D-region plasma disturbance we analyse a very low frequency signal emitted by the DHO transmitter located in Germany and recorded in Serbia using Wait's model of the ionosphere. The results of the conducted research can help in further improvement and precision in modeling and measuring regarding SAR instruments.

1. INTRODUCTION

Satellite measurements and their contribution in observing and monitoring the planet Earth has become significant in many scientific fields. Some types of satellites only detect the radiation that comes from the Earth or outer space, whereas others are emitting their own signals which propagate towards the Earth's layers and reflect from some area.

In this paper we only consider the latter type of satellites. Satellites such as Sentinel-1, NASA-ISRO Synthetic Aperture Radar (NISAR) and Constellation of Small Satellites for Mediterranean basin Observations or (SkyMed) hold a

Synthetic Aperture Radar (SAR) which transmits microwave signals towards the Earth. SAR has the ability to operate at wavelengths not hindered by a cloud cover and acquires data over a specific place during day time or night time regardless the weather conditions. Synthetic aperture radar interferometry (InSAR) is a specific method of making observations which has many applications such as providing data for meteorological purposes. In order to acquire information about the target, the satellite emits the signal such as electromagnetic radiation of a certain frequency. During its path through the atmosphere the signal becomes prone to its current state. Moreover, one of the atmospheric layers which can significantly influence the signal and the layer which we contemplated is the ionosphere. Specifically, the D-region which when perturbed can cause a delay which cannot be neglected. The main reason for the signal deviation is the increased electron density which affects signal propagation path. The electron density has larger values in the upper part of the ionosphere, and its and the influences of the lower ionosphere above 100 km are taken into account in various models. However, during perturbations caused by solar X-ray flares the total electron content (TEC) present in the ionospheric D-region (60 km – 90 km) can affect the SAR signal propagation (see Nina et al. 2020). The main goal of this study is to show the example of how the perturbed D-region can affect the propagation of a SAR signal and calculate the D-region phase delay (P_{D}) for different frequencies and incident angles. To calculate the D-region electron density and TEC in the D-region ($\mathrm{TEC_D}$), we process DHO VLF signal used for the lower ionosphere observations and Wait's model of the ionosphere (Wait and Spies 1946).

2. OBSERVATIONS AND MODELLING

The event which caused perturbations in the ionosphere considered in this paper is the X-ray solar flare which happened on 1 May, 2013. Data used for modeling are derived by the $23.4kH_z$ VLF signal emitted by the DHO transmitter located in Rhauderfehn, Germany, and received at the Institute of Physics in Belgrade, Serbia, (Nina et al. 2020). Furthermore, the contemplated SAR frequencies are$f_1 = 1.257GH_z$,$f_2 = 5.405GH_z$ and $f_3 = 9.6$ GHz used in NISAR mission, Sentinel-1 and COSMO-SkyMed, respectively. In order to calculate the influence that the D-region has on the signal propagation it is necessary to determine the total electron content present in the mentioned region ($\mathrm{TEC_D}$) represented by

$$TEC_D = \int_{l_D} N_e dl_D, \tag{1}$$

where l_D represents the signal propagation path in the D-region and N_e represents the electron density. The vertical and temporal electron density distribution is calculated by equation (Tomson 1993):

$$N_e(h,t) = 1.43 \times 10^{13} e^{-\beta(t)H'(t)} e^{(\beta(t)-0.15)h} \quad , \tag{2}$$

where temporal evolution of the "sharpness" β and signal reflection height H' are obtained as the best fit of the recorded and modeled amplitude and phase of the analyzed VLF signal using procedure based on Wait's model of the ionosphere (Wait and Spies, 1964) explained in Grubor et al. 2008 and references therein. In order to calculate TEC, the D-region is divided into N_D horizontally uniform layers of thickness δH_D, each with its own electron densityN_{ei}. Ultimately, equation used for calculating the phase delay $P_D$produced by the D-region can be expressed as (Nina et al. 2019):

$$P_D = \frac{C\delta H_D}{f^2} \sum_{i=1}^{N_D} \frac{N_{ei} n_i}{\sqrt{n_i^2 - \left(n_0 sin(\Theta_0)\right)^2}} \quad (3)$$

where $C = 40.3$ and n_i is the refractive index in the layer i. Θ_0 is the incident angle of the SAR signal in the D-region and f stands for the signal frequency.

3. RESULTS AND DISCUSSION

As mentioned above there are three different SAR frequencies from three different satellites. The first frequency is f_1 = 1.257 GHz (NISAR Earth-observing mission) and it belongs to L-band satellite frequency range (1-2 GHz). Furthermore, the second frequency is f_2 = 5.405 GHz, and it is taken from Sentinel-1 SAR instrument. This frequency is the part of the C-band range (4-8 GHz). Finally, the third frequency is from the X-band range (8-12 GHz). Its value is f_3 = 9.6 GHz, and it is taken from COSMO-SkyMed satellites.

We observed dependency of signal delay in the D-region at the moment when the D-region electron density maximum is attained which happened during disturbance induced by the analyzed solar X-ray flare. It is visible from Fig. 1 that the signal delay increases with incident angle for each of the three frequencies. Apparently the signal delay is the smallest for the highest frequency which is in our case f_3 and the highest for the lowest frequency which is f_1 frequency. It is worth noting that the value of P_D decreases as the value frequency is doubled, (see Eq. (3)) which implies that with increasing the frequency value one can get smaller ionospheric D-region influence on the signal.

The highest signal delay is obtained for the lowest, f_1, frequency and it reaches $30mm$which is not negligible for modeling and applications of SAR signals. Bearing in mind the above-mentioned one can conclude that the signal delay induced by the X-ray solar flare needs to be taken into account.

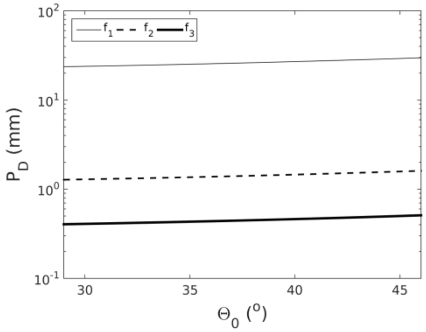

Figure 1: P_D dependence on the signal incident angle Θ_0 in the range from 29° to 46° and SAR frequencies f_1=1.257 GHz, f_2=5.405 GHz and f_3=9.6 GHz.

3. SUMMARY

The final outcome of this work was to present the signal delay that occurs during the ionospheric D-region disturbance. This was achievable by using the proposed modeling methods and the collected data. The signal delay dependence on the signal incident angle was calculated for three different SAR signal frequencies. For each one of the frequencies the signal delay was observed, which indicates the influence that the perturbed D-region has. One prominent thing which needs to be pointed out is that the signal delay decreases with the SAR signal frequency. Furthermore, the increase of the signal incident angle results in higher signal delay. Acquired values of the signal delay, obtained during a not so strong solar flare, indicate that the D-region influence on the SAR signal propagation cannot be neglected.

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