Application of VLF/LF databases in improving of Earth observations and positioning by SAR and GNSS signals

Aleksandra Nina SANDRAST@IPB.AC.RS
Institute of Physics, University of Belgrade, Belgrade, Serbia

Giovanni Nico G.NICO@BA.IAC.CNR.IT
Istituto per le Applicazioni del Calcolo (IAC), Consiglio Nazionale delle Ricerche (CNR), Bari, Italy

Abstract

In this study we present one example of application of the databases collected in low ionospheric monitoring by VLF/LF radio waves relevant for the Earth's observations and positioning by SAR and GNSS signals. We analyze contribution of the perturbed ionospheric D-region in propagation delay of this signals and the results of this analysis indicate the need for inclusion of this atmospheric layer in modeling of SAR/GNSS signal propagation. Keeping in mind that its influence is usually ignored in modeling of the ionospheric influence on satellite signals, this conclusion can be of high priority in preciously positioning, Earth's observations, analyses and emergency responses to changes caused by natural disasters and in many other areas of human activities.

Keywords: VLF/LF database, GNSS, SAR

1. Introduction

Information obtained in the Earth observations by satellites are very important in many areas of human activities. Namely, positioning, displacements, navigation and timing play significant role in telecommunications, geodesy, all forms of transportation etc. In addition, many scientific studies as well as analyses and emergency responses to changes caused by natural disasters are based on these measurements. Keeping in mind that many of these applications, primarily provided by the Global Navigation Satellite Systems (GNSS) and Synthetic Aperture Radar (SAR) interferometry, require high precision (less than 1 cm) knowledge of the signal propagation between satellite and Earth surface is required. Consequently, studies of different influences on these signals are of high priority.

There are many sources which cause delay in satellite signal propagation. The largest contributions have the ionosphere and troposphere. For calculation of ionospheric influence it is necessary to know the total electron content (TEC) but its modelling is not trivial and due to lack of data needed for detail studies using methods are based on different approximations. One of them which is usually used is neglecting the contribution of the ionospheric part below 90 km. This approximation is correct in quiet conditions but in the case of intensive disturbances in the low ionosphere it can causes significant errors in modeling of GNSS and SAR signal propagation properties. For this reason, it is necessary to have information about this ionospheric layer.

One of the most important technique for the low ionospheric monitoring is based on very low and low frequency (VLF/LF) radio wave propagations. Here it is important to say that intensive disturbances in this atmospheric part are sudden and, in some cases, short time lasting and localized. Consequently, the necessary information requires continuous D-region observations at different geographical locations and with high time resolution. In addition, to study rare sudden phenomena it is necessary to analyze long time periods.

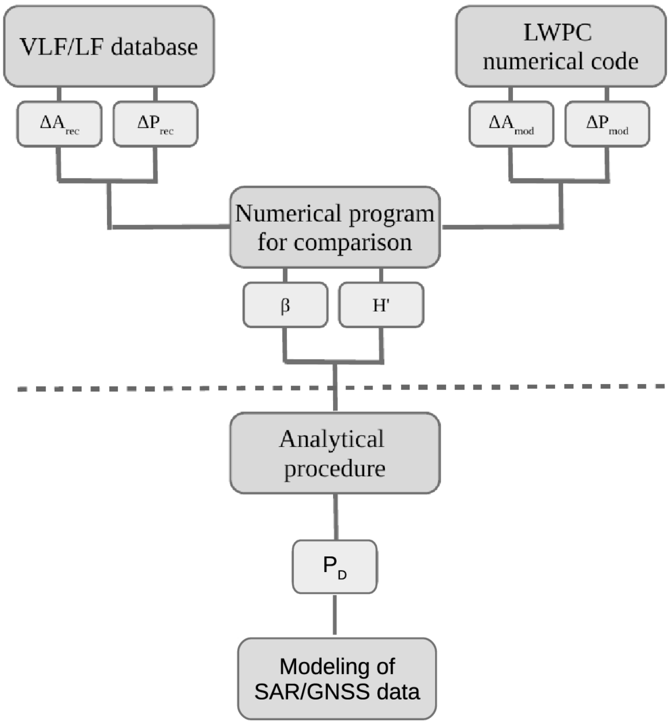

Figure 1: Schematic representation of a database application in modeling of SAR/GNSS data.

For these reasons the collected databases are big databases. They can reach several tens of GB/day or several TB/year. Consequently, some analyses based on these observations require applications of procedures relevant for big databases.

In this work, we show an example of application of data collected in the D-region monitoring on spaceborne SAR and GNSS signals during strong perturbations.

2. Theory

Generally speaking, application of the databases collected in the low ionospheric observation for modelling of this atmospheric layer is needed for determination od the electron density time and space distributions. There are a few procedures for determination of the electron density from the data collected by the VLF/LF receiver. They are based on processing of values of amplitude values (Thomson, 1993), phase (Inan et al., 2007) or both, amplitude and phase (Grubor et al., 2008), and implementation of numerical models like the Long-Wave Propagation Capability LWPC Ferguson (1998) or Modefinder/Modesearch Morfitt and Shellman (1976).

One of the frequently used procedure for the low ionospheric studies (see for example Bajčetić et al. (2015); Nina et al. (2011, 2012); Nina and Čadež (2014)) is shown in schematic representation in Figure 2. This procedure has two parts: 1) comparison of databases with relevant modeled values by LWPC numerical code, and 2) analytical procedures for modeling different plasma parameters.

In the upper part of the presented scheme (above dashed line) it is presented a comparison of values of the signal amplitude and phase changes from the considered database

($\Delta A_{\rm rec}$ and $\Delta P_{\rm rec}$) and relevant values obtained by modeling of the VLF/LF signal propagation path by LWPC numerical code ($\Delta A_{\rm rec}$ and $\Delta P_{\rm rec}$). The result of this procedure is determination of time evolutions of the Wait's parameters β and H' (Wait and Spies, 1964), the input parameters for the following analytical procedure indicated in the bottom part of the given scheme.

In this work, the D-region delay is calculated by expression:

$$P_{\rm D} = \alpha_{\rm I} {\rm TEC_D}/f^2. \tag{1}$$

where $\alpha_{\rm I} = 40.3$ m^{3}s^{-2} and the total electron content $TEC_{\rm D} = \int_{l_{\rm D}} N_{\rm e} dl_{\rm D}$ for the signal propagation path $l_{\rm D}$ in the D-region can be obtained from models of the electron density space and time distributions $N_{\rm e}$, and from determination of the GNSS/SAR signal propagation path which is determined by applying Snell's low on horizontal layers.

The electron density $N_{\rm e}(h,t)$ (in m^{-3}) at fixed altitude h (in km) is calculated from Wait's parameters estimated by fitting of data presented in Thomson et al. (2005) by equation Thomson (1993):

$$N_{\rm e}(h,t) = 1.43 \cdot 10^{13} e^{-\beta(t)H'(t)} e^{(\beta(t)-0.15)h}. \tag{2}$$

3. Results and conclusions

Here, we present an example of influence of the perturbed D-region on SAR signals which determination is based on VLF data. We take β and H' which are determined in study of solar X-ray flare influences on the D-region (see Todorović Drakul et al. (2016) and references therein) and consider frequencies of $f_1 = 1.2$ GHz and $f_2 = 5.4$ GHz which are relevant for the Earth observations with ALOS-2 or the future NISAR mission (f_1) and Sentinel-1 and Radarsat-2 (f_2).

Using the procedure given in Section 2 we obtained the propagation delays presented in Figure 3. The values for β and H' are estimated for D-region disturbances induced by the X-ray flare of classes C5, M1 and M5.

In this graph, one can see that propagation delay significantly depends on the signal frequency and that increases with incident angle of the considered signals, Θ_0 and the X-radiation intensity. Although, the estimated delay is smaller than 1 cm for C5 class X-ray flares, its values are significant for the analyzed M class X-ray flares which finally confirm the need for the inclusion of the ionospheric D-region part in modeling of the SAR signal propagations within intensive perturbed low ionosphere.

To conclude, the presented study points out one example of importance of the collected databases in low ionospheric monitoring by VLF/LF radio waves for practical applications relevant for SAR and GNSS signals. This conclusion can be of high priority in preciously positioning, Earth's observations, analyses and emergency responses to changes caused by natural disasters and in many other areas of human activities.

References

J. Bajčetić, A. Nina, V. M. Čadež, and B. M. Todorović. Ionospheric d-region temperature relaxation and its influences on radio signal propagation after solar x-flares occurrence. *Thermal Science*, 19(Suppl.2):S299–S309, 2015.

J. A. Ferguson. *Computer Programs for Assessment of Long-Wavelength Radio Communications, Version 2.0.* Space and Naval Warfare Systems Center, San Diego, CA, 1998.

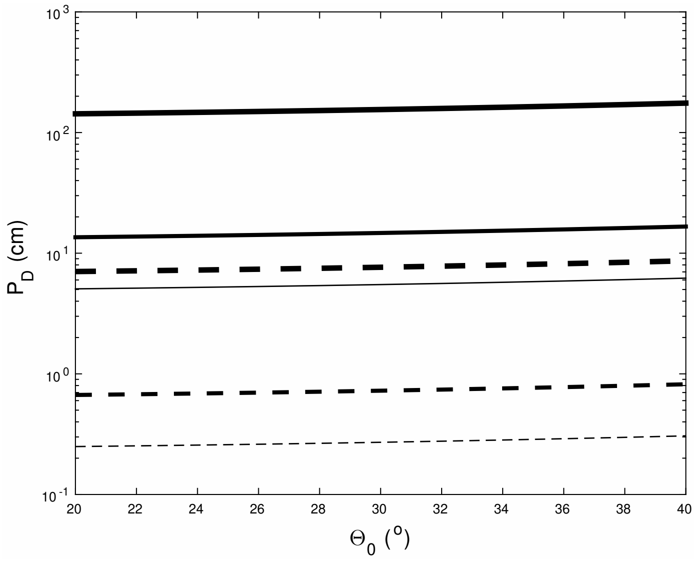

Figure 2: Propagation delay in the D-region as a function of the angle for frequencies 1.2 GHz (solid lines) and 5.4 GHz (dash lines) and different X-ray flare classes (C5 - the thinner lines, M1 - lines of medium thickness, M5 - the thickest lines).

D. P. Grubor, D. M. Šulić, and V. Žigman. Classification of X-ray solar flares regarding their effects on the lower ionosphere electron density profile. *Annales Geophysicae*, 26: 1731–1740, 2008.

U. S. Inan, M. Golkowski, M. K. Casey, R. C. Moore, W. Peter, P. Kulkarni, P. Kossey, E. Kennedy, S. Meth, and P. Smit. Subionospheric vlf observations of transmitter-induced precipitation of inner radiation belt electrons. *Geophysical Research Letters*, 34(2):L02106, 2007.

D. G. Morfitt and C. H. Shellman. *MODESRCH, an Improved Computer Program for Obtaining ELF/VLF Mode Constants in an Earth-Ionosphere Waveguide*. Interim Report 77T, NTIS, ADA 032473, Naval Electronics Laboratory Center, USA, 1976.

A. Nina and V.M. Čadež. Electron production by solar ly-α line radiation in the ionospheric d-region. *Advances in Space Research*, 54(7):1276–1284, 2014.

A. Nina, V. Čadež, V. A. Srećković, and D. Šulić. The influence of solar spectral lines on electron concentration in terrestrial ionosphere. *Baltic Astronomy*, 20:609–612, 2011.

A. Nina, V. Čadež, D. Šulić, V. Srećković, and V. Žigman. Effective electron recombination coefficient in ionospheric D-region during the relaxation regime after solar flare from February 18, 2011. *Nuclear Instruments and Methods in Physics Research B*, 279:106–109, 2012.

N. R. Thomson. Experimental daytime VLF ionospheric parameters. *Journal of Atmospheric and Terrestrial Physics*, 55:173–184, February 1993.

N. R. Thomson, C. J. Rodger, and M. A. Clilverd. Large solar flares and their ionospheric D region enhancements. *Journal of Geophysical Research (Space Physics)*, 110:A06306, 2005.

M. Todorović Drakul, V. M. Čadež, J. Bajčetić, D. Blagojević L. C. Popović, and A. Nina. Behaviour of electron content in the ionospheric d-region during solar x-ray flares. *Serbian Astronomical Journal*, 193:11–18, Dec. 2016.

J. R. Wait and K. P. Spies. *Characteristics of the Earth-ionosphere waveguide for VLF radio waves.* NBS Technical Note, CO, 1964.