IONOSPHERE IMPACT ON LOW-FREQUENCY SAR SIGNALS

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ABSTRACT

Ionospheric propagation effects have a significant impact on the signal properties of SAR observations, especially at low operation frequencies. Dispersion, group delay, Faraday Rotation (FR), and phase shifts are all a function of the so-called Total Electron Content (TEC), the operating frequency and the system bandwidth. In order to choose the right acquisition time with lower ionospheric impact, the TEC maps can be used to estimate the FR impact on a potential SAR mission, taking advantage on the periodicity shown by the ionosphere.

1. INTRODUCTION

Remote sensing using space-borne sensors is a key tool for obtaining repetitive and global coverage observations. Currently, due to their higher capability of investigation the interest on developing SAR systems at low-frequency is increased. An important element that has to be accounted when planning a low-frequency SAR mission is the effects of the ionosphere. The main scope of this paper is to characterize the background ionosphere, also called as the non turbulent ionosphere, and its impact on SAR images. Ionospheric effects are all function of the so-called Total Electron Content (TEC), so that TEC maps can be used to estimate the ionospheric impact on a systematic mission acquisition scenario. In this paper FR maps on a global scale are evaluated by means GPS-derived TEC time series (section 2). A temporal baseline of 8 days is introduced, in order to provide a sample of differential TEC statistics on a global scale. This provides statistical calculation for the FR and differential FR. Noteworthy, the FR effect can be evaluated and removed from SAR data if fully polarimetric measurements, as in the case of ALOS-PALSAR mission, are available [2], [3].

For a general case, the two way FR effect results in a loss of reciprocity of the measured scattering matrix X:

\[ X_{HH} = S_{HH} \cos^2 \Omega - S_{VV} \sin^2 \Omega \]
\[ X_{HV} = S_{HV} + (S_{HH} + S_{VV}) \sin \Omega \cos \Omega \]
\[ X_{VH} = S_{HV} - (S_{HH} + S_{VV}) \sin \Omega \cos \Omega \]
\[ X_{VV} = S_{VV} \cos^2 \Omega - S_{HH} \sin^2 \Omega \]

where we have invoked backscatter reciprocity, i.e., \( S_{HV} = S_{VH} \). Therefore, the presence of FR can be deduced by assuming a well calibrated data set. Considering Eq.2.4, two different methods have been used and compared, to evaluate the amount of FR [4]:

- Direct estimation: with the Freeman method (TF) the FR angle, is obtained by exploiting the normalized value of the difference of the linear cross-pol channels VH-HV, according to:

\[ \hat{\Omega} = \frac{1}{2} \tan^{-1} \left( \frac{X_{VV} - X_{HV}}{X_{HH} + X_{VV}} \right) \]
• Circular basis estimation: the Bickel and Bates method (B&B). In this method, instead, a polarimetric basis transformation of the measured matrix to the circular basis is performed via $Z$ and the Faraday rotation angle estimation is:

$$\tilde{\alpha} = \frac{1}{4} \arg(Z_{21}Z_{12}^*)$$

where $*$ denotes, the complex conjugate.

Both methods have been applied on the L-band (1.27 GHz) ALOS-PALSAR images. Besides SAR polarimetry, the Faraday rotation may also affect SAR interferometry if two contributing images are acquired in two different ionospheric states.

3. IONOSPHERE FROM TEC MAPS

Two different years have been chosen for the following analysis: 2007, with a solar minimum and 2001, with a solar maximum. For these two years, annual mean TEC maps have been produced. Moreover, the analysis has been done for two different local time (LT) of the day: 6.00 and 18.00, corresponding to the maximum and minimum of the daily variation of TEC values and corresponding to the down and dusk orbits of a potential SAR mission.

3.1. TEC maps

To evaluate ionosphere features, TEC maps all over the globe are required. The computation of those maps is based on global TEC recorded by GPS satellites and stored in IONEX (Ionosphere Map EXchange) files. The data used in this paper have spatial resolution of 2.5 degrees in latitude (from -87.5 to 87.5 degrees) and 5 degrees in longitude (from -180 to 180 degrees), with a time resolution of about 2 hours. Most of the mean TEC values, for 2007, lie between 0 and 30 TECU across the geomagnetic equator. Instead, the mean TEC value in 2001 is globally higher (see Fig.3.1), with values that reach up to 60 TECU across the geomagnetic equator. In both cases the global mean value at 6.00 p.m. is greater than the one at 6.00 a.m., related to the daily solar activity. It is important to remark that those maps are in longitude and latitude coordinates and local time.

3.2. Differential TEC maps

Introducing a temporal baseline of 8 days it is possible to compute the differential TEC map (see Fig.3.2), for 2001 and 2007. Most of the mean values for 2007, lie between 0 and 4 TECU. The 2001 is a worse case, with a greater level of ionosphere the mean value lies between 5 and 10 TECU.

3.3. Faraday rotation maps.

The global TEC maps shown in section 3.1 have been used to calculate the FR global maps showed in Fig.3.3, considering the ALOS-PALSAR system parameters. For 2007, the mean value of FR is between 0 and 10 degrees, whereas in 2001 the mean value of Faraday rotation angle reaches up to 40 degrees (2-way FR).

3.4. Differential Faraday rotation maps.

Introducing a temporal baseline of 8 days ΔFR maps have been produced (see Fig.3.4). Both for a low Sun activity and high Sun activity the FR mean values are globally next to zero which means that the ionosphere is a quite stationary and the TEC values do not change in the repeat pass time selected.

3. IONOSPHERE FROM ALOS DATA

In order to validate the FR estimation over a long time period, ten L-band fully polarimetric ALOS-PALSAR acquisitions have been processed, covering a time interval of 850 days, indeed more than two years. The selected test site is Munich, south Germany.

4. VALIDATION

In Fig.4.1 the trend of the 2-way FR over a 850-day period is depicted. The solid blue and red lines denote the FR estimation from TEC maps at 6.00 a.m. and 6.00 p.m., respectively. The green asterisks are the FR values obtained.
by using the TF and B&B. An underestimation of both methods with respect to the values derived from TEC maps is experienced even if the trend is respected. In Fig.4.1 SAR-estimated FR is plotted versus the TEC-derived. Indeed the underestimation of FR with respect to TEC-estimated FR is pointed out. A good correlation between the observed and estimated Faraday rotation angle is clear.

5. CONCLUSIONS

In this paper we have first of all analyzed the TEC maps, and the corresponding derived FR maps, relative to two years: 2001, with a solar maximum, and 2007, with a solar minimum. Moreover, looking on a daily scale variation, the maps have been evaluated for a dawn-dusk orbit. Furthermore, to complete the statistical analysis, a temporal baseline of 8 days has been introduced, in order to provide a sample ionospheric impact on interferometric applications. As expected, the global mean value at dusk is greater than the one at dawn, for both years. Note that the difference of mean TEC value between the dawn and dusk for a turbulent year, as 2001, is smaller comparing with the difference between the mean TEC value at dawn of 2001 and 2007. For interferometric applications purposes differential TEC maps have been compiled. Note that, the delta TEC level is globally five to six time lower than TEC. The global TEC maps have been used to calculate the maps of FR and differential FR distortion (section 3).

The amount of FR angle can be estimated directly from SAR data, by using the Freeman and the Bickel and Bates method. For any image, both methods have been used to estimate the mean FR on the whole image. The values of Faraday rotation angle estimated are all under 5 degrees, which is not a strong rotation of the polarization plane. This is in agreement with the years of acquisitions characterized by a low Sun activity. Indeed the acquisition period covers the years from 2006 to 2009, where 2007 the solar cycle was near its minimum. The GPS-derived maps of Faraday rotation have been used in order to compare and validate the results obtained by the estimation algorithms. The good correlation between Faraday rotation estimated and observed is shown in the validation plots in section 4.

8. REFERENCES