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IMAGING IONOSPHERIC INHOMOGENEITIES USING SPACEBORNE SYNTHETIC APERTURE RADAR

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1 INTRODUCTION

Spaceborne interferometric synthetic aperture radar (InSAR) operating at L-band and lower frequencies is susceptible to inhomogeneous ionosphere with spatial structures on scales comparable to targeted remote sensing features, i.e., from tens of kilometers to meters. The concerned ionospheric variations include medium-to-small scale electron density or total electron content (TEC) structures associated with auroral arcs, plasma bubbles and patches, traveling ionospheric disturbances (TID's), horizontal gradient, and irregularities. These ionospheric inhomogeneities can cause phase, power, and polarization changes of the radio signal within a radar scene. The effects can produce distortions in InSAR images if not detected and removed. To detect, measure, and correct such ionospheric effects, high resolution 2-dimensional (2D) ionospheric imaging is required.

2 IMAGING THE IONOSPHERE USING POLARIMETRIC SAR

Ionospheric variations have been measured using various radio and optical techniques from ground and space for many decades, but high-resolution measurements suitable for spaceborne radar applications, which requires global coverage, have not been available until recently. Recent effort has been made to make use of spaceborne polarimetric SAR measurements to calibrate the SAR data in presence of Faraday rotation [1][2], and to image ionospheric inhomogeneities [3][4]. The technique makes use of calibrated polarimetric measurements of SAR to perform 2D Faraday rotation imaging. As Faraday rotation at each pixel of the image is obtained, the corresponding TEC can also be derived as follows using also an empirical magnetic model,

$$\Omega = \frac{K}{f^2}\int_{\mathbf{r}_t}^{\mathbf{r}_r} n_e B_0 \cos\theta \, ds = \frac{K}{f^2}\langle B_0 \cos\theta \rangle \mathrm{TEC} \tag{1}$$

where Ω is the Faraday rotation, n_e the electron volume density, B_0 the magnitude of ambient magnetic field, θ the angle between the magnetic field and radio ray path, f the radio frequency, and K a constant (= 2.365×10^4 [MKS]). The integration is along the ray path. An averaged value of $B_0\cos(\theta)$ could be taken out of the equation since the product varies little in a radar scene (10^1~10^2 km in each of the 2D dimensions). Note that Ω is inversely proportional to f^2, indicating that Faraday rotation becomes appreciable at L-band and lower frequencies.

In this paper, we will demonstrate that the radar technique allows 2D ionospheric imaging with spatial resolutions of kilometer or smaller. Figure 1 shows an example of the Faraday rotation images that are obtained over a polar region (Alaska) under perturbed space weather conditions. It is obtained by applying the technique to polarimetric data collected using Phase Array type L-band Synthetic Aperture Radar (PALSAR) onboard the JAXA's Advance Land Observing Satellite. These images are believed to be associated with auroral arcs. In addition, such ionospheric images associated with low-latitude plasma bubbles and scintillation, mid-latitude trough, and mid-latitude TID's have also been obtained. Comparisons with ionospheric observations made using ground-based GPS networks have also been made, to examine ionospheric features captured in SAR-derived 2D images.

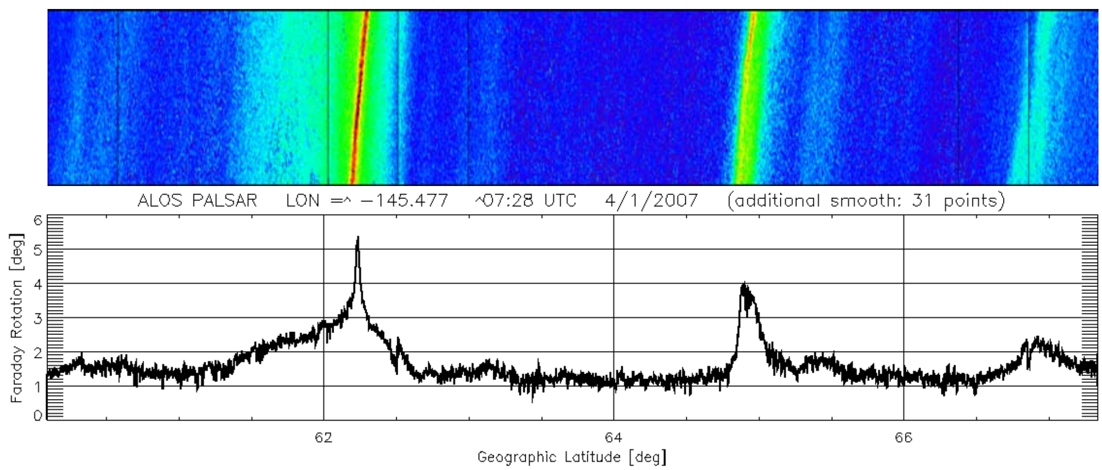

Figure 1: The upper panel shows a Faraday rotation image strip composed of 15 individual images obtained by processing ALOS L-band PALSAR polarimetric data. The SAR data was collected over Alaska in 2007 during a space weather storm day. The images are rotated 90° from the original south-to-north orientation (roughly) to accommodate page limitation. The lower panel shows 1D measurements extracked from the middle of the 2D images above. The images present enhanced Faraday rotation features that are believed to be associated with auroral arcs.

3 CORRECTION OF IONOSPHERIC EFFECT IN INSAR IMAGERY

The radar technique is not only capable of imaging the ionosphere at high spatial resolutions, but also applicable in correction of ionospheric effects in Earth science remote sensing images. The correction can be accomplished by removing Faraday rotation or phase delay induced by the ionosphere through the polarimetric or split-spectrum methods [1][5][6]. A key requirement of the correction is ionospheric imaging at high spatial resolutions. The related issues and implications to the SAR-based ionospheric imaging and other techniques will be discussed.

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