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Measurement Of Faraday Rotation In SAR Data Using MST Radar Data

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Abstract

The propagation of radar signals through the atmosphere results in the signals being seriously affected by the ionosphere. Though there are many ionospheric effects on the signal like reflection, refraction, diffraction, absorption, scintillation, and dispersion, this paper focuses on the issue of Faraday Rotation (FR). FR is significant at L-band frequencies and is a major error source deteriorating the quality of the received Synthetic Aperture Radar (SAR) images. FR reduces the accuracy of SAR data recovery if uncorrected. Consequently, the estimation and rectification for FR effects is a prerequisite for valid image interpretation and data analysis. In this paper, we estimate FR from the Mesosphere-Stratosphere-Troposphere(MST) radar data and then apply the calculated FR angle to the corrupted SAR images.

Keywords—*Faraday rotation (FR), Advanced Land Observing Satellite (ALOS), Mesosphere-Stratosphere-Troposphere (MST), Phased Array L-band Synthetic Aperture Radar (PALSAR), total electron content (TEC).*

1. Introduction

It has long been known that radio waves passing through the Earth's atmosphere are subject to various ionospheric effects like reflection, refraction, dispersion, diffraction, scintillation [1] and Faraday rotation (FR). L-band spaceborne Synthetic Aperture Radar (SAR) provide critical earth science measurements. L-band's ability to penetrate into dry sand and vegetation makes it a valuable tool for diverse fields such as archaeology and biomass retrieval. However, radar performance degradation due to the ionosphere remains a major concern for L-band and lower frequency spaceborne radars. In this paper we focus on the issue of Faraday rotation. Faraday rotation is an effect in which a linearly polarized radio wave has its plane of polarization rotated as it propagates through the ionospheric plasma. The rotation is caused due to the anisotropic nature of the ionosphere in presence of a persistent magnetic fieldsuch as the Earth's magnetic field. Linearly polarized SAR data quality can be significantly impacted if the effect is not corrected [2], [3]. Thus, the Faraday rotation may cause significant errors in SAR image interpretation and data analysis. It reduces the accuracy of geophysical parameter recovery if uncorrected.

FR effect is frequency dependent and so it is much severe for L-band and P-band frequency than for C-band even under the same ionospheric conditions [4]. Hence the low frequency signals are more susceptible to Faraday rotation. We have used the SAR data from Phased Array type L-band Synthetic Aperture Radar (PALSAR), put onboard the Advanced Land Observing Satellite (ALOS), to study the ionospheric effects and to rectify the images for the rotational error.

In Section 2, the ionospheric effects on electromagnetic waves are outlined. In Section 3, the estimation of Faraday rotation angle from MST radar data is presented. In Section 4, correction for Faraday rotation on real SAR data is presented followed by the conclusion in Section 5.

2. Effects of the Ionosphere

2.1. Ionosphere

The ionosphere is defined to be the upper region of the atmosphere extending from about 90 Km to 1000 Km. This region contains large quantities of charged particles which becomes ionized in presence of UV rays, X-rays and solar radiation. These ionized particles have several important effects on electromagnetic wave propagation. Variations in the electron density (N_e) cause the electromagnetic waves to bend back towards Earth, but this phenomenon occurs only if specific frequency and angle criteria are satisfied. The Earth's magnetic field causes the ionosphere to behave like an anisotropic medium. Due to this radio waves propagating through the ionosphere experiences a polarization rotation of the electric field vector called Faraday rotation.

The electron density distribution of the ionosphere is a key factor in determining the plasma frequency [5], the refractive index of ionosphere and the magnitude of Faraday rotation angle. The density varies with the location on the earth, the time of the year, the time of day and the solar activity. The electron density distribution with height as observed by the MST radar on 19th May, 2010 is shown in Figure 1. The effect of the ionosphere on electromagnetic signals is described by the Appleton-Hartree equation which relates the refractive index of a medium to its state of ionization.For SAR systems, which operate well above the ionosphere's plasma frequency, the Appleton–Hartree equation can be approximated by [5]

$$n \approx 1+\frac{f_N^2}{2f^2} \qquad (1)$$

$$f_N = \sqrt{\frac{(N_e e^2)}{4\Pi^2 \varepsilon_o m}} \qquad (2)$$

where n is the group refractive index of the ionosphere,$f_N$is the plasma frequency, f is the signal frequency, e is

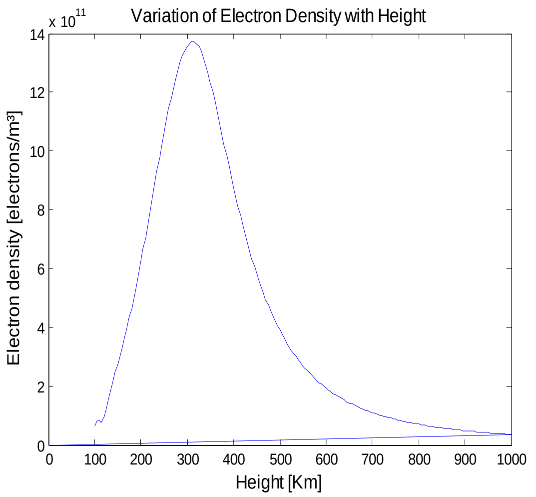


Figure 1.The variation of electron density distribution with height as observed by MST radar operating at Norway on 19th May, 2010.

the charge of an electron (1.602 x 10^{-19} C), m is the electron mass (9.1x10^{-31} kg), ε_o is the dielectric permittivity (8.85x10^{-12} farad m^{-1}), N_e is the electron density(electrons/m³). The propagation constant for an electromagnetic signal propagating through the ionosphere is given by,

$$K_c = K_o\sqrt{1-\frac{\omega_p^2}{\omega^2}} \qquad (3)$$

with$K_o = \omega\sqrt{\mu_o \varepsilon_o}$, μ_o is the magnetic permeability (1.2566 x 10^{-6}), $\omega_p$is the plasma frequency,ω is the angular frequency of the signal. For $\omega = \omega_p$, $K_c = 0$ and this value of ω is called critical frequency. The radio waves with $\omega \geq \omega_p$ are reflected back by the ionosphere and these waves also undergo a rotation of the electric field vector.

2.2. Faraday Rotation

As already mentioned in the introduction, radio waves travelling through the ionosphere experiences FR. Entering an ionized medium, a linearly polarized wave can be regarded as the superposition of two separate counter-rotating circular polarized waves, travelling on slightly different paths with different velocities. Leaving the ionized medium, these waves recombine with a resulting polarization which is different from that of the incident polarization angle. This effect of rotation of polarization vector is called Faraday rotation. Thus, the radio waves experiences two instances of FR in propagating from a satellite to the Earth and from the Earth to the satellite. The sense of FR in each direction is same relative to the Earth's magnetic field and so traversing up and down does not compensate for this effect. Instead, the effect is cumulative in nature. So FR doubles as does the path delay [6].

In general, the Faraday rotation angle of a linearly polarized wave integrated over the path length is half the phase difference between the right and left circularly polarized waves. The magnitude of FR angle depends on the frequency of the wave, the electron density along the propagation path, the flux density of the Earth's magnetic field and the angle of wave propagation direction with respect to the direction of the magnetic field vector. Since the ionospheric parameters are dynamic and their fluctuations depend on diurnal, seasonal, latitudinal, longitudinal and solar cycle effects, the exact calculation of the FR angle is difficult. Therefore, the nominal values of the Earth's magnetic field and electron density are used to estimate FR angle. The magnitude of FR angle for a wave of frequency f that has travelled vertically one way through the ionosphere is given by [7]

$$\Omega = \frac{K}{f^2}\int_{path} B\, N_e \cos\theta dr$$

$$= \frac{K}{f^2} B \cos\theta \; TEC \qquad (4)$$

where TEC = $\int_{path} N_e dr$ is the ionospheric total electron content and K= $\frac{1}{2}\left(\frac{e}{4\Pi^2 m\varepsilon_o}\right)$ = 40.28 [m^3/s^2].

TEC has large diurnal and seasonal variations so its value is significant in determining the FR through the ionosphere. Equation (4) indicates that FR scale with frequency and it can be inferred that the degree of FR angle is proportional to the inverse square of the frequency. As a result, the FR effects can be usually ignored for radio frequencies above C-band but may be significant at lower frequencies such as L-band and P-band.

3. Estimation of FR Angle from MST Radar Data

The Mesosphere-Stratosphere-Troposphere (MST) radar technique is used for probing the atmosphere from near the ground to an altitude of about 1000 Km. MST radars operated al VHF and UHF frequencies work on the principle that radio waves in these frequency bands are backscattered and reflected by fluctuations in the refractive index of the atmosphere. MST radar technique has the unique ability of measuring the electron density along the propagation path.

The data used for FR estimation was obtained from the MST Radar Facility at Andøya, Norway. Data was recorded on 19th May, 2010 at 11:50 a.m. The details of the geomagnetic elements namely, the latitude, longitude, magnetic field, inclination and declination are given in the data. The data contains the electron densities for an altitude ranging from 100 Km to 1000 Km. Using Equation (4) the FR angles are estimated which is listed in Table 1 and the variation of FR angle as a function of height is shown in Figure 2.The FR angles are specified for heights varying from 690 Km to 710 Km as the ALOS satellite (from which the PALSAR images are obtained) is operating at an altitude of about 700 Km.

Table 1
Estimated FR Angle from MST Radar Data

Height [Km]	**Electron density [electrons/m³]**	**FR angle [degrees]**
690	1.1541E+11	4.879496117
695	1.125E+11	5.005712416
700	1.0968E+11	5.134415088
705	1.0697E+11	5.264491416
710	1.0435E+11	5.396671268

4. Correction of Faraday Rotation in SAR Data

At L-band FR has considerable effects on the SAR imagery [8], [9]. FR can cause azimuth streaking and phase error for SAR interferometry. The FR needs to be corrected in order to avoid shifts in range,image deformations, blurring in SAR images. With the launch of the PALSAR, put onboard the ALOS a rich archive of SAR images are available.

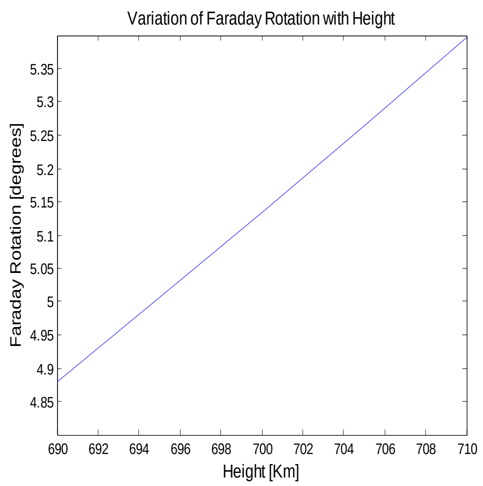
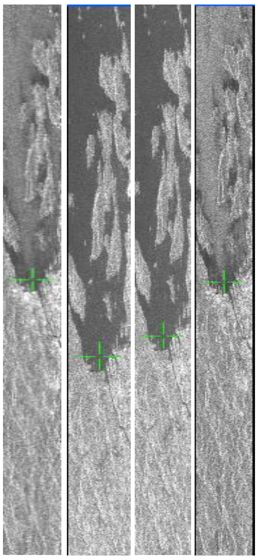


Figure 2. The variation of FR angle with height as estimated from the MST Radar data

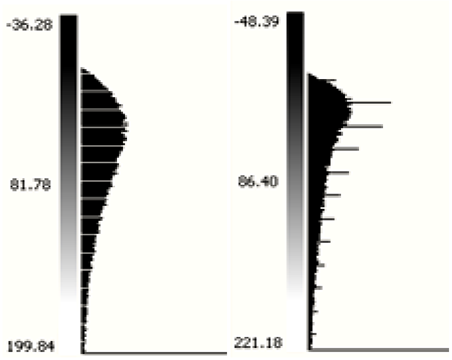
The full polarimetric PALSAR data (HH, HV, VH, VV) has been used to correct the Faraday rotation in them. Figure 3(a) shows the bands before FR correction is applied and Figure 3(b) shows the corresponding image statistics for these four bands. The FR correction is done by applying the estimated FR angle from the

MST radar data for an altitude of about 700 Km since the ALOS satellite orbits the earth at an altitude of 698.722 Km. PALSAR Level 1.1 processed images has been used for analysis. The Faraday correction threshold is set as 5° The FR corrected PALSAR images are shown in Figure 4(a) and the corresponding image statistics are shown in Figure 4(b). We then combined all the four bands into a single composite band which carries a higher wealth of information of the feature being imaged. The distortion due to FR will be more in composite bands and hence FR correction in composite band is highly necessary for reliable data analysis. Figure 5(a) shows the composite band (HH+HV+VH+VV) before and after applying FR correction and Figure 5(b) shows the image statistics of the composite band before and after FR correction.

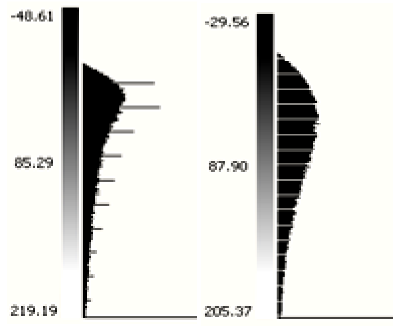


HH HV VH VV

Figure 3(a)



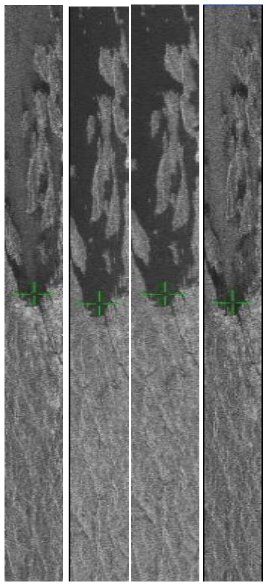
HH HV



VH VV

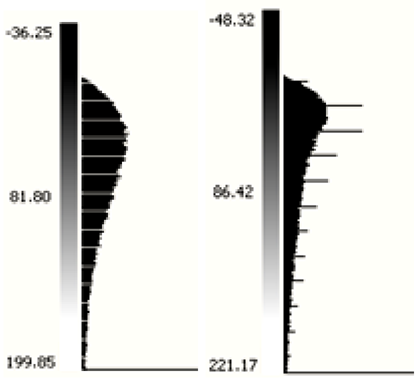
Figure 3(b)

Figure 3(a). Four bands from fully polarimetricPALSAR acquisition before applying FR correction. (b) Image statistics of the 4 bands before FR correction



HH HV VH VV

Figure 4(a)



HH HV

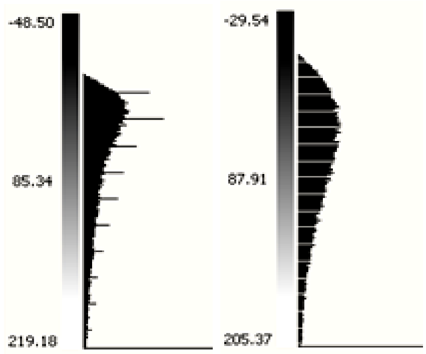


Figure 4(b)

Figure 4(a). Four bands from fully polarimetric PALSAR acquisition after applying FR correction. (b) Image statistics of the 4 bands after FR correction.

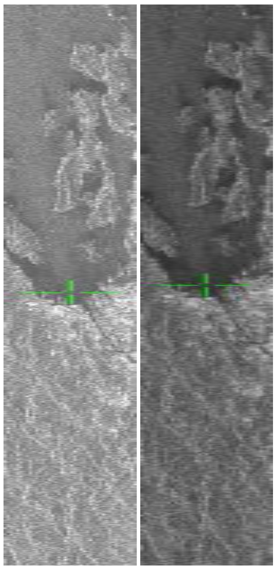
Table 2
Pixel Values and Standard Deviation before and after FR Correction

Band	Before FR Correction		After FR Correction	
	Average pixel value	**Standard deviation**	**Average pixel value**	**Standard deviation**
HH	81.780	59.028	81.802	59.024
HV	86.396	67.393	86.422	67.373
VH	85.290	66.948	85.339	66.921
VV	87.903	58.732	87.914	58.728
HH+HV+ VH+VV	352274.291	341957.350	352331.356	341911.358

Table 2 shows the average pixel values and the corresponding standard deviation for the four polarimetric bands as well as the composite band, before and after FR correction. An analysis of the image histograms and Table 2 shows that the original PALSAR image has higher deviation from the mean value, which means the noise level is high. But after FR correction, the standard deviation has reduced there by increasing the mean pixel value, implying that the FR effects have been compensated in the polarimetric bands. The reduction in standard deviation is higher in the compositebands as the cumulative FR effects due to all the four bands have been removed simultaneously. But the reduction in standard deviation of the individual polarimetric bands compared with the original bands is less as FR is due to one single band.

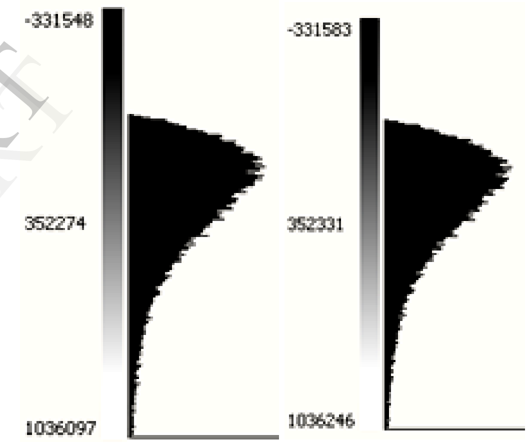
5. Conclusion

Frequency dependent propagation effects are a result of the influence of the ionosphere's electron content along the ray path and the Earth's magnetic field. The performance of spaceborne SAR system at lower is



Before FR Correction   After FR Correction

Figure 5(a)



Before FR Correction   After FR Correction

Figure 5(b)

Figure 5 (a).Composite band (HH+HV+VH+VV) before and after applying FR correction. (b) Image statistics of the composite band before and after FR correction.

degraded by the ionospheric effects like FR which affects the SAR data. The FR degradation in SAR data willbe larger as we progress towards peak solar activity. A method of estimating the FR angle (Ω) from actual MST radar data has been done, and application of the calculated FR angle to correct FR related distortions in the ALOS-PALSAR images has been presented in this paper.By comparing the image statistics of the uncorrected and FR corrected PALSAR images, it can be seen that distribution for FR corrected images is more smoother when compared to the FR affected images. After FR correction, the standard deviation has reduced with an increase in mean pixel value which means that noise due to FR has been removed. This method compares well with the recovery of FR angle from polarimetricbackscatter measurements made by L-band PALSAR. Further work will focus on denoising the PALSAR images using wavelet techniques.

6. References

[1] X. Pi and S. F. Chan, "Analysis of ionospheric scintillation effects on space-based radar systems," Tech. Report, Jet Propulsion Laboratory, Pasadena, CA, Tech. Rep., September 2005.

[2] P. A. Wright, S. Quegan, N. S. Wheadon, and C. D. Hall, "Faraday rotation effects on L-band spaceborne SAR data," *IEEE Trans. Geosci. RemoteSens.*, vol. 41, no. 12, pp. 2735–2744, Dec. 2003.

[3] R.-Y. Qi and Y.-Q.Jin, "Analysis of the effects of Faraday rotation on spaceborne polarimetric SAR observations at P-band," *IEEE Trans.Geosci. Remote Sens.*, vol. 45, no. 5, pp. 1115–1122, May 2007.

[4] A. Freeman and S. Saatchi, "On the detection of Faraday rotation in linearly polarized L-band SAR backscatter signatures," *IEEE Trans. Geosci.Remote Sens.*, vol. 42, no. 8, pp. 1607–1616, Aug. 2004.

[5] A. L. Gray and K. E. Mattar, "Influence of ionospheric electron density fluctuations on satellite radar interferometry," *Geophys. Res. Lett.*, vol. 27, no. 10, pp. 1451–1454, May 2000.

[6] B. K. Banerjea, "On the propagation of electromagnetic waves through the atmosphere," *Proc. R. Soc. Lond. A, Math. Phys. Sci.*, vol. 190, no. 1020, pp. 67–81, Jun. 1947.

[7] Z.-W. Xu, J. Wu, and Z.-S.Wu, "A survey of ionospheric effects on space-based radar," *Waves Random Media*, vol. 14, no. 2, pp. S189–S273, Apr. 2004.

[8] Franz J. Meyer, Jeremy B. Nicoli, "Prediction, Detection, and Correction of Faraday Rotation in Full-Polarimetric L-band SAR Data," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 10, pp. 3076-3086, Oct. 2008.

[9] P. A. Wright, S. Quegan, N. S. Wheadon, and C. D. Hall, "Faraday rotation effects on L-band spaceborne data," *IEEE Trans. Geosci. Remote Sens.*, vol. 41, no. 12, pp. 2735–2744, Dec. 2003.