Ionospheric Effects on Polarimetric and Interferometric Space-borne SAR

Yunjin Kim and Jakob van Zyl
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109-8099

Tel: (818) 354-9500
Fax: (818) 354-0495
E-mail: ykim@delphi.jpl.nasa.gov

ABSTRACT

In recent years, both polarimetric and interferometric SAR techniques have provided important scientific results. To be useful for science applications, these techniques require precise phase and amplitude calibration. In order to cover large areas using these techniques, it is necessary to use a space-borne SAR. Due to ionospheric disturbance, a space-borne SAR may not be able to produce data useful for science applications. In this paper, we present ionospheric effects on polarimetric and interferometric SAR images, especially at lower frequencies. First, we derive analytic equations to investigate ionospheric effects on both range and azimuth compressions. Then, using these equations, we examine important parameters such as pulse dispersion, time delay, and loss of azimuth resolution. We will also present possible correction schemes to compensate ionospheric disturbance.

PROBLEM FORMULATION

In this section, we formulate problems related to ionospheric effects on SAR images. For a relatively high frequency (higher than 400 MHz) SAR, three major ionospheric effects on SAR images are expected.

- The incident wave polarization is rotated (Faraday rotation).
- The inter-pulse dispersion changes the incident pulse shape since the ionosphere is a dispersive medium. In addition, the return pulse delay is not the same as the free space case.
- Loss of azimuth resolution is expected if proper optical path length compensation is not applied to a matched filter. The optical path length o is defined as

$$o = \int_0^L n(\rho) d\rho$$

where $n(\rho)$ is the refractive index profile over the radar signal path ρ.

The Faraday rotation effects and compensation techniques are discussed in [1] for space-borne polarimetric SAR measurements. Therefore, we will not discuss Faraday rotation effects further in this paper. Instead, we will present the mathematical formulation of both range and azimuth SAR compressions including ionospheric effects. Then, we will discuss potential compensation techniques that can minimize the SAR image quality degradation.

SOLUTIONS

In order to obtain high resolution images, while conserving peak power, the transmit pulse is modulated. The most commonly used waveform is a chirp (linear FM) signal. The waveform p(t) can be written as

$$p(t) = \begin{matrix} Ae^{i(\varpi_0+\gamma t)t} & -T/2 < t < T/2 \\ 0 & otherwise \end{matrix} \qquad (1)$$

where A is the pulse amplitude, ϖ_0 is the center frequency, and γ is the frequency slope in the linear FM modulation. After this pulse is reflected from a point target, the received signal spectrum $S_r(\varpi)$ is contaminated by the ionosphere induced phase $\varepsilon(\varpi)$ as

$$S_r(\varpi) = S(\varpi)e^{i\varepsilon(\varpi)} \qquad (2)$$

where $S(\varpi)$ is the return signal spectrum and

$$\varepsilon(\varpi) = -\frac{\varpi}{c} 2R\left[1 - \frac{a(2\pi)^2 N}{\varpi^2}\right]. \qquad (3)$$

Here, R is the slant range, a is a constant. For a homogeneous slab of ionosphere, if the thickness is L, the total electron content (TEC) is NL. After the range compression, the resulting compressed pulse y(t) can be written as

$$y(t) \approx \frac{A^2\pi}{\gamma} e^{-i\frac{\varpi_0}{c}2R} e^{i\varpi_0 t} e^{i\alpha.TEC/\varpi_0} \left\{ 2\gamma T \frac{\sin(p\gamma T)}{p\gamma T} + iq\left[2(\gamma T)^3 \frac{\sin(p\gamma T)}{p\gamma T} + \frac{4}{p^3}(p\gamma T\cos(p\gamma T) - \sin(p\gamma T))\right] \right\}$$

where

$$\alpha = \frac{2(2\pi)^2 a}{c}$$
$$p = t - \frac{2R}{c} - \frac{\alpha TEC}{\varpi_0^{\,2}}$$
$$q = \alpha TEC / \varpi_0^{\,3} \tag{4}$$

Note that the compressed pulse distortion depends on the total electron content (TEC), center frequency (ϖ_0), and the radar bandwidth (γT). As can be seen from the variable p, the pulse return time delay has been changed. This time delay change will place the target at the incorrect location. In addition, the phase is also biased by the total electron content.

In order to understand the ionospheric effects on the SAR azimuth compression, we derive SAR phase history data y(t,s) in terms of the along track variable s as

$$y(t,s) \approx \frac{A^2\pi}{\gamma} e^{-i\frac{\varpi_0}{c}2R_i(s)} e^{i\varpi_0 t} e^{i\frac{2\alpha TEC}{\varpi_0}} e^{i\alpha a_1(s-s_c)/\varpi_0} e^{i(\alpha/2\varpi_0)(a_2-\frac{TEC}{R_c^2})(s-s_c)^2} \left\{ 2\gamma T\frac{\sin(p\gamma T)}{p\gamma T} + iq\left[2(\gamma T)^3\frac{\sin(p\gamma T)}{p\gamma T} + \frac{4}{p^3}(p\gamma T\cos(p\gamma T) - \sin(p\gamma T))\right] \right\} \tag{5}$$

where the target is at $s=s_c$ and the TEC variation is expressed as

$$TEC(s) \approx TEC\big|_{s=s_c} + a_1(s-s_c) + \frac{a_2}{2}(s-s_c)^2 . \tag{6}$$

Notice that the azimuth compression is done by using the apparent range $R_i(s)$. Using (5), three ionospheric effects on a SAR image can be discussed.

- Absolute phase bias
- SAR image shift
- SAR image defocus

The azimuth resolution degradation comes from the phase fluctuation due to ionosphere. Examples of this phase fluctuation can be found in [2].

For an interferometric SAR, a differential phase bias to two antennas due to ionosphere can cause severe height degradation. This problem is more serious for repeat track interferometry since the two rays may pass through completely different propagation media. In addition, mis-registration can cause serious DEM (Digital Elevation Model) accuracy degradation. These issues can be studied in terms of the signal decorrelation of interferometric images.

It is important to compensate for the ionospheric effects during SAR image processing. One can apply phase correction factors to both range and azimuth compression steps. We are currently considering two approaches.

- Split spectrum processing: The signal spectrum is divided into several spectrum components. Since ionosphere is a dispersive medium, the phase bias can be estimated from each spectrum phase.

- GPS technique: Using GPS information, one can derive a global ionosphere TEC map. Using this map, one can estimate phase corrections to apply during SAR image processing.

ACKNOWLEDGMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

[1] A. Freeman and S. Saatchi, "The effects of Faraday rotation on backscatter signatures in SAR image data," Proceedings of SPIE, Vol. 3120, pp. 37-44, 1997.

[2] E. J. Fremouw, R. L. Leadabrand, R. C. Livingston, M. D. Cousins, C. L. Rino, B. C. Fair, and R. A. Long, "Early results from the DNA wideband satellite experiment – Complex-signal scintillation," Radio Science, Vol. 13, pp. 167-187, 1978.