Impact of the Ionosphere on an L-band Space Based Radar.

Elaine Chapin, Samuel F. Chan, Bruce D. Chapman, Curtis W. Chen, Jan M. Martin, Thierry R. Michel,
Ronald J. Muellerschoen, Xiaoqing Pi, Paul A. Rosen
Jet Propulsion Laboratory, California Institute of Technology, USA

Abstract

We have quantified the impact that the ionosphere would have on a L-band interferometric Synthetic Aperture Radar (SAR) mission using a combination of simulation, modeling, Global Positioning System (GPS) data collected during the last solar maximum, and existing spaceborne SAR data. We conclude that, except for high latitude scintillation related effects, the ionosphere will not significantly impact the performance of an L-band InSAR mission in an appropriate orbit. We evaluated the strength of the ionospheric irregularities using GPS scintillation data collected at Fairbanks, Alaska and modeled the impact of these irregularities on azimuth resolution, azimuth displacement, peak sidelobe ratio (PSLR), and integrated sidelobe ratio (ISLR). Although we predict that less than 5% of auroral zone data would show scintillation related artifacts, certain sites imaged near the equinoxes could be effected up to 25% of the time because the frequency of occurrence of scintillation is is a strong function of season and local time of day. Our examination of ionospheric artifacts observed in InSAR data has revealed that the artifacts occur primarily in the polar cap data, not auroral zone data as was previously thought.

1 Introduction

L-band spaceborne SARs provide critical earth science measurements. Solid earth studies of seismic and volcanic deformation benefit from the low temporal decorrelation of L-band data, a critical performance element for repeat pass interferometric SAR (InSAR). L-band's demonstrated 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 concern for L-band and lower frequency spaceborne radars, despite the success of previous L-band spaceborne SARs such as SeaSAT, the JERS-1 SAR, and the Shuttle Imaging Radar (SIR-A/B/C). (See, for example, the recent comprehensive review by Xu et al. [1] and the references therein.) We have examined several of those concerns and have concluded that, except at high latitudes, the ionosphere will not significantly impact the performance of an L-band InSAR mission.

Using the Jet Propulsion Laboratory's Global Ionospheric Maps (GIM) total electron content (TEC) estimates derived from the worldwide array of GPS stations, we determined that the sun synchronous orbit which would minimize TEC at the time of imaging has dawn and dusk equator crossings. Such an orbit also avoids the equatorial post-sunset irregularities. We used the GIM data to examine the day-to-day variability in the background ionosphere and to quantify the impact of the background ionosphere on single pass SAR performance. With the exception of Faraday rotation related effects on single polarization systems, degradation due to the background ionosphere can be avoided if a reasonable model for the ionosphere is used during processing. Our studies reveal that Faraday rotation angles rarely exceeded the 10° threshold that impacts biomass retrieval and that repeat pass interferometric SAR decorrelation due to variations in the background ionosphere causing variable Faraday rotations is a negligible effect. These topics are discussed in more detail in [2].

2 Impact of Auroral Zone Scintillation

Although the orbit can be selected to avoid the post-sunset equatorial ionospheric scintillation, auroral zone and polar cap ionospheric irregularities may still create artifacts in L-band spaceborne SAR data. We investigated the impact auroral zone scintillation would have on SAR performance using GPS L1 phase scintillation measurements [3] collected at Fairbanks, Alaska, during the peak of solar activity of the last solar cycle, the year 2000. For this work, we assumed that the ionospheric irregularities were 350 km above the surface in a layer 50 km thick, that the anisotropic irregularity axis ratio was 5, that the irregularities obeyed a two-slope spectrum with inner and outer spectral indices of 1.5 and 2.5, that the inner scale and break scale were 100 m and 500 m, that the outer scale for the GPS phase scintillation measurements was 10 km, and that the outer scale for the radar measurements was 30 km. We developed a method of estimating the strength of the irregularity spectrum from each GPS phase scintillation measurement [4] using these assumptions and using a phase screen model with an anisotropic irregularity spectrum with irregularities elongated along the geomagnetic field lines [5]. We then used each spectrum to calculate the impact on radar performance for an L-band radar on a spacecraft 506 km above the surface with a 10 m long antenna viewing targets at a look angle of $35°$. The impact of ionospheric scintillation on the azimuth resolution, range resolution, and pulse broadening was calculated based on a published model [6] [7] while a model following Tartarski [8] was used to estimate the effects on radar image azimuth displacement. The thousands of estimates of radar performance degradation were accumulated to produce statistical measures of the impact of scintillation.

Figure 1 shows summary histograms of the frequency of occurrence of various levels of ionospheric degradation. The histograms were built using all of the available GPS scintillation data without sorting the data in time or by geomagnetic activity level. An azimuth resolution degradation of 10% indicates that the resolution was 10% worse than the azimuth resolution expected in the presence of no ionosphere. Similarly, an azimuth displacement degradation of 10% indicates that a target would be displaced by one tenth of an azimuth resolution element. It is clear from the figure that only a small percentage, less than 5%, of the data shows any significant degradation in performance. The probability of azimuth resolution degradation by more than 2% of the ideal value is less than 4%. The likelihood of PSLR or ISLR degradation larger than 2 dB is less than 3%. The probability of azimuth displacements larger than 10% is less than 5%.

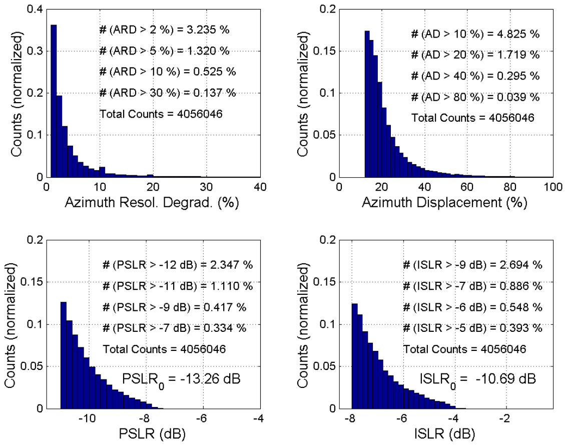

Figure 1: Normalized histograms showing the frequency of occurrence of degradations in radar performance due to ionospheric scintillation. Only the tails are plotted for clarity. The system resolution, PSLR, and ISLR if no ionosphere were present are 5 m, -13.26 dB, and -10.69 dB.

Auroral zone scintillation has a well known dependence on time of day, time of year, and geomagnetic activity – an effect that is averaged over in Figure 1. In particular, scintillation is more common at night, especially in the midnight to dawn sector near the equinoxes. Figure 2 shows how frequently the azimuth displacement is one tenth of an azimuth pixel or greater as a function of local time of day and month. Because auroral zone sites imaged in the pre-dawn hours have a non-negligible probability of being corrupted with ionospheric irregularity artifacts, careful planning of data acquisitions with respect to season and ascending vs. descending pass is recommended. For any sun-synchronous orbit, scintillation will be more probable for some auroral zone longitudes than others because the local time of imaging will vary due to the offset between geographic and geomagnetic latitude.

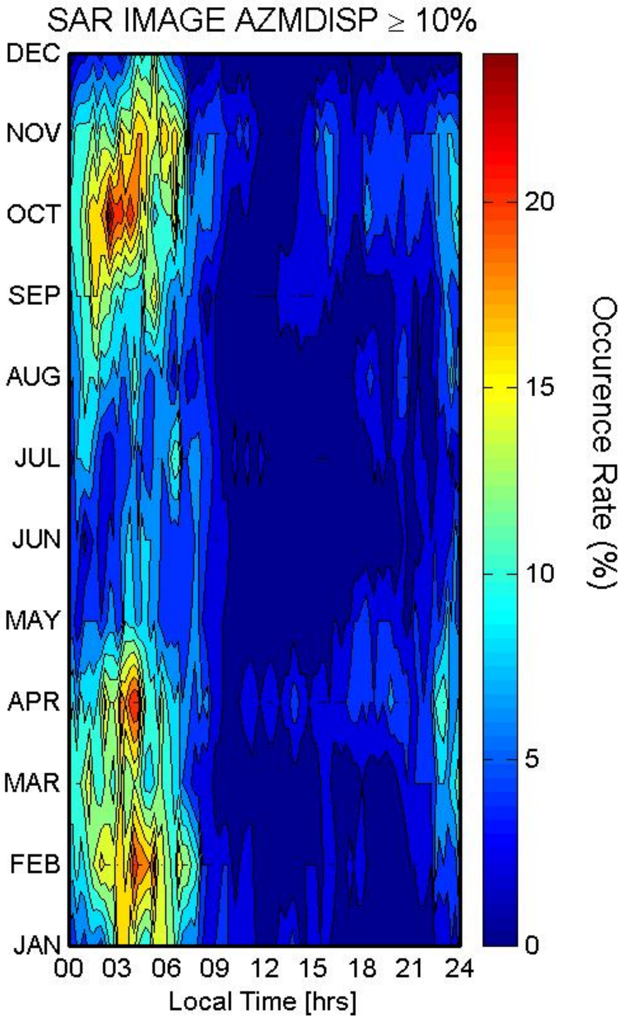

Figure 2: Frequency of occurrence that the azimuth displacement due to ionospheric scintillation exceeds 10% (a tenth of an azimuth resolution element which is 50 cm) plotted as a function of time of year and local time.

The ionospheric irregularities at auroral latitudes are closely correlated to space weather conditions that enhance the auroral electrojet causing magnetic field perturbations in the ionosphere and on the ground. These magnetic field perturbations can be an indicator of the effects on possible degradation of radar images. There is a clear correlation between the degradation of space based radar performance in the auroral zone passes and auroral electrojet activity characterized by the AE index. The latter significantly increases with disturbed space weather conditions. Figure 3 shows the mean degradation of radar azimuth resolution vs. the auroral electrojet index (AE). To obtain the plot, the estimated azimuth resolution degradation (R) was binned at 50 γ intervals and then averaged. As AE increases to the 1000 γ level, the average degradation of azimuth resolution can be larger than 2%. A quadratic fit is also included in the plot. It is clear that the AE index could be used to predict which auroral zone SAR scenes might be corrupted by ionospheric irregularities.

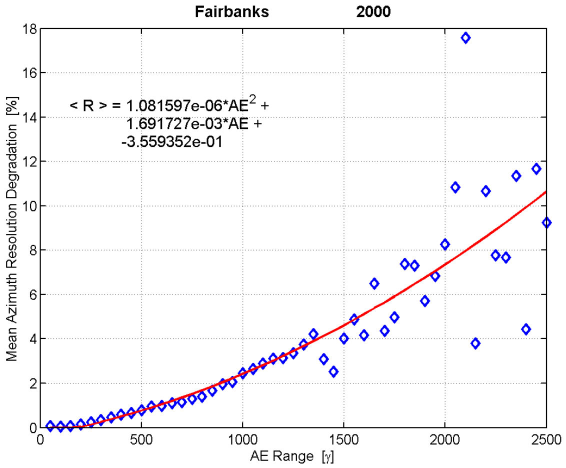

Figure 3: Mean degradation of the azimuth resolution due to ionospheric scintillation versus the auroral electrojet activity as characterized by the AE index.

3 Azimuth Shifts

Repeat pass SAR interferometry is affected by the ionosphere. Changes in background ionosphere between passes lead to phase ramps which are generally absorbed by the baseline estimation procedure. Of more concern are ionospheric irregularities which produce high frequency (kilometer horizontal scale) bands of azimuth mis-registration (up to half a pixel) and ripples in the interferometric phase [9] [10]. Glaciologists have observed these "azimuth streaks" in much of the high latitude data from the ERS-1, ERS-2, RADARSAT-1, JERS-1, and ENVISAT satellites. If irregularities are present on either of the two collections used for an interferometric pair, the data can be corrupted. A preliminary evaluation of already processed in-house InSAR data imaging both Antarctica and Greenland revealed that azimuth streaks occur much more frequently in polar cap data than for sites in the auroral zone. This conclusion that azimuth streaks are essentially a polar cap phenomenon is supported by observations of scintillation caused by kilometer scale irregularities in the polar cap [11] and is consistent with the auroral zone analysis of the previous section which showed that auroral zone azimuth displacements are too infrequent to account for the fraction of InSAR data effected.

We obtained RADARSAT-1 data covering two polar cap sites, Petermann Gletscher in Northern Greenland (Petermann) and a site in coastal Antarctica near McMurdo (McMurdo). We processed 15 passes making 11 offset fields at Petermann and 5 passes making 7 offset fields at McMurdo. 87% (13/15) of the Petermann pairs and all of the McMurdo pairs exhibited streaks. For each interferometric pair where streaks were present, we evaluated the density of streaks per kilometer of spacecraft travel along track, the width of the streaks, the maximum azimuth shift, and the orientation of the streaks. Each site showed a consistent orientation of the azimuth streaks which may be related to the angle between the look vector and the magnetic field. However, with only two sites it is difficult to make firm conclusions on this point.

We found no correlation between the presence of azimuth streaks or the severity of azimuth streaks with ionospheric indices such as Kp or the polar cap index, the orientation of the interplanetary magnetic field (IMF), the convection maps measured by the SuperDARN network, or fluctuations in the magnetometer data collected at Qanaaq located near the Petermann site. The lack of correlation with ionospheric measurements is surprising given the known qualitative differences in polar cap ionospheric phenomena (patches, blobs, sun-aligned arcs, etc.) as a function of the IMF driven convection [12] [13].

There was a correlation with season and TEC. Streaks were less frequent during local winter. For the two Petermann offset fields with no streaks, all four passes were collected in the local winter when the TEC extracted from the GIM data was very low ($<$ 4 TECU). This correlation is surprising given the pronounced minimum in measured polar cap scintillation during local summer [14] [15]. The scintillation causing the azimuth streaks may be associated with the relative scintillation maximum observed during summer months near magnetic noon [16]. The seasonal dependence implies that azimuth streaks are not associated with polar cap patches [17]. The seasonal dependence may also explain the lack of correlation of the frequency of occurrence with ionospheric measurements because convection is less important in the summer hemisphere when convecting structures decay more rapidly [18].

4 Conclusions and Future Work

Our analysis indicates that auroral zone scintillation which could impact SAR performance occurs less than 5% of the time. The probability of degradation is strongly correlated with ionospheric activity as characterized by the ionospheric indices and has a distinct time of day and time of year dependence. Consequently, the frequency of occurrence of scintillation will vary for different locations in the auroral zone because they will be imaged at different local times due to the mis-alignment of geographic and geomagnetic latitude. Appropriate acquisition planning of auroral zone collections is recommended. An analysis of artifacts in JERS-1 and PALSAR auroral data to verify our conclusions would be valuable.

Additional work characterizing polar cap scintillation and the observed azimuth shifts is needed. Azimuth shifts are more commonly observed in the polar cap than in the auroral zone and are least frequent during local winter. We observed no correlation between the occurrence of streaks with the ionospheric Kp or PC indices or northward or southward IMF. Given the prevalence of azimuth shifts in the existing polar cap C-band SAR data and the increased sensitivity to scintillation expected at L-band, development of a scheme to compensate for the shifts would be valuable.

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