CHARACTERISATION AND CORRECTION OF IONOSPHARIC EFFECTS IN LOW FREQUENCY (L- AND P-BAND) SAR IMAGERY

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ABSTRACT

Earth's ionosphere impacts in different ways the band-limited radio pulse transmitted / received by a SAR sensor and can critically affect the quality of the obtained images:
- Mean or large-scale ionospheric structures (known also as background ionosphere) cause attenuation, absorption, phase shift, time delay, dispersion, refraction and polarisation rotation.
- Small-scale ionospheric structures, formed by electron density irregularities (known also as turbulent ionosphere), cause signal scintillation which comprises essentially random fluctuations in phase, amplitude and polarisation.

The distortion of SAR images acquired through the ionopshere can be distinguished into range and azimuth relevant effects:
- In range the time delay due to the non-unity refrective index induces a (range) shift and a phase offset. At the same time the frequency dependent refractive index leads to a spreading of the transmitted / received pulse that degrades the range resolution and defocus the image in range depending on the size of the system bandwidth. However, the limited (6 MHz due to ITU-R regulations) bandwidth available at P-band makes dispersion effects of secondary importance.
- In azimuth, a variable phase shift due to a variable ionosphere can be seen as a variable frequency modulation resulting into a Doppler frequency shift. A more severe distortion is azimuth defocusing caused by small-scale electron density irregularities across the synthetic aperture. The introduced phase scintillations degrade image quality in different ways. The most important effect is image defocusing associated with an degradation of azimuth resolution caused by uncorrelated quadratic and higher order phase errors.

Finally, Faraday rotation appears as a direct consequence of the ionospheric birefringence induced by the presence of Earth's magnetic field. The polarization ellipse of the wave rotates as the wave propagates through the ionospheric layer. The scattering matrix of the underlying scattering process biasing the individual scattering amplitudes.

In this paper we discuss and assess different methods for detecting and correcting ionospheric scintillation and Faraday rotation effects in SAR data.

Phase scintillations can be distinguished into High frequency phase disturbances resulting from small-scale variations of the electron density and low frequency phase variations due to the finite ionosphere correlation interval [Ref]. The most promising correction approaches are based on Auto-Focus (AF) techniques [Ref]: AF techniques are adaptive techniques that allow the estimation and/or compensation of second and / or higher orders phase errors along the integration path improving image focus. Depending on the scene characteristics, i.e. the choice of the reference scatterers one can distinguish the AF techniques into three main categories:

1. AF techniques based on the evaluation of the phase history of individual deterministic points. In this case, the high signal to noise ratio SNR (and/or signal to clutter ration SCR) allow a direct estimation of the phase error on each of these points. Accordingly it is the most efficient and direct AF approach but is limited by the availability of dominant point-like scatterterers.
2. Coherent AF techniques are based on range compressed images and vary the phase history in azimuth to optimise image parameters. Such AF techniques are the Phase Gradient or the Phase Difference approaches.
3. Incoherent AF techniques are based on intensity of the final (range & azimuth) compressed images ignoring completely phase information. Representatives are the Sub-Look Registration and the Contrast Optimisation AF approaches.

Faraday rotation: The availability of fully polarimetric data allows accurate estimation and compensation of Faraday rotation distortion. Several schemes have been proposed and successfully validated on data acquired by JAXA's ALOS-PalSAR satellite that operates at L-band. The achieved estimation accuracy was surprisingly high on the order of 1 degree. One note of caution is however required: The estimation of the Faraday rotation can be biased in the presence of system induced distortion on transmit or receive (system x-talk). However, in the case of low x-talk levels (< -25 dB) the estimation is unbiased. Finally, alternative approaches for the mitigation of Faraday distortion as the transmission and reception of circular instead of the conventional linear polarised pulses are discussed.