Ionospheric Irregularity Height Estimation Based on Scintillation Signatures in SAR

Felipe Betancourt-Payan[1], Jun Su Kim[1], Kostas Papathanassiou[1], Marc Rodriguez-Cassola[1], Gerhard Krieger[1]

[1]) German Aerospace Center (DLR)
felipe.betancourtpayan@dlr.de

Low-frequency synthetic aperture radar (SAR) benefits from its penetration capability to image volumetric and sub-surface scatterers (e.g., ice, dense forest and the ground below tree canopies). At the frequency of the ALOS-PALSAR instrument (L-band or 1.27 GHz), the quality of the products is highly affected by the ionosphere and its irregularities. In particular, the turbulent component of the equatorial ionosphere (with the local variations in electron density and total electron content) introduces rapid spatially changing phase errors to the propagating radar wavefronts. Assuming the turbulent irregularities are located in a narrow vertical space, it is common to approximate the disturbances to a phase-modulating screen. The one-way wave propagation model is the following: free-space propagation between the satellite and the ionospheric turbulent layer, followed by phase modulation and then free-space propagation from the turbulent layer to the ground. As a result, the radar cross-section of the imaged scatterers is modified with the so-called intensity scintillations. Because of the elongated nature of the equatorial ionospheric irregularities, the signature is also known as *stripes*. The stripe signature has been well-known since the beginning of the ALOS-PALSAR operations. The stripes are known to be oriented along the geomagnetic field and their structure is directly related to the spatial structure of the ionospheric irregularities. It is also known that the stripes are usually more visible when the satellite track is parallel to the geomagnetic field vector projected on the horizontal plane, as seen from the line of sight. Even in the presence of irregularities, the stripes are not necessarily visible if the flight direction is off this geomagnetic field projection.

In the literature, the ionospheric irregularity height is usually related to the height of maximum ionization, which can be estimated from standard models such as NeQuick and IRI. Besides considering the model uncertainties, we are particularly interested in the accurate estimation of the irregularity height (which can be or not the same as the one of maximum ionization). This information is crucial from the calibration point of view and as a geophysical parameter that serves the community.

SAR accomplishes its high along-track (azimuth) resolution by coherently processing the returned phase history, which relates to the varying range between targets on the ground and the satellite as it moves. This way, it is possible to synthesize a very large antenna with a sharper resolution than the real aperture. The azimuth processing takes place with a matched filter, which acts as an averaging filter. The matched filter is adapted to the range between the satellite and the imaged targets. Consequently, if we consider the ionosphere *is a target in-between*, its signature is smeared in azimuth in the raw and compressed data. *Semi-focusing* of the data is accomplished by tunning the range parameter in the matched filter. In particular, it has previously been shown that using this approach (with knowledge of the ionospheric irregularity height and consequently the range between the satellite and the phase screen) allows estimating the Faraday rotation angle in quad-pol data in principle at a resolution limited only by the radar resolution, the sampling frequency and the noise.

In this presentation, we show that semi-focusing can also be used to visualize the ionospheric stripes even when they are initially not visible in the focused data. By semi-focusing, it is possible to decouple the scintillation from the azimuth processing. In other words, it is possible to undo the synthetic aperture averaging to see the scintillation at high resolution. With a maximum contrast autofocus, it is possible to estimate the irregularity height. The methodology is validated with an ALOS-PALSAR dataset. We also present another method for estimating the ionospheric irregularity height based on azimuth sub-looks (less averaging takes place and the stripes are visible by processing only parts of the full synthetic aperture). Sub-look processing has been used in the past, for example, in the state-of-the-art method for ionospheric irregularity height estimation at high latitudes known as the *Faraday rotation parallax*. We show it is possible to use a similar principle with the scintillation signature instead. The two main benefits are (i) the scintillation parallax proposed in this work operates at equatorial latitudes (where there is not Faraday rotation signature) and (ii) there is no need for full polarimetry since the scintillation can be measured in the single-channel images.