SAR Autofocus Scheme for the Retrieval of Ionospheric Signatures in the Ground Prototype Processor of Biomass

Felipe Betancourt-Payan, Marc Rodriguez-Cassola, Pau Prats-Iraola, Andreas Benedikter, Gerhard Krieger, Vinicius Queiroz de Almeida, Maria J. Sanjuan-Ferrer

Microwaves and Radar Institute, DLR, Muenchnerstrasse 20, Wessling, Germany
Contact e-mail: felipe.betancourtpayan@dlr.de

As sufficiently recognised in the literature, the quality of SAR measurements may be affected by the propagation of the radar signals through the ionosphere. The introduced propagation delays and the dispersive nature of the ionosphere may cause strong geolocation errors, defocussing in range and azimuth in the radar images, as well as the local rotation of the polarisation reference of fully-polarimetric acquisitions. The impact of the ionosphere is more critical for lower frequencies and higher bandwidths.

These effects have been assessed for ESA's Earth Explorer Biomass mission [1], which will be the first P-band SAR in space and is expected to be launched in 2023. The baseline approach for the estimation of ionospheric perturbations in Biomass consists of exploiting the Faraday rotation estimates provided by the Bickel and Bates algorithm [2]. This approach necessitates very accurate Faraday rotation estimates (e.g., typically better than one tenth of a degree) if they are to be used for correcting the phase history of the data and not the depolarisation alone. Such high accuracies typically require high averaging and low-pass estimates which might be incompatible with strong scintillations scenarios.

As part of the Ground Processor Prototype (GPP) of the mission [3], we are developing an autofocus algorithm for the recovery of ionospheric phase signatures which can handle such strong scintillation cases. To support this development, we have enhanced the Biomass end-to-end performance simulator (BEEPS) [4] with tailored ionospheric and scene generators. The scene generator of BEEPS is extended to use real spaceborne SAR reflectivity images (e.g., Sentinel-1) which provide similar coverage and realistic contrast, essential for the tuning of the autofocus. For the ionospheric generation, BEEPS is able to create thin-layer realizations including background and turbulent contributions. The incorporation of the background part (based on the NeQuick2 [5]) in the development environment is essential for the characterization of integration errors in azimuth. The turbulent part is based on the well-known Rino's power law [6]. The superposition of the background and turbulent components is incorporated in the simulated data as locally-variant phase and delay perturbations, as well as Faraday rotation.

The classical references on autofocus are typically targeted on the recovery of the contrast of the image, only minorly worrying about the fidelity of the phase of the images after the correction [7]. A phase gradient autofocus approach for Biomass was suggested in [8] to mitigate the effect of ionospheric irregularities along the synthetic aperture. This approach has the limitation of requiring the presence of point-like targets within the image, which makes it a difficult choice for operational environments. We propose in this paper a combined approach based on a map-drift kernel [7] and therefore capable of delivering robust phase error estimates over extended areas in the absence of point-like targets, while at the same time integrating the information of any point-like or coherent scatterer present in the image [9] with the purpose of locally improving the estimation accuracy. Due to the similarity of the phase perturbations for all polarimetric channels, the suggested algorithm integrates the autofocus estimates of all four polarimetric channels into a single inversion step, which can be also supported by the residual Faraday rotation estimates as postulated in [10]. An assessment of the usefulness of estimates of the dispersion in the integration step of the autofocus will be provided in the final version of the paper. In the paper we will also show how the algorithm uses the residual errors introduced after each iteration of the algorithm to optimally generate the ionospheric phase error estimates.

References

[1] Rogers, Neil C., *et al.,* "Impacts of ionospheric scintillation on the BIOMASS P-band satellite SAR." IEEE Transactions on Geoscience and Remote Sensing 52.3 (2013): 1856-1868.

[2] Kim, Jun Su, *et al.,* "Correcting distortion of polarimetric SAR data induced by ionospheric scintillation." IEEE Transactions on Geoscience and Remote Sensing 53.12 (2015): 6319-6335.

[3] Prats-Iraola, Pau, *et al.,* "The BIOMASS ground processor prototype: An overview." EUSAR 2018; 12th European Conference on Synthetic Aperture Radar. VDE, 2018.

[4] Sanjuan-Ferrer, Maria Jose, *et al.,* "End-to-end performance simulator for the BIOMASS mission." EUSAR 2018; 12th European Conference on Synthetic Aperture Radar. VDE, 2018.

[5] Nava, B., P. Coisson, and S. M. Radicella. "A new version of the NeQuick ionosphere electron density model." Journal of Atmospheric and Solar-Terrestrial Physics 70.15 (2008): 1856-1862.

[6] Rino, C. L. "A power law phase screen model for ionospheric scintillation: 1. Weak scatter." Radio Science 14.6 (1979): 1135-1145.

[7] Carrara, Walter G., R. S. Goodman, and Rd M. Majewski. "Spotlight synthetic radar: signal processing algorithms." Artech House (1995).

[8] Li, Zhuo, *et al.,* "Performance analysis of phase gradient autofocus for compensating ionospheric phase scintillation in BIOMASS P-band SAR data." IEEE Geoscience and Remote Sensing Letters 12.6 (2015): 1367-1371.

[9] Dexin Li. "Research on the technology of sinal processing and simulation of geosynchronous SAR". PhD Thesis.

[10] Gracheva, Valeria, *et al.,* "Combined Estimation of Ionospheric Effects in SAR Images Exploiting Faraday Rotation and Autofocus." IEEE Geoscience and Remote Sensing Letters (2021)