Towards NRT Sentinel-1 ARD products: model based atmospheric corrections for improved geolocation

Authors:
Antonio Valentino | RHEA for ESA - European Space Agency | Italy
Muriel Pinheiro | ESA | Italy
Dr. Clement Albinet | ESA | Italy
Dr. Christoph Gisinger | DLR | Germany
Dr. Lukas Krieger | DLR | Germany
Helko Breit | DLR | Germany
Michael Eineder | DLR, TUM | Germany
John Truckenbrodt | Jena University, Institute of Data Science, German Aerospace Centre DLR, Jena, Germany | Germany
Ulrich Balss | DLR | Germany

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Ongoing activities in the context of the definition of Analysis Ready Data (ARD) products for Sentinel-1 showed that one of the critical points for the compliance to CEOS Analysis Ready Data for Land (CARD4L) specification [1] for the Normalized Radar Backscatter (NRB) product is the geo-location accuracy.
Version 5.5 of the specification [2] has a target requirement for geo-location accuracy that is 0.1 pixels rRMSE (radial Root Mean Square Error). The S1-NRB product is planned to have a pixel spacing of 10m resulting in a target requirement for geolocation accuracy of 1m rRMSE.
According to S1-MPC annual reports the Sentinel-1 geolocation accuracy is very good once one compensates the known approximations and propagation effects. The “out of the box” geo-location performance (i.e. the accuracy of the product without the compensation of known effects) suffers of a relatively small loss of precision but a significantly higher bias (3-4m) that makes it not suitable, as it is, for the generation of S1-NRB products with the target geo-location accuracy.

Recently ESA developed a new auxiliary product, the Sentinel-1 Extended Timing Annotation Dataset (S1-ETAD) [3], that consists of a set of layers for S1 SLC timing corrections that, used in combination with the corresponding S1 SLC, can ensure a geo-location accuracy better than 20cm.
S1-ETAD would be the obvious solution to the problem, unfortunately the generation of ETAD products has a latency of 21 days that is too long for some of the application scenarios connected to the use of S1-NRB products, like e.g. landside monitoring applications.
To overcome the issue, one option is to use a S1-ETAD product with better timeliness but degraded accuracy. This solution would fit needs of NRT S1-NRB products provided that the performance of the “degraded” S1-ETAD products are compatible with the geo-location accuracy requirements of the NRB product itself.

The main sources of geo-location error that are addressed by the S1-ETAD product are:
- orbits: for 5cm to 1m (1σ) accuracy depending on the orbit product type
- atmosphere: 2-4 m (slant range direction), including ionosphere and wet and dry troposphere components
- system effects and processing approximations: < 3 m (both range and azimuth directions)

- geodetic effects: < 20 cm (both range and azimuth directions)

Among the above listed error sources, the ones mostly impacting the timeliness of the S1-ETAD product are:
- POEORB orbit products, with a latency of 20 days,
- ionosphere: final auxiliary products (TEC maps) necessary to compute ionosphere corrections, with a latency of 11 days,
- troposphere: Numerical Weather Prediction products necessary to compute corrections, with a latency of 1 day

Corrections for system effects and geodetic effects have basically no constraints in terms of timeliness and can be computed as soon as the S1 SLC product is available.
In principle, exploiting RESORB orbits, it could be possible to generate a “degraded” or “fast” S1-ETAD product with a timeliness between 3 and 6 hours, by replacing the very accurate models and auxiliary product used to compute atmospheric corrections with something less accurate but faster to compute.
The overall accuracy of the new models for atmospheric corrections should be compatible with the 1m rRMSE accuracy required for the S1-NRB (10m sampling) product to be compliant with the target requirement of CARD4L specifications.
The slant range component of the ETAD correction would be the one more impacted by the change, the azimuth component, 10cm (1σ) nominal accuracy in standard S1-ETAD products, would have a minimal impact related to the slightly worse accuracy of RESORB orbit products (10cm) with respect to POEORB ones (5cm).

In order to achieve the reduced latency, possible options to be investigated are:
- using a different set of auxiliary products for ionosphere (CODE) and troposphere (NWP), e.g., derived from forecasting, to improve the timeliness.
- using very simple analytical models to represent the propagation delay in the atmosphere.

For the first option, and in particular the ionospheric corrections, the final TEC maps can be replaced by “rapid” or even “predicted” ones at the cost of accuracy. While rapid TEC maps still have a latency of about 1 day, predicted TEC maps are available few days in advance and do not affect the timeliness of the S1-ETAD product.
Similar considerations should be possible for troposphere products considering forecasting solutions.

Regarding the second option, analytic models considered in this study are very simple and have important limitations, in particular they do not consider the spatial and temporal variations of the propagation delay of the electromagnetic signal in the atmosphere linked to local conditions of the ionosphere and troposphere at different levels. Moreover, some of the models considered do not even take into account the dependency on the viewing angle or the dependency on the topography, which is a very important element for the tropospheric delay computation.

Mixed solutions including different approaches for the ionospheric and tropospheric components will be also considered.

The main expected improvement deriving from the use of simple analytic models for atmospheric propagation error correction is to reduce as much as possible the mean error bias currently observed in the “out of the box” geolocation measurement on 1 SLC products.

All the models considered require a proper calibration in order to be used in a production context.

The key point of this study is to assess the performance of the different models considered to understand if they are compatible with the “very fast” generation of S1-NRB products compliant with the target CARD4L specifications in terms of geo-location accuracy.

The methodology for calibration and validation is outlined and main results are presented and discussed.

References

[1] CEOS Analysis Ready Data (https://ceos.org/ard)
[2] CEOS (2021) Analysis Ready Data For Land: Normalized Radar Backscatter. Version 5.5 (https://ceos.org/ard/files/PFS/NRB/v5.5/CARD4L-PFS_NRB_v5.5.pdf)
[3] Sentinel-1 Extended Timing Annotation Dataset (ETAD) (https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/data-products/etad-dataset).