ADVANCING SENTINEL-1 INSAR APPLICATIONS USING ESA'S EXTENDED TIMING ANNOTATION DATASET PRODUCT

Victor Navarro Sanchez[1], Christoph Gisinger[1], Ramon Brcic[1], Steffen Suchandt[1], Lukas Krieger[1], Thomas Fritz[1], Antonio Valentino[2], Muriel Pinheiro[3]

1) Remote Sensing Technology Institute (IMF), German Aerospace Center (DLR)
2) Rhea for European Space Agency (ESA)
3) European Space Agency (ESA)

The Extended Timing Annotation Dataset (ETAD) product was designed for the Sentinel-1 Synthetic Aperture Radar (SAR) mission to provide users with ready-to-use gridded timing corrections for level 1 image data [1]. The timing corrections comprise atmospheric path delays, Earth's tidal deformation signals, and systematic effects not captured by the SAR image processor to enhance geolocation accuracy of Sentinel-1 data and serve applications such as accurate geocoding or feature tracking [1][2]. The ETAD product closely replicates the internal swath and burst structure of the L1 single look complex (SLC) image data to allow for a straightforward correction of the annotated radar timings or for a post-processing correction in existing workflows. Product generation and provision are planned to become a routine part of Sentinel-1 ground segment and shall be performed along with every Sentinel-1 scene acquired in Interferometric Wide Swath (IW) and Stripmap (SM) mode.

In this paper we will present results of an evolution study aiming to extend the geodetic correction scheme, improve the flexibility and timeliness and to expand the envelope of ETAD to SAR interferometry (InSAR) applications with Sentinel-1. Although the product's primary target is timing corrections, it certainly has the potential to serve as the basis for phase corrections in InSAR. As already discussed in [1], the provided timing corrections may be converted to phase offsets, which can be used to derive interferometric phase screens between pairs of repeat-pass acquisitions. However, InSAR applications can be sensitive to errors as small as 1 mm [3], so high quality, consistent corrections are necessary.

Depending on the InSAR application, some ETAD corrections might not be relevant because they cancel out on interferogram formation, or are compensated during coregistration to the reference image geometry. Based on DLR's well-established InSAR processing workflows targeting wide area processing [4], and leveraging the outcome of ETAD product validation and preliminary results on InSAR time series [1], the following correction layers available in ETAD are deemed as the most relevant for the majority of scenarios:

- Tropospheric range delay correction associated with changes in signal propagation velocity due to tropospheric conditions along the traversed path.
- Ionospheric range delay related to ionospheric activity, modelled as a function of the slant total electron content. Since the ETAD product considers the group delays and not the corresponding phase delays acting in the opposite direction, the change of sign must be accounted for when deriving phase corrections.
- Timing correction related to solid Earth tidal deformations caused by the gravitational force of the Sun and Moon.
- Instrument timing calibration in range that has an effect on the absolute phase difference if the ETAD configuration or instrument calibration changed between the SLC data acquisition or the generation of the two ETAD products (also required if acquisitions of S1-A and S1-B are combined for the interferogram).

Ocean tidal loading is another well-known solid Earth deformation effect which has significant impact on InSAR time series in many of the coastal regions [5]. It is not yet a part of ETAD but we investigate the effect in our evolution study as a possible future ETAD product extension.

While most relevant corrections layers are expected to vary smoothly in space (e.g. solid Earth tides or ionospheric range delay), tropospheric corrections have a strong dependence on the topography and the resolution of the ETAD product can have difficulties to capture small scale atmospheric disturbances caused by pronounced stratification. When considering an aligned (coregistered) stack of ETAD products, variations on the coregistered height layer (Figure 1) are observed that are inherent to ETAD grid definition and product generation and cannot be fully eliminated when applying the product as is for high resolution InSAR processing with minimal or no multi-looking. The differential height introduces a differential delay proportional to the reference delay-to-height slope, causing artifacts in areas with steep topography (Figure 2 right). To resolve the artifacts and create smooth tropospheric phase screens, we study methods to include in ETAD a layer for the local

derivative of tropospheric delay over height that can be used to translate height differences to path delay differences and compensate for the variations. A preliminary result of such an approach is shown in Figure 2 right.
In our final publication we will present the additional experimental ETAD correction layers for tropospheric delay gradients over height as well as ocean tidal loading displacements. Study cases in the European Alps and the French Brittany region will be shown to discuss usage of ETAD products for phase corrections in InSAR.

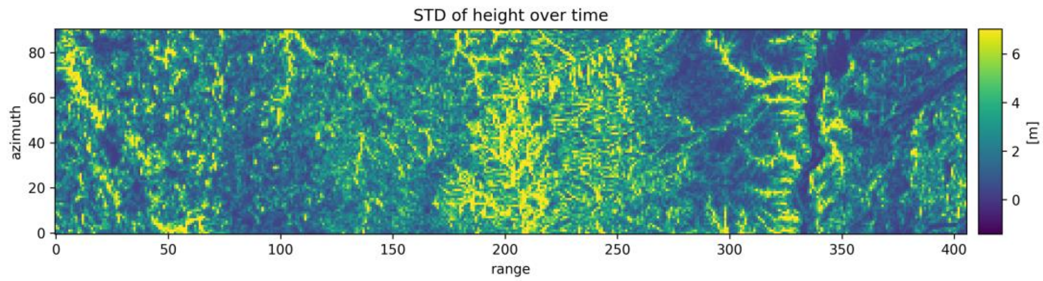

Figure 1: Height variation within a stack of co-registered ETAD height layers for products in the European Alps. Typical variations are in the order of up 10 meters but difference values of more than 100 m can be observed in areas with steep topography.

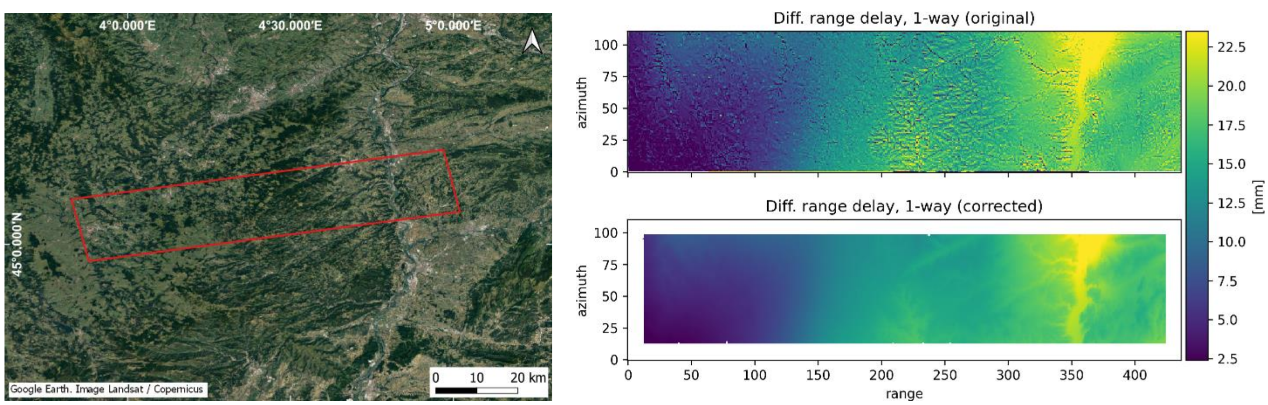

Figure 2: Differential tropospheric path delay derived from two dates of coregistered ETAD tropospheric correction layers for the region shown on the left. Applying the layers as is can lead to artifacts due to temporal variation in product height layers (upper right). When accounting for the differential heights using tropospheric delay gradients over height, the artifacts are very effectively removed (lower right).

REFERENCES

[1] Gisinger, C., Libert, L., Marinkovic, P., Krieger, L., Larsen, Y., Valentino, A., Breit, H., Balss, U., Suchandt, S., Nagler, T., Eineder, M., Miranda, N., "The Extended Timing Annotation Dataset for Sentinel-1—Product Description and First Evaluation Results," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-22, 2022, doi: 10.1109/TGRS.2022.3194216.

[2] Yunjun, Z., Fattahi, H., Pi, X., Rosen, P., Simons, M., Agram, P., Aoki, Y., "Range Geolocation Accuracy of C-/L-Band SAR and its Implications for Operational Stack Coregistration," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-19, 2022, doi: 10.1109/TGRS.2022.3168509.

[3] Ferretti, A., Savio, G., Barzaghi, R., Borghi, A., Musazzi, S., Novali, F., Prati, C., Rocca, F., "Submillimeter Accuracy of InSAR Time Series: Experimental Validation," in IEEE Transactions on Geoscience and Remote Sensing, vol. 45, no. 5, pp. 1142-1153, May 2007, doi: 10.1109/TGRS.2007.894440.

[4] A. Parizzi, R. Brcic and F. De Zan, "InSAR Performance for Large-Scale Deformation Measurement," in IEEE Transactions on Geoscience and Remote Sensing, vol. 59, no. 10, pp. 8510-8520, Oct. 2021, doi:10.1109/TGRS.2020.3039006.

[5] Yu, C., Penna, N. T., Li, Z., “Ocean tide loading effects on InSAR observations over wide regions,” in Geophysical Research Letters, 47, 2020. Doi: 10.1029/2020GL088184.