An overview of Sentinel-1 instruments status, L1 product performance and evolution

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The Copernicus Sentinel-1 (S-1) mission ensures the continuity of C-band SAR observations over Europe. The routine operations of the constellation are on-going and performed at the maximum capacity allowed by the Sentinel-1 A unit. The Sentinel-1 B unit has not been operational since December 2021 and the new Sentinel-1C unit is going to be launched in December 2024. The mission is characterized by large-scale and repetitive observations, systematic production and free and open data policy. Sentinel-1 data are routinely used by Copernicus and many other operational services, as well as in the scientific and commercial domain. A key aspect of the Copernicus program is the constant provision of open and free high-quality data. This requires long term engagement to carefully monitor, preserve, and improve the system and product performances. The Sentinel-1 SAR Mission Performance Cluster (SAR-MPC) is an international consortium of SAR experts and is in charge of the continuous monitoring of the S-1 instruments status, as well as the monitoring of the quality of the L1 and L2 products. This is typically done by analyzing the variation of key parameters over time using dedicated auxiliary products or standard data available to the public, e.g., antenna monitoring trough RFC products, radiometry and geolocation using standard data and dedicated Fiducial Reference Measurements (FRM). The SAR MPC is also responsible to implement any actions necessary to prevent or minimize quality degradation, e.g., in the event of instrument anomaly. This includes the update of processor configuration files and updates of the S-1 Instrument Processing Facility (IPF) algorithms and/or their implementation [1]. A Sentinel-1A platform anomaly impacting the thruster in charge of the orbit inclination control occurred in 2024. After the event, ESA has decided in agreement with the European Commission to suspend the orbit inclination control manoeuvres, for spacecraft safety reasons. This decision has further consequences on the Sentinel-1 orbit which had, since the beginning of the mission, been maintained within 200m RMS diameter tube. The impact in interferometry, in particular due to the increased perpendicular baselines, have been analysed and considered acceptable. Starting mid-April 2024, the orbit inclination is naturally evolving following a yearly pattern further modulated by a secular drift. The monitoring of baseline and burst synchronization continues to be done routinely and has been evolved to better track the effects of the change in orbit control, e.g., to better identify dependencies with latitude for baseline and burst synchronization. The monitoring of burst synchronization has also been extended to verify variations within the data-take, which are along-track baseline dependent, and to include verification using information from the Orbit (on-board) Position Schedule (OPS) angle, which allows to monitor the capability of the instrument to perform synchronization. The monitoring of both the SAR antenna health status and of the SAR instrument is carried out exploiting the dedicated auxiliary products and ensures to minimize degradation of SAR data quality originated by instrument aging or

element’s failures. In the case of antenna health, the analysis is performed using the RF Characterization (RFC) products which allows to assess the status of the 280 TRMs composing the SAR antenna. In April 2024 the antenna monitoring of the antenna error matrices obtained using S1A RFC products identified a failure of a single antenna TRM module of Sentinel-1A. The identification of the anomaly was followed by a dedicated quality impact assessment that confirmed no appreciable degradation of the performance. A small degradation of one element in H pol of Sentinel-1A has been observed since January 2021 (loss of about 3 dB gain in Rx and 1 dB gain in Tx), but with no impact in the data quality at the moment. In general the antenna monitoring shows that there has been no considerable degradation since 2017 for Sentinel-1A. The instrument status is monitored through the internal calibration and noise products, which can be used, for example, to generate time series of the PG product. Currently analysis shows that the overall behavior of both instruments is quite stable, with the slope of the PG gain trend below 0.1 dB/year for both units. The radiometric and geolocation performance of L1 products is performed using standard Sentinel-1A data and are also stable and within specifications. In particular, the DLR calibration site composed of transponders and corner reflectors is used to assess the stability of the radiometry, and current analysis including data from 2017 until 2024 shows a mean value of -0.1 dB and standard deviations below 0.25 dB for both units. In addition to the point-target analysis, gamma measurements over uniformly distributed targets like rainforest are also used to assess the relative radiometric accuracy of Sentinel-1 products. Evaluating the flatness of such profiles, updates of the antenna patterns and processing gains are performed in order to ensure radiometric accuracy. The geolocation accuracy is monitored using dedicated acquisitions over additional corner reflector calibration sites such as Surat Basin, Australia, and includes the compensation of known instrument and environmental effects, e.g., propagation through troposphere and ionosphere or solid Earth deformation signals [2]. Current analysis of the point targets shows an absolute mean value of less than 20 cm in azimuth and less than 10 cm in range for the Sentinel-1A unit, and respective standard deviations of less than 10 cm and 30 cm. The regular monitoring also shows a few centimeters of impact by the presently very high solar activity on Sentinel-1 geolocation performance, which is attributed to accuracy limitations in the ionospheric delay corrections applying the GNSS-based Total Electron Content (TEC) maps. Toward the beginning of 2024, Doppler jumps larger than usual have been observed between different star-tracker (STT) configurations (up to 50Hz). A STT re-calibration has then been proposed and implemented in June 2024 and shows positive results in terms of Doppler time series continuity. In general, with the only exception of a small degradation of the orbital tube of Sentinel-1A, the SAR-MPC monitoring activities show that the performance is nominal and stable. The quality of the L2 products is also continuously monitored by the SAR-MPC (see dedicated presentation in [4]). The IPF has also continuously evolved to improve the data quality and its usability. The latest version is IPF 3.9, which has been deployed on November 25th, 2024. Main evolutions which have been included in the latest IPF versions deployed are: - Support of specific timeline for S-1C and D - Annotation of used L0 A/C/N products in the manifest - Correction of the ANX date annotated in the manifest - Improve the robustness of annotation of burst ID - Compensate for the effect of RFI in the denoising vector annotation - Correction and calibration of denoising vectors Refer to https://sar-mpc.eu/processor/ipf/ for a full list of deployed changes. Together with the deployment of S1-IPF v3.9, the configuration of the SW module for Radio Frequency Interferences (RFI) detection and mitigation has been updated. The change consists in a fine tuning of the parameters aimed at reducing the mis-detection, which currently typically affects less than 2% of the slices. SAR-MPC also maintains a set of tools to support its own activities of monitoring and expert analysis of Sentinel-1 data. Recently a new tool has been developed that has two main purposes: - to generate the engineering products (L0N) that are needed to exploit rank echoes for the de-noising of products acquired before 2018, and - to generate accurate de-noising vectors starting form L1 products and

exploiting the updated algorithms and the latest calibration data. The tools will be made available to the public, e.g., to support ad hoc generation of noise vectors for archive products.

[1] Sentinel-1 Annual Performance Report 2023, on-line document, https://sentiwiki.copernicus.eu/web/document-library

[2] R. Piantanida et al., "Accurate Geometric Calibration of Sentinel-1 Data," EUSAR 2018; 12th European Conference on Synthetic Aperture Radar, 2018

[3] Franceschi et al., “Operational RFI Mitigation Approach in Sentinel-1 IPF”, submitted to EUSAR 2022

[4] A. Benchaabane,” Sentinel 1 Level 2 Ocean Products Performance Monitoring: current status and evolutions”, submitted to the LPS2022

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