

# ROSE-L E2ES and Ground Processor Prototype: Architecture, Status and Relevant Results

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## Abstract

This paper provides an overview on the up-to-date implementation status of the ROSE-L End-to-End Performance Simulator (E2ES) and the Ground Processor Prototype (GPP), which are two tools been currently developed to support the overall mission performance verification of the upcoming ROSE-L mission. The modular software architecture of both tools is shortly revisited and some relevant results for ROSE-L tailored scenarios are presented.

## 1 Introduction

ROSE-L (Radar Observing System for Europe in L-band) is one of the six Copernicus Expansion missions for the European Space Agency (ESA) [1]. The mission consists on the deployment of two twin satellites, named as PFM (Proto-Flight Model) and FM2 (Flight Model 2), to be launch around 2029 and 2031, respectively, and an expected lifetime of 7.5 years. Each satellite corresponds to a L-band synthetic aperture radar (SAR) which will provide high-resolution data with a revisit time of 6 days in order to support and complement the already available Sentinel-1 C-band satellites. The combination of both frequencies will improve the overall performance and quality of current applications and will also boost new user services [2].

In terms of scientific objectives, ROSE-L is meant to complement the monitoring of natural and anthropogenic hazards, to enhance land monitoring services such as soil moisture, crop type discrimination and forest type / forest cover classification, to increase the observations over the Artic and cryosphere with focus on sea ice mapping, iceberg detection, glacier and ice caps monitoring, and snow water content (SWE) retrieval, and to improve European maritime surveillance in terms of sea state, surface wind and swell information retrieval [1][2].

To achieve this, ROSE-L is being designed to follow the same orbit as Sentinel-1 (i.e., sun-synchronous orbit with a reference height of 693 km at the equator), and also allow the same swath coverage as Sentinel-1 Interferometric Wide Swath (IW) mode, maximizing the complementary aspect of the mission. In particular, three main imaging modes are being considered: the dual-pol ROSE-L Interferometric Wide Swath mode (RIWS), for overlapping with Sentinel-1 IW, the quad-pol Wide Swath mode (QWS), and the ROSE-L Wave mode (RWM). Both

dual-pol RIWS and quad-pol QWS provide 260 km swath, with RIWS achieving a 50 m<sup>2</sup> spatial resolution while QWS is reduced to 100 m<sup>2</sup>. RWM instead will focus on small 20 x 20 km vignettes of the ocean at 50 m<sup>2</sup> resolution.

To fulfil such specific and ambitious needs, a deployable 11 m x 3.6 m active planar array antenna is featured, with digital beamforming (DBF) capabilities both on-board (SCORE) and on-ground (MAPS) [3].

With the objective of supporting the ROSE-L mission in several verification aspects, a complete end-to-end simulation tool, named C-REEPS (Complete ROSE-L End-to-End Performance Simulator), is being implemented. The tool is divided into three main software (SW) blocks, which are:

- ROSE-L E2E Performance Simulator (**E2ES**), in charge of the simulation of raw data as per ROSE-L SAR, including the incorporation of the applicable observation geometry and all relevant effects from the platform, instrument and environment;
- Ground Processor Prototype (**GPP**), in charge of generating the ROSE-L Level-1 products;
- Performance Evaluation Module (**PEM**), generating the statistics of the quality parameters investigated in the simulation, including a cross-check with the mission requirements.

Further details concerning this tool are provided in the following, together with some relevant results.

## 2 C-REEPS SW Architecture and Status

Both ROSE-L E2E Performance Simulator (E2ES) and ROSE-L Ground Prototype Processor (GPP) are modular

SW, written in a combination of Python and C programming languages. The ROSE-L E2ES architecture is depicted in **Figure 1**, while the corresponding one for the ROSE-L GPP is shown in **Figure 2**. The modules are run sequentially, incorporating into the simulation chain all relevant effects applicable to the ROSE-L mission such as an accurate instrument and platform characterization, including DBF and on-board processing units, an accurate scene generation module with polarimetric and interferometric capabilities, an atmospheric simulator capable of generating tropospheric and ionospheric realisations affecting repeat-pass interferograms and radio frequency interferers (RFIs) with L-band representability. Then, the GPP will be in charge of focusing the raw data while correcting as much as possible for the different disturbances and producing the relevant L1 products for the ROSE-L mission.

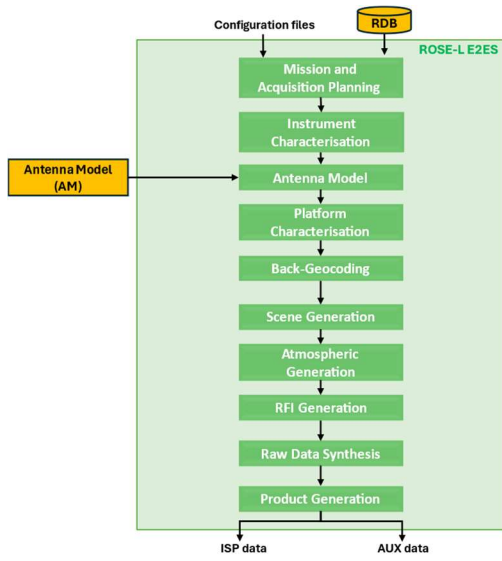


**Figure 1:** The ROSE-L E2ES architecture.

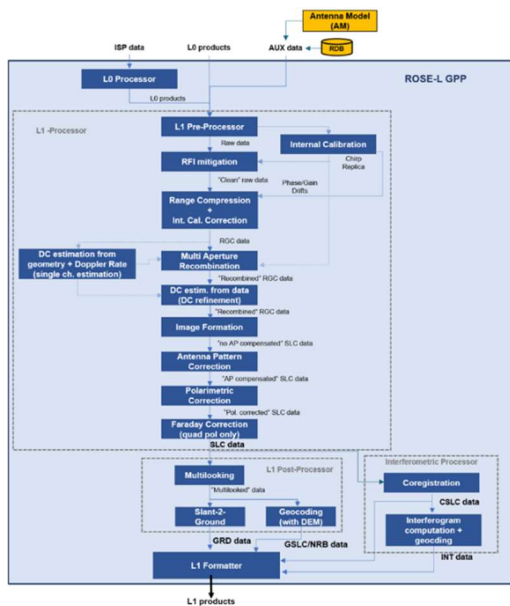


**Figure 2:** The ROSE-L GPP architecture.

The reader shall refer to [4] for more details concerning the functionalities and assumed algorithms for the overall simulation chain.

At the time of writing, a second version of the SW (C-REEPS V2) has been completed to support the System Critical Design Review (CDR), successfully closed in June 2025. This SW version allows almost complete simulation capabilities, only missing aspects related to the ROSE-L instrument which are still under consolidation (e.g., fully populated radar data base [RDB], official data formatting of products, or internal calibration final approach).

### 3 Some Relevant Results

#### 3.1 Error-Free Simulations

**Figure 3** shows the generated quicklooks of an error-free simulation with only point-targets (nine point targets per sub-swath, distributed along and across the sub-swath). In particular, this was a simulation assuming the RIWS acquisition mode at a location corresponding to the minimum orbital height (e.g.,  $\sim 697$  km), in which all relevant system, acquisition geometry and timing parameters were considered as per user configuration. In terms of perturbations, only the impact of antenna pattern was incorporated into both the simulation and the processing. Then, **Figure 3** (a) displays the L1a SLC data for the first sub-swath, first burst and HH polarisation, and (b) the corresponding L1b GRD data at HH polarisation.

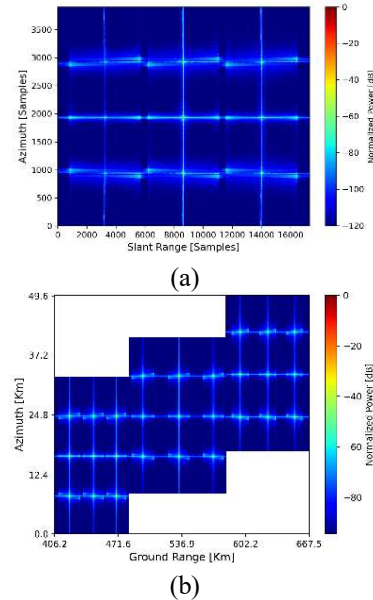


**Figure 3:** Quick-looks of focused data: (a) L1a SLC (first sub-swath, first burst, HH pol) and (b) corresponding L1b GRD (HH pol).

Despite their seemingly trivial nature, these simulations are in fact crucial for the proper calibration of the E2E chain, and help us to build complexity in a more coherent way. **Table 1** summarizes the error-free achievable E2E

performance for the different acquisition modes of ROSE-L at two different orbital height positions (i.e., minimum orbit height and maximum orbit height), including the impact of antenna pattern simulation and correction. In general, the radiometric accuracy of C-REEPS is in the order of centibels (cB), also between sub-swaths, and the accuracy is in the centimetre range.

**Table 1:** Error-free achievable E2E simulation performance.

| Acq. mode | Orbit height [km] | Radiometric accuracy ( $3\sigma$ ) | Residual azimuth geolocation error ( $3\sigma$ ) | Residual gr. range geolocation error ( $3\sigma$ ) |
|-----------|-------------------|------------------------------------|--------------------------------------------------|----------------------------------------------------|
| RIWS      | 697               | 0.03 dB                            | 0.04 m                                           | 0.05 m                                             |
|           | 725               | 0.05 dB                            | 0.01 m                                           | 0.03 m                                             |
| QWS       | 697               | 0.05 dB                            | 0.05 m                                           | 0.02 m                                             |
|           | 725               | 0.1 dB                             | 0.05 m                                           | 0.02 m                                             |
| RWM 1     | 697               | 0.01 dB                            | 0.02 m                                           | 0.0 m                                              |
|           | 725               | 0.01 dB                            | 0.0 m                                            | 0.01 m                                             |
| RWM 2     | 697               | 0.01 dB                            | 0.09 m                                           | 0.0 m                                              |
|           | 725               | 0.01 dB                            | 0.02 m                                           | 0.0 m                                              |

**Figure 4** instead displays the generated quicklooks of a C-REEPS run assuming a scene with distributed targets. This is a simulation over Alicante (Spain) according to RIWS mode, considering the underlying topography as per Copernicus Digital Elevation Model (DEM) with 30 m resolution [5]. Once again, the upper plot corresponds to the amplitude of the SLC product for the first sub-swath, first burst and HH polarisation, and the lower one is the corresponding amplitude for the GRD product (i.e., de-bursted, sub-swath merged, and multi-looked) in HH polarisation.

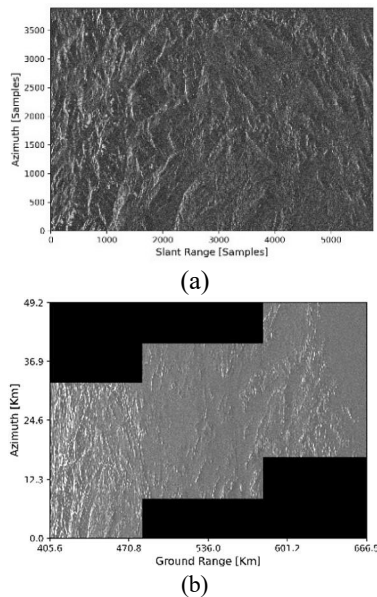


**Figure 4:** Quick-looks of focused data: (a) L1a SLC (first sub-swath, first burst, HH pol) and (b) corresponding L1b GRD (HH pol).

### 3.2 Simulations with Impairments

After implementation and calibration of the base simulation chain, additional disturbances can be incorporated to allow the evaluation of more complex and realistic scenarios. A relevant one is the incorporation of ionospheric propagation effects to test the performance of the GPP correction algorithms. It is well-known that the key effects on an Earth-space path due to a radio signal passing through the ionosphere are mainly Faraday rotation, group delay and phase advance, scintillations and wave dispersion, and these effects are directly proportional to the carrier wavelength. Therefore, lower-frequency SAR is more affected by these effects, and mitigation algorithms are required to ensure data quality and interpretability of the data.

The first simulation set-up corresponds to an interferometric pair with zero baseline configuration in which a background ionosphere with a gradient along range was only applied for the slave acquisition. Since the pertinent decorrelation contributions (e.g., temporal, volumetric, SNR, baseline) can be considered negligible in this particular set-up, the estimated interferometric phase by the L1 interferometric processor is directly related to the impact of the ionosphere. **Figure 5** (a) shows the estimated interferometric phase error before applying any correction while **Figure 5** (b) shows the remaining interferometric phase error after applying the split-bandwidth correction technique [6]. As can be seen, there is a residual phase still present, but the bulk contribution to the phase error has been correctly removed.

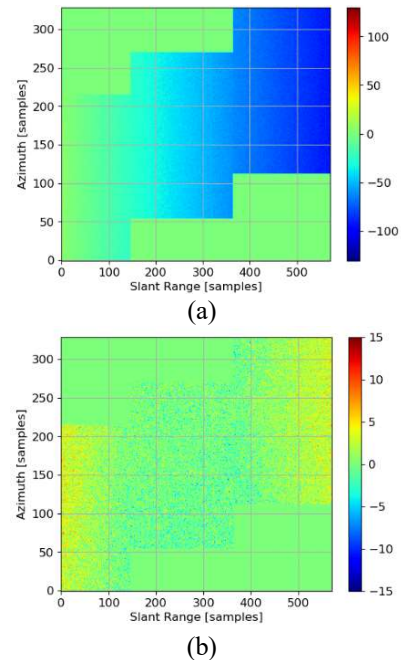


**Figure 5:** Interferometric phase (in degree) for the mosaicked product (HH pol): (a) before and (b) after GPP split-bandwidth correction.

A second simulation set-up can be considered to analyse the performance of the Faraday rotation correction algorithm [7]. In this case, a fully-polarimetric simulation as per QWS mode was performed, and the impact of Faraday rotation was injected into the raw data, and sequentially corrected by the GPP during the processing. **Figure 6 (a)** shows the residual re-estimated Faraday rotation after applying the GPP correction and **Figure 6 (b)** the corresponding geolocation error associated to the residual ionosphere after GPP correction. The residual error is mostly very small, only noticeable towards the edge of the swath in azimuth.

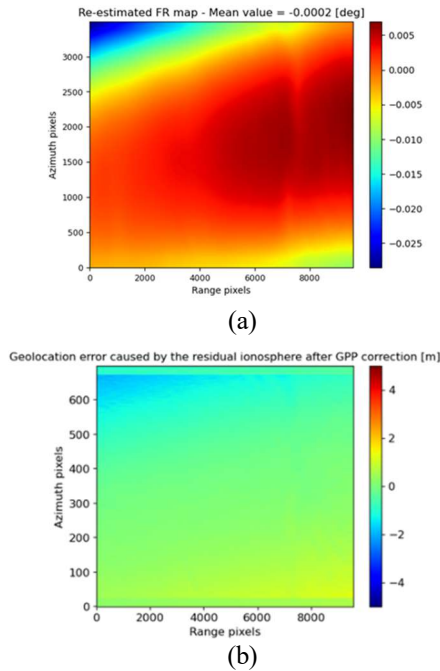


**Figure 6:** (a) Residual Faraday rotation map (in degrees) after applying GPP correction, and (b) corresponding geolocation error (in m) caused by the residual ionosphere after GPP correction (first sub-swath, first burst).

Another very relevant aspect for ROSE-L is the impact of thermo-elastic distortions (TED). The large and lightweight SAR antenna in ROSE-L is rather sensible to changes in thermal conditions, impacting the actual shape of the antenna beam, and therefore affecting the achievable SAR performance and product quality. In order to mitigate such effect, a dedicated TED modelling and compensation strategies are being investigated. However, even after correction, one might assume a remaining deformation caused by the uncertainty of the TED deformation model itself. For illustration purposes, we consider a scenario with a residual displacement of approximately 3 mm for the edge antenna panels, while the inner panels are much less affected. Then, a similar simulation set-up as for the first ionospheric case presented above has been considered, but in this case no ionospheric contribution has been incorporated; instead, the impact of the residual TED has been considered only for

the slave acquisition, while keeping the master acquisition error-free. **Figure 7 (a)** shows the interferometric phase error caused only by the accuracy of the TED deformation model, and **Figure 7 (b)** shows a profile of the averaged interferometric phase error along azimuth for each of the individual sub-swaths. Overall, the mean value of the residual error is rather small, but the sinusoidal pattern might have an impact on interferometric-based applications.

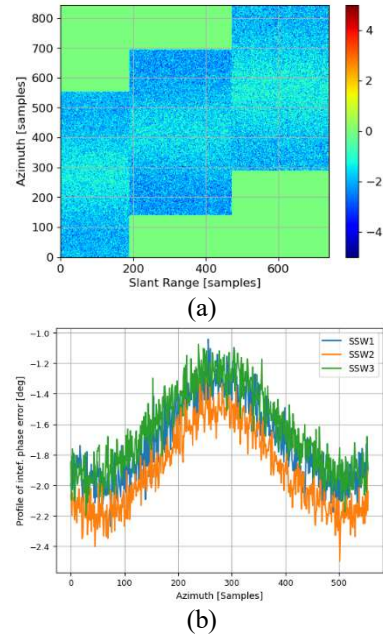


**Figure 7:** (a) Interferometric phase error (in degrees) caused by the accuracy of the TED correction algorithm, and (b) corresponding averaged phase profiles (in degrees) as a function of azimuth samples for each sub-swath.

## 4 Conclusions

ROSE-L is a next SAR Copernicus mission meant to complement the Sentinel-1 family. By exploiting a lower central frequency, ROSE-L will support applications which rely on higher penetration capabilities in different application domains. However, this ambitious mission will need to overcome some challenges to achieve all mission requirements. To support the mission verification during the Phases B2 and C/D in terms of instrument design, pre-launch mission performance assessment, ground segment development, ground processor simulation, development of calibration algorithms and in-orbit mission performance verification, a dedicated E2E simulation tool named C-REEPS was conceived and is being developed. The tool allows the simulation of raw data including all relevant effects expected by ROSE-L, and also the focusing of the L1 products as will be delivered by the mission. Besides some basic scenarios, other relevant scenarios have been simulated and analysed as well for this paper, which might require further attention in the immediate mission stages.

## Acknowledgments

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