EOEP-5
Infrastructure Mapping and Planning (EO4Infrastructures)

Final Report

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AMENDMENT RECORD SHEET

Issue	Page(s)	Section(s)	Description
1.1	14	3. Project Tasks and Developed Products	Columns “Scope” and “Service updates frequency” added to Table 2: Developed products per End User and AOIs

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LIST OF ACRONYMS

AOI Area Of Interest
AWARE Agile Monitoring of Assets and Resource - Application platform
CLC Corine Land Cover
CSV Comma Separated Value
CLMS Copernicus Land Monitoring Services
DEM Digital Elevation Model
DS Distributed Scatters
EO Earth Observation
ESA European Space Agency
EU European Union
EGMS European Ground Motion Service
GIS Geographic Information System
GNSS Global Navigation Satellite System
HR High Resolution
InSAR Interferometric Synthetic Aperture Radar
NDVI Normalized Difference Vegetation Index
NDWI Normalized Difference Water Index
OGC Open Geospatial Consortium
OSO Occupation des Sols (Land Cover Map for France)
PS Persistent Scatters
PSI Persistent Scatters Interferometry
PSP Persistent Scatters Pairs
RFI Rete Ferroviaria Italiana
RPAS Remotely Piloted Aircraft Systems Services
SAR Synthetic Aperture Radar
SNCF Société Nationale des Chemins de fer Français
TS Technical Specification
UN User Need
VA Value Added
VHR Very High Resolution

1. INTRODUCTION

The Copernicus Land Monitoring Service CLMS already makes available a set of EO derived products, useful for the monitoring of the European infrastructures, and a new service, the European Ground Motion Service EGMS, became operational in this period. The combined use of these assets can greatly improve the quantity and quality of information available to the European infrastructure monitoring systems.

1.1. PROJECT GOAL

The key goal of this Project is to demonstrate that these Copernicus Services, combined with other EO derived products and in-situ data, provide a real benefit to End Users.

The Project has been focused on the monitoring of railways. This choice has several motivations. First of all, the EU considers the railway infrastructure a strategic sector with a significant economical relevance. The sector is also subject to specific EU regulations, and this fosters the standardization of workflows and best practice among the EU, easing the adoption of standardised EU Copernicus core Services like the newcomer European Ground Motion Service. At the same time the railways End Users are already used to share information and best practices in the many existing EU working groups.
Furthermore, the management of railways is in charge of national centralized entities and the End User identification and involvement is straightforward. This element is crucial because the key factor to reach the project objective is represented by the level of End User engagement and support to the Project activities.

To this purpose, the End Users managing the national railways of three countries, Italy, France and Germany, have been enrolled in the Project Team. Actually, in each of these countries there are very motivated End Users, already aware of the potential of Ground Motion and other EO-based services and ready to operationally validate their use in the monitoring systems they manage.

1.2. PROJECT TEAM

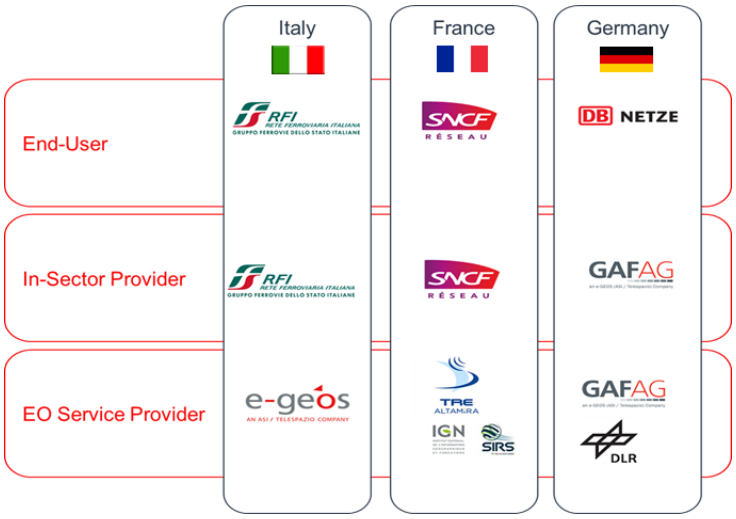
The approach adopted for **the Project Team**, has been to set-up, for each of the involved country, an Integrated Country Team composed by:

- The End User: The entity in charge of the railways network management in the country;
- The in-sector Provider: A public or private entity involved in the provision of data and information used in the national railways monitoring system;
- The EO Service Country Provider: A player with long experience in the provision of EO services to private and public market.

According to this, the Project team is composed by a manifold group of entities and companies and it is organized with very clear responsibilities, as defined in the next figure, to assure the achievement of the project objectives and to maximise the know-how and the background experience of all the teammates.

In the following the team members with their backgrounds and roles in the Project, are described.

Figure 1: Project Team and Integrated Country Teams



The Project team is led by **e-GEOS**, an ASI (20%) / Telespazio (80%) company, within the Leonardo Group.

> e-GEOS is a leading international player in the Earth Observation and Geo-Spatial Information *business. e-GEOS offers a unique portfolio of applications services, also thanks to the monitoring capabilities of COSMO-SkyMed Constellation, and has acquired leading position within European Copernicus Program. Application services include: monitoring for environmental protection, rush mapping in support to natural disaster management, specialized products for defence and intelligence, oil spill and ship detection for maritime surveillance, interferometric measurements for landslides and ground subsidence analysis, thematic mapping for agriculture and forestry.*

e-GEOS is supported by 4 subcontractors:

- **TRE Altamira** is a subcontractor acting as EO Service Provider in France and Worldwide Ground Motion Services Provider;
  > *TRE ALTAMIRA is a company specialized in Earth observation that offers millimeter measurements of ground motion and mapping solutions from radar satellite image processing. TRE ALTAMIRA is the result of the merger within the CLS group of the companies ALTAMIRA INFORMATION and TRE (Tele-Rilevamento Europa, created in the late 1990s by radar experts from the French Space Agency (CNES) and the Politecnico di Milano respectively. These world-renowned teams developed their own advanced interferometric processing chains, known as Stables Points and Permanent Scatterer Interferometry, creating a technological break from the chains used by the scientific community to study seismic events and monitor volcanological phenomena.*
- **SNCF**, in particular the unit of SNCF named “ATT” is a subcontractor acting as end user and in-sector Provider in France;
  > *SNCF Réseau is the owner and main manager of the French national rail network. The company is responsible for the maintenance of the rail network, the construction of new railway lines and manages the traffic of all trains using the national rail network.*
- **RFI** is a subcontractor acting as end user and in-sector Provider in Italy;
  > *RFI - Rete Ferroviaria Italiana is the company of the Ferrovie dello Stato Italiane Group with the public role of Infrastructure Manager, responsible for management and for safety of the rail traffic on the whole national network, track, stations and installations.*
- **GAF** is a subcontractor acting in Germany as in-sector Provider and EO Service Provider.

GAF is a private sector enterprise founded in 1985 in Munich, Germany and is one of the leading European companies in the field of geo-information. GAF has more than 30 years of international experience in working with EO data, covering all technical aspects in the fields of forestry, land use and land cover, security and disaster monitoring, urban mapping, agriculture and others.

In addition to the subcontractors, the Team is supported by:

- In the provision of EO products / information in France by **SIRS** and **IGN** as external service of TRE Altamira;

  SIRS *(Spatially Referenced Information Systems), a CLS group company, supports international and local players in the management of land resources. For more than 30 years, the company has been producing geographical data based on satellite and airborne platforms (aircraft and drones) but also in situ measurements.*

  IGN *(National Institute of Geographic and Forest Information) is the French National Mapping Agency, placed under the responsibility of the Ministry for Sustainable Development and of the Ministry of Agriculture. IGN is the official reference for geographic and forest information in France, certified to be neutral and interoperable.*
- In the provision of the Ground Motion products from Sentinel-1 in Germany by **DLR** as external service of GAF.

  DLR *is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures.*
- By **DB NETZE** in the provision of external support to GAF as end user and in-sector Provider in Germany.

  As a subsidiary of Deutsche Bahn AG (the national railway company of Germany), DB Netz AG is responsible for the country's rail infrastructure. DB Netz AG's most important mission is to guarantee the basis for safe and reliable rail transport operations.

2. BACKGROUND, OBJECTIVES AND WORK-LOGIC

2.1. BACKGROUND CONTEXT AND OBJECTIVES

The approach proposed in this project is to integrate into the monitoring systems of the End Users a set of baseline products, based on Copernicus programme, able to provide a reliable analysis over very large areas, together with a combination of EO products, based on very high resolution optical and SAR commercial data, able to provide an on-demand, detailed analysis over limited critical areas.

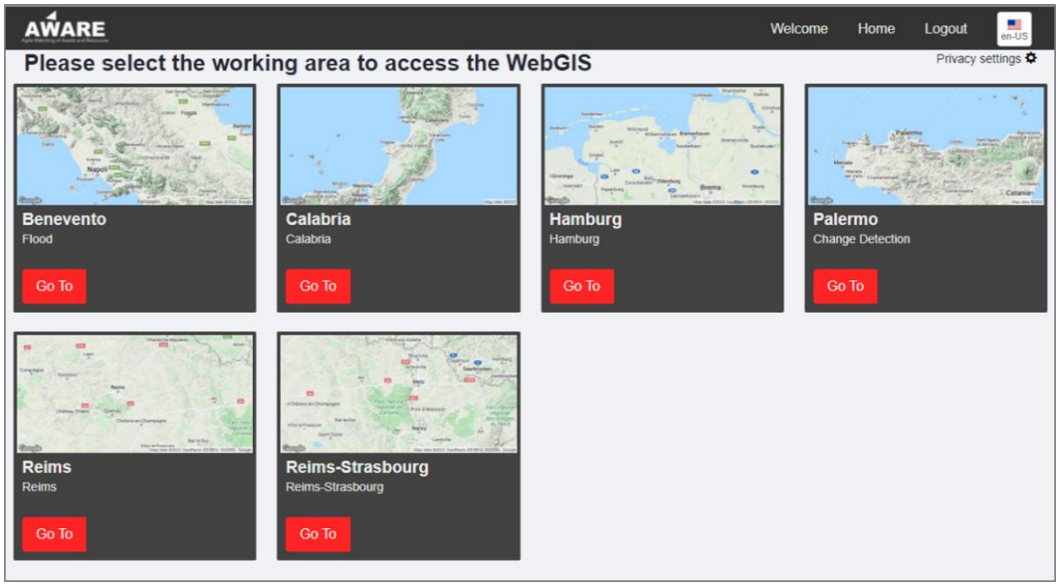
In particular, Copernicus Land Monitoring Services (CLMS), which is based on Sentinel-1 SAR and Sentinel-2 optical data analysis, represents part of the baseline products. These products enabled the identification, through the collaboration between each End User and the Contractor, of areas, which show dangerous phenomena that are relevant with the infrastructure monitoring.

The preliminary product portfolio identified in the Proposal, based on Contractor's previous research projects and operational experiences in railway infrastructure monitoring and maintenance services, was structured as follows:

- Baseline products (Copernicus Land Monitoring Services - CLMS):
  - European Ground Motion Service (EGMS) from Sentinel-1 SAR
  - Corine Land Cover (CLC)
- Very high-resolution additional products:
  - Ground motion from VHR commercial constellations (e.g. Cosmo-SkyMed, CSG, TerraSAR-X)
  - Land Cover based on high resolution optical data
  - Flood map & risk assessment
  - Change detection and encroachment analysis
  - SAR Change Detection

Furthermore, the Project leveraged on the AWARE Platform, designed to provide access to a wide variety of users to the Ground Motion, as well as to other EO and non-EO products. The AWARE platform was customised for the selected End Users acting as the **EO4Infrastructure Platform**.

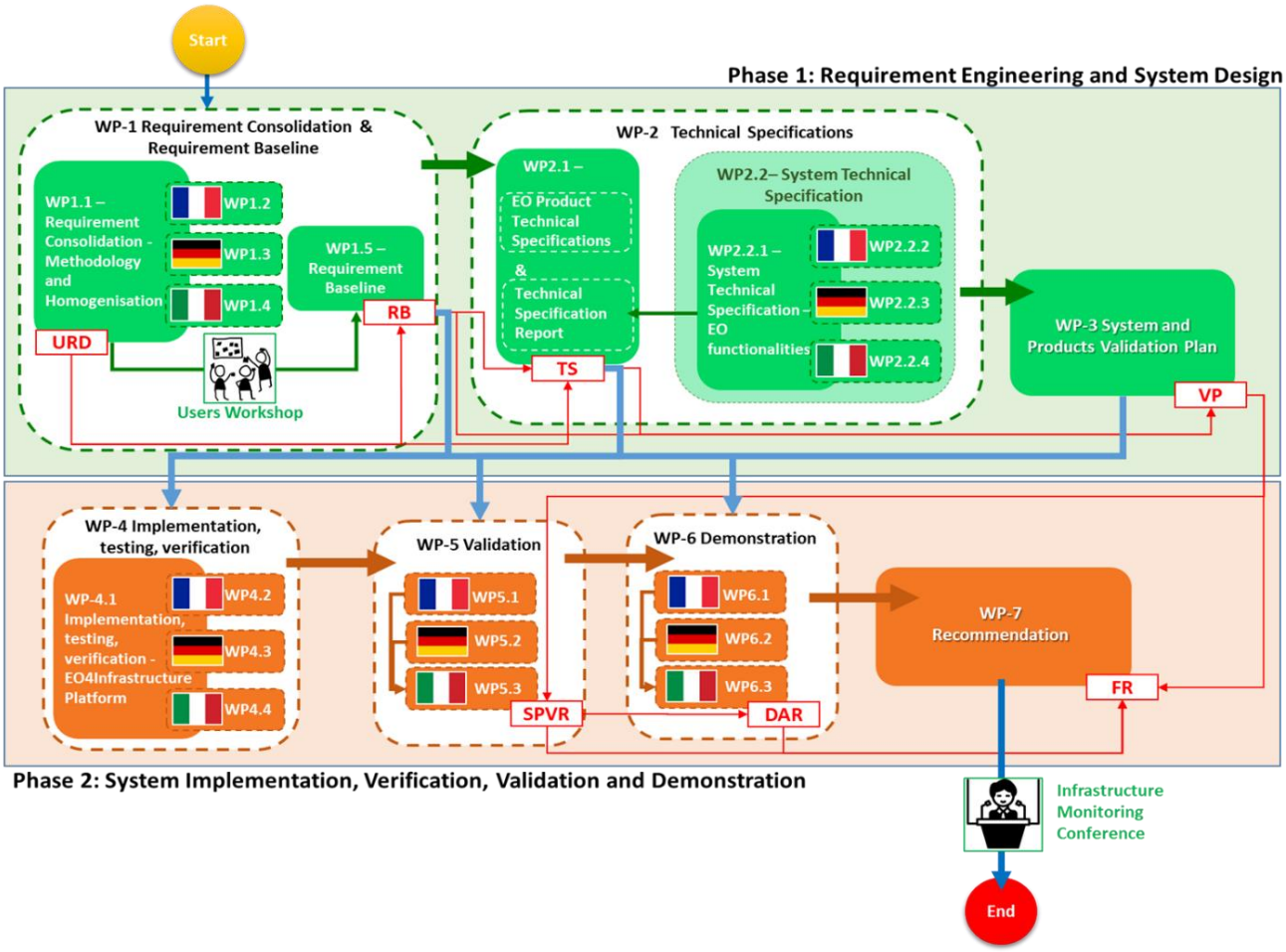
Figure 2: EO4I access page on the AWARE Platform



2.2. WORK-LOGIC

The work-logic followed by the Project indicates the steps for reaching this goal.

Figure 3: Project work logic



The work was structured in two main phases:

<u>Phase 1: Requirement Engineering and System Design</u>

- Key End Users have been engaged since the proposal preparation activities. Through the End Users engagement,
- It had been possible to have a real and complete knowledge of the information needs of the operational infrastructure monitoring systems. For this reason, user requirements consolidation and requirements baseline definition activities characterized more than half of the first phase of the EO4Infrastructure Project.
- The subsequent activities, focused on the definition of the Technical Specifications, has further analysed and detailed the requirement baseline. This activity provided the Agency and the End User with a clear and unambiguous technical description of all the EO products and systems at the detail level necessary to the End User to evaluate not only the Technical Specifications, but also the System and Products Validation Plan adopted for the validation performed in the second phase of the Project.

Phase 2: System Implementation, Verification, Validation and Demonstration

- The engagement of the Users has not been limited to the requirements collection. They played a crucial role also in Validation and Demonstration phases. During the Validation phase, users have been asked to operate the monitoring system, analyse the products and verify the integration of the whole solution within their internal systems and operational workflows.
- The successive Demonstration phase has been a rehearsal of the operational implementation of the solution within end users' systems. During this step the user had access to the system and to the additional services that the system was configured to provide, always supported by the EO service providers for the analysis of the data and the identification of anomalies.
- The end of the Demonstration phase has been used to draw conclusions, analysing results, lessons learnt and gaps still to be filled for a complete adoption of the proposed portfolio and system.

Each of the phases was complemented by a workshop:

- The End User Workshop, held on March 19th 2021 during the phase 1 to assess the effectiveness of the identified user needs and consolidate the requirements in a robust and shared structure to be used for the definition of the requirement baseline.
- The final Conference, held on November 7th 2022 at the end of phase 2 to assess the overall results of the Project and draw recommendations.

3. Project Tasks and Developed Products

Seven main tasks were identified in accordance to the Figure 3: Project work logic.

They are summarised in Table 1: Project tasks:

Table 1: Project tasks

Phase 1: Requirement Engineering and System Design	▪ Task 1 Requirement Consolidation & Requirement Baseline With the collection of user needs documented in the [DIL-4] "User Requirement" deliverable. A user workshop open to an enlarged audience has been organized, and a first definition of the product portfolio has been defined in the [DIL-4] "Requirement Baseline" deliverable.
	▪ Task 2 Technical Specifications With the specification in terms of products and system functionalities. The output has been the [DIL-6] "Technical Specification" document.
	▪ Task 3 System and Products Validation Plan The validation plan for products and for the systems has been defined and released within the [DIL-7] "System and Product Validation Plan"
Phase 2: System Implementation, Verification, Validation and Demonstration	▪ Task 4 Implementation, testing, verification The system has been implemented in terms of new functionalities to be added and of interfaces with users' systems. Sample products over the AOI has been procured or retrieved and prepared for their use during the Validation phase.
	▪ Task 5 Validation To demonstrate the benefits of the whole solution in terms of systems and product portfolio. EO service provider supported the end user in the testing operation according to specific scenario defined in Task 3. An analysis of the demonstration results has been reported in [DIL-7] "System and Product Validation Report".
	▪ Task 6 Demonstration During the Demonstration phase, the end user practice with the system within its operation environment, exploiting the product portfolio integrated with its own reference data. An analysis of the demonstration results has been reported in [DIL-9] "Demonstration Analysis Report".
	▪ Task 7 Recommendations A complete review of the whole project has been released in this [DIL-11] "Final Report", including lessons learnt and recommendations for the future evolution of the system, analysis benefits brought by the proposed solution, and gaps to be filled in order to foster the use of EGMS and other Copernicus services by the railway industry.

Fourteen specific needs have been identified by the end users and associated to a set of six different Value added EO products composing the Project product's portfolio.

Seven target areas of investigation (AOIs) were identified to run the production and the validation. These areas are located in Italy, France and Germany.

The outcomes of the work carried out during the first phase is summarised in the following Table 2: Developed products per End User and AOIs.

Table 2: Developed products per End User and AOIs

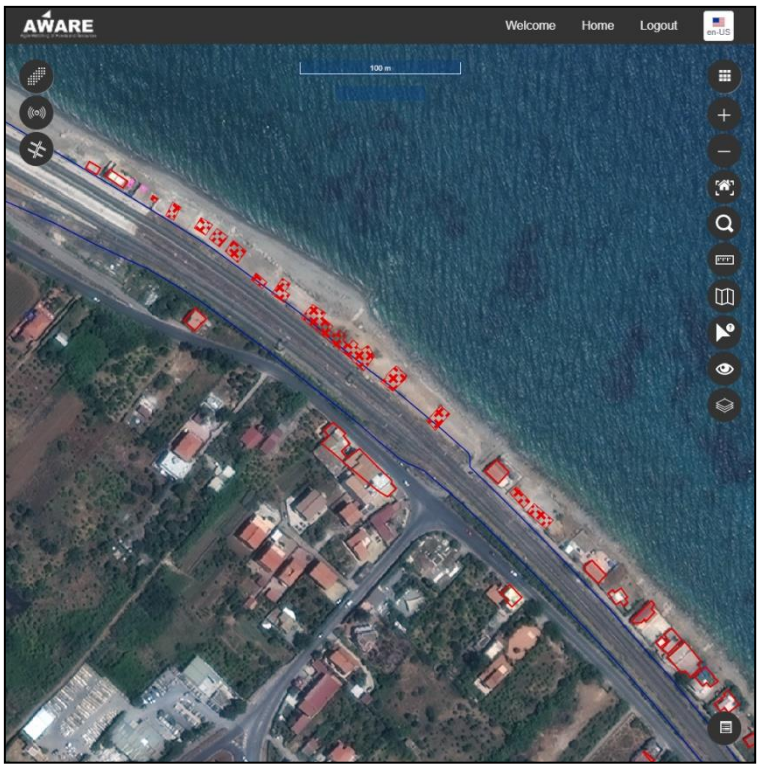
End User	Reference User Need	AOIs	Value added EO Product	Scope	Service updates frequency
RFI	[UN-08] Building monitoring within reserved Areas	Palermo and Fiumetorto	[VA-01] Building Monitoring	To identify any change in buildings inside an area of 60 meters centred on the railway	Every six months over the whole infrastructure. Historical Archive of the service with at least the last 10 years.
RFI	[UN-09] Vegetation Encroachment Monitoring	Palermo and Fiumetorto	[VA-02] Vegetation Encroachment Monitoring	To monitor an area of 100 metres centred on the railway, to detect the presence of vegetation that could interfere with the railway service and its safety.	Monthly updates for major lines and bimonthly for minor lines. Historical Archive of the service starting from 2010.
DB NETZE	[UN-03] Geologically induced Movements - Sub erosion in the Karst, Salt DOMES, Mining sites and tectonically active areas	Hamburg extended	[VA-03] Medium Resolution Ground Motion Maps	Long-term subsidence analysis in broader area of the track of about 1000m both sides of the corridor.	Updates every 3 months or 1 month, depending on cause. The service should go back 5 years.
DB NETZE	[UN-04] Ground movements due to groundwater fluctuations	Hamburg extended	[VA-03] Medium Resolution Ground Motion Maps	To provide long-term ground movement information in areas with significant groundwater fluctuations in a distance of about 1000 along both sides of the track of the entire railway network to avoid rising maintenance costs in the future.	Quarterly updates for main routes. Biannual updates for secondary routes. The service should go back at least to 2015.

End User	Reference User Need	AOIs	Value added EO Product	Scope	Service updates frequency
DB NETZE	[UN-06] Long-term monitoring of climate changes	Hamburg extended	[VA-03] Medium Resolution Ground Motion Maps	Long term monitoring of ground movement related to climate changes in regional scale at least over a corridor of 1000m along both sides of the railway for the entire network, but possible including the whole area of the country.	Annual updates. The service should provide archives dating back to 2010.
DB NETZE	[UN-01] Monitoring of Soundproof Walls	Hamburg Altenwerder	[VA-04] High Resolution Ground Motion map	Monitoring of soundproof walls, which may suffer critical inclination or severe damages mainly caused by turbulences from high speed trains or storms, but also due to local geological or hydrological conditions, is an important need for DB infrastructure managers and life cycle managers.	Monthly updates along high-speed lines. Quarterly updates along non-high-speed lines. An information age of 2 years is desirable.
DB NETZE	[UN-02] Monitoring of Bridges	Hamburg Altenwerder	[VA-04] High Resolution Ground Motion map	Long-term subsidence analysis in broader area of the track of about 1000m both sides of the corridor.	Weekly-monthly updates for main routes. Monthly-quarterly updates for secondary routes. The service should go back at least to 2015.

End User	Reference User Need	AOIs	Value added EO Product	Scope	Service updates frequency
DB NETZE	[UN-05] Slope and embankment Monitoring	Hamburg Altenwerder & Hamburg extended	[VA-03] Medium Resolution Ground Motion Maps [VA-04] High Resolution Ground Motion Maps	Detection of active ground movements related to landslide, rock falls, mudflows, debris flows in a wider area of 1000 meters along both sides of the track in mountainous areas, as well in a narrow area 30 m along both sides of the entire railway network to support the infrastructure experts with updated valuable information regarding stability and security of the track.	Weekly-monthly updates for main routes. Monthly-quarterly updates for secondary routes. The service should go back at least to 2015.
DB NETZE	[UN-07] Monitoring of slow driving points that are induced by ground movements	Hamburg Altenwerder & Hamburg extended	[VA-03] Medium Resolution Ground Motion Maps [VA-04] High Resolution Ground Motion Maps	Long term monitoring of geologically induced Slow Driving Points, but also others, like temporary slow driving points related to earthworks between 30m and 1000m on both sides along the railway, depending on the type and characteristic of the slow driving point/section.	Quarterly monitoring. The service should go back at least to 2015.

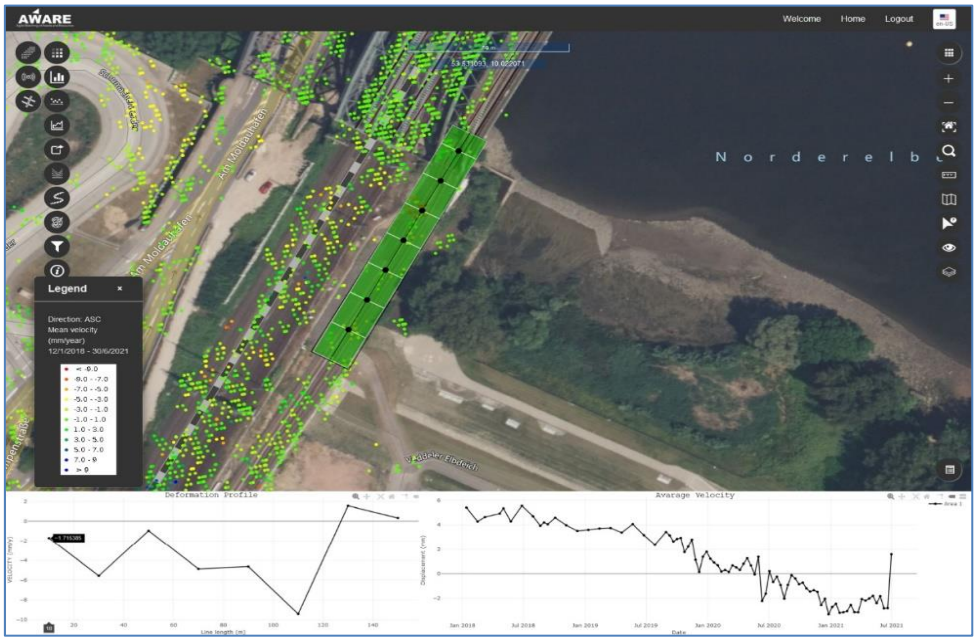
End User	Reference User Need	AOIs	Value added EO Product	Scope	Service updates frequency
RFI	[UN-10] Hydrogeological Instability Monitoring	Rosarno and Parghelia	[VA-03] Medium Resolution Ground Motion Maps [VA-04] High Resolution Ground Motion Maps	Detect and monitoring of all the areas over a 2km wide corridor and centred on the railway track that are affected by hydrogeological instability.	Monthly frequency of monitoring updates. An archive of the measurements dating back to 2010.
SNCF	[UN-12] Earthworks monitoring	Paris and Strasbourg	[VA-03] Medium Resolution Ground Motion Maps [VA-04] High Resolution Ground Motion Maps	For the detection of ground movements affecting railway infrastructures	Monthly or bimonthly frequency updates.
SNCF	[UN-13] Land coverage in the environment of the lines	Paris and Strasbourg	[VA-05] Medium Resolution Change Detection Map	To provide a detailed analysis of changes that occurred over a specific land cover.	Weekly updates based on the monitoring of NDVI. Update of the land cover map based on one year of monitoring.
SNCF	[UN-14] Soil Moisture Content	Reims	[VA-05] Medium Resolution Change Detection Map	To provide a detailed analysis of changes that occurred over a specific land cover.	Weekly update of the soil moisture based on the monitoring of NDWI. Update of the land cover map based on one year of monitoring.
RFI	[UN-11] Flooding Risk Mitigation	Benevento	[VA-06] Advanced Flooding Models and Map	To represent the impact of a flooding event by modelling the water fluxes and the water levels in the area under investigation.	On demand /event based Archive with analysis of past events to map areas of risk dating back to 2010.

Figure 4: Example of Building Monitoring within reserved areas



Change detection over VHR WV-2 mosaic 2017-2020 / Palermo – Fiumetorto (Sicilia, Italy)

Figure 5: Example of Bridge Monitoring using High Resolution Ground Motion map



PSP-IfSAR analysis with HR TerraSAR-X acks 2018 to 2021 / Hamburg-Altenwerder (Germany)

Figure 6: Example of Earthworks monitoring using Medium Resolution Ground Motion map

Earthworks correlated to ground motion identified with InSAR S-1 results along the railroad network between Reims and Strasbourg

The list of EO satellite data used to generate the EO products is reported in Table 3: EO satellite input data.

They are both commercial and free (from Copernicus and ESA Third Party Mission).

Table 3: EO satellite input data

EO data used	Num images	VA Product	VA Product
WorldView-2 over Sicily region	2	01 02	01 - Building Monitoring 02 - Vegetation Encroachment Monitoring
Sentinel-1 IW ascending stack over Hamburg	~250	03	03 - Medium Resolution Ground Motion Maps
Sentinel-2 stack over Hamburg	~300	03	
TerraSAR-X Stripmap ascending stack over Hamburg	83	04	04 - High Resolution Ground Motion map
Sentinel-1 IW ascending stack over Calabria	~320	03 & 04	03 - Medium Resolution Ground Motion Maps and 04 - High Resolution Ground Motion Maps
Sentinel-1 IW descending stack over Calabria	~320	03 & 04	
COSMO-SkyMed HI ascending stack over Calabria	78	03 & 04	
COSMO-SkyMed HI descending stack over Calabria	43	03 & 04	
Sentinel-1 IW ascending stack over NE of France	~330	03 & 04	
Sentinel-1 IW descending stack over NE of France	~330	03 & 04	
COSMO-SkyMed HI descending stack over NE of France	52	03 & 04	
Two Sentinel-2 descending stacks over Reims	~350	05	05 - Medium Resolution Change Detection Map
COSMO-SkyMed HI images over Benevento	2	06	06 - Advanced Flooding Models and Map
Sentinel-1 IW image over Benevento	1	06	

4. EXECUTION AND OUTPUTS OF THE VALIDATION ACTIVITIES

The validation activity started with the preparation of the Validation Plan. The plan contained several test scenarios designed to validate that the Value Added EO products are suitable to cover the end user needs. Some other tests were focused on the project platform and its suitability for the validation and demonstration phases.

The validation plan contained 28 test cases. Each test case was defined with a short description, the requirement addressed, the input and output specifications and the pass/fail criteria.

Eight test cases were defined over the user needs identified by RFI, six in relation with SNCF and fourteen regarding DB-Netze. There were two test cases for each pair [UN#, VA#]:

- One to validate the capability of the VA product to accomplish the user need, and
- One to validate the capability of the project platform to access the VA product in relation with this user need.

After finishing the Validation Plan, all the tests were run and the results were collected in the Validation Report. The test evaluation was performed by both, the end user and the service provider.

Figure 7 shows and example of the test case assessment collected from the analysis done over Italy in relation with the Flooding Risk Mitigation user need. This test was run by RFI and e-GEOS.

Figure 7: Example of Test case evaluation over Italy related with the Flooding Risk Mitigation user need

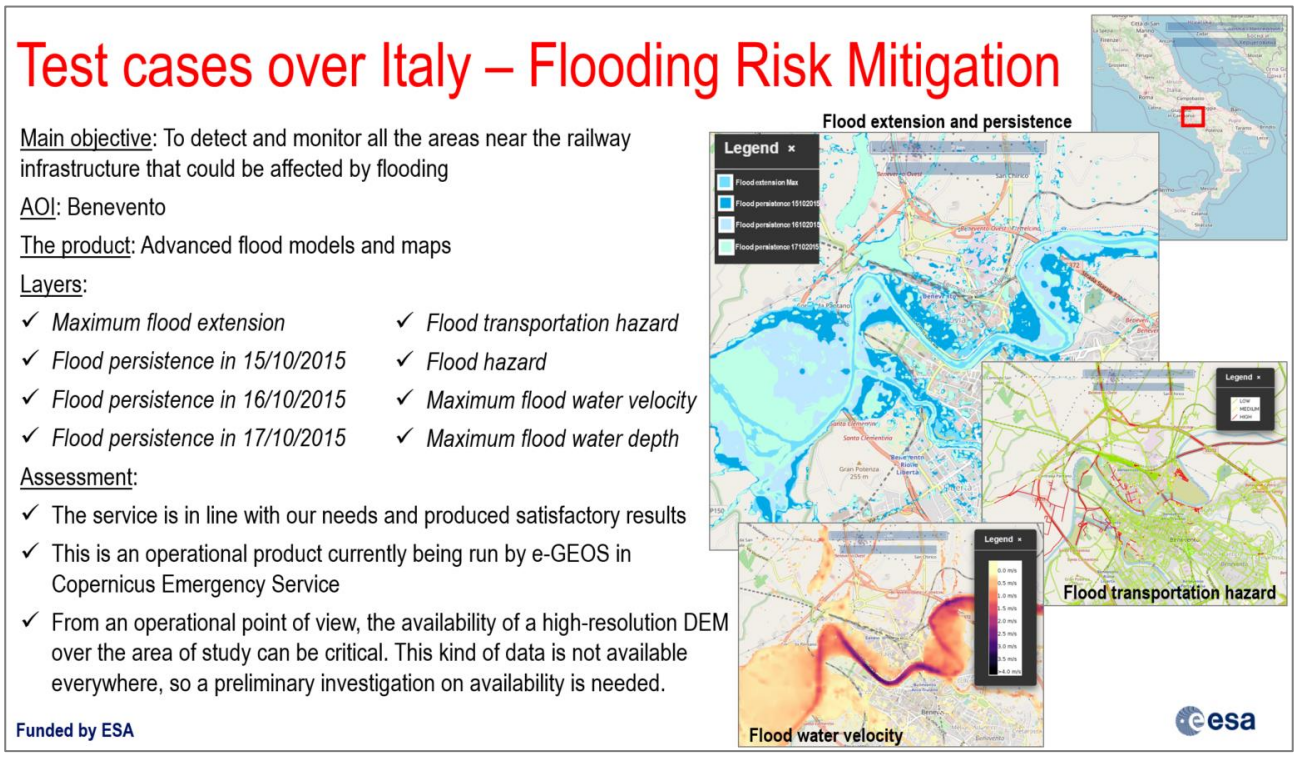


Figure 8 shows and example of test case assessment collected from the analysis done over France in relation with the Earthworks Monitoring user need. This test was run by SNCF and TRE Altamira.

Figure 8: Example of Test case evaluation over France related with the Earthworks Monitoring user need

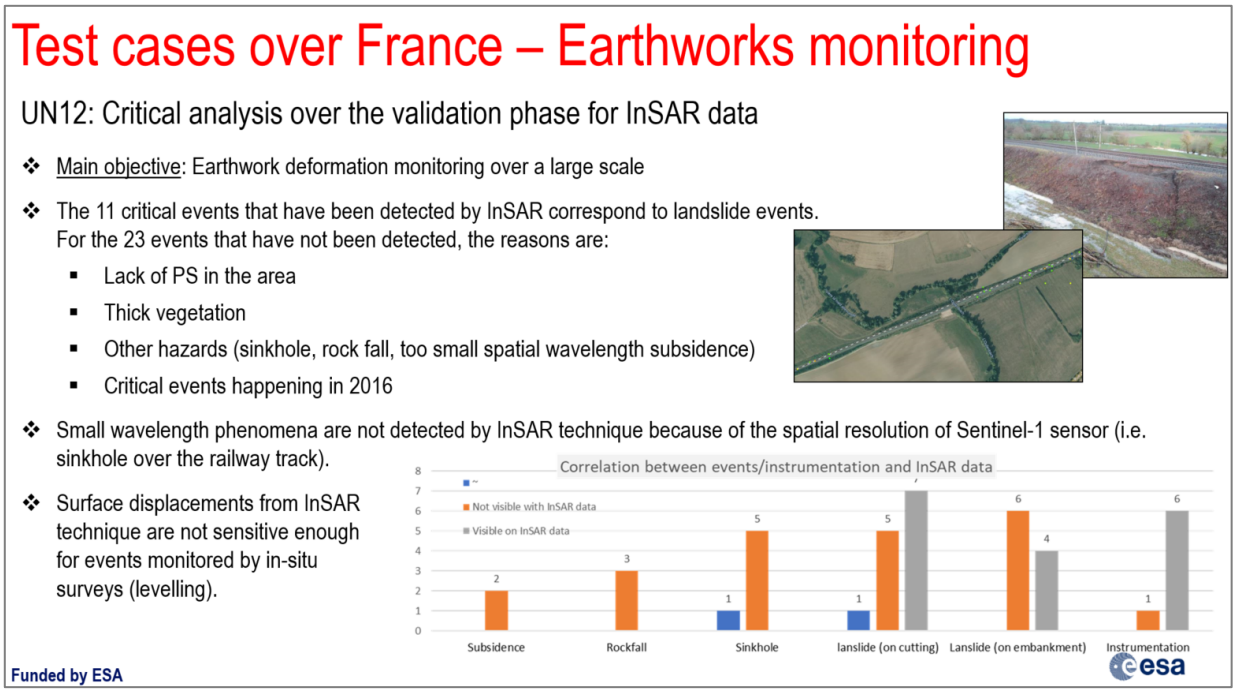
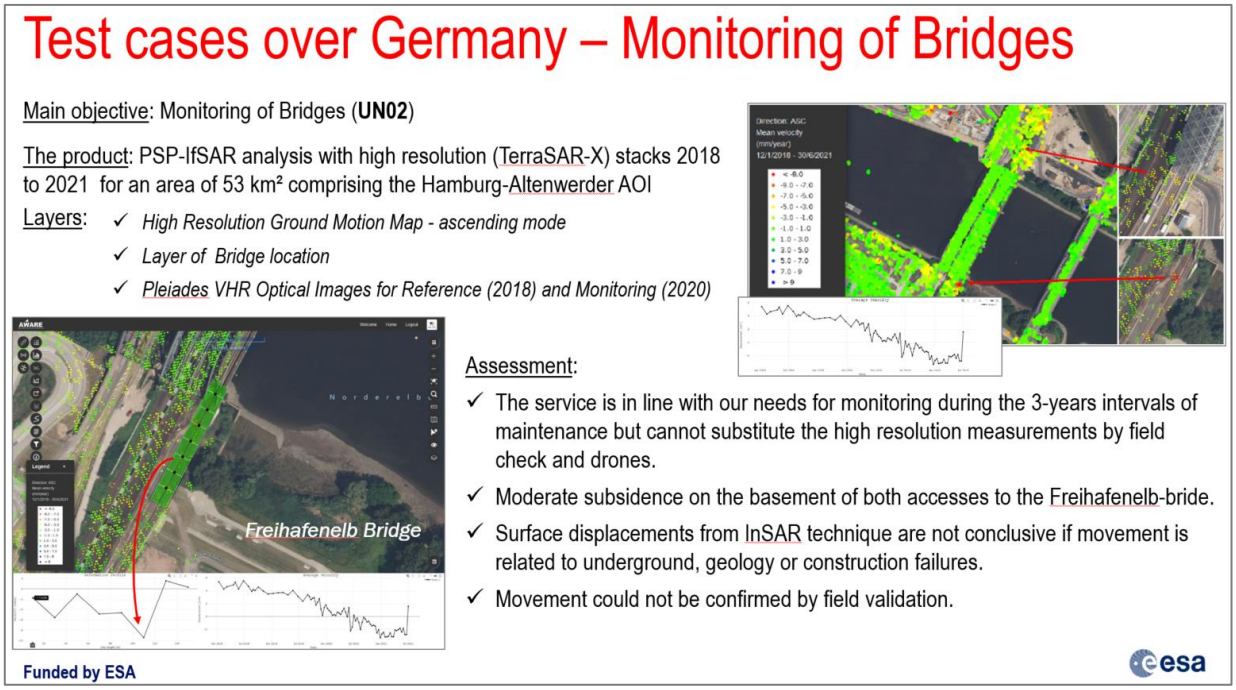


Figure 9 shows and example of test case assessment collected from the analysis done over Germany in relation with the Monitoring of Bridges user need. This test was run by DB-Netze and GAF.

Figure 9: Example of Test case evaluation over Germany related with the Monitoring of Bridges user need



All the EO products were successfully validated to address the identified user needs although some limitations on the techniques/products were highlighted:

- Vegetation height not estimated by Vegetation Encroachment Monitoring [RFI]
- Some deformation critical events not detected by medium resolution InSAR [SNCF, RFI]

The assessment collected during the validation process contains recommendations for the definition of the operational scenario in the demonstration activities. E.g.:

- Use of short (few months) temporal periods for Building and Vegetation Encroachment Monitoring [RFI]
- To facilitate the extraction of information from InSAR products [RFI, DB-Netze]

The test cases run to validate the project platform provided the following assessment:

- The platform allows the visualisation and downloading of all the products derived in this project
- The ingestion process needs to be done by an AWARE/e-GEOS operator
- The ingestion of InSAR datasets (VA03 and VA04) is an operational process in AWARE platform
- The ingestion of all the other products are not a standard for the platform and some ad-hoc work was needed in order to provide a proper visualisation
- The platform is in line with the needs described in the requirements with the exception of:
    - [EO4I-AWAR-FUNC-0120] as it is not possible to save the last view done by an user
- e-GEOS collected a list of recommendations from the End Users in order to improve the user experience with the platform

5. EXECUTION AND OUTPUTS OF THE DEMONSTRATION ACTIVITIES

The Demonstration activities were defined as a rehearsal of an operational implementation of the identified solutions within the end users' systems.

The objective was to show how the availability of the information provided by the VA products technical specifications, over the Areas of Interest in the three countries, contributes to the End Users' workflow, and what type of changes are required to streamline its exploitation.

The approach followed in each country consisted in:

- Assisting the end user in operating the monitoring system
- Gathering Use Cases. Proper Use Cases scenarios, based on those defined in the System and Product Validation Plan, were analysed from the end user point of view by analysing the impact of the baseline and additional VHR EO products, the system/user interfaces implemented and their integration within the End User's workflows.
- Evaluating the utility of baseline and additional VHR EO products. The Service Providers supported the End User in all the relevant tasks, from the identification of the most suitable products, up to their interpretation and correct utilization within the End User's workflows.

The main highlights on the demonstration activities over the three countries are described in the following subsections.

5.1. DEMONSTRATION ACTIVITY OVER ITALY

The demonstration activities performed by RFI and e-GEOS over Italy covered the four user needs identified by this End User. Table 4 details the Use Cases identified by RFI.

Table 4: Use Cases identified over the RFI's user needs

Building Monitoring	
UC1 - Periodic monitoring of the whole network	Periodic monitoring of the 30m buffer strip. The service must show any changes to existing buildings, new buildings and highlight any interference with the 6m buffer.
UC2 - On Demand monitoring in specific areas and times	ON DEMAND monitoring of the 30m buffer strip. The service must show any changes to existing buildings, new buildings and highlight any interference with the area of respect
UC3 - Historical database	Creation of a database listing buildings and related information, including cadastral information and any granting of specific RFI authorisations
Vegetation Encroachment Monitoring	
UC1 - Periodic monitoring of the whole network	Periodic monitoring of the 50m buffer strip. The service must show any changes in vegetated areas, new ones and highlight any interference with the 5m buffer.
UC2 - On Demand monitoring in specific areas and times	ON DEMAND monitoring of the 50m buffer strip. The service must show any changes to vegetated areas, new ones and highlight any interference with the area of respect (5m from each rail)

Vegetation Encroachment Monitoring	
UC3 - Historical database	Creation of a database listing vegetated areas and related information (e.g. inspections carried out, mowing of vegetation, etc.)

Hydrogeological Instability Monitoring	
UC1 - Periodic monitoring of the whole network and of surrounding area	Periodic monitoring of the 1km buffer strip. The service must detect and monitor all the areas near the railway infrastructure that are affected by hydrogeological instability, which could interest the railway and its infrastructures by using multi-images InSAR analysis with medium resolution Sentinel-1 data. Frequency: monthly.
UC2 - Complementary monitoring in specific areas and times	Complementary monitoring in specific areas and timing. The service includes the monitoring specific areas of interest by using multi-images InSAR analysis with high resolution COSMO-SkyMed data.
UC3 - Historical database	The service must provide a historical maps of the surface movements (ideally form 2010), the identification of active landslides, a land use cartography, the measurement of vertical and horizontal displacements of the railway by using both high resolution COSMO-SkyMed data and medium resolution images (e.g. ERS, Envisat, Sentinel-1).

Flooding Risk Mitigation	
UC1 - Analysis of past events to map areas of risk	The service must provide historical maps of major floods interfered with the railway infrastructure (ideally form 2010) providing measurements over a corridor that is at least 2 km wide and centred on the railway track, but possible including the whole area of the basin.
UC2 - Plan analysis for forecasted events	The service must provide in the shortest time possible after the activation of the service maps of floods interfering with the railway infrastructure and advanced food models and maps (e.g. Maximum flood extension, flood persistence, flood transportation hazard, etc.).
UC3 - Emergency mapping	The service must provide maps of floods interfering with the railway infrastructure in the shortest possible time after a flood event, including advanced food models and maps (e.g. Maximum flood extension, flood persistence, flood transportation hazard, etc.)

The assessment performed on these Use Cases concluded that the VA EO products are in line with RFI needs, however some limitations and gaps could be identified:

- **Optical images limited by sun illumination and cloud coverage**. This limitation impacts in the generation of VA01 and VA02 as both are based on satellite optical images. During winter months, the acquisition of suitable data can be limited, especially in the northern area of RFI's territory.
- **Vegetation Encroachment monitoring products** (VA02) **present some limits in providing accurate vegetation height** in order to distinguish between bushes and trees. However, the information provided by the product is considered positive although it doesn't reach all the requirements.

- The delivered product is in line with the needs described in the requirements collecting phase: < 5% of the buildings were not mapped; the vegetation reference/change detection maps provide a classification linked to the vegetation height: bush (1-4m) and trees (more than 3m) (< 5% of the vegetation was not mapped);
- Sentinel-1 based Medium Resolution Ground Motion Maps, even providing a high temporal resolution (up to 6 days with S1B), **detected a limited number of critical phenomena** interfering with the railway. However, in many cases, they permit the identification of potential local instabilities and their usage is envisaged for the availability of historical database (UC1 in Table 4) and for allowing a periodic monitoring of the entire national network (UC2 in Table 4).
- **Vegetation** influenced the capability of **InSAR** technique to monitor known landslide processes developing in rural areas interfering with the railway network. The gap could be partially filled with L-band data.
- From **ground motion maps** a great effort must be made by the end-user to extract valuable information about the critical areas. It would be highly **desirable to obtain value-added products in terms of identification and classification of the critical sections/anomalies**, or rather a synthetic product derived from InSAR ground motion maps that is directly interpretable by the end-user (e.g., interference maps, active landslide mapping, risk classification, etc.).

In order to include the analysed EO products into RFI operational process, the following steps are needed:

- **Design satellite data acquisition plan**. A suitable acquisition plan should be designed for optical and high resolution radar satellite data in order to allow periodic monitoring. The medium resolution radar satellite is already continuously acquiring data over all Italy thanks to Copernicus service Sentinel-1 satellite.
- **Standardisation of outputs** of the VA products to match the current RFI database format used for each identified UN, in particular for buildings.
- The **emergency service for floods should be as short as possible** (i.e. data acquisition, processing and delivery), possibly enabling to detect interferences with the network before on-site operators.
- For the Flooding Risk Mitigation user need, a **criteria** based on forecasted events **should be defined to trigger a planned analysis**.

5.2. DEMONSTRATION ACTIVITY OVER FRANCE

The demonstration activities over France were performed by SNCF as end user and TRE Altamira as EO services provider.

The analysis on the project platform detected some difficulties when using it:

- The workflow is not intuitive and slow because of the number of images which have to be charged separately. Loading the graph of a PS is too long (just clicking and having a pop-up graph of the time series within the workspace would be much easier). Data graphs have to be resized every time you want to display another point.

- The searching button works for names of cities or longitude/latitude information. For an end-user such as a railway company, a search service with line and kilometre points is important.
- Different possibilities of modifying (colours and shape) of the input would be interesting.

A part from the difficulties detected using the platform, the VA product analysed by the SNCF and TRE Altamira can be used and the project showed good results. The identified needs were partially satisfied.

SNCF has a continuous need of preventing critical events and deformation movement over the railway network. In this sense, this study has shown great possibilities and it can be concluded that the generated products can be used as macro-monitoring products. InSAR technique with Sentinel-1 data allows to the generation of ground deformation maps at a large scale and offers an overview of the railway network.

The assessment performed over France was focused in three cases:

- Case A: Monitoring of a well-known event - Clay swelling over a bridge. The comparison between InSAR results and in-situ topographic survey showed consistency in terms of accuracy and consistency in terms of temporal behavior, see Figure 10. The SqueeSAR® analysis enables us to observe that the area that is affected by the highest displacements is not already monitored and can induce an expansion of the in-situ monitoring.
- Case B: Detection of a new behaviour - Prevention over an earthwork bound to a civil engineering structure. The comparison between InSAR results and in-situ topographic measurements shows consistency in terms of accuracy and velocity, see Figure 11. These results show the added-value of using EO products from a prevention perspective which can be validated with in-situ measurements.
- Case C: Contribution of multi-data analysis. There is a real interest from SNCF to integrate several types of data on the same platform (piezometers, inclinometers, topographic measures, etc.). The addition of several types of data can allow a complete analysis of earthwork and its health. This type of cross-analysis shows that it is possible to extract a large amount of information only when exploiting EO products. These EO products are often associated with the constraint of being blind to the ground truth (in the case where there is no visual inspection or topographic survey). This allows the coverage of a large portion of the railway network with different types of information and does not require systematic in-situ observations. The challenge is to centralise all this information on an ergonomic visualisation platform.

Figure 10: On the left: SqueeSAR® results from Sentinel-1 data (T139) over Case A Structure. Spatial representation of the deformation profile. On the right: comparison between InSAR and levelling (SqueeSAR® in blue and levelling in orange show the same slope)

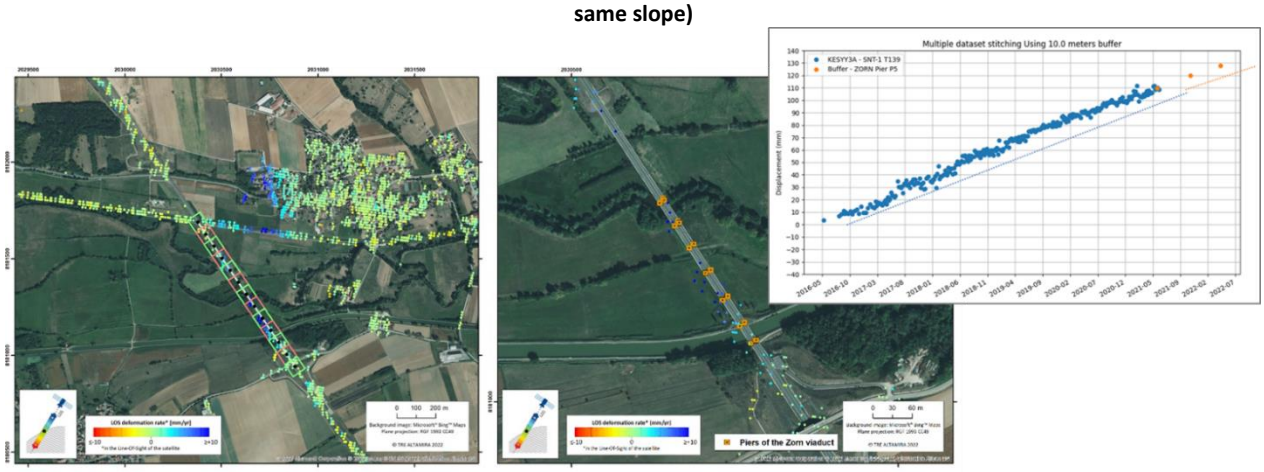
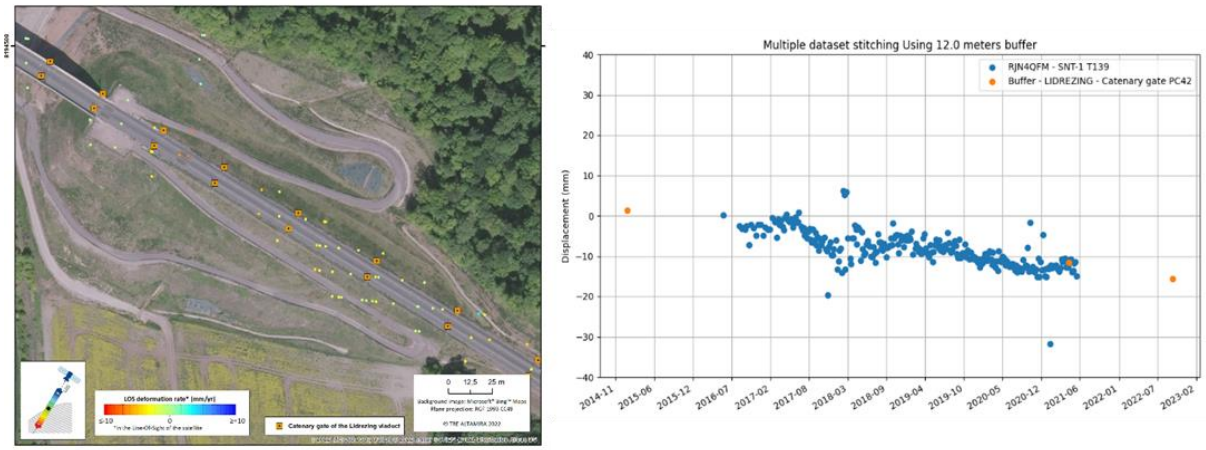


Figure 11: Case B – PC 324-42 comparison between InSAR (in blue) and levelling (in orange)



The demonstration activity over France detected some limits of the techniques and the products used which have to be developed in the future for better use are:

- Too many measurement points that make it difficult to detect a new sensitive area quickly (using displacements, velocity or acceleration) ;
- There is a limitation of using Sentinel-1 data because its pixel size is not suited to monitor every phenomenon affecting railway infrastructures such as small spatial wavelength events, and the lack of measurement points over vegetated areas.
- The COSMO-SkyMED data (and X-band data in general) offer a better spatial resolution but have the disadvantage of being more expensive than Sentinel-1 data.

As a network rail user, this project has shown a good added value of EO products and can be used regarding the limits and recommendations listed in this document.

As a railway infrastructure manager, the product can be recommended to other infrastructure users such as road operators.

Different possibilities can be considered in order to continue the exploitation of EO products. The recommendations are listed below:

- Drastically decrease the number of measurement points (define a motion velocity threshold to highlight only the ground motion) in order to ease the analysis and quickly detect a new sensitive area (using displacements, velocity or acceleration);
- Add a DEM and select earthworks over 3 m high susceptible to having a critical event associated with like a landslide;
- Easily add inputs from the end-user (new earthworks, monitoring, information, etc.);
- Use and monitor measurement points over the earthwork already known;
- Perform a temporal behaviour analysis for each measurement point in order to extract only the ones with significant value of displacement or velocity change decided in advance with the service provider;
- Colour-coded shape files of the earthworks with information from the InSAR results in order to only focus the attention of the end-user on the relevant information.

In order to follow the process of integrating Sentinel-1 data for the railway infrastructure manager, an automatic integration should be done:

- Over specific earthworks ;
- Over the entire railway network (200 m wide centred on the railway) with a sampling of data previously analysed and calculated (with significant value of displacement or velocity change decided in advance with the service provider)
- With a platform updated after every season change (4 times a year, quarterly updates).

5.3. DEMONSTRATION ACTIVITY OVER GERMANY

GAF AG supported DB Netze during the demonstration activity over Germany where the VA EO products exploitation was analyzed for each identified UN though specific Use Cases.

During the VA product exploitation various scenarios were investigated. In direct comparison between High Resolution Ground Motion Maps (HRGM) and Medium Resolution Ground Motion Maps (MRGM) the most significant ground displacements were clearly detected in both products. In many cases, for minor displacements could be observed in MRGM a tendency of displacements. These locations may be mapped automatically and forwarded to the validation group to decide whether a HRGM for that areas will be purchased or other actions and measures are taken.

Table 5 summarize the seven use cases and the conclusions derived from the analysis.

Table 5: Use Cases identified over Germany

Use Case	Conclusion
Case 1 - Sound Wall Monitoring	The Service derived by InSAR technique is not conclusive but may be treated similar as embankment monitoring.
Case 2 - Monitoring of Bridges	The service is in line with DB Netze needs for monitoring during the 3-years intervals of maintenance but cannot substitute the high-resolution measurements by field inspections and drones.
Case 3 - Geologically induced Movements	The service is in line with the end user needs. This is already an operational product currently being run by GAF AG in EGMS.
Case 4 - Groundwater Fluctuations	The service is in line with the end user needs. This is already an operational product currently being run by GAF AG in EGMS.

Use Case	Conclusion
Case 5 - Slope embankment monitoring	User needs of Embankment monitoring fulfilled with HRGM and with limitations for MRGM (lack of points).
Case 6 - Climate Changes	The service is in line with our needs and is valuable for route and infrastructure planning. This is an operational product currently being run by GAF AG in EGMS.
Case 7 - Monitoring of Slow Driving Points	The service with high-resolution ground motion maps is in line with DB Netze needs. The service with medium-resolution ground motion maps is partly in line with DB Netze needs.

For the VA products integration into DB-Netze workflow, two mainly concepts are highlighted:

- A coherent product acquisition plan adapted to end users.
- Data reduction to provide only user relevant information for some of the UN, see Figure 12.

Figure 12: Proposed PSI data reduction plan resulting from DB Netze user needs.

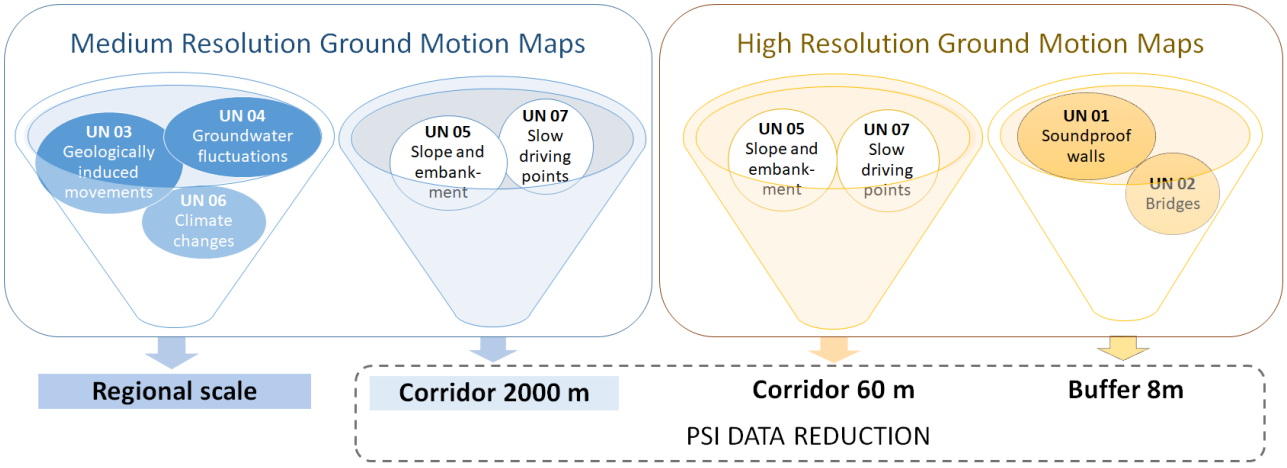
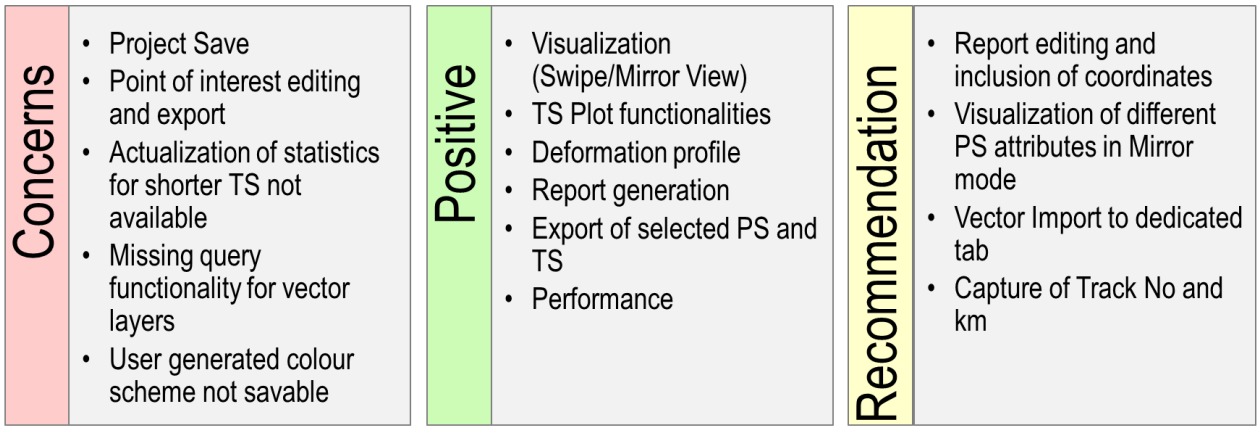


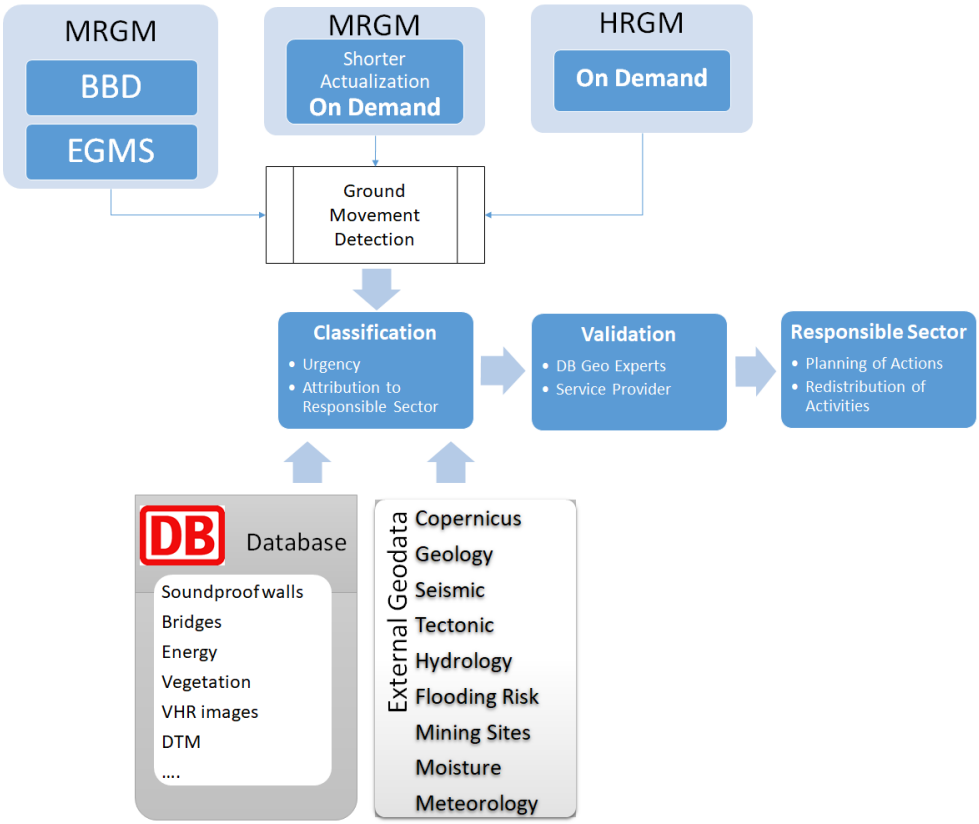
Figure 13 summarize the comments from DB Netze regarding the use of the platform proposed in EO4Infrastructure project.

Figure 13: Comments on the project platform from DB Netze



GAF-AG elaborated together with DB-Netze a potential operational plan (Figure 14) on purpose that only case relevant sectors of DB Netze are involved in the decision-making process.

Figure 14: Potential Operational Plan for Medium Resolution Ground Motion Maps (MRGM) and High Resolution Ground Motion Maps (HRGM) value added product integration at DB Netze



All the EO products were successfully validated to address the identified user needs although some limitations on the techniques/products are highlighted:

- Soundproof Wall Monitoring [UN01] not conclusive whether PS lies on the protection element and, therefore, could be treated similar to slope and embankment monitoring.
- In many cases, also MRGM permits the identification of possible instabilities on bridges [UN02] and their immediate surroundings. The service with HRGM fulfils the needs for monitoring during the 3-years intervals of maintenance but cannot substitute the high-resolution measurements by field inspections and drones.
- Regional monitoring user needs related to geologically induced displacements [UN03], Groundwater Fluctuation [UN04] and Climate Changes [UN06] were mostly fulfilled but are suffering by coarse point density in rural and vegetated areas. These UN could be treated in a customized platform dedicated to infrastructure planners.
- Slope and Embankment Monitoring [UN05] and Monitoring of Slow driving points [UN07] is fulfilled with HRGM and strongly limited with MRGM.
- The achieved results are indicating that especially HRGM are suitable to provide useful information for monitoring of energy supply networks and installations.

6. CONCLUSIONS AND USER'S FEEDBACK

The EO4Infrastructure project team, composed by three pairs of railway sector End Users and EO Service providers, allowed to successfully run this project.

The first phase of the project was focused on the identification of a set of real user needs from the End Users and a list of EO products that can be used to address those user needs. Afterwards, the collection of the specific user requirements and the products technical specifications, allowed the definition of a plan to validate the generated EO products vs the user needs. This phase was concluded with a workshop held online.

The second phase of the project allowed the End Users to work with the EO products applied to their user needs. The validation and demonstration activities were successfully run concluding that the identified EO products were useful for the operational activities with some limitations described in chapter 5 and summarized below. It was also highlighted the importance of combining those products with specific in situ data and complementary information layers as cadastre data, railway network or landslide inventory. This phase was closed with the presentation of the main outcomes in a Final Conference hold on ESRIN premises on November 7th, 2022. The conference was also used to wrap up the main conclusions from the project.

The main comments with regarding the EO products are:

- The EO service providers present in the Project team demonstrate their readiness to deliver all this VA EO products following the end user requirements.
- Most of the end user team have good experience in interpreting EO products, especially if based on optical data. Anyway, massive change detection productions are usually delegated to external EO service providers.
- The situation is different for InSAR-based products. In this case, both the production and interpretation phases require specific knowledge and adequate HW/SW infrastructure. So that the information extracted from the analysis of such products should be provided accompanying the products themselves with a report that synthesise the obtained results in a user-friendly form.
- Although a cost benefit analysis was not under assessment within this Project, the potential usefulness of the proposed EO services has been positively assessed from a technical point of view, applied to specific user needs/use cases. In this context, the reduction of operational costs that could be obtained by adopting the EO services is an expectation that could be eventually assessed with a proper cost-benefit analysis.
- Worth noting that a significant part of the VA products in this Project have been obtained from the available Copernicus Services:
    - All the VA 03 Medium Resolution Ground Motion Maps InSAR products has been provided by the European Ground Motion Service (EGMS). As of the writing date of this report, the EGMS products are available with time series ranging from 2016 to 2020, yearly updates will then follow. This is effectively a push for the use of medium resolution ground motion maps in various user scenarios.
    - The VA 06 - Advanced Flooding Models and Map has been derived from the Emergency Management Service (EMS) and used, as input, land cover maps from Corine Land Cover (CLC) service.

- The Vegetation Encroachment Monitoring needs more detailed results for what concern the evaluation of the vegetation height along the railway tracks. The results obtained with WV-2 as EO input dataset provide classification in two classes (bushes and trees) that in most cases is not enough to provide useful operational information for the end user. Most advanced techniques should be considered (e.g., aerial images, optical EO images with higher resolution, vegetation growth models, etc.) along with a careful cost-benefit analysis.
- The ground motion maps derived from InSAR are extremely useful to be used to decide where to place in-situ measurements and to provide general areal information. However, in most cases, they have to be considered as significant part of an integrated monitoring solution.
- The update frequency of the Medium-Resolution ground motion maps should be seasonal, ideally four times a year, although twice a year could also work. The end users also recommend this update frequency for the EGMS Copernicus service. For special areas, higher update frequencies may be required.
- The number of measurement points provided by the ground motion maps is very high, making the product difficult to use. Relevant information should be provided accompanying the products themselves with a report that synthesise the obtained results in a user-friendly format.
- The classification of urgencies is needed for the decision makers (e.g., for triggering on demand monitoring). Hereby, the availability of homogeneous and actualized complementary information layers for the whole country is required. The association of pluviometry and/or soil moisture data with TS may improve the classification accuracy and contribute to a better understanding of ongoing processes.

In addition, the analysis highlights the usefulness of having a dedicated platform to visualise and analyse the EO products generated over the area of interest and to complement them with georeferenced in situ/information layers provided by the users.

The project also concluded that the EO products identified in this activity are also applicable to other infrastructures sectors as road networks, energy supply systems and transmission lines.

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