EARTH OBSERVATION BEST PRACTICES-ROAD & RAIL

ESA APEX GEOSPATIAL EXPLORER USER MANUAL

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1. INTRODUCTION

The ESA APEX Geospatial Explorer is an interactive platform designed to support decision-making in the Road & Rail sector through advanced Earth Observation (EO) analytics. This tool integrates mature and validated EO products with sector-specific datasets to address high-priority geospatial requirements.

Explore the Geospatial Explorer here→ https://explorer.eo-bestpractices-transport.apex.esa.int/

The current release focuses on three core services->

- **Flood Risk Maps:** Maps flood-prone areas along Italy's railway network using hydraulic models and satellite data to support risk management and infrastructure resilience.
- **Extreme Rainfall Events Risk Maps:** Identifies regions vulnerable to intense rainfall events to help protect railway and road infrastructure from extreme weather impacts.
- **Ground Movement Risk Maps:** Assesses landslide and subsidence risks using InSAR-based ground motion data to safeguard transport networks

The service is offering broad spatial coverage to address a variety of challenges comprehensively. Additionally, hosting multiple risk products on a single platform ensures a streamlined approach for the industry, eliminating the need to seek separate solutions for each hazard. This integration saves time, simplifies decision-making, and promotes cost-effective risk management for road and rail infrastructure.

1.1. PURPOSE

The purpose of this user manual is to guide stakeholders and end-users in effectively navigating and utilizing the ESA APEX Geospatial Explorer for Earth Observation Best Practices (EOBP) rail and road risk analysis. Specifically, the manual aims to:

- Explain the functionalities, tools, and datasets available within the platform.
- Provide step-by-step instructions for analysing Road & Rail sites and surface temperature analysis.
- Support informed decision-making by enabling the integration of EO insights into Road & Rail planning workflows.

1.2. SCOPE

This manual covers the functionalities of the ESA APEX Geospatial Explorer relevant to the Road & Rail Flood Risk , Extreme Rainfall Events Risk and Ground Movement Risk services. It includes:

- Overview of the platform interface and navigation tools.
- Guidance on accessing, visualizing, and interpreting geospatial datasets.
- Examples of practical use cases for the Road & Rail sector.

The manual does not cover related APEX services or advanced customization features beyond the scope of the two prototype services. Future versions may include additional modules as new EO capabilities are integrated.

1.3. DEFINITIONS AND ACRONYMS

1.3.1. DEFINITIONS

Concepts and terms used in this document and needing a definition are included in the following table:

Table 1-1 Definitions

Term	Definition
Flood Hazard Map	A spatial representation of areas exposed to flooding based on hydraulic models and satellite observations.
Hydraulic Model	A computer-based simulation of water flow used to predict flood extent, depth, and frequency.
VIIRS (Visible Infrared Imaging Radiometer Suite)	A satellite sensor providing near-real-time flood mapping using optical and infrared imagery.
Sentinel-1 (SAR)	A European Space Agency (ESA) radar satellite used for flood mapping and ground motion monitoring.
Extreme Rainfall Events	Intense and short-duration precipitation events that may lead to flash floods, landslides, and infrastructure damage.
Return Period	The estimated interval between extreme events of a given magnitude, e.g., 1-in-100-year rainfall.
Percentile Analysis	A statistical method that evaluates rainfall intensity based on thresholds like 90th, 95th, and 99th percentiles.
Ground Movement Risk	The likelihood of land subsidence or landslides that may destabilize infrastructure.
InSAR (Interferometric Synthetic Aperture Radar)	A satellite-based technique that measures ground deformation with millimeter-level accuracy.
EGMS (European Ground Motion Service)	A European service providing ground displacement measurements using InSAR data.
Earth Observation (EO)	The collection, analysis, and interpretation of data about the Earth's physical, chemical, and biological systems, often obtained from satellite or airborne sensors.
ESA APEX Geospatial Explorer	The specific Application Propagation Environments (APEX) based application developed for solar farm site selection and surface temperature analysis, integrating EO and sector-specific data.
EOBP	Earth Observation best Practices project funded by ESA

1.3.2. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 1-2 Acronyms

Acronym	Definition
APEX	Application Propagation Environments
EO	Earth Observation
EOBP	Earth Observation Best Practices
ESA	European Space Agency
GIS	Geographical Information System
JRC	Joint Research Commission
VIIRS	Visible Infrared Imaging Radiometer Suite
InSAR	Interferometric Synthetic Aperture Radar

2. ABOUT ESA APEX GEOSPATIAL EXPLORER

Launched in April 2024, ESA's APEx initiative is designed to expand the practical use of Earth Observation (EO) data and services by transforming research-driven EO tools into reliable, scalable solutions hosted in the cloud. APEx offers a suite of algorithm services and cloud-based applications that simplify the process of turning EO algorithms and prototypes into operational, FAIR-compliant services. By closing the gap between research and real-world deployment, APEx enables projects, companies, and researchers to build on existing EO developments, enhance performance, and ensure sustained, long-term accessibility to valuable EO resources.

Geospatial Explorer (feature of APEx) which is a configurable web dashboard to display and visualize geospatial data. It is an interactive, cloud-based platform that enables users to visualize and analyse Earth Observation (EO) data alongside related geospatial information. It supports viewing EO imagery, derived products, and vector layers with control over transparency, ordering, and split-screen comparisons. Users can inspect data with tools for spatial queries, distance measurement, and interactive charts, while metadata access ensures transparency. Flexible and user-friendly, it integrates EO and non-EO data into custom dashboards for diverse audiences.

Figure 1: Landing page of ESA APEX Geospatial Explore. Explore a Demo here→ https://explorer.demo.apex.esa.int/

3. EOBP ROAD & RAIL SERVICE

Earth Observation technology provides valuable tools for generating risk maps for physical hazards such as floods, extreme precipitation events, and ground instability, specifically for monitoring road and rail infrastructure. By offering broad spatial coverage, consistent monitoring, and access to historical data, EO enables the identification of areas with high exposure and long-term trends that may affect transport networks. Historical EO data can be used to analyse past events, such as flooding or ground deformation, to better understand patterns and predict future risks. This information supports the detection of surface deformation, land subsidence, and flood-prone regions, allowing infrastructure managers to assess risks, prioritise maintenance, and implement cost-effective, proactive strategies to enhance the resilience of road and rail systems.

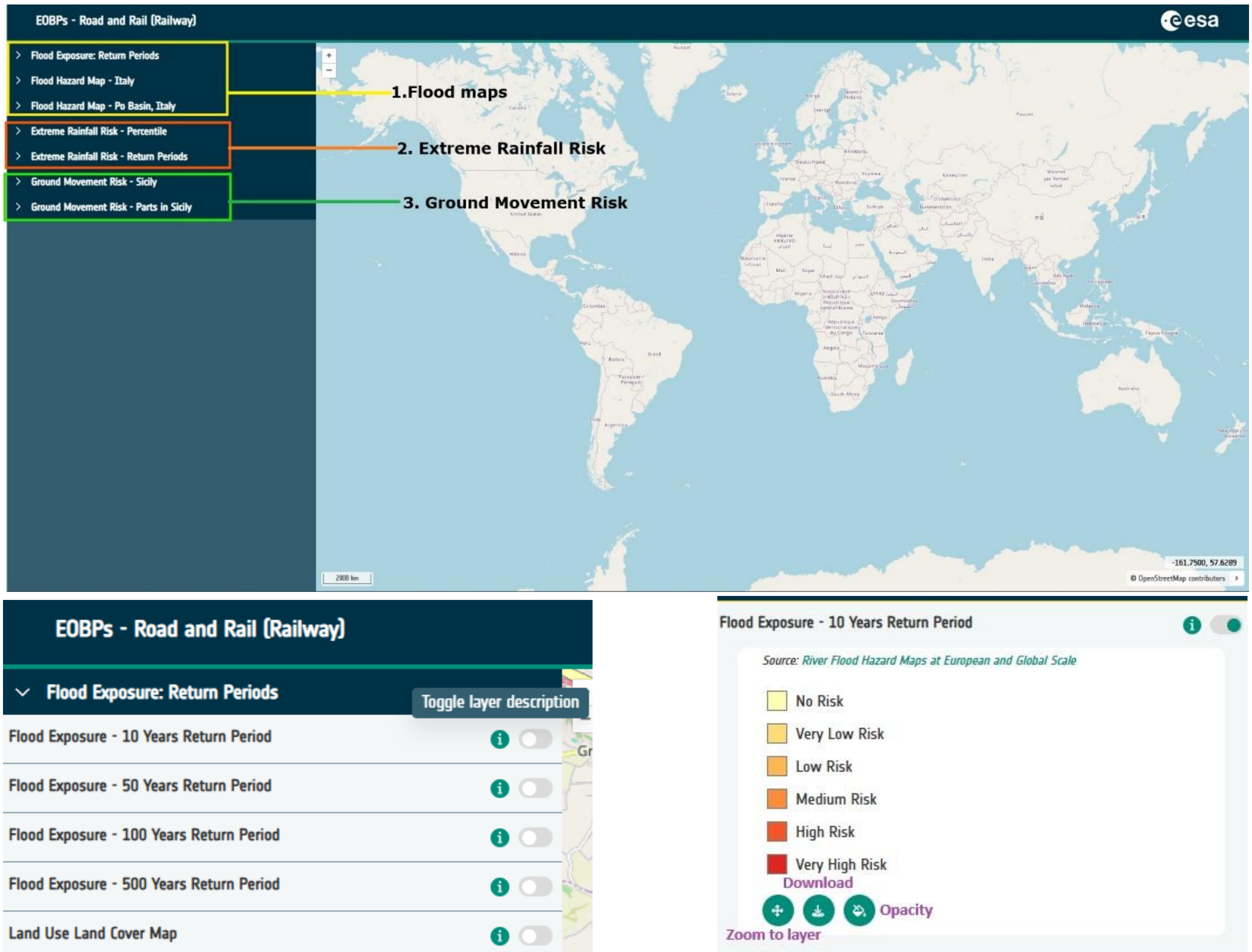


Figure 2: Top: Screenshot of the APEX EOBPs Road & Rail (Railway) landing page. The left panel displays the platform title *"EOBPs – Road and Rail (Railway)"* and lists three groups of available data layers. **Bottom Left:** Screenshot showing the option to expand/collapse the layer description, along with a button to enable visualisation of the layer. **Bottom Right:** Once a layer is enabled, the legend and additional controls appear. These include options to:

- **Zoom to Layer** (required for each layer individually),
- **Download Data**, and
- **Adjust Layer Opacity**.

3.1. Flood Hazard Map

1. Flood Hazard Map

Flooding is a major concern for transport infrastructure, leading to road closures, rail track damage, and disruptions in connectivity. This set of maps helps identify areas at the rail network prone to flooding, enabling proactive measures such as drainage system improvements and flood-resistant design enhancements, ensuring smoother operations and minimised downtime. It utilizes flood hazard maps derived from hydraulic models provided by the Joint Research Centre (JRC) and flood extent delineation and frequency analysis based on remote sensing data from VIIRS and Sentinel satellites. The analysis delivers three key outputs:

a) **Hydraulic model: Return Period Analysis** – A nationwide evaluation of flood by return periods, helping to understand the probability of extreme flood events affecting railway lines. To facilitate risk analysis, the flood hazard levels have been categorized based on simulated **flow depth**, classified into **five categories.**

Table 3-1 Flood Risk Classification

Flood Risk	Flood Depth (m)
No risk	0
Very low risk	0 – 0.5
Low risk	0.5 – 1.2
Moderate risk	1.2 – 2
High risk	2 – 4
Very high risk	> 4

b) **VIIRS - Flood Hazard Mapping** – Satellite imagery-based Flood hazard analysis covering the entire country, offering insights into flood-prone areas along railway networks. Table below shows the flood frequencies have been used to categorize the flood risk map.

Table 3-2 Flood Risk Classification

Flood Risk	Frequency Range (%)
No risk	0
Low risk	0 - 25
Moderate risk	25 - 50
High risk	> 50

c) **Sentinel-1 (S1) Flood Mapping for the Po Basin** – A detailed, satellite-based analysis of recent flood events in the Po Basin, one of Italy's most flood-prone regions.

Table 3-3 Flood Risk Classification

Flood Risk	Frequency Range (%)
No risk	0
Low risk	0 - 25
Moderate risk	25 - 50
High risk	> 50

By integrating these outputs, this study assesses the exposure of Italy's railway network to flooding, categorizing its vulnerability and providing valuable insights for risk management, infrastructure resilience, and future planning. Below is an example of flood hazard risk near the town of Pasaro (Figure 8). Explore further on APEX platform to understand other products such as flood exposure return period.

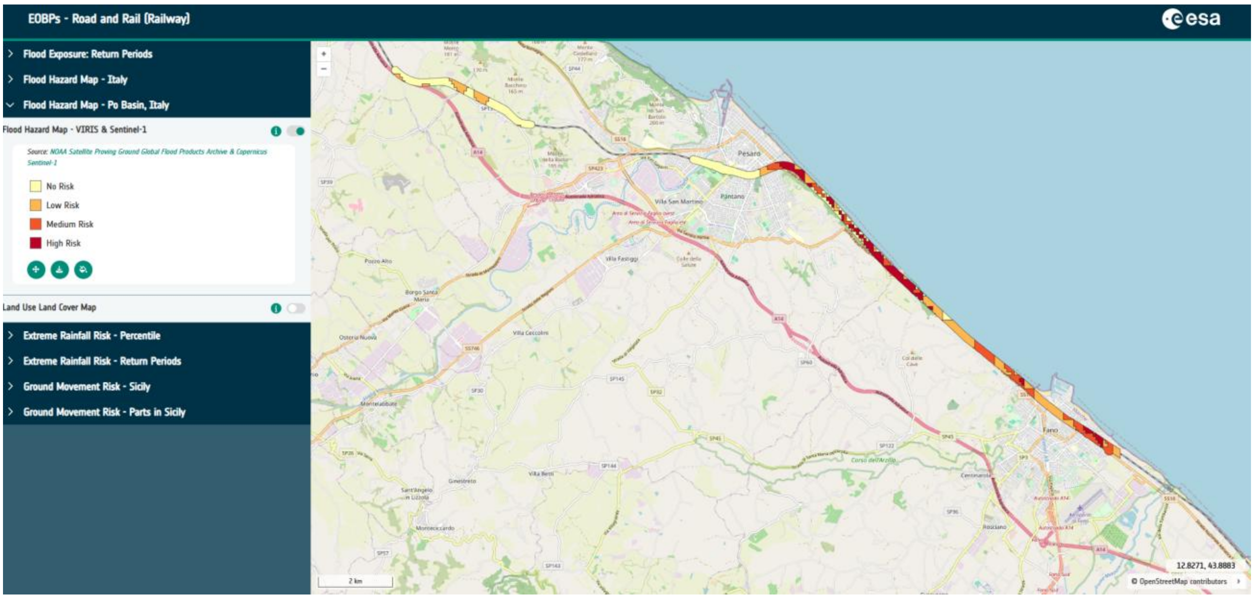


Figure 3 Flood hazard map showing levels of risk associated with railway lines in Italy's North-Eastern town of Pesaro, with sections of the railway lines classified between low and high risk.

3.2. EXTREME RAINFALL EVENTS RISK MAPS

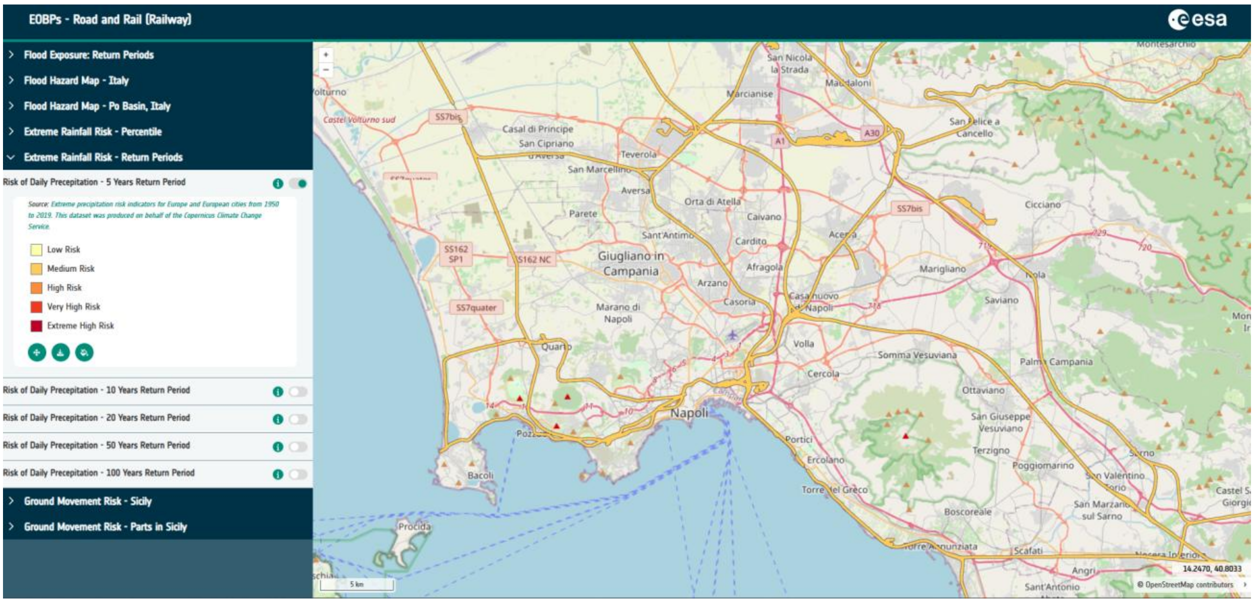
Heavy rainfall can cause surface runoff, erosion, and structural weaknesses in road and rail infrastructure. This map identifies areas exposed to extreme rainfall events risks, enabling infrastructure managers to prepare and take preventative measures in advance. We selected two key indicators to assess extreme rainfall events: Maximum 1-day precipitation (mm) per year, representing rainfall intensity, and Number of precipitation days exceeding 20 mm per year, representing frequency.

a) Extreme rainfall risk- Return Periods

The calculated return levels represent the magnitude of extreme precipitation events for different return periods. For example, for a return period of 100 years, there is a 1% chance of exceeding the return level in any given year. The return period is often used as a measure of the rarity of an extreme event. Shorter return periods (e.g., 5 or 10 years) correspond to less extreme events, while **longer return periods** (e.g., 50 or 100 years) correspond to **more severe, but rarer, events**.

Table 3-4 Rainfall Risk classification

Extreme Rainfall Risk	Daily Rainfall (mm)
Low risk	0 – 20
Medium risk	20 – 60
High risk	60 - 100
Very high risk	100 – 150
Extreme high risk	> 150



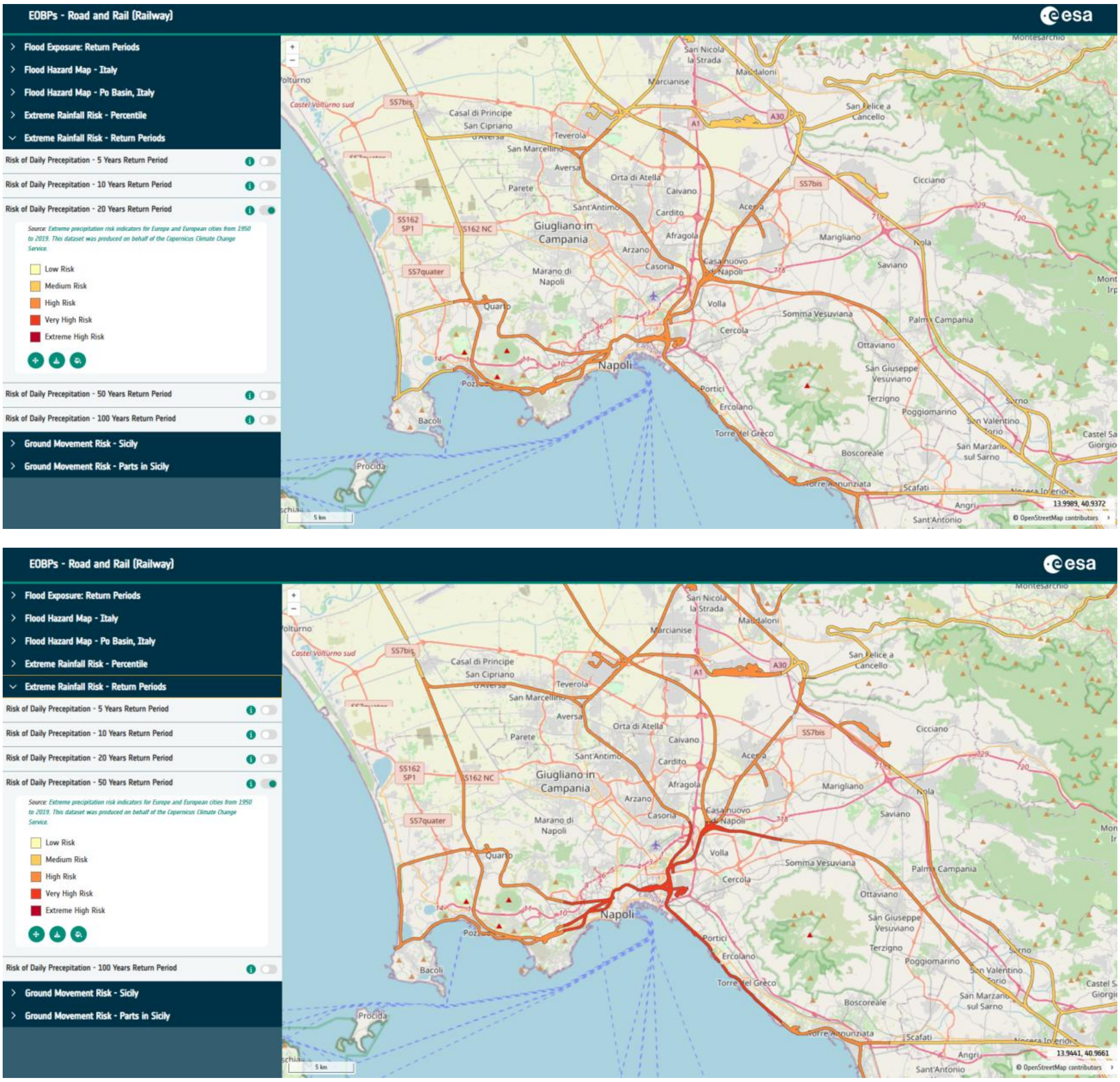


Figure 4 – Map showing risk of daily precipitation return periods over railway lines in Naples, Italy for 5 Years (Top), 20 Years (Middle) and 50 Years (Bottom).

b) Number of precipitation days exceeding 20 mm: Percentile Analysis

These percentiles represent different levels of extreme precipitation events, with the 99% percentile being the most severe and rare, indicating precipitation events that exceed 99% of all observed values. The 90% and 95% percentiles represent progressively less extreme events, providing a range of thresholds that help to assess varying degrees of rainfall intensity and their associated risks.

Table 3-5 Extreme Rainfall Risk classification

Extreme Rainfall Risk	No. of Days Rainfall exceed 20mm
Low risk	0 – 5
Medium risk	5 – 10

High risk	10 - 20
Very high risk	> 20

3.3. GROUND MOVEMENT RISK MAPS

This product, when combined with a slope map, identifies areas at risk of landslides and land subsidence. These hazards pose significant threats to the stability of roads and rail networks, potentially causing structural damage and service disruptions. Early detection of such risks allows for targeted maintenance and mitigation measures, reducing long-term repair costs. This analysis is to detect risks related to slow moving land subsidence (when slope < 10%) and landslides (when slope > 10%). The analysis is based on synthetic aperture radar interferometry (InSAR) analysis. Learn more about this technique here→ https://www.esa.int/About_Us/ESA_Publications/InSAR_Principles_Guidelines_for_SAR_Interferometry_Processing_and_Interpretation_br_ESA_TM-19

a) **For entire Sicily:** This analysis is based on European Ground Motion Service. For the **entire region of Sicily**, the analysis relies on the **European Ground Motion Service (EGMS)**, which provides point-based measurements of ground displacement across Europe using satellite-based InSAR data. These discrete EGMS point measurements were **mosaicked into a spatially continuous 100-meter resolution grid**, enabling regional-scale assessment of ground motion trends, including areas affected by subsidence or slope instability. This approach is valuable for broad, consistent coverage and helps identify areas of interest that may require more targeted investigation.

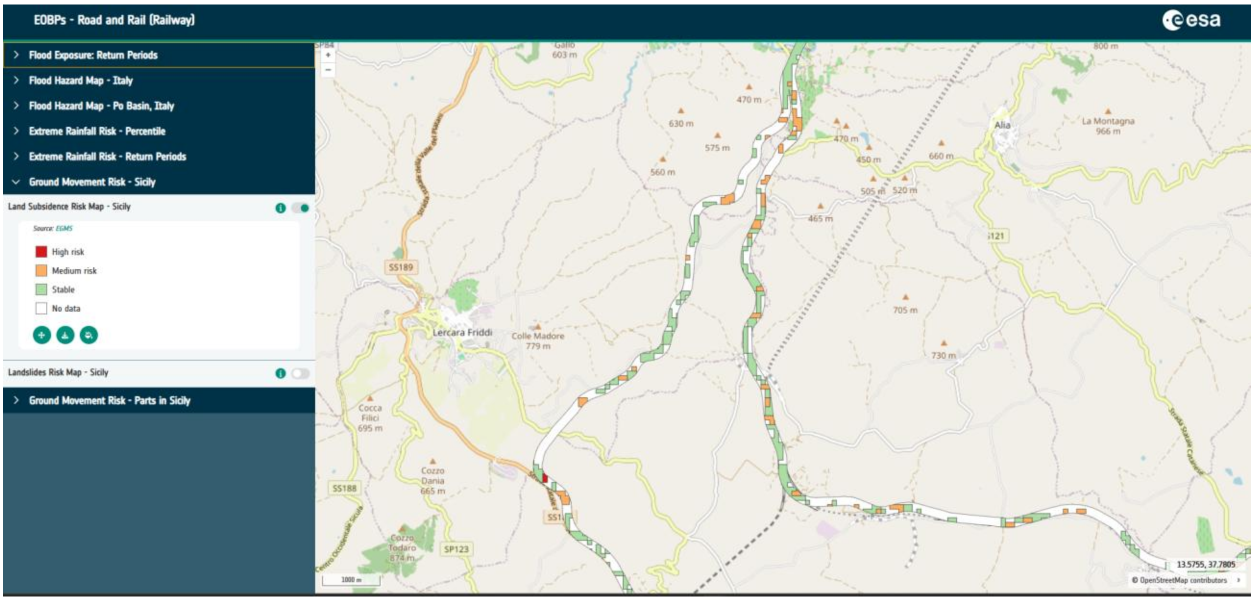


Figure 5: Screenshot of land subsidence risk map over central Sicily.

Table 3-6 Ground Movement Risk

Ground Movement Risk	Velocity (mm/year)
Stable	-3 – 0
Medium risk	-10 – -3

High risk	< -10

b) **Specific regions in Sicily:** In **three specific regions in Sicily**, a more detailed and tailored ground motion analysis was performed using **Interferometric Synthetic Aperture Radar (InSAR)** data from **Sentinel-1**

Table 3-7 Ground Movement Risk

Ground Movement Risk	Velocity (mm/year)
Stable	-3 – 3
Medium risk	-10 – -3 (Or) 3 – 10
High risk	< -10 (Or) > 10

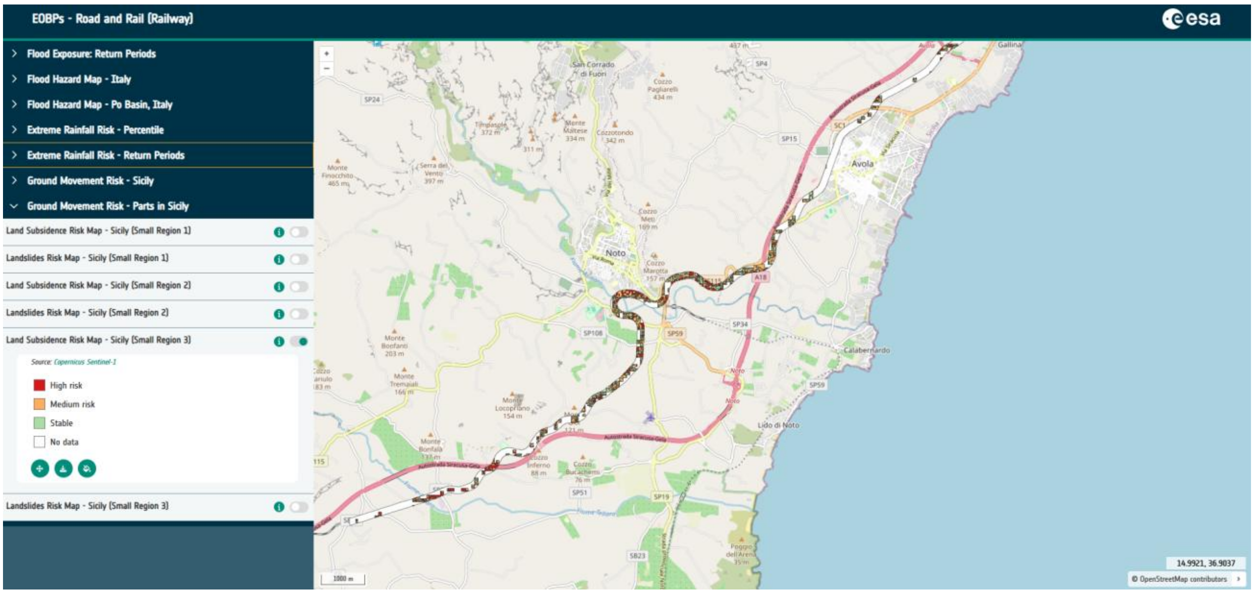


Figure 6: Screenshot of land subsidence risk map near the town of Noto (South-eastern Sicily).

In conclusion, the ESA APEX Geospatial Explorer provides an accessible and powerful platform for integrating Earth observation data into rail and road infrastructure planning, monitoring, and management. By following the best practices outlined in this manual, users can ensure accurate analysis, streamlined workflows, and improved decision-making. We encourage users to continue exploring the tool's advanced functionalities, experiment with datasets, and apply insights to support sustainable transport development.

ESA APEX→ https://apex.esa.int/

Geospatial Explorer→ https://apex.esa.int/services/geospatial-explorer

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