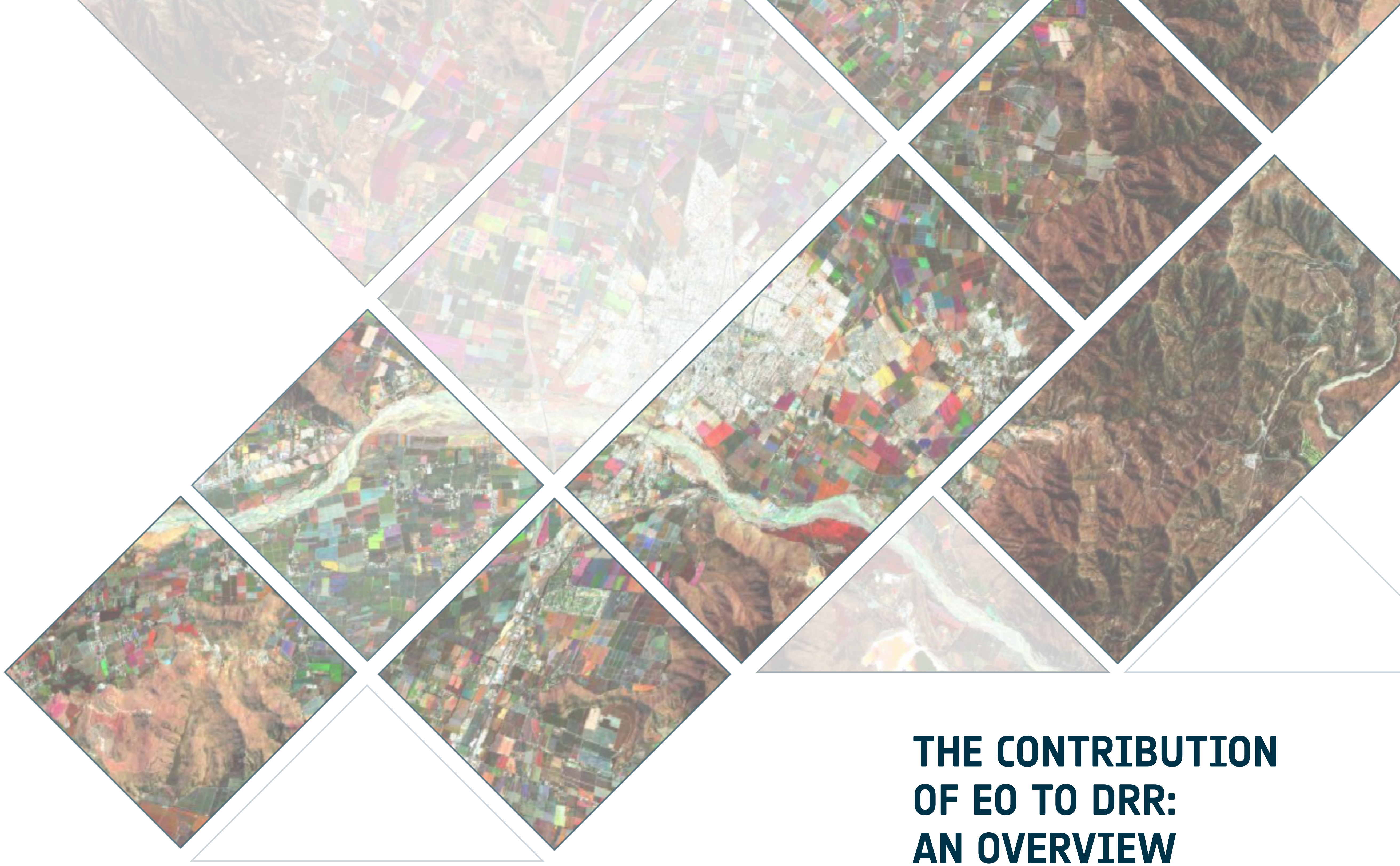
THE CONTRIBUTION OF EO TO DRR: AN OVERVIEW



THE CONTRIBUTION OF EO TO DRR: AN OVERVIEW

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INTRODUCTION

The purpose of this document is to provide an overview of how satellite Earth Observation (EO) can contribute to Disaster Risk Reduction (DRR). This is based on the experience from public and private organisations from the European EO sector with both European and international application.

development projects. It includes a series of application developments performed in the framework of the collaboration between the European Space Agency and International Financing Institutions initiated in 2008[4] . Examples of EO capabilities mentioned in this document are primarily related to activities involving European organisations. For this reason, there may be EO capabilities developed by organisations not based in Europe that are directly relevant and that are not mentioned in this document.

Disasters caused by natural hazards are increasing in frequency and severity and their impacts on human lives, infrastructures and the economy are becoming extremely important, given that urbanization continues to increase the amount of people exposed to these hazards.

Disaster Risk Reduction (DRR) is the initiative of reducing the damage caused by a hazard, while Disaster Risk Management (DRM) is the application of DRR policies and strategies to prevent new disaster risk, reduce existing disaster risk, and manage residual risk. This in turn contributes to the strengthening of resilience and the reduction of disaster loss (United Nations, 2009). For an effective implementation of DRM strategies, the availability, accessibility, and reliability of information is of extreme importance, as well as the knowledge and engagement of the communities. Moreover, this information must have sustainable mechanisms in place for its generation and management.

As defined by United Nations (2009)[5] :

- **Hazard**: process/phenomenon with the potential to produce harm to an asset (a person, an infrastructure). Hazards can be of natural or anthropogenic origin and can be single, sequential (domino hazard) or combined (compound hazard) in their origin and effects.

4 The Global Disaster Assistance initiative, a global partnership to mainstream the use of Earth observation into development operations: https://gda.esa.int/ and https://gda.esa.int/story/esa-and-the-world-bank-15-years-of-collaboration.

5 United Nations International Strategy for Disaster Reduction. (2009). UNISDR terminology on disaster risk reduction.

- **Exposed element (or asset)**: people, property, system, or function that could be affected or lost in consequence of a hazard.
- **Vulnerability**: direct or indirect susceptibility of the exposed element/asset to physical, economic, or social damage or loss. It depends on the asset`s construction mode, content, economic value, and function.

As highlighted in the "Sendai Framework for Disaster Risk Reduction 2015 - 2030"[6], hazards encompass a variety of origins including biological (organic), environmental (chemical, natural, and biological), geological or geophysical (derived from internal earth processes), hydrometeorological (atmospheric, hydrological, or oceanographic), and technological (stemming from technical or industrial conditions) processes.

Geo-information derived from Earth Observation (EO) satellite data and modelling addresses many of the priorities outlined by the Sendai Framework for Disaster Risk Reduction. This includes (i) understanding disaster risks in their multi-faceted forms, (ii) strengthening disaster risk governance to manage the hazards, (iii) investing in disaster reduction strategies for bolstering resilience, and (iv) enhancing disaster preparedness for effective response, with an emphasis on the "Build Back Better" principle in the stages of recovery, rehabilitation, and reconstruction.

DRM is looking at either disaster response (emergencies) or DRR (prevention). DRM is concerned with hazard mapping, mapping exposure (the assets at risk), and assessing vulnerability. EO is an important element for improved knowledge of hazards and risks and a basis for more efficient decision making and better mitigation and preparedness for disasters. Satellite EO can support scientists and operational users for a range of applications.

1. Concerning **disaster risk** reduction: geo-information, with satellite observations and/or models, can provide key information before the emergency phase i.e., before a disaster occurs. It can be used to better understand hazards, for prevention and preparedness. Combined with models it can be used for simulations and what-if scenario analysis in the context of Climate Change Adaptation (extreme events).

- In terms of exposure, asset mapping refers to the integration of socio-economic statistics into EO-derived geo-information products on land use and cover. The result serves as a basis to characterise the asset at risk and assess the direct impact (e.g., economic) and consequences of a hazard on the population and infrastructure. EO can help prepare plans at different administrative levels since geospatial data is scalable. EO data can provide information about social conditions present in the territory over the requested time. Also, linkages to sustainable development and climate change adaptation plans can be considered. Typically, exposure data can be derived from high-resolution optical (Sentinel-2) to very high-resolution optical (commercial) imagery.

6 *Center, A. D. R. (2015). Sendai framework for disaster risk reduction 2015–2030. United Nations Office for Disaster Risk Reduction: Geneva, Switzerland.*

- As for hazards, historical analysis of long time series allows to derive hazard maps that represent the spatial and temporal event occurrences. Susceptibility maps (spatial occurrence), event return period maps (time occurrence) and severity/intensity maps can be generated and then combined (e.g., hazard maps) to support prevention planning. Typically, this requires accessing long time series by working with missions which have a background acquisition plan or systematic missions such as the Copernicus Sentinel missions, and access to catalogues of events and information on the forcing/triggering factors.

- Finally, regarding preparedness, access to near real-time data is fundamental to establish Early Warning Systems which help communities prepare themselves for hazardous events such as floods, landslides, severe storms, fires, volcanic eruptions, tsunamis, among others. These systems are crucial, especially considering that climate change is increasing the severity and frequency of disaster events. For that reason, the United Nations recently announced the Global Early Warning Initiative for the Implementation of Climate Adaptation, and geospatial data will be key for achieving the proposed goals. Using satellite EO data requires ensuring proper latency and is generally based on multiple missions to achieve high temporal sampling of observations.

2. Disaster response: EO data can help to better manage and mitigate the effects of a disaster. Once the disaster has occurred, fast and efficient response is vital for minimising the effects on communities. Satellite based information can provide rescue teams with the most up to date synoptic and objective information. User requirements typically translate into a requirement for 1:25 000 to 1:100 000 scale reference (background) mapping within 6 hours following a request for EO based emergency response and 1:10 000 to 1:50 000 scale damage mapping available within 24 hrs and updated daily. Rapid mapping services include reference data and crisis data to generate damage assessment maps and situation maps. Currently, there are many satellites operated by institutions and private companies which ensure full data acquisition multiple times per day, in some cases regardless of the meteorological and illumination conditions. Cutting-edge algorithms based on Artificial Intelligence (machine/deep learning techniques), or inversion/assimilation may significantly reduce the delivery time of EO products such as damage assessment or delineation of the affected area, when compared to products done manually by operators and technicians.

3. Post-disaster: Finally, in the case of disaster response, EO information can be used to determine the nature and extent of the damage, providing the community with a detailed damage assessment once the rescue activities have been concluded. Such information not only has a direct impact on individuals and communities but also can be crucial when declaring the disaster and seeking restoration funding. Further damage estimations required for a Post Disaster Needs Assessment (PDNA) can be produced with the aid of satellite imagery. Besides, geospatial technologies also provide information about humanitarian aid such as estimations of the number of displaced people. In the medium- and long-term, geo-information is also a valuable input for estimating the time required for the community to return to normal through monitoring the advances of reconstruction activities.

The main product types for DRM are listed below. Additionally, some products such as reference maps, digital elevation models, land use/cover maps, and asset maps may apply to all phases of the disaster risk management cycle.

- Pre-disaster: exposure mapping, vulnerability assessment, hazard mapping, and risk assessment, early warning systems.
- Disaster response: rapid mapping (e.g., reference, delineation, and grading mapping).
- Post-disaster: detailed damage assessment, risk assessment, recovery mapping, and reconstruction monitoring.

All weather conditions

All light conditions

Free satellite data

Near-real time data

Consistent monitoring

Worldwide coverage

Satellite Earth Observation (EO) arises as a powerful tool capable of generating uniform information across wide swaths of territory, covering a broad range of risk scenarios.

It is a unique source of information at the global, regional, and local scales, able to provide coherent, consistent, and accurate information that is comparable and easy to update.

Moreover, it can provide near real-time data, cooperating under all kinds of weather conditions, day, and night, and can contribute to all disaster phases, from preparedness to response and recovery.

The data collection platform is not vulnerable to the disaster itself, and inaccessible and hazardous areas can be monitored without risk.

Box 1 Benefits of satellite EO

Satellite EO has applications which can address the entire DRM cycle. An overview of the EO services which support each phase is provided in the following table:

	Ex - Ante		Ex-post		
	Prevention	Preparedness	Response	PDNA	Rehabilitation Reconstruction
Hazard assessment	✓	✓			
Exposure mapping	✓	✓			
Vulnerability assessment	✓	✓			
Risk assessment	✓	✓			
Supporting EO services	✓	✓	✓	✓	✓
Damage assessment			✓	✓	✓
Reconstruction monitoring			✓	✓	✓

Table 1 EO applications for different phases of the disaster cycle. Note that some applications concern Early Warning systems that are related to the Preparedness phase.

1.1 DOCUMENT ORGANIZATION

In the broader context of **Disaster Risk Management (DRM), Earth Observation (EO)** operates as an outstanding tool with the ability to reveal insights related to hazard identification, risk assessment, disaster response, resilience enhancement, and climate change adaptation. This document provides an overview of EO can support DRM, placing emphasis on a range of integral themes: EO products and services, data acquisition techniques, processing platforms, key elements of disaster resilience, and the execution of response initiatives.

The document showcases EO products and services, from **off the shelf datasets to tailored on-request data and real-time on-demand services**. Each modality presents its advantages and applications, collectively constituting the cornerstone of EO's adaptability within DRM. A fundamental aspect of EO that is especially relevant to on-demand products pertains to the sophisticated processing platforms that convert raw EO data into more user-friendly, readily accessible formats. The discourse seeks to elaborate on the indispensable role these platforms play in the DRM ecosystem.

The document further extends to the examination of the traditional **disaster resilience facets, such as hazards, exposure, vulnerability, impact, and risk assessment**. A detailed comparison of readily available products and bespoke solutions is conducted for each topic, including an assessment of their potential integration with various modelling tools and methodologies, thereby amplifying the inherent capabilities of EO.

Moreover, the document **explores the sphere of response initiatives, detailing damage assessment methods and several support programmes**, including the International Charter Space and Major Disasters, the Copernicus Emergency Management Service and Sentinel Asia, and the NASA's Advanced Rapid Imaging and Analysis (ARIA) a collaboration between the Jet Propulsion Laboratory (JPL) and the California Institute of Technology (Caltech) among others. These capabilities exemplify the pragmatic application of EO in streamlining effective disaster response and management. Other relevant EO capabilities not described in this document include capabilities developed under the initiative of public agencies such as NASA, USGS and NOAA in the USA, CNSA in China, ISRO in India, and other initiatives developed in other countries. Some of these initiatives are developed under international collaborations such as the CEOS Working Group Disasters (https://ceo s.org/ourwork/workinggroups/disasters). In the United Nations relevant EO capabilities include the UN Satellite Centre UNOSAT (see unitar.org) and the UN SPIDER programme of the UN Office for Outer Space Affairs (see https://www.unoosa.org).

This document can be used is as a guide to understanding the current role EO plays in user communities concerned with natural hazards.

HOW EO CAN SUPPORT DRM

The chapter is organized by the different steps of the DRM cycle and how EO can contribute to those, either with products and services (off-the-shelf, standard, or bespoke) or processing environments where the user is able to generate products by themselves. Some of these environments, deployed on the cloud and reachable by any personal computer with internet connection, have the capability to provide solutions for multiple topics and are therefore explained in a separate chapter.

1.2 EO PRODUCTS AND SERVICES

Earth observation-based products and services are the result of applying algorithms or processing chains to satellite data, either pre-processing to improve the radiometric or geometric characteristics of images or value-added processing to transform data into readily available geographic information. by the users.

Earth observation products can be generated with offline processing chains, or they can be generated in processing environments, or Earth observation platforms, where online access to data and processing capacity is guaranteed, i.e., the service runs without the need to download images.

Online services can be divided into three main categories, each with unique modalities and functionalities to meet a wide range of user needs and applications. These categories are on request, on demand and Off-the-shelf:

1. Services on request

These are personalized services made at the user's request. The production of geo-information is carried out by the owner of the service, which operates the chain of services in a processing environment. Users can order a production based on parameters provided by them and access the processing result.

Examples of Services on request:

- Mapping of the value of assets on a national scale customized for a user, providing the value €/m2 by urban type.
- Damage assessment by photo interpretation after an earthquake.

2. Services on demand

These are services that are integrated into a processing environment with data and resources available online and can be triggered by the user upon specification of the input data / parameters. These can be semi-automated or bespoke, and users can access the processing results.

Examples of Services on Demand:

- Ground movement services over a given area (the datum can be used as an input variable, but the algorithm is applied as is).
- Flood mapping services using Sentinel 1.

In addition, some additional types of services can be listed:

- Systematic online service: the production of geoinformation is carried out in the background, with a certain frequency (routine, monthly, annual, etc.) and the user directly accesses the result of the processing.
- Service or platform component associated with an Earth Observation-based processing environment, for example: Earth Observation data cataloguing (ingestion, query, discovery), Earth Observation data processing, data storage. geospatial, sharing, viewing, downloading, etc.
- Analysis service to exploit products based on Earth observation (Added Value).

3. Off-the-shelf services

These are geoinformation products that are generated in advance, allowing users to directly access the processing results. They are mainly produced at a predetermined frequency, such as monthly or annually. Due to the large amount of data that needs to be systematically processed, it is increasingly being generated on large on-premises or cloud infrastructures.

Some EO services may employ Artificial Intelligence (AI) models, use inversion techniques and data assimilation techniques, or integrate EO data with modelling for enhanced sensitivity, accuracy, and precision.

The selection of the type of EO service best suited to an application is based on several criteria:

- What relevant open-source tools and components are available, considering community-based repositories of open-source solutions for geospatial data exploitation,
- The open-source licensing conditions, and a readily identifiable and accessible link to the community maintaining and developing the open-source code, thereby fostering the development of sustainable value-added services,
- The availability of the documentation, using FAIR principles, that describes the methodology and algorithms used.

1.3 EXAMPLES OF EO PROCESSING ENVIRONMENTS

EO processing environments provide on-line access to EO data and processing services allowing to generate value added products without downloading imagery. Data access, querying the best suited imagery for an application, retrieving readily available value-added products, or executing value added processing are performed on-line without the burden of transferring EO data collections.

Compared to off-line solutions on-line EO services can help experts and users in the DRM community for several reasons. Firstly, DRM applications often require customization and flexibility of the EO based service. Conventional services generally provide standardized products with limited customization options. In contrast, EO processing environments enable users to adapt and modify processing chains, algorithms, and parameters according to their specific needs. This customization capability empowers users allowing them to generate bespoke products and analyses that align more closely with their DRM strategies, enhancing the relevance and effectiveness of the products.

Secondly, EO processing environments allow to execute product generation on-demand as and when needed, which is crucial in time-sensitive DRM activities. Disasters often require immediate access to updated information for early warning, rapid response, and informed decision-making. While conventional services may have predefined production schedules, processing environments allow users to trigger the production of geoinformation themselves, enabling timely access to critical data. This on-demand capability ensures that DRM practitioners can obtain the required information when they need it. Additionally, the integration of AI models and other modelling techniques within EO processing environments further enhances the functionality and precision of the generated products, enabling advanced simulations, scenario analysis, and improved risk assessments.

In addition, some processing environments have demonstrated that they can provide operational solutions at reduced cost providing affordable services for several applications such as wide area terrain motion mapping and wide area flood hazard mapping as in the example of the eDrift project with World Bank (http://edrift.cimafoundation.org/DRF/).

The following table provides a detailed overview of a selection of platforms currently offering geospatial services. These platforms, provided by various entities, extend to a wide array of functionalities, and cater to different levels of expertise. Please note that the conditions of access to these platforms varies; some are web-based, and others utilize cloud technology for enhanced data storage, processing, and analysis capabilities.

Platform Name	Provider	Description	Main Applications	Expertise level
Google Earth Engine	Google	Access to extensive satellite imagery; JavaScript and Python APIs for processing and analysis; Powerful computing resources for large-scale geospatial analysis	Geospatial data analysis, environmental monitoring, land use planning	Intermediate to Advanced
Amazon Web Services (AWS)	Amazon	Various cloud services including storage and computation; Access to geospatial data through Amazon S3; AWS Public Dataset Program includes satellite imagery	Data storage and processing, satellite imagery analysis, environmental monitoring	Beginner to Advanced
Microsoft Azure Planetary Computer	Microsoft	Access to a wide variety of environmental data; Machine learning tools and powerful computational resources; Integration with Azure's suite of services	Geospatial data analysis, machine learning, environmental monitoring	Intermediate to Advanced
ESRI ArcGIS Online	ESRI	Cloud-based mapping and analysis solution; Tools for creating maps, analysing data, and sharing results; Integration with other ESRI software	Mapping, data analysis, environmental monitoring, land use planning	Beginner to Advanced
openEO Platform	ESA	openEO provides user-friendly libraries for processing diverse Earth Observation data across multiple infrastructures, enabling research to large-scale EO-derived map production	Forest monitoring, land cover mapping, carbon monitoring	Intermediate
SEPAL	FAO	System for Earth Observation Data Access, Processing and Analysis for Land Monitoring. It's developed by FAO for forest and land monitoring	Forest monitoring, land cover mapping, carbon monitoring	Beginner to Intermediate

Platform Name	Provider	Description	Main Applications	Expertise level
DIAS	Creodias, Mundi, ONDA, sobloo, WEkEO	Offers a cloud-based environment with full, free, and open access to EO data, including a virtual workspace with processing capabilities	Data storage and processing, satellite imagery analysis, environmental monitoring	Intermediate
Geohazards Exploitation Platform	ESA	A platform developed by the European Space Agency for the exploitation of satellite data for geohazard applications	Geohazard monitoring, disaster risk assessment, land slide detection	Intermediate to Advanced
WASDI	WASDI sarl	Web Advanced Synthetic aperture radar Data Interface is a web-based platform designed to work with SAR data and products	SAR data processing, flood mapping, land deformation, forest monitoring	Intermediate
Rheticus	Planetek	An automatic cloud-based geo-information service platform that provides thematic maps for monitoring earth's surface changes	Land use change detection, infrastructure monitoring, environmental management	Beginner to Intermediate
mCube	Terradue	Provides cloud-based geospatial analysis tools, particularly for analysing multidimensional data cubes	Geospatial data analysis, environmental monitoring, urban planning	Intermediate
ARIA	JPL/ Caltech	JPL-Caltech initiative that uses remote sensing and geodesy for analysing natural hazards	improving disaster response and hazard resilience via satellite-based monitoring	Intermediate

Table 2 Overview of Geospatial Platforms, their Providers, Descriptions, Main Applications, Required Expertise Level, and Web Access Information

DISASTER RESILIENCE TOPICS

The section is organized against the three main components of the Disaster Risk Management function: exposure, vulnerability, and hazard.

1.4 EXPOSURE

In the context of disaster risk reduction, exposure is defined as the combination of population and assets that are either potentially at risk or may sustain damage because of the detrimental effects of hazards. The acquisition of such exposure information can leverage the current EO capabilities. The following are the most common EO applications to support the gathering of exposure information:

1.4.1 Land Use / Land Cover (LULC)

In a nutshell

What is LULC?	LULC stands for Land Use/Land Cover. It is a term used to describe the human and natural activity on the land surface and the physical coverage of the land, respectively. This includes aspects such as forests, water bodies, residential areas, agricultural land, and more.
Why is LULC relevant for exposure?	LULC provides vital information about the location and distribution of population and assets. This directly contributes to exposure analysis by identifying areas and specific assets at risk.
What are the benefits of EO-based LULC?	EO-based LULC offers comprehensive, accurate, and frequently updated information at various scales. It supports temporal analysis, allowing change detection and trend analysis, contributing to more robust risk assessments.
How can LULC benefit Disaster Risk Reduction (DRR)?	LULC data helps in DRR by identifying areas that are vulnerable to specific hazards, enabling targeted mitigation strategies. Changes in LULC can signal increasing risk levels, thus informing the need for pre-emptive measures. Furthermore, LULC data can support post-disaster recovery efforts by providing a clear picture of land use before and after a disaster, aiding in efficient resource allocation.

Off-the-shelf products and services

Product Name	Provider	Pixel size	Time Span	Updating
ESA WorldCover	European Space Agency	10 m	2020 and 2021	Yearly
Dynamic World	Google and World Resources Institute	10 m	2015 - present	2-5 days
GlobLand30	National Geomatics Center of China	30 m	2000, 2010, and 2020	10 years
Copernicus Global Land Service	Copernicus Global Land Service	100 m	2015 - present	Yearly
CCI-LC	ESA's Climate Change Initiative	300 m	1992 - 2015	Yearly

On-demand and on-request EO based products and services

Features	Off-the-shelf products	On-demand and on-request products
Spatial Resolution	Fixed, based on satellite capabilities (e.g., 10m, 30m, 100m, 300m)	Customizable, can utilize Very High Resolution (VHR) imagery
Classification Categories	Standard categories (e.g., forests, crops, grasslands, urban, water)	Customizable, can be adjusted to specific user requirements
Temporal Coverage	Defined by the product (e.g., annually, every decade)	Customizable, based on user's needs
Geographical Coverage	Global	Can be global, regional, or specific to a user-defined area
Availability	Readily available, no extra processing time	Requires additional processing time
Cost	Mostly free of charge	Likely to be charged, based on the complexity of the require-ments
Expertise Required	General knowledge in EO data interpretation	High level of expertise and ma-turity in EO data processing and interpretation

Potential combination with modelling

Tools, Techniques or Methodologies	Description
Hydrological Modelling	LULC data serves as a key input for hydrological models, enabling the prediction of water flow and potential flooding. This is highly beneficial for flood risk assessment and water resource management[4].
Climate and Ecological Modelling	LULC data can be employed in climate models to comprehend the effects of land use changes on climate variables. Similarly, ecological models utilize LULC data to evaluate impacts on biodiversity and ecosystem services[5].
Urban Growth and Land Use Change Models	These models leverage current and historical LULC data to project future trends of urban growth and land use changes. This is informative for urban planning and policymaking[6].
Economic Models	LULC data can be integrated into economic models to evaluate the economic impacts of land use changes, such as alterations in agricultural productivity or property values[7].
Event susceptibility modelling	LULC data serves as base layer for constructing any event (landslides, avalanches, flood, fires, etc) susceptibility maps, describing the spatial occurrence of the events

4 Gochis, D. J., Schumacher, R., Friedrich, K., Doesken, N., Kelsch, M., Sun, J., ... & Cifelli, R. (2015). The Great Colorado Flood of September 2013. Bulletin of the American Meteorological Society, 96(9), 1461-1487.
5 Pielke Sr, R. A., Pitman, A., Niyogi, D., Mahmood, R., McAlpine, C., Hossain, F., ... & de Noblet, N. (2011). Land use/land cover changes and climate: modelling analysis and observational evidence. Wiley Interdisciplinary Reviews: Climate Change, 2(6), 828-850.
6 Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences, 109(40), 16083-16088.
7 Nelson, E., Polasky, S., Lewis, D. J., Plantinga, A. J., Lonsdorf, E., White, D., ... & Lawler, J. J. (2008). Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. Proceedings of the National Academy of Science, 105(28), 9471-9476.

1.4.2 Urban spatial Characterization and Evolution (UCE)

In a nutshell

What is UCE?	UCE stands for Urban Characterization and Evolution. It refers to the mapping and analysis of urban areas. This could involve elements such as built-up classification, detection of isolated buildings and infrastructure, settlement maps, among others.
Why is UCE relevant for exposure?	UCE is pertinent to exposure as urban areas are concentration points for both human populations and high-value infrastructures. Understanding the status and evolution of these urban landscapes helps in determining potential areas at risk from natural hazards and assists in assessing the potential impact of such events.
What are the benefits of EO-based UCE?	EO-based UCE offers a regularly updated, comprehensive view of urban elements[8]. It enables up-to-date mapping of features of interest, assists in economic assessments of land use and change, and allows tracking of natural and manmade changes in urban areas. The use of EO in this context can provide accurate infrastructure information, aiding in risk assessments and disaster management strategies.
How can UCE benefit Disaster Risk Reduction (DRR)?	UCE can significantly contribute to DRR by providing detailed insights into urban landscapes and their evolution. This helps in identifying areas vulnerable to disasters and facilitates the implementation of mitigation measures, such as nature-based solutions. For instance, in areas prone to floods or landslides, UCE data can guide the restoration of natural buffers like wetlands, forests, and coastal ecosystems. Moreover, UCE enables efficient planning for urban green corridors, promoting more sustainable and resilient urban environments.

Off-the-shelf urban mapping

Product Name	Provider	Pixel size	Time Span	Updating
World Settlement Footprint[9]	German Aerospace Center (DLR) and ESA	10m	1985 - Present	Annually
Global Urban Footprint[10]	German Aerospace Center (DLR)	12m	2011 - Present	Every 5 years
GHSL (Global Human Settlement Layer)[11]	Joint Research Centre of the European Commission	30m - 250m	1975 - Present	Every 5 years
Urban Change Detection Dataset	Google Earth Engine	30m	1985 - Present	Annually

8 Reba, M., & Seto, K. C. (2020). A systematic review and assessment of algorithms to detect, characterize, and monitor urban land change. Remote sensing of environment, 242, 111739.
9 Marconcini, M., Metz-Marconcini, A., Üreyen, S., Palacios-Lopez, D., Hanke, W., Bachofer, F., ... & Strano, E. (2020). Outlining where humans live, the World Settlement Footprint 2015. Scientific Data, 7(1), 242.
10 Global Urban Footprint (GUF), https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-9628/16557_read-40454/ [accessed 10 April 2019
11 Global Human Settlement Layer (GHSL), https://ghsl.jrc.ec.europa.eu/about.php [accessed 10 April 2019]

Urban Spatial Characterization and Evolution products provide essential insights into the dynamic and complex nature of urban landscapes. These products, derived from EO data, offer an array of information that aids in urban planning, environmental management, and policymaking. Among the above-mentioned readily available data, products include:

- Temporal Evolution of Settlements: This product provides a historical perspective on the growth and development of human settlements over time. It allows for the analysis of urbanization trends and patterns, offering vital clues about factors driving urban growth and expansion.
- Imperviousness Mapping: Impervious surfaces, like concrete and asphalt, have a significant impact on urban environments, affecting everything from water runoff to heat absorption. Mapping these surfaces helps in understanding urban heat islands, managing stormwater, and planning urban green spaces.
- Built-up Height Estimation Mapping: This product provides information on the height of built-up areas, essential in urban planning, risk assessment, and understanding population density and distribution.

However, readily available products may not always meet specific user requirements, such as when a higher degree of spatial detail is needed, or when classification categories need to be adjusted to suit a particular study or project. This is where bespoke products come into play, offering tailored solutions that can maximize the potential of Very High Resolution (VHR) imagery. Bespoke products include:

- Building Classification and Urban Land Use Classification (Residential, Industrial, Commercial): These products provide detailed insights into the types of buildings and land use within an urban area, essential for urban planning, resource allocation, and infrastructure development.
- Building Footprint Extraction: This product involves the extraction of building footprints from satellite imagery, an invaluable resource for urban planning, disaster management, and assessing urban growth.
- Ad-hoc Delineation of Features: Customized delineation of specific urban features (soil sealing, green areas, residential parts, etc) based on user requirements can be provided, aiding in targeted urban studies and planning.
- Urban Target Detection (e.g., Critical Infrastructures): This product facilitates the identification and location of specific urban targets like critical facilities, essential for emergency management, security planning, and infrastructure development.

Following, the main differences between available and bespoke urban characterization and evolution products are summarized.

Features	Global Readily Available Products	Bespoke Products
Spatial Resolution	Medium to High (10m - 30m typically)	Very High (up to 0.5m typically)
Classification Categories	General (e.g., impervious surfaces, built-up areas)	Specific (e.g., building types, targeted urban features)
Temporal Coverage	Fixed (e.g., annual, every 5 years)	Customizable
Geographical Coverage	Global or Regional	Customizable
Availability	Pre-processed and readily available	Requires processing time
Cost	Low to Medium	High (due to customization)
Expertise Required	Basic to Intermediate (for data interpretation)	High (for data processing and interpretation)
Urban Change Detection Dataset	Google Earth Engine	30m

Potential combination with modelling

Tools, Techniques or Methodologies	Description
Land Change Modeler[12]	An application integrated into the TerrSet Geospatial Monitoring and Modelling Software, used for analysing and predicting future land cover scenarios based on current trends.
UrbanSim[13]	A software-based simulation system for supporting planning and analysis of urban development. It incorporates interactions between land use, transportation, the economy, and the environment.
SLEUTH (Clarke Urban Growth Model)[14]	A cellular automaton model used to simulate and predict urban growth, with a specific focus on understanding the impacts of different growth scenarios on urban sprawl and the environment.
CLUE-S (Conversion of Land Use and its Effects)[15]	A model that simulates changes in land use on various scales. It helps in understanding the drivers of land use change and predicting future land use scenarios.
AGENT (Agent-based Geospatial Simulation of Networked Entities)	A model that integrates social, economic, and environmental data to simulate the behaviour of individual 'agents' (like households or businesses) and their impact on urban growth and development.

12 https://clarklabs.org/terrset/land-change-modeler
13 https://www.urbansim.com
14 http://www.ncgia.ucsb.edu/projects/gig/Dnload/download.htm
15 https://www.environmentalgeography.nl/site/data-models/data/clue-model/

Tools, Techniques or Methodologies	Description
LEAM (Land-use Evolution and impact Assessment Model)[16]	A model that simulates land use changes and allows users to assess the potential impacts of various land use policies and environmental changes on future land use patterns.
InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)[17]	A suite of models developed by the Natural Capital Project, used to map, and value the goods and services provided by natural and managed landscapes, including urban ones.

1.4.3 Population mapping

What is population mapping?	Population mapping is the process of creating geospatial products of population distribution within a given area, often beyond the usual administrative levels and using dasymetric modelling . It uses various data sources, including EO; however, it does not extract population directly using EO. It based on relevant indicators such as land use, urban characteristics, and ancillary data like census figures.
Why is population mapping relevant for exposure?	Population mapping is critical for exposure analysis as it provides insights into the distribution of people across territory. This information can identify areas and populations exposed to hazards, thereby facilitating effective disaster risk reduction strategies.
What are the benefits of EO-based population mapping?	EO-based population mapping offers a detailed, objective, and up-to-date perspective on the global distribution of people within predefined areas. It allows for flexibility in aggregating population data beyond traditional administrative boundaries, thus providing a more comprehensive understanding of population distribution. While these datasets do not replace comprehensive socio-demographic details provided by a full census, they serve as valuable complementary resources.
How can population mapping benefit Disaster Risk Reduction (DRR)?	Population mapping is an essential tool in DRR as it can identify areas with high population density that may be vulnerable to specific hazards. This data is critical for implementing evacuation plans, both in preparation for and response to disaster situations. Moreover, it can guide urban planning, disaster management, and social development strategies, all of which contribute to reducing disaster risks and enhancing community resilience.

16 http://www.leam.uiuc.edu/
17 https://naturalcapitalproject.stanford.edu/software/invest
18 A technique used to refine population distribution maps. It uses ancillary data (like land use or urban characteristics) to distribute population figures more accurately within a geographic area, typically at a higher spatial resolution than the original census data. This model provides more accurate depictions of population distributions, especially in areas with diverse land use types.

Off-the-shelf data on population distribution

Product Name	Provider	Spatial Resolution	Time Span	Updating
GHSL (Global Human Settlement Layer)[19]	European Commission, Joint Research Centre	250m	1975, 1990, 2000, 2014	Every few years
WorldPop[20]	University of Southampton	100m - 1km	Annually from 2000	Annually
WSF Population[21]	DLR (German Aerospace Center) and ESA (European Space Agency)	10m	2015, 2019	Every few years
LandScan[22]	Oak Ridge National Laboratory	1 km	2000 - Present	Annually

Products and services

Population-based services offer a range of products that support demographic studies. These resources incorporate a vast array of datasets, shedding light on diverse elements such as age and sex structures, birth rates, and trends, in addition to specialized data sets like dependency ratios. Beyond the basic demographic data, these products extend to cover wider socio-economic indicators, offering a holistic view of the populations under study. The provision of dynamic mapping datasets and grid-cell surface areas further enhances the depth and detail of the spatial information available. The scope of these resources also extends to more niche sectors. For example, they incorporate global flight data, providing insights into human mobility patterns, while the inclusion of global holiday data reveals societal patterns and rhythms. The Global Settlement Growth category offers an intriguing exploration of the expansion of human habitats. Key aspects of population dynamics, such as migration flows, are also represented, enriching our understanding of population movement. The fundamental elements of this collection are the raw population counts, drawn from a variety of regions and time periods. Furthermore, data related to urban change and population density add an additional dimension to our demographic comprehension.

However, it is important to recognize that while these population products are comprehensive, there may be specific requirements or niche areas that are not covered. In these instances, bespoke data products may be necessary to fill the gaps and provide more customized and tailored information for specific projects or research

19 https://ghsl.jrc.ec.europa.eu
20 https://www.worldpop.org
21 https://www.eoportal.org/other-space-activities/world-settlement-footprint
22 https://landscan.ornl.gov

objectives. These bespoke products offer flexibility and adaptability, providing data solutions that cater to the unique needs of the end-user.

Following, the main differences between readily available and bespoke products are summarized.

Features	Global Readily Available Products	Bespoke Products
Spatial Resolution	Varies, often lower due to global coverage	Can be high, tailored to specific needs
Classification Categories	Predefined, limited flexibility	Customizable based on project requirements
Temporal Coverage	Fixed, often historical to present	Flexible, can be tailored to needs
Geographical Coverage	Broad, usually regional, or global	Can be specific to a location
Availability	High, readily available to anyone	Depends on the creation timeline
Cost	Typically lower, costs spread over many users	Can be higher, depends on the requirements
Expertise Required	Lower, user-friendly interfaces common	Higher, may require specialized knowledge

Table 3 Comparative analysis of global readily available versus bespoke population products

Potential combination with modelling

Tools, Techniques or Methodologies	Description
Logistic Population Growth Model	A mathematical model used to describe population growth that is limited by density-dependent factors such as carrying capacity.
Gravity Model of Migration	A model used to predict the degree of interaction between two places, often used to understand and predict migration patterns.
Cohort-Component Method	A common method for making population projections, considering factors like fertility, mortality, and migration.
Leslie Matrix Model	A demographic model used to predict population growth or decline by age and gender in a closed population.
Bayesian Hierarchical Modelling	A statistical model that estimates the parameters of the posterior distribution using Bayesian methodology. Used in population studies for data analysis and trend prediction.
Potential consequence modelling	A modelling framework, based on SMCE techniques, to identify and estimate the population exposure to hazards, and used as a proxy of vulnerability when quantitative vulnerability cannot be assessed. Can be applied to any hazard type.

1.4.4 Territory monetization

What is territory monetization?	Territory monetization is the process of assessing the monetary worth of tangible assets within a specific area, typically as value per area unit (€/m2). It involves creating a comprehensive map of these assets using various data sources, including EO. Please note that the monetary value is not derived directly from EO data but is calculated through a combination of ancillary datasets such as GDP per capita, inflation value, and replacement costs, as well as other EO-based products like urban characterization.
Why is territory monetization relevant for exposure?	Territory monetization is relevant for exposure as it allows for the quantification of assets that are exposed to hazards. This can help in understanding potential financial impacts and inform risk reduction strategies, planning, and decision-making.
What are the benefits of EO-based territory monetization?	EO-based territory monetization offers up-to-date, objective, and comprehensive information on asset distribution within a defined territory. It enables the creation of detailed asset maps at various scales, allowing for accurate and timely updates. Moreover, the methodology can be applied to various types of assets, including urban infrastructure and agricultural lands.
How can territory monetization benefit Disaster Risk Reduction (DRR)?	Territory monetization can significantly contribute to DRR by providing a clear picture of the potential economic losses in the event of a disaster. The monetary value of assets can guide disaster management strategies and plans, facilitating a better allocation of resources for risk reduction and preparedness measures. It can also assist in estimating recovery costs and compensation needs post-disaster, thereby enhancing the efficiency of recovery and rebuilding efforts.

Products and services

The territory monetization product tool delivers an assessment of the economic worth of diverse assets within a user-specified area, based on their distinct characteristics. This product features a fully customizable and automated process chain, designed to cater to specific requirements. It allows for the replication of results across various geographical contexts while ensuring standardized and precise outcomes. As such, the product offers significant utility in estimating the potential economic costs associated with hazards in each respective area.

Modelling tools that can be combined with EO

Tools, Techniques or Methodologies	Description
Insurance Industry Tools: Risk Assessment & Underwriting	Insurance companies can use territory monetization data to adjust policy premiums, especially for property and casualty insurance. The economic value of an area can helps determine the potential loss in the event of a disaster.
Disaster Risk Reduction Tools	These applications can use territory monetization data to estimate potential economic losses from natural disasters, guiding preventive measures and emergency response planning.
Urban Planning Tools	City planners can utilize territory monetization data to prioritize areas for development or conservation based on their economic value.
Environmental Conservation Tools	Conservation organizations could use this data to highlight the economic importance of preserving certain areas, providing a financial argument to support their conservation efforts.

1.4.5 Digital Elevation Models (DEM)

What is a DEM?	A Digital Elevation Model (DEM) is a three-dimensional representation of a terrain, both built and natural. It is a superset of a (i) Digital Surface Model (DSM), which represents the Earth's surface, including natural or man-made objects located on it, essentially a canopy over the surface of the bare earth, and (ii) a Digital Terrain Model (DTM), which is a bare-earth representation of a terrain, consisting of an array of points with a defined height but excludes natural or man-made objects like canopy or buildings, respectively.
Why are DEMs relevant for exposure?	DEMs are relevant for exposure as they provide critical information about the topography and elevation of an area. This data is useful in locating the conditions of the actual and future hazards, in Early Warning systems, and in assessing the potential impact of various hazards on the built and natural environments. DEMs are especially relevant for urban exposure analysis as they include built structures and vegetation.
What are the benefits of EO-based DEM?	EO-based DEMs provide three-dimensional representation of Earth's terrain with high precision, enabling detailed study of topography, geomorphology, and surface processes. They offer a fundamental resource for a wide range of applications, including the monitoring of temporal changes in the Earth's surface, essential for studying phenomena such as land subsidence, glacier retreat, volcanoes, landslides, and coastal erosion. DEMs are vital in urban planning, landscape modelling, city modelling and any hazard visualization applications.
How can DEMs benefit Disaster Risk Reduction (DRR)?	In the context of DRR, DEMs provide valuable information for the creation of hazard maps, planning of evacuation routes, and other DRR measures. By understanding the terrain features and changes over time, planners and decision-makers can better assess risk and design effective mitigation strategies. DSMs, which include the heights of built structures and vegetation, are particularly important in urban areas for assessing the risks and impacts of disasters such as flooding and earthquakes.

Off-the-shelf DEMs

Product Name	Provider	Spatial Resolution	Time Span	Updating
Shuttle Radar Topography Mission	NASA, USGS	~90 meters	2000	Not updated
ASTER Global DEM	NASA, METI	30 meters	2000-2019	Not updated
NEXTMap World 30	Intermap Technologies	30 meters	Ongoing	Periodic updates
TanDEM-X Global DEM	Airbus Defence and Space	12 meters	2010-2020	Completed
Copernicus DEM	European Space Agency (ESA)	30 meters (World) 10 meters (Europe)	Ongoing	Periodic updates

On-request generation of DEMs

When generating Digital Elevation Models (DEMs), including Digital Terrain Models (DTMs) and Digital Surface Models (DSMs), several considerations are factored in:

- **Data Source Selection**: Various sources can be utilized, including radar data (e.g., Sentinel-1, ALOS PALSAR, TerraSAR-X), and LiDAR data from airborne platforms. The choice depends on specific project requirements.
- **Project Requirements**: Key considerations for selecting the data source include:
  - Desired resolution and needed sensitivity/accuracy
  - Geographical location
  - Environmental conditions
  - Available budget
- **Data Processing**: After choosing the appropriate source, the following steps are taken:
  - Correction of satellite data for topographic effects
  - Alignment of the satellite point clouds to reference datasets
  - Identification and removal of non-ground points (for DSMs and DTMs)
  - Interpolation of elevation data to generate a continuous surface

Following, the main differences between available and bespoke products are summarized:

Features	Readily Available Products	Bespoke Products
Spatial Resolution	Generally coarse (e.g., 30m for SRTM)	Can be very high, depending on data acquisition method
Temporal Coverage	Often static, representing a particular point in time	Can be current or historical, and can also be regularly updated
Geographical Coverage	Global or regional, depending on the product	Can be as specific as a single site or as broad as a region
Availability	Often freely available or available at a low cost	Requires commissioning, may take time to produce
Cost	Usually free or low cost	Higher cost, due to customization and data acquisition
Expertise Required	Basic to intermediate GIS skills required	Basic to intermediate GIS skills required

Modelling tools that can be combined with EO

Tools, Techniques or Methodologies	Description
Hydrological Modelling	This is a methodology for simulating water movement within catchments. DEMs are used to derive important inputs such as flow direction, flow accumulation, and stream networks.
3D Visualisation	DEMs are used to create realistic three-dimensional visualisations of the terrain. These visualisations can be utilised for a range of applications, from video game development to urban planning.
Flood Modelling	This technique involves the simulation of flood events to predict their impact. High-resolution DEMs are used to model the terrain and to simulate how water would flow across it during a flood event.
Event susceptibility modelling	DEMs serves as a base layer for constructing any event (landslides, avalanches, floods, fires, etc) susceptibility maps, describing the spatial occurrence of the events

1.5 VULNERABILITY

Vulnerability is a crucial aspect that defines the characteristics and conditions of an asset, by describing the possible loss / damage according to the hazard impact intensity. It serves as a fundamental component of risk assessment, necessitating a comprehensive understanding to develop effective risk reduction strategies.
When evaluating vulnerability, three key concepts come into play: damage loss functions, lack of coping capacities, and lack of adaptive capacities. These components typically rely on socio-economic and environmental parameters derived from non-Earth Observation (non-EO) data, such as national statistics including Gross Domestic Product (GDP), public health expenditure, gender-related factors, and the presence of protected areas. These parameters are weighted in conjunction with exposure to generate a quantitative risk index.

The utilization of Earth Observation data enhances the representation of dynamic vulnerability aspects and aids in the detection of changes. Earth Observation contributes to various physical dimensions of vulnerability. For instance:

The structure of the physical environment, encompassing urban configuration, building density, material composition, and building types.
Asset construction factors, like the construction mode, including access to damage loss functions

- Spatial factors like location and accessibility of the asset.
- Criticality of the asset (such as transportation networks, energy supply systems)
- Natural resources, covering land cover and forestry/aquaculture.
- Population aspects, including population density, day/night-time population variations, and urbanization trends.
- Accessibility to critical local services (like hospitals, schools, fire brigades, emergency services, accommodation facilities, and shelters).

Vulnerability is commonly assessed using qualitative or semi-quantitative methods, with levels categorized as very low, low, medium, high, and very high. These levels are assigned to geo-located assets, and vulnerability is specific to the type of hazard (and of its intensity) being considered. For instance, certain characteristics of an asset, such as the use of brick shelters, may render it more vulnerable to earthquakes compared to other hazards like windstorms. This hazard-specific nature of vulnerability makes it challenging to present a comprehensive view of indicators applicable to every hazard type, necessitating a case-by-case assessment approach.

	Components	Causes	Indicators / Variables
Vulnerability indicators	Physical vulnerability	Physical structure	Urban structure, building density, building height, building material (roofs), building type, fragility of buildings, number of buildings
		Location	Accessibility, surface slope, soil type, height information
		Criticality of infrastructure	Street network, public transport, communication, pipelines, supply units
		Population structure	Water supply, agriculture, land cover type, aquaculture
	Demographic vulnerability	Population development	Population density, day- and night-time population density, age structure, gender
		Social status	Population growth, migrations rate, urban sprawl
	Social vulnerability	Accessibility to local supply	Education, health. Social network
		Individual financial potential	Hospital, school, fire brigade, emergency, accommodation
	Economic vulnerability	Governmental potential	Income per capita, insurance, property, unemployment rate
		Soundness of decision structures	Gross National Product (GDP), inflation, Humanitarian aid organisations, Human Poverty Index (HPI)
	Political vulnerability	Presence of natural resources	Political system, early warning system
	Environmental vulnerability	Biodiversity	Water supply, agriculture, land cover type, aquaculture, fisheries
		Physical structure	Protected areas, fisheries

Table 4 Some identified indicators of vulnerability, underlined are the ones which can be addressed through EO applications. Modified from Taubenböck et al. 2008[23]

To gain insights into the vulnerability of assets exposed to hazards, historical event data can be analysed. However, due to its complex nature, vulnerability cannot be adequately represented by a single variable alone. Therefore, composite indicators are utilized to combine multiple factors, creating a vulnerability index that represents vulnerability as a dimension of risk – such indicators are commonly referred as "potential consequence index" (Puissant et al., 2014) [24]. Earth Observation (EO) plays a crucial role in this context by facilitating the integration of vulnerability indicators. It serves as a powerful tool through which specific vulnerability levels can be assigned to geolocated assets. Furthermore, EO enables the consideration of coping capacities possessed by assets in relation to specific hazards. This means that the ability of assets to effectively handle and respond to specific types of hazards can also be considered, providing a more comprehensive understanding of their vulnerability.

Readily available data

There is a lack of readily available datasets that provide granular, specific, and up-to-date vulnerability indicators tailored to specific locations or types of disasters. This gap exists due to the complex and context-dependent nature of vulnerability, which can be influenced by a myriad of social, economic, environmental, and institutional factors that vary significantly across different locales and communities.

Products and services

Vulnerability is influenced by an array of factors that span the physical, social, economic, and environmental domains. Quantifying vulnerability is a complex task, necessitating a nuanced and context-specific approach. Therefore, a bespoke strategy to generate vulnerability indicators that are acutely attuned to the specific characteristics and requirements of the communities and environments is the most appropriate. This approach is not predicated on a fixed formula but rather is adjusted and refined based on the unique circumstances of each case. This customised methodology typically necessitates the gathering and examination of data describing historical damage, sourced through techniques like surveys, interviews, and participatory assessments, and further enriched by integrating data gleaned from local and national resources. The result is a tailored set of indicators, uniquely generated to capture the factors most relevant to the susceptibility of the specific population or system being analysed. These customised indicators offer the flexibility to cater to specific hazards, dovetail with available resources, and resonate with the unique capacities and vulnerabilities of the communities or systems in focus. Their value in the field of disaster risk reduction is significant, enabling targeted and effective strategies that confront the underlying causes of vulnerability, thereby fostering resilience.

23 Taubenböck, H., Post, J., Roth, A., Zosseder, K., Strunz, G., & Dech, S. (2008). A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing. Natural Hazards and Earth System Science, 8(3), 409-420.

24 Puissant, A., van Den Eeckhaut, M., Malet, J.-P., Hervas, J., Maquaire, O. 2014. Landslide consequence analysis: a region-scale indicator-based methodology. Landslides, 11(5): 843-858. doi:10.1007/s10346-013-0429-x

Modelling tools that can be combined with EO

Tools, Techniques or Methodologies	Description
Risk Assessment Modelling	Risk assessment models, such as HAZUS[25] developed by FEMA[26], use vulnerability data to estimate potential losses from disasters, including physical damage, economic losses, and human casualties.
Climate Change Impact Models	These models, such as Delft3D[27], use vulnerability data to predict the impact of climate change on specific areas. They can simulate sea-level rise, increased temperature, and other climate hazards.
Social Vulnerability Indices	These indices, such as the SoVI[28], leverage vulnerability data to identify communities that are particularly susceptible to specific hazards.
SMCE (Spatial-Multi-Criteria Evaluation) modelling and Agent-Based Modelling (ABM)	SMCE and ABM are models that can incorporate any exposure indicator and vulnerability data to simulate the actions and interactions of autonomous agents (individuals, households, or entities) in response to specific hazards.

1.6 HAZARDS

Taking into account the hazard classification established at the "Sendai Framework for Disaster Risk Reduction 2015 - 2030"[29], EO can support DRR related (geological or geophysical and hydrometeorological) processes and phenomena. The benefits of its application are discussed in the following sub-sections.

1.6.1 EO for Geohazards

The Earth's surface is continuously changing due to geological events such as earthquakes, volcanic activity, and gravitational activity. After these events, natural hazards such as landslides, tsunamis, snow/rock/debris avalanches or subsidence phenomena cause millions of casualties and severe economic damage. Policy makers and disaster management stakeholders need to make informed decisions before managing these events, firstly understanding the hazard, involving generally very long timescales, and secondly at the operational level.

25 www.fema.gov/es/flood-maps/products-tools/hazus
26 /www.fema.gov/
27 oss.deltares.nl/web/delft3d
28 sc.edu/study/colleges_schools/artsandsciences/centers_and_institutes/hvri/data_and_resources/sovi/sovi_recipe/index.php
29 Center, A. D. R. (2015). Sendai framework for disaster risk reduction 2015–2030. United Nations Office for Disaster Risk Reduction: Geneva, Switzerland.

Satellite data provide the capacity of monitoring the Earth`s surface at a regional to global scale. Satellites such as Sentinel-1 can help to understand ground deformations caused by earthquakes or volcanoes providing very precise measurements of terrain deformation. In combination with other techniques such as geophysical models, essential insights on Earth`s sub-surface processes are possible.

Table 5 displays a selection of techniques for EO data analysis addressing different geophysical hazards. Moreover, further details of these products and services are provided below.

Definitions of EO for geohazards are mostly based on "Memorandum of the International Forum on Satellite Earth Observation and Geohazards" (aka the Santorini report)[30]

Hazard group	Hazard type	Hazard	Hazard sub-type
Geohazards	Ground instabilities	Subsidence	Sudden subsidence
			Long-lasting subsidence
		Landslides	Shallow slides
			Deep-seated slides
			Debris flows and lahars
			Snow/Rock/Debris avalanches
			Sensitive clay deformation
		Avalanche	Snow/Rock/Debris avalanches
		Shrinking/swelling	Sensitive clay deformation
	Seismic	Earthquake	Ground shaking
		Tsunami	
	Volcanic	Volcano	Eruption / explosion
			(atmospheric) ash flows Lava flows
	Shoreline changes	Coastal erosion	

Table 5 EO for Geophysical hazards

30 Bally, Ph. (Ed.). (2014). Memorandum of the International Forum on Satellite Earth Observation and Geohazards, Santorini, Greece, 21-23 May 2012. European Space Agency; see: https://esamultimedia.esa.int/multimedia/publications/STM-282/STM-282_web.pdf

1.6.1.1 Subsidence

In a nutshell

What is subsidence?	Subsidence refers to a phenomenon marked by the gradual settling or sudden sinking of Earth's crust, triggered by the underground movement of soil and sub-surface layers. This can be measured from space with remarkable millimetric precision.
Why is subsidence relevant for hazards analysis?	Subsidence poses tangible threats to vital infrastructures and built environments, especially in coastal areas where the risk of flooding is compounded due to accelerated subsidence rates. In combination with rising sea levels, receding land could potentially amplify the destruction caused by hurricanes and other related natural disasters.
What are the benefits of EO-based subsidence?	EO-based techniques, such as Interferometric Synthetic Aperture Radar (InSAR), can remotely detect minute variations in land surface elevation with high precision. They facilitate the creation of detailed displacement maps, thereby enhancing our ability to monitor and manage subsidence triggered by the compaction of susceptible aquifer systems. Furthermore, they provide insights into the underlying physical processes governing these phenomena. EO-based subsidence techniques also enable mass production and wide area monitoring.
How can subsidence benefit Disaster Risk Reduction (DRR)?	EO using techniques like DInSAR provides accurate, high-resolution subsidence monitoring. In terms of DRR, EO aids in forecasting potential hazards, enabling proactive risk mitigation. The data enhances preparedness, facilitates efficient recovery post-event, and informs long-term resilience strategies, making EO a critical tool for subsidence-induced disaster management.

Off-The-Shelf EO products for Subsidence

European Ground Motion Service. The EGMS is based on the multi-temporal interferometric analysis of Sentinel-1 radar images at full resolution. This technique allows identifying reliable measurement points for which ground motion velocity values and time series of deformation are extracted. Such measurement points usually coincide with buildings, artificial structures, and non-vegetated areas in general. Global navigation satellite systems data are used as calibration of the interferometric measurements.
https://land.copernicus.eu/pan-european/european-ground-motion-service

On request solutions

Subsidence monitoring and assessment. The subsidence assessment product reveals ground motion changes, providing average motion rates (mm/year) and complete displacements in a specific period. In this sense, this product allows for the monitoring of terrain deformation due to subsidence, which is mainly caused by the removal of subsurface water for irrigation purposes. In addition, the product also allows monitoring of specific infrastructures, such as road networks, buildings, and bridges, as well as critical facilities such as airports, harbours, dams, or electric plants, among others.

Medium resolution ground motion services. Calculation of subsidence with satellites was performed in the framework of the EO4SD DRR project with medium resolution for the City Resilience Program of the World Bank. Detailed assessment was performed in Banjul (Gambia) for the World Bank West Africa Coastal Management Program[31] (WACA) and for the World Bank Resident Mission in Vietnam in the city of Vinh Long.

Figure 1. Subsidence measurements over Vinh Long (Vietnam) performed by BRGM using the P-SBAS service on the Geohazards Exploitation Platform.

[31] https://www.wacaprogram.org/

On Demand solutions

The Geohazards Exploitation Platform (GEP) is a cloud-based environment providing access to satellite imagery and processing services that allow for the mapping of hazard-prone land surfaces and the monitoring of terrain motion. The platform is continuously expanding to address the continuously evolving objectives of the geohazards community, by integrating a broad range of on-demand and systematic services hosted on cloud resources.

Among the operational services of GEP for monitoring of terrain deformation is the Surface motioN mAPPING (SNAPPING)[32] and Parallel Small BAseline Subset (P-SBAS)[33, 34] services. Both are advanced multi-temporal InSAR services utilising Copernicus Sentinel-1 mission data for the measurement of the average terrain motion and the corresponding displacement time series. The implementation design of these algorithms permits the exploitation of distributed computing infrastructures (i.e. grid and cloud), making use of both multi-core and multi-node programming techniques, and is based on an ad-hoc designed distributed-storage aimed at guaranteeing sustained scalable performances also for massive amounts of data to process.

The P-SBAS service generates terrain motion measurements along a regular grid of 90x90 metres spacing, while SNAPPING Persistent Scatterer Interferometry (PSI) provides irregularly distributed point measurements detected along natural terrain or infrastructures. The chains have gone through several years of validation using various independent geodetic measurements (in-situ and spaceborne) to ensure the robustness of the measurements.

The conceptual idea of SNAPPING is based on a twofold processing scheme, including first the generation and storage of an independent interferometric stack, followed by the time series analysis. The above split procedure provides flexibility in storing the interferometric stack for future use, either by applying different PSI processing parameters or when regular updates of the solution are required (newly acquired S-1 scenes). This considerably reduces the con-sumption of resources and the processing time, especially when the actual monitoring of an area is intended. The SNAPPING service is offered at medium (approx. 100m) and full spatial resolutions. That was found as an optimal configuration when the low-cost coverage of a wide area is necessary before focusing on a more thorough analysis of specific regions or infrastructures.

32 *Foumelis, M.; Delgado Blasco, J.M.; Brito, F.; Pacini, F.; Papageorgiou, E.; Pishehvar, P.; Bally, P. SNAPPING Services on the Geohazards Exploitation Platform for Copernicus Sentinel-1 Surface Motion Mapping. Remote Sens. 2022, 14, 6075. https://doi.org/10.3390/rs14236075.*
33 *Casu, F., Elefante, E., Imperatore, P., Zinno, I., Manunta, M., De Luca, C., Lanari, R. (2014) "SBAS-DInSAR Parallel Processing for Deformation Time Series Computation", IEEE JSTARS, doi: 10.1109/JSTARS.2014.2322671*
34 *Manunta, M., De Luca, C., Zinno I., Casu, F., Manzo, M., Bonano, M., Fusco, A., Pepe, A., Onorato, G., Berardino, P., De Martino, P., Lanari, R. (2019) "The Parallel SBAS Approach for Sentinel-1 Interferometric Wide Swath Deformation Time-Series Generation: Algorithm Description and Products Quality Assessment", IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2019.2904912*

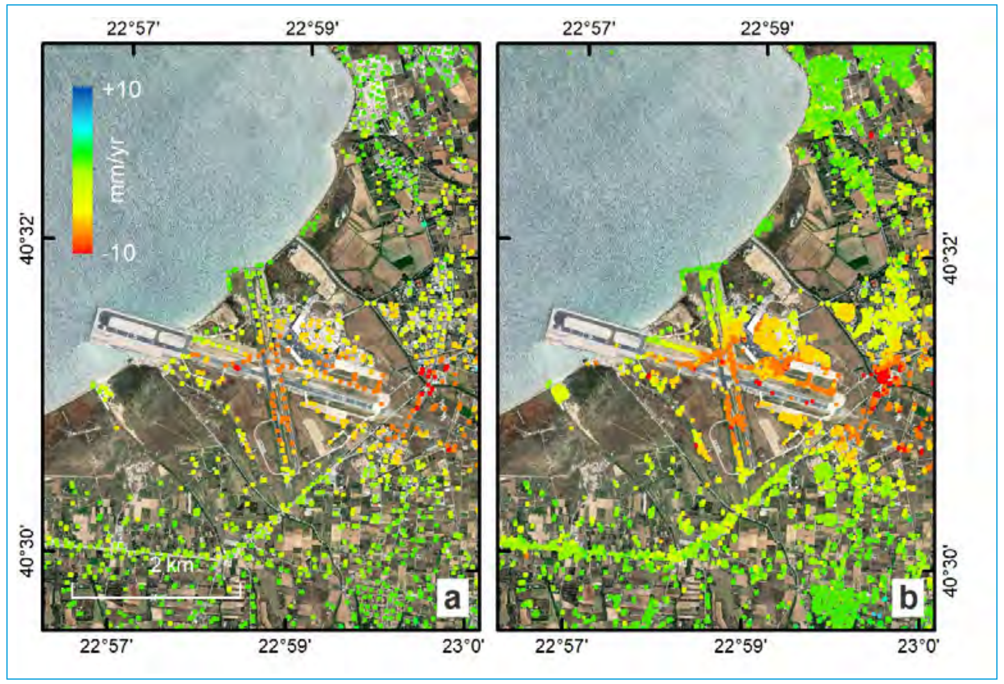


Figure 2. Sentinel-1 PSI average displacement rates for the period 2015–2020 over Thessaloniki International Airport using the SNAPPING PSI (a) Med and (b) Full resolution services. Contains modified Copernicus Sentinel-1 mission data (2015–2020), processed by AUTh on GEP.

1.6.1.2 Landslides

In a nutshell

What are landslides?	Landslides are downslope movements of rock, soil, or debris triggered by geophysical or hydro-meteorological events like extreme/prolonged rainfall, earthquakes, volcanic eruptions, rapid snowmelt, and anthropogenic actions (slope undercutting, construction)
Why are landslides relevant for hazards analysis?	Landslides are frequent natural hazards which occur globally. They can cause significant disruptions, damage, and casualties, particularly in hilly areas with high vulnerability and limited preparedness.
What are the benefits of EO-based landslide products?	EO enables effective landslide management creating landslide inventories, susceptibility assessment, and near real-time monitoring. Innovations like advanced In SAR (SBAS, PSI) and time series offset tracking (image correlation) offer unprecedented accuracy in mapping, monitoring, and modelling landslides, contributing to valuable data to early warning systems and disaster recovery efforts.

How can landslide products benefit Disaster Risk Reduction (DRR)?	EO-based landslide products bolster DRR by improving the accuracy of risk predictions, enhancing preparedness, and informing mitigation measures. They facilitate rapid detection of unstable areas, monitor temporal evolution of landslides, and contribute to emergency management. Post-landslide, EO data helps in the delineation and monitoring of affected areas, supporting effective recovery and future risk management.

Off-The-Shelf EO Products for Landslides

Landslides assessment: Landslides assessment product is a map that identifies areas prone to terrain sliding. It depicts landslide susceptibility values across the studied territory, based on multivariable analysis, assuming different triggering factors and scenarios (rainfall and earthquake as causing event). In this manner, the end user becomes aware of the distribution, extent, and threat of hot-spot zones over the area. It is especially useful, to cover the assessment of large remote territories, where damage mitigation measures should be prioritized based on proven indicators.

Landslide assessments were performed by Gisat in the frame of the EO4SD DRR project for World Bank and the Asian Development Bank in Bhutan.

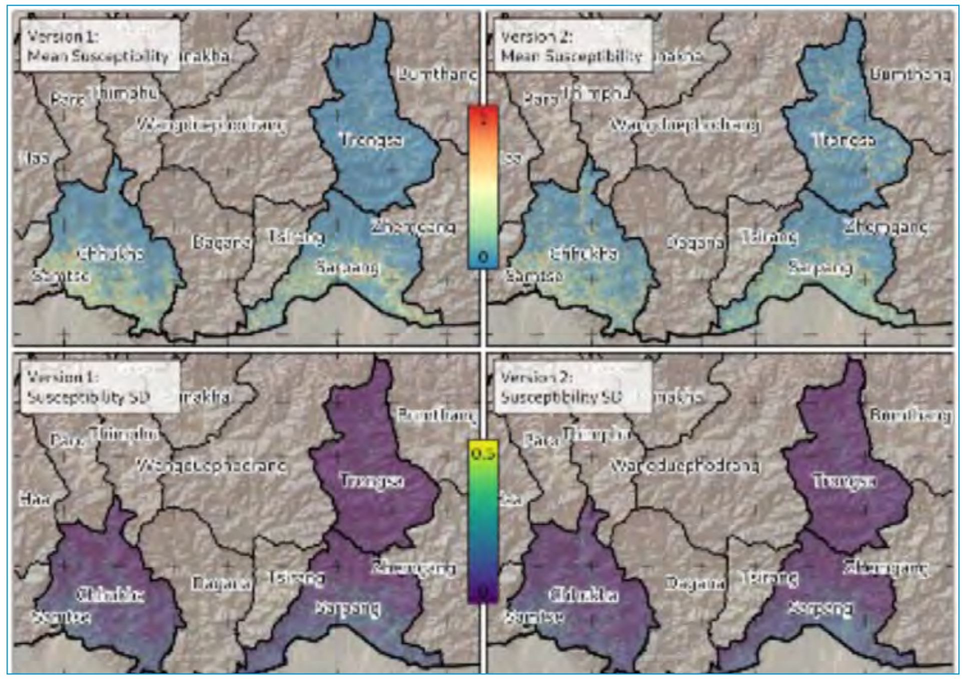


Figure 3. Landslide susceptibility mapping performed by ZAMG and Gisat over dzongkhags in Bhutan for a pilot of EO4SD DRR project.

On Demand EO Solutions

There are automatic processing tools available for landslide detection and inventory as ALADIM-S2, a mapping tool from Sentinel-2 data developed by the French National Centre for Scientific Research and the School and Observatory of Earth Sciences of the University of Strasbourg (CNRS-EOST).

InSARviz platform developed by Gisat allows integration and interactive dissemination of results from proprietary cloud-based interferometric workflows which detect ground motions and slope instabilities. The platform is aimed at visualising MT-InSAR results as well as exposed assets, road segments, or zones. Exposure visualisations combine results from landslide susceptibility mapping, landslide inventories, and terrain motion active cluster mapping, either side by side or in an aggregated manner.

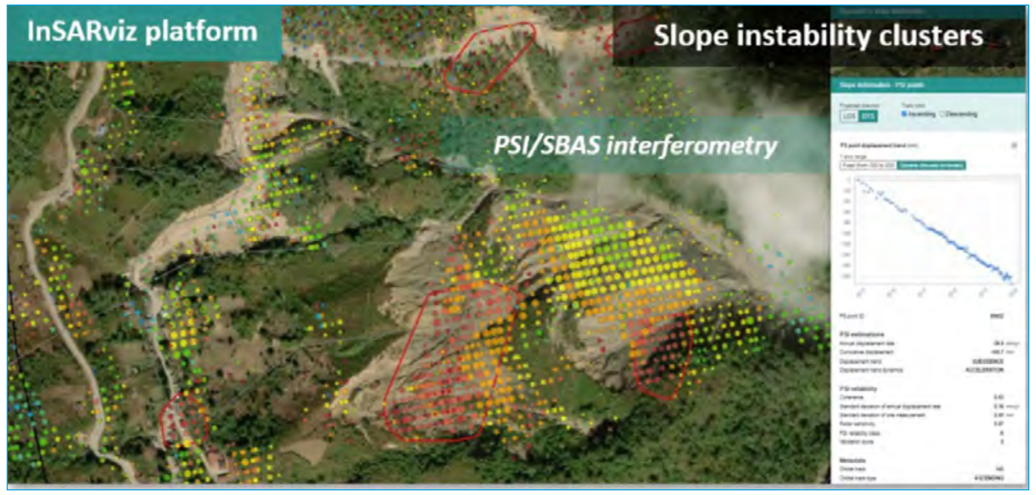


Figure 4. Interactive visualisations of slope instabilities in the InSARviz platform. Use case: Chin Road, Myanmar. Credits: Gisat 2020.

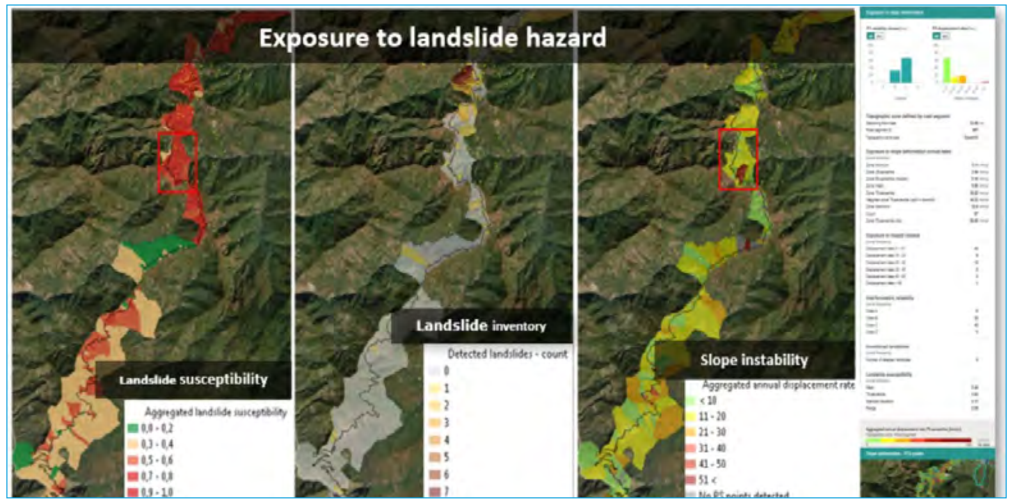


Figure 5. Hazard and exposure interactive visualisations in InSARviz platform. Use case: Chin Road, Myanmar. Credits: Gisat 2020.

Modelling Solutions Usually Combined With EO

Flow-R is a service implemented on the GEP. Flow-R stands for "Flow path assessment of gravitational hazards at a regional scale" and is a service for rapid, robust, and reliable propagation modelling of natural hazards. It allows for the assessment of the propagation extent based on several published empirical run-out models at local and regional scales. Details on the Flow-R model can be found in Horton et al. (2013) [35]. Up to now, Flow-R has been adapted to run computations of: Debris flows, Rockfalls, Rock avalanches, Shallow landslides, and Snow avalanches. The Flow-R service on the GEP contains parameter pre-sets for these hazard types calibrated for extreme events in the Alps (standard mode). Using these hazard pre-sets therefore leads to conservative propagation extents appropriated for susceptibility or indicative hazard mapping at a regional scale. The owner of Flow-R, Terranum Sàrl, provides on-demand advanced processing including the calibration of propagation parameters to local landslide inventories and the distinction between extreme, rare, and current landslide events using susceptibility levels (bespoke mode).

LHIS-HAZARD is a service implemented on the GEP. LHIS-HAZARD stands for 'Landslide Hazard Information System" and is a service for forecasting/nowcasting landslide hazard and risk at day+3 and day+1 over local and regional territories, by simulating the landslide source areas and the landslide propagation areas. LHIS currently targets the forecast of landslide triggered by precipitation (rain, snow) using as input either satellite-based precipitation products or, when accessible, in-situ meteorological precipitation predictions[36]. The LHIS service can be used in systematic mode (daily prediction) on the GEP after parameterization; the service owner, CNRS/EOST and Terranum Sàrl, provide on-demand support.

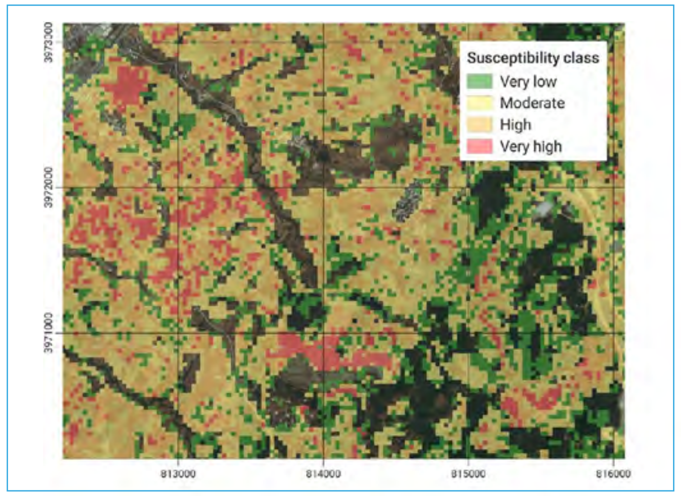


Figure 6. Landslide hazard forecast over a region in Morocco from continuous forecast of daily precipitation, as a service available on GEP. Credits: CNRS/EOST, Terranum Sàrl and Terradue, 2021 .

35 Horton, P., Jaboyedoff, M., Rudaz, B., and Zimmermann, M. (2013). Flow-R, a model for susceptibility mapping of debris flows and other gravitational hazards at a regional scale, Nat. Hazards Earth Syst. Sci., 13, 869-885, doi:10.5194/nhess-13-869-2013.

36 Malet, J.-P., Michoud, C., Oppikoffer, R., Emberson, R., Kirschbaum, D., Pacini, F., Horton, P., Puissant, A. et al. (2021). Landslide Information System for Disaster Risk Financing: Earth Observation and Modelling Products for Near-Real- Time Assessment. IEEE International Geoscience and Remote Sensing Symposium IGARSS, Brussels, Belgium, 2021, pp. 1812-1814

The GEP also provides access to a landslide-community portfolio of services[37] with several InSAR, optical, time series post-processing, and modelling services specifically tailored for landslide applications, ranging from landslide detection and inventory mapping to landslide systematic monitoring and landslide modelling.

1.6.1.3 Avalanches

In a nutshell

On Request EO Products and Services

Potential problem sites may be indicated by terrain instability of glacial moraines composed of loose debris material. Moreover, the detection of landslides, mudflows, or newly established debris cones using SAR change detection techniques may aid in the early identification of specific triggering elements within the cascading chain of events that could potentially lead to LDOF. These EO methods may serve as non-critical components of the Early Warning System (with seasonal observation frequency).

What are avalanches?	Avalanches are rapid downhill movements of snow or debris in mountainous areas. They pose a risk to infrastructure and human life. Debris avalanches can also form natural dams at valley bottoms, potentially causing flash floods with catastrophic outcomes downstream.
Why are avalanches relevant for hazards analysis?	Avalanches are significant natural hazards in mountainous regions, threatening lives, infrastructure, and property. The aftermath, including landslide dam outburst floods and glacial lake outburst floods, can have devastating downstream effects.
What are the benefits of EO-based avalanche products?	EO-based products allow for efficient avalanche detection and monitoring, primarily using SAR imagery. Techniques like Doppler shift measurement provide reliable monitoring systems. High-resolution optical remote sensing imagery can aid in identifying avalanche-prone zones and maintaining databases of past avalanche events.
How can avalanche products benefit Disaster Risk Reduction (DRR)?	Avalanche products contribute to DRR by enhancing risk prediction and preparedness. They provide data for monitoring avalanche activity, identifying avalanche-prone areas, and tracking past events. In case of an event, they assist in determining avalanche extent and facilitate efficient recovery efforts.

37 https://geohazards-tep.eu/#!pages/eo4alps and https://geohazards-tep.eu/#!web_store

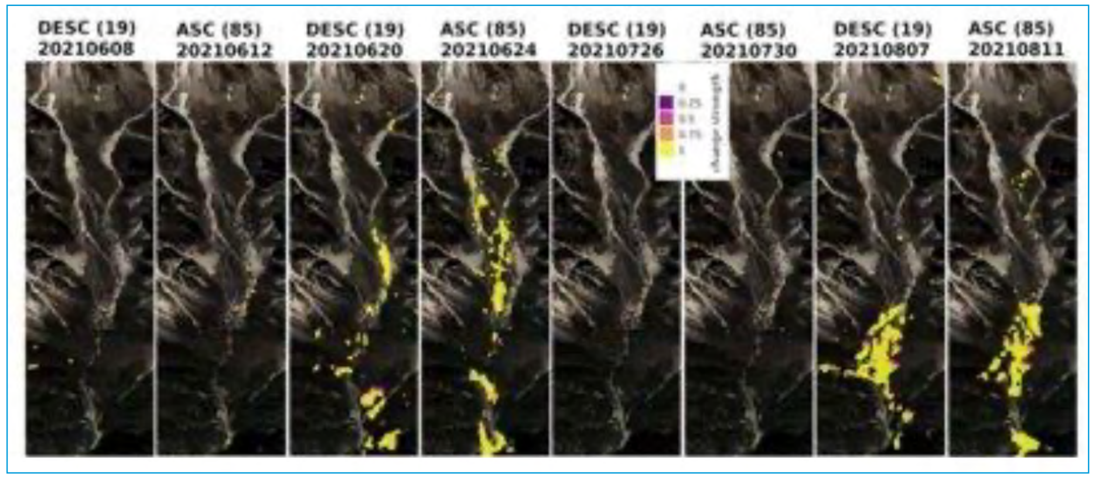


Figure 7. Example of detection of debris and terrain changes related to LDOF event from SAR amplitude.

1.6.1.4 Earthquakes

In a nutshell

What are earthquakes?	Earthquakes are natural seismic events caused by the release of energy accumulated in the Earth's crust due to tectonic forces. They result in ground shaking and surface ruptures.
Why are earthquakes relevant for hazards analysis?	Earthquakes are among the most destructive natural disasters, causing severe structural damage, landslides, tsunamis, and loss of life. Understanding their distribution and behaviour is crucial for hazard analysis and mitigation planning.
What are the benefits of EO-based earthquakes products?	EO-based products provide valuable insights into surface deformations associated with earthquakes. Techniques such as advanced InSAR and optical image correlation offer the ability to monitor temporal evolution of surface deformations, contributing to a better understanding of seismic phenomena and ultimately hazard. These methods offer wide area coverage, access to large historic archives, are relatively inexpensive, and are very sensitive to either small (InSAR) or large (image correlation) surface displacements.
How can earthquakes products benefit Disaster Risk Reduction (DRR)?	EO-based earthquake products contribute to DRR by identifying and mapping potential active faults, monitoring ground deformations, and aiding in post-event recovery. While it is not possible to predict earthquakes, these products help understand hazards, their distribution, and inform mitigation strategies. This aids in disaster preparedness and recovery, reducing risk and enhancing resilience.

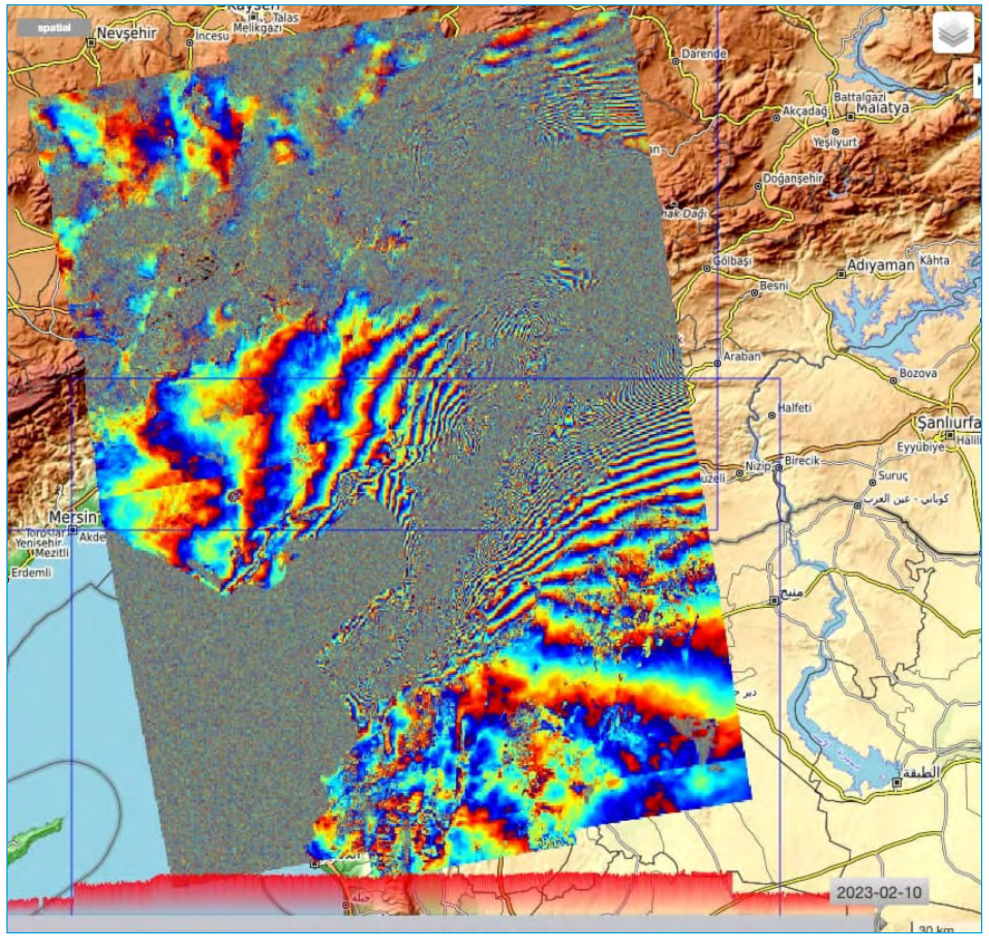


Figure 8. Radar interferogram generated using acquisitions of 9 February and 28 January 2023 and the DIAPASON InSAR processing service integrated on the GEP. Contains modified Copernicus Sentinel-1 mission. data (2020), processed by ESA on GEP.

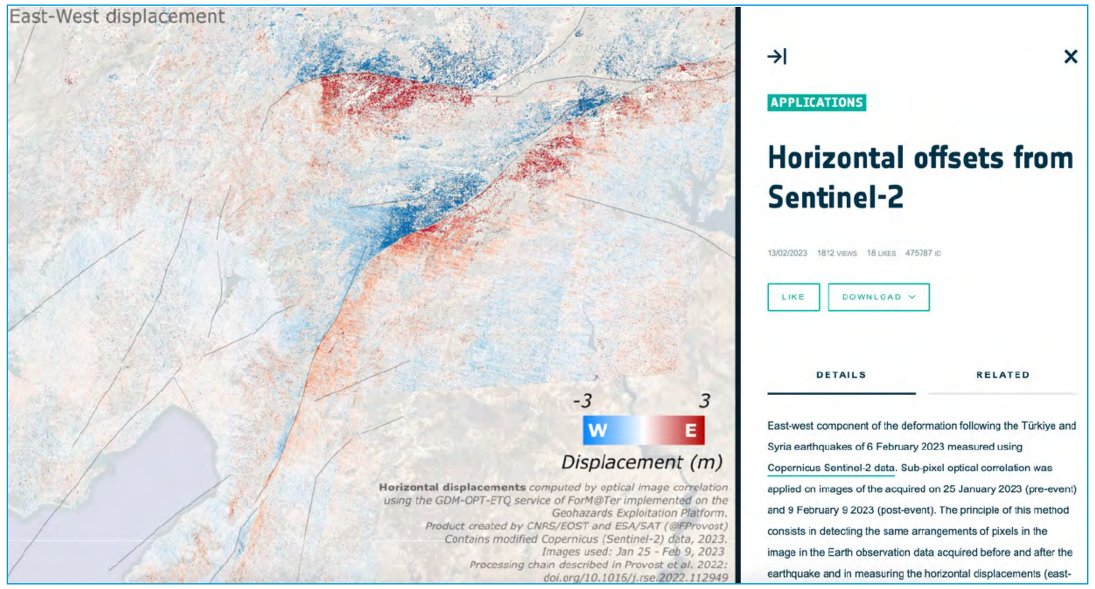


Figure 9. Example of surface motion quantification (East-West component of the deformation) following the Turkey and Syria earthquakes of 6 February 2023 measured using Copernicus Sentinel-2 data and the GDM-OPT-ETQ service for sub-pixel optical correlation.

On Demand EO Solutions

Several services on GEP, among which DIAPASON, SNAP-InSAR and P-SBAS (IFG mode), are applying the conventional Differential InSAR (DInSAR) technique for the detection of abrupt terrain deformation, well-suited for investigation of earthquake-induced motion. Some services are supporting exclusively Copernicus Sentinel-1 mission data, while others also support other national SAR missions. Outputs of the DInSAR analysis include wrapped differential interferograms, interferometric coherence and Line-of-Sight (LoS) displacement maps.

Apart from interferometric services, especially when significant horizontal surface displacements are involved, image correlation services (also known as "offset tracking"), such as GDM-OPT-ETQ on GEP, can be beneficial for measuring North-South and East-West motion components.

1.6.1.5 Tsunami

In a nutshell

What are tsunamis?	Tsunamis are oceanic phenomena triggered by events such as earthquakes, volcanic eruptions, or landslides, both above and below water. They result in potentially catastrophic coastal water-related hazards, characterized by massive sea waves.
Why are tsunamis relevant for hazards analysis?	Tsunamis can cause extensive damage to coastal areas, including flooding, erosion, and contamination of water quality. This puts populations, assets, and infrastructure at risk, necessitating their consideration in hazard analysis for proper planning and response.
What are the benefits of EO-based tsunamis products?	While direct observation of tsunamis via EO is not possible, EO data assists in modelling simulations for predicting tsunami-induced coastal inundation, by calibrating hazard parameters like wave propagation velocity and height. Post-tsunami, EO data can aid in assessing the extent of inundation, coastal erosion, coastline retreat, and water quality due to contaminants and debris flow.
How can tsunamis products benefit Disaster Risk Reduction (DRR)?	EO-based tsunami products, combined with robust modelling, can inform risk maps, improving tsunami preparedness by highlighting vulnerable areas and assisting in strategic planning for mitigation measures. Post-tsunami, these products can guide recovery efforts, assess damage, and support rebuilding strategies. Thus, they play a crucial role in DRR.

Modelling Solutions Usually Combined With EO

Simulations of propagations of tsunami waves can be used for estimating wave power and height and producing information on run-up, water extent, and depth. This information, combined with exposure and vulnerability mapping from space, can allow for the generation of risk maps.

One of the most reputed and accepted tools is the Global Tsunami Model of the group Edanya, from the University of Malaga (Spain) that is available worldwide free of charge. http://edanya.uma.es/gtm/index.php/products/probabilistic-tsunami-hazard-analisys-ptha

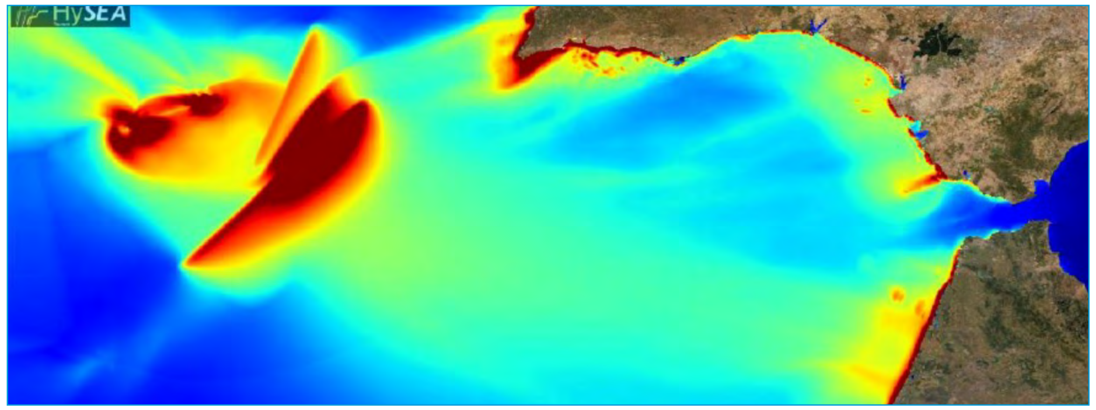


Figure 10. Model simulating tsunami waves, used for assessing the risk in the coast of Andalucía for the EC Emergency Management Service by the group Edanya from University of Malaga. Vulnerability and risk mapping cannot be disclosed due to confidentiality restrictions.

NGDC/WDS Global Historical Tsunami Database. The Global Historical Tsunami Database consists of two related files containing information on tsunami events from 2000 B.C. to the present in the Atlantic, Indian, and Pacific Oceans, as well as the Mediterranean and Caribbean Seas.

1. **Volcanoes**

What are volcanoes?	Volcanoes are geological objects that allow magma, ash, and gases to escape from beneath the Earth's surface, often leading to hazardous events such as pyroclastic and lava flows, ash falls and gas emissions.
Why are volcanoes relevant for hazards analysis?	Volcanic activity can result in short-term localized hazards (like pyroclastic and lava flows) as well as longer-lasting, far-reaching impacts (like ash and gas dispersal). Volcanoes can be remote, hazardous to access, and their impacts can extend across vast areas, making them a critical consideration in hazards analysis. Worldwide there are more than 250+ volcanoes considered active.

What are the benefits of EO-based volcanoes products?	EO-based volcano products allow for the identification and characterization of eruption types and their probabilities, characterization of volcanic state through elevation and deformation measurements, monitoring of thermal outputs and eruption estimates and monitoring of lava flow propagation. Such products offer unique insights into volcanic activity, especially in hard-to-reach locations.
How can volcanoes products benefit Disaster Risk Reduction (DRR)?	In terms of prevention and preparedness, EO-based products can detect precursors to eruptions, such as ground deformation and increased superficial heat flow, and support predictive modelling, like lava-flow path simulations. During the recovery phase, they can assist in monitoring continued volcanic activity, delineating the extent of lava flows, and tracking the movement and dispersal of ash clouds. Hence, these products can significantly contribute to DRR by informing early warning systems, supporting strategic planning for mitigation measures, and guiding post-eruption recovery efforts.

In a nutshell

On Request EO Products and Services

The CEOS WG on disasters has performed a demonstration activity consisting of a regional study in the Latin American volcanic arc (from Mexico through to Chile) to develop methodologies and protocols. The regional demonstration is a precursor to showcase how volcano monitoring would work on a global scale. The method is the analysis of SAR data to assess deformation of volcanoes, which provides insights on the types of data and repeat times best suited to monitor volcanoes in different environments and supplies deformation information to local users.

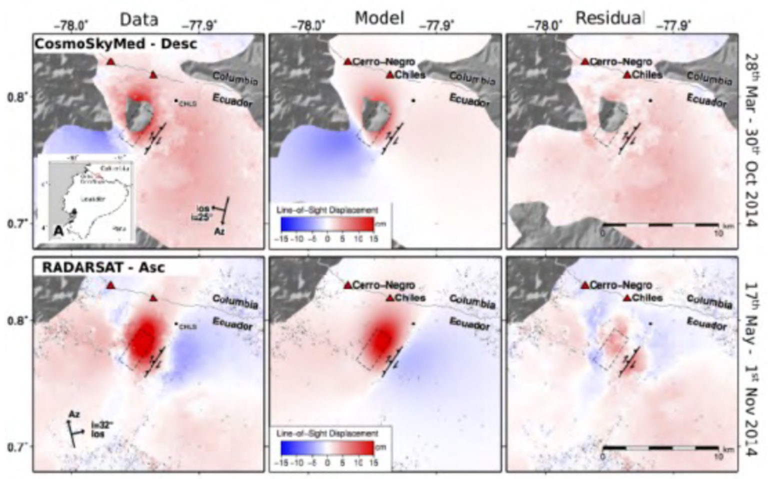


Figure 11. Volcano Monitoring using Earth Observing Satellites – CEOS WG Disasters Volcano Pilot

On Demand EO Solutions

Volcanic hazard monitoring: The Geohazards Exploitation Platform has the processing chain STEMP L8 – Surface Temperature Map developed and integrated by INGV, that processes systematically Landsat-8 data to measure the temperature for areas identified as «thermally active» in volcanic areas (22 volcanoes worldwide).
Several other GEP services for measuring terrain deformation, such as P-SBAS and SNAPPING, are also applicable in the case of volcano monitoring.

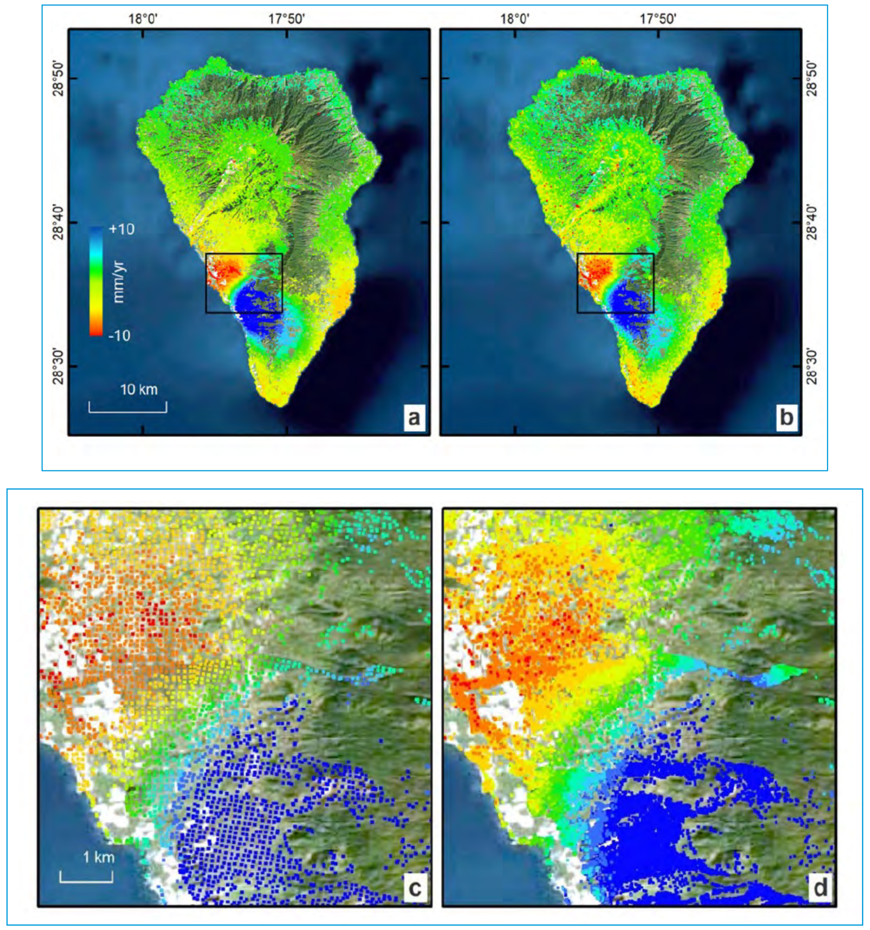


Figure 12. Sentinel-1 PSI motion rates (from June 2019 to December 2021) for the La Palma 2021 volcano unrest derived using (a) SNAPPING PSI Med and (b) SNAPPING PSI Full services and (c,d) a zoom over the outlined area (black rectangle). Over the depicted area in c-d frames, about 3000 and 72,700 point targets were detected by PSI Med and PSI Full, respectively. Contains modified Copernicus Sentinel-1 mission data (2019–2021), processed by AUTh on GEP.

Modelling Solutions Usually Combined With EO

Q-LavHa is a freeware plugin running on QGIS which simulates lava flow inundation probability from one or regularly distributed eruptive vents on a Digital Elevation Model (DEM). It combines existing probabilistic and deterministic models and proposes some improvements to calculate the probability of lava flow's spatial propagation and terminal length. Spatial propagation is constrained by the probabilistic steepest slope. Volcflow (https://lmv.uca.fr/volcflow/) is a family of modelling tools used for determining the rheological behaviour of dense pyroclastic flows and debris avalanches. This allows for visualizing deformations of the surface of debris avalanche and interpret or compare with field structures for volcanic hazard mapping, simulation of tsunami generated by volcanic flows, reproducing the emplacement of fluidized flows in laboratory, simulation of lava flows and simulation of dense and dilute pyroclastic flows.

DEFVolc (https://www.opgc.fr/defvolc/Vue/MainPage.php) is a modelling tool able to s to simulate volcano deformation data using both InSAR and GNSS, in order to understand the sources of displacement (e.g. fractures -fluid filled fracture or faults-, or massive magmatic reservoirs), thus allowing better understanding of the volcanic hazard.

1.6.1.1 Coastal erosion

In a nutshell

On Request EO Products and Services

What is coastal erosion?	Coastal erosion refers to the range of geomorphological processes affecting the retreating position of the shoreline. In addition, accretion refers to build up of sediments. Factors like met-oceanic conditions can instigate nearshore circulations strong enough to displace the sediment along the shore. This phenomenon, varying spatially and temporally, can result in sudden, significant erosion of coastlines, sometimes triggered by a single storm event.
Why is coastal erosion relevant for hazards analysis?	Coastal erosion is critical in hazard analysis because it directly impacts shoreline stability, influencing human settlements, infrastructure, and ecosystems. It can be triggered by both human activity and natural events like severe storms. However, its effects and rates of change can vary greatly over time and space, sometimes involving seasonal changes, which underscores the need for careful, ongoing assessment.
What are the benefits of EO-based coastal erosion products?	EO-based coastal change products provide a synoptic view of the coastal system and can detect local changes in shoreline position with high precision. These tools enable mapping, monitoring, and managing erosion caused by storm surges and human activity. They can supply information on shoreline distribution at a regional scale, track the temporal evolution of coastal erosion, and offer rapid detection of unstable areas. Regular observations enable planners to follow the migration of their shorelines, identify weak areas (ie those contributing most to accretion or erosion) and therefore effectively plan where coastal defences may be appropriate.

How can coastal erosion products benefit Disaster Risk Reduction (DRR)?	For prevention, these products support the mapping and inventorying of coastlines, as well as monitoring and characterizing temporal erosion developments. In terms of preparedness, they contribute to early warning systems and forecasting, allowing rapid detection of unstable regions, their spatial extent, and temporal evolution. This supports emergency management processes and real-time assessment of coastal erosion activity. Thus, EO-based coastal erosion products can aid in strategic planning, mitigation initiatives, and emergency responses, making them valuable for DRR.

Coastal erosion: The products of shoreline and sediment monitoring allows for the detection of significant changes in coastal areas as well as the identification of hot spots where erosion or even sedimentation is anomalous. The analysis of the shoreline product through time allows the detection of coastal change (accretion and erosion) along the coast. The historical analysis of the shorelines identifies coastal change associated with seasonal variation, storm events, human interventions (such as sea defences and coastal construction) as well as long-term trends, which in turn should prevent hasty investment decisions based on insufficient knowledge. The sediment transport product allows for assessing the sediment source, volume, and flow (Figure 10). The sediment flow product can be used to identify the areas which are most susceptible to potentially damaging impact in the future, i.e., the "weakest" areas of the coastal zone. The combination of coastal change indicators and sediment dynamics is a crucial part of a risk assessment for coastal facilities and infrastructures as well as for planning new investments. This real evidence is also important in monitoring the effects of illegal changes such as unauthorized coastal development and sand mining.
Application in ESA projects

Time series analysis of erosion and accretion trends was performed by ARGANS Ltd in the frame of the GDA DR project with the West Africa Coastal Management Program and local users in Ghana.

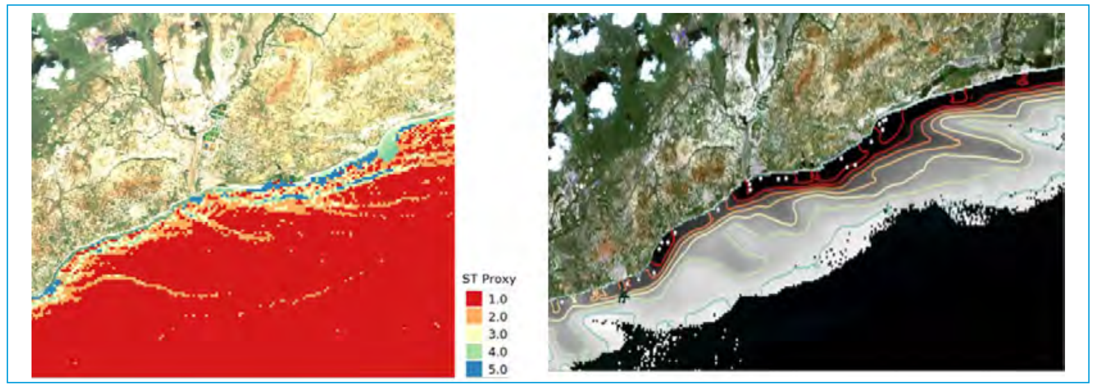


Figure 13. Sediment flow product, which was developed under a new agile methodology that allowed for the demonstration of the products.

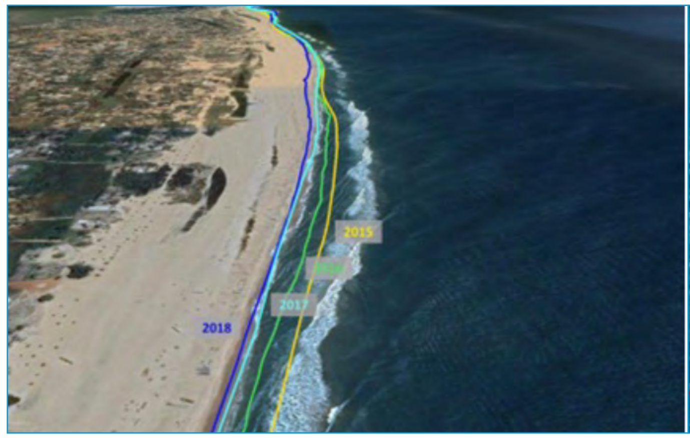


Figure 14. Evolution of the shorelines in different moments.

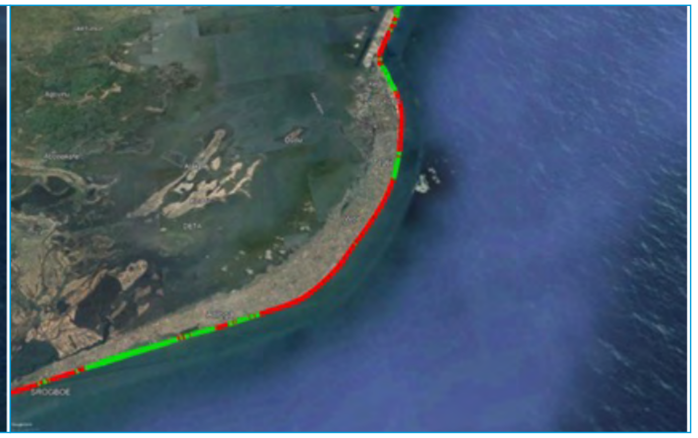


Figure 15. Identification of erosion and accretion zones after calculation of changes across time series.

Modelling Solutions Usually Combined With EO

Satellite observations play a crucial role in monitoring coastal areas. However, it is important to recognize their limitations, especially regarding the lack of vertical resolution, with no detailed information about the water column's dynamics or incomplete coverage of the seabed evolution. By integrating satellite observations into numerical models at global, regional, or coastal scales, it becomes possible to achieve a synoptic 4D monitoring of coastal processes, such as shoreline change (longshore or cross-shore). This integration would enhance the accuracy and prediction capabilities of numerical models, which simulate physical processes along the coastline, helping to understand erosion mechanisms and predict future scenarios. The integration of satellite data could be done using data assimilation techniques, by using data such as sediment concentration or wave heights. This would allow the model to be calibrated and adjusted to reflect real-world conditions more accurately, providing the user with information related to the mechanisms and processes involved in the observed patterns provided by the satellite data. Popular coastal modelling software includes Delft3D, SWAM (Simulating Waves Nearshore) or cross-beach.

1.6.2 EO for Hydro-meteorological Hazards

Hydro-meteorological hazards conditioned by atmospheric, hydrological, climatological or oceanographic triggers and cause concatenated occurrences of other hazards such as landslides, wildfires, plagues, epidemics and the transport and dispersal of toxic substances and volcanic eruption material (United Nations, 2009).

Like all natural hazards, hydro-meteorological events cannot be avoided, but Early Warning Systems and forecasts provide lead-time, which together with public awareness, education, and preparedness, allow for a quick response, increasing human safety and reducing losses.

Hazard group	Hazard type	Hazard	Hazard sub-type
Meteorological	Storm	HCW (Hazardous Convective Weather)	Hurricane
			Typhoon
			Thunderstorm (Lighting)
			Snowstorm (Blizzard)
			Sand/Dust-storm
			Tornado
Hydrological	Flooding	Inland flooding	
		Flash floods	
		Coastal flooding	
Climatological	Climatic Variability	Drought	
		Wildfires	

Table 6 EO for hydro-meteorological hazards.

The potential of EO satellites lies in their ability to inform users about hydro-meteorological events around the globe, therefore the provision of their vital information allows to mitigate and prepare for those disasters. For example, mapping floodwater extent during an active flood event is critical for disaster managers to focus their efforts. Initiatives such as the Copernicus Sentinel missions work well for covering large areas, for more specific studies, VHR data could be needed.

As explained previously and according to UNISDR (United Nations, 2009), ground instabilities can be of geophysical or hydro-meteorological origin. The following section covers all EO services applicable for terrain deformation analysis, they are described with the aim of unifying these types of hazards (using the same methodologies).

1.6.2.1 Floods

In a nutshell

What are floods?	Floods are natural disasters characterized by an overflow of water that submerges land which is dry under normal conditions. They can occur because of excessive rainfall, rapid snowmelt, or dam failure, leading to the inundation of land areas.

Why are floods relevant for hazards analysis?	Floods are among the most destructive natural disasters, causing substantial damage to infrastructure and property, and the loss of human life. They can disrupt the normal function of affected communities and lead to significant economic losses. As such, they are a critical focus in hazard analysis to be able to predict their occurrence and mitigate their impacts.
What are the benefits of EO-based floods products?	EO-based flood products allow for effective flood monitoring, providing crucial information on areas affected by flooding. They can provide historical records of flooding, aid in creating hazard maps, and support the development of flood event simulations. These products can map flood extent in near-real-time, which is invaluable in emergency response efforts. They also enable the detection of floods in both rural and urban areas, which can be challenging due to dense vegetation and built-up areas. Both optical and Synthetic Aperture Radar (SAR) imagery can be used to enhance flood detection capabilities.
How can floods products benefit Disaster Risk Reduction (DRR)?	Flood products are essential for DRR as they can identify flood-prone areas, thereby informing mitigation strategies and land-use planning. They can also help prepare for floods by providing predictive data on expected water depth, flow velocity, and direction. In the aftermath of a flood, these products can assess the extent of the flood and the associated damage, which is crucial for recovery and reconstruction efforts. They can also contribute to the development and improvement of early warning systems, which are critical in reducing the impact of flood events.

Off-the-shelf EO products for floods

Global:

- Global Surface Water Explorer - The European Commission's Joint Research Centre developed the Global Surface Water Explorer dataset in the framework of the Copernicus Programme. This maps the location and temporal distribution of water surfaces at the global scale over the past 3.8 decades and provides statistics on the extent and change of those water surfaces. The dataset, produced from Landsat imagery, supports applications including water resource management, climate modelling, biodiversity conservation and food security.
- Global Flood Monitoring (GFM) is an integrated part of Global Flood Awareness System (GloFAS) in the Copernicus Emergency Management Service (EMS). GFM is designed to provide a continuous global, systematic monitoring of flood events, with significantly enhanced timeliness of flood maps for emergency response and improved effectiveness of Rapid Mapping activation requests through a better identification of the area of interest. Its service fully exploits the unique capabilities of the Sentinel-1 mission to realize a continuous global and automated monitoring of all land surface areas.
- The Dartmouth Flood Observatory (DFO) is a research institution that specializes in flood monitoring and assessment using satellite data. DFO provides valuable data and tools for understanding and monitoring global flood events. They produce on a regular basis:
    - Global Flood Database: The Global Flood Database maintained by DFO is a comprehensive collection of flood event information from around the world. It includes data on flood occurrence, extent, duration, and impacts. This database serves as a valuable resource for analysing historical flood events, understanding flood patterns, and identifying high-risk areas prone to flooding.
    - Flood Extent and Severity Maps: DFO produces flood extent maps that indicate the spatial coverage of flooding during significant flood events. These maps are derived from satellite imagery and provide valuable information on the affected areas. They help in assessing the severity of flooding, identifying vulnerable regions, and supporting emergency response and relief efforts.
    - Flood Event Database and Archive: DFO maintains a flood event database and archive that contains detailed information on specific flood events, including satellite imagery, hydrological data, and flood characteristics. Researchers and stakeholders can access this data to study the dynamics of individual flood events, investigate flood patterns, and develop flood models for improved flood risk management.
    - The data and resources provided by the Dartmouth Flood Observatory are instrumental in flood monitoring using satellite data. They enable the identification of flood-prone areas, analysis of flood patterns and trends, and support decision-making processes related to flood management and disaster response. By utilizing satellite imagery and remote sensing technologies, DFO contributes to a better understanding of flood events and aids in building resilience to future flooding.
- The SERVIR initiative, a collaboration between NASA and the United States Agency for International Development (USAID), provides a range of products and services relevant to flood monitoring and management. SERVIR leverages satellite data and geospatial technologies to support decision-making and address environmental challenges in developing regions. Here are some examples of products offered by SERVIR related to floods:

1. **Flood Extent Mapping:** SERVIR generates flood extent maps using satellite imagery and remote sensing techniques. These maps depict the spatial extent of flooding during and after flood events, providing valuable information for emergency response and flood management efforts.
2. **Early Warning Systems:** SERVIR develops and supports the implementation of early warning systems for floods. These systems integrate real-time satellite

data, weather forecasts, hydrological modelling, and ground-based observations to provide timely alerts and warnings of potential flood events. They help communities and authorities take preventive measures and evacuate areas at risk.

3. **Rainfall and River Gauging:** SERVIR utilizes satellite-based rainfall estimates and river gauging data to monitor precipitation patterns and river levels. This information helps in understanding rainfall intensity, river flow, and potential flood conditions. It aids in assessing flood risks, forecasting flood events, and managing water resources.

4. **Hydrological Modelling:** SERVIR employs hydrological models that utilize satellite data and other inputs to simulate and forecast water movement in river basins. These models provide insights into river flow, flood inundation, and water availability. They support flood forecasting, watershed management, and the evaluation of flood mitigation strategies.

5. **Decision Support Tools:** SERVIR develops decision support tools that integrate satellite data, geospatial information, and modelling outputs to facilitate data-driven decision-making in flood management. These tools help stakeholders assess flood risks, prioritize response actions, and plan resilience measures.

6. **Capacity Building and Training:** SERVIR conducts capacity building activities and training programs to enhance the use of satellite data and geospatial technologies for flood monitoring and management. These initiatives aim to empower local institutions, decision-makers, and communities with the knowledge and skills necessary to effectively utilize the available flood-related products and services.

Continental:

In 2012, as part of the Copernicus Emergency Management Service (EMS), the European Commission launched the European Flood Awareness System (EFAS) [38]. EFAS provides overview maps of flood probabilities on a European scale. Moreover, it provides overviews on ongoing and forecasted floods in Europe up to 10 days in advance and can contribute to the activation of the EMS in" rush mode". Within the African region, the Africa RiskView River Flood Model (AFM-R) provides daily information on flood extent, focusing on large-scale river flooding at the continental level.

Several past initiatives have produced global flood hazard maps, some of which are openly accessible while others are covered by commercial licenses. A non-exhaustive list of those data and their essential characteristics are summarized in the table below.

38 European Flood Awareness System (EFAS) https://www.efas.eu/ [accessed 22 April 2019]

MODEL	Climate Forcing	Land Surface Model	River Routing	Floodplain	Flood Frequency	Down-scaling	Output Data Resolution	Smallest River size or upstream catchment area considerede
GLOFRIS	EU-Watch reanalysis 1960-1999	Hydrological model PCR-GLOBWB 0.5 degree	Kinematic 0.5 deg	30 arc sec SRTM model	Flood volume Gumbel distributon for 1960 to 1999	Volume redistribution on 30 arc sec SRTM model	30 arc sed ~900m	Strahler order >=6 only
CaMa-Flood	JRA-25 Reanalysis 1979-2010 +GPCP rain gauge correction	MARSIRO=GW Energy and Water Balance (1 degree)	Inertia 0.25 deg	Sub-grid topo. Upscaled from 3 arc sec Hydro-SHEDS & SRTM	Water Level Gumbel distribution for 1979 to 2014	Flood depth downscaled onto 18 arc sec DEM	18 arc sec ~540m	Drainage area> 0.25 degree grid box (Approximately~ 500KM²)
ECMWF	ERAInterim reanalysis 1979-2014	HTESSEL, T255 (~80km)	3 methods Kinematic, Inertia (x2) 0.25 deg	Sub-grid topo. Upscaled from 3 arc sec Hydro-SHEDS & SRTM	Flood depth GEV distribution for 1979 to 2014	Depth down-scaled onto 19 arc sec DEM	18 arc sec ~540m	~500km²
JRC	GloFAS ERA-Interim reanalysis	HTESSEL	LISFLOOD Global (0.1 DEG) + Inertia (30 arc sec)	Sub-grid topo. Upscaled from 3 arc sec Hydro-SHEDS & SRTM	Gumbel distribution for 1980 to 2013	N/A	30 arc sec ~90m	~5000km²
SSBN	Regional Flood Frequency Analysis (FFA) from global gauge data	N/A	Inertia 30 arc sec	Hydro-SHEDS & SRTM 30 arc sec	From FFA	Depth down-scaled onto 3 arc sec DEM	3 arc sec ~90m	~50km²
CINE-UNEP	Regional FFA from global gauge data +ECEarth bias corrected	Continuum Model to improve FFA	Manning's al multiple points	Reconditioned HydroSHEDS & SRTM	From FFA, GEV fitting	Native at 3 arc sec	3 arc sec ~90m	~1000km²

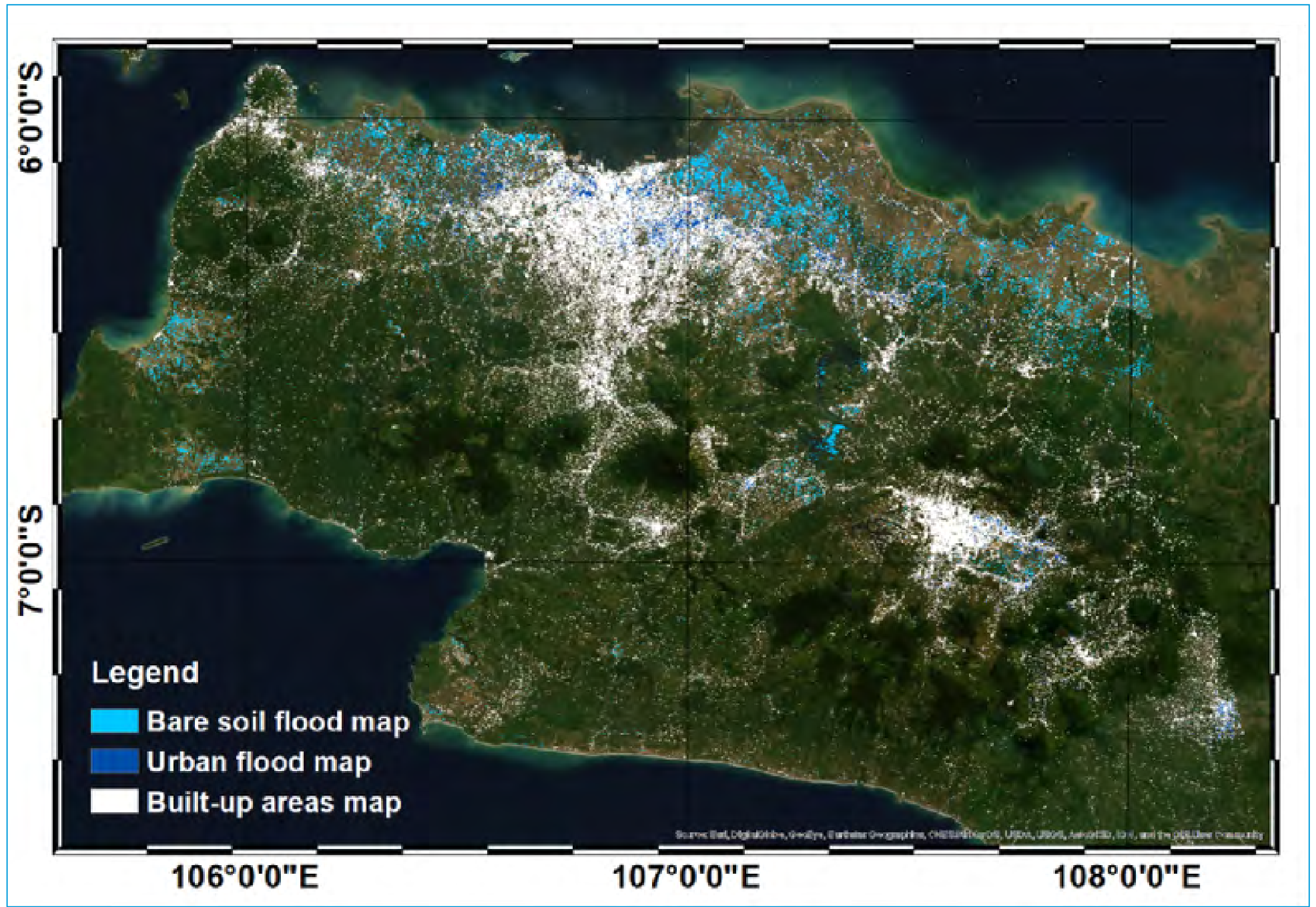
Table 7. Table describing available Global flood hazard maps adapted from "Bernhofen M. V., Whyman C., Trigg M., Sleigh P.A., Smith A.M., Sampson C.C., Yamazaki D., Ward P.J., Rudari R., Pappenberger F., Dottori F., Salamon P., Winsemius H.C. A first collective validation of global fluvial flood models for major floods in Nigeria and Mozambique, 2018, Environmental Research Letters, Volume 13, Number 10".

Evolutions of the datasets mentioned above are currently available, such as the one developed by GloFAS that will soon publish a 90 m version of the global maps, or CIMA/UNEP-GRID that will publish a new 90 m resolution global map accounting for climate change scenarios. GLOFRIS, GloFAS, and CIMA/UNEP-GRID maps are publicly available, while others such as Fathom maps are subject to commercial licences but are widely used by IFIs in their studies.

On Request EO Products and Services

The flood mapping extraction will rely on observational data (i.e., EO) and modelling, extracting ad-hoc products of flood delineation, flood temporal monitoring, and flood hazard mapping, as follows:

EO-based flood products: The EO-based flood delineation product enables the identification of flood-affected areas, inclusive of both urban and non-urban terrains. This tool is comprehensive, accounting for both coastal and inland flooding events. Various causes of inland floods like dam disruptions, melting of ice and snow, rainfall, river ice jams, and excessive runoff are considered. Meanwhile, coastal floods are evaluated based on factors such as waves, astronomical tides, storm surges, relative mean sea level, and river discharges in estuaries. This product is foundational to creating other valuable satellite-derived products. It leverages either SAR or optical acquisitions to assess specific flood events, with the most advanced versions using a combination of SAR intensity, coherence, and optical acquisition for the best possible flood representation, even in complex urban areas.



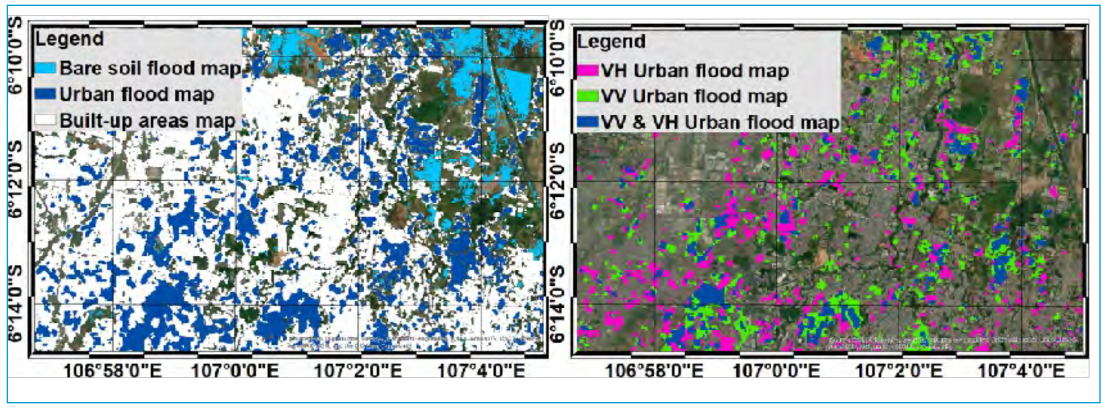


Figure 16. Flood delineation maps for a Flood event in Jakarta (January 2020). The first panel shows the maximum extension of the flooded areas on bare soil (Cian colour, using SAR intensity) and in urban areas (blue colour, Using SAR coherence), in white are the building footprints detected from the S1 acquisition. The lower left panel shows a detail of the map in a peripheral urban area, the lower right panel shows the separate contribution to flood detection in urban areas from the coherence computed on two different polarizations. Credits to LIST and CIMA.

Flood temporal monitoring: This product is a multi-temporal application of the flood delineation product and aims to provide temporal analyses of occurred flood events within a defined area of interest, delivering information on maximum flood extent, and the temporal evolution of the flood, which provides information about the persistence of the water in the area. In the most advanced cases the temporal analysis can be extended to a full stack of acquired images over the years on an area providing information not only about the temporal evolution during a specific flood event or a season, but also on the flood frequency in an area of interest. Knowing in advance areas worldwide where flood events occur has important advantages for urban planning and setting mitigation measures for infrastructures and the population.

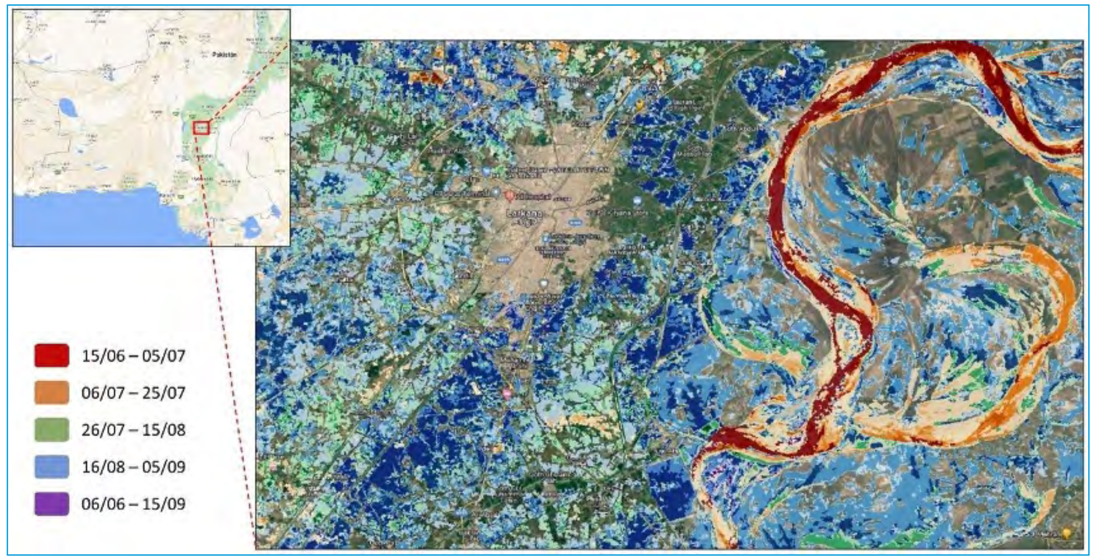


Figure 17. Flood progression in surrounding areas of the city of Larkana, Pakistan (Source: posted on ESA Sentinel Success Stories, contains modified Copernicus Sentinel data (2022), processed by LIST/CIMA/Wasdi Sarl).

Figure 18. Flood frequency in Surabaya (Indonesia) darker colours depict areas that have been flooded more frequently in the monitoring period here from 2015 to 2023, processed by LIST/CIMA/Wasdi Sarl).

Model-based flood products: Flood modelling is a method used to predict the characteristics of water during floods. These characteristics can include velocity, depth, and extent of the flood. There are generally two types of flood modelling: hydraulic and hydrologic.

- Hydrologic modelling is concerned with how precipitation (rainfall and snow) is converted into runoff in the watershed. The model will take various factors into account, such as soil type, vegetation cover, and land usage, to predict how much of the rainfall will become runoff. This process is also influenced by the existing conditions, for example, if the soil is already saturated from a previous storm.

- Hydraulic modelling involves predicting how this runoff will move downstream and in extreme cases how it will expand in the river flood plain. The model will consider the physical characteristics of the river or stream, including its shape, size, and roughness, as well as the presence of structures like bridges and culverts.

A variety of software tools are available to carry out these flood models. Some of the most used include HEC-HMS for hydrologic modelling, and HEC-RAS or TELEMAC-2D for hydraulic modelling.

EO and modelling integration for flood products: Flood hazard mapping is a product that synthesizes flood delineation or temporal flood analysis based on EO with DEM and/or hydrological/hydraulic models. This combination enables us to estimate flood water depth and calculate return periods (if model simulations are available). The primary output is a hazard map that outlines water extension and depth for different return periods (I.e. Frequencies), with the capacity to also produce water depth maps for single-episode analysis. The significant advantage of this product lies in its predictive capabilities, allowing for future flood threat anticipation and facilitating susceptibility assessment of relevant assets within a specified area of interest.

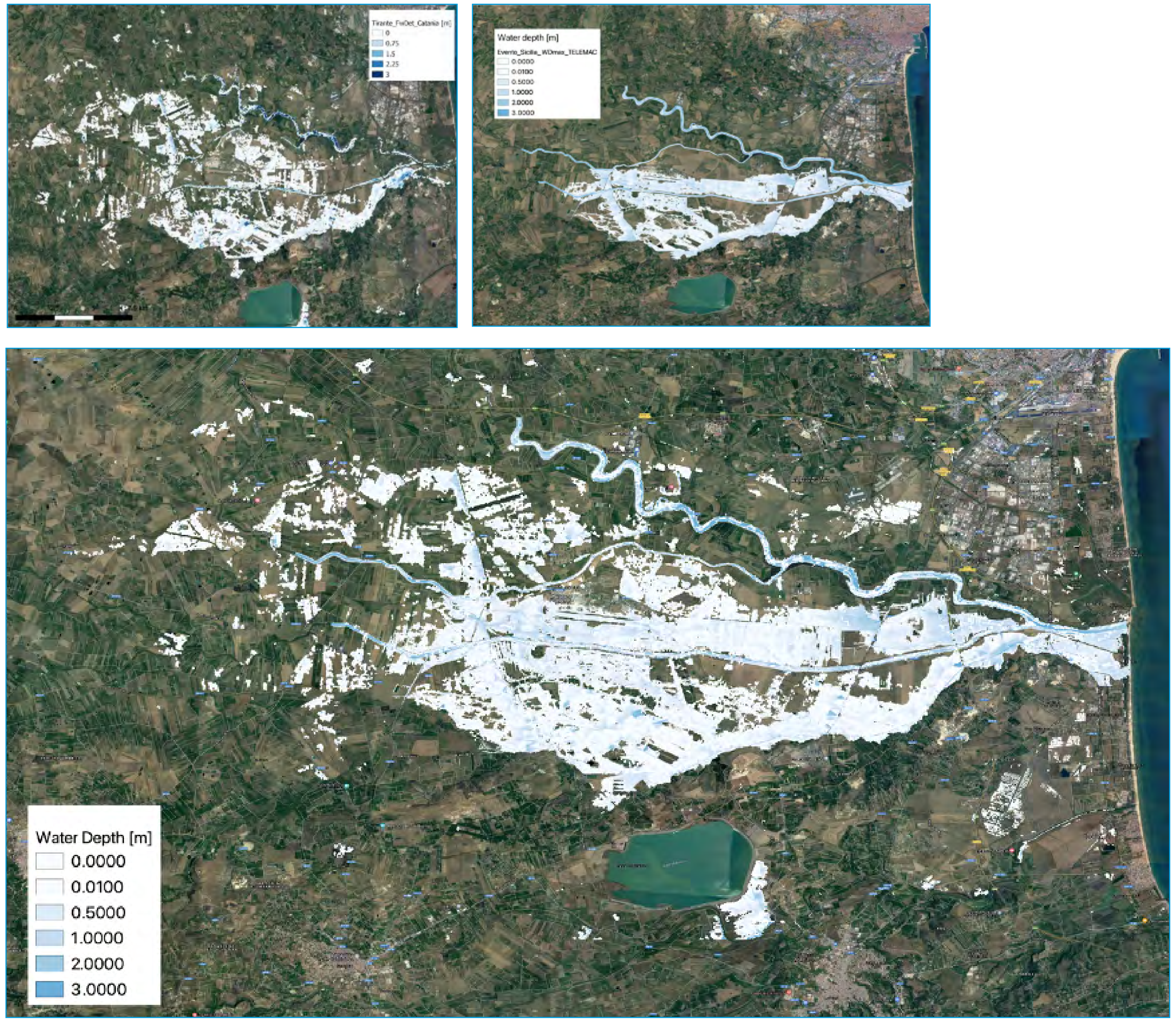


Figure 19. Maximum Flood Water depths in Catania (Italy). Top left: water depth as derived from a full hydraulic simulation using the free software Telemac-2D. Top right: water depths derived combining the S1 flood detection and a DTM. Bottom: illustration combining the above results obtaining a maximum extent of the flood and a reliable value for the Flood water depths. Courtesy of CIMA Foundation.

On Demand EO Solutions

Presently, the capability to produce useful products and services from satellite imagery depends on the enabling technology. The large amount of available data has changed the dynamic of the value adding segment, currently it is heavily supervised by analysts in services that are becoming more and more automated. These processors integrate the strong experience of experts and analysts into an easy-to access service.

Some examples of platforms that allow users to access data and algorithms are described here.

The first one is WASDI (www.wasdi.cloud). WASDI is a cloud-based platform that provides users with access to a wide range of satellite data and processing tools. It allows users to perform complex algorithms on satellite data, leveraging the power of cloud computing to process large volumes of data quickly and efficiently. WASDI is designed to be user-friendly, with a simple and intuitive interface that allows users to easily upload, process, and analyse satellite data. One of the key features of WASDI is its ability to integrate with other cloud-based services, such as Google Earth Engine and Amazon Web Services. This allows users to access a wide range of additional processing tools and resources, further enhancing the capabilities of the platform.

Another example of these platforms is m-Cube (https://docs.mcube.terradue.com/) that is directly derived from the Cloud processing platform used in the International Charter Space & Major Disasters that is called the Charter Mapper (https://docs.disasterscharter.org/). m-Cube is a cloud-based platform that provides users with access to satellite data and processing tools. It is designed to be highly scalable, allowing users to process large volumes of data quickly and efficiently. m-Cube is particularly well-suited for processing and analysing data from multiple satellite sources using several change detection tools and values added processing chains, making it a platform suitable for mapping the impact of hazards using satellite imagery.

One of the key advantages of both WASDI and m-Cube is that they are provided as services, rather than standalone software applications. This means that users can access the platforms from anywhere with an internet connection, without the need for expensive hardware or software installations. This makes it much easier for organizations to deploy and use these platforms, particularly in remote or resource-constrained areas. The importance of having platforms like WASDI and m-Cube as tools for monitoring floods using satellite imagery cannot be overstated. Flood monitoring requires the processing and analysis of large volumes of data from multiple satellite sources, which can be a time-consuming and resource-intensive task. By leveraging the power of cloud computing, these platforms make it possible to process and analyse this data quickly and efficiently, providing critical information to decision-makers in a rapid fashion.

In addition, the cloud-based nature of these platforms makes it possible to scale up or down as needed, depending on the volume of data being processed. This is based on the ability to allocate processing resources as and when needed in an automated fashion according to demand. This means that organizations can quickly respond to changing flood conditions, without the need for significant investments in hardware or software.

Overall, platforms like WASDI and m-Cube are essential tools for monitoring floods using satellite imagery. By providing users with access to powerful processing tools and resources, these platforms make it possible to process and analyse large volumes of data, providing critical information to decision-makers in real-time quickly and efficiently.

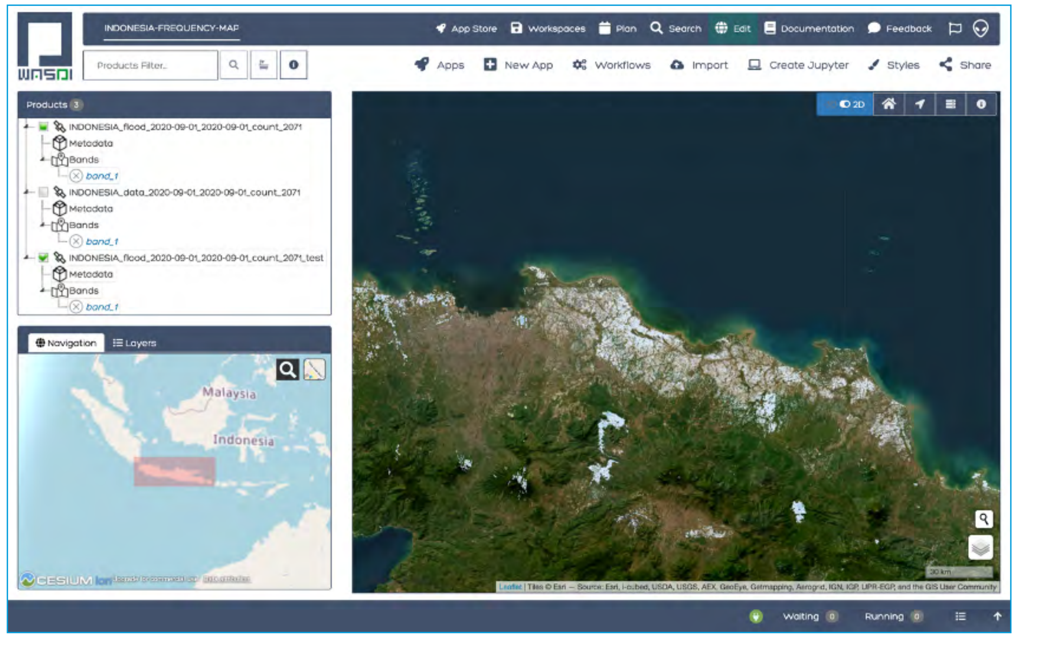


Figure 20. Typical workspace for the WASDI Platform. Courtesy of Wasdi Sarl.

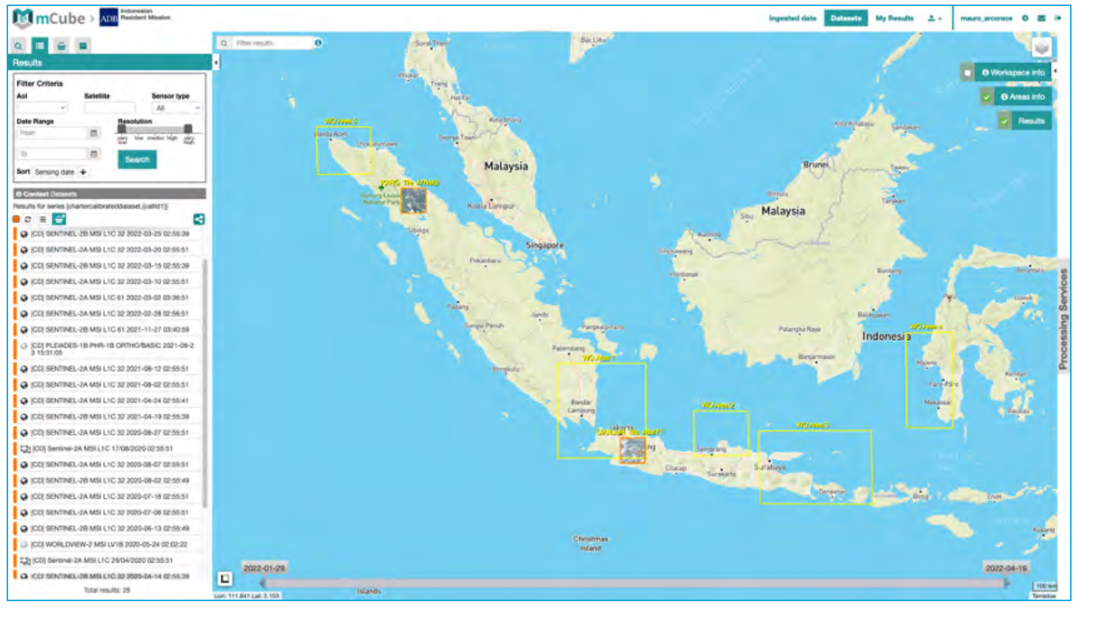


Figure 21. Typical workspace for the m-Cube Platform. Courtesy of Terradue Srl.

On Modelling Solutions Usually Combined With EO

Flood simulation tools such as HEC-RAS and TELEMAC-2D are essential in supporting flood monitoring efforts. These tools allow for the creation of detailed models of river systems and floodplains, which can be used to simulate and predict the behaviour of floodwaters under various conditions.

HEC-RAS is a widely used hydraulic modelling software developed by the US Army Corps of Engineers. It can be used to simulate water flow, sediment transport, and water quality in rivers, lakes, and estuaries. HEC-RAS is particularly useful for floodplain mapping and flood risk assessment, as it can simulate the effects of different flood scenarios and help identify areas at risk of flooding.

TELEMAC-2D is another popular flood simulation tool, developed by the French research organization Electricité de France. It is a two-dimensional numerical model that can simulate the behaviour of water and sediment in rivers, estuaries, and coastal areas. TELEMAC-2D is particularly useful for simulating complex flow patterns and the interaction between water and sediment.

Both cited tools are examples of open software available to the community.
When used in combination with satellite imagery, flood simulation tools can provide even more accurate and detailed information about flood conditions. Satellite imagery can be used to identify areas at risk of flooding, monitor flood extent and severity, and track changes in water levels over time. This information can then be used to calibrate and validate flood simulation models, improving their accuracy and reliability.

Overall, flood simulation tools such as HEC-RAS and TELEMAC-2D are essential for effective flood monitoring and risk assessment. By combining these tools with satellite imagery, we can gain a more comprehensive understanding of flood conditions and better prepare for and respond to flood events.

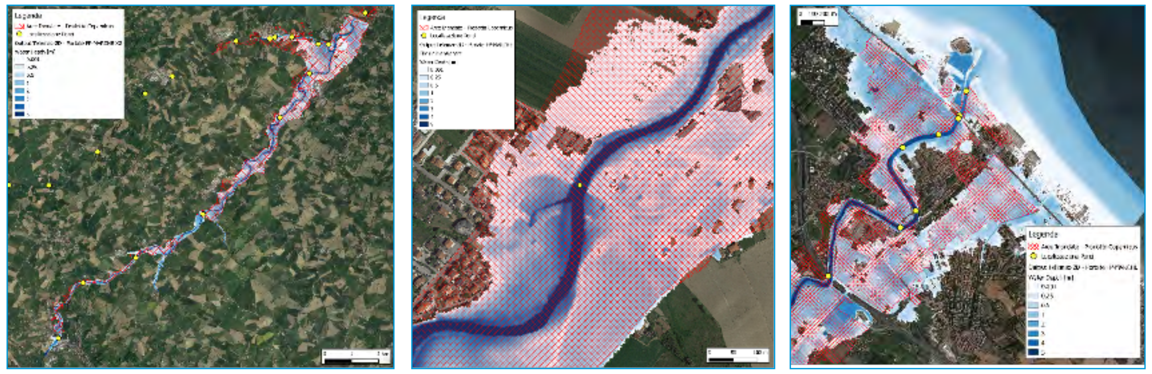


Figure 22. Maximum Flood Water depths in the Misa River (Marche Region, Italy) in the immediate aftermath of the event that took place from 15 to 16 September 2022. The figures show a comparison of the TELEMAC-2D (blue scale) with the flooded area as detected by Copernicus-EMS (Sentinel-1, Cosmo-SkyMED, in red) synoptic view and 2 details. Courtesy of CIMA Foundation.

1.6.2.2 Coastal floods

In a nutshell

What are coastal floods?	Coastal floods are natural disasters that occur when land areas close to the shore are submerged by seawater. This can happen due to sea level rise, storm surges, high tides, tsunamis, or a combination of these factors. Coastal floods are particularly damaging due to saltwater intrusion, which can have long-lasting effects on the land and infrastructure.
Why are coastal floods relevant for hazards analysis?	Coastal floods are relevant for hazard analysis because they can cause significant damage to coastal communities, infrastructure, and ecosystems. The impact of coastal flooding is expected to increase due to climate change and subsequent sea-level rise. Therefore, it's crucial to understand these hazards for the effective planning and implementation of mitigation and adaptation strategies.
What are the benefits of EO-based coastal floods products?	EO-based coastal flood products provide vital data for the modelling and prediction of coastal floods. They offer detailed terrain information and improve Digital Terrain Models (DTMs), improving the understanding of at-risk areas. This can aid in the creation of accurate flood models, understanding the temporal evolution of city landscapes, and identifying areas at risk for more effective planning and mitigation strategies.
How can coastal floods products benefit Disaster Risk Reduction (DRR)?	Coastal flood products can greatly benefit DRR by enhancing preparedness and response strategies. They contribute to the development of early warning systems and enable near-real-time assessment of areas likely to experience water capture and flood channelling. Furthermore, they support the recovery phase by mapping flood extent and updating prevention plans based on the most recent flood event, which can improve planning for future events.

Off-the-shelf EO products for coastal floods

The databases of https://coastal.climatecentral.org/ provide inundated areas modelled under different scenarios of sea level rise.

Off-the-shelf EO products for coastal On Request EO Products and Services

Coastal flood mapping:

The coastal city flooding series of products have been introduced to bridge the gap between current global data sets and models that provide too little detail, which often lead to erroneous outputs compared to very expensive and highly detailed LIDAR models.

Through the comparison of various elevation models such as the Copernicus DEM, it has been observed that there is a large variation in their output. In addition, the output delivers a “canopy” view and not a “terrain” or ground view. By employing sensors such as GEDI and Icesat-2, it is possible to correct the areas found in global elevation models to form terrain or ground models. These additional datasets, however, do not give complete coverage so an interpolation is required to cover the gaps. This can be achieved by assigning heights gathered in GEDI covered areas to similar areas, I.e., areas with the same land cover class. This improved terrain surface is much more representative of the true ground. In addition, it is well known that coastal floods from severe storm events and tsunamis approach coastal cities from a horizontal perspective, having overtopped any sea defence. Therefore, a knowledge of the ground’s friction that will impede or accelerate sea flow is required as well as the geolocation of different ground types (or classes) and buildings that might channel or block flooding. Combining these factors to generate new products which consider friction, channelling and a more probable ground shape enable much more realistic modelling and therefore allow for better mitigation strategies to be derived. This estimation service is tailored to each city; however, a standard approach can be adopted to allow for a quick translation to other cities. This makes it possible to generate results in a limited time frame (I.e., a few weeks). in addition, a very detailed tailored approach could be adopted if more detailed flood modelling was invested in.

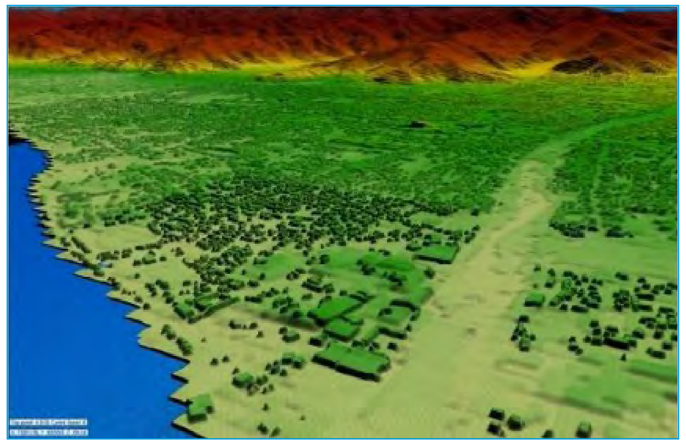


Figure 23. Digital Terrain Model + Buildings, Dili

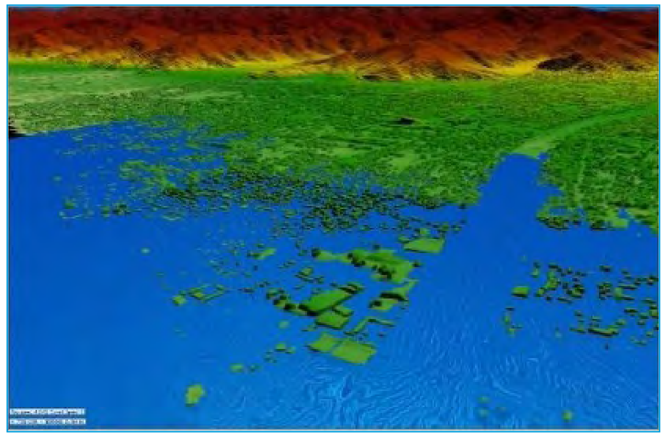


Figure 24. DTM with 10m of flooding

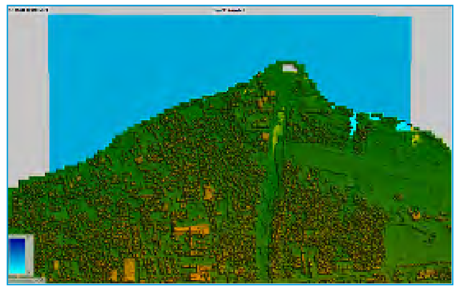


Figure 25. Plan view of DTM + Buildings, Dili

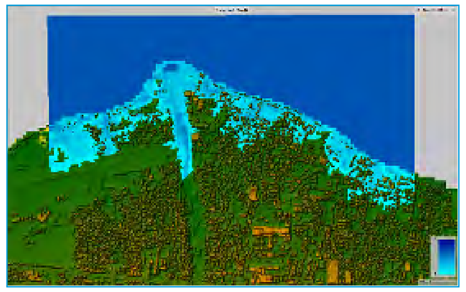


Figure 26. Plan view of DTM + Buildings, Dili with 5 m flood

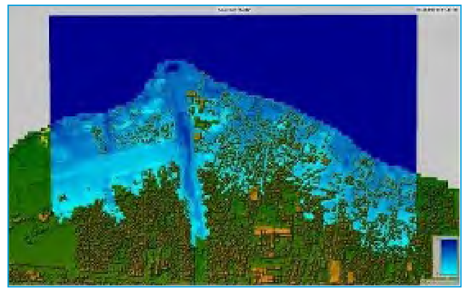


Figure 27. Plan view of DTM + Buildings, Dili with 10 m flood

1.6.2.3 Droughts

In a nutshell

What are droughts?	Droughts are complex natural hazards characterized by a prolonged period of abnormally low rainfall, leading to a shortage of water. They typically develop slowly, often without a clear beginning, and do not have direct structural impact like other disasters. However, they can have significant implications for water and food security, leading to economic risks, especially in developing economies. Droughts can be classified into meteorological, agricultural, hydrological, and socio-economic types, each reflecting a different aspect of water deficiency.
Why are droughts relevant for hazards analysis?	Droughts are relevant for hazard analysis due to their potential to cause widespread damage over large geographic areas and over long periods. They can lead to severe water shortages, crop failures, livestock death, and increased fire risk. As climate change continues to alter weather patterns, understanding and analysing drought hazards is essential for mitigating their effects and enhancing societal resilience.
What are the benefits of EO-based droughts products?	Earth Observation (EO)-based drought products provide critical data for drought monitoring, impact assessment, and mitigation planning. They utilize optical, infrared, or microwave data from satellites to retrieve drought-related variables such as precipitation, soil moisture, and evapotranspiration. These variables are then converted into drought indicators, which help to assess and categorize drought severity. Furthermore, EO methods also aid in understanding the impacts of drought on ecosystems by assessing changes in plant photosynthetic capacity.

How can coastal floods products benefit Disaster Risk Reduction (DRR)?	Drought products can significantly benefit DRR by aiding in the early detection and monitoring of drought conditions. They support drought prevention by analysing spatio-temporal patterns and modelling drought probability. They contribute to preparedness through drought monitoring and early warning systems based on climate data, soil moisture, and vegetation indices. In the recovery phase, these products can be used to monitor the impacts of drought, enabling more effective response and recovery strategies to be implemented.

Off-the-shelf EO products for droughts

The **European Drought Observatory** (EDO - https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000) and the **Global Drought Observatory** (GDO) are initiatives aimed at predicting and monitoring drought conditions using satellite data.

The European Drought Observatory (EDO) is a platform developed by the European Commission's Joint Research Centre. Its primary goal is to provide timely information on drought conditions across Europe. EDO combines various data sources, including satellite observations, meteorological data, and hydrological models, to assess drought severity and spatial extent. It offers drought monitoring maps, indicators, and reports that help policymakers, water managers, and other stakeholders make informed decisions regarding water resource management and drought mitigation strategies in Europe.

The Global Drought Observatory (GDO) is an international initiative also led by the European Commission's Joint Research Centre. The GDO focuses on monitoring and predicting drought conditions on a global scale. It collects and analyses data from multiple sources, including satellite observations, meteorological and hydrological measurements, and socioeconomic indicators. The GDO provides global drought information, maps, and early warning systems to support drought preparedness and response efforts worldwide. It aims to improve the understanding of drought patterns and their impacts across different regions. The Global Drought Observatory provides drought-relevant information such as maps of indicators derived from different data sources (e.g., precipitation measurements, satellite measurements, modelled soil moisture content). It uses the Combined Drought Indicator (CDI) for agricultural/ecosystem drought, which is based on three indicators: Precipitation Anomalies (SPI), Soil Moisture Anomalies, and Fraction of Absorbed Photosynthetically Active Radiation (fAPAR).

Exposure layers used by GDO are gridded population data (based on the Global Human Settlement Layer at 1 km resolution for 2015); agricultural lands (based on the Global Agricultural Lands in the Year 2000 dataset, the result of a combination of MODIS and SPOT-VEGETATION data with agricultural inventories); gridded livestock of the world (at a spatial resolution of 3 min x 3 min latitude-longitude for 2005); and baseline water stress (an indicator of relative water demand for 2010).

The Risk of Drought Impacts for Agriculture (RDrI-Agri) indicator is based on the combination of exposure and vulnerability (social, economic, and infrastructural) factors and the real-time evolution of the drought hazard. The location, extent, and magnitude of the RDrIs is then further analysed against the number of people and the land use/land cover types affected to provide the decision bodies with information on the potential humanitarian and economic bearings in the affected regions. The Global Drought Observatory therefore includes a dynamic assessment of the risk of impact for different sectors based on hazard, exposure, and vulnerability.

The GDO is built on open web services, and it connects drought data providers to users from global to regional levels. In case of severe drought events, the GDO team also produces reports with a detailed description of the situation.

Both the EDO and GDO heavily rely on satellite data in their drought monitoring and prediction activities. Satellite observations offer valuable information on various drought-related variables, such as precipitation, soil moisture, vegetation health, and evapotranspiration. These data help assess the severity and extent of drought conditions, identify regions at risk, and provide early warning signals for drought onset or persistence. The spatial coverage and frequency of satellite data make them indispensable for monitoring large-scale drought patterns and understanding the complex interactions between climatic factors and water resources.

By leveraging satellite data, the EDO and GDO enhance the accuracy and timeliness of drought monitoring and prediction. They play a crucial role in supporting decision-making processes, enabling proactive measures to mitigate the impacts of droughts on water resources, agriculture, ecosystems, and socioeconomic sectors.

In addition to the previously mentioned EDO and GDO, Copernicus Global Land Services offers various products that are relevant for drought monitoring and land-related applications. Some of these products include:

- **Soil Water Index (SWI):** The SWI product provides information on soil moisture conditions. It is derived from satellite observations and combines information from both the surface and subsurface layers of the soil. The SWI helps in assessing soil water availability and drought conditions, supporting decision-making in agriculture, water management, and irrigation planning.
- **Leaf Area Index (LAI):** The LAI product provides information on the amount and density of leaves in vegetation canopies. It is derived from satellite data and helps in monitoring vegetation growth and vigour. LAI is relevant for drought monitoring as it indicates changes in vegetation productivity and can be used to assess drought impacts on ecosystems and agriculture.

- **Fraction of Absorbed Photosynthetically Active Radiation (FAPAR):** FAPAR measures the fraction of incoming solar radiation absorbed by plants for photosynthesis. This product provides insights into vegetation health, productivity, and stress levels. Monitoring changes in FAPAR helps in identifying areas affected by drought and estimating the impact on ecosystems and agricultural yields.

- **Land Surface Temperature (LST):** LST measures the temperature of the Earth's surface. It is derived from satellite thermal infrared data and is useful for monitoring land surface conditions. LST data is relevant for drought monitoring as it helps identify areas experiencing heat stress, drought-induced temperature anomalies, and changes in land-atmosphere interactions.

- **Land Cover and Land Use Maps:** Copernicus Global Land Services provide high-resolution land cover and land use maps. These maps classify and categorize land surfaces into different classes, such as urban areas, croplands, forests, and water bodies. They are essential for understanding the distribution of different land types and their vulnerability to drought.

- **Dynamic Land Cover Change Maps:** These products capture changes in land cover over time, indicating land cover transitions, such as deforestation, urban expansion, or agricultural changes. Tracking land cover changes helps assess the impact of land-use changes on drought vulnerability and ecosystem health.

- **Vegetation Condition Index (VCI):** VCI is an indicator that measures the relative health and vigoro of vegetation compared to normal or expected conditions. It is derived from satellite observations and is based on the comparison of current vegetation status (such as NDVI) with historical data. VCI is particularly useful for drought monitoring as it quantifies vegetation stress and can indicate the severity and extent of drought impacts on vegetation health.

- **Vegetation Productivity Index (VPI):** VPI measures the relative productivity or growth potential of vegetation. It provides insights into the ability of vegetation to photosynthesize and produce biomass. VPI is derived from satellite data, often using vegetation indices such as NDVI or Enhanced Vegetation Index (EVI). Monitoring changes in VPI helps assess the impact of drought on vegetation productivity, agricultural yields, and ecosystem functioning.

These products, among others offered by Copernicus Global Land Services, provide valuable information for drought monitoring, land management, and for the decision-making processes. They contribute to assessing drought impacts, identifying areas at risk, and supporting measures to mitigate the effects of drought on various sectors, including agriculture, water resources, and ecosystems.

On Request EO Products and Services

Satellite observations provide several relevant products and services for drought monitoring and mitigation. Some of the most significant ones include:

Precipitation Monitoring: Satellites can estimate precipitation patterns and provide information on rainfall distribution and intensity. This data helps in tracking precipitation deficits and identifying regions experiencing drought conditions.

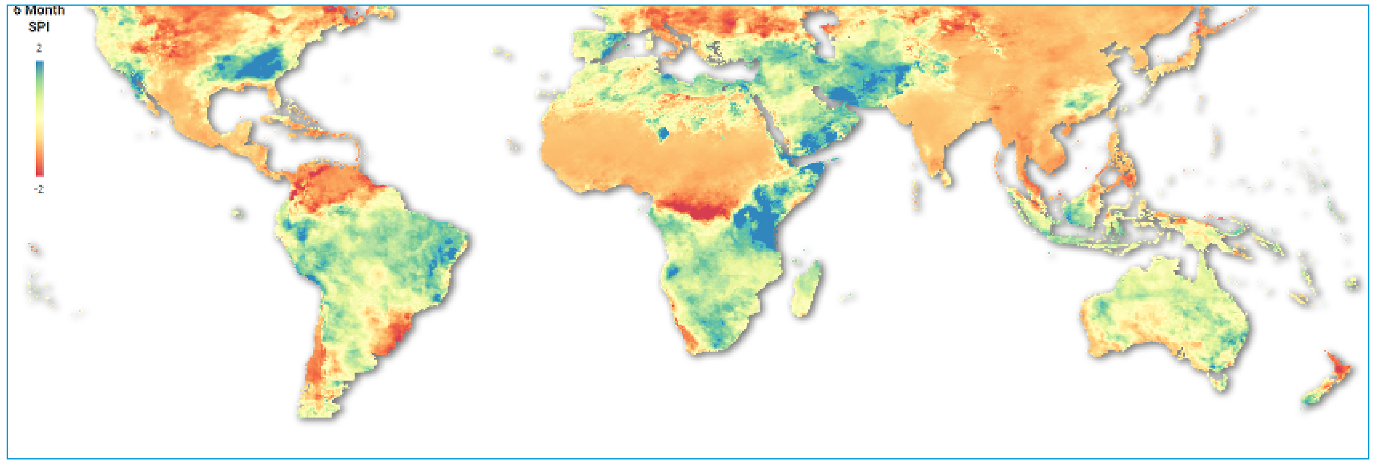


Figure 28. 6-month global Standardised Precipitation Index (SPI) derived from CHIRPS data. Source UN-spider.org

Soil Moisture Monitoring: Satellites can measure soil moisture content, which is crucial for assessing drought impacts on agriculture and water availability. Monitoring soil moisture helps in identifying areas with dry or water-stressed soils, aiding in irrigation planning and agricultural management.

Vegetation Health Monitoring: Satellites can assess vegetation health and vigour by measuring vegetation indices, such as the Normalized Difference Vegetation Index (NDVI). Monitoring changes in vegetation health helps identify areas affected by drought stress and vegetation loss, supporting early warning systems for drought impacts on ecosystems and agriculture.

Evapotranspiration Monitoring: Satellites can estimate evapotranspiration rates, which represent the combined process of water evaporation from the soil surface and transpiration from plants. Monitoring evapotranspiration provides insights into water demand and can help identify water-stressed areas.

Drought Severity Mapping: By combining various satellite-derived data, including precipitation, soil moisture, and vegetation health, drought severity indices and maps can be generated. These maps provide a visual representation of drought conditions, enabling decision-makers to prioritize and allocate resources for drought mitigation.

Early Warning Systems: Satellite data, combined with hydrological and meteorological models, can contribute to the development of early warning systems for droughts. These systems provide timely alerts and predictions of drought onset, allowing for proactive measures in water resource management, agriculture, and disaster preparedness.

Historical Drought Analysis: Satellite observations with long-term archives enable the analysis of historical drought events and their patterns. This information is valuable for understanding drought dynamics, assessing trends, and improving drought forecasting and resilience strategies.

Overall, satellite observations play a crucial role in providing essential data and products for drought monitoring, early warning, and mitigation efforts. These tools support decision-making processes, facilitate effective resource allocation, and contribute to building resilience in water management, agriculture, and ecosystems impacted by drought conditions.

An example of Drought monitoring based on satellite data is reported below. The monitoring system of Bolivia is based on several satellite derived indicators and a composite index has been created that combines some of them based on their relevance to past drought observed impacts. An example is reported in the figure below.

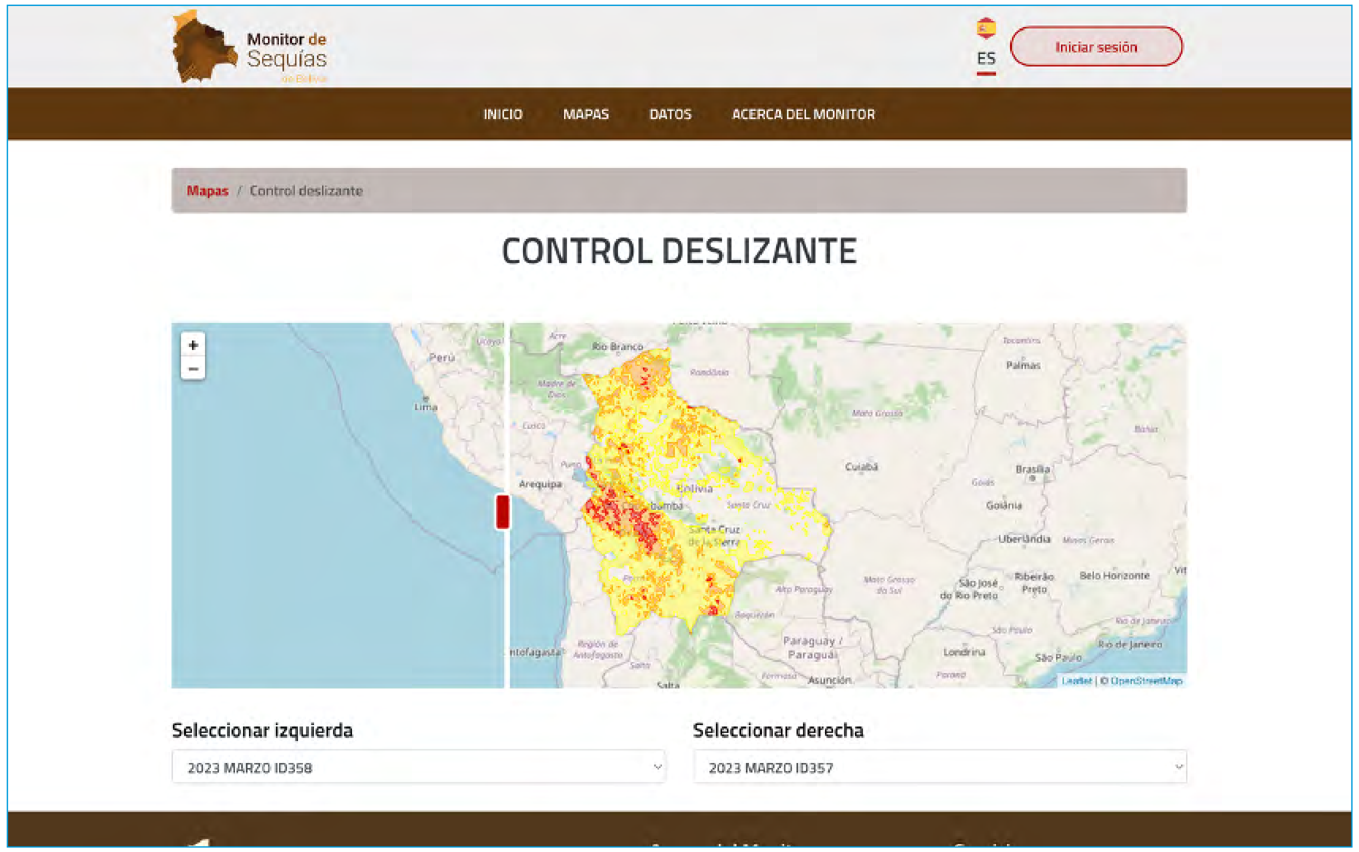


Figure 29. Satellite composite index to monitor drought conditions in Bolivia. The composite index has been developed by CIMA Research Foundation together with SENAMHI the Meteorological centre of Bolivia.

On Demand EO Solutions

Presently, the capability to produce useful products and services from satellite imagery depends on the enabling technology. The large amount of available data has changed the dynamic of the value adding segment, currently it is heavily supervised by analysts in services that are becoming more and more automated. These processors integrate the strong experience of experts and analysts into an easy-to access service.

Some platforms that allow users to access data and algorithms are described here as examples.

Google Earth Engine (GEE) is a cloud-based platform that provides access to an extensive collection of satellite imagery and geospatial data. It offers a wide range of tools and functions that can be utilized for processing and analysing satellite data for drought monitoring. Here's how Google Earth Engine can be useful in treating satellite data for drought monitoring:

1. **Data Access and Management:** Google Earth Engine provides a vast archive of satellite imagery, including multispectral, radar, and thermal data. It allows users to access and manage these data in a centralized and cloud-based environment, eliminating the need for extensive data storage and processing infrastructure.

2. **Pre-processing and Calibration:** GEE offers built-in tools for pre-processing satellite data. It includes functionalities for atmospheric correction, geometric correction, and radiometric calibration, ensuring that the satellite images are properly corrected and calibrated before analysis. This step is essential for accurate and consistent results in drought monitoring.

3. **Image Analysis and Processing:** GEE provides a range of powerful tools for image analysis and processing. It offers a wide variety of spectral indices, such as Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), which are commonly used for vegetation monitoring during drought events. These indices can be calculated and analysed at scale across large areas and over long time periods.

4. **Temporal Analysis and Time Series:** GEE enables the analysis of satellite data as a time series, allowing for the detection of long-term trends and patterns. Time series analysis can help identify drought events, track their duration and severity, and assess their impact on vegetation, soil moisture, and other relevant variables. GEE facilitates the creation of time series algorithms and the generation of meaningful metrics for drought monitoring.

5. **Spatial Analysis and Mapping:** GEE offers a range of spatial analysis capabilities, including classification, segmentation, and spatial statistics. These tools can be used to generate drought-related maps, such as drought severity maps, soil moisture maps, or vegetation health maps. The ability to visualize and map satellite-derived information helps in understanding the spatial extent and distribution of drought conditions.

6. **Integration with Ancillary Data**: GEE allows for the integration of satellite data with other geospatial and environmental data sources, such as climate data, topographic data, or land cover maps. This integration enhances the analysis of drought-related variables by considering additional contextual information, improving the accuracy and robustness of drought monitoring.

Overall, Google Earth Engine provides a powerful and accessible platform for treating satellite data for drought monitoring. Its capabilities for data access, pre-processing, analysis, and integration enable the processing and analysis of large-scale satellite imagery for timely and accurate assessment of drought conditions.

Another open system to consider is WASDI (www.wasdi.cloud). WASDI is a cloud-based platform that provides users with access to a wide range of satellite data and processing tools. It allows users to perform complex algorithms on satellite data, leveraging the power of cloud computing to process large volumes of data quickly and efficiently. WASDI is designed to be user-friendly, with a simple and intuitive interface that allows users to easily upload, process, and analyse satellite data. One of the key features of WASDI is its ability to integrate with other cloud-based services, such as Google Earth Engine and Amazon Web Services. This allows users to access a wide range of additional processing tools and resources, further enhancing the capabilities of the platform.

One of the key advantages of both platforms is that they are provided as services, rather than standalone software applications. This means that users can access the platforms from anywhere with an internet connection, without the need for expensive hardware or software installations. This makes it much easier for organizations to deploy and use these platforms, particularly in remote or resource-constrained areas. The importance of having platforms as services for monitoring droughts and drought impacts using satellite imagery cannot be overstated. Drought monitoring, as with other hazards, requires the processing and analysis of large volumes of data from multiple satellite sources, which can be a time-consuming and resource-intensive task. By leveraging the power of cloud computing, these platforms make it possible to process and analyse this data quickly and efficiently, providing critical information to decision-makers in near real-time.

In addition, the cloud-based nature of these platforms makes it possible to scale up or down as needed, depending on the volume of data being processed. This means that organizations can quickly respond to changing flood conditions, without the need for significant investments in hardware or software.

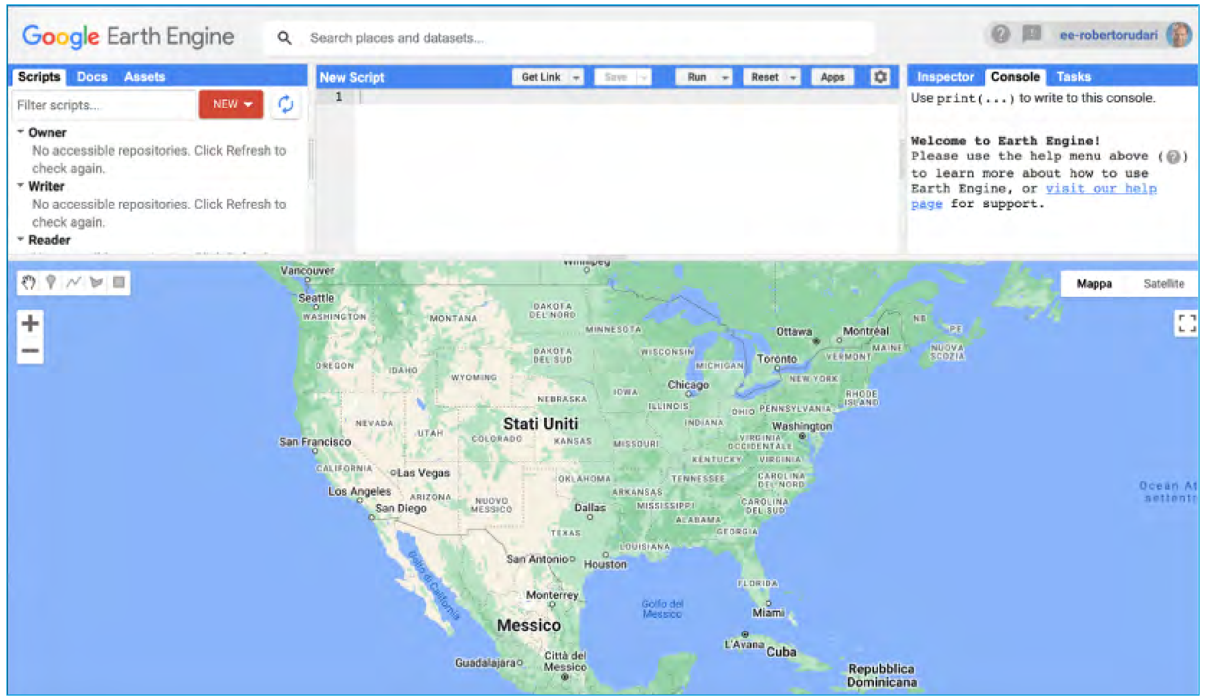


Figure 30. Typical workspace for the GEE Platform.

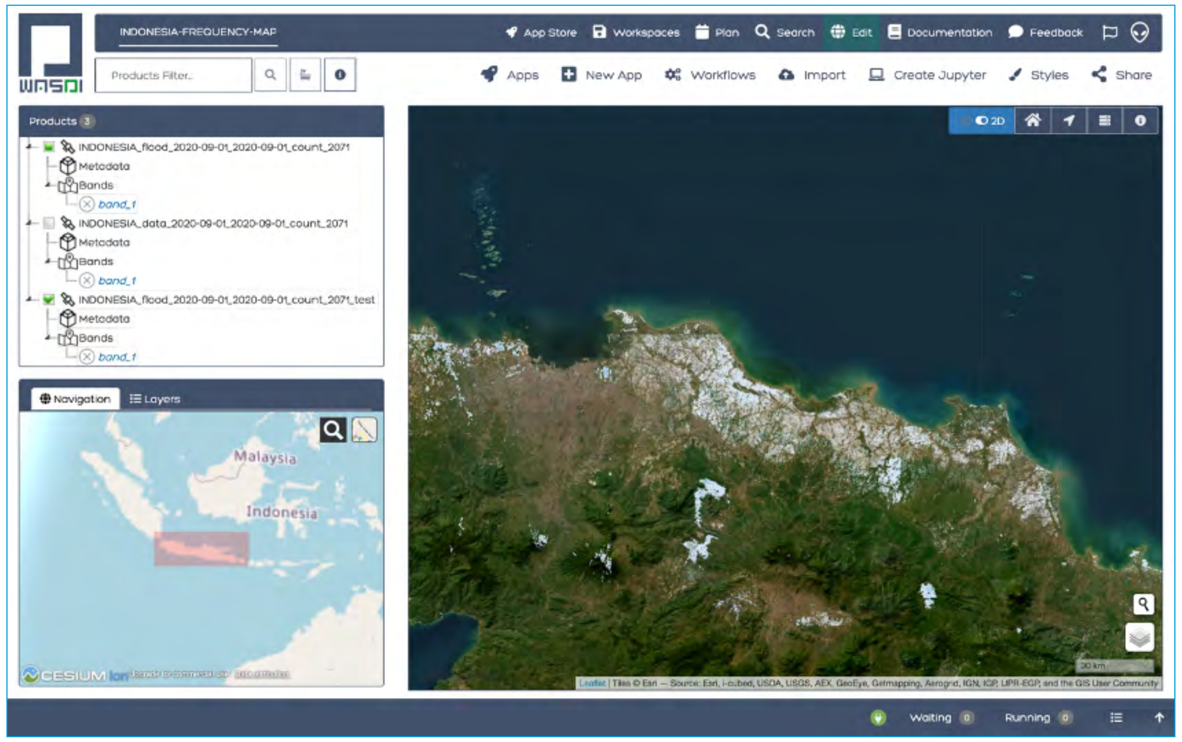


Figure 31. Typical workspace for the WASDI Platform. Courtesy of Wasdi Sarl.

On Modelling Solutions Usually Combined With EO

To support satellite data estimations, it is possible to use hydrological models or specialised land-surface models to improve the estimations of some key complex variables that are used in the drought characterization. Examples include model derived Soil moisture, evapotranspiration fluxes, and streamflow.

A classical method is to assimilate data in hydrologically distributed, physically based models to obtain better fields of such variables.

There are several open hydrological models that are commonly used in combination with satellite data to monitor and assess drought-relevant variables. Here are a few examples:

1. **Variable Infiltration Capacity (VIC):** VIC is a widely used open hydrological model that simulates the distribution of water and energy fluxes in the land surface and subsurface. It can be coupled with satellite data, such as precipitation estimates and satellite-derived soil moisture, to improve the accuracy of drought monitoring and assessment.

2. **Soil and Water Assessment Tool (SWAT):** SWAT is a hydrological model that simulates water movement and quality in large, complex watersheds. It can incorporate satellite data, including precipitation, evapotranspiration, and vegetation indices, to enhance the representation of hydrological processes and assess drought conditions.

3. **Soil Water Atmosphere Plant (SWAP)**: SWAP is a physically based hydrological model that simulates water flow in the soil-plant-atmosphere continuum. It can be integrated with satellite data, such as soil moisture observations and remote sensing-based evapotranspiration estimates, to improve drought monitoring and evaluation of water availability for crops.

4. **Distributed Hydrology Soil Vegetation Model (DHSVM):** DHSVM is a process-based hydrological model that simulates surface water and energy fluxes, soil moisture dynamics, and streamflow. Satellite data, including precipitation, snow cover, and vegetation indices, can be integrated with DHSVM to monitor and assess drought-relevant variables and their spatial distribution.

5. **JULES (Joint UK Land Environment Simulator):** JULES is a community land surface model that simulates land-atmosphere interactions, including water and energy fluxes. It can be coupled with satellite-derived data, such as precipitation, vegetation indices, and land surface temperature, to monitor and assess drought-related variables and their impact on ecosystems.

The use of LISFLOOD for drought assessment provides a comprehensive understanding of hydrological processes and their response to drought conditions. By integrating various data sources, including precipitation, soil moisture, and streamflow data, the model enhances the monitoring and assessment of droughts, supporting decision-making in water resource management, agriculture, and disaster preparedness. Analogously another model can be cited such as the Continuum Model from CIMA research foundation, which has been recently employed.

1.6.2.4 Wildfires

In a nutshell

What are wildfires?	Wildfires, also known as forest fires, irrespective of their origin (natural or anthropogenic), are uncontrolled fires that spread rapidly across vegetated and forested areas, significantly impacting the environment, human health, and often leading to loss of life and property.
Why are wildfires relevant for hazards analysis?	The information related to burnt areas at a global scale is essential. It plays a critical role in monitoring progress towards Sustainable Development Goals (SDGs), as the impact of fire is considered a crucial variable. Wildfires pose significant threats to communities and ecosystems, so it's essential for hazard analysis to prevent, mitigate, and recover from such events.
What are the benefits of EO-based wildfire products?	Advancements in Earth Observation (EO) technology have facilitated the utilization of medium-resolution datasets. These datasets have recently become invaluable for discerning the distribution of fire, estimating re-burning rates, and providing insights into the specific types of vegetation or forest age groups afflicted by fire. These datasets enhance our understanding of fire patterns and their impacts, contributing to more informed decision-making in forest management and fire prevention strategies.
How can wildfire products benefit Disaster Risk Reduction (DRR)?	For Prevention: EO technology aids in the elaboration and modelling of fuel type maps, a crucial factor in wildfire risk. For Preparedness: EO aids in identifying forest fire risk areas by considering the actual and predicted meteorological conditions and vegetation state before the fire, enabling necessary control and precautionary measures. For Recovery: EO aids in mapping burnt areas, assessing wildfire severity, and providing improved remote-sensing techniques to date older fire scars and estimate burn severity. Moreover, EO assists in wildfire detection and monitoring, playing an essential role in DRR.

Off-the-shelf EO products for wildfires

The following table presents a comprehensive overview of Earth Observation (EO)-derived Burnt Area (BA) products. Each product is depicted in terms of their provider, spatial resolution, time span, and updating frequency. This holistic representation helps to appreciate the strides made in this field in recent years, with the aim to offer more refined tools to aid in effective wildfire management.

Product Name	Provider	Spatial Resolution	Time Span	Updating
Copernicus Global Land Service	European Commission (Copernicus Programme)	300 m	Since April 2014	Yearly
MCD64 Burned Area Product	NASA (MODIS sensors)	500 m	2000-Present	Daily
FireCCI5.1	European Space Agency (Climate Change Initiative)	250 m	2001-2020	Monthly
MODIS Thermal Anomalies/Fire	NASA (MODIS sensors)	1 km	2000-Present	Daily
VIIRS Active Fire	NASA (VIIRS sensors)	375 m	2012-Present	Near real-time
Sentinel-3 Thermal Anomaly	European Space Agency (Sentinel-3 sensors)	1 km	2016-Present	Daily

Table 8 Fire global and free of charge products.

Products and services

EO demonstrates its value remarkably in the context of wildfire management. It exhibits an extraordinary capacity to facilitate a comprehensive understanding of fire events, encompassing not only the identification and monitoring of active fires, but also the mapping of burnt areas, the assessment of fire severity, and the appraisal of the recovery process post-fire. The products making this possible are listed below:

- **Burnt Area Mapping:** The capacity of EO to conduct precise mapping of burnt areas stands as an exemplar of its utility. This function is particularly advantageous in the aftermath of a fire incident, offering a detailed illustration of the geographic extent of the damage inflicted. By meticulously delineating the boundaries of the affected area, EO assists decision-makers in understanding the scale of the catastrophe and in formulating pertinent strategies for recovery and regeneration.

- **Active Fire Monitoring:** The proactive monitoring of active fires constitutes another noteworthy application of EO technology. By harnessing thermal infrared sensors, EO can detect heat sources and therefore identify and track wildfires in real-time. This timely information is invaluable for fire management teams, enabling them to react swiftly and effectively, thereby minimising both the extent of the damage and the risk to human lives and property.

- **Fire Severity:** In addition to mapping and monitoring, EO provides insights into the severity of the fire. This is achieved by analysing changes in vegetation and soil properties, as well as the emission of specific gases. The severity index, thus obtained, serves as a critical indicator of the intensity of the fire and the extent of the ecological damage, assisting in the formulation of targeted strategies for recovery and mitigation.

- **Recovery:** EO plays an instrumental role in tracking and assessing the recovery of an ecosystem post-fire. By repeatedly monitoring the same area over time, EO can detect regrowth of vegetation and changes in the landscape, thereby gauging the pace and pattern of ecological recovery. This long-term observation provides critical data that inform strategies for forest management and climate change mitigation.

While the applications of EO offer a vast array of readily available products related to wildfire management, it is essential to recognise that the requirements and constraints of users can vary significantly depending on multiple factors, such as the specific geographical location, the type of ecosystem involved, or the objectives of a wildfire management strategy.

In certain instances, the most appropriate approach may be the development of bespoke solutions. Such tailored applications of EO can be specifically designed to meet unique user requirements, thereby providing the most relevant, accurate, and actionable information. Customised solutions can facilitate more nuanced insights, enabling decision-makers to respond more effectively to the challenges posed by wildfires. By considering the specific needs and contexts of different users, EO technology can be harnessed in a truly user-centric manner, thereby maximising its potential to support proactive, informed, and effective wildfire management.

Features	Global Readily Available LULC Products	Bespoke LULC Products
Spatial Resolution	Tend to offer moderate to coarse spatial resolution, suitable for large-scale studies and global monitoring. Products like MODIS and Sentinel offer 10-500m resolution.	Can be designed to offer very high resolution (sub-meter to a few meters), suitable for detailed local studies and fine-scale monitoring. EO products like WorldView or QuickBird can be used.
Classification Categories	Offer standardised land-use/land-cover categories, suitable for broad global comparisons and large-scale studies.	Can be tailored to offer specific, detailed classification categories, suitable for nuanced local studies and specialised applications.
Temporal Coverage	Generally, offer long-term and continuous temporal coverage, suitable for trend analysis and long-term monitoring.	Can be tailored to offer specific temporal coverage based on the needs of the project, such as focused time-periods or seasonal windows.
Geographical Coverage	Offer global coverage, suitable for international studies and comparisons between different regions.	Can be tailored to offer specific geographical coverage, focusing on a particular region, country, or local area.
Availability	Generally, freely available, and easily accessible through various online platforms (e.g., NASA Earth data, Copernicus Open Access Hub).	Costs can be higher due to the need for specific data acquisition, processing, and analysis, but this cost can be justified by the value of the customised product.
Cost	Generally, freely available, or available at a low cost for users around the world.	Costs can be higher due to the need for specific data acquisition, processing, and analysis, but this cost can be justified by the value of the customised product.
Expertise Required	Standardised processing and analysis methods mean moderate levels of expertise are required. Online tutorials and user guides are often available.	Bespoke products may require a higher level of expertise due to the need for specialised processing, analysis, and interpretation methods. The team creating the bespoke product typically provides the necessary expertise.

Table 9 Comparative analysis of global readily available versus bespoke wildfire products

Modelling tools that can be combined with EO

The following table presents various modelling tools, techniques, and methodologies that can be integrated with wildfire products to provide high-value services.

Tools, Techniques or Methodologies	Description
FARSITE (Fire Area Simulator)	This is a fire behaviour and growth simulator developed by the United States Forest Service. It uses spatial information on topography and fuels along with weather and wind files to simulate potential fire behaviour. By integrating real-time EO data, FARSITE can provide more accurate predictions of fire spread and intensity.
FlamMap	FlamMap is a fire behaviour mapping and analysis tool that uses spatial information on topography, fuels, weather, and wind to compute potential fire behaviour for every point on the landscape. It can be used in conjunction with EO technology to create more accurate and detailed fire behaviour maps.
BEHAVE	BEHAVE, or the BehavePlus fire modelling system, is a computer application that predicts wildland fire behaviour for fire management purposes. It uses fuel models, weather observations, and topographic data to predict fire spread, intensity, and other fire behaviour characteristics. The integration of EO data can enhance the accuracy of these predictions.
Prometheus: The Canadian Wildland Fire Growth Simulation Model	Prometheus is the Canadian Forest Service's wildland fire growth simulator. It uses weather data, topography, and the type and condition of fuel to predict how fires will spread. EO data, such as information about current fuel moisture levels, can be used to refine these predictions.
The Australian Fire Spread Prediction (AFSP) System	This system predicts the spread of bushfires under a range of conditions and fuel types. It uses weather data, fuel maps, and topographic information. EO technology can provide real-time updates on these variables, leading to more accurate fire behaviour predictions.
The Rothermel Fire Spread Model	This model predicts the rate of spread and the intensity of a fire front. It uses inputs such as fuel type, fuel moisture, wind speed, and slope of the land. EO data can provide real-time updates on these variables, enhancing the model's predictive power.
CFSM (Crown Fire Simulation Model)	This model, developed by the Canadian Forest Service, simulates the spread of crown fires in coniferous forests. It uses inputs such as fuel type, weather conditions, and the characteristics of the forest canopy. Integrating EO data can improve the accuracy of these simulations..

Table 10. Modelling tools, techniques, and methodologies integrated with wildfire data to offer high-value services

◆ 1.7 IMPACT AND RISK

A disaster risk assessment is the methodology used to determine the nature and extent of a particular risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed assets and the environment on which they depend (United Nations, 2009)

> A disaster risk assessment shall always combine a hazard identification and assessment together with a review of its technical characteristics (i.e., location, intensity, frequency, and probability) and an analysis of the exposure and vulnerability of the exposed assets including the physical, social, health, economic and environmental dimensions.
>
> On top of that, disaster risk assessments generally include an **evaluation of coping capacities** in respect to likely risk scenarios, which is difficult to provide with Earth Observation.

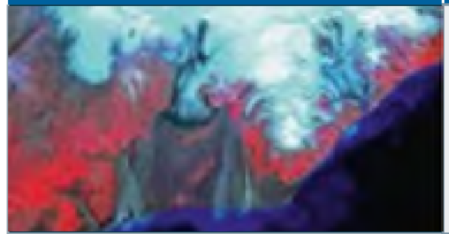
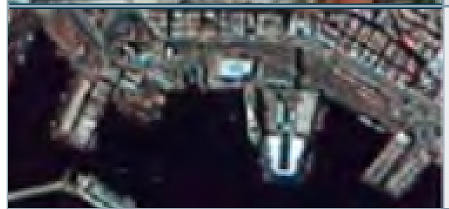
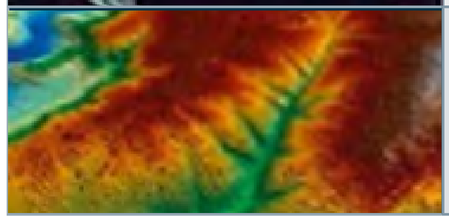
EO raw data	Hazard	Exposure	Vulnerability
	Landslide Subsidence	-Reference mapping	**Structural vulnerability** (Urban structure, building density, building material, building type, number of buildings, etc.)
	Earthquake Tsunami	-Hazard modelling outputs -Natural resources (land cover)	**Physical vulnerability** (Accessibility, distances, number of structures, surface slope, etc.)
	Flooding Storm surge/ Coastal flooding	-Population density -Digital Elevation Models (DEMs)	**Social vulnerability** (Social status, accessibility to and supply of local facilities, etc.)
	Drought Wildfires		**Others** (Hospitals, schools, fire brigades, emergency services, accommodation, etc.)

Table 11. Elements composing a Disaster risk Assessment

Geospatial information is therefore crucial to understand disaster risk.

The state of the art of EO to assess hazards has already been approached earlier on in this document as well as the methods for obtaining exposure and vulnerability from EO (population density, land use/land cover, settlements, and infrastructures) and auxiliary data (census with socio-economic and environmental data).

For each hazard type (flooding, landslide, wildfire, tsunami, etc.), hazard scenarios should be defined and should be assigned a certain magnitude/intensity/frequency relationship (e.g., tsunami inundation depths for different earthquake scenarios).

To evaluate the components of risk, the information should be spatially distributed, and Geographic Information Systems (GIS) are therefore used to generate the data on several of the risk components and for its analysis. The risk assessment process covers risk identification, hazard assessment, determining exposure and understanding vulnerability.

	Hazard	Exposure	Vulnerability
Hazard assessment	Hazard identification and assessment to identify and assess the various types of hazards that may threaten a territory and/or its assets	The date and update frequency of the risk assessment product depends on the date of the satellite observations used; observations using Optical VHR, and HR sensors are available globally depending on cloud coverage. Some regions have very frequent cloud coverage, such as in tropical zones, making reliable Optical VHR coverage difficult to obtain. As a surrogate, all weather SAR based basic mapping can be provided in these areas. The service can be delivered at various observation scales. By using high and very high-resolution satellite imagery, different levels of accuracy can be provided. For overview purposes, decametric products (5 to 10-meter resolution) are possible, where metric products with a resolution between one meter and five meters can focus on small areas.	Support risk assessment in the mitigation/prevention/ preparedness phase
Exposure	Exposure assessment and mapping of assets, to specific hazards		
Vulnerability	Specific vulnerability assessment of geo-located assets		
Analysis of coping capacities			

DISASTER RISK ASSESSMENT

Risk assessment methodologies can be qualitative or quantitative. Within the qualitative approach, the risk is considered equal to the product of hazard, exposure, and vulnerability.

The qualitative hazard assessment is estimated by the likelihood to experience the hazard under indicative return periods. The risk is classified from very low to very high values in respect to different hazards (flood return periods, slope angles for landslide hazards, inundation elevation for sea level rise in coastal environments, etc.). The qualitative exposure can be assessed by a built environment density map (buildings and roads) over a spatial grid cell as a proxy for the location of population and infrastructures.

The qualitative assessment of each hazard is combined with the exposure/vulnerability estimates in the form of a risk matrix. This is used to produce a qualitative estimate of the risk for each spatial grid cell over the analysed area. The qualitative risk map provides a general overview of the risk in the form of a grid cells whose values range from very low, low, medium, high, and very high.

Quantitative risk assessments are more complex by nature, given that they use analytical functions to quantify potential financial losses for simulated events that may potentially occur in the future. Simulated events use complex modelling including non-EO variables such as flooding river gauge data or rainfall records, fragility functions for vulnerability assessment functions related to the damage caused to infrastructural assets (as per building construction types) or probability of fatalities and injuries for exposed people (indoors and outdoors).

1.7.1 Impact assessments

It is the more basic level of identifying areas at risk. It consists merely in the spatial overlaying of the assets or population. In each location, generally prone to a natural hazard, exposure and hazard are overlaid.

1.7.2 Risk assessments

ON REQUEST

- Risk assessments are normally bespoke products, given that it is required to customize all inputs (exposure, hazard, and vulnerability) as well as apply parametrization and fine tuning of results.
- The key aspect that differentiates this product from the impact assessment is the vulnerability. Vulnerability curves are applied to certain physical characteristics of the assets and are always in relation to a specific natural hazard.
- There are generic vulnerability curves available for flood[39] and earthquakes[40]. These curves can be customized according to the conditions of the building stock or the information available for each location.

ON DEMAND

- Risk Mapping Engine: a tool developed by Indra that can automatically produce Risk Estimations if provided with certain elements like flood extent (flood depth is automatically computed) and building stock. The system has pre-charged vulnerability curves for flood, but these can be easily modified by the user. The result is a measure of risk in several categories that can be customized as well.
- Rasor: A single tool to integrate diverse data and products across hazards, update exposure data quickly and make scenario-based predictions to support both short and long-term risk-related decisions. It is a platform to perform multi-hazard risk analysis for the full cycle of disaster management, including targeted support to critical infrastructure monitoring and climate change impact assessment. It has the capacity to improve automated processing chains for the generation of geo-information products and services for risk assessment and loss estimation

1.7.3 Disaster risk financing

ON REQUEST

- Risk assessments are normally bespoke products, given that there is the need for customizing all inputs (exposure, hazard, and vulnerability) as well as applying parametrization and fine tuning.

ON DEMAND

- **E-drift.** A virtual Platform that enables accessing and processing satellite EO data in combination with non-EO data and model-based flood simulations to generate added value services to support risk financing applications. It supports economic evaluations on specific sectors, based on the WASDI, connected to ESA's GPOD and Urban TEP, which uses the Rapid Analysis and Spatialisation of Risk (RASOR – www.rasor.eu) engine for post processing, and the RASOR platform for visualization and analysis.

39 Huizinga, J., De Moel, H. and Szewczyk, W., Global flood depth-damage functions: Methodology and the database with guidelines, EUR 28552 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-67781-6, doi:10.2760/16510, JRC105688.
40 https://docs.openquake.org/vulnerability/vulnerabilityvulnerability_dam2loss_computing_vul.html

RESPONSE

1.8 DAMAGE ASSESSMENT

The ability of satellite EO to support damage assessment depends on the hazard type. Timeliness is a key parameter and typically, a crisis or damage map is produced within the hours or days following a disaster. Timeliness is dependent on the type and number of EO missions programmed to cover the disaster. Many EO satellites can be used, typically HR and VHR optical satellites and VHR SAR satellites. Data sources and sensor options depend on the hazard type, for example, all-weather SAR is preferred for flood monitoring and optical VHR is usually preferred for post-earthquake damage assessment.

The development of a post-event damage assessment is based on retrieving a series of downstream products. This is where methodologies such as the Global Rapid post-disaster Damage Estimation (GRADE) approach come into play. The GRADE approach uses a combination of remote sensing data, such as satellite imagery, and ground-based observations, along with pre-existing data on the built environment, to estimate the extent and severity of damage (see section 1.8.1).

Damage assessment maps aim to identify in a rapid manner the damage: the extent of the zones affected and the damage grade. This can be done through the identification of the physical characteristics of the disaster when these are directly visible because they persist in space and time and can be captured (extent of a flood or a landslide) or though the identification of the impact caused in assets (buildings or crops destroyed, mud covering areas after a flood event)

Copernicus Emergency mapping Services proposes a family of four products applicable to the disaster response phase, ordered here chronologically from the event:

- **Reference products:** “selected topographic features on the area affected by the disaster”
- **First Estimate Products:** “extremely fast (yet rough) assessment of most affected locations within the area of interest”
- **Delineation products:** “assessment of the event impact and extent”
- **Grading products:** “provide information about the damage grade, its spatial distribution and extent”

	Ex-Ante	Ex-post (impacted area)	Ex-post (impacted assets)
Earthquake	Reference mapping (pre/post-disaster)	Displacement maps	First estimate Delineation Grading
Tsunami		Tsunami-induced coastal inundation extent Coastal erosion & coastline retreat Tsunami-related water pollution	
Flooding		Flood water extent (pre- and post-event) Monitoring of terrigenous inputs Flood traces extent Flood-related water pollution	
Landslides		Landslide delineation Mudflow extents	
Wildfire		Fire detection Active fire maps Burnt areas	
Volcanic eruption		Lava flow extent Ash plume extent Ash residuals	

Table 12. Damage assessment and downstream products

1.8.1 Reference products

	Information content	Resolution, frequency, availability	Benefits and use
Reference mapping	Multi-purpose cartographic product containing a combination of layers that can be adapted to specific DRR needs. The information usually applicable in a DRR context is: -Points of Interest (POIs) -Built-up areas and settlements -Industry/Utilities -ransportation network -Land use/Land cover -Hydrography -Physiography -Administrative limits -Place names	The update frequency of a reference map can be anytime when required EO sources are available. It can be produced at any phase of the DRR cycle and adapted to any date. The coverage and extent depend on the user requirements and the sources used. Positional accuracy thresholds depend on the resolution of the source and mapping scale required. Thematic accuracies are usually assessed by the generation of confusion matrices analysed using the Kappa coefficient, assuring strong agreement in the global classification.	Geographical context providing an overview of the ex-ante situation at a glance: Situation Map. Base data layers for further Asset Maps, key inputs for exposure and risk mapping analysis within the DRR service portfolio.

1.8.2 First estimate, delineation, and grading products

A Damage assessment is generally understood as a preliminary evaluation of damage or loss by an accident or natural event. It records the extent of damage and is important information for an effective and efficient response.

The use of satellite images, radar, and other remote-sensing technologies has become an essential tool in post-disaster response, even though it can be considered more challenging than base data mapping. A damage assessment requires labels assigned to assets, however, for the detection of damage indicators, direct observation is often impossible; instead, a variety of proxies need to be used depending on the hazard studied. Remote sensing-based damage assessments can play an important role in providing data during the period between one week and few months following a disaster.

	Information content	Resolution, frequency, availability	Benefits and use
Damage Assessment	It consists of the rapid provision of hazard impact maps (e.g., flood extent, active fires, etc.), hazard damage extent (e.g., destruction of infrastructure) and damage classification maps (i.e., damage zoning). An assessment of the state or availability of infrastructure in areas during humanitarian crises or after catastrophic events.	A damage assessment should be available at any scale (local 1:5,000/1:10,000 to global) on a 24/7 basis. The spatial resolution is in the range of a few meters depending on the satellite data used. Typically, Very High Resolution (VHR) data allows map elaboration at the scale of 1:5,000 to 1:10,000 and 1:25,000 to 1:50,000 using HR data. It is an assessment based on rapid and repeat observations over a short period (typically a few days to a few weeks) It is frequently based on reference mapping products described earlier in this document	Up-to-date geographic information and situation assessment Damage grading and zonation maps

The difference between first estimate and delineation product is the time when they are produced, generally the first one within the hours following the event and the second one in the following days.

Grading products are a detailed damage assessment (extent of the impacted area and damage grade). As explained, these products can be related to the physical impact of the disaster as perceived by the sensor (extent) or to an evaluation of the damage produced by the disaster.

STANDARD PRODUCTS

Detailed damage assessment analyses over affected areas

The damage assessment product offers a thorough evaluation of the impact caused by an event on the population, infrastructure, and quality of service provision in affected regions. It primarily relies on available satellite imagery captured after the event and secondary sources of information. The purpose of this product is to address both man-made and natural disasters, emphasizing the humanitarian aspects of the population and affected assets.

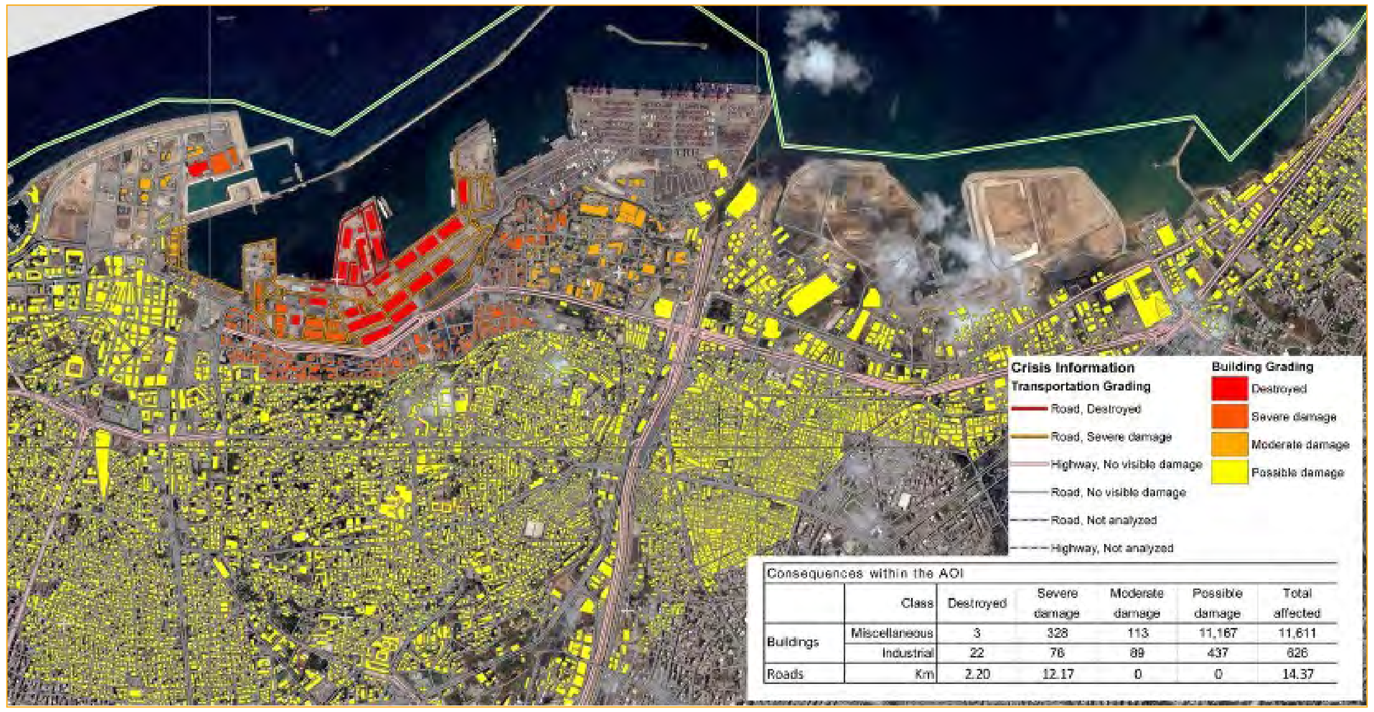


Figure 32. Example of a damage assessment product. Credits: CEMS R&R Standard P08

Reconstruction monitoring

The primary objective of this product is to assess the progress of reconstruction efforts in areas affected by disasters, providing valuable information about the status of specific objects of interest. The monitoring product accurately captures and reflects the changes resulting from reconstruction activities and tracks the status of objects under reconstruction. Observations are systematically conducted within predetermined timeframes, and data is recorded manually using either archived or up-to-date imagery. The status of the identified or extracted structures is categorized using the following values:

- **New:** Refers to new structures or features that are present in the T1 image but did not exist in the T0 image.

41 *https://emergency.copernicus.eu/mapping/ems/p08-detailed-damage-assessment-analyses-over-affected-areas*

- **Unchanged:** Denotes structures that remain unchanged between the T0 and T1 images.
- **Reconstruction ongoing:** Indicates structures that were damaged in the T0 image and are currently under construction in the T1 image.
- **Demolished/removed:** Represents structures that were damaged in the T0 image but have been subsequently demolished or removed in the T1 image.
- **Reconstructed:** Signifies structures that were damaged in the T0 image but have been fully reconstructed and are now fully functional in the T1 image.
- **NA:** Stands for "not analysed" and pertains to structures that could not be evaluated due to factors such as extensive cloud coverage.

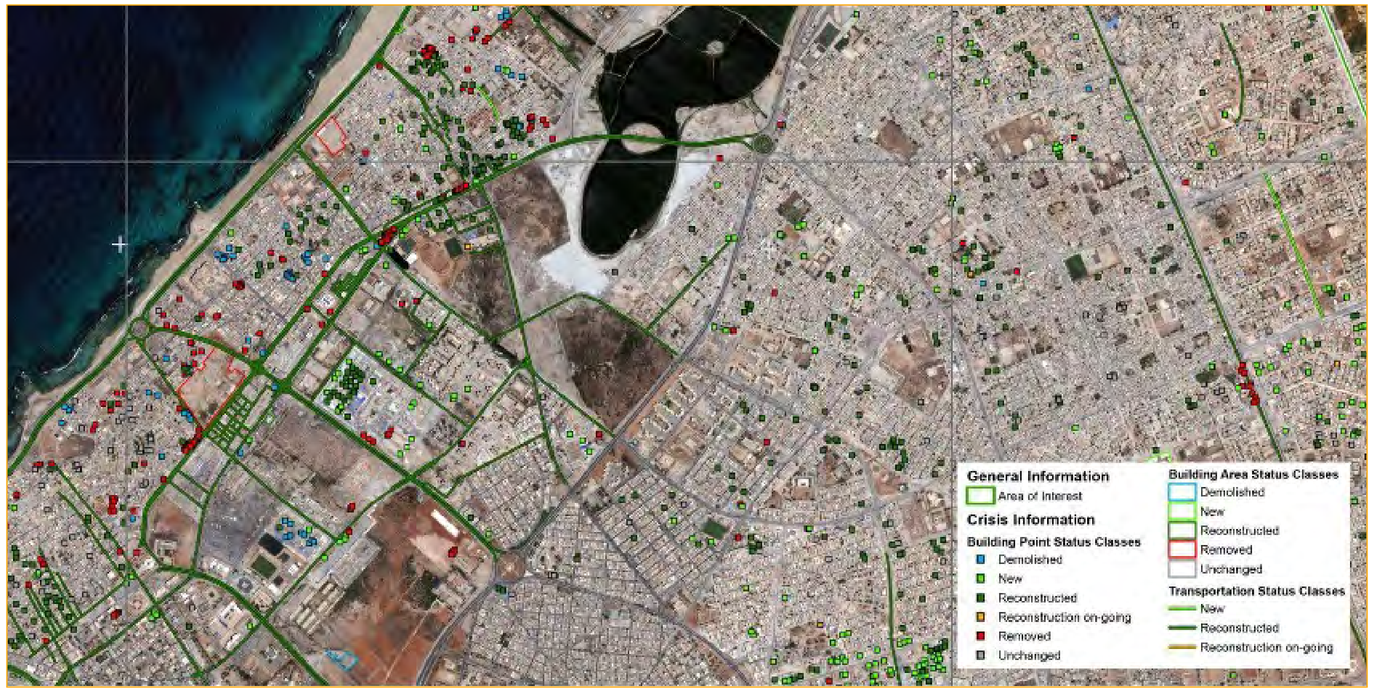


Figure 33. Example of a reconstruction monitoring product. Credits: CEMS R&R Standard P08[42].

Impact assessment/exposure analysis on assets and population

The objective of this product is to provide an analysis of the impact on assets and population in events where the extent of a disaster is known. Additionally, it aims to conduct an exposure analysis on assets and population for predicted or modelled events. These analyses are carried out using reference datasets and/or land use/land cover (LULC) information as the basis[43].

42 *https://emergency.copernicus.eu/mapping/ems/p09-reconstruction-monitoring*
43 *https://emergency.copernicus.eu/mapping/ems/p14-impact-assessmentexposure-analysis-assets-and-population*__Impact assessment/exposure analysis on assets and population__

Detailed impact assessment/exposure analysis on selected aspect

The objective of this product is to provide in-depth analyses of specific thematic aspects or object types. In a similar manner to impact assessment and exposure analysis on assets and population, this product aims to deliver two types of analyses on impact or exposure. However, it relies on user-provided data regarding selected assets such as agricultural production and crops, forest stand information, and economic values.

The primary outputs of this product consist of detailed statistical information tailored to the user's needs, focusing on a particular asset that is exposed to or affected by an event. These statistics are presented in tabular form, offering a comprehensive summary of the findings[44].

1.8.1 GRADE approach

The Global Rapid post-disaster Damage Estimation (GRADE) approach is a swift, desk-based damage assessment method activated shortly after a disaster. It leverages advanced natural hazard risk modelling technology to promptly meet post-event damage assessment needs. GRADE evaluates damages to housing and critical infrastructure sectors by integrating hazard parameters, exposure databases, structural vulnerability extent, and relevant repair and replacement costs. These elements are overlaid on a GIS platform, and expert knowledge is applied to generate results within two weeks of major disasters. The method is versatile, applicable to modelling any type of natural hazard for which reliable hazard, vulnerability, and risk model platforms exist. It utilizes population layers, remotely sensed data for damage and consequences, social media updates, local situation reports, and other relief-related information flows, along with pre-existing scientific, engineering, and socioeconomic datasets and loss-damage statistics, to identify the distribution of damage and quantify sectoral damages and human casualties.

The GRADE approach can be tailored to different client priorities and dataset availability, without compromising its swift delivery and accuracy. It ensures inherent independence and scientific objectivity as the analysis is based on open sources of information for each of the three main components (hazard, exposure, and vulnerability), is conducted by experienced researchers and practitioners, and is accompanied by a transparent summary report. The approach incorporates information from a wide variety of datasets, continually verifying results and employing pioneering methods to achieve improved accuracy.

It involves calculating direct damages to property, direct damage estimations by economic sector, potential impacts on GDP and the economy, and estimations of human casualties. The approach employs hazard modelling, exposure value assessment, vulnerability assessment of the various assets to the hazards, and a summary of impact. The outputs include the likely costs associated with damage to property,

44 *ttps://emergency.copernicus.eu/mapping/ems/p15-detailed-impact-assessmentexposure-analyses-selected-aspect*

critical infrastructure, and key production sectors, as well as social impacts, including fatalities (in the case of earthquakes), displaced people, and references to local reports of the socioeconomic impacts.

Compared to other models, which are quick but lack detailed underlying assumptions or sector-based details, GRADE provides a more comprehensive and detailed assessment. Unlike insurance/reinsurance companies that generally publish only aggregate estimates for certain sectors, GRADE provides a detailed breakdown of damages and losses. In the public sector, the Damage and Loss Assessment[45] (DALA) framework and the PDNA framework provide detailed damage and loss assessments. However, these assessments often take more than a month to be released due to the difficulty of synthesizing diverse data, reliance on completion of government damage surveys, administrative difficulties, and lack of access and sector-based loss determination. The GRADE approach fills this gap by providing a rapid and detailed damage assessment, enabling faster understanding of needs and acquisition of resources.

Hazard Modeling	Exposure Modeling	Vulnerability Modeling	Demage Estimation
• Seismic ground motion map • Wind field map • Flood extent map due to excess rainfall during storms, riverine, flash flooding • Storm surge inundation map • Tsunami inundation map	• Mapping population and asset values • Global housing census data • Gross capital stock data • Residential buildings by structural type, age, height • Non-residential buildings by use, structure • Infrastruvture (roads, bridges ports, airports.) • iURBAN tool for spatial distribution • Urban/rural consideration	• Global database of building damage data • Damage vs. hazard severity by structure type • Real-time event data from social media (photo, video, drone, footage) • Remote sensing data • Post-disaster analytical structural vulnerability tool	• Cost of direct damage to buildings, critical infrastructure • Cost of direct damage to crops • Human casualties due to building collapse • Estimation of direct and indirect damage to other importatnt economic sectors • Potential impacts on GDP and the economy
Event Footprint Generation	Exposed Values by Asset Type & Resistance Class	Vulnerability Curves by Resistance Class	GRADE Event Report

Figure 32. Figure 34. Diagram of the GRADE approach: Essential elements (top boxes) and resultant outputs (bottom boxes). Source: The Global Rapid post-disaster Damage Estimation (GRADE) approach .

45 https://www.gfdrr.org/en/damage-loss-and-needs-assessment-tools-and-methodology
46 https://www.gfdrr.org/en/publication/methodology-note-global-rapid-post-disaster-damage-estimation-grade-approach

INTERNATIONAL INITIATIVES IN SUPPORT OF DRR

Focusing on emergency response, the available capabilities based on international collaborations among countries, institutions and organizations are:

1.9 THE INTERNATIONAL CHARTER ON SPACE AND MAJOR DISASTERS

The Charter is an international collaboration focusing on the immediate response phase (only) . Concerning other phases of disaster risk management, examples of international collaboration concerning EO include the CEOS Working Group Disasters (see https://ceos.org/ourwork/workinggroups/disasters/) and the Geohazards Supersites & Natural Laboratories initiative under the Group on Earth Observations (see https://geo-gsnl.org/).

The Charter was initiated by the European Space Agency and the French space agency CNES in July 1999, and it is operational since November 1, 2000, after the Canadian Space Agency signed onto the Charter on October 20, 2000. Charter members are ESA, CNES, CSA, NOAA, CONAE, ISRO, JAXA, USGS, UKSA/DMCii, CNSA, DLR, KARI, INPE, EUMETSAT, ROSCOSMOS, ABAE and UAESA/MBRSC. Since 2000, and as of July 2023 the International Charter has been activated more than 825 times in more than 130 countries for various natural or man-made hazards such as: floods, ocean storms, earthquakes, wildfires, volcano eruptions, landslides, oil spills, search & rescue of aircrafts, vessels and submarines, Ebola epidemic, train accidents, dam collapse, ice jams, and snowfall.

It can be activated at the request of Authorised Users (AU), usually representatives of the national civil protection agency, rescue operators, or other security organisation. Several conditions need to be met for the activation of the mechanism and a request can only be accepted within the emergency response phase (up to ten days after the occurrence of the disaster). The activation request works through a telephone number available 24 hours a day, 7 days a week and follows several stages until the final delivery to the user ().

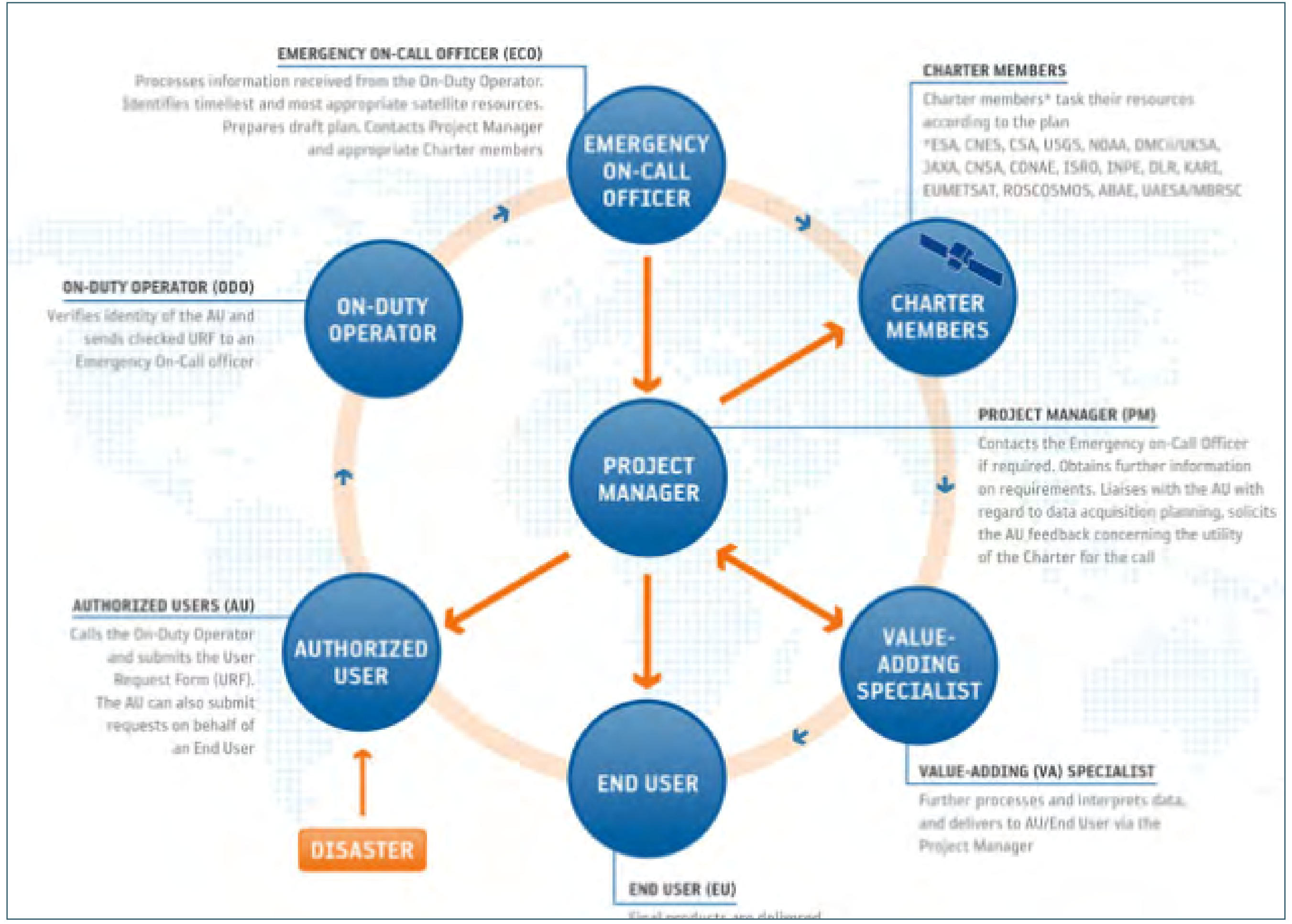
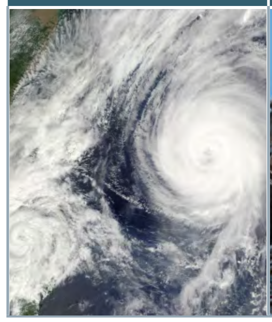
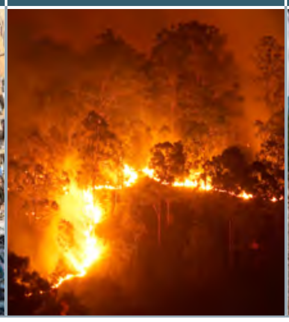
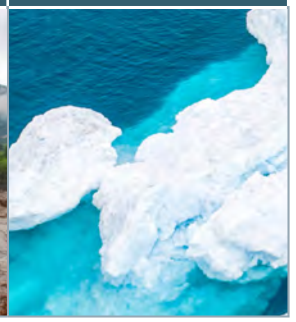


Figure 35. Sequence of events once the International Charter is activated. It begins with an authorised user (bottom left) and follows the sequence in a clockwise rotation. Source: https://disasterscharter.org/web/guest/how-the-charter-works

Depending on the scope of the request, the end user receives final maps delineating the affected area (may also include other features), free of charge. These products are made available to the public on the Charter`s webpage.

Cyclones	Earthquakes	Fires	Floods	Snow and Ice
				

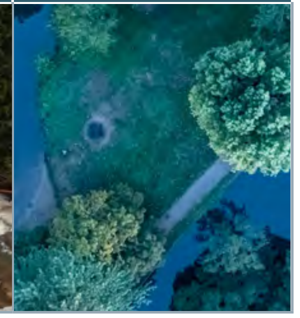
Ocean Waves	Oil spills	Volcanoes	Flood Landslides	Others
				

Table 13. Types of disasters most addressed by The Disasters Charter

1.10 COPERNICUS EMERGENCY MANAGEMENT SERVICE

The Copernicus Emergency Management Service (EMS) is designed to support Disaster Risk Management (DRM) regarding natural and man-made disasters both during the emergency response phase and beyond. It consists of geoinformation products and services to better understand and manage disaster risks and is provided by the European Union's Earth Observation Program, Copernicus. The Copernicus EMS involves the implementation of different components, each having several modules:

- CEMS Mapping including Rapid Mapping; Copernicus Risk and Recovery Mapping (CEMS RRM); Validation; Aerial component. The Rapid Mapping service and the Risk and Recovery Mapping are both EO based services.

- Early Warning and Monitoring with both EU wide and global services with monitoring and forecasting components. For instance, the European Drought Observatory (EDO) is continuously extended to the global scale (GDO for droughts); the same applies concerning Flooding and Forest Fires (GloFAS for floods, GWIS for forest fires).

- Exposure Mapping service: the goal is the periodic production of global geospatial information on human settlements in the form of built-up area grids.

National Disaster Management Authorities (NDMAs i.e., DRM user organisations) are the primary requesters of the Copernicus EMS services. NDMAs from outside Europe can activate the Copernicus EMS through the Emergency Response Coordination Centre of the European Union (ERCC, https://erccportal.jrc.ec.europa.eu/).

1.10.1 Copernicus Risk and Recovery Mapping service

The RRM is developed in the international context of the Sendai Framework for Disaster Risk Reduction. It aims to supply information layers that support decision making in the emergency management phases that are not directly related to response. The RRM focuses on information extraction for hazard and risk characterization in a range of prevention, mitigation, preparedness, and recovery contexts.

Emergency response is managed using the CEMS Rapid Mapping service while the RRM is supporting other phases of DRM cycle, typically the phases after the immediate disaster response including recovery, rehabilitation, reconstruction, and risk mitigation activities. Therefore, the RRM service concerns the on-demand provision of geo-spatial information in support of emergency management activities during the phases of the disaster management cycle which are preceding (prevention or preparedness) or following (recovery phase) a disaster event. In addition, the CEMS has a component called Early Warning and Monitoring.

While both the Rapid Mapping service and the RRM service use satellite imagery and other geospatial data, there are some key differences between them. The main difference is their focus and scope. Overall, Copernicus Risk and Recovery Mapping has the goal to improve disaster response and management in a complementary fashion to the immediate response phase (days to weeks) by looking at both disaster recovery following the emergency (weeks to months) and long-term risk mitigation efforts outside an emergency basis.

Examples of Copernicus EMS Rapid Mapping include damage maps of disaster-affected areas with information on the extent and severity of the disaster, as well as the location of affected populations and infrastructure. This information is used by emergency responders and disaster management authorities to plan and coordinate response efforts. These products are typically used in the immediate aftermath of a disaster when timely information is critical for saving lives and minimizing damage.

The RRM service provides a range of different geoinformation products such as mapping the potential impact of future disasters, allowing authorities to take proactive measures to mitigate risks and minimize the impact of future events. The RRM service provides detailed information on the extent and severity of natural and man-made disasters, as well as potential risks and vulnerabilities. This information is used to plan and coordinate DRM activities including the development of strategies for recovery and risk reduction. This includes identifying areas that are at high risk of natural disasters such as floods, landslides, and wildfires and characterizing the hazard (susceptibility mapping). In addition, the RRM service supports post-disaster recovery efforts by providing detailed information on the extent of damage and the location of affected populations and infrastructure, with more details than rapid mapping products and generally with longer production time. This information can help the planning and prioritizing of recovery efforts, including the allocation of resources and the development of rebuilding plans. RRM is designed to support both emergency response and long-term recovery efforts, providing detailed information on a wide range of factors, while the CEMS Rapid Mapping service is focused primarily on rapid response, providing fast and accurate mapping products in the immediate aftermath of a disaster.
Since 2012 the CEMS Risk and Recovery Mapping products have been effectively used in risk reduction studies and recovery efforts for all types of disasters or humanitarian crises around the world.

The Copernicus RRM combines standard Services and flexible i.e., tailored services. Standard services comprise 20 different components divided into nine categories from the list provided in Annex.

Overall, the Risk and Recovery activity provides information and services relevant for supporting activities both on an emergency basis (disaster response) and activities not on an emergency basis (e.g., post-disaster recovery efforts, risk mitigation, preparedness, etc).

1.10.1.1 Copernicus Rapid Mapping Services

"**Reference products** aim at quickly providing knowledge on the territory and assets prior to the emergency in case such information is not available. The content consists of selected topographic features on the area affected by the disaster, in particular exposed assets and other available information that can assist the users in their specific crisis management tasks. A reference product is normally based on a pre-event image captured as close as possible prior to the event."

"The **First Estimate Product** (FEP) is an early information product which aims at providing an extremely fast (yet rough) assessment of most affected locations within the area of interest. Such information will be derived from the earliest suitable available post-event image and can be of different resolution and sensor type than the image used for producing delineation and grading products. FEP can be used to 1) highlight possibly affected areas, 2) review the initial product specifications (product type, areas of interest) or 3) decide on cancellation of initially requested delineation or grading products."

"**Delineation products** provide an assessment of the event impact and extent and, if requested, an update of the situation (monitoring). They are derived from images acquired as soon as possible after the emergency event."

"**Grading products** provide information about the damage grade, its spatial distribution and extent. An update (monitoring) can be requested. They are derived from images acquired as soon as possible after the emergency event. The grading product is a superset of the delineation product as it contains the event type, impact extent (delineation) and the damage grading. They can only be released in combination if the request for a grading product comes after the request for the delineation product."

1.10.1.2 Risk And Recovery Mapping Services

The CRRM provides 20 different types of services through the Copernicus program. These services are divided into nine categories. CRRM offers to the users the possibility to request any of the twenty (20) standard products from the list in Annex, covering the analysis of impact and risk of certain hazards (flood, wildfires, soil erosion, ground deformation), as well as damage assessment, reconstruction monitoring and reference products.

These services are provided through framework contracts with pre-selected teams. When requests for services are submitted to Copernicus, the pre-selected teams are asked to propose services based on their areas of expertise. These products can be requested separately or in combination with other products, depending on the Users' needs. They are known as the standard products.

1.10.1.3 Risk and Recovery FLEX Services

RRM is designed to allow users the ability to request a wide range of products, based on their needs. In particular, the RRM service supports Member States with risk and recovery products in the context of the Union Civil Protection Mechanism and the Sendai Framework for Disaster Risk Reduction. By providing locally relevant information, the RRM products are relevant at city and regional level and can support processes such as cost-benefit analysis of major investment projects for disaster prevention and climate change adaptation and help effective investments under the European Structural and Investment Funds.

Users can formulate a request containing all the elements relevant to their requirements. The request can be related to natural or man-made hazards and include studies to support the different phases of the emergency management cycle.

Overall, the Risk and Recovery activity provides information and services relevant for supporting activities both on an emergency basis (disaster response) and activities not on an emergency basis (e.g., post-disaster recovery efforts, risk mitigation, preparedness, etc).

1.10.2 Copernicus EMS Early Warning and Monitoring services

This includes:

- The European Flood Awareness System (EFAS) and the Global Flood Awareness System (GloFAS, see: https://www.efas.eu/en). These services combine satellite information, hydrological, modelling, meteorological predictions and in situ measurements. In addition, the Copernicus EMS provides a continuous global, systematic, and automated monitoring of all land surface areas possibly affected by flooding called global flood monitoring (GFM) product.
(See: https://www.globalfloods.eu/technical-information/glofas-gfm/).
- The European & Global Drought Observatories (EDO & GDO). The observatories gather drought-relevant information such as maps of indicators derived from different data sources and produce reports with detailed descriptions on severe drought events (e.g., precipitation measurements, satellite measurements, modelled soil moisture content,(
(See: https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000).
- The European Forest Fire Information System (EFFIS, see: https://effis.jrc.ec.europa.eu/) that lies in the integration and processing of multiple data sources, including satellite imagery, and converting them into real-time information on forest fire management, in complement to different national systems. The compatibility of EFFIS with national systems makes it flexible and adaptable to specific methodologies and needs.

1.10.3 Copernicus EMS Exposure Mapping service

The Copernicus EMS offers Exposure-related services that utilize EO data to support risk assessments. These services include the provision of geospatial information and maps that help identify and analyse elements at risk, such as buildings, critical infrastructure, and land use. The data and products provided by the Copernicus EMS can assist in understanding the potential impacts of natural or man-made disasters on these assets.

The **Copernicus EMS exposure mapping** component provides highly accurate and continuously updated information on the presence of human settlements and population with the Global Human Settlement Layer (GHSL). It is Supported by the Joint Research Centre (JRC) and the DG for Regional and Urban Policy (DG REGIO) of the European Commission, together with the international partnership GEO Human Planet Initiative.

The **Global Human Settlement Layer** (GHSL, see: https://ghsl.jrc.ec.europa.eu/) provides detailed information on disaster exposure to support crisis management and the assessment of disaster risks. The scope of the exposure mapping component of the CEMS is to provide, with the Global Human Settlements Layer, highly accurate information derived from satellite and census data on the presence of settlements and population. GHSL datasets are available globally and can be downloaded for free by tile. They are available for different epochs ranging from 1975-2030, as well as different coordinate systems. Not all combinations of options are available i.e., some products are only available at certain resolutions and/or certain years. The data is downloaded by selecting the desired options then the tile on the map. A global visualization of the data is also available as a map preview. The different products available are Built-up surface (with height and volume options), population gird (with settlement and functional urban area options), and other more specific characteristics. Population grids are effective datasets to assess the amount of resident population at fine spatial resolution. Population counts per grid cell quantify the amount of people exposed to hazards. Built-up surface grids are essential information to map human settlements and their characteristics (like land use and density). The amount of built-up surface per grid cell is useful to estimate settlement typologies and is used as covariate for population disaggregation.

1.11 SENTINEL ASIA

https://sentinel.tksc.jaxa.jp/sentinel2/topControl.jsp

Sentinel Asia is a voluntary basis initiative led by the APRSAF (Asia-Pacific Regional Space Agency Forum) to support disaster management activity in the Asia-Pacific region by applying the WEB-GIS technology and space-based technology, such as earth observation satellites data.

Eligible requestors for Sentinel Asia are Asian Disaster Reduction Centre (ADRC) member organizations and representative organizations of the JPT. The activations are upon request.

Sentinel Asia provides satellite imagery and value-added maps highlighting the affected areas, as well as on-site digital photos of the disaster area. It also shares data on wildfire hotspots and rainfall information derived from satellite data and meteorological satellite information. This information is then made available on the web, or via satellite communication.

Currently, the initiative is based on data received from the following satellites: ALOS (JAXA), IRS (ISRO), THEOS (GISTDA), and KOMPSAT (KARI). It acquires and analyses the satellite data and discloses the information through the Sentinel Asia website.

1.12 THE UNITED NATIONS OPERATIONAL SATELLITE APPLICATIONS PROGRAMME (UNOSAT)

https://unitar.org/unosat/

It is a program under the United Nations Institute for Training and Research (UNITAR) implemented with the support of the European Organisation for Nuclear Research (CERN) and in partnership with other UN and non-UN organisations.
With Geographic Information Systems (DIS) and satellite imagery, UNOSAT provides timely and high-quality geospatial information to UN decision makers, member states, international organisations, and non-governmental organisations such as OCHA, UNHCR, UNICEF, WFP, UNDP, WHO, IFRC, ICRC. They develop solutions integrating field data with remote sensing products to deliver solutions in support of human security, peace, and socio-economic development.

The activation of the UNOSAT mechanisms can be requested in case of a natural disaster and the service involves very quick acquisition and processing of satellite imagery to produce geospatial information and analytical reports in addition to GIS layers.

They are available by phone or by email 24 hours per day, 7 days per week and the Geospatial Catalogue offers a full range of products to supply the humanitarian community with timely reliable information needed during humanitarian operations.

1.13 COMMITTEE ON EARTH OBSERVATION SATELLITES (CEOS) WORKING GROUP DISASTERS

The Committee on Earth Observation Satellites (CEOS) was established in September 1984 with the aim of coordinating international Earth Observation efforts to benefit society. Its original function was to coordinate and harmonise Earth Observations to provide the user community with an easier access and use of data. It has evolved becoming more complex and expanding the number and scope of its activities, continuing with its role of international coordination of space-based Earth Observations.

CEOS is composed by five Working Groups, one of them, the Working Group on Disasters (WGDisasters), created in 2013. WGDisasters goals are to increase and strengthen satellite Earth observation contributions to the various Disaster Risk Management (DRM) phases and to inform politicians, decision-makers, and major stakeholders on the benefits of using satellite Earth Observations in each of those phases.

The WG Disasters is currently chaired by the Italian Space Agency (ASI) and has two dozen regular members representing as many organizations involved in the use of satellite imagery for disaster risk reduction, response, and recovery. The WGDisasters meets by teleconference every two months and in person every six months, to review progress on pilots, demonstrators, and other on-going disaster-related activity.

ANNEX: STANDARD COPERNICUS RISK & RECOVERY MAPPING SERVICES

1. Floods
- Flood delineation
- Modelled flood extent for major events
- Temporal analyses of occurred flood events

2. Forest Fires / Wildfires
- Wildfire delineation and grading

3. Humanitarian crisis
- Urban growth analysis
Human footprint evaluation of cities through nightlight analysis
- Human settlements mapping
- Population displacement location/monitoring

4. Soil erosion / Landslide risk
- Soil erosion risk assessment
- Landslide risk assessment

5. Ground deformation
- Ground deformation analysis

6. Damage assessment and reconstruction monitoring
- Detailed damage assessment analyses over affected areas
- Reconstruction monitoring

7. Impact assessment/exposure after disaster
- Impact assessment/exposure analysis on assets and population
- Detailed impact assessment/exposure analysis on selected aspect

8. Reference data
- Reference dataset
- Land use and land cover dataset
- Detailed reference dataset for high-importance areas
- Digital surface model

9. Map layouts for printing
- Ready to print maps and map books for field campaigns

These services are provided through framework contracts with pre-selected teams. When requests for services are submitted to Copernicus, the pre-selected teams are asked to propose services based on their areas of expertise. These products can be requested separately or in combination with other products, depending on the Users' needs. They are known as the standard products.