Disaster risk reduction using innovative data exploitation methods and space assets

Executive Summary

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1 Executive Summary

The difficult and costly access to reliable and quality Earth Observation (EO) satellite data has historically often limited the development of operational and sustainable services in multiple application domains (among which Disaster Risk Management) and, as a consequence, it has impaired the benefit that the society could have been receiving back as a return of huge multi annual investments in the space sector. Publicly funded programs such as the Copernicus Sentinels, the Landsat generation and MODIS Terra/Aqua are today complemented by national commercial EO missions (COSMO-SkyMed, DEIMOS, Pleiades, Terrasar-X just to cite a few), thus offering a significant variety in terms of resolution (spatial/spectral), sensor modes (optical/SAR), revisit capabilities (multi-mission constellations). However, it is a matter of fact that user organizations active in the DRM field are not yet taking full benefit from this technology due to different potential reasons: past background far from the space culture, availability of alternative methods that requires a lower technological investment, the costs associated to EO based services (data procurement, processing facilities etc.).
Given this state of affairs, the ESA funded GSP project "**Disaster Risk reduction using innovative data exploitation methods and space assets"** has been conducted having two main objectives:
- analyse to which extent the state-of- the-art EO and data exploitation systems fit for purpose to support DRM actors in real life scenarios and
- assess the contribution of current and firmly planned in-orbit space assets to the broad Disaster Risk Management (DRM) activity framework, to identify gaps in the fulfilment of the user needs, identifying new types of dedicated missions (gap-fillers) that could be designed by ESA and by the international space community to better meet the user needs.
The study focuses primarily on Disaster Risk Reduction (DRR). In this domain, priority theme areas may encompass floods, seismic hazards, landslides, subsidence and volcanoes, etc. Two themes (i.e. hazard types) have been selected to be analysed in details in the study through dedicated trial cases. The in-orbit capability assessment and gap analysis deals with the user requirements associated to these hazard types, namely floods and volcanoes, thus providing the inputs for the identification and feasibility analysis of new mission concepts.

1.1.1 Implementation Approach

The following main phases have been followed to reach the main technological objectives:

- **Phase 1**: Analysis of current user geo-information needs in DRR, current contribution
- of space technologies and new ICT and definition of trial cases;
- **Phase 2**: Execution of the trial cases designed to promote unexploited functionalities by using already existing space assets;
- **Phase 3**: Review of the user need analysis and trial cases results in order to identify new possible contribution to space assets given the current future outlook.

2 Definition and execution of DRR Trial cases

Based on the analysis presented in the above sections, a set of Trial cases have been selected and performed during the project activities. The common goal for the Trials has been to propose and integrate in the Geo Hazard Exploitation platform (GEP) managed by ESA a set on innovative prototyping services based on already existing satellite assets with particular emphasis in the exploitation of Copernicus Sentinel data.

The candidates Trial case have been selected after a User Consultation event. The ***User Consultation on Disaster Risk Reduction (DRR) using new satellite EO methods*** event took place in ESA ESRIN (Frascati) on November 27th, 2015. A total number of more than **40 participants** belonging to more than **20 different public or private organizations** from **10 different countries** (and staff from international organisations like the United Nations) joined the event and actively contributed to the different working sessions. The organizations present at the event represented players of the European EO sector and a range of users and practitioners of remote sensing from the DRR domain.

2.1.1 Trial Case Flood – FL01

The FL-1 Trial Case originally aimed to combine flood hazard mapping and asset mapping based on an automatic processing of large historical data collections, but during the design and development phase it was clear that the original goal was not effective due to different reasons:

1. Lack of a standard approach on the combination of flood hazard maps and asset maps for different Users.
2. Lack of a standard approach to retrieve flood hazard maps from historical flood information for different Users.

With this in mind, during the development stage we shifted the focus toward the implementation of two tools, one able to extract flood masks from optical images (using a single image) and another from multi-temporal SAR series. The main goal of the tools Optical Flood Extraction and SAR Flood Extraction is to enable the extraction of Flood extent Maps from Sentinel 2 and Landast 8 (optical) and from Sentinel 2 interferometric stacks (SAR). These tools are integrate on the Geohazard TEP (GEP, https://geohazards-tep.eo.esa.int/geobrowser) and can be applied globally (limitation are only related to data availability). The tools work on-demand, referring to the expert Users the possibility of selecting the images to analyse and produce as output GeoTiff water masks.

Products generation

The new capabilities have been tested over York (United Kingdom), highly affected from floods between November 2015 and January 2016. Under normal circumstances, is very difficult to acquire a cloud-free optical image during a flooding event, while clouds do not affect the performance of a SAR-based product. The two products are slightly different.

Optical tool product:

The optical-derived product is actually a water mask extracted from a single optical image (either Landsat-8 or Sentinel-2). It includes permanent water bodies (river, lakes, sea) and water from flooding events. It's easy to obtain just permanent water bodies using an image with no flooding event on the same area of interest. The output format is a GeoTiff file where each water pixel is represented with the value "100".

SAR tool product:

The SAR derived product is a series of flood masks extracted from an interferometric stack of Sentinel-1 images (at least 3). As an example, with three images (date_1, date_2 and date_3, with date_1 being the oldest and date_3 being the most recent), the processor would generate two flood masks:

- **date_2-date_1-flood_mask**: flood extent on date_2 with respect to date_1.
- **date_3-date_2-flood_mask**: flood extent on date_3 with respect to date_2.

The algorithm works on a change detection fashion, so the output is actually only the flood extent (if a flood event is present) and no permanent water bodies are present in the resulting mask. Of course there is a certain level of false alarms (mostly isolated pixels or small clusters) that need to be taken care of during the post processing. The user has to decide which sub-swath (1, 2 or 3) will be analysed. The resulting flood masks are GeoTiff file, where each pixel identified as "flooded" has value 1.

Benefits of the services

The services provide access to tools with a simple interface to automatically generate flood masks (raster files) on a specific area. The two tools available (optical and SAR) should be seen as complementary, to cover different dates and to cross validate the results. It is important to bear in mind that while the optical tool extracts water bodies (either temporary or permanent) from a single image (Landsat-8 or Sentinel-2), the SAR tool generates only the temporary water bodies. An expert user can combine the information retrieved from the services to analyse the phenomenon occurred in the area with little effort on the generation of the flood layers.

Trial Flood results portfolio

The execution of the trial over York (United Kingdom) has generated results for the optical and the SAR imagery. In the following section the results obtained with the optical and SAR processor are shown. The tools are able to work anywhere, so we strongly suggest the Users to analyse different regions and different events to have a comprehensive understanding of the tool and to help in the improvement of the interface. After the download, the result can be visualized in a GIS environment.

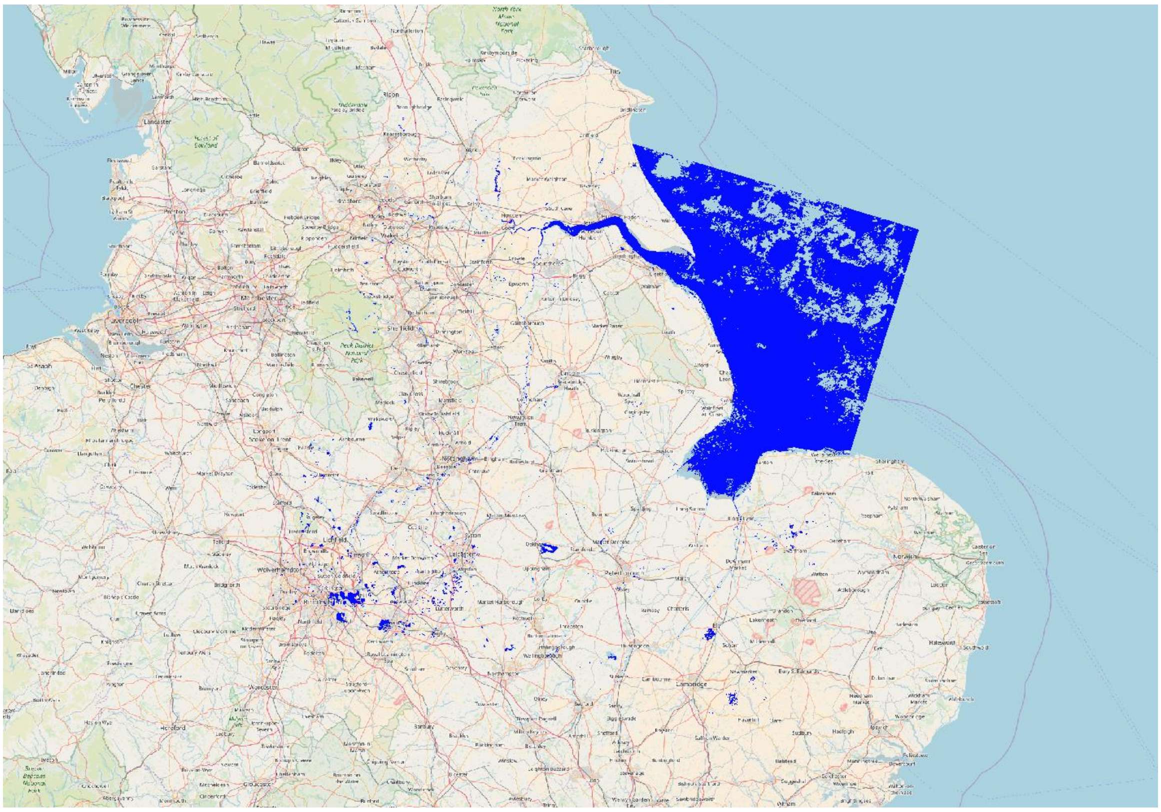


Figure 1: result superimposed to OpenStreetMap layer.

SAR flood extraction tool

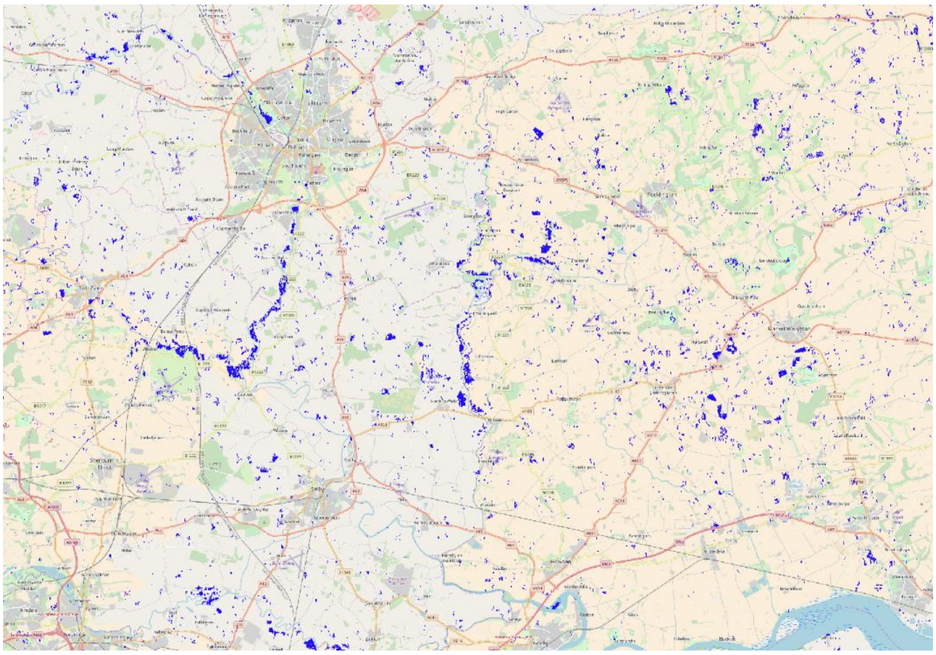


Figure 2: flood mask as of 2016-12-05

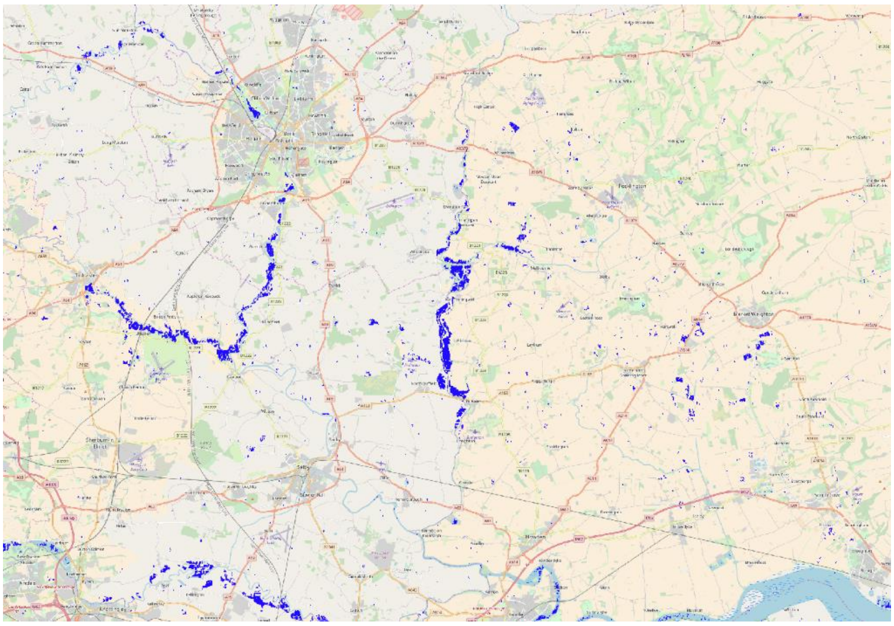


Figure 3: flood mask as of 2016-12-17

It’s worth stressing that using more images would decrease the noise level in the detection. The difference is quite evident between Figure 2 and Figure 3.

2.1.2 Trial Case Volcano – V01

The new capabilities have been tested for an historic volcano in Santorini island, Greece, aiming to create a unique database of diachronic InSAR measurements spanning from 1992 to 2015 (~23 years of data). The processing of the five different SAR stacks was done entirely within the GEP environment, by managing the StaMPS processor in ad-hoc versions (branches) for each of the five satellite missions selected for the trial. The generated results are presented in detail further below. The trial case inclusion of in-situ measurements from geodetic monitoring networks (e.g. Dionysos Satellite Observatory , and COMET+) for the Santorini Volcano, accessed by users via the GSAC service, provides them with a natural laboratory work environment.

Benefits of the service

The benefits of the service are identified as follows:

- For managing InSAR processor resources:
    - The tools and services on Terradue Cloud Platform supported the NOA team for the management of StaMPS codebase evolutions (versioned) as open source and re-usable processing chains. Each StaMPS version could be allocated to a dedicated data processing task over an EO data source collection. This allowed NOA to separate problems and work on well defined test cases so that each production workflow of the trail case was tackled with a good level of focus, as well as a good level of coordination for the transfer to production once validated.

  - In particular, the NOA team could extend the current processing capabilities of GEP by developing scripts for the StaMPS processor, to process COSMO-SkyMed, TerraSAR-X and Radarsat-2 SAR data, in addition to the current StaMPS processing capacities for ERS and Envisat.
- For accessing Cloud processing resources:
  - The tools and services on Terradue Cloud Platform supported the NOA team for the management of different StaMPS processing instances, and for the retrieval of the PSI results from associated Cloud storage, for ingestion in the NOA in-house tools performing the velocity maps generation.
- For benchmarking studies, performed by NOA during the Trial Case, to assess the performance, reliability, accuracy and consistency of the StaMPS-based GEP implementation.
- For sharing velocity map results on the Web:
  - Zenodo: a Cloud service operated by CERN, where researchers receive credit by making their research results referenced with a DOI (a Digital Object Identifier issued to every published record) and citable. All the data records on Zenodo are following the FAIR principles (findable, accessible, interoperable, reusable). All metadata is openly available under Creative Commons CC0 licence, and all open content is openly accessible through open APIs.
  - GEP Geobrowser “community” area: a data products search and visualisation space on the GEP Geobrowser opened to the Geohazards community to bring their results, including via the use of APIs, the inclusion of results ublished on the Zenodo community “Geohazards Exploitation Platform” (given their approval, on Zenodo ‘curate’ workspace, by the GEP Scientific Communicator team).
  - GEP blog:
- For end-users, they can for the first time easily access a consistent, diachronic and central hub of measurements for the Santorini Volcano, overcoming the current issues with fragmented data product sources. This allows scientists to perform reliable time-series analysis, geophysical interpretation and modeling.
- Also for end-users, make available data (in RINEX format) from several permanent GPS stations operating in Santorini, with at least weekly updates, and allow the re-use of this information by other scientists.
- Overall, for modeling experts that have the know-how to exploit InSAR and GPS geodetic measurements, the capacity to do some geophysical modeling and parameter estimation; and for decision makers the possibility to adopt PSI velocity products in their work processes (e.g. assess the landslide hazard potential near the volcano).

Trial V01 results portfolio

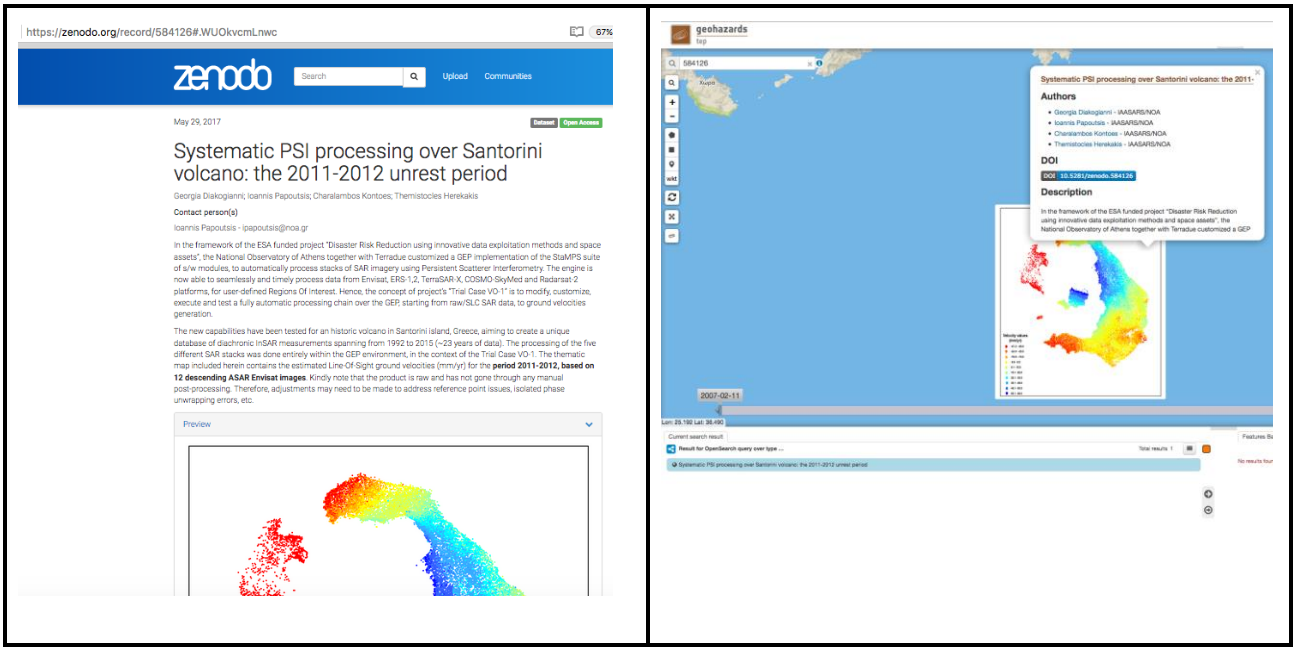
VO-1 GPS / GSAC web service

The database implemented in the context of the trial case is accessible online at this URL: http://ddrgsac.noa-gsp.terradue.com/ddrgsac

VO-1 ENVISAT PSI processing results as Velocity maps

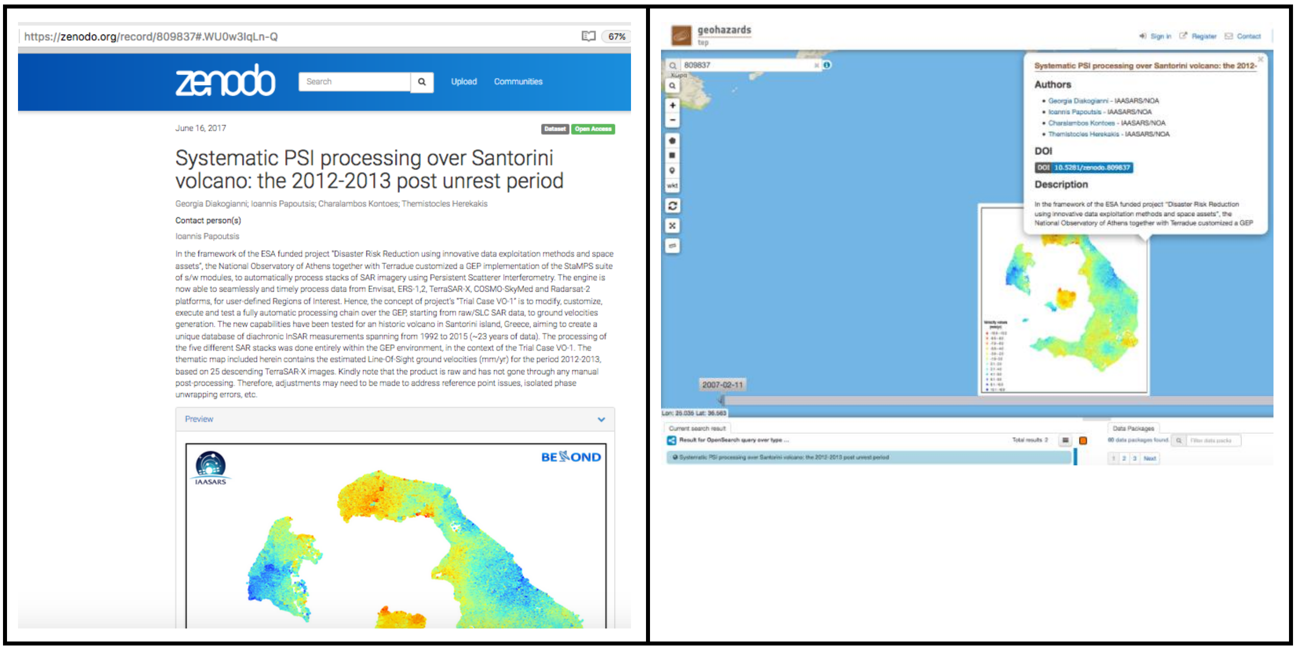
GEP references for the results publication:

- Record on the Zenodo “Geohazards Exploitation Platform” community:
    - https://zenodo.org/record/584126 Systematic PSI processing over Santorini volcano: the **2011-2012 unrest period** (ENVISAT)
- On the GEP Geobrowser “Community” area:
    - https://geohazards-tep.eo.esa.int/geobrowser/#!&context=Community
    - search for the DOI reference "584126”



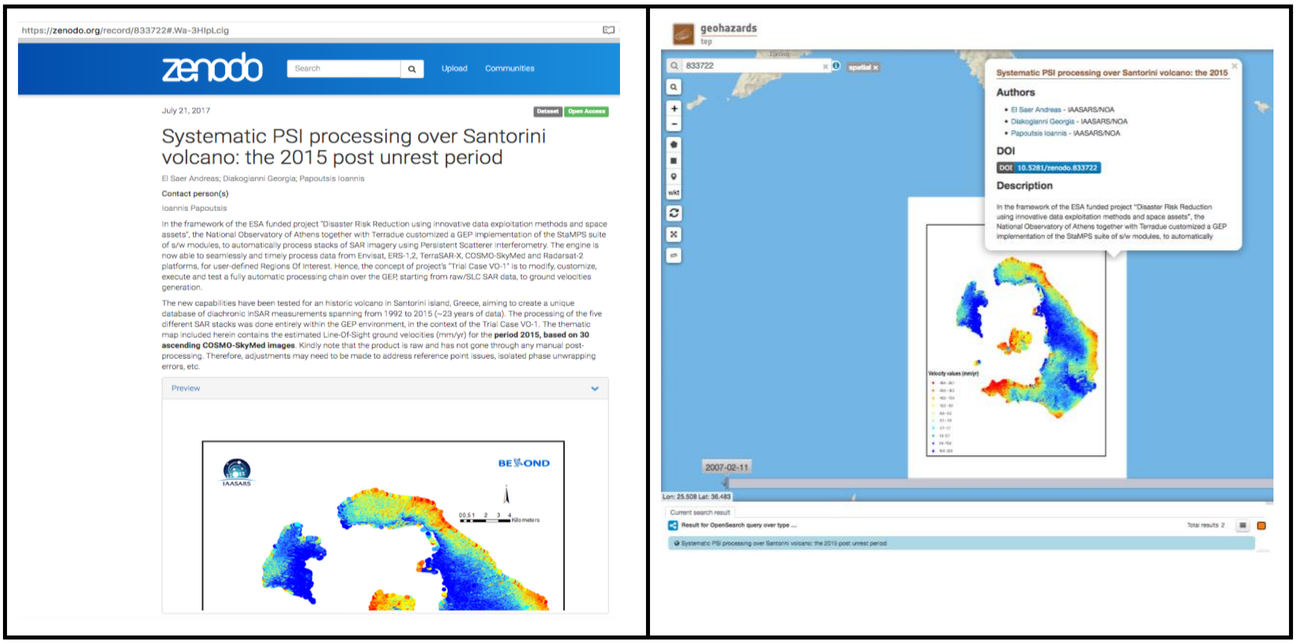
ENVISAT PSI processing results, shared on Zenodo (584126) and on GEP

VO-1 TerraSAR-X PSI processing results as Velocity maps



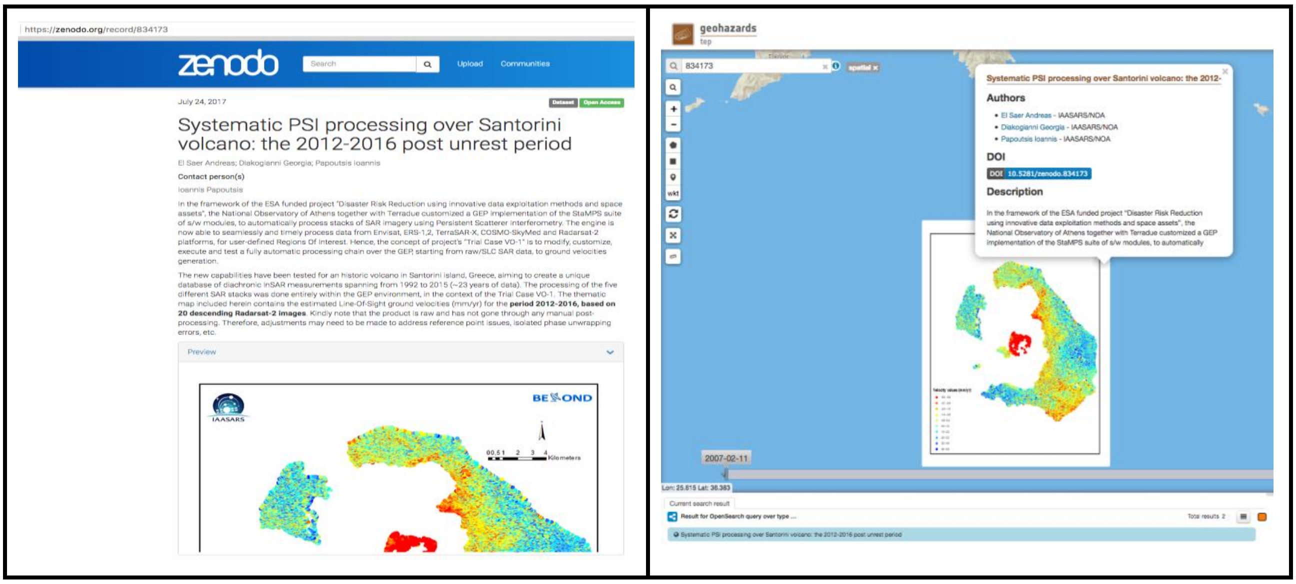
TerraSAR-X PSI processing results, shared on Zenodo (809837) and on GEP

VO-1 CosmoSkymed PSI processing results as Velocity maps



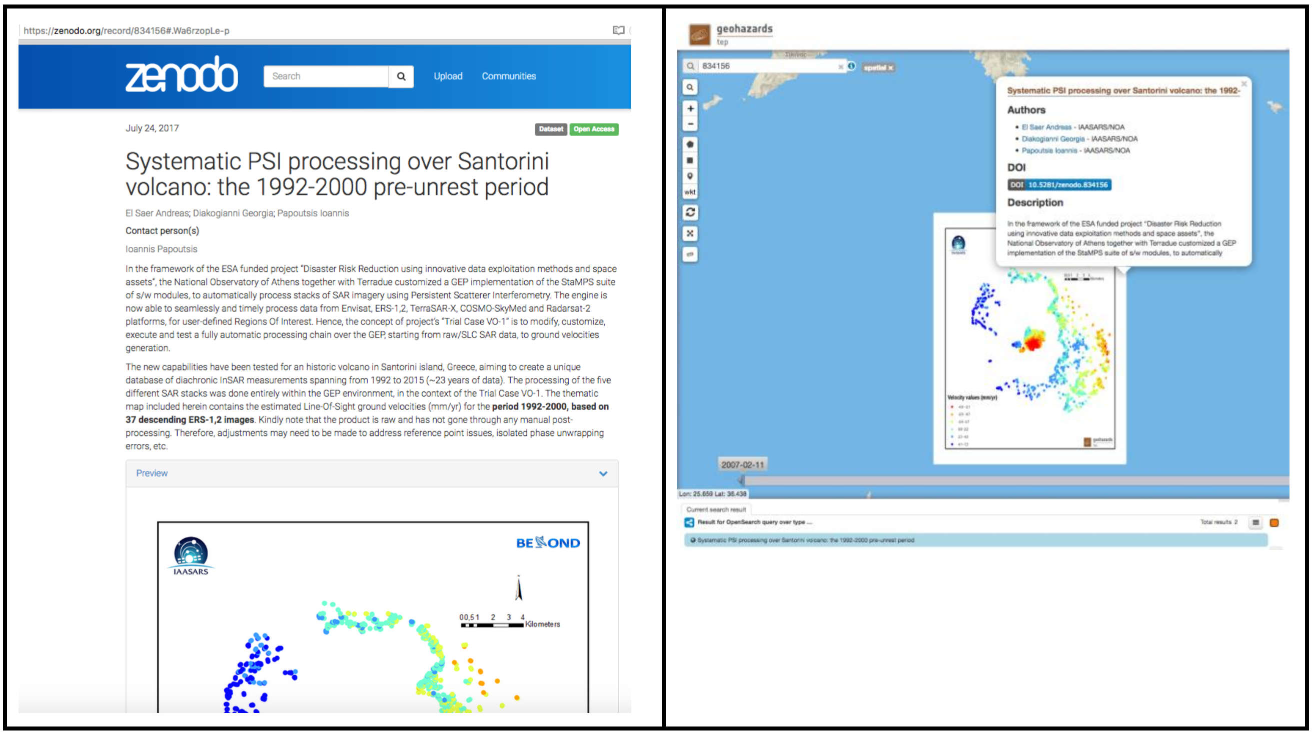
CosmoSkymed PSI processing results, shared on Zenodo (833722) and on GEP

VO-1 Radarsat-2 PSI processing results as Velocity maps



Radarsat-2 PSI processing results, shared on Zenodo (834173) and on GEP

VO-1 ERS PSI processing results as Velocity maps



ERS PSI processing results, shared on Zenodo (834156) and on GEP

2.1.3 Trial Case Volcano – V02

Service VO2-SV01 - MONITOR Sentinel-1 High Res Change Monitoring (DLR)

The Sentinel-1 High-Resolution Change Monitoring (MONITOR) service will provide an amplitude and coherence product at 50m, systematically processed from the S-1 co-seismic pairs acquisition, for the selected volcanoes. The general goal of this DLR service is the automatic and systematic provision of InSAR products over the global tectonic and volcanic areas, totaling 25% of the earth's land area. The coverage of the service includes initially the European tectonic areas, then a ramping up to the world tectonic areas and including Volcanoes (in particular those defined in the present Trial Case).

The service is hosted on GEP under a canonical Scenario 3 of "New EO Product Development", including systematic processing and publication of the resulting browse products. It contributes to the GEP thematic workflow "C" to support provision of systematic InSAR Quick Look imagery using repeat Sentinel-1 observations, systematically generating interferograms and coherence images using Sentinel-1 data collections. It assists the seismic and volcanic hazards communities by supporting the objectives of the CEOS pilots on seismic and volcanic hazards. The products may be of interest to all InSAR users although the primary focus is on geohazards science users exploiting InSAR. The continuous, systematic production approach for data processing allows for inter- and post-seismic analysis, as well as pre- and post eruption monitoring.

The InSAR Browse products published in the GeoBrowser consists of 5 GeoTIFF layers with an average ground resolution of 50m for the high-resolution change monitoring service. These are the terrain corrected interferometric coherence, the master and slave calibrated amplitude and two change composites combining the calibrated amplitudes and the coherence. Staring in July the InSAR Browse layers will change to include RGB composites combining amplitude (Red and Green) and Coherence (Red) and amplitude (in all three RGB Bands) and adding an amplitude change mask (threshold based saturation in Red: backscatter increase and saturation in Blue: backscatter decrease).

Service VO2-SV02 - STEMP Surface Temperature of volcanoes (INGV)

The "STEMP" service for Surface Temperature of Volcanoes is also hosted on GEP, and aims at the development and integration of processing chains suitable for added value product generation for volcanic monitoring starting from EO optical data. Different volcanoes in Europe and Latin America are selected as test sites. A particular emphasis during the implementation activity is dedicated to atmospheric correction procedure that is a steppingstone for all processing chains aimed to thematic extraction.

The estimation of the surface temperature is a considerable interest in the volcanology field because it allows the detection of new thermal anomalies or of changes in existing ones, giving particular value for hazard evaluation. To this end, the measure of the temperature for areas identified as "thermally active" in the volcanic areas in quiescent phases (fumarole fields within active craters along fracture zones of volcanic edifices, or other areas with anomalous heat fluxes associated to volcanic activity) is analyzed by the service. The surface temperature map product is obtained by processing of the TIR channels of ASTER and Landsat-8 data. Outputs of this service are the analysis of surface temperature time series and its applicability in the DRR and preparedness policies. Moreover, GEP may support the enlarging of the use of EO optical satellite data acquisition over volcanoes, demonstrating efficiency of EO-based monitoring methodologies as a complement to in-situ measurements.

Service VO2-SV03 - VEGAN Lava flow and Vegetation stress (NOVELTIS)

The VEGAN service provides processing chains highlighting impacted vegetation and agriculture areas after volcanic eruptions, based on EO optical data and mainly on Sentinel-2. It will focus on two volcanoes. The first one is Mt Etna (Italy) and the second one is the Cordon Caulle Volcano (Chile) and its impact in Chile and Argentina. It will be then extended to all volcanoes of the VO2 Trial Case.

The VEGAN project will integrate two different processing chains:

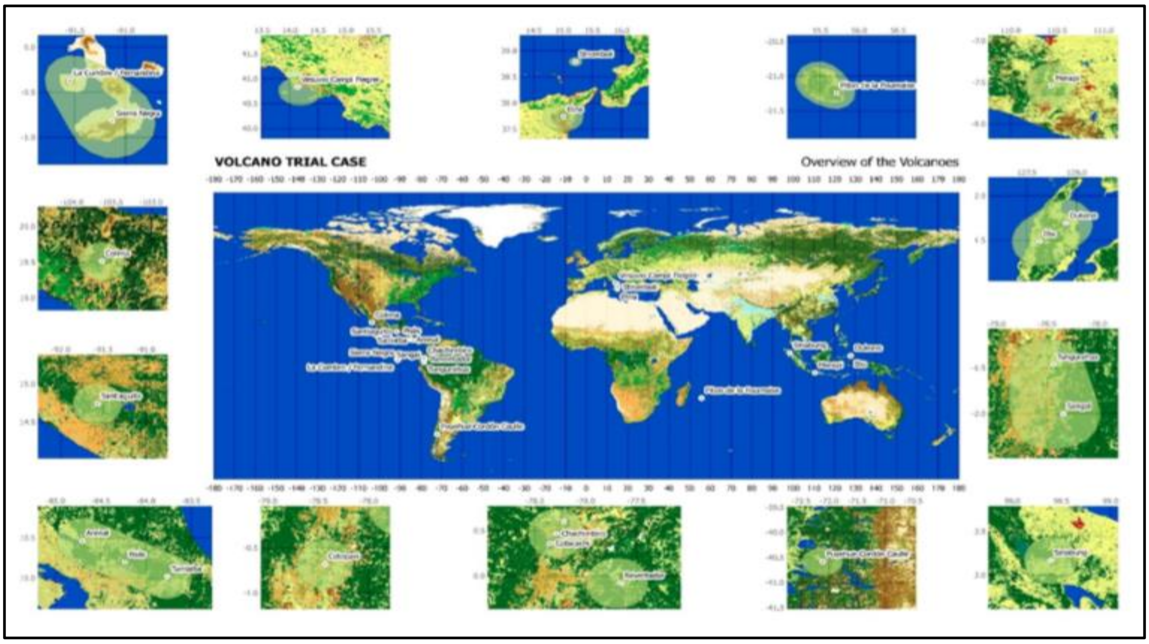
- High temperature phenomena (hot spots) maps, to identify the evolution of the lava flows during and after eruption, based on Sentinel-2 data;
- Vegetation vigor maps to evaluate the impact of the eruption on the vegetation health during a long period, based on Sentinel-2 data (and potentially combining Landsat-8 data).

Each processing chain can be run systematically or on-demand over a period of time. The images acquired over the two selected volcanoes will be processed systematically.

The result of this service is a set of maps providing information on hot spots and vegetation health.

Trial results generation

The new capabilities aiming to create a unique database of Volcanoes monitoring worldwide, have been tested progressively to cover the selected 22 volcanoes showed in the following pictures:



Overview on the Volcanoes monitored by the VO-2 trial case (locations)

The processing of the different VO-2 products was done entirely within the GEP environment, by managing the VEGAN, STEMP and InSAR Browse processor in versions (branches) for each of the ad-hoc satellite missions selected for the trial. The generated results are presented in detail further below.

VO-2 Hotspot detection maps - VEGAN HSP service

GEP references for the VO-2 VEGAN HSP results publication:

- On the GEP Geobrowser "EO Data" area:
    - https://geohazards-tep.eo.esa.int/geobrowser/#!&context=VEGAN-HSP

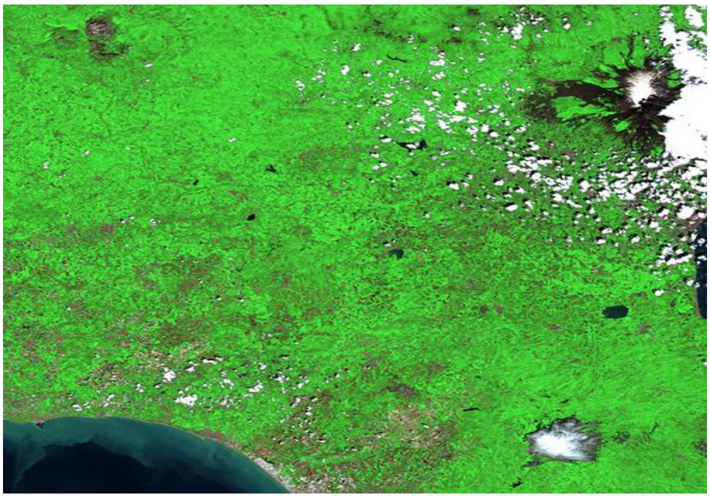
Etna Hot Spot Map based on S-2 acquisition of 19th March 2017
(NOVELTIS VEGAN HSP service)
Read more: http://discuss.terradue.com/t/volcano-trial-case-on-gep-systematically-processing-eo-data/212

The High temperature phenomena (hot spots) map product allow users to identify the evolution of the lava flows during and after an eruption, based on Sentinel-2 data.

VO-2 Vegetation vigor maps - VEGAN VHON service

GEP references for the VO-2 VEGAN VHON results publication:

- On the GEP Geobrowser "EO Data" area:
    - https://geohazards-tep.eo.esa.int/geobrowser/#!&context=VEGAN-VHON



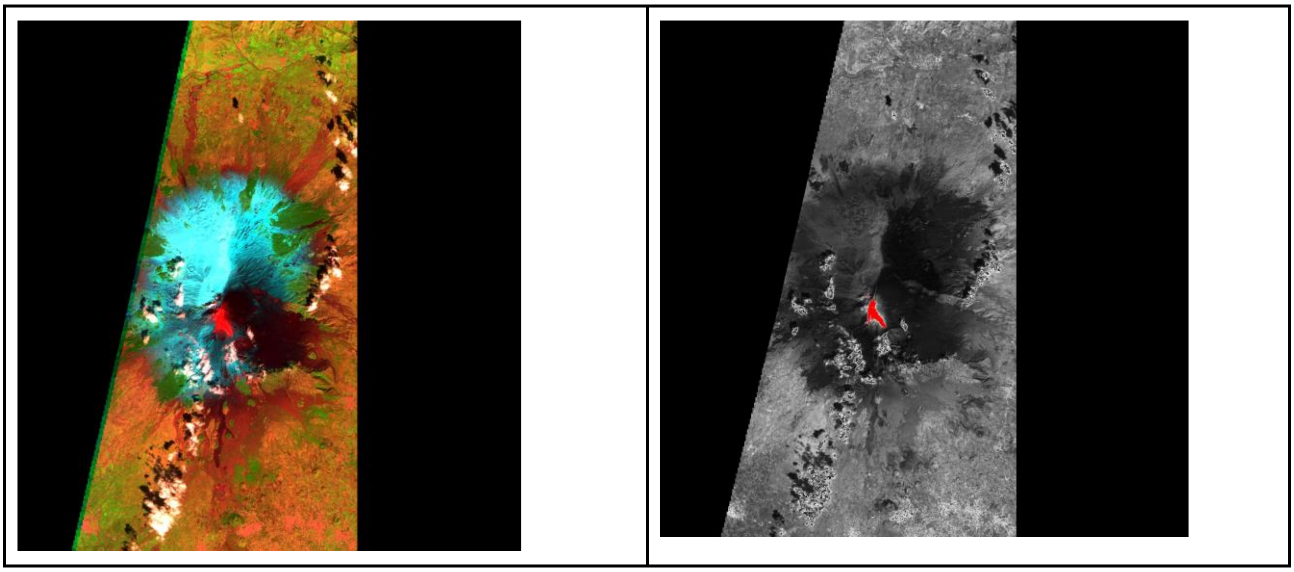
Etna (south-western part) vegetation vigor map (NDVI) from S-2 acquisition of 18th April 2017
(VEGAN VHON service)
Read more: http://discuss.terradue.com/t/volcano-trial-case-on-gep-systematically-processing-eo-data/212

The Vegetation vigor map products allow users to evaluate the impact of the eruption on the vegetation health and agriculture areas after volcanic eruptions and during long periods, based on Sentinel-2 acquisitions. It started initially on two volcanoes. The first one is Mt Etna (Italy) and the second one is the Cordon Caulle Volcano (Chile) and its impact in Chile and Argentina. It was then extended to all volcanoes of the VO2 Trial Case.

VO-2 Surface temperature map - STEMP L8 service

GEP references for the VO-2 STEMP L8 results publication:

- On the GEP Geobrowser "EO Data" area:
    - https://geohazards-tep.eo.esa.int/geobrowser/#!&context=INGV-Stemp



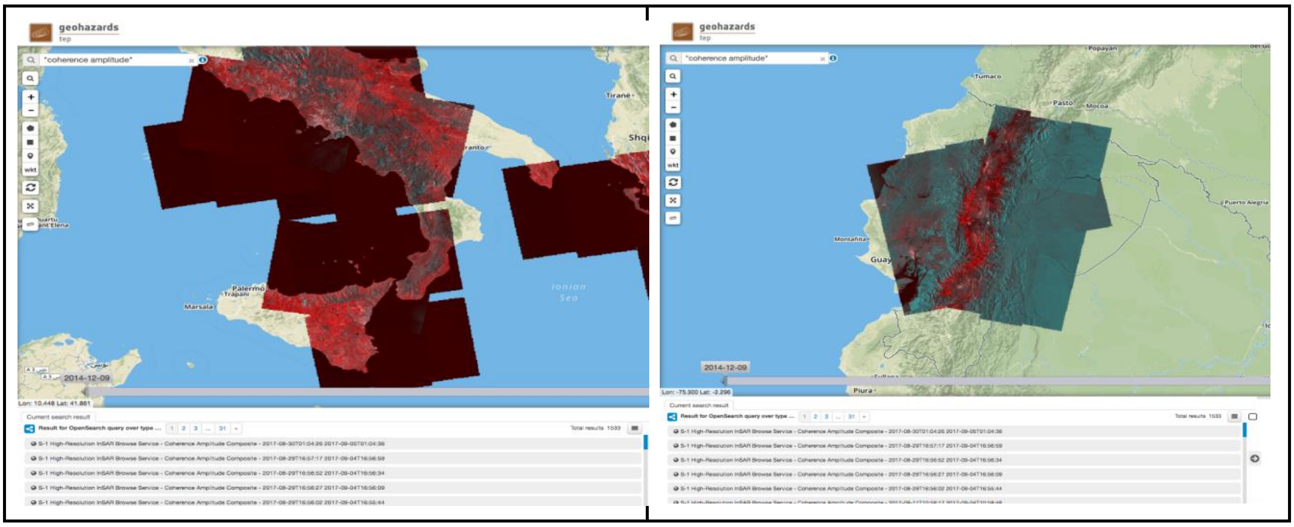
Etna Surface Temperature Map based on S-2 acquisition of 16th March 2017
(INGV STEMP S-2 preview)

The generation of STEMP time series of surface temperature maps, starting from 2015 acquisitions, is covering the chosen volcanoes.

VO-2 Sentinel-1 high resolution InSAR browse service - HR InSAR browse service

GEP references for the VO-2 HR InSAR Browse results publication:

- On the GEP Geobrowser “EO Data” area:
    - https://geohazards-tep.eo.esa.int/geobrowser/#!&context=InSAR_QL_HR



Users with an interests for InSAR techniques can view coherence products to assess the feasibility of Sentinel-1 interferometry over their area of interest.

3 New Mission Concepts and Feasibility Analysis

A gap analysis has been performed to assess the capability of current and firmly planned EO missions (both European and international) to meet specific DRM/DRR-related requirements (with focus on DRR). The gap analysis has compared the baseline requirements associated to DRR (and options associated to DRM / emergency response) for the identified hazard cases (volcanoes and floods) with the results of the in-orbit capability assessment. The outcome has allowed identifying the gaps in in-orbit capability and characterising them in terms of system architecture (e.g. mission data type / payload) and performance criteria (revisit time, data latency, data availability, etc.). The Detailed GAP analysis is included in the D 5.3 Gap Analysis concerning Space Assets to support DRR. Here after a summary of relevant results are presented.

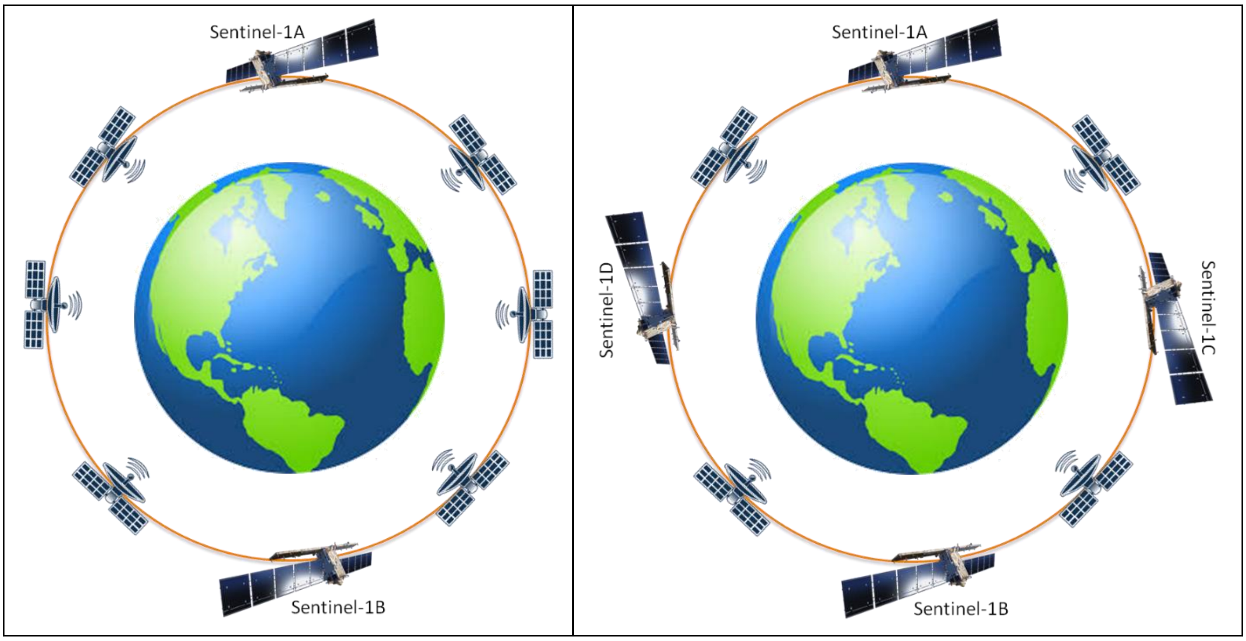
Based on the DRR-related requirements specified for **Volcano Hazard Case VO-01**, among the present and firmly planned EO missions embarking SAR instruments, **COSMO-SkyMed** is able to comply with both requirements of spatial resolution (5 m) and revisit time over Santorini (1 day). Continuity of COSMO-SkyMed (or similar/compatible system) data provision with the required revisit time and resolution performances should be guaranteed to support DRR applications in the long-time term.

As for the **Volcano Hazard Case VO-02**, the DRR-related requirements on resolution (5 m) and "access time" capability (1 week) can be fulfilled by the Pleiades mission (if fully available) and by a virtual constellation of optical instruments, considering present and firmly planned EO missions embarking optical payloads. However, if real 1-week revisit time is required, a gap in space assets should be covered.

A candidate mission concept to fill the detected gaps for Volcano Hazard Case VO-02 has been proposed (details are included in the D5.3 Gap Analysis concerning Space Assets to support DRR) namely a **constellation of optical satellites**. To fulfil the requirement of guaranteeing about 1-week revisit time with optical instrument at about 5-m spatial resolution for accurate mapping, space assets embarking optical payloads with the required resolution should be added to the existing or firmly-planned ones. The space assets are assumed to fly on Sun-Synchronous repeating and frozen orbits with an orbital altitude between 450 km and 800 km. For a comprehensive analysis, parametric swath-width values providing 5m resolution are considered, ranging from 50 km to 350 km. Swath widths on the order of 350 km can be achieved by combining multiple detectors with smaller swaths, where each detector yields the required spatial resolution. Depending on the swath width and on the orbit altitude, the number of satellites in the constellation can vary from 2 to 8. Supposing the constellation of 2 satellites to be composed of new-EO-mission-like satellites and the constellation of 8 composed by Sentinel-2-like satellites, the data volume generated per day by the entire constellation is on the order of 50 Tbit.

For the **Flood Hazard Case FL-01**, the DRR-related requirements on spatial resolution (50-100 m) can be fulfilled with present and firmly planned EO missions embarking SAR instruments. For what concerns revisit time, the only mission able to comply with daily revisit is COSMO-SkyMed, considering its full availability for DRR applications. However, in case of lower availability of COSMO-SkyMed, a virtual constellation of SAR missions could help improve the number of observations over the areas of interest, while guaranteeing daily revisit.

A candidate mission concept to fill the detected gaps for Flood Hazard Case FL-01 has been proposed, namely a **convoy of Sentinel-1-like satellites**. In order to exploit the synergies with the Copernicus Sentinels missions, the proposed mission concept consists of a constellation of Sentinel-1-like satellites that will fly in convoy with Sentinel-1A and Sentinel-1B. These Sentinel-1-like satellites will embark simpler SAR instrument working in C-band with respect to the one on-board Sentinel-1. The number of satellites needed to guarantee 1-day maximum revisit time would be 8. Assuming a convoy with Sentinel-1 A and Sentinel-1 B, depending on the Sentinel-1-like instrument acquisition data rate, the entire convoy of 8 satellites would generate per day a volume of data ranging from 38.6 Tbit to 75.2 Tbit. If the convoy included also Sentinel-1 C and D, the entire convoy of 8 satellites would generate a daily volume of data ranging from 50.8 Tbit to 75.2 Tbit.



Graphical Representation of Sentinel-1-Like Convoy with Sentinel-1 Satellites.

Since data latency is not a requirement for DRR applications, near-real-time (NRT) data availability is not considered as a driving requirement and the selection of the **ground station network** to support the mission is expected to be mainly driven by the data flow and data volume issues. To respond to the emerging DRR observation needs, improved instrument resolution and constellations of multiple satellites will lead to the need of a proper ground segment to handle the considerable volume of data generated. The ground segment should be able to manage multiple satellites and should be sized to guarantee the appropriate availability to support the space segment operations. For SSO orbits, ground station networks comprising multiple stations located at high latitudes (e.g. Svalbard, Kiruna, Inuvik, etc.) provide frequent contacts intervals with the satellites of the constellation. Ground stations at medium latitudes can be added to enable longer daily contact times, if the data volume to be handled is especially large.

Data flow analysis has been carried out to provide the data volume generated vs. time, considering the instrument data production rate, the download data rate to the ground stations and the on-board mass memory capacity. This analysis has considered representative ground station networks and parametric values of the satellite data production and data download rates. The objective of this analysis was to assess the impact of the data volumes generated for DRR applications on the space segment and ground segment design in terms of infrastructure and resource allocation, with the corresponding cost impact.

A key need emerged from the analysis of the hazard scenarios (both for volcano and flood hazard cases) is the **long-term continuity of SAR and optical acquisitions**, encompassing the following aspects:

- Coherent SAR data acquisitions for interferometric measurements, requiring similar sensor characteristics and similar sensing mode.
- "Sparse" satellite acquisitions in time to build time series of data and data archives.

This emerging data continuity/availability need based on systematic long-term acquisitions can become a driver for the definition of future SAR and optical missions. For example, if Sentinel-1 is assumed as the reference mission for InSAR data provision in the context of DRR applications, future SAR missions should provide at least one sensing mode that is consistent with the Sentinel-1 InSAR mode. From a general perspective, the acquisition of SAR and optical data should be guaranteed over long periods of time (years) to generate similar product types, which could be used for DRR. Availability of open SAR and optical data (e.g. Copernicus Data Services) could help cover this need, at least partially. Ad-hoc tasking of the acquisitions performed by commercial EO missions (embarking SAR and/or optical payloads) during the emergency response phase could provide additional coverage and response capability.

From a general perspective, **federated satellite systems** emerge as a possible gap-filling solution to guarantee long-term continuity of SAR and optical acquisitions, so as **to build time series of data and data archives** that are paramount **for DRR applications**. The long-term continuity of SAR and optical acquisitions could be guaranteed by launching a tailored version of already-flying satellites, but embarking simpler instruments that cover specifically the spectral bands identified for DRR. These ad-hoc and likely simpler and smaller satellites could fly in a federated system with already in-orbit missions. Synergy of the acquisitions performed by federated satellite missions could also be conducive to **fulfilling revisit time requirements that are not met by existing EO missions**.

From the **application and processing** point of view, what emerged from the gap analysis, for both Flood and Volcano Hazard Cases, is that the main needs for the DRM and DRR domains are not strictly dependent on mission architecture or payload concepts; rather, they should be essentially fulfilled through the development of specific solutions aimed to support two main issues:

- **Efficient management of a large amount of data** from the point of view of downloading, archiving and processing.
- **Easy access and integrated use of** multiple **multi-source data** having different complexity of heterogeneity, depending on data source (e.g. satellite data, social data, GPS data, etc.).

Analysing the trends from different points of view as technological, political and social, in the last years some main trends emerge clearly:

- Technology evolution in terms of **improvement of computational resources**, capabilities of real-time processing of large amount of data, data infrastructures and bandwidth.
- Increasing **availability of large amount of satellite data**, due to the proliferation of satellite constellations planned to guarantee, with a high resolution, a high revisit time (e.g. mini-satellites) and/or the data continuity with past missions (e.g.: Sentinels).
- Increasing **availability of social data**, retrievable through collaborative information systems (citizens are usually very interested in helping other citizens when they could also be potentially affected by the same problem in another time frame or place) and social media indirect monitoring systems.
- Increasing **availability of databases** related to different themes (building, population, hydrology, transportation, aerial orthoimages, etc.), providing information useful for exposure and damage assessment.

This augmented availability of different types of data, supported by the technology evolution in terms of efficient storage and computing capabilities, allows enriching the quality and the timeline of the products related to flood and volcano, but requires **specific developments** that should support efficient data exploitation, depending on the data type. These developments, identified as gap fillers, are based on the main concept of **data collector**, which means a solution having specific capabilities depending on the data of interest (**satellite, social or reference auxiliary data**), able to access, select, download, filter, harmonize and store in a common geo data model, heterogeneous data sources to be immediately ready for use.

For what concerns satellite data for both flood and volcano applications and especially for systematic monitoring scopes as, for example, **an early warning system**, the **satellite data collector** should implement mechanisms for optical and SAR data access (through the implementation of the methods available in the corresponding data source interfaces), data repository and **processing**. This solution requires in parallel **suitable ICT resources** in terms of storage, efficient processing (cloud computing, parallel processing) for the management of a large quantity of data. The same approach should be implemented for an **efficient exploitation of social data,** useful especially in the rapid mapping domain to provide information about the crisis event, integrating those provided by remote sensing, through a mechanism able to **automatically retrieve, target the right data and find out relevant information** from the social networks as Twitter, YouTube, news, etc. In the domain of risk management, and in particular in the DRR domain, it is important to assess the exposure of the territory or to quickly estimate the damages of a crisis event collecting heterogeneous datasets related to population, infrastructure, etc. The **reference auxiliary data collector** follows the same approach as the other data collectors proposed. It should implement mechanisms to **retrieve and harmonize data having different structures and upload them into a master common reference geodatabase**. In addition to data collection needs, a specific requirement related to GPS data processing has been identified for the Volcano Hazard case. It refers to the set-up of a **robust access mechanism of GPS data**, in particular for **post-processing issues**, dedicated to end users, offering pre-compiled solutions, and to expert users, who should be able to deploy their own GPS processors.