

Geoenvironmental Disaster Reduction

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Citizens' Observatories on Geohazards

Lessons from Five Pilots

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AGEO Citizens' Observatory, users' manual: <https://ageo-manual.web.app/>



AGEO Mobile app (iOS)



AGEO Mobile app (android)










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Copernicus Services and Geohazards Management. Lessons Learnt from Citizens' Observatories

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4.1 Introduction

Copernicus is the Earth Observation programme,¹ of the European Union (EU). It is aimed at developing European information services based on satellite Earth Observation and in situ data collection (Jutz & Milagro-Pérez, 2018). The

objectives of this programme are: (i) to monitor and forecast the state of the environment on land, sea and in the atmosphere; (ii) to support climate change mitigation and adaptation strategies, (iii) to increase the efficient management of emergencies and (iv) to improve the security of every citizen. By providing information on natural disasters, such as forest fires or floods, Copernicus helps to

¹ <https://www.copernicus.eu/en/about-copernicus/copernicus-detail> (accessed 06/02/2023).

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prevent the loss of lives, property, and damage to the environment.²

The Copernicus program is led by the European Commission (EC), acting on behalf of the EU, and is in charge also of the users' requirements and of the implementation of the services component. The European Space Agency (ESA) is responsible for the technical

²Copernicus Emergency Management Service. <https://emergency.copernicus.eu/> (accessed 06/02/2023).

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coordination of the space-based component, which comprises two types of satellite missions: the dedicated Sentinel missions, developed by ESA specifically to meet the Earth observation needs of Copernicus users, and the Contributing Missions, several existing and planned Earth observation satellites that are operated by other space agencies or organizations which provide some data to the program. Both the Sentinel and the Contributing Missions ensure the long-term availability of critical observations for operational and scientific applications. The Sentinel satellites carry a range of technologies, such as radar and multispectral imaging instruments, to cover all environmental domains (Jutz & Milagro-Pérez, 2018).

Vast amounts of global data from satellites and from ground-based, airborne and seaborne measurement systems are being used to provide information to help service providers, public authorities and other international organisations to improve the quality of life for the citizens of Europe and beyond. Most of the information delivered by Copernicus is made available and accessible to any citizen and to any organisation around the world on a free, full, and open basis.

Copernicus provides essential information for six thematic domains in the form of the following services:

-Copernicus Marine Environment Monitoring Service (CMEMS)—provides regular and systematic reference information on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems. The observations and forecasts support all marine applications, including marine safety (oil-spill detection and transport), coastal and marine environment applications, water quality, weather forecasting and climate.

-Copernicus Land Monitoring Service (CLMS)—relevant to the land environment, includes monitoring for water management, agriculture and food security, land-use change, forest monitoring, soil quality, urban planning and natural protection services. A European Ground Motion Service product portfolio was released in 2022. This new service measures ground

displacements, including landslides and subsidence, as well as deformation of infrastructure.

-Copernicus Atmosphere Monitoring Service (CAMS)—provides continuous data and information on atmospheric composition, including monitoring for air quality and ultraviolet radiation forecasts, greenhouse gases and climate forcing.

-Copernicus Emergency Management Service (EMS)—provides all actors involved in the management of natural disasters (floods, forests fires, volcanoes, earthquakes, etc.), of human made emergency situations, or of humanitarian crisis with timely and accurate geo-spatial information derived from satellite remote sensing. The remotely sensed data are complemented by available in situ or open data sources.

-Copernicus Service for Security (CSS)—provides information in response to Europe's security challenges. It improves crisis prevention, preparedness and response in three key areas: border surveillance; maritime surveillance and support to EU External Actions.

-Copernicus Climate Change Service (C3S)—supports society by providing authoritative information about the past, present and future climate in Europe and the rest of the World. C3C cross-cuts all of the above domains.

With the AGEO Project focused on the assessment and management of geohazards, particular attention was paid to Copernicus EMS, as it supports all phases of the emergency management cycle: preparedness, prevention, disaster risk reduction, emergency response and recovery. The Copernicus EMS has been operational since 2012. It is composed of two main components: (i) on-demand mapping and (ii) early warning and monitoring. The on-demand mapping component is the EMS Mapping Service.³ This provides a “Rapid Mapping” option for emergency response and a “Risk and Recovery Mapping” option for disaster prevention and

planning. The early warning and monitoring component comprises three elements currently: the European Flood Awareness System (EFAS), the European Forest Fire Information System (EFFIS) and European Drought Observatory (EDO).⁴

The EMS Rapid Mapping (EMSR) option provides geo-spatial information within hours or days from its activation in support of emergency management activities immediately following a disaster. Local authorities can demand activations of the service through their Copernicus national contact point, i.e. the authorised service user (QSG, 2015) while emergencies are occurring. This activation will allow access to several products such as: (i) pre-event maps (reference maps), (ii) affected areas' identification and assessment (first estimate product), (iii) event impact and affected geographical extent (delineation products), and (iv) damage intensity assessment (grading products). The workflow, guidelines and products portfolio are available in QSG (2015), Dorati et al. (2018), MOP (2018) and Joubert-Boitat et al. (2020).

The EMS Risk and Recovery Mapping (EMSN) option consists of the on-demand provision of geospatial information in support of disaster management activities not related to immediate response, i.e. in a non-rush mode. This applies to activities dealing with prevention, preparedness, disaster risk reduction and post-event recovery phases. The EMSN can also be demanded by local authorities in a similar procedure to that for the Rapid Mapping. Tailored studies can be undertaken, compatible with a different timescale, as well as predefined set of standardised products.⁵ Thus, Copernicus EMS enables monitoring of geological hazards and provides tools to prepare for emergency response. The mapping services intended to homogenize and centralize the collection of

³ https://www.copernicus.eu/sites/default/files/documents/Copernicus_EmergencyMonitoring_Feb2017_0.pdf (accessed on 20 February 2023).

⁴ <https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000><https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000> (accessed on 20 February 2023).

⁵ <https://emergency.copernicus.eu/mapping/ems/risk-and-recovery-mapping-portfolio> (accessed 02 March 2023).

data with a set of indicators such as date, location, type and damage, providing factsheets as part of the service. In this sense, the analysis of Copernicus products and services highlights the importance of the necessary cooperation among civil protection, public authorities and private companies when emergency plans are developed, as key players giving suggestions and recommendations to spread awareness of these natural disasters.

The timeframe of the AGEO project has allowed us to review the Copernicus products and to promote their use by the various citizen observatories that have been established in the project. Not only has the use of the Copernicus program been disseminated, but it has also been actively used in the AGEO pilots through activations of the Copernicus EMS service and through the use of satellite images for hazard assessment or for estimating ground deformations.

Ground movements such as subsidence, uplift or landslides can be detected through radar image processing techniques, such as Interferometry of Synthetic Aperture Radar (InSAR) (Hansen, 2001; Hooper, 2008; Barra et al., 2017). Since Sentinel-1 provides free data access and achieves short revisit times (6–12 days), its images have been widely used for hazard monitoring and assessment related to landslides (Auflič et al., 2023; Reyes-Carmona et al., 2020), subsidence impacts (Hussain et al., 2022; Nduji et al., 2023) or geotechnical issues (Scoular et al., 2019). In addition, optical and multispectral data available from Sentinel-2 also highly contribute to hazard monitoring (Caballero et al., 2019).

Thus, within the AGEO project, both radar (Sentinel-1) and optical images (Sentinel-2) were processed. The former was used to estimate the deformation of some pilot areas with mass movements hazard, subsidence, uplift, or geotechnical problems (see Chap. 6). In the case of mass movements, radar images not only were used for the detection of slow movements, but also to validate the method with faster movements. Furthermore, Sentinel-1 has also been processed to attempt to map the extent of flooding for two different events.

Several Sentinel-2 images were processed to gain better knowledge of the pilot areas. The data were used to create several false-colour band combination maps that highlighted different aspects of the pilot areas, such as vegetation, built-up areas, water features, etc. Moreover, multivariate data analysis with algorithms such as Principal Component Analysis (PCA) and minimum noise fraction (MNF) were used for visualisation.

In addition, a step forward in risk assessment was taken with the characterisation of the elements at risk obtained for each AGEO pilot, the results of which may have important implications for geohazard management and emergency planning (Papathoma-Köhle et al., 2007).

In this chapter the uptake of the Copernicus EMS is reviewed for the AGEO partner countries in the EU Atlantic Region from 2012–2022. Surveys undertaken during the AGEO project highlighting the perception and awareness of stakeholders, as well as their suggestions for improvements or new requirements, are summarised. Uptake of Copernicus and Earth Observation (EO) products in the frame of the citizen observatories on geohazards is also addressed. Finally, strategic recommendations for strengthening the use of Copernicus products and services, and for new Copernicus products for the Atlantic Region, are given.

4.2 Status Review on the Use of Copernicus Products and Services in the Atlantic Region

The Atlantic region is exposed to a range of low-probability/high-impact events and to various hazard/risk scenarios. Due to the low likelihood of occurrence and/or the high cost of mitigating action, many parts of the Atlantic region may lack the level of preparedness for effective monitoring and response. Copernicus aims to make useful products, services and tools available to the public and to managers dealing with natural hazards, with the aim of improving the management of natural hazard emergencies.

Table 4.1 Summary of the overall responses from the stakeholders' survey

Question to the stakeholders	Possible answers	France	Ireland	Portugal	Spain	UK
User interface interpretation	Easy		x	x	x	
	Difficult	x				x
Preferences regarding Copernicus EMS information products	Download of Copernicus data and further processing of the data to produce other value-added products			x	x	x
	Display/share/redistribute the Copernicus service information products without any modification	x	x			
	Further process of the Copernicus service information to produce other value-added products		x			
Preferred way to get Copernicus EMS information from the Web Portal	Automated mode			x	x	x
	Manual mode	x	x			

One aim of the AGEO project was to assess the knowledge that end-users have about Copernicus products and services and about the extent of the use of those products and services. Additionally, the project aimed to identify potential user needs and to elicit suggestions for improvement of Copernicus services.

Thus, questionnaires were designed within the AGEO project to check the level of engagement and satisfaction with service providers, training, data access and the user interface. A total of 128 stakeholders responses, gathered in 2020, revealed that although most of the stakeholders used satellite data, they did not use Copernicus services. An exception is the case of Portugal, where half of the participants used Copernicus services and demonstrated a medium to high knowledge about Copernicus and EO systems. However, a common point among the whole group of survey participants, except in Portugal, is that most of them did not acquire any training on the use of data from the Copernicus Programme. In Portugal, half of the stakeholders surveyed did not acquire specific training.

Table 4.1 summarizes the overall responses from the stakeholders' survey. Globally, stakeholders' feedback let us know about data they

demand, interaction quality with Copernicus services, involvement degree, tools usefulness, users' interests, needs and difficulties, so it contributes relevant information about the efficiency of the service. In France, Ireland and Spain, just a small number of participants had requested data from Copernicus services; however, in UK and Portugal most of the stakeholders' organizations did already request Copernicus data. Those who have done, requested data mainly related to risk prevention, emergency responses and geological risk research. Research projects (in UK and Portugal) and unspecified reasons (in France and Spain) are the main motivations that led the users to request Copernicus data. Most of the stakeholders are not involved in the development or implementation of any tool in the Copernicus Emergency Management Service. The Web Portal was the preferred means of display for Copernicus EMS information. All the participants agree with the purpose to use Copernicus EMS products: risk management. Table 4.1 summarizes the overall responses from the stakeholders' survey.

Stakeholders' organizations in Portugal and UK had already downloaded data from Copernicus EMS, but in any of the participating regions it is not clear the reason that gave rise to

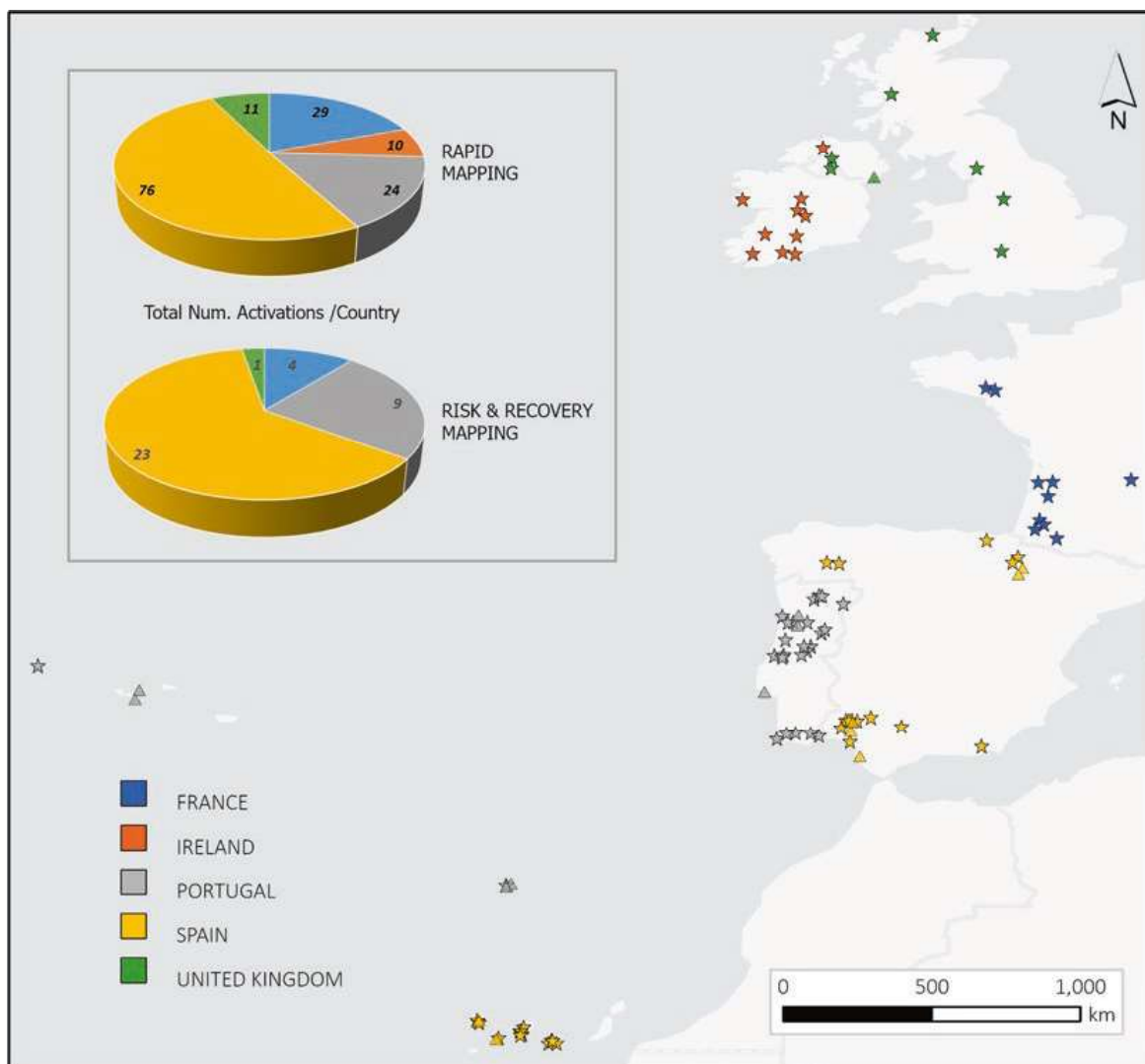


Fig. 4.1 Map of Copernicus EMS activations in the Atlantic Area from 2012 to 2022. Stars correspond to EMS Rapid Mapping activations; Triangles correspond to EMS Risk and Recovery activations. Pie charts present the total number of activations in the participating countries. Notice that not all the activations in

France, Portugal, Spain and United Kingdom, are in the EU Atlantic area. (Data compilation from <https://emergency.copernicus.eu/mapping/list-of-activations-rapid#> accessed 02 March 2023 and from <https://emergency.copernicus.eu/mapping/list-of-activations-risk-and-recovery> accessed 02 March 2023)

the impediments to downloading information. It is in general thought that the information provided by Copernicus EMS is useful for an emergency planning and response and that the experiences with Copernicus are considered useful.

Complementarily, to assess the use of Copernicus services and products in the Atlantic Area, we reviewed the Copernicus EMS activations for the last 10 years (2012–2022) for the EU Atlantic region, while paying attention either to the EMS Rapid Mapping or to the Risk

and Recovery Mapping Activations.⁶ Results are shown in Figs. 4.1 and 4.2 respectively.

The review of the Copernicus EMS activations in the participating EU Atlantic Area countries, revealed that 150 EMSR activations and

⁶ <https://emergency.copernicus.eu/mapping/list-of-activations-rapid>; <https://emergency.copernicus.eu/mapping/list-of-activations-risk-and-recovery> accessed on 20 February 2023.

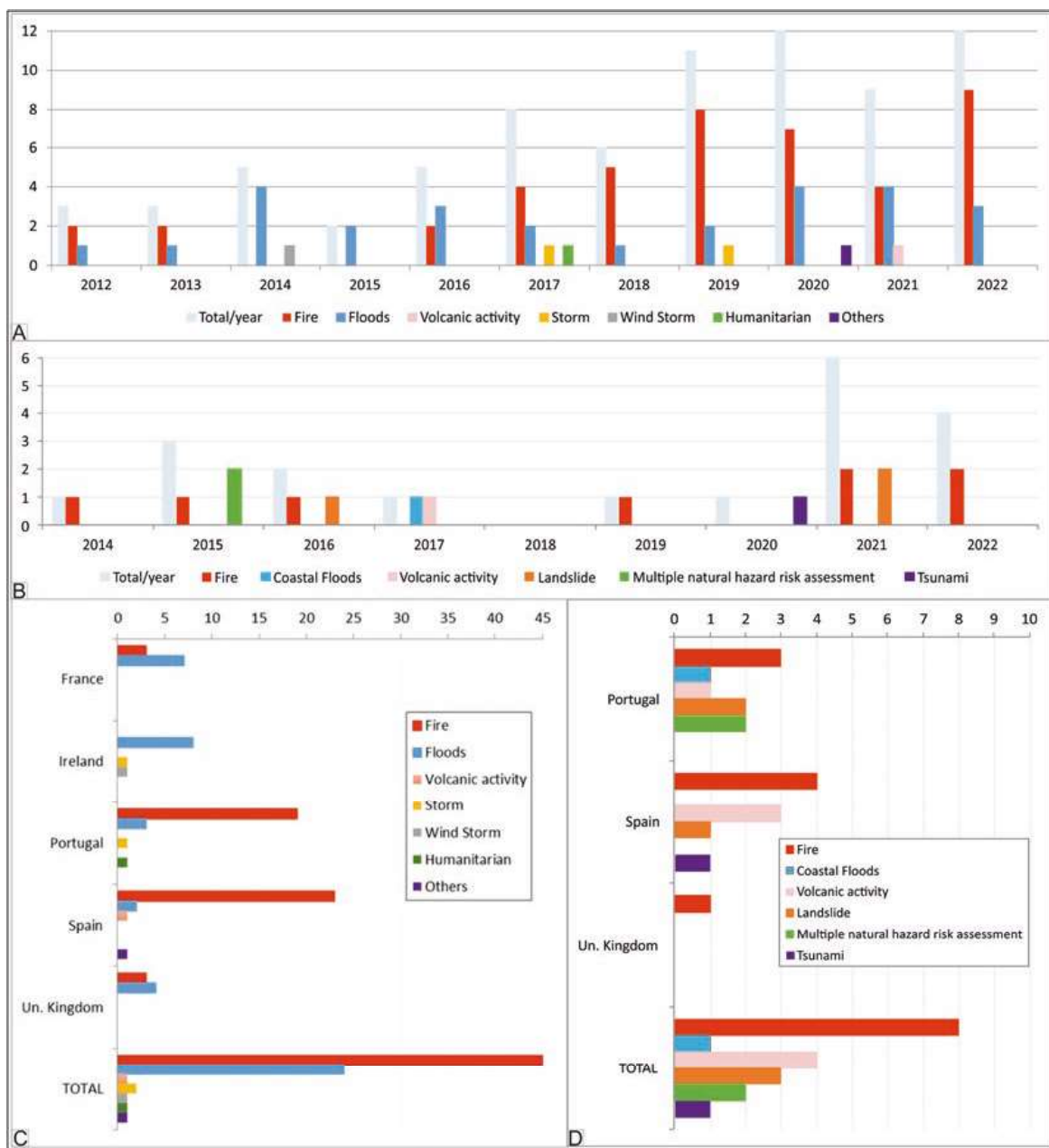


Fig. 4.2 Copernicus Emergency Management Service activations in the Atlantic area from 2012 to 2022: **a**, **c** Rapid Mapping (EMSR). Data compilation from <https://emergency.copernicus.eu/mapping/list-of-activations-rapid#> accessed 02 March 2023). **b**, **d** Risk and Recovery Mapping (EMSN). Data compilation from <https://emergency.copernicus.eu/mapping/list-of-activations-risk-and-recovery> accessed 02 March 2023).

copernicus.eu/mapping/list-of-activations-risk-and-recovery accessed 02 March 2023). **a** and **b** represent number of activations along time differentiated by type of hazard. **c** and **d** represent number of activations differentiated by type of hazard and by country

37 EMSN activations, were implemented from 2012 to 2022, being that 78 (EMSR) and 19 (EMSN) correspond strictly to EU Atlantic Area (Figs. 4.1 and 4.2). Rapid Mapping activations have thus far greatly outnumbered Risk and Recovery Mapping activations (ratio of

4:1). Floods or fires accounted for 91% of the Rapid Mapping activations in the EU Atlantic Area. The rest of the activation types were storms, windstorms, and other anthropogenic or biogenic hazards. Portugal and Spain were the countries with highest number of rapid

activations (75%). The total number of activations has increased through the years, revealing the growing participation and engagement of the countries (Fig. 2a, b). This fact gives Copernicus EMS Programme significance and demonstrates its usefulness as a risk management tool. For the activations of Copernicus EMS in the Atlantic Area in the timeframe 2012–2022 (Fig. 4.1 and 4.2), a few details per country are given below. Details and in-depth analysis can be found in the technical reports and geodatabases of all these activations available on the EMS website.⁷

4.2.1 France

The EMSR was activated 29 times in the country and 10 times in the EU Atlantic area between 2012 and 2022 (Figs. 4.1 and 4.2). Most of these Atlantic area activations concerned floods (70%) and wildfires (30%). The Risk and Recovery Mapping (EMSN) mode was only activated 4 times in the country, but none of them were in the Atlantic area. The activations of the Copernicus EMS in the Atlantic area resulted in 89 products: 4 ‘First Estimate’, 7 ‘Reference’, 71 ‘Delineation’ and 7 ‘Grading’ products. The number of activations has increased in the last years, namely 2021 and 2022. For France, the authority empowered to activate the Copernicus EMS is the *Centre Opérationnel de Gestion Interministérielle des Crises* (COGIC).

4.2.2 Ireland

There have been 10 activations of the Copernicus EMS for Ireland to end-2022. All activations were for the EMSR mode of Copernicus EMS. It appears that the EMSN mode of Copernicus EMS, has yet to be

activated for Ireland. All of the past activations of Copernicus EMS for Ireland are associated to meteorological hazards, principally storms and floods. Activations have been made at a rate of one or two per year in the years 2014–2022, except for 2018–2019, when no activations were made. Geographically, the activations relate predominantly to emergencies or impacts in the Northern, Western and Southern parts of Ireland (Fig. 4.1). This reflects the facts that the average precipitation and wind speeds in Ireland are stronger along the island’s western seaboard and diminish eastward, and that low-pressure weather systems and storms from the Atlantic Ocean typically migrate eastward and across Ireland. Overall, the Copernicus EMS in rapid mapping mode has so far delivered a total of 184 mapping products related to activation in Ireland. Of the four rapid mapping products that can be supplied by the Copernicus EMS Rapid mapping mode, by far the most delivered for Ireland has been the ‘Delineation’ product, which comprises 172 of the total. In addition, 8 ‘Reference’ and 4 ‘Grading’ products have been supplied for three of the events in Ireland. No ‘First Estimate’ products have been supplied. The National Directorate for Fire and Emergency Management (NDFEM) acts as the national focal point for the Copernicus EMS in Ireland.

4.2.3 Portugal

The EMSR was activated 24 times, with most (79%) of the activations concerning wildfire/forest fire, followed by floods (13%), with one humanitarian and one storm events. The EMSN was activated nine times and in this type of activation fires are more balanced with respect to geological hazards. The geological hazards result from internal or external geodynamic processes, such as volcanic hazard, seismic, mass movement, coastal flood risk or multiple natural risk assessment, i.e. seismic, lava flow, tsunami and storm surge, landslide, coastal erosion, flood, etc., as demanded by the Autonomous Regions of Azores and Madeira for risk assessment

⁷ <https://emergency.copernicus.eu/mapping/ems/risk-and-recovery-mapping-portfolio> (accessed 02 March 2023).

products for planning and recovery. The latter led to the production of maps of exposure, vulnerability and risk for the various hazards under analysis. For the multiple natural hazard and risk assessments in both archipelagos of Madeira and Azores, 2285 maps were produced.

Hazards of *s.s.* geological origin only correspond to 5 EMSN activations (018, 020, 034, partially 031, and 129), and exceptionally floods, as mixed natural hazard, in EMSR activation 072. The *Autoridade Nacional de Emergência e Proteção Civil* is the national focal point for Copernicus EMS in Portugal.

4.2.4 Spain

There were 33 EMS activations in the Spanish Atlantic area (27 EMSR and 9 EMSN). Collectively, 86% of these activations related to wildfire hazards. Activations were mainly requested in the Andalusia region, with a few in the Canary archipelago the Basque Country and the Navarre region. 85% of EMSR activations were concerning fire hazard. The rest are related to floods, volcanic activity and a collapse of a dumping site. The climatic characteristics of this country, with dry and arid regions, create the ideal conditions for wildfire occurrence. Seasonal heavy rains are also frequent in some regions, especially in Mediterranean areas, where flood events normally occur. For the EMSN service, on its own, activations are related to fire hazard (45%), volcanic activity (33%) and rock-fall hazard (11%). The vast majority of products generated are delineation and grading products. Both are derived from images acquired as soon as possible after the emergency event. These products are very interesting and useful for emergency managers, because updates to the maps can be supplied, so that the evolution of the event can be monitored. Even with a high number of activations if compared with other countries, Copernicus services are not used by the majority of stakeholders as it would be desirable. However, Copernicus EMS has been activated every year from 2012 to 2022, and an increase in the number of activations is observed through time, which

means that the service is progressively being integrated in the national hazard management systems. The Ministry of Interior—*Centro de Coordinación Operativa (CECOP)*—*Dirección General de Protección Civil y Emergencias* is the national focal point for Copernicus EMS in Spain.

4.2.5 United Kingdom

United Kingdom authorities activated Copernicus EMSR 11 times from 2012 to 2022, and 7 of them were in the Atlantic area. 57% were related to floods and 43% related to fires. From 2012 to 2018, EMSR was activated nearly every year in the UK Atlantic area (except for 2014). In 2021, the EMSN was activated due to wildfire emergency for the first and only time to date. The activations generated a total of 81 products. 25 of them were ‘Reference’ products, 51 were ‘delineation’ products, and 5 were ‘grading’ products. The United Kingdom Cabinet Office—Civil Contingencies Secretariat and the EU Intelligence Analysis Centre were the authorised users in United Kingdom.

4.3 Copernicus Services in the Frame of Geohazards Citizens’ Observatories

Citizens’ observatories on geohazards in the AGEO project encouraged the local use of innovative EO products and services provided by European data infrastructures, in particular Copernicus. Valuable information can be obtained for different geohazards (Table 4.2), to complement data from citizens and stakeholders and to contribute to the hazard assessment in each observatory. In addition, its use serves to promote and disseminate the possibilities it offers for any organisation involved in geohazard management.

Thus, considering the risk assessment process (Table 4.2): (i) during the pre-event phase, Copernicus can contribute with a general characterization and, in some cases, with early warning systems through the weather

Table 4.2 Attributes derived from Copernicus products and services*, for each stage of emergency management and risk analysis stage for each specific geohazard

Geohazard	Pre-event stage	During-event stage	Post-event stage
Floods	Precipitation, vegetation, weather forecast, EFAS, digital elevation model (slope), elements throughout the sensitivity area, sea level, waves	Affected areas, elements for crisis management	Affected areas map with different levels of characterization, maps
Rockfalls	Precipitation, vegetation, new constructions (update landcover), fires burning (loss vegetation, temperature), land use, geomorphology, digital elevation model, deformation, settlements, landscape dynamics monitoring in coastal zones, soil moisture index, exposed elements	Precipitation	Affected area map
Coastal erosion	Exposed elements, settlements, landscape dynamics monitoring in coastal zones, Digital Elevation Model, water and wetness, land cover, riparian zones	Wave height, wind, sea level	Affected area map
Earthquakes	Area prone to deformation, tectonic plate movement	Tectonic plate movement, wave height, sea-level, affected areas, elements for crisis management, deformation	Affected area map (access for rescue teams)
Landslides	Area prone to movement or instability, precipitation, vegetation cover, weather forecast, new construction, land use, geomorphology, digital elevation model, settlements, soil moisture index, exposed elements	Precipitation, deformation, affected areas, revised digital elevation models elements for crisis management	Affected area map
Volcanic eruptions	Area prone to deformation, satellite images, digital elevation model, temperature, gas emissions, exposed elements	Deformation, wind, temperature, emissions, affected areas, elements for crisis management	Affected area map
Geotechnical risks	Area prone to deformation, tectonic plate movement, satellite images, precipitation, vegetation cover, weather forecast, new construction	Precipitation, deformation, affected areas, elements for crisis management	Affected area map

* Copernicus (Marine Environment Monitoring Service-CMEMS, Land Monitoring Service-CLMS, Atmosphere Monitoring Service-CAMS, Emergency Management Service-EMS, service for Security, Climate Change Service-C3S)

forecast or ocean condition; (ii) in the during-event phase, affected areas might be identified with Copernicus data and also the elements for crisis management, and variables to consider to manage the emergency; (iii) during the post-event phase, Copernicus again may provide the users with the affected areas map with different levels of characterization.

4.3.1 Copernicus Emergency Management Service Activations in AGEO

Activations of Copernicus EMS were requested by some of the pilots in the frame of AGEO project, thus involving the citizens' observatories directly in the use of Copernicus products. The Canary Islands and Madeira citizens' observatories requested the activation of the service, each for their specific purposes.

Canary Islands Observatory (Spain)

Two activations of Copernicus EMS were requested in the frame of AGEO project in the Citizens' Observatory on Rockfalls in the Canary Islands. The Spanish General Directorate of Civil Protection and Emergencies (CENEM), on behalf of the Geological and Mining Institute of Spain (IGME-CSIC), activated the service.

- *Activation EMSN093 La Gomera.* An important rockfall occur on 14th November 2020 in a cliff at SW coast of La Gomera. The objective of this EMS activation within the Canary Islands Pilot was to contribute to the Copernicus products usage at local level and it was intended to demonstrate that Copernicus data could be used to study small-medium sized rockfalls.

Thus, the Risk & Recovery Flex Mapping Service was activated, and the following products were requested⁸:

- PR1. Reference data;
- PR2. Pre-event digital elevation model (DEM);
- PR3. Post-event DEM;
- PR4. Delineation of source and deposit area extent;
- PR5. Estimation of the volume of mass moved;
- PR6. Assessment of rockfall/avalanche hazard in area of interest (Fig. 4.3);
- PR7. Exposure of services and population to rockfall/avalanche hazards;
- PR8. Rockfall/avalanche risk assessment;
- PR9. Ground deformation analysis.

Every product includes topographical elements (place names and administrative boundaries, hydrology, physiography), population (based on recent and/or alternative census data), settlements (urban, suburban, rural, etc.) with buildings, road network and other related transport networks, location of hospitals, schools, local services, food and distribution infrastructure, location and type of industry or potential industrial accident sites, and finally, land use coverages.

Since the result constitutes a tailor-made product, numerous exchanges of information were needed to approach the question in the most effective way. The time length taken to produce the whole new dataset lasted from Feb 21 to Oct 21. Volume estimation of the mass movement was not satisfactory due to difficulties with the pre-event DEM. However, from a combination of Sentinel-1 images interesting results were achieved from deformation analysis by applying Differential Interferometry and Multi-Temporal interferometry. Several local displacements were identified. In particular, at the cliff where the November 2020 rockfall event occurred, the time series revealed that acceleration had started several months before the fall occurred (CEMS, 2021). Therefore, it highlights the enormous potential of this tool for monitoring potentially hazardous slopes.

- *Activations EMSN112/I24, EMSR546 and EMSN119.* Due to the volcanic emergency on La Palma on 19 September 2021, Copernicus EMS was activated in its different modalities:

⁸ https://emergency.copernicus.eu/mapping/ems-product-component/EMSN093_01GOMERA_ROCKFAZ_OVERVIEWA1/2 (accessed 25th February 2023).

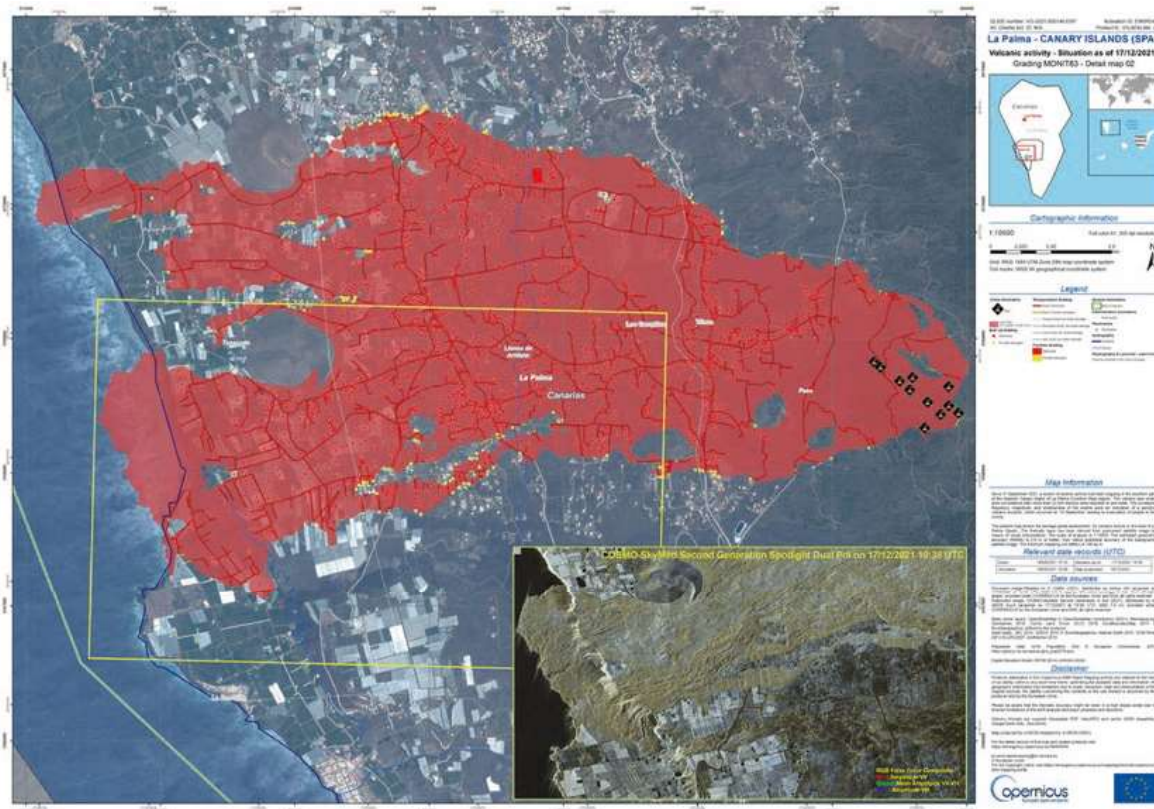


Fig. 4.4 Volcanic activity in La Palma Island. Map of situation as of 17/12/2021; grading product from Copernicus EMSR546 Activation. [<https://emergency.copernicus.eu/mapping/list-of-components/EMSR546>].

Copernicus Emergency Management Service (© 2021 European Union), EMSR546

- Rapid Mapping, obtaining the following products: delimitation of the extent of the lava flows, estimation of affected buildings and services (Fig. 4.4).
- Risk and Recovery Standard Mapping, obtaining the following products: ground deformation monitoring, mass movement risk map (pre- and post-eruption) and soil erosion risk map (pre- and post-eruption);
- Risk and Recovery Flex Mapping, obtaining the following products: DEM of the cone and lava flows, changes in ground elevation, volume of lava flows, discharge rate: DEM of the cone and lavas, changes in ground elevation, volume of lavas, discharge rate.

The products received provided valuable information during the emergency and were very useful for many national and international institutions. Specifically, the IGME-CSIC working group that collaborated during the emergency

used the Copernicus data to: (i) complement the topographic data obtained by the Island Government in La Palma, Emergency and Rescue Group of Canary Government (GES) and IGME-CSIC's Aerial Works Service (STA) during the emergency and obtain a more detailed mapping of the advance of the lava flows; (ii) analyse ground deformation; (iii) analyse and understand morphological changes in the volcanic cone; (iv) detect changes in the lava flows; (v) analyse mass movements associated with seismic activity.

Madeira Observatory (Portugal)

- Activation EMSN089.* On 25th December 2020 and 7th January 2021, a storm brought strong winds and heavy rain to Madeira Island. Flooding and landslides occurred in the municipality of São Vicente, 20 people were evacuated in Ponta Delgada and 7 in Boaventura.

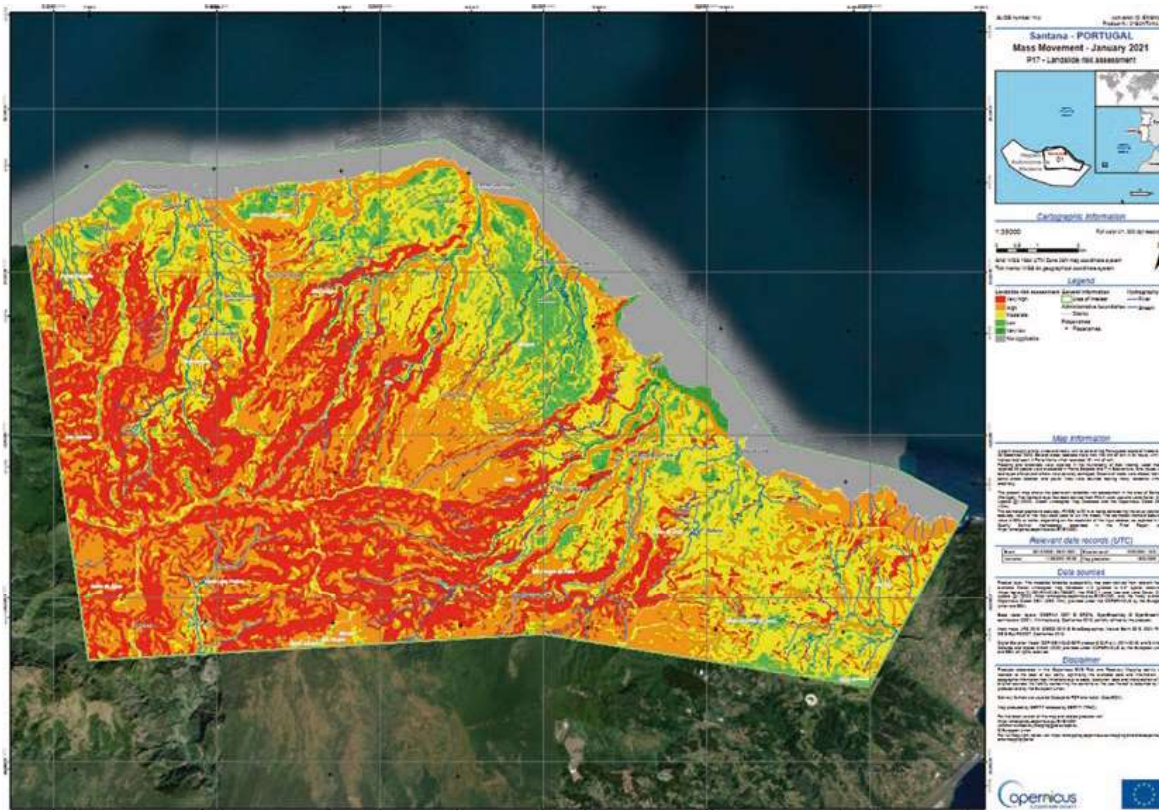


Fig. 4.5 Post-disaster landslide susceptibility assessment map in São Vicente region (Madeira, Portugal). Map of situation as of 17/12/2021; product from Copernicus EMSN089 Activation. [<https://emergency.copernicus.eu/mapping/list-of-components/EMSN089>]

accessed 02 March 2023. Copernicus Emergency Management Service (© 2021 European Union), EMSN089

One house was destroyed, and several others were severely damaged. Dozens of roads were closed, leaving some areas isolated, and power lines were downed, leaving many residents without electricity. Several areas recorded more than 100 mm of rain in 24 h on 25 December 2020, with the highest total seen in Porto Moniz, which recorded 161 mm of rain.

A request for activation of the RRM (Risk and Recovery Mapping) service was made.⁹ The goal of the activation was to get a more accurate picture of the mass movements induced by the heavy rainfall that occurred over the period ranging from 25/12/2020 to 08/01/2021. The products generated within this activation were:

- P01.1 Digital Surface Model (DSM) that required a new VHR tri-stereo acquisition, and hence was part of a separate delivery.
- P02.1a Reference dataset was provided over AOI01 Santana.
- P03.2 Land Use and Land Cover dataset, which was required as an input for landslide risk assessment.
- P08.1 Detailed damage assessment analyses over affected areas based on VHR imagery acquired on the 10/02/2021.
- P09 Reconstruction monitoring was provided for AOI01 Santana based on new VHR imagery acquired.
- P17 Post-disaster landslide risk assessment was provided (Fig. 4.5).
- 2 × P14 Impact assessment/exposure analyses on assets and population is provided based on both P08.1 (impact assessment) and P17 (exposure).

⁹<https://emergency.copernicus.eu/mapping/list-of-components/EMSN089><https://emergency.copernicus.eu/mapping/list-of-components/EMSN089> (accessed 02 March 2023).

4.3.2 Other Uses of Copernicus Services and Products for Geohazards

Undoubtedly, Copernicus EMS represents an extremely valuable service in the management of geohazards, as depicted in previous sections. However, interesting data are also provided from this platform through other services such as the European Ground Motion service (EGMS)¹⁰ (EGMS, 2017), launched in 2022, as part of the Copernicus Land Monitoring Service (CLMS).

The EGMS provides products oriented to analyze hazards related to ground deformation such as landslides, subsidence, volcanic unrest, on local, regional and national scales, through use of InSAR processing techniques on Sentinel-1 images. Three types of products are offered: basic, calibrated and ortho. The Basic products provide points with the average displacement velocity referred to a local reference point. Calibrated products give same information, but they are absolute, referenced to the European GNSS positioning framework. Ortho products provide purely vertical and purely horizontal motions through the combination of different satellite view angles. Basic and Calibrated products are provided in the satellite line of sight. Moreover, 50 × 50 km gridded velocity model is also available (European Union, 2022).

Complementing these products, in the framework of the AGEO project, one of the consortium partners, University College of Dublin (UCD), developed an InSAR processing toolkit – EZ-InSAR – to cover the specific needs of some pilot areas of the citizen’ observatories on geohazards created in the framework of the project (Hrysiewicz et al., 2023). Details about the EZ-InSAR tool can be found in Chap. 6.

Moreover, activities and actions were organized by the partners of AGEO project in order to promote knowledge and use of Copernicus,

to contribute to a better use of Copernicus products, to increase the use of the available services, and subsequently to help also to identify possible bottlenecks in the use of the programme. Each of the pilot observatories implemented the use of EO products as explained below.

Canary Islands Observatory (Spain)

The characterisation of the pilot areas, in terms of stability, was essential for further studies in the framework of the Citizen’s Observatory on Rockfalls in the Canary Islands. In addition to the Copernicus EMS activations mentioned in section before (La Gomera and La Palma), the identification of instabilities from Sentinel images and LIDAR data was carried out for the regions of San Bartolomé de Tirajana (Gran Canaria), La Laguna (Tenerife) and Valle Gran Rey (La Gomera) (see Chap. 9). Source areas mapping, susceptibility maps (considering slope, lithology, land use, precipitation and proximity to public works), and deformation analyses were obtained (Fig. 4.6).

Results were satisfactory for the identification of ground movements with LIDAR, because it detects variations in ground height quite well. However, results for identification of rockfalls with radar data were not very promising due to several factors involved in the final results: inadequate scale, velocity of the process, displacement orientation. Some details are presented in Chap. 9.

Madeira Observatory (Portugal)

The Citizens’ Observatory in Madeira, focused in landslides and rockfalls, selected some areas of interest to evaluate the feasibility of using InSAR for monitoring slow mass movements. The main findings from the InSAR observations on the creep movements in talus deposits that take place in the municipality of Machico (Madeira), are explained below.

The identified point targets are mainly concentrated in the Machico valley and Ponta de S. Lourenço (eastern part of the Madeira island). Few PS (Persistent Scatterers) targets were identified at the mountainous region, where the topography is steep and the vegetation coverage

¹⁰ <https://land.copernicus.eu/pan-european/european-ground-motion-service> (accessed 1st March 2023).

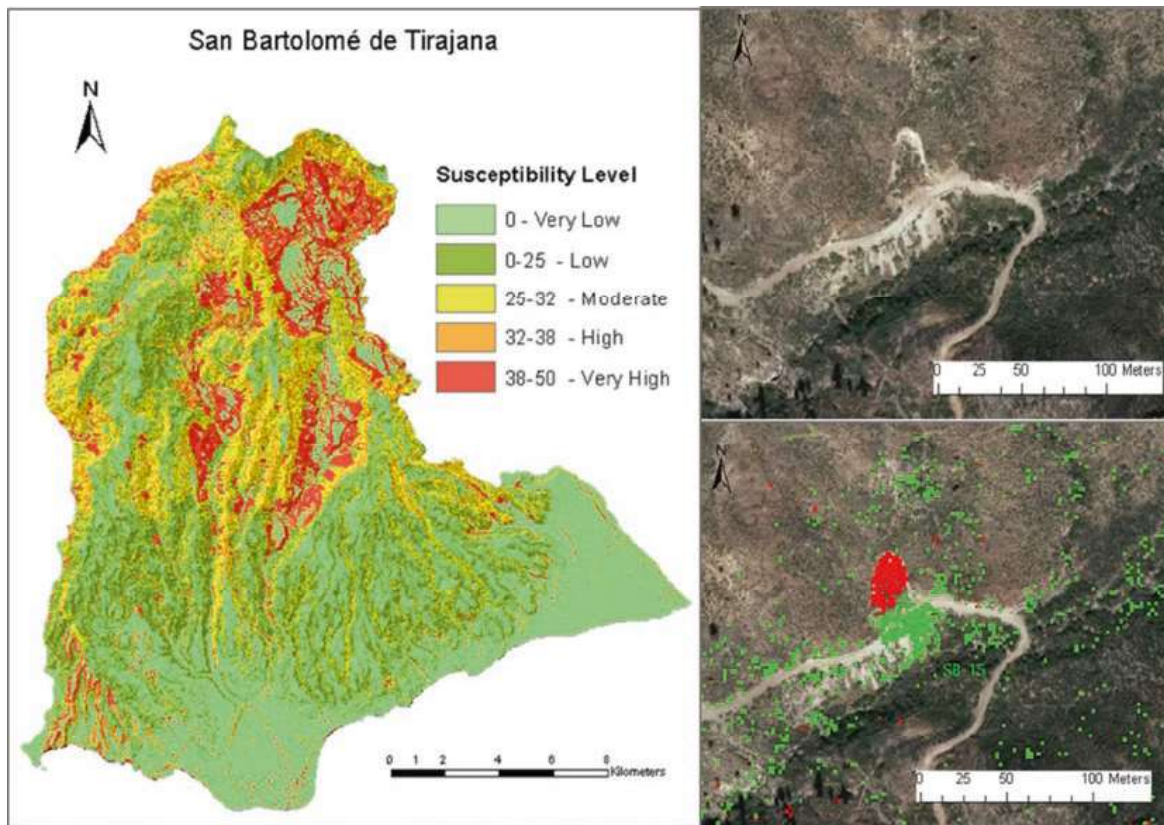


Fig. 4.6 (Left) Rockfalls susceptibility map for San Bartolomé de Tirajana municipality in Gran Canaria. (Right) Instabilities identification with LIDAR data in San Bartolomé de Tirajana municipality

is dense. At the Machico valley, the movements on the east side of the valley are overall more active than those on the west side. The maximum slope-parallel movement velocity reached is about 7 mm/yr over the three identified slope units. Compared to the landslide susceptibility map released by Rodrigues and Ayala (1994), our InSAR measurements confirmed some of the unstable slopes (creep movements) at the Machico valley. However, some small ones were not identified, likely due to the moderate resolution of Sentinel-1 SAR images and the low displacement of these movements.

At Ponta de S. Lourenço with a different geological setting than in the Machico valley the observed displacements are well correlated with active erosion process in some areas or the presence of loose sediments (eolian sands).

Moreover, interesting use of Sentinel Playground was carried out for educational purposes in the frame of the Observatory.

Lisbon Observatory (Portugal)

The Citizens' Observatory in the city of Lisbon is a pilot project focusing on seismic risks, urban flooding, landslides and geotechnical risks.

A spatial database of relevant information from Copernicus products was created to improve the characterisation and information about the pilot site. Various information themes from the Copernicus Land Portfolio were used, such as urban atlas, land cover and land cover changes, impervious surfaces, building heights, etc., ranging from very high (Hot Spot) to medium/low resolution, resulting in the creation of several maps.

Several Sentinel-2 images were acquired and processed to gain better knowledge of the pilot area. The data was used to create several false colour combination maps highlighting different aspects of the pilot area, such as vegetation, built-up area, water features, etc. Multivariate

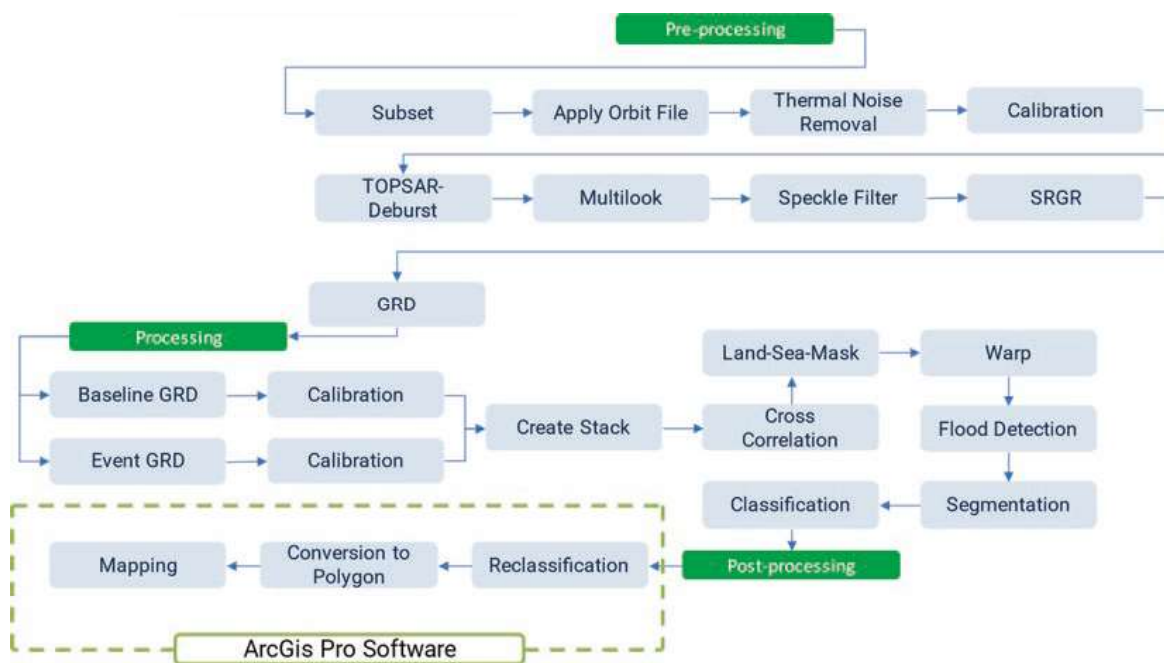


Fig. 4.7 Methodology used to process Sentinel-1 data in order to map flood extent

data analysis such as Principal Component Analysis (PCA) and Minimum Noise Fraction (MNF), were used for visualisation and to reduce the dimensionality of data. PCA aims to reduce the dimension of correlated variables (such as bands) to a new set of uncorrelated variables (PC's) that can be used for a variety of purposes such as visualisation, compression, feature extraction, segmentation and classification. MNF aims to reduce noise in the dataset while preserving important information that can be used for image classification, target recognition and data visualisation.

The Lisbon pilot site is prone to flooding, especially urban flooding. To attempt to map the extent of flooding for two different events, Sentinel-1 data were used. The events of 18/02/2017 and 13/12/2022 were chosen as the availability of data close to the event dates increases the chance of producing accurate post-event data.

The process of converting the data from Sentinel-1 to the extent of inundation is shown in Fig. 4.7. In this case, the data from the pre-event image must be compared with the post-event image to determine the areas potentially affected by flooding. The data was processed in

SNAP¹¹ and then visualised in desktop mapping software.

The resulting data shows the areas potentially affected by flooding, with the most accurate representation of the extent of flooding being found on large flat areas, such as airport runways or football field, where water accumulated for the longest period. Smaller areas, on the other hand, are not mapped well, possibly due to two reasons: the spatial resolution of the sensor and the image acquisition by the satellite did not take place during the event, but 10/18 h afterwards.

Brittany Observatory (France)

Since the Brittany pilot (OSIRISC observatory) is focused on the analysis of coastal flooding and erosion hazards, the use of Copernicus EMS was not envisaged because coastal hazards need regular and long-term monitoring rather than a rapid activation for an emergency, as these phenomena occur progressively. In addition, although

¹¹ <https://earth.esa.int/eogateway/tools/snap> Accessed 02 March 2023.

of the Copernicus services, gives the opportunity to better identify numerous elements at risk and to monitor coastline evolution.

Finally, the Pleiades imagery and the Copernicus database complement each other, one being of interest on a local scale while the other is of interest on a larger scale, whether regional, national or European. It could therefore be interesting for observatories to have annual access to Pleiades imagery to complete and update their databases of elements at risk and coastline evolution at regional scale.

Causeway Coast Observatory (Northern Ireland—UK)

The Causeway Coast pilot is coordinated by Geological Survey of Northern Ireland (GSNI), which has not used Copernicus data and services but has used other Earth Observation techniques including satellite radar interferometry (InSAR) techniques to remotely assess small ground movements in geotechnical or structural infrastructure. The satellite radar data has been used to assess and monitor landslide instability and subsidence.

A Copernicus database of several thematic maps has been collected to improve the characterisation and information about the pilot site, similarly to the Lisbon Observatory, focusing on the regional framework and resulting also in the creation of several maps.

Since GSNI is staffed by scientists of the British Geological Survey (BGS), the Citizens' Observatory in NI also benefits from BGS experience in using Copernicus data and services. Thus, the BGS team played a major role in delivering the European Space Agency's (ESA) TerraFirma project. TerraFirma provides a pan-European ground motion hazard information service based on InSAR techniques in EU member states, and supports civil protection agencies, disaster management organisations and coastal, rail and motorway authorities in the process of risk assessment and mitigation. The BGS was also part of the Coastal Erosion Project within the Science for Society slice of the 5th Earth Observation Envelope Programme (EOEP-5) run by the ESA, exploring coastal change from space to prepare the ground for

long-term exploitation of remote sensing from satellites, including Copernicus data, by large user communities.

Progressions have been achieved in the framework of the AGEO project related to Earth observation. The Northern Ireland Earth Observation Steering Group (NI-EOSG) and Northern Ireland

Earth Observation User Group (NI-EOUG) were established in 2021. The groups are addressed to increase the awareness of EO data, services and applications (GSNI, 2021), being that one element of focus is Copernicus Rapid Mapping Service for emergency planning & response. Moreover, NI Space Agency is more and more promoting EO data and on the other hand, increasing EO use to deliver tasks by Government departments i.e. agriculture, land mapping etc. In addition, NI Executive Office is Disaster Charter Authorised User, then, Copernicus Rapid Mapping Service is now included within Civil Contingency disaster response. Positively, there is a growing awareness of EO capability, but it is limited to specific users and at the research stage.

The experience gained from both GSNI and the wider network from BGS was used to develop the uptake of Copernicus data and services in Northern Ireland through the AGEO project framework. This assists in the culture change towards remote sensing and Earth observation for the assessment and monitoring of geological hazards in Northern Ireland.

4.4 Strategic Recommendations for Strengthening the Use of Copernicus Products and Services, and New Copernicus Products Suggestions for the Atlantic Region

Strengthening the use of Copernicus products and services is one of the pillars of this European program since there were established mechanisms to monitor user needs and ensure their adoption through mechanisms for programming, monitoring, reporting and evaluating Copernicus.

AGEO and its citizen observatories implemented and encouraged the use of Copernicus services to help managers and stakeholders to improve their efficiency in emergency management. At the same time, these users provided feedback to AGEO with valuable information about their needs and suggestions for improving Copernicus EMS. Thus, this two-way communication enriched both the risk management plans and the Copernicus program itself by allowing assessment of its limitations, and suggesting recommendations for its strengthening.

Assessment of the two types of satellite data available on Copernicus Programme.

Impressions and requirements of stakeholders in participating regions in the timeframe of AGEO project, helped the experts to analyse limitations on the two main types of satellite data available in the Copernicus Programme, captured with passive or active sensors: optical and radar products. Concerning the optical sensors, the 2.5 m pixel resolution provided within the European image mosaic is the better resolution achieved. This value can be adequate for several tasks carried out in risk management, such as site characterization, triggering factors analysis, vulnerability assessment and geohazards monitoring through Copernicus Early Warning & Monitoring systems that are already in place (e.g. EFAS). Services such as the EMS offer rapid risk and recovery mapping with very high resolution by using the data coming from unmanned aerial platforms or contributing missions. Moreover, it is interesting that in case of an alert of a potential flood hazard, the EFAS warning system has an alert that works as a trigger for satellite activation to capture images, expecting, in this way, to reduce the time required for obtaining post-event imagery.

Thus, regarding optical data, Sentinel-2 is useful for a general characterization of the regions but quite limited for monitoring tasks in some cases such as very active and small-sized processes (rockfalls). Some of the products offered could be very interesting and valuable for the analysis of triggering conditions, such as moisture index. However, its temporal resolution is limited if compared with the

high temporal variability of this parameter in some areas so it would not be useful for such regions. Likewise, changes detection exploiting Sentinel-1 and Sentinel-2 could be a useful tool for coastal erosion analysis in those shorelines with high rates of retreat. However, spatial resolution is limited in those cases with low variability. Nonetheless, even with its limitations, Copernicus optical products, as shown in the AGEO project, can be used not only in a scientific way but also as part of dissemination activities with schools and general public.

Radar products through the measurement of ground deformation are useful in geohazards management to detect where the active geohazard is located, to monitor the evolution of deformation, to characterize the geohazard parameters, to model it and even to predict its impact in the infrastructures. There are opportunities to exploit Copernicus satellite images products through European Space Agency online processing tools of satellite images. Processing satellite SAR images with Radar Interferometry tools allows for monitoring ground surface deformation related to landslides and subsidence phenomena. However, for this purpose it is necessary to have some knowledge and expertise both for INSAR processing of satellite images and for the analysis of INSAR displacement data to study those geohazards. In order to attend users' necessities regarding ground motion issues, the European Ground Motion monitoring service was implemented in 2022.

The use of radar data (Sentinel-1) in the specific cases of the AGEO pilots is fully recommended in those cases in which deformations are slow and large enough to be detected by InSAR techniques. Landslides, subsidence or earthquakes are some examples of the geohazards present in the Atlantic regions that might be assessed. As part of the protocol of radar data usage on geohazard analysis, some important points should not be neglected:

- (i) Validation of results. The use of radar data and its analysis should be carefully done and detailed validation protocol is needed in order to get results with guaranteed quality.

Sometimes results do not completely agree with what is seen in the ground, therefore, reliability analysis of the data is needed through the use of complementary data (GPS, piezometric information, etc.) to validate the results.

- (ii) Resolution might be limited for some cases and loss of information could occur. For example, it would be possible to find regions with deformation data and without statistical significance, but if resolution is improved then those points could become statistically significant. Likewise, very active processes but with small dimensions could not be analysed with resolutions available up to now.
- (iii) Costs and timing of processing procedures must be considered. Depending on the resolution required, processing costs could be very expensive.
- (iv) Integrability on the management systems should be evaluated. Requirements on software and hardware needed to processing data, should be considered. GIS software, even if open source, is necessary in order to do spatial and temporal analysis once the displacement maps are obtained.

Assessment of the Copernicus products and procedures for the management and prevention of geohazards.

Limitations of Copernicus products and procedures for the management and prevention of geohazards through the experience of AGEO partners on its use on pilot areas were compiled. Suggestions for the improvement of the existing services and also for the introduction of new Copernicus products and services for geohazard risk reduction and monitoring in the Atlantic region are presented below. They are related to activation procedures of Emergency Management Service, data access, monitoring, training, spatial resolution and new products.

- *Activation procedures.* Clarification and simplification of activation protocols is highly demanded by users to ease the process, because, up to now, it is considered complex and bureaucratic. In addition, some users proposed that it would be interesting to enable a

direct activation of Copernicus services by public research institutions or local authorities, with the knowledge of the focal point. However, it is worth noting that the focal point validates the data according to reliable rules, so its presence on the protocol is justified.

Improvements in timing and communications would be also desirable. Some delays on delivery time of mapping products have been detected. This could potentially compromise subsequent stages in the emergency management plans. However, those delivery time delays are expected to improve by reducing the time required for obtaining post-event imagery and by optimizing the acquisition time with respect to an event's evolution (MOP, 2018), as it happens with the procedure used in floods since 2017, using EFAS floods warning to pre-task image acquisitions without an official service activation (Wania et al., 2021).

European Flood Awareness System (EFAS) activation could include flash floods associated with pluvial or urban flooding besides flash flooding related only to river networks. Moreover, some stakeholders suggested a better connection with the national EFAS focal point in order to better understand the early warning system procedure and to know, for example, which is the threshold to issue an alert.

Easy access to high resolution products (for example data from contributing missions) would help for local event analysis, which requires detailed resolutions. However, those events are too localised for the activation request to be validated.

Ancillary data are needed to get a higher quality in EMS activations and resulting products. Those cases in which the data cannot be provided by the user, this will not be considered at the final product causing a lack of quality. Nevertheless, for the cases in which data are provided, the results are significantly improved (Quental and Machado, 2020).

- *Data access.* Global database with all the products derived from activations, instead of searching manually within each activation, is demanded. In addition, each Copernicus

service is a different subsystem so they need different registration processes and passwords. It would be interesting to have a common user-register for all the services. Furthermore, to homogenize the web sites of each Copernicus service with commonalities on the interfaces, will contribute to the user friendliness and therefore to facilitate the information access.

- *Monitoring.* Unfortunately, for continuous monitoring, up to now, it is necessary to rely in user own capabilities. It is not possible rely on Copernicus EMS Mapping (EMSR and EMSN) because it does not have this continuous capability. Undoubtedly, its implementation would be very valuable. A higher temporal resolution of data offered would allow analysing active geological processes with high accuracy. However, fortunately, this capability is present in Copernicus EMS Early Warning and Monitoring component in EFFIS and EFAS and EDO systems, as well as in most of other Services.
- *Training.* Open training (webinars) in several languages, about Copernicus services and potentialities is the most demanded improvement among the users. Thus, interesting issues would be: promotion of EO capabilities and limitations to assist emergency response, promotion of how to access portals and integration to user systems and improved training for access, use, integration and interpretation of datasets. Furthermore, Massive Open Online Courses (MOOC's) about InSAR are also requested. A remarkable suggestion to spread EO knowledge would be to embed EO education in school/university. In this respect, the alignment with established networks such as Copernicus Academy would be very profitable given the synergies. Part of the goals of this network are the development of lectures, training sessions, traineeships as well as educational and training material to empower the next generation of researchers, scientists, and entrepreneurs with suitable skill sets to use Copernicus data and information services to their full potential. Moreover, it seems necessary to increase dissemination of platforms and sites such as Sentinel Playground, powered by Sinergise Lab., Education site in Sentinel Hub, EO Browser in Sentinel Hub, Copernicus Mooc and Research and User Support (RUS), that offer tools, educational resources and courses to improve the knowledge in Copernicus programme. Thus, investment in training and dissemination will lead to an increasing uptake of Copernicus products.
- *Spatial Resolution.* Improvement of the spatial resolution in the obtained products is one of the most requested issues. Local studies and small-sized geohazards require high resolution data. Available information and thematic mapping for local areas is also a highly demanded improvement. Up to date, the existing data allow general characterization of these local areas. Therefore, the better the resolution, the higher the number of users accessing Copernicus data, and the better the quality of the results.
- *New products.* Based on the experience of the stakeholders analysing Copernicus services, a few new products were suggested to be created or developed by Copernicus authorities:
 - InSAR processing and post-processing tools (interferogram atmospheric corrections and unwrapping).
 - InSAR processing tools integrated in fire detection capabilities
 - Real time fire detection.
 - Wider information on Coastal zones. The specific satellite from which the used product was derived is indicated, along with some elements on the method to compute the data product that is provided. However, there is very limited information on the precise methodology used to derive other products, so more details will be desirable.
 - Improvements in the tools offered by the viewers in order to enable wider possibilities to access and select the data available.
 - Database including historical geohazards events detected by Copernicus tools or from other ancillary sources.

Requirements and limitations on Copernicus EMS presented before could be partially solved with the products offered by Copernicus on its existing services. Thus, open access to data (like contributing missions) could be available when required by some specialised users not related to research or public administration. Likewise, the European Ground Motion Service could cover part of the requirements of the users regarding InSAR. Early Warning Systems linked to the Copernicus EMS can facilitate data acquisition by linking pre-tasking of satellite images to the Early Warning System without an official service activation, and thus minimising time gaps to improve the EMS response if activated (Wania, et al., 2021).

Moreover, synergies among the academic, institutional and economic spheres would ensure that Copernicus services are appropriated for risk managers and would support the development of new products derived from satellite image processing (Copernicus and others).

Therefore, it would be desirable to have the promotion of a policy of each National Authority/Response Agency developing in-house EO skills, as well as the consideration of EO at development stage of national/local strategic action plans, emergency plans etc.

4.5 Conclusions

Copernicus is the European Union Earth Observation and Monitoring Programme, which helps the users to understand and manage the environment through satellite and in situ observations. Free and open data are provided to the users (citizens, public authorities and international organizations). The programme covers several information services such as atmosphere, marine, land, climate change, security and emergency.

The role of Copernicus EMS in monitoring geological hazards is to provide adequate tools for emergency response, through the rapid mapping (EMSR) and for prevention and planning, through the risk and recovery mapping (EMSN). The analysis of Copernicus products and

services highlights the importance of the necessary cooperation with civil protection, public authorities and private companies when emergency plans are developed, as these key players give suggestions and recommendations to spread awareness of these natural disasters.

Copernicus EMS constitutes a powerful tool for stakeholders in their emergency management. The Copernicus program is continuously improving and developing new products following the stakeholders requirements. Users feedback, monitored by Copernicus EMS, provides useful information to enable the improvement of the service and, in addition, to strengthen the risk managements systems of the participating Atlantic regions. Thus, the stakeholder feedback questionnaires revealed that satellite data are normally used. However, Copernicus use is less extensive and largely restricted to academic or research institutions.

97 Copernicus EMS activations have been requested in the Atlantic Area by the participating countries from 2012 until 2022. Wildfires and floods are the most common hazards causing the activations, and Portugal and Spain are the countries with a higher number of activations. Timeline of activations reveals the growing participation and engagement of the countries in the use of the Copernicus Emergency Service.

Copernicus products offer a variety of possibilities in geohazards analysis, contributing to risk assessment in each of its stages (pre-event, during-event, post-event). Efforts to integrate Copernicus and EO products in the citizens observatories on geohazards implemented in the frame of AGEO project have been made. Thus, Copernicus EMS activations proposed by some of the AGEO partners contributed to enhance and reinforce the knowledge about the geological processes acting as well as to give support to the emergency in case of Rapid Mapping activations.

Projects and activities using Copernicus products and services presented in previous sections are some examples that highlight the multidisciplinary uses, different working scales, and varied purposes where Sentinel products

have turned out to be useful. Thus, rockfalls source areas mapping, rockfalls susceptibility maps, slow mass movements detection, mapping extension of flooding, inventory and cartography of elements at risk and/or relevant for geohazard analysis, and landslide and subsidence monitoring, are examples of use cases that have been explored in the timeframe of AGEO project.

Optical and radar data provided by the Copernicus programme have been demonstrated to be very useful, as long as the scale of work is appropriate. Risk monitoring, as well as localization, characterization and modelling are some of the utilities that this type of data allows for in the assessment and management of geohazards. On one hand, Sentinel-2 provides useful optical data to obtain a general characterization of the acting geological process and environmental conditions. Monitoring will be possible whenever the spatial and temporal scale and variability of the process allow it. On the other hand, radar data from Sentinel-1 are useful to detect ground deformations which are slow and large enough to be detected by InSAR techniques. Special attention must be paid to validation of results, resolution limitations, costs and timing of procedures and integrability on management systems.

Regarding the assessment of Copernicus products and procedures for the management and prevention of geohazards, suggestions were collected from partners in Atlantic area. They were related to activation procedures of Emergency Management Service, data access, monitoring, training, spatial resolution, and new products. Easier activation procedures, open training and improvements in data resolution are the most demanded aspects by users in Atlantic region.

Knowledge of Copernicus products and services should be widely disseminated and popularised. This should lead to an increasing number of users and thus to the enrichment and growth of the Copernicus programme.

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