Satellite mapping in response to the 2016 7.8 magnitude earthquake in Muisne, Ecuador

Theodora Papadopoulou[1], Philippe Bally[2], Françoise Villette[3], Francesco Casu[4], Floriane Provost[2]

1: ARGANS Ltd., 260 rue du Pin Montard, BP 234, 06904 Sophia Antipolis Cedex, France

2: European Space Agency (ESA), ESRIN, Largo Galileo Galilei 1, 00044 Frascati, Italy

3: European Commission Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), Avenue d'Auderghem 45, 1040 Bruxelles, Belgium

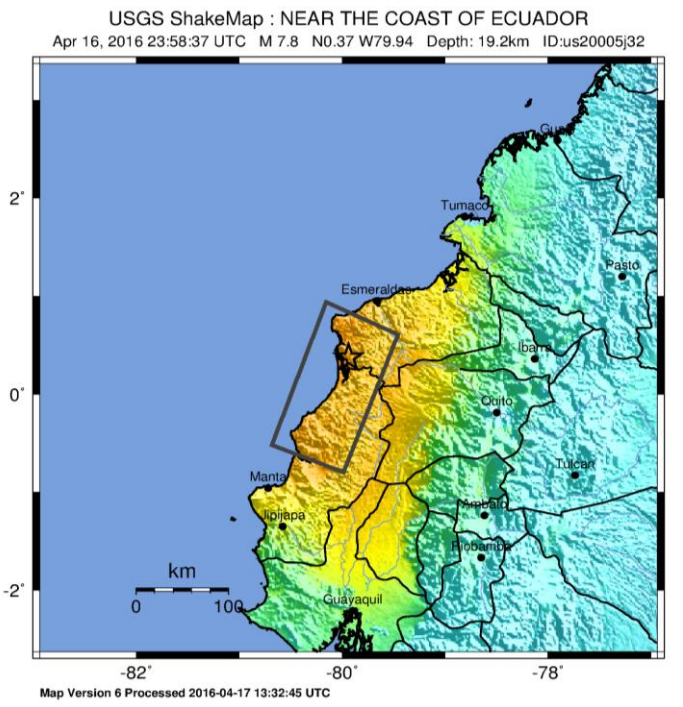
4: CNR IREA, Via Diocleziano 328, 80124 Napoli, Italy

This document describes how satellite Earth Observation (EO) contributed to the response of the 2016 earthquake in Ecuador. It focuses on the available EO disaster response capabilities and how they supported the local disaster management authorities by gathering satellite images and generating satellite-derived maps and reports to identify the extent of the affected area, assess the damage and provide a clearer view about the nature of the event.

I. The earthquake and its impact to society

A 7.8 magnitude earthquake struck the coast of Ecuador on 16 April 2016 at 23:58 UTC (18:58 local time), approximately 27 km south-southeast of Muisne, in the province of Esmeraldas at a depth of 20.6 km. This part of the country is sparsely populated and is situated 170 km northwest from the capital, Quito. [1] The earthquake caused severe damage in the country in terms of casualties and infrastructure.

At least 676 people are known to have been killed, and almost thirty thousand more were injured. This event has been the worst natural disaster to hit Ecuador since the 1949 Ambato earthquake. [2]



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Figure 1: Shakemap near the coast of Ecuador. Credits: USGS

The shallow earthquake, the worst to affect the country in almost forty years, struck near the town of Muisne on the western coast of Ecuador, and caused widespread damage. There were concerns of potential tsunami in the aftermath. The earthquake was presaged by a magnitude 4.8 foreshock eleven minutes before the main quake struck. [3] Over a hundred aftershocks have been reported. [4]

A state of emergency has been declared in the Guayas, Manabi, Santo Domingo, Los Rios, Esmeraldas and Galapagos Provinces, all of which are on the coast of the nation. Rescue operations and the search for survivors are ongoing. Soldiers have been deployed to aid the rescue operations in the north-west, but landslides have made it difficult to reach some areas. Ecuador received international aid and relief from eight separate countries. The Manabi Province suffered the most damage, with the town of Pedernales, which was close to the earthquake, reportedly flattened and further south the cities of Manta and Portoviejo have also suffered severe damage.

Thousands of people have been left homeless, and it is estimated it will take years for the worst-affected areas to recover and rebuild.

In response to the earthquake, a state of emergency was declared throughout the country and the national guard was mobilized to assist in rescue and relief efforts. [5] Approximately 10,000 military personnel and 3,500 police officers were deployed. [6]

On April 17, both the European Commission's Copernicus Emergency Management Service (EMS) Rapid Mapping and the International Charter on Space and Major Disasters were activated, respectively providing satellite–based disaster impact maps and the tasking of satellite assets. [7]

On April 20, a 6.1–6.2 magnitude aftershock struck 24 km west of Muisne around 3:30AM, local time. [8][9] The quake had a depth of about 14.5 km. José Joaquín de Olmedo International Airport in Guayaquil was also closed due to communication issues. [10]

A UNICEF representative reported that the government is considering relocating "one or two" towns in the aftermath of the earthquake. There were also concerns about the Zika virus outbreak and the risk of dengue fever for people displaced by the quake. [11]

Days after the earthquake, the country experienced difficulties distributing food and water to those in need, including the over 26 thousand survivors relocated to shelters. President Correa acknowledged that the poor infrastructure of the country might be to blame. [12] The President estimated the damage at $3 billion, and has obtained credit from the World Bank, Inter-American Development Bank, and other sources, anticipated to reach a total of $2 billion; national sales tax has been raised as have income taxes on Ecuadorians. [13]

II. EO satellite capabilities in support to Disaster Risk Management

Earth Observation (EO) using satellite and other non-space remote sensing instruments can provide accurate information for the Earth's surface. At present, the most commonly used remote sensing data acquisition platforms are satellites and aircrafts. Earth observation data are also used for monitoring disasters as they can provide crucial information throughout the entire disaster management cycle.

Today there is a number of disaster management capabilities able to provide satellite data and derived information to cover the mitigation, preparedness, response, and recovery phase of a natural or man-made disaster. Focusing on emergency response, the available capabilities based on international collaborations among countries, institutions and organizations are the International Charter 'Space and Major Disasters', the Copernicus Emergency Management Service (EMS) which also supports prevention, preparedness and recovery activities, Sentinel Asia, UNITAR's Operational Satellite Applications Programme (UNOSAT) and the Committee on Earth Observation Satellites (CEOS) Working Group Disasters.

The International Charter "Space and Major Disasters" is a collaboration among 17 space agencies and space operators through which satellite-derived information and products are made available to support disaster response efforts in the event of major disasters. The Charter was initiated by the European Space Agency and the French space agency CNES in July 1999, and it is operational since November 1, 2000, after the Canadian Space Agency signed onto the Charter on October 20, 2000. Charter members are ESA, CNES, CSA, NOAA, CONAE, ISRO, JAXA, USGS, UKSA/DMCii, CNSA, DLR, KARI, INPE, EUMETSAT, ROSCOSMOS, ABAE and UAESA/MBRSC.

Since 2000, the Charter has been activated for 576 times in 124 countries for various natural or man-made hazards such as: floods, ocean storms, earthquakes, wildfires, volcano eruptions, landslides, oil spills, search & rescue of aircrafts, vessels and submarines, Ebola epidemic, train accidents, dam collapse, ice jam and snowfall.

The EU-funded Copernicus Emergency Management Service (EMS) provides information for emergency response in relation to different types of disasters, including meteorological hazards, geophysical hazards, deliberate and accidental man-made disasters and other humanitarian disasters as well as prevention, preparedness, response and recovery activities. Since 2012, the Copernicus EMS Rapid Mapping has been activated over 400 times to address a wide range of emergency situations resulting from large natural or man-made disasters that occurred worldwide.

At the end of 2016, Copernicus EMS and the Charter initiated discussions for cooperation in order to ensure synergies between the two mechanisms and provide optimal assistance in case of large disasters. The two entities signed in April 2018 a cooperation agreement, with the view to (i) exchange operational information on an emergency basis and (ii) apply operational procedures to allow EMS to access EO data from the

Charter for use in its Rapid Mapping Service and to allow the Charter to access mapping products of the EMS Rapid Mapping Service to support the Charter when it is activated.

The Committee on Earth Observation Satellites (CEOS) [14] was established in 1984 in response to a recommendation from a Panel of Experts on Remote Sensing from Space who recognized the multidisciplinary nature of satellite Earth observation and the value of coordinating international EO efforts to benefit society. Its main function was initially to coordinate and harmonize Earth observations to facilitate the user community to access and use data, but as the collection and use of satellite EO increased and became more complex, CEOS involved its function focusing on validated requirements levied by external organizations, works closely with satellite cooperating bodies and continues its role as the primary forum for international coordination of space-based EO. [15]

CEOS is composed by five Working groups, one of them being the Working Group (WG) on Disasters. [16] The WG Disasters aims at increasing and strengthening satellite EO contributions to the various Disaster Risk Management (DRM) and to inform decision-makers and major stakeholders on the benefits of using satellite EO. In order to achieve that, the WG Disasters has launched pilot activities under specific themes such as Floods, Seismic Hazards, Volcano and Landslide as well as the Recovery Observatory (RO) activity. [17, 18, 19, 20, 21] Today, the Landslide Pilot and RO continue their activities, while the Flood, Seismic Hazards and Volcano Pilots have been successfully completed and new Demonstrator activities are upcoming to expand their objectives from regional to global coverage, pursue capacity building and reach more end users to increase the benefit to local communities.

In the case of the 2016 Ecuador earthquake, some of the hereabove mentioned emergency response capabilities such as for instance the International Charter ‘Space and Major Disasters’, Copernicus EMS Rapid Mapping Service and the CEOS Working Group Disasters Seismic Hazards Pilot activity have provided satellite imagery and derived information products to support the local disaster management authorities within a few days after the earthquake hit Muisne. The following sections detail how the three capabilities have been activated by the local authorities, how they responded and what type of satellite imagery and products were delivered to the Ecuadorian disaster management organisations.

III. International Charter ‘Space and Major Disasters’: response to the 2016 Muisne earthquake

On April 16, 2016, UNITAR/UNOSAT activated the Charter on behalf of UN OCHA for the 7.8 magnitude earthquake that struck Muisne, Ecuador.

The Charter made available images from more than 7 satellite EO missions such as: Pleiades, UK-DMD, UK-DMC-2, WorldView-2, WorldView-3, Resurs-P, KOMPSAT-2, KOMPSAT-3 which were used by UNITAR/UNOSAT to produce damage assessment maps (see Figure 2). Furthermore, the British Geological Survey (BGS) and UNITAR/UNOSAT generated co-seismic landslide inventory maps using Pleiades and UK-DMC data (see example: Figure 3).

These maps have been disseminated through the International Charter ‘Space and Major Disasters’ website, UNOSAT, UK Government Departments and MapAction. The maps helped the relief efforts of local authorities by showing in which areas the population has been affected by landslide debris, including information on blocked roads or rivers.

Five post-earthquake satellite images (Pleiades) have been interpreted covering the areas of Portoviejo, Bahía de Caráquez, Chone, Muisne and Crucita. These images were compared with pre-earthquake images from Google Earth (2013–2015). The analysis resulted in the identification of over 500 landslides that are likely to have been triggered by the earthquake (70 per cent having an extent smaller than 10 × 10 m).

More than 70% of these landslides did not have a discernible impact; 13% affected fields, river banks and coastal cliffs; 8% affected roads, 3% affected dyke failures, 1% affected houses.

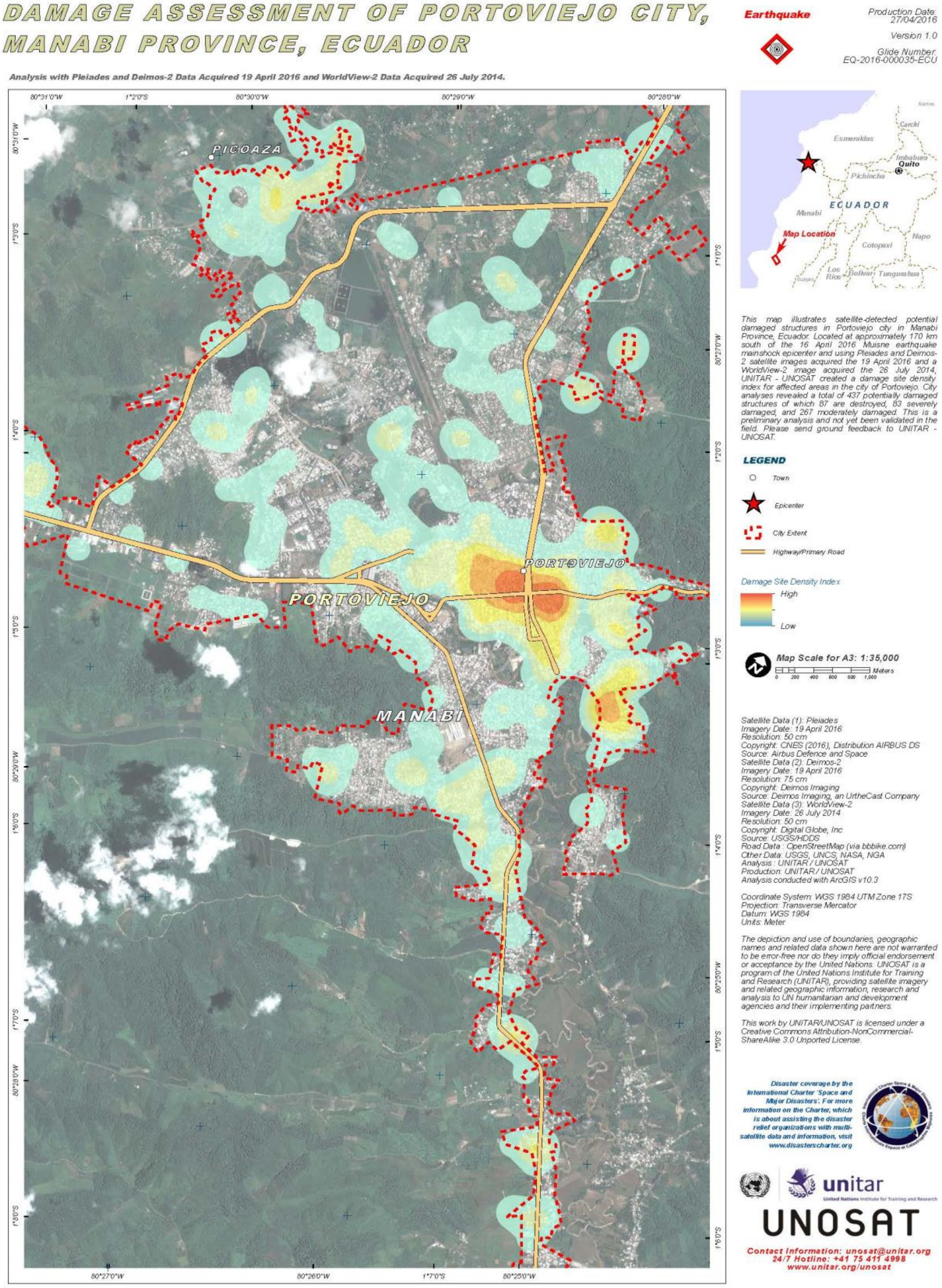


Figure 2: Damage assessment of Portoviejo City, Manabi Province produced by UNITAR/UNOSAT using Pleiades © CNES 2016 - Distribution: Airbus Defence and Space, Deimos-2 © Deimos Imaging and WorldView-2 © DigitalGlobe Inc. data.

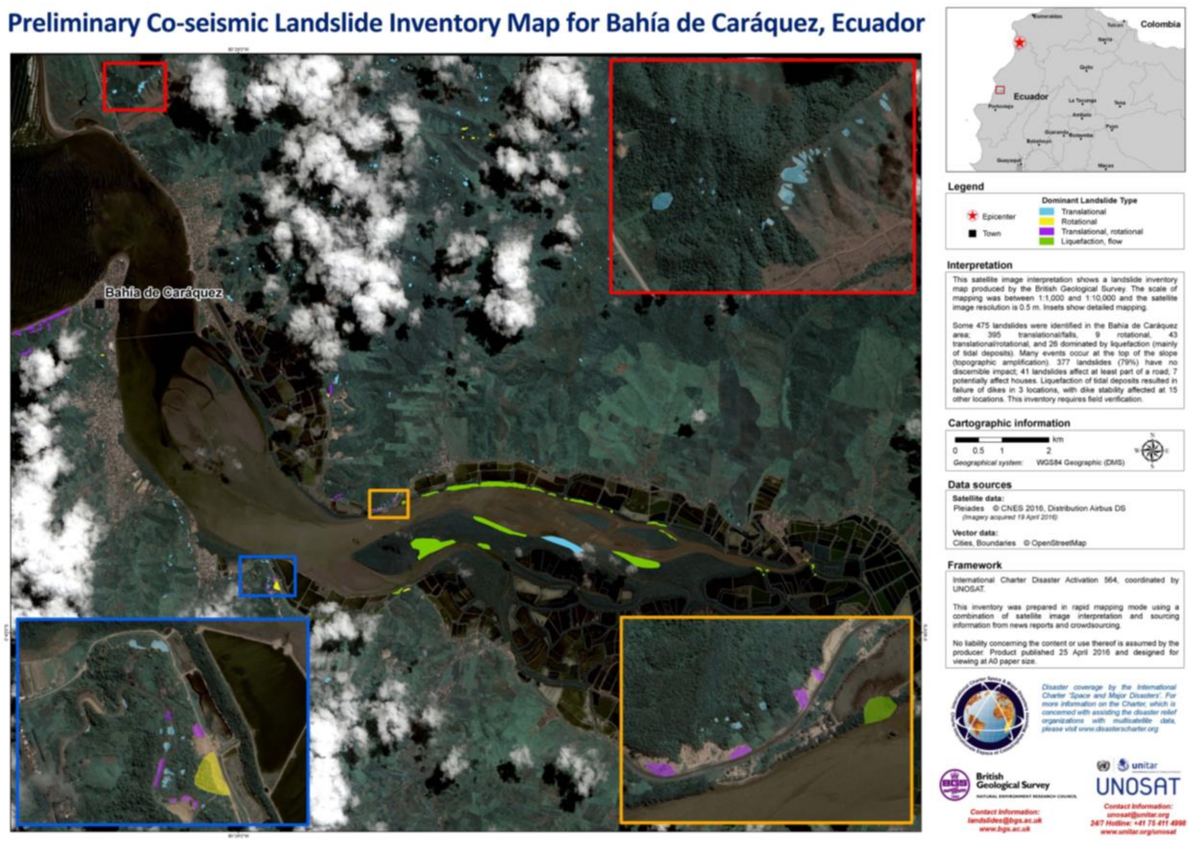


Figure 3: Preliminary Co-seismic Landslide Inventory Map for Bahia de Caraquez produced by the British Geological Survey (BGS) using Pleiades data © CNES 2016 Distribution Airbus Defence and Space obtained via the International Charter.

End users stated that the Charter-derived maps and reports that were produced by UNOSAT and BGS were used for operations, planning, communication, lessons learned, training and documentation. In particular end users quoted the following:

"Special thanks to UNOSAT and the Charter for the excellent support."
Fawad Hussain Syed, UNOCHA

"I would first like to thank you for your services in terms of providing early response information and reports generated for the affected areas during the emergency phase after the 16th April earthquake that struck Ecuador…"
Leonardo Javier Espinosa Galarza of the National Secretariat of Planning and Development (SENPLADES: Secretaría Nacional de Planificación y Desarrollo)

IV. Copernicus EMS Rapid Mapping Service: response to the 2016 Muisne earthquake

On April 17, the Copernicus EMS Rapid Mapping Service was activated[1] by the European Union's Emergency Response Coordination Centre (ERCC) to provide assistance to civil protection actors and decision-makers with the assessment of the impact of the powerful earthquake that struck Ecuador. In total 18 satellite-based grading maps and 16 reference maps covering 17 affected areas showing the widespread severe damage have been generated and published on the Copernicus EMS Rapid Mapping website [22]. The figures below show the location of the areas which were mapped and an example of one of the damage assessments.

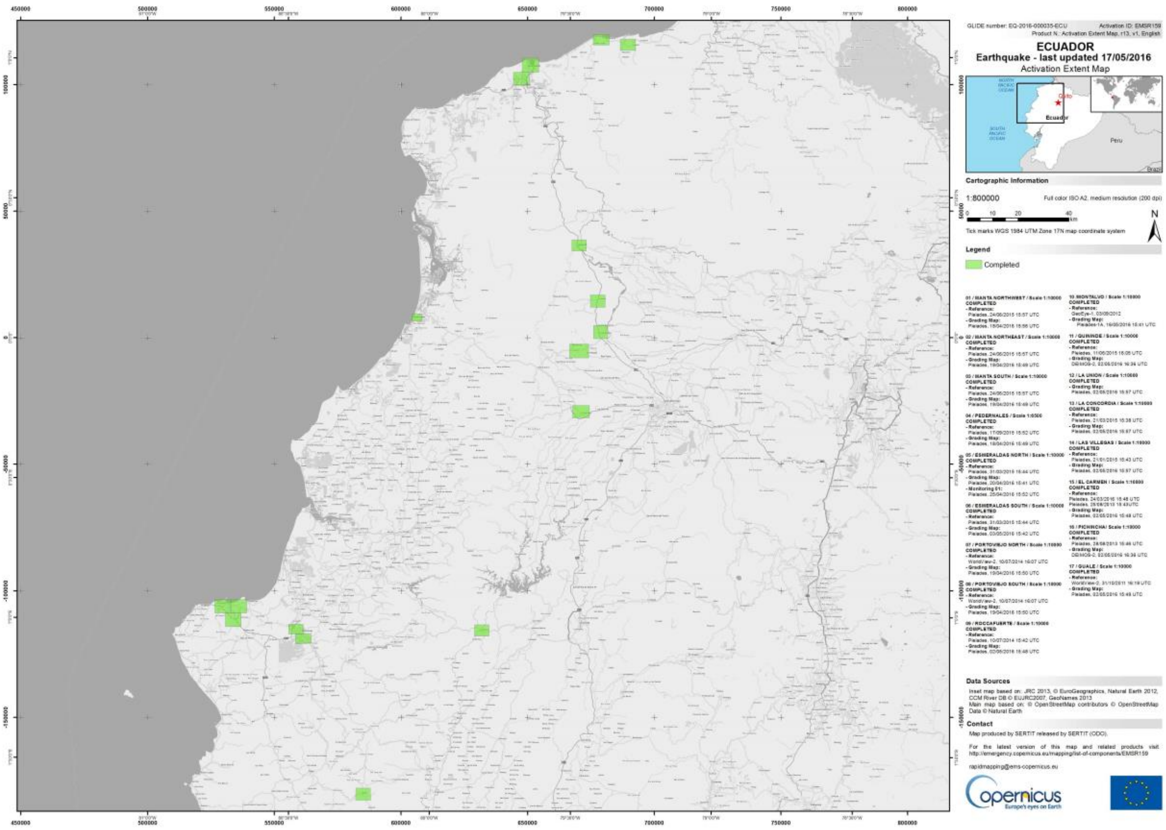


Figure 4. Overview map of the Copernicus EMS activation for the Ecuador earthquake showing the mapped areas. Copernicus Emergency Management Service (© 2016 European Union), [EMSR159] Activation Extent Map

[1] Activation of Copernicus Emergency Management Service on April 17, 2016: https://emergency.copernicus.eu/mapping/list-of-components/EMSR159

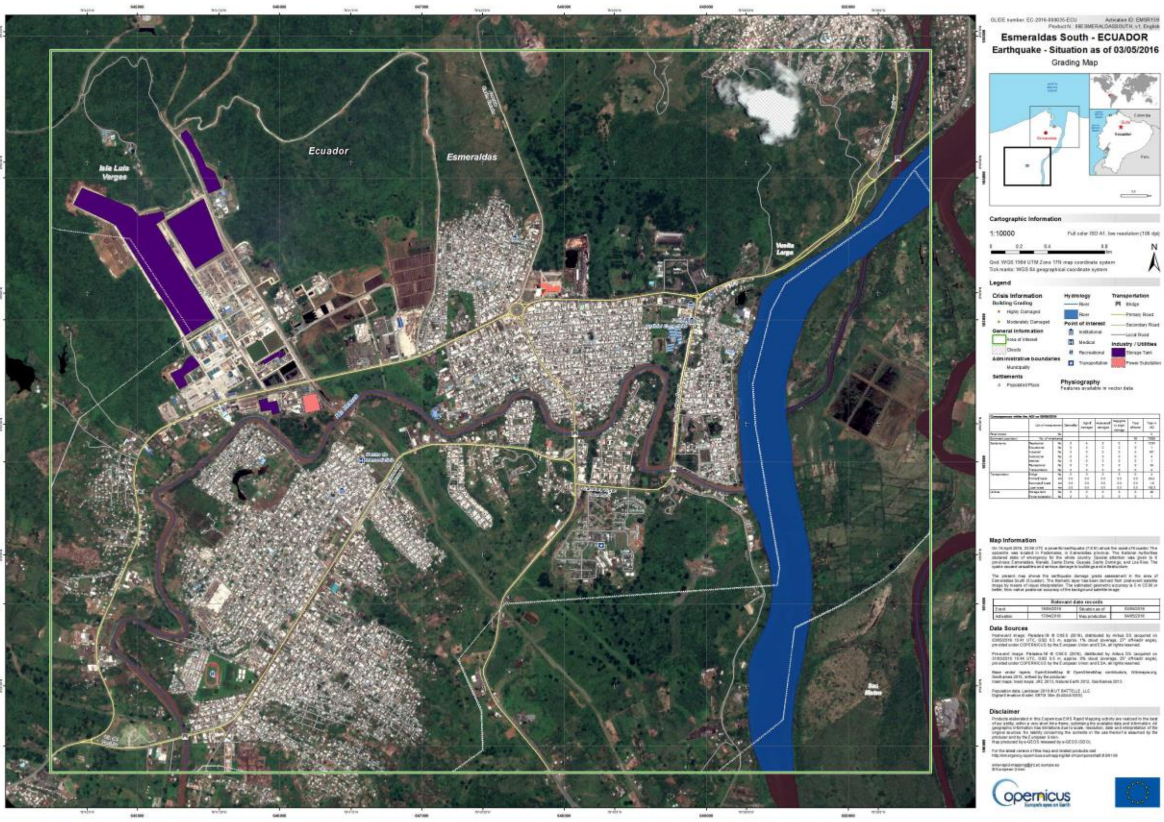


Figure 5: Grading map over South Esmeraldas produced by e-GEOS for the Copernicus EMS Rapid Mapping using Pleiades-1B data © CNES (2016). Copernicus Emergency Management Service (© 2016 European Union), [EMSR159] South Esmeraldas: Grading Map

Figure 6: Grading map over Pedernales produced by the Copernicus EMS Rapid Mapping using Pleiades-1B data © CNES (2016) Copernicus Emergency Management Service (© 2016 European Union), [EMSR159] Pedernales: Grading Map

V. CEOS WG Disasters Seismic Hazards Pilot: contribution to the scientific community and local authorities

The CEOS WG Disasters Seismic Hazards Pilot contributed to the assessment of the Muisne earthquake with advance scientific products that are complementary to the damage mapping products from disaster response capabilities such the International Charter ‘Space and Major Disasters’ and the Copernicus EMS.

During the period 2014 to 2017, the WG Disasters Seismic Hazards Pilot managed to address seismic hazards by providing access to data, but also access to tools and hosted processing to generate needed information mainly after emergencies, as well as linking to available EO capacities thanks to the contribution of expert users (partner geoscience centers with EO expertise). A successful example of response to seismic hazard is the 2016 earthquake in Muisne, Ecuador.

The Institute for the Electromagnetic Sensing of the Environment (IREA) of the National Research Council of Italy (CNR) contributing to the CEOS WG Seismic Hazards Pilot since early 2016 (as partner geoscience centre) has responded to the Ecuadorian authorities by providing advanced hazard mapping products based on satellite Differential Interferometric Synthetic Aperture Radar (DInSAR) measurements. DInSAR is a technique that, by exploiting two SAR acquisitions taken at different times over the same area, allows detecting with centimetre accuracy the Earth’s surface displacements occurred between the two acquisitions.

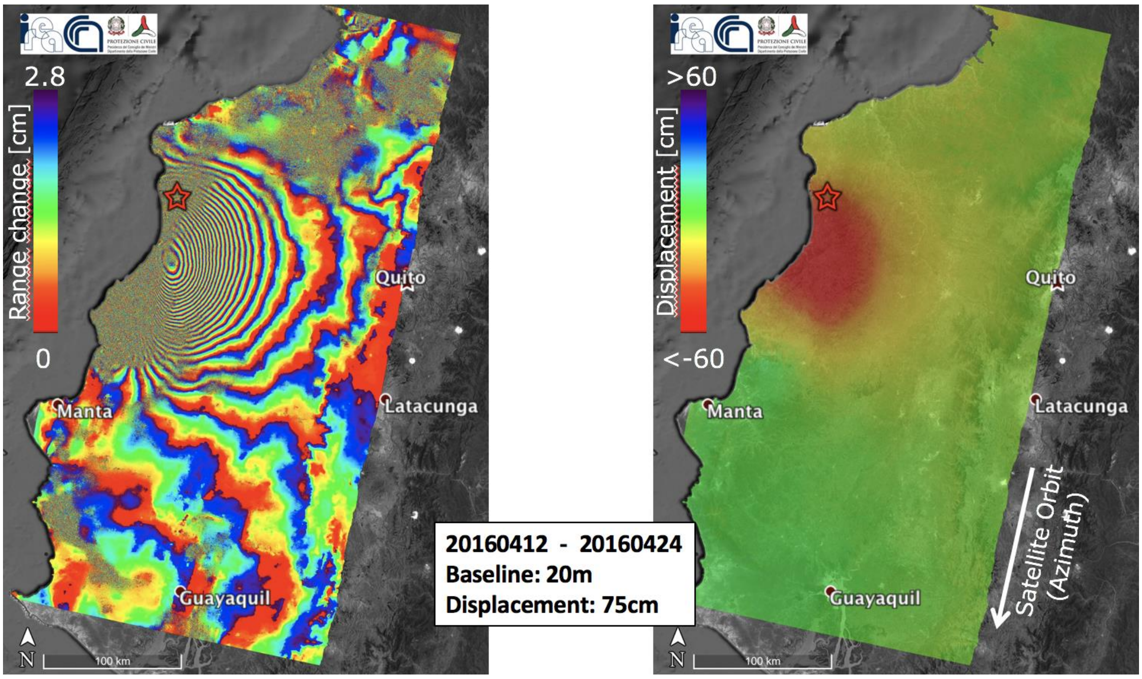


Figure 7: Interferogram generated by CNR-IREA, exploiting two Copernicus Sentinel-1© 2016 images acquired from descending orbits (Track 40) before (12 April) and after (24 April) the Mw 7.8 event, whose epicentre is indicated by a red star. Left: Differential Interferogram; each colour cycle corresponds to about 2.8 cm of displacement. Right: Line of Sight (interpolated) Displacement map derived from the interferogram shown on the left; negative values represent pixels moving away from the satellite orbit path (indicated with a with arrow). The reference point for the measurement is located in correspondence to the Guayaquil town.

CNR-IREA is a Centre of Competence (CoC) on DInSAR for the Italian Civil Protection Department (DPC). In case of major (Magnitude >6) and shallow earthquakes occurred within the Italian territory, CNR-IREA has the mandate to rapidly provide DPC with DInSAR Earth surface deformation maps, as soon as the first post-seismic SAR acquisition is available.

Generated deformation maps are used by DPC and others DPC’s CoC to understand the extension of the area affected by displacement and better focus the activities during emergency. Maps can also be used to model the seismogenic fault in order to increase the knowledge on the earthquake causes, as in the case of the 2016-2017 Central Italy (Amatrice and Norcia) seismic sequence [23-24].

In some cases, DPC may also ask to provide displacement measurements for earthquakes occurred abroad, in the framework of international collaborations with foreign authorities, as in the case of the 2016 earthquake in Ecuador. For this event, on April 17, 2016, the Ecuador government asked assistance to the

Directorate-General Humanitarian Aid and Civil Protection of the European Commission. On this basis, and under the coordination of the United Nations, Italy declared the emergency state for the Ecuador earthquake, which allowed Italian logistic support and technical experts to be provided for the evaluation of strategic buildings on site.

Within this frame, DPC asked CNR-IREA a detailed report on the surface deformations due to the mainshock, which was also forwarded to the Ecuadorian authorities of civil protection. To accomplish this task, CNR-IREA exploited the SAR data acquired by the Sentinel-1 Copernicus satellite over the region and, immediately after the data availability, generated the relevant co-seismic DInSAR deformation maps. In particular, Figure 5 shows the surface displacement induced by the earthquake as measured from Sentinel-1 descending orbits. Thanks to the Sentinel-1 wide swath characteristics, it was possible to observe the area interested by a significant displacement that extended for about 200 km along the North-South direction and 180 km Eastward from the coastline. The location of the epicentre of the Mw 7.8 event is also reported. The maximum deforming area is in correspondence to the high fringe rates (left panel on Figure 5), located about 46 km to the South of the epicentre. DInSAR results allowed also quantifying the amount of the displacement induced by the earthquake, which reach about 75 cm in the satellite Line of Sight (LOS), corresponding to a ground movement away from the satellite orbit (the latter being identified in Figure 5 by a white arrow). This evidence is consistent with the estimation provided by the USGS on geometric and kinematic parameters of the seismogenic fault, which is a megathrust slipping on two major Nazca and South America plates.

It is finally worth noting that, the Ecuador region is extremely vegetated and it is then particularly challenging for applying DInSAR techniques, thus meaning that short repeat pass between subsequent SAR acquisitions is needed to preserve the capability to detect the deformation signal. However, thanks to an *ad hoc* reduction of the Sentinel-1 repeat pass interval operated by ESA, it was possible to generate an interferogram with a 12-day time span (being 24 days the usual repeat pass of Sentinel-1 on South America). Such a reduced time interval between the pre- and post-event acquisitions strongly helped on preserving the radar signal coherence and the DInSAR quality, allowing us to generate the accurate displacement maps shown in Figure 7.

VI.Conclusion

As illustrated in this document, satellite EO can contribute to (i) damage assessment (cf. International Charter 'Space and Major Disasters' and Copernicus EMS) by mapping the extent of the event and the severity of damages and (ii) geohazard assessment (cf. CEOS WG Disasters Seismic Hazards Pilot) by measuring the displacement occurred by the earthquake and modelling the event to better understand its nature and potential lateral hazards such as landslides and subsidence.

The available disaster response EO capabilities focusing on damage mapping are continuously looking for ways to optimize support to relief efforts i.e. the International Charter and Copernicus EMS have a cooperation agreement to avoid duplicating the consumption of resources (e.g. satellite images over the same area) when both mechanisms are activated for the same event. In addition, the CEOS WG Disasters compliments their efforts by providing information on the scientific nature and potential impact of hazards. Furthermore, EO can also provide valuable information to other phases of Disaster Risk Management such as preparedness through risk assessment, prevention and recovery.

Abbreviations

ADRC	Asian Disaster Reduction Centre
ALOS	Advanced Land Observation Satellite
ASI	Agenzia Spaziale Italiana
CBERS	China-Brazil Earth Resources Satellite
CEOS	Committee on Earth Observation Satellites
CNES	Centre National d’Etudes Spatiales
CRESDA	China Centre for Resources Satellite Data and Application
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DMC	Disaster Monitoring Constellation
EMS	Copernicus Emergency Management Service
ESA	European Space Agency
FEMA	Federal Emergency Management Agency
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GSNL	Geohazards Supersites and Natural Laboratories
HDDS	Hazards Data Distribution System
INGV	Istituto Nazionale di Geofisica e Vulcanologia
InSAR	Interferometric Synthetic Aperture Radar
JAXA	JapanAerospaceExplorationAgency
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Centre
NOAA	The National Oceanic and Atmospheric Administration NSF: National Science Foundation
SJ-9A	Shijian-9A satellite
SPOT	Systeme Probatoire d'Observation dela Tarre
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNITAR	United Nations Institute for Training and Research
UNOSAT	UNITAR Operational Satellite Applications Programme
UNSPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
USGS	United States Geological Survey

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