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Earth observations into action: the systemic integration of earth observation applications into national risk reduction decision structures

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Abstract

Purpose – As stated in the United Nations Global Assessment Report 2022 Concept Note, decision-makers everywhere need data and statistics that are accurate, timely, sufficiently disaggregated, relevant, accessible and easy to use. The purpose of this paper is to demonstrate scalable and replicable methods to advance and integrate the use of earth observation (EO), specifically ongoing efforts within the Group on Earth Observations (GEO) Work Programme and the Committee on Earth Observation Satellites (CEOS) Work Plan, to support risk-informed decision-making, based on documented national and subnational needs and requirements.

Design/methodology/approach – Promotion of open data sharing and geospatial technology solutions at national and subnational scales encourages the accelerated implementation of successful EO applications. These solutions may also be linked to specific Sendai Framework for Disaster Risk Reduction (DRR) 2015–2030 Global Targets that provide trusted answers to risk-oriented decision frameworks, as well as critical synergies between the Sendai Framework and the 2030 Agenda for Sustainable Development. This paper provides examples of these efforts in the form of platforms and knowledge hubs that leverage latest developments in analysis ready data and support evidence-based DRR measures.

Findings – The climate crisis is forcing countries to face unprecedented frequency and severity of disasters. At the same time, there are growing demands to respond to policy at the national and international level. EOs offer insights and intelligence for evidence-based policy development and decision-making to support key

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aspects of the Sendai Framework. The GEO DRR Working Group and CEOS Working Group Disasters are ideally placed to help national government agencies, particularly national Sendai focal points to learn more about EOs and understand their role in supporting DRR.

Originality/value – The unique perspective of EOs provide unrealized value to decision-makers addressing DRR. This paper highlights tangible methods and practices that leverage free and open source EO insights that can benefit all DRR practitioners.

Keywords Earth observations, Sendai framework, Disaster risk reduction, Open science, Geospatial

Paper type Research paper

Significant progress has been made specifically on developing integrated geospatial and statistical data to address the Sustainable Development Goals (SDGs) (e.g. United Nations Expert Group on the Integration of Statistical and Geospatial Information). A lesser degree of focus to date has been placed on merging the scientific earth observation (EO), global geospatial, statistical and disaster risk reduction (DRR) communities at technical and policy levels. Accelerated uptake and improved usefulness of existing and planned EOs is expected if the UN Office for Disaster Risk Reduction (UNDRR), UN Committee of Experts on Global Geospatial Information Management (UN-GGIM), Group on Earth Observations (GEO) and Committee on Earth Observation Satellites (CEOS) increase collaboration and focus on practical applications guided by high level frameworks, such as the UN-GGIM Strategic Framework on Geospatial Information and Services for Disasters.

GEO is an international partnership of governments and international organizations working on coordinated, comprehensive and sustained EOs. As a Participating Organization, i.e. a partner of GEO, CEOS and its Working Group on Disasters (WGDisasters) ensures international coordination of civil space-based EO programs and promotes exchange of data to help address global challenges, including DRR.

GEO and CEOS activities focused on DRR leverage public and private sector memberships at regional and national levels, through regionally oriented GEOs (AfriGEO, AOGEO, EuroGEO and AmeriGEO) to understand requirements and work to reduce uncertainty through applications of scientific and policy developments.

Promotion of open data sharing and geospatial technology solutions that are scalable and replicable at national and subnational scales encourages accelerated implementation of successful EO applications. These solutions may also be linked to specific Sendai Framework for Disaster Risk Reduction (2015–2030) (Sendai Framework) Global Targets (E, F and G) that provide trusted answers to risk-oriented decision frameworks, as well as critical synergies between the Sendai Framework and the 2030 Agenda for Sustainable Development (SDGs). This paper provides examples of these efforts in the form of platforms and knowledge hubs that leverage latest developments in analysis ready data and support evidence-based DRR measures.

Relevant case studies in reducing risk

GEO Global Agricultural Monitoring (GEOGLAM) flagship

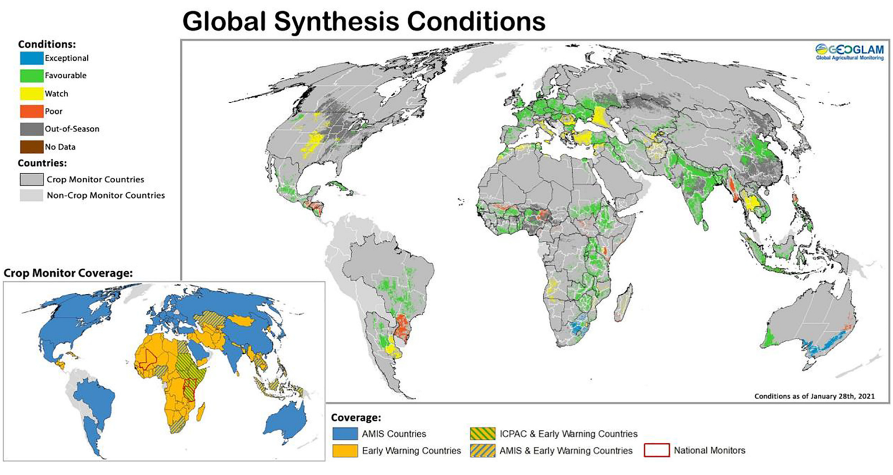
Global food security is currently in a critical state and is deteriorating at an alarming rate, exacerbated by the impact of the COVID-19 pandemic. Before the onset of the pandemic, an estimated 690 million people went hungry in 2019 and the impact of the pandemic is estimated to push an additional 130 million more people into hunger (Food and Agricultural Organization *et al.*, 2020). Climate change and the increasing frequency and severity of weather extremes are among the key factors contributing to the rise in food insecurity and the leading cause of severe food crises (Food and Agricultural Organization *et al.*, 2018). Food insecurity is itself a significant risk that can both exacerbate and be exacerbated by disasters, but early warning of events and conditions that threaten food security at local to global levels can significantly mitigate risks to human well-being. Global, timely and reliable information on crop conditions and early warning of impending shortfalls of crop production that inform early action are therefore critical components for achieving food security and ensuring sufficient, reliable food availability and access. Satellite-based EO provides a significant contribution toward supplying crucial information about crop conditions and production. This is due to their global, repeatable, synoptic nature and ability to provide quantitative indicators of crop development and outlooks for crop production throughout the growing season, from local to global scales. The application of EO to agricultural monitoring can provide early warning of extreme weather events, such as droughts. It can also monitor the impact of these events as they develop, providing governments and humanitarian organizations time to mitigate damage from these shocks and trigger safety nets to offset agricultural losses.

The Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) Crop Monitor (http://cropmonitor.org/) initiative, based largely on EO, is a source of such information in support of early warning. The GEOGLAM Crop Monitor was developed under the framework of the 2011 G20 Action Plan on Food Price Volatility in Agriculture in response to the need for timely science-driven information on global crop conditions that would strengthen existing monitoring systems and provide early warning of potential production shortfalls (Becker-Reshef *et al.*, 2020). The main objective of the GEOGLAM Crop Monitor initiative is to reduce uncertainty in global food markets and fill gaps related to agricultural production and food security by providing a monthly consensus on global crop conditions. The GEOGLAM Crop Monitor monthly bulletin for the G20 Agricultural Market Information System (AMIS) was launched in 2013 to focus on conditions of the four primary global commodity crops (maize, soy, rice, wheat) in the major global producers and exporters. The GEOGLAM Crop Monitor for Early Warning (CM4EW) was established in 2016 to address the pressing need for enhanced reliability and trusted information regarding countries at risk of shortfalls in production of their most important crops (Becker-Reshef *et al.*, 2020). CM4EW uses EO data together with meteorological information, field observations and ground reports to fill information gaps related to food security at the global scale. This addresses the need for more complete and reliable information for countries at risk of food insecurity. This information gives critical support to humanitarian and food security decision-making and policy implementation and is often used to inform food allocation and assistance and, in the process, has come to support the SDGs, primarily Goals 2 (Zero Hunger), 13 (Climate Change Impacts) and 17 (Global Partnerships) (Whitcraft *et al.*, 2019).

More recently, CM4EW has developed a mechanism to publish Special Reports that rapidly provide critical, science-based, consensus information on acute developing threats to crop production including droughts, floods and extreme events that are likely to result in yield shortfalls with negative food security outcomes. Since the commencement of this rapid reporting mechanism, the Crop Monitor Special Reports have supported national and regional agencies and humanitarian organizations in their disaster relief response, strategy and planning. In 2020, Special Reports on Eastern Africa flooding were used as a key resource in the development of Eastern Africa's Intergovernmental Authority on Development (IGAD) 2020 Food Security and Nutrition Response Strategy Report. This provides support for Sendai Framework Targets A and B; by issuing up-to-date information earlier and more responsively to emerging threats and triggering humanitarian mobilization in advance of crises, the information provided by CM4EW has informed critical decisions that resulted in a reduced number of people who experience acute food insecurity (Becker-Reshef *et al.*, 2020) (see Figure 1).

Recognizing the value of adapting the GEOGLAM Crop Monitor's monitoring and evaluation framework to decisions taking place at sub-national to regional scales, instances of the GEOGLAM Crop Monitor have been co-developed with both national and regional monitoring agencies in Eastern and broader Sub-Saharan Africa (EA and SSA, respectively) to support critical early warning and early action in the face of agricultural production shocks (Nakalembe *et al.*, 2021a,b). SSA has the highest prevalence of undernourished people in the world and over 60% of the SSA population are dependent on agriculture for their livelihood (Food and Agricultural Organization *et al.*, 2020). Crop losses from drought, floods, pests and disease in this region represent even higher food security risks. Therefore, enhanced, reliable and trusted information is critical in these countries in order to meet Sendai Framework Targets A, B and E. National Crop Monitors have now been adopted in agricultural ministries in Kenya, Tanzania, Uganda, MAli and Rwanda and regionally with the Eastern Africa Intergovernmental Authority on Development Climate Prediction and Applications Center (IGAD ICPAC), providing actionable information to their governments and member countries to trigger disaster response funds supporting smallholders directly supporting SDG 2 Zero Hunger, target 2.1. In addition, through the development of Crop Monitors at scale and specifically within the regional organizations and national governments mandated to do this monitoring, Crop Monitor is also supporting SDG Goal 13: Climate Change under Target 13.3 to improve institutional capacity towards impact reduction and early warning.

The IGAD ICPAC Eastern Africa Crop Monitor (EACM, https://www.icpac.net/crop-monitor/) launched in 2018 and has been critical in providing timely early warning information on crop conditions throughout the growing season, supporting analysis of the food situation in the region in near real-time. This activity comprises a regional network of key informants from national ministries and government agencies of 11 countries that come together under the Greater Horn of Africa Climate Forum (GHACOF) to report on crop conditions and their associated drivers and develop bulletins aimed at national agricultural sector advisories and decision-makers. The outputs of the EACM have been used in regional food security analysis and in triggering emergency actions by national governments in the region in response to droughts and potential food shortages (Nakalembe *et al.*, 2021a,b). In a specific national example in Uganda, the successful uptake of EO to support regular monitoring activities has resulted in the creation of an EO evidence-based Disaster Risk Financing (DRF) program that provides alternative income sources to farmers facing crop shortages so that they can re-sow their crops and mitigate risk of acute food insecurity



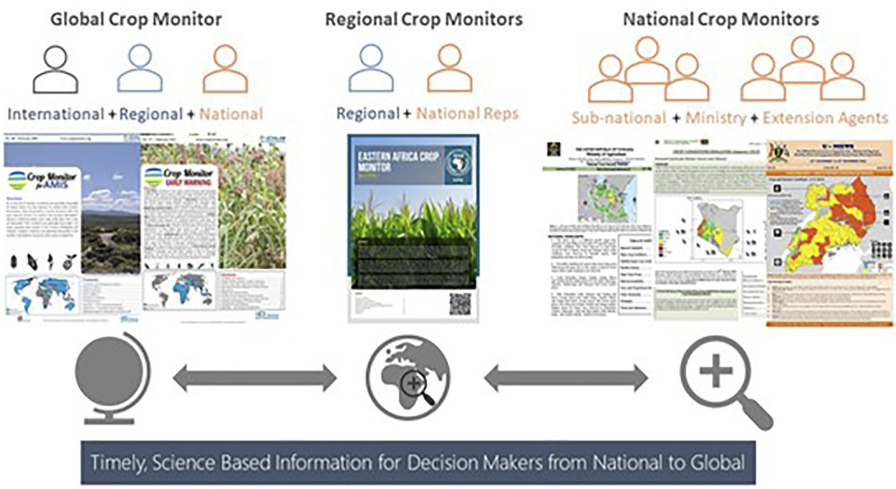
Source(s): GEOGLAM Crop Monitor

Figure 1.
GEOGLAM crop monitor global crop conditions as of January 28th, 2021 and crop monitor coverage map showing the geographic coverage and overlap of the crop monitor for AMIS, the crop monitor for early warning, the IGAD ICPAC Eastern Africa crop monitor and national crop monitors currently active in Uganda, Kenya, Tanzania, Rwanda and Mali

(Nakalembe *et al.*, 2021a,b). The DRF program has supported over 300,000 people in Karamoja, Uganda by acting proactively to protect household assets and food security when droughts hit, thereby saving the country millions of dollars spent otherwise on disaster response. In 2017, the Government of Uganda saved 2.5 million dollars (50%) of their emergency budget through proactive vs. reactive response. These use case examples are championing the uptake of EO in the region and other ministries are now doing the same, strengthening national and local DRR strategies in more and more locations (Target E) (Nakalembe *et al.*, 2021a,b).

The GEOGLAM Crop Monitor process has become an international standard approach for crop condition monitoring and has proven to be adaptable, scalable and sustainable through its successful integration within regional and national contexts. Through collaboration and coordination at scale, the GEOGLAM Crop Monitors are supporting cross-agency discussion and information sharing to support disaster preparedness systems and processes (Priorities 1–3, Target E and G) (Figure 2). As a tool for early warning, the GEOGLAM Crop Monitors aim to reduce vulnerability to food production crises and increase resilience and preparedness in advance of realized impacts (Priorities 1–3, Targets A, B and D). By providing early warning of shocks to agricultural production and increased reliability in these alerts through cross-agency consensus, the GEOGLAM Crop Monitor initiative is reducing vulnerability to climate-related extreme events along with the economic, social and environmental shocks that can result, supporting the aforementioned Sendai Framework Priorities and Targets as well as Target C (reducing economic losses).

Early warning, as provided by the GEOGLAM Crop Monitor, builds resilience to risk at scale through strengthening the disaster risk governance and enhancing preparedness and early response across national, regional and international agencies. Looking ahead,



Note(s): The operational national and regional instances of the Crop Monitors – valuable to their own usership – contribute to the global scale GEOGLAM Crop Monitors by verifying conditions that are emphasized in international assessments, and vice versa. This coordination ensures that the information provided to decision-makers is consensus based timely and fills information gaps

Source(s): NASA Harvest

Figure 2. A diagram describing how the GEOGLAM crop monitor process has been successfully adapted from global to national contexts

addressing both the COVID-19 pandemic and the sheer scale of food insecurity in the context of global environmental change requires us to work across disciplines and sectors and come together as a community to use the tools and technology available to us to mitigate shocks to food production and threats to food security and most critically support those national agencies at the front lines of these impacts. The GEOGLAM Crop Monitor has demonstrated a flexible, repeatable and scalable process for operationalizing linkages between science and action that can serve as a model to deliver on Sendai Framework Priorities and Targets while also supporting other national to global policy drivers from the G20 to the SDGs to UNFCCC activities relating to climate action (Whitcraft *et al.*, 2019).

GEO Geohazard Supersites and Natural Laboratories (GSNL) Initiative

The Geohazard Supersites and Natural Laboratories (GSNL) Initiative (http://geo-gsnl.org/) is an international partnership established under GEO, whose mission is to create effective conditions for improving geophysical science and geohazard assessment in support of DRR.

GSNL partners cooperate, using an open science approach, to understand risk causes in areas of the world subject to high seismic and volcanic risks, i.e., the Supersites. Over these areas each partner plays a specific role. For example, local observatories and research institutes provide access to ground-based monitoring data. CEOS space agencies make extensive satellite EO data available at no cost and the scientific community uses this data together with the ground data to generate scientific results which are then delivered to the local decision-makers to take action.

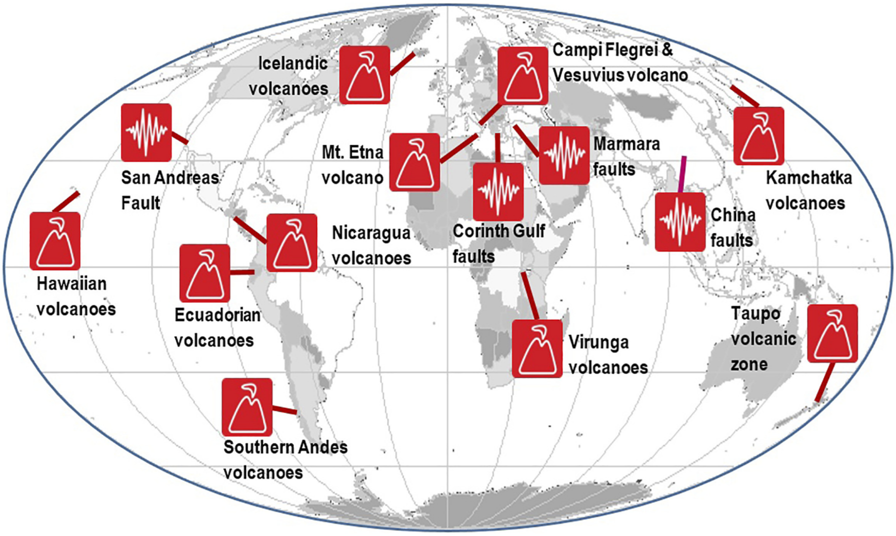
To support decisions effectively, the geohazard information must reach the local stakeholders in the correct method and form. Supersite coordinator institutions have an official role in the national risk management frameworks, therefore they use their official channels to ensure fast and effective communication to stakeholders, including citizens.

GSNL builds the Supersite network maintaining a balance between sites in developed and least developed countries. In 2017 the network included a high-risk volcanic area in the Democratic Republic of Congo, a UN Least Developed Country (LDC). The Virunga Volcanoes Supersite (VVS) was established following a proposal coordinated by the Goma Volcano Observatory (GVO). The Virunga region is located in the western branch of the East African Rift, on the border between Rwanda, Uganda and the Democratic Republic of the Congo (DRC). The VVS proposal was supported by 25 international scientists expert in volcano monitoring, volcano hazards and risk assessment. The main goal was improving geophysical scientific research and geohazards assessment in support of DRR over the Virunga region. The GVO expectations were to increase international collaboration, while at the same time ensuring the local development of strong research and monitoring capacities, as the most efficient pathway to improve geohazards assessment and risk management (see Figure 3).

The Virunga and Lake Kivu basin are regions where a number of concurrent and interacting natural hazards are linked to the volcanism and to the tectonic rifting movements. About 1.5 million people are permanently exposed to these volcanic hazards in the cities of Goma in the DRC, Gisenyi in Rwanda and in several villages located in the neighborhoods of Nyiragongo and Nyamulagira volcanoes.

The Supersite initiative supports the achievement of Target G of the Sendai Framework, i.e. "Substantially increase the availability of and access to multi-hazard early warning systems (MHEWS) and disaster risk information and assessments to people by 2030". As shown above, there is a strong need for an efficient MHEWS in the Virunga-Lake Kivu region. The Supersite represents an attempt by the local scientific community at GVO, to reach this objective through effective international cooperation efforts.

The VVS represents the first steps made towards open science in the DRC. Previously unavailable satellite EO data are now acquired and made accessible to the scientific



Note(s): The network is composed of fourteen sites with the highest seismic and volcanic risk at the global scale

Figure 3. The Geohazard Supersites and Natural Laboratories (GEO-GSNL) network as of 2021

community. Global researchers are supporting the Goma Volcano Observatory for EO data processing and interpretation (see https://doi.org/10.5281/zenodo.3910912). GSNL promotes international collaboration based on fair exchange of knowledge and aiming to develop the local research capacities. To this aim the Supersite has developed data policy terms which adapt the open science principles to the local situation, while still making all the data and research results openly accessible.

While the development of the GVO capacities for volcanic hazard assessment is a long term goal, the GSNL open science approach as applied to the VVS has already produced important results: capacity development for young GVO researchers, raised interest for the Virunga volcanoes science, monitoring of ground deformation by satellite SAR Interferometry, generation of a number of hazard and exposure maps for Goma City (see https://emergency.copernicus.eu/mapping/list-of-components/EMSN047), access to new instruments and external laboratories for ground data analysis. Before the establishment of the VVS these activities were either conducted at a limited extent, or not at all. The VVS has set the conditions for a broad international collaboration aiming to make local scientists and agencies able to independently conduct effective monitoring and geohazard assessment in the Virunga-Lake Kivu region.

GEO Global Wildfire Information System (GWIS) Initiative

The Global Wildfire Information System (GWIS) is a Web Map Service (https://gwis.jrc.ec.europa.eu) that serves near real-time updated EO information at regional and national levels, in order to provide a comprehensive view and evaluation of fire regimes and fire effects for the entire globe. GWIS services align with six of the SDGs, as well as the Paris Agreement (Mitigation) and the Sendai Framework (Target G: Increase availability of and access to multi-hazard early warning systems and disaster risk information and assessments). GWIS builds on the ongoing activities of the European Forest Fire Information System (EFFIS), the Global Terrestrial Observing System (GTOS), the Global Observation of Forest Cover- Global

Observation of Land Dynamics (GOFC-GOLD) - Fire Implementation Team (GOFC Fire IT) and its associated Regional Networks. GWIS complements ongoing activities around the world with respect to wildfire information gathering. GWIS is supported by GEO, the EC Copernicus Work Programme and NASA and is maintained and further developed by the European Commission, Joint Research Centre in Ispra, Italy.

GWIS provides harmonized information on wildfires at different scales, from national to global. At the global level, where information on wildfires is scattered and not harmonized, GWIS is a unique source of information for global initiatives and policies, while supporting the analysis of wildfire regimes at this scale (San-Miguel-Ayanz *et al.*, 2020). The calibration of the system and the validation of the different modules requires close collaboration with regional and national partners. In countries that currently do not have a wildfire information system, GWIS fills this gap. For countries and regions where wildfire information systems exist, GWIS provides a complementary and independent source of harmonized information adding to national and regional information sources.

In addition to the standards-based WMS mapping portal, GWIS provides a data and services component where archived fire information data layers can be quickly accessed and downloaded for analysis and shared in other web map services or statistical and graphics packages.

The expansion of the GWIS data and services has improved the fire information available to the global community, with particular emphasis on the integration of new EO sensor system data sets, improved fire weather forecasting options, and an addition of a statistical and graphics analysis capability derived from the MODIS/VIIRS Fire Data Record for all parts of the world. These GWIS services are already being used where wildfires are a concern and in countries where active fire analysis data is needed to fulfill national and international reporting requirements. With the support of GEO and NASA, GWIS has become a unique source of data that provides near real-time information on wildfire impacts and a global to sub-national summary, science-quality information on fire seasonality, fire size and annual rankings of fire activity, in easily accessible formats for scientists, fire and natural resource managers and policymakers.

Various organizations are currently utilizing these enhanced features in an operational environment, even while these additions are in their final beta-evaluation version. A series of workshops, showcasing the GWIS services have been conducted for agencies and personnel in Brazil, Indonesia, Guatemala, Paraguay and Colombia. The NASA Applied Remote Sensing Training Program (ARSET) has conducted a GWIS webinar in 2018 and is adding further wildfire webinars in 2021 for access and training for the international community.

GWIS will focus on developing methods for the global assessment of wildfire risk and implementation of this assessment at the global scale though collaboration with UNDRR on the Global Assessment Report and the Global Risk Assessment Framework. Focus will also be on the addition of future EO system data sets supporting the objectives of GWIS (near real-time fire detection, improved burned area determination, additional risk and fire forecasting capabilities). The GWIS team will coordinate and promote capacity building and training activities in close cooperation with NASA, Copernicus Communication Services, the GEO Secretariat, the GOFC-GOLD Fire Implementation Team regional networks and the EFFIS network, to promote dissemination of information and training on the use of GWIS methods and tools to the wildfire community and the general public.

GEO Earth Observations for Sendai Framework Monitoring (EO4SFM) community activity

The Sendai Framework aims at reducing disaster risk and losses globally. To achieve this goal information about disaster impacts and losses are essential. Disaster loss databases can help evaluating disaster risks and inform the development of DRR strategies (De Groeve *et al.*, 2014; Gall *et al.*, 2014).

At the beginning of 2021, the UNDRR Sendai Monitor, an online system created for countries to report on the Sendai Framework indicators, shows only limited data entries. Most of the countries have yet to begin reporting against or validating the 38 indicators (UNDRR Sendai Monitor, 2021). The UNDRR data readiness review indicated that only 60% of reporting countries have a database for disaster losses, and only 41% of the participating countries report data records for the entire baseline period (2005–2015) of the Sendai Framework (UNISDR, 2017a). A challenge for the national Sendai focal points remains closing these gaps to accomplish comprehensive monitoring and reporting. Monitoring the status and degree of Sendai Framework target achievement requires the use of various data sources, which should be consistent and comparable in time and space. Existing data sources for disaster losses fall short of the Sendai Framework's requirements as (1) datasets are not always available for the whole baseline period, (2) damage information and economic losses might only be recorded for individual disasters or hazard types and (3) data is often not collected consistently or only for individual sectors.

Space-based EO has a demonstrated potential for the Sendai Framework (UN-SPIDER, 2021). O'Connor *et al.* (2020) for example show how EO technologies can be used to derive disaster-related indicators of the SDGs, which are adopted from the Sendai Framework Indicator set. Yet, to the best knowledge of the authors, and despite this potential, EO has not yet become a cornerstone in the national reporting systems. Therefore, case studies and applications that provide concrete guidance for the use of EO, considering differences in EO data availability, statistical data sources and capabilities across countries and national reporting agencies, are essential to leverage the potential of EO for disaster damage assessment and SFDRR monitoring.

The GEO EO4SendaiMonitoring Community Activity will promote the use of EO data and the collaborative development of EO tools for creating useful datasets, analytical tools and quality standards to support the implementation and the monitoring of Sendai Framework indicators. By bringing together EO data providers, researchers and end users, such as Sendai national focal points and political stakeholders, EO4SendaiMonitoring aims to develop good practice guidance and an application that demonstrated the specific implementation of EO to derive selected Sendai indicators.

In the aftermath of a disaster, satellite images of the affected areas can identify the spatial extent of a disaster and identify the degree of destruction. Such information is of potential value to support the reporting of the indicators relevant for Sendai Targets B (Affected People), C (Economic Losses) and D (Critical Infrastructure). Previous studies in Germany have also shown that some of the indicators for Targets B, C and D have great potential to be supported by EO. In addition, it became clear that the assessment of economic damages experiences the biggest data gaps (ZKI-DE, 2019). The difficulty in deriving a Sendai indicator from EO is the vast amount of data needed to address the requirements of the Sendai monitor.

The SFDRR indicators in general require three different kinds of information and data: (1) disaster extent, (2) exposition data and in the case of Target C (3) information on economic damages and assets (UNISDR, 2017b). It is not possible to derive all of these parameters from one data source alone, hence the combination of EO data with other national statistics and geospatial data is vital. Various EO programs (e.g. Landsat missions, Copernicus program) and data providers can contribute to the identification of disaster extent and hazard information, as well as identification of exposed objects (see Table 1).

Methods to identify the extent of a disaster with EO are well established within the EO community and conceptually clear for several disaster types (Joyce *et al.*, 2009). However, these EO techniques do not meet the Sendai monitoring requirements. Thus, it is necessary

	SFDRR parameter	Data sources (selection)	Data type
Disaster Extent	Spatial extent of disaster (e.g. flooding, drought, storm, earthquakes, volcanos, wildfires)	Analysis of free and open satellite imagery archives (e.g. Landsat, Sentinel)	EO data
		The International Charter Space and Major Disasters–limited and controlled access	EO datda
		Copernicus Emergency Management Service (Rapid Mapping/Risk and Recovery)	EO data
		EM-DAT - The International disaster database	Statistical data
		Monitoring systems, e.g. Global/ European Forest Fire Information System	EO data
Exposition Data	Population data	National population statistics	Statistical data
	Number of residential buildings	The Global Urban Footprint/World Settlement Footprint The Global Human Settlement Layer	EO data
	Land use information (crops, livestock, forest, fisheries, aquaculture)	EO-based land use information	EO data
	Number of business and industrial sites	OpenStreetMap	Geospatial data
	Number of critical infrastructure	OpenStreetMap	Geospatial data
	Labor market data	Labor market statistics	Statistical data
	Economic Assets	/	/
Economic Damage and Assets	Damage grading (residential, industrial, agriculture, infrastructure, cultural heritage)	National disaster damage assessments Damage grading with satellite data	Statistical data EO data
	Damage functions	Damage functions (according to hazard type and economic sector)	Statistical models

Table 1. Overview of data requirements of the Sendai monitor and possible data sources

for EO practitioners to understand the requirements and needs national Sendai focal points might have to incorporate EO-based information into the official procedures of their respective national monitoring systems. By explicitly including Sendai national focal points in the EO4SendaiMonitoring activity, the developed guidance and applications can directly be tailored to their needs. The EO4SendaiMonitoring activity aims at selecting those Sendai indicators, most in demand from the national focal points and at the same time with the highest potential for being derived by EO techniques.

The activity will provide concrete guidance and highlight cases for Sendai national focal points to update their disaster loss databases based on EO data and will therefore support creating a benchmark of relevant disaster damage and economic losses that can be used to build upon disaster risk management plans and strategies.

GEO Global Flood Risk Monitoring (GFRM) community activity

Humanitarian catastrophes caused by flooding are preventable or can be minimized when prompt and objective knowledge of the impact of a flood event is made freely available. This need is particularly urgent for the distribution and quantities of support for water, food, medical care and shelters (Benight *et al.*, 1999). The number of satellite missions that include instruments that can be utilized to map flooding have increased significantly (Schumann *et al.*, 2018). At the same time, numerical models have been developed and deployed as early warning systems (Alfieri *et al.*, 2018).

Satellite data and model efforts are typically geared to capture flood events on a global scale. However, data products needed are often regional to local. And there is a major challenge in linking the data service providers to local end users. Increasingly, web map services (WMS) are assisting, as they allow for instant access to the latest available data and enable interoperability of various geospatial data systems. Focusing on the impact of Tropical Cyclone (TC) Eloise (January 2021), the below described case study is used to distill prompt and informative flood information and make this freely available, within the scope of the GEO Global Flood Risk Monitoring (GFRM) Community Activity. GEO GFRM promotes integration of information from multiple EO systems to provide flood risk information for the benefit of decision-makers. A wealth of flood data from different initiatives is integrated, to a) make flood information accessible through one portal and b) integrate the data such that it delivers more informative flood information. These efforts directly address Sendai Framework Priorities 1 (Understanding disaster risk) and 3 (Investing in DRR for resilience).

One example where GEO GFRM efforts illustrate well its inherent links to the Sendai Framework and associated foundational priorities for action, is in the response activities to the flooding in Mozambique in late January as a result of TC Eloise. Preliminary reports from the Mozambique disaster management agency indicate over 300,000 people were affected (Reliefweb, 2021). As part of the GFRM efforts, a number of EO and model datasets were integrated in an effort to provide actionable flood information as soon as the underlying data became available. The comprehensive dataset, illustrated in Figure 4, included simulations from the operational Global Flood Monitoring System (GFMS, Wu *et al.*, 2014; http://flood.umd.edu), inundation maps utilizing high spatial resolution (10 m) synthetic-aperture radar (SAR) data (Shen *et al.*, 2019) and daily updated satellite-based river discharge timeseries (also known as RiverWatch) that are produced and updated daily by the DFO – Flood Observatory (Brakenridge *et al.*, 2012; https://floodobservatory.colorado.edu/DischargeAccess.html). The well-known operational near real-time, MODIS based global flood maps (Nigro *et al.*, 2014) were also part of the GFRM response efforts.

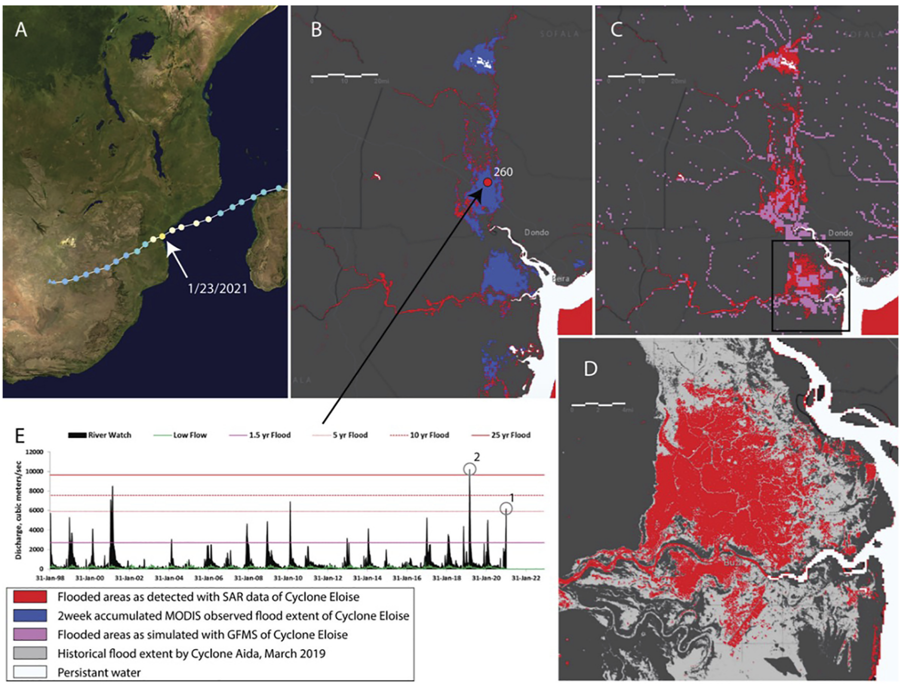
The above-described data products are transformed to open standard Web Map Services (WMS; de la Beaujardiere, 2006) and hosted at the DFO – Flood Observatory (http://floodobservatory.colorado.edu/WebMapServerDataLinks.html), where end-users can visualize and examine datasets typically produced by GEO GFRM response activities.

As the example of TC Eloise shows, important progress is made by integrating the model simulations and remote sensing products. Such advances in EO-based products and services are underpinning the objectives of the Sendai Framework. Science-based products and sharing of open-access datasets foster understanding of disaster risk and, as a result, help strengthen disaster risk governance to better manage disaster risk. This, in turn, enables investing in disaster reduction for resilience and also enhancing disaster preparedness for effective response. Even more importantly, as a direct consequence, it allows affected communities and entire nations to recover faster and rebuild stronger after the next flood disaster.

EuroGEO Disaster Resilience Action Group

The huge amounts of satellite EO data, also regarded as big EO data, provide high scientific value and support the development of scalable and informative applications in order to address operational Emergency Management and DRR. Two EuroGEO Action Groups addressing DRR, are the Disaster Resilience Showcase in the framework of the e-shape EU project and the Action Group for Epidemics Risk Monitoring and Control, both running under the coordination of BEYOND/NOA (http://www.beyond-eocenter.eu). The overarching goal of both is to deliver scientific excellence and open innovation, technology, science and user centric services/platforms, for the benefit of citizens, public authorities and business sectors. Today, a number of studies are conducted under the EuroGEO flag, leveraging partner experience and the GEO heritage, in line with the triptych Advocate-Engage-Deliver. Advocate inventorying of needs and integration of capacities, skills, data and key co-designers from the vast stakeholder community. Engage users, data provides, scientists, beneficiaries and decision/policymakers across the entire value added chain. Deliver novel services and advanced knowledge to decision-makers, along with networking capacity building and user training.

DRR in EuroGEO receives support from the e-shape EU project (https://e-shape.eu/) and the complementary voluntary activity from partners and covers a large variety of studies in the disasters domain indicatively relating to, (a) Flash flood early warning and situation awareness, (b) Wildfires risk assessment, combined with early detection and real time monitoring directly in support to the crisis management centers, (c) Anticipation of protective measures against geo-hazards in the built up environment, (d) Food protection and farmer resilience, (e) Adaptation to climate change in the agriculture, water, energy, insurance and food sectors, (f) Business continuity and citizen resilience, (g) Health sector support and early warning for epidemics related to vector-borne diseases.



Note(s): Interesting to note is that Cyclone Idai in 2019 had the flood of record since 1998 (flood extent in Figure 1d), but Cyclone Eloise generated discharges over 6,000 m3/s and has a recurrence interval of 5 years

Figure 4.
Cyclone Eloise and associated flooding impact; (a) Path and intensity according to the Saffir–Simpson scale of TC Eloise; (b) In red inundation extent based multiple SAR images with the MODIS-derived 2-week inundation extent on top (in blue; January 19 – February 2), also, the virtual discharge gaging station (#260) is shown, indicating "Major flooding"; (c) GFMS simulated maximum flood extent projected on the SAR observed flooded area (red); (d) Zoom in (inset of 1C) to the inundated area caused by Cyclone Eloise (red) compared to the flood extent (light grey) caused by Cyclone Idai, March 2019; (e) River discharge time series of virtual gage 260 of the Pungue River, Mozambique (http://floodobservatory.colorado.edu/SiteDisplays/260.htm)

The BEYOND/NOA Center for EO Research and Satellite Remote Sensing of the National Observatory of Athens, in its capacity as coordinator of the EuroGEO Disasters Resilience and Epidemics Action Groups, runs monthly assessments and guidance to the involved groups and facilitates the scientific exchange between pilots, in order to enhance collaboration, raise synergies between the innovators/developers of the actions and engage stakeholders for EO market uptake. At the same time BEYOND/NOA brings forward research and innovation with significant societal impact, leveraging on its observational capacities and multidisciplinary skills and delivers sustainable and user centric services and Decision Support Systems for the effective management of risks in the different fields of DRR (www.beyond-eocente.eu). In the following section, the operational platform EYWA that is an Early Warning System for Mosquito Borne Disease (MBD) outbreaks (e.g. West Nile Virus (WNV) developed under the EuroGEO flag, is presented. It consists a highlighted voluntary and self-sustained action, attracting the interest of key stakeholders acting in the Health sector worldwide.

Today there is a constantly increasing need to innovate on how the continuous threat of MBDs are confronted, treated but most of all foreseen (Parselia, 2019). This need gave birth to the EYWA platform (http://beyond-eocenter.eu/index.php/web-services/eywa), an integrated and contemporary EarlY WArning System (EWS), which stands on rock solid state-of-the-art technological foundations and builds European scientific excellence in the field. From the concept point of view, EYWA is a standardized, integrated, robust, transferable and user-centric DSS, operational primarily in Europe, but with the prospect to be migrated and deployed globally. Its demonstration, in real world operational control actions, provided timely warning and risk assessments for different mosquitoes and related diseases. It proved its scalability and applicability in different spatiotemporal scales, ranging from the local municipal to regional and European level. The system capitalizes on the analyses of multi-source and multi-spatiotemporal data along with big series of EO images and EO derived essential and climatic parameters. EYWA with its scientific, technical, conceptual and operational characteristics is expected to contribute significantly to the goals of the newly established Health Emergency Preparedness and Response Authority (HERA), WHO, ECDC and national Health Authorities.

Today EYWA addresses operational and pre-operational needs of five European countries as Greece, Italy, Serbia, France and Germany and delivers during the entire mosquito season reports on (a) mosquito abundance, (b) mosquito nuisance, (c) WNV risk, (d) guidelines and best practices for optimizing the planning of monitoring actions, trap deployment, mosquito control and door-to-door operations (e.g. for effective larviciding). From the Societal benefit point of view, EYWA contributes significantly to the decrease of mosquito population and the reported WNV human cases. To be noted that in the several demonstrations run, EYWA helped in the decrease of mosquitoes compared to the average and worst-case scenarios for the last decade and has averted WNV infections and WNND cases (i.e. meningitis and encephalitis).

CEOS WGDisasters Recovery Observatory Demonstrator

The CEOS WGDisasters Recovery Observatory Demonstrator began as a pilot activity after Hurricane Matthew in Haiti in 2016, directly addressing Sendai Framework Priority IV: “Build Back Better” (https://ceos.org/ourwork/workinggroups/disasters/recovery-observatory/). The Demonstrator aims to bring together the full range of useful satellite data before, during and after a disaster–without any disruption and as long as needed for recovery purposes and to link to resources to generate satellite-based information products geared to the specific recovery needs and customized to recovery actors’ requirements. In addition, the RO is distinguished by a tailored capacity building component that identifies existing capacity and develops a dedicated development plan to integrate valued added EO applications and products. Typically, a RO would have a range of different satellite data addressing a variety of needs depending upon the disaster type, the sectors impacted, the geographic area and the progress in recovery timeline. While existing services such as Copernicus or UNOSAT can provide standard and even adapted products, a RO would define a dedicated acquisition plan, program regular updates over the entire recovery period and seek out science-based products not typically used during response but valuable to recovery end users.

The RO Demonstrator has already, through its early pilot activities focused on post Hurricane Matthew needs in Haiti, greatly contributed to increasing awareness with the RO community of the value and usefulness of satellite EO-derived recovery products. Through the Demonstrator, the community aims to experiment with concrete challenges and establish a standard set of operating procedures for the application of satellite EO for disaster recovery. The lessons learned from the Haiti RO Pilot were critical in defining the structure and objectives of the new Demonstrator to include:

(1) Recovery satellite EO needs are different from those of other phases of disasters.

(2) Specific approaches and adapted strategies are required, before events occur.

(3) A coordinated approach from event to National Recovery Plan is required.

(4) Strong involvement of local users (and EO data providers when applicable) is necessary to success, however support of the international stakeholder community is also important.

(5) Local capacity building should be a standard component during efforts to integrate EO into recovery situations.

Having demonstrated the feasibility and the benefits of applying satellite EO to early recovery on a systematic basis, using a range of examples from different parts of the world, CEOS aims to establish a sustainable partnership with the international DRM stakeholder community to ensure that satellite EO can be regularly applied to recovery, not only to early warning and response. The first RO Demo activation has already taken place in 2021, in four countries in Central America, after Hurricanes Eta and Iota. Satellite imagery is being used to further evaluate damages in remote areas, understand recovery efforts and especially to assess new risk caused by damaged infrastructure.

CEOS WGDisasters Landslide Demonstrator

Extreme rainfall resulting from tropical storms is a potential trigger of landslides in mountainous regions around the world. The intense rain can rapidly saturate hillslopes and lead to failures, and if people and infrastructure are caught in the runout paths of landslides severe damage and loss of life can occur. For decision-makers, information on the likely location of landslides during a major rainfall event can help prioritize disaster response resources in mountainous regions and rapid mapping of landslide locations in the immediate aftermath can quickly highlight impacted communities. EO data can provide a regional and local perspective on the likely location of landslides and their impacts, as well as rapidly mapping the landslides that occur as a result of rainfall. The CEOS WGDisasters Landslide Demonstrator effort has pioneered some new techniques to leverage remote sensing data for increased situational awareness of landslide hazards. These include high resolution optical data, Synthetic Aperture Radar (SAR), and the surface and atmospheric variables that contribute to landslide hazard such as rainfall, topography and land cover. A case study outlining some of these activities is provided here.

In late 2020, two major hurricanes (Eta and Iota) made landfall in Central America within only a few days of one another. Both hurricanes brought intense rainfall to parts of Nicaragua, Guatemala and Honduras and led to significant landsliding. Hillslopes saturated by rain from the first event (Eta) were further destabilized by rainfall from Iota, creating a more hazardous scenario than if the events were spaced further apart. Critical infrastructure and populations throughout the region were exposed to landslide hazards, and decision-makers both at a national level and within multinational agencies requested information about the likely location of landslides and potential distribution of the hazard.

NASA researchers provided a number of experimental products based on EO data to highlight the potential impacts of these events, including near-real time modeling of landslide hazard for each day of both Hurricane events and associated estimates of exposure of people and infrastructure. This information draws upon satellite rainfall data and landslide susceptibility information to highlighted areas where hazard and exposure are elevated. In the immediate aftermath of the storms, the NASA team also mapped landslides that occurred as a result of both storms using high resolution, rapid return optical data from Planet. The information was provided to a number of decision-makers in the affected areas to help inform critical decisions about landslide impact mitigation.

The CEOS Landslide efforts have explored additional ways to fuse SAR and optical data to further characterize the distribution of landslide hazards, particularly when cloud cover is pervasive over affected regions. These activities demonstrate the feasibility and utility of remote sensing to inform landslide hazard and risk at a local to global scale. They also support Sendai Framework Priority 1 (Understanding disaster risk) by improving availability of rapid-response information for a range of end-users. By focusing on population and infrastructure concerns and informed by targeted collaboration with decision-makers, these activities can help reduce the economic and human impacts of landslide disasters, with a future objective of supporting Priority 2 (Strengthening disaster risk governance to manage disaster risk) (see Figure 5).

Earth observations in the context of national risk reduction decision structures leveraging geospatial solutions

The GEO and CEOS case studies addressed in the previous section speak to the extensive efforts underway to integrate EO into national DRR decision structures, across diverse geographies, thematic natural hazard and exposure focus areas, leveraging a variety of geospatial solutions. This reality prompted the creation of a GEO Disaster Risk Reduction Working Group (DRR WG) in 2020 to develop and implement a coherent and crosscutting approach to advance the use of EO in support of countries' DRR efforts, strengthen collaboration directly with UNDRR and UN-GGIM and improve linkages between DRR, SDG and climate change activities.

One specific method the GEO DRR WG is utilizing to achieve these objectives is the promotion of existing and relevant policy frameworks that can support and expedite uptake of GEO and CEOS activities, such as the UN-GGIM Working Group on Geospatial Information and Services for Disasters' (WG-Disasters) Strategic Framework on Geospatial Information and Services for Disasters 2016–2030 (https://ggim.un.org/documents/UN-GGIM_Strategic_Framework_Disasters_final.pdf).

The UN-GGIM WG-Disasters was established under decision 5/110 by the UN-GGIM in August 2015, to develop and implement a strategic framework aimed at improving geospatial information policy, processes and services to support emergency response and disaster risk management and aligned with the outcome and follow up to the Sendai Framework and its implementation.

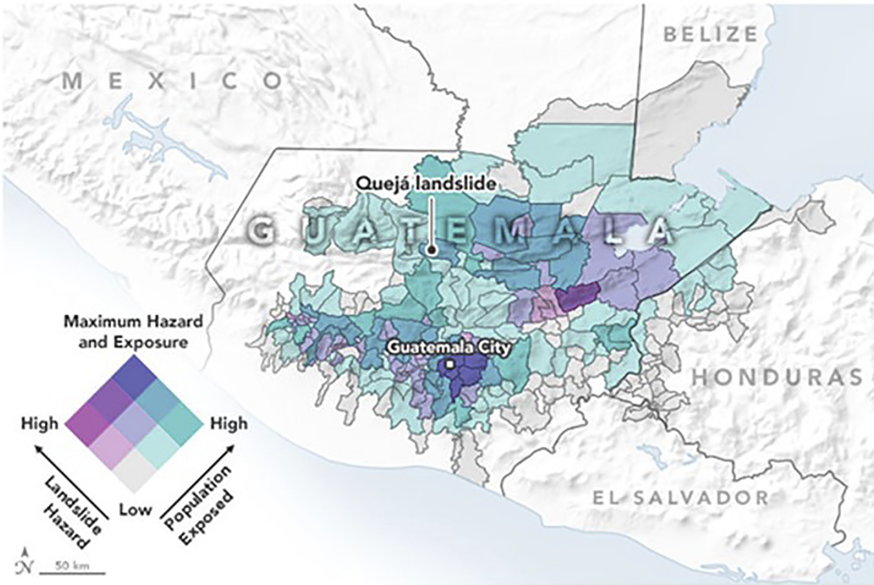


Figure 5.
Estimated population exposure to landslide hazard in Central America on November 5, 2020

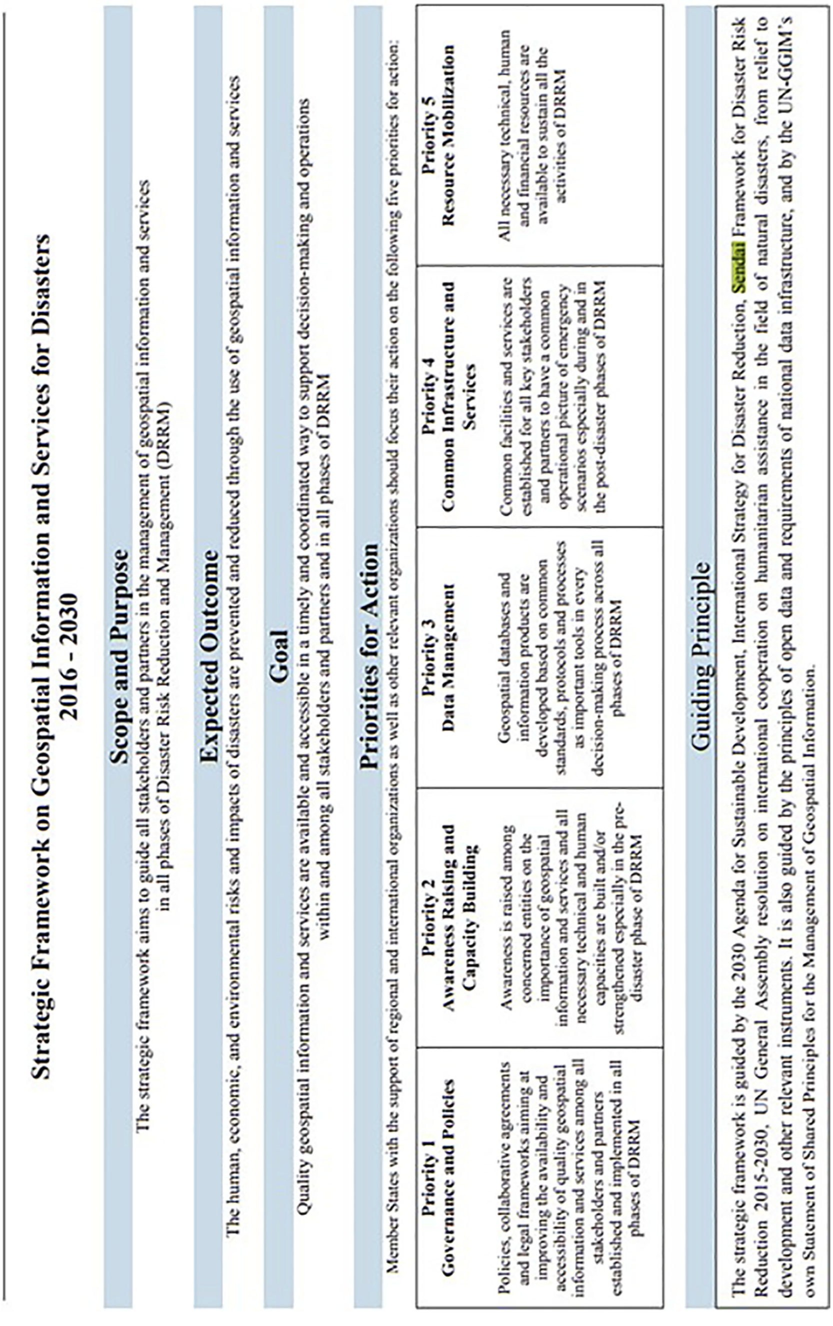
Note(s): Image highlights areas of high hazard and associated exposure of population to landslides associated with each Level-2 administrative district. This data is generated from NASA's LHASA model (Stanley *et al.*, 2021)

The Strategic Framework (see Figure 6), was endorsed and adopted by the United Nations Economic and Social Council (ECOSOC) in July 2018. The resolution invited Member States, their relevant government bodies, the United Nations system, international organizations, donors, the private sector, academia and non-governmental organizations with responsibility for DRR and management, in accordance with their mandates, to adopt the Strategic Framework, recognizing that disaster risk management requires the commitment and cooperation of all stakeholders.

The Strategic Framework is a guiding policy document to assist countries in preventing and reducing the impact of disasters using geospatial information. It provides a platform for the integration of spatial and non-spatial data sets in disaster risk management (DRM) and unites communities of users to promote dialogue, collaboration and innovation concerning interoperability and harmonization of data standards.

Importantly the Strategic Framework is strongly aligned with relevant global policy frameworks including, but not limited to, the 2030 Agenda for Sustainable Development and the Global Statistical Geospatial Framework.

The structure, language, timeline for implementation and the fundamental tenets of the Strategic Framework is modeled on that of the Sendai Framework. As with the Sendai Framework, the Strategic Framework is structured along similar headings including the expected outcome and goals, guiding principles, priorities for action which are divided into local, national, regional and global levels, with additional focus on the role of stakeholders. This is all undertaken in the context of defining the pivotal importance of geospatial information and services across all phases of disaster risk management to support decision-making.



Strategic Framework on Geospatial Information and Services for Disasters 2016 - 2030

Scope and Purpose

The strategic framework aims to guide all stakeholders and partners in the management of geospatial information and services in all phases of Disaster Risk Reduction and Management (DRRM)

Expected Outcome

The human, economic, and environmental risks and impacts of disasters are prevented and reduced through the use of geospatial information and services

Goal

Quality geospatial information and services are available and accessible in a timely and coordinated way to support decision-making and operations within and among all stakeholders and partners and in all phases of DRRM

Priorities for Action

Member States with the support of regional and international organizations as well as other relevant organizations should focus their action on the following five priorities for action:

Priority 1 Governance and Policies	Priority 2 Awareness Raising and Capacity Building	Priority 3 Data Management	Priority 4 Common Infrastructure and Services	Priority 5 Resource Mobilization
Policies, collaborative agreements and legal frameworks aiming at improving the availability and accessibility of quality geospatial information and services among all stakeholders and partners established and implemented in all phases of DRRM	Awareness is raised among concerned entities on the importance of geospatial information and services and all necessary technical and human capacities are built and/or strengthened especially in the pre-disaster phase of DRRM	Geospatial databases and information products are developed based on common standards, protocols and processes as important tools in every decision-making process across all phases of DRRM	Common facilities and services are established for all key stakeholders and partners to have a common operational picture of emergency scenarios especially during and in the post-disaster phases of DRRM	All necessary technical, human and financial resources are available to sustain all the activities of DRRM

Guiding Principle

The strategic framework is guided by the 2030 Agenda for Sustainable Development, International Strategy for Disaster Reduction, Sendai Framework for Disaster Risk Reduction 2015-2030, UN General Assembly resolution on international cooperation on humanitarian assistance in the field of natural disasters, from relief to development and other relevant instruments. It is also guided by the principles of open data and requirements of national data infrastructure, and by the UN-GGIM's own Statement of Shared Principles for the Management of Geospatial Information.

Figure 6. Strategic framework on geospatial information and services for disasters

Gaps and challenges

The task of integrating EO applications into national DRR decision structures leveraging geospatial technology brings many challenges. The clear identification of these challenges and associated gaps is critical to ensure relevant solutions can be pursued that are replicable and scalable.

One example includes the UN-GGIM WG-Disasters' Strategic Framework Assessment Survey, which provides insight into existing challenges. As with the Sendai Framework, the Strategic Framework comes with an Assessment Survey aimed at gauging the level and status of implementation of geospatial information and services for disasters initiatives relative to the Strategic Framework among countries. It is also geared to assist countries to better develop their national implementation plans for geospatial information and services in support of disaster risk management.

The first round of the Assessment Survey was conducted in the last quarter of 2020 and an initial analysis was undertaken of sixteen (16) responses from twelve (12) countries within the Americas–North, Central, South and the Caribbean. The results from this analysis are provided here which gives an indication of the status of disaster risk management in the Americas. The global assessment and resulting report is expected to be presented at the 11th session of the UN-GGIM in August 2021.

For the assessment, each respondent determined their level of readiness for implementing the Strategic Framework for Disasters on a scale of 1–5, with 1 indicating being unaware of the initiative and its implementation within their country, while 5 indicates the initiative being fully implemented (Table 2).

For priority areas 1 through 4, an overwhelming majority of the respondents indicated achieving level 3, whereby the geospatial information and services enabled DRM initiative is currently being implemented in their country, with major tasks still needing to be undertaken. Of this, 40% indicated level 3 for Governance and Policies, 55% Awareness Raising and Capacity Building, 53% Data Management and 55% Common Infrastructure and Resources. This is very promising as the countries are aware of and have started to implement actions towards ensuring the use of geospatial information (include EO technology and products) and related services in response to disasters. On the other hand, forty seven percent (47%) indicated attaining level 2 for Resource Mobilization. This indicates that Resource Mobilization activities towards enabling utilizing of geospatial information and services for DRM initiatives have not yet been implemented in their country (Figure 7).

Responding countries indicated experiencing challenges or gaps in leveraging geospatial data and related infrastructures. This included a lack of sufficient financial resources or that financial support for DRM is decentralized at local levels. Some communication channels rely on personal network contacts rather than institutional arrangements. In other cases, communication channels exist but their maturity and operation needed improvement. A lack of or outdated DRM laws and policies were other challenges identified. In addition, the analysis showed that DRR related actions exist but are ad hoc, diffused, intermittent and not systematized in a roadmap. The availability and integration of geospatial information

Category	Description
5	The initiative is fully implemented in my country
4	The initiatve is currently being implemented in my country, with minor tasks still need to be done
3	The inititive is currently being implemented in my country, with major tasks still need to be done
2	The initiative is not yet implemented in my country
1	Unaware of the initiative, and its implementation in my country

Table 2.
Strategic framework categories

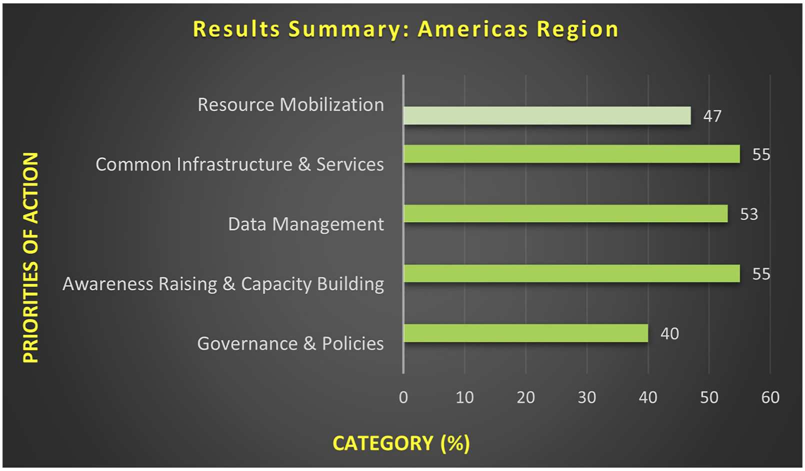


Figure 7.
Strategic framework assessment tool results summary – Americas region

including free and open EO data for DRR needs further strengthening. Additionally, the difficulty in advocating for the use of geospatial information, as many policymakers and stakeholders find it hard to understand geospatial information and related products. These gaps and challenges provide opportunities for DRR bodies to collaborate with countries towards improving their readiness in utilizing geospatial information and services for disasters.

Recommendations: now and looking towards 2030

A collaborative effort between UNDRR, GEO and CEOS has begun that will bring more policymakers and decision-makers up to speed with EO technological developments that open new possibilities for DRR. Awareness raising about the availability and application of open EO data is critical for policy development in several policy areas, not only DRR but sustainable development, environmental services, health services and climate change adaptation. Such capacity building efforts must be coupled with careful, application-specific considerations about what appropriate and balanced applications of EO's for DRR would look like. For instance, EO has great potential to contribute to quantifying the ecological nuances underpinning the benefits of large-scale ecosystem regeneration for flood risk reduction–a particularly timely and useful tool given the unprecedented need to implement large-scale flood risk reduction projects across large spatial scales (Bradshaw *et al.*, 2007; Gao and Yu, 2017; Cooley and Reichenbach, in prep). Despite this potential, many of the costs and benefits associated with such complex intersections of governance, land use policy and risk reduction trade-offs cannot be appropriately understood or assessed by remote sensing approaches alone. Thus the EO community must effectively communicate EO limitations while also emphasizing that this information complements but does not replace the need for *in situ* observations, local knowledge and indigenous wisdom (Balsamo *et al.*, 2018; Ban *et al.*, 2018; Pause *et al.*, 2016). This allows for successful implementation of the Sendai Framework guiding principle of inclusion of all of society in decision-making processes via the coupling scientific data with indigenous and local knowledge.

Regional and global cooperation is recognized as a critical element in managing geospatial information and services during disasters, and the UN-GGIM WG-Disasters has been focused on building such partnerships. The Aguascalientes Declaration, "Better Together: Geospatial

Information for decision-making in the Americas", September 2020, is one such regional initiative which aims to strengthen and improve collaboration among regional bodies in the Americas on the use of EO, geospatial, statistical and other information to support national development priorities. As the current extent of EO in national DRR strategies is better understood, increased activities can be targeted towards enhanced use of EO as a powerful tool, in the appropriate context noted above, that can strengthen our ability to reduce current and emerging risks.

Conclusion

The climate crisis is forcing countries to face unprecedented frequency and severity of disasters. At the same time, there are growing demands to respond to policy at the national and international level. EOs offer insights and intelligence for evidence-based policy development and decision-making to support key aspects of the Sendai Framework. The GEO DRR WG and CEOS WGDisasters are ideally placed to help national government agencies, particularly national Sendai focal points to learn more about EOs and understand its role in supporting DRR.

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