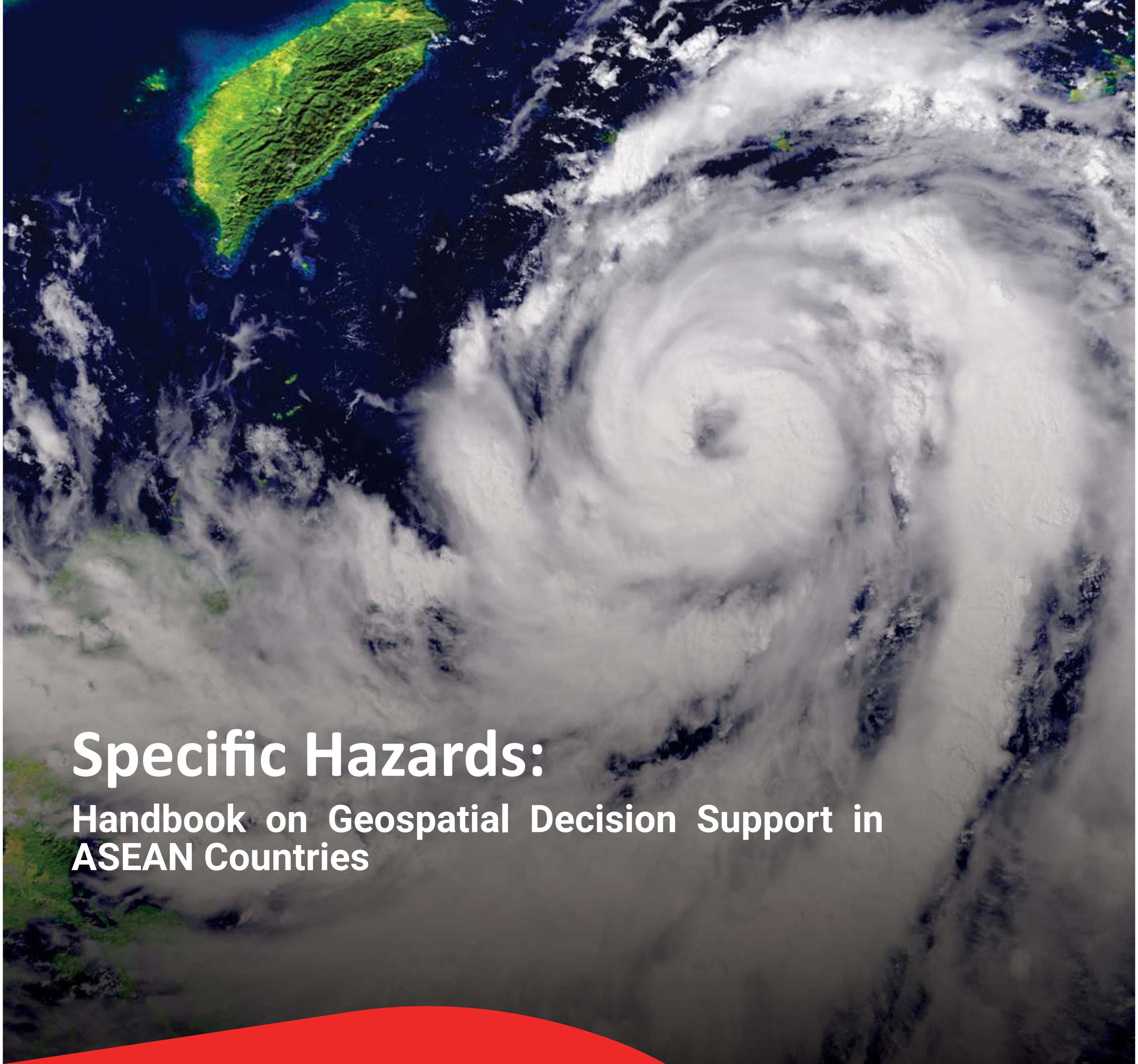

Specific Hazards:

Handbook on Geospatial Decision Support in ASEAN Countries

UNITED NATIONS
ESCAP
Economic and Social Commission for Asia and the Pacific

The shaded areas of the map indicate ESCAP members and associate members.

The Economic and Social Commission for Asia and the Pacific (ESCAP) serves as the United Nations' regional hub promoting cooperation among countries to achieve inclusive and sustainable development. The largest regional intergovernmental platform with 53 Member States and 9 associate members, ESCAP has emerged as a strong regional think-tank offering countries sound analytical products that shed insight into the evolving economic, social and environmental dynamics of the region. The Commission's strategic focus is to deliver on the 2030 Agenda for Sustainable Development, which is reinforced and deepened by promoting regional cooperation and integration to advance responses to shared vulnerabilities, connectivity, financial cooperation and market integration. ESCAP's research and analysis coupled with its policy advisory services, capacity building and technical assistance to governments aims to support countries' sustainable and inclusive development ambitions.

Specific Hazards:

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Specific Hazards:
Handbook on Geospatial Decision Support in ASEAN Countries

United Nations publication

Printed in Bangkok

Preface

This handbook forms part of a series of knowledge products developed in collaboration with Association of Southeast Asian Nations (ASEAN) institutions and ASEAN member countries. The series is designed to increase skills and promote institutional development for countries wishing to embrace innovative space-based information in disaster risk management. The products can be used as training manuals and reference guides, addressing the needs of both geospatial information providers and disaster decision makers.

This handbook explains the techniques, methodologies and best practices for using geospatial information in support of decision making for disaster risk management. The focus is on specific hazards. While space-based information can significantly enhance disaster emergency response and preparedness, maps may often look similar. The nature of different types of hazards requires a range of theme-specific information or data sets that may not be immediately apparent, or available in one single map or information product. This handbook thus addresses the needs of disaster managers and geospatial information providers who must remain aware of the decision-making considerations for different hazard contexts.

ESCAP, in collaboration with United Nations partners and the ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management, has developed this handbook in response to the expressed needs of ASEAN countries. ESCAP worked in close collaboration with analysts with extensive regional and international experience in the provision of earth observation data and information to countries in the aftermath of disasters. It is based on standard techniques and methodologies used to develop such geospatial information products, and has been developed together with ASEAN counterparts, keeping the institutional and operational needs of the region in mind. Through extensive consultations, the techniques and methodologies have been field tested during simulation exercises conducted in 2016.

It is our hope that this handbook and its innovative techniques, methodologies and best practices, will significantly contribute to strengthening the disaster risk resilience of countries in the ASEAN region.

Acknowledgements

Under the overall guidance of Tiziana Bonapace, Director, of the Information and Communications Technology and Disaster Risk Reduction Division (IDD) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), development of the handbook was coordinated by Syed T. Ahmed, Space Applications Section (SAS), IDD, ESCAP, through extensive consultation with experts from space agencies and national disaster management authorities (NDMAs) of the Association of Southeast Asian Nations (ASEAN) member countries. Initial background research was provided by an ESCAP consultant, Syams Nashrrullah, while Valentina Spanu, also an ESCAP consultant, reviewed and finalized the handbook, working on the specific case studies for natural hazards and providing technical edits.

Substantive contributions and comments were received from Kaveh Zahedi, Deputy Executive Secretary for Sustainable Development, ESCAP, Keran Wang, former Chief of SAS, IDD; Werner Balogh, Chief, a.i., of SAS, IDD, and Khaled Mashfiq, Regional Liaison Officer, United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme (UNOSAT).

Further technical inputs were received from the GeoInformatics Centre of the Asian Institute of Technology (AIT), as well as space agencies and NDMAs from the ASEAN region for the relevant case studies and decision-making considerations that they normally encounter. The handbook has been cross-referenced with the Emergency Mapping Guidelines produced by the International Working Group on Satellite-based Emergency Mapping (IWG-SEM) and its specific section on floods.

The handbook also benefited from peer reviews by national focal points of the ESCAP Regional Space Applications Programme for Sustainable Development, partners across other United Nations agencies and the ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management (AHA Centre). ESCAP acknowledges the joint efforts of ESCAP, UN-SPIDER and AHA Centre in conceptualising this initiative to support ASEAN countries, through a series of workshops conducted with ASEAN countries over the course of 2016 and 2017.

The team acknowledges the support of Jiae Kim for assisting with research during her internship with SAS, IDD, ESCAP. Editorial revision was provided by Marnie McDonald.

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Acronyms and abbreviations

AHA Centre	ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management
ASEAN	Association of Southeast Asian Nations
AVHRR	Advanced Very High Resolution Radiometer
BTD	Brightness Temperature Difference
DEM	Digital Elevation Model
EO	Earth Observation
GIS	Geographic Information System
GISTDA	Geo-Informatics and Space Technology Development Agency (Thailand)
GOES	Geostationary Operational Environmental Satellite
GSMaP	Global Satellite Mapping of Precipitation
HR	High Resolution
InSAR	Interferometry Synthetic Aperture Radar
IWG-SEM	International Working Group on Satellite-based Emergency Mapping
LAPAN	National Institute of Aeronautics and Space (Indonesia)
LULC	Land Use and Land Cover
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration (United States of America)
NBR	Normalized Burn Ratio
NDMA	National Disaster Management Authority
NDVI	Normalized Difference Vegetation Index
OSM	Open Street Map
PHIVOLCS	Philippine Institute of Volcanology and Seismology
SAR	Synthetic Aperture Radar
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNITAR	United Nations Institute for Training and Research
UNOSAT	UNITAR's Operational Satellite Applications Programme
VHR	Very High Spatial Resolution

Overview

Introduction

This handbook was developed by ESCAP with technical input from partners and in consultation with experts from space agencies and NDMAs of ASEAN member countries. The development of this handbook was based on direct country requests which were made during a workshop jointly organized by ESCAP, the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) of the United Nations Office for Outer Space Affairs, AHA Centre and the National Institute of Aeronautics and Space of Indonesia (LAPAN): 'Simulation exercise on the procedural guidelines for sharing space-based information during emergency response', held in April 2016 in Bogor, Indonesia. During the workshop, countries identified the need for a technical manual that was specific for each hazard common to the ASEAN region. ESCAP then undertook this project to develop the Geospatial Decision Support Handbook: for specific hazards in ASEAN countries.

This handbook provides a detailed reference manual and a supporting Quick Guide to be used for operational purposes when coordinating earth observation (EO) information during emergency response. The hazards outlined in the handbook have been selected through consultation with disaster management experts in the ASEAN region and are based on analytical research of common disaster types from ***The Asia-Pacific Disaster Report 2015 – Disasters without Borders*** [1] and the ***United Nations Global Assessment Report on Disaster Risk Reduction 2015***. [2] Good practices have been incorporated from the UNOSAT

1 See www.ESCAP.org/resources/asia-pacific-disaster-report-2015.
2 See www.unisdr.org/we/inform/publications/42809.

Rapid Mapping Service, [3] Copernicus Emergency Management Service [4] and the Emergency Mapping Guidelines developed by IWG-SEM, [5] while maintaining standards based on humanitarian practice as indicated in the guidance provided by the United Nations Office for the Coordination of Humanitarian Affairs through its Multi-Cluster/Sector Initial Rapid Assessment. [6]

This handbook has been designed to be used by disaster decision makers and end users of EO information and can also provide some guidance to geospatial information providers. It contains contextual information on each specific hazard, including the main characteristics of the hazard and the subsequent considerations when developing EO products in relation to the specific nature of the hazard. It also lists the types of geospatial products that are available at different time frames of the disaster cycle, as well as the techniques and methodologies used to develop them. Decision makers will learn what information may be required from them in order to support the development of necessary products.

A dedicated section on decision-making is provided for each hazard and places all of this information into the context of the type of decisions that need to be made and how EO data and products can support those decisions for a given hazard. In addition to this handbook, a supplementary Quick Guide is also available for use as an operational field tool.

3 See www.unitar.org/unosat/rapid-mapping.
4 See http://emergency.copernicus.eu/.
5 See www.un-spider.org/news-and-events/news/iwg-sem-released-emergency-mapping-guidelines.
6 See www.humanitarianresponse.info/en/programme-cycle/space/document/multi-sector-initial-rapid-assessment-guidance-revision-july-2015.

Geospatial data sets for disaster emergency response

Geospatial data provides essential information for effective and timely response during an emergency. Ideally, baseline data should be readily available before a disaster occurs so it can be easily incorporated with observation data collected during the disaster itself. The official national data set is the most reliable source for data preparation. However, lack of data sharing mechanisms in some countries often limits data accessibility. To overcome this problem, some countries have established a national spatial data infrastructure to promote the coordinated use, sharing and dissemination of geospatial data. Alternatively, free global data sets are available to fill these gaps. Table 1 shows some of the important baseline and observation data sets for disaster response, including freely available data sources.

More detailed guidance on the Common Operational Data sets (COD) for disaster preparedness and response has been prepared by the United Nations Office for the Coordination of Humanitarian Affairs. A list of available baseline data sets and documentation of the guidelines can be found at the following websites:

- https://data.humdata.org/
- https://www.humanitarianresponse.info/en/applications/tools/category/operational-datasets

Table 1: List of important baseline and observation data for disaster response

	Data set	Data source (free)
Baseline Data	Administrative boundaries	GADM (Database of Global Administrative Areas)
	Transportation networks (roads, railways, bridges, etc.)	OpenStreetMap (OSM), collaborative data updates available from Humanitarian OSM
	Critical facilities (hospitals, fire stations, police stations, schools, government offices, etc.)	OSM, Collaborative data updates available from Humanitarian OSM and Humanitarian Data Exchange
	Land use and land cover (LULC)	GlobCover, Moderate Resolution Imaging Spectroradiometer (MODIS) Global Land Cover, OSM
	Building footprints	OSM, collaborative data updates available from Humanitarian OSM
	Population	WorldPop, LandScan, Gridded Population of the World, Global Rural-Urban Mapping Project
	Digital Elevation Model (DEM)	Shuttle Radar Topography Mission, Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model Version, Advanced Land Observing Satellite Global Digital Surface Model
	Satellite images (pre-disaster)	United States Geological Survey EarthExplorer, Sentinel Asia (restricted), Sci-Hub (Sentinel data)
Observation Data	Satellite images (before, during and after a disaster)	United States Geological Survey EarthExplorer, Sentinel Asia (restricted), International Charter on Space and Major Disasters (restricted), Sci-Hub (Sentinel imagery)
	Rainfall data	Global Satellite Mapping of Precipitation (GSMaP), Tropical Rainfall Measuring Mission, Global Precipitation Measurement
	Cyclone track and forecast data	Global Disaster Alert and Coordination System
	Fire hotspots	Fire Information for Resource Management System

Figures 1 and 2 below show how space technology applications provide support for monitoring and planning, especially in disaster management. These examples are from the Malaysian space agency (ANGKASA) and the Indonesian space agency (LAPAN) respectively, and promote the applicability and use of space technology as well as the development and strengthening of regional cooperation and networking to exchange and share space-based information with localized space-based information services.

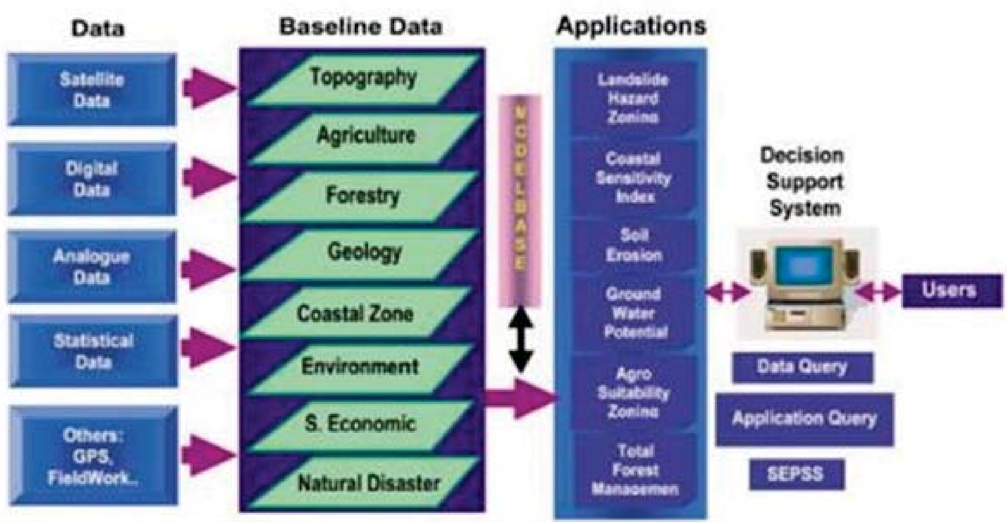

Figure 1: The role of spatial technology in disaster management

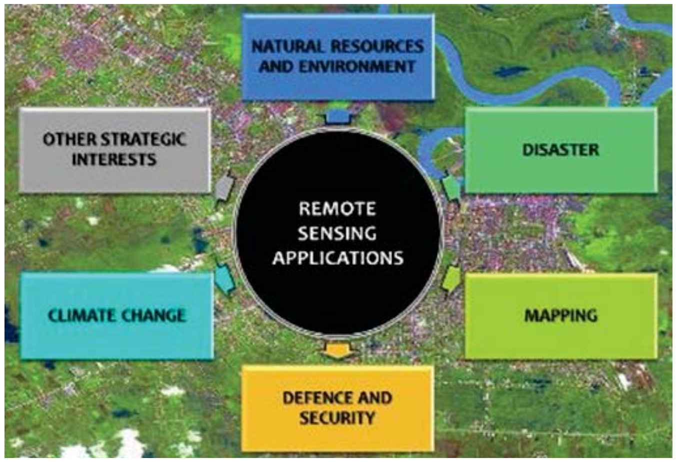

Figure 2: Remote sensing applications for monitoring and planning

Information and mapping needs for disaster hazards

Table 2 shows the main information needs for each type of disaster hazard.

Table 2: Information needs for different disaster hazards

Disaster hazards	Flood	Cyclone	Earthquake	Landslide	Volcano	Forest fire
Information needs common to all disasters						
General information about the disaster: information about location and preliminary overview of possible affected areas	X	+ landfall	+ epicentre, depth & magnitude	X	+ volcano name & eruption type	X
Identification of critical facilities and infrastructures: information on the location of facilities (hospitals, police stations, fire stations, emergency shelters, etc.) and infrastructures (transportation, telecommunication, power, water supplies, etc.) which can be vital during a disaster situation or would cause serious disruption to services if damaged	X	X	X	X	X	X
Identification of disaster extent: information on areas affected	X	X	X	X	X	X
Monitoring and situation updates: updated information on the evolution of the disaster event and weather conditions (especially rainfall)	+ continued flood situation	X	+ aftershocks or smaller earthquakes	+ possibility of landslides occurring in other locations	+ expected evolution as the eruption continues	+ vegetation status (including fuel moisture condition) and expected evolution as the fire continues
Estimate of the number of people affected by the disaster event	X	X	X	X	X	X
Estimate of affected buildings, infrastructure, LULC and other assets: how much infrastructure and how many buildings are affected, as well as how many hectares of crops and agricultural land, etc.	X	X	X	X	X	X

Disaster hazards	Flood	Cyclone	Earthquake	Landslide	Volcano	Forest fire
Information needs common to all disasters continued						
Evaluation of accessibility: information on the condition of transportation networks such as roads, bridges, etc. and their efficiency regarding accessibility to basic needs and services	X	X	X	X	X	X
Estimate of damage: information on the severity of damage to buildings, infrastructure and other valuable assets	X	X	X	X	X	X
Information needs for specific disasters						
Identification of secondary effects: information on the occurrence of secondary effects such as floods, landslides, mudslides (including lahars), and fires; the extent of each of them and where the affected areas are		X	X	X	X	
Identification of ground deformation: information on the relative displacement of terrain			X		+ track evolution of eruptions	
Cyclone tracks and forecasts, as well as potential impacts: necessary in order to monitor recent movements and forecast the path of the cyclone over the next few days. This information includes a preliminary overview of potentially affected settlements, population and infrastructure along the cyclone's path		X				
Identification of ash clouds: the movement, direction and extent of volcanic ash clouds, and affected areas that should be avoided by aircraft					X	
Identification of volcanic deposition: the extent of lava and pyroclastic flows and the location of affected areas					X	
Identification of active fire hotspots: the location and spatial distribution of fire hotspots						X
Identification of haze and smoke plumes: the distribution and direction of haze due to forest fires, the affected areas and possibility of transboundary effects						X
Identification of burned areas: the extent and location of burned areas						X

Table 3 lists the thematic mapping needs for each type of disaster event.

Table 3: Thematic mapping needs for different disasters

Thematic information product	Flood	Cyclone	Earthquake	Landslide	Volcano	Forest fire
Common to all disasters						
Reference maps (providing important information about administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.)	X	X	X	X	X	X
Impact maps – basic components: • affected areas • impact on population • building footprints • roads • bridges • buildings • LULC	+ flood extent	+ landfall + baseline data	X	X	X	X
Damage maps	X	X	X	X	X	X
Satellite images (archive)	X	X	X	X	X	X
For specific disasters						
Maps of secondary effects (if triggered)		X	X	X	X	
Rainfall monitoring maps	X	X		X		
Cyclone track (with information on population, building footprints, roads, bridges, buildings, LULC and baseline data)		X				
Forecast and probable impact maps (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.)		X				
Flood extent maps	X					
Ground deformation maps			X		X	
Volcanic deposition maps					X	
Ash cloud maps					X	
Fire hotspot maps						X
Haze and smoke plume maps						X
Vegetation monitoring maps						X
Burned area maps						X

Photo credit: IRIN/Shamsuddin Ahmed

Flood

What is the nature of the hazard?

A flood is a temporary condition in which normally dry land areas are partially or completely inundated due to overflow of inland or tidal waters, or due to the run-off of unusual and excessive surface water from any water source including rivers, streams, lakes, canals or the ocean. In 2015, flooding was the most frequent disaster in Asia and the Pacific, accounting for 40 per cent of all disasters in the region. In total, 37 per cent of the region's population was affected by flooding. [7] In addition, the economic damage caused by the floods was estimated at US $11.5 billion, the second-highest figure overall, accounting for 25 per cent of the total economic damage caused by disasters in the region. [8]

Understanding the characteristics of different types of floods is important for rapid and appropriate response during floods and to alleviate the consequences or limit the damage of flooding. The various categorizations of flood depend on the combination of sources, causes and impacts, and the speed of the flood onset. [9] Flood is a very dynamic hazard, which means that it can spread to other areas very easily, especially along sloping terrain and other water bodies. The energy from the flow of water causes erosion and – in worst-case scenarios – ground movements that represent the secondary effects of this main hazard.

7 ESCAP, Disasters in Asia and the Pacific: 2015 Year in Review.
8 Centre for Research on the Epidemiology of Disasters, EM-DAT Database. Available from http://www.emdat.be/ (accessed February 2016).
9 Jha, K.A., Bloch, R. and Lamond, J., Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century (World Bank, 2011).

- **Riverine (or fluvial) flooding** occurs when surface water run-off increases the water level of rivers or streams, exceeding their capacity, and watercourse banks consequently overflow towards downstream or adjacent floodplain areas. The increase in water volume can be caused by heavy rainfall associated with monsoons or tropical cyclones, or snowmelt upstream. Floodwater can be slow-moving and shallow and the flooded areas may remain inundated for days or even weeks. It can also move fast as a result of rapid snowmelt.

- **Overland (or pluvial) flooding** occurs when heavy rainfall or snowmelt directly flows over land and the saturated surface cannot absorb the excess water. It can happen anywhere outside the fluvial floodplain and can be particularly disruptive in urban areas. Floodwater develops gradually and it can affect a large area for a prolonged period.

- **Coastal** flooding occurs as the result of extreme tidal conditions caused by severe weather such as storm surges. When high tidal waves move inland, the water body rises and inundates coastal areas. A tsunami can also inundate coastal areas, resulting in flooding which is less frequent but can easily cause huge losses and kill thousands of people. Floodwater from tidal waves may increase at high tide and recede at low tide in a relatively short period of time.

- **Flash flooding** is caused by fast-flowing water, especially in areas with steep slopes. It can be caused by torrential rainfall or the movement of any other large body of water down sloping terrain; for instance, after a failed levee or dam or a sudden release of water by debris or ice jam. Because of the sudden onset and high velocity of the water, flash floods can be very dangerous. The water can also carry large amounts of debris such as rocks, trees and cars. A typical characteristic of flash flood is that the flood happens in a very short period of time and the duration is generally less than six hours.

- **Urban flooding** occurs in urban areas and is typically caused by poor drainage systems. Urban areas can be flooded by heavy rains, rivers, coastal, pluvial and groundwater floods when the city sewage system and drainage canals do not have enough capacity to drain away excess water. Floodwater develops relatively slowly and the inundation can remain for several days.

Information needs for operational purpose

To cope with the effect of floods, the information needed typically includes the location and affected areas; analysis of the impact on people, infrastructure and accessibility; and assessment of damage to buildings and other valuable assets. Accurate information on the extent of flooding and the development of the situation is crucial for quick and effective decisions during the response phase. Refer to table 2 for the information needed to coordinate emergency response for floods.

Key elements of information that can be detected from earth observation for floods

EO can provide regular updates on the status of flood conditions through the use of remote sensing data. A Synthetic Aperture Radar (SAR) satellite sensor is particularly useful to map the extent of floods because of its all-weather capabilities and the ability to provide cloud-free images. Very High Resolution (VHR) optical sensors can be used to update databases on physical assets (especially building footprints), which is crucial for assessing the damage caused by floods. Satellite-based rainfall data is also helpful to monitor a prolonged flood situation. Depending on data availability and estimated processing time, information for floods can be prepared in three phases, as described in table 4.

Table 4: Information detected by earth observation for floods

Phase	Detected information	Remarks
Phase 1 (0–24 hours)	Preliminary definition of flooded area	• Pinpoint the location of flooding and preliminary overview of the affected area • Reference information with available baseline data
	Rainfall monitoring	• Near real-time data on rainfall
Phase 2 (24–72 hours)	Flood extent	• SAR data is preferred due to its cloud penetration capabilities
	Impact analysis	• Estimate the impact on people, buildings, infrastructures, LULC and other assets • Evaluate accessibility to basic needs and services
	Rainfall monitoring	• Continuous observation of rainfall
Phase 3 (72 hours to 3 weeks)	Damage assessment	• Rapid damage assessment on buildings, infrastructure and other physical assets • Detailed assessment requires field data
	Flood extent	• Continuous observation if flood persists
	Rainfall monitoring	• Continuous observation of rainfall

Pros and cons [10]

EO can quickly identify flood extent and affected areas, which is important for planning and managing response activities. The accuracy of flood extent derived from SAR data depends on the sensor characteristics and the terrain of the area being observed. The accuracy is generally reliable, especially for open floodplain areas where standing water or inundation creates a flat surface. However, there are some limitations and concerns regarding the use of SAR data to map flood extent, especially in urban areas and flash flooding where surface water is likely to be moving or not as flat.

- In the case of urban flooding, the spatial resolution of SAR data is not sufficient to map flood extent with high accuracy due to the complex landscapes and highly structured built-up areas. Furthermore, the 'double bouncing' effect caused by the side-looking imaging geometry of SAR sensors results in strong backscatter and often misclassifies water areas, whereas flat roofs and roads may have low backscatter similar to a water surface. It is often difficult to distinguish between such flat surfaces because both appear dark on the imagery being analysed. Shadow effects from tall buildings can also appear similar to water bodies. In this case, unmanned aerial vehicle and high-resolution aerial photos may be a better method to map urban flood extent with greater accuracy.

- In the case of flash flooding, the satellite data acquisition time often misses the floodwater since it remains for only a few hours. The acquisition of satellite imagery needs to be planned based on rainfall and flood forecasts; however, uncertainty about the location of flash floods, both in space and time, makes such forecasts prone to be erroneous.

10 European Space Agency, Satellite Earth Observations in Support of Disaster Risk Reduction: Special 2015 WCDRR Edition.

Techniques and methodologies

Based on the identification of information that could be obtained for floods, common techniques and methodologies for generating information products during emergency response are discussed here. Table 5 provides an overview of the data and methodologies used to derive such information products.

Table 5: Techniques and methodologies to derive information products for floods

Information product	Data used	Methodology
Reference maps*	• Baseline data (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.) • Satellite images (archived)	• Overlaying geospatial data • Visualization (static)
Rainfall monitoring maps	• Satellite-based rainfall • Baseline data, DEM	• Extracting rainfall data • Visualization (static or dynamic)
Flood extent maps	• Satellite images (before and during)	• Thresholding • Visualization (static)
Impact maps	• Flood extent • Population, building footprints, roads, bridges, buildings, LULC, etc. • Baseline data	• Spatial analysis • Visualization (static)
Damage maps	• Flood extent • VHR satellite images (pre- and post-) • Building footprints, field data • Baseline data	• Stage-damage function • Visualization (static)

* Copernicus (Emergency Management Service – Rapid Mapping Products Copernicus Emergency)

Reference maps [11]

A reference map is based on existing baseline data and archived images, if available. VHR or High Resolution (HR) optical imagery of pre-event (or if possible even post-event) condition is preferred as background information. A simple Geographic Information System (GIS) overlaying technique can provide an overview of the disaster event, basic information and geographic features of the concerned area (administrative boundaries, transportation networks, hydrology, critical facilities, infrastructure, LULC, etc.), and preliminary identification of possible affected areas prior to crisis management tasks being undertaken.

Rainfall monitoring maps [12]

Satellite-based precipitation data provide near real-time global rainfall data with high spatial and temporal resolution. The Global Precipitation Measurement (GPM) mission is a joint mission led by the United States National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency; it is a constellation of EO satellites that collect global precipitation data. This constellation will ensure the expansion of observation coverage, increase the observation frequency and improve the accuracy of rainfall estimates.

There are several global rainfall products developed towards the Global Precipitation Measurement programme, each one with different spatial and temporal characteristics. For example, GSMaP provides hourly rainfall data available four hours after the observation. The GSMaP product is derived using both microwave and infrared radiometer data with a grid resolution of 0.1 degree. The latest GSMaP product (version 6) was released in September 2014 as a Global Precipitation Measurement product.

11 IWG-SEM, Emergency Mapping Guidelines, Working Paper Version 1.0 (2015).
12 Kidd, C., Huffman, G., Review: "Global precipitation measurement", Meteorological Applications vol. 18, pp. 334–353 (2011).

Using satellite-based global rainfall measurement products, the distribution and progression of rainfall in affected areas can be frequently monitored in order to assess the disaster situation. GIS tools can visualize this information, either in static or dynamic representation. DEM can also be used to provide additional information about the terrain of the affected area.

Box 1. Flood forecasting [13]

An accurate estimate of rainfall is needed to develop a flood forecasting system. A numerical model such as the European Centre for Medium-Range Weather Forecasts (ECMWF) or the Weather Research and Forecasting Model are commonly used to forecast rainfall for the next few days. Satellite-based rainfall data can also be used for this purpose, especially in areas where ground-based data are limited. Coupled with hydro-meteorological data, a flood forecasting system can be built using rainfall run-off and channel routing models. One example of real-time global flood estimation using satellite-based data is the NASA-funded experimental system, Global Flood Monitoring System.

13 Wu, H. and others, "Real-time global flood estimation using satellite-based precipitation and coupled land surface and routing model", Water Resources Research, vol. 50 (3), pp. 2,693–2,717 (2014).

Flood extent maps [14]

SAR is the most useful satellite sensor for data and information about floods, which often occur under heavy rain and cloudy conditions. Operational spaceborne SAR systems work at different wavelengths, including L-band (Advanced Land Observing Satellite-2), C-band (Radarsat-1, Radarsat-2, RISAT-1) and X-band (TerraSAR-X, COSMO-SkyMed). Optical sensors can also be useful in relatively cloud-free situations, especially to map an extensive flood that affects a large area. Optical satellite data systems with high temporal resolution, such as MODIS, can cover the entire surface of the Earth every one or two days. With both free and commercial data from satellites increasingly available, it is now possible to make regular observations during floods which may last for several days. Low spatial resolution data provide wide coverage and are useful to map a large floodplain, while high-resolution data allow flood extent mapping in more detail and with better accuracy.

The basic concept of flood detection and mapping using SAR data is the difference in backscatter response between water and land surfaces. SAR backscatter for smooth water surfaces is very low due to specular reflection, while rough land surfaces produce diffused reflection resulting in strong backscatter. Therefore, water areas appear dark because only a little backscatter is directed back to the sensor, whereas land areas have brighter tones. This tonal variation caused by the different levels of surface roughness in SAR data can be used to distinguish water from land. It is worth mentioning that in general the horizontal transmit and horizontal receive polarization of a SAR image shows a noticeably stronger contrast between water and non-water, so it is preferred over other polarizations to map flood extent.

Thresholding is the most popular technique to separate floodwater from land areas in a SAR image. The threshold value will depend on the contrast between water and non-water classes, with careful consideration of the influences of wind-induced waves, shadows, corner-reflecting vegetation and other objects with low backscatter response such as sand dunes and airstrips. Shadows in high mountainous areas with steep terrain can falsely be identified as water bodies; auxiliary data like DEM can be used to remove this effect. A single SAR image can be used to map a flooded area; however, a time series of SAR data with the same sensor characteristics (geometry, orbit direction, polarization) can provide better results in separating floodwater from perennial or normal water bodies. The thresholding method is computationally straightforward and therefore suitable for rapid mapping. The results are reliable and generally this method works satisfactorily for calm water surfaces.

14 Voigt, S. and others, "Extraction of flood masks using satellite-based very high resolution SAR data for flood management and modelling", paper presented at 4th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability, Toronto, Canada, May 2008.

Impact maps

Data on population, building footprints, LULC, infrastructure, transportation networks and other assets are coupled with the extent of the disaster to calculate the direct impact caused by an event. A simple GIS overlaying technique can visualize the exposure within the affected area, then spatial analysis can be used to calculate the total impact to people, LULC such as agricultural and settlement areas, buildings, infrastructure and other physical structures. This method can also be used to evaluate accessibility (condition of roads, bridges, etc.) to basic infrastructure and services.

Damage maps

Damage to buildings, infrastructure and other physical structures due to floods will depend on the flood intensity and characteristics of the structures. Exhaustive data – which could be difficult to collect during emergency response – is needed to calculate damage. Flood damage information is particularly useful for the post-disaster or reconstruction phase.

A standard approach to estimating direct physical damage is to group it into categories depending on the level of damage, and apply it to different building types, materials or building characteristics. Field data is required to collect detailed building attributes. Damage measured as monetary loss is also related to flood intensity. Flood depth is commonly used to indicate flood intensity. The use of EO to derive inundation depth requires the incorporation of an HR digital terrain model. Nowadays, Light Detection and Ranging systems (LIDAR) can provide high spatial resolution digital terrain models with sub-meter height accuracy. Other, more complex damage modelling approaches can include flood duration and flow velocity.

Box 2. Case study: use of remote sensing technology for flooding: GISTDA, Thailand

One of the roles of GISTDA is to develop technology and applications of benefit to the general public. GISTDA works together with the Flood Relief Operation Centre and provides flood maps from satellite data on a daily basis as a major source of information to support decision-making. The final products, maps and geospatial data, are delivered within four hours of the acquisition of satellite data. The Geospatial Database includes various data from different sources: satellite data, fundamental geographic data set of Thailand and data collected in situ.

The final products and information obtained from satellite images are flood maps, comparison floods, flood duration, house damage assessment, water volume assessment and flood prediction. It is possible to find the updated information on the GISTDA website, http://flood.gistda.or.th/. Figure 3 shows how GISTDA and the Flood Relief Operation Centre work together in the management of data and information to support decision-making.

Figure 3: Interaction of GISTDA and the Flood Relief Operation Centre to support decision-making with combined data and information coming from different sources

Source: Provided to ESCAP by GISTDA

How this earth observation information can be used for decision-making

To respond effectively, decision- and policymakers require up-to-date, accessible and reliable scientific information that is complemented by local knowledge from the affected community. EO satellite data provides a unique source of synoptic information at global, regional and local levels, and detected information from EO can provide useful information in all phases of emergency response activities.

EO information products can be provided in different formats and through a range of platforms. A website is usually the preferred platform to share and disseminate the products. In many cases the products are only available in map format and therefore it is not possible to modify or update them. The original product, if available, either in vector format, such as shapefile, or raster format, such as GeoTIFF, makes it possible to derive additional information at a later stage, incorporating more detailed and updated data, or even new data sets. Figure 5 shows the general model for geospatial decision support when applied in the context of floods.

Figure 4 provides a snapshot of the decision-making considerations involved during emergency response in the case of floods. A general template has been used to illustrate the decision-making process for each hazard. This includes two groups of actors (as shown top left and top right). The two groups of actors are decision makers for the coordination of emergency response, such as disaster managers or senior staff at NDMAs, and providers of geospatial information, such as technical staff from national remote sensing agencies or space agencies.

- 'Coordination decision makers' are concerned with ongoing monitoring and assessment as indicated by the red arrow on the left side. This may begin as a fragmented or sporadic activity during the early stages of a disaster as there may be scarce resources, limited information and little time to plan response activities. This has been indicated using a fragmented arrow in the illustration.
- 'Geospatial information providers' are concerned with providing the right data and information to the right people at the right time, so they can make informed, evidence-based decisions. This has been indicated using a green arrow on the right-hand side. During the early stages of a disaster, data and information can also be scarce, fragmented and sporadic. This has again been indicated using a fragmented arrow.

There are five main components to each hazard-specific diagram which have been used to illustrate the points of interaction and collaboration between both 'coordination decision makers' and 'geospatial information providers'. These include:

- Understanding the nature of the hazard;
- The operational information needs during the disaster;
- The key elements of information necessary to support decision-making during each phase of emergency response;
- A strategy pyramid for evidence-based decision-making at the strategic, tactical and operational levels;
- The thematic information products necessary to make localized decisions.

The diagram for each hazard outlines the hazard-specific components and shows the interactions and complementarity between both the 'coordination decision makers' and 'geospatial information providers' in order to ensure a seamless and collaborative approach to geospatial decision support.

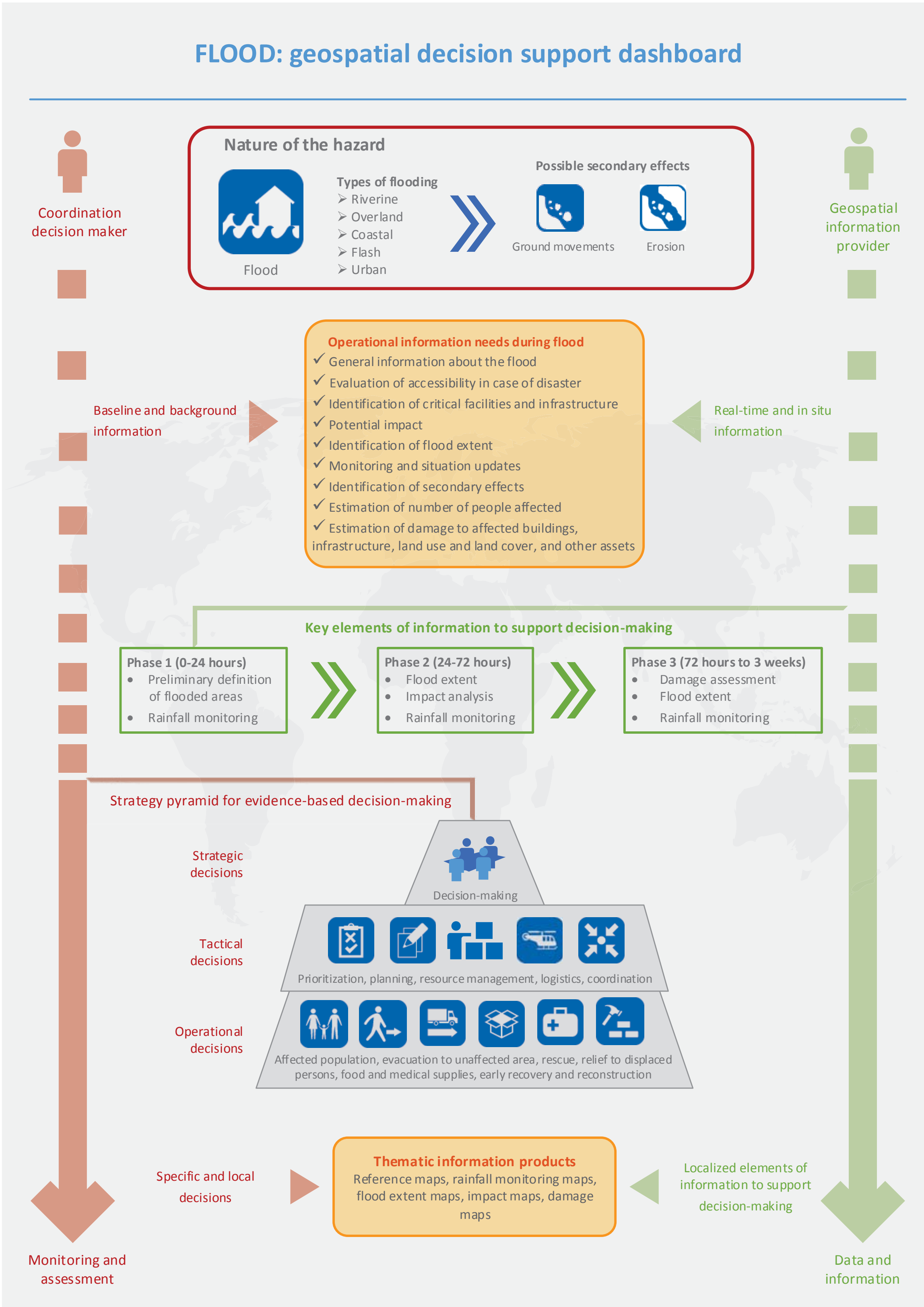

Figure 4: Geospatial decision support model for floods

Nature of the hazard

It is necessary to consider what kind of possible secondary effects can be triggered by the main disaster. Floods can easily spread, creating more damage wherever there are other water bodies. If the flood reaches existing unstable geomorphological conditions it can also lead to erosion and ground movements.

Operational information needs

Operational information needs are concerned with bringing baseline and background information together with real-time and in situ information. The two types of information become more substantial over time as information is naturally very scarce in the initial period of a disaster. Depending on the nature of the hazard, possible secondary effects may be triggered from the main disaster. The 'coordination decision makers' and the 'geospatial information providers' can pool information from their respective fields in order to create the operational information required for situation analysis. Refer to table 2 for a list of operational information needs.

Elements of information to support decision-making

This stage is important in deciding how to operate during the different phases of the disaster. For floods there are three phases, starting from the moment the disaster strikes and lasting until approximately three weeks after the impact of the event. This phased assessment includes general information about the current disaster, identification of possible extent, monitoring processes and all the information needed to deal with the situation and its possible evolution over time.

Strategy pyramid for evidence-based decision-making

The strategy pyramid for evidence-based decision-making is similar for every hazard. It describes the work priorities of decision makers regarding strategic, tactical and operational decisions. The top of the pyramid identifies strategic decisions, which can often be based on a high-level national response. Further down the pyramid there are tactical decisions. These can include the prioritization of actions, planning, resource management, logistics and coordination in the area where disaster has struck. At the bottom of the pyramid are operational decisions. These involve work in the field: for example, how to deal with the affected population, evacuation to unaffected areas, rescue, relief to displaced persons, food and medical supplies, early recovery and reconstruction. This simplified model is valid for every hazard, even though tactical and operational decisions depend strictly on the type of hazard that the decision makers need to deal with.

In the case of floods, for example, decision makers have to consider the nature of the hazard, integrating local knowledge where possible as this can provide additional value added information regarding the characteristics of the flood in a specific territory and the characteristics of the territory itself. This can take into account factors influencing the development of the flood such as natural flood barriers, topography, geomorphology, vegetation and the nature of the ground (depending on whether the area of interest is an urban area or agricultural fields, for example). The scale of the event can influence the type of response required and public reaction to the disaster itself. This can be more or less managed depending on the level of panic and chaos that the disaster creates. For example, in the case of flood, evacuation should be to safer and higher grounds above the rising water level. Accessibility to the affected areas should also be carefully evaluated, taking into consideration the potential for vehicles to safely transit those areas and the reliability of infrastructure.

It is very important to try and prevent the secondary effects of floods. These can significantly affect urban areas, causing damage to buildings or the proper functioning of sewage and drainage systems. In rural areas floods can significantly affect agriculture and livestock. These challenges have a direct impact on the local population, who may be more vulnerable to hypothermia or infections that can spread from dirty water.

The time of day and of the year can also have an effect. Local communities can be more or less vulnerable depending on such factors. For example, a population is more vulnerable at night when the level of alert and the response time are very low because most people are sleeping. Vulnerability can also increase if an extreme event takes place during the cold season due to the impact of cold weather on the human body, or during the hot season, which creates optimal conditions for infections and diseases to spread.

Thematic information products

Thematic information products can support specific and local decision-making. Refer to table 3 for the thematic information products required for floods.

UN Photo/Marco Dormino

Photo credit: IRIN/ Unknown contributor

Cyclone

What is the nature of the hazard?

A cyclone is a violent storm that is characterized by inward-spiralling wind around a low-pressure centre. It is formed when warm ocean water warms the air and creates areas of intense low pressure, making water evaporate and condense into clouds and producing strong winds. The most common type of cyclone that develops in Asia and the Pacific is a tropical cyclone, which is usually accompanied by thunderstorms with heavy rain and strong winds. A tropical cyclone is called a hurricane, a typhoon or simply a cyclone, depending on its location.

Globally, the average number of tropical cyclones in a year is 86. [15] In 2015, 48 per cent of storms in the world occurred in Asia and the Pacific, the coastlines of which are shared by several countries, affecting over 9 million people and causing US$11.8 billion of economic damage. [16] A tropical cyclone can endanger lives and destroy property by generating torrential rain that often leads to flooding, landslides and coastal erosion; and high winds that can cause seawater to rise and form a high wave called a 'storm surge'.

In fact, extensive damage occurs from secondary events such as storm surges, flooding, tornadoes, heavy precipitation (including hail in some cases) and ground movements. In volcanic areas ground movements can include lahar. A tropical cyclone, however, weakens rapidly as it moves inland because it

15 ESCAP, Disaster without borders: Regional Resilience for Sustainable Development, Asia-Pacific Disaster Report 2015.

16 Centre for Research on the Epidemiology of Disasters, EM-DAT Database. Available from http://www.emdat.be/ (accessed February 2016).

develops over warm water, which makes coastal regions both the most exposed to the hazard and the most damaged by strong winds, while inland regions are more affected by flooding from heavy rains. Understanding the main impacts of a tropical cyclone is critical to taking prompt action and therefore minimizing negative impacts.

- **Strong winds** can damage or destroy infrastructure such as key roads and bridges as well as buildings and personal property. In addition to the economic damage caused directly, strong winds can bring down communication and power lines, which consequently hampers effective emergency response. A tornado – a violently rotating column of air – is often spawned by a tropical cyclone moving over land. A tornado can cause heavy damage and loss of life.

- **A storm surge** is often the greatest threat that tropical cyclone poses to life and property. A quick increase in sea level resulting from a tropical cyclone can wipe out entire coastal communities, intrude inland for miles, flood homes and businesses, and cut off roads.

- **Heavy rainfall** potentially results in flooding, mudslides and landslides. Inland areas are particularly vulnerable to freshwater flooding due to drainage systems being overwhelmed by sudden heavy rainfall.

Information needs for operational purpose

Hazards associated with tropical cyclones are mainly strong winds, storm surges, flooding, landslides and tornadoes. The information required to cope with the effect of cyclones typically includes the location and affected areas; analysis of the impact on people, infrastructure and accessibility; and assessment of damage to buildings and other valuable assets. Monitoring and forecasting of cyclone tracks is important for early warning and to estimate the probable impacts of a cyclone along its path. Secondary effects should also be identified since cyclones can trigger floods, landslides and mudslides. Refer to table 2 to see the information needed to coordinate emergency response for cyclones.

Key information for cyclones that can be detected by earth observation

The effect of cyclones can be widespread and coastal areas often suffer the most significant damage when the cyclone travels across coastlines. Continuous monitoring of the expected evolution and intensity of cyclones is important as they reach inland areas and make landfall. Thermal infrared and thermal microwave bands are used to track and forecast a cyclone's movement. VHR optical sensors are particularly useful for damage assessment and updating databases of physical assets (especially building footprints). Satellite-based rainfall data is also helpful to monitor the weather and rainfall situation. Depending on data availability and estimated processing time, the information for cyclones can be prepared in four phases, as described in table 6.

Table 6: Information detected by earth observation for cyclones

Phase	Detected information	Remarks
Phase 0 (-72–0 hours)	Cyclone track, forecast and probable impact	• Near real-time data and prediction on the movement of the cyclone • Monitor the probable impact along the cyclone path
	Rainfall monitoring	• Near real-time data on rainfall
Phase 1 (0–24 hours)	Preliminary definition of cyclone-affected area	• Pinpoint the location of the cyclone (and landfall) and preliminary overview of the affected area • Reference information with available baseline data
	Cyclone track, forecast and probable impact	• Continuous tracks and forecasts
	Rainfall monitoring	• Continuous observation of rainfall
Phase 2 (24–72 hours)	Impact analysis	• Estimate the impact on people, buildings, infrastructure, LULC and other assets • Evaluate accessibility to basic needs and services
	Secondary effects	• In the case of occurrence of secondary effects such as floods and landslides
	Cyclone track, forecast and probable impact	• Continuous observation and forecasts of the cyclone
	Rainfall monitoring	• Continuous observation of rainfall
Phase 3 (72 hours to 3 weeks)	Damage assessment	• Rapid damage assessment on buildings, infrastructure, and other physical assets • Detailed assessment requires field data
	Secondary effects	• Continuous observation
	Cyclone track, forecast and probable impact	• Continuous observation and forecasts of the cyclone • Transboundary considerations
	Rainfall monitoring	• Continuous observation of rainfall

Pros and cons

With the limited coverage of direct observation data, satellite-based measurement can provide valuable information to forecast a cyclone's tracks and intensity over the vast expanse of the oceans before it makes landfall. Using such technology has improved the operational use of the forecasting system. It is important to note that a satellite-based forecast is the best estimate of a cyclone's future movement and intensity so there is always some uncertainty associated with tropical cyclone forecasting.

Cyclones (and their landfall) cause extensive damage to buildings, infrastructure and other physical structures. Damage assessment using satellite sensor provides a relatively quick analysis to identify the severity of structural damage. Using VHR optical satellite images, damage can be easily identified by visual observation, especially in the case of complete collapse of buildings. However, there are some limitations or concerns on the use of EO for damage assessment tasks:

- Manual or visual observation of damage is a subjective interpretation which can vary from one analyst to another. Operational use for a large area becomes problematic, especially if there are a number of analysts involved in the interpretation process, as this can lead to some inconsistency in the overall output. Automatic or semi-automatic methods have been developed to ensure output consistency and they could even shorten processing time; however, the accuracy is not yet sufficient to replace manual interpretation for operational purposes.
- It is often difficult to capture the full range of damage level and intensity. EO satellite data may not be able to clearly distinguish this varying level of damage; therefore, in practice, the classification is simplified by aggregating several damage grades.
- Damage assessment is based on the detection of the roofs of buildings and whether the roofs are visually intact or not when viewed from above. Depending on the roof condition and the geometry of the sensor, the interpretation can be underestimated or overestimated.
- Cloud cover limits the availability of VHR optical satellite images. SAR data can be used as an alternative but the complexity of the data, especially in urban areas (oblique viewing geometry, occlusion and shadow) makes it rather difficult to interpret the data.

Techniques and methodologies

Based on identification of the information that could be obtained for cyclone-associated disasters, common techniques and methodologies for generating information products during emergency response are discussed here. Table 7 shows the overview of data and methodologies used to derive the information products.

Table 7: Techniques and methodologies to derive information products for cyclones

Information product	Data used	Methodology
Cyclone track, forecast and probable impact maps	• Cyclone track and forecast data • Population, building footprints, roads, bridges, buildings, LULC, etc. • Baseline data	• Manual interpretation • Overlaying geospatial data • Visualization (static or dynamic)
Reference maps*	• Baseline data (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.) • Satellite images (archive)	• Overlaying geospatial data • Visualization (static)
Rainfall monitoring maps	• Satellite-based rainfall • Baseline data, DEM	• Extracting rainfall data • Visualization (static or dynamic)
Impact maps	• Landfall and affected areas • Population, building footprints, roads, bridges, buildings, LULC, etc. • Baseline data	• Spatial analysis • Visualization (static)
Maps of secondary effects	• Refer to data used for the same type of hazard	• Refer to methodology used for the same type of hazard
Damage maps	• Landfall and affected areas • VHR satellite images (pre and post) • Building footprints, field data • Baseline data	• Manual visual interpretation • Visualization (static)

*Copernicus

Cyclone track, forecast and probable impact maps [17, 18]

The thermal infrared band of geostationary and polar-orbiting satellites can be used to analyse cloud patterns and their changes over time. Tracking and forecasting using satellite data involves manual interpretation of cloud patterns associated with the cyclone in order to locate the centre of the cyclone and to indicate specific types of motion or changes in track. Empirical forecasting approaches such as the Dvorak technique are widely used. This technique can provide a good result but it requires image interpretation skills and is limited to visually detected cloud patterns.

Artificial Neural Network is one image processing approach that can be used to automate cyclone track and intensity forecasting. Microwave sensors have also been explored to improve operational forecasting, through the use of both active and passive instruments such as scatterometers that provide both wind speed and direction, SAR, microwave radiometers, altimeters, microwave sounders, rain radar and cloud profiling radar.

Data on population, buildings footprints, LULC, infrastructure, transportation networks and other assets can be overlaid with the predicted cyclone path to analyse the probable impact of the cyclone. GIS tools can visualize this information, either in static or dynamic representation.

17 Katsaros, K.B., Vachon, P.W., Liu, W.T. and Black, P.G., "Microwave remote sensing of tropical cyclones from space", Journal of Oceanography, vol. 58, pp. 137 – 151, 2002.
18 Roy, C., and Kovordanyi, R., "Tropical cyclone track forecasting techniques: a review", Atmospheric Research, vol. 104–105, pp. 40–69, 2012.

Reference maps

Refer to the section on techniques and methodologies for reference maps in the flood chapter.
Rainfall monitoring maps
Refer to the section on techniques and methodologies for rainfall monitoring maps in the flood chapter.

Rainfall monitoring maps

Refer to the section on techniques and methodologies for rainfall monitoring maps in the flood chapter.

Impact maps

Refer to the section on techniques and methodologies for impact maps in the flood chapter.

Maps of secondary effects

Cyclones making landfall can trigger secondary effects such as floods, landslides and mudslides. Refer to the relevant chapter for the same type of hazard.

Damage maps [19]

A wide range of EO satellite data are used for damage assessment, in different spatial resolutions (from HR to VHR), spectral resolution (from panchromatic to multispectral) or even in frequency (from visible to near-infrared to microwaves). Nadir-looking VHR satellite images or aerial photos are preferred, and manual interpretation as well as semi-automatic techniques have been widely used for many events.

The most common approach for damage assessment is manual interpretation of post-event VHR optical data. When pre-event and post-event data are available, changes can be detected and interpretation is usually more accurate. Damage identification is based on changes in spectral characteristics (textures, tones) and building shapes. Other indications of damage are roof condition (intact or not intact) and the presence or absence of debris close to building walls. Interpretation is relatively straightforward, especially in the case of complete collapse of buildings, because damage to man-made objects usually changes their shape and texture. The characterization of damage level should also consider wall condition. Oblique images such as those from unmanned aerial vehicles or aerial photos are more useful for identifying detailed damage features on facades and roofs. However, the problem with matching the image or photo with the ground must be considered.

In the case of persistent cloud cover in the affected area, SAR data may become an alternative. In general, the use of VHR SAR data in urban areas is very challenging due to the complexity of SAR geometry, such as the oblique view and different incidence angles. Currently, the results of SAR data for damage assessment are more useful at the aggregated level and could work as preliminary interpretation in the absence of VHR optical data. Nevertheless, multitemporal SAR data may provide unique information as they can exploit both intensity and phase change.

19 Dell'Acqua, F., "Remote sensing and earthquake damage assessment: experiences, limits, and perspectives", Proceedings of the IEEE, vol. 100, issue 10, pp. 2,876-2,890, 2012.

Box 3. Case study: Tropical cyclones in the Philippines

Tropical cyclones are a constant threat in the Philippines. The Philippine Atmospheric Geophysical and Astronomical Services Administration is one of the agencies of the Department of Science and Technology. It provides support and protection against natural calamities through the use of scientific knowledge as an effective instrument to ensure the safety, well-being and economic security of all people, and for the promotion of national progress. [20]

The Weather Division collects real-time high-quality meteorological data and aims to be a relevant service for communities vulnerable to meteorological hazards. It undertakes continuous monitoring, analysis and prediction of atmospheric conditions and issues forecasts daily, together with warnings and bulletins on tropical cyclones and other potentially dangerous meteorological conditions. It also maintains an efficient meteorological telecommunication system for effective collection / receipt of data and local and international exchange of data and warning bulletins, weather forecasts and other relevant information; and conducts operational studies/investigations for the continuing development/improvement of weather analysis and prediction techniques. [21]

The Weather Division is organized in sections: the Weather Forecasting Section provides services such as improving the quality of real-time weather analysis and forecasting, forecasts and warning bulletins using the telecommunication systems, with continuous surveillance of severe tropical disturbances that can possibly affect the country. The Marine Meteorological Service Section focuses mainly on the analysis of data regarding weather and sea conditions and carrying on a continuous surveillance of these aspects. It disseminates forecasts and provides updated marine bulletins and other marine-related information to several stakeholders. The Techniques Application and Meteorological Satellite Section maintains the entire system for general weather forecasting and keeps the Weather Division home page up-to-date; all the operation systems and programmes, technical assistance, satellite tracking and archive maintenance are performed by this section. The Meteorological Data and Information Exchange Section takes care of all the telecommunication facilities, forecast dissemination and data exchange. The last section is the Aeronautical Meteorological Services Section, which undertakes continuous monitoring and surveys, especially on the use of aerodromes. The 2015 tropical cyclone tracks are shown in figure 5, which is a screen shot from the Department of Science and Technology / Philippine Atmospheric Geophysical and Astronomical Services Administration website (http://pagasa.dost.gov.ph/).

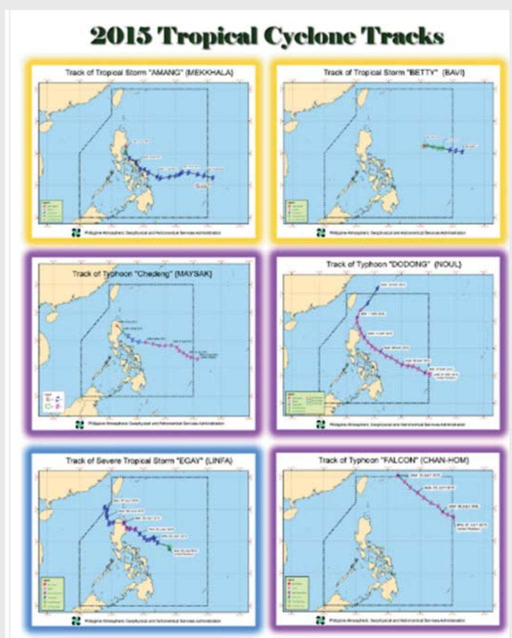

Figure 5: Example of tropical cyclone tracks for 2015 from the

Source: Department of Science and Technology/Philippine Atmospheric Geophysical and Astronomical Services Administration.
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

20 See http://pagasa.dost.gov.ph/.
21 See http://www1.pagasa.dost.gov.ph/index.php/transparency/about-pagasa#weather-division.

How this earth observation information can be used for decision-making

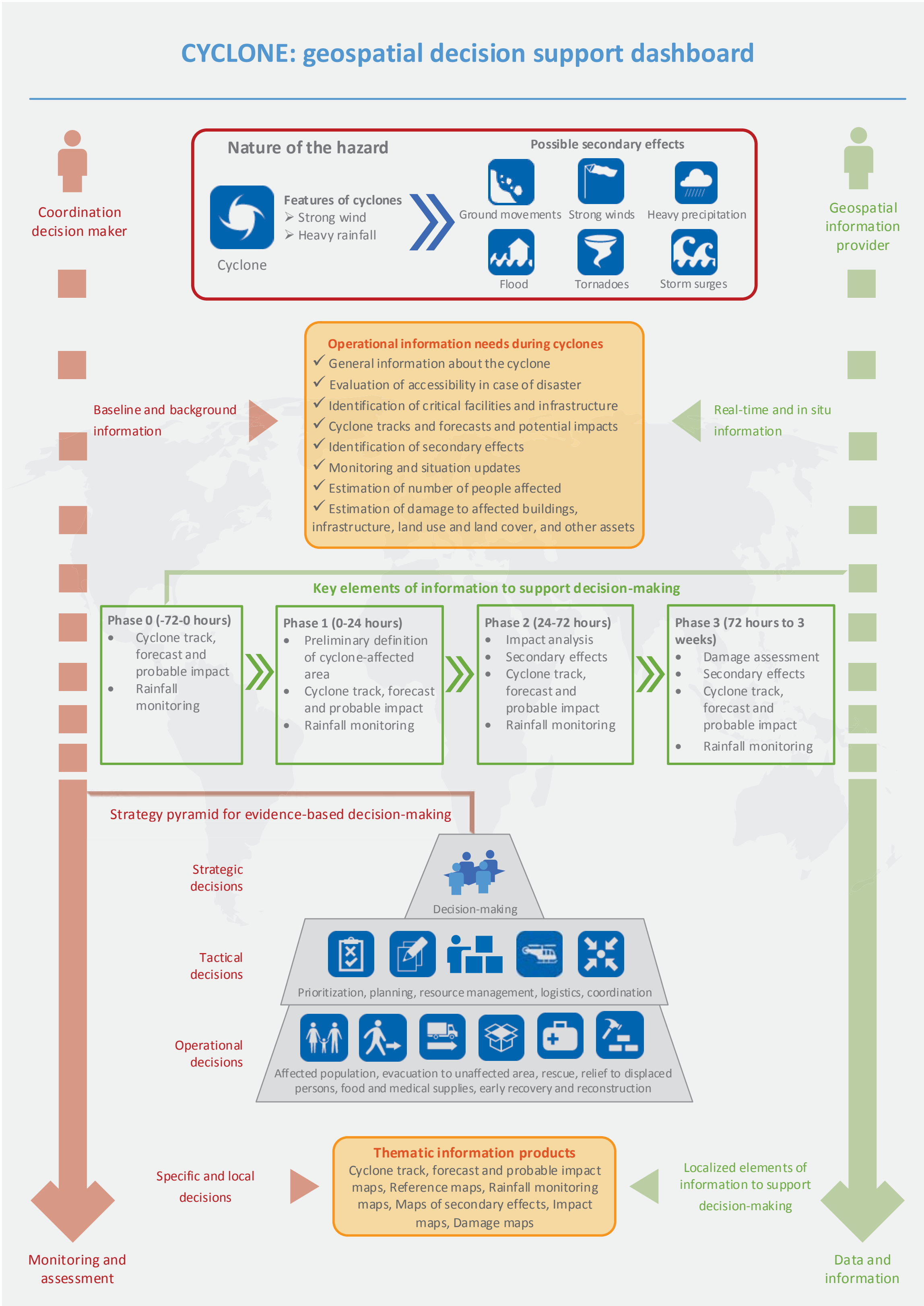

Figure 6: Geospatial decision support model for cyclones

Nature of the hazard

Figure 6 shows the general model for geospatial decision support when applied in the context of cyclones. Cyclones are a complex phenomenon: they are characterized by violent storms accompanied by strong winds and heavy rainfall. They can trigger several secondary effects such as ground movements (including lahars in volcanic areas), strong winds, floods, tornadoes, storm surges and heavy precipitation that in some cases can include hail.

Operational information needs

Refer to table 2 for a list of operational information needs.

Elements of information to support decision-making

Cyclones are different from other hazards because they are the only events that can be predicted relatively accurately. There are four decision-making phases for cyclones. This is because there is also a 'phase 0' which covers the range of time before the cyclone strikes, when it is possible to forecast the evolution of the cyclone through its predicted trajectory. Rainfall monitoring is constant throughout the four phases. After a preliminary definition of the possible areas where the cyclone may cause damage, impact analysis can be developed together with a map of secondary effects that can be triggered by the main event.

Strategy pyramid for evidence-based decision-making

In the pyramid for evidence-based decision-making, decision makers need to take into account the possible secondary hazards that can contribute to damage to infrastructure and affect the operations of evacuation, rescue and relief. One advantage for decision makers during cyclones is the possibility of prediction. This can reduce the exposure of the population during the actual impact. In places that often experience cyclones, there should already be effective emergency plans and facilities for evacuation (such as cyclone shelters) in place. Monitoring is essential before, during and after the cyclone, especially in the case of secondary effects. Evacuation and rescue and relief operations need to take into account accessibility to and from the affected areas as well as suitable transport vehicles in case of limited accessibility.

Thematic information products

Refer to table 3 for the thematic information products required for cyclones.


Photo credit: IRIN/ Unknown contributor

Earthquake

What is the nature of the hazard?

An earthquake is a series of vibrations resulting from a sudden release of energy in the earth's crust caused by movement along a fault plane. It is also possible to register some seismic activity along volcanic hotspots (please refer to the section dedicated to volcanoes). Depending on the magnitude, an earthquake can pose a destructive threat to communities by destroying the natural and built environment. Also, it often results in catastrophic consequences by triggering secondary hazards such as landslides, floods, tsunamis, liquefaction and surface rupture.

Over the period 2005–2014 the greatest loss of life in Asia and the Pacific (200,000 people) resulted from earthquakes and tsunamis. [22] Many South-East Asian countries located along the Pacific 'Ring of Fire' are especially prone to high seismic risk and its secondary hazards. In 2015, the devastating earthquake in Nepal claimed the lives of 8,790 people and caused approximately US$5.2 billion in damage and losses, giving earthquakes the highest number of fatalities that year. [23] Therefore, understanding the main earthquake hazards will help make emergency response more effective and reduce the negative impacts on people living in earthquake-prone countries.

22 ESCAP, Disaster Without Borders: Regional Resilience for Sustainable Development, Asia-Pacific Disaster Report 2015.

23 Centre for Research on the Epidemiology of Disasters, EM-DAT Database. Available from http://www.emdat.be/ (accessed February 2016).

- **Ground shaking** during an earthquake can damage buildings by shaking their structures or the ground beneath them. Buildings in the path of surface waves can lean or be tipped over by the movement. Ground shaking may also cause soil liquefaction in areas that have groundwater near the surface and sandy soil, which can make buildings and roads sink into the ground.

- **Flooding** can occur from an earthquake by rupturing dams or levees along a river. Water flooding from broken dams or reservoirs may inundate surrounding areas, seriously damage buildings and sweep away people.

- **Landslides, mudslides and avalanches** on mountains can be triggered by earthquakes, all of which can affect buildings considerably and cause many deaths.

- **Tsunamis** are one of the main earthquake hazards and can cause a great deal of damage. They arise from an earthquake under the ocean and can hit the shore with a huge wave several metres high, bringing enormous damage to people near coastlines.

- **Fire** can be caused by broken gas lines and electrical lines. It can be a serious problem, especially if water lines are also broken, leaving no water to extinguish the fire.

Information needs for operational purpose

Earthquakes can be very destructive, especially when they occur in densely populated urban areas. They cause tremendous damage to buildings and infrastructure, especially those built with substandard construction and materials. Collapse of buildings causes the majority of injuries and deaths, and the destruction and economic damage is often worsened by landslides, mudslides, liquefaction, tsunamis and floods. Information required to cope with the effect of earthquakes typically includes the location of the epicentre and the affected area, as well as analysis of the impact on people, infrastructure and accessibility. Assessment of damage to buildings and other valuable assets is the main focus in collecting information for the immediate response. Refer to table 2 for the information needed to coordinate emergency response for earthquakes.

Key information for earthquakes that can be detected by earth observation

The extent and severity of damage due to earthquake strongly depends on location and distance from the epicentre, as well as the magnitude and depth of the earthquake. Responders must also be keenly aware of the possibility of secondary effects. This information is crucial to defining the level of damage, together with the local geologic condition of the affected area and the characteristics of buildings. VHR optical sensors are particularly useful for damage assessment and updating databases of physical assets (especially building footprints). Updated information on the affected area, the emergency situation and damage assessment should be provided in time

to minimize the impact of earthquake. In addition, SAR satellite sensors can detect and measure ground deformation after the earthquake. Depending on data availability and estimated processing time, information for earthquakes can be prepared in three phases, as described in table 8.

Table 8: Information detected by earth observation for earthquakes

Phase	Detected information	Remarks
Phase 1 (0–24 hours)	Preliminary definition of earthquake-affected area	• Pinpoint the location of epicentre and preliminary overview of the affected area • Reference information with available baseline data
Phase 2 (24–72 hours)	Impact analysis	• Estimate impact to people, buildings, infrastructures, LULC and other assets • Evaluate accessibility to basic needs and services
	Ground deformation	• Interferometric SAR data is required
	Secondary effects	• In the case of occurrence of secondary effects, such as landslides, tsunamis, etc.
Phase 3 (72 hours to 3 weeks)	Damage assessment	• Rapid damage assessment of buildings, infrastructure and other physical assets • Detailed assessment requires field data
	Secondary effects	• Continuous observation

Pros and cons

Earthquakes cause massive destruction to buildings, infrastructure and other physical structures, and rapid assessment of the earthquake-induced damage is crucial for quick and accurate disaster response operations following the event. The same advantages and disadvantages of using EO data for damage assessment for cyclones are applied here.

SAR interferometry enables high-accuracy measurement of ground deformation over large areas, to the centimetre or even millimetre. It can detect small changes or displacements in ground surface due to an earthquake and its aftershocks, thus providing early detection of severely affected areas. The main limitation on the use of SAR interferometry, especially during time-limited disaster response activities, is the availability of SAR interferometric data. For instance, the International Charter on Space and Major Disasters does not provide SAR data suited for interferometric application under its primary support. Sentinel Asia may provide interferometric data from the Japan Aerospace Exploration Agency's Advanced Land Observing Satellite-2 SAR if there is a need and it is requested through their mechanism for such specific application. Furthermore, an advanced data processing technique such as SAR interferometry requires high-level processing skills and specific software packages.

Techniques and methodologies

Based on the identification of information that could be obtained for earthquakes, common techniques and methodologies for generating information products during emergency response are discussed here. Table 9 gives an overview of the data and methodologies used to derive information products.

Table 9: Techniques and methodologies to derive information products for earthquakes

Information product	Data used	Methodology
Reference maps*	• Baseline data (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.) • Satellite images (archive)	• Overlaying geospatial data • Visualization (static)
Impact maps	• Location of the epicentre and the affected areas • Population, building footprints, roads, bridges, buildings, LULC, etc. • Baseline data	• Spatial analysis • Visualization (static)
Ground deformation maps	• Interferometric SAR data	• Interferometry SAR (InSAR) • Visualization (static)
Maps of secondary effects	• Refer to data used for the same type of hazard	• Refer to methodology used for the same type of hazard

Damage maps	• Location of affected areas • VHR satellite images (pre and post) • Building footprints, field data • Baseline data	• Manual visual interpretation • Visualization (static)

*Copernicus

Reference maps

Refer to the section on techniques and methodologies for reference maps in the flood chapter.

Impact maps

Refer to the section on techniques and methodologies for impact maps in the flood chapter.

Ground deformation maps [24, 25, 26]

InSAR is a well-established method that measures changes in the position of important terrestrial parameters such as surface topography, ground deformation, land subsidence and glacier movements. The basic concept of InSAR is to calculate the phase difference between two or more complex radar images which are observed from slightly different positions of radar antenna or at different acquisition times. The interferometric phase difference can be formed by coherently combining the signals from at least two antennae. The result is called an interferogram and it is an interference pattern of fringes containing all information on the relative geometry.

Topographic information can be extracted from the interferogram using an external DEM or another interferogram, which leads to the calculation of differential interferometry SAR and the detection of surface changes between the two acquisitions. A more advanced InSAR-based technique called Persistent Scatterer Interferometry exploits multiple SAR images (typically more than 20 images) that allow the time series observation of the deformation and calculate the average displacement rates over the observed period.

Maps of secondary effects

Earthquake-triggered secondary effects such as floods, landslides, mudslides and tsunamis. Tsunami itself causes serious inundation or flooding in coastal areas and the strong waves damage shorelines, buildings and infrastructure. Refer to the relevant chapters for the same types of hazards.

Damage maps

Refer to the section on techniques and methodologies for damage maps in the cyclone chapter.

24 Massonnet, D. and Feigl, K.L., "Radar interferometry and its application to changes in the Earth's surface", Reviews of Geophysics, vol. 36, issue 4, pp. 441–500, 1998.

25 Moreira, A. and others, "A tutorial on synthetic aperture radar", IEEE Geoscience and Remote Sensing Magazine, vol. 1, issue 1, pp. 6–43, 2013.

26 Crosetto, M. and others, "Persistent scatterer interferometry: a review", ISPRS Journal of Photogrammetry and Remote Sensing, vol. 115, pp. 78–89, 2016.

Box 4. Timely and quality information and services for warning, disaster preparedness and mitigation

Philippine Institute of Volcanology and Seismology (PHIVOLCS) [27] is a service institute of the Department of Science and Technology that is principally mandated to mitigate disasters that may arise from volcanic eruptions, earthquakes, tsunamis and other related geotectonic phenomena. The mandates covered by PHILVOLCS are:

1. Predict the occurrence of volcanic eruptions and earthquakes and their related geotectonic phenomena.
2. Determine how eruptions and earthquakes shall occur and also areas likely to be affected.
3. Generate sufficient data for forecasting volcanic eruptions and earthquakes.
4. Mitigate hazards of volcanic activities through appropriate detection, forecast and warning systems.
5. Formulate appropriate disaster preparedness plans.

Providing timely and quality information and services for warning, disaster preparedness and mitigation can make a big difference in dealing with disasters, and it is possible to do so through the development and application of technologies for the monitoring, accurate prediction and determination of areas prone to volcanic eruptions, earthquakes, tsunamis and other related hazards, and capacity enhancement for comprehensive disaster risk reduction.

In order to study and monitor seismic activity to reduce the damage caused by earthquakes, PHILVOLCS started to map the entire territory of the Philippines using interpretation of remotely sensed images, extensive detailed field mapping and paleoseismological investigation along known active faults in the Philippines. The focus in the last two decades has been the Philippines Fault Zone and the Valley Fault System. The Active Fault Map of the Philippines is constantly updated using conventional aerial photograph interpretation, field mapping and paleoseismic studies. These maps are incorporated in GIS platforms for systematic archiving and use. GIS-format hazards data are shared with end users and stakeholders such as academia, planners, administrators, policymakers and the general public. Active fault maps and paleoseismic data are used in various applications such as hazard assessment, land-use planning and policy formulation.

As a result of the detailed study about the faults, 65 seismic stations have been positioned in the Philippines, 29 of which are manned, 30 are unmanned and six are volcano stations. The central operating station is located at PHIVOLCS Main Office, Diliman, Quezon City. All information is received at the Data Receiving Centre, which is operated 24/7 by the Seismological Observation and Prediction Division. Figures 7 and 8 show the revised map of the Philippines Fault Zone in eastern Mindanao and where PHIVOLCS monitoring stations have been placed around the country.

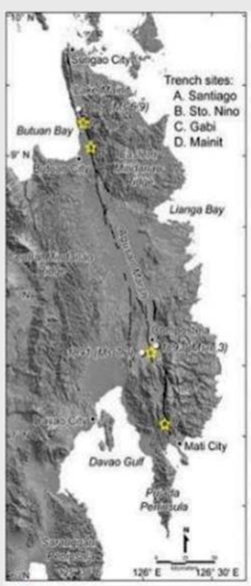

Figure 7: Fault lines in western Mindanao, Philippines

Figure 8: The 65 PHIVOLCS seismic stations

Notes: The black lines represent the fault lines, the circles represent epicentres of historical earthquakes, with year and magnitude, while yellow stars represent location of paleoseismic trench sites.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

27 See http://www.phivolcs.dost.gov.ph/.

How this earth observation information can be used for decision-making

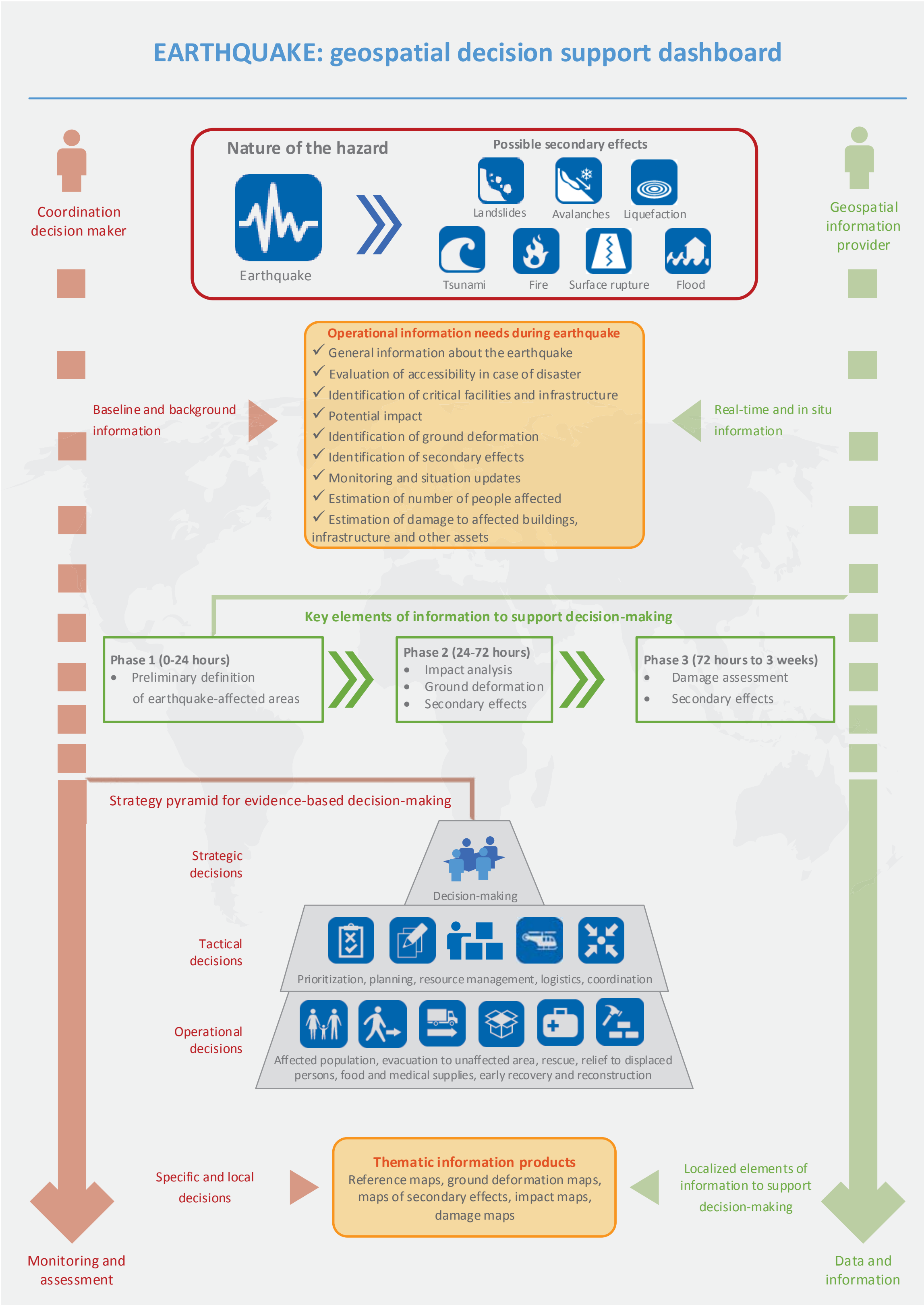

Figure 9: Geospatial decision support model for earthquakes

Nature of the hazard

Figure 9 shows the general considerations for geospatial decision support when applied in the context of earthquakes. This kind of hazard, which transmits vibrations across long distances along the earth's surface, can trigger several secondary effects including landslides, avalanches, floods, tsunamis, liquefaction, surface rupture and fires. The occurrence of secondary effects depends on the intensity of the event.

Operational information needs

Refer to table 2 for a list of operational information needs.

Elements of information to support decision-making

There are three phases to consider for this type of hazard. Phase 1 covers the range of time from the moment of the impact up to the first 24 hours and is focused on defining the areas affected by the earthquake. The second phase covers the following 24–72 hours and focuses on impact analysis, analysis of ground deformation and any secondary effects. Phase 3 assesses the damages and further development of secondary effects.

Strategy pyramid for evidence-based decision-making

Decision makers should consider several elements for their tactical and operational decisions. Earthquakes in general do not stop after the first shake; they usually develop several shakes with different intensities (intensity can decrease over time but may also increase) and at the same time other severe threats can develop, creating further complications. In urban areas damage to structures and infrastructure is not always apparent through satellite imagery observation. Therefore, preliminary assessments may not provide a full picture of what has actually happened on the ground. In some cases, buildings and roads may be seriously compromised yet still appear intact, through the 'pancake' effect where the sides are damaged but the roof or top remains intact, hence appearing undamaged from above. This can be very dangerous if they are considered as safe places to use as shelters. Some buildings can also collapse after a period of time if they have been structurally compromised or if the ground has been affected by soil liquefaction.

Unlike cyclones, earthquakes are very difficult to predict and this is one of the reasons communities living in seismically active areas are particularly vulnerable, since it is very difficult to set an efficient early warning system in order to evacuate the population in time. One of the most effective ways of reducing the vulnerability of the population is to build using anti-seismic criteria and train local communities to respond in efficient ways during earthquakes. This can involve understanding how and where to find safe places during shakes, how to communicate with the several actors involved in the management of the disaster and how to contribute to the disaster response.

Thematic information products

Refer to table 3 for the thematic information products required for earthquakes.

UN Photo/Kim Haughton

Landslide

What is the nature of the hazard?

A landslide consists of ground movement that includes the motion of rock, earth or debris down the slope of a hill or cliff. In volcanic areas lahars can also be part of this ground movement. It can include different types of movements: falls, slides, topples, lateral spread and flows. Landslides can result from either natural phenomena or human-related activities. There are three major causes of landslides: geomorphological factors, physical factors and human activity.

Geological factors refer to characteristics of the material itself. Weak earth or fractured rock can result in landslides. Morphologic factors refer to the structure of the land. For example, slopes without vegetation are more likely to slide away because they lack vegetation that holds soil in place. Extensive land sliding can be a secondary effect of intense rainfall, floods, earthquakes or volcanic eruptions that make a slope unstable. Human activity can also increase the risk of a landslide. Deforestation, excavation and construction are some of the common human activities that can destabilize or weaken a slope.

In 2015, there were 15 landslides in the Asia-Pacific region which caused 626 deaths and affected 45,234 people. [28] Landslides near populated areas often pose a serious threat to property and claim the lives of many people. Therefore, preparing for emergency response is critical to reducing the impact of landslides.

28 Centre for Research on the Epidemiology of Disasters, EM-DAT Database. Available from http://www.emdat.be/ (accessed February 2016).

Information needs for operational purpose

Information required to cope with the effect of landslides typically includes the location and affected areas; analysis of the impact on people, infrastructure and accessibility; and assessment of damage to buildings and other valuable assets. Rainfall monitoring can also be useful to update the weather situation and the possibility of landslides in other locations. In some cases, landslides may also trigger a flash flood if rocks or debris from the landslides block a river. Refer to table 2 for the information needed to coordinate emergency response for landslides.

Key information for landslides that can be detected by earth observation

Landslides are typically localized events that only affect a limited area, though they can also have widespread consequences if they disrupt transportation networks (roads, bridges, railway lines) or damage critical infrastructure. Therefore, the resolution of the EO sensor is an important consideration with regard to the scale of a landslide. VHR optical satellite data are preferred to map the landslide extent and are also essential for damage assessment and updating databases of physical assets (especially building-footprints). Satellite-based rainfall data are also helpful to monitor the weather and rainfall situation. Depending on data availability and estimated processing time, information for landslides can be prepared in three phases, as described in table 10.

Table 10: Information detected by earth observation for landslides

Phase	Detected information	Remarks
Phase 1 (0–24 hours)	Preliminary definition of landslide-affected area	• Pinpoint the location of the landslide and preliminary overview of the affected area • Reference information with available baseline data
	Rainfall monitoring	• Near real-time data on rainfall
Phase 2 (24–72 hours)	Landslide extent	• VHR optical data is preferred but SAR data can be useful if clouds obstruct
	Impact analysis	• Estimate impact on people, buildings, infrastructure, LULC and other assets • Evaluate accessibility to basic needs and services
	Secondary effects	• In the case of occurrence of secondary effects such as flash floods due to artificial dams
	Rainfall monitoring	• Continuous observation of rainfall
Phase 3 (72 hours to 3 weeks)	Damage assessment	• Rapid assessment of damage to buildings, infrastructure and other physical assets • Detailed assessment requires field data
	Landslide extent	• Continuous observation if landslides occur in other locations
	Secondary effects	• Continuous observation
	Rainfall monitoring	• Continuous observation of rainfall

Pros and cons

Landslide identification using EO satellite data is a quick and straightforward process and mapping of the landslide area can be very accurate, especially with VHR optical data. The wide coverage of EO sensors offers the advantage of detecting landslides over large areas, including remote areas which can be difficult to access from the ground.

Due to cloud coverage, the availability of optical data for operational use can be limited because most landslides occur during wet season. It may take several days after a landslide until relatively cloud-free data become available. With the ability to penetrate clouds, SAR data can be a valuable alternative for rapid response and they may also provide unique information; for example, as obtained from a specific technique such as SAR interferometry. However, delineating the exact boundary of a landslide may not be possible because of the 'noise' characteristic of SAR backscatter.

Similarly to other hazards, landslides can cause significant damage to buildings and other physical structures. The same advantages and disadvantages of using EO data for damage assessment are applied here. Note that the classification of damage level due to landslide can be less complicated because generally landslides cause total damage to buildings.

Techniques and methodologies

Based on the identification of information that could be obtained for landslides, common techniques and methodologies for generating information products during emergency response are discussed here. Table 11 shows an overview of data and methodologies used to derive the information products.

Table 11: Techniques and methodologies to derive information products for landslides

Information product	Data used	Methodology
Reference maps*	• Baseline data (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.) • Satellite images (archive)	• Overlaying geospatial data • Visualization (static)
Rainfall monitoring maps	• Satellite-based rainfall • Baseline data, DEM	• Extracting rainfall data • Visualization (static or dynamic)
Landslide extent maps	• Satellite images (pre and post)	• Manual visual interpretation • Visualization (static)
Impact maps	• Landslide extent • Population, building footprints, roads, bridges, buildings, LULC, etc. • Baseline data	• Spatial analysis • Visualization (static)
Maps of secondary effects	• Refer to data used for the same type of hazard	• Refer to methodology used for the same type of hazard
Damage maps	• Landslide extent • VHR satellite images (pre and post) • Building footprints, LULC, field data • Baseline data	• Manual visual interpretation • Visualization (static)

*Copernicus

Reference maps

Refer to the section on techniques and methodologies for reference maps in the flood chapter.

Rainfall monitoring maps

Refer to the section on techniques and methodologies for rainfall monitoring maps in the flood chapter.

Box 5. Landslide prediction [29]

Rainfall thresholds are often used to predict rainfall-induced landslides and in some cases have become the basis for early warning systems. An empirical threshold is defined from long-term rainfall data and a database of historical landslides using the rainfall intensity-duration method. When rainfall reaches or exceeds the threshold, landslides are likely to occur. Rain gauge data are typically the source of rainfall information; however, satellite-based rainfall measurements can provide observations over wide areas with sparse or non-existent in situ rain gauge stations. The uncertainty of rainfall estimation using satellite data should be taken into account when a satellite-based landslide early warning system is established for operational purposes.

29 Maggioni, V. and others, "Satellite-rainfall estimation for identification of rainfall thresholds used for landslide/debris flow prediction", paper presented at the European Geosciences Union General Assembly in Vienna, Austria, 17–22 April, 2016.

Landslide extent maps [30]

The most common approach to mapping landslide extent is manual visual interpretation of HR or VHR optical images, comparing pre- and post-event images. In the case of fresh landslides, the detection of the landslide is generally based on the identification of vegetation removal or any other visible sign of changes in the surface. Furthermore, the boundaries between the landslide zones (depletion, transport and deposition) and the unaffected terrain are usually distinct, especially for shallow landslides.

Depending on the size of a landslide, geometry and terrain conditions, a combination of pre- and post-event SAR data can also detect the changes even though delineating the exact boundary of the landslide is relatively difficult. Unmanned aerial vehicle and aerial photos can also be a flexible and cost-effective method to delineate the area of a landslide, particularly when weather conditions allow flights.

Impact maps

Refer to the section on techniques and methodologies for impact maps in the flood chapter.

Maps of secondary effects

A landslide can trigger secondary effects such as floods, creating a compound disaster with a variety of impacts across a larger region. Refer to the relevant chapters for the same type of hazard.

Damage maps

Refer to the section on techniques and methodologies for damage maps in the cyclone chapter.

Box 6. Case study: Use of remote sensing in support of disaster management efforts in Indonesia by LAPAN

LAPAN is the National Institute of Aeronautics and Space in Indonesia. It is involved in projects concerning space science, remote sensing, space technology mastery, platform launching and space commercial activities. In particular, in the field of remote sensing, LAPAN is responsible for data acquisition, processing, storage and distribution; the use of remote sensing data; and the dissemination of space-based information. It has implemented several projects on assessment of disasters and emergency response for catastrophes such as landslides, tsunamis, earthquakes and volcanic eruption. Very recently, LAPAN supported the assessment and monitoring of the landslides triggered by heavy rain in June 2016 in Purworejo. Figure 10 shows the areas affected by several landslides in that territory.

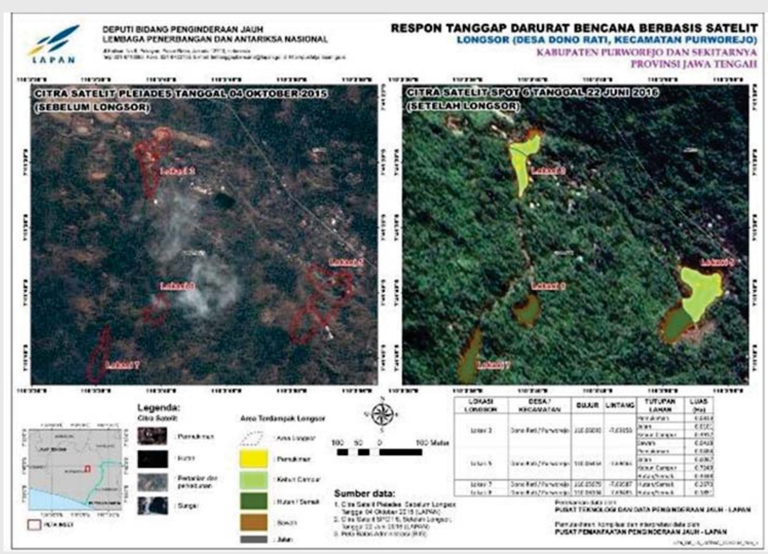

Figure 10: Satellite images comparing the same area within one year

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

30 Scaioni M. and others, "Remote sensing for landslide investigations: an overview of recent achievements and perspectives", Remote Sensing vol. 6, issue 10, pp. 9,600-9,652, 2014.

How this earth observation information can be used for decision-making

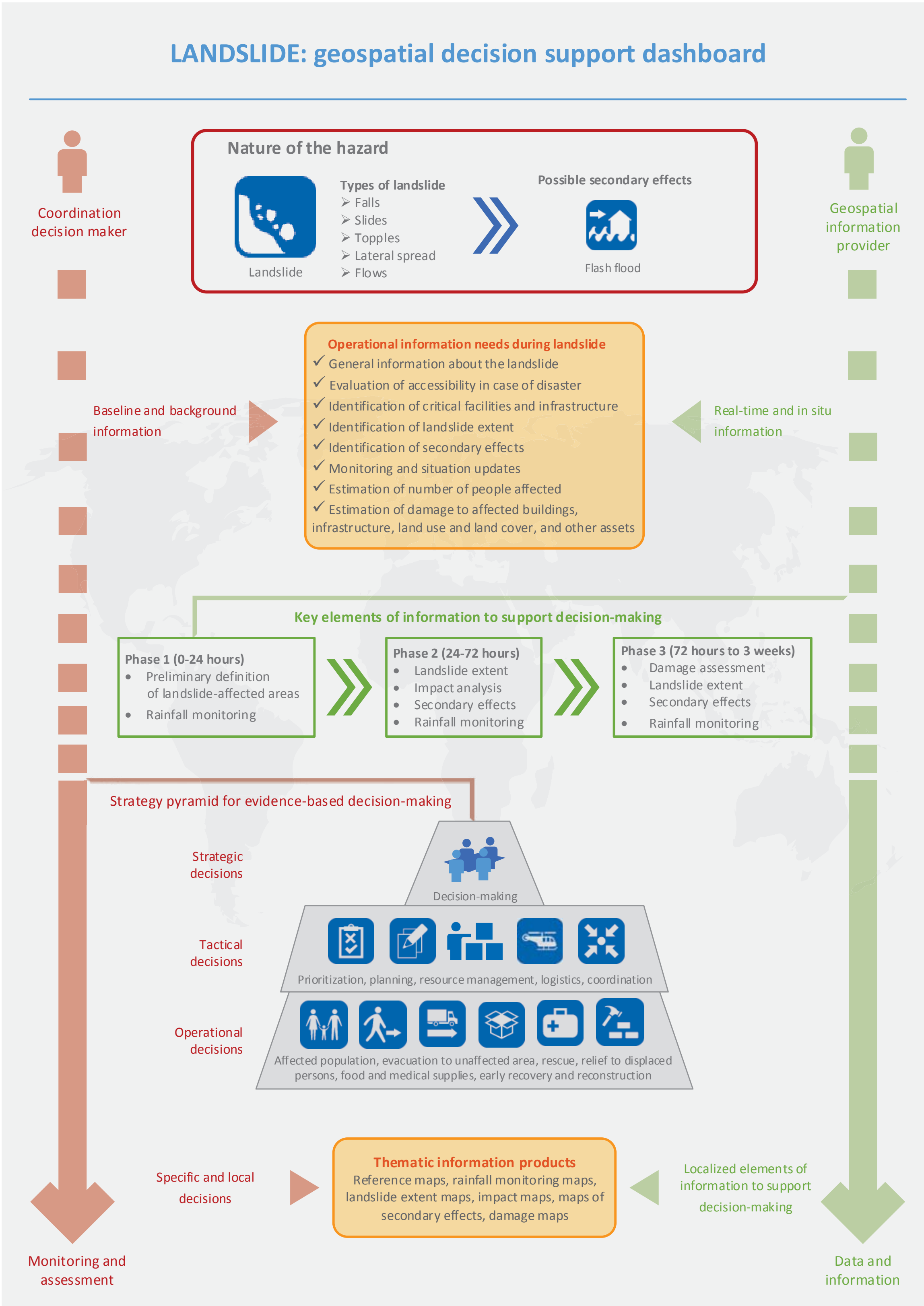

Figure 11: Geospatial decision support model for landslides

Nature of the hazard

Figure 11 shows the general model for geospatial decision support when applied in the context of landslides. Landslides are usually localized events even though they can have a very large impact. Possible secondary effects that can be triggered by landslides arise if there are water bodies in the surrounding area, such as a dam or a river that can be obstructed by a huge amount of collapsing material. The different types of landslides include:

- Falls
- Slides
- Topples
- Lateral spread
- Flows

When a landslide is associated with other factors such as high altitude and rain or snow melt, the materials moving towards the valley can be a mix of unconsolidated sediments, creating mudflow or debris flow.

Operational information needs

Refer to table 2 for a list of operational information needs.

Elements of information to support decision-making

Landslides have three phases as key elements of information to support decision-making: during all three phases rainfall monitoring remains a constant. Phase one occurs from the moment of impact up to 24 hours and focuses on preliminary definition of the affected areas. Phase two occurs between 24 and 72 hours and focuses on impact analysis. Phase three occurs from 72 hours and up to three weeks after impact: it focuses on an assessment of the damage. For both phases two and three, rainfall monitoring is accompanied by an assessment of the landslide extent and an evaluation of secondary effects that can arise following the landslide.

Strategy pyramid for evidence-based decision-making

Decision makers need to keep in mind the type of landslide that has occurred, because it can be circumscribed or evolving depending on its nature and other environmental factors. Human activities can increase the intensity or duration of a landslide. Time for evacuation can be very limited but in general it is possible to estimate where a landslide may occur by assessing the slope stability and monitoring external factors such as rainfall, deforestation, agricultural activities, and snowmelt. It is also important to evaluate accessibility to and from affected areas and consider alternative routes in case primary passages are blocked, as often landslides occur in mountainous or high-altitude terrain. Heavy machinery and digging equipment is always required in the affected areas.

Thematic information products

Refer to table 3 for the thematic information products required for landslides.

Volcanic activity

What is the nature of the hazard?

Volcanic eruptions are one of the most devastating natural disasters, endangering human life, damaging property and causing considerable environmental changes. In 2014 there were five volcanic activities in Asia and the Pacific that affected approximately 170,000 people and led to 101 deaths. Economic losses were estimated at US$186 million. [31] Whether large or small, when a volcano erupts, it typically affects humans by covering their environment with ash and lava and emitting toxic gases. Some seismic activity can also be recorded along volcanic hotspots by sensitive instruments; however, it is usually too weak to be felt. The distribution of these waves, called harmonic tremors, provides information about magma pathways and the structure of volcanoes and can be used to monitor volcanic activity.

Some volcanoes also produce pyroclastic flows, lahars and debris avalanches that are lethal to anyone in their path. Though the occurrence of such activities cannot be prevented, their devastating effects can be reduced and losses minimized by understanding the hazards resulting from volcanic eruptions.

- **Lava flows** are generally less dangerous to humans. Casualties are rare because lava moves slowly and the path of lava flows can be roughly predicted, though how far and fast a lava flow travels depends on the temperature of lava, its viscosity and extrusion rate, and the steepness of the ground over which it flows. However, lava flows are enormously destructive to property in their path. They can bury homes and agricultural land, and ignite and burn buildings and fields.

31 ESCAP, Disasters in Asia and the Pacific: 2014 Year in Review.

- **Pyroclastic flows** consist of hot volcanic gases and ash that are often generated during explosive volcanic eruptions. They can sweep down from an erupting volcano with high velocity. Coarse particles from the flows can lead to deaths by choking the lungs and causing burns when inhaled. The most hazardous situation, however, develops if pyroclastic flows are spawned on snow- or glacier-covered volcanoes. The flows can melt the cover and pose a serious threat to humans by engulfing people and property in their path.

- **Poisonous gases** can be emitted from volcanoes during eruptions or without triggering eruptions. The gases spread out from vents and form noxious acids that damage eyes, skin and respiratory systems, causing mass fatalities.

- **Ash falls and tephra falls** released after a volcanic eruption can cause serious injury and even death to people living in areas far away from a vent as well as in its vicinity. If continually piled up on houses and other structures, they can cause roofs and houses to collapse by increasing the weight beyond what a roof can endure.

- **Lahars,** flows of volcanic mud and debris, can occur as a secondary hazard caused by volcanic eruptions. Lahars move swiftly and have destructive power. They often develop as a result of heavy rainfall during or after eruptions. In most cases it is hard to control the volume and force of lahars.

Two secondary effects can be triggered by a volcanic eruption:

- **Debris avalanches**, catastrophic landslides from a steep and unstable side of a volcano, are also commonly triggered by volcanic eruptions. Since these avalanches are highly mobile, they can generate lahars and floods, causing a great deal of damage.

- **Tsunamis** are another important secondary hazard that can be produced from eruptions. They can arise from large-scale landslides like a debris avalanche or by volcanic earthquakes that rapidly move volcanic material into the sea.

Information needs for operational purpose

Information required to cope with volcanic eruptions typically includes the location and affected areas, analysis of the impact on people and accessibility, and assessment of damage to valuable assets. Identification of the volcanic deposition area is important to estimate the severity of the impact and of damage caused by eruptions, while monitoring of ash clouds is crucial to aviation safety. Secondary effects should also be identified, as in many cases volcanic eruptions trigger lahars (mudflows), landslides, floods and fires. Refer to table 2 for the information needed to coordinate emergency response for volcanic activity.

Key information for volcanic activity that can be detected by earth observation

EO contributes to providing information through the use of a wide range of wavelengths and resolutions of remote sensing data. VHR and HR optical data are preferred to map the extent of volcanic deposition and are also essential for damage assessment and updating databases of physical assets (especially building footprints). Thermal infrared can be used to identify and quantify volcanic ash emitted by the volcano. SAR data are useful to evaluate ground deformation and can also be used as an alternative to optical data for mapping volcanic deposition. Depending on data availability and estimated processing time, the information for volcanic eruption can be prepared in three phases, as described in table 12.

Table 12: Information detected by earth observation for volcanic eruptions

Phase	Detected information	Remarks
Phase 1 (0–24 hours)	Preliminary definition of affected area	• Pinpoint the location of the eruption and preliminary overview of the affected area • Reference information with available baseline data
Phase 2 (24–72 hours)	Volcanic deposition	• VHR optical data is preferred but SAR data can be useful if clouds or ashes obstruct
	Ash clouds	• Thermal infrared is commonly used
	Impact analysis	• Estimate impact on people, buildings, infrastructures, LULC and other assets • Evaluate accessibility to basic needs and services
	Ground deformation	• Interferometric SAR data is required
	Secondary effects	• In the case of secondary effects such as lahars (mudflows), floods, landslides, fires
Phase 3 (72 hours to 3 weeks)	Damage assessment	• Rapid damage assessment of buildings, infrastructures and other physical assets • Detailed assessment requires field data
	Volcanic deposition	• Continuous observation as eruption evolves
	Ash clouds	• Continuous observation as eruption evolves
	Secondary effects	• Continuous observation

Pros and cons [32, 33]

Volcanic eruption is a catastrophic event that causes widespread damage and far-reaching threats to populations, health, infrastructures and air traffic. The wide coverage of EO offers a cost-effective method of detecting and monitoring volcanic activity over a large area, including inaccessible areas. EO can also provide quick identification of volcanic deposition and affected areas, which is crucial to minimizing the casualties, disruption and damage caused by the eruption.

Due to extensive cloud coverage, the availability of optical data for operational use can be limited. Detection and monitoring of volcanic ash clouds also have certain limitations in both spatial and temporal resolution. The timeliness requirement for aircraft safety warnings is very short (up to every five minutes) and may not be met with the current satellite constellations. Geostationary satellites such as the Geostationary Operational Environmental Satellite (GOES) provide data every 15 minutes; however, the spatial resolution is poor and coverage is limited. The Brightness Temperature Difference (BTD) method is also known to be subject to errors or false alarms when the volcanic plume lies over very cold surfaces, over clear land surfaces at night, over soils with high quartz content, over ice-covered surfaces and in the presence of high water vapour content.

Similarly to other hazards, volcanic eruption causes significant damage to buildings and other physical structures. The same advantages and disadvantages of using EO data for damage assessment are applied here.

32 Zehner, C., ed., Monitoring Volcanic Ash from Space: ESA–EUMETSAT workshop on the 14 April to 23 May 2010 eruption at the Eyjafjöll volcano, South Iceland (ESA/ESRIN, 26–27 May 2010), (ESA Publication STM-280, 2012).
33 Picchiani and others, "Volcanic ash detection and retrievals using MODIS data by means of neural networks", Atmospheric Measurement Technique, vol. 4, issue 12, pp. 2,619–2,631, 2011.

Techniques and methodologies

Based on the identification of information that could be obtained for volcanic eruption, common techniques and methodologies for generating information products during emergency response are discussed here. Table 13 shows the overview of data and methodologies used to derive information products.

Table 13: Techniques and methodologies to derive information products for volcanic eruption

Information product	Data used	Methodology
Reference maps*	• Baseline data (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.) • Satellite images (archive)	• Overlaying geospatial data • Visualization (static)
Volcanic deposition maps	• HR satellite images (pre and post) • Baseline data	• Manual visual interpretation • Visualization (static)
Ash cloud maps	• Satellite images (thermal bands) • Baseline data	• BTD • Visualization (static)
Ground deformation maps	• Interferometric SAR data	• InSAR • Visualization (static)
Impact maps	• Volcanic deposition and ash clouds • Population, building footprints, roads, bridges, buildings, LULC, etc. • Global flight data (International Air Transport Association) • Baseline data	• Spatial analysis • Visualization (static)
Maps of secondary effects	• Refer to data used for the same type of hazard	• Refer to methodology used for the same type of hazard
Damage maps	• Volcanic deposition • VHR satellite images (pre and post) • Building footprints, field data • Baseline data	• Manual visual interpretation • Visualization (static)

*Copernicus

Reference maps

Refer to the section on techniques and methodologies for reference maps in the flood chapter.

Volcanic deposition maps [34]

Visual interpretation is the most commonly used technique to estimate the extent of volcanic deposition. HR satellite images such as SPOT, Landsat, and ASTERare suitable for detecting the deposition area and show clear visible differences from surrounding areas. The Normalized Difference Vegetation Index (NDVI) can also be used to enhance the difference from vegetated areas.

Ash cloud maps [35, 36]

Among the available EO sensors, visible and infrared channels of optical sensors are commonly used for ash cloud detection and monitoring. The most widely used approach to detect volcanic ash is based on the BTD method, also known as split window or reverse absorption technique. The method compares the brightness temperature of two channels centred at around 11 and 12 μm, which behave differently when they pass through different cloud compositions. Cloud particles such as water droplets, water vapour and ice particles absorb infrared at longer wavelengths than volcanic ash. The BTD method has been applied to geostationary satellite sensors such as

34 Joyce, K.E. and others, "A review of the status of satellite remote sensing and image processing techniques for mapping natural hazards and disasters", Progress in Physical Geography, vol. 33, issue 2, pp. 183–207, 2009.
35 Picchiani, M. and others., "Volcanic ash detection and retrievals using MODIS data by means of neural networks", Atmospheric Measurement Technique, vol. 4, issue 12, pp. 2,619–2,631, 2011.
36 Stevenson, John A., "How do satellites map volcanic ash clouds?", 30 April 2015. Available from http://all-geo.org/volcan01010/2015/04/how-do-satellites-map-volcanic-ash-clouds/.

GOES and the Spinning Enhanced Visible and Infrared Imager, as well as geosynchronous satellite sensors such as the Advanced Very High Resolution Radiometer (AVHRR) and MODIS, which all have thermal infrared channels.

Impact maps

Refer to the section on techniques and methodologies for impact maps in the flood chapter.

Ground deformation maps

Refer to the section on techniques and methodologies for ground deformation maps in the earthquake chapter.

Maps of secondary effects

Volcanic eruption can trigger secondary effects such as lahars (mudflows), landslides, floods and fires. Refer to the relevant chapter for the same type of hazard.

Damage maps

Refer to the section on techniques and methodologies for damage maps in the cyclone chapter.

Box 7. Case study: Space-based disaster emergency response for volcano eruption, Indonesia, LAPAN

Indonesia faces as a natural hazard the risk of volcanic eruptions. In its work supporting disaster risk management, LAPAN concentrates on space-based disaster emergency response for volcanic eruptions. It tries to analyse the conditions around the volcano from several images (such as SPOT-6, SPOT-7 and Shuttle Radar Topography Mission images). The LAPAN team also supervises the field rescue officer and local government on the use and gathering of information from the images during disaster mitigation efforts. These assessments are very useful to understand if residents around the volcano should be evacuated to safe areas during critical moments. Figure 12 shows some images of the eruption of the Sinabung volcano that had some activity between April and May 2016.

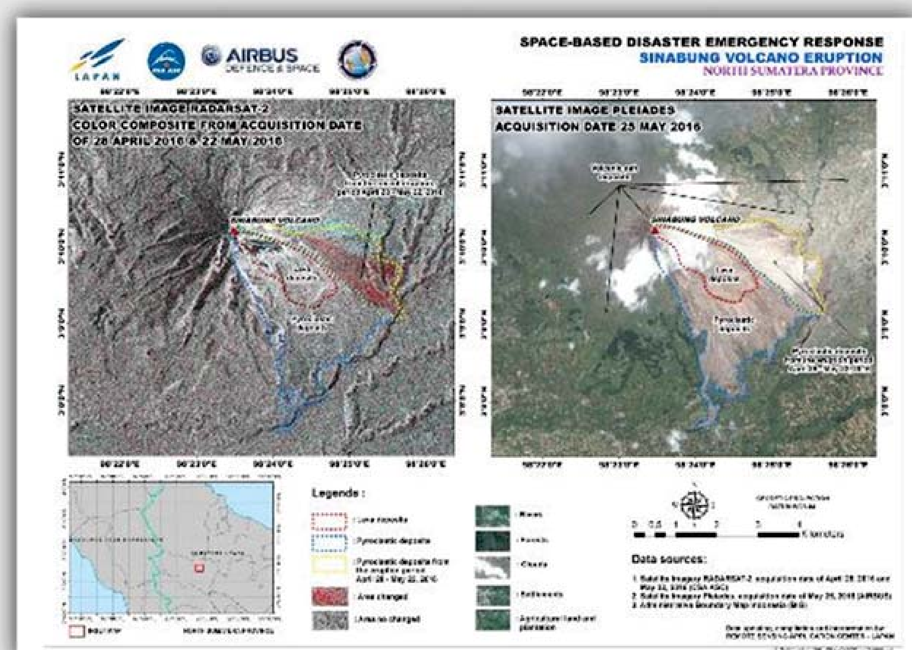

Figure 12: LAPAN satellite images to monitor the eruption of Sinabung volcano April–May 2016

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

How this earth observation information can be used for decision-making

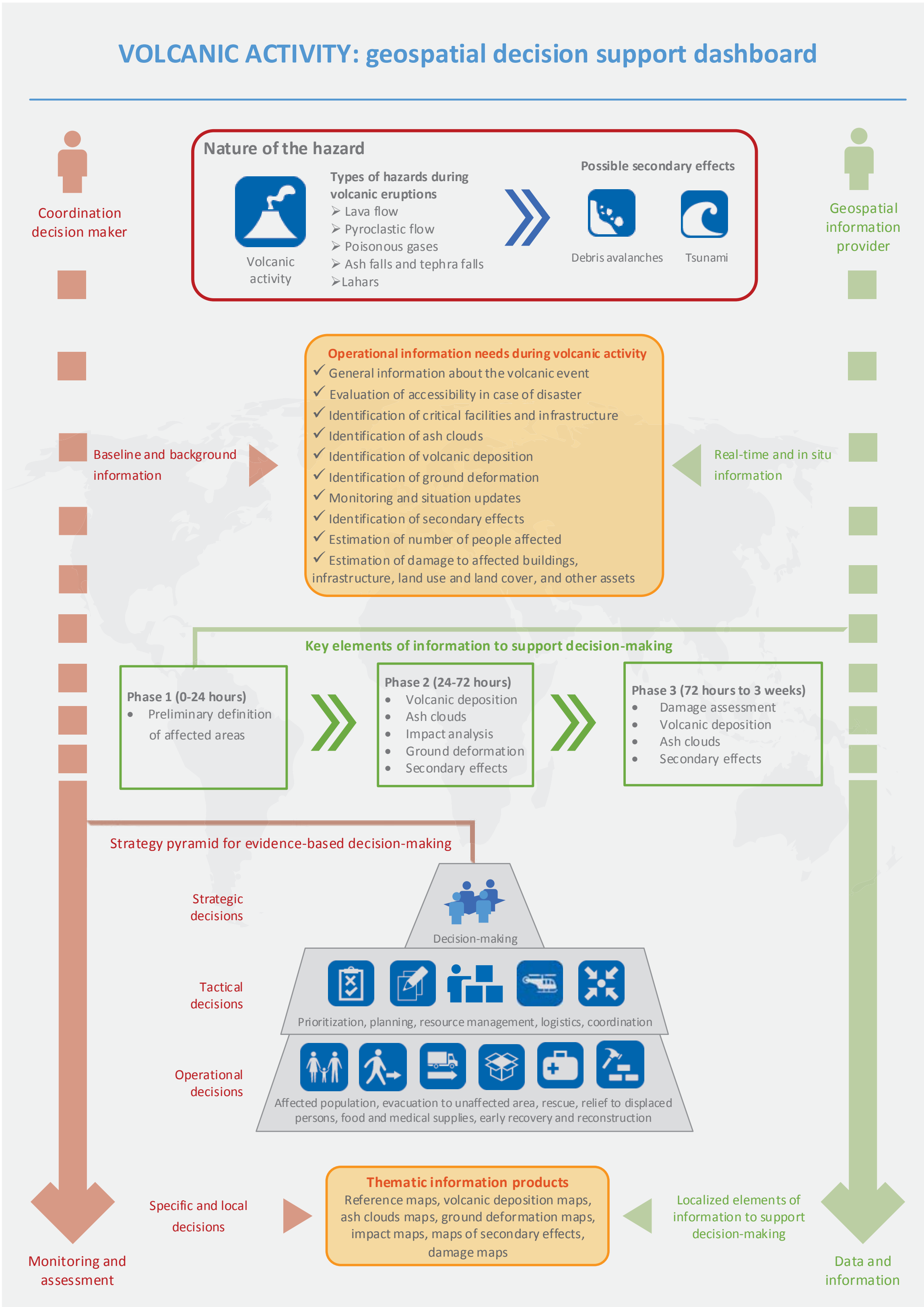

Figure 13: Geospatial decision support model for volcanic activity

Nature of the hazard

Figure 13 shows the general model for geospatial decision support when applied in the context of volcanic activity. Volcanic activity can be monitored but it is not always possible to forecast the moment of an eruption, especially if they are explosive. Sometimes it is possible to monitor the movement of underground lava inside the magmatic chambers and this can give some warning regarding intense activity that can lead to an eruption. In general the material erupted by a volcano is lava, pyroclastic flow, poisonous gases, ash falls, tephra falls and lahars. Secondary effects of intense volcanic activity are avalanches and tsunamis.

Operational information needs

Refer to table 2 for a list of operational information needs.

Elements of information to support decision-making

Three phases are considered, including the definition of the affected areas, the impacts of the volcanic activity and the secondary effects.

Strategy pyramid for evidence-based decision-making

Decision makers should take into account accessibility to and from affected areas and the possibility of secondary effects such as landslides and tsunamis.

Thematic information products

Refer to table 3 for the thematic information products required for volcanic activity.

UN Photo/Jean-Marc Ferré


Photo credit: Shutterstock / Elzbieta Sekowska

Forest fire

What is the nature of the hazard?

Forest fire refers to an uncontrolled fire that spreads in a forested area. It is one type of wildfire, a classification that generally includes forest fires, grassland fires, bushfires and any other vegetation fires in rural areas. Forest fires can be started naturally by lightning or volcanic eruptions but can also be started by humans, accidentally or deliberately. Green vegetation dries out during the late dry season in the Asia-Pacific region, becoming highly flammable, and strong winds can spread fire fast. As part of land management practices, people in the region slash and burn to clear and manage agricultural landscapes and this often leads to forest fires.

Forest fires can threaten the lives of many in their vicinity and cause extensive damage to communities by destroying vast amounts of timber resources, leading to tremendous economic losses. They also compromise air quality and consequently pose risks to human health, increase the level of greenhouse gases and affect forest ecosystems extensively. In 2015, forest fire and haze across South-East Asia affected Indonesia and its neighbouring countries such as Singapore and Malaysia. The haze caused serious respiratory problems for more than 500,000 people and reportedly killed at least 10 people in Indonesia alone. According to the Centre for International Forestry Research, the economic losses resulting from forest fire and haze that year were estimated at US$14 billion. [37] Therefore, preparing for emergency response is critical to reducing the negative impacts of forest fires.

37 ESCAP, Disasters in Asia and the Pacific: 2015 Year in Review.

Information needs for operational purpose

Forest fires can be spread over a very wide area, affecting humans and property, as well as the environment, on a large scale. A forest fire can last for weeks or even months before the fires can be suppressed or controlled. Therefore, monitoring the distribution of fire hotspots, haze dispersion, fuel moisture condition and vegetation status are important to update the situation as a fire continues. Identification of burned areas is also essential to estimate damage and losses, especially to forest and agricultural areas. Refer to table 2 for the information needed to coordinate emergency response for forest fires.

Key information for forest fires that can be detected by earth observation

EO satellites with geostationary orbits can provide extensive and frequent coverage of forest fires and affected areas. Thermal infrared sensors measure heat and can detect hotspots which indicate active forest fires. The visible and infrared bands can identify burn scars, detect haze and smoke plumes, and monitor vegetation status. Depending on data availability and estimated processing time, information for forest fires can be prepared in three phases, as described in table 14.

Table 14: Information detected by earth observation for forest fires

Phase	Detected information	Remarks
Phase 1 (0–24 hours)	Preliminary definition of affected area	• Pinpoint the location of the forest fire and preliminary overview of the affected area • Reference information with available baseline data
	Active fire hotspots	• Near real-time data on active fires
	Haze and smoke plumes	• Moderate resolution optical sensors with high temporal and multispectral bands are the most efficient
	Vegetation monitoring	• Information on vegetation status
Phase 2 (24–72 hours)	Burned area	• Moderate resolution optical sensors with multispectral bands are the most efficient
	Impact analysis	• Estimate the impact on people, buildings, infrastructures, LULC and other assets • Evaluate accessibility to basic needs and services
	Active fire hotspots	• Continuous observation of active fires
	Haze and smoke plumes	• Continuous observation of haze
	Vegetation monitoring	• Continuous observation of vegetation status
Phase 3 (72 hours to 3 weeks)	Damage assessment	• Rapid assessment of damage to buildings, infrastructures, LULC and other assets • Detailed assessment requires field data
	Active fire hotspots	• Continuous observation of active fires
	Haze and smoke plumes	• Continuous observation of haze
	Vegetation monitoring	• Continuous observation of vegetation status

Pros and cons

The wide coverage of EO offers a cost-effective method of detecting and monitoring forest fires over a large area, including inaccessible areas. Quick detection of fires and identification of the affected areas are both crucial to minimize the casualties and damage caused by forest fire and can be effectively provided by EO. Furthermore, the frequent and repetitive coverage of EO can ensure regular updates to information.

The limitations to detection of active fires from EO sensors are associated with the spatial and temporal resolution of the sensor as well as differences in fire characteristics among different regions. With a spatial resolution of 1 km – such as for fire detection using MODIS and AVHRR sensors – fires within a detected hotspot cannot always be determined and this causes underestimation of the number of fires. False alarms may also arise due to sun glitter and warm land surface. Meanwhile, to accurately map the burned area, a medium-to-high resolution (10m to 30m ground spatial resolution) is commonly used. However, the increase in spatial resolution is often accompanied by a decrease in revisit time of the sensor, which prevents the acquisition of this imagery over extensive areas. Cloud cover and thick haze further limit the availability of clear optical images.

Techniques and methodologies

Based on the identification of information that could be obtained for forest fires, common techniques and methodologies for generating information products during emergency response are discussed here. Table 15 shows the overview of data and methodologies used to derive these information products.

Table 15: Techniques and methodologies to derive information products for forest fires

Information product	Data used	Methodology
Reference maps*	• Baseline data (administrative boundaries, transportation networks, hydrology, critical facilities, LULC, etc.) • Satellite images (archive)	• Overlaying geospatial data • Visualization (static)
Fire hotspot maps	• Satellite-based active fire hotspots • Baseline data	• Extracting fire hotspots data • Visualization (static or dynamic)
Haze and smoke plume maps	• Satellite images • Baseline data	• Band combination • Calculating haze index • Visualization (static or dynamic)
Vegetation monitoring maps	• Satellite image (near-infrared and red bands) • Baseline data	• Calculating NDVI index • Visualization (static or dynamic)
Burned area maps	• Satellite images (pre and post) • Baseline data	• Manual visual interpretation or image classification • Visualization (static)
Impact maps	• Burned areas • Population, building footprints, roads, bridges, buildings, LULC, etc. • Baseline data	• Spatial analysis • Visualization (static)
Damage maps	• Burned areas • VHR satellite images (pre and post) • Building footprints, LULC, field data • Baseline data	• Manual visual interpretation (when inhabited areas are affected) • Spatial analysis • Visualization (static)

*Copernicus

Reference maps

Refer to the section on techniques and methodologies for reference maps in the flood chapter.

Fire hotspot maps [38]

The use of EO satellite data is indispensable for forest fire monitoring through the application of geostationary satellite sensors such as GOES or the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board the Meteosat Second Generation satellites, and geosynchronous satellite sensors such as the AVHRR aboard the United States National Oceanic and Atmospheric Administration satellite; Visible Infrared Imaging Radiometer Suite aboard the Suomi National Polar-orbiting Partnership weather satellite; and MODIS aboard the Terra and Aqua satellites.

38 Leblon, B., Bourgeau-Chavez, L. and San-Miguel-Ayanz, J., "Use of Remote Sensing in Wildfire Management" in Sustainable Development – Authoritative and Leading Edge Content for Environmental Management, Sime Curkovic, ed. (InTech, 2012).

Meteorological satellites offer frequent diurnal sampling (up to every 5-15 minutes), allowing close monitoring of fire development but at the expense of relatively poor spatial resolution (1 km or coarser). MODIS and AVHRR provide a reasonable trade-off between spatial and temporal coverage, providing daily or twice-daily passes with spatial resolution of around 1 km. The latest Visible Infrared Imaging Radiometer Suite sensor offers multispectral bands with a 24-hour revisit time and spatial resolution of 375 metres.

Fire hotspots can be detected by mid-infrared and thermal infrared bands, using thresholding algorithms. The threshold is based on the local or absolute maximum of temperature. A pixel is considered a fire when it exceeds the given threshold. For each detected hotspot, a confidence level is calculated and the values can be between 0 and 100 per cent. Furthermore, a fire danger can be classified into three classes: low confidence, nominal confidence or high confidence. There are a number of global operational fire monitoring systems; for instance, the NASA Fire Information for Resource Management System provides active fire detection using MODIS and the Visible Infrared Imaging Radiometer Suite. [39]

Haze and smoke plume maps [40]

The visible bands can detect haze and smoke plumes from fires. Manual interpretation or image classification can be used to take out smoke plumes in contrast to the background and associate them with a fire. Smoke plumes can be visually identified in an image as fuzzy bright strips converging to a point on the ground and oriented along the direction of the wind. Image processing can also be done here; for example, using the normalized difference haze index (NDHI),calculated from the visible and thermal infrared channels.

Vegetation monitoring maps

NDVI has been widely used to measure forest vegetation response to fire. NDVI and other vegetation indices are indirectly related to fuel moisture condition as it measures greenness. NDVI is calculated from the visible and near-infrared bands. Healthy vegetation strongly absorbs the visible (red) light and reflects most of the near-infrared light. In contrast, the unhealthy vegetation reflects more red light and less near-infrared light.

Burned area maps [41]

Visual interpretation is one method of mapping burned areas. Using a false colour composite – for example combining the red, near-infrared and green bands – a strong contrast of burned areas can be discriminated in an image due to the strong contrast with unburned areas. The image classification method can also be used to automatically classify the image using an unsupervised or supervised approach.

Burned areas, including the severity of fire, can also be identified using Normalized Burn Ratio (NBR). NBR uses the near-infrared and shortwave-infrared bands. The NBR is normally calculated for at least two images, taken before and after a forest fire. The NBR difference between these two images is then used to indicate an area that has been burned using a threshold approach. This threshold value can be calculated based on the long-term NBR data of the affected area.

Impact maps

Refer to the section on techniques and methodologies for impact maps in the flood chapter.

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39 https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms

40 Liew, S.C. and others, “Remote sensing of fire and haze” in Forest Fires and Regional Haze in Southeast Asia, P. Eaton and M. Radojevic, eds., pp. 67–89, (New York, Nova Science Publishers, 2001).

41 United Nations Platform for Space-based Information for Disaster Management and Emergency Response. Data Application of the Month: Forest Fires. Available from http://www.un-spider.org/links-and-resources/data-sources/daotm-fire.

Damage maps

Burned area, coupled with land cover information, provides the basis for damage assessment, especially to forest and agricultural areas. Land cover maps can be derived from satellite images using the reflectance signatures of various land cover types and the image classification technique can be performed to automatically classify the land cover. For damage to buildings and other physical assets, refer to the section on techniques and methodologies for damage maps in the cyclone chapter.

Box 8. Case study: Use of remote sensing in support of disaster management efforts in Indonesia, LAPAN

Among the several projects implemented for disaster management in Indonesia by LAPAN, the Forest Fire Hotspot and Fire Danger Rating System provides an interesting case study. With the Fire Weather Index system it is possible to combine indicators such as temperature, relative humidity, wind speed and rainfall with the moisture content of fuel. The satellite remote sensing data coming from the National Oceanic and Atmospheric Administration and MODIS allow daily fire danger monitoring. The Fire Danger Rating System is shown in figure 14.

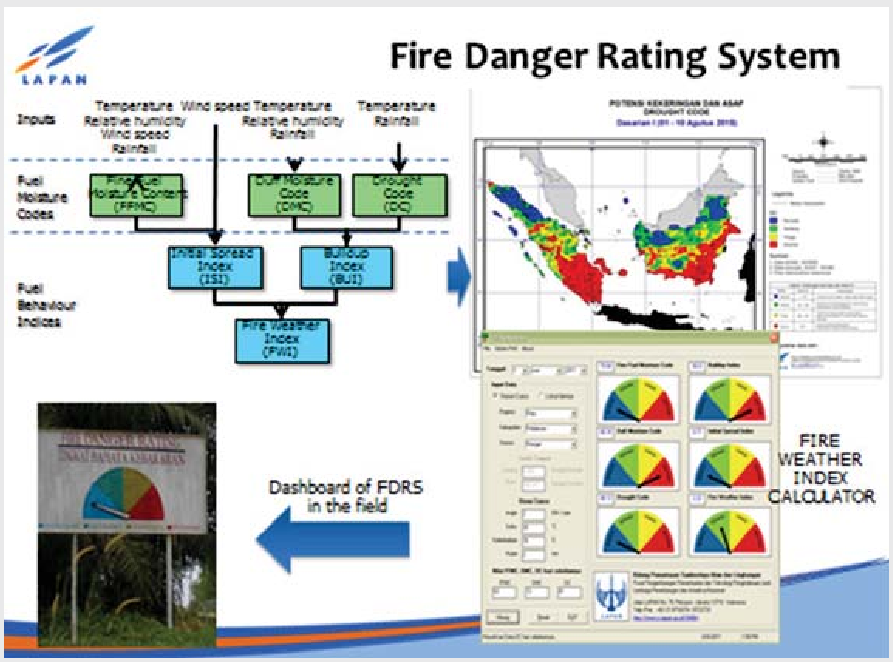

Figure 14: The LAPAN Fire Danger Rating System

How this earth observation information can be used for decision-making

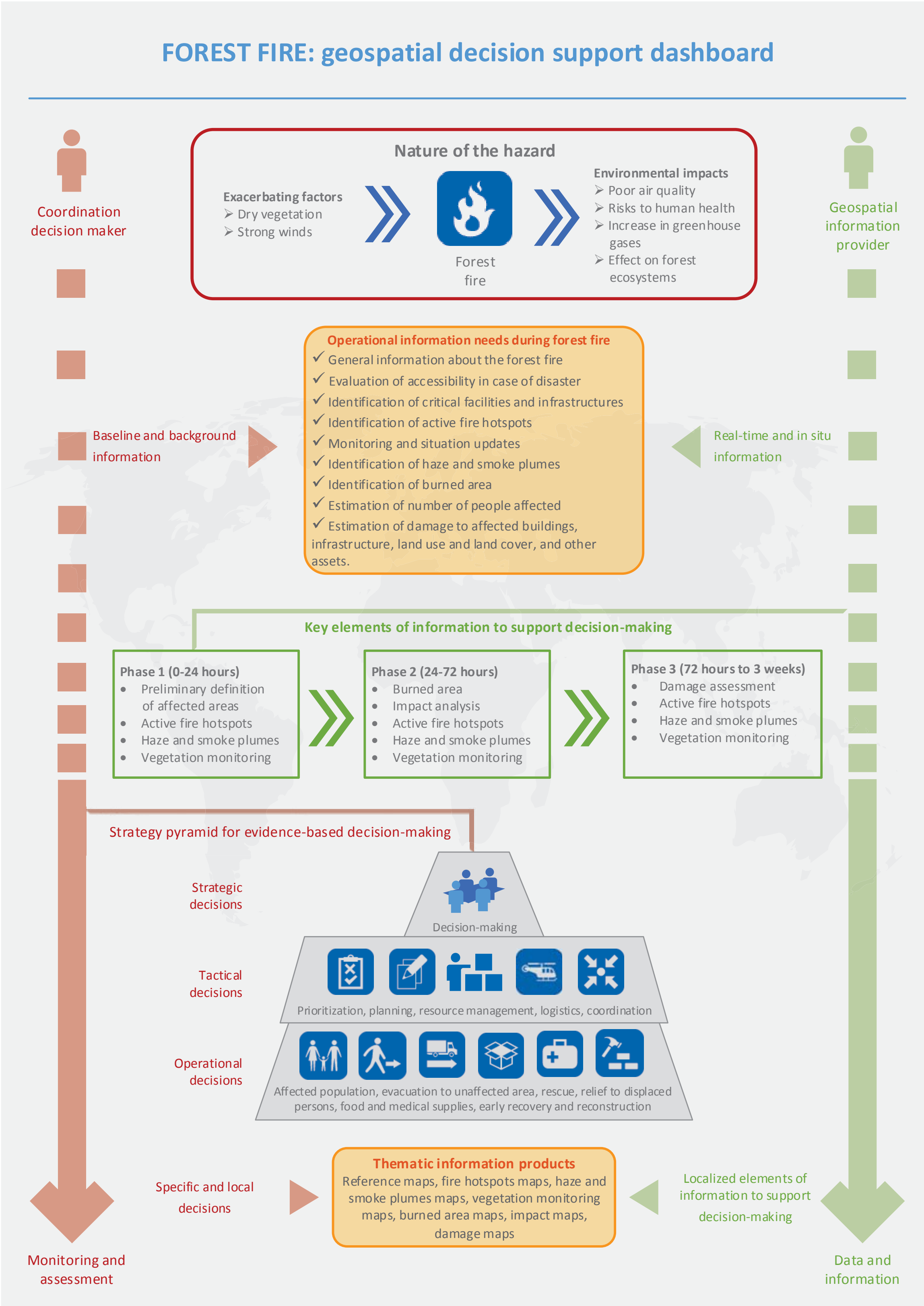

Figure 15: Geospatial decision support model for forest fire

Nature of the hazard

Figure 15 shows the general model for geospatial decision support when applied in the context of landslides. Forest fires can be exacerbated by the characteristics of the surrounding territory, such as dry vegetation and strong winds. Fires can have an impact on multiple levels, including to the environment and human health, as they affect the quality of the air. Subsequently, this can elevate greenhouse gases and risks to human health and forest ecosystems.

Operational information needs

Refer to table 2 for a list of operational information needs.

Elements of information to support decision-making

There are three phases following the start of a forest fire. These all include constant monitoring of active fire hotspots, haze and smoke plumes, and vegetation. Furthermore, specific actions for each phase include a preliminary definition of affected areas in phase one, an assessment of burned areas and impact analysis in phase two, and damage assessment in phase three.

Strategy pyramid for evidence-based decision-making

Decision makers should take into account external elements influencing the development of forest fires, such as strong winds that can spread easily and fan the flames into new territories and in different directions, and dry vegetation that can act as fuel to feed the fire. It is necessary to consider which types of vehicles will be used to extinguish the fire – such as helicopters, aeroplanes and fire trucks – and plan their routes accordingly. Evacuation and rescue operations should also take into account the possible directions where fire can spread. Therefore, monitoring should be a constant activity throughout the entire process.

Thematic information products

Refer to table 3 for the thematic information products required for forest fires.

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