USE OF EARTH OBSERVATION SATELLITES TO IMPROVE EFFECTIVENESS OF HUMANITARIAN OPERATIONS

UCLouvain

Centre for Research on the Epidemiology of Disasters CRED

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CRED:

The Centre for Research on the Epidemiology of Disasters (CRED) is one of the world's foremost agencies for the study of public health during mass emergencies, including the epidemiology of diseases, plus the structural and socio-economic impacts of natural and technological disasters and human conflicts. Based since 1973 at the School of Public Health of UCLouvain, Belgium, CRED became a World Health Organization (WHO) collaboration centre in 1980. Since then, CRED has worked closely with United Nations agencies, inter-governmental and governmental institutions, non-governmental organizations (NGOs), research institutes and other universities. Disaster preparedness, mitigation and prevention for vulnerable populations have also gained a higher profile within CRED's activities in recent years.

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1. Introduction

Throughout human history, technological innovations have changed the way humans view and understand the world. Satellite-based earth observation is one such innovations that radically changed how we monitor the state of the Earth. We are now for example capable of monitoring the melting of glaciers in near real-time (Kääb et al. 2018). Nowadays, earth observation is an essential source of information for a large variety of societal applications such as monitoring disasters, health, energy, climate, agriculture, ecosystems, biodiversity, water and weather (Dowman and Reuter 2017).

The humanitarian sector did not miss this opportunity and adopted earth observation to face its own challenges. Every year, humanitarian actors respond to disasters affecting millions of people and causing thousands of deaths. In 2019 alone, 396 natural disasters were recorded around the world, resulting in 11,755 fatalities, 95 million people affected and 103 billion US$ in economic losses (CRED 2020). Humanitarian actors use satellite images not only to monitor disasters emerging from natural hazards but also to assess human rights abuse and conflict. Earth observation satellites are used in this context to monitor the presence of mass graves or the destruction of buildings, for example.

The field of earth observation is in constant evolution and recent advances in data processing offer new sources of information, as well as new applications (Popkin 2018b). This report focuses specifically on space-based earth observation systems. It presents a critical review on the current use of earth observation data in the humanitarian sector based on the current scientific and grey literature.

The second section, “Methods”, describes the methodology applied to gather the scientific and grey literature used as a source of information, as well as the analysis to process this information. The third section of this report, “History”, is a brief summary of the birth, evolution and adoption of the earth observation technology by the humanitarian community. The fourth section summarises the most common applications of satellite images and products derived from them, as used by humanitarian actors. The fifth section, “Current challenges and trends” is dedicated to compile the current challenges that earth observation technology faces and the trends that may influence the future of this field of application.

2. Methods

A large variety of document sources was consulted to construct the overview of the current use of remote sensing data in the humanitarian context. Two main categories of documents can be distinguished: scientific literature and grey literature. For both of them the selection process is explained in the next two subsections.

2.1 Scientific literature

We defined a series of eligibility criteria at the beginning of the research to select scientific documents:

- Type of publication: peer-reviewed publications, book chapters and conference proceedings.
- Language: English and French.
- Publication date: until June 2020 (no lower limit).
- Scope: applications of remote sensing technology in natural disasters, conflicts situation or related to the humanitarian context.

Five scientific publication databases were selected for this review with the help of a librarian of the Bibliothèque des sciences et technologies (Science and Technology Library) from UCLouvain. These were: PubMed, SCOPUS, Environment complete, Science Direct, SpringerLink.

A search strategy was also defined with the librarian, with different research equations, based on a list of keywords:

- ("remote sensing" OR "earth observation" OR "satellite imagery" OR "satellite-based" OR "emergency mapping" OR SAR) AND (humanitarian OR ngo)
- ("remote sensing" OR "earth observation" OR "satellite imagery" OR "satellite-based" OR "emergency mapping") AND ("natural disaster" OR hazard) AND (earthquake OR volcan* OR heatwave OR fog OR storm OR flood OR landslide OR drought OR wildfire)
- ("remote sensing" OR "earth observation" OR "satellite imagery" OR "satellite-based" OR "emergency mapping") AND ("violent conflict" OR violence OR peacekeeping)

When the database allowed for it, the search was limited to the title, abstract and keywords of the article. If not, the search covered the complete article. A manual selection was then performed to filter the most relevant documents and analyse them.

This was first based on the reading of the title, followed by the abstract and eventually the full text of the document.

2.2 Grey literature

A panel of major international organizations and NGOs were selected based on the potential availability of their reports describing the use of earth observation.

The documents analysed were retrieved from the website of each organization. When possible, their internal search engine was used to select relevant documents. In this case, the following list of key words was used for United Nations (UN) agencies, international organisation and NGOs: satellite image, satellite imagery, remote sensing and earth observation. For space agencies, the keyword list was: conflict, violence, peacekeeping and (natural) disaster. Each document was read and useful information was compiled. Even though the list of selected organisations is not exhaustive we consider it representative for the current state of use of satellite technology in humanitarian operations.

We selected the following international organisations and NGOs:

- **UN**: Unicef, FAO, UNDRR, OCHA, UNHCR, UNITAR/UNOSAT, WHO, WFP, UNDP, World Bank.
- **International/national organisations**: IOM, USAID, Europeaid, DFID/UKaid, JRC (European Commission), DG ECHO (European Commission), Reliefweb, American Association for the Advancement of Science (AAAS), The International Charter Space and Major Disasters, Committee on Earth Observation Satellites (CEOS).
- **NGOs**: MSF, Mapaction, International Federation of Red Cross and Red Crescent Societies, Refugees International, International Rescue Committee, CartONG, Human Right Watch, Amnesty, Shelter cluster, Reach.
- **Space agencies**: ESA, NASA, JAXA.

In this report, the spatial resolution of satellite images is defined following the guidelines of the ESA “Newcomers Earth Observation Guide”[1]: Medium resolution is from 300 m to 30 m, high resolution from 30 to 5 m and very high resolution (VHR) below 5 m.

[1] https://business.esa.int/newcomers-earth-observation-guide

3. History

Space-based earth observation satellites emerged in the 1960s. This technology was initially used by the military, followed by commercial and civil uses. During the 1960s, the Earth Resources Technology Satellites program was initiated by the United States National Aeronautics and Space Administration (NASA). It was later renamed Landsat. The Landsat-1 satellite drastically changed opportunities for civilian uses by being the first satellite covering the entire world with a digital multispectral sensor, following a predictable and repetitive pattern (Read, Chambers, and Torrado 2020). The Landsat program is still active these days and the Landsat-9 satellite is scheduled to be launched in mid-2021. Other national and international space programs continued to launch new satellites, expending our capacity to monitor the earth from space. One current example is the Sentinel program, developed by the European Space Agency. Satellite development is not restricted to classic space agencies of Europe, Japan, and the United States. In the last 20 years, countries from Latin America, Africa, and Asia have also launched their own satellite programs (Voigt et al. 2016). Private companies also entered the satellite market and in 2000, images captured by the first commercial satellite, IKONOS, started to be sold (UNOSAT 2011).

When a disaster occurs, being able to acquire information rapidly on large, and sometimes difficult to access areas, is crucial to effectively coordinate the response (Delmonteil and Rancourt 2017). However, the large-scale use of satellite images for disaster management really expanded during the late 1980s and early 1990s with the arrival of affordable desktop computers and software (Thomas, Ertugay, and Kemec ̧ 2007; Walter 1990). Having a quick turnaround of insights on the extent of a flood or an early estimate of the number of internally displaced people (IDPs) in a camp are examples of the current use of satellite data by the humanitarian sector (Quinn et al. 2018). The creation of satellite-based emergency mapping services in many organisations responding to natural hazards and disasters shows the adoption of earth observation technology to increase the resilience of human populations to such events (Voigt et al. 2016).

The use of earth observation satellites in the assessment of conflicts really developed after the use of satellite images for disaster management. Indeed, to assess human rights abuse and conflicts, very high spatial resolution is essential. Such satellite images were only available for civilian use from the early 2000s onwards with the first very high spatial definition commercial satellites (UNOSAT 2011).

4. Applications

4.1 Natural hazards and disasters

The following subsections are organised by the application of satellite observations for different natural disaster types.

4.1.1 Earthquakes and volcanic eruptions

Earthquakes are a challenging type of disaster since they cannot be predicted. A rapid response is needed to save lives after a major earthquake and acquiring timely information is critical (CEOS 2015). Infrastructures, such as buildings, roads and critical facilities, can be severely affected. Thus, it is important for relief managers to know where the affected areas are and how severe the destruction is. Knowing which roads are passable is key information to physically access affected areas, which can be assessed with satellite images. One strength of satellites is the fact that they are not affected by the loss of surface-based local infrastructures, such as in-situ sensors and communication systems (UNOSAT 2017).

By comparing before and after situations from archive images and post-disaster situations, a damage assessment can be generated to help the management of relief (Ehrlich et al. 2009). The spatial resolution of satellite images is important to assess the damage caused by an earthquake. High resolution images are used to have an overview of the affected area. An example is the monitoring of landslides caused by the earthquake. These landslides can obstruct waterways and create barriers, forming lakes and presenting a risk of flooding (CEOS 2015). At 10 m resolution, satellite images can be used to spot damage at the urban block level (Dong and Shan 2013). VHR images are suited to assess with more precision the damage to buildings or transport network (partially destroyed or completely destroyed). To detect damage at the scale of individual buildings, a spatial resolution of 1 m is needed. Finer resolutions, such as 0.5 m, improve the quality of the assessment (Dong and Shan 2013). The rate of successful building damage detection ranges from 70 % to 90%. This rate depends on the availability and quality of the data, with a higher rate when pre- and post-event data are both available (Dong and Shan 2013). The assessment of destruction also helps to estimate the affected population. Satellite images are also used to identify temporary gathering sites and the mapping of IDPs camps (UNOSAT 2017). Due to the unpredictable nature of earthquakes, the global coverage of satellites and their fast mobilisation are particularly well suited to improve the response to face major earthquakes. Satellite images are also used in the earthquake recovery phase for monitoring the reconstruction and sectorial assessment (UNOSAT 2017).

Another important threat for human populations is the risk of eruption of volcanoes (World Bank 2015). Determining when a volcano will erupt is challenging. Satellite data help monitor ground deformation around the volcano with radar sensors. Ground deformations signal a change in the inner magma flow and can be an indicator of a future eruption. However, the presence of ground deformation does not always lead to an eruption. Still, eruptions that take place without the apparition of any prior ground deformation are rare. Satellites add new information to the existing ground-based monitoring and offer the capacity to monitor such deformation even for hard to reach volcanoes or those without ground instruments, without any risk to workers during data collection (CEOS 2015).

Satellite data are also useful to monitor volcanic ash plumes. Information such as ash particle size and height can be derived from multispectral sensors. Such information is important for the aviation sector but also for the on-the-ground air quality (CEOS 2015).

Satellite images are also used during the emergency disaster response phase. Various types of information can be derived from them such as mapping the lava flow extent, estimating the affected population, rapid damage assessment, assessment of physical access to affected areas or locating temporary gathering sites and IDPs camp mapping (UNOSAT 2017).

4.1.2 Floods and storms

Floods and storms are the most prevalent disasters on earth. In 2019, 194 floods and 90 storms were registered in the Emergency Events Database (CRED 2020).

Meteorological satellites are an important component of flood and storm early warning systems, such as The European Flood Awareness System and Global Flood Awareness Systems (Wu et al. 2019). Data generated by these satellites allow experts to track the path of storms and help to designate areas most at risk. This capacity allows local authorities and relief organisations to be warned about a potential storm or flood. Prevention measures can then be taken to save lives. When the storm or flood hits the affected area, high and very high spatial resolution satellite images are used to assess the gravity of the damage and delimit the affected area (Khaing et al. 2019).

In 2014, satellite images and other technologies helped predict Cyclone Hudhud's strength, track, location and time of landfall five days in advance. This prediction helped the Indian government to send warnings to the most vulnerable population and activate an evacuation plan. OCHA estimate that a comparable cyclone in 1999 killed 10,000 people, while Cyclone Hudhud caused only 46 deaths (United Nations 2015).

Aid workers checking up-to-date paper and digital maps after Typhoon Haiyan in the Philippines, 2013. Photo: Tracy Reines / American Red Cross

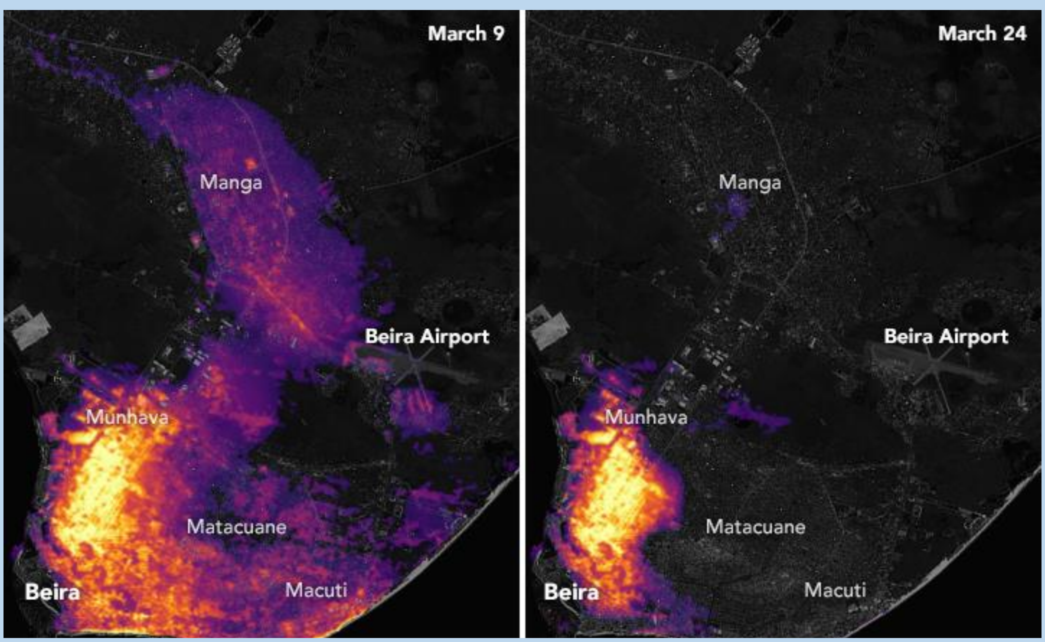
Cloudy and rainy conditions are common over flooded areas. These conditions create a challenge for satellite sensors to capture the affected areas. Radar imagery is in this case well suited, since its functioning is not affected by the presence of clouds. Moreover, this technology can capture images during both day and night to detect stagnant flood water. Such information can be mapped and distributed to relief organisations on the ground in the form of flood-extent maps (World Bank 2015).

The availability of food to the population suffering from disasters is also an important aspect of the response. The FAO, together with partners, is developing projects based on satellite images to assess the impact of floods on local agriculture, and if and how much food relief is necessary in the flooded region (FAO 2019).

Example: Cyclone Idai in Mozambique

Mozambique was hit on the night of 14 to 15 March 2019 by Cyclone Idai near Beira City, Sofala Province, in central Mozambique. It is considered as one of the worst storms that affected the south-eastern coast of Africa. The cyclone brought heavy rains and winds over Mozambique. It did not stop there and continued across land as a tropical storm. It finally, hit eastern Zimbabwe with heavy rains and strong winds. The storm also resulted in riverine and flash floods. It became a disaster resulting in deaths and destruction of livelihoods and properties. The storm destroyed large areas of cropland. Cyclone Idai killed more than 600 people and affected an estimated 1.85 million people in Mozambique (OCHA).

In response to this disaster, the Charter received a request for help from the Ministry of Regional Development (CENAD) in Brazil, and a request from UNOSAT (UNITAR's Operational Satellite Applications) on behalf of the International Federation of Red Cross and Red Crescent societies (IFRC). Following the activations, Charter members acquired a series of satellites images from their satellite constellations to map the flood extend and the impact of the storm. The data analysis allowed the creation of flood duration maps and reports on the evolving situation. The Ministry of National Integration in Brazil served as the Project Manager of the Charter activation. The goal was to coordinate the provision of maps and reports produced by a large number of actors: the Brazilian Department of Civil Protection and Defense, Copernicus Emergency Management Service, the Universities of Leicester and Edinburgh, DLR's Center for Satellite Based Crisis Information (ZKI), UNITAR/ UNOSAT, and SERTIT.



Comparison of the light emitted by human activities over the city of Beira, before and after Cyclone Idai. Image: NASA

4.1.3 Droughts and famines

Droughts are caused by several factors. Some of these can be monitored by satellite images, such as anomalous sea surface temperatures of the El Niño Southern Oscillation, that influences seasonal precipitation levels across the tropics and subtropics (CEOS 2015).

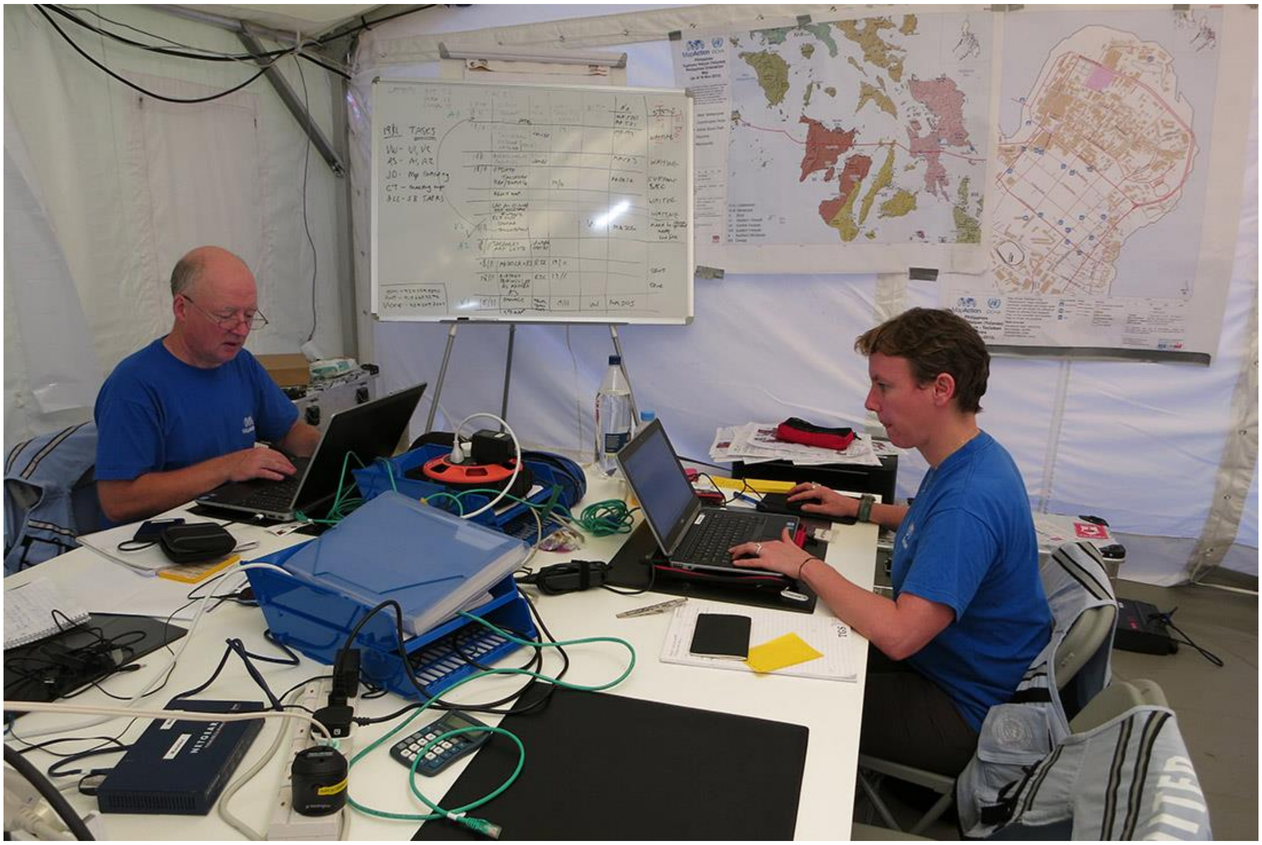
To avoid famine, the Food and Agriculture Organization (FAO) shares information on agricultural water productivity over Africa and the Near East through its web-portal WaPOR. The FAO has several projects monitoring the agricultural system in different regions of the worlds. Satellite imagery is one source of data used in these monitoring products.

Collecting data and preparing models to have a first estimate of the impact of disasters on food security is another important step of the mitigation process. The Rapid Agricultural Disaster Assessment Routine (RADAR) project is one example of such a process (Borgia and Food and Agriculture Organization of the United Nations 2008). This project collects useful information and models to quickly estimate the impact of a disaster on the agricultural system. It uses satellite data to continuously monitor important variables of the agricultural system and also to rapidly access pre- and post-impact data. The Agriculture Stress Index System (ASIS) from the FAO is another project that was designed to detect possible “hotspots” around the world where crops could be affected by severe droughts at a global level (FAO 2016b). Standalone versions of ASIS were also developed within regional and national scale warning systems. The Famine Early Warning Systems Network is another example of a program aiming at locating regions were actions are needed to prevent famine. Such programs are using products generated with contributions of satellite images.

Insurance is also considered as a mitigation strategy. One example of an insurance product is developed by the African Risk Capacity (ARC), a Specialized Agency of the African Union. It is a public-private structure that takes advantages of the satellite weather surveillance software Africa RiskView, developed by the World Food Programme. It allows ARC to estimate the impact of drought on farmers and the response cost to overcome it. With the help of satellite data and other sources of information, it is possible to produce these estimates both before the agricultural season begins, and as it progresses. It allows the ARC to take early interventions if needed (Demeke et al. 2016).

4.1.4 Landslides

Landslides can result from earthquakes (Williams et al. 2017) but can also be triggered by precipitations (CEOS 2015). Satellites play a major role in monitoring the risk of landslides. Radar imagery is used to provide important information on slope (Tofani et al. 2013). Stereography on very high spatial resolution satellite images can generate fine resolution digital elevation models (DEM) (World Bank 2015). Optical satellites can capture information such as forest loss, which plays a major role in the creation of favourable conditions for triggering landslides. Weather satellite data are used to create estimates of past and future precipitation all over the world. Combined with additional information (local geology, fault zones, etc), landslide susceptibility models can be used to generate early warnings, so local measures can be taken (CEOS 2015).



The MapAction team deployed in the Philippines in 2013 Photo: MapAction

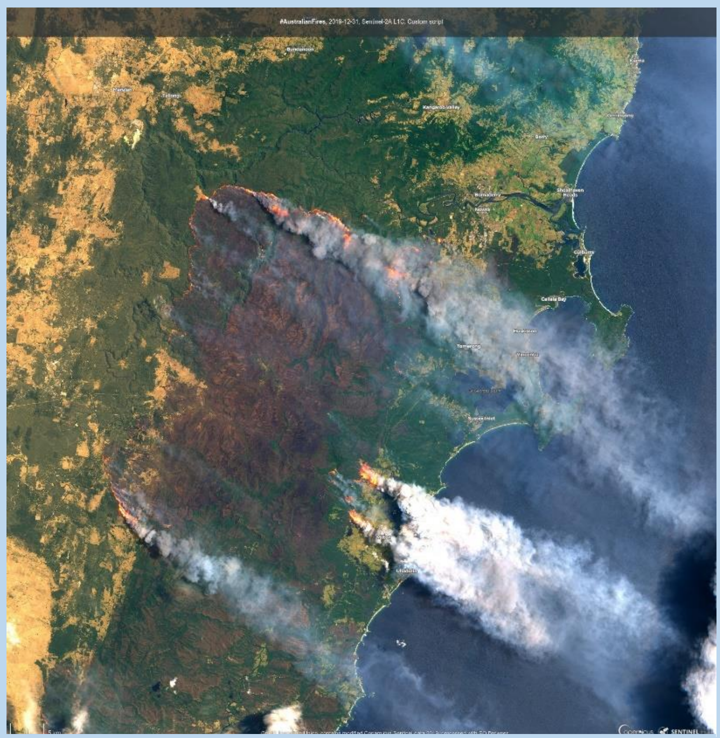
4.1.5 Wildfires

Satellite observation can provide valuable information about wildfire risk conditions, such as drought stress in vegetation, which can help emergency managers to identify areas with the highest fire risk. This information helps installing of precautionary measures and reduce response times. Early warning systems have also been developed to locate starting wildfires (Pickell et al. 2017). In addition, satellites are monitoring lightning flashes, a natural cause of wildfires (CEOS 2015).

Satellites are also useful during an ongoing wildfire. They can track the extent of the fire and its intensity on large and remote areas, helping disaster management. In addition, air quality monitoring is possible through satellite data (World Bank 2015).

Example: Wildfires in Australia

Southeast Australia was hit by wildfires from June 2019 until early 2020. It is estimated that over 18.6 million hectares of land were burned and almost 5900 buildings were destroyed, including 3500 homes in New South Wales and Victoria. More than 150 fires were registered. This high number is partly explained by a combination of extremely dry conditions, high temperatures, unpredictable winds and lightning.

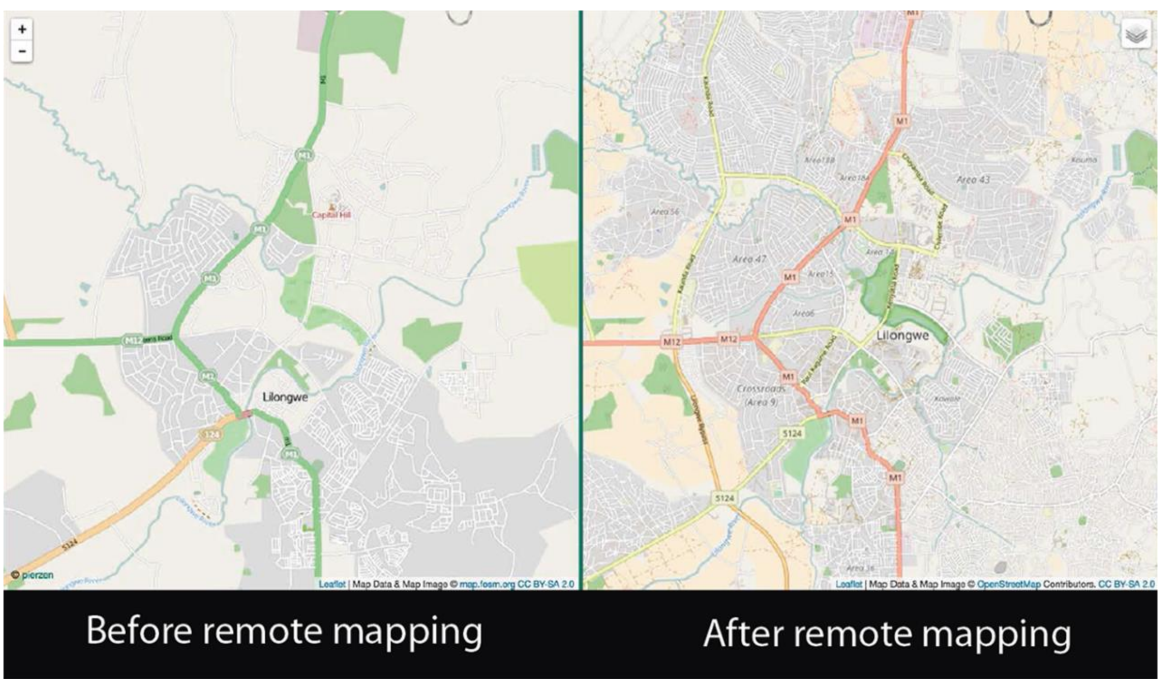


Clyde Mountain Fire, 200 km south from Sydney, as seen by Sentinel2. Image: Copernicus EMS

Geoscience Australia requested help from the Charter on behalf of the Emergency Management Australia Crisis Coordination Centre (CCC) and New South Wales Rural Fire Service (NSWRFS). During this disaster, the Charter members produced over 2,000 satellite images. NASA satellites were used to detect wildfires burning in remote regions. When a new fire was detected, its location was sent directly to local authorities within hours of the satellite overpass.

4.1.6 Epidemics

Some regions of the world are poorly mapped or with outdated data. Satellite images can be used to create city maps. However, this transformation requires a large amount of work and is time-consuming. To overcome this problem, one solution is to ask input from a community of volunteer mappers. An example of the use of such a methodology is the mapping of three cities in Guinea by the Humanitarian OpenStreetMap Team (HOT OSM) for the NGO Médecins sans frontières (MSF), which was used to fight Ebola virus disease outbreaks. In only 5 days, 244 volunteers succeeded in mapping over 90,000 buildings based on satellite images. These data were used for the sampling of households in an epidemiological survey (Lessard-Fontaine, Soupart, and de Laborderie 2015). Many similar actions have since been carried out and it is an ongoing effort. Another example is the use of satellite imagery in the polio eradication campaign. Satellites images can help create up-to-date maps. Combined with GPS measurements, vaccination campaign coverage and performance were improved (Bjorgo 2013; Eckhoff and Tatem 2015).



Map improvement based on satellite imagery for a Red Cross measles vaccination campaign in Malawi. Image: The International Federation of Red Cross and Red Crescent Societies, 2017.

4.1.7 Other applications:

Satellite data are also useful for disaster mitigation of small regions. Local knowledge is an important source of information to better prepare local populations to face disasters. Meeting with different local actors can reveal important information on unknown local disaster impacts. Satellite imagery is one of the supports used to help map high risk areas during such meetings (also called "participatory geographic information system mapping exercises")(Raveloson, Rajoelison, and Madagascar 2014)

Community mapping session by the Ger Community Mapping Center, Mongolia. Photo: The Ger Community Mapping Center.

Adapting infrastructures to lower the vulnerability of a population to natural hazards is in some cases necessary. NGOs sometimes hire local workers in Cash for Work programs to carry out repair works or modifications to the local infrastructure. However, monitoring the evolution of work can be difficult for NGOs and risky due to the insecurity in some regions. Somalia is an example of such a country where considerable security constraints affect the planning and execution of assessment missions in the field. The Somalia Water and Land Information Management Project (SWALIM), managed by the FAO, uses very high spatial definition satellite images to overcome these challenges. This project is composed of a Cash for Work activity and monitors the 'before and after' status of infrastructure rehabilitation and adaptation with the help of satellite images and others tools (FAO 2016c) .

When facing a disaster, some populations are forced to flee their home and find refuge in displacement camps. Satellite images are useful to find locations for displaced communities. In some regions, such camps are strongly dependent of wood fuel in the surrounding area. To organise these camps in such a way that they are sustainable in the long run, it is important to understand how many people the local environment can support. Satellite images are a great tool to quickly assess the available resources and monitor the evolution of the surrounding environment. With information gathered by satellites, it is possible to understand the wood fuel demand, model the impact of such camps on the environment (wood fuel supply) and take action if needed (FAO 2016a).

4.2 Conflict settings

It is nowadays common for NGOs and other organisations to monitor human rights abuse and conflicts with the help of satellite images. However, the usage of earth observation technology for this purpose is more recent than the one for disaster responses. Indeed, the monitoring of human rights abuse and conflicts is essentially done, with a few exceptions, with very high spatial resolution satellite images. This type of satellite image is only available to non-governmental actors since 2000, since commercial very high spatial resolution became available (AAAS 2015).

Analyses on human rights abuse and conflict settings are carried out by different kinds of actors: The first ones are NGOs, such as Human Rights Watch and Amnesty. Intergovernmental organisations are also active in this field. One example is UNOSAT, a program of the United Nations, providing satellites images and analysis to other UN humanitarian and development agencies.

The identification and assessment of damaged or destroyed buildings (such as schools, hospitals, and cultural/religious buildings) is one the most common uses of satellite images to monitor conflict settings. When good quality high-resolution images are available, it is possible to count the number of structures destroyed in the area of interest and thus provide a quantitative estimate of the damage (Amnesty International 2014). The monitoring of civilian populations at risk is also partly done with the help of satellite images. One example is assessing the exposed population to artillery fire. Another example is ethnic targeting, which can also be observed from satellite images by identifying barricades or “SOS” distress sign, such as seen in Kyrgyzstan in 2010. Population displacement in reaction to a conflict is also monitored with the help of satellite images (UNOSAT 2011).

Satellite images are also an important source of complementary information. Organisations such as Amnesty receive information from local sources, which can then be confirmed by satellite images, such as evidence of burned villages. Satellite images are also used to corroborate the presence of mass graves by spotting areas of disturbed earth (Amnesty International 2016).

Fire detection is another technique for conflict analysis. Fire is used as a weapon in some conflicts to destroy villages and agricultural fields. These fires can be detected by satellites such as the MODIS sensors operated by NASA. Researchers at UNOSAT analysed the relation between fire detection and attacks on the civilian population and found a strong relationship in the Darfur region of Sudan during 2003 (UNOSAT 2011).

NGOs also monitor military activities to evaluate their lawfulness. Such an analysis was carried out by Human Rights Watch by investigating the NATO airstrikes in Libya (Human Rights Watch 2012b).

Another application is the Satellite Sentinel Project, that used satellite technology to monitor the border region of Sudan and South Sudan. By using high-resolution satellite imagery and reports from the ground, the project was able to detect troop-massing, movements and razed villages. Satellite images were also used to document alleged mass graves (Harvard Humanitarian Initiative 2012).

The use of satellite images to identify indicators for early warning of conflict is less common (AAAS 2015). In 2013, the project "Territory: Revealing Trends in Cross-Border Conflict Using Satellite Imagery" evaluated the capacity of satellite technology to detect early indicators of an imminent conflict within previous well-known conflicts between state actors over a common border.

NGOs can also monitor the development of prison camps of authoritarian regimes and estimate the population inside. An example of such monitoring was done by Amnesty in 2013, which acquired satellite images of the political prison camps in North Korea to complement information provided by former detainees and prison officials (Amnesty International 2013). Human Rights Watch also used this methodology to locate detention centres where torture took place in Syria and complement their information about the facilities from victims and defectors with satellite images (Human Rights Watch 2012a).

Satellite images can also be an element used to confirm the authenticity of videos from exactions in a forensic analysis. Distinguishable features from the video and from the satellite images, such as roof colour and types of trees, are compared and can confirm the location where the video was shot. Such an analysis has been done by the

NGO Human Rights Watch in Cameroon (Human Rights Watch 2018). This can also be done to assist the creation of bombing location maps from videos uploaded by the local population (Human Rights Watch 2013).

Satellite images used to document a crisis situation are a powerful tool to raise awareness of the public. It can show a wide audience a complex and remote situation where human rights are violated (UNOSAT 2011). This visual tool is used in different information campaign by various NGOs (examples: Amnesty and Human Rights Watch) with the aim of mobilising an international response.

5. Current challenges and trends

5.1 Possible improvements

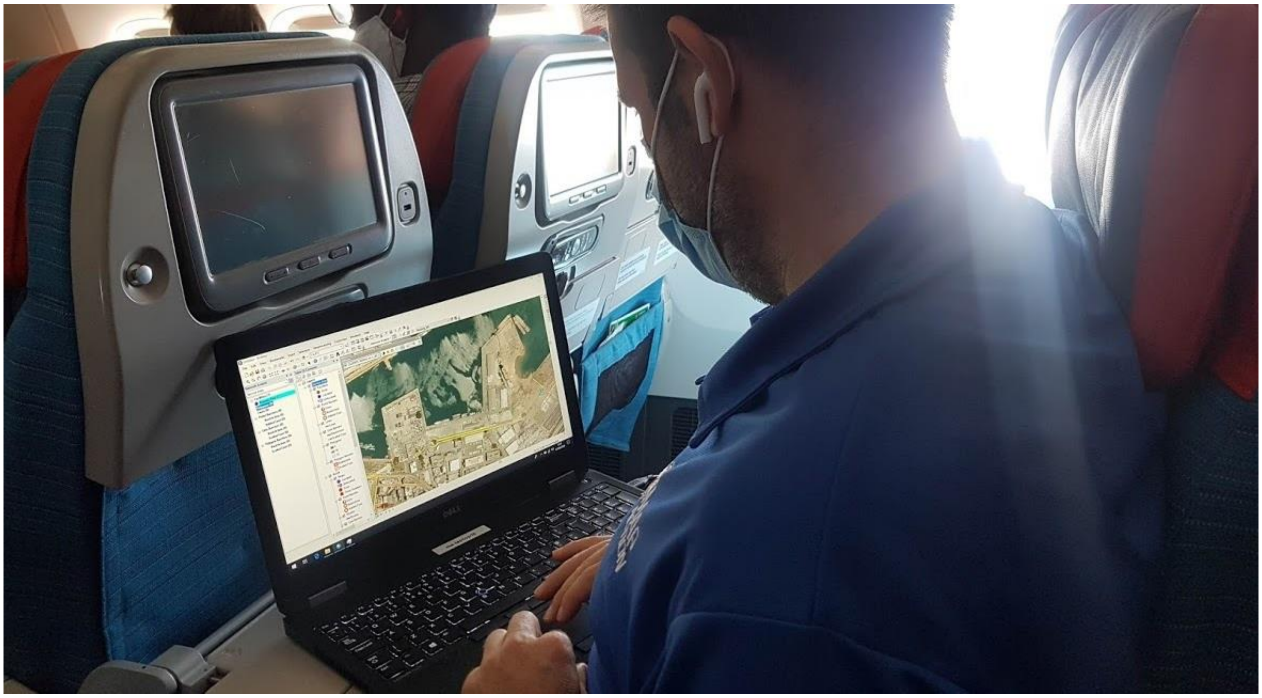
Several characteristics of earth observation data and workflow limit its applications to the monitoring of disasters, conflicts and human right violations. A summary is presented in this section.

Optical satellite sensors are physically limited by the presence of clouds due to the nature of the signal captured by the sensor. This situation is problematic as clouds are often present during a number of disaster types, such as storms and floods (NASA 2019). Some regions, such as the Andes, Himalayas, Arctic, Antarctic and tropical regions in Africa and Indonesia, are also regularly covered by clouds, limiting the acquisition of satellite imagery by such sensors (Sudmanns et al. 2020). Moreover, in some regions, dense vegetation cover limits the detection and monitoring of human features on the ground. As seen in the section “Applications”, active radar sensors, such as SAR, can partially overcome these limitations and add the possibility of capturing satellite data at night-time.

The spatial resolution of available satellite images can be insufficient to detect important ground details and thus be a limiting factor in the analysis (UNOSAT 2011). A poor quality or small amount of satellite images in the archive of some regions can limit, for example, the possibility of undertaking a before-after event analysis in the case of conflicts and human right violations (Amnesty International 2006). An overview of the major operational satellites with their characteristics (revisit time, spatial resolution, etc) can be found in the document “Satellites of the International Charter 'Space and Major Disasters”[2].

Depending on their spatial resolution and other characteristics, satellite images can represent a large amount of data. This can create problems when such data need to be transmitted to ground operations after a disaster, with sometimes poor internet connection. Under such conditions, processed data, rather than raw images, are more suited, such as vector datasets, raster files cropped to the extent of interest, maps or reports (Map Action 2018; Canon, Schipper, and International Federation of Red Cross and Red Crescent Societies 2015).

[2] https://disasterscharter.org/documents/10180/897997/Charter-Satellites-Poster.pdf



The MapAction team on its way to Beirut. Photo: MapAction 2020.

In the case of conflict monitoring, photo-interpretation still represents a huge part of the analysis (UNOSAT 2011). To do this accurately, local knowledge is necessary to interpret the ground reality represented by the satellite image. Such a methodology can lead to mistakes on the interpretation and diverging conclusions from the analysis of the same satellite images (AAAS 2015). The frequency of image acquisition can also create confusion and give the impression that damage resulting from multiple distinct periods of conflict is the result of a single event (UNOSAT 2011).

Even if a number of satellite images are now freely available, such as the ones from the Sentinel and Landsat programs, the cost of purchasing satellite images is still a limitation for a number of organisations wishing to use this material in their workflow. This is particularly true for very-high resolution images. It is difficult to provide an estimate of the price since it relates to a high number of variables: spatial resolution of the image, a new image or an archived one, the number of images requested, location of the area of interest, area to cover, etc. Usually, there is a minimal area that needs to be ordered to the reseller of satellite images, and the price can range from $250 for a small area, to several thousands of US dollars for a new image of a larger area (AAAS 2015). The cost of purchase can limit the type of analysis that is practically feasible. An example is the study of cross border conflicts covering large area (AAAS 2015). The cost of purchasing satellite images is not the only one limiting its use . The cost of software licences and computational infrastructure (PC or servers) also need to be considered (Berman, Rosa, and Accone 2018).

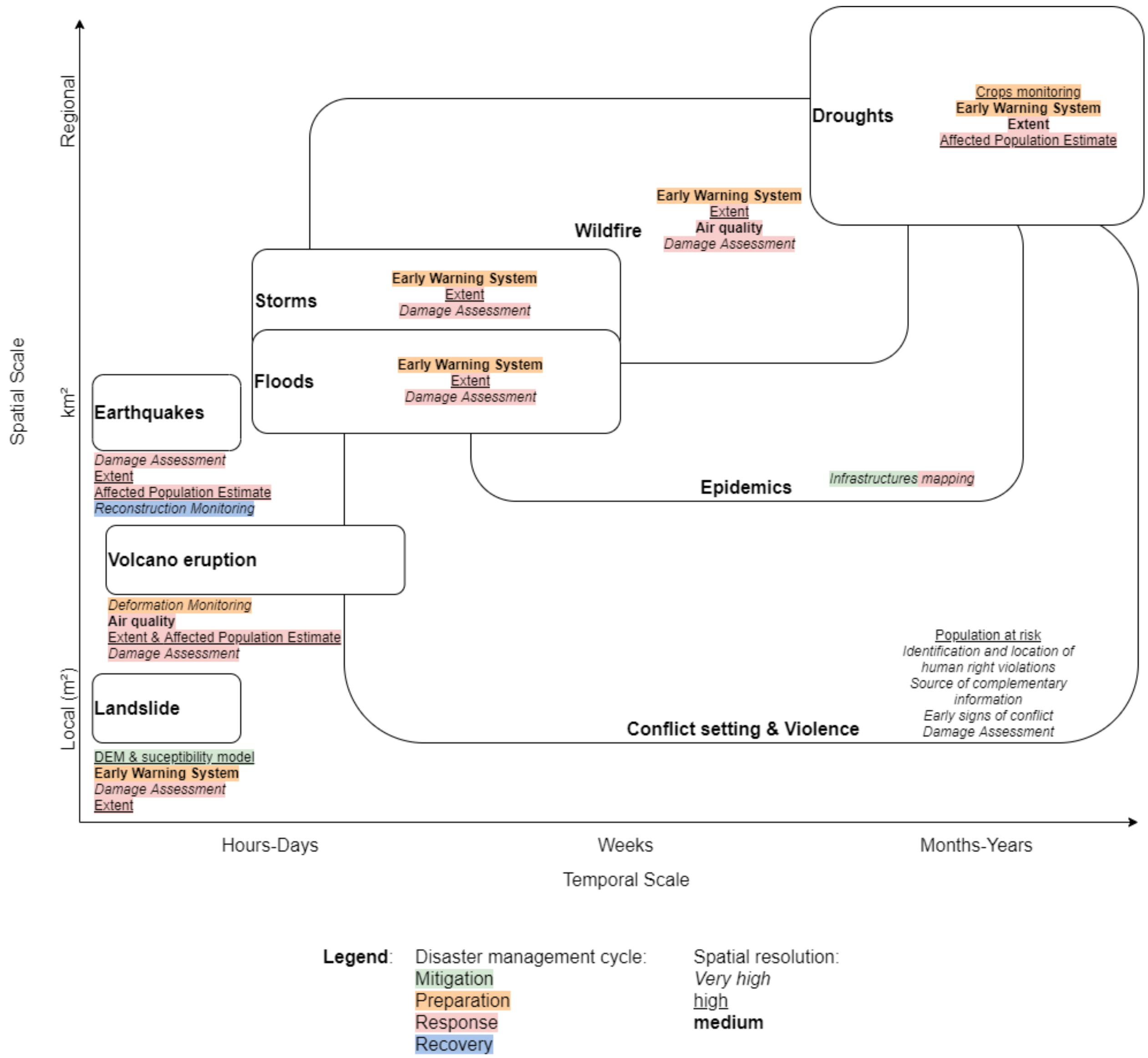
These limitations have pushed some users to establish partnerships with private companies to access these satellite images and their computational infrastructure at lower cost (see section 5.5: Framing collaborations between private companies, researchers and humanitarian actors).

Extracting useful information from satellite images is challenging and expertise is needed within organisations that are undertaking such work. Various organisations, such as UNOSAT, offer training opportunities for organizations. Some organisations, such as AAAS or the NGO MSF, even have dedicated teams to process such data. MSF has a partnership with the Z_GIS University of Salzburg to support its remote-sensing analysis and satellite imagery acquisition (Lang et al. 2020).

To overcome the problem of the price and expertise needed to process satellite images into useful information, different organisations, such as UNOSAT and The International Charter "Space and Major Disasters", are processing satellite images into products that can be used and interpreted by a broad audience in the humanitarian sector, without costs (CEOS 2015). Another example is CartONG, which is an NGO that helps humanitarian actors with training and support to handle spatial data and satellite images[3].

The figure bellow summarises the Earth observation applications of humanitarian actors according to their spatial extent and time scale. It can help organisations to choose the type of application that best meets their needs.

[3] https://cartong.org/



Earth observation applications by humanitarian actors according to their spatial extent and temporal scale. The typical spatial resolution of satellite images is given for each application. For applications related to natural disasters, the typical phase of the disaster management cycle is indicated.

5.2 Importance of international cooperation and recent progress

Since the launch of Landsat-1 in 1972, new actors arrived in the public earth observation sector, and in the 1990s, the need for a better coordination between them came up. The International Charter "Space and Major Disasters" (The Charter) is an international initiative that tried to fill this need for a better coordination between space agencies and other operators of satellites. Since its creation in 2000 by three space agencies, the idea of a collective response to disasters has attracted more actors. The Charter currently consists of 17 members participating in the capture and processing of space data. Combined, it covers 61 different satellites that can be used to monitor disasters all around the world. The idea of such a cooperation led also to regional level initiatives. Two of these transborder cooperation initiatives, Sentinel Asia and the Copernicus Emergency Management Service (EMS), are presented below.

Sentinel Asia was created in 2005 by regional space agencies and disaster management agencies from the Asia-Pacific region. In 2020, Sentinel Asia is composed of 111 organisations from 28 countries and international agencies. The collaboration between these actors aims at sharing satellite images and analyses to improve disaster management in the region. Sentinel Asia also contributes to capacity building and exchange of information to develop more effective disaster response among its members.

Control centre of the Emergency Response Coordination Centre (ERCC) in Brussels. Photo: Alexandros Michailidis

The EMS is another form of international cooperation for a collective response to disasters, either resulting from natural hazards or man-made. The service is managed by the Joint Research Centre and the Directorate-General for European Civil Protection and Humanitarian Aid Operations (ECHO). The EMS is composed of two main components: the first one, an on-demand mapping component, is designed to help authorities in all phases of the disaster management cycle: mitigation, preparedness, response and recovery. The second component is an early warning and monitoring system. Its goal is to deliver warnings and risk evaluation for floods, droughts and wildfires. EMS primarily serves the need of the EU but operates all over the world.

The creation of regional hubs around the world in the past two decades changed the way the Chapter is used. For example, a decrease in the number of Chapter activations was noticed in Europe. In other regions of the world, several other national or regional initiatives have been developed to complement the Charter capacity (Voigt et al. 2016).

5.3 Increase of Automation

In the context of monitoring disasters and conflicts, automation is a challenge for satellite image users. During a crisis or post-crisis situation, extracting useful information from satellite images has to be as quick as possible. The Emergency Management Service from the European Copernicus Program can process satellite images into useful information in a matter of hours from image reception, in the case of emergency situations (See Table 1). For less urgent cases, the process can take between 1-5 days. Nasa has published a complete catalogue of its disaster-related products[4]. For each type of disaster, a list of products and the delay between the acquisition of satellite images and the delivery of the products are available. The automation of satellite image processing is partly targeting the objective of speeding up this process (Witharana, Civco, and Meyer 2013).

Table 1: The available EMS products and respective delivery times (from image reception)

Product type	**Content**	**Delivery times**	
		Vector	Ready-to-print maps
Reference	Pre-event situation	10h	12h
First Estimate	Fast impact assessment	2h	3h
Delineation	Detailed assessment of the impacted area (extent)	7h	9h
Grading	Detailed damage assessment (extent of the impacted area and damage grade)	10h	12h

The automation of satellite analyses in the context of conflict and human right violation is particularly challenging, since a majority of the applications of this field are

[4] https://disasters.nasa.gov/sites/default/files/misc-files/portal/NASA%20Disasters%20Mapping%20Portal%20Product%20Guide%2020191122.pdf

based on visual interpretation by experts. However, some applications have been automated. Fire detection based on satellite images is one methodology used to spot potential acts of violence. UNOSAT researchers identified the occurrence of abnormal fires in locations with no previous fire activity during the period of violence surrounding the Kenyan election, the Georgian conflict, and the conflict in Kyrgyzstan. These fire detections helped them to identify damaged buildings with the help of high-resolution satellites images. UNOSAT researchers feel that this methodology could detect violence in the earliest phases of conflict so early action could be undertaken to stop or limit the consequences of the conflict (UNOSAT 2011).

Automation also helps to speed up repetitive and time-consuming work. It can for example be used to assess the number of damaged buildings of a city in a conflict during a long period of time, such as Aleppo in Syria between 2011 and 2017 (Lubin and Saleem 2019). Efforts are also made for example to automate the monitoring of refugee camp developments. By estimating the number of structures, an estimate of the number of people in the camp can be generated (UNOSAT 2011). Another example is the monitoring of land cover change around the camp to understand its impact to the local environment and food security (Friedrich and Van Den Hoek 2020). The automation of such processes helps providing results more quickly and with more frequent updates (Quinn et al. 2018).

The use of machine learning technology for earth observation in the humanitarian context is rapidly developing to help automation. However, the majority of its current applications are prototypes and few are already deployed in action (Quinn et al. 2018).

Even if the automation of the earth observation field has already produced important results, visual satellite image interpretation is still relevant. Visual interpretation of satellite images is strongly linked to the automation of the field. Indeed, the quality of automatic workflows has to be evaluated and benchmarked. Visual interpretation is still the most reliable method to assess the quality of automatic satellite analysis for a number of applications, such as the assessment of low level damage after an earthquake (Dong and Shan 2013).

From the scientific and grey literature, two categories of automated processes can be identified: 1) Automated processes to detect abnormalities in large areas, followed by a human validation; and 2) automation of a process applied to a limited area designated by a human operator.

5.4 Small satellites and satellite constellations

The use of satellite images from current governmental programs in disaster management, such as the Landsat and Sentinel-2 programs, is partly limited by their revisit time intervals. To overcome this issue, other satellite operators deploy smaller satellites, also known as CubeSats, but in a larger quantity. Once launched in space, they form a satellite constellation. Different private companies are exploring this option. Solving the limitation of having data gaps is crucial for the humanitarian field (Santilli et al. 2018). However, CubeSats have several drawbacks. The spatial resolution of CubeSats is currently not the finest available on the commercial market, and CubeSats are more limited in the number of spectral bands they can capture. Nonetheless, they are offering the capacity of acquiring satellite images over the same area of interest more frequently (Strauss 2017). One example of a company offering such a service is Planet, which is nowadays capable of acquiring images around the whole globe at a daily frequency[5]. Such an increase in capacity allows researchers to monitor conflict settings or certain natural disasters, such as landslides, more frequently (Santilli et al. 2018; Strauss 2017).Researchers are already using the Planet satellite images archive to detect village burning in conflict regions (Marx, Windisch, and Kim 2019). Another example is the practical application of The Copernicus Emergency Management Service that is already using Planet data to monitor emergency situations since the beginning of 2020[6].

Optical sensors are not the only ones mounted on satellite constellations. Satellite radar sensor are also used by companies such as Iceye[7]

5.5 Framing collaboration between private companies, researchers and humanitarian actors

Private companies are also involved in the use of satellite images as a tool to help local populations and humanitarian actors face disaster consequences. One example is Google, which activated a dedicated crisis site during the 2012 flood near Manila in the

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[5] https://www.planet.com/pulse/planet-launches-satellite-constellation-to-image-the-whole-planet-daily/
[6] https://spacedata.copernicus.eu/web/cscda/blogs/-/blogs/planetscope-and-skysat-constellations-data-now-available-to-copernicus-users-1
[7] https://www.iceye.com/

Philippines. The website was designed to provide useful information and tools related to this disaster. One example of data shared were satellite images of the situation.

Tech-companies are nowadays part of the workflow of researchers using earth observation technology. Services such as Google Earth Engine modify the workflow by allowing to process data in minutes with a simple web browser on the servers of the companies, when such a task could have taken hours or days if researchers would use common computers. Such cloud-computing resources exceed computing clusters of most universities (Popkin 2018a). It allows researchers to conduct research at a large scale, for example exploiting high spatial resolution satellite images from several satellites over several years at the scale of Canada (Mahdianpari et al. 2020). In addition to the processing power, the Google Earth Engine stores hundreds of public satellite images and derivate products (Gorelick et al. 2017).

The cost of high-resolution commercial satellite images is also a factor pushing researchers to team up with tech-companies involved in this field. When an agreement is made, research teams conduct their analysis on datasets produced by tech-companies and are sometime funded by them (Popkin 2018a). In return, tech-companies can use their findings (Quinn et al. 2018). An example of such a collaboration is the partnership between Columbia University and Facebook, in order to produce high-resolution population maps of rural areas for 140 countries (Facebook 2019). Facebook is not the only companies to create these partnerships. Microsoft Amazon and others also work on different kind of programs (example: AI forEarth, Earth on AWS) to make satellite data more accessible and processable at a large scale (Quinn et al. 2018).

Private satellite operator companies such as DigitalGlobe or Planet have also developed programs to make their high-resolution satellite data available to a selection of researchers. However, the accessible data are most of the time satellite data acquired at the request of customers. Under such conditions, data of interest can be unavailable to researchers. Moreover, in contrast to public government data, the use of commercial satellites is typically limiting the publication of the results (Quinn et al. 2018).

Charitable foundations such as the Bill and Melinda Gates Foundation and Schmidt Futures (foundation created by Eric Schmidt, ex Google CEO) are also investing initiatives with earth observation at its core, such as the Radiant Earth Foundation.

5.6 Unresolved politico-legal questions

Politico-legal questions can interfere with satellite image acquisition. One example of such a restriction was faced by US companies, when they wanted to distribute extremely high-resolution images for a selection of countries, such as Israel. US laws also prohibit the exchange of data with data providers living in Iran and North Korea (Popkin 2018b).

Earth observation researchers can also face ethical dilemmas. An example of such a problem was reported by Steven Livingston (the Carr Center for Human Rights Policy) and Jonathan Drake (American Association for the Advancement of Science). During the Syrian conflict, the Harvard Humanitarian Initiative received a distress message from the White Helmets. They requested help of researchers to find an escape route for them and their families (approximately 150 people) from Aleppo, which was being bombed at the time. The message was urgent, and the operation had to be done in the next 48 hours. Suddenly, researchers were asked to take actions in real time. The Carr Center was involved and contacted private satellite companies to access their most recent image archives. Commercial satellites were at the same time tasked with acquiring new images. In addition, diplomats were negotiating to define a safe route for the civilians blocked. Any interference could affect these negotiations. The full story is accessible at the Washington Post journal website[8].

In addition to ethical dilemmas that researchers face, such an example shows the capacity of private actors and NGOs to collect intelligence information. Other examples are the revelation of undisclosed nuclear facilities in Iran by an NGOs in 2002, or the Satellite Sentinel Project monitoring violence between northern and southern Sudan (Harvard Humanitarian Initiative 2012). Such applications raise questions over state control of information (Aday and Livingston 2009) and concerns over private actors making charges, such as war crimes based on satellite images. A number of academics are questioning the use of satellite images for human rights monitoring, possibly leading to a reduction in the role of the eye-witness. The nature of satellite images as “objective” truth is also a question that is debated (Walker 2020).

[8] https://www.washingtonpost.com/news/monkey-cage/wp/2017/01/09/we-tried-to-save-150-people-in-aleppo-from-5000-miles-away/

6. Conclusions

Due to major advances of Earth observation satellites, such as their secure and fast acquisition technology, they have been integrated as an important source of information in the monitoring of conflict and human right violations and disasters management, already for several decades. However, this report outlined several limitations of the use of satellite images that are still present for humanitarian usage, like the presence of clouds over regions of interest, the availability of satellite data with a suitable spatial resolution, and the human interpretation of information from satellite images, to name some of them.

Thanks to recent technological progress and sources of data that arose in the past decades, such as the European Sentinel program and the CubeSat constellations, and the development of active radar sensors, previous limitations of earth observation technology in humanitarian applications can be partly overcome. New satellite operators and constructors are developing, partly thanks to previous public investments that help mature the technology and use of earth observation. With this development, new private companies, such as giant tech-companies like Google, Facebook or Amazon, are now part of the data processing workflow by providing computing power to researchers and increase data accessibility by storing the huge amount of generated satellite data on their own infrastructure. Different kinds of partnerships between them and researchers have emerged, resulting in innovations previously unfeasible. However, the use of private satellite images for researchers can lead to different restrictions on the publication of results, limiting the reproducibility of their findings or the availability of data, which are generally generated for paid consumers.

The new applications and capacities available to NGOs and private companies in the field of earth observation, resulting from this rapid technological progress, are in some situations comparable to the capacities of intelligence agencies. This situation confronts NGOs and private companies with new ethical dilemmas and new limits to the use of these technologies that they have to set themselves.

Humanitarian actors must carefully evaluate the usefulness of using satellite images in their workflow. Situations where data are needed either for large areas, in a short among of time, in remote area or in dangerous area are examples of situations in which satellite images can be used. However, the amount of information that can be extracted from satellite images is by nature limited.

Humanitarian actors need to consider also the cost of developing a workflow involving the use of satellite images. This process can be time consuming, expensive and require trained personnel. Some major NGOs such as MSF have a dedicated team to accomplish this task. If an organisation cannot develop such a structure, it can create partnerships with private actors, academic institutions or other specialized NGOs (such as CartONG) to help them in this process. It is important to evaluate the need to develop new products based on satellite images. Several organisations, such as the Charter, EMS, HOT OSM and others, produce already a number of useful data outputs and products accessible to everyone.

As seen in this report, international cooperation and partnerships between various actors are already in place and will continue to develop the field of earth observation in the humanitarian sector in the years to come.

In 1990, a review of satellite technology in disaster management stated that “Though much of this technological capacity has existed for a decade or longer, only a very small fraction of it is being used routinely” (Walter 1990). As seen in this report, the sector has radically changed since then, and satellite imagery has become an essential technology.

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