Beyond Borders: Satellite Applications for Humanitarian Emergencies

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Caribou Space
United Kingdom Humanitarian Innovation Hub
UKaid from the British people

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Executive summary

Executive summary

— *Background*

The UK Humanitarian Innovation Hub is a pilot programme, funded by the UK Foreign, Commonwealth and Development Office (FCDO) and hosted by Elrha, that seeks to identify the biggest challenges within and opportunities to address global humanitarian responses.

The objective of this report is to provide a consolidated view on the current use of satellite applications in humanitarian settings. Satellite applications are digital services and products that serve several functions for society, the environment, and the economy. UKHIH selected a consortium of organisations to author this report, including Caribou Space, Satellite Applications Catapult (SAC), and the United Nations Institute for Training and Research (UNITAR).

— *Overview*

This report includes the following:

- A categorisation of supply- and demand-side stakeholders of satellite technology for the humanitarian sector with examples.
- A consolidated overview of examples where satellite technologies have been used effectively for humanitarian domains.
- A landscaping of over 500 humanitarian satellite applications.
- Identification of key barriers to the adoption of satellite applications and potential interventions from the development community to overcome them.
- A summary of two case studies from Asia-Pacific and East Africa to provide real-world insight from specific regions.

— *Humanitarian emergencies*

Humanitarian emergencies are "*events or series of events that represent a critical threat to the health, safety, security, or wellbeing of a community or other large group of people.*" They are widely geographically distributed, often covering large areas and multiple populations. They are diverse and complex, and require coordinated efforts and resources across a variety of local, national, and international stakeholders.

Humanitarian emergencies share common characteristics related to the domains in which they occur and the type of events leading to them.

— *Satellite applications industry*

Satellite applications utilise three types of satellite technology:

- **Satellite Earth Observation (EO)** is the gathering of information about the physical, chemical, and biological systems of the planet via remote-sensing technologies.
- **Global Navigation Satellite Systems (GNSS)** are a constellation of satellites providing positioning, navigation, and timing (PNT) signals from space. GNSS is used to track people and physical objects at any time, globally. It is also widely used in humanitarian emergencies for geo-tagging of relevant issues in the humanitarian context, e.g., infrastructure, disasters, damages, conflict incidents, response activities, etc.
- **Satellite Communications (SatComms)** provide voice and data/internet connectivity in regions that are not covered by terrestrial mobile networks.

Platform and cloud services, together with technologies like machine learning, are simplifying access to and use of satellite applications. In parallel, new entrants and developments in SatComms and Satellite Internet of Things (IoT) have the potential to enable new and more cost-effective connectivity to people and things in the near future.

— *Satellite applications*

The most persistent and extensive humanitarian data gaps include a lack of information on affected schools, malnutrition, damaged infrastructure like buildings and roads, and refugees, internally displaced persons, and persons of concern. Satellites are valuable in addressing data gaps across all of these areas for every humanitarian emergency. Satellite applications support all stages of the event life cycle, from Hazard and Risk Assessment to Recovery. Satellite EO can be particularly powerful in supporting predictive analytics for slow-developing crises, for example, in the context of food insecurity predicting weak crop yields months before the harvest season, or to anticipate violence and understand the drivers of conflict.

The improving awareness and acceptance of satellite applications is leading to broader adoption by humanitarian actors across a wide range of use cases. Such use cases include population and poverty mapping, infrastructure mapping and exposure, crop yield and productivity forecasting, hazardous event detection and severity evaluation, and many other applications across humanitarian domains.

— *Environmental and situational data for humanitarian decision-making*

The World Bank's Data for Better Lives report highlights how the production and collection of data enable humanitarian and development outcomes. Satellite applications, as digital technology, provide a unique source of such data about people and their surrounding environment—with the potential to fill significant data and information gaps in humanitarian management and decision-making processes. Satellite applications provide:

- More timely decision-making through real-time and predictive modelling
- Decision-making supported by greater accuracy of data
- Greater confidence in the decision-making process
- Greater accountability across stakeholders

Data from satellite applications has the specific advantages of coverage, objectivity, repeatability, thematic detail, speed, and affordability.

— *Ecosystem of satellite applications for humanitarian emergencies*

There is a complex network of stakeholders involved in satellite applications for humanitarian emergencies; the report provides a comprehensive list of actors on this topic. All stakeholders can be positioned along a spectrum from the supply-side to the demand-side, or both in a few cases. The supply-side provides the satellite applications, whereas the demand-side uses those applications to address their humanitarian emergencies.

Supply-side organisations include:

- Private suppliers: satellite operators and resellers, cloud computing providers, platform/solution providers, and hardware/software suppliers
- Public suppliers: satellite operators, and analytics providers
- Academia
- NGOs
- Media
- Development Agencies

Demand-side organisations include:

- Governments
- First Responders
- Private Sector
- Academia
- NGOs
- Media
- Development Agencies
- Affected Public
- General Public

— *Landscape of humanitarian satellite applications*

This report includes a landscaping of over 500 humanitarian satellite applications which identified that:

- 42% of identified humanitarian satellite applications targeted government users.
- 62% of identified satellite applications are "customised" for a specific user.
- The highest number (92) of identified applications are for "food, security, nutrition and famine" events in Africa.
- Many of the data gaps identified by Humanitarian Data Exchange (HDX) in sectors such as health and education could be addressed by satellite applications.

— *Overcoming barriers to uptake of satellite applications in humanitarian emergencies*

Thirteen barriers to the uptake of satellite applications in humanitarian emergencies have been identified. Industry, governments, and the development community are addressing each barrier to varying degrees. Based on the ability of the development community to help address the issue, a subset of eight barriers are prioritised for interventions:

- User awareness and resistance
- Inadequate monitoring and evaluation
- Data availability
- Ethics and privacy
- Technical expertise and skills
- Financing for application development and scaling
- Procurement challenges
- Piloting and duplication

- Recommended development community interventions are defined for the eight prioritised barriers.

Barrier	Recommended Development Community Interventions
User awareness & resistance	• Document existing examples and case studies • Share information via an open online knowledge base • Virtual and real-world knowledge events
Inadequate monitoring & evaluation	• Publish impact evaluations via an online knowledge base • Donors ensure impact evaluations are project deliverables • Training to supply-side organisations on M&E techniques
Data availability	• Online open knowledge base of who is doing what and where • Virtual and real-world knowledge events • Donors to fund high-resolution EO data for use by humanitarian organisations
Ethics & privacy	• Document and share ethics and privacy best practices • Upscale community involvement in data generation through community mapping and validation exercises
Technical expertise & skills	• A playbook of principles and case studies that showcase good practice • Support regional centres of expertise
Financing for application development & scaling	• Appropriate patient capital from development agencies and philanthropic organisations through the creation of new financing mechanisms
Procurement challenges	• Training for demand-side organisations on satellite application procurement, processes, and pricing • Mechanisms to aggregate demand into bulk procurement agreements across multiple demand-side organisations
Piloting & duplication	• Information of who is doing what and where via an online knowledge base • Virtual and real-world knowledge events • Encouraging shared access to data

— *Conclusions*

Satellite applications are being developed by an increasingly complex web of supply-side stakeholders and are being applied across a range of use cases in the life cycle of a humanitarian emergency. However, there is a limited body of evidence to offer humanitarians guidance on where satellite technology generates the best outcomes for affected populations due to the identified barriers. Now is the time for public and private sector stakeholders to act in order to increase the use of and impact derived from satellite applications in humanitarian assistance.

Background

Background

Key points

- The UK Humanitarian Innovation Hub is a pilot programme, funded by the UK Foreign, Commonwealth and Development Office (FCDO) and hosted by Elrha, that seeks to identify the biggest challenges within and opportunities to address global humanitarian responses.
- The objective of this report is to provide a consolidated view on the current use of satellite applications in humanitarian settings.
- UKHIH selected a consortium of organisations to author this report, including Caribou Space, Satellite Applications Catapult (SAC), and the United Nations Institute for Training and Research (UNITAR).
- Satellite applications are digital services and products that serve several functions for society, the environment, and the economy by deploying three types of satellite technology: Satellite Earth Observation, Satellite Communications, and Global Navigation Satellite Systems.

Humanitarian Innovation Hub

The UK Humanitarian Innovation Hub (UKHIH) has been established to reduce the human impact of conflict and disasters by leveraging UK expertise in science, technology, and innovation. It is funded by the UK Foreign, Commonwealth & Development Office (FCDO) and hosted by Elrha, a global humanitarian organisation and the UK's leading independent supporter of humanitarian innovation and research.

UKHIH is leveraging world-class UK science, technology, and innovation to support humanitarian action around the world. It is a convening mechanism to promote collaboration across the UK and provide a coherent, accessible, and impactful innovation offer from the UK to the international humanitarian community.

By facilitating a network of UK humanitarian innovators focused on new and improved processes and technologies, the UKHIH aims to make humanitarian action more effective and efficient, with a particular focus on data and digital. They convene and coordinate across UK government departments and attract key communities of interest in the UK and globally.

UKHIH selected a consortium of organisations to support this task, including Caribou Space, Satellite Applications Catapult (SAC), and the United Nations Institute for Training and Research (UNITAR).

The objective of this report is to provide a consolidated view on the use of satellite applications in humanitarian settings.

Satellite applications

Satellite applications are digital services and products that serve several functions for society, the environment, and the economy by deploying three types of satellite technology.

— *Satellite Earth Observation*

Earth Observation (EO) is the gathering of information about the physical, chemical, and biological systems of the planet via remote-sensing technologies. EO is used to monitor and assess the status of, and changes within, the earth's atmosphere, oceans, land surface, and built environments.

— *Satellite Communications*

Satellite Communications (SatComms) is the use of satellites to provide communication links between various points on Earth. It is used to provide voice and internet connectivity in regions that are not covered by terrestrial mobile networks. This allows communication between people and enables remote monitoring and operation of machines, sensors, and equipment (Internet of Things (IoT)).

— *Global Navigation Satellite Systems*

Global Navigation Satellite Systems (GNSS) are constellations of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. GNSS are used to track people and physical objects at any time, globally.

Humanitarian emergencies

Humanitarian emergencies

Key points

- Humanitarian emergencies are "*events or series of events that represent a critical threat to the health, safety, security, or wellbeing of a community or other large group of people.*" They are widely geographically distributed, often covering large areas and multiple populations. They are diverse and complex, and require coordinated efforts and resources across a variety of local, national, and international stakeholders.
- Humanitarian emergencies share common characteristics related to the domains in which they occur and the type of events leading to them.

What are humanitarian emergencies?

A humanitarian emergency is "*an event or series of events that represents a critical threat to the health, safety, security or wellbeing of a community or other large group of people, usually over a wide area.*"[1]

They are broad and diverse; whilst no two humanitarian emergencies are the same, they can share common characteristics. They are based around an event in time that can be either slow to emerge (e.g., drought) or rapid (e.g., a flood). They pose a threat to large groups of people. There are typically well-defined phases of an emergency or disaster management situation that follow a life-cycle process.

Across these phases, information is necessary to support assessment of what is happening, where, and how. However, this information may be unavailable, incomplete, or slow to acquire, especially in the immediate aftermath of a humanitarian emergency. This report is concerned with understanding common information needs during humanitarian emergencies and identifying critical elements of these needs that could be addressed using satellite technology.

1 Humanitarian Coalition, 'What is a Humanitarian Emergency?,' www.humanitariancoalition.ca/what-is-a-humanitarian-emergency

Research framework

The purpose of the research framework is to define the scope of this report and to highlight key considerations for the use of satellites in humanitarian decision-making and risk assessment. The research framework draws on existing concepts, models, and other frameworks to provide a concise knowledge set and theoretical basis. It is used consistently and built upon in subsequent chapters, providing structure to the analysis of the research questions.

No obvious, preexisting, "off-the-shelf" framework for humanitarian events in the broadest sense has been identified in surveying existing frameworks with project team input. For example, a United Nations University (UNU) publications search (terms: "humanitarian" + "framework") shows 136 results.[2] These publications generally include coverage of events in only one domain or cluster. Brauch, for example, does provide a number of useful and relevant multi-domain conceptual frameworks for environment and human security.[3] However, the "causes" (e.g., Land, Air, Water, etc.) relevant to emergencies are too abstract to classify and analyse individual projects in this work. In considering the structure for this research framework, the primary concerns are to:

- Determine the high-level scope for this report in terms of which existing "domains," e.g., food insecurity, and disasters, should be included in scope for humanitarian emergencies.[4]
- Provide a non-exhaustive typology of "humanitarian events" that cause humanitarian emergencies.
- Identify key stakeholders and their needs in the phases of a humanitarian emergency.

Domains of humanitarian emergencies

A domain is a broad grouping of different humanitarian crises with common characteristics using simple naming and common terminology.

Domains are used to illustrate and define the scope for the report. Domains are simpler but less specific than the sector and cluster groupings often used by humanitarian organisations, such as the sphere response sectors and UN Inter-Agency Standing Committee (IASC) clusters.[5] Domains are often closely related and more than one may apply to an individual humanitarian emergency. This section describes the most common domains in humanitarian response where satellite technology has the potential to support. For the purposes of the research, the domains are shown in Figure 1.

FIGURE 1: Domains of Humanitarian Emergency in Scope

2 United Nations University, 'Collections,' http://collections.unu.edu/adv_search.php

3 Hans G. Brauch, 'Environment and human security: Towards freedom from hazard impacts,' UNU-EHS InterSecTions 2 (2005), http://collections.unu.edu/view/UNU:1856

4 This report does not attempt to define new domains.

5 The Sphere Project, *The Sphere Handbook* 2018, 6 November 2018, https://spherestandards.org/handbook-2018; UN Office for the Coordination of Humanitarian Affairs Inter-Agency Standing Committee, 'Reference Module for Cluster Coordination at Country Level, 27 July 2015, https://interagencystandingcommittee.org/iasc-transformative-agenda/iasc-reference-module-cluster-coordination-country-level-revised-july-2015

Disasters: Natural hazards that can lead to humanitarian situations include floods, storm surges, earthquakes, landslides, droughts, wildfires, and extreme temperatures. These events can lead to a humanitarian crisis if they restrict a large group of people from accessing fundamental needs, such as food, clean water, or safe shelter. Flooding-related disasters are the most commonly reported and/or recorded.[6]

Security and conflict: When the protection of the territorial integrity, stability, and vital interests of states through the use of political, legal, or coercive instruments at the state or international level fails, violent conflict and insecurity result. Violent conflicts lead to death and destruction, the crumbling of weak states, local and international insecurity, a vicious cycle of underdevelopment, instability, and large-scale humanitarian crises.[7]

Food insecurity: Food security means that all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their preferences and dietary needs for an active and healthy life. Natural hazards, conflict, and supply chain inefficiencies can disrupt access and contribute to food insecurity. Existing food insecurity is often exacerbated by conflict that displaces communities that are unable to carry out day-to-day activities, such as managing crop fields.

Population displacement: At the end of 2020, United Nations High Commissioner for Refugees (UNHCR) estimated global displacement surpassed 80 million people.[8] Refugees are people who have fled war, violence, conflict, or persecution and have crossed an international border to find safety in another country.[9] An estimated 26 million people are refugees, 68% of whom are from Syria, Venezuela, Afghanistan, South Sudan, and Myanmar. Further, 39% of refugees are hosted in five countries: Turkey, Colombia, Pakistan, Uganda, and Germany.[10] Internally displaced persons (IDPs) are those forced to flee their homes, but stay within their own country. IDPs also include people displaced by internal strife and natural disasters. Over 46 million people are estimated to be IDPs.[11]

Health emergencies: Public health emergencies include significant outbreaks of infectious diseases; epidemics, in which a disease affects a large number of people within a community, population, or region; and pandemics, when an epidemic spreads over multiple countries or continents (e.g., COVID-19).[12]

6 For example, 43% of all disasters between 1995 and 2015 in the CRED dataset were flooding-related; Asia and Africa were most at risk. Beatriz Ravilla Romero, 'Improving Global Flood Forecasting using Satellite Detected Flood Extent' (PhD diss., Utrecht University, 2016); Centre for Research on the Epidemiology of Disasters, *The Human Cost of Weather Related Disasters*, 1995–2015, 2015, www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf

7 UN International Peace Academy, *The Security-Development Nexus: Conflict, Peace and Development in the 21st Century*, May 2004, www.ipinst.org/wp-content/uploads/publications/security_dev_nexus.pdf

8 UN High Commissioner for Refugees, 'Refugee Data Finder,' updated 18 June 2021, www.unhcr.org/refugee-statistics/

9 Same as above.

10 Same as above.

11 UN High Commissioner for Refugees, 'Refugee Facts: What Is a Refugee?,' www.unrefugees.org/refugee-facts/what-is-a-refugee/

12 US Centers for Disease Control and Prevention, 'COVID-19: Identifying the Source of the Outbreak,' updated 1 July 2020, www.cdc.gov/coronavirus/2019-ncov/science/about-epidemiology/identifying-source-outbreak.html

Humanitarian events

A humanitarian event is a potential starting point for a humanitarian emergency and the need for humanitarian action. It is a specific occurrence that initiates the need for decision-making or action by stakeholders within identified common processes. This report is concerned with humanitarian events that encompass one or more hazards that may precipitate a humanitarian crisis and have significant consequences for those affected. The term "event" is used broadly to describe circumstances wider than hazards, which can have context-specific meanings.

The research framework includes events and hazards in the identified domains rather than an exhaustive review. Humanitarian events are rarely discrete and are often the result of other related events; for example, an IDP crisis may be precipitated by conflict or a disaster. The exact definition of scope for a specific event and, ultimately, responsibility for the response to an event is the role of one or more stakeholders. This may vary by geography and organisational structure, but this report attempts to identify commonalities across events. It is increasingly common practice to name individual instances of a realised hazard to aid communications, e.g., the naming of individual cyclones by meteorological services. Due to the interrelated and combined nature of events, the term **event cluster** is used below.

— *Hazards*

Humanitarian events include "hazardous events" as defined by the United Nations Office for Disaster Risk Reduction (UNDRR).[13] They have location, timing, and measurable risk for associated hazards. The cluster approach and disciplines such as Disaster Risk Reduction (DRR) and emergency management require preparedness that relies on hazard identification and understanding.[14]

Humanitarian events include newly emerged and changing hazards. Hazards are often described as natural (e.g., fire) or technological (e.g., radiation), with a socio-natural hazard (e.g., increased flood risk due to environmental degradation) being a combination of the two. Caribou Space also noted the use of "Natech," which refers to a technological hazard caused by a natural one.[15] Hazards are global in nature, occurring with varying severity and frequency in all countries.

Time is an important factor for events, hazards, and their resulting crises and disasters. They may be permanent, temporary, or episodic.[16]

- **Permanent hazards**, for the purposes of risk management, are always present (e.g., coastal erosion and climate change).
- **Temporary hazards** can be long-duration (e.g., slow onset) but have a clear start and end point (e.g., drought).
- **Episodic hazards** tend to be shorter in duration but recurring (e.g., hurricanes, winter storms, tsunamis, and river floods).

13 UN Office for Disaster Risk Reduction, 'Terminology: Online Glossary,' www.undrr.org/terminology

14 UN OCHA IASC, 'Reference Module for Cluster Coordination at Country Level,' revised July 2015, https://interagencystandingcommittee.org/iasc-transformative-agenda/iasc-reference-module-cluster-coordination-country-level-revised-july-2015

15 UN Office for Disaster Risk Reduction, 'Natech Hazard and Risk Assessment,' in *Words into Action Guidelines: National Disaster Risk Assessment Hazard Specific Risk Assessment, Part Three: Hazard Specific Risk Assessment*, 2017, 90–98, https://www.undrr.org/publication/words-action-guidelines-national-disaster-risk-assessment

16 Nirupama Agrawal, *Natural Disasters and Risk Management in Canada: An Introduction* (Springer, 2018)

Episodic and temporary events are the focus of this research, including early warning systems, rather than permanent hazards that require continuous, ongoing monitoring. For similar reasons, this report also considers very slow onset events and monitoring longer-term changes in the natural environment to be out of scope.

Hazards or events that have not exceeded defined risk thresholds may require monitoring to determine if they will. Some events may be impossible, or at least difficult, to identify as hazardous in advance with sufficient detail to mitigate, e.g., long-term consequences of a political decision.

Existing typologies and records of hazards and disasters, such as the Centre for Research on the Epidemiology of Disasters (CRED) Emergency Events Database (EM-DAT), are essential datasets and schemas.[17] However, they are typically more detailed and granular than those found in common usage by humanitarian actors and stakeholders. The event types used in this report are derived from the existing typologies within the UNDRR Hazard Clusters.[18]

These events relate well to the "disasters" domain, but less so to the other four domains. Therefore, other sources such as *The Sphere Handbook* have also been used.[19] Caribou Space do not seek to redefine hazard or event types, but rather to highlight those practically applicable to this research; therefore, some omission and consolidation have been made. Omissions include cyber hazards, mental health, and food safety, as these were felt to be outside the direct scope of satellite tools to address.

— *Risk*

For this report risk means "*the probability of an outcome having a negative effect on people, systems or assets.*"[20] We also note the importance of valuing potential outcomes from risks where measured value may be less tangible (e.g., sustainability) or measured and defined differently by separate stakeholders.[21]

Major components of risk include "exposure," to hazardous events, for example; "vulnerability," and its related concepts of autonomy, dependency, care, and exploitation;[22] and "adaptive capacity" or "coping capacity" to respond to and recover from the impacts of humanitarian emergencies.

An important aspect of risk management and risk reduction is understanding risk through hazards, exposure, vulnerabilities, and adaptive capacity. A key goal in understanding risk is to quantitatively measure the likelihood of an event happening and its impacts and consequences.[23] Understanding and measuring risk is fundamental to the use cases within the life-cycle phase 'Hazard & Risk Assessment' and all subsequent stages (see Table 3: List of Use Cases by Event Life-Cycle Phase). Risk is complex and changes over time through all the event life cycle phases.[24] Therefore, the importance of also addressing multiple hazards and interrelated and dynamic changes to risk is increasingly recognised.[25]

17 Centre for Research on the Epidemiology of Disasters, 'EM-DAT: The International Disaster Database,' https://emdat.be

18 UNDRR International Science Council, *Hazard Definition and Classification Review*, 2020, https://www.undrr.org/publication/hazard-definition-and-classification-review

19 The Sphere Project, *The Sphere Handbook 2018*, 6 November 2018, https://spherestandards.org/handbook-2018/

20 UNDRR, 'Understanding risk,' https://www.undrr.org/building-risk-knowledge/understanding-risk

21 Baruch Fischhoff and John David Kadvany, *Risk: A Very Short Introduction* (Oxford University Press, 2011)

22 Catriona Mackenzie, Wendy Rogers, and Susan Dodds, eds., *Vulnerability: New Essays in Ethics and Feminist Philosophy* (Oxford University Press, 2013)

23 Jake Ansell and Frank Wharton, eds., *Risk: Analysis, Assessment and Management* (Wiley, 1992)

24 UNDRR, *Global Assessment Report on Disaster Risk Reduction 2019*, 2019, www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019

25 Melanie S. Kappes, Margreth Keiler, Kirsten von Elverfeldt, and Thomas Glade, 'Challenges of Analyzing Multi-Hazard Risk: A Review,' *Natural Hazards* 64 (2012): 1925–58, https://doi.org/10.1007/s11069-012-0294-2

— *Compound risks and complex emergencies*

Increasingly, we face compounding and interrelated environmental, socioeconomic, and political crises. The current pandemic, for instance, continues to collide with a number of other threats to human life and livelihoods.[26] When multiple risks occur at the same time, outcomes become significantly worse. As is often the case at the interrelation between conflict, forced displacement, food security, and disasters. For example, an area with ongoing or imminent food insecurity hit by a conflict that reduces access to markets and resources can be particularly devastating. Related to this is the term "complex emergency," which can be defined as a humanitarian crisis in a country, region, or society where there is a total or considerable breakdown of authority resulting from internal or external conflict.[27]

This section has focused on introducing a research framework to outline the wider humanitarian context and define the scope of the research in terms of priority domains and hazards.

26 A. Kruczkiewicz, et al., 'Opinion: Compound risks and complex emergencies require new approaches to preparedness,' *PNAS* 118, no. 19 (2021): article e2106795118, https://doi.org/10.1073/pnas.2106795118

27 UNHCR, 'Coordination in Complex Emergencies,' 1 September 2001, https://www.unhcr.org/en-us/partners/partners/3ba88e7c6/coordination-complex-emergencies.html

Environmental and situational data for humanitarian decision-making

Environmental and situational data for humanitarian decision-making

Key points

- Satellite applications, as digital technology, provide a unique source of data about people and their surrounding environment—with the potential to fill significant data and information gaps in humanitarian management and decision-making processes.
- The World Bank's Data for Better Lives report highlights how the production and collection of data enable humanitarian and development outcomes.
- Satellite applications provide:
  - More timely decision-making through real-time and predictive modelling
  - Decision-making supported by greater accuracy of data
  - Greater confidence in the decision-making process
  - Greater accountability across stakeholders
- Data from satellite applications has the specific advantages of coverage, objectivity, repeatability, thematic detail, speed, and affordability.

The World Bank's Data for Better Lives highlights how the production and collection of data enables humanitarian and development outcomes. Individuals, civil society, and academia gain greater accountability and government and international organisations improve policymaking and service delivery, whilst the private sector gain increased business opportunities. However, these positive outcomes come with the risks of greater criminal activity, political surveillance, market concentration, widening inequality, and discrimination.

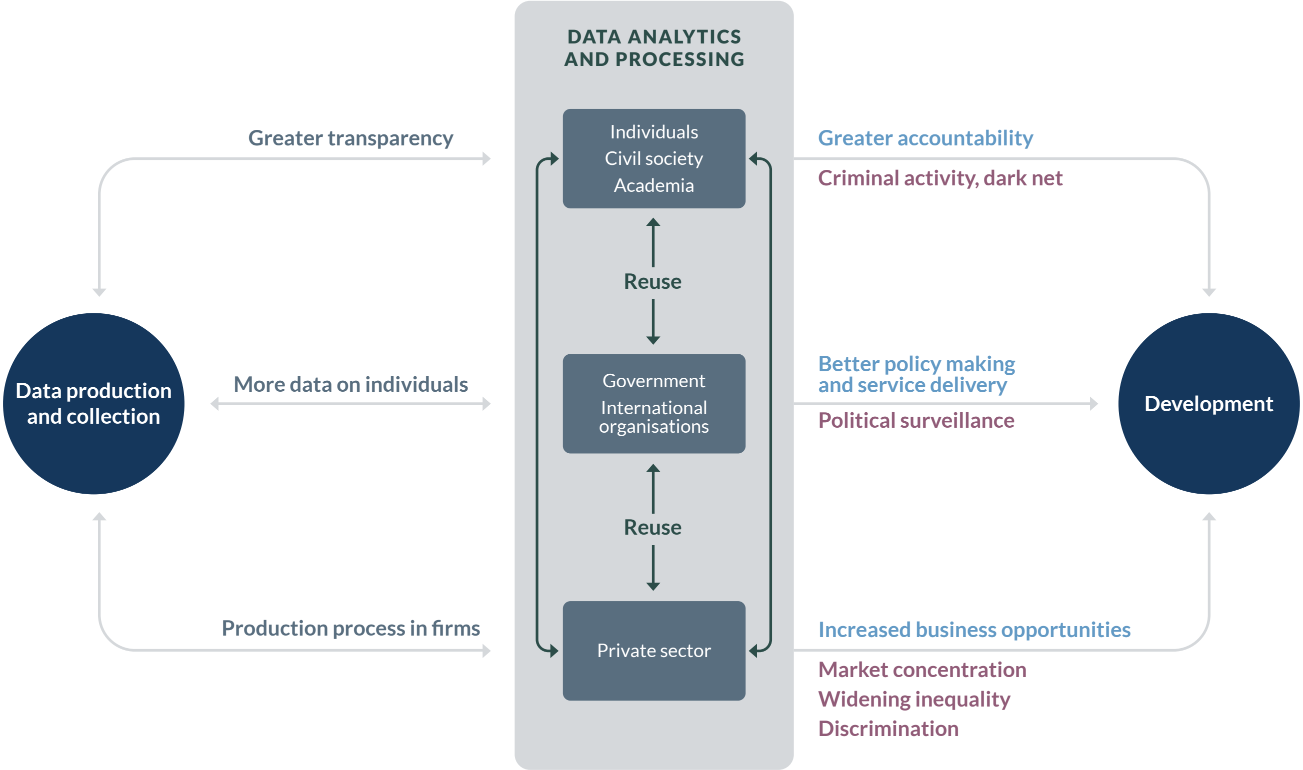


FIGURE 2: World Bank: How Data Can Support Development: A Theory of Change[28]

Humanitarian actors continually make complex decisions in the preparation for, and response to, humanitarian emergencies. Digital technologies support these decision-making processes by providing large volumes of high-quality data that enables insight. The term "digital data for development (D4D)" refers to the use of data generated by mobile, satellite, and digital devices to inform and strengthen nonprofit, humanitarian, and public-sector decision-making.[29]

Satellite applications, as digital technology, provide a unique source of data about people and their surrounding environment and can fill significant data and information gaps in management and decision-making processes. Often this data may not exist in any other form (e.g., in remote or conflict areas). In other cases, satellite applications may offer data that is more frequent, more detailed, and more affordable than ground-based data sources, such as traditional maps, census data, bespoke surveys, ground teams, or even innovative methods like the use of drones.[30]

Satellite applications allow:

- More timely decision-making through real-time and predictive modelling
- Decision-making supported by greater accuracy of data
- Greater confidence in the decision-making process
- Greater accountability across stakeholders

28 World Bank, *World Development Report 2021* Data for Better Lives, 2021, www.worldbank.org/en/publication/wdr2021

29 Digital Impact Alliance, *Leveraging Data for Development to Achieve Your Triple Bottom Line*, July 2018, http://digitalimpactalliance.org/wp-content/uploads/2018/07/DIAL_D4D_MNO-Paper2_2018-v9.pdf

30 London Economics, *Economic evaluation of the International Partnership Programme (IPP): Cost-Effectiveness Analysis*, October 2019, https://londoneconomics.co.uk/blog/publication/economic-evaluation-of-the-international-partnership-programme-ipp-cost-effectiveness-analysis-october-2019/

Data from satellite applications has the specific advantages of:

- **Coverage:** Satellites have global coverage that makes it possible to consistently monitor vast, remote, and even conflict regions across countries and continents.
- **Objectivity:** Satellite observations derive from the satellite instrument's measurements, which have a known and controlled range of error and are thus less susceptible to many of the biases detected in other measures of the same phenomena.
- **Repeatability:** Satellite observations are collected along a periodic orbit of the Earth's surface, so they are repeatable and comparable over time.
- **Continuity:** The continuity of satellite data streams allows time to build experience and refine the systems that use the data.
- **Thematic detail:** The range of satellite sensors now available allows for application to a wide range of humanitarian domains.
- **Analysis-ready data:** Satellite data is organised and processed according to defined industry standards and provided in forms that allow immediate further analysis.
- **Speed:** Increasingly, satellite data is available for use soon (days or even hours) after it is acquired, enabling stakeholders to receive the derived information they need to act quickly—critical in, for example, disaster scenarios.
- **Affordability:** Along with the increase in commercial satellites, there is also an increase in satellites that allow free and open access to data, such as the Copernicus Sentinel missions.

Ecosystem of satellite applications for humanitarian emergencies

Ecosystem of satellite applications for humanitarian emergencies

Key points

- There is a complex network of stakeholders involved in satellite applications for humanitarian emergencies; the report provides a comprehensive list of actors on this topic.
- All stakeholders can be positioned along a spectrum from the supply-side to the demand-side, or both in a few cases. The supply-side provides the satellite applications, whereas the demand-side uses those applications to address their humanitarian emergencies.
- Supply-side organisations include:
  - Private suppliers: satellite operators and resellers, cloud computing providers, platform/solution providers, hardware/software suppliers
  - Public suppliers: satellite operators, analytics providers
  - Academia
  - NGOs
  - Media
  - Development Agencies
- Demand-side organisations include:
  - Governments
  - First Responders
  - Private Sector
  - Academia
  - NGOs
  - Media
  - Development Agencies
  - Affected Public

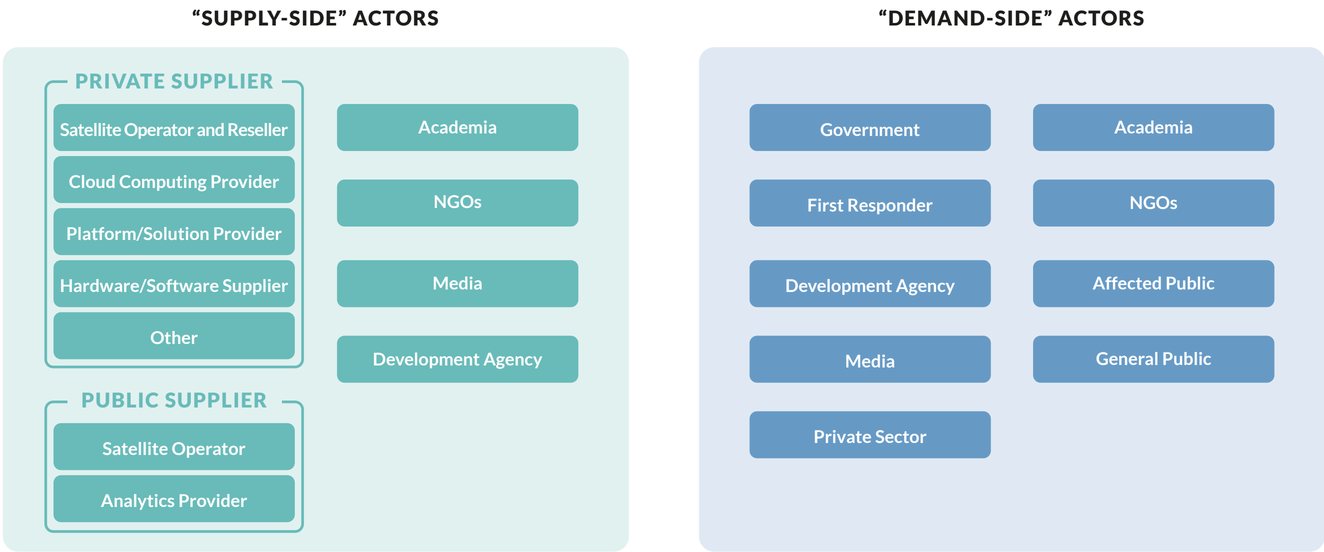


FIGURE 3: Supply-side and Demand-side Actors

All stakeholders related to the use of satellite applications for humanitarian emergencies can be positioned along a spectrum from the supply-side to the demand-side. The supply-side provides the satellite applications, whereas the demand-side uses those applications to address their humanitarian emergencies.

Supply-side actors

The humanitarian ecosystem is composed of an inherently heterogeneous mix of traditional actors (NGOs and Governments) as well as non-traditional actors (voluntary technical organisations, e.g., DataKind and the OpenStreetMap community, Private Suppliers, Academia, Media).

Each stakeholder group has a particular set of interests, motives, assets, skills, and capacities which directly influence their use of data and value derived from these assets. Humanitarian actors, their partners, and the Affected Public are producing, capturing, and accessing growing volumes of data about vulnerable populations and their environments. These data providers and users together make up a diverse and complex "humanitarian data ecosystem."

Supply-side actors

Private Suppliers and Public Suppliers represent the majority of providers of satellite applications for humanitarian emergencies.

Private Suppliers are a diverse group that is further subdivided. **Satellite Operators and Resellers**, such as Inmarsat (SatComms) and Maxar (EO), own and operate satellites and sell data streams from them, either directly or via resellers. **Cloud Computing Providers**, such as Google Cloud Platform, Amazon Web Services, and Microsoft Azure, make it possible to process this data into products by providing on-demand cloud infrastructure. This software as a service and infrastructure enables all data analysis and product generation to be implemented in the cloud instead of the user's desktop.[31] Google Earth Engine (GEE), a cloud-based platform, combines a multi-petabyte catalogue of satellite imagery and geospatial datasets with planetary-scale analysis capabilities needed to detect changes, map trends, and quantify differences on the Earth's surface. GEE is open access and allows users to conduct analyses that would otherwise require enormous resources to access, download, store, and analyse.[32] **Platform/Solution Providers**, such as Descartes Labs, build satellite applications that address specific humanitarian use cases. Examples of **Hardware/Software Suppliers** include Garmin GPS for navigation and companies that build large commercial geosynchronous satellite platforms, e.g., Thales Alenia Space and Airbus Defence and Space. **Other Private Suppliers** include miscellaneous private companies in areas such as agri-business, insurance, mobile operators, and drone operators.

Public Suppliers include two subgroups: first, **Satellite Operators**, which includes government space agencies such as the European Space Agency (on behalf of the European Commission) with their Copernicus constellation and the US National Aeronautics and Space Administration (NASA). Second, **Analytics Providers**, such as mapping agencies, statistical bureaus, land ministries, health ministries, defence and intelligence agencies, and disaster response agencies use satellite data alongside other data sources to create and contribute analyses and reports.

Academia and **NGOs** play roles on the supply-side as data providers and on the demand-side as users. Academic institutions lead the development of methods required to extract satellite data to develop products and often make these publicly available for further use. NGOs rely on insights from this data and play a critical role in collecting on-the-ground data often needed for training, contextualising, and validating satellite products.

Media often source and use satellite imagery in news articles to raise awareness among the public about humanitarian emergencies.

Development Agencies are occasionally on the supply-side, such as the World Bank or other International Financial Institutions (IFIs), and have internal specialist teams able to produce satellite applications for humanitarian contexts.

31 Catherine Nakalembe et al., 'A review of satellite-based global agricultural monitoring systems available for Africa,' *Global Food Security* 29 (June 2021): article 100543, https://doi.org/10.1016/j.gfs.2021.100543

32 Noel Gorelick et al., 'Google Earth Engine: Planetary-scale geospatial analysis for everyone,' *Remote Sensing of Environment* 202 (December 2017): 18–27, https://doi.org/10.1016/j.rse.2017.06.031

TABLE 1: Supply-Side Stakeholder Groups

Stakeholder Group	Subgroup	Examples
Private Suppliers	Satellite Operators & Resellers	• Airbus, Capella Space, Earth-i, GHGSat Inc., Planet Labs, Inmarsat, Maxar Technologies, OneWeb, Satellogic, Telespazio
	Cloud Computing Providers	• Alibaba Cloud, Amazon Web Services, Google Cloud Platform, IBM Cloud, Microsoft Azure, Oracle, Salesforce, SAP Cloud Platform
	Platform/ Solution Providers	• Google Earth Engine, Microsoft Planetary Computer, Orbital Insight, Descartes Labs, CrowdAI, Ecometrica, MapBox
	Hardware/ Software Suppliers	• Hardware: Garmin, Thales Alenia Space, Gilat Satellite Networks, Airbus • Software: Harris (ENVI), ESRI, PCI Geomatica • Open access: QGIS
	Other	• Agri-business, Disaster Monitoring Constellation (DMC), generalist consulting firms, insurance companies, mobile operators, and drone operators
Public Suppliers	Satellite Operators	• European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), European Space Agency (ESA), National Aeronautics and Space Administration (NASA), South African National Space Agency (SANSA), India Space Research Organisation (ISRO)
	Analytics Providers	• Mapping agencies: Instituto Nacional de Estadística y Geografía (INEGI), Geoscience Australia • Innovation units: Country Directorate of Science, Technology and Innovation (DSTI) in Sierra Leone, CONCYTEC-Peru's National Council of Science, Technology, and Innovation • Statistical offices: UK Office for National Statistics, National Bureau of Statistics • Defence and intelligence open source projects: xView Challenge, SpaceNet
Academia		• Research institutes: Norwegian Centre for Humanitarian Studies, Canadian Research Institute on Humanitarian Crisis and Aid (OCCAH), African Centres for Disease Control • Universities: University of Geneva, Harvard Humanitarian Initiative, Nanyang Technological University • Think tanks: Chatham House, Freedom House, Center for Strategic International Studies (CSIS)
NGOs		• Local NGOs: OpenStreetMap (OSM) communities, Map Kibera, iCitizens • International NGOs: Doctors Without Borders, International Rescue Committee, CARE International, Mercy Corps, Lutheran World Relief • Regional organisations: Asia Disaster Preparedness Center (ADPC), Regional Centre for Mapping of Resources for Development (RCMRD) • UN agencies: United Nations Office for Disaster Risk Reduction (UNDRR), United Nations High Commissioner for Refugees (UNHCR) • Human rights organisations: Amnesty International, Human Rights Watch • Initiatives: Digital Earth Africa
Media		• Local journalists: Associated Press • International journalists: The Guardian, Al Jazeera, Devex, The New Humanitarian
Development Agency		• International Financial Institutions: World Bank, Asian Development Bank

Demand-side actors

The diverse community of "data providers" is met by an even more diverse community of global humanitarian data users. Many of these humanitarian actors focus on specific domains or event types, as discussed in the previous chapter, while others are better categorised by their roles and workflows during an event.

Government includes senior members of government, such as ministers and national coordinators, e.g., Pacific Community (SPC) and US Federal Emergency Management Agency (FEMA). They liaise with other government agencies and lead teams overseeing analysts and first responders. They engage with the public by directly briefing the media and public. They also coordinate funding requests from **Development Agency(s)**. **Government** also includes mapping agencies, e.g., UK Ordnance Survey or Survey of India, and defence and intelligence, e.g., Ministries of Defence. They provide other parts of government with analysis to support decision-making. They also produce detailed reports for media briefings.

First Responders include emergency services, military response units, and in-country aid agencies. They provide support in terms of evacuations, search and rescue, and emergency food, shelter, and medical supplies.

Development Agencies include bilateral and multilateral donors, IFIs, private foundations, and corporate philanthropies. They provide funding and assistance to governments, NGOs, and the private sector.

Media include local and international journalists. They report on the humanitarian emergency to the broader public.

Private Sector includes insurance and reinsurance firms that provide cover against asset losses, e.g., infrastructure, vehicles, or crops, in the event of a humanitarian emergency, e.g., a disaster. It also includes multinational companies like Coca-Cola and Nestlé that have supply chains across the world, which are affected by humanitarian events.

Academia plays roles on both the supply-side as data providers and also as demand-side users.

NGOs include local and international NGOs and human rights organisations. They often provide on-the-ground support in the case of humanitarian events, including providing basic needs such as shelter, water, and healthcare.

Affected Public includes affected communities who play a role in working with humanitarian stakeholders, especially those on the front lines, to direct and prioritise assistance.

General Public includes the local and international public. They are government constituents and influencers, and in some cases contribute to philanthropic funding appeals to support NGOs in their humanitarian response.

TABLE 2: Demand-Side Stakeholder Groups

Humanitarian Stakeholder Group	Examples
Government	• Ministers • National coordinators: National Disaster Risk Reduction & Management Council (NDRRMC), Civil Contingencies Secretariat, Pacific Community (SPC) • Regional: African Risk Capacity • Mapping agencies: Ordnance Survey, Survey of India, National Geographic Department of Lao (NGD) • Defence and intelligence: Ministries of Defence, United States Africa Command (AFRICOM)
First Responders	• Emergency services: fire, police, medical • Military response units: Army Corps of Engineers, military medical staff • In-country aid agencies (local and international): Red Cross, United Nations High Commissioner for Refugees (UNHCR), United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), World Food Program (WFP), Médecins Sans Frontières (MSF)
Development Agencies	• Bilaterals and multilaterals: UK Foreign, Commonwealth and Development Office (FCDO), Japan International Cooperation Agency (JICA) • IFIs: World Bank, International Finance Corporation (IFC), Asian Development Bank, International Development Bank (IDB) • Private foundations: Bill and Melinda Gates Foundation, Rockefeller Foundation • Corporate philanthropies: Mastercard Foundation
Media	• Local journalists: Associated Press • International journalists: The Guardian, Al Jazeera, Devex, The New Humanitarian
Private Sector	• Insurance companies: Swiss Re, Munich Re • Multinational companies: Coca-Cola, IKEA, Alibaba, Starbucks, Nestlé
Academia	• See examples in Table 1
NGOs	• See examples in Table 1
Affected Public	• Communities directly affected by humanitarian events, who are also volunteers and crowdsourcing contributors • Vulnerable groups like refugees and IDPs, slum dwellers, farmers, children, etc.
General Public	• Broader national or international public following news of the humanitarian event • Volunteers and crowdsourcing contributors, e.g., OpenStreetMap volunteers

Humanitarian data roles

Beyond thinking about these actors by their traditional stakeholder groupings, e.g., Government, Development Agency, etc., it can also be helpful to understand these groups vis-à-vis their interactions with data. In their paper, Haak et al. present four different stakeholder data-oriented roles involved in developing, disseminating, and using a "toolbox" of information derived from public and private sources of data:[33]

- **Initiator/Coordinator**, which is the leading agency, most likely a United Nations agency (e.g., UNHCR, World Food Programme (WFP)), setting up the humanitarian data ecosystem. In the toolbox context, this party should initiate, coordinate, and support the development of the toolbox in a country, bringing all relevant actors together and incentivising them to facilitate data-sharing and use the toolbox.
- **Local Lead**, which is a national body (e.g., Department of Disasters, Department of Refugees, Food Security Division) that becomes the local manager after the Initiator/Coordinator has set out the initial data ecosystem responsible for locally promoting participation. This role is important to ensure the sustainability of the ecosystem.
- **Data Suppliers** are responsible for sharing relevant data.
- **Toolbox Users** are humanitarian or government agencies who should use the toolbox (i.e., the data processed into understandable information) and incorporate the outputs into their operations and decision-making.

In some cases, a given stakeholder group can play multiple roles. For example, governments are often Local Leads, Data Suppliers, and Toolbox Users; their primary data roles usually vary across departments or agencies. As Local Leads, governments are on the front lines of a humanitarian crisis and coordinating response efforts. As Data Suppliers, governments have made significant investments in providing free and open, continuous and consistent satellite data streams.

In recent years, these governments and the agencies that design and operate satellites have more actively engaged with the broader humanitarian community to ensure optimal return on taxpayer investment by encouraging applications to maximise the societal benefit of the data. For example, the US Geological Survey touts the economic value of Landsat for the US taxpayer, claiming an estimated US$3.45 billion in economic benefits to users worldwide in 2017. Similarly, the European Space Agency showcases the benefits brought by the usage of the Copernicus Sentinel satellite's data to society, environment, and economy through a bottom-up assessment of traceable impacts along selected value chains.[34]

As Toolbox Users, government agencies leverage public and private satellite data alongside other sources to inform their analyses, findings, and reports. For example, national statistical offices use satellite imagery to streamline enumeration campaigns and more efficiently complete censuses.[35]

33 Elise Haak et al., 'A framework for strengthening data ecosystems to serve humanitarian purposes,' *Proceedings of the 19th Annual International Conference on Digital Government Research: Governance in the Data Age* (May 2018): article 85, https://doi.org/10.1145/3209281.3209326

34 US Geological Survey, 'Landsat's Economic Value to the Nation Continues to Increase,' 4 March 2021, www.usgs.gov/center-news/landsat-s-economic-value-nation-continues-increase; European Commission, *Copernicus Market Report*, February 2019, www.copernicus.eu/sites/default/files/PwC_Copernicus_Market_Report_2019.pdf

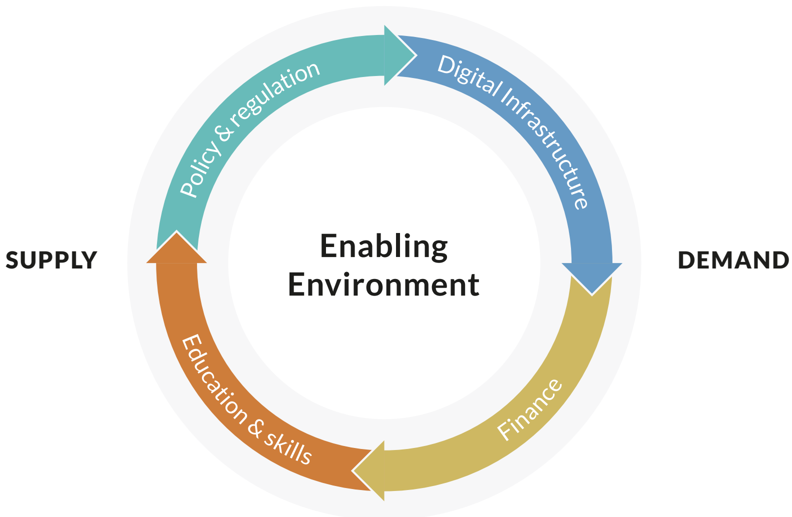
35 Sarchil Qader, 'Semi-automatic mapping of pre-census enumeration areas and population sampling frames,' *Humanities and Social Sciences Communications* 8 (2021): article 3, https://doi.org/10.1057/s41599-020-00670-0

Enabling environment

Surrounding the supply- and demand-side is an environment that is required to enable and make best use of satellite applications. Components of the enabling environment are listed below and detailed later (see section Overcoming barriers to uptake of satellite applications in humanitarian emergencies):

- **Policy and regulation** includes satellite-specific policies and regulations as well as those covering related topics, like data privacy e.g., European Union's General Data Protection Regulation (GDPR), international charters (e.g., Disaster Charter), cybersecurity, data hosting, etc.
- **Education and skills** encompasses the general awareness, domain expertise, and technical skills needed to produce or use satellite applications for humanitarian applications.
- **Finance** involves the financial organisations providing funding to both supply- and demand-side organisations, and to other parts of the enabling environment, to facilitate the development and use of satellite applications.
- **Digital/IT infrastructure** accounts for the associated technologies and data required to leverage satellite data streams, including but not limited to cloud computing, internet connectivity, ground stations, geospatial software, mobile applications and tools, and other data sources to enhance satellite-derived insights.

FIGURE 4: Enabling Environments



Satellite applications

Satellite applications

Key points

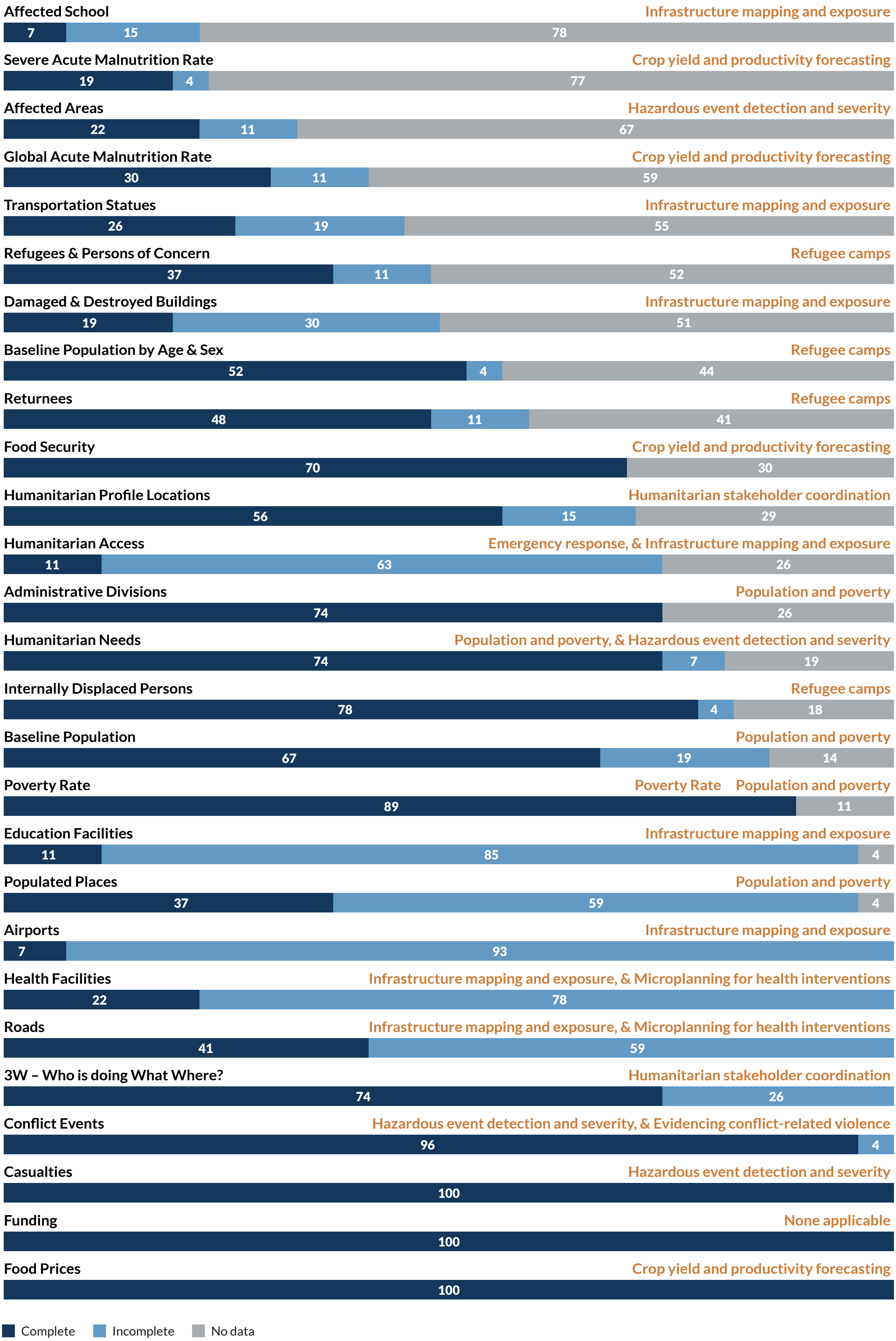
- The most persistent and extensive humanitarian data gaps include a lack of information on affected schools, malnutrition, damaged infrastructure like buildings and roads, and refugees, internally displaced persons, and persons of concern.
- Satellites are valuable in addressing data gaps across all of these areas for every humanitarian emergency.
- Satellite applications support all stages of the event life cycle, from Hazard and Risk Assessment to Recovery. Satellite EO can be particularly powerful in supporting predictive analytics for slow-developing crises, for example, in the context of food insecurity predicting weak crop yields months before the harvest season, or to anticipate violence and understand the drivers of conflict.
- The improving awareness and acceptance of satellite applications is leading to broader adoption by humanitarian actors across a wide range of use cases.
- Use cases include population and poverty mapping, infrastructure mapping and exposure, crop yield and productivity forecasting, hazardous event detection and severity evaluation, and many other applications across the five humanitarian domains.

Use cases of greatest need

At the start of 2021, Humanitarian Data Exchange (HDX) estimated that just 51% of relevant, complete crisis data is available across 27 categories of humanitarian operations.[36] Population and socio-economy is the most complete data category, while health and education were the least complete categories. Figure 5 plots HDX's data gaps against the most relevant satellite-enabled use case from those listed in this report.

36 Sarah Telford, 'The State of Open Humanitarian Data,' OCHA Centre for Humanitarian Data, 10 February 2021, https://centre.humdata.org/the-state-of-open-humanitarian-data-2021/

FIGURE 5: Completeness of Data Required Across Humanitarian Operations (left) Mapped to Satellite Use Case (right)



While data on affected schools is largely missing (up to 78%), satellite applications help fill this gap when used for pre-event infrastructure mapping (exposure) and post-event damage assessment. Before and after imagery helps identify damaged or destroyed infrastructure, allowing humanitarian actors to assess the near real-time status of schools and whether they have been affected. This satellite-data-driven approach could address data gaps related to schools, as well as transport, damaged and destroyed buildings, and health facilities.

Data on severe acute malnutrition rates is also largely unavailable. However, combining detection, extent, and severity of events with population and poverty mapping and forecasts of crop yield can improve these estimates. While satellites cannot directly observe nutrition levels, they can offer useful proxy information that, when combined with other data sources, closes some of this data gap. While there has been extensive usage of satellite imagery for crop models, a focus on nutrition is relatively early-stage research.[37]

Across most data categories, there were uniform calls for improving data quality, as well as access to persistent, real-time data and information streams.[38] Beyond types of data needed, the following requirements emerged from this study, many of which are closely related:

- Needs assessments and targeting humanitarian operations[39]
- Democratisation of access to data, especially for affected communities[40]
- Monitoring and evaluation of the efficacy of interventions[41]
- Predictive analytics[42]

Needs assessments are critical during humanitarian crises, as they provide baseline information (e.g., the number of people affected) upon which situation monitoring, response planning, and severity assessments are based. Needs assessments provide evidence for the strategic decisions that need to be made, such as where to allocate or where to deliver aid. In some cases, the availability of such data has been constrained due to limited access to insecure and remote areas. Moreover, many governments do not have access to adequate data on their entire populations. This is particularly true for the poorest and most marginalised communities. Satellites can help provide comprehensive population data regardless of insecurity or distance from urban centres.

37 Jeremy Irvin, Dillon Laird, and Pranav Rajpurkar, 'Using Satellite Imagery to Predict Health,' 2017, http://cs231n.stanford.edu/reports/2017/pdfs/559.pdf; Elizabeth Bondi et al., 'Mapping for Public Health: Initial Plan for Using Satellite Imagery for Micronutrient Deficiency,' KDD 2020 Workshop on Humanitarian Mapping, 2020, https://teamcore.seas.harvard.edu/files/teamcore/files/kdd_humanitarian_mapping_workshop_2020_4.pdf

38 Henry Lewis and Gary Forster, *Humanitarian Research Brief 4: Data Use Capacity in Protracted Humanitarian Crises*, Humanitarian Data Transparency Series Brief 4, Publish What You Fund, June 2020, https://www.publishwhatyoufund.org/wp-content/uploads/dlm_uploads/2020/06/Humanitarian-Research-Brief-4.pdf

39 Same as above; United Nations, 'Big Data for Sustainable Development,' www.un.org/en/global-issues/big-data-for-sustainable-development

40 Kees Boersma and Chiara Fonio, eds., *Big Data, Surveillance and Crisis Management* (Routledge, 2017); Tina Comes, Kenny Meesters, and Stina Torjesen, 'Making sense of crises: The implications of information asymmetries for resilience and social justice in disaster-ridden communities,' *Sustainable and Resilient Infrastructure* 4, no. 3 (2019): 124–36, https://www.researchgate.net/publication/321691714_Making_sense_of_crises_the_implications_of_information_asymmetries_for_resilience_and_social_justice_in_disaster-ridden_communities

41 Comes, Meesters, and Torjesen, 'Making sense of crises.'

42 UN Committee of Experts on Global Geospatial Information Management, *Future Trends in Geospatial Information Management: The Five to Ten Year Vision*, August 2020, https://ggim.un.org/documents/DRAFT_Future_Trends_report_3rd_edition.pdf; Kevin Hernandez and Tony Roberts, Predictive Analytics in Humanitarian Action: A Preliminary Mapping and Analysis, *K4D Emerging Issues Report* 33, Institute of Development Studies, June 2020, https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/15455/EIR33_Humanitarian_Predictive_Analytics.pdf?sequence=1&isAllowed=y

Democratisation of access to data, especially for affected communities, ensures that humanitarians can better collect data, share information, and validate findings with communities on the ground. This can inform intervention priorities and locations to target resources and services. In a context of increasing social and digital inequalities, technologies run the risk of continuing to benefit more resilient and less at-risk populations. However, with intentional humanitarian data stewards—people responsible for championing improved data usage—satellites can help address digital divides during events rather than exacerbate them. For example, satellite imagery provides context and maps of every community regardless of geographic spread, size, wealth, political affiliations, or administrative boundaries. By enabling feedback loops with affected communities, humanitarians would not only ensure the right to access the data collected about these populations but also gain the best possible "groundtruth," or confirmation of their interpretation of remotely collected data.

Monitoring and evaluation of the efficacy of interventions is another key use for satellite applications. Government and UN coordinators need more oversight information, while NGOs and other demand-side organisations require specific information to design and implement their programmes. Given their revisit rates and ongoing data streams, satellites are an important source for monitoring and evaluating humanitarian programmes. During a conflict or disaster, for example, satellite imagery can evidence which buildings and roads have been damaged, as well as which have been subsequently rebuilt. Combinations of satellite data sources like EO constellations and GNSS alongside ancillary data, such as surveys, offer even more complete monitoring and evaluation.

Predictive analytics, in addition to observed data, allow anticipatory action. By monitoring sources, patterns, and trends, potential crises can be detected and averted. Insights from predictive models can improve humanitarian supply chains, reduce deployment costs, forecast food shortages, suggest migration routes, identify disease transmission patterns, and track malnutrition trends. The ever-increasing scale of data collected provides important historical and current observations to support more accurate forecasts and predictions. Importantly, predictive analytics allows the use of satellite applications not only for responding to emergencies but also for preventing emergencies. In this regard, EO can be particularly powerful for slow-developing crises, for example, in the context of food insecurity predicting weak crop yields months before the harvest season. Every dollar invested in the prevention of humanitarian emergencies might save several dollars/pounds as compared to an emergency response.

Use of satellite applications across the event life cycle

Satellite applications have a role across all stages of a humanitarian emergency, which are visualised in Figure 6.

1 **Hazard and Risk Assessment** – The first stage whereby hazards and risk factors that have the potential to lead to a humanitarian situation are identified. Hazard identification involves characterising hazards according to the probability of the hazard becoming reality and its potential severity.

2 **Mitigation** – This stage includes any action or sustained effort undertaken to reduce a hazard through the reduction of the likelihood and/or the consequence component of that hazard's risk.

3 **Preparedness** – This stage includes knowing what to do in the aftermath of an event and being equipped with the right tools and information to act effectively.

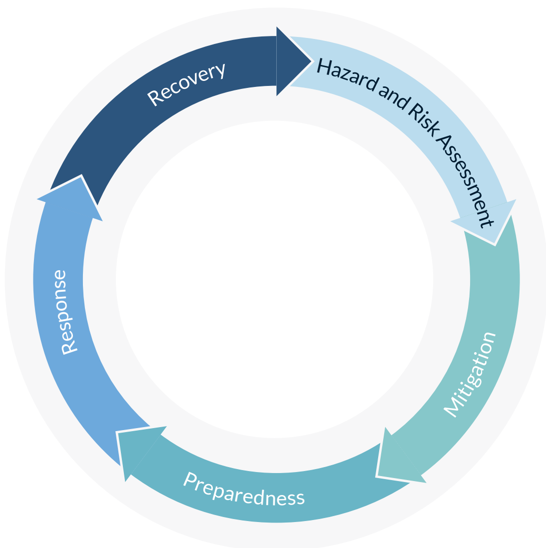
4 **Response** – The following stage involves actions aimed at limiting injuries, loss of life, and damage to property and the environment taken before, during, and immediately after an event. Response processes begin as soon as it becomes apparent that an event is imminent and last until the emergency is declared to be over.[43]

5 **Recovery** – The stage when communities, systems, and lives are rebuilt, repaired, and otherwise returned to functional conditions.

Table 3 provides use case examples categorised by the humanitarian event life cycle. These examples are not exhaustive but are indicative of the wide-ranging and persistent applicability of satellite data across the humanitarian spectrum.

Each use case is categorised as to whether satellite data provides **direct value** in providing insights or **indirect value** because it needs to be combined with other data, improved with ground validation, and/or integrated into a more sophisticated analysis or model. For example, predicting and analysing crop yields remotely is a powerful use case of EO in the humanitarian context, for technical reasons and given the potential impact on saving lives. In turn, poverty mapping is of course important for the creation of baselines, but EO can only effectively help in this case if combined with other datasets and (often complex) analyses, and faces caveats and margins of error.

FIGURE 6: Multi-stage Life Cycle of Humanitarian Emergencies



43 Damon P. Coppola, *Introduction to International Disaster Management*, 3rd ed. (Elsevier Science, 2007)

Table 3: List of Use Cases by Event Life Cycle Phase

Life Cycle Phase	Use Case	Satellite Data Value	Domain-Specific Examples
Hazard & Risk Assessment	Monitoring nuclear facilities	Direct value	• Monitoring of suspected proliferation installations for the detection of undeclared nuclear facilities and processes
	Monitoring prison camps	Direct value	• Estimating populations at prison camps • Evidencing the existence of prison camps in inaccessible areas
	Infrastructure mapping and exposure	Direct value	• Mapping roads to determine access to resources/services • Reducing seismic risk for buildings • Quantifying financial exposure of assets
	Natural resource mapping	Indirect value	• Identifying resource scarcity and likely drivers of conflict
	Population and poverty mapping	Indirect value	• Disease outbreak modelling and hotspot identification • Identifying coastal communities at risk for flooding and surge
	Subsidence and erosion mapping	Indirect value	• Warning about potential infrastructure instability • Prioritising and reinforcing engineering projects to address hazards
	Disaster risk financing and insurance	Indirect value	• Property underwriting and recommendations • Predicting how many claims insurers will receive
Mitigation	Crop/livestock insurance	Direct value	• Analysing climate impact on crops and fields' productivity • Evidencing number of large livestock owned or lost
	Rangelands management	Direct value	• Forecasting food insecurity in pastoralist communities using livestock loss • Evidencing conflict-related cattle rustling
	Access to finance and credit	Indirect value	• Evidencing good agricultural practices to determine creditworthiness
	Early warning systems	Indirect value	• Identifying conditions for disease outbreak, famine, or disasters • Dam monitoring as part of flood early warning systems
	Extraction and trafficking of illegal resources or humans	Indirect value	• Advocating traceability across supply chains • Tracking illicit mines, logging, and other trafficked goods
Preparedness	Crop yield and productivity forecasting	Direct value	• Early warning systems for crop failure or seasonal decline • Yield gaps based on potential and observed crop growth
	Election polling site monitoring	Direct value	• Preventing electoral violence with monitoring of election sites • Ensuring vulnerable populations have access to polling sites
	Micro-planning for health interventions	Indirect value	• Guiding immunisation campaigns and distribution of vaccines • Navigating community health workers to reach every household
	Humanitarian supply chain management	Indirect value	• Tracking conflict-sourced goods and disrupting trafficking • Improving humanitarian operations and resource distribution • Asset tracking of high-value resources (vaccines, food, water, etc.)

Response	Agricultural pest and disease response	Direct value	• Monitoring conditions on-farm and assessing risk for pests and disease • Allocating limited supplies (e.g., pesticides, sprayers) to affected areas
	Connectivity for public or remote populations	Direct value	• Providing communications to refugee camps • Coordinating delivery of aid • Communicating in remote functions like border or forest patrol
	Damage assessment	Direct value	• Identifying destroyed infrastructure in conflict settings • Identifying burned buildings from wildfires • Evidencing impact of event on natural resources
	Emergency response	Direct value	• Conducting preliminary needs assessment to add to local knowledge • Identifying evacuation routes and ingress/egress routes
	Financial payments	Direct value	• Providing cash transfers in emergency settings • Connectivity for rural/remote banking
	Search and rescue missions	Direct value	• Identifying indications of human activity or presence along with terrain models to focus search areas
	Contaminated sites	Direct value	• Determining likely source and spread of contamination as well as at-risk populations
	Access routes and evacuation plans	Direct value	• Identifying traversable routes based on debris and roadblocks • Assessing access to markets and trade hubs in rainy season
	Public crisis awareness	Direct value	• Evidencing humanitarian need for fundraising appeals • Using imagery in news stories to provide context
	Contact tracing	Direct value	• Mapping patients' movements to limit transmission • Identifying the origins of an outbreak to inform treatment
	Humanitarian stakeholder coordination	Direct value	• Providing situational awareness to enable stakeholders to coordinate
	Evidencing conflict-related violence	Indirect value	• Providing before and after images of destroyed communities and property destruction • Evidencing mass burial sites
	Hazardous event detection and severity	Indirect value	• Detecting conflict-related events, natural disasters, crop failures • Forecasting disaster intensity and impacts
	Guiding drones	Indirect value	• Mapping digital terrain and surfaces to chart flight paths • Identifying communities with least access for drone deliveries
	Refugee camps	Indirect value	• Assessing quality of life in camps • Monitoring camp growth and effects on host communities
	Disease prevalence and transmission	Indirect value	• Predicting the location and spread of diseases
Recovery	Infrastructure reconstruction	Direct value	• Evidencing progress of reconstructed infrastructure • Increasing infrastructure resilience based on reconstruction
	Compliance with peace treaties	Indirect value	• Verifying disarmament per peace treaty terms • Preventing escalation of conflict by proving claims of disarmament
	Monitoring and evaluation	Indirect value	• Evidencing baseline conditions • Monitoring impacts (e.g., infrastructure rebuilt, camp populations, etc.)
	Analysing refugee resettlement suitability	Indirect value	• Identifying and planning locations to resettle refugees

Use cases by domain

Satellites provide critical data across all domains of humanitarian activity. This section provides a broad overview of use cases by humanitarian domain.

— *Disasters*

Spatially disaggregated risk maps showing exposure to hazards and vulnerability to events and their impacts are derived from satellite data. During hazard identification, data sources like satellite imagery are critical and are often the only option for mapping the extent of previous flooding events, as one example, and for modelling flooding threat thresholds. Moreover, during the response phase, satellite-derived maps provide information on extent, severity, and impacts post-disaster. The data can inform appropriate mitigation measures and response plans, as well as optimise evacuation routes and guide response teams. The data is useful to identify affected communities and prioritise most-affected areas based on damage assessments, population, vulnerability, and other variables that are derived from satellites.

Beyond situational information, SatComms systems are often essential to enable stakeholder coordination in remote regions without mobile coverage or where mobile networks have been damaged by the event. SatComms systems ensure connectivity for first responders as well as affected communities.

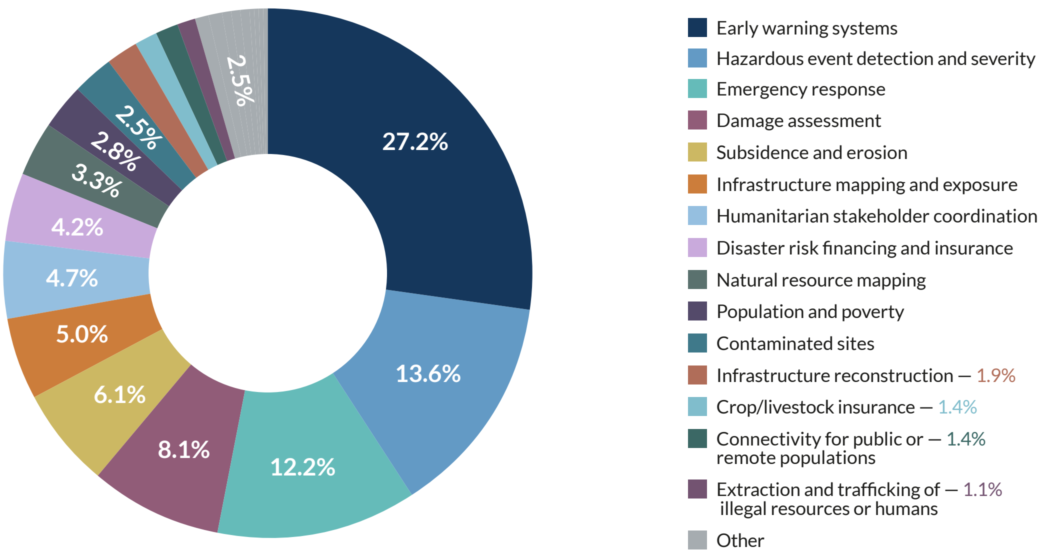


FIGURE 7: Frequency of Use Case in Disasters Domain (n =>500)

— *Security and conflict*

Satellites are valuable assets in conflict situations, where access to the affected area is often problematic for ground teams aiming to conduct conventional field mapping during early phases. Without a physical presence on the ground, satellites can provide timely intelligence on conflict-related destruction, displaced populations, refugee and IDP camp growth, and human rights abuses, as well as inform post-conflict reconstruction and monitoring of peace treaties.

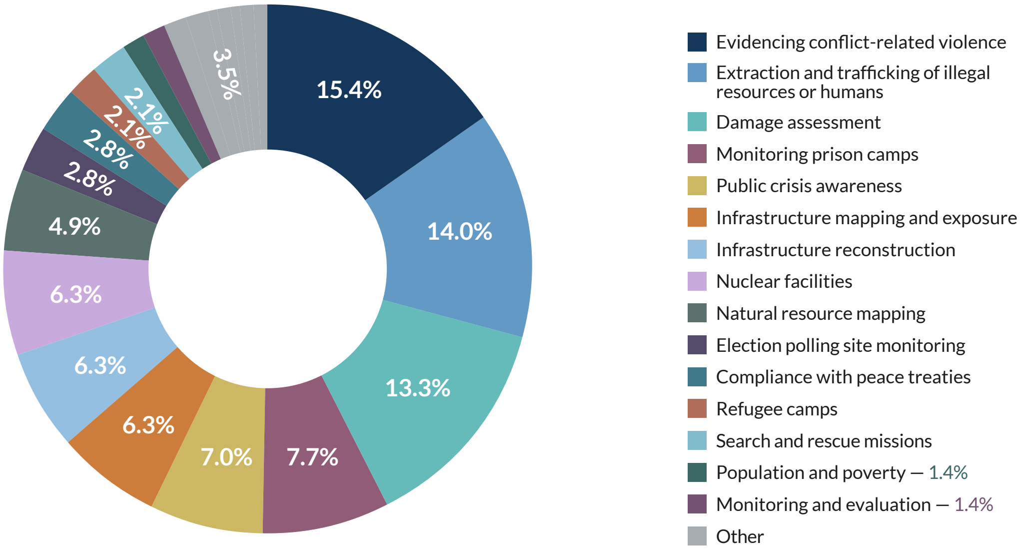


FIGURE 8: Frequency of Use Case in Security and Conflict Domain (n =>500)

In some cases, satellites can also help prevent conflict by evidencing de-escalation of militarisation and adherence to international humanitarian law. As documentation tools, satellites have the potential to collect important real-time evidence for alleged war crimes and crimes against humanity. Because these events often occur in inaccessible environments, over large geographic areas, and/or across long and multiple time frames, high-resolution satellite imagery, in particular, has value for international tribunals investigating these crimes.

— *Food insecurity*

Information on crop conditions and yield estimates required to stabilise markets, mitigate food supply crises, and mobilise humanitarian assistance efforts to evaluate and target production-enhancing interventions can be derived from EO satellites. For food insecurity use cases, the consistent revisit rate of satellite constellations allows for crop monitoring to support early warning systems. Beyond revisit rates, spectral information in satellite imagery can unlock important dimensions like crop health, crop-type mapping, soil moisture, suitability maps, and many other food security–related indicators that support more complex crop performance models, pest and disease models, food demand, and more. Combining these agricultural datasets with population and poverty data can be critical for assessing the scale of humanitarian needs and planning rapid response measures.

In the mitigation phase, satellite data, including both EO and SatComms, can inform the implementation of disaster risk financing, agricultural insurance, and access to credit, supporting more resilience in communities especially vulnerable to climate shocks and stressors.

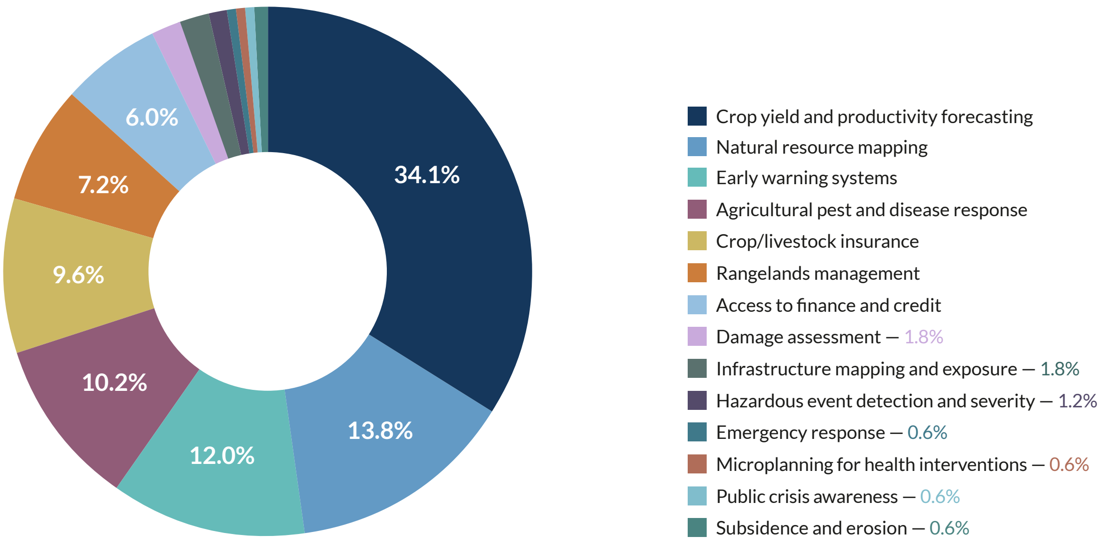


FIGURE 9: Frequency of Use Case in Food Insecurity Domain (n =>500)

— *Population displacement*

Owing to its continuous spatial coverage and frequency of collection, satellite data, like optical and synthetic aperture radar (SAR), provides insightful, near-real-time context for analyses.[44] By linking this data with GNSS data, population displacement can be mapped and monitored.

Data derived from optical imagery, like temporary settlements, cattle, boats, vegetation, water, and other features, can be used to estimate the number of people displaced or the extent and status of infrastructure and natural resources in resettlement areas. It also provides context-specific natural hazard risk assessment for informing mitigation measures to protect already vulnerable communities.[45]

Satellite imagery supplements conventional data—in "hard to reach areas" satellite imagery can be the only source available—to provide detailed insights on local population patterns without raising data privacy concerns or endangering staff with unknown risks. Immediate needs are quickly evidenced, and humanitarians can effectively respond and target scarce resources. Whether monitoring the growth of refugee and IDP camps or the nearby resources and host communities, satellites can reduce the need for ground-based surveys.

Combining data on nearby communities, the surrounding environment, livelihoods, infrastructure, and topography helps target interventions and avert cascading humanitarian emergencies. Historical satellite data on migratory movements, alongside various biophysical and socioeconomic indices, can help build machine learning models to improve forecasting of population displacement and simulate optimal response scenarios.

For governments, satellite imagery is an important tool to monitor border crossings, assess the origin and cause of displacement, understand the scale of migration, and prepare to host and eventually resettle refugees.

44 International Organization for Migration, 'Migration Data Portal,' updated 26 May 2021, https://migrationdataportal.org/data-innovation/interactive-tool-map-world-internally-displaced-satellite-imagery

45 Nistara Randhawa et al., 'Fine scale infectious disease modeling using satellite-derived data,' *Scientific Reports* 11 (2021): article 6946, https://doi.org/10.1038/s41598-021-86124-2; Shifeng Wang, Emily So, and Pete Smith, 'Detecting tents to estimate the displaced populations of post-disaster relief using high resolution satellite imagery,' *International Journal of Applied Earth Observation and Geoinformation* 36 (April 2015): 87–93, https://doi.org/10.1016/j.jag.2014.11.013; A. Heslin, L. Thalheimer, and M. J. Purma, 'Using Remote Sensing to Measure Displacement and Assess Environmental Conditions at Host Locations' abstract, American Geophysical Union Fall Meeting 2019, https://ui.adsabs.harvard.edu/abs/2019AGUFMGC13G1225H/abstract

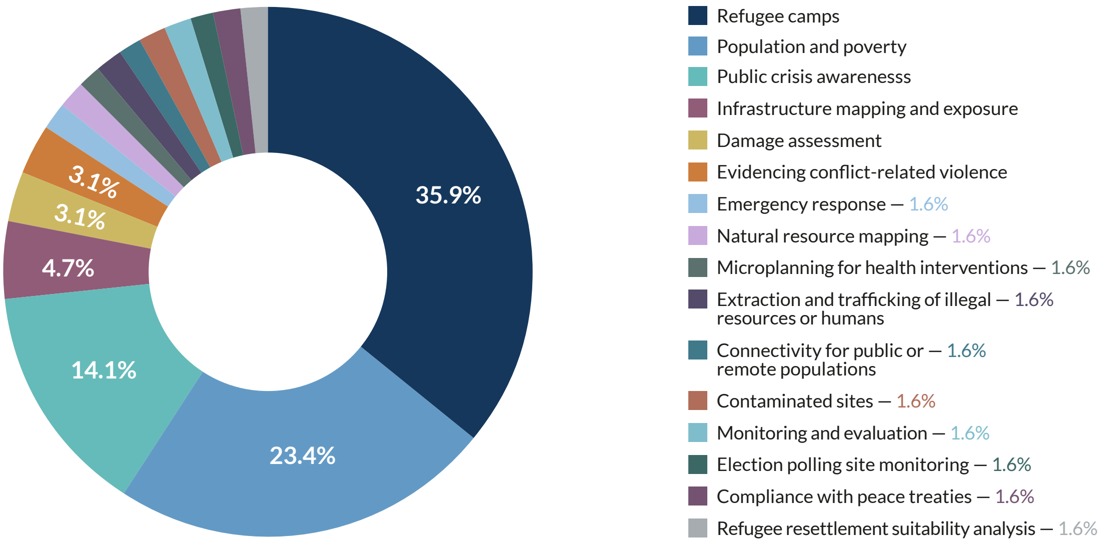


FIGURE 10: Frequency of Use Case in Population Displacement Domain (n =>500)

— *Health emergencies*

Across health emergencies, satellite data serves a number of important functions. GNSS and GIS are used for the study and forecasting of communicable and noncommunicable diseases; SatComms for telemedicine and tele-education; satellite imagery for microplanning interventions; and GNSS to deliver access to healthcare and safely and efficiently transport patients and medical supplies.

Satellite applications can produce more detailed maps of population demographics and locations connected by human movements. Data on health facilities, roads, and populations can be used for real-time tracking of disease spread, planning and control of contact tracing, and immunisation programmes during epidemics and pandemics. Spatial models for disease transmission and risk profiles are possible when combining satellite imagery with GNSS, population density, and clinic data, for example, identifying areas of malaria risk by identifying breeding grounds via stagnant water mapping and consequently targeted interventions.

It is also possible to combine these data sources to forecast capacity and demand by health clinics. Satellite applications can also be used to continuously assess national health systems and generate health facility readiness scores for COVID-19 response.

While not specific to health, population and poverty mapping are critical to any health surveillance approach, especially in an emergency setting where a lack of understanding of health catchment areas can cost precious time and resources. High-resolution population estimates support the measurement of programme targets, coverage, and improved programme planning.

Satellite data is valuable for mapping digital elevation models to chart navigation and guide drones for vaccine delivery to remote clinics; however, this is a newer application, as most cargo drones are still prototypes.[46]

46 Swiss Foundation for Mine Action, *Drones in Humanitarian Action: A guide to the use of airborne systems in humanitarian crises*, December 2016, https://reliefweb.int/report/world/drones-humanitarian-action-guide-use-airborne-systems-humanitarian-crises

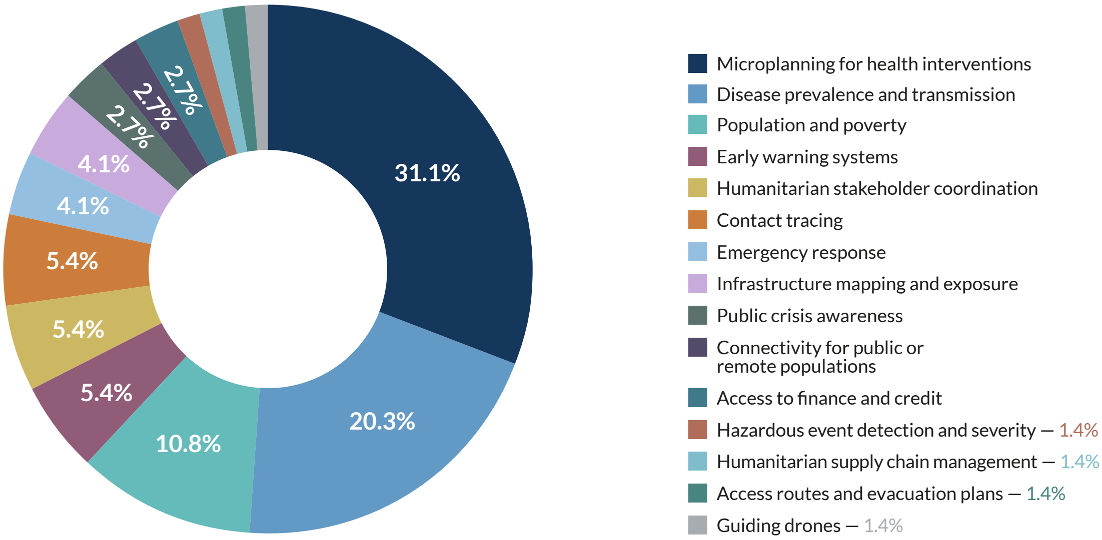


FIGURE 11: Frequency of Use Case in Health Emergencies Domain (n =>500)

— *Cross-cutting use cases*

As highlighted by population and poverty mapping, many use cases are valuable across multiple domains and humanitarian events. For example, mapping damaged infrastructure due to disaster or conflict can also inform better estimates of the impacted and displaced populations and where food aid and other resources are required. Other cross-cutting use cases include connectivity for public or remote populations and early warning systems.

Satellite applications that support cross-cutting use cases are particularly relevant for compound risks and complex emergencies. For example, in Lake Chad Basin environmental degradation, a very high fertility rate, forced displacement, and repeated herder–farmer conflicts create significant compound risk.[47] EO is a powerful tool to understand the dynamics and interrelation between such factors.

Satellites provide wide-reaching value in answering foundational humanitarian questions: Who is vulnerable? What help is needed? How can communities in need be reached? What are likely risks and impacts? Satellite applications offer a consistent, global common operating picture for stakeholders to consider risks and impacts and then coordinate to make targeted, effective decisions. Few other sources provide such valuable information across the entire event life cycle, across so many different domains, and over an entire global population.

47 Personal communication to Caribou Space, 2021.

Satellite applications industry

Satellite applications industry

Key points

- Satellite Earth Observation (EO) is the gathering of information about the physical, chemical, and biological systems of the planet via remote-sensing technologies.
- Global Navigation Satellite Systems (GNSS) are a constellation of satellites providing positioning, navigation, and timing (PNT) signals from space. GNSS is used to track people and physical objects at any time, globally. It is also widely used in humanitarian emergencies for geo-tagging of relevant issues in the humanitarian context, e.g., infrastructure, disasters, damages, conflict incidents, response activities, etc.
- Satellite Communications (SatComms) provide voice and data/internet connectivity in regions that are not covered by terrestrial mobile networks.
- Platform and cloud services, together with technologies like machine learning, are simplifying access to and use of satellite applications.
- New entrants and developments in SatComms and Satellite Internet of Things (IoT) have the potential to enable new and more cost-effective connectivity to people and things in the near future.

The use of satellite technologies and systems is referred to as an "application." A satellite application commonly incorporates non-satellite data and systems. Many have common elements through shared needs, suppliers, and underlying components. Satellite applications rely on a mix of technologies and expertise, some simple and widely available and others advanced and specialist in nature.

Satellite applications can be a basic product or service from satellites, e.g., visual imagery in a map to show urban infrastructure or satellite phone calls. Other applications are the result of significant data processing and additional modelling, e.g., asset exposure to floods within urban environments. For some applications, the satellite data element may be small in comparison to overall activity. As introduced earlier, suppliers are either Private Suppliers, Public Suppliers, Academia, NGOs, Development Agencies, or a combination of these. Figure 12 describes the types of services and products provided by suppliers.

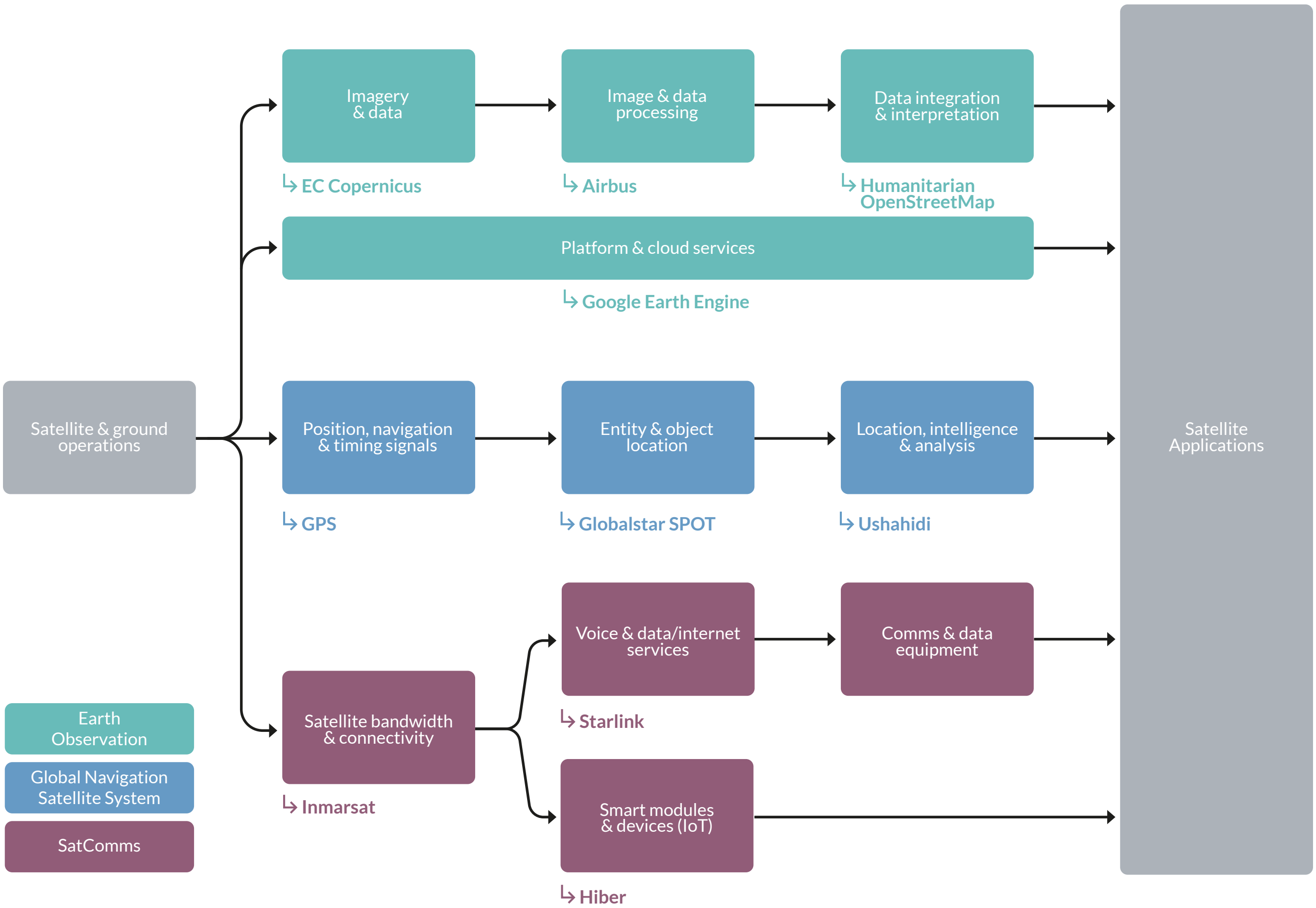


FIGURE 12: Components of Satellite Applications

Satellite Earth Observation (EO)

Satellite EO is the gathering of information about the physical, chemical, and biological systems of the planet via remote-sensing technologies. The components of EO applications include activities for the collection, delivery, and processing of satellite imagery and data. Data is interpreted, summarised, and presented in a way that is accessible and useful to the intended audience using both Information and Communications Technology (ICT) and offline technologies.

— *Imagery and data*

For EO-based applications, basic imagery and its supply are core components. "**Basic imagery**" is satellite imagery that has been acquired, downloaded, and made available with minimal processing; this includes "raw" imagery straight from the satellite and imagery that has been processed in several common ways, such as refining to give a more precise location, transforming for measurement accuracy, and correcting for various data artefacts that depend on the type of instrument or camera. These are typically referred to as level one and level two imagery products.

"**Analysis Ready Data**" (ARD), an important development for comparative analysis between imagery from different satellites, involves a higher level of processing. Whilst not required for all applications, efforts like ARD decrease barriers to using multiple sources of data and simplify the more rigorous analysis and scientific approaches required for some applications.

An important attribute of imagery is its "**resolution**": the smallest thing that can typically be seen (resolved) on the ground. More correctly termed Ground Sample Distance (GSD), this defines how much detail is available in imagery. Very High Resolution (VHR) EO data is needed for many humanitarian use cases, particularly when the emphasis shifts from broad environmental monitoring (e.g., forest change) to observing features related to individuals and buildings (e.g., mapping informal settlements). The resolution grades are listed below:

- Very High Resolution (VHR) (<1m)
- High Resolution (HR) (1m–4m)
- Medium Resolution (MR) (5m–25m)
- Low Resolution (LR) (25m–60m)
- Very Low Resolution (VLR) (>60m)

VHR data is more expensive than lower resolution data, as it is sourced from Private Suppliers at commercial costs. Moreover, VHR data is also computationally more expensive. Lower resolution imagery, such as 10 metres to 200 metres, is available from Public Suppliers at low or no cost.

Coverage is a broad term that describes the amount of imagery and data collected over an area or region with a given frequency. In general, Public Suppliers, such as the European Commission's Copernicus, have revisit times of five to eight days with global coverage. Private Suppliers offer higher revisit times for smaller areas as standard. For example, Planet provides new imagery at 0.5m resolution up to twelve times daily from its SkySat constellation.[48] Timely availability of data following a humanitarian emergency (particularly in the Response Phase) is critical. Conversely, it is also important to have access to fresh data for the Preparedness Phase, for example, in order to quantify hazard risk scenarios. Imagery is often made available to humanitarian organisations after an event but not preceding it.

The core delivery modes for satellite imagery are direct reception, tasked and repeat imagery, archive imagery, and platform and cloud services, as detailed below.

Direct reception – In direct reception, a customer or partner receives imagery in near real-time within their ground station footprint or by downloading pre-acquired stored imagery. Direct reception within the field of view of a satellite overpass is the quickest way to receive satellite data with latency of seconds and minutes. Direct reception requires a ground station facility with capital outlay and ongoing maintenance for large capital items, such as a satellite dish and reception equipment. Commercial suppliers will typically supply licensed ground station equipment and software to facilitate reception, simplifying implementation but at additional cost.

Tasked and repeat imagery – Tasked imagery is the requesting of single or multiple satellite images in the future. Procurers of these services typically specify a geographical area (Area of Interest (AOI)), timeframe, and frequency of observations for imagery. Cloud-free or low-cloud imagery may only be possible by preparing a mosaic of a number of images acquired over a period of time. Imagery is often supplied via online systems from satellite operators, distributors, and resellers through web and API access. Satellites have capacity constraints; therefore, imagery needed for a given time and location may not always be available. For some applications and imagery types, a prior arrangement to task imagery is necessary to ensure that required imagery is collected by satellites and made available.

48 Martin Van Ryswyck, 'Planet Announces 50 Cm SkySat Imagery, Tasking Dashboard and Up To 12× Revisit,' Planet, June 9, 2020, www.planet.com/pulse/tasking-dashboard-50cm-12x-revisit-announcement/

Whilst tasking is still common, imagery from some providers is not tasked and provides regular and routine "repeat" imaging of global regions according to a defined schedule. This approach is common for large public sector satellites (e.g., USGS Landsat series and EC Copernicus Sentinels) and increasingly for large constellations (e.g., Planet).

Archive imagery – Many Private Satellite Operators and Public Satellite Operators make their recent and historical imagery available via online or offline archives. Some suppliers opt to make imagery available as soon as it is collected, downloaded, and processed, thus reducing or removing the need for tasked imagery. Public archives of global satellite imagery are available, including ISRO[49] (India), USGS[50] and NASA[51] (USA), EC[52] (Europe), JAXA[53] (Japan), and INPE[54] (Brazil). Regular global imagery at resolutions generally between 10m and 200m can be acquired from these archives. The archives typically require registration and, whilst data access is generally free and open, terms and conditions can apply. APIs for direct access via software and apps are also commonly provided.

Private Satellite Operators provide online and API access to their archives for imagery that generally has much higher resolution than that of public archives. Examples include Maxar's SecureWatch,[55] Airbus' OneAtlas,[56] and Planet's Platform.[57] In many cases tools for viewing and using the imagery are provided; they can be easy to use but potentially limited in comparison to the more comprehensive cloud services or platforms described below.

For some archives, users can experience delays between the collection of imagery and its release due to data policy or commercial reasons that differentiate the service from tasked imagery. In many cases, priority access is available in advance or by prior arrangement for humanitarian events. Some commercial satellite operators offer free data access for disasters and emergencies (e.g., Planet's Disaster Data[58] and Maxar's Open Data[59] Program), and the Disaster Charter[60] provides rapid access to nationally mandated disaster management authorities upon request.

International actors within the EO community (CEOS and GEO) are encouraging the use of open data cubes to host easily accessible datasets in a standard format ready for use. Several projects are at various stages within several countries.[61]

— *Image and data processing*

Satellite imagery commonly requires processing and analysis in order to derive useful information from it. For small numbers of images, this can often be performed on workstations with freely available software. However, satellite imagery data tends to require significant storage and computing power to routinely process and analyse large datasets.

49 Indian Space Organisation National Remote Sensing Centre, 'Bhuvan: Indian Geo-Platform of ISRO,' https://bhuvan-app1.nrsc.gov.in/bhuvan2d/

50 US Geological Survey, 'EarthExplorer,' https://earthexplorer.usgs.gov

51 NASA Earthdata, 'Earthdata Search,' https://search.earthdata.nasa.gov/

52 ESA, 'Copernicus Open Access Hub,' https://scihub.copernicus.eu/dhus/#/home

53 Japan Aerospace Exploration Agency Earth Observation Center, 'ALOS Global Digital Service Model,' www.eorc.jaxa.jp/ALOS/aw3d30/l_map_v2003.htm

54 Instituto Nacional de Pesquisas Espaciais Earth Observation General Coordination, 'Image Generation Division Catalogue,' www.dgi.inpe.br/catalogo/

55 Maxar, 'SecureWatch,' www.maxar.com/products/securewatch

56 Airbus, 'OneAtlas Data,' www.intelligence-airbusds.com/imagery/oneatlas/data/

57 Planet, 'Planet Platform,' www.planet.com/products/platform/

58 Planet, 'Disaster Data,' www.planet.com/disasterdata/

59 Maxar, 'Open Data Program,' www.maxar.com/open-data

60 The International Charter Space and Major Disasters, https://disasterscharter.org/

61 Committee on Earth Observation Satellites, 'CEOS Open Data Cube,' www.opendatacube.org/ceos

Satellite imagery can be processed to derive physical attributes of geography within an observed area, such as elevation,[62] surface,[63] and soil moisture.[64] Dynamic natural and man-made phenomena can be routinely mapped, such as fires,[65] floods,[66] ocean waves,[67] and weather warnings.[68] Imagery can be processed for features and objects extracted so that entities such as building footprints[69] and roads can be mapped and counted.[70] Many commercial services now offer detailed and dynamic services, such as vehicle and facility[71] detection.[72] For supply-chain management and cargo tracking, Automatic Identification System (AIS)[73] and IoT[74] services exist.

Broad indices can be derived from the values of pixels, such as for vegetation,[75] water,[76] and ocean colour.[77] Pixel content within imagery can be classified, such as for water, a type of vegetation, or artificial surfaces, to create maps of land cover,[78] land use,[79] and urban areas.

Change detection, a common processing task, takes sets of collocated imagery and detects changes over time. This can be used to detect new settlements, settlement growth, or settlement removal, for example. Changes in the condition of infrastructure can be determined for access routes.

There are a variety of software tools and techniques in the public domain to assist in data processing.[80] Machine learning (ML) is proving an increasingly important area for satellite applications[81] due to its ability to process large imagery datasets more rapidly with a variety of learning algorithms in combination with changes in the affordability of highly parallel processing technology. Several initiatives exist to provide access to necessary tools and training data, notably Radiant Earth Foundation.[82] Most existing suppliers are adopting ML techniques, and new private sector companies are emerging to specifically address opportunities, e.g., Impact Observatory.[83]

— *Data integration and interpretation*

Satellite data is rarely the sole source of information required to address a humanitarian emergency. Therefore, consideration must be given to existing sources of national and local data and expertise, including scientific and research institutions, statistical authorities, and domain expertise from the public and private sectors. For example, crisis mapping organisations like the Humanitarian OpenStreetMap Team and MapAction

62 NASA Jet Propulsion Laboratory, 'Shuttle Radar Topography Mission,' updated 9 October 2021, www2.jpl.nasa.gov/srtm/
63 JAXA EORC, 'ALOS Global Digital Surface Model,' www.eorc.jaxa.jp/ALOS/en/aw3d30/
64 ESA, 'SMOS Data—Earth Online,' https://earth.esa.int/eogateway/missions/smos/data
65 NASA Earthdata, 'VIIRS I-Band 375 m Active Fire Data,' updated 7 July 2021, https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/viirs-i-band-active-fire-data
66 Institute of Arctic and Alpine Research University of Colorado, 'The Flood Observatory,' http://floodobservatory.colorado.edu
67 Copernicus Marine Services, 'Global Ocean Waves Analysis and Forecast,' https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=GLOBAL_ANALYSIS_FORECAST_WAV_001_027
68 Indian Meteorological Department, 'Warnings,' https://mausam.imd.gov.in/imd_latest/contents/subdivisionwise-warning.php
69 European Commission, 'Global Human Settlement Layer,' https://ghsl.jrc.ec.europa.eu
70 Geo-Referenced Infrastructure and Demographic Data for Development, 'GRID3 Data Hub,' data.grid3.org
71 Aventior, 'Insights from Aerial and Satellite Images,' aventior.com/aerial-satellite-image-analysis/
72 4 Earth Intelligence, 'Object and Vehicle Detection,' www.4earthintelligence.com/products/object-and-vehicle-detection/
73 exactEarth, 'exactAIS,' www.exactearth.com/product-exactais
74 Hiber, 'IoT Solutions,' https://hiber.global
75 USGS, 'NDVI, the Foundation for Remote Sensing Phenology,' www.usgs.gov/core-science-systems/eros/phenology/science/ndvi-foundation-remote-sensing-phenology?qt-science_center_objects=0#qt-science_center_objects
76 European Commission, 'Global Surface Water Explorer,' https://global-surface-water.appspot.com
77 NASA Goddard Space Flight Centre, 'Ocean Color Web,' https://oceancolor.gsfc.nasa.gov
78 ESA Climate Change Initiative, 'Landcover,' www.esa-landcover-cci.org/?q=node/164
79 OpenStreetMap, 'Landuse Landcover,' https://osmlanduse.org
80 ESA, 'Sentinel Application Platform,' http://step.esa.int/main/toolboxes/snap/; QGIS, 'A Free and Open Source Geographic Information System,' https://www.qgis.org/en/site/; OSGeo, 'The Open Source Geospatial Foundation,' www.osgeo.org
81 David J. Lary et al., 'Machine Learning Applications for Earth Observation,' in *Earth Observation Science and Open Innovation*, ed. Pierre-Phillippe Mathieu and Christoph Aubrecht, 165–218 (Cham: Springer Open, 2018), https://doi.org/10.1007/978-3-319-65633-5_8.
82 Radiant Earth Foundation, 'Who We Are,' www.radiant.earth/about/
83 Impact Observatory, 'About,' www.impactobservatory.com/about

rely on international and local volunteers to ensure that the tracing of geographic features in satellite imagery is correct and acceptable to affected communities.

Through the integration and interpretation of multiple data sources, a better understanding of the risk of events emerges, for example, crop yield and productivity forecasting for food insecurity,[84] early warning systems for flood risk,[85] infrastructure mapping and exposure for multi-hazards,[86] emergency response,[87] and infrastructure reconstruction.[88] Given the complex nature of risk, satellite applications are increasingly understanding and finding ways to address multiple hazards and risks.[89]

— *Platform and cloud services*

Cloud services are a prominent model in the supply of satellite data by either cloud suppliers or satellite operators. Cloud services with Infrastructure as a Service (IaaS) make large imagery archives available within a cloud environment (storage) and provide the IT infrastructure to run and host applications (computing). They also provide a wide variety of supporting software tools, such as popular software development libraries and environments, processing tools and algorithms, ML tools, and databases and hardware (e.g., AI accelerators and sensors). Cloud services can provide quick access to infrastructure that can be complex to independently develop and maintain but still requires skills and expertise. Many cloud services make satellite imagery available alongside tool sets as a standard service; examples include AWS,[90] Planetary Computer,[91] and IBM Agriculture.[92] What sets this model apart from "archive imagery" is the range of additional tools, data, and services available.

Cloud providers also provide integrated ground stations, satellite operations, and data handling services, including AWS Ground Station[93] and Azure Orbital.[94]

Platforms provide a more specific and ready-to-use set of online tools and data that often run on top of cloud services. Examples include Descartes Labs[95] and Sentinel Hub.[96] Platforms can bring together mapping and geospatial analysis tools with online imagery access. These include services from GIS suppliers and online mapping/virtual globe providers, such as commercial suppliers ESRI,[97] MapBox,[98] Google,[99] and OpenStreetMap (OSM).[100]

Some platform options exist to specifically benefit humanitarian activity. OSM's Humanitarian OpenStreetMap Team (HOT) is a volunteer-based *"international team dedicated to humanitarian action and community development through open mapping"* that uses OSM to undertake projects and response actions across humanitarian impact areas.[101] HOT also trains and activates crisis mappers for major emergencies, like Super Typhoon Haiyan, the Nepal earthquake, the Ebola epidemic in West Africa, and other

84 United States Agency for International Development, 'Famine Early Warning System,' https://fews.net
85 European Commission's Copernicus Emergency Management Service, 'Global Flood Awareness System,' www.globalfloods.eu
86 British Geological Survey, 'METEOR,' www.bgs.ac.uk/geology-projects/geodesy/meteor/
87 Copernicus, 'Copernicus Emergency Management Service,' https://emergency.copernicus.eu
88 Committee on Earth Observation Satellites, 'Recovery Observatory,' https://ceos.org/ourwork/workinggroups/disasters/recovery-observatory/
89 Mostapha Mohammad Harb and Fabio Dell'Acqua, 'Remote Sensing in Multirisk Assessment: Improving Disaster Preparedness,' *IEEE Geoscience and Remote Sensing Magazine* 5, no. 1 (March 2017): 53–65 https://doi.org/10.1109/MGRS.2016.2625100
90 Amazon Web Services, 'Registry of Open Data on AWS,' egistry.opendata.aws/tag/satellite-imagery/
91 Microsoft, 'Planetary Computer,' planetarycomputer.microsoft.com
92 IBM, 'IBM Agriculture,' www.ibm.com/products/agriculture
93 Amazon Web Services, 'AWS Ground Station,' https://aws.amazon.com/ground-station/
94 Microsoft, 'Azure Orbital,' https://azure.microsoft.com/en-us/services/orbital/
95 Descartes Labs, 'Products,' www.descarteslabs.com/products/
96 Sinergise, 'Sentinel Hub,' www.sentinel-hub.com
97 Esri, 'ArcGIS Image for ArcGIS Online,' www.esri.com/en-us/arcgis/products/arcgis-online-imagery/overview
98 Mapbox, 'Mapbox Satellite,' www.mapbox.com/maps/satellite/
99 Google, 'Google Earth Engine,' https://earthengine.google.com
100 A global crowdsourcing and mapping project similar to open knowledge movements like Wikipedia. See www.openstreetmap.org.
101 Humanitarian OpenStreetMap Team, 'Our Work,' www.hotosm.org/our-work

crises that get major international attention. The UN's Global Pulse initiative also uses big data and ML for crisis insights.[102]

Google's Earth Engine *"is free for research, education, and nonprofit use"* and the Amazon Sustainability Data Initiative (ASDI) *"seeks to accelerate sustainability research and innovation by minimizing the cost and time required to acquire and analyze large sustainability datasets."*[103]

Some platforms can be termed "specialised." A specialised platform is a collection of data and software tools that serves a particular user community with interests in a particular domain, sector, or field, such as the Geohazards Thematic Exploitation Platform (TEP).[104]

Global Navigation Satellite System (GNSS)

— *Position, Navigation, and Timing (PNT)*

PNT signals are broadcast from a GNSS from space. These signals are augmented to improve accuracy by ground stations for applications such as safety-critical aircraft systems.[105] Many operational GNSS satellite constellations now exist and are operated by national governments.[106] These include GPS (USA), BeiDou (China), Galileo (EU), GLONASS (Russia), NavIC (India), and QZSS (Japan).

Whilst GNSS signals can be received globally with relative ease, augmentation systems using ground-based infrastructure are needed for specific use cases such as civil aviation. As augmentation systems are not yet available in some regions, the full benefits of GNSS are not yet uniformly deployed globally.[107] The EU, for example, is cooperating[108] with African countries[109] in the deployment of Satellite Based Augmentation Systems (SBAS) for aircraft which reduce position errors for safer landing, fuel-saving route optimisation, and airport equipment cost reduction.

— *Entity and object location*

GNSS receivers are found in a wide variety of devices; examples include mobile phones, farming machinery, industrial assets, and navigation systems for ships and aircraft. PNT signals are received by these receivers to establish accurate time and position for the object. To describe "where things are," GNSS positioning can be used together with local reference systems (e.g., national mapping grids and street names) to record an object's location both globally and locally.

An older but comprehensive EC and industry project, HARMLESS,[110] found existing GNSS humanitarian aid solutions for food distribution and tracking (use case: population and poverty mapping; humanitarian supply chain management), mapping of

102 UN Global Pulse, 'Crisis Insights Team,' www.unglobalpulse.org/crisis-insights-team/

103 'Amazon Sustainability Data Initiative,' Amazon, https://sustainability.aboutamazon.com/environment/the-cloud/asdi

104 Geohazards TEP, 'Background: The Geohazards Exploitation Platform and Portal,' https://geohazards-tep.eu/#!pages/initiative

105 ESA, 'What is EGNOS?,' www.esa.int/Applications/Navigation/EGNOS/What_is_EGNOS

106 US National Coordination Office for Space-Based Positioning, Navigation, and Timing, 'Other Global Navigation Satellite Systems (GNSS),' www.gps.gov/systems/gnss/

107 Space in Africa, 'Expert Views On GNSS and Satellite-Based Augmentation Systems Initiatives in Africa,' 23 September 2019, https://africanews.space/expert-views-on-gnss-and-satellite-based-augmentation-systems-initiatives-in-africa/

108 European Union Agency for the Space Programme, 'International Co-operation,' www.euspa.europa.eu/about/international-co-operation

109 European Union Agency for the Space Programme, 'ASECNA provides Africa's First Early SBAS Open Service Based on the European EGNOS Technology,' 30 October 2020, https://www.euspa.europa.eu/newsroom/news/asecna-provides-africa's-first-early-sbas-open-service-based-european-egnos-technology

110 European Union Agency for the Space Programme, 'HARMLESS,' www.euspa.europa.eu/harmless-humanitarian-aid-emergency-management-and-law-enforcement-support-applications

land parcels (use case: natural resource mapping), and field staff location for safety (use case: humanitarian stakeholder coordination; search and rescue missions).[111]

Road transportation is critical to humanitarian logistics. Intelligent transport systems feature communication with drivers through mobile or SatComms in combination with precise GNSS-based location. For long routes this enables real-time rerouting for weather and hazards, tracking of personnel and cargo, alerting for safety and security, and collecting situational intelligence from transportation teams. For example, Globalstar's SPOT devices are designed to track position and notify search and rescue in the event of an emergency.[112]

— *Location intelligence and analysis*

The combination of frequently updated location data for multiple assets, entities, and objects (e.g., emergency vehicles or rescue team members in search and rescue missions) together with timing and other datasets gives rise to location intelligence and analysis. Also, geo-tagging relevant issues in the humanitarian context (e.g., infrastructure, disasters, damages, conflict incidents, response activities, etc.) on the ground via GNSS technology provides detailed contextual and positioning data to humanitarian actors. Free and commercial platforms aimed at humanitarian and development work are broadly available to assist in the collection, analysis, and management of location data.[113]

KoBoToolbox, developed by Harvard Humanitarian Initiative, is a popular tool used extensively in humanitarian emergencies around the world, with 132 million survey submissions by 640,000 users in 2020.[114] It is based on OpenDataKit, a fully open-source and free data platform used by a broad range of humanitarian actors (UNOCHA, UNHCR, ICRC, etc.), e.g., for disaster management, COVID response coordination, and many other use cases.[115]

Ushahidi is a humanitarian-focused, open-source, crowdsourcing platform that supports mapping and location data.[116] Examples of usage include mapping election violence, earthquake crisis response, and Collective Platform for Community Resilience and Social Innovation during Crises (COMRADES).

The accuracy and management of location data is an increasingly important issue for humanitarian organisations, as highlighted in the 2015 public discourse around USAID's Afghanistan health facilities data.[117]

The Sharing the Land project at the Université Chrétienne Bilingue du Congo uses GNSS and GIS to map neighbourhood conflicts and land claims to assist in dispute resolution. In improving land administration, the project seeks to address land conflict in eastern DRC with government and local community members and "*to improve land use planning by introducing a citywide strategic planning approach that takes into consideration the informal growth of cities in peri-urban contexts.*"[118]

> "A GPS unit (or maybe a satellite phone with built-in GPS) is a very useful extra item, if you have one or can get access to one."[119]

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111 HARMLESS Consortium, Critical Analysis Report, European GNSS Supervisory Authority, 2007, www.euspa.europa.eu/simplecount_pdf/tracker?file=virtual_library/2007-04-19_Critical_Analysis_Report_for_the_HARMLESS_Project.pdf

112 SPOT, 'About SPOT,' www.findmespot.com/en-us/about-spot/company-info

113 Eyad Ghattasheh, 'Managing Syrian Refugee Camps Using ArcGIS,' Esri, Fall 2017, www.esri.com/about/newsroom/arcuser/managing-syrian-refugee-camps-using-arcgis/

114 Personal communication to Caribou Space, 2021

115 Harvard Humanitarian Initiative, 'KoBoToolbox,' www.kobotoolbox.org

116 Ushahidi, 'The Ushahidi Platform,' www.ushahidi.com/features

117 Tom Esslemont, 'U.S. Incorrectly Mapped Afghan Health Facilities Twice—Watchdog,' Reuters, 24 August 2015, www.reuters.com/article/usaid-afghanistan-gps-idINKCN0QT25120150824

118 Integrated Research Institute IRI-UCB, 'Sharing the Land,' https://iriucbc.org/current-projects/sharing-the-land/

119 MapAction, *Field Guide to Humanitarian Mapping*, 2nd ed., July 2011, https://mapaction.org/wp-content/uploads/2016/12/mapaction_field_guide_to_humanitarian_mapping_low_res.pdf

— *Custom satellite applications*

Mobile apps for specific use cases are increasingly available from global app stores or sideloading sources. Safecity, for example, facilitates anonymous crowdsourced incident reporting of sexual violence which can reach epidemic proportions during mass demonstrations and complex emergencies.[120] These datasets assist stakeholder groups and individuals in identifying high-risk areas, and additional apps facilitate alerting and requesting assistance.[121]

Satellite Communications (SatComms)

— *Satellite bandwidth and connectivity*

Commercial and national satellite operators provide global connectivity from telecommunications satellites. These satellites communicate with ground facilities, called "teleports," to make additional connections to terrestrial communications networks, such as the public internet or telephone networks. Teleports are broadly globally distributed, although with higher concentrations in areas of high connectivity demand and economic activity. Satellite telecoms services have traditionally been provided by geographically focused geostationary satellites that are "fixed" over a region (e.g., Inmarsat[122] and Intelsat[123]), which often also provide broadcast/television services.

— *Voice and data/internet services*

Voice and data/internet services are now commonly available from both geostationary satellites and numerous satellites in low earth orbit (LEO) constellations, e.g., OneWeb[124] and Starlink.[125] Common SatComms-based services include telephony, mobile satellite services (MSS), and internet connectivity with all its associated digital services.

— *Comms and data equipment*

Comms and data equipment are required to use SatComms services and include very-small-aperture terminals (VSAT) to provide reliable voice and data connections. These can be deployed for permanent use at a single location, but most can be easily relocated. Small data modems provide device and computer connectivity at lower speeds, and widely available satellite phones (handsets) often include messaging and other service options.

For emergencies, many satellite operators have signed the Crisis Connectivity Charter. Led by the WFP and the Emergency Telecommunications Cluster (ETC),[126] operators are *"committing satellite equipment and capacity that will be dedicated for humanitarian purposes during emergency responses."*[127] The International Telecommunication Union (ITU), a UN agency, supplies satellite phones, terminals, and telecommunications equipment upon request to its 193 Member States during a disaster response.[128]

120 Human Rights Watch, 'Egypt: Epidemic of Sexual Violence,' 3 July 2013, www.hrw.org/news/2013/07/03/egypt-epidemic-sexual-violence
121 bSafe, 'Feature,' www.getbsafe.com/features; Circle of 6, 'Home,' www.circleof6app.com
122 Inmarsat, 'Satellites,' www.inmarsat.com/en/about/technology/satellites.html
123 Intelsat, 'Global Network,' www.intelsat.com/global-network/
124 OneWeb, 'Network,' https://oneweb.net/network
125 SpaceX, 'Starlink,' www.starlink.com
126 UN OCHA Inter-Agency Standing Committee, 'Emergency Telecommunications Cluster,' www.etcluster.org
127 EMEA Satellite Operators Association, 'Satellite Industry and UN to Enter Operational Phase of Crisis Connectivity Charter,' 17 May 2018, https://esoa.net/news/satellite-industry-and-united-nations-to-enter-operational-phase-of-crisis-connectivity-charter-for-support-of-global-disaster-relief/
128 International Telecommunications Union, 'ITU Disaster Response,' www.itu.int/en/ITU-D/Emergency-Telecommunications/Pages/Response.aspx

— *Smart modules and devices (IoT)*

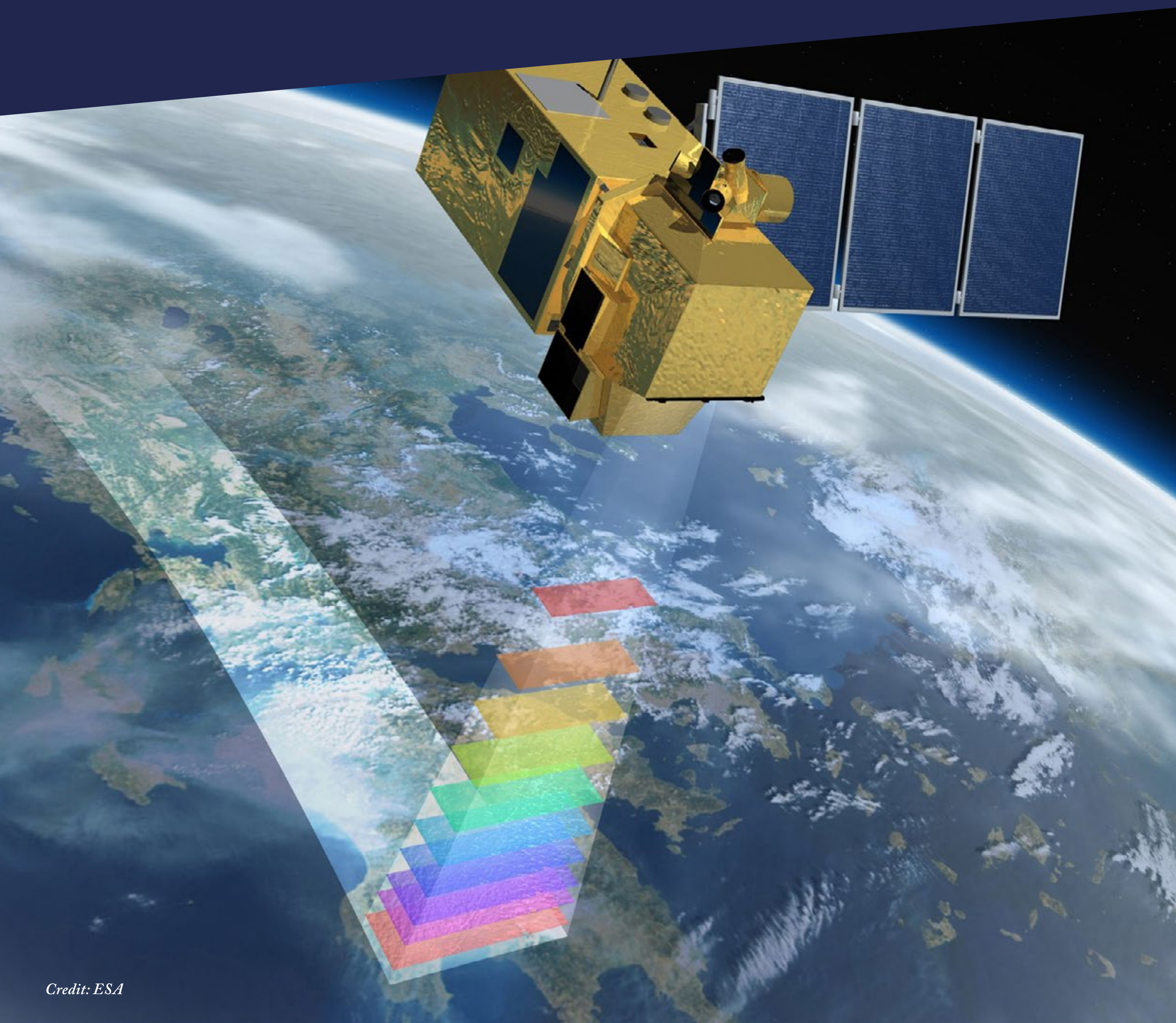
Smart modules are installed in small devices, IT equipment, and machinery to connect to networks of devices in the wider Internet of Things (IoT). Communication satellites can receive transmissions from and connect to these devices; remote IoT devices can connect to the internet directly via satellite. Connected sensors include water-level gauges, air pollution sensors, container-borne GPS trackers, and temperature/humidity sensors in food storage.

— *Custom satellite applications*

A wide variety of commercial, off-the-shelf, SatComms services and tailored humanitarian applications are available for land, maritime, and aviation use. Rural and remote connectivity link local authorities, community leaders, aid workers, and citizens to regional, national, and international contacts. Communications connectivity supports education, social and political engagement, and public service delivery (e.g., remote medical assistance and telehealth.)[129] During emergencies, remote communications are vital for risk and incident reporting and requests for support and assistance. Camp and logistics connectivity for digital services may include staff and asset location tracking for safety and resource optimisation and aid worker welfare, e.g., messaging, social, and recreational applications.

129 World Health Organization, *Telemedicine: Opportunities and Developments in Member States, Report on the Second Global Survey on eHealth*, 2009 (Geneva: WHO, 2010), https://apps.who.int/iris/bitstream/handle/10665/44497/9789241564144_eng.pdf?sequence=1&isAllowed=y

Landscape of humanitarian satellite applications



Credit: ESA

Landscape of humanitarian satellite applications

Key points

- 42% of identified humanitarian satellite applications targeted government users.
- 62% of identified satellite applications are "customised" for a specific user.
- The highest number (92) of identified applications are for "food, security, nutrition and famine" events in Africa.
- Many of the data gaps identified by Humanitarian Data Exchange (HDX) in sectors such as health and education could be addressed by satellite applications.

To gain a quantitative picture of the landscape of satellite applications for humanitarian emergencies, the broadest known dataset to-date has been collected and analysed. Details of these satellite applications were derived from public sources, including reports, web pages, news media, and outreach materials. Over 500 applications with sufficient public information to be categorised were found. The real number of applications is likely much larger, but this research—collecting data, gaining confidence in coding, and analysing—was bound by time and resource constraints.

The criteria for including a satellite application in the analysis are shown in Figure 13. Additional details of the information collected are provided in Annex 3: Methodology and limitations.

FIGURE 13: Satellite Application Inclusion Criteria for Analysis

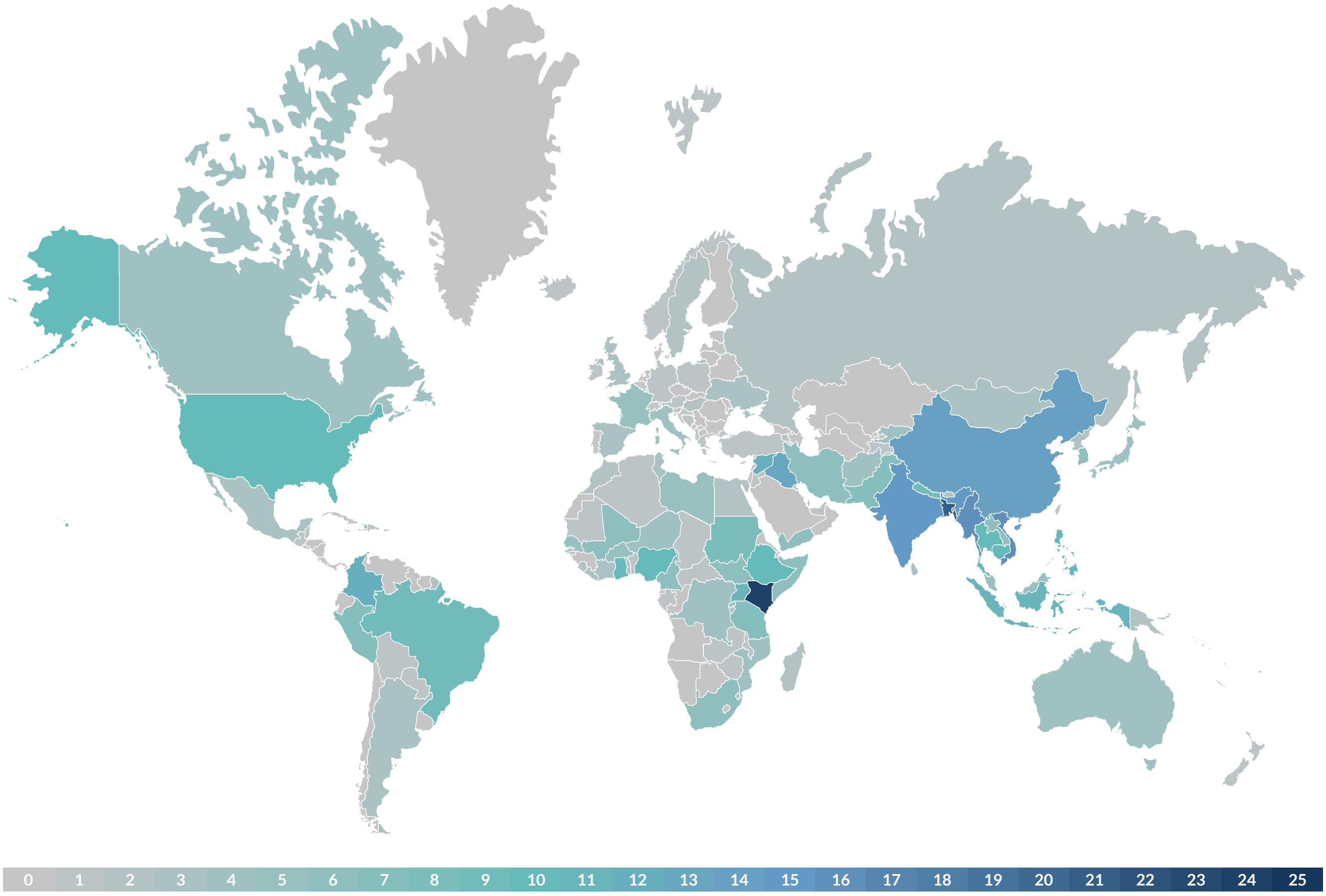


FIGURE 14: Frequency of Satellite Applications by Country (n =>500)

Geography

Satellite applications for humanitarian emergencies are delivered globally. The dataset's geographical concentrations are mapped in Figure 14.

Kenya (24) is the country with the highest number of applications recorded, followed by Bangladesh (21), Myanmar (16), Vietnam (16), India (15), and China (14).[130]

Whilst no countries have been explicitly excluded, the dataset was assembled with a preference for applications in developing regions. It is also recognised that the search was conducted in English, which may omit a significant percentage of non-English-described applications.

Some satellite applications are present in multiple countries and are tagged "multiple," but not included in the map in Figure 14. Of the 127 of 248 countries with no applications recorded, some are known to be addressed by this subset of applications. This subset contains a variety of domains and use cases, but those related to "health emergencies" are more prominent than in the whole dataset.

The spread of applications across regions is shown in Figure 15.

130 Kenya hosts two regional centres (RCMRD and ICPAC) that lead many EO-based regional projects. Kenya also hosts regional offices for the UN.

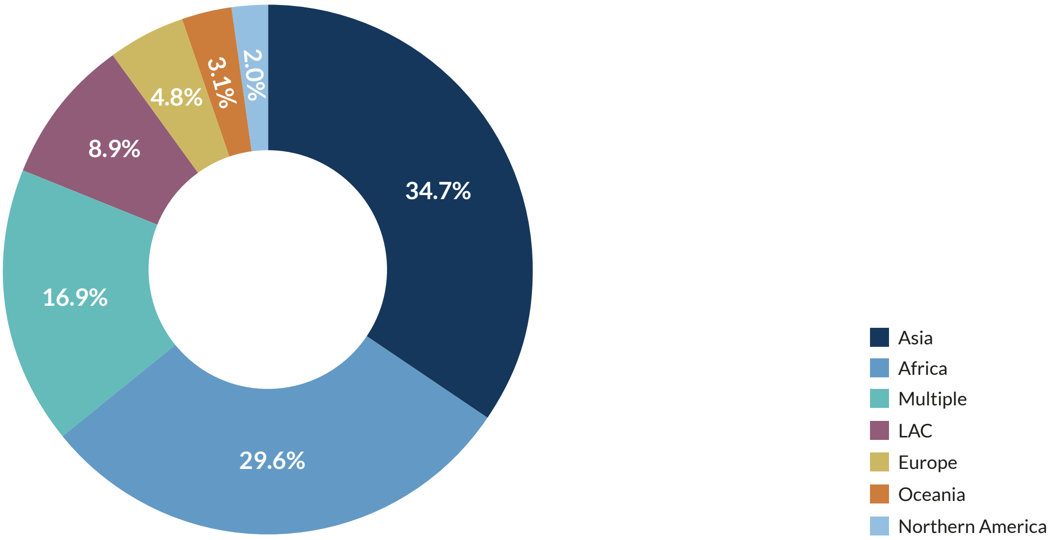


FIGURE 15: Proportion of Satellite Applications by Region (%) (n =>500)

The region with the most occurrences of applications is Asia, followed by Africa and applications that address multiple regions.

The lowest number of applications found was in Northern America. Northern America is understood to have a high use of satellite applications as one of the world's most developed regions; its low percentage in the dataset is considered the result of its economic status and lack of emergency-related applications termed "humanitarian" rather than, for example, public services. This distinction is not applied methodically in all regions.

Event type

Different regions have varying concentrations of satellite applications for event clusters, as shown in Figure 16. Specific events might have a higher or lower frequency than expected, e.g., cyclones, as explained in Annex 3: Methodology and limitations.

Event clusters with the highest number of recorded applications are:

1. **Food, Security, Nutrition, and Famine (92)**, occurring mostly in Africa.
2. **Multiple Event Types (91)**, occurring mostly across multiple regions. These 91 applications are mostly EO (56%), but have a larger percentage of SatComms (27%) compared to the dataset as a whole (6.6%), highlighting the general applicability of SatComms to multiple event clusters and use cases. Within the EO applications, many are used for more strategic/generic purposes, such as stakeholder coordination, damage assessment, or emergency response planning. Applications that cover Multiple Event Types are relevant for use in analysis of compound risks and in complex emergencies (see section Compound risks and complex emergencies).
3. **Flood (83)**, occurring mostly in Asia.

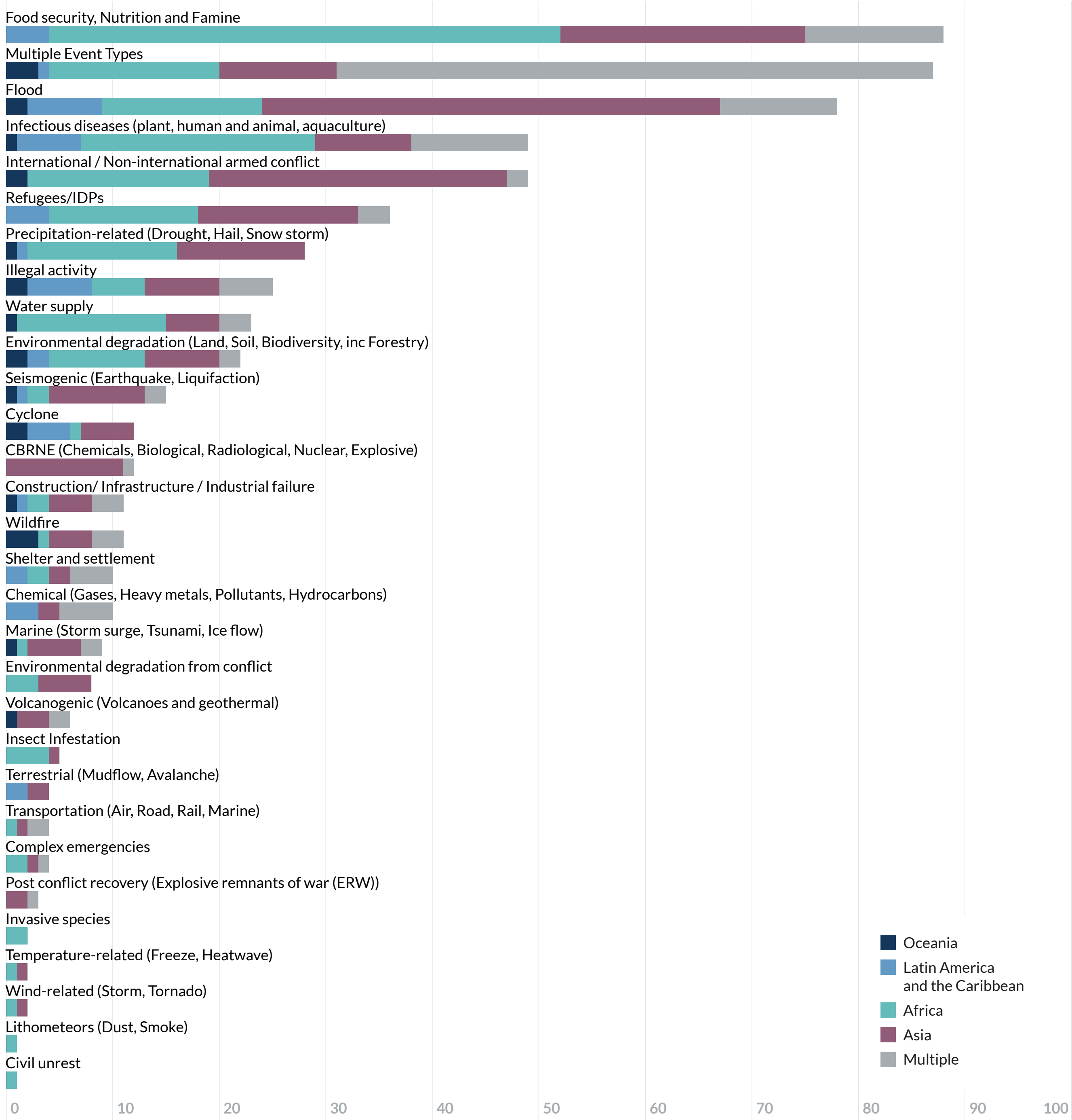


FIGURE 16: Frequency of Satellite Applications by Event Cluster and Region (n =>500)

There are a variety of event clusters less represented in the dataset, which may indicate underserved areas requiring further investigation. However, these are hazard types that are more common with greater sections of the global population and economy affected, e.g., floods.

Separating applications into individual event clusters for event-based analysis is imperfect; for example, it does not account for event chaining, when one event cascades into another. However, coding applications against up to three event clusters and up to five use cases was considered a practical approach that captures the most relevant details for each satellite application. Alternative approaches such as impact-based analysis were not considered practical with the time and information available.

User types

Satellite applications have demand-side users; Figure 17 shows the percentage of satellite applications that have those user types, highlighting the relative concentration of certain types of user.

Users of satellite applications within the dataset are predominantly Government, NGOs, Private Sector, and Development Agencies. Lower usage is seen in First Responders and Affected Public.

Supplier types

Applications come predominantly from Private Suppliers, followed by NGOs, Public Suppliers, and Academia. There is little evidence of direct provision by Media and Development Agencies.

As Private Suppliers is a large and diverse group, this is further subdivided. Supply by Platform/Solution Providers is the most common, followed by Satellite Operator/Resellers, Hardware/Software Suppliers, Cloud Computing Providers, and Other.

FIGURE 17: Proportion of Satellite Application by User Type (%) (n =>500)

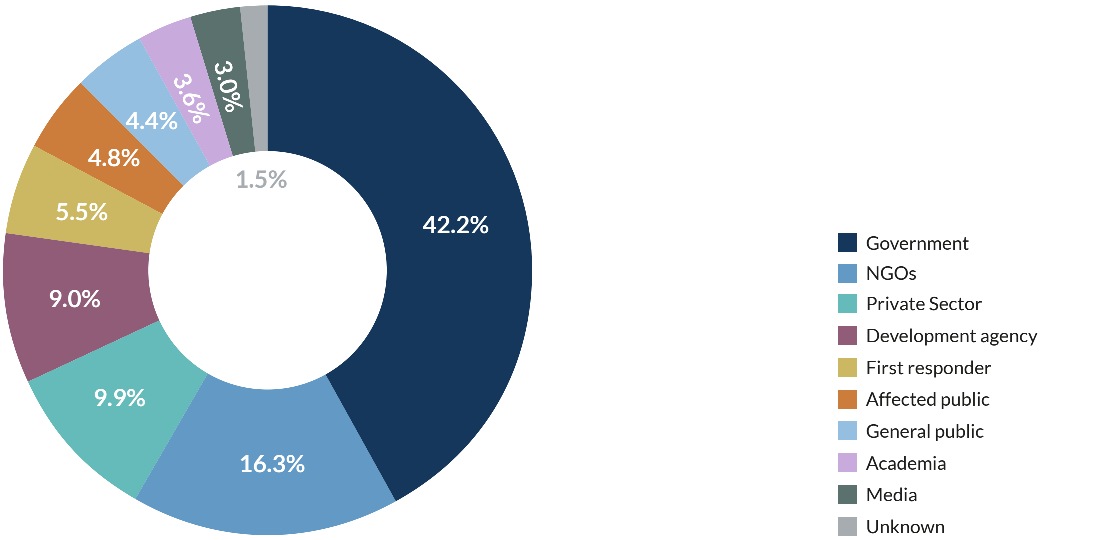
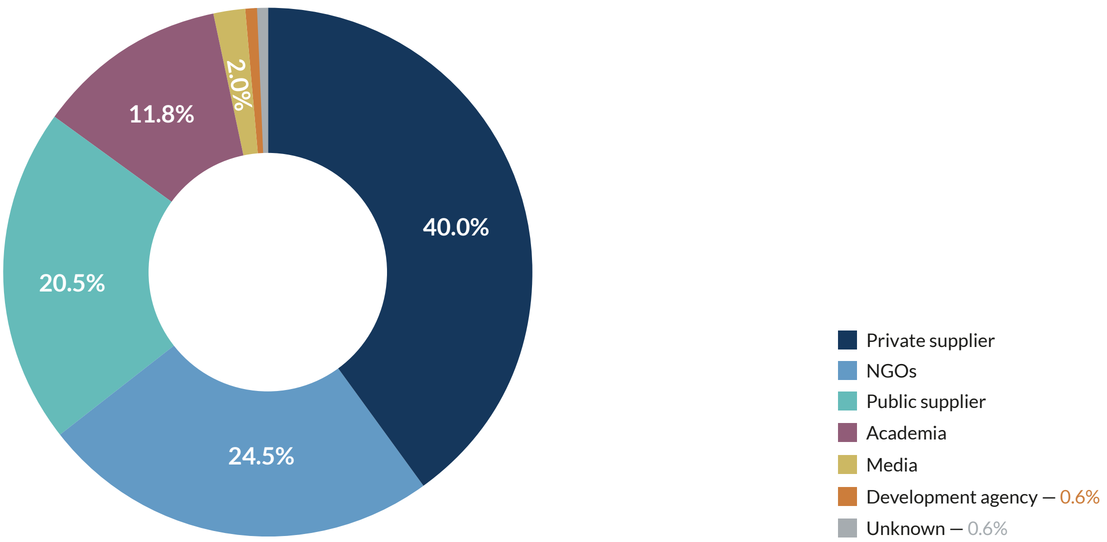


FIGURE 18: Proportion of Satellite Application by Supplier Type (%) (n =>500)



Satellite Operator/Resellers supply 25.9% of applications, highlighting extensive vertical integration as those satellite operators move downstream, not only selling the data streams but also developing specific applications. Conversely, as 51.2% are Platform/Solution Providers, which are downstream-only players, they need to access the data streams from potentially competitive upstream Satellite Operator/Resellers.

Satellite applications may service more than one type of user; Figure 20 highlights the relationships in terms of provision of satellite applications from the supply-side to demand-side—which is different to the count of suppliers shown in Figure 18 and 19.

Figure 20 shows that satellite applications are predominantly provided by Private Suppliers to Government (42%) and NGOs (16%). This structure causes a barrier to adoption in that Private Suppliers have very different missions, cultures, and processes compared to their Government and NGO customers. This barrier is detailed in section Mission alignment. Also, the differences between Private Suppliers and Government and NGOs create procurement challenges; this barrier is detailed in section Procurement challenges.

FIGURE 19: Proportion of Satellite Applications by Private Supplier Subtype (%) (n =>500)

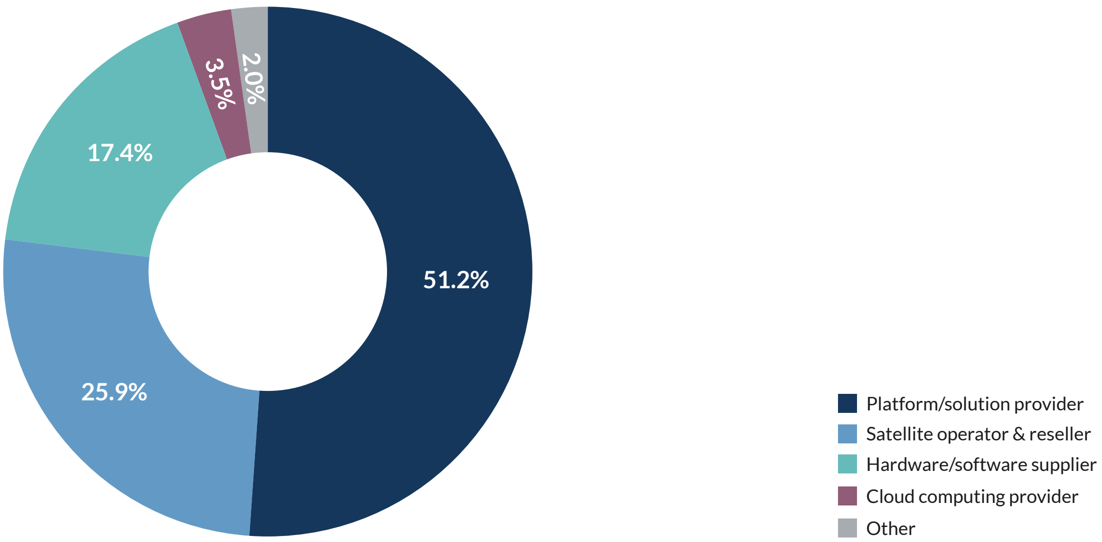
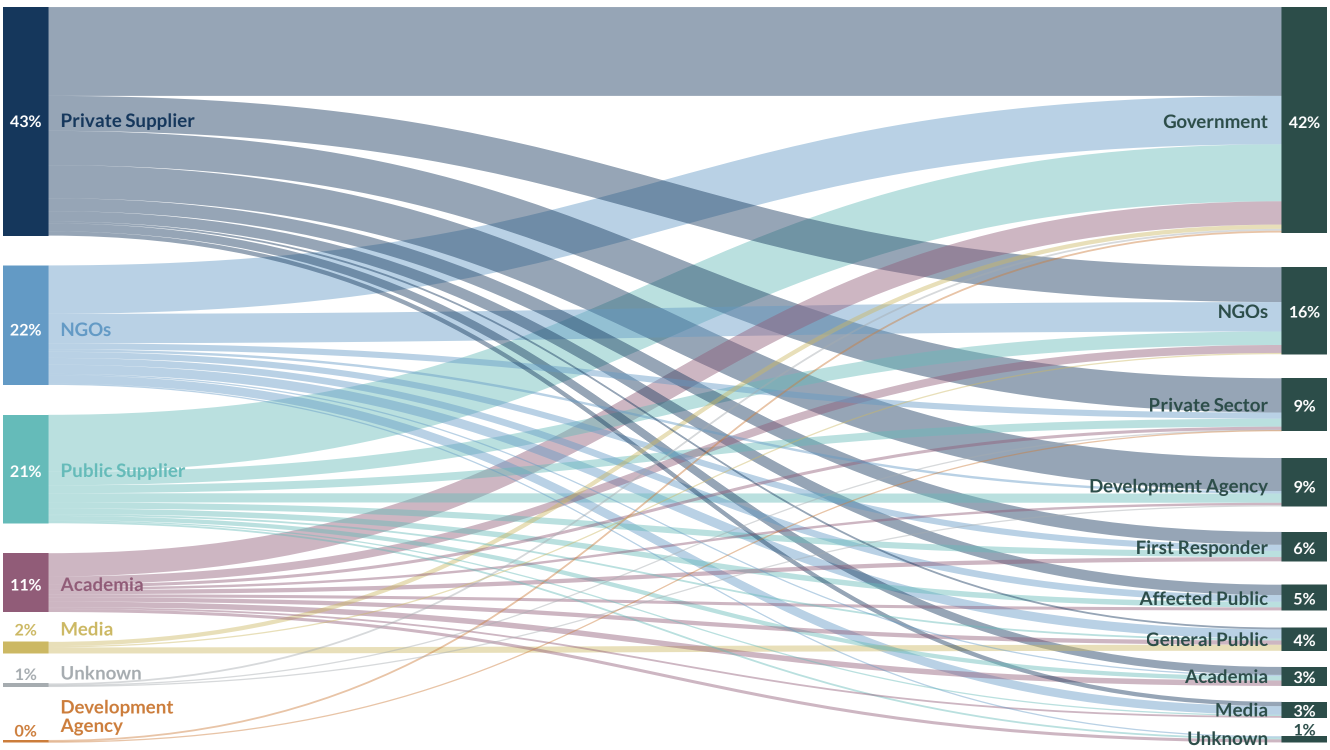


FIGURE 20: Proportion of Satellite Applications in Terms of Relationship between Supplier Type and User Type (Supplier Count ≥500, Relationship Count ≥850)



Domains and events

As detailed previously, for the purposes of this report, humanitarian events are classified according to five domains. Figure 21 shows the percentage of satellite applications per domain.

Satellite applications occur mostly within the disasters (36.3%) domain, followed by food insecurity (18.7%) and security and conflict (18.7%). Population displacement (6.8%) and health emergencies (8.4%) contain the least number of applications.

11.2% of satellite applications address all domains. Of those, the vast majority also address multiple event clusters, indicating a cross-cutting capability across domains, events, and use cases. There are specific use cases that support all domains, for example: infrastructure mapping and exposure, early warning systems, population and poverty mapping, humanitarian stakeholder coordination, and connectivity for public or remote populations. Also, from a technological point of view, SatComms applications commonly cut across all domains and event types.

This highlights the potential of individual satellite applications to address multiple humanitarian contexts.

— *Use cases*

The range of addressable problems for satellite applications is broad and diverse, as shown by the variety of use cases detailed earlier. The use cases with the most applications found are early warning systems (128), emergency response (60), and damage assessment (60).

FIGURE 21: Proportion of Satellite Applications per Domain (n ≥500)

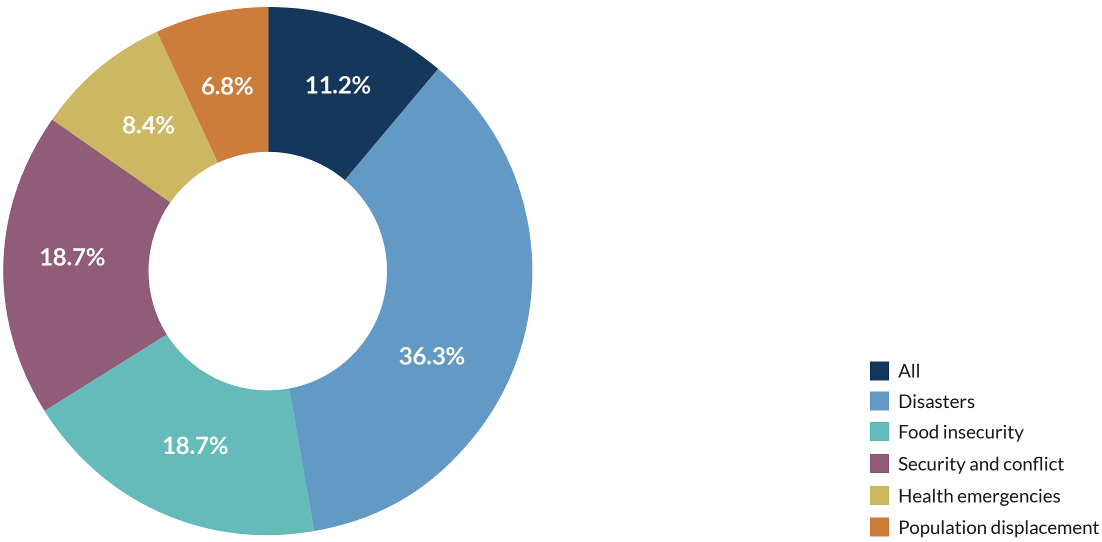
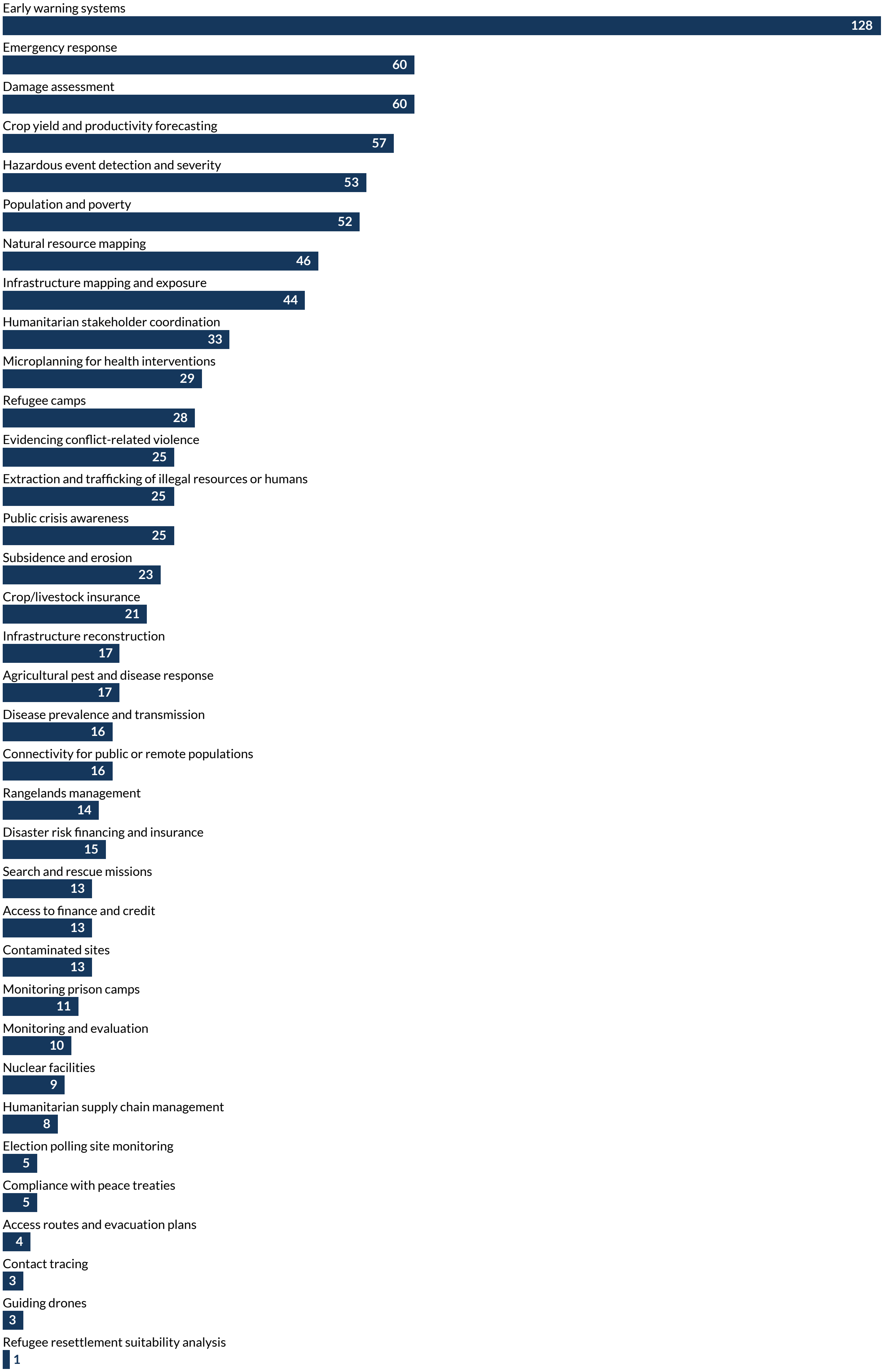


FIGURE 22: Frequency of Satellite Applications by Use Case (n =>500)



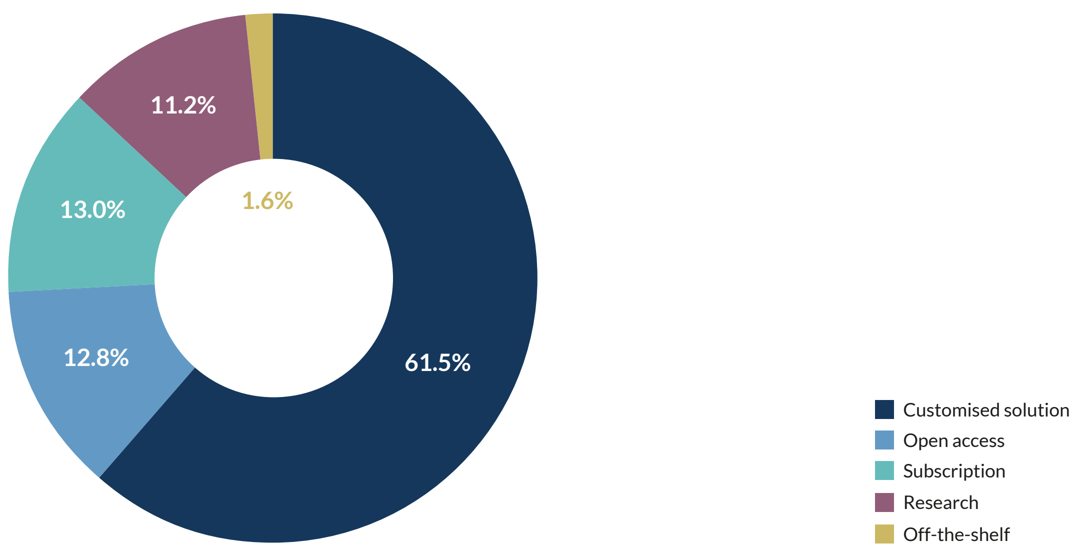
Business model

Supply-side actors use a variety of business models to fund the development and operation of satellite applications, as highlighted in Figure 23.

The most common business model is a customised solution where the user pays for a customised/bespoke application from a supplier. Open access applications are available in the public domain to use free of cost and other access barriers. In the subscription model, a user pays an ongoing fee for access to the service, but doesn't own it. In research, the satellite application has been developed primarily for research or academic purposes. Finally, stakeholders can purchase "off-the-shelf" and own the application from a supplier with minimal customisation required.

There is a dominance of the customised solution business model, whereby members of the supply chain often see the "project" as the final result, without planning or aiming for developing a long-term, sustainable offering. This naturally leads to many one-off implementations or pilots, which can lead to unnecessary piloting and duplication. This barrier is detailed in section Piloting and duplication.

FIGURE 23: Proportion of Satellite Applications by Business Model (%) (n =>500)



Scale

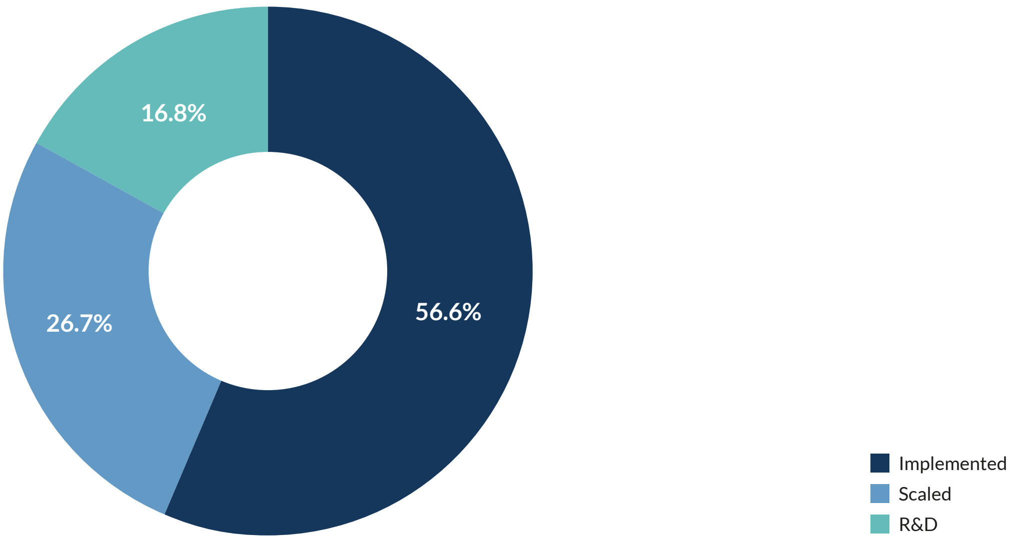
In terms of geographies and numbers of users, satellite applications have scaled on a spectrum, as highlighted in Figure 24. Each scale corresponds to an Application Readiness Level (ARL). The following options are used for 'Scale':

- **R&D** applications have reached a research and development or prototyping stage of application development, but are not yet deployed within a user's operational environment (ARL 1–6).[131]
- **Implemented** applications are operational services with limited geographic reach and users (ARL 7–8).
- **Scaled** applications have sustained, long-term use across wide geographies, multiple countries, and with multiple users (ARL 9). Evidence of repurposing a 'successful' pilot or cross-applicability across multiple domains/events/use cases is also a contributor to selection of this option, but is often not visible in the available literature.

The scale of each satellite application is recorded according to available literature at a specific time and therefore will not accurately account for current situation, continuation, and failure rates. Academia is underrepresented, as no comprehensive review of scientific literature was conducted.

The most common scale for satellite applications is implemented. A factor in the high proportion of Implemented projects is the many programmes that provide funding to supply-side players for projects that are usually designed to deliver to specific users in specific countries. These initiatives focus on supporting 'pilot-scale implementation' but are not intended to offer long-term financing for resulting applications. This topic is explored further in section Financing for application development and scaling.

FIGURE 24: Proportion of Satellite Applications by Scale (%) (n =>500)



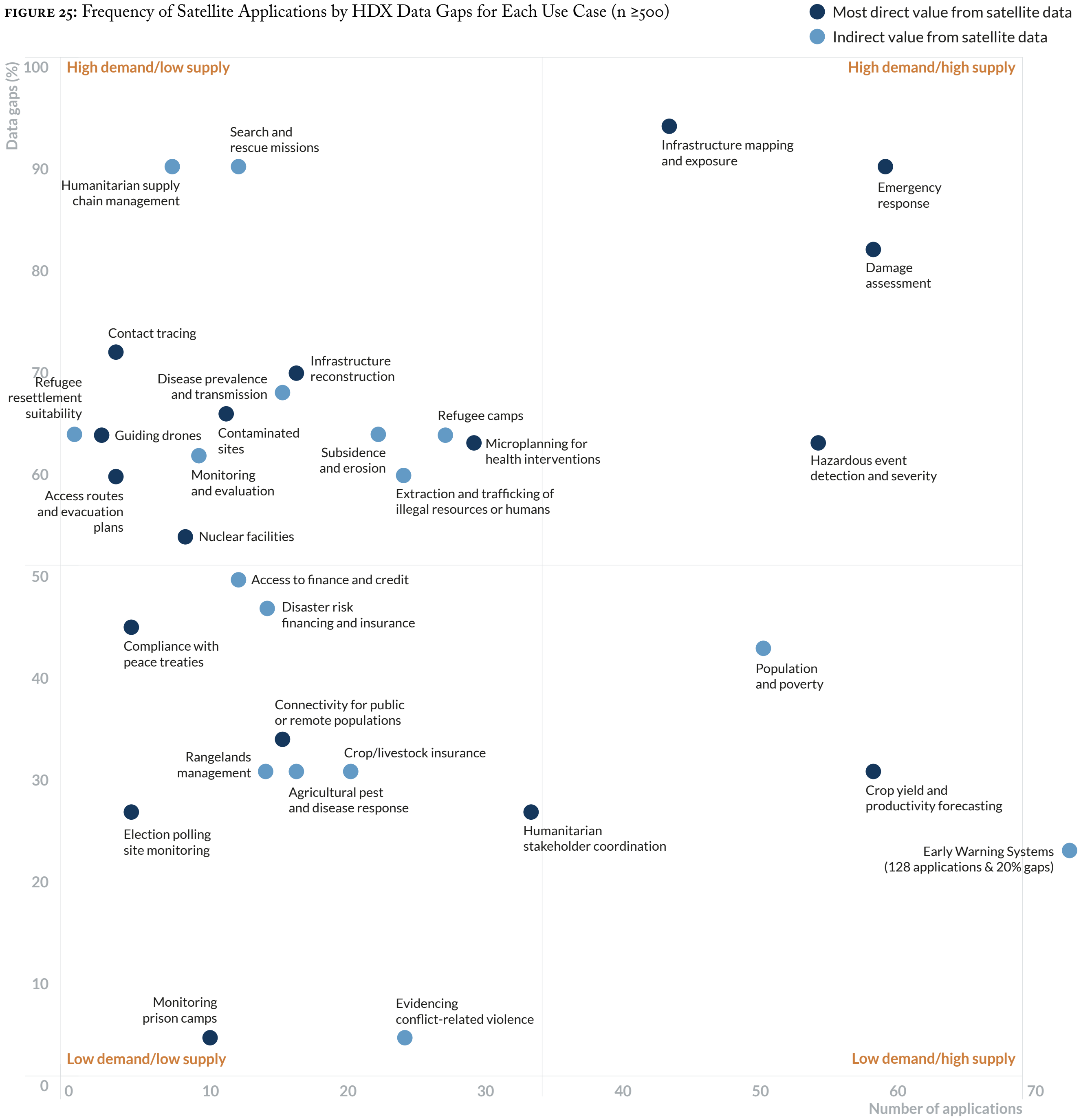
131 NASA, 'The Application Readiness Level Metric,' www.nasa.gov/sites/default/files/files/ExpandedARLDefinitions4813.pdf

Data gaps versus availability

By mapping the HDX data gaps to the satellite-enabled use cases and number of applications identified in this report, Figure 25 illustrates humanitarian data gaps vis-à-vis supply of satellite applications.

In the top-left of Figure 25 are use cases, including humanitarian supply chain management, which have significant data gaps and only eight satellite applications. Supply chain management, like many other use cases, realises indirect value from satellite imagery but necessitates other data sources like supply inventories, warehouse locations, needs inventories, and more. Other use cases directly benefit from satellite data (e.g., classifying damaged buildings from imagery) and do not require additional datasets. The bottom-right shows use cases, like early warning systems or crop yield and productivity forecasting, that have less extensive data gaps and many more applications currently in use.

FIGURE 25: Frequency of Satellite Applications by HDX Data Gaps for Each Use Case (n ≥500)



Overcoming barriers to uptake of satellite applications in humanitarian emergencies

Overcoming barriers to uptake of satellite applications in humanitarian emergencies

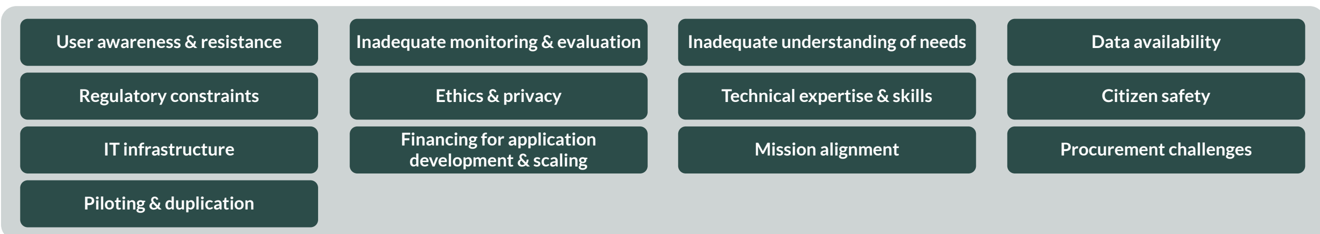
Key points

- Thirteen barriers to the uptake of satellite applications in humanitarian emergencies are identified.
- Industry, governments, and the development community are addressing each barrier to varying degrees.
- Based on the ability of the development community to help address the issue, a subset of eight barriers are prioritised for interventions:
  - User awareness and resistance
  - Inadequate monitoring and evaluation
  - Data availability
  - Ethics and privacy
  - Technical expertise and skills
  - Financing for application development and scaling
  - Procurement challenges
  - Piloting and duplication
- Recommended development community interventions are defined for the eight prioritised barriers.

Barriers to uptake

This section identifies the barriers to uptake of satellite applications for humanitarian emergencies and describes each barrier in detail. It also states whether addressing each barrier is a priority for a development community intervention. Figure 26 identifies the main barriers to increasing the uptake of satellite applications in humanitarian emergencies.

FIGURE 26: Barriers to Uptake



— *User awareness and resistance*

Across the demand-side, within the humanitarian community there are specific organisations that champion the use of satellite applications, for example, UNOSAT within the UN system. Equally, inside organisations, there are often individual advocates who trial and test such innovations. However, there is significant variation across the user community in the level of awareness of satellite applications, their use cases, and their advantages over terrestrial data sources.

Cost structures can be unfamiliar and confusing (see section Procurement challenges). Supply-side players are often unknown to members of the humanitarian community, and it can be difficult to understand the technical capabilities within the supply-side (i.e., the "art of the possible") in order to appropriately articulate the user requirements that need to be met. Thus, satellite applications might never be fully explored as an option for the humanitarian community, or inappropriate or over-specified technical solutions may be developed, which are then not valued by their users (see section Inadequate understanding of needs).

Introduction of new technology, including satellite applications, carries the potential for human and political resistance, as such technologies change—sometimes radically—the methods for achieving a goal. For example, if national crop yield forecasts are produced within the Ministry of Agriculture, the national government controls them. The same forecast produced via a satellite application provided by a national or even international Private or Public Supplier would mean a loss of control over such statistics. Many people still fear job loss due to emerging technologies and new methods replacing them. If they do not have experience with satellite data, these technologies can be intimidating and involve steep learning curves in terms of technical specifications, appropriate use cases, business models, and more.

Trust in traditional methods has developed over many decades or centuries, and a similar trust needs to be built with any replacement satellite-based method. The issue of trust is often compounded by the so-called Black Box Problem with ML-derived applications, whereby "*a black box is a system which can be viewed in terms of its inputs and outputs, without any knowledge of its internal workings.*" [132] There are some efforts tackling these transparency and replicability issues in terms of sharing guidance on metadata standards, advocating for open source licensing, adopting frameworks based on international human rights law and ethics, and more.

There are often numerous satellite applications that serve a similar purpose, for example, global land cover. This makes it difficult for users to filter through the options and know which is most appropriate for their context. Whilst there is strong supply-side and demand-side expertise, what is lacking is 'connector/bridge' organisations and persons that can link the two sides.

132 Wikipedia, 'Black Box,' updated 5 October 2021, https://en.wikipedia.org/wiki/Black_box

Addressing user awareness and resistance is a priority for development community interventions.

Sharing knowledge and raising awareness of the opportunities, use cases, existing examples, and outcomes and impacts of satellite applications is a public good that is appropriate for development community interventions.

Existing initiatives addressing the awareness barrier include UKSA International Partnership Programme,[133] ESA Global Development Assistance (GDA),[134] UNOOSA,[135] GEO,[136] and Anticipation Hub.[137] However, this is a long-term barrier which will require continued, extensive effort from multiple parties to address.

Examples of potential interventions include continuing to document existing examples and case studies, and sharing such information via an online knowledge base and virtual and real-world knowledge events. Future interventions should seek to go beyond individual initiatives in order to compile a more holistic landscape of case studies.

— *Inadequate monitoring and evaluation*

Monitoring and evaluation (M&E) is an objective process of understanding how a project was implemented, what effects it had, for whom, how, and why. Broadly, in the satellite applications sector, there is a lack of quality M&E and a weak evidence base of the development outcomes and impacts of using satellite applications. Traditionally, supply-side organisations have been focused on measuring and communicating the scientific and technical achievements of their products, for example, the accuracy of an EO algorithm, as opposed to quantifying the benefits for the demand-side users, for example, in terms of lives saved in a disaster. Humanitarian organisations also need to understand if and how satellite data can improve or add value to their decision-making, as well as the specific circumstances in which satellite data is particularly cost effective. In many cases, the return-on-investment thesis is not well documented or understood.

As identified in Table 3, with the use case Monitoring and evaluation, satellite applications can directly support the M&E process. This includes "*Geospatial Impact Evaluations (GIEs) that rigorously evaluate the impacts and cost-effectiveness of specific development interventions and large investment portfolios with spatial data. GIEs methods leverage readily available data, like satellite observations or household surveys, to establish a reliable counterfactual for measuring impacts—at a fraction of the time and cost of a 'traditional' randomized controlled trial (RCT).*"[138] However, such techniques and impact evaluations are currently rare.

133 UK Space Agency, 'International Partnership Programme,' www.gov.uk/government/collections/international-partnership-programme

134 Caribou Space, *Adoption and Impact of Earth Observation for the 2030 Agenda for Sustainable Development* (Farnham, Surry, UK: Caribou Space, 2020) https://eo4society.esa.int/wp-content/uploads/2020/07/Caribou-Space_ESA-EO-for-Agenda-2030-v2.pdf

135 UN Institute for Training and Research, 'United Nations Satellite Centre UNOSAT,' www.unitar.org/sustainable-development-goals/united-nations-satellite-centre-UNOSAT

136 Group on Earth Observations, 'Disaster Risk Reduction Working Group,' https://earthobservations.org/drr_wg.php

137 Anticipation Hub, 'Earth Observation for Anticipatory Action (EO4AA),' www.anticipation-hub.org/exchange/working-groups/earth-observation-for-anticipatory-action-eo4aa/

138 AidData, 'Geospatial Impact Evaluations,' www.aiddata.org/gie

Addressing inadequate monitoring and evaluation is a priority for development community interventions.

There are existing initiatives upskilling the satellite applications sector on M&E techniques. For example, UKSA IPP has embedded robust M&E throughout the programme design and has trained, via Caribou Space, ~50 organisations on M&E. However, IPP worked with only a subset of organisations from the global sector. This is a long-term barrier which will require continued, extensive effort from multiple parties to address.

Examples of potential interventions would include publishing impact evaluations and providing access to these via an online knowledge base, and donors ensuring these are core project deliverables. Also providing training and capacity building to supply-side organisations on M&E techniques adapted specifically to satellite applications.

— *Inadequate understanding of needs*

Often, there is a misalignment between the technical solution and the nature of the problem (user requirements). Supply-side organisations often don't fully understand the intricacies of the humanitarian domains, and if demand-side organisations are not available or able to communicate specific user requirements, misalignment occurs. This commonly manifests in over-engineering, over-customisation, and/or over-simplification of the satellite application, leading to lengthy delivery time frames, high costs, and complex operations/maintenance.

A related issue is "over-selling" the capabilities of satellite applications, which can lead to inaccurate and non-validated information. This can then lead to disappointment and mistrust in user communities when results are not achieved or even relevant for a specific stakeholder.

In the humanitarian data ecosystem, there are intermediaries, typically multinational NGOs, between the communities in need of humanitarian assistance and those making decisions about how those needs are met. This produces a gatekeeper effect where the needs and priorities of Affected Communities are not always best represented.[139] However, in some situations, technology has enabled Affected Communities to further engage in more valuable ways, both as data providers and users. Communities are becoming involved in the Preparedness and Response Phases, especially as technology enables improved data provision, including through, for example, crowdsourcing. However, for many who have lived through traumatic events, volunteering time to crowdsource insights from imagery can trigger stressful reactions.[140] Humanitarians need to be more aware of the psychological effects on such communities, especially when members are asked to support response and recovery efforts. David Garcia, a volunteer at Humanitarian OpenStreetMap team, highlights that care should be taken to not separate the social and technical aspects of geospatial analysis, to ensure the trust of communities, their leaders, and local governments, whilst also being technically astute to conduct the technical analysis.

Much more interaction, especially between Affected Communities and data producers, is needed to better determine the appropriate use of data and technology.

139 Jos Berens et al., 'The Humanitarian Data Ecosystem: The Case for Collective Responsibility,' Stanford Center on Philanthropy and Civil Society, 2017, https://pacscenter.stanford.edu/wp-content/uploads/2017/11/humanitarian_data_ecosystem.pdf

140 Caribou Space, 'Beyond Borders. Community Engagement Workshop 3,' 2021

Addressing inadequate understanding of needs is not a priority for development community interventions.

This barrier is common when any form of technology is applied to humanitarian contexts, including, for example, mobile or other ICT-based applications. The importance of understanding user needs is embedded into the Principles for Digital Development.[141] Under these principles, donor organisations are expected to place a high priority on the supply-side organisations to ensure robust understanding of needs via grant-funded deliverables such as Political Economy Analysis, User Requirements Documents, and Long-Term Sustainability Plans. Understanding user needs should continue to be a principle for any donor-funded programme.

Given the ongoing existing initiatives to address this barrier, we do not identify it as a priority barrier for a new development community intervention.

— *Data availability*

Large public sector investments in initiatives such as the European Copernicus programme have made large volumes of data openly available and free to use. However, for some humanitarian use cases, these data sources are of insufficient spatial resolution or may not be readily available for use during a crisis. Furthermore, despite the increasing availability of Earth imagery from private sector actors, such as Planet and Maxar, the cost of licensing this imagery may be prohibitive for some humanitarian organisations; the time-intensive procurement process may also be too lengthy. In addition, accessing data in a timely fashion may be affected by other demands and tasking requests on the available satellites, meaning that humanitarian needs may not be met as rapidly as required.

Within the demand-side, a lack of coordination between user organisations, and even within single organisations, can lead to a lack of awareness of who owns or has procured satellite applications or data. Organisational silos are common for both supply-side and demand-side organisations, equally affecting private and public organisations. These silos are *"business divisions that operate independently and avoid sharing information."*[142] This can lead to duplicative resource-intensive procurements of EO data, inefficient costs, and limited usage. Further, the products are often inaccessible to local communities. This is compounded by data-sharing agreements that often do not allow sharing raw data.

For satellite applications to have value, they need significant data from terrestrial sources to be combined. For example, in assessment of damaged buildings, satellite data will not highlight how many people were inside the building. For flooding applications, population datasets need to be combined to forecast how many people are affected by the flood.

Figure 23 shows that the most common business model is a customised solution where the user pays for a customised/bespoke application from a supplier (61.5%). This highlights that there may be many duplicative satellite applications being developed for separate users but with very similar requirements.

141 Principles for Digital Development, 'Principles,' https://digitalprinciples.org/
142 Will Kenton, 'Silo Mentality,' Investopedia, 24 November 2020, https://www.investopedia.com/terms/s/silo-mentality.asp

Addressing data availability is a priority for development community interventions.

Part of the cause of this barrier is a lack of visibility of who is doing what and where, leading to coordination failures and duplication of effort. This is a classic issue across the development community and equally in satellite applications. Addressing it requires continued, extensive effort from multiple parties.

Examples of potential interventions would include open and free information sources of who is doing what and where on the topic of satellite applications for humanitarian contexts. An example of such an information source is an online open knowledge base, and virtual or real-world knowledge events (same as for User awareness and resistance barrier).

Other potential interventions include donors funding access to high-resolution EO data for usage by humanitarian organisations.

— *Regulatory constraints*

Regulation and legislation can introduce significant operational and legal barriers for the use of satellite applications. Conversely, an absence of regulation or enforcement is potentially undesirable; for example, unregulated spectrum use can lead to radio interference in satellite signals.[143]

There are five UN Committee on the Peaceful Uses of Outer Space (COPUOS) international treaties and five sets of principles generally beneficial to humanitarian solutions that have been ratified by many countries.[144] The UN Office for Outer Space Affairs (UNOOSA) records the existence of 29 national space agencies[145] and a collection of 27 countries' space laws.[146] Many national space laws reference the UN treaties and principles. However, barriers exist in national regulation influenced by multiple policy areas, including defence and security, industrial policy, economic development, ICT and geospatial data, innovation, and international cooperation.

A recent example of national law reducing barriers is India's February 2021 geospatial guidelines, which removed the need for licences and approvals for Indian organisations to create and publish geospatial data (with sensitive exceptions).[147] Indian entities are now allowed to access ground stations and augmentation services for more accurate GNSS real-time positioning and other previously restricted public survey datasets.

The UN International Telecommunication Union (ITU) coordinates radio-frequency spectrum, satellite orbits, and technical standards. By agreement and convention of the 193 member states, all satellites require registration with the ITU by national administrations (e.g., a communications regulator or space agency). To enable deconfliction of radio spectrum usage, the ITU reviews frequency assignment notices submitted by administrations for formal coordination procedures or recorded in the Master International Frequency Register (MIFR).

143 Jonathan Amos, 'Europe's Smos 'Water Mission' Battles Interference,' BBC News, 5 May 2010, http://news.bbc.co.uk/1/hi/sci/tech/8661228.stm

144 UN Committee on the Peaceful Use of Outer Space Legal Subcommittee, 60th Sess., Status and Application of the Five United Nations Treaties on Outer Space, UN Doc A/AC.105/C.2/2021/CRP.10 (31 May 2021), www.unoosa.org/res/oosadoc/data/documents/2021/aac_105c_22021crp/aac_105c_22021crp_10_0_html/AC105_C2_2021_CRP10E.pdf

145 UN Office for Outer Space Affairs, 'World Space Agencies,' www.unoosa.org/oosa/en/ourwork/space-agencies.html

146 UN Office for Outer Space Affairs, 'National Space Law,' www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/index.html

147 Government of India, 'Guidelines for acquiring and producing Geospatial Data and Geospatial Data Services including Maps,' 15 February 2021, https://dst.gov.in/sites/default/files/Final%20Approved%20Guidelines%20on%20Geospatial%20Data.pdf

These processes face considerable evolving challenges, including:

- Increasing impact of radio interference
- Limited availability of "slots" for geostationary satellites
- Inactive, exaggerated, or updated registrations unnecessarily reserving valuable telecoms capacity[148]
- Increasing collision and debris risk from satellites, constellations, and mega-constellations in LEO
- Political challenges[149]

There are many standards relevant to the implementation and delivery of humanitarian solutions (e.g., OGC,[150] EU INSPIRE,[151] UN-GGIM[152]) that address interoperability and common mapping representations, for example. Absence of such standards represents a barrier to uptake, transferability, and integration into wider solutions. However, standards can be complex and difficult to implement, and may also represent a complexity and cost barrier for humanitarian organisations.

Humanitarian organisations must also be aware of export controls, which are used by countries *"to protect national security interests and promote foreign policy objectives."*[153] Governments control the export of sensitive equipment, software, and technology for reasons of national security and foreign policy; these regulations cover SatComms, GNSS, and EO. Suppliers assume responsibility for compliance; for every potential customer, they must know the intended use, end user contact details, and ultimate destination of the data.[154] Supply-side providers cannot distribute export-controlled materials to individuals or companies in "embargoed countries."[155] Commercial and export controls make states having access to *"available analysed information concerning the territory under its jurisdiction"* difficult to implement universally across borders. When humanitarian emergencies occur in "embargoed countries," it is not possible to purchase from supply-side companies based in supplier countries with such export controls. Organisations based in those embargoed countries are also restricted from purchasing data from these supply-side companies due to such government-specific regulations.

Besides specific regulations, many national governments have policies in place to direct spending to domestic businesses; as a result, the countries that spend the most on space programmes are home to the largest suppliers. There is an intentional bias to keeping that spending in-country, and this directly influences countries' technical capacity to use satellite data.

148 Peter B. de Selding, 'Signal Interference Proposal Could Make the ICT a Watchdog with Some Teeth,' SpaceNews, 10 October 2014, https://spacenews.com/42147signal-interference-proposal-could-make-the-itu-a-watchdog-with-some/

149 Elizabeth Hoffman and Kristen Cordell, 'An Obscure UN Agency Guides Digital Communications—Congress Must Endorse US Leadership', The Hill, 23 July 2021, https://thehill.com/opinion/international/564527-an-obscure-un-agency-guides-digital-communications-congress-must

150 Open Geospatial Consortium, 'About OGC,' www.ogc.org/about

151 European Commission, 'INSPIRE Geoportal,' https://inspire-geoportal.ec.europa.eu/theme_selection.html?view=qsTheme

152 UN Statistics Division, 'Committee of Experts on Global Geospatial Information Management,' https://ggim.un.org

153 International Trade Administration, 'US Export Control,' www.trade.gov/us-export-controls

154 Maxar, 'Maxar Trade Compliance Policy,' 2021, https://maxar-marketing.s3.amazonaws.com/files/legal/201112%20Maxar%20Trade%20Compliance%20Policy%20-%20final%20EXTERNAL.pdf

155 United States Treasury, 'Sanctions Programs and Country Information,' https://home.treasury.gov/policy-issues/financial-sanctions/sanctions-programs-and-country-information

Addressing regulatory constraints is not a priority for development community interventions.

Addressing the barrier of regulatory constraints at a national level is the responsibility of national governments. However, the need for international regulation requires intergovernmental organisations such as UNOOSA, COPUOS, and UN ITU.

These UN agencies are part of the development community, and their interventions are required over the long term to address this barrier. However, we do not identify this as a barrier for development community organisations outside of the UN system.

— *Ethics and privacy*

The many advantages of satellite applications, including coverage, repeatability, thematic detail/resolution, and speed, also carry risks in terms of ethics and privacy. All forms of satellite technology, EO, SatComms, and GNSS carry the risk of observing and conveying personal information, and thus carry privacy and ethical implications. This risk is heightened when satellite data is used in combination with other data sources that confer even more detailed information about individuals and/or households. This is increasingly the case with machine-learning based approaches, IoT technology, and other data-intensive methods that leverage satellite data alongside other disparate sources.

For humanitarians, anticipating potential risks in using satellite data can also be difficult, as many of these issues are context-specific. For example, VHR EO can produce detailed geo-referenced datasets over populations, including vulnerable communities, as well as military bases, peacekeeping operations, and critical infrastructure.[156] Having this data is essential for humanitarian missions, but can also be compromising for the communities and households being imaged. SatComms can relay sensitive personal information as well as key information from actors on the ground of a humanitarian event. GNSS provides location data from mobile devices which details an individual's whereabouts. With new cloud-based GNSS, device anonymisation is not always guaranteed.[157]

Informed consent is also impossible when using satellite data sources. The person or groups involved may not be aware of this invasion of privacy or, if they are aware, are unlikely to be able to mitigate it or easily take remedial action, in real time or retrospectively.[158] Rupert Allan, former country manager of HOT in Uganda, recommends that organisations think about who is directing and controlling the collection of data, and to what degree it is actually *"accessible and accountable to and by local communities."*[159]

Machine learning is a part of many EO-based satellite applications used to process the data into information and insight. ML, both inside and outside of satellite applications, has a range of ethical risks, including automated decision-making, inherent bias, and misleading synthetic data.[160] These risks can diminish trust in ML-produced results and, given that much of the world's ML talent resides in wealthier countries, algorithms are biased to reflect those cultures and societal needs.

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156 Matt Swayne, 'Researchers Detail Privacy-Related Legal, Ethical Challenges with Satellite Data,' Phys.Org, 12 July 2019, https://phys.org/news/2019-07-privacy-related-legal-ethical-satellite.html

157 Günter W. Hein, 'Location Privacy Challenges and Solutions, Part 1,' Inside GNSS, 18 September 2017, https://insidegnss.com/location-privacy-challenges-and-solutions/

158 G. Berman, S. de La Rosa, and T. Accone, *Ethical Considerations when Using Geospatial Technologies for Evidence Generation*, Innocenti Discussion Paper 2018-02, (Innocenti, Florence: UNICEF Office of Research, June 2018), www.unicef-irc.org/publications/pdf/DP%202018%2002.pdf

159 Malia Politzer, 'Why We Need to Think about Ethics when Using Satellite Data for Development,' Devex, 25 February 2021, www.devex.com/news/why-we-need-to-think-about-ethics-when-using-satellite-data-for-development-99148

160 Cem Dilmegani, 'AI Ethics: Top 9 Ethical Dilemmas of AI and How to Navigate Them,' AI Multiple, updated 5 October 2021, https://research.aimultiple.com/ai-ethics/

Addressing ethics and privacy is a priority for development community interventions.

Addressing ethics and privacy is not the natural focus of industry actors, and national governments have varying standards and regulations regarding ethics and privacy. The development community, with its focus on improving the lives of the world's citizens, is an appropriate group to address this barrier.

Examples of potential interventions would include documenting and sharing best practices for both supply- and demand-side actors. Harvard Humanitarian Initiative's Signal Code provides a human rights-based approach to information in crises; these are ethical obligations for humanitarian actors and minimum technical standards for the safe, ethical, and responsible conduct of humanitarian information activities before, during, and after a crisis.[161] Locus Charter is a proposed set of common international principles to support ethical and responsible practice when using location data.[162]

Modelling and upscaling community involvement in data generation through community mapping and validation exercises to ensure and make data open-source, available in the public space, accountable to —and also updateable by—local communities. Models like Taqadam, a for-profit company that offers a ML platform to help organisations optimise data training cycles, train refugees to annotate satellite imagery. Their annotators learn basics of data science, principles of ML, and quality control processes. While this approach does not address the open sharing of data with community stakeholders, it does involve them in key aspects of data generation and provides valuable employment opportunities.

— *Technical expertise and skills*

Specific skills are required by people in supply-side organisations (see Supply-side actors), for example a software engineer in a Platform/Solution Provider or a GIS specialist in an NGO, to produce satellite applications. This includes skills in EO, remote sensing, GIS, software engineering, data science, ML, and co-development with domain-specific expertise to ensure relevance and usefulness. All these skills are highly prized, and staff turnover following training programmes is an issue for skills retention.

Skills are also required by the demand-side actors (see Demand-side actors), such as an analyst in Government or a First Responder, to use satellite applications. This includes skills in model development, application operation, data interpretation, combination with other datasets, integration of ML approaches, and linkage of outputs to existing workflows.

However, there is also the need for very basic, simple-to-use tools that support humanitarian emergencies. An example of this is Field Papers, which allows maps to be printed and used rapidly in emergency contexts.[163] Many of these tools are built as open source by the open knowledge community.

There are many online learning resources available that support the development of these skills, including tools, platforms, workshops, and tutorials. For example, Radiant Earth's ML Hub provides such resources specifically for machine learning for EO.[164]

161 Faine Greenwood, Caitlin Howarth, Danielle Escudero Poole, Nathaniel A. Raymond, and Daniel P. Scarnecchia, *The Signal Code: A Human Rights Approach to Information During Crisis*, Harvard Humanitarian Initiative, January 2017, https://hhi.harvard.edu/publications/signal-code-human-rights-approach-information-during-crisis

162 EthicalGEO, 'Locus Charter,' https://ethicalgeo.org/wp-content/uploads/2021/03/Locus_Charter_March21.pdf

163 Field Papers, 'Welcome to Field Papers,' http://fieldpapers.org

164 Radiant Earth Foundation, 'Machine Learning for Earth Observation,' www.radiant.earth/mlhub

Addressing technical expertise and skills is a priority for development community interventions.

There are existing initiatives addressing the technical expertise and skills barrier, including UKSA IPP via training of 7,200 persons and ESA GDA via Activity 3 Skills Transfer.[165] There are extensive online training courses, both paid and free, for developing or using satellite applications,[166] including those provided by UNITAR.[167] However, this is a long-term barrier which will require continued, extensive effort from multiple parties to address it. Development interventions to support technical expertise and skills are a classic public good with both direct benefits to the uptake of satellite applications and spillover benefits to other sectors from general upskilling.

Examples of potential interventions would include developing a playbook of principles and case studies that showcase good practice in using satellite technologies for humanitarian emergencies.

Also, there could be support to regional centres of expertise, such as the Regional Centre For Mapping of Resources for Development (RCMRD)[168] and/or IGAD Climate Prediction and Applications Center (ICPAC)[169] in Eastern Africa, AGRHYMET[170] in west Africa, and Asian Disaster Preparedness Center (ADCP)[171] and/or ICIMOD[172] in Asia.

— *Citizen safety*

Powerful technologies often carry the risk of malevolent use. Satellites transmit sometimes sensitive data to and from Earth, making them a potential target for hackers or malicious actors. Satellite data can be doctored to spread misinformation, for example, with erroneous positioning, deep fake imagery, or falsified communications intercepts. In addition to intentional misinformation, there is also the potential for well-intended analysts to incorrectly interpret an image or release information that undermines the well-being of populations.[173] As technical barriers are lowered, there is increasing risk that SatComms can be hacked and transmitted information can be leveraged by bad actors, affecting military command systems, launch systems, communications, telemetry, and tracking.[174] From a security perspective, the radio frequency interference from electronic devices, radio antennas, or modems is strong enough to drown out the relatively weak signals to GNSS receivers. That vulnerability creates a tempting target for bad actors.[175]

165 Caribou Space, *Adoption and Impact of Earth Observation for the 2030 Agenda for Sustainable Development*, (Farnham, Surrey, United Kingdom. Caribou Space, 2020), https://eo4society.esa.int/wp-content/uploads/2020/07/Caribou-Space_ESA-EO-for-Agenda-2030-v2.pdf

166 UK Space Agency, Space for Smarter Government Programme, 'Training,' https://spaceforsmartergovernment.uk/training

167 UNITAR, 'UN Satellite Centre UNOSAT,' https://unitar.org/event/event-pillars/united-nations-satellite-centre-unosat

168 Regional Centre for Mapping of Resources for Development, 'About RCMRD,' www.rcmrd.org/about-us/about-rcmrd

169 IGAD Climate Prediction and Applications Centre, 'About Us,' www.icpac.net/about-us/

170 UN Office for Outer Space Affairs, UN-SPIDER Knowledge Portal, 'AGRHYMET Regional Centre,' www.un-spider.org/agrhymet-regional-centre

171 Asian Disaster Preparedness Center, 'About Us,' https://www.adpc.net/igo/contents/adpcpage.asp?pid=2

172 International Centre for Integrated Mountain Development, 'Who We Are,' https://www.icimod.org/who-we-are/

173 Steven Livingston, 'Satellite Imagery Augments Power and Responsibility of Human Rights Groups,' Brookings Institution, 23 June 2016, www.brookings.edu/blog/techtank/2016/06/23/satellite-imagery-augments-power-and-responsibility-of-human-rights-groups/; Stefan Voigt et al., 'Towards Semi-Automated Satellite Mapping for Humanitarian Situational Awareness,' IEEE 2014 Global Humanitarian Technology Conference, https://elib.dlr.de/95502/1/VoigtEtAl_IEEE_GHTC_06970315.pdf

174 Airbus, 'Protecting Everyday Life—How Airbus Protects Satellite Systems Against Attacks,' https://airbus-cyber-security.com/news/protecting-everyday-life-how-airbus-protects-satellites-against-attacks/

175 Ingo Baumann, 'GNSS Cybersecurity Threats: An International Law Perspective, Inside GNSS, 3 June 2019, https://insidegnss.com/gnss-cybersecurity-threats-an-international-law-perspective/

Malevolent actors might use satellite applications directly against either other countries or their own citizens, for example, the use of Satellite Sentinel Project's imagery analysis to guide combatants' next attack on civilians.[176] The Project's goal was to acquire and analyse imagery that would deter further aggression prior to the Sudan referendum. By broadcasting perceived indicators of impending aggression, SSP inserted itself directly into events and inadvertently provided valuable intelligence to bad actors, which resulted in the kidnapping and ransoming of Chinese construction workers.[177]

BOX 8: Overcoming Citizen Safety

Addressing citizen safety is not a priority for development community interventions.

Similarly to regulatory constraints, addressing this barrier is the remit of national governments, their militaries, and the UN system. We do not identify this as a barrier for development community organisations outside of the UN system.

— *IT infrastructure*

Infrastructure is required to use and/or produce satellite applications. This includes access to local or cloud-based processing and storage platforms, and internet access to EO data and the outputs of executed algorithms.

Cloud platforms, such as Google Cloud Platform (GCP), Amazon Web Services (AWS), and Microsoft Azure, address these challenges by storing and processing large EO datasets in the cloud rather than on local IT infrastructure. They are significantly more cost effective and have enabled large processing that was previously not possible without sophisticated computing clusters. However, these platforms still require subscriptions and robust internet connections to retrieve results. Google Earth Engine (GEE) is a cloud platform that uses GCP and provides free access for users to conduct analyses that would otherwise require enormous resources to access (download), store, and analyse. This data and GEE's cloud computing capabilities are available to scientists, researchers, and developers, lowering the cost and time of obtaining, pre-processing, and developing products from satellite imagery and building use-case specific applications that ease data analysis and visualisation.

"Vendor lock-in" can be an issue, whereby supply-side organisations build their initial EO applications on a specific cloud platform and then later face issues with switching to other providers; for example, workflows built on AWS might not necessarily run on GCP.

Whilst cloud platforms reduce storage and processing requirements, they still require a robust internet connection to access outputs. Internet access in developing regions is a well-documented issue, so is not a major focus of this report. Barriers to internet access include lack of mobile coverage, poor access to smartphones or desktop computers, government taxes raising prices on bandwidth, and many more.[178]

176 Steven Livingston, 'Satellite Imagery Augments Power and Responsibility of Human Rights Groups,' Brookings Institution, 23 June 2016, www.brookings.edu/blog/techtank/2016/06/23/satellite-imagery-augments-power-and-responsibility-of-human-rights-groups/

177 Michael Blanding, 'Inside Harvard's spy lab: How a team of Harvard geeks is using a satellite—plus a little help from George Clooney—to rewrite the rules of humanitarianism,' *New York Times*, 29 April 2012, www.bostonglobe.com/magazine/2012/04/28/inside-george-clooney-harvard-spy-lab/RB6fK8MUYkBn3RvWFZpPqO/story.html

178 Alliance for Affordable Internet, 'A4AI Policy and Regulatory Good Practices,' https://a4ai.org/good-practices/; GSMA Connected Society, *Accelerating Mobile Internet: Policy Considerations to Bridge the Digital Divide in Low- and Middle-Income Countries*, May 2021, www.gsma.com/mobilefordevelopment/wp-content/uploads/2021/05/Accelerating-Mobile-Internet-Adoption-Policy-Considerations.pdf

Many countries have invested in National Spatial Data Infrastructures to efficiently manage geographic data, metadata, users, and tools that are interactively connected.[179] However, the majority of these are in developed countries or multi-governmental institutions, such as the European INSPIRE Initiative, UN Spatial Data Infrastructure (UNSDI), or World Meteorological Organization (WMO) Regional Climate Centres (RCCs).

However, cloud platforms now significantly reduce the need for these at a national level for each individual country. Cloud platforms provide three basic services: 1) Infrastructure as a Service (IaaS) that provides flexibility for consumer-created software; 2) Platform as a Service (PaaS) that enables the operation of consumer-created software with a convenient operation complexity following resource efficient application architectures; and 3) Software as a Service (SaaS) that hides operation complexity.[180] Key characteristics of these platforms include: broad network access, resource pooling, rapid elasticity, and capability to measure services to control and optimise resources which are critical when processing and making available big datasets such as satellite EO, thereby reducing the cost of physical hardware.[181]

BOX 9: Overcoming IT Infrastructure

Addressing IT infrastructure is not a priority for development community interventions.

As detailed above, the IT infrastructure barrier is being addressed by multiple industry efforts, for example, cloud platforms. Also, the sub-barrier of internet bandwidth, whilst a major issue, is being addressed by industry, governments, and the broader digital development community.

— *Financing for applications development and scaling*

Individual satellite applications, and the supply-side organisations that produce them, require financing. When these applications—or the core purpose of an organisation—are considered to be of value to society (i.e., a public good), there may be a solid rationale to support the provision of public, taxpayer-generated funding via grants. Grants tend to be provided by governments and development agencies for a very specific "public good" purpose. This purpose might include academic research, or work to support sustainable development or humanitarian efforts. Typically, funding will be required for short-term projects lasting one to three years, with reporting obligations and M&E activities attached to encourage full accountability of the grant recipients. For many NGOs, this project-based funding is an important contribution towards their operating costs, with core "unallocated" funding much harder to attract.

Private companies seeking these grants may go from grant to grant, seeking funds for specific projects, thus neglecting longer-term commercialisation prospects or scalability. As a result, organisations reliant on publicly funded grants may have less scope to innovate and to adopt a longer-term perspective, to the detriment of building organisational capacity and expertise. Project funding may also be limited in scope, with insufficient funds for needs assessments of on-the-ground organisations or to cover salaries of highly technical staff with in-demand skills.

179 Wikipedia, 'Spatial data infrastructure,' updated 4 March 2022, https://en.wikipedia.org/wiki/Spatial_data_infrastructure

180 Nina Kratzke, 'A Brief History of Cloud Application Architectures,' Applied Sciences 8, no. 8 (2018): article 1368, http://dx.doi.org/10.3390/app8081368

181 Catherine Nakalembe et al., 'A review of satellite-based global agricultural monitoring systems available for Africa,' *Global Food Security* 29 (June 2021): article 100543, https://doi.org/10.1016/j.gfs.2021.100543

Addressing financing for applications development and scaling is a priority for development community interventions.

The landscaping work in this report has highlighted that there are a number of initiatives that have provided financing to support industry to develop and pilot applications in humanitarian settings, resulting in a high number of applications at the "implemented" phase. However, a challenge with this "project-based" funding is that industry players may struggle to continue to operate a solution or take it into a new context. This growth or scaling capital is currently limited; as a result, only those applications for which organisations can present a clear and compelling business case are likely to find direct financing to be adopted by a paying customer or attract venture capital investment. In the humanitarian sector, such commercially viable applications may be limited to those targeting private sector players, such as insurance companies, for whom there is an obvious financial benefit. Such customers and "investment cases" are still relatively few and far between in the humanitarian sector.

Addressing this "valley of death" with appropriate patient capital could be accomplished by development agencies or other philanthropic organisations, through the creation of new financing mechanisms, for example.

When satellite applications or supplier organisations are unable to attract (sufficient) public funding, they might look to other forms of capital, including debt and equity investment. Unlike grants, this capital will require repayment or an exchange of equity and can be particularly difficult and/or expensive to attract. This type of financing is typically even more difficult to find in developing regions where the existence of "venture" and early-stage capital is limited. Here, the nascent satellite application sector may find it difficult to access the capital they need to develop and then market their products.

— *Mission misalignment*

As highlighted in Figure 20: Proportion of Satellite Applications in Terms of Relationship between Supplier Type and User Type, Private Suppliers are the most dominant supplier (43%) and Government the dominant user (42%).

The business model of Private Suppliers is focused on extracting the maximum value from a product, so reselling an EO dataset multiple times is sensible. However, if the user is a Government or NGO with multiple agencies, like the UN, they might be able to reuse that dataset across many agencies. The private sector's focus on profit also leads to proprietary ownership in data processing algorithms, which again makes good business sense, but potentially leads to concentrations of power within a few suppliers.

Satellite Operators have data licensing and ownership agreements with private and national ground-receiving stations. There have been cases where receiving stations with data rights have been slow to release imagery during humanitarian emergencies outside the control of the satellite operator.[182]

Demand-side organisations, e.g., Government, Development Agency, and NGOs, are united in advancing social benefits, albeit with different specific missions. These differences in mission translate to wide gaps in the organisational behaviours and processes of the suppliers and users. However, whilst these differences exist, Private Suppliers are valuable members of the supply-side, and efforts should therefore be placed on bridging the differences.

Even if supply-side and demand-side organisations use the same formal language, huge differences in vocabulary, from scientific/technical (suppliers) to domain-specific language (users), often lead to confusion. For example, complex disaster resilience terminology may not be shared across organisations.

A similar set of differences have prevented traditional humanitarian stakeholders from further engaging with defence and intelligence agencies.[183] For many civil society and non-governmental organisations, the need and desire for political impartiality contradicts the inherently political nature of military operations. Beyond the political, differing perceptions of security requirements and distinct modes of operating in-country have been other issues affecting collaboration. Despite these challenges, defence and intelligence agencies have sophisticated data capacity and have long applied cutting-edge technologies that have relevant humanitarian applications.[184]

BOX 11: Overcoming Mission Misalignment

Addressing mission misalignment is not a priority for development community interventions.

Organisations naturally and healthily have different missions and processes, so that issue in itself is not directly addressable. However, it is possible for organisations with differences in mission and processes to gain a better understanding of those differences through ongoing engagement and collaboration.

Therefore, no specific development community interventions for this barrier are identified.

— *Procurement challenges*

Procurement processes are ultimately the connecting and contractual link between the supply-side and demand-side, and there are many challenges within them.

Being an intelligent customer is *"the capability of the organisation to have a clear understanding and knowledge of the product or service being supplied."*[185] It requires the user to be able to discern between the array of satellite applications that the supply-side offers, along with what meets their requirements and budget. This includes understanding cost

182 Personal communication to Caribou Space, 2021.

183 Nicolas De Torrenté, 'Humanitarian NGOs Must Not Ally with the Military,' Doctors Without Borders, 1 May 2006, www.doctorswithoutborders.org/what-we-do/news-stories/research/humanitarian-ngos-must-not-ally-military

184 Tyler J. Knox, 'US Military Innovation In The 21st Century: The Era Of The "Spin-On,"' (undergraduate thesis, Wharton School, University of Pennsylvania, 2020), https://repository.upenn.edu/wharton_research_scholars/194

185 UK Health and Safety Executive, 'Human Factors: Intelligent Customer Capability,' www.hse.gov.uk/humanfactors/topics/customers.htm

ranges and variables, such as geographic coverage, data formatting, spatial resolution, IT infrastructure costs like cloud computing, intended use, duration of access, ability to commit to multi-year agreements, and licensing terms like derivative rights (the ability to create data or analytics from satellite imagery or ability to publish).

While many across the supply-side freely share technical specifications and demonstrations, they rarely publish pricing. To understand which applications are fit-for-purpose but also affordable, demand-side actors must engage with each provider and/or manage a time- and resource-intensive Request for Proposals (RFP) process. Also, understanding the supply-side's licensing terms requires procurement and legal teams who are knowledgeable on these topics that might not be available in house.[186]

Companies often cannot offer lower prices to the public than those offered to government customers. Thus pricing is driven by their primary customer base: defence and intelligence agencies. This outside purchasing power leads to unaffordable satellite data and pricing for the nonprofits and startups in the demand-side, as well as licensing terms tailored to those defence and intelligence customers.[187]

However, most Private Suppliers have discounts for humanitarian organisations and host open data repositories where humanitarians can leverage released datasets for disaster response or other noncommercial purposes. Companies like Planet[188] and Maxar offer free satellite imagery to universities for research purposes, as well as support disaster response with public releases of before and after imagery over affected communities.[189]

As highlighted above (see section Data availability), aggregation of demand would lead to greater data sharing and cost efficiency. However, there are challenges when customised legal agreements and licences are needed to provide access across multiple organisations. Some operators are recognising the need for data sharing across partners in humanitarian response and offering more flexible data licensing terms for those users.[190] Along these lines, PLACE is a non-profit data trust that creates and manages hyperlocal mapping data for a membership community that is open to all and serves the public interest.[191] In the forestry sector, the Norwegian Government's International Climate and Forests Initiative (NICFI) is sponsoring universal access to high-resolution satellite monitoring of the tropical forests.[192] The NICFI has awarded a US$44M (£33M) contract to EO specialists Airbus, Planet, and Kongsberg Satellite Services (KSAT). Andreas Dahl-Jørgensen, managing director of NICFI, said, *"the offered licensing terms are particularly good in this bid. It allows everyone to access high-resolution satellite data, without restrictions on use and distribution."*[193]

186 Caribou Space, 'Beyond Borders. Community Engagement Workshop 2,' 2021

187 Joe Morrison, 'The Commercial Satellite Imagery Business Model is Broken,' Medium, 7 August 2020, https://joemorrison.medium.com/the-commercial-satellite-imagery-business-model-is-broken-6f0e437ec29d

188 Planet, 'Disaster Data,' www.planet.com/disasterdata/

189 Maxar, 'Open Data Program,' www.maxar.com/open-data

190 Amazon Web Services, 'Solving Problems with Open Data Imagery: Q&A with DigitalGlobe and HOT,' AWS Public Sector Blog, 1 February 2017, https://aws.amazon.com/blogs/publicsector/solving-problems-with-open-data-imagery-qa-with-digitalglobe-and-hot/

191 Stefaan Verhulst et al., 'Establishing a Data Trust: From Concept to Reality,' PLACE, www.thisisplace.org/blog-1/introducingplace/establishing-a-data-trust

192 Tara O'Shea, 'Universal Access to Satellite Monitoring Paves The Way To Protect The World's Tropical Forests,' Planet, 2 March 2021, www.planet.com/pulse/universal-access-to-satellite-monitoring-paves-the-way-to-protect-the-worlds-tropical-forests/

193 Norway's International Climate and Forest Initiative, 'New Satellite Images to Allow Anyone, Anywhere, to Monitor Tropical Deforestation,' 23 September 2020, www.nicfi.no/current/new-satellite-images-to-allow-anyone-anywhere-to-monitor-tropical-deforestation/

Addressing procurement challenges is a priority for development community interventions.

Ensuring that procurement processes are simple and effective is the remit of supply-side organisations. However, supporting demand-side organisations, e.g., Development Agencies and NGOs, to be more intelligent customers isn't always in the best interest of supply-side organisations. Also, as detailed above for the forestry sector, bulk procurement is a mechanism that could address this barrier.

Examples of potential interventions would include training for demand-side organisations on satellite application procurement processes and pricing and mechanisms to aggregate demand into a bulk procurement agreement across multiple demand-side organisations.

— *Piloting and duplication*

Figure 23: Proportion of Satellite Applications by Business Model shows that the most common business model is a customised solution where the user pays for a customised/bespoke application from a supplier (61.5%). Also, Figure 24: Proportion of Satellite Applications by Scale shows that most satellite applications are categorised as implemented (56.6%), with only 26.7% categorised as scaled.

These statistics reflect a well-known barrier in the use of satellite applications for humanitarian and broader development purposes: piloting and duplication. That is where projects or products are implemented with a single user or a small group, often in a single country, but do not scale beyond that initial implementation to become a more broadly adopted application, often termed pilots. One-off, customised solutions or pilots will struggle to satisfy global market demand.

Piloting and duplication is driven by multiple factors. First, members of the supply-side often see the "project" as the final result, without planning or aiming for development of a long-term sustainable offering.

Second, multiple funders, be they Government or Development Agency, often provide project-based funding, leading to multiple projects that provide similar solutions, (see section Financing for applications development and scaling) and their recipients therefore move from one grant-based project to the next. This is often due to a lack of transparency and visibility as to who is doing what and where, which leads to duplication. This is also an issue in the research/academic arena, where there is a drive to new/innovative research, with less funding available for scaling proven concepts.

Finally, the greater the need for local customisation of a solution, e.g., the need to combine large volumes of local ancillary data, or for local languages, the more likely this barrier will be an issue.

BOX 13: Overcoming Piloting and Duplication

Addressing piloting and duplication is a priority for development community interventions.

Whilst piloting and duplication is natural, effort should be made where possible to avoid unnecessary duplication. Multiple applications developed for the same and/or different stakeholders can cause confusion for end users (e.g., deciding what application to use). It is also important for donors to consider the long-term sustainability and scalability of their investments and for financing to align well to operational needs beyond the shorter-term testing of new ideas and innovations.

Examples of potential interventions to reduce duplication of applications would include improved information sources of who is doing what and where on the topic of satellite applications for humanitarian contexts. An example of such an information source is an online open knowledge base, and virtual or real-world knowledge events (same as for User awareness and resistance barrier). Establishing more openness among the humanitarian community and potentially encouraging shared access to data could also address the duplication issues (see Data availability).

Priority barriers for development community interventions

As detailed above, Figure 27 identifies those barriers which are defined as priorities for development community interventions.

FIGURE 27: Priority Barriers to be Addressed by Development Community Interventions

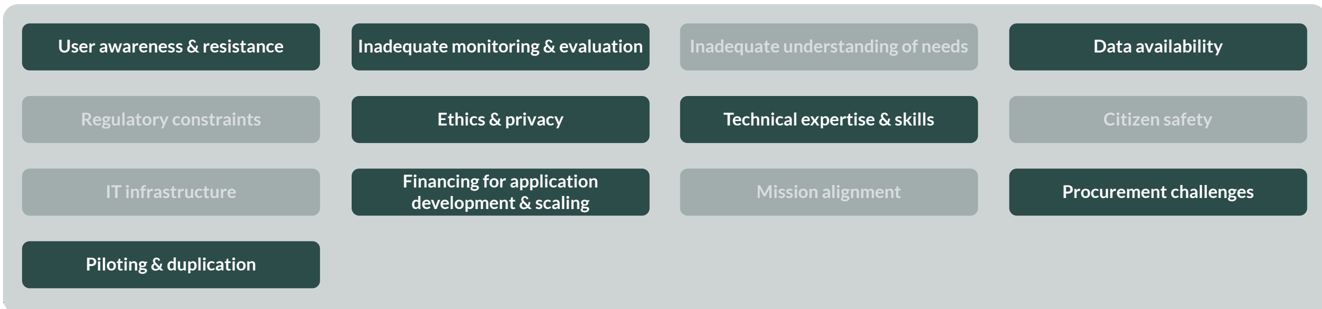

TABLE 4: Summary of Priority Barriers and Recommended Development Community Interventions

Use Case	Recommended Development Community Interventions
User awareness & resistance	• Document existing examples and case studies • Share information via an open, online knowledge base • Virtual and real-world knowledge events
Inadequate monitoring & evaluation	• Publishing impact evaluations via an online knowledge base • Donors ensure impact evaluations are project deliverables • Training to supply-side organisations on M&E techniques
Data availability	• Online open knowledge base of who is doing what and where • Virtual and real-world knowledge events • Donors to fund high-resolution EO data for use by humanitarian organisations
Ethics & privacy	• Documenting and sharing ethics and privacy best practices • Upscaling community involvement in data generation through community mapping and validation exercises
Technical expertise & skills	• A playbook of principles and case studies that showcase good practice • Support to regional centres of expertise
Financing for application development & scaling	• Appropriate patient capital from development agencies and philanthropic organisations through the creation of new financing mechanisms
Procurement challenges	• Training for demand-side organisations on satellite application procurement processes and pricing • Mechanisms to aggregate demand into a bulk procurement agreements across multiple demand-side organisations
Piloting & duplication	• Information of who is doing what and where via an online knowledge base • Virtual and real-world knowledge events • Encouraging shared access to data

Conclusions

Conclusions

This report describes the current landscape of satellite applications being used in humanitarian emergencies and provides a 'state of play' snapshot of a rapidly evolving sector. Satellite applications developed by an increasingly complex web of supply-side stakeholders can be used across a wide range of use cases throughout the life cycle of an emergency to improve our understanding of hazards, assessment of vulnerabilities, and deployment of capabilities.

However, despite a large number of applications that have been piloted in the humanitarian sector, there is a limited body of evidence to offer humanitarians guidance on where satellite technology can be used most cost-effectively and with the best outcomes for affected populations. Furthermore, rapid innovation and increasing piloting has led to some duplication of effort on the supply-side, and the user community has not yet fully acquired an understanding of the potential relevance for their work and the capabilities of the technology. Regulatory and legal frameworks have also struggled to keep pace with new developments.

There is now an opportunity for public and private sector stakeholders to reflect on what more could be done to increase the use of, and impact derived from, satellite applications in humanitarian assistance. Over the coming months, the Beyond Borders project will be developing recommendations on what actions could be taken and the potential outcomes for such interventions.

Annexes

Annex 1
Philippines Typhoon Haiyan case study

David Garcia, a team member, has documented a specific case study regarding Philippines Typhoon Haiyan – a summary of which is below.

Satellite applications and other geospatial technologies continue to be used in preparing for, dealing with, and recovering from crises. A major turning point in the use of such social and technical practices was around Super Typhoon Haiyan (Philippine name: Yolanda) in 2013. The cyclone cut through the central part of the archipelago. The disaster caused thousands of deaths and tremendous damage and loss to ecosystems, livelihood, and property.

Before, during, and after the disaster, hundreds of mapping projects, exercises, and research studies were undertaken to assist in the planning, response, and reconstruction. Many of these projects were done in coordination with Filipino mapmakers, emergency professionals, and internet users who dealt with both the social and technical aspects of making humanitarian geospatial work useful for, and relevant to, affected populations.

The case study provides an overview of how geospatial technologies, including those related to satellites, EO, and remote sensing, can be useful in a major disaster like Super Typhoon Haiyan. This includes the use of geohazard mapping and satellite systems, crisis dashboards and government geoportals, and community, non-profit, and private sector mapping. The case study also highlights three key issues in the production of geographic information. These are detailed in the full case study to be published in 2022 and summarised here:

- **Accuracy –** The accuracy of the spatial data is important in terms of coverage, error, damage, and other aspects of how features like buildings and roads were traced. In this challenge, higher-resolution imagery is demanded to increase the quality of spatial data.
- **Accessibility –** Lack of access, complex software systems, and poor internet connections impede the usability of the maps for the communities who directly respond to crises.
- **Accountability –** Continuous support must be given to open knowledge communities who create, maintain, curate, care for, and disseminate geospatial data. The open knowledge communities fulfil an important role of accountability to affected populations.

Annex 2
East Africa case study

Stella Chelangat Mutai, a team member, has documented a specific case study regarding East Africa – a summary of which is below.

Geospatial and satellite-based technologies have increasingly become popular in the humanitarian community within Eastern Africa (EA). In recent decades, the increase in humanitarian crises caused by natural disasters such as drought and famine in EA has led to high demand for the use of satellite image mapping and for rapid situational awareness.[194] However, turning this data into relevant geospatial information products for humanitarian actors remains a major challenge within the region, as reports are often inaccurate, in conflict with other reports, or incomplete in terms of geographical and temporal details.[195]

This case study analyses the use of satellite applications in the humanitarian context in EA. It also seeks to understand stakeholder engagement and contributions by highlighting gaps and determining possible entry points in the use of satellites in humanitarian decision-making and policy-driven assessments within the identified countries. This research focused on the following EA countries: Ethiopia, Democratic Republic of Congo, Kenya, South Sudan, Tanzania, and Uganda. An online survey was used to understand current activity and capacity to use satellite applications from humanitarian organisations within the EA region. The outcome of our online survey focused on:

- Potential use cases in which satellite data uptake can be harnessed
- The level of awareness of technical specifications of data required by humanitarian organisations
- The level of capacity and knowledge within EA to identify modalities of training that are needed

Climate Change, Land Cover, Natural Hazards, and Food Insecurity, respectively, were voted as the potential use case domains in which increasing satellite technology capacity would have great impact. This was influenced by the fact that most domains affect day-to-day livelihoods of people within the case study region, and there is a dire need for efficient early warning systems and actionable information for decision-making.

The research also sought to understand the level of awareness of existing satellite applications and the technical specifications of satellite data within existing humanitarian organisations. The survey found:

- 73% of humanitarian organisations within the scope of study have a broad knowledge of existing data and use cases; however, 27% have limited to no information.

194 Rhoda Margesson et al., *Horn of Africa Region: The Humanitarian Crisis and International Response 2012*, US Congressional Research Service, 12 January 2012, https://sgp.fas.org/crs/row/R42046.pdf; UN OCHA, *Global Humanitarian Overview 2022*, https://gho.unocha.org/

195 John Bryant, *Digital mapping and inclusion in humanitarian response*, Humanitarian Policy Group Working Paper, October 2021, https://cdn.odi.org/media/documents/Digital_IP_Mapping_case_study_web_EDSoP6n.pdf

- 68% of the humanitarian organisations surveyed understand the technical specifications of satellite applications required for different use cases; however, 32% have little to zero capacity and awareness.

  The respondents to the survey identified a number of thematic domains in which they considered the use of satellite applications to be paramount. However, there is a gap in the level of awareness of the technical specifications which relies on professionals having the technical expertise, knowledge/awareness of satellite data, and frequent use of satellite information during relief efforts.

  To understand how to bridge this capability gap, the survey asked respondents to assess their perceived requirements for training on satellite data knowledge within their organisation. The survey found:

- 40% preferred to receive advanced level training
- 44% requested intermediate level training
- 16% requested introductory level training

  This study recommends the institutionalisation of capacity building to support proficiency in the development of satellite applications and awareness of new applications within humanitarian organisations. Additionally, extending the availability, access, and distribution of data and information portals would reduce data redundancy and might enhance collaboration during humanitarian aid response. The survey suggested that there is a need for partnerships that bring technical professionals together with domain experts who can champion, and demonstrate the use of EO in relevant thematic areas across the humanitarian sector.

Annex 3
Methodology and limitations

— *General methodology*

For this report, the team used desk-research to conduct the landscape of satellite applications for humanitarian emergencies. Information has been gathered from sources including academic papers, grey literature, organisation's websites, media publications, etc.

External input and review were gathered from:

- Stakeholder Workshops. Three virtual workshops were held with over 40 participants from 20 countries to gain their experiences and challenges with using satellite technologies in humanitarian situations.
- Advisory Group. Two Advisory Group meetings were held to gain feedback on scope, findings and conclusions. See the acknowledgments for the members of this group.

— *Methodology for section landscape of humanitarian satellite applications*

A Google Sheet database was created to capture consistent attributes for each application. The team found and categorised over 500 satellite applications. Caribou Space intends to make this information available publicly in 2022.

The inclusion criteria were:

- The satellite application applies to the domains, use cases and hazards, in scope
- The satellite application includes satellite technology as a core component of the solution, not a peripheral part

The following attributes were used:

- **Organisation** – the primary provider of the application
- **Product or Project Name** – the commonly used name of the application
- **Source URL** – a website reference
- **Country** – the International Organization for Standardization (ISO) short English name with the addition of multiple. A maximum of five individual countries are recorded for each application.
- **Region** – the UN Statistic division (UNSD) geoscheme and Unknown[196]
- **User Organisation Type** – as *Government*, *First Responder*, *Development Agency*, *Media*, *Private Sector*, *Academia*, *NGOs*, *Affected Public*, *General Public*, and *Unknown*

196 Wikipedia, 'United Nations Geoscheme,' updated 4 October 2021, https://en.wikipedia.org/wiki/United_Nations_geoscheme

– It was not possible to meaningfully disaggregate the classes further (e.g., Government subcategories) given the information available for applications.

– A maximum of three user organisations are recorded.

– See details in section Supply-side actors.

- **Supplier Organisation Type** – as *Private Supplier*, *Public Supplier*, *Academia*, *NGOs*, *Media*, *Development Agency*, or *Unknown*

– Private Supplier is sub-categorised into *Satellite Operator & Reseller, Cloud Computing Provider*, *Platform/Solution Provider*, *Hardware/Software Supplier*, and *Other*.

– Public Supplier is sub-categorised into *Satellite Operator* and *Analytics Provider*.

– See detail in section Demand-side actors.

- **Domain** – either *Disasters*, S*ecurity and Conflict*, *Food insecurity*, *Population displacement*, *Health emergencies*, and *All* (see section Domains of humanitarian emergencies)
- **Event Cluster** – up to three event clusters
- **Use Case** – up to five use cases (see section Use of satellite applications across the event life cycle)
- **Satellite Technology Used** – *EO*, *GNSS*, *SatComms*, *SatComms – IoT*, or *Multiple*
- **Business Model**

– *Off-the-shelf*, meaning a customer can purchase and own the satellite application from a supplier with minimal customisation required.

– *Subscription*, meaning a customer pays an ongoing fee for access to the service, but doesn't own it.

– *Customised solution*, meaning a customer pays for a customised/bespoke satellite application from a supplier.

– *Open Access*, meaning the application is available free of cost or other access barriers.

– *Research*, meaning the application is completed as research/academic study only.

– *Unknown*.

- **Scale**

– *Scaled*, meaning sustained, long-term use of application across wide geographies or multiple countries with multiple users at Application Readiness Level (ARL) 9.

– *Implemented*, meaning operational use of application within limited geographic reach and limited number of users at ARL 7–8.

– *R&D*, meaning R&D and prototyping stage of application development, not yet deployed within a user's operational environment (ARL 1–6).

– *Unknown*

This data collection methodology has the following limitations and challenges:

- The dataset is a non-probability sample based on the judgement sampling of contributors. As a first iteration, it is not exhaustive or saturated. Where possible, generalisations about the supply of satellite applications for humanitarian emergencies are shown, but not statistical conclusions. The dataset will inevitably include biases; these are identified where possible.

- Desk research searching was conducted with English keywords, which may limit visibility to applications in specific regions in Latin America (Spanish dominant) and West Africa (French dominant).
- Sources didn't always have enough detail to define all attributes.
- It is a 'snapshot' of solutions developed in the recent past, in response to humanitarian emergencies over that period.
- For some attributes, use of 'multiple', 'all', and 'unknown' creates issues in charting and analytics.

Annex 4
Glossary

AOI – Area of Interest is the geographic extent of analysis

API – Application Programming Interface

ARL – Application Readiness Level

AWS – Amazon Web Services

CEOS – Committee on Earth Observation Satellites

Copernicus – The European Union's Earth Observation Programme, looking at our planet and its environment for the ultimate benefit of all European citizens

Demand-side – Community of global humanitarian data users

Domain – A domain is a broad grouping for different humanitarian crises with common characteristics using simple naming and common terminology

DRR – Disaster Risk Reduction

EO – Earth Observation is the gathering of information about the physical, chemical, and biological systems of the planet via remote-sensing technologies

ESA – European Space Agency

GEO – The Group on Earth Observations (GEO) is an intergovernmental organisation working to improve the availability, access and use of Earth observations for the benefit of society

Geostationary orbit – A geostationary orbit is a circular geosynchronous orbit ~35,000 kilometres in altitude above Earth's equator and following the direction of Earth's rotation

GCP – Google Cloud Platform

GEE – Google Earth Engine

GSD – Ground Sample Distance

GIS – A geographic information system is a system designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data

GNSS – Global Navigation Satellite Systems are a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers

Hazard – Circumstance, event or entity with potential to cause harm or loss

HDX – Humanitarian Data Exchange

HR – High resolution EO data with a resolution of 1m–4m

HIH – Humanitarian Innovation Hub

Humanitarian event – A humanitarian event is a potential starting point for a humanitarian crisis and the need for humanitarian action.

Humanitarian emergencies – Are events or series of events that represent a critical threat to the health, safety, security or wellbeing of a community or other large group of people

IaaS – Infrastructure as a Service

IDP – Internally Displaced Persons

IPP – International Partnership Programme, a five-year programme run by the UK Space Agency. IPP uses the UK Space sector's research and innovation strengths to deliver a sustainable, economic or societal benefit to developing countries.

IOT – Internet of Things describes physical objects that are embedded with sensors, processing ability, software, and other technologies, and that connect and exchange data with other devices and systems over the Internet or other communications networks

LR – Low resolution EO data with a resolution of 25–60m

LEO – Low Earth Orbit is an Earth-centred orbit close to the planet, often specified as an orbital period of 128 minutes or less.

M&E – Monitoring & Evaluation is an objective process of understanding how a project was implemented, what effects it had, for whom, how and why

ML – Machine Learning

MSS – Mobile satellite services provide two-way voice and data communications to global users who are on the go or in remote locations

MR – Medium resolution EO data with a resolution of 5m–25m

ODA – Official Development Assistance is a term defined by the Development Assistance Committee (DAC) of the Organisation for Economic Co-operation and Development (OECD) to measure aid

OSM – OpenStreetMap

PNT – Position, Navigation & Timing signals broadcast from a global navigation satellite system (GNSS) from space

Resilience – The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management

Response – Actions taken directly before, during or immediately after a disaster to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected

Risk – The probability of an outcome having a negative effect on people, systems or assets

Satellite application – Digital services and products that serve a number of functions for society, the environment and the economy, deploying satellite technology

SatComms – Satellite communications is the use of satellites to provide communication links between various points on Earth

Supply-side – Providers of satellite applications for humanitarian emergencies

UK FCDO – Foreign, Commonwealth and Development Office

Use case – A specific problem for the demand-side users that is addressed by a satellite application

SAR – Synthetic Aperture Radar (SAR) satellites are a form of radar using the motion of the satellite to create a larger 'virtual' antenna that is used to create two or three-dimensional images of objects, such as landscapes

UKSA – UK Space Agency

UNOSAT – The United Nations Institute for Training and Research (UNITAR)'s Operational Satellite Applications Programme

VHR – Very High Resolution EO data with a resolution of (<1m)

VLR – Very Low Resolution EO data with a resolution of (>60m)

VSAT – Very-small-aperture Terminals are small-sized earth stations used to transmit and receive data, voice, and video signals over a satellite communication network, excluding broadcast television

Caribou Space supports organisations to bridge the space and development worlds by working with governments, space agencies, development agencies, and private sector space companies.

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