Satellites and the climate crisis: what are we orbiting towards?

On World Humanitarian Day, ***Alice Pellegrino, Ria Sen,*** *and* ***Federica Angeletti*** *look at the humanitarian development potential of satellite technology, especially its ability to improve disaster and climate risk management. They discuss specific ways in which satellites can be used to manage disaster and climate risk, together with the current and future evolution of the satellite industry.*

Application of satellite technology for disaster and climate risk management has transformative humanitarian development potential, now and in the years to come. World Humanitarian Day, celebrated globally on 19 August, acknowledges the climate crisis as a critical driver that amplifies the risks faced by vulnerable peoples across the world, especially in humanitarian crises. Technology is valuable for emergency preparedness and response because it provides insights and granularity for unpacking disaster vulnerability and hazard exposure – who is affected, to what extent, and where they are located. These applications are also essential for realising the 2030 Agenda for Sustainable Development, which seeks to leave no one behind in achieving inclusive global development.

In addition to the indisputable socio-economic advantages space-based platforms offer, they have two very useful characteristics for the management of complex disaster and climate risks. Firstly, via Earth and ocean observation, they address pressing global needs (defined by end-users on our planet) such as monitoring of migration trends, resource use, and population expansion. Earth and ocean observation provides decision-making insights to civil protection and public infrastructure authorities, amongst others. Secondly, they are essentially based on the coordinated and optimised exploitation of existing and pre-planned space systems, without a short- or medium-term demand to develop new technological solutions. These advantages demonstrate easy wins all around and provide opportunities for early assessment and management of complex risks.

In this essay, we unpack some of the applications for disaster risk management: sections I on risk management applications and II on resilience applications of satellite technology. We also look at directions the satellite industry is evolving in sections III on evolution of the industry and IV on ways ahead.

Environment and populations in disaster and climate 'hotspots'

Disasters cause tremendous socio-economic disruptions, often affecting large areas or territories in a fell swoop. It is also well-established that the strength and intensity of disasters are being amplified by a changing climate. Collecting continuous data on disasters by using conventional methods is no longer an easy task. However, space technology and remote sensing tools offer useful possibilities to gather such vital data – aggregating reliable information at global and regional scales quickly and repetitively, in secure digital formats.

Satellite technology and remote sensing techniques can be used to monitor a (potential) disaster situation – before, during, and after the event has taken place – providing useful baseline data against which future changes can be measured. Geographic Information System (GIS) remote sensing approaches utilise satellite imagery, Global Positioning System (GPS) recordings, and textual attributes associated with a space, thereby integrating and analysing many types of data sources required for disaster monitoring. For example, the Disaster Monitoring Constellation (DMC), constructed by Surrey Satellite Technology Ltd., is a unique earth observation satellite constellation, delivering high frequency imaging anywhere on the globe from a long established collection of satellites since 2010.

Satellite technologies also have important early warning applications. Being able to detect where growing concentrations of population, especially the more vulnerable (e.g., in hazard-exposed coastal zones), are in disaster 'hotspots' and being able to characterise physical exposure represent fundamental inputs for both disaster and climate risk assessments. For example, the Pacific Tsunami Warning System is satellite-based, relying on timely and reliable data gathered from buoys at sea or tidal gauges in ports, and subsequently transmit data to warning centres.

Emergency response insights to 'build back better'

International cooperation is most valuable for recovery needs, and for planning recovery measures in post-disaster situations. Demonstrating this, the International Charter: Space and Major Disasters is a worldwide collaboration, whereby satellite data is made available for disaster management and risk reduction insights. Through combining Earth observation assets from different space agencies, the Charter allows resources and expertise to be coordinated for rapid response to major disasters – helping civil protection authorities and the international humanitarian community to serve the most vulnerable fastest. This initiative essentially provides a single access point that operates 24 hours a day, 7 days a week, at no cost to the user. Activated by the Emergency Telecommunications Cluster, the Crisis Connectivity Charter is another key international initiative, which is built on principles to improve existing satellite-based response and enhance connectivity in crises.

In a similar collaborative vein, the European Commission, the United Nations Development Group and the World Bank established a partnership platform to strengthen coordination for early response capacities, as well as for recovery planning. A multi-stakeholder post disaster needs assessment (PDNA) recovery framework for decision makers – to be used during the early phases of disaster recovery planning – was adopted. The guide includes sector-specific tools, including approaches for damage assessment from remotely sensed and other data sources. Many recent PDNAs use satellite data insights post-disaster, for example, the 2018 floods in Lao PDR and the 2018 Sulawesi earthquake and tsunami in Indonesia. PDNAs typically inform national recovery plans after a disaster strikes, and therefore are essential for longer-range resilience building.

Whilst satellites have traditionally been used more for predictive applications related to disaster risk management, their value in informing emergency response cannot be underscored. The European Union's Copernicus Emergency Management Service provides access to free satellite data during response to major disasters. Copernicus produces reference maps for comprehensive and updated knowledge of the territory and relevant assets. It also produces pre-disaster situation maps that provide relevant and up-to-date thematic information to plan for contingencies, and post-disaster situation maps for informing reconstruction planning and progress monitoring, mapping long-term disaster impact, etc.

Space technologies are driving decisions made by the public and private sector alike. So what direction is the satellite industry moving in?

Evolution of satellite technology to meet current risks

Nowadays, there is an urgent need to switch to more innovative and agile approaches to observe the environment and monitor population distribution based on remote sensing measurements. Such a trend is reflected in more performing platforms and more accurate, repeatable, and frequently updated data acquisition and processing solutions. In this scenario, constellations of small satellites – with their ability to provide frequent coverage and/or repeat measurements – are the future of the satellite industry. Indeed, the trend towards smaller satellites has not only reduced the costs of building, launching, and operating satellites, but has also enabled faster and more flexible deployment, and made satellite mega-constellations feasible.

More and more private and public players in the space sector are planning to launch and operate swarms of small satellites in the coming years. Currently, around 3,000 active artificial objects are orbiting the Earth, according to the Union of Concerned Scientists' Satellite Database. By 2030, estimates show that this number could rise up to 100,000, due to missions such as SpaceX's Starlink or Amazon's Kuiper constellations aiming at delivering Internet access to remote places. Also China, as of early 2021, has been undertaking the construction and operation of a national satellite Internet mega constellation called "Guowang" (GW), consisting of "GW Low Earth Orbit" constellations totalling 12,992 satellites, and sub-constellations ranging from 500-1,145 kilometres in altitude with inclinations between 30-85 degrees. These types of satellite swarms offer a few key advantages over traditional satellites, especially for communications and Internet access, particularly in remote and high disaster risk zones of the planet. As you can imagine, global Internet coverage has manifold implications for disaster risk management, especially when land-based telecoms networks are down. Indeed, it permits communications system redundancy and network resilience, by reducing the risk of total communications blackouts and of missing relevant information.

Earth observation satellites are mainly located in the so-called low-Earth orbit (LEO). Consequently, they can provide global coverage with comparatively low temporal – but medium to very high spatial – resolution, depending on the on-board instrument and mission objectives. A low earth orbit constellation with enough satellites and the proper instrument could ensure the required operations, communications, and monitoring up to a 24/7 basis at every point on the planet. For example, the Italian COSMO-SkyMed Earth-imaging constellation consists of four identical satellites, owned and operated by the Italian Space Agency (ASI), operating since 2017, to provide global Earth observations that can be repeated several times a day in all-weather conditions. Indeed, having four satellites allows a reduction in the time needed to acquire an image on the same geographical area from five days to a few hours on a global-scale – which also poses strong value for reduction in crisis response time.

Ways ahead for satellite evolution to manage complex risks

To be able to provide emergency preparedness and response services for large geographical areas or across the globe, new ways to improve satellite performance, coordination, autonomy, and management are needed. A few recommendations are provided as follows.

Inter-Satellite Link (ISL) communication technology will enable improvement of the coordination between small satellites in the same constellation, allowing very precise formation flights. This is needed for applications such as Synthetic Aperture Radar (SAR), which require high-level resolution. Indeed, SAR instruments can be used in all-weather conditions to acquire data to create rapid maps of land areas after a disaster (such as digital maps of surface movements after an earthquake), with the aim of supporting immediate response and creating maps for risk prevention and mitigation activities.

Moreover, artificial intelligence (AI) for on-board information processing and data management allows to identify only the most useful information to be sent to ground via a preliminary screening, regardless of ground commands that have been so far necessary. Another key aspect of future AI applications is related to autonomous learning systems for the management of satellite constellations. Intelligent ground station networks and automatic learning systems will optimise the control of large small satellites constellations, leading to benefits such as smart flight formations and intelligent collision avoidance manoeuvres.

In addition, AI can be used to increase spacecraft on-board autonomy, specifically when it comes to enhancing the satellite pointing performance. Indeed, in general, Earth observation satellites are required to schedule what and when terrestrial areas should be observed (by following an observation task planning logic), and hence to plan in advance the altitude manoeuvres needed to point their sensors towards such lands. In this scenario, innovative autonomous task planning algorithms will be key to achieve a quicker and more precise response and to optimise the limited on-board resources for data acquisition. Finally, artificial intelligence can also be used for the processing of the data on the ground, and for improving the operations performed within the ground stations network.

The multitude of mega small-satellite-constellations planned and/or launched from countries around the world could soon represent an interference hazard for satellites in geostationary orbit, even if those new systems comply with existing rules defined by the International Telecommunication Union (ITU), the United Nations specialised agency for information and communication technologies. Data traffic is increasingly bandwidth hungry, and spectrum is a limited resource. Therefore, the desirability of higher bandwidth satellites is pushing the industry to higher frequencies or different communications systems. Ku-Band/Ka-Band or light-based/laser communication systems are the key to reach high data processing and transmission rates of several hundred megabits (Mb) per second, given the need to communicate greater data volumes more reliably and faster. Moreover, optical-based communications offer possibly wider bandwidths within the optical spectrum, and are therefore a viable alternative. Optical communications do not have regulatory restrictions or face licensing issues yet. Therefore, it could suitably transform space system architecture, also providing a powerful means to solve security issues. This technology enables quantum communication, a technique that relies on specific protocols to send encrypted messages to ground-based stations using light photons. The usage of quantum cryptography will increase communication security, thus ensuring resilience to future hacking threats, especially when it comes to many security-critical services such as finance, defence and telecommunication.

Another key technology when dealing with constellations is represented by on-board spacecraft thrusters based on electric, chemical or water propellants. A dedicated on-board propulsion system is fundamental to perform orbital manoeuvres and altitude corrections when precise pointing or distance is required by the satellite's mission. Remote sensing acquisitions generally require the satellite to stay in an orbit respecting rigid parameters, and to have a specific orientation to allow it to successfully carry out Earth observation tasks (such as view angles, inclination, distance, etc). Hence, the spacecraft is often required to perform corrections to its orbit, which is periodically modified by orbital perturbations and external disturbance forces (such as atmospheric drag), and to reorient itself in the tri-dimensional space by using its propulsion system, which, consequently, has to be precise, quick, and reliable. In this regard, there is growing interest in electric propulsion (EP) technology, because it is more mass efficient than traditional methods (EP propulsion requires lower propellant mass, which is ejected faster than standard chemical systems). This is a crucial point, as mass is one of the most important factors that increases the overall cost of a space mission.

Conclusion

Enhanced awareness of the existence, and application, of guiding international frameworks, such as the "*International Charter: Space and Major Disasters*" and the "*Crisis Connectivity Charter*" is required. When activated, this conduit offers free satellite data quickly in a humanitarian crisis. Other important initiatives are the International Working Group on Satellite-based Emergency Mapping, the Committee on Earth-observation Satellites (CEOS), UN-SPIDER (a United Nations space-related programme), Copernicus, and the Global Earth Observation (GEO) System of Systems.

Sharing of critical data and information during a crisis is critical to improve disaster risk management. Satellite data is no exception. This should translate into freely sharing disaster information and data on reliable and secure platforms, to transmit data to authorized persons. Positioning and communication satellites are useful for data transmission and early warning message delivery, amongst other applications.

User needs should be the central focus for satellite data providers to improve emergency observation services, and thereby emergency management. This includes reduction in response time, availability of different data types (optical/SAR, wide-range, high-resolution, etc.), together with reliability/validation of value-added products. This should be complemented by effective use coordination, and emergency management applications.

End-user feedback is critical for improving and building better satellite systems for managing complex risks. Though engaging in such two-way feedback loops is not easy in a post-disaster context, it is possible through site-based surveys, where system recommendation reviews can be presented.

Mega-constellations, global Internet coverage, and improved communication systems are currently regarded as some of the main key revolutionary technologies for forthcoming generations of satellites. Initiatives in this field all over the world are aimed at the development of competitive new generations of space systems. Encouraging fair industrial competitiveness is proving effective in boosting research, design, and innovation in this industry.

Improvement in spectral efficiency, and spectrum-reuse rates, can surely enhance data quantity a satellite system delivers. Large low-Earth-orbit constellations mainly utilise (or plan to use) higher frequencies, to increase data rates and ensure greater security. However, higher frequencies are more vulnerable to weather- and rain-fade (absorption of a radio-frequency signal by atmospheric rain, snow, or ice). Redeeming factors are better ground-station design, signal modulation, and adaptive coding, which together diminish such exposure.

As the number of space missions rises, the efforts to better manage space debris and ensure the space realm is safe from cybersecurity risks emanating from Earth are vital. Countries around the world are anticipating such risks, but greater efforts are needed.

Authors' disclaimer: *Views presented in this writing are those of the authors and not of their organisations of study/hire.*

♣♣♣

Notes:

- *This blog post expresses the views of its author(s), not the position of LSE Business Review or the London School of Economics.*
- *Featured image by NASA on Unsplash*
- *When you leave a comment, you're agreeing to our Comment Policy*