Bridging Space and Earth

THE ROLE OF 7/8 GHZ IN DELIVERING SPACE-BASED INSIGHTS

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V2.4

This white paper was contributed by

EXECUTIVE SUMMARY

Remote sensing, or Earth observation (EO), satellites monitor the Earth's surface, subsurface, and natural phenomena. Over the past thirty years, EO capabilities have been proliferating. Approximately 1,200 EO government and commercial spacecraft were operational as of May 2023. [3] But they are under threat. The upcoming 2027 International Telecommunication Union (ITU) World Radiocommunication Conference (WRC-27) is considering allowing International Mobile Telecommunications (IMT), future sixth-generation (6G) mobile and fixed service (IMT-2030) deployment in the following currently allocated and used EO frequencies: 7125-7235 MHz; 7235-7250 MHz; and 8025-8400 MHz (7/8 GHz or X-band). The EO community operates in these critical frequencies today. **To preserve these workhorse EO frequencies for current and future deployments, this white paper recommends opposing any IMT identification in the 7125-7235 MHz, 7235-7250 MHz, and 8025-8400 MHz bands.**

I. WHY SHOULD YOU CARE?

- Remote sensing is essential for various applications and domains, including defense, security, agriculture, risk and disaster management, climate change and environmental monitoring and adaptation, urban planning, scientific research, etc. It provides critical observation data across several key industries, including aviation, shipping, oil and gas, and transportation.
- Remote sensing data and derived products, combined with artificial intelligence advances, play a crucial role in EO and the pursuit of the United Nations (UN) 2030 Sustainable Development Goals (SDGs).
- By 2030, remote sensing satellites will contribute up to **$700 billion USD to the global gross domestic product (GDP) annually**.
- Remote sensing operations include uplink and downlink radiofrequency operations.
    - Space-based platforms may carry cameras, radars, radio occultation and reflectometry equipment, and/or other EO payloads that observe the Earth's surface, subsurface, and natural phenomena and downlink this data for further analysis.
    - Earth-based terminals (fixed and transportable) may measure Earth surface, subsurface, and natural phenomena features and transmit this data to satellites that downlink this data for further analysis.
    - For both space and Earth-based operations, the satellites and terminals will route telemetry, tracking, and command data to ensure the health, safety, and accuracy of such operations.
- The 7/8 GHz frequencies' physical characteristics and growing technology availability have made this frequency segment **an EO workhorse** essential to disseminating

space-based EO collection and associated satellite telemetry and tracking data and has made it ever more affordable and widespread among operators around the globe.

- For these reasons, X-band enables equitable space access. It is far less expensive, less complex, and ultimately more adoptable than alternatives and fosters future remote sensing programs for aspiring spacefaring nations and emerging commercial endeavours.

II. INTRODUCING IMT-2030 TECHNOLOGIES IN 7/8 GHZ FREQUENCIES WOULD SIGNIFICANTLY DISRUPT REMOTE SENSING OPERATIONS AND THE RELATED DATA OUTPUTS.

This white paper recommends **opposing any IMT identification in the 7125-7235 MHz, 7235-7250 MHz, and 8025-8400 MHz bands** for the following reasons:

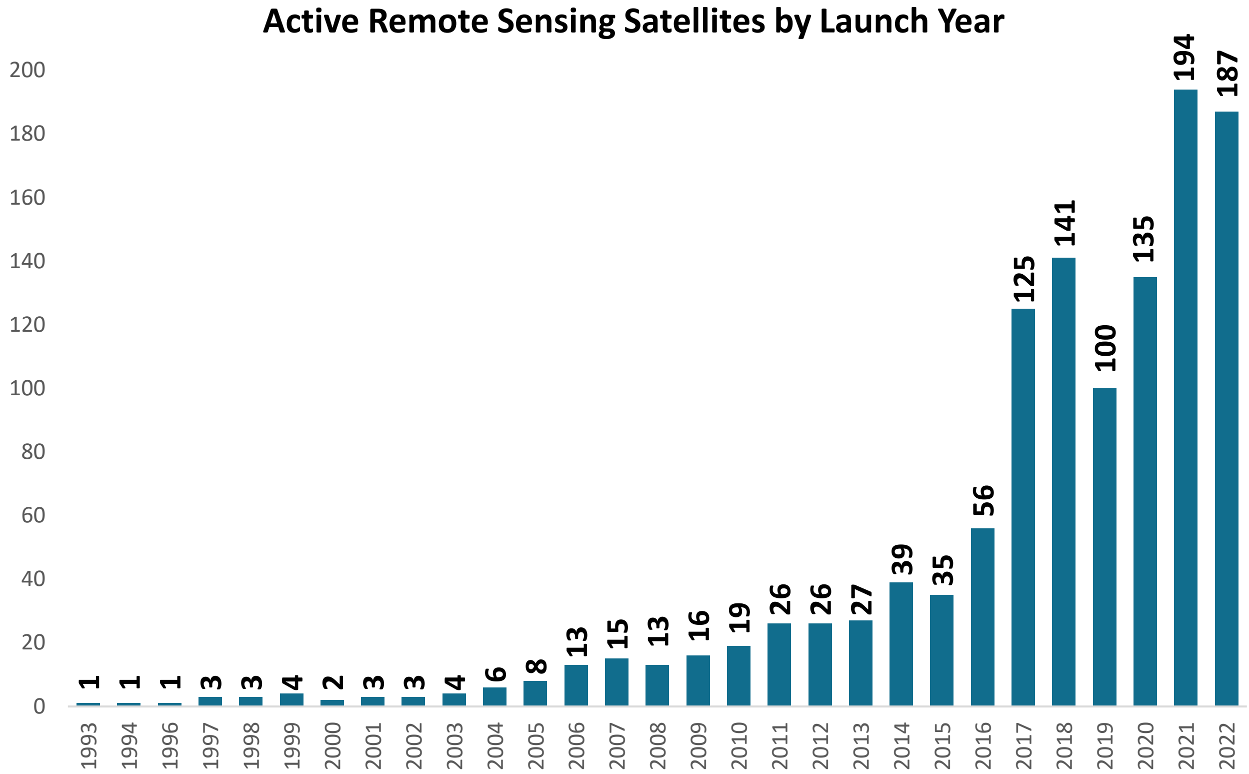
- *Substantial existing EO use.* The band is widely used and shared today among governmental, institutional, and commercial remote sensing missions producing invaluable socio-economic benefits globally and across sectors as mentioned above.
- *Satellite-terrestrial coexistence issues.* Coexistence between terrestrial IMT and space services (including those for satellite remote sensing) is often impractical, restrictive, and fraught with difficulties to achieve adequate protection for sensitive receiving satellite ground stations. [58]
- *Limited EO spectrum availability.* Size, weight, and power constraints limit most EO operations to UHF, S-band, and X-band. In total, commercial EO frequency allocations include 147 megahertz for uplink and 466.85 megahertz for downlink. [70] But only 62 megahertz of uplink and 356.2 megahertz of downlink are usable for commercial EO operations given ITU-R guidance, extreme UHF and S-band congestion, and adjacent X-band deep space network protections. [70, 63] IMT does not face similar challenges, however. The IMT industry has already secured 18,550 megahertz (1,900 megahertz before WRC-19; 15,350 megahertz at WRC-19; and 1,300 megahertz at WRC-23), much of which it has not yet built out, making the desire for additional bands difficult to justify. [71, 72, 73]
- *Other EO challenges.* Uncertainty regarding future 7/8 GHz frequency usage and the actual lack of alternative bands with similar characteristics pose challenges for long-term planning in the space sector – deterring industry growth and equitable EO data access while limiting the benefits derived from it.

X-band is a lifeline to the Earth Observation sector, with no current viable alternative.

INTRODUCTION

Space, scientific, meteorological, and governmental agencies around the world, as well as companies across a wide range of sectors, leverage satellites for applications and domains, including defense, security, agriculture, risk and disaster management, climate change and environmental monitoring and adaptation, urban planning, and scientific research, among others. When a satellite has imaging or remote sensing capabilities, or when its mission includes "the collection of information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment," this satellite is defined by the International Telecommunication Union (ITU) as a space (radio)station in the "Earth Exploration-Satellite Service," and the EESS acronym generally indicates Earth observation remote sensing satellites in the ITU regulatory context. [2]

In the last 30 years, an increasing number of governmental actors around the world, as well as commercial and private entities, have launched, operated, and successfully exploited data from EESS/remote sensing satellites. As of January 2023, the Union of Concerned Scientists listed **approximately 1200 active remote sensing satellites, including Earth observation, Earth science and surveillance satellites** with a growing number of satellites launched on a year-by-year basis. [3]



Source: Union of Concerned Scientists

Commercial companies have emerged since the 2000s to provide cheaper, faster, universal access to remote sensing data, with adoption of diverse remote sensing satellite technology (such as Synthetic Aperture Radar, Optical, Hyperspectral, Infrared, Fire detection and Weather forecasting-related sensors and sounders), incentivized by the socioeconomic benefits that these have generated and promise to generate. **Today, 50% of global remote sensing satellites are commercial in nature** [3], and this percentage is set to increase, with new countries joining the group of space-faring nations. This increasing trend in the need for remote sensing satellites is also reflected in the number of requests for new EESS satellite networks [4] being submitted to the ITU. In 2023 alone, there were more than 150 EESS/remote sensing satellite networks requests for coordination containing X-band (or a portion of), a number amounting to more filings than 2021 and 2022 combined. [5] These are more than 150 systems (either individual satellites or constellations) that would be operating in X-band.

The amount of data that is being generated by these spacecrafts, combined with this data's ever-improving quality and availability, as well as the burgeoning capability to sort and analyze large volumes of it by using Artificial Intelligence, has made Remote Sensing a vital segment of the satellite industry. Remote sensing data also constitutes a global tool that can help achieve the United Nations (UN) 2030 Sustainable Development Goals (SDGs) [6] and contribute to an ever-growing significant size of the global GDP (up to $700 billion USD per year by 2030). [59]

The functionality of these satellites, the benefits that come from them and the applications stemming from the analysis and interpretation of this space-based data, all depend on **reliable access to the radiofrequency spectrum**. Without spectrum, these satellites cannot timely downlink and redistribute the data collected in space. The greater the quality and quantity of this data, the larger the spectrum bandwidth that is needed to transfer this data to the ground, consequently increasing dependence on/need for spectrum; it is therefore expected that the spectrum needs of the satellite remote sensing community will continue to grow. **X-band is a lifeline to the sector with no current viable alternative.**

REGULATORY CONTEXT

Every four years, the ITU organizes the World Radiocommunication Conference (WRC) to review and update the Radio Regulations – the international treaty which memorializes the rules and sharing conditions of radio frequencies and space orbits between countries and among different sectors of activities.

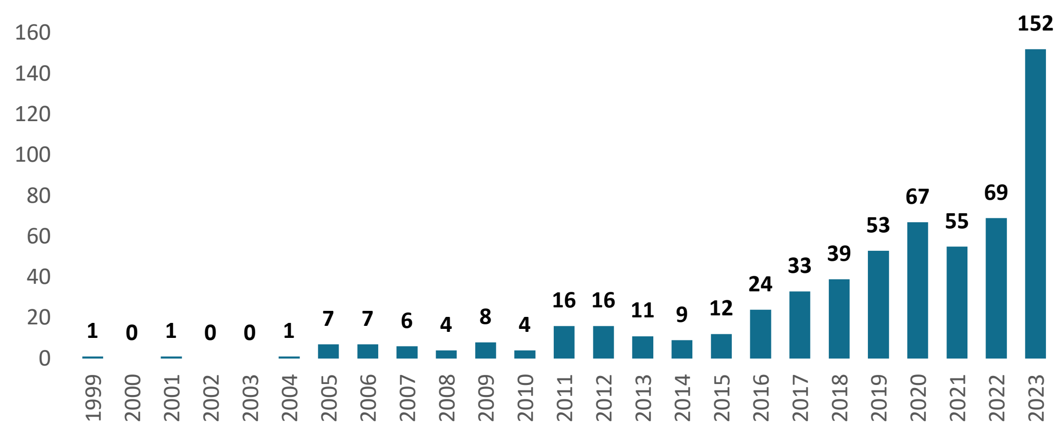
At the end of 2023, the WRC adopted its new four-year agenda for studies to be conducted in preparation for WRC-27. This agenda invites administrations, under Agenda Item 1.7, to perform studies on the possible introduction of new mobile phone networks (i.e., 6G or International Mobile Telecommunications (IMT)-2030) in the frequency band 7 125-8 400 MHz (or parts thereof). [51]

ITU Studies will assess the technical and regulatory regime for the possible sharing of frequencies between mobile phone networks and ground stations receiving satellite remote sensing data, among others (military and widely deployed ultrawideband (unlicensed) communications).

Given the balance of opinions observed in 2023 and in the absence of any strong reaction and position, it is likely that all or part of these frequency bands will be identified for wireless networks at WRC-27.

For example, for remote sensing satellites operating in the segment 8025-8400 MHz (space-to-Earth), a new co-frequency IMT spectrum identification could eventually constrain and possibly prevent the operation of existing and future civil, governmental, scientific, and commercial space systems in the numerous areas and countries where these mobile networks would be deployed.

Number of EESS filings per year in the 8025-8400 MHz band (first submission)



Source: ITU-R Bureau's International Frequency Information Circular (IFIC) no. 3022

REMOTE SENSING SATELLITE SPECTRUM ACCESS

As described in more detail in this document's Appendices 1 and 2, satellite remote sensing use cases are vital, and the corresponding societal, economic, and security-related benefits that stem from these would be jeopardized if the radiofrequency spectrum that these satellites rely upon was to be identified for IMT-2030.

Allocations to the EESS, and hence remote sensing satellites, are divided across different frequency bands to optimize and enable specific functions of satellite systems, based on physics, engineering complexity, and coexistence with other terrestrial and space services.

Today EESS systems are operated across a limited number of frequency segments, as described below:

UHF

Covering the 401-403 MHz (Earth-to-space) segment, this band is utilized for TT&C. However, the limited bandwidth available, coupled with the EIRP limitations introduced by the WRC-19 (RR Provisions 5.264A and 5.264B), restrict the viability of this band for most systems. Moreover, some administrations have imposed license conditions that require EESS operators to transition future operations out of this band. [60]

S-band

Consisting of the segments 2025-2110 MHz (Earth-to-space) and 2200-2290 MHz (space-to-Earth), this band is utilized primarily for TT&C, not only by the EESS, but also the Space Operation Service (SOS) and the Space Research Service (SRS). This band has good propagation characteristics, and it is heavily utilized although it does not enable heavy bandwidth use. ITU guidelines recommend a maximum of two megahertz for Earth-to-space [61] and 6.2 megahertz for space-to-Earth [62] transmissions, limiting the amount and the speed at which remote sensing data can be downlinked on the space-to-Earth segment.

X-band

Divided across various sub-bands between 7125 MHz and 10 GHz, this spectrum is utilized by various satellite radiocommunication services including EESS/remote sensing.

This band hosts two relevant allocations for EESS systems:

- The segment **7190-7250 MHz (Earth-to-space)** is being used and further explored by EESS systems to complement the highly demanded S-band and is experiencing a growing demand also due to its SRS co-allocation.
- The segment **8025-8400 MHz (space-to-Earth)** is heavily utilized today by EESS systems and is pivotal for remote sensing payload data downlink, with a growing number of remote sensing satellites also relying on this band for telemetry and tracking given the growing utilization of S-band. Worth noting, despite its vitality, the segment is already not fully usable, given its usage restrictions imposed to protect SRS

services and deep space communications in the adjacent 8400-8450 MHz band.[63, 68, and 69]

Ka-band

Among the Ka-band segments, the 25.5-27 GHz (space-to-Earth) band, for example, is allocated to EESS, but robust use is impeded by two main obstacles, one physical and one regulatory:

- From a physical perspective, Ka-band radio waves suffer in performance due to weather conditions (phenomenon called "rain fade"), thus limiting the geographical areas where the band can reliably be used and severely undercutting EESS systems and potential global ground stations coverage.
- From a regulatory perspective, the 2019 World Radiocommunication Conference (WRC-19) identified the band for the technology standard IMT-2020, or 5G, resulting in a higher risk of receiving harmful interferences and introducing the need for EESS systems to operate on a non-protection basis from Fixed/Mobile services in some countries and nearby national borders worldwide. [74]

Both obstacles reinforce the uncertainty surrounding the use of Ka-band spectrum for payload operations. Weather uncertainties may impede resilient data downlink planning, potentially undermining all the applications that are built on reliable data access. Licensing uncertainties and risks of interference from IMT undermine network planning and operations, limiting the scope, timelines, and global reach of EESS systems relying on this band.

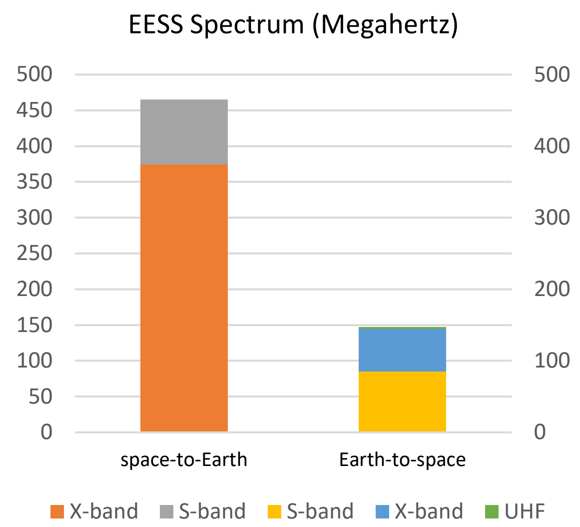
Considerations for EESS Systems

From a space-to-Earth perspective, one thing is clear: X-band is the single most significant spectrum for downlinking EESS earth observation data acquired by satellites due to:

- The physical characteristics of 8025-8400 MHz waves;
- The global harmonization of this band for remote sensing satellite applications;
- The widespread equipment availability because of such global harmonization; and
- The ease of coexistence with current coprimary services, including Fixed and Fixed-Satellite services.

Additionally, **no current alternative to X-band downlink seriously exists at scale** due to:

- Lack of available large enough bandwidth in other frequency ranges;
- Lack of standardization and/or technological maturity; and
- Reasons intrinsic to the physical properties of the concerned frequencies.



In the Earth-to-space direction, EESS systems are very limited in allocations, for a total of less than approximately 150 cumulated megahertz, of which:

- The 401-403 MHz portion is limited in size and power of transmission [60];
- The 2025-2110 MHz portion is the most used despite the ITU recommending a maximum two-megahertz bandwidth per emission [61]; and
- The 7190-7250 MHz portion is an obvious next step to solve congestion and regulatory hurdles existing in the first two segments.

THE THREAT TO REMOTE SENSING SATELLITES' SPECTRUM

The benefits provided via satellite remote sensing are enabled by reliable spectrum access. Today, X-band is the only band able to provide reliable access for these operations because of the physical characteristics of radio spectrum and due to regulatory decisions (e.g., the WRC-19 decisions to limit the Earth-to-space EIRP in the 401-403 MHz band and to erode EESS/remote sensing spectrum allocations in the 25.5-27 GHz band by identifying it for IMT).

X-band is the default band for remote sensing payload downlink and increasingly for satellite telemetry and tracking operations, enabling high data rates, reliable link closure, and narrow beamwidths that can facilitate coexistence between satellites and existing terrestrial services.

X-band is also the obvious way forward for Earth-to-space transmissions, as the 85 megahertz of S-band (2025-2110 MHz) becomes increasingly more utilized, congested, and limited in its usage by national administrations following ITU [61] and CEPT ECC [64] recommendations.

Satellite operators, including remote sensing satellite operators, expressed, therefore, uneasiness during WRC-23 at the possibility, raised by national administrations and regional organizations, to study the viability of deploying IMT-2030 services in the band 7-24 GHz, as highlighted clearly and succinctly by the Global Satellite Operators Association (GSOA). [54] This uneasiness has become serious concern when the WRC resolved, with Resolution 256 (WRC-23), to initiate "Sharing and compatibility studies and development of technical conditions for the use of International Mobile Telecommunications (IMT) in the frequency bands 4 400-4 800 MHz, 7 125-8 400 MHz (or parts thereof), and 14.8-15.35 GHz for the terrestrial component of IMT" for decisions to be taken at a future WRC, to be held in 2027 [51].

The European Union Copernicus Programme provides one example. Copernicus alone generates 16 Terabytes of Earth observation data daily, which is downlinked to the ground via the European Space Agency's "Sentinel" satellites, as well as programme partners, that rely on X-band downlink. [52] By 2032, it is forecasted that **the Earth Observation space segment will generate more than 2 Exabytes of data every year**, more than 5,600 terabytes per day. [53] This amount is about 350 times more than what the Copernicus programme delivers daily today. This anticipated volume of data calls for more, not less, spectrum to support satellite remote sensing operations.

As already highlighted by GSOA, "Co-frequency sharing between satellite and IMT services would not be practicable and the introduction of IMT services would cause harmful interference, interruption, and displacement of satellite services in these bands." [54]

The Role of 7/8 GHz in Delivering Space-Based Insights

Satellites operating under the EESS and the Meteorological Satellite-Service would struggle to relocate due to the lack of available other bands.

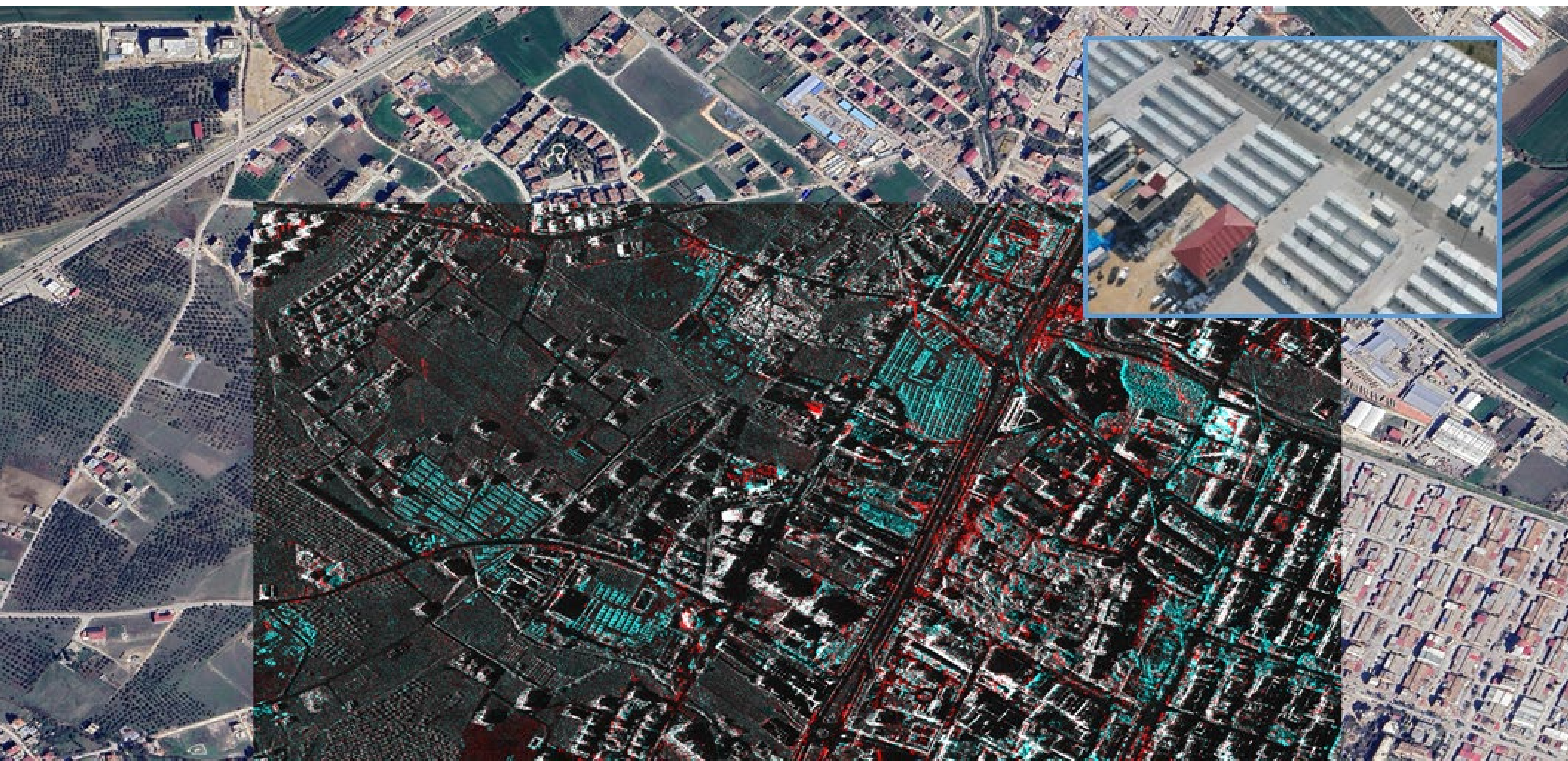
Given the discussions on identifying X-band for IMT, remote sensing satellite operators face the challenge of uncertainty on multiple fronts. If EESS bands were to be undermined through the introduction of new IMT / 6G transmissions:

- What other bands could be selected by remote sensing satellite operators?
- Will existing receiving Earth stations become unusable or obsolete?
- Will these stations even be authorized to operate?
- Will commercial-off-the-shelf solutions for satellite radios and Earth stations exist at scale, if satellites must relocate to other frequency bands?

Space is a sector that relies on long-term planning: benefits that are being reaped today are the results of a decade or more of planning, public funding, private investments, long design and manufacture timelines, and technology and infrastructure deployments. Uncertainty on the status of X-band harms current and future satellite operations, a sword of Damocles over the societal benefits that stem from leveraging remote sensing data.

With no viable alternative to X-band for remote sensing satellites, it is important to consider what socioeconomic benefits are currently at stake. The interested reader can further explore the importance of Satellite Remote Sensing, its socioeconomic benefits, and its contribution to the UN Sustainable Development Goals by reading Appendices 1 and 2, as attached.

EARTHQUAKE IN TURKEY & SYRIA • PAZ SAR satellite product • Hisdesat Servicios Estratégicos S.A.



OPPOSING AN IMT SPECTRUM IDENTIFICATION IN THE 7/8 GHz BAND

Based on the benefits provided by remote sensing satellites, limited spectrum available for this satellite system type, and inability for co-frequency IMT and satellite service spectrum sharing, **this whitepaper recommends opposing the identification of the 7125-8400 MHz band for IMT-2030 as explored by WRC-27 Agenda Item 1.7.**

In fact:

1. **Coexistence between satellite services and IMT is impractical, with satellite services facing harmful interference or the need to relocate, as also reported by GSOA [54]**:
    a. Earth station receivers could be easily saturated by IMT transmissions;
    b. Earth station transmitters in Earth-to-space bands between 7.125 and 8.4 GHz could be hampered and prevented to transmit to avoid interfering to IMT receivers;
    c. Satellite systems already in orbit or past the design phase will be unable to change the band in which they operate, even when equipped with software-defined radios; and
    d. Earth station networks already deployed will be unable to easily change operating bands.
2. **Access to ground stations, the critical entry point of space-based data, remains uncertain.**
    a. Operators of existing ground station networks, particularly transportable EESS ground stations, would not know whether any prescribed geographical separation from IMT areas will be enough to avoid harmful interference; and
    b. Operators of existing ground station networks would not know whether national administrations would continue to authorize satellite transmissions and Earth station reception in X-band, preventing or seriously limiting operators' ability to grow their ground station networks to reduce latency and coverage in the delivery of time-sensitive data to customers and accommodate downlink of additional data as demand grows.
3. **The regulatory uncertainty caused by such studies makes it difficult for the space sector to grow and limits the future innovation and benefits that would come with it.** Certainty of access to spectrum enables early decisions on satellite system design, clear ground station network architectures, and access to financial support for operators.
4. **EESS satellites currently have access to approximately 600 megahertz of allocated spectrum while IMT has already been granted access to nearly 3x more spectrum than EESS (18,550 megahertz), without substantial IMT deployments to date**. [71, 72, 73] Currently, few IMT operators have requested or actually been allocated such bands by National Administrations [55, 56, 57].

APPENDIX 1 - Remote Sensing Satellites Need Reliable Spectrum Access to Deliver Socioeconomic Benefits

Satellite remote sensing offers a wide range of applications and consequent socioeconomic benefits [7], making it an indispensable tool for governments, businesses, and researchers worldwide. Although it is beyond the scope of this paper to cover all the use cases, some practical applications are detailed in the following sections.

Today, remote-sensing data is instrumental in optimizing resource usage, a crucial aspect of sustainable development. It also aids in preparing for and protecting people from natural disasters, monitoring climate patterns, and adjusting agricultural, shipping, and development practices to optimize emission efficiency. Additionally, it is used to safeguard people from non-state armed actors, monitor war crimes during armed conflict, and ensure the safe delivery of humanitarian aid and establishment of humanitarian corridors.

Further examples of how remote-sensing data contributes specifically to the achievement of the UN Sustainable Development Goals (SDGs) are listed in Appendix 2.

Risk and Disaster Management and Response

Satellite remote sensing plays a pivotal role in disaster management [8] in order to mitigate, prepare, respond and recover in response to a specific risk. Satellites provide real-time data on natural disasters such as floods, hurricanes, wildfires, and earthquakes, allowing authorities to monitor their progress and plan response and evacuation efforts more effectively. This capability not only saves lives but also minimizes property damage, reducing the economic burden on affected communities and governments.

1.1. Climate resilience

One example of satellite remote sensing applications is that of the initiative from the Asian Development Bank to help strengthen climate resilience in the Hindu Kush Himalayas-Bhutan and Nepal. The objective of this initiative is to is set the stage for knowledge solutions across the region, with a focus on climate resilient investment planning, development, and risk management [11] to mitigate and prevent climate change-related disasters. To successfully complete this project, satellite remote sensing data is fundamental.

1.2. Fire detection and monitoring

Both private actors and governmental agencies have deployed satellite-based tools for wildfire early-warning, detection, and monitoring. Remote sensing satellites can today offer real-time warning, issuing a notice within 3 minutes of detecting a wildfire.[9] Efforts are currently underway to leverage remote sensing data to train algorithms to detect areas at high risk of wildfires and facilitate the implementation of early preventive measures [10].

WILDFIRE • Valparaiso, Chile • Optical • Planet Labs PBC

WILDFIRE • Lahaina, Hawaii • Two-Color Multiview • Umbra

Environmental monitoring and resource management

In addition to risk and disaster management and response, satellite remote sensing contributes significantly to environmental monitoring and resource management. Satellites can help track deforestation, assess land use changes, and measure agricultural productivity. This information is invaluable for governments and organizations working on sustainable land management and conservation efforts. Additionally, satellite data aids in the efficient management of water resources, enhancing agricultural practices, and mitigating the impact of climate change. These applications translate into economic benefits by increasing agricultural yields, ensuring sustainable resource utilization, and reducing the costs associated with environmental degradation. In essence, satellite remote sensing is a vital tool that empowers societies to make informed decisions, leading to improved environmental sustainability, and economic growth.

1.3. GRACE mission

A clear example of the need for satellite data for climate monitoring is GRACE, a joint mission between the German Space Agency at the German Aerospace Center (DLR) and the US space agency, NASA. GRACE is an environmental satellite mission that has recently been extended with GRACE-C. The data sets from the missions GRACE (2002-2017) and GRACE-FO (2018 until now) are now one of the foundations for the reports created by the Intergovernmental Panel on Climate Change (IPCC). The data from these satellites has been used for decades, among other things, to obtain an accurate picture of the groundwater levels and the global water balance [12,13].

1.4. Remote sensing for food security and agriculture enhancement

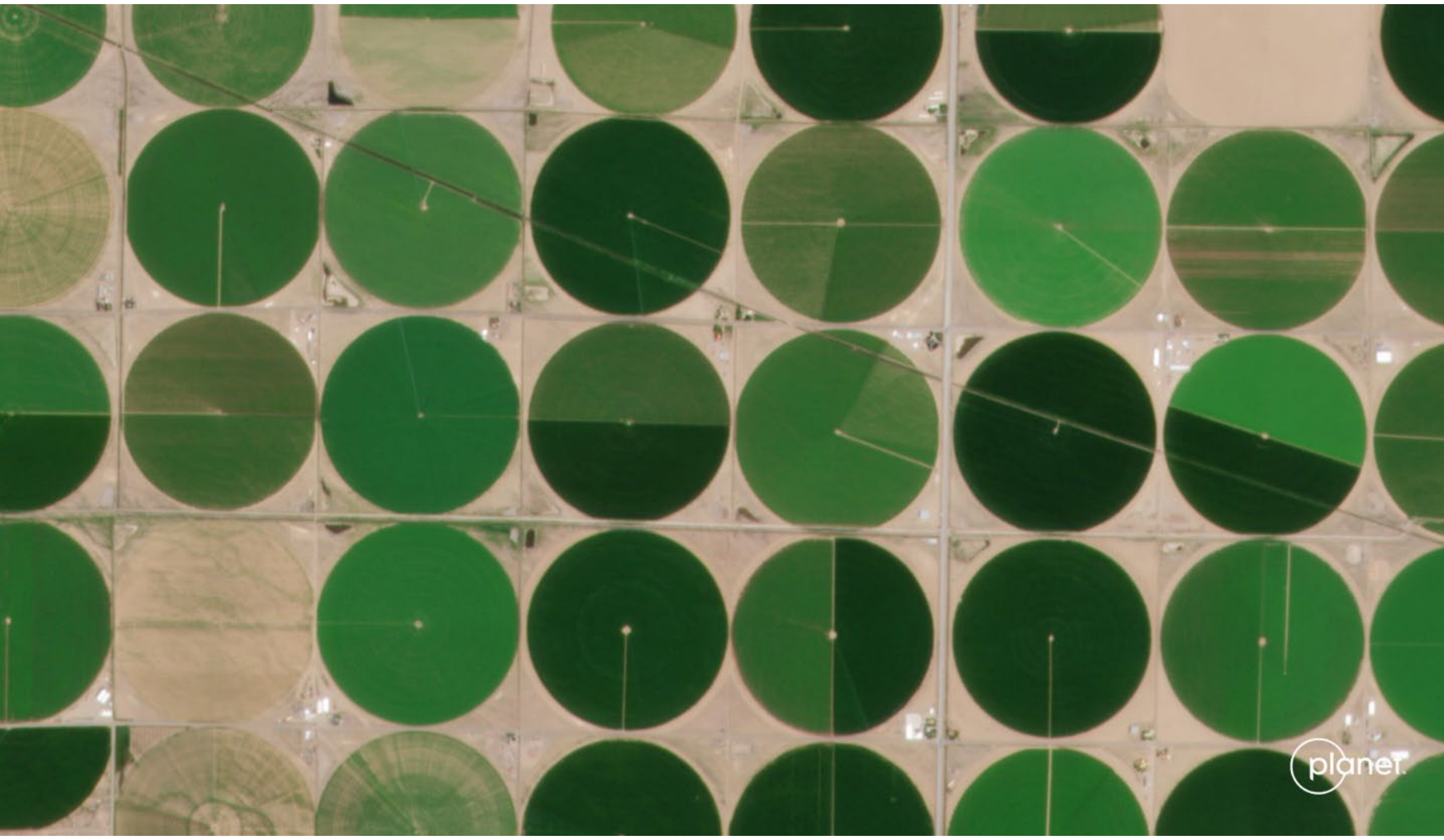
Space-based data can be used to enhance agricultural yields and ensure food security, with satellite operators providing access to data and imagery to relevant Ministries and Agencies globally and helping farmers to better assess crop health and more precisely utilize water and chemicals such as pesticides. An example of this can be the case of the Netherlands Space Office supporting Ugandan farmers via the MUIIS project, delivering weather forecasting information applied to agricultural practices and advice. [14] Remote sensing data is being used extensively by public and private actors to track and monitor status of soil quality worldwide, mapping vegetation and moisture, and enabling precision farming. [15]

1.5. Optimisation of maritime routes and fuel efficiency

Remote sensing technology is crucial in reducing carbon emissions and supporting the maritime industry's shift towards sustainability. For instance, DeepSea and Spire Global have partnered to utilise remote sensing data to help DeepSea's vessels identify the most fuel-efficient routes and improve vessel-specific performance models by predicting the impact of weather and nautical conditions on fuel consumption. This collaboration resulted in approximately $11 billion in annual global fuel cost savings and a 57 million tons of carbon emissions reduction by optimising voyages to avoid unfavourable weather conditions. These valuable advancements in maritime efficiency and environmental impact reduction were made possible through satellite-based sensors.

1.6. Identifying and developing offshore wind solutions

To support global decarbonization efforts, remote-sensing data is utilised to pinpoint optimal locations for offshore wind farms. Offshore wind solutions play a vital role in generating the clean energy necessary for transitioning to a carbon-neutral economy. The European Union has committed to achieving a capacity of 60 GW for offshore wind by 2030. Accurate ocean condition forecasts derived from remote-sensing data are essential for ensuring operational efficiency and crew safety during the planning, construction, operation, and maintenance of offshore wind farms.



AGRICULTURE • Rio Grande County, Colorado • Optical • Planet Labs PBC

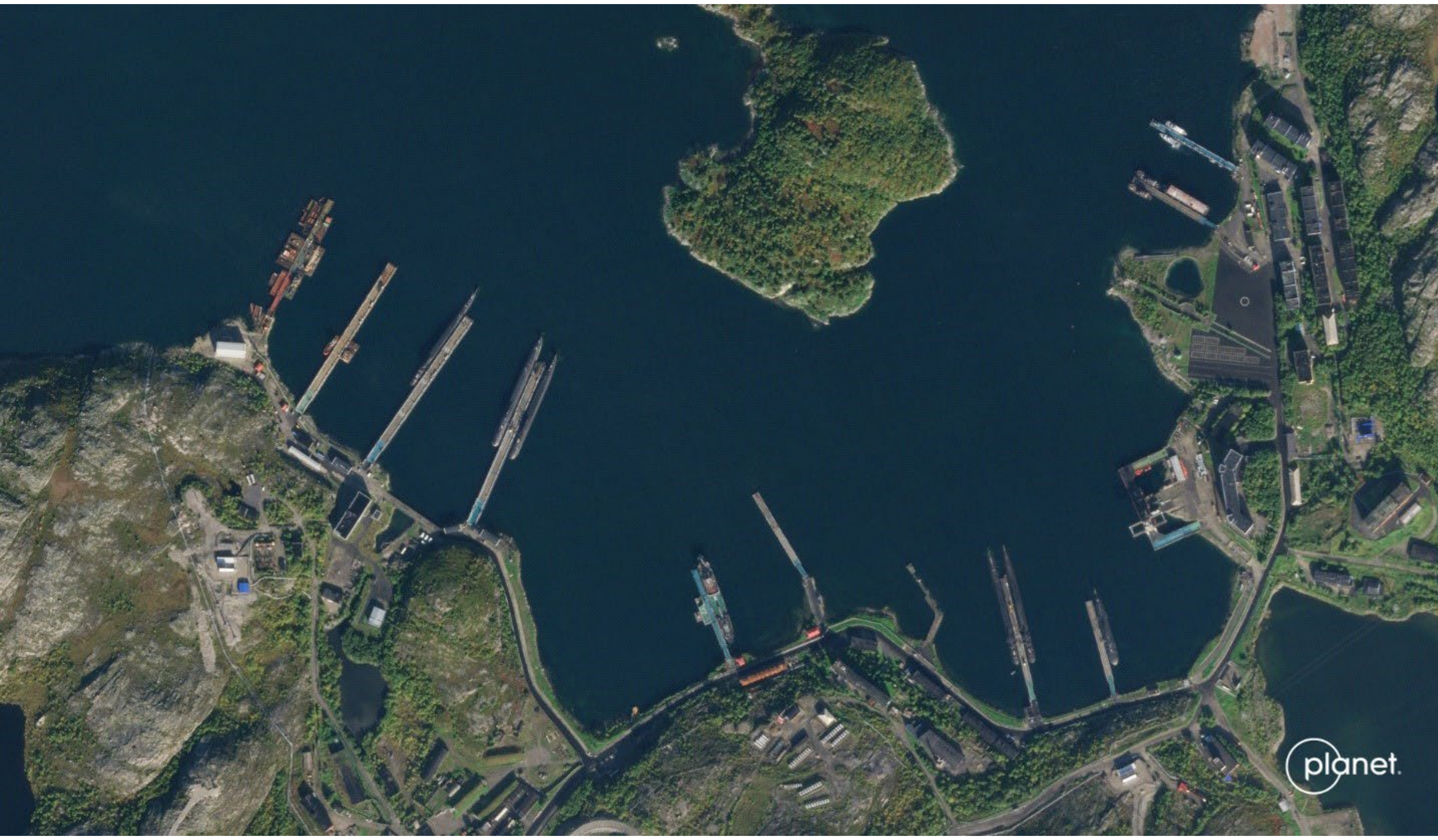
Security and Safety from Space

In addition to its socioeconomic advantages, satellite remote sensing also plays a crucial role in enhancing national and global security. Satellites provide vital information for monitoring and responding to security threats, illegal activities, and humanitarian crises. They enable governments, researchers, think tanks, journalists, and other organizations, to track movements of people and goods, detect illegal fishing and logging, or monitor the proliferation of weapons of mass destruction or compliance with international treaties. This data not only aids in preventing security breaches but also assists in rapid response and disaster relief operations, contributing to the stability and security of regions affected by conflicts or natural disasters. Overall, satellite remote sensing significantly bolsters security efforts at both national and international levels, safeguarding societies and economies from various threats.

PORT • Sevastopol, Crimea • Optical • Planet Labs PBC

1.7. Transparency from global actors

Satellite remote sensing, combined with open source and transparency policies, significantly contributes to holding international actors accountable. High-rate revisit remote sensing satellites, for instance, enable stakeholders to hold accountable international partners and actors in the face of denied accidents or unclaimed events, that can be visible and verifiable from space thanks to remote sensing satellites. [18]



SUBMARINE BASE • Murmansk Oblast, Russia • Optical • Planet Labs PBC

1.8. Monitoring and mapping of illegal fishing activities

Satellite remote sensing data is an essential and unique source to map, track and fight illegal fishing activities. A combination of remote sensing techniques and AI has brought to light how 75% of the world's industrial fishing vessels are hidden from public view, [16] and RF-monitoring satellites have been deployed to triangulate and track RF transmissions not detectable by existing maritime Automatic Identification Systems. [17]

1.9. Humanitarian Aid

Satellite imagery is utilized by a multitude of organizations to facilitate humanitarian aid response, helping in for the identification of mass refugee movements, defining new sites for refugee camps, and organizing logistic response such as on-site food distribution, among other things. One example of this application is the UN World Food Programme (WFP)'s SKAI project [65], the tracking of Sudanese refugees by the UN High Commissioner for Refugees (UNHCR)[66], or the European Union Satellite Centre (EU SatCen) GeoInt products [67].

APPENDIX 2 – Remote Sensing Satellites Support the Achievement of the UN SDGs

The commercial satellite remote sensing industry leverages innovative technology to facilitate global sustainability and improve efforts such as natural resource conservation and management. [19] Satellite remote sensing is vital in achieving the UN SDGs, as illustrated by the following examples:

- **SDG 1: No Poverty.** Remote sensing satellites can enable early warning and mitigation of events that can impact and further worsen the condition of the poorest global population, as represented by initiatives such as the International Disaster Charter. [8]
- **SDG 2: Zero Hunger.** Satellite data can be leveraged to identify drivers of food insecurity throughout the world, for example allowing early warning of potential food shortages and identification of areas that need help. Satellite remote sensing data can also provide information on soil temperature and soil water content, allowing farmers to optimize fertilizer and water usage. Crop monitoring and yield estimation are also possible through the use of satellite remote sensing data and analytics. [20]

SOIL WATER CONTENT • Oklahoma & Kansas, USA • Derived Data Product • Planet Labs PBC

FLOODING • Luuq, Somalia • Optical • Planet Labs PBC

- **SDG 3: Good Health and Well-Being.** Using population and area-mapping data provided by satellites, efforts have been successful in providing healthcare in marginalized communities. For example, satellite data has been used to update maps of remote areas and track areas missed during a vaccination campaign. Remote sensing satellites can also generate data useful for air quality monitoring and researching environmental factors that influence the spread of disease. [19]
- **SDG 4: Quality Education.** Remote sensing satellites provide data on adequate classroom space to support governments in improving access to high-quality education in rural areas. For example, the Centre for Environment and Sustainability used remote sensing satellites together with Nigerian government data to find that 81.4% of 1900 randomly selected schools across 19 Nigerian states were overcrowded according to the minimum standard threshold for school size of at least 1.2 m^2 of classroom space per pupil defined by the Federal Government of Nigeria. [21]
- **SDG 5: Gender Equality**. Remote sensing satellites are used to document data on gender vulnerability in remote and dangerous areas. For example, data is collected on three populations of women living in various states of vulnerability: those experiencing forced migration, those living in refugee camps, and smallholder farmers. NGOs and governments use such data to identify situations where there is an elevated risk of gender inequality and design equitable interventions accordingly. [22, 23]

- **SDG 6: Clean Water and Sanitation**. Remote sensing satellites aid in water resource management by monitoring water bodies, assessing water quality, and identifying changes in water availability, which is essential for managing water resources sustainably. With this data, actors can monitor global water cycles, map water courses, and mitigate the effects of floods and droughts. For example, to mitigate the effects of drought, HE-Delft funded the ITSET and SIML project, to use multispectral and thermal satellite imagery, local weather data, and farmer-supplied agricultural data for estimating crop water use in near real-time at the agricultural field scale. [24, 25, 26, 27, 28]
- **SDG 7: Affordable and Clean Energy.** Remote sensing data is used as an indicator to address sustainable energy investments and rural electricity access needs by identifying optimum photovoltaics investment locations, optimum small hydropower plant sites, CAM plant cultivation locations, and to map remote off-grid homes for improvement of energy access. For example, aboard the NASA/NOAA Suomi National Polar-orbiting Partnership (NPP) satellite mission, images were captured at night to measure access to electricity and to track the progress of electrification, particularly in fragile and conflict-affected countries where household surveys and censuses are conducted infrequently and irregularly, leaving substantial data gaps. [29, 30]

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- **SDG 8: Decent Work and Economic Growth**. For countries that lack traditional data sources and indicators, particularly at the local level, remotely sensed satellite imagery can be utilized to assess changes in economic outcomes, which can be translated into employment data. Harnessing such information is valuable in analyzing economic shocks from events and highlighting the impacts of interventions targeted at increasing employment, including investments in infrastructure. For example, the International Labour Organization's STRENGTHEN2 project uses remote sensing data to assess the long-term impacts of infrastructure investments in sub-Saharan Africa. [31]
- **SDG 9: Industry, Innovation, and Infrastructure**. Governments and private companies use remote sensing satellites to support infrastructure development by documenting data for construction, planning, and monitoring. SDG indicator 9.1.1 - rural access to roads - measures the proportion of a country's rural population that lives within two kilometers' walking distance of an all-season road. The metric for assessing rural populations' access to transport consistently across countries and time is based on three sets of remote sensing data: where people live, the spatial distribution of the road network, and road quality. For example, CIESIN calculated this metric for Nigeria, Colombia, and Spain using openly available road data from OpenStreetMap (OSM, via Geofabrik) and gridded population data from the High-Resolution Settlement Layer (HRSL, via HDX) and the Global Human Settlement Layer (GHS-POP). [33, 34]
- **SDG 10: Reduced Inequalities**. Remote sensing satellites allow the mapping of socioeconomic data at different spatial scales. By overlaying demographic, economic, and social indicators onto maps, inequalities can be identified. For example, the Guangzhou Urban Planning & Design Survey Research Institute used remote sensing satellites to identify regions with high poverty rates, gender imbalances, or limited access to healthcare and education. This data was vital in ensuring equitable access to essential healthcare, education, and clean water services. By mapping the distribution of these services and overlaying them with demographic data, decision-makers could identify underserved areas and plan for the establishment of new facilities. [35, 36]
- **SDG 11: Sustainable Cities and Communities.** Satellite imagery data is helpful for urban planning, both revealing how development has occurred and identifying areas where future development is likely to be focused. Satellite remote sensing imagery can also assist in detecting new structures and monitoring for environmental compliance, site selection for new infrastructure builds, and assessing changes in vegetation health, ground water, and human activity. [37, 38]
- **SDG 12: Responsible Consumption and Production.** Remote sensing data is crucial in improving supply chain management by enabling companies to map their supply chains, identify potential bottlenecks, and assess the environmental impact of their operations. By incorporating remote sensing data into decision-making processes, businesses can optimize transportation routes, reduce emissions, and ensure responsible sourcing practices, thus promoting sustainable production and

consumption. For example, the company EY, an advanced manufacturing and mobility supply chain leader, used remote sensing data to improve their supply chain during the COVID-19 Pandemic to anticipate customer demand while maintaining the flow of goods through key ports. [39, 40, 41]

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- **SDG 13: Climate Action.** Remote sensing satellites can contribute to global monitoring of greenhouse gas emissions, detecting carbon emissions and methane leaks. [42, 43, 44, 45]
- **DG 14: Life Below Water.** Remote sensing satellites provide improved maritime domain awareness, identify changes in arctic sea ice, and identify human behavior, such as illegal fishing, in remote marine domains. [17, 45]
- **SDG 15: Life on Land.** Commercial satellite imagery and data is leveraged to monitor forests, identify illegal deforestation, and detect forest fires, preventing biodiversity loss and promoting carbon sequestration. Remote sensing satellites can also be used to identify poaching activity over large areas, which allows for better use of limited interdiction resources to preserve wildlife and biodiversity. [46, 47, 48]
- **SDG 16: Justice.** Satellite remote sensing can be effectively employed to promote peace, stability, human rights, and good governance based on the rule of law, enabling numerous non-governmental organisations (NGOs), open-source investigation initiatives, international organisations, domestic, regional, and international (human rights and criminal) courts, and governments to gather evidence of human rights and public international law violations. For example, the Bellingcat Open-Source initiative aims to use open-source information, including remote sensing imagery from Planet, to combat disinformation about conflicts globally. Bellingcat has used access to remote sensing satellites to identify burnt villages in Nigeria and Myanmar to expose evidence of human rights abuses. [49]
- **SDG 17: Partnership for the Goal.** Satellite remote sensing enables international stakeholders to monitor and measure progress towards achieving the SDGs. Remote sensing operators, private and public alike, have opened up part or the entirety of their collected data, enabling collaboration and exploitation of said data for this purpose and fostering an ecosystem of public and private exchange of information. A satellite was specifically developed and launched for this purpose. [50]

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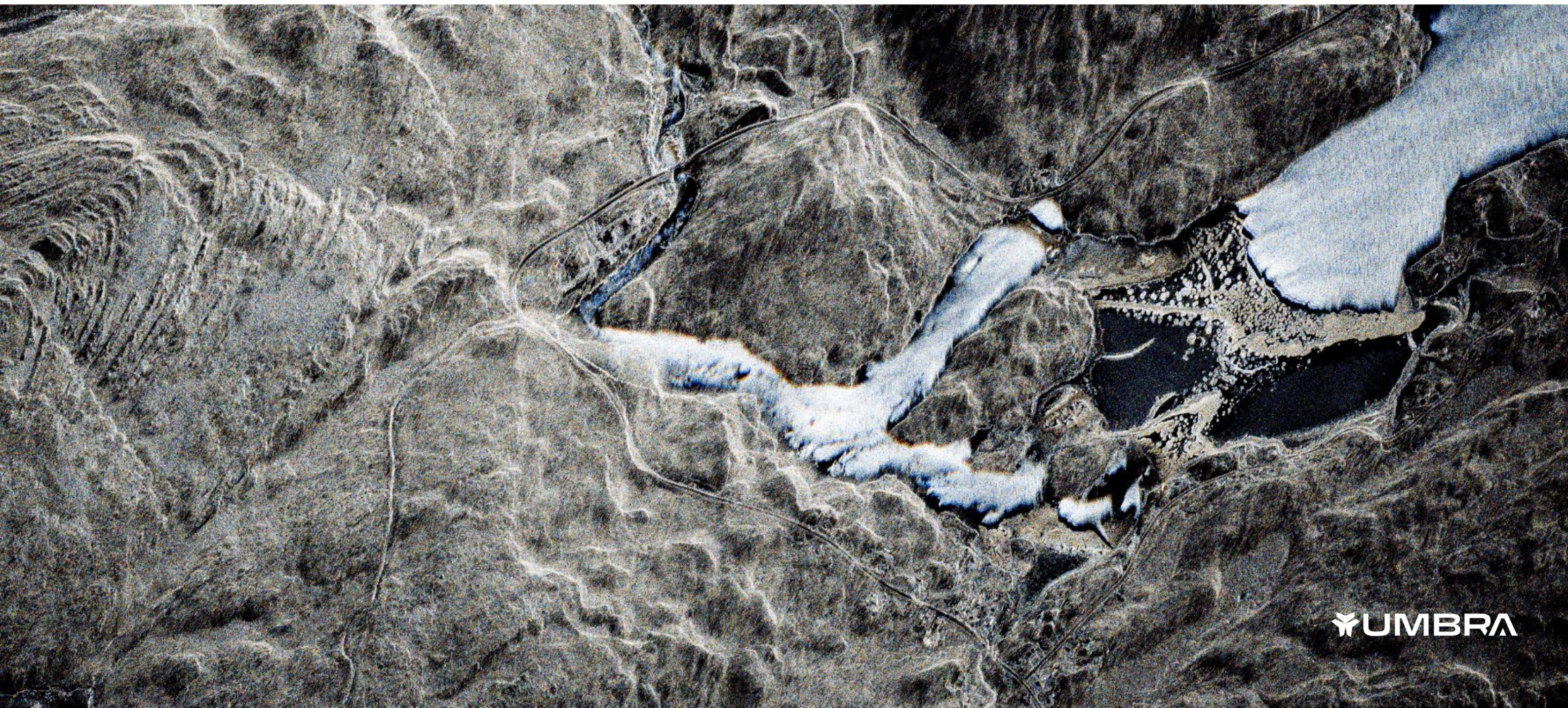

Acronyms

Acronym	Definition
AI	Artificial Intelligence
CAM	Crassulacean acid metabolism
CEPT	Conference of European Postal and Telecommunications Administrations
CIESIN	Center for International Earth Science Information Network
COPUOS	Committee on the Peaceful Uses of Outer Space
DLR	German Aerospace Center
ECC	Electronic Communications Committee (of the CEPT)
EESS	Earth Exploration Satellite-Service
EIRP	Equivalent Isotropic Radiated Power
EO	Earth Observation
ESA	European Space Agency
EU	European Union
EUSPA	European Union Space Programme Agency
FCC	Federal Communications Commission
FSS	Fixed Satellite Service
GDP	Gross Domestic Product
GSOA	Global Satellite Operator's Association
IFIC	International Frequency Information Circular
IMT	International Mobile Telecommunication
IPCC	Intergovernmental Panel on Climate Change
ITU	International Telecommunication Union
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OFCOM	(British) Office of Communications
RF	Radio Frequency
RR	Radio Regulations
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goal
SFCG	Space Frequency Coordination Group
SOS	Space Operation Service
SRS	Space Research Service
TT&C	Telemetry, Tracking and Control
UCS	Union of Concerned Scientists
UHF	Ultra-High Frequency
UN	United Nations
WHO	World Health Organization
WRC	World Radiocommunication Conference

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