UK Earth Observation – International EO Programmes

Prepared for the Satellite Applications Catapult and the Space Partnership by Red Kite Management Consulting

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This report reviews international Earth Observation (EO) programmes, upstream and downstream, and draws learnings to inform UK EO policy and strategy.

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The Red Kite Team

Red Kite Management Consulting

- Lead: Robin Tucker
- Strategy, marketing, public policy
- Knowledge of space application markets: telecoms, transport, agri/environment

Connected Economics

- Lead: Dominic Walley
- Economics, data and public policy
- Experience with space, related markets and regional development

Commercial Space Technologies

- Lead: Alan Webb
- Launch and satellite industry experts for over 35 years
- Contacts through space & supplier industry

Red Kite Management Consulting Limited
www.redkiteconsulting.uk, info@redkiteconsulting.uk, +44 (0)1865 507500

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Executive Summary

The use of satellite technology has revolutionised the way we study and understand the Earth's environment and natural resources. Satellite programmes are launched by both public and private sectors, with a diverse range of applications such as monitoring climate change, natural disasters, and human activities.

International Earth Observation (EO) programmes show great diversity, both in the upstream and the downstream. Their aims include national or international technology development, broader national goals (e.g. national security or economic development) and/or commercial gain – usually in combination.

The most successful have a clearly defined purpose, provide new data or insights, often use the latest technology, establish partnerships, and adopt a user-focused approach to ensure their outputs are of maximum value. Funding is achieved through many approaches, but a state (or group of states) is usually the core funder – either directly, in partnership, or increasingly by being an anchor customer, but enabling the supplier to sell to other customers as well.

Taking a view of international EO programmes and capabilities

This study aims to inform policy and strategy decisions about the UK's Earth observation programmes. To make best use of the limited resources available, we focused on programmes that we considered had something to show in their business models and linkage to policy, and towards operational programmes, rather than satellites aimed more at research and technology development (although many are a mix). We catalogue a wider range of programmes in an Annex for completeness.

- First we examine six contrasting satellite programme case studies that cover a range of funding and benefits, that we consider relevant to decisions to be made in the UK. These are:
    - **Copernicus** – the EU Earth observation programme, including a focus on its non-EU partners
    - **ICEYE** – a business of Finnish origin, with a small, high-resolution SAR constellation
    - **Spire Global** – a US nanosat constellation specialising in maritime, aviation and weather markets, with state anchor customers
    - **Planet** – a large US constellation business aiming to provide medium resolution imagery at high cadence
    - **Airbus** – the once national, now commercial EO programmes of the European aerospace multinational
    - **CHEOS** – the China High-resolution Earth Observation System, which is available to commercial and state customers
- A brief note on **national satellite programmes**
- We review **nine Downstream-only businesses and programmes** in brief, to give a sense of the range of capabilities, funding models and possibilities of these programmes.
- In an Annex we list 59 EO satellite programmes, from nations across the globe.

At the end of the report are **learnings and conclusions** drawn from the trends and case studies, that are relevant to UK decisions.

International Satellite Programmes

Copernicus

The Copernicus programme is a joint initiative of the European Union (EU) and the European Space Agency (ESA). It is a comprehensive Earth observation programme that provides data on a range of environmental factors, including land use, climate change, and natural disasters.

Sentinel 2 satellite imagery of Abu Dhabi, January 27, 2019

Origin:

The Copernicus programme, after the famous astronomer Nicolaus Copernicus, was established in 2014. It was built on the previous EU's Earth monitoring initiative Global Monitoring for Environment and Security (GMES). [1]

Funding:

The Copernicus programme is funded by the European Union (EU) through its multi-annual financial framework. The EU provides funding for the development and operation of the satellite infrastructure, as well as the collection and distribution of data. In addition, member states of ESA contribute to the programme's funding through their membership fees.

User Base:

The Copernicus programme has a global range of users, including government agencies, research institutions, private companies, and any citizen in the world. Many of these use Copernicus data as the basis of their own products, for their own user bases, with the expected future longevity of Copernicus and open access to data underpinning the business model.

International Usage:

The Copernicus programme has gained international recognition and has been used by various organizations around the world.

The programme has also been used to support environmental monitoring efforts in developing countries. In 2018, ESA partnered with the African Union to provide data on land use and deforestation in Africa, helping to inform policy decisions and support sustainable development in the region.[2]

In addition, the Copernicus programme has been used to support global climate change monitoring efforts. In 2020, ESA launched a new Copernicus satellite, Sentinel-6 Michael Freilich, which is designed to provide data on sea level rise and ocean circulation patterns, helping to improve our understanding of climate change impacts on the oceans.[3]

Overall, the Copernicus programme demonstrates the potential for Earth observation programmes to provide critical data for environmental monitoring and disaster response efforts. With its wide user base and international usage, the programme has become a leading example of the growing trend of global satellite programmes for environmental monitoring and climate change research.

[1] https://op.europa.eu/en/publication-detail/-/publication/7b511d06-becf-4a8b-b2fa-adc08c1a79d9

[2] https://www.un-spider.org/news-and-events/news/african-union-signs-cooperation-arrangement-eu-copernicus-programme

[3] https://www.sciencedirect.com/science/article/pii/S0034425721001139?via%3Dihub

Copernicus’ non-EU Partners

The Copernicus programme is an ambitious and complex project that requires close cooperation and collaboration among its partners. While the programme is led by the European Union (EU), it also involves participation from non-EU countries. These countries participate in Copernicus to learn lessons and identify partnership opportunities, which can help them in their own efforts to monitor and manage the environment and natural resources.

One such example is the United States, which became a partner in Copernicus in 2015. The US has a long history of space exploration and has developed advanced satellite technology and data analysis capabilities. By participating in Copernicus, the US can share its expertise with EU partners and learn from them as well. For instance, the US has contributed to the development of Copernicus' land monitoring services, which provide detailed information on land use and land cover changes over time.

Similarly, Australia also became a partner in Copernicus in 2015. The country faces unique environmental challenges, such as drought and bushfires, and the Copernicus programme can help Australia monitor these issues in real-time. Additionally, the programme can assist with marine and coastal monitoring, which is important for Australia's fishing and tourism industries.

Other non-EU countries that have joined the Copernicus programme include India, Ukraine, Serbia, the African Union, Canada, Panama, and Japan.[4] These countries bring their own expertise and experience to the programme and can benefit from the resources and knowledge available through the EU partnership. The partnership also provides opportunities for joint research projects and data-sharing initiatives, which can help improve environmental management and policymaking.

Additionally, Switzerland has played a role in the Copernicus programme, despite not being a member of the EU. Switzerland was a contributing member between 2014 and 2020, then left, but has since sought to rejoin. “Association to Copernicus would allow Switzerland to have a say in shaping the programme, ensure access to this data in the long term and allow industry to participate in the programme's procurements,” according to a government statement in February 2022..[5]

Previously, Swiss company RUAG Space (now Beyond Gravity) had won contracts to supply navigation systems and computers for Copernicus satellites[6,7].

RUAG Space computer assembly

In both cases, association to Copernicus is important for access to data and the ability to shape the programme. This would also enable industry in both countries to participate in the programme's procurements, providing opportunities for collaboration and the exchange of expertise. The frosty ties between Switzerland and the EU highlight the complex and interdependent nature of European cooperation.

Two non-EU countries, India and Korea, have used their satellite programmes to join Copernicus as ‘Copernicus Contributing Missions[8]’. India’s ResourceSat (e.g. IRS-R2) and Korea’s Kompsat series. These supply data to Copernicus services, and allow those nations to benefit from those services.

Overall, the participation of non-EU countries in the Copernicus programme, such as the United States, Australia, India, Korea, Ukraine, Serbia, Canada, and Switzerland, is a testament to the importance of international cooperation in addressing environmental challenges. By working together and sharing expertise and resources, countries can better understand and manage their natural resources and protect the environment for future generations.

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[4] https://www.copernicus.eu/en/international-cooperation-area-data-exchange

[5] https://www.swissinfo.ch/eng/politics/switzerland-wants-to-join-eu-copernicus-scheme/47356240

[6] https://evertiq.com/news/44374

[7] https://news.satnews.com/2020/10/29/ruag-space-computer-will-control-esas-sentinel-6-satellite/

[8] https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_contributing_missions

ICEYE

ICEYE is a Finnish Earth observation company that provides radar satellite imaging services to government agencies, commercial entities, and other organizations around the world. Its satellite program, also known as ICEYE, is a constellation of small Synthetic Aperture Radar (SAR) satellites that provide high-resolution imaging data.[9]

Image of the container ship Ever Given stuck in the Suez Canal, acquired by an ICEYE SAR satellite.

Origin:

The ICEYE satellite program originated with a univeristy project in 2012, and led to a proof-of-concept satellite in 2018, It was the world's first SAR satellite weighing less than 100 kilogrammes[10] and validated ice detection using SAR.[11]. The company was founded in 2014 as a spin-off of Aalto University's Radio Technology Department, and is headquartered in Espoo, Finland.

Funding:

ICEYE has received funding from various sources to support the development and launch of its satellite constellation. In 2015, ICEYE received $2.8m from EU Horizon R&D funding and $2.8m from True Ventures and other partners[12]. In 2017, funding was raised from the Finnish Funding Agency for Innovations and a $8.5m round led by Draper Nexus. It also received an €10m loan from Business Finland for satellite manufacturing capital[13]. Following further rounds led by True Ventures and Seraphim Space. ICEYE has raised a total of $304M in financing since 2015[14]

User Base:

Government agencies, business enterprises, and other organisations in marine, defence, and disaster response use ICEYE's products.They have adapted to manufacture, launch and operate satellites in the USA, to win US government contract including the NRO and US Army.[15]

International Usage:

The ICEYE satellite program has gained international recognition and has been used by various organizations around the world. In 2021, ICEYE partnered with the European Space Agency (ESA) to contribute to Europe's Copernicus environmental monitoring programme.[16] In addition, ICEYE has partnered with a range of companies and organizations in the United States, Europe, and Asia to provide SAR imaging services for various applications.

Overall, the ICEYE satellite program demonstrates the potential for small SAR satellite constellations to provide reliable and affordable imaging services for a variety of industries and applications. With its diverse user base and international usage, the program has become a leading example of the growing trend of small satellite networks for Earth observation and imaging.

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[9] https://www.eoportal.org/satellite-missions/iceye-constellation#mission--development-status-of-the-iceye-x-satellite-constellation

[10]https://web.archive.org/web/20180117070229/https://nordic.businessinsider.com/finnish-startup-iceye-just-launched-worlds-first-sar-microsatellite-into-orbit--/

[11] https://onepetro.org/OTCARCTIC/proceedings-abstract/16OARC/All-16OARC/OTC-27447-MS/84814

[12] https://www.iceye.com/company

[13] https://www.iceye.com/press/press-releases/iceye-receives-10-million-euro-capital-loan-business-finland-to-initiate-internet-of-locations

[14] https://www.iceye.com/press/press-releases/iceye-raises-usd-136m-in-series-d-funding-round

[15] https://www.iceye.com/en-us/

[16]https://www.esa.int/Applications/Observing_the_Earth/Copernicus/ICEYE_commercial_satellites_join_the_EU_Copernicus_programme

Spire Global

Spire Global, Inc., formerly NanoSatisfi Inc., is a San Francisco-based company that specializes in providing data and analytics services through its network of small satellites.[17] One of Spire's most prominent satellite programs is the Lemur program, which is a constellation of small CubeSats that collect data on various environmental factors, including weather patterns, shipping traffic, and radio signals. These satellites are designed and built in-house at their Glasgow offices

Spire Global's AIS data

Origin:

Building off of the first US commercial sat deployed from the ISS, the Lemur program began in 2015 when Spire was founded by Peter Platzer, Joel Spark, and Jeroen Cappaert. The company's goal was to "demoncratise access to space"

Funding:

Initially funded as a Kick-Starter, Spire has received funding from several sources to support the development and launch of the Lemur program. In 2015, the company raised $40 million in a funding round led by Promus Ventures, with participation from Bessemer Venture Partners and Jump Capital.[18] Spire was awarded a contract by NOAA in 2016 to demonstrate the potential of commercial data to enhance NOAA's meteorological models as part of the Commercial Weather Data Pilot programme. The experiment was a success, and NOAA has become an anchor customer.[19,20] In 2019, Spire raised an additional $40 million in a funding round led by Seraphim Capital, with participation from Mitsui & Co. Ltd. and others.[21]

User Base:

Spire's Lemur program has a diverse user base, including governments, private companies, and research institutions. The data collected by the Lemur satellites can be used for various purposes, such as weather forecasting, maritime surveillance, and telecommunications.

International Usage:

The Lemur program has gained international recognition and has been used by various organizations around the world. In 2019, Spire partnered with the European Space Agency (ESA) to provide data on ship tracking.[22] The data collected by the Lemur satellites helped improve the safety of shipping routes in the region.

Overall, the Spire Lemur program demonstrates the potential for small satellite constellations to provide affordable and accessible data services for a variety of industries and applications. With its diverse user base and international usage, the program has become a leading example of the growing trend of small satellite networks for data collection and analytics.

[17] https://spire.com/
[18] https://spacenews.com/spire-raises-40-million-for-weather-satellite-constellation/
[19] https://www.space.commerce.gov/noaa-awards-commercial-space-weather-pilot-contracts/
[20] https://ir.spire.com/news-events/press-releases/detail/134/spire-global-awarded-4-million-noaa-contract-to-deliver
[21] https://seraphim.vc/news/https-seraphimcapital-passle-net-post-102frn8-spire-globals-series-d-funding/
[22]https://earth.esa.int/eogateway/documents/20142/37627/Spire-Product-Guide.pdf

Planet

Origin:

Planet, formerly Planet Labs nee Cosmogia,, is a San Francisco-based company that was founded in 2010 by three former NASA scientists.[23] The company aims to moniter the entire earth daily and to provide provide online access to images used for climate monitoring, crop yield prediction, urban planning, and disaster response - including the acquisition of BlackBridge and Google's Terra Bella's SkySat satellite constellation Planet has over 450 satellites launched and 150 active.

SkySat (Terra Bella) imagery of deforestation in Peru

Funding:

Planet has raised more than $570 million in funding from investors, including venture capital firms, corporate partners, and strategic investors.[24] Planet also secured contracts with NASA and the National Oceanic and Atmospheric Administration (NOAA), which provided funding for the company's satellite projects.[25]

User Base:

Planet's satellite program is used by a variety of customers, including governments, non-governmental organizations (NGOs), and commercial businesses. Some of the key users of Planet's satellite data include:

Governments: Planet's data is used by governments for a range of applications, such as monitoring crop yields, tracking deforestation, and assessing infrastructure damage after natural disasters.

NGOs: NGOs use Planet's data to monitor environmental changes and assess the impact of humanitarian crises.

Commercial businesses: Planet's data is used by businesses for a variety of purposes, such as monitoring supply chains and assessing the impact of weather events on their operations.

International Usage:

Planet's satellite data is used by customers in more than 100 countries around the world. Some examples of international usage of Planet's data include:

Forest monitoring: Funded through Norway's Climate & Forest Initiative (NICFI) and FAO's Framework for Ecosystem Monitoring - Planet's data is used to monitor deforestation in 64 countries[26][27]

Disaster response in Mexico: After a 7.1 magnitude earthquake struck Mexico City in 2017, Planet provided satellite data to help with the disaster response efforts.[28]

Land Use in India: Planet's data is used to monitor unauthorised land use and encroachment[29]

Conclusion:

Planet's satellite program has revolutionized the satellite industry by developing a low-cost, high-frequency imaging system that has enabled customers, including various agencies of the US government, including the FAS, NOAA, Oak Ridge, Sandia, the Bureau of Reclamation, and NASA,[30] to monitor the Earth's surface in near-real-time. The international usage of Planet's data demonstrates the company's ability to provide value to customers around the world

[23] https://web.archive.org/web/20160304224114/https://www.wired.co.uk/news/archive/2013-08/13/planet-labs-nanosatellites

[24] https://www.crunchbase.com/organization/planet-labs

[25] https://www.earthdata.nasa.gov/news/planet-contract-extension-2022

[26] https://www.bbc.com/news/science-environment-54651453

[27] https://www.bbc.com/news/business-62264710

[28] https://www.planet.com/disaster/earthquake-in-mexico-2017-09-20/

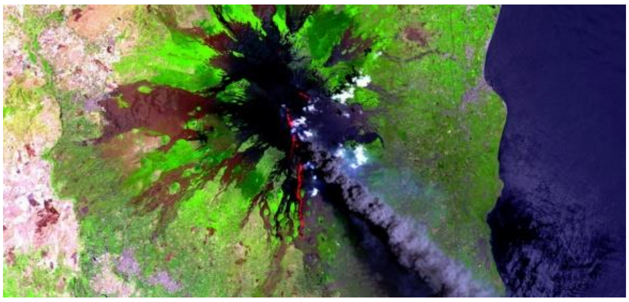
[29] https://www.planet.com/pulse/using-satellite-data-to-spot-early-signs-of-unauthorized-government-land-use-and-encroachment-in-india/

[30] https://www.gao.gov/assets/gao-23-106042.pdf

Airbus (SPOT and Pleiades)

Origin:

Airbus's Earth Observation satellite programmes, which include Pléiades, SPOT, WorldDEM, and a number of national satellites (Vietnam, Chlie, Peru) are a part of the company's broader space sector efforts.[31] Pléiades was introduced in 2011, although SPOT and WorldDEM have been in existence since the 1980s.



SPOT imagery of Mount Etna

Funding:

Airbus's commercial EO business began with public sector-funded projects such as SPOT[32] and Pleiades, through CNES and ORFEO respectively. However, later projects such as SPOT 6 and 7, and the recent Pleiades Neo constellation,[33] are funded solely by Airbus, demonstrating their confidence in revenues from both public and commercial sources.

User Base:

Airbus's satellite programmes have a diverse user base, including government agencies, military organizations, commercial businesses, and academic institutions. Some of the key users of Airbus's satellite data include:

Governments: Airbus's satellite data is used by governments for a variety of applications, including intelligence gathering, defense and security, and environmental monitoring.

Military organizations: The military uses Airbus's satellite data for reconnaissance and surveillance missions.

Commercial businesses: Airbus's satellite data is used by businesses for a range of applications, including agriculture, mining, and oil and gas exploration.

Academic institutions: Airbus's satellite data is used by academic institutions for research and teaching purposes.

International Usage:

Airbus's satellite data is used by customers around the world, including in Europe, Asia, Africa, and the Americas. Some examples of international usage of Airbus's satellite data include:

Environmental monitoring in China: Airbus's SPOT satellite imagery is used to monitor environmental changes in China, such as deforestation and desertification.[34]

Defense and security in Europe: Airbus's satellite data is used by European military and security organizations for surveillance and intelligence gathering.[35]

Digital Earth Africa: Airbus's WorldDEM data is used as the basis for many Digital Elevation Models, including the open project Digital Earth Africa.[36]

Conclusion:

Airbus's EO satellite programmes have a diverse user base and are used for a range of applications around the world. They have made a transition from being funded by government programmes to funding their own EO satellites and offering imagery and data services to defence, other public and commercial customers. The international usage of Airbus's satellite data demonstrates the company's ability to provide value to customers around the world.

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[31] https://www.airbus.com/en/products-services/space/earth-observation/satellite-imagery
[32] https://earth.esa.int/eogateway/missions/spot-6/description
[33] https://www.intelligence-airbusds.com/newsroom/news/what-does-airbus-pleiades-neo-bring-to-the-geospatial-market/
[34] https://www.sciencedirect.com/science/article/abs/pii/S0140196306000735
[35] https://www.joint-forces.com/space-and-aero/60956-airbus-to-provide-optical-satellite-system-to-poland
[36] Digital Earth Africa

China High-resolution Earth Observation System (CHEOS)

Origin and Funding:

The China High-resolution Earth Observation System (CHEOS) satellite programme[37] was initiated in 2006 by the Chinese government to develop an advanced Earth observation system providing high-quality images for civil and military purposes. The project was guided by the Chinese Academy of Sciences (CAS), in collaboration with the Ministry of Science and Technology, National Development and Reform Commission, and other bodies.

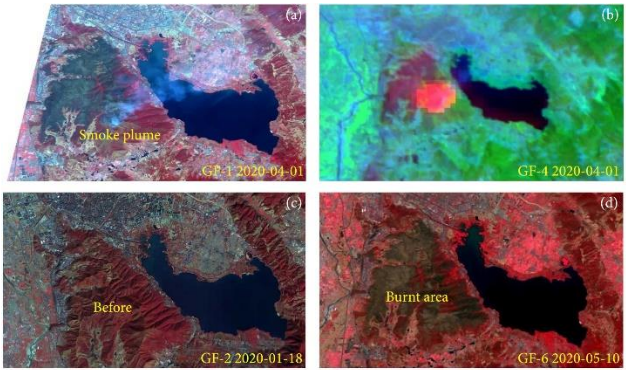
The funding for CHEOS was provided by the Chinese government, with contributions from both central and local government agencies. The programme was seen as a strategic initiative for China, aimed at developing a world-class Earth observation system that could support China's economic development, national security, and global leadership ambitions.

CAS played a crucial role in the CHEOS programme, providing scientific guidance, research and development, and operational support for the satellites. As China's premier research institution, CAS has a wealth of expertise in Earth observation, remote sensing, and related fields.

The Ministry of Science and Technology oversaw implementation of the CHEOS programme and ensured it met strategic objectives. The ministry worked closely with CAS and others to coordinate development of the satellites, establish operational procedures, and promote the use of CHEOS data for scientific, economic, and social purposes.

User Base:

Since the programme's start in 2013,[38] the People's Republic of China has launched 30 Gaofen-series satellites (gaofen means high resolution). 14 variations have been launched, including optical, multispectral, hyperspectral, and synthetic aperture radar. The programme also includes a near space segment, which comprises airships, air flight platforms, airborne Earth observation instruments, and data processing systems to augment its capabilities and data collection. However, there is limited information available about this aspect of the programme.



High-resolution satellite images during the "3 ·30" Xichang forest fire

Some Gaofen satellites remain classified, suggesting military applications. For example, four Gaofen-11 have been launched, which are believed to be capable of capturing optical imagery at 10cm resolution.[39] Additionally, China has also announced plans to launch a synthetic aperture radar satellite with a resolution of 20 meters into geostationary orbit in 2023.[40]

The primary applications for the CHEOS programme are land use planning, environmental governance, meteorological early warning and forecasting, and disaster prevention and mitigation. However, Chinese companies, universities, and research institutions have used CHEOS programme data for other purposes.

International Usage:

In addition to domestic use, China's Gaofen satellites likely contribute to its foreign policy objectives by providing overhead imagery for the 'Belt and Road' project. The CHEOS programme has also received international attention and has been utilised by other nations for various purposes. For example, Gaofen-1 and 2 have been used for monitoring and evaluating floods in Sri Lanka and Bangladesh. This demonstrates the potential for the CHEOS programme to contribute to disaster response and management efforts beyond China's borders, and for projection of 'soft power'.[41]

Conclusion

The CHEOS programme has provided high-resolution data for various applications, including disaster response, environmental monitoring, and military purposes. The programme continues to develop new satellites and expand its user base, including both domestic and international users to meet China's national needs and foreign policy objectives.

[37] https://spj.science.org/doi/10.34133/2022/9769536
[38] https://www.unoosa.org/pdf/pres/stsc2014/tech-47E.pdf
[39] https://spacenews.com/china-launches-second-classified-Telespazio Italia gaofen-13-remote-sensing-satellite/
[40] https://mp.weixin.qq.com/s/YeaQNaVA0A5vERyNgPcCVg
[41] http://vienna.china-mission.gov.cn/eng/hyyfy/201802/t20180214_8848287.htm

National satellite programmes

National satellite programmes play a significant role in stimulating national technology and industrial development while providing valuable data for Earth observation. These programs vary in size and scope, ranging from small initiatives that kick-start technology development and national pride to large-scale projects involving multiple satellites and substantial investment. Here are some salient examples:

- Small-scale programmes: Developing nations often initiate a small satellite programme to foster technology development and national pride. For instance, Nigeria's Nigeriasat-1 & -2 and South Africa's SunSat-1 were aimed at stimulating their respective space sectors. While South Africa's programme has thrived, Nigeria's programme has faced challenges.[42]
- Mid-scale, focused programmes: In these cases technically advanced nations develop their own satellite programmes with a small number of satellites with capabilities focused on national objectives. Two examples are India and Korea.
  - India's Resourcesat-2 (IRS-R2)[43] features optical sensors with resolutions ranging from 60m to 6m, along with an AIS receiver. IRS-R2 is focused on applications to support India's economic and governmental needs: agricultural monitoring, natural resources management, infrastructure planning and disaster management support[44].
  - Korea's latest satellites in the 'Korean Multi-purpose Satellite' or Arirang series focus on high-resolution imaging with KOMPSAT-3/3A having optical sensors of resolution down to 0.7m (sensor built with support from Astrium) and KOMPSAT-5,[45] having Synthetic Aperture Radar (SAR) sensors to 0.85m. The multiple purposes include imagery for defence[46].
  - Both India and Korea have incorporated their national Earth observation programmes as Copernicus Contributing Missions to gain access Copernicus services.
- Large-scale programmes: Italy's IRIDE[47] Earth observation programme exemplifies a large-scale initiative with significant investment. Managed by the European Space Agency (ESA) and valued at €1.1 billion, IRIDE will deploy over 60 small and medium satellites into Low Earth Orbit by 2026. The project involves the collaboration of 47 companies, including Leonardo and OHB-Italia, and utilizes the Vega launch vehicle, with Italian firm Avio serving as the prime contractor.

These programmes show a diverse range of capabilities and objectives pursued by different countries. Each nation's programme appears to be strongly shaped by a combination of national objectives and resources available, for example India and Korea may have lofted similar numbers of satellites, but India focuses on policy priorities that are priorities for a large, developing country, whereas Korea has a

[42] https://guardian.ng/features/how-far-with-nigerias-space-dream/
[43] https://earth.esa.int/eogateway/missions/resourcesat-2
[44] https://web.archive.org/web/20150927084822/http://www.isro.org/update/28-apr-2011/resourcesat-2-sends-high-quality-images
[45] https://spacedata.copernicus.eu/kompsat-5
[46] https://www.eoportal.org/satellite-missions/kompsat-3a
[47] https://europeanspaceflight.com/wp-content/uploads/2023/04/IRIDE-12-april-_News-ESA_EN.pdf

focus on national security as well as civilian purposes. Italy appears to have invested over and above its share of Copernicus to develop national industrial capability.

Downstream programmes and capabilities

A variety of international downstream programmes for Earth observation help turn raw satellite data into useful information for decision-makers in fields such as environmental management, disaster response, and agriculture. Here are a few examples:

Geographically-focused platforms

Digital Earth Australia: Digital Earth Australia is a programme that provides free access to analysis-ready satellite data and tools for analysing the data. It is designed to support a range of applications, including policy, agriculture, environmental monitoring, disaster response and business applications. Investment in DEA was planned at A$52m for five years[48].

Swiss Data Cube: Another programme to create a national 'library' of Analysis Ready Data from a range of Earth observation sources. The Swiss Data Cube (SDC) includes data from Sentinel and Landsat satellites, dating back to 1984 and updated daily on a cloud computing platform. To make analysis easier, the data are transformed into a consistent space-time format and is built on Open Data Cube standards.

CommonSensing: CommonSensing is a partnership between several organizations that uses satellite data to support disaster response and climate resilience in three Pacific Islands. CommonSensing's data and tools are used to monitor weather patterns, track the spread of diseases, support disaster preparedness and response, and enable climate finance.

Application-focused platforms

European Space Agency Climate Change Initiative (ESA-CCI): ESA-CCI provides long-term climate data records derived from satellite observations, focusing on key climate variables such as sea level, ice sheets, and greenhouse gases. ESA-CCI's data is used by climate scientists to improve their understanding of climate change and to develop more accurate climate models.

Global Forest Watch (GFW): GFW, a partnership between several organisations, uses satellite imagery to monitor global forests and detect deforestation in near-real time. GFW's data and tools are used by governments, non-governmental organizations, and the private sector to support forest management and conservation efforts.

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[48] https://www.ga.gov.au/news-events/news/latest-news/ceo-statement-on-budget-2018-19

AquaWatch: AquaWatch, a partnership between several organizations, uses satellite data to monitor and manage freshwater resources. AquaWatch's data and tools are used by governments and other stakeholders to support water management and conservation efforts.

Broad service platforms

Amazon Web Services Ground Station: AWS Ground Station is a service that makes it easy for customers to download satellite data from a variety of sources, including the USGS Landsat program, the European Space Agency's Copernicus program, and many commercial satellite providers. AWS Ground Station provides cloud-based tools for processing, analysing, and sharing satellite data.

Google Earth Engine: Google Earth Engine is a platform for processing and analysing large amounts of satellite data. It includes a library of satellite imagery and other geospatial data, as well as a suite of tools for performing analysis and creating visualizations.

Microsoft Planetary Computer: Planetary Computer is a cloud-based platform for Earth observation analysis that provides access to a wide range of satellite data, computing resources, and conventional and machine learning tools for processing and analysing the data.

Earth-i: Earth-i originally planned to be a commercial satellite operator, but pivoted to focus on data, analytics and insight. They provide high-resolution satellite imagery and other data products and services for a range of applications, including environmental monitoring, urban planning, and defence.

Common features of these and other downstream programmes is that they lower the barriers to entry for Earth observation analysis, and they provide flexible resources – enormously so in the case of Amazon, Google and Microsoft. Together, they demonstrate the wide range of applications for satellite data and the importance of making this data accessible and useful to a broad range of stakeholders.

Learnings and conclusions

Earth observation (EO) satellites have become an increasingly important tool for monitoring and understanding the environment. In the last decade, there has been a significant growth in the number of EO satellites, particularly with the launch of commercial constellations. Companies like Planet have dominated the market, with their large constellations providing high-frequency imaging of the Earth's surface.

One of the emerging segments in the EO satellite industry is maritime observation. Satellites are now being used to monitor ship traffic, detect oil spills, and track weather patterns at sea. This information can be used by governments and shipping companies to improve safety and efficiency, as well as to prevent environmental disasters.

In recent years, there has been a shift in the landscape of EO satellite launches. While the US Government was once a significant player in the industry, this is now dwarfed by commercial satellites and increasingly the US Government uses commercially-sourced data to the benefit of both Government operations and the private companies. Meanwhile, China has emerged as the largest launcher of government EO satellites, with a focus on military and strategic applications. This shift reflects the changing priorities and strategies of countries around the world, as well as the increasing role of commercial operators in the EO satellite market.

Overall, the growth of EO satellites and their increasing use in a variety of applications highlights the value of space-based technologies for understanding and managing our planet. As the industry continues to evolve, it will be important to balance the potential benefits of these technologies with concerns around privacy, security, and sustainability.

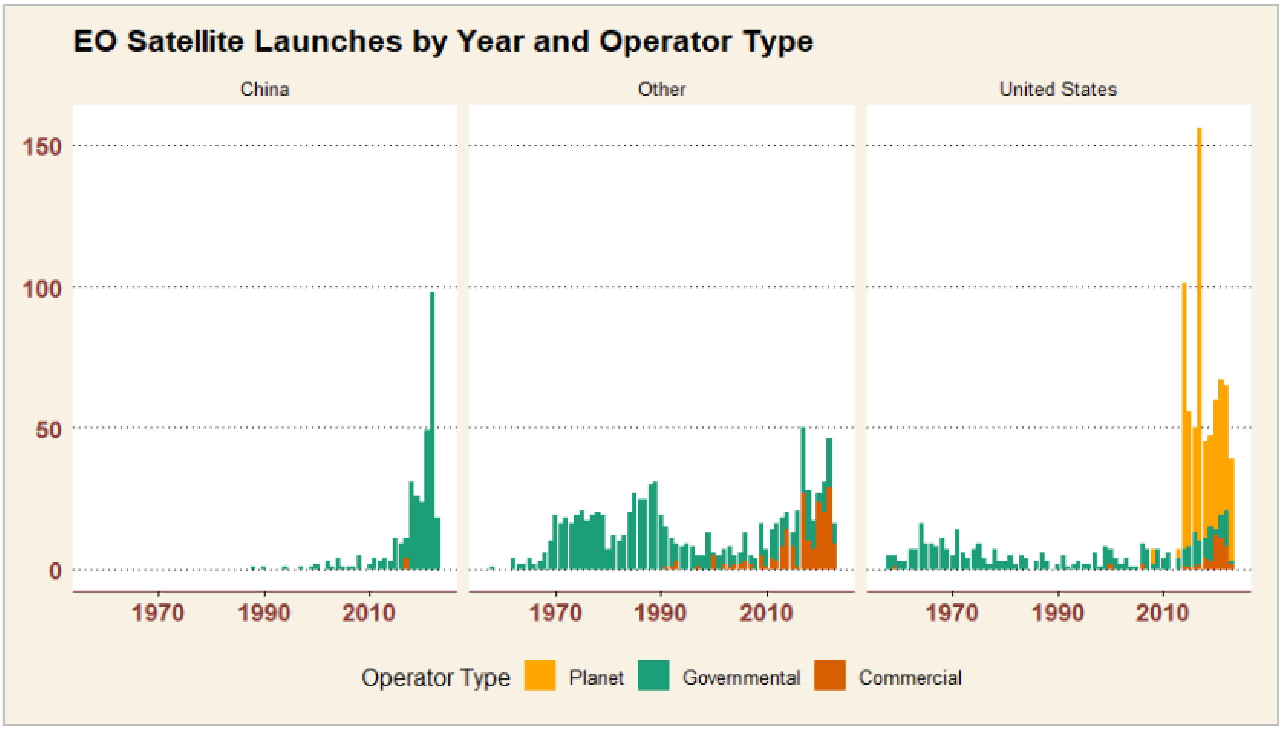

Figure 1: Earth Observation Satellite Launches by Year and Operator Type

Success factors

Several key factors contribute to the success of Earth observation programmes, whether upstream or downstream.

Firstly, having a **clear and well-defined purpose** for the programme is essential, whether it be monitoring climate change, tracking natural disasters, or providing insights into human activities. This purpose should be supported by a clear mandate from relevant authorities and robust funding to give confidence its longevity so that applications or long-term research projects can be based on it.

Secondly, successful Earth observation programmes are often **providing new data or insight**. This often uses the **latest technology and data processing** techniques, sometimes enabling more accurate and timely analysis of data, sometimes enabling lower costs for delivery at scale. Programmes such as the Microsoft Planetary Computer and the European Climate Change Initiative have both embraced modern technology and data analysis techniques to provide valuable insights into the environment and natural resources, for example by including AI land coverage analysis.

Thirdly, establishing **partnerships and collaborations** with other organisations and stakeholders can be a key driver of success for Earth observation programmes. Digital Earth Australia, for example, has worked with a range of partners to improve the accuracy and availability of satellite imagery for Australian users.

Finally, successful Earth observation programmes often have a **user-focused approach**, ensuring that the data and insights generated are accessible and useful to a range of stakeholders, from researchers and policymakers to businesses and the general public. This trend towards open data and user-focused approaches is evident in programmes such as the Swiss Data Cube, AWS Ground Station and Copernicus, which provide data and tools to support a wide range of users in a flexible way.

Dual-use, offering data to military and civilian users, is seen in most of our case studies. This can be as simple as a defence customer buying data from an otherwise civilian satellite programme[49], and in several cases is large enough to be considered an 'anchor customer'.

The programmes have been enabled by a variety of funding approaches.

Programme	Funding approach
Copernicus	Direct investment, Public Private Partnership
ICEYE	R&D Grants, Public Private Partnership, Dual-use
Spire Global	Anchor customers, Dual-use
Planet	Anchor customers, Dual-use
Airbus	Originally (Pleiades, Spot 1-5) Direct investment, Dual-use Now (Pleiades Neo, SPOT 6,7) Anchor customer, Dual-use
CHEOS	Direct investment, Dual-use

We observe a strong trend towards 'anchor customer' funding, particularly in the USA, which had an early success with NASA's use for COTS (Commercial Orbital Transportation Services) and CRS

[49] Defence customers are likely to have requirements on secrecy about the exact data they are actually buying.

(Commercial Resupply Services) to the International Space Station[50], and now seems a common approach, most recently used by the US National Reconnaissance Office to award contracts to a mix of established and start-up businesses for hyperspectral imagery[51].

In summary, successful Earth observation programmes tend to combine a clear purpose, the provision of new data or insights, the use of the most innovative technology and data analysis techniques, partnerships and collaborations, and a user-centred approach to provide valuable insights into the environment and natural resources. They combine this with a variety of funding strategies, although typically a state (or group of states) is ultimately the major customer or funder.

[50] https://www.nasa.gov/content/cots-final-report
[51] https://spacenews.com/nro-signs-agreements-with-commercial-providers-of-hyperspectral-imagery/

Annexe: International EO Satellite Programmes

Satellite Programme	Satellites	Start of Operations	End of Operations	Types of Instruments/ Bands	Resolution	Revisit Frequency	Operator
Public EO Satellite programmes (1)							
Meteosat	Meteosat-1 to Meteosat-11	1977	-	Visible, infrared, and water vapor imaging	3-5 kilometres	15 minutes to 1 hour	EUMETSAT
Satélite de Coleta de Dados	SCD-2	1998	2021	DCS	-	-	National Institute for Space Research (INPE)
ASTER	ASTER	1999	-	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	15 - 90 metres	16 days	NASA
Envisat	Envisat	2002	-	Advanced Synthetic Aperture Radar (ASAR)	30 - 150 metres	35 days	ESA
Meteosat Second Generation	MSG-1 to -4	July 2002 to June 2022	-	Visible, infrared, and water vapor imaging	1-3 kilometres	15 minutes to 1 hour	EUMETSAT
Aqua	Aqua	2002	-	Moderate Resolution Imaging Spectroradiometer (MODIS)	250 - 1000 metres	1 - 2 days	NASA
Resourcesat	Resourcesat-1, Resourcesat-2, Resourcesat-2A	2003, 2011, 2016	-	LISS-III, AWiFS, LISS-IV	23.5 m, 56 m, 5.8m	24 days	ISRO
CartoSat	CartoSat-1, -2,-2[A -F], 3	2005-2021	-	Panchromatic	0.8 m - 0.25 m	2-5 days	Indian Space Research Organisation (ISRO)
MetOp	MetOp-A, B, C	2006, 2012, 2018	-	Microwave and infrared sounders, visible and infrared imagers	N/A	Twice daily	EUMETSAT
GOES	GOES- 14-18	2009-2022	-	EO, IR, lightning detection, advanced Baseline Imager (ABI)	500 m - 2 km	5-15 min	National Oceanic and Atmospheric Administration (NOAA)
Pleiades	Pléiades-1A,1B	2011,12	-	High Resolution Visible (HRV)	0.5 - 2 metres	26 days	Airbus, CNES

Satellite Programme	Satellites	Start of Operations	End of Operations	Types of Instruments/ Bands	Resolution	Revisit Frequency	Operator
Public EO Satellite programmes (2)							
Suomi NPP	Suomi NPP	2011	2026	OMPS, VIIRS, ATMS, CrIS, OMPS-L, CERES	375 metres (VIIRS)	1	NASA
Kanopus-V	Kanopus-V-IK, Kanopus-V-No.1 to No.6	2012 to 2018	-	Optical multispectral imager (Kanopus-V-IK), multispectral camera, wide-angle camera, and high-resolution camera (Kanopus-V-No.1 to No.6)	2.1 to 30 meters (depending on the camera)	2-3 days (depending on the satellite)	ROSCOSMOS, Russia
INSAT	INSAT-3D, INSAT-3DR	2013, 2016	-	6 channel multi-spectral Imager 19 channel sounder Data Relay Transponder (DRT) Satellite Aided Search and Rescue (SAS&R)	1 km - 4 km	15-30 min	Indian Space Research Organisation (ISRO)
China High-resolution Earth Observation System (CHEOS)	Gaofen (32 different)	2013	-	Multispectral (visible, near-infrared)	0.5 - 2 metres	2 - 4 day	CNSA (public)
Landsat	Landsat-8	2013	-	Multispectral (visible, near-infrared, shortwave infrared)	15 - 60 metres	16 days	NASA / USGS
China-Brazil Earth Resources Satellite	CBERS-4	2014	-	MUXCAM, WFI, IRMSS, WPM, PANMUX	2.7m (PAN) 20m (MUXCAM), 80m (WFI, IRMSS, WPM)	5 days	China National Space Administration (CNSA) and Brazilian National Institute for Space Research (INPE)
Copernicus	Sentinel-1A, 1B	2014	1B 2022	Synthetic Aperture Radar (SAR)	5 - 20 metres	12 days	ESA
Copernicus	Sentinel-2A, 2B	2015	-	Multispectral (visible, near-infrared, shortwave infrared)	10 - 60 metres	5 days	ESA
Copernicus	Sentinel-3A, Sentinel-3B	2016, 2018	-	Sea and Land Surface Temperature Radiometer (SLSTR), Ocean and Land Colour Instrument (OLCI), Synthetic Aperture Radar Altimeter (SRAL)	300 metres (SLSTR), 300 metres (OLCI), 300 metres (SRAL)	1 - 3 days	ESA, eumetsat

Satellite Programme	Satellites	Start of Operations	End of Operations	Types of Instruments/ Bands	Resolution	Revisit Frequency	Operator
Public EO Satellite programmes (3)							
Copernicus	Sentinel-5P	2017	-	Tropospheric Monitoring Instrument (TROPOMI)	5.5 - 7.5 kilometres	1 da	ESA
Copernicus	Sentinel-6	2020	-	Altimeter, Advanced Microwave Radiometer (AMR)	1.3cm (altimeter), 6 - 50km (AMR)	10 days	ESA
COSMIC	COSMIC-2 (othes cancelled)	2018-2020	-	Tri-band GNSS (TriG) RO and POD Receiver	-	-	National Space Organization (NSPO), NOAA (USA)
SSTL NovaSAR	NovaSAR-1	2018	-	S-band Synthetic Aperture Radar (SAR)	6-30 m (depending on mode)	4-12 hours	SSTL, Airbus
Landsat	Landsat-9	2021	-	Multispectral (visible, near-infrared, shortwave infrared)	15 - 100 metres	17 days	NASA / USGS
CAS500-1	CAS500-1	2021	-	panchromatic multispectral	0.5 m, 2 m	-	Korea Aerospace Research Institute (KARI), Korea Aerospace Industries (KAI)
MethaneSAT	MethaneSAT	Planned for 2023	-	Spectrometer (near-infrared)	2 kilometres	N/A	Environmental Defense Fund / NZSA
ALOS	ALOS-3	2023	2023	Phased Array type L-band Synthetic Aperture Radar (PALSAR)	10 - 100 metres	46 days	JAXA
NISAR	NISAR	Planned for 2024	2027	L-band synthetic aperture radar (SAR)	12 metres (SAR)	12 days	NASA / ISRO
ALOS	ALOS-3	2023	2023	Phased Array type L-band Synthetic Aperture Radar (PALSAR)	10 - 100 metres	46 days	JAXA
NISAR	NISAR	Planned for 2024	2027	L-band synthetic aperture radar (SAR)	12 metres (SAR)	12 days	NASA / ISRO
WorldDEM (Digital Elevation Model)	TerraSAR-X, TanDEM-X	2007, 2010	-	Synthetic Aperture Radar (SAR)	0.25 - 20 metres	11 days	Airbus, DLR (PPP)
COSMO-SkyMed	COSMO-1 - 4	2007, 2010	-	Synthetic Aperture Radar (SAR)	1 - 100 metres	1 - 3 days	ASI

Satellite Programme	Satellites	Start of Operations	End of Operations	Types of Instruments/ Bands	Resolution	Revisit Frequency	Operator
Commercial EO Satellite programmes (1)							
WorldView	Worldview-1, Worldview-2, Worldview-3	2007, 2009, 2014	-	Multispectral (visible, near-infrared, shortwave infrared)	0.31 - 7.5 metres	1 - 3.7 days	DigitalGlobe (Maxar)
Radarsat-2	Radarsat-2	2007	-	C-band SAR	Up to 1m	24 days	Canadian Space Agency, MDA Corporation
RapidEye	RapidEye-1 to -5	2008, 2020	Mar-20	5-band multispectral imaging	5 metres	Daily	Planet
Deimos	Deimos-1, Deimos-2	2009, 2014	-	Pan: 420-720 nm MS1: 420-510 nm (Blue) MS2: 510-580 nm (Green) MS3: 600-720 nm (Red) MS4: 760-890 nm (Near	0.75 m (Pan), 5 m (MS)	1-4 days	Deimos Imaging, Spain, EarthDaily
DubaiSat-1	DubaiSat-1, DubaiSat-2	2009 (DubaiSat-1), 2013 (DubaiSat-2)	-	Pan: 420-720 nm MS1: 420-510 nm (blue) MS2: 510-580 nm (green) MS3: 600-720 nm (red) MS4: 760-890 nm (near infrared)	2.5 m pan, 5 m MS [DubaiSat-1] 1 m [DubaiSat-2]	2-5 days (depending on the satellite)	Mohammed bin Rashid Space Centre, United Arab Emirates
SPOT	SPOT 6, 7	2012,14	-	High Resolution Visible (HRV)	Panchromatic: 1.5m Colour merge: 1.5m Multi-spectral: 6m	1 - 5 days	Airbus
Flock / Dove	Doves, Flock 1-4 (Approx 174 in orbit 31/3/23)	2013 to present	-	4-band multispectral imaging	3-5 metres	Daily	Planet
SkySat	SkySat-1 to SkySat-21	2013 to 2021	-	Panchromatic and multispectral imaging	0.8-2.4 metres	Multiple per day	Planet
Spire / Lemur	Lemur-2 (various models)	2014	-	Automatic Identification System (AIS) receiver, GPS radio occultation	N/A	Varies by mission	Spire

Satellite Programme	Satellites	Start of Operations	End of Operations	Types of Instruments/ Bands	Resolution	Revisit Frequency	Operator
Commercial EO Satellite programmes (2)							
TripleSat Constellation	DMC-3	2015	-	MSI (BJ-2), PAN (BJ-2)	3 m MS, 1.0 m Pan	1-3 days	SSTL, DMC International Imaging (DMCii)
GHGSAT	GHGSat-C1, -C2, -C3, -C4, C5	2016, 2021, 2021	-	Hyperspectral imaging spectrometer	50 metres	Every few days	GHGSat
BlackSky Global	Pathfinder-1	2016	-	EO, IR	1 m	90 min	BlackSky Global
Aleph-1	ÑuSat-1 to 35	2016-2023	-	multispectral, hyperspectral	99 cm, 25 m	2-3 days	Satellogic
SuperView-1 (GaoJing-1) Constellation	SuperView-1 01, SuperView-1 02, SuperView-1 03, SuperView-1 04	2016 (SuperView-1 01-02), 2018 (SuperView-1 03-04)	-	PAN: 0.45-0.89 µm B1/blue: 0.45-0.52 µm B2/green: 0.52-0.59 µm B3/red: 0.63-0.69 µm B4/NIR: 0.77-0.89 µm	0.5-1 meter (panchromatic), 2-4 meters (multispectral)	2 days	Beijing Space View Tech Co Ltd
Cicero	Cicero-6, 7, 10, 8, & OSM-1	2017-2020	-	GNSS radio occultation	-	-	GeoOptics
Canon - CE-SAT	CE-SAT-1, CE-Sat-1B, CE-SAT-2B	2017, 2020, 2020,	-	Multispectral imager (red, green, blue)	90 cm (panchromatic), 5.1 m ,	3 days	Canon Electronics Japan
ICEYE	ICEYE-X1-X27 (24 in total)	2018- present	-	Synthetic Aperture Radar (SAR)	1 metre	Approx daily in 2023	ICEYE
BlackSky Global	Global (1 -9), (14 - 20)	2018-2022	-	EO, IR	1 m Gen-2) 50 cm (Gen-3)	90 min	BlackSky Global
Landmapper	CORVUS BC3 v2 , BC 4	2018	-	3-band multi-spectral imager	22 m	daily	Astro Digital
AxelGlobe	GRUS-1A - 1H	2018-2023	-	Panchromatic, Multispectral	2.5 m, 5.0 m	3-5 days	Axelspace
Unseen Labs	BRO 1 - BRO 9	2019 - 2022	-	RF, AIS	-	-	Unseen Labs

Satellite Programme	Satellites	Start of Operations	End of Operations	Types of Instruments/ Bands	Resolution	Revisit Frequency	Operator
Commercial EO Satellite programmes (3)							
Unseen Labs	BRO 1 - BRO 9	2019 - 2022	-	RF, AIS	-	-	Unseen Labs
Satellite Vu	SV-1, -2	Nov 2020, March 2021	-	12-band multispectral imaging, including thermal infrared	0.5-1 metres	Every 90 minutes	Satellite Vu
Capella	Capella 1 - 10	2020-2023	-	X-band SAR	50 cm - 1 m	4-6 hours	Capella Space
FSSCAT	FSSCAT-5/A, FSSCAT-5/B	2020	-	(GNSS-R) and a L-band Radiometer	-	-	Nanosat Lab (Polytechnic University of Catalonia)
Scouting, Vigilance, Patrol, Observer Missions	KSM1, KSF1, KSF2, KSF3	2020, 2021, 2022, 2023	-	RF	-	-	Kleos Space
STORK	STORK 1-6	2021 to 2023	(STORK-6 2023)	Vision-300 imager	up to 5 m	-	SatRevolution
Pleiades Neo	Pléiades Neo-3, 4	2021	-	5 Visible bands and Panchromatic	0.3m	Daily	Airbus
EOS SAT Constellation	EOS SAT-1	2023	-	Multispectral imager (red, green, blue)	1.4 m pan, 2.8 m MS	1-3 days	EOS Data Analytics, Dragonfly