REPORT: SATELLITE-BASED EARTH OBSERVATION TECHNOLOGY, INNOVATION, AND MARKET TRENDS

Published by Access Hub - Space, Defence, & Security

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Introduction

The report aims to provide a brief outlook on the satellite-based earth observation (EO) industry, trends, and applications on a global scale.

The report consists of multiple chapters, each covering dynamic aspects of the industry, market trends, and action-oriented case studies.

It also gives a brief introduction of the basic concepts, value chain, and industry development status of EO. Considering the upstream and downstream market segments, the report further analyzes the technology and business development status of EO over the past few decades.

The report also provides an extended outlook on new technology trends and multidimensional forecasts for the global satellite EO market up to 2030; which estimates that the satellite-based EO market will reach $1 trillion+ in market value.

1. Satellite-based EO

1.1 Overview

EO (EO) is the gathering of information about planet Earth via photoelectric sensors carried by satellites, spacecraft, space shuttles, aircraft, near-space vehicles, etc. EO involves detection of the environment which is critical to human survival as well as human activities, using detection methods such as visible light, infrared, microwave, and hyperspectral imaging. This report focuses on satellite EO.

There are several ways to classify EO satellites:

1) By electromagnetic wavelength - ultraviolet, visible light, infrared, microwave, etc.

2) By energy source of the sensor - active sensors (e.g., radars), and passive sensors (e.g., optical cameras).

3) By orbital altitude - Low Earth Orbit (LEO, orbital altitude below 2,000KM), Medium Earth Orbit (MEO, orbital altitude of 2,000-20,000 KM), and Geosynchronous Orbit (GEO, orbital altitude close to 36,000 KM), etc.

4) By application - meteorological satellites, land resources satellites, marine satellites, etc.

5) By mass - large satellites (>1,000 kg), medium satellites (500-1,000 kg), small satellites (100-500 kg), micro-satellites (10-100 kg), nano-satellites (1-10 kg), etc.

Currently, the Medium Earth orbit (MEO) and Geostationary Earth orbit (GEO) satellites primarily belong to government institutions. While New Space companies in the EO sector have now directed focus on the Low Earth Orbit (LEO) satellite constellations.

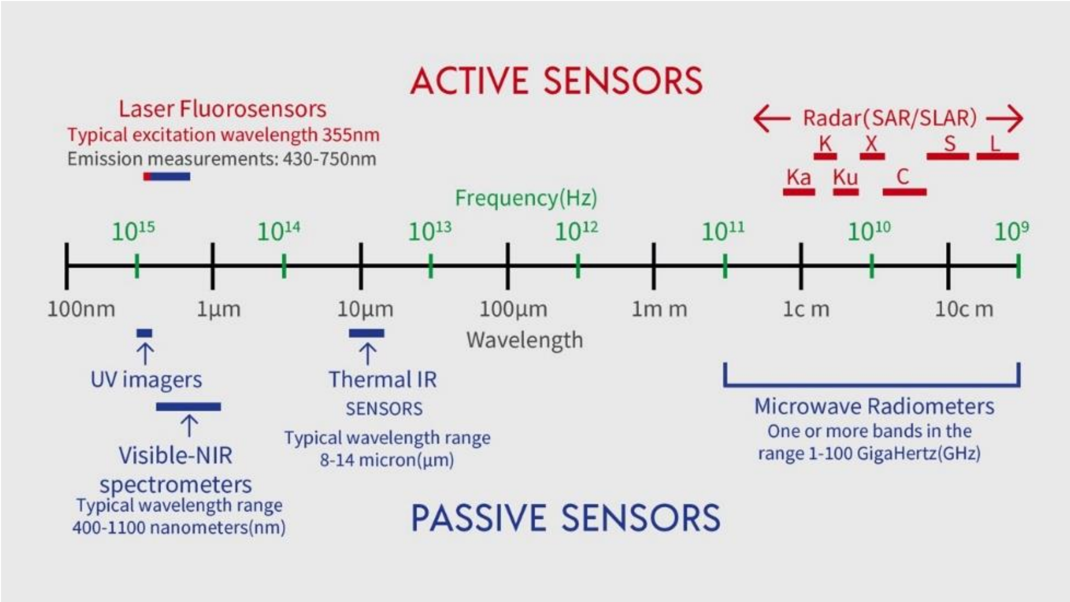


Figure 1 Electromagnetic Spectrum Bands used by EO Satellites

1.2 Satellite EO Industry Value Chain

The satellite EO value chain can be categorized into data acquisition, data processing, and data application.

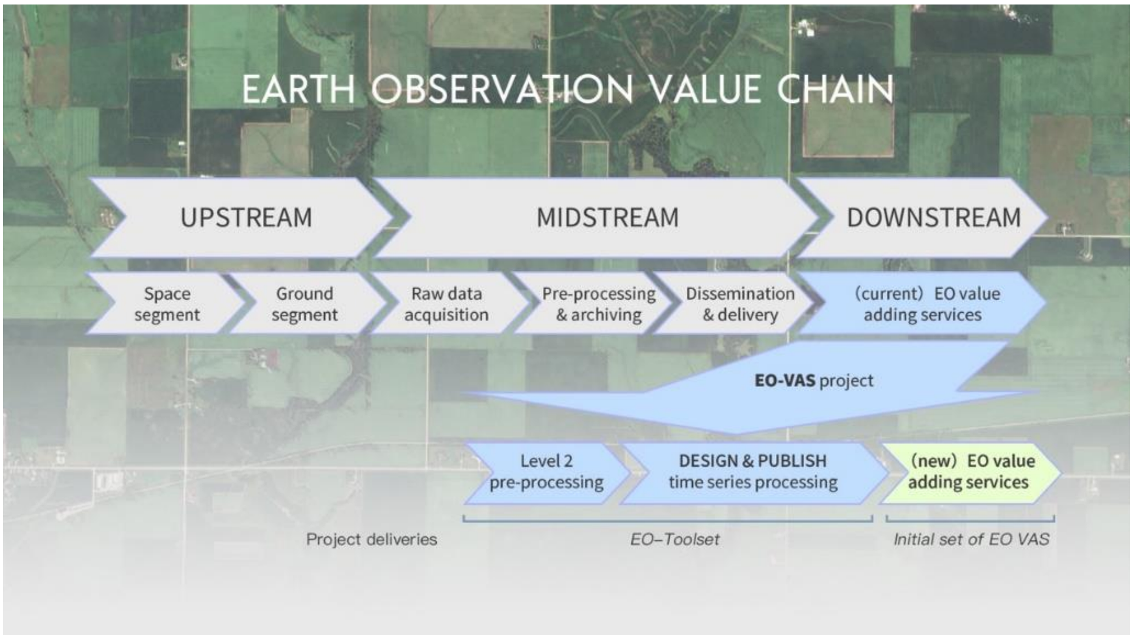


Figure 2 Diagram of Satellite EO Value Chain

Upstream data acquisition: EO data acquisition includes the R&D and launch of EO satellites in the space segment, as well as the construction of ground control systems in the ground segment. EO satellites are composed of satellite platforms, sensors, information transmission and reception devices, image processing devices, etc.

Midstream data processing: data processing refers to ground stations receiving EO image data and transmitting the data to ground processing systems, which offer different industries a diversity of products, such as control positioning, standardized production, advanced image processing, typical industry applications, etc.

Downstream data application: EO can be widely used by various government agencies for land, transportation, environment, mining, meteorology, defense, etc.

In addition to the EO satellites, drones and aerial information collection systems are also important sources of EO data.

2. Development Status of Satellite EO

2.1 A Retrospect of Technological Development

Higher spatial resolution. Measured by ground sampling distance (GSD) or the pixel size of remote imaging, spatial resolution refers to the smallest size at which ground features can be detected. During the 1970s and early 1980s, many Landsat satellites had spatial resolutions of 30m-120m, used mostly for global census. The SPOT-1 satellite launched by France in 1986 brought the spatial resolution within the dekameter range, reaching 5-20m, allowing the satellites to conduct regional surveys. Launched in 2002 and later, the SPOT-5/6 satellites further brought the spatial resolution within the meter range, reaching 1.5-2.5m. Since the 21st century, a series of satellites, including IKONOS, Quickbird, GeoEye, WorldView, and Pleiades, have been capable of capturing sub-meter EO imagery. A few large-scale reconnaissance satellites can capture images with a spatial resolution of 0.1m, reaching or even exceeding the spatial resolution capability of drones.

Higher abundance in spectral information. Spectral sensors are generally classified as panchromatic, multispectral, and hyperspectral sensors. Multispectral sensors have fewer than ten bands, whereas hyperspectral sensors typically have hundreds of bands. Early EO satellites could only capture panchromatic images, with all objects displayed in grayscale. Most of the current optical EO satellites carry four multispectral bands of red, green, blue, and near-infrared, which can synthesize true-color images familiar to the human eye. Landsat multispectral satellites and WorldView-2 carry eight spectral bands. WorldView-3 carries sixteen spectral bands, which significantly improved the applications in defense, agriculture, and environmental monitoring. In addition, the U.S. AVIRIS sensor has 224 bands in the wavelength range of 0.38-2.51 microns, displaying hyperspectral information far more detailed than multispectral images, and detecting ground objects more accurately.

Higher temporal resolution. Temporal resolution refers to the frequency of satellite platforms revisiting a given location on Earth. Traditionally, a high-resolution EO satellite has a revisit rate of 2-4 days. Since the 21st century, EO satellites can deliver daily revisit globally thanks to satellite maneuverability, swath size, and constellation size. These systems acquire an enormous quantity of data globally, such as WorldView-1, WorldView-2, GeoEye-1, Pleiades-1A, and Pleiades-1B. At present, the potential capacity of ultra-high spatial resolution satellites is 1.8-2.4 billion square kilometers, equivalent to more than ten times Earth's land surface area.

Smaller satellite platform. Satellite platform largely determines the size and weight of EO satellites, which are important constraints for launch vehicles. The Landsat-1 satellite launched in 1972 has a volume of ~7m^3 (3m in height, 1.5m in diameter) and a weight of ~816kg, with a maximum spatial resolution of 30m. Launched in 2011, the Pleiades measures ~3.5m^3 in volume and ~940kg in weight, achieving a spatial resolution of up to 0.7m. The SkySat-3 launched in 2016 and subsequent satellites measure 110kg in weight and less than 0.35m^3 in volume, reaching a spatial resolution of ~1m. Similar to the development of computers in the IT industry, EO satellites have achieved an exponential degree of advancement in miniaturization and performance.

Figure 3 Satellite Size Comparison: Landsat-1 (Left) vs. Skysat (Right)

Higher diversity in detection methods. The observational function of EO satellites mainly relies on sensors (i.e., payloads). The field of optical sensors has witnessed a growing variety of EO satellite spectrums, evolving from visible light to multispectral to customized hyperspectral bands. EO satellites can now perform more precise detection of different matters such as carbon dioxide, methane, aerosol, inorganic substances in soil, biomass, etc. In the field of microwave sensors, with the growing maturity of synthetic aperture radar (SAR) technology, satellite EO can achieve 24-hour, all-weather ground observation.

2.2 Market Verticals and Segments

According to the latest report from the Euroconsult, the global satellite EO data and value-added service market size reached ~$4.1 billion in 2020.

EO satellites are widely used in agriculture, forestry, water conservation, environment, energy, land planning, meteorology, maritime, defense, etc., via processing and applying observable information. The following are several common application scenarios:

- *Disaster Prevention & Relief* - Reducing life and property damages caused by natural or man-made disasters. Satellite EO data can monitor the geographical location and surrounding features of disaster sites (e.g., epicenters, fire points, dam failure points, etc.), as well as damage range change and rescue progress.

- *Forestry* - Satellite EO can be used to perform analysis of forest resources, wetland resources, desertification, ecological engineering, carbon sink monitoring, and pest monitoring.

- *Energy* - Optimizing energy resource management (e.g., pipeline site selection and planning). Satellite EO reduces project difficulty and workload, lowers investment cost, and enhances project safety. Satellite EO also contributes to monitoring oil refineries and oil tank reserves.

- *Meteorology* - Monitoring precipitation, temperature, smog, humidity, and aerosols. Satellite EO helps to monitor and predict meteorological events such as sea ice, floods, droughts, sandstorms, and typhoons.

- *Water Environment & Water Resources* - Satellite EO can efficiently detect the type, distribution, and range of water pollution sources. For hydrological applications, EO can monitor surface runoff, precipitation, soil/surface moisture and evaporation, for the purpose of monitoring and predicting watershed floods.

- *Agriculture* - Satellite EO can monitor crops, including crop area, growth, yield estimation, soil moisture, pests, etc. EO can rapidly gather information on a macro level, monitoring the quantity, quality, and distribution of natural resources. In addition, EO contributes to the monitoring and assessment of major natural disasters such as droughts and floods.

- *Urban Planning & Management* - EO applications in this field include land use survey, historical change research, water system research, road network research, pollution distribution research, waste research, urban heat island effect research, etc.

- *Defense & National Security* - Satellite EO applications include military reconnaissance, missile warning, weapon guidance, military mapping. For instance, EO devices (e.g., infrared detectors, side-looking radars, radio receivers) can accurately determine the location, course, and speed of naval ships, via intersecting signals sent from radars or telecommunication devices.

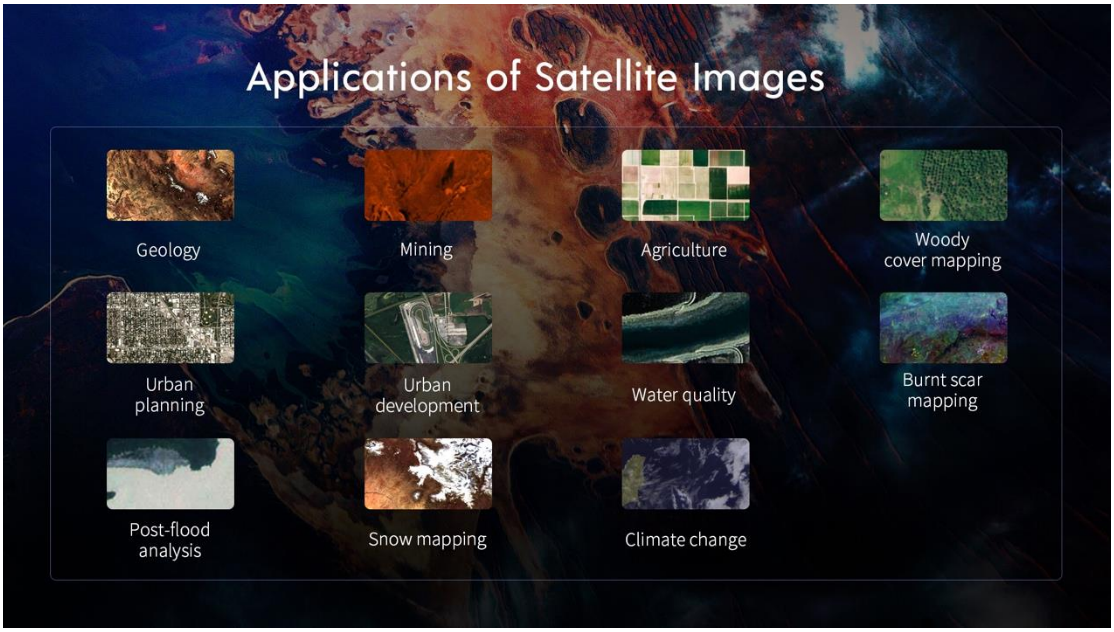


Figure 4 Illustration of Satellite EO Applications

2.3 Traditional Key Stakeholders

In addition to national space agencies, traditional participants in satellite EO data and services market are mainly large military enterprises from the United States, Canada, Europe. Simultaneously, Airbus from Europe and Maxar from the U.S. are some of the key players in the global EO market.

NASA: NASA has deployed hundreds of EO satellites for a plethora of applications in atmosphere, climate, continental drift, geodynamics, gravity, typhoon, ice, land, vegetation, ocean, ozone layer, water cycle, wildfire, etc. Among them, NASA focalizes on six areas: climate change/variability, carbon cycle/ecosystems, Earth's surface/interior, atmospheric composition, weather, and water/energy cycles.

China Centre for Resources Satellite Data and Applications (CRESDA): Founded on October 5, 1991, CRESDA is a scientific research institution led by the National Development and Reform Commission (NDRC) and the State Administration of Science, Technology and Industry for National Defense (SASTIND), and co-managed by China Aerospace Science and Technology Corporation (CASC). The center is responsible for implementing national policies on EO satellite applications, proposing user requirements and development directions, implementing strategies and mid/long-term plans. The center undertakes the construction and operation of China's EO satellite data processing, archiving, distribution and service facilities. CRESDA facilitates macro decision-making for national economic and social development by offering a variety of EO data products, services, and research studies. The center is one of the three largest national satellite application institutions in China.

Airbus: A division of Airbus, Airbus Defence and Space is the operator and service provider of SPOT series and Pleiades series. Renamed from the European Aeronautic Defense and Space Company (EADS) on January 1, 2014, Airbus is now the largest aerospace company in Europe. The company merged Astrium, Cassidian, and Airbus Military to form Airbus Defence and Space, offering defense and aerospace products and services. According to its 2021 annual report, Airbus Defence and Space reported a revenue of 10.186 billion euros and a profit of 568 million euros.

Maxar: As the world's leading provider of commercial high-resolution Earth imagery products and services, Maxar is the service provider of GeoEye series and WorldView series. Using data from its own satellite constellation, Maxar offers imaging solutions in defense and intelligence, civilian institutions, mapping, environmental monitoring, oil and gas exploration, infrastructure management, web portals, and navigation. On October 5, 2017, Maxar was acquired by MacDonald Dettwiler & Associates (MDA). After the merger, MDA was renamed as Maxar Technologies, a company dual-listed on the Toronto Stock Exchange and New York Stock Exchange as MAXR. According to its latest annual report, Maxar reported a revenue of $1.723 billion and a profit of $422 million in FY 2020.

Space View: As the largest remote sensing service provider in China, Space View offers mid-resolution and high-resolution global image data and EO services. The company owns eight high-resolution remote sensing satellites, which could provide users with worldwide ultra-high-resolution images promptly. Space View also offers data production and application services from mid-to-high resolution satellites.

2.4 Aligning With United Nations Sustainable Development Group

Figure 5 United Nations

The United Nations Sustainable Development Goals (SDG) are an important factor for the EO companies to develop and deploy solutions that will help counter global challenges in areas like disaster management, urban development, infrastructure management, climate change, etc.

EO industry's current line up of products and services inculcates the values displayed in the SDG and has the ability to progress further for international cooperation in order to deploy these solutions in the international markets.

The UNSDGs have helped bring more orderly navigation for opportunities as well as provide the government and civil agencies to effectively respond to the social and national issues. From managing resources to counter natural disasters to reduce pollution levels, UNSDGs play key role in modern economy to experiment and deploy sustainable solutions in the global market.

Satellite-based EO has historically played a key role in predicting weather patterns as well as providing emergency alerts in disaster management. With the inception of New Space applications, EO companies are now able to cast a wide net over several industrial sectors as well as bridge the gap between consumers and upstream market.

The SAR satellite imageries are one of the key examples where governments and other entities can ensure appropriate security measures to counter illegal activities offshore. Similarly, the high-resolution satellite imageries are now enabling the emerging markets like, green energy, to effectively operate across multiple domains, which in turn helps the countries to take necessary steps to deploy sustainable solutions.

- **Case Study Applications: Republic of Kiribati**

Climate change has already started impacting the world, with Arctic, Antarctica, and Iceland, recording a sharp drop in the ice sheets, leading to the rise in seal levels. While several nations have been impacted in this change, the Pacific Island nations have particularly taken more hit in these climate crises.

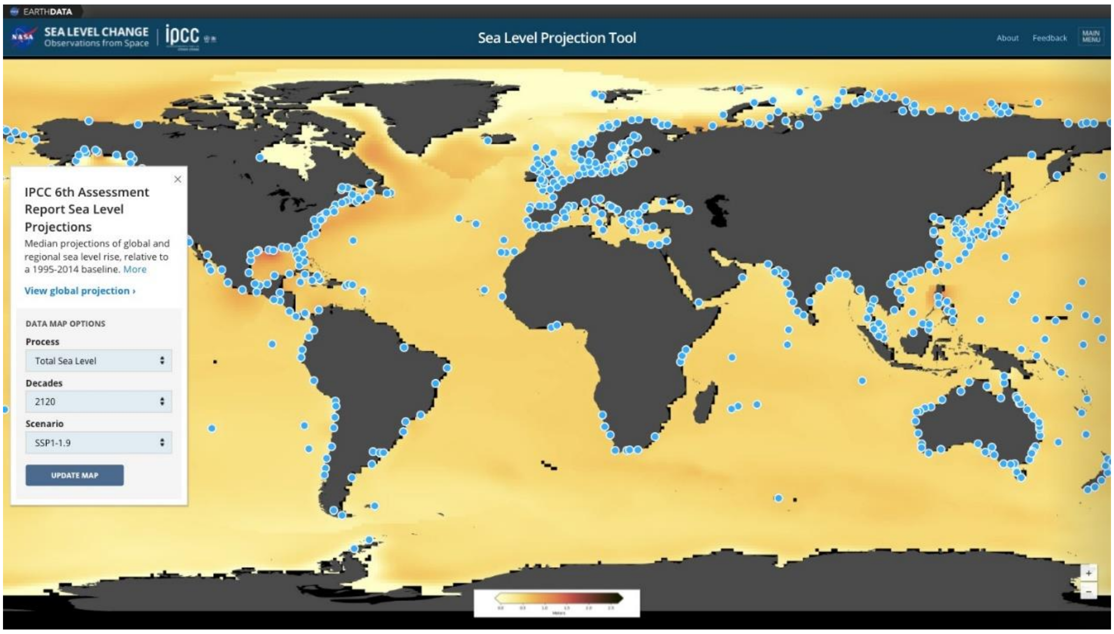


Figure 6 [NASA Sea Level Change Observations From Space]

The Republic of Kiribati is a prominent example from the pacific, a country which is currently surfing through the rising sea levels. The country consists of 33 islands that have an average height of 2 meters above sea level. As most of the country's land has been swallowed by the rising sea levels, most of its Citizens have started migrating to neighboring nations like New Zealand. According to the latest reports from Iberdrola, *the Kiribati government has bought land in Fiji to grow crops and possibly even serve* *as somewhere to evacuate the country's entire population if the worst does happen.*

In future, there is a high possibility that multiple nations will be facing similar crises, especially the coastal areas. Prominent cities like Mumbai and Jakarta have gradually started experiencing the wave of climate change. To counter such events and to conserve the existing natural ecosystem, EO applications will be crucial for the global economies. Following are some of the key pointers that can be considered to utilize EO applications:

1. *Monitoring and Asset Management:* One of the important applications in the modern day economies. Monitoring and asset management helps in mapping resources as well as create a significant forecast for the agencies and organizations to prepare in advance to counter multiple challenges.
2. *Scientific Research:* Downstream data utility is the key to increase consumer awareness in the EO sector. And scientific community remains one of the important consumers of satellite remote sensing data.
3. *Disaster Management and Environmental Protection:* While emergency alerts are key in the disaster management, the New Space applications have also uplifted EO's role in post-disaster management. Insurance and financial mapping are a crucial part of post-disaster events.

3 Technology & Business Model Innovations Drive Satellite EO Development

3.1 New Technology Trends

In recent years, technologies including Artificial Intelligence (AI), data warehouse, cloud computing, and microchip have undergone significant growth. These technological advancements have transformed the entire satellite EO value chain, enhancing the supply capability of satellite EO in data acquisition, data management, data application, etc.

- *AI:* Over sixty years of development has brought major AI breakthroughs in algorithm, computing power, and data. There are four notable trends in AI development. First, a shift from specialized intelligence to general intelligence. Second, a shift from artificial intelligence to human-computer interaction (HCI) intelligence. Incorporating research findings from neuroscience and cognitive science is a crucial research direction in AI. Third, a shift from "artificial + intelligence" to an autonomous intelligent system with substantial reduction in manual intervention. Fourth, an acceleration of AI converging with other fields, such as ultra-high resolution and hyperspectral data processing in satellite EO.

- *Data Warehouse:* Data Warehouse technology refers to the data capability platform for digitized business operations, providing self-service data tools for various departments. This platform facilitates the sharing, abstraction, and reuse of data capabilities. A typical big data platform has basic big data capabilities. A set of data pipelines will run on the basic components for data collection, data processing, and data analysis. With the integration of machine learning capabilities, such platform achieves monetization of data assets. In the future, Data Warehouse will evolve towards real-time computing, upper layer applications will transition to mobile terminals, and the entire Data Warehouse will become more intelligent.

- *Cloud Computing:* The cloud computing can divide a colossal processing program into numerous smaller sub-programs through the network. After searching, calculating, and analyzing, a system composed of multiple servers then sends the processing results back to users. Network service providers can process tens of millions or even billions of information in seconds. In the future, cloud computing will progress towards cloud artificial intelligence, optimized SaaS operations, stronger security, and industry leaders offering containerization of software.

- *Microchip Technology:* There are currently two development paths for AI microchips. The first path continues the traditional computing architecture, which aims to accelerate hardware computing capabilities. The most prevalent types include GPU, FPGA, ASIC, though the CPU still plays an irreplaceable role. The second path is to subvert the classic Von Neumann architecture, using brain-inspired neural structures to improve computing power. Main examples include the Loihi chip from Intel and the TrueNorth chip from IBM. The evolution roadmap of AI chips can be categorized into three stages: short-term goals - to accelerate the implementation of various application algorithms based on heterogeneous computing; medium-term goals - to develop self-reconfiguration, self-learning, self-adaptive, self-organizing heterogeneous AI chips to support the evolvement of AI algorithms and human-like intelligence; long-term goal - to advance towards the ultimate goal of creating general artificial intelligence (GAI) chips.

3.2 Technological Innovations Drive Satellite EO Development

3.2.1 Higher Feasibility to Operate Satellites/Obtain Data Using "Ground Cloud Service"

Traditionally, satellite operation and data acquisition can only be done by professional satellite service companies. Users suffer from long cycles, complex procedures, and unsatisfying user experience. In the future, supported by cloud services, laser communication, AI, etc., users can directly communicate with the ground via mobile phones. These technologies construct a satellite control link of network + ground station (ground cloud) + satellite + mobile phone, making it easier for users to operate satellites and to obtain data.

- **Case Study: Amazon AWS Ground Station**

In 2018, Amazon launched the AWS Ground Station - "Ground Station as a Service." Relying on AWS global ground stations, this service provides instant satellite data services according to customer needs, saving customization costs. This is a spatial data service innovation based on satellite networks and cloud services. Due to the capacity to deliver inter-satellite laser communication and high-speed data downlink, satellite network systems, including the Starlink system, will supply this service with denser infrastructure coverage in time and space. In September 2020, Microsoft challenged Amazon by launching its own version of "Ground Station as a Service" - Azure Orbital. This service has integrated more satellites, ground stations, algorithms, and AI data. Microsoft partners with SpaceX to provide satellite data cloud services to global users via the Starlink satellite network.

With the foreseeable intensified deployment of satellite networks, these satellite data subscription cloud services will become the basis for removing EO complications. Yet challenges and obstacles remain. For commercial organizations, higher precision and simplicity in data services mean higher efficiency in workflow integration. For instance, AI selection, processing, decoding, and extraction of satellite data driven by specific business needs.

Therefore, in order to maximize market share and to make satellite EO data services as universal as GPS, future EO subscription services should be more hands-on, instant, and adaptive to mobile applications.

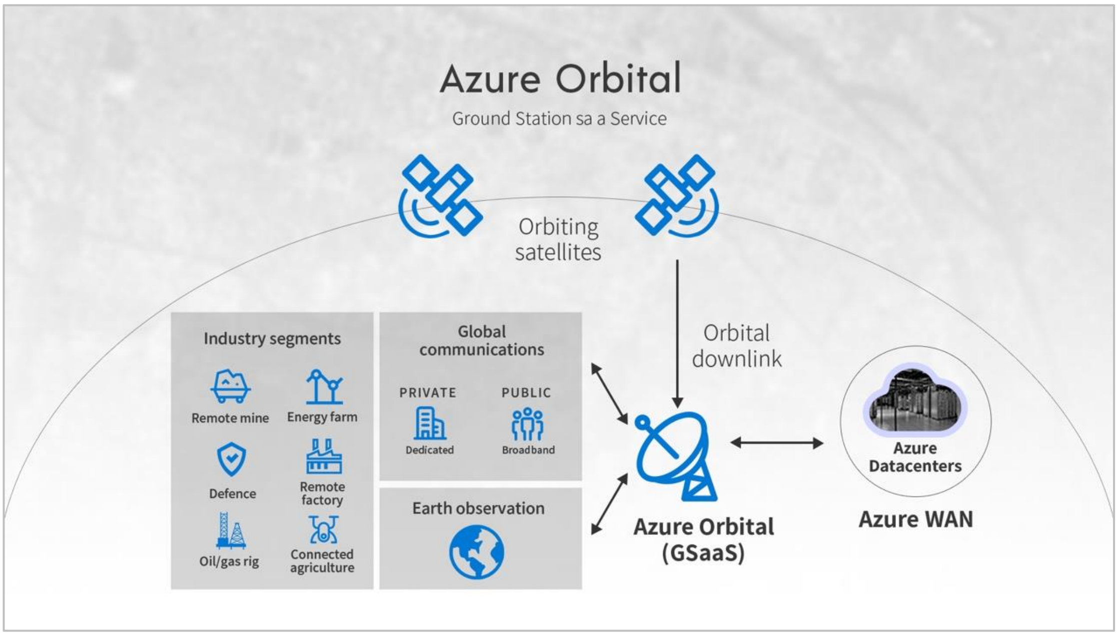


Figure 7 Microsoft Azure Orbital System Architecture

3.2.2 Onboard Processing Enhances Data Application Efficiency

In the traditional processing model, satellites transmit raw image data to the ground for processing, which is inefficient and ineffective. With the development of AI and chip technology, onboard processing has become a reality. In the future, imaging and data processing will be completed on satellites, which then transmit the processed information.

In 2022, technology trend reports from Alibaba and Tencent both mentioned the "satellite-ground computing" and "satellite-ground collaboration" models. This is an emerging computing architecture that integrates satellite systems, air networks, ground communications, and cloud computing to expand the digital service space.

It is expected that the number of LEO satellites will experience exponential growth in the next three years, forming a satellite network with GSO satellites, driving the formation of a new cloud-network convergent computing system. Satellites combining ground systems will form new computing nodes, creating a new cloud system that can cover the blind spots of ground networks and distribute computing power according to specific needs of satellite data, thus optimizing the AI processing capability of mass data. Acting as a "satellite center," this system maximizes the utility of satellite data resources, transmitting to the ground processed images and data services that fulfill client orders after AI on-board processing.

- **Case Study: Analytical Space, Inc. (United States)**

Founded in 2016, satellite communications startup Analytical Space is headquartered in Virginia, U.S. In February 2021, the company won a $26.4 million contract to develop and launch six CubeSats and two hosted payloads to begin establishing the Fast Pixel Network for optical communications. The three-year contract was awarded by AF Ventures, the service's venture arm, with funding from the U.S. Space Force Space and Missile Systems Center (SMC) and the Air Force Research Laboratory as part of the Air Force Strategic Financing program. Investors from commercial organizations will match the Air Force funding. At present, the gap time without data transmission to the ground amounts to 70% during remote sensing satellite operation. Through Fast Pixel Network, Analytical Space plans to establish a data transport network in low Earth orbit to ingest data from geospatial intelligence satellites, send data from node to node via high speed optical intersatellite links, and deliver high-quality data in real time to its clients.

3.2.3 Spatial Laser Communication Renders the Possibility of Satellite Cloud Services

Traditional communication model uses microwaves for satellite-to-ground communication, which faces problems such as low transmission efficiency, dependency on frequency resources, and failure of continuous communication. In the future, laser communication can vastly improve transmission efficiency, resolve real-time inter-satellite data transmission, thus making satellite cloud-based services possible.

The existing space laser communication technology is close to maturity. In November 2017, the innovative 1.5U cube satellite from NASA's Optical Communications and Sensor Demonstration (OCSD) project verified the technology of high-speed laser data transmission for future small satellites. Satellite-to-ground downlink rate reaches 2.5Gb/s. In 2015, Germany built a transportable adaptive optical ground station (TOGS), enabling high-speed transmission between transportable adaptive laser communication terminals and LEO, with a transmission rate of 5.625Gb/s. Meanwhile, TOGS enables bidirectional communication with Alphasat's laser communication terminal, with a bandwidth of 2.8125Gb/s and an effective transmission rate of 1.8Gb/s. In 2017, Shijian-13, China's first high-throughput communications satellite, successfully conducted the world's first experiment on high-orbit laser communication. The satellite orbits ~40,000km above the Earth with a maximum data rate/transmission rate of 5 Gb/s.

3.2.4 Multisource Spatiotemporal Integrated Satellite EO Data Tool

Compared with higher-level distribution networks, decentralized clients need small-scale EO data management tools, influenced by the digital twin and metaverse trends. As opposed to complex professional data processing software, such tools can integrate multisource geospatial data (e.g., drones, raster maps, elevations, lidars), then publish and share the data in a timely manner. Integration tools will enhance the ease of use of satellite EO data, making it more accessible and applicable for the general public.

3.2.5 Formation of Large-Scale Centralized EO Data Channels & Distribution Networks

Satellite EO and the monitoring of carbon neutrality/natural resources are increasingly converging. Satellite EO can perceive and quantify with precision changes in the environment. Meanwhile, space technology can accurately detect and measure emission sources, gathering data on greenhouse gas emissions, climate patterns, ice cover, etc., playing a key role in carbon neutrality initiatives.

Due to the time-sensitive nature of spatial data applications, the satellite EO industry is undergoing rapid transformations. Software-based production and networks are expanding in various segments of the aerospace economy. Large-scale EO data platforms and networks based on cloud computing are now possible. A systematic sharing platform integrating data, applications, standards, and software tools can provide user-friendly and stable high-resolution image data services. Such platform can meet the diverse demands of natural resource monitoring and research, making full use of EO infrastructure, centralizing data time series logic to form an efficient and collaborative spatiotemporal data structure.

3.2.6 Direct Link between Satellite EO Data and AI without Manual Processing

A frequently mentioned drawback of traditional EO is low processing efficiency. The data processing process is too human-dependent and the data acquisition chain is too long. Large amount of manual processing increases costs, slows down data flow and collaboration rate. Nonetheless, AI development has brought new possibilities for satellite EO data processing. For instance, applying AI to multisource satellite image processing to form intelligent, automated processing frameworks; advancing the intelligent processing of high-resolution multisource EO satellite image processing to the next level via the closed-loop cross integration of semantic information extraction and precise geometric processing.

3.3 Business Model Innovations Drive Satellite EO Development

3.3.1 Maturity of Professional Small Satellite Constellations

In the past, satellite EO pursued high spatial resolution and high performance of a single satellite. However, temporal resolution and application efficiency were far from meeting user expectations. In the future, specialized small satellite constellation networks will develop continuously, with the following trends:

- *Emergence of specialized high-efficiency small satellite constellations to solve specific problems:* Some examples include AIS/VDES satellites for maritime communications, ADS-B satellites for aviation navigation, InSAR satellites for resolving land subsidence and displacement, etc. In the future, there will be multispectral satellite constellations for water quality analysis and forest resource research etc. An increasing number of specialized, high-efficiency small satellite constellations will emerge at a large scale.

- *Emergence of diverse observation methods:* As technology advances, EO satellite constellations that integrate radio signals, visible light, and multispectral payloads have immensely enhanced the efficiency and quality of EO, making multisource data and spatiotemporal data accessible in a more economic and efficient way. These satellite constellations have diversified data sources, service models, and customer groups.
- Satellite being more than a sensor: Future satellites are more than mere sensors. With the continuous upgrade of satellite computing power and intersatellite/satellite-to-ground laser communication technology, future satellites will form networks, evolving into a satellite-cloud system in which cloud computing networks and sensor networks interconnect.
- Possibility of higher temporal and spatial resolution constellations: As reusable launch technology progresses, the cost of launching satellites is decreasing. With the advancement of electronic component/microchip productions, the manufacturing cost of satellites is also rapidly declining. Supported by new propulsion technologies, EO satellites could potentially operate at altitudes closer to the ground, such as 200km. Consequently, large-scale EO satellite constellations will emerge, rendering the possibility of revisit rates within minutes. Commercial satellite EO data with a spatial resolution of 10cm will also be probable.

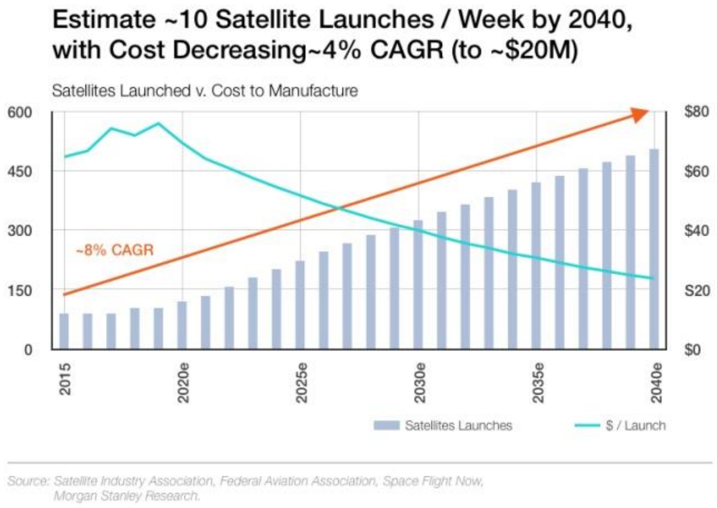


Figure 8 Satellite Launch Costs in Rapid Decline

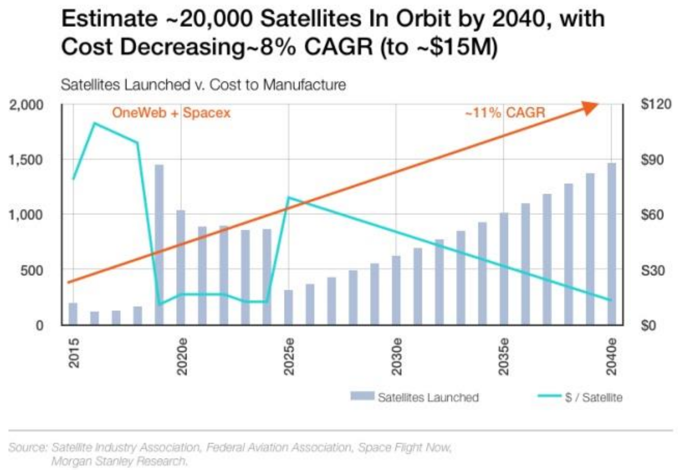


Figure 9 Estimated Decrease in Satellite Costs

3.3.2 Model Innovations in AI+ Satellite EO

Traditional satellite EO is essentially what you see is what you get, acting as a porter of information. Future EO satellites can generate more insights after processing image data via AI. For instance, through multi-angle, multi-sequence, and multi-location image data, satellite EO can pinpoint landfill locations, as well as predicting which areas are more prone to landfill and where management needs to be reinforced. Such information is more valuable and actionable. In addition to acquiring information such as soil moisture and fertility, satellite EO can also deliver useful insights on means to grow different varieties in rotation and to improve yield. Integrating EO data into economic development policy-making can amplify the value of satellite EO.

3.3.3 High Spatiotemporal Resolution Brings Forth New Market Opportunities

Traditional satellites have poor maneuverability, observing a certain area at a certain time by strips or squares. Due to the decrease of satellite EO data costs and the enhancement of data acquisition capabilities, EO satellites with high spatiotemporal resolutions will become possible. New service capabilities will lead to new applications and new markets. There used to be limited application scenarios for landline telephones. Then, mobile communication brought radical change to application possibilities. Now, the scale of day-to-day applications has grown exponentially thanks to mobile internet devices (e.g., smartphones). A similar evolution will occur in EO.

3.3.4 Metaverse Gives Rise to New Market Opportunities

"Virtual Earth" is no longer a novel concept. It is described as a computer-generated 3D virtual Earth with visualization and interactive features. The buzzword "Metaverse" has pushed 3D visualization development to the forefront.

In December 2021, metaverse and GIS developer Blackshark.ai raised $20 million in Round A to develop and scale its replica Earth technology. Blackshark provides a 3D digital twin of Earth by extracting information from satellite imagery, combining geospatial data and a 3D simulation environment.

There is more to virtual mapping applications utilizing high-resolution satellites. Real-time changes of ground objects detected by satellite EO will reshape forms of information communication, geographic education, tourism, etc.

- **Case Study: EO Spatiotemporal News**

Satellite imagery is a veritable "God's-eye view" of the world. Satellite EO has been widely used in news broadcasts. Dramatic satellite images have captured the sheer power of the recent Tonga volcano eruption. Through retrieval algorithms, satellite EO can further track volcanic activities, forming continual and real-time reports. For metaverse applications, a virtual world constructed by high-resolution satellite imagery, satellite footages, and other aerial photography data will act as a medium for multitemporal EO news information, creating a more dynamic and up-to-date form of news reporting.

- **Case Study: Geographic Education & Virtual Tourism**

Based on high-resolution EO, 3D Immersive Virtual Reality, and 3D GIS technologies, digital twins developed via game engines are virtual representations of physical entities. This technology has generated true-to-life digital replicas of historical sites, topographical features, natural sceneries, etc. These data are stored in digital archives accessible to the general public. Such immersive digital learning experiences will help students gain insights into cultural heritage and historical artifacts. Meanwhile, digital twin technology takes virtual tourism to the next level, offering tourists interactive and immersive sightseeing experiences.

- **Case Study: Metaverse Digital Earth NFT (Non-Fungible Tokens)**

Dreamverse is a virtual platform where users can create their own digital worlds via purchasing virtual land in the platform as NFTs using blockchain technology. According to Dappradar data, “The total market value of virtual land NFT had reached $4.6 billion in November 2021, with a monthly growth rate exceeding 200%. Virtual land traders had reached a record number of 27,600, a 145% increase from October 2021.”

3.3.5 New Model of Cloud Computing + Sensor Network

New business models of cloud computing + sensor networks will emerge in the satellite EO field, including the rental of space computing power, the distribution of space cloud computing resources, and other integrations of cloud computing and sensor networks.

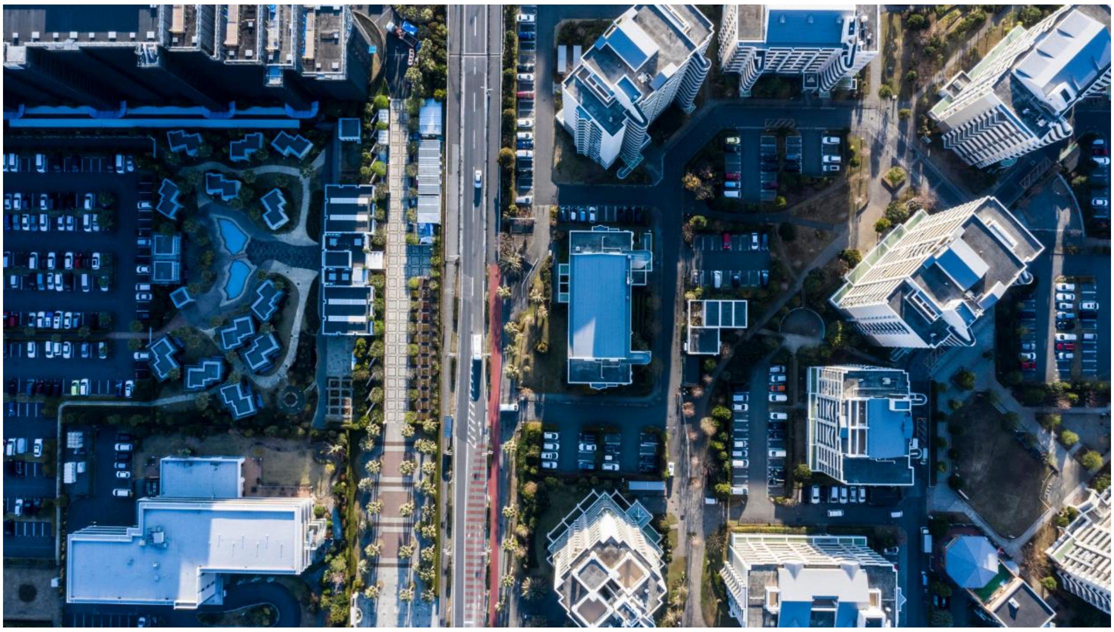
In addition to investments in spatial network infrastructure, technological research and application development will continue to progress. Software-defined satellites, commercial AI platforms, and in-orbit computing will render the above-mentioned business model possible.

3.4 New Technology, New Players

The world has seen a surge of satellite EO startups in the last decade. Since 2021, a series of satellite EO startups including Planet Labs, Spire Global, Satellogic, Terran Orbital have gone public after closing SPAC deals.

- Planet Labs: Founded in 2010, Planet Labs is the world's largest EO satellite company. The company has launched over 460 CubeSats, acquiring over 30PB of data, employing machine learning to process and analyze image data. According to its latest quarterly report, Planet Labs reported a record $31.7 million in revenue for Q3 2021, a 16% increase from Q3 2020. The company also reported a total of 742 clients, a 32% increase from a year prior. Planet estimated an annual revenue of $130 million in 2021 and ~$700 million in 2026. In a broader perspective, the company is targeting the $75 billion digital transformation market, the $35 billion sustainability market, and the $19 billion EO data and service market.
- Spire Global: Founded in 2012, Spire Global is a space-to-cloud data analytics company specializing in tracking global datasets powered by large CubeSat constellations, such as tracking maritime, aviation, and climate patterns. The company currently operates a constellation composed of over 110 CubeSats, the second-largest commercial constellation by satellite quantity, and the largest by sensor quantity. Since 2012, the company has launched over 140 satellites into orbit. According to its financial report, Spire estimated a quarterly revenue of $15.3 million for Q4 2021, a 111% increase from Q4 2020. Meanwhile, the company estimated an annual revenue of $43.7 million for FY 2021, a 53% increase from the previous fiscal year. Spire started delivering satellite Automatic Identification System (AIS) data services to the Indian Navy in the fourth quarter. Under this contract, Spire is tracking maritime activity and offshore resources across more than 7,500 km of coastline which is paramount to maintaining India's security and economic activity.

4 Technology & Model Innovations Fuel Trillion-Dollar Market of Satellite EO



4.1 Traditional Satellite EO Services

Considering the growing market penetration rate, the global market for EO satellite data and services is estimated to reach $10 billion in 2030, with a CAGR of ~10%. Security applications including defense and maritime surveillance will continue to expand. Change detection and analytics services based on high-frequency data acquisition of a given area via satellite constellations will benefit emerging market segments, such as financial services (e.g., business intelligence, insurance, etc.) or location-based services (LBS).

4.2 Market Estimate of AI+ EO Services

In order to tackle major challenges facing our planet today, such as predicting natural disasters, the multi-series, multitemporal, multispatial, multispectral, and multi-sensor data from satellite EO will offer new solutions. As AI+ EO technology continues to mature, the market value of AI+ EO services is estimated to reach $740 billion with a CAGR of 40% in the decade.

4.3 Market Estimate of High Spatiotemporal Resolution Services

The continuous enhancement in spatial and temporal resolutions will bring forth new application scenarios. Considering a 30m revisit time, the annual market value is estimated to reach $30 billion; for a 10m revisit time, an estimated $80 billion; for a 1m revisit time, an estimated $200 billion; for real-time monitoring, an estimated $500 billion.

4.4 Metaverse Forges New Market Opportunities

The market size of the Metaverse industry will exceed $1 trillion in the next five years. There are numerous ways the Metaverse industry could utilize the power of satellite EO, which could contribute a 10% increase in revenue growth (i.e., $100 billion).

4.5 Market Estimate of Cloud Computing + Sensor Networks

Satellite constellations acquire massive amounts of real-time remote sensing, PNT, and IoT data, then process and analyze these data via edge computing. Building space-cloud service infrastructure will facilitate satellite constellations in maximizing application efficiency.

This new model of cloud computing + sensor networks will engender new growth for the cloud computing industry. In 2022, the market size of global ground cloud computing is estimated to exceed $270 billion. Considering a 10%-15% market share, the estimated revenue for the "cloud computing + sensor networks" model will reach $27-$40.5 billion by 2030.

5 Satellite EO Market Summary

Per analysis in the previous chapter, in addition to traditional satellite EO services, new services including AI+ EO, high spatiotemporal resolution satellites, metaverse, and cloud computing will experience exponential growth, reaching a cumulative total market revenue of $0.9-$1.4 trillion.

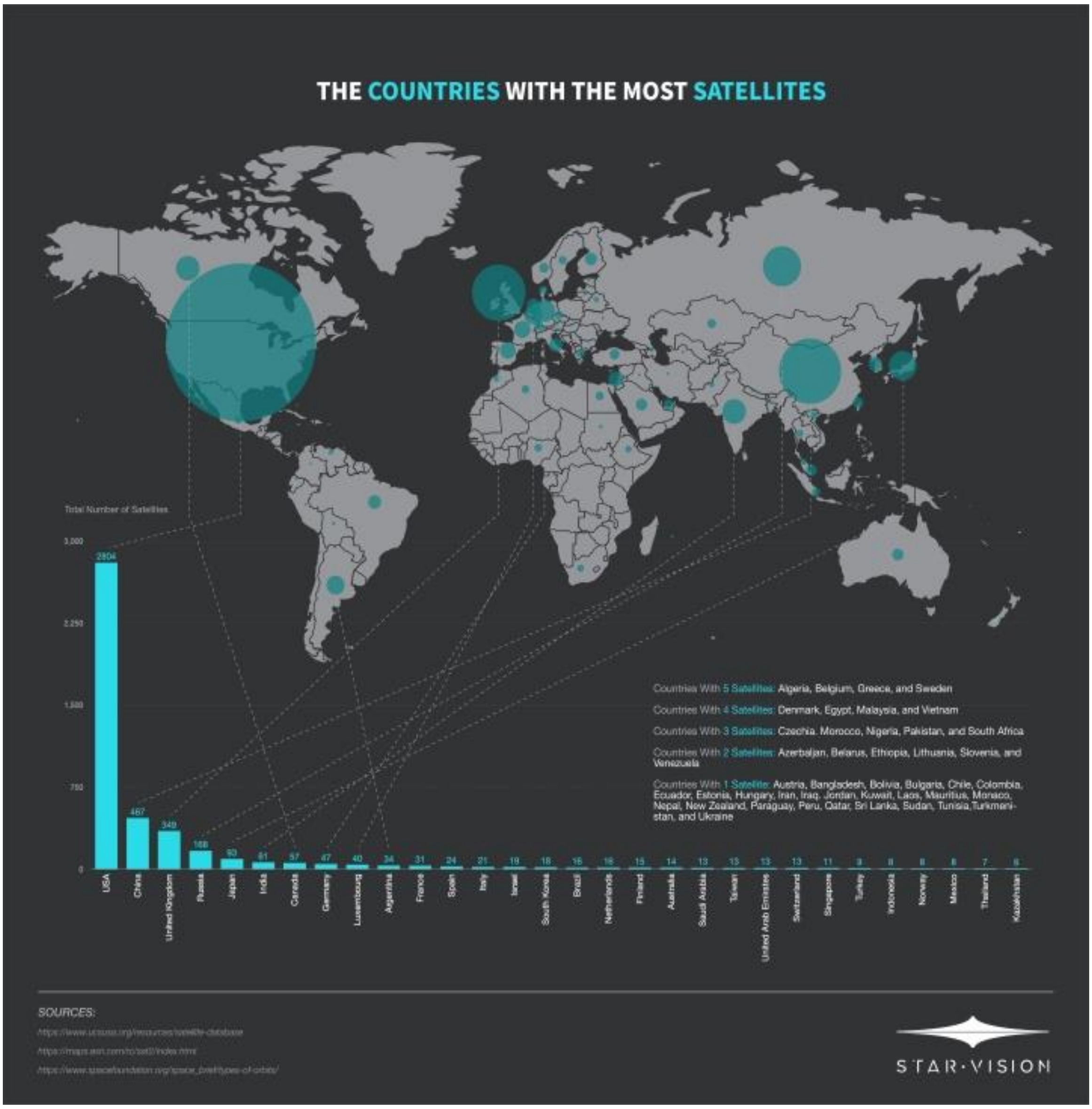


Figure 10 Number of satellites in-orbit from different countries

Since the launch of the first meteorological satellite by the U.S. in 1961, sixty years of EO satellite development has made profound impact on myriad aspects of the economy. Approximately 75 countries currently own satellites, with EO satellite often being the first satellite launched by these countries.

Over the last decade, satellite R&D and launch costs have dramatically decreased. New technologies such as AI and cloud computing have continuously evolved, enhancing the potential of satellite EO. New market demands such as the digital economy, climate change, the metaverse have emerged, expanding the horizon of EO applications. Led by modern aerospace companies, the satellite EO industry sees new opportunities ahead, targeting a trillion-dollar global market by 2030.

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