# 1. Artificial Satellites

## 1.1. What are Artificial Satellites?

- Artificial satellites are **human-built objects orbiting the Earth and other planets** in the Solar System.
- They are used to study the Earth, other planets, aiding communication, and even to observe the distant universe. Satellites can even have people in them, like the International Space Station.
- The first artificial satellite was the Soviet Sputnik 1 mission, launched in 1957.

## 1.2. Types of Artificial Satellites

The most common types of artificial satellites based on their application are:

- Communication
- Earth observation
- Navigation
- Astronomical

# 2. Communication Satellites

## 2.1. What are Communication Satellites?

- Communication satellites are launched to orbit around the earth or any other planet to collect information and transmit it back to the planet.
- They are launched to **expand the ability of networks and connections** on the planet.
- Such a satellite can make long-distance communication and information transfer much more effortless.

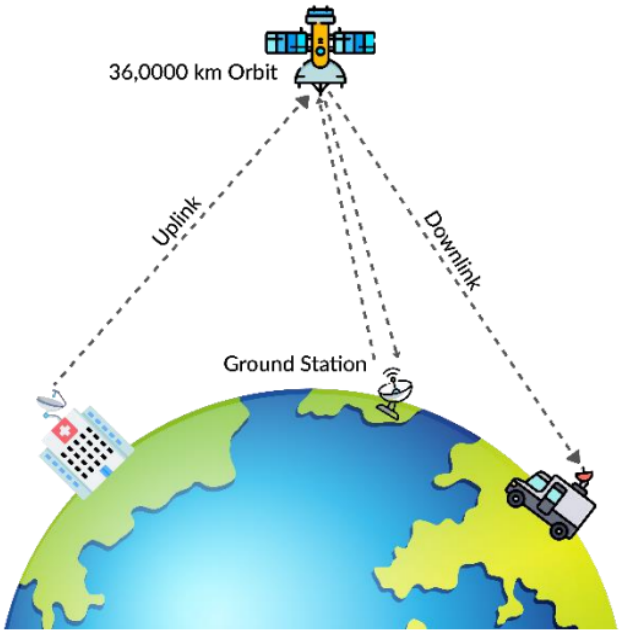


**Figure.1. Working of Communication Satellite**

## 2.2. Working of Communication Satellite

The process of communicating with satellites involves four significant steps:

- A **signal transmission** will occur from an **Uplink Earth station** or other equipment transmitting the desired signal to the satellite.
- The received signal is **amplified** by the satellite.
- The signal is transmitted back to the earth as a **downlink.**
- The antennas or **receiving equipment** will receive this signal.

### 2.3. Applications of Communication Satellites

- **Telecommunication:** To efficiently provide voice and data communication with the local and far-flung areas.
- **Telemedicine:** Mobile units are being connected seamlessly to the major hospitals and medical hubs, and medical practitioners are able to access the data rapidly.
- **Tele-education:** Communication satellites make education available to the students and professionals in remote locations.
- **Banking:** Banks and ATMs require a secured and reliable connectivity to transmit data and satellites provide that reliable connectivity for all the limitless transactions.
- **Development of Internet of Things (IoT) technology through smallsats:** Through the launch of small communication satellites in low earth orbits, the number of IoT devices being connected with the internet can be increased.
- **Real-time tracking:** To track the real-time data for earth observations such as climate change, disaster management, and also for military applications.
- **TV Broadcasting:** Various programs such as movies, live sports and live news are available on television through direct broadcast satellite.
- **Radio Broadcast:** A satellite radio provider uses satellites to broadcast audio channels of entertainment, sports, and news programs.

## 3. Indian National Satellite (INSAT) system

- The Indian National Satellite (INSAT) system is one of the largest domestic communication satellite systems in the Asia-Pacific region with nine operational communication satellites placed in Geo-stationary orbit.
- It was **established in 1983** with commissioning of the first satellite in the series, INSAT-1B.

### 3.1. Impact of INSAT Programme on India

- The communication satellite series of India has grown into a very large constellation of satellites in the INSAT and GSAT series.
- The INSAT satellite system is one of the largest domestic communication satellite systems providing regular services in the areas of television, telecommunications, radio networking, business and personal communication and weather forecasting and meteorological services.
- Newer initiatives have been taken to expand the INSAT applications to newer areas like:
    - Tele-education
        - **EDUSAT**: used extensively to cater to a wide range of interactive educational delivery modes like one-way TV broadcast, video conferencing, web-based instructions, etc.

    - Tele-medicine
        - ISRO Telemedicine pilot project was started in the year 2001 as part of proof-of-concept demonstration programme.
    - Village Resource Centre (VRC)
        - VRCs have provided various space technology enabled services such as tele-healthcare, tele-education, natural resources information, etc.
        - Major benefits include advisories related to agriculture like crop pests and diseases, crop insurance etc.; career guidance to rural students, skill development and vocational training etc., to the rural population.
    - Disaster Management Support (DMS)
        - ISRO disseminates relevant information in interactive **geo-spatial domains** through various geoportals like Bhuvan, National Database for Emergency Management and MOSDAC (Meteorological and Oceanographic Satellite Data Archival Centre).
    - Satellite news gathering
    - Satellite Aided Search and Rescue (SAS&R)
    - Internet services and e-governance
    - Financial service network, such as the banking, the stock exchanges etc.
    - Standard Time and Frequency Signal (STFS) Dissemination Services
- The INSAT system has also extended the outreach to less accessible areas like North-East, other far-flung areas and islands.

### 3.2. List of Important Communication Satellites

| Satellite | Launch Date | Launch Vehicle | Application |
|---|---|---|---|
| CMS-01 | Dec 17, 2020 | PSLV-C50/CMS-01 | Communication |
| GSAT-30 | Jan 17, 2020 | Ariane-5 VA-251 | Communication |
| GSAT-31 | Feb 06, 2019 | Ariane-5 VA-247 | Communication |
| GSAT-11 Mission | Dec 05, 2018 | Ariane-5 VA-246 | Communication |
| GSAT-17 | Jun 29, 2017 | Ariane-5 VA-238 | Communication |
| GSAT-15 | Nov 11, 2015 | Ariane-5 VA-227 | Communication, Navigation |
| GSAT-8 | May 21, 2011 | Ariane-5 VA-202 | Communication, Navigation |
| EDUSAT | Sep 20, 2004 | GSLV-F01 / EDUSAT(GSAT-3) | Communication |

| | | | |
|---|---|---|---|
| INSAT-3A | Apr 10, 2003 | Ariane5-V160 | Climate & Environment, Communication |
| KALPANA-1 | Sep 12, 2002 | PSLV-C4 /KALPANA-1 | Climate & Environment, Communication |

# 4. Earth Observation Systems

## 4.1. What is Earth Observation?

- Earth Observation (EO) refers to the **use of remote sensing technologies to monitor land, marine** (seas, rivers, lakes) **and atmosphere.**

## 4.2. Earth Observation Satellites

- The purpose of Earth observation type of satellites is to monitor the Earth from space and report back on any changes they observe.
- The equipped sensors are different depending on the purpose such as observation of natural phenomena, disaster monitoring, changes in the Earth caused by human activity and so on.
- Observation results are provided as satellite images or observation data, and can be interpreted into various information regarding the Earth.
- Earth observation spacecraft can be classified as:
    - **Weather satellites:** employed for monitoring and forecasting weather trends and providing actual weather data.
    - **Remote sensing satellites:** its primary applications are all types of environmental monitoring and geographical mapping.

## 4.3. Applications of Earth Observation Satellites

- **Agriculture and Soil:** Information on crop statistics such as distribution and storage of food grains, government policies, pricing, procurement and food security, saline/sodic soils mapping.
- **Renewable Energy:** Winds, solar and wave energy resources can be assessed with the help of Earth observation data.
- **Forest and Environment:** Biodiversity characterization, wetlands, forest and biomass mapping, land degradation and desertification processes, coastal wetlands, coral reefs, mangroves, glaciers, air and water pollution assessment, etc.
- **Geology, Geomorphology and Mineral Resources:** Lithological, geomorphological and structural mapping, landslide hazard zonation, mineral /oil exploration, mining areas, seismotectonic studies, and geo-environmental studies.
- **Land Resources:** Coverage of natural resources, land use coverage, land degradation mapping, wasteland mapping, and desertification status mapping.
- **Ocean Science:** Identification of potential fishing zones, sea state forecasting, coastal zone studies and inputs for weather forecasting and climatic studies.

- **Rural Development:** Wasteland mapping/updation, watershed development and monitoring and land records modernization plan.
- **Urban Development:** Satellite-based remote sensing is advantageous in monitoring urban land use dynamics because of the extensive spatial coverage for mapping applications, frequent revisit periods, and wide availability.
- **Water Resources:** Irrigation infrastructure assessment, water resource information system, snowmelt run-off estimation, reservoir capacity evaluation and site selection for hydro-power.
- **Weather and Climate:** Weather satellites carry instruments called radiometers that scan the Earth to form images. Through these data, hurricanes, tornadoes, heavy rainfall, cloudy sky and even the high temperature in summer, drought, etc. can be predicted.
- **Disaster Management Support:** Operationally addressing various natural disasters like floods, cyclone, drought, landslide, earthquake and forest fire; research and development on early warning systems and decision support tools.

## 5. Earth Observation Satellites of India

- Starting with IRS-1A in 1988, ISRO has launched many Earth Observation satellites.
- The data from these satellites are used for several applications covering agriculture, water resources, urban planning, rural development, mineral prospecting, environment, forestry, ocean resources and disaster management.

### 5.1. List of Important Earth Observation Satellites

| Satellite | Launch Date | Launch Vehicle | Application |
|---|---|---|---|
| EOS-04 | Feb 14, 2022 | PSLV-C52/ EOS-04 Mission | Earth Observation |
| EOS-01 | Nov 07, 2020 | PSLV-C49/ EOS-01 | Disaster Management System, Earth Observation |
| RISAT-2BR1 | Dec 11, 2019 | PSLV-C48/ RISAT-2BR1 | Disaster Management System, Earth Observation |
| Cartosat-3 | Nov 27, 2019 | PSLV-C47 / Cartosat-3 Mission | Earth Observation |

| | | | |
|---|---|---|---|
| Cartosat-2 Series Satellite | Jan 12, 2018 | PSLV-C40/Cartosat-2 Series Satellite Mission | Earth Observation |
| RESOURCESAT-2A | Dec 07, 2016 | PSLV-C36 / RESOURCESAT-2 A | Earth Observation |
| INSAT-3DR | Sep 08, 2016 | GSLV-F05 / INSAT-3DR | Climate & Environment, Disaster Management System |
| Oceansat-2 | Sep 23, 2009 | PSLV-C14 / OCEANSAT-2 | Climate & Environment, Earth Observation |
| Rohini Satellite RS-D1 | May 31, 1981 | SLV-3D1 | Earth Observation |
| Bhaskara-I | Jun 07, 1979 | C-1 Intercosmos | Earth Observation, Experimental |

## 6. Satellite Navigation Systems

### 6.1. What is a Satellite Navigation System?

- Satellite navigation or SatNav system is a system of artificial **satellites capable of providing geo specific positioning** everywhere in the world.
- Satellite navigation allows satellite navigation devices to determine their location to high precision using time signals transmitted along a line of sight by radio from satellites.
- Global coverage for each system is generally achieved by a satellite constellation of 18–30 medium Earth orbit (MEO) satellites spread between several orbital planes.

### 6.2. Types of Space Navigation System

There are two major types of space navigation systems:

**Global Navigation Satellite System (GNSS)**

- The spacecraft of the Global Navigation Satellite System (GNSS) broadcast signals that GNSS receivers pick up and utilize for geolocation purposes, providing global coverage.
- As of 2023, four global systems are operational:
    - United States' Global Positioning System (GPS) (became fully operational in 1993),
    - Russia's Global Navigation Satellite System (GLONASS),

    - China's BeiDou Navigation Satellite System, and
    - European Union's Galileo.

**Regional Navigation Satellite System (RNSS)**

- The Regional Navigation Satellite System (RNSS) is an autonomous regional navigation system that provides coverage on a regional scale.
- RNSS in operation are:
    - Japan's Quasi-Zenith Satellite System (QZSS), and
    - Indian Regional Navigation Satellite System (IRNSS) or NavIC.

### 6.3. Applications of Satellite Navigation

- **Travel:** Satellite navigation made travel to unknown places simple.
- **Tracking & Monitoring:** It has become common to track a package location, whether a parcel or food delivery.
- **Aviation:** Aircraft with SatNav services decreases the load on the pilot and decreases accidents.
- **Marine:** Navigation aid, self steering and automatic chart plotters technology made sailing easy.
- **Surveying:** Building, roads and other construction companies used SatNav technologies for precise and accurate readings.
- **Mining and Archaeology:** Both sectors use satnav for 3D mapping of sites for excavation and detailed site features.
- **Space Applications:** Spacecraft with SatNav receivers enables orbit determination precisely. It also helps in performing autonomous navigation and rendezvous tasks.
- **Military Operations:** Unmanned Aerial Vehicles (UAV), missiles, and bombers are updated with guided technology that was achieved with the integration of SatNav technology.

## 7. Navigation Satellites of India

### 7.1. GPS Aided GEO Augmented Navigation (GAGAN)

- It is a **Space Based Augmentation System** (SBAS) **jointly developed by ISRO and Airport Authority of India** to provide the best possible **navigational services over Indian FIR** (Flight Information Region) with the capability of expanding to neighbouring FIRs.
- After launching the GAGAN on 13 July, 2015, India joined the select league comprising the United States, Europe Union (EU) and Japan which have similar systems.
- GAGAN is a system of satellites and ground stations that **provide GPS signal corrections.** It corrects for GPS signal errors caused by Ionospheric disturbances, timing and satellite orbit errors and also it provides vital information regarding the health of each satellite.

**Working of GAGAN**

- GAGAN consists of a set of ground reference stations positioned across various locations in India called **Indian Reference Station** (INRES), which gathers GPS satellite data.

- A master station, **Indian Master Control Centre** (INMCC) collects data from reference stations and creates GPS correction messages.
- The corrected differential messages are uplinked via **Indian Uplink Station** (INLUS) and then broadcasted on a signal from three geostationary satellites (GSAT-8, GSAT-10 and GSAT-15).
- The information on this signal is compatible with basic GPS signal structure, which means any SBAS enabled GPS receiver can read this signal.

### Coverage Area

- Two GEOs simultaneously transmit the GAGAN signal in space. GAGAN GEO footprint **expands from Africa to Australia** and GAGAN system has capability to cater 45 reference stations for expansion to neighbouring countries.
- GAGAN provides a **civil aeronautical navigation signal consistent with International Civil Aviation Organization (ICAO) Standards** and Recommended Practices (SARPs) as established by the **Global Navigation Satellite System (GNSS) Panel.**
- The system is interoperable with other international SBAS systems such as the United States Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), and the Japanese MTSAT Satellite Augmentation System (MSAS), and provides seamless air navigation across regional boundaries.

### Gagan Applications

- The GAGAN system is being used for effective management of wildlife resources and monitoring of forests.
- It can provide navigational support to the Indian railway for signaling when a train approaches a no man crossing and also for alignment of railway tracks.
- The Road Asset Management System (RAMS) is likely to be developed for all National Highways in the country and a modern management system that will use the GAGAN system.
- GAGAN signals can also be used to manage traffic in real time to avoid traffic jams.
- Other areas include scientific research for atmospheric studies, natural resource and land management, location based services, mobile and tourism.

## 7.2. Navigation with Indian Constellation (NavIC)

- To meet the **positioning, navigation and timing requirements** of the nation, ISRO has established a regional navigation satellite system called Navigation with Indian Constellation (NavIC).
- NavIC was **erstwhile known as Indian Regional Navigation Satellite System** (IRNSS).
- The main objective is to provide Reliable Position, Navigation and Timing services over India and its neighbourhood, and to provide fairly good accuracy to the user.
- NavIC offers two services:
    - **Standard Position Service** (SPS) for civilian users
    - **Restricted Service** (RS) for strategic users

### Organisation of the NavIC

- The system has essentially two-part. The first part is the **Space Segment,** made up of seven navigation satellites. Then there is **Ground Segment,** which receives signals from these satellites and puts them to different applications.

- In the space segment, there are **three satellites in Geostationary orbit** (GEO) and **four satellites in Geosynchronous orbit** (GSO) with inclination of 29° to the equatorial plane. All the satellites are visible at all times in the Indian region.
- India finished the launching of all the seven navigation satellites by the year 2016. In the middle of 2016, the satellite system also became operational. It has started with providing restricted services for military and other strategic operations.
- The ground network consists of a control centre, precise timing facility, range and integrity monitoring stations, two-way ranging stations, etc.
- Ground Segment is responsible for the maintenance and operation of the IRNSS constellation. It provides the monitoring of the constellation status, computation of the orbital and clock parameters and navigation data uploading.
- The system is intended to provide an absolute position accuracy of better than 10 meters throughout Indian landmass and better than 20 meters in the Indian Ocean as well as a region extending approximately 1,500 km around India.
- ISRO, in May, 2023, launched a new NavIC satellite (NVS-01), that belongs to the second generation of the NavIC, to overcome some of the previous issues faced by NavIC.
    - Issues faced by NavIC include atomic clock failure, satellite replacement, limited coverage, mobile incompatibility, security and encryption.

### Why Does India Need its Own Navigation System?

- The requirement of such a navigation system is driven by the fact that access to foreign government-controlled global navigation satellite systems is not guaranteed in hostile situations.
- Furthermore, its own navigation system will allow India to have a greater accuracy in positioning services.

### What are the Other Services Available from the System?

- Apart from navigation, the system helps in **precise time keeping, disaster management, fleet management and mapping.**
- The applications of NavIC include terrestrial, aerial and marine navigation, vehicle tracking, integration with mobile phones, geodetic data capture, terrestrial navigation aid for hikers and travellers and visual and voice navigation for drivers.

## 8. Astronomical Satellites

### 8.1. What is an Astronomical Satellite?

- An astronomical satellite is a giant telescope in orbit. It is able to see well without interference from the Earth's atmosphere.
- Its infrared imaging technology can function normally without being disturbed by the planet's surface temperature.

### 8.2. Types of Spacecraft Used in Astronomy

Spacecraft used in astronomy can be broken down into several distinct types:

- **Astronomy satellites:** used to investigate different types of celestial bodies and phenomena in space.

- **Climate research satellites:** fitted with specific types of sensors that allows scientists to gather comprehensive, multi-faceted data on the world's oceans and ice, land, biosphere, and atmosphere.
- **Biosatellites:** space-based studies on plant and animal cells and structures; plays a crucial role in the progress of medicine and biology.

### 8.3. Applications of Astronomical Satellites

- Make star maps and study mysterious phenomena such as black holes and quasars.
- Take pictures of the planets in the solar system.
- Make maps of different planetary surfaces.

## 9. Research Satellite: ASTROSAT

- PSLV-C30 successfully launched ASTROSAT, India's **Multi Wavelength Space Observatory** in lower earth orbit on September 28, 2015.
- ASTROSAT is designed to observe the universe in the Visible, Ultraviolet, low and high energy X-ray regions of the electromagnetic spectrum simultaneously with the help of its five payloads.
- With the success of this satellite, ISRO has proposed launching AstroSat-2 as a successor for ASTROSAT.
- The observatory had a planned lifespan of five years but completed its mission in 2022.
- With the successful launch of the space observatory, ASTROSAT, ISRO had put India in a select group of countries that have a space telescope to study celestial objects and processes.

### Scientific Objectives of ASTROSAT

- To understand high energy processes in binary star systems containing neutron stars and black holes.
- Estimate magnetic fields of neutron stars.
- Study star birth regions and high energy processes in star systems lying beyond our galaxy.
- Detect new briefly bright X-ray sources in the sky.
- Perform a limited deep field survey of the Universe in the Ultraviolet region.

## 10. Remote Sensing Applications

### 10.1. What is Remote Sensing?

- Remote sensing is the process of **detecting and monitoring the physical characteristics of an area by measuring** its reflected and **emitted radiation energy** without going physically into that particular area.
- Special cameras collect remotely sensed images, which help researchers sense things about the Earth.

### 10.2. Applications of Remote Sensing

- **Agriculture:** identifying crop conditions; determining crop type, soil moisture content and water content of the field crop; mapping of soil characteristics, soil management practices, crop production forecasting; and drought monitoring.

- **Forestry:** determine the forest cover and type of forest; vegetation density; control of deforestation and forest fires; and biomass estimation.
- **Oceans and Coastal Monitoring:** identification of ocean patterns; assessment of fish stock and marine mammal; monitoring of water quality, temperature and effects of tides and storms; mapping of coastal vegetation; and determining ocean salinity.
- **Geology:** bedrock and structural mapping; mineral and hydrocarbon exploration; environmental geology; sedimentation mapping and monitoring; and geo-hazard mapping.
- **Hydrology**: wetlands mapping and monitoring; measuring snow thickness; river and lake ice monitoring; flood mapping and monitoring; monitoring of glacier dynamics; and mapping of drainage basin.

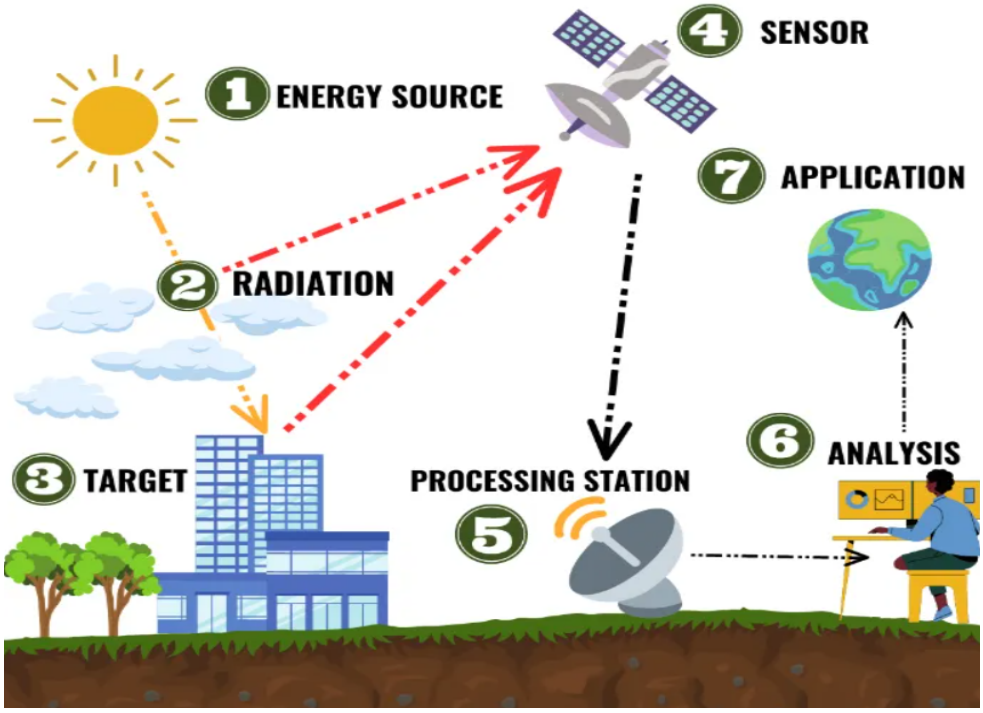


**Figure.2. Remote Sensing Process**

## 11. Indian Remote Sensing (IRS) Satellite Program

### 11.1. Introduction

- Following the successful demonstration flights of **Bhaskara-1 and Bhaskara-2** satellites launched in 1979 and 1981, respectively, India began to develop the indigenous IRS satellite program.
- The program was developed to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, watersheds, marine fisheries and coastal management.
- The remote sensing programme in India under the ISRO **started off in 1988 with the IRS-1A** (first of the series of indigenous state-of-art operating remote sensing satellites).

### 11.2. Principal Capabilities

The program involved the expansion of three principal capabilities:

- To design, build and launch satellites to a sun synchronous orbit.
- To establish and operate ground stations for spacecraft control, data transfer along with data processing and archival.
- To use the data obtained for various applications on the ground.

### 11.3. Important Indian Remote Sensing Satellites

| Name | | Launch Year | Importance |
|---|---|---|---|
| IRS | IRS-1A | 1988 | Used for remote sensing applications such as cartography, land use mapping, and forestry. |
| | IRS-1B | 1991 | |
| | IRS-1C | 1995 | Had improved capabilities.<br>Used for a wide range of applications such as mineral exploration, coastal monitoring, and disaster management. |
| | IRS-1D | 1997 | |
| Resourcesat | Resourcesat-1 | 2003 | Used for resource mapping and management applications such as soil moisture mapping, crop inventory, and forestry. |
| | Resourcesat-2 | 2011 | |
| | Resourcesat-2A | 2016 | |
| Cartosat | Cartosat-1 | 2005 | Used for cartography and high-resolution imaging applications.<br>Cartosat-3 also has an additional capability of capturing hyperspectral images. |
| | Cartosat-2 | 2007 | |
| | Cartosat-3 | 2019 | |
| Oceansat | Oceansat-1 | 1999 | Used for oceanographic applications such as sea surface temperature mapping, ocean color mapping, and ocean wind vector mapping. |
| | Oceansat-2 | 2009 | |
| RISAT | RISAT-1 | 2012 | These satellites had synthetic aperture radar (SAR) sensors that allowed them to capture images of the earth even in cloudy or dark conditions. |
| | RISAT-2 | 2009 | |