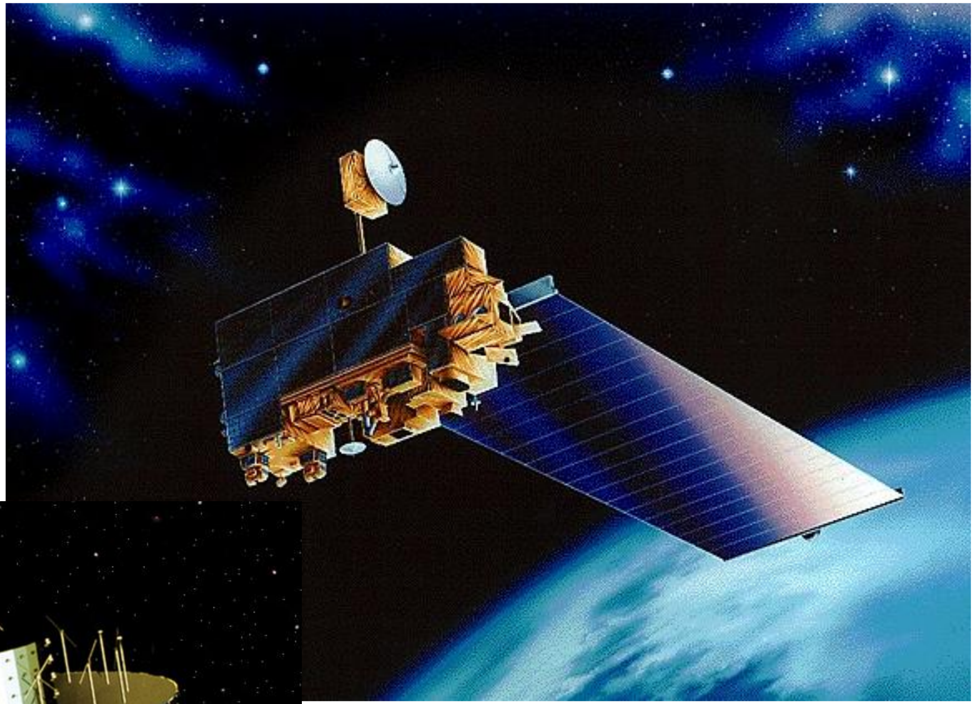
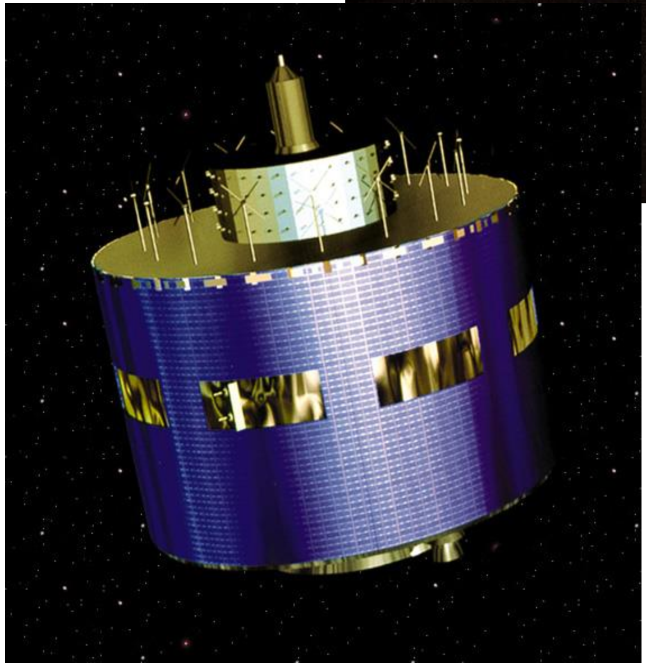
Introduction to Earth Observing Satellites





Dr Humaid AlBadi

5 March 2023

Satellites: Definition

- What is a satellite?

Satellite: In astronomical terms, a satellite is a celestial body that orbits around a planet.

Example: The moon is a satellite of Earth.

In aerospace terms, a satellite is a space vehicle launched by humans and orbits around Earth or another celestial body.

How do satellites observe the Earth?

- ## How do satellites observe the Earth?

Via radiometer device (Imager, Sounder, Receiver) that measures radiation.

> Earth Observation Satellites usually carry many radiometers

- ## What is the difference between satellite imagers, sounders, and receivers?

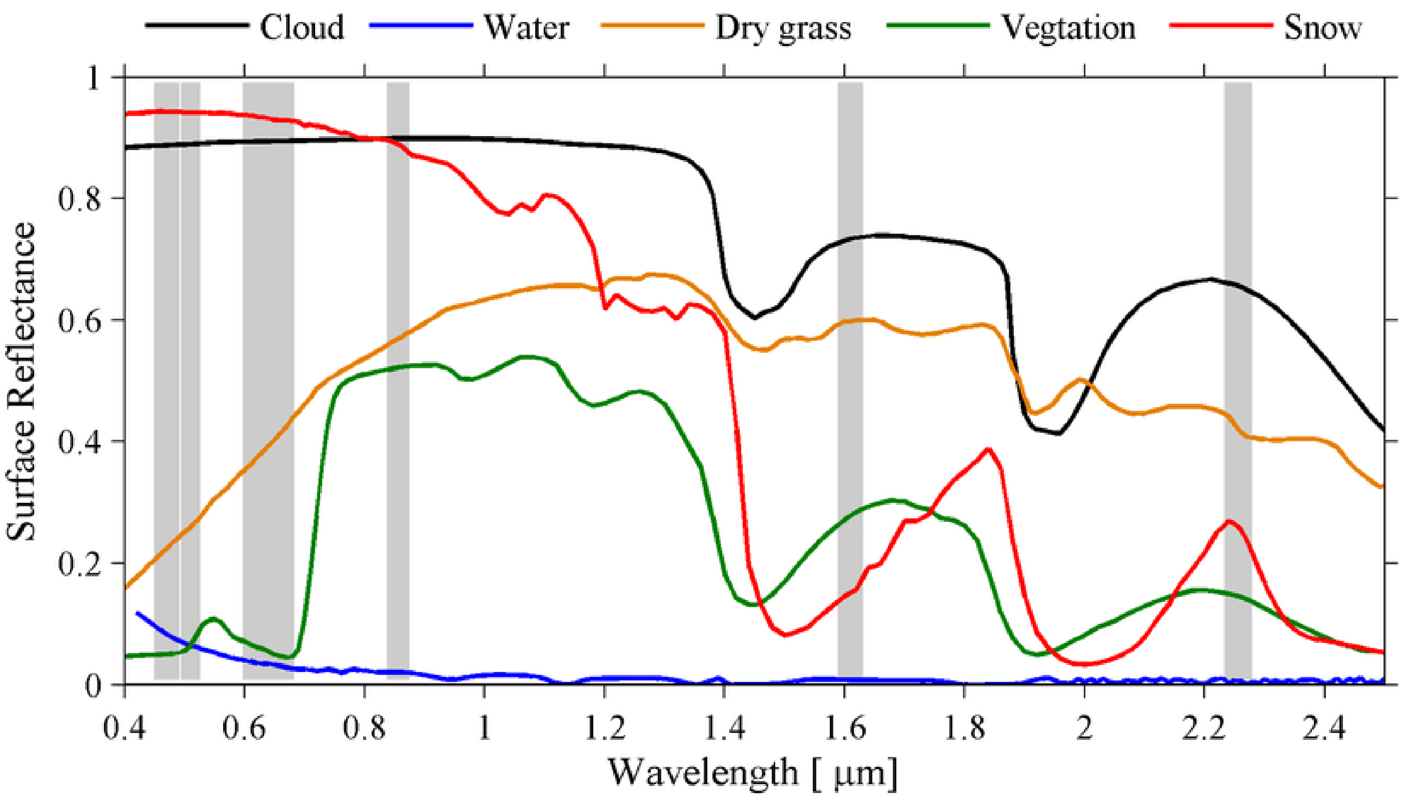
An imager radiometer is a passive nadir broadband sounder.
A receiver is a radiometer for radar backscattering.

How do satellites observe the Earth?

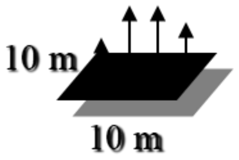
Spectral Signature

- Spectral signature of an object is the variation of reflectance or emittance of the object with respect to wavelengths

- Spectral signature is principle behind the satellite applications

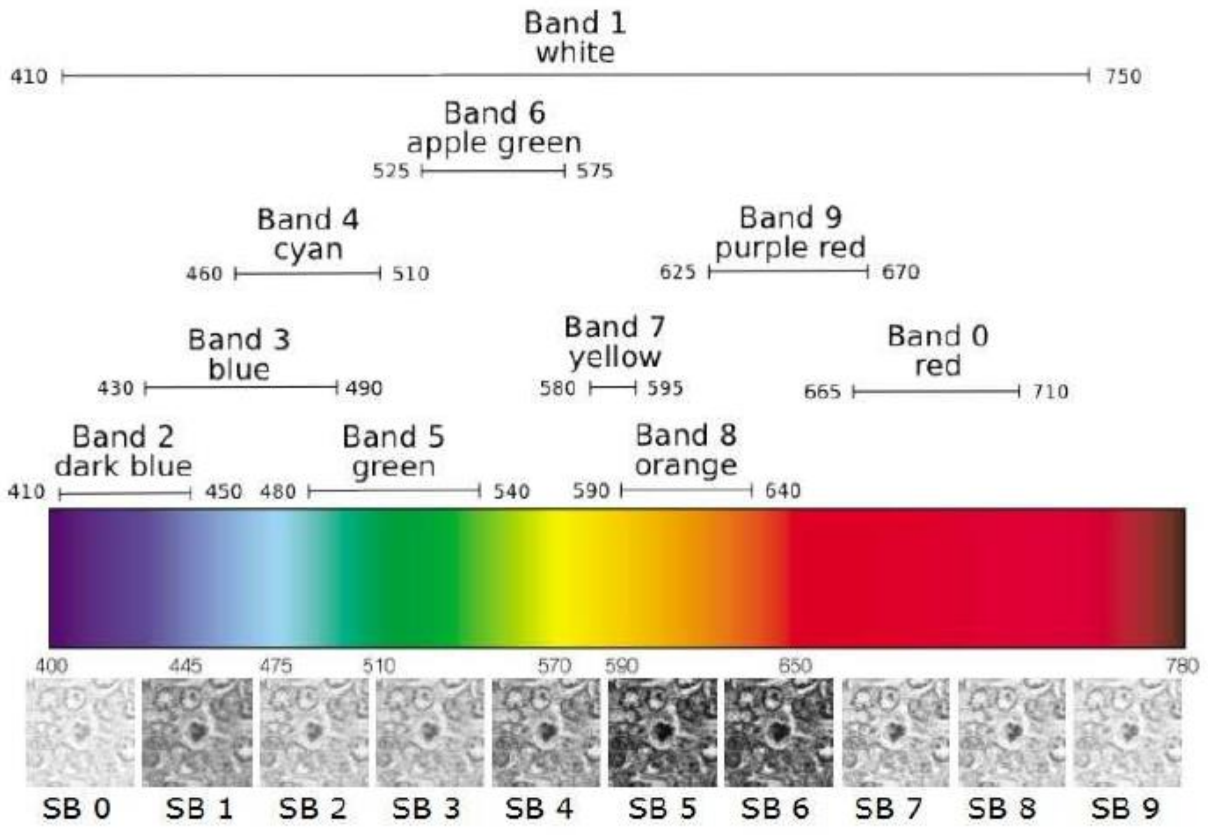


Satellite Resolutions



- **Spatial** - the size of the pixel represented in the field of view, e.g. 10 x 10 m.

- **Spectral** - the size of spectral regions. The shorter, the higher the spectral resolution.



How do satellites observe the Earth?

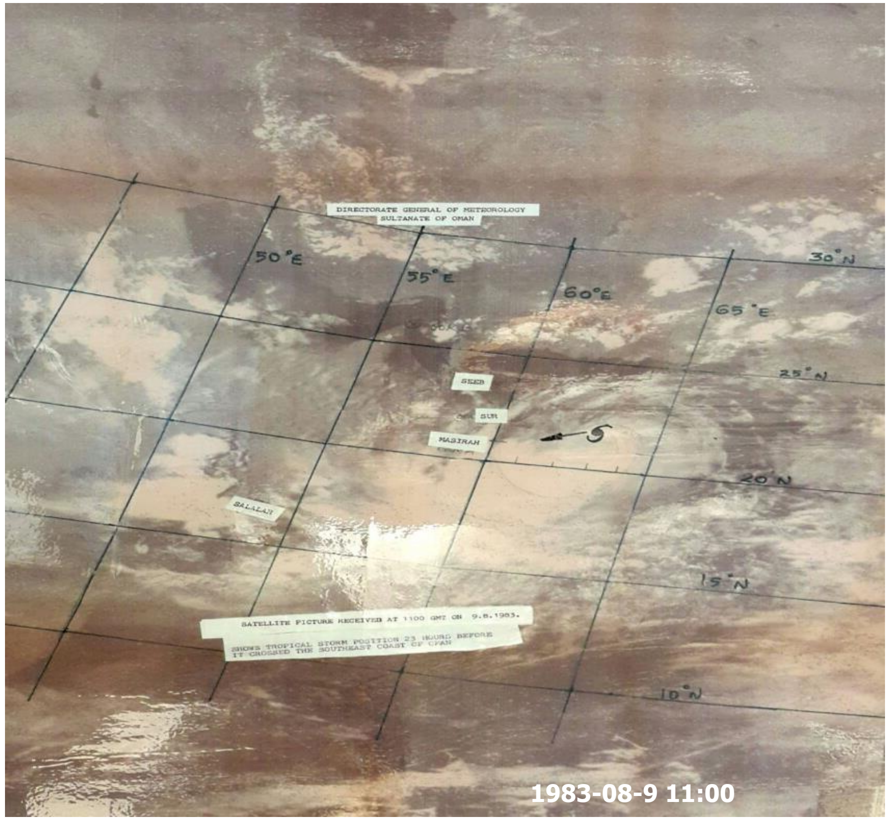
- Via radiometer device (Imager, Sounder, Receiver) that measures radiation.

> Earth Observation Satellites usually carry many radiometers

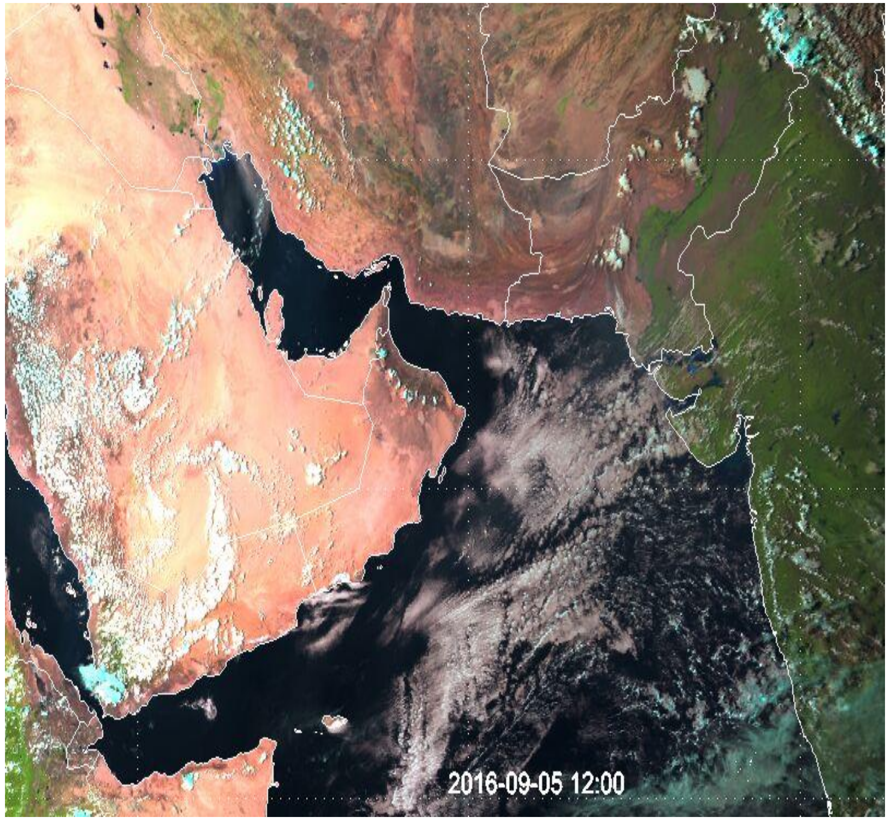
History of Satellites

History of Satellites

Satellite data at Oman Meteorological Service



Receiving images from Low Earth Orbiting since 1983



Geostationary Satellite Receiving Station since 1996

History of Satellites

- The satellite concept evolution

1945 → Theorist Arthur C. Clarke predicted that a satellite orbiting in equatorial orbit would look stationary if moving at a specific speed. 3 satellites in space, 120 degrees apart, can cover the whole world if placed in an orbit with a radius of approximately 42,000 km.

History of Satellites

- 1950’s and 1960’s – Putting the pieces together

1957 → Sputnik-1 was the first satellite launched by the former USSR. It was used to identify the atmospheric density of various orbital layers. It provided data about radio-signal distribution in the ionosphere.

1958 → First US satellite was launched (Explorer 1)

1960 → TIROS-1 was the first full-scale weather satellite, the first of a series of television Infrared Observation Satellites placed in low Earth orbit.

History of Satellites

- 1970's – The start of the routine operational Satellites

1970 → Landsat-1 was launched

1977 → Meteosat-1

1979 → NOAA -1

2021 → Landsat-9

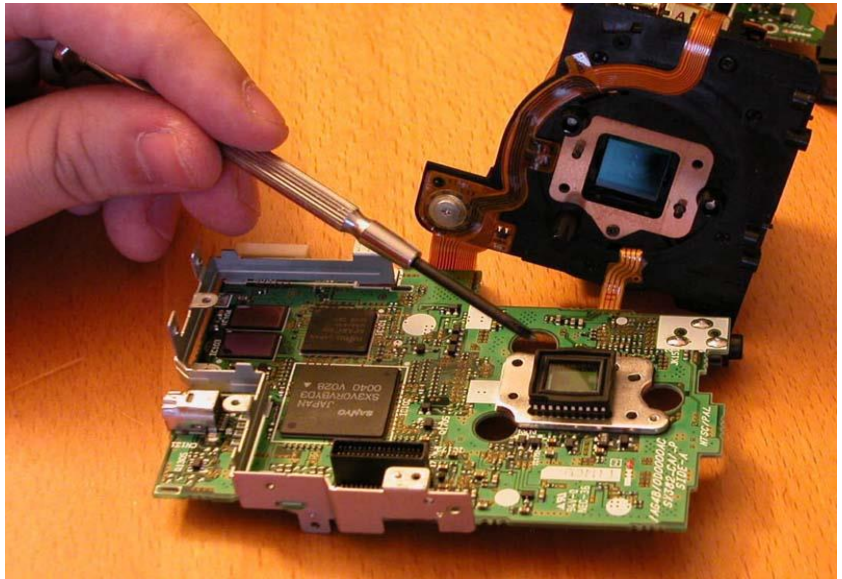
2022 → Meteosat-12

2021 → NOAA-21

History of Satellites

- 1970's – The introduction of two key instruments to Satellite remotes sensing
  - 1972 - Multispectral sensors, first used in Landsat-1
  - 1976 - Charge Couple Device Array

It's lightweight, low-powered and about 15 times more sensitive to light than regular photographic film.



History of Satellites

- 1980's and 1990's – The decades of new experimental sensors
    - **Satellite hyperspectral sensors** that combine information from several spectral bands.
    - **Multi-angle spectrometers** that combine the views from several azimuths
    - **Spaceborne radar**, active microwave systems that can sense through cloud cover and without daylight, measuring the time delay between emission and return, thus establishing the location, height and scattering properties of the Earth's surface.

History of Satellites

- The last two decades – The decades of the operational space Radars (Synthetic Aperture Radars, scatterometers and altimeters)

Satellite radar applications have now diversified considerably

- **Altimeters** sensitive enough to measure sea-level height with a precision of several millimetres
- **scatterometers** to measure surface roughness.
- **Interferometric imagers,** which sense the superposition of different wavelengths, to monitor minute land movements.

Earth Observation data providers

Public EO data providers

ESA	https://earth.esa.int/eogateway/missions
Copernicus-Sentinel	https://sentinel.esa.int/web/sentinel/ https://www.sentinel-hub.com/
Eumetsat	http://www.eumetsat.int/website/home/index.html
USGS (Landsat)	http://earthexplorer.usgs.gov/
NOAA	http://www.ospo.noaa.gov/
NASA	https://earthdata.nasa.gov/earth-observation-data
Japan	http://www.eorc.jaxa.jp/en/about/distribution/index.html
China	http://www.cma.gov.cn/en
India	http://bhuvan.nrsc.gov.in/bhuvan_links.php

More: Go to WMO OSCAR | List of all space agencies

Earth Observation data providers

Examples of Global Commercial EO data providers

Digital Globe resellers (MAXAR)	http://www.digitalglobe.com/partners/certified-resellers
Airbus	https://www.intelligence-airbusds.com/access-to-our-products/
Deimos	https://www.deimos-imaging.com/imagery-store/
Planet Labs	https://www.planet.com
Urthecast	https://www.urthecast.com
MDA Geospatial Services	http://gs.mdacorporation.com/Partners/Partners.aspx
E-geos	http://www.e-geos.it/index.html
Satellite Imaging Corporation	http://www.satimagingcorp.com/
CGG	http://www.cgg.com/default.aspx?cid=7450
European Space Imaging	http://www.euspaceimaging.com/
Land info	http://www.landinfo.com/
Precision Hawk	https://www.precisionhawk.com/satellite
Apollo Mapping	https://apollomapping.com/
GHGSat	https://www.ghgsat.com/

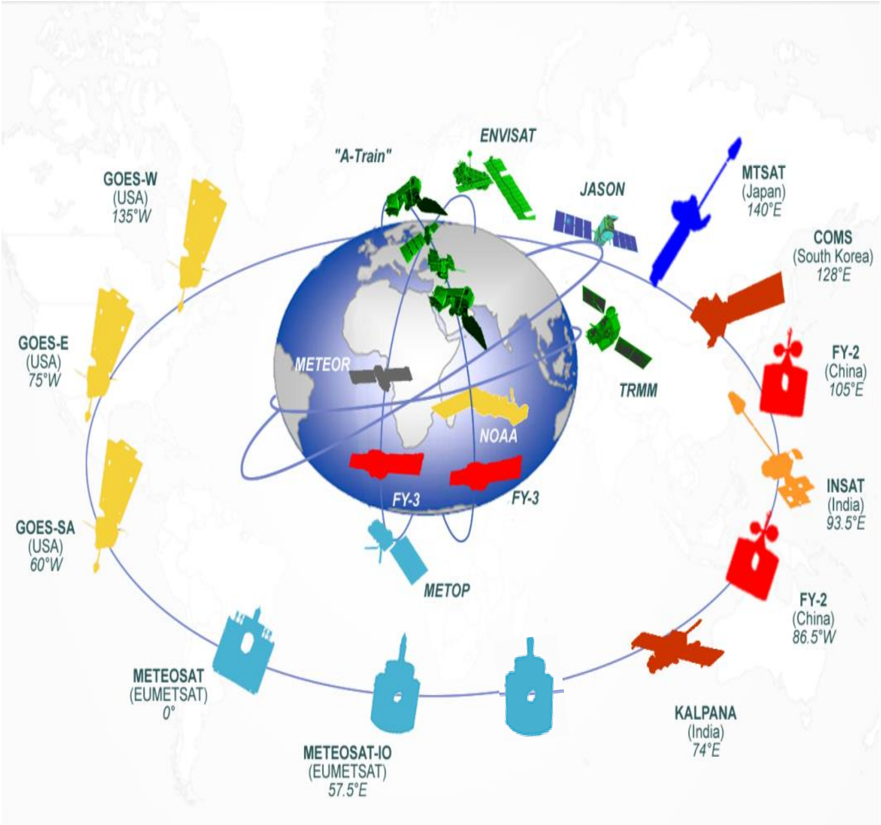
More: Go to WMO OSCAR | List of all space agencies

Practical
Task 1

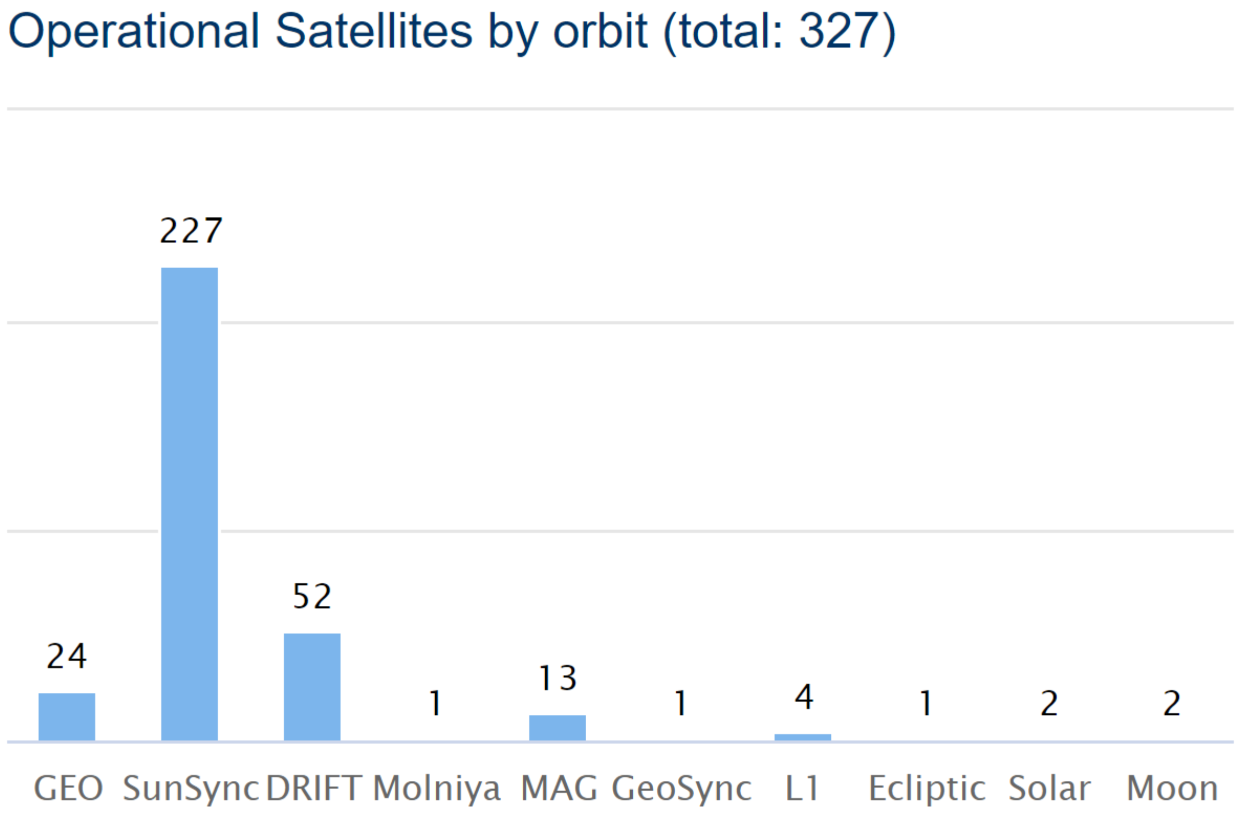
Go to https://space.oscar.wmo.int/satellites

1. Use the **Filter table** on the page to answer how many operation Earth Observation Satellite?
2. Search for information about an Earth Observation satellite you have used before and talk about
   - Its operator
   - How to get the data
   - Its applications

Practical
Task 1



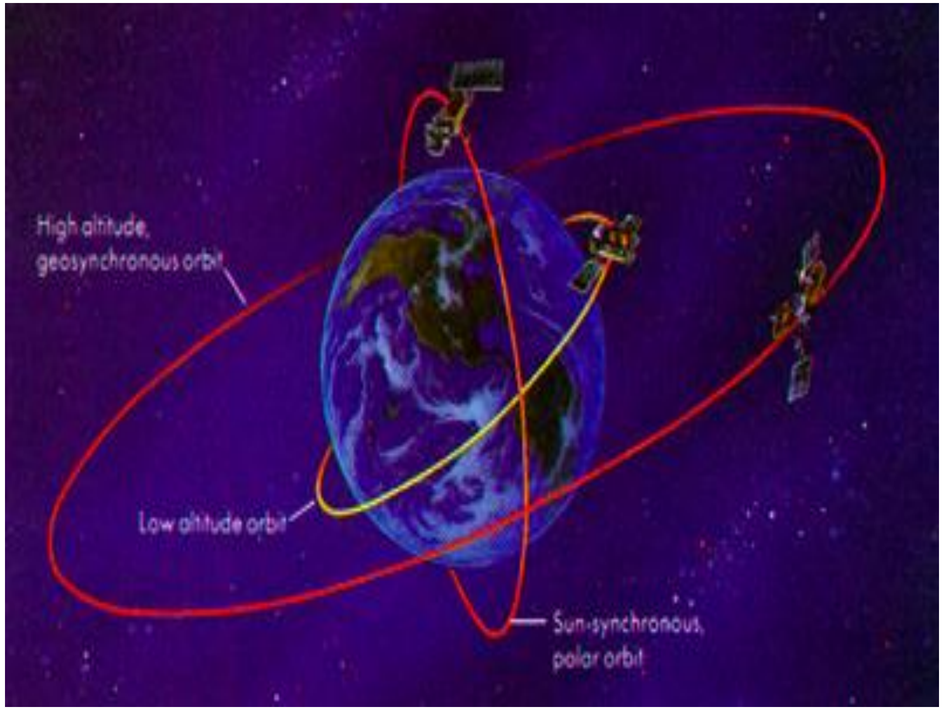
https://space.oscar.wmo.int/satellites



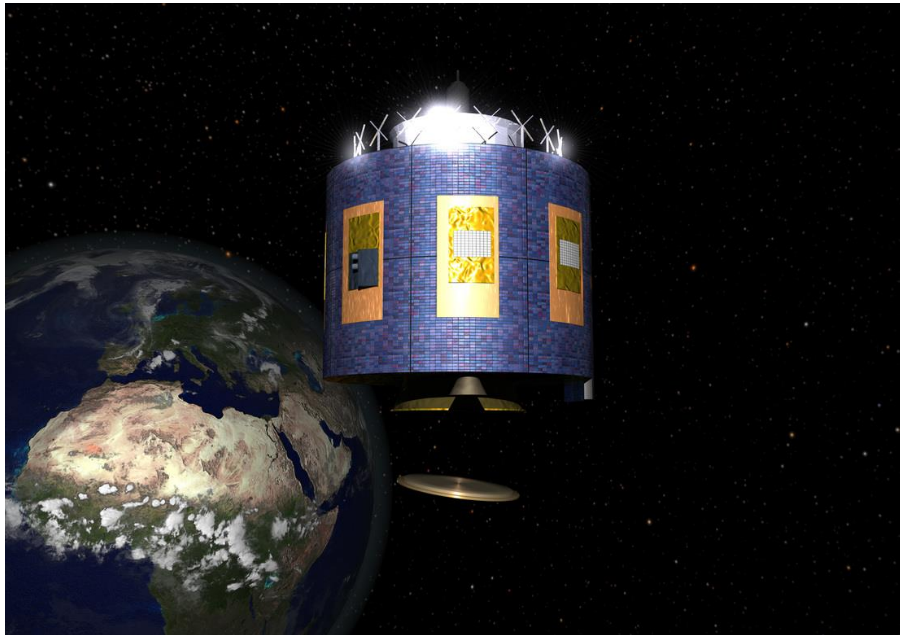
Earth Observing Satellites: Types

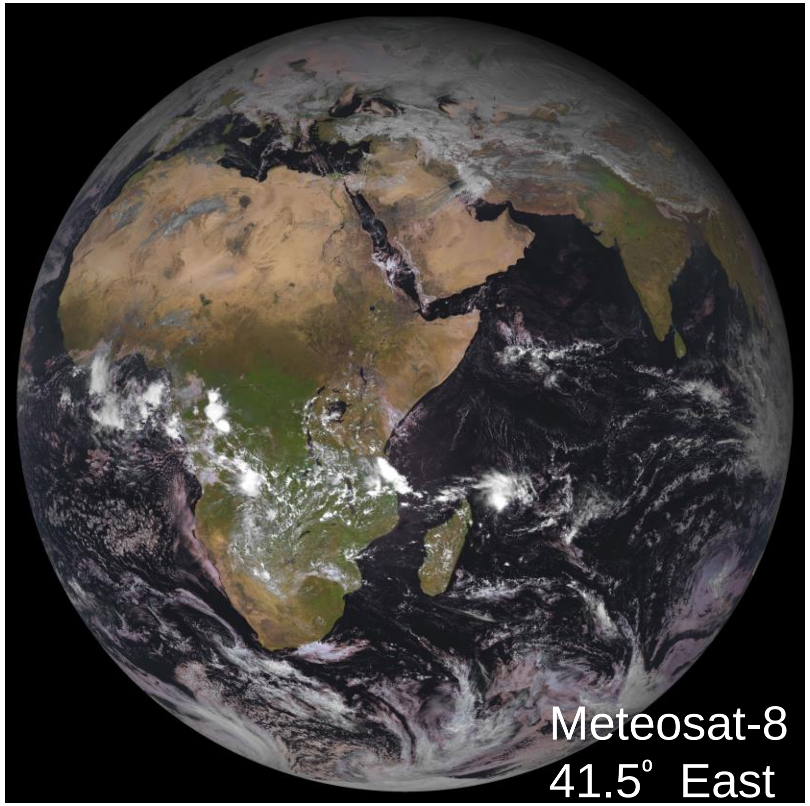
There are two main types of EO satellites

1. **Geostationary**
   (other name: Geo Synchronized)
2. **Low Orbiting**



Geostationary Satellites





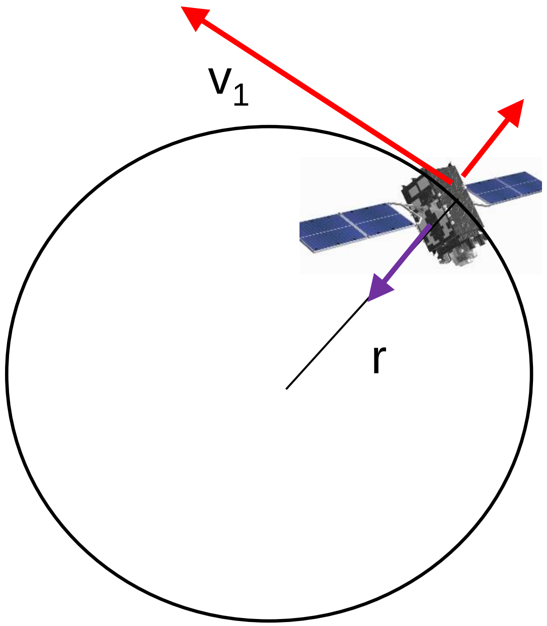
- located over the equator at a height of 36000 km.
- remain stationary with respect to the Earth's surface.
- give images at a high and constant rate (good for animation).

Geostationary Satellites

Why Satellites do not fall on Earth ?

Why Should it be at 36000 km?

Any object travelling in a circle at constant speed is *always* accelerating away from the centre of the circle by the centrifugal force .



Gravity keeps satellites in circular motion because it acts as a constant force opposing the direction of centrifugal

Geostationary Satellites

Why should it be at 36000 km?

In 1687 Newton published his gravitational F_G force theory

$$F_G = G\frac{Mm}{r^2}$$

where ***G*** is the universal gravitational constant, M is the mass of the earth and ***m*** is the mass of the satellite.

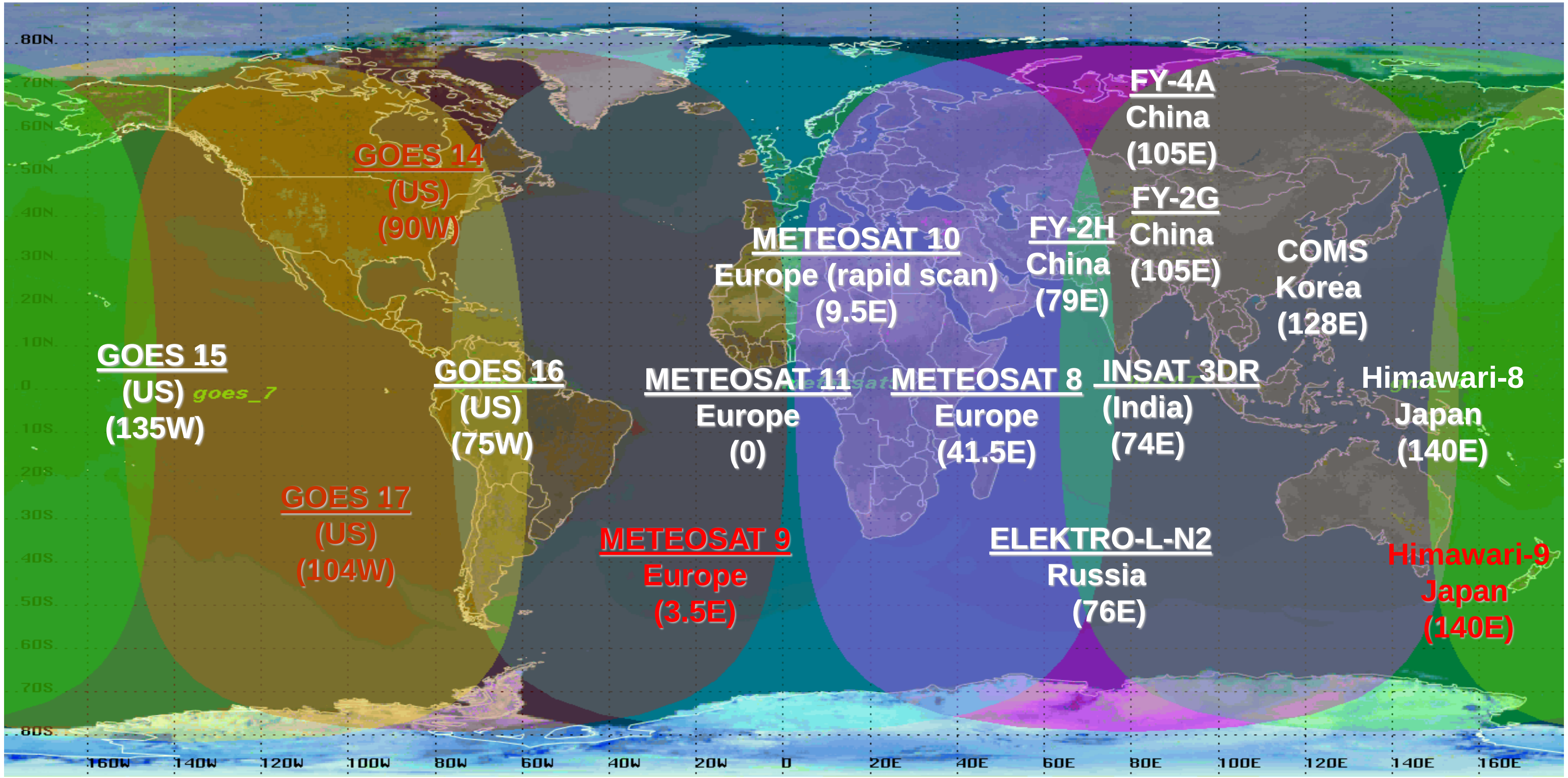
It can be shown that ***r*** ; the distance between the earth and the satellite, can be calculated from τ; the period of rotation around the earth

$$r = \sqrt[3]{G\frac{M\tau^2}{4\pi^2}}$$

For τ = 24 hours the distance is 36000 km

Geostationary Satellites

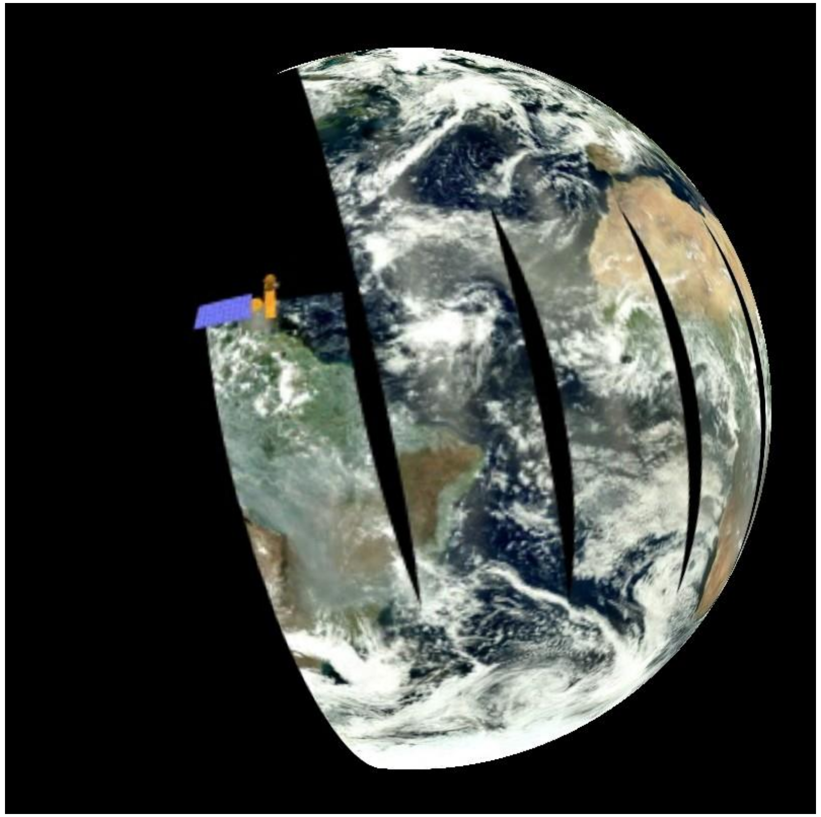
Current coverage of the WMO Integrated Global Observing System (WIGOS)

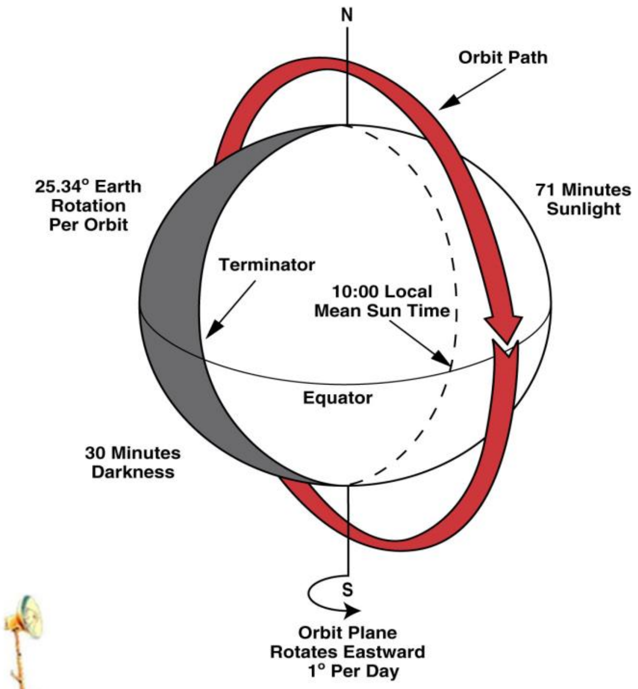


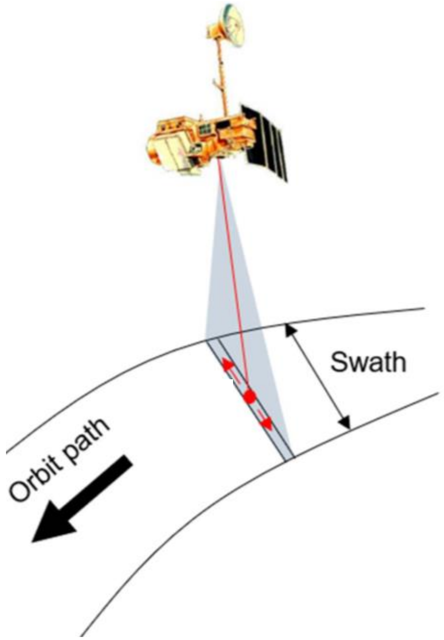
Low Orbiting Satellites

Low Orbiting Satellites

Features

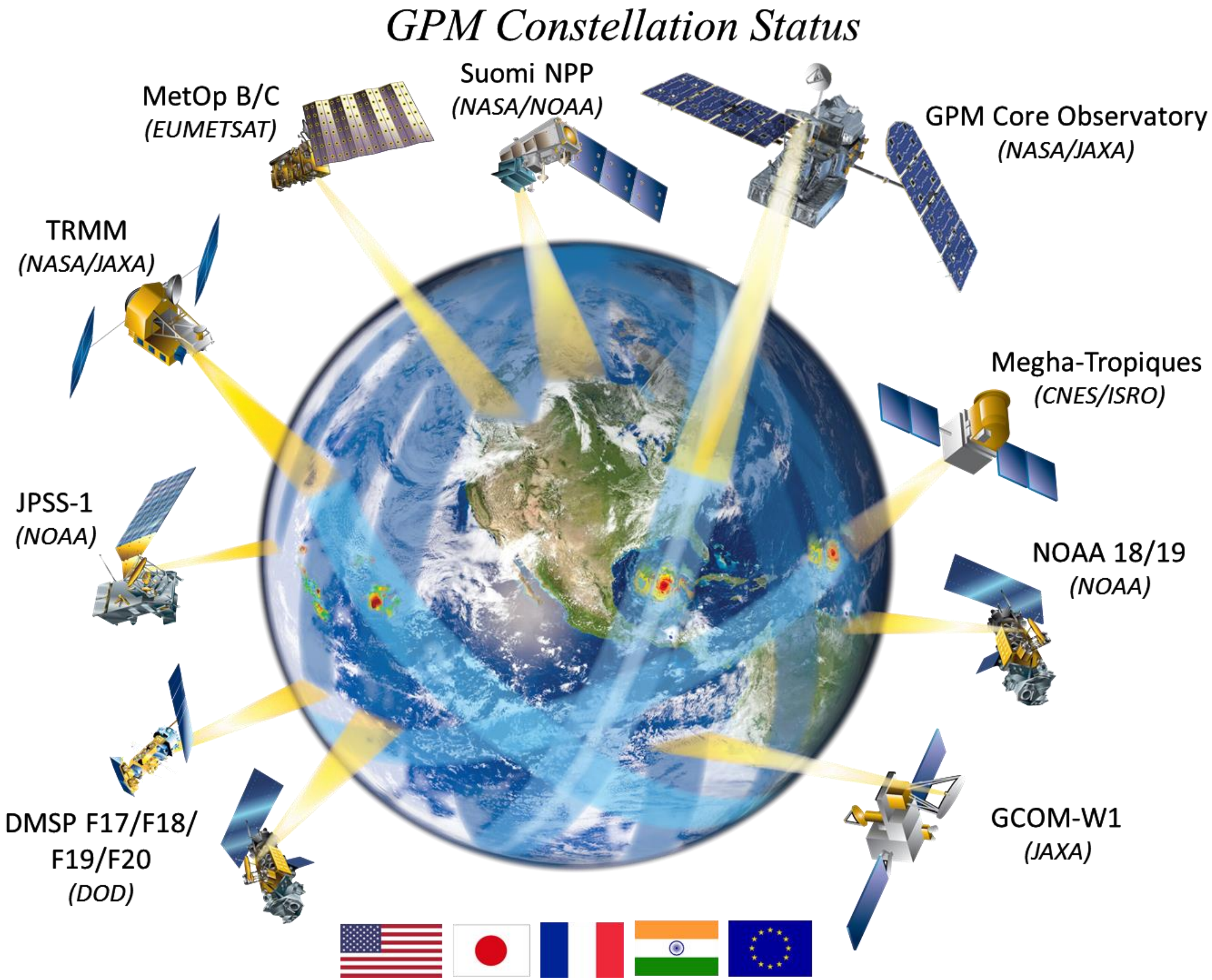






- lower altitude of 200 to 2000 km.
- orbit from pole to pole in about 100 minutes.
- more detailed but less frequent images.

Low Orbiting Satellites



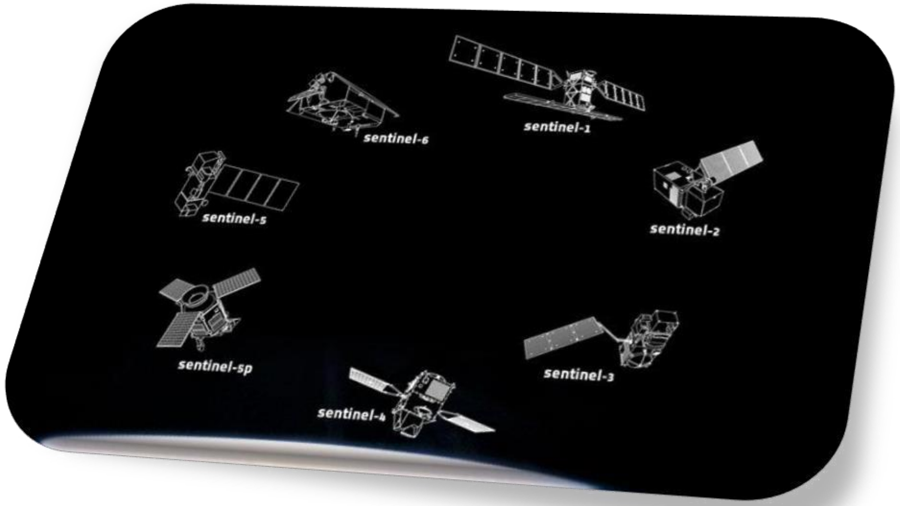
Low Orbiting Satellites

The Copernicus Sentinel missions and their applications

Sentinel-1

Polar orbit for the Sentinel-1A and Sentinel-1B satellites. Sentinel1 uses a **radar imaging sensor** with cloud penetration, all-weather, day-and-night conditions mission

Used for land and ocean services; oil spills, flood detection, forestry & agriculture, ground movement, icebergs, sea Ice



Sentinel-2

Polar orbit for the Sentinel-2A and Sentinel-2B satellites. Equipped with a **multispectral high-resolution imaging sensor**

Applications in land monitoring; vegetation, soil, inland waters, coast, agriculture & forestry, water quality, and emergency

Sentinel-3

Also, polar orbit for the Sentinel-3A and Sentinel-3B satellites. Provided with **multi-instrument** for measuring sea-surface topography, surface temperature, ocean and land colour

To support ocean forecasting, environmental and climate monitoring; Water quality, sea level, altimetry, biomass

Sentinel-5P

The forerunner satellite of Sentinel-5 mission. With **sensors to acquire concentrations** of trace gases and aerosols

For air quality and climate analysis; Greenhouse gases, air pollution, SO_2, CO_2, aerosols, PM, CH_4, formaldehyde, etc.

Sentinel-6

A **radar altimeter measurement** system for measuring sea-surface height and map sea-surface topography

To support oceanography, climate studies, and sea monitoring

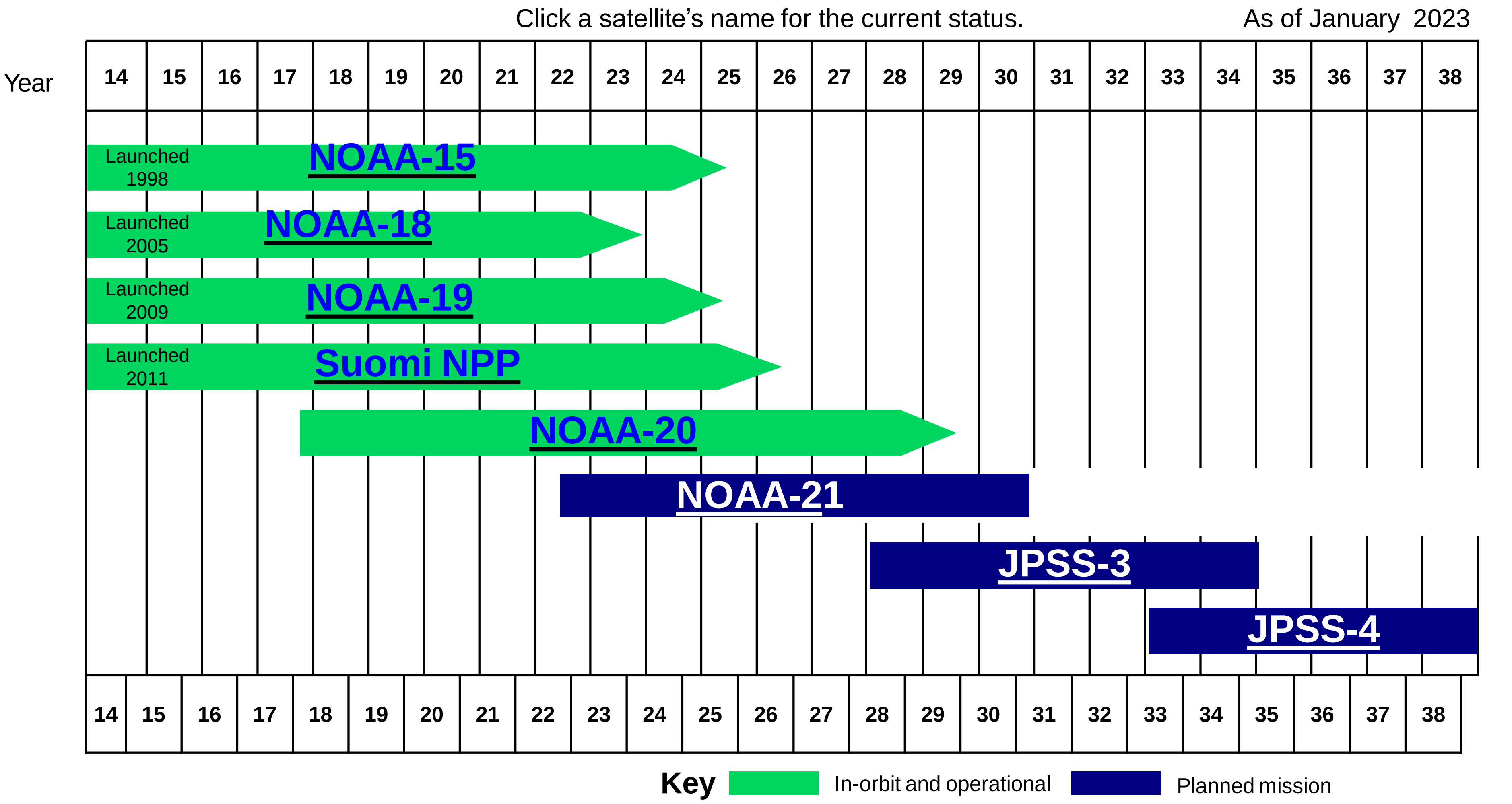
Low Orbiting Satellites

MetOP
Europe - EUMETSAT

- IASI - Infrared Atmospheric Sounding Interferometer
- MHS - Microwave Humidity Sounder
- GRAS - Global Navigation Satellite System Receiver for Atmospheric Sounding
- ASCAT - Advanced Scatterometer
- GOME-2 - Global Ozone Monitoring Experiment-2
- AMSU-A1/AMSU-A2 - Advanced Microwave Sounding Units
- HIRS/4 - High-resolution Infrared Radiation Sounder
- AVHRR/3 - Advanced Very High Resolution Radiometer
- A-DCS - Advanced Data Collection System
- SEM-2 - Space Environment Monitor
- SARP-3 - Search And Rescue Processor
- SARR - Search And Rescue Repeater

Spacecraft	Mission Operational Status
METOP-A	deorbited
METOP-B	AM Primary
METOP-C	PM Primary

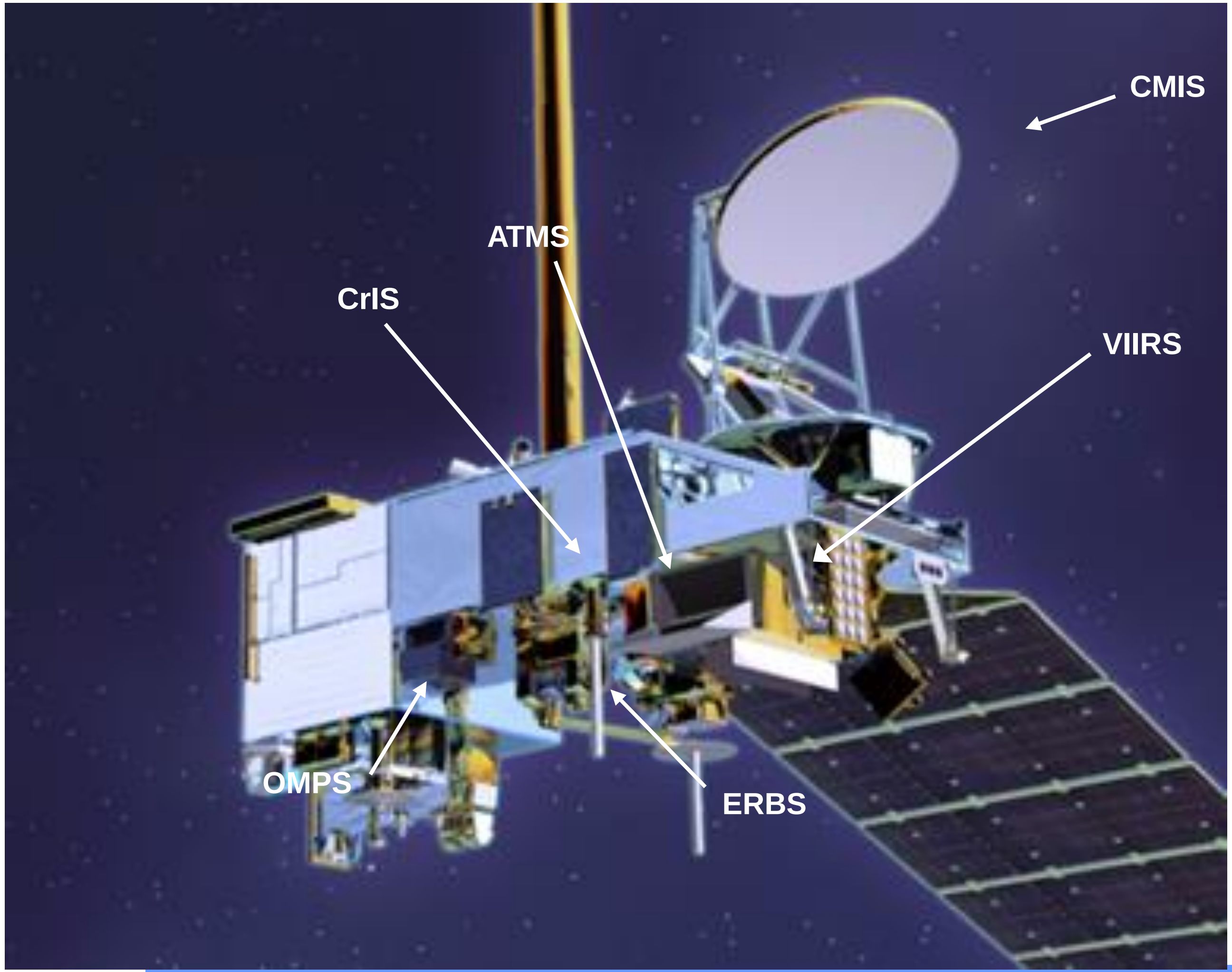
Earth Observing Satellites: Example



Operational satellite extended life estimates (indicated by an arrow) are based on July 2022 reliability analyses (60% confidence) for satellites in orbit for at least one year.
Suomi NPP: Suomi National Polar-orbiting Partnership; JPSS: Joint Polar Satellite System

Earth Observing Satellites: Example

NOAA Satellite Series

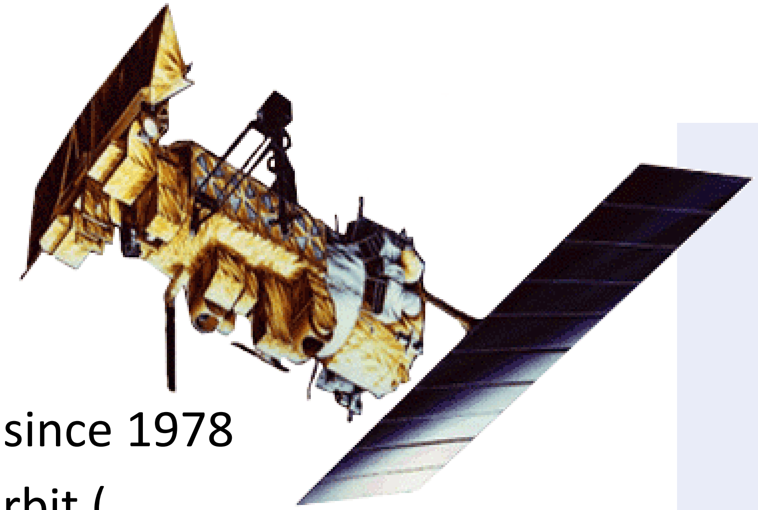


Single satellite design with common sensor locations

AVHRR- Vis/IR imager
VIIRS - vis/IR imager
CMIS - µwave imager
CrIS - IR sounder
ATMS - µwave sounder
SESS - space environment
GPSOS - GPS occultation
OMPS - ozone
ADCS - data collection
SARSAT - search & rescue
APS - aerosol polarimeter
ERBS - Earth radiation budget
SS - laser sensor
ALT - altimeter
TSIS - solar irradiance

Low Orbiting Satellites

NOAA Satellite Series



AVHRR

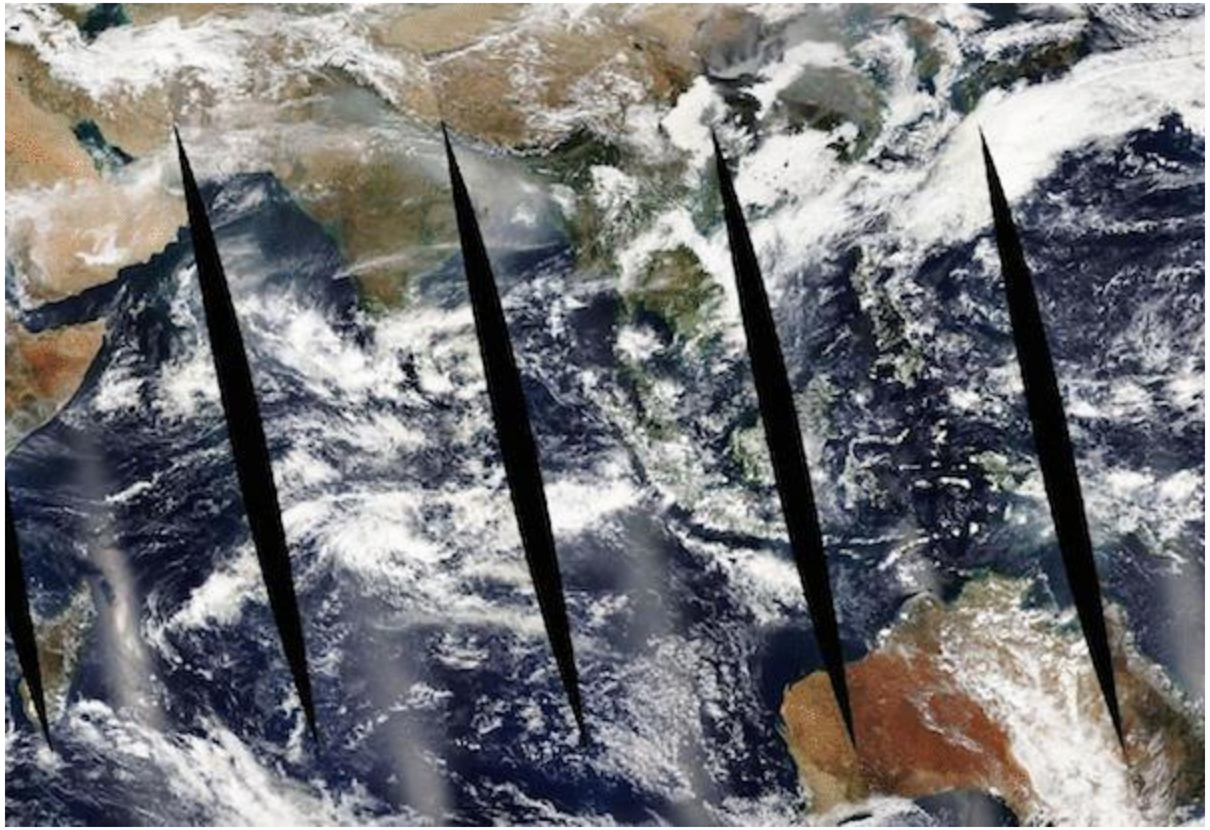
- Collecting data since 1978
- Currently 6 in orbit (
- 2 to 15 images a day
- Whiskbroom scanning pattern
- 1.1 km^2 resolution
- 5+ spectral channels
  - Infrared - channels 3, 4, 5
  - Visible - channels 1, 2

Spacecraft	Mission Operational Status
NOAA 15	AM Secondary
NOAA 18	AM Backup
NOAA 19	PM Primary
NOAA 20	PM Primary

Low Orbiting Satellites

NOAA Satellite Series

Instrument: MODIS on board Suomi NPP, Aqua & Terra Satellites



Low Orbiting Satellites

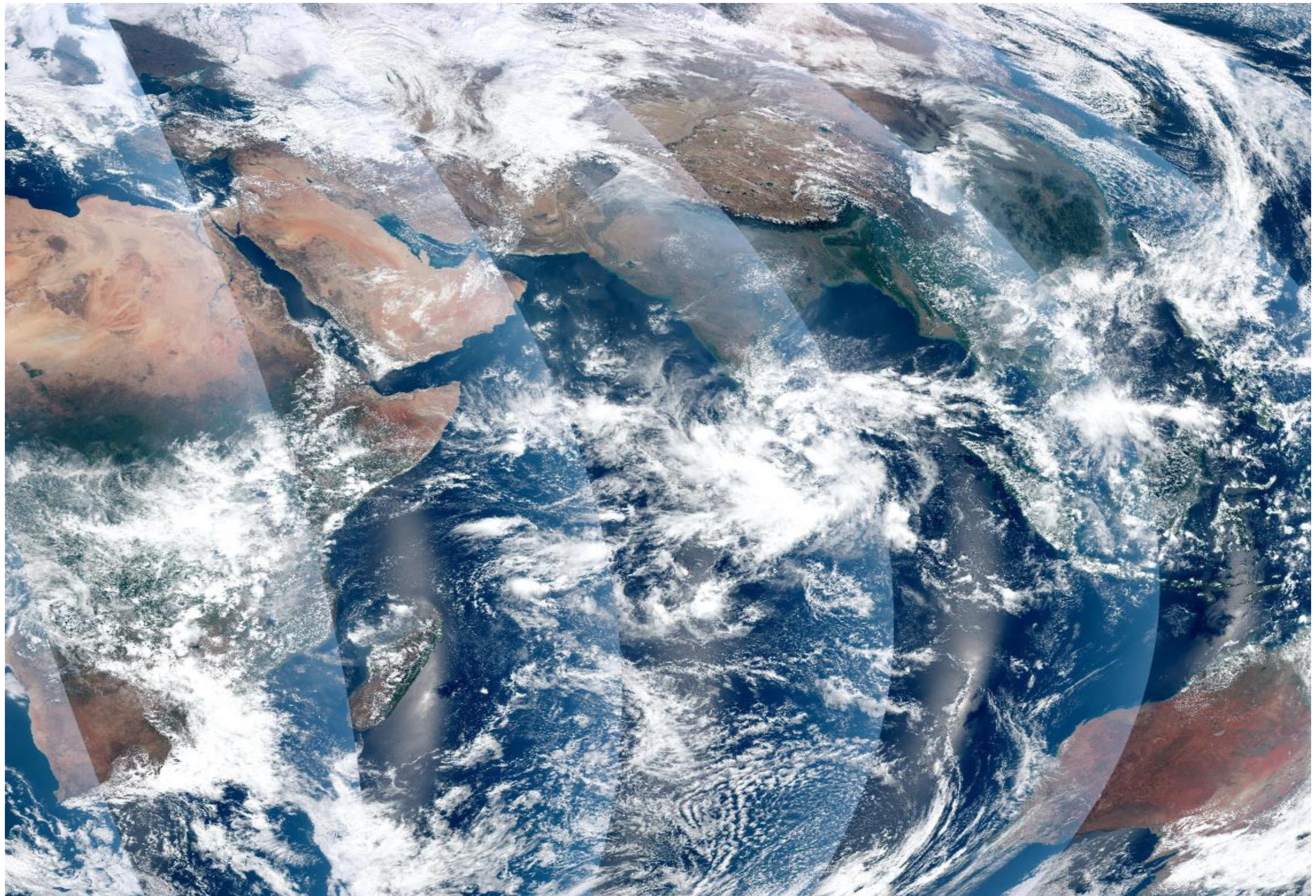
NOAA Satellite Series

VIIRS

on board Suomi NPP and NOAA-20

MODIS and AVHRR successor, high resolution with wide swath

VIIRS swath – 3040km



Low Orbiting Satellites

NOAA Satellite Series

VIIRS

on board Suomi NPP and NOAA-20

MODIS and AVHRR successor, high resolution with a wide swath of 3040 km

VIIRS bands

	Band	Primary parameter	Wave length (μm)	Spatial resolution [km] Nadir	Spatial resolution [km] Edge	Gain	Typical value [W/m2/sr /μm or K]	Max value [W/m2/sr/ μm or K]	Specs SNR/ NΔT	Observed SNR/ NΔT
		Imaging bands								
reflective	I1	Vis Imagery/NDVI	0.600 - 0.680	0.375	0.8	Single	22	718	119	214
reflective	I2	Land Imagery/NDVI	0.846 - 0.885	0.375	0.8	Single	25	349	150	251
reflective	I3	Snow/ice	1.580 - 1.640	0.375	0.8	Single	7.3	72.5	6	149
emis sive	I4	Imagery clouds	3.550 - 3.930	0.375	0.8	Single	270	353	2.5	0.4
emis sive	I5	Imagery clouds	10.50 - 12.40	0.375	0.8	Single	210	340	1.5	0.4
		Moderate resolution bands								
reflective	M1	Ocn color/Aerosol	0.402 - 0.422	0.75	1.6	H/L	44.9/155	135/615	352/316	578/974
reflective	M2	Ocn color/Aerosol	0.436 - 0.454	0.75	1.6	H/L	40/146	127/687	380/409	564/975
reflective	M3	Ocn color/Aerosol	0.478 - 0.498	0.75	1.6	H/L	32/123	107/702	416/414	611/989
reflective	M4	Ocn color/Aerosol	0.545 - 0.565	0.75	1.6	H/L	21/90	78/667	362/315	522/846
reflective	M5	Ocn color/Aerosol	0.662 - 0.682	0.75	1.6	H/L	10/68	59/651	242/360	321/631
reflective	M6	Atrm correction	0.739 - 0.754	0.75	1.6	Single	9.6	41	199	355
reflective	M7	Ocn color/Aerosol	0.846 - 0.885	0.75	1.6	H/L	6.4/33.4	29/349	215/340	435/631
reflective	M8	Cloud particle/ snow grain size	1.230 - 1.250	0.75	1.6	Single	5.4	165	74	221
reflective	M9	Ci cloud detection	1.371 - 1.386	0.75	1.6	Single	6	77.1	83	227
reflective	M10	Snow fraction	1.580 - 1.640	0.75	1.6	Single	7.3	71.2	342	550
reflective	M11	Clouds/Aerosol	2.225 - 2.275	0.75	1.6	Single	0.12	31.8	10	22
emissive	M12	SST	3.660 - 3.840	0.75	1.6	Single	270	353	0.396	0.13
emissive	M13	SST/Fire detection	3.973 - 4.128	0.75	1.6	H/L	300/380	343/634	0.107/0.423	0.042
emissive	M14	Cloud Top	8.400 - 8.700	0.75	1.6	Single	270	336	0.091	0.06
emissive	M15	SST	10.263 - 11.263	0.75	1.6	Single	300	343	0.07	0.03
emissive	M16	SST	11.538 - 12.488	0.75	1.6	Single	300	340	0.072	0.03
	DND	Day/ Night Band	0.5 – 0.9	0.75	0.75					

12 bit quantization

Source: NOAA on May 1, 2012

Low Orbiting Vs. Geostationary Satellites

Geostationary Orbit Advantages:

- large coverage area (about a third of Earth's surface)

- High image frequency (Less than 15 minutes) -> enabling monitoring of rapidly-evolving events.

Low Orbiting Vs. Geostationary Satellites

Geostationary Orbit Limitations:

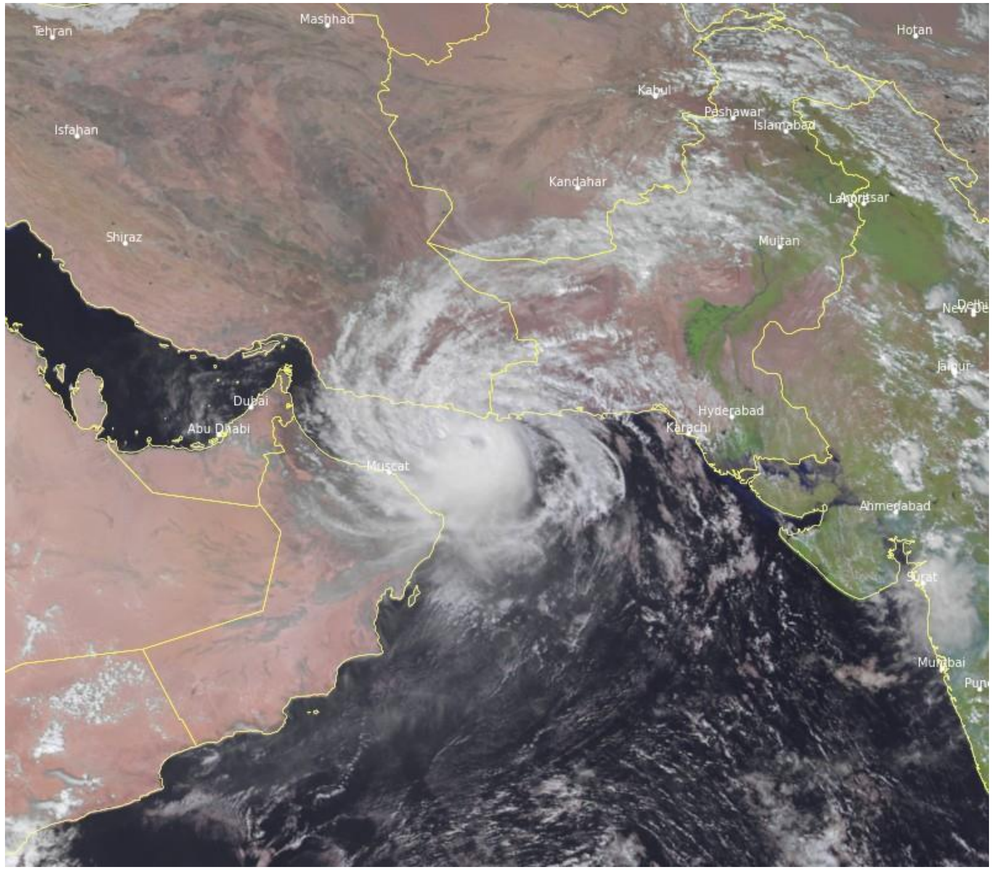
- Polar regions are not observed.
- Relatively Low ground spatial resolution. The high orbit imposes a limit of about 1 km at best with current instrument technology.

Low Orbiting Vs. Geostationary Satellites

Polar Orbit Advantages:

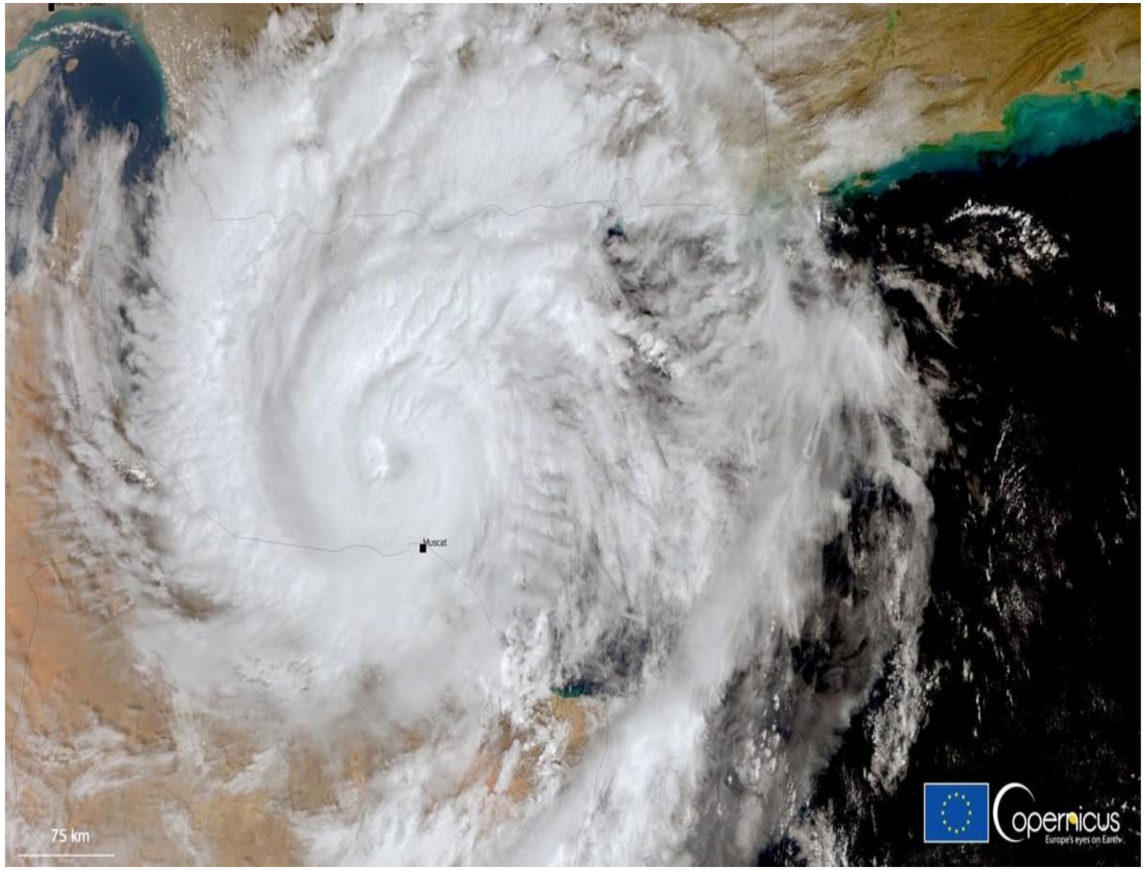
- Global coverage.
- Good ground resolution because of low orbit.

Low Orbiting Vs. Geostationary Satellites



Geostationary Satellite

Tropical Cyclone Shaheen at 09:15 UTC on October 2, 2021. (EUMETSAT/Meteosat-8, RAMMB/CIRA)



Polar Orbiting Satellite

Sentinel-3 visible satellite image of Cyclone Shaheen in the Gulf of Oman, approaching landfall west of Muscat, Oman, on October 3, 2021([Copernicus EU])

Low Orbiting Vs. Geostationary Satellites

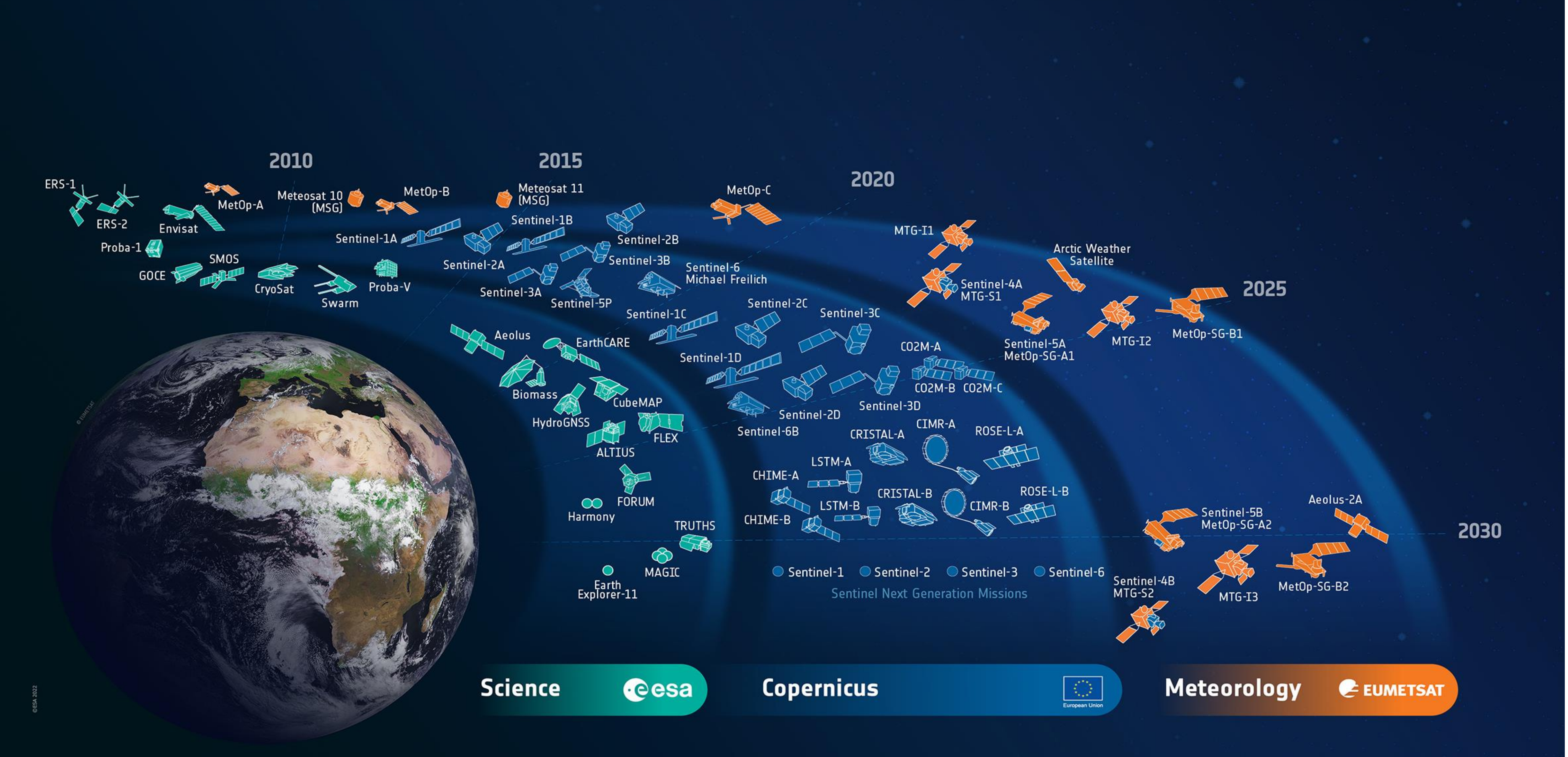
Polar Orbit Limitations:

- Low image Frequency -> Each point on Earth's surface is observed at best every orbit for polar regions (100 minutes), at worst twice per day for equatorial regions. Multi-satellite systems solve this problem.

Future of Earth Observation Satellites

Future of Earth Observation Satellites

New Wave of Satellites



Meteosat Third Generation Satellites

Twin satellite concept :

4 geostationary imaging satellites **(MTG-Imager)**
2 geostationary sounding satellites **(MTG-Sounder)**

MTG-Imager:

- **Flexible Combined Imager (FCI) - Improved**
- **Lightning Imager Instrument (LI) - New**

MTG-Sounder:

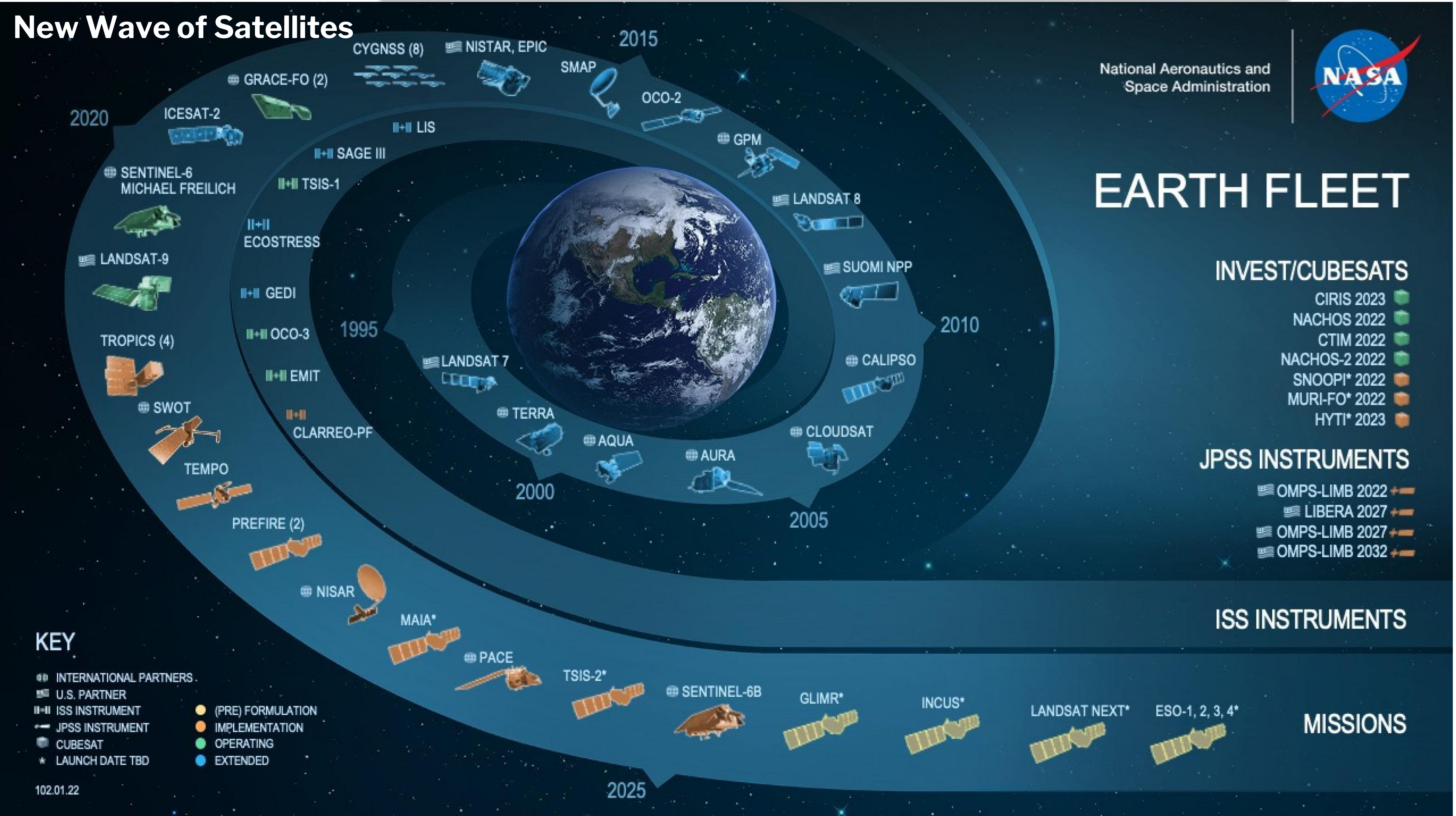
- **Infrared Sounder (IRS) - New**
- **Ultra-violet, Visible and Near-infrared Sounder (UVN) - New**

Meteosat Third Generation Satellites - Launch plan

SATELLITE	PLANNED LAUNCH DATE	DETAILS
MTG Imager1	Q4 2022	Imaging (FCI, LI)
MTG Sounder1	Q4 2023	Sounding (IRS, UVN)
MTG Imager2	Q3 2025	Imaging (FCI, LI)
MTG Imager3	Q2 2028	Imaging (FCI, LI)
MTG Sounder2	Q4 2030	Sounding (IRS, UVN)
MTG Imager4	Q4 2032	Imaging (FCI, LI)

Flexible Combined Imager (FCI),
Lightning Imager (LI),
Infrared Sounder (IRS),
Copernicus Sentinel-4 ultraviolet visible & near-infrared mission (UVN)

Future of Earth Observation Satellites



Practical
Task 2

Go to
https://view.eumetsat.int/productviewer?v=default

add layer -> **MSG – IODC -> Natural Colour Enhanced RGB**

- identify the time when the convective cell affected AlAmerat on 3rd March 2023
- Use an infrared band to see the convective cell.
  What is the difference between infrared images and visible images?

Practical
Task 2

Go to
https://view.eumetsat.int/productviewer?v=default

add layer -> **MSG – IODC -> Natural Colour Enhanced RGB**

- identify the time when the convective cell affected AlAmerat on 3rd March 2023
- Use an infrared band to see the convective cell.
  What is the difference between infrared images and visible images?

Answer : Visible images has texture such as apparent cloud depth and shadows

Practical
Task 3

Go to https://worldview.earthdata.nasa.gov/

- For 01/06/2007 12 UTC and 06/06/2007
  - add layer -> Sea Surface Temperature (*Multi-mission / GHRSST)*

- Compare Oman Sea surface Surface Temperature for the two days. Which is higher? What do you think the cause of the difference?