EUMESAT and ESA satellite missions

EUMETSAT

Satellites

EUMETSAT operates fleets of satellites from its control center in Darmstadt, Germany

EPS-SG and MTG missions

MTG-S

Another important component of the MTG satellite system is the MTG-Sounder. Unlike the Imagers, which focus on capturing images of the Earth's surface, Sounders are designed to measure the composition and structure of the atmosphere.

The MTG-Sounder consists of two primary instruments: the UVN Sounder and the Infrared Sounder (IRS).

- The UVN Sounder measures ultraviolet, visible, and near-infrared radiation to track trace gases like ozone and nitrogen dioxide. This data is essential for air quality monitoring and climate research.
- The IRS, on the other hand, focuses on infrared radiation. It provides detailed 3D profiles of temperature and humidity in the atmosphere. This information is crucial for improving short-term weather forecasts and understanding severe weather events.

Both instruments play a vital role in understanding the Earth's atmosphere and climate. By providing accurate measurements of atmospheric composition and structure, they help scientists and meteorologists make informed decisions about weather forecasting, air quality, and climate change

MTG-I

MTG satellites come in two main types: Imagers (MTG-I) and Sounders (MTG-S).

- Imagers capture high-resolution images of the Earth's surface and atmosphere. One of the key instruments on MTG-I is the Flexible Converter Instrument (FCI), which can observe a wide range of wavelengths from visible to infrared. This allows for detailed analysis of various atmospheric and surface features.
- The Lightning Imager (LI) on MTG-I is specifically designed to detect lightning flashes. It operates in the near-infrared spectrum and provides high-resolution data on lightning activity. This is particularly important for understanding severe weather events and improving early warning systems.

Copernicus Senitnel-4 UVN

Sounders

MTG Instruments (MTG-I LI instrument will complement the NOAA Geostationary Lightning Mapper (GLM) on the GOES-R and the GOES-S satellites)	• Infrared sounder (IRS), • Ultraviolet Visible and Near Infrared sounder (UVN), • Flexible combined imager (FCI), • Lightening Imager (LI)

Imagers

MTG-S

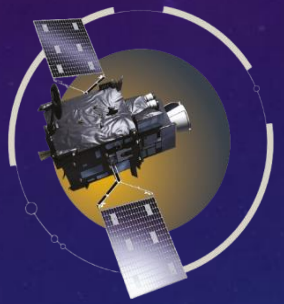
Reference: https://eo.belspo.be/en/satellites-and-sensors/mtg-i1

Feature/Aspect	UVN Sounder	IRS (Infrared Sounder)
Purpose	Monitors atmospheric composition by measuring trace gases and pollutants.	Provides detailed 3D atmospheric profiles of temperature and humidity.
Spectral Coverage	Ultraviolet (UV), Visible (VIS), and Near-Infrared (NIR) spectral ranges.	Long-Wave Infrared (LWIR) and Medium-Wave Infrared (MWIR) spectral bands.
Primary Functions	- Tracks key atmospheric trace gases (e.g., ozone, NO2). - Supports air quality monitoring and climate research. - Part of the Copernicus Sentinel-4 mission.	- Tracks 3D structure of atmospheric water vapor and temperature. - Improves short-term weather forecasts and severe weather predictions. - Assesses pollution levels in the boundary layer.
Spatial Resolution	Not explicitly stated but optimized for regional to global monitoring.	4 km x 4 km resolution.
Temporal Resolution	High temporal resolution, providing continuous monitoring.	Full Earth disc every 60 minutes; Europe Local Area Coverage (LAC) every 30 minutes.
Field of View	Covers a large portion of the Earth's disc, focusing on Europe and adjacent areas.	Full Earth disc coverage with focused regional scans.
Technology	Spectrometers measuring light absorption by atmospheric gases.	Hyperspectral infrared sounder using interferometric techniques.
Calibration	Regular in-flight calibration using onboard reference sources.	Utilizes onboard calibration sources to maintain measurement accuracy.
Operational Mode	Continuous monitoring with regular updates to ground stations.	Regular scanning modes for both full disc and regional coverage.
Importance for Weather Forecasting	Critical for monitoring atmospheric chemistry, aiding in both weather forecasting and environmental policy-making.	Vital for accurate short-term weather forecasting, particularly in predicting severe weather events.
Developers/Contractors	Provided by ESA as part of the Copernicus program.	Developed by Kayser Threde, part of OHB, and supported by ESA.

MTG-I

Feature/Aspect	FCI (Flexible Combined Imager)	LI (Lightning Imager)
Purpose	Captures high-resolution images of Earth in various spectral bands, enhancing weather forecasting and monitoring.	Detects and monitors lightning activity in real-time across the Earth's surface, aiding in the prediction of severe storms.
Spectral Coverage	Visible, near-infrared, and infrared spectral ranges (16 channels).	Visible spectrum, specifically at 777.4 nm.
Primary Functions	- Monitoring of clouds, aerosols, moisture, and fires. - Enhancing predictions of severe weather through high spatial, temporal, and radiometric resolution. - Supports various meteorological observations like cloud top temperature, surface temperature, and aerosol properties.	- Detects cloud-to-cloud, cloud-to-ground, and intra-cloud lightning. - Provides data for early warnings of severe thunderstorms. - Monitors atmospheric turbulence, a precursor to extreme weather events.
Spatial Resolution	0.5 to 2 km, depending on the spectral channel.	4.5 km at nadir.
Temporal Resolution	Full Earth disc every 10 minutes; local area coverage every 2.5 minutes.	Continuous monitoring with near-instantaneous detection.
Field of View	Full Earth disc and localized areas (adjustable).	Covers more than 80% of Earth's disc.
Technology	Imaging multispectral radiometers (visible, infrared).	Optical telescopes sensitive to lightning flashes.
Calibration	In-flight radiometric calibration using the Sun (VIS/NIR) and blackbody sources (IR).	Not specified.
Operational Mode	Nominal imaging and rapid scan modes.	Continuous real-time monitoring.
Importance for Weather Forecasting	Critical for cloud type identification, temperature profiling, and monitoring of surface and atmospheric conditions.	Enhances nowcasting capabilities, particularly in predicting severe weather events.
Developers/Contractors	Thales Alenia Space, Kayser Threde.	Developed by ESA with collaboration from industry partners.

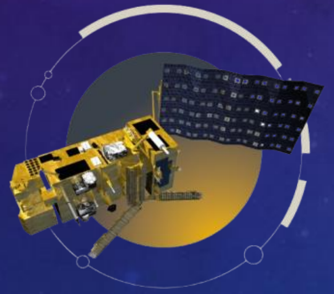
Satellite Program	Number of Satellites	Orbit	Orbit Height	Mission	First Launch	End Date
Meteosat	12 (3 Generations)	Geostationary	36,000 km	Weather forecasting, severe weather detection, climate monitoring	November 1977	Third Generation ongoing
Metop	3 (First Generation)	Polar (LEO)	817 km	Detailed atmospheric, ocean, and land observations for weather forecasts (12 hours to 10 days), climate monitoring	2006	Second Generation planned for 2025
Sentinel-1, -2, -3, -6	Varies	Polar/Geostationary	Varies	Earth observation for Copernicus program; Sentinel-4 and -5 are instruments on Meteosat and Metop satellites	2014 (Sentinel-1)	Ongoing
Jason	3 (Jason-1, -2, -3)	Polar (LEO)	1,336 km	Precise measurements of global mean sea level, climate monitoring, seasonal weather forecasting	1992 (TOPEX-Poseidon)	April 2022 (Replaced by Sentinel-6)



Meteosat

3rd Generation: (Meteosat-9, 10, 11)

Operates over Europe, Africa and part of the Indian Ocean.



Metop

Sentinel

JSON

EUMETSAT

METEOSAT

Geostationary orbit

Meteosat only has around 33% of the Earth's surface in its field of view, which is not enough to cover the polar regions and high latitudes of northern Europe and deliver the global view expected by climatologists for monitoring the changing climate of our planet.

Meteosat provide vital imagery for forecasts of high impact weather ranging from minutes to a few hours, they cannot deliver all the highly detailed and diverse observations required by meteorologists for short and medium range forecasts (up to ten days ahead), due to their position high above the Earth.

Satellites in a low Earth orbit (like METOP) complement the more frequent data from geostationary orbit by providing greater global coverage and more diverse data sets.

MSG sensor name: Spinning Enhanced Visible and Infrared Imager (SEVIRI)

Meteosat-1
Launched on 23 November 1977, retired 25 November 1979

Meteosat-2
Launched on 19 June 1981, retired 11 August 1988

Meteosat-3
Launched on 15 June 1988, retired 31 May 1995

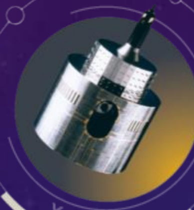
Meteosat-4
Launched on 6 March 1989, retired 8 November 1995

Meteosat-5
Launched on 2 March 1991, retired 16 April 2007

Meteosat-6
Launched on 19 November 1993, retired 15 April 2011

Meteosat-7
Launched on 2 September 1997, retired 31 March 2017

First Generation



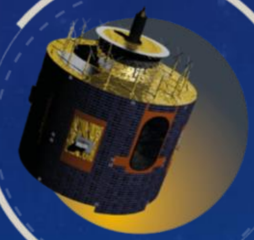
Meteosat-8
Launched on 28 August 2002, retired 1 July 2022

Meteosat-9
Launched on 22 December 2005 - provides imagery over the Indian Ocean. Operating until 2027.
Working

Meteosat-10
Launched on 5 July 2012 - prime operational satellite at 0 degrees providing full disc imagery every 15 minutes
Working

Meteosat-11
Launched on 15 July 2015 - provides imagery every 5 minutes over Europe and North Africa
Working

Second Generation (MSG)



Meteosat Third Generation Imager (MTG-I) and Sounder (MTG-S)

- More than 50 leading experts in a variety of disciplines were involved, representing operational and research organizations from Europe, the United States and other international partners, as well as WMO (World Meteorological Organization).
- The definition of the requirements was driven by the EUMETSAT customers' long-term strategic objectives.
- **Customers:** The main customers include
  - National Meteorological Services and other operational organizations from EUMETSAT Member States
  - ECMWF (European Centre for Medium-Range Weather Forecasts) and
  - EUMETNET
- Based on these assessments, five candidate observation missions were identified for MTG:
  - **HRFI** (High Resolution Fast Imagery) mission.
  - **FDHSI** (Full Disk High Spectral Imagery) mission
  - **LI** (Lightning Imagery) mission
  - **UVS** (UV-VIS Sounding) mission.
  - **IRS** (Infrared Sounding) mission

Flexible Combined Imager (FCI)

MTG-Imager

MTG-Sounder

- Regarding the MTG missions, the satellite availability shall be at least **96%** calculated on an annual basis for the duration of the satellite nominal operational life.
  - From this outage, 1% is allocated to unscheduled outages (e.g. safe mode) and
  - 3% to scheduled outages (e.g. station keeping maneuver and operations like satellite decontamination).

Apart from FCI, LI, UVS, IRS following are the some other instruments on board:

- DCS (Data Collection System)
- Search and rescue from GEO (GEOSAR).

Imager

MTG-I1
(to be renamed Meteosat-12 after commissioning) launched on 13 December 2022

MTG-I2
(to be renamed Meteosat-14 after commissioning) planned April – September 2026

MTG-I3
(to be renamed Meteosat-15 after commissioning) planned around 2033

MTG-I4
(to be renamed Meteosat-17 after commissioning) planned around 10 years after MTG-I3

Sounder

MTG-S1
(to be renamed Meteosat-13 after commissioning), planned October 2024-March 2025

MTG-S2
(to be renamed Meteosat-16 after commissioning), planned around 10 years after MTG-S1

EUMETSAT

https://www.eoportal.org/satellite-missions/meteosat-third-generation#fci-flexible-combined-imager

MTG-I satellite

MTG-I1 Instruments

(MTG-I LI instrument will complement the NOAA Geostationary Lightning Mapper (GLM) on the GOES-R and the GOES-S satellites)	• Flexible combined imager (FCI), • Lightening Imager (LI)

Imagers

LI:

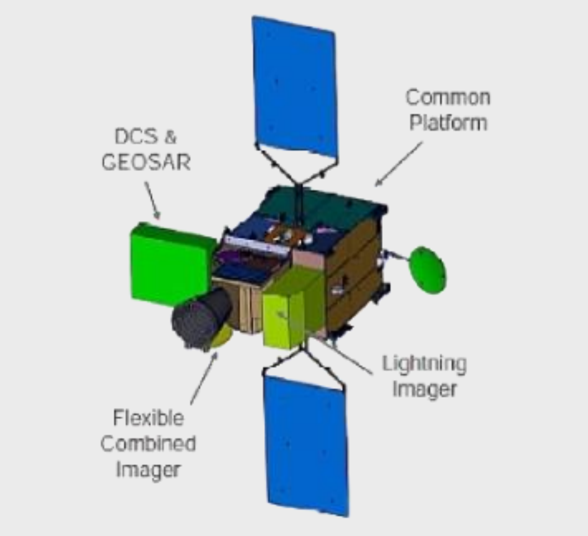
- LI consists of four identical optical telescopes.
- LI provides real-time data on the location and intensity of lightning flashes, to enable more precise forecasts of severe thunderstorms.
- The presence of lightning is a clear sign of atmospheric turbulence, which can be associated with extreme weather events. LI can detect all types of lightning: cloud to cloud, cloud to ground, and intra-cloud flashes, providing an advantage over ground based lightning detection networks.
- LI will Continuously measure at a wave-length of **777.4nm (NIR)** with a very narrow bandwidth, with a spatial resolution **4.5km** at NADIR, triggered by a optical pulses above a variable threshold that are initiated by lightning (between 4 and 7μJm^{-2}sr^{-1}).
- IRS uses interferometric techniques in two spectral bands:
  - **Longwave IR (LWIR)** at 8.26 - 14.70 μm (far-infrared) and
  - **Midwave IR (MWIR)** at 4.44 - 6.25 μm (far-infrared),

  with a spectral resolution of 0.625 cm^{-1} and a spatial resolution of 4 km x 4 km.
- It will be able to cover the full disc of Earth in 60 minutes with a Europe Local Area Coverage (LAC) time of 30 minutes.

FCI:

- FCI is an optical imager that covers the visible, near-infrared and infrared spectrum with 16 channels.
- It offers significant enhancement in detection capabilities with respect to radiometric, spectral and spatial resolution over its predecessor, the Spinning Enhanced Visible and Infrared Imager (SEVIRI), resulting in improved forecasts and earlier prediction of severe weather events
- FCI will operate at wavelengths between **0.3 - 13.3 μm** (near-ultraviolet light (300 nm) to far-infrared light (13.3 μm)), will have a spatial resolution of 1-2 km, and will be able to scan the full Earth disc i.e. ***FDHSI (Full Disk High Spectral Resolution Imagery***) mode in 10 minutes
  - 8 channels are placed in the solar spectral domain between 0.4μm to 2.2μm, delivering data at a 1km spatial sampling distance (resolution) at nadir and
  - 8 channels are in the thermal spectral domain between 3.8μm and 13.3μm, delivering data at 2km spatial sampling distance at nadir.
- FCI will also operate in a '***high spatial resolution fast imagery mode***' which can zoom in on smaller areas and deliver data images of selected regions every 2.5 minutes, but for a tradeoff spatial resolution of 500 m.

Spectral Band	Wavelength (μm)
Visible	0.4-0.9
Near-Infrared (NIR)	1.3-2.2
Infrared (IR)	3.8
WV (Water vapour)	6.3-7.3
IR (O3)	9.7
Thermal IR (TIR)	10.5-13.3



MTG-S satellite

IRS:

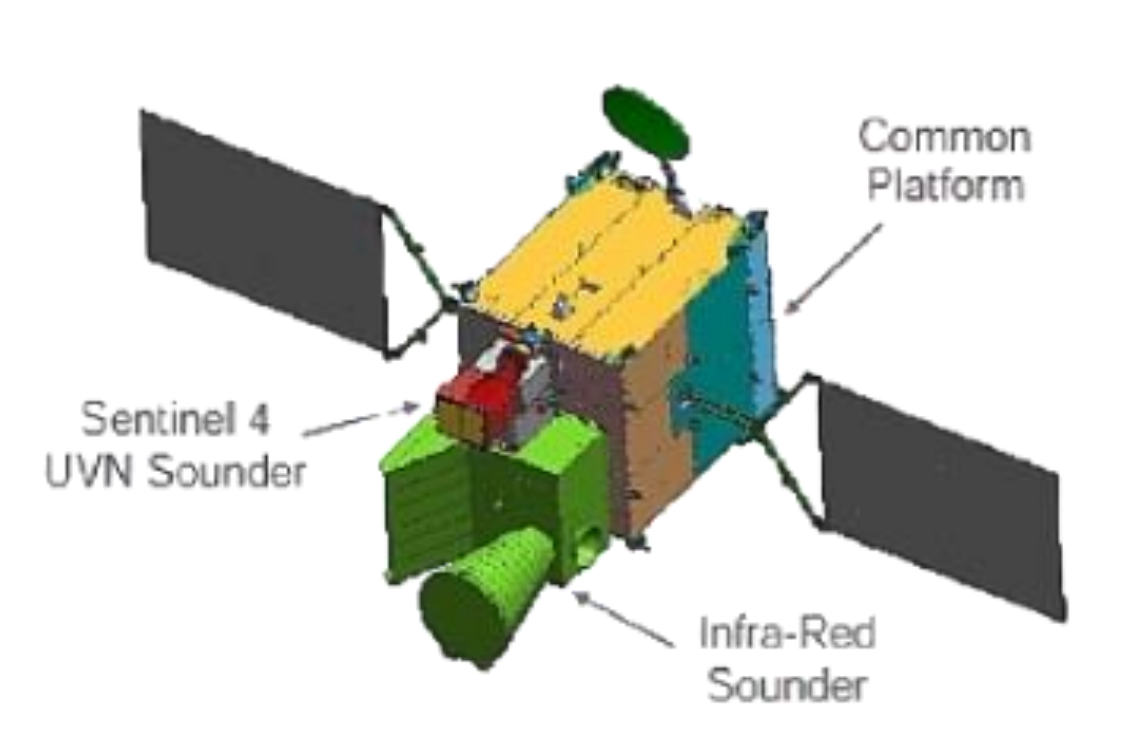
- IRS is a hyperspectral infrared sounder set to revolutionise weather forecasting by tracking the 3D structure of atmospheric water vapour and temperature for the first time on an operational basis.
- IRS includes the ozone band within the Long-Wave Infrared (LWIR) and the carbon monoxide band within Medium-Wave Infrared (MWIR)
- This will allow measurement within the free troposphere, leading to information on enhanced levels of pollution in the boundary layer below.

GEOSAR is part of the COSPAS-SARSAT international system; the objective is to provide distress alert and location information to appropriate rescue authorities for maritime, aviation and land users in distress.

Ultraviolet Visible Near-infrared Short-wave infrared (UVNS)

UVN (Ultra-Violet Near-infrared) Sounder:

- The UVN sounder on MTG-S is the GEO component of the joint Copernicus Sentinel-4 (GEO) and Sentinel-5 (LEO) concept for climate protocol monitoring and air quality applications expected to deliver data products on ozone, nitrogen dioxide, sulphur dioxide, formaldehyde, aerosol optical depth, and aerosol scattering height



https://www.eoportal.org/satellite-missions/meteosat-third-generation#eop-quick-facts-section

MetOp series

Agency	ESA, CNES, NOAA, EUMETSAT

Meteorological Operational Satellite Program of Europe (MetOp series)

Sun-Synchronous orbit

Low earth orbit Satellites: 817km (LEO) providing "morning" service for operational meteorology.

The MetOp satellites are part of the **EUMETSAT Polar System (EPS)** and are Europe's first polar-orbiting satellites dedicated to operational meteorology.

Key Features and Objectives:

- **Mission Purpose:** The MetOp satellites provide temperature and humidity profiles, wind speed and direction data over oceans, and various other atmospheric measurements that are crucial for Numerical Weather Prediction (NWP) and climate monitoring.
- **Instruments:** Each MetOp satellite carries a suite of instruments, such as the Infrared Atmospheric Sounding Interferometer (IASI), Advanced Scatterometer (ASCAT), and Global Ozone Monitoring Experiment-2 (GOME-2), among others, to perform diverse meteorological observations.
- **Orbit:** MetOp satellites operate in a sun-synchronous polar orbit at an altitude of approximately 824 km, with an inclination of 98.7°. This orbit allows for global coverage, crucial for monitoring the Earth's atmosphere and surface.
- **Collaborative Effort:** While the MetOp satellites operate independently, they complement other systems such as the NOAA POES (Polar Operational Environmental Satellites) system from the United States, providing the "morning" orbit service, while NOAA provides the "afternoon" service.
- **Launch and Operations:** The first satellite, MetOp-A, was launched in 2006, followed by MetOp-B in 2012 and MetOp-C in 2018. These satellites have exceeded their design lifetimes, and their data have significantly enhanced weather forecasting accuracy.

Mission Contributions:

- **Weather Forecasting:** The data from MetOp satellites are essential for improving short to medium-range weather forecasts globally.
- **Climate Monitoring:** The satellites contribute to long-term climate datasets, which are vital for understanding global climate change.
- **Operational Lifespan:** Although each satellite had an expected operational life of around 5 years, they have been operating well beyond this, with MetOp-A, for example, being retired only in 2021 after 15 years of service.

First Generation

Metop-A
Launched on 19 October 2006, retired 30 November 2021

Working

Metop-B
Launched on 17 September 2012

Metop-C
Launched on 7 November 2018

These two B and C satellites, are identical, have an orbital period of around 100 minutes

Metop (First Generation)

Instruments	Wavelength range		Function
Infrared Atmospheric Sounding Interferometer (IASI)	3.62 µm to 15.5 µm (Infrared)		Measures infrared radiation for atmospheric temperature, humidity profiles, and trace gases like ozone.
Advanced Very High Resolution Radiometer (AVHRR/3)	0.58 µm to 12.50 µm (Visible to Infrared)		Provides day/night imaging of land, water, clouds, and measures sea surface temperature, ice, snow, and vegetation cover.
	Channel 1	0.58 µm to 0.68 µm (Visible)	Imaging in the visible spectrum for cloud and surface observations.
	Channel 2	0.725 µm to 1.00 µm (Near-Infrared)	Near-infrared imaging for vegetation and surface water bodies.
	Channel 3A	1.58 µm to 1.64 µm (Near-Infrared)	Near-infrared imaging for detecting ice and snow cover.
	Channel 3B	3.55 µm to 3.93 µm (Mid-Infrared)	Detects mid-infrared radiation for temperature and fire detection.
	Channel 4	10.30 µm to 11.30 µm (Thermal Infrared)	Measures thermal infrared radiation for sea surface temperature and cloud top temperature.
	Channel 5	11.50 µm to 12.50 µm (Thermal Infrared)	Measures thermal infrared radiation for sea surface temperature and cloud top temperature.
Advanced Microwave Sounding Unit-A (AMSU-A)	23.8 GHz to 89 GHz (Microwave)		Measures atmospheric temperature profiles from the Earth's surface to the upper stratosphere.
Microwave Humidity Sounder (MHS)	89 GHz to 190.311 GHz (Microwave)		Measures atmospheric humidity and provides data on rain, snow, and other precipitation types.
Global Ozone Monitoring Experiment-2 (GOME-2)	240 nm to 790 nm (Ultraviolet to Visible)		Measures ozone and other atmospheric gases by analyzing scattered sunlight.
Scatterometer (ASCAT)	5.255 GHz (C-band Microwave)		Measures wind speed and direction over the ocean, critical for weather forecasting.
Space Environment Monitor (SEM-2)	Varies by sensor (X-ray, UV, Electron flux)		Monitors Earth's radiation belts and charged particle flux, providing data on space weather.
High Resolution Infrared Radiation Sounder (HIRS/4)	3.7 µm to 15.0 µm (Infrared)		Measures radiance in the infrared spectrum to derive atmospheric temperature and humidity profiles.
Search and Rescue Transponder	406 MHz (UHF)		Detects emergency distress signals from ships, aircraft, and individuals in distress.

EUMETSAT Polar System – Second Generation (EPS-SG) programme

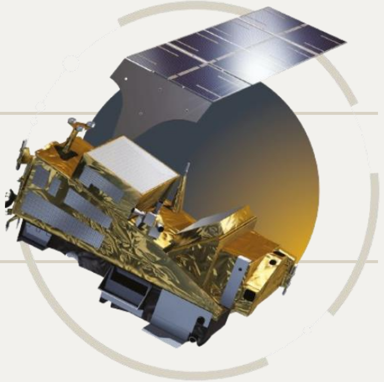
(sun-synchronous polar orbit)

Follow-up to the original MetOp satellite series

Metop-SGA1
Planned: April – June 2025

Metop-SGB1
Planned: January – March 2026

Metop-SGA2
Planned: April – June 2032



Metop-SGB2
Planned: January – March 2033

Metop-SGA3
Planned: April – June 2039

Metop-SGB3
Planned: January – March 2040

Key Features and Objectives:

- **Advanced Instruments:** MetOp-SG satellites will carry a more advanced set of instruments compared to their predecessors. These instruments will offer higher accuracy, better resolution, and a broader range of observations. The payload will include new and improved sensors for measuring atmospheric temperature and humidity, wind speed and direction over the ocean, as well as various other environmental parameters.
- **Dual-Satellite Configuration:** The MetOp-SG program will feature a dual-satellite configuration, with two series of satellites, MetOp-SG A and MetOp-SG B, each carrying different instruments to complement each other.
    - **MetOp-SG A** will carry optical and infrared instruments, including an advanced sounding interferometer for temperature and humidity profiles, and imaging instruments for visible, infrared, and microwave observations.
    - **MetOp-SG B** will focus on microwave sensing, with instruments to measure microwave humidity, temperature, and wind over the ocean, among other parameters.
- **Orbit and Mission Lifespan:** Like the first-generation MetOp satellites, MetOp-SG will operate in a sun-synchronous polar orbit. The mission is planned to ensure continuous coverage and data availability for at least two decades, with launches scheduled to span several years to maintain a continuous flow of data.

- **Enhanced Data Products:** The data from MetOp-SG will be more precise and extensive, significantly improving Numerical Weather Prediction (NWP) and contributing to climate research. The satellites will provide critical information for weather forecasts, environmental monitoring, and disaster response.
- **Collaboration and Contribution:** The MetOp-SG program is a collaboration between the European Space Agency (ESA) and EUMETSAT, with contributions from various European industries. It forms part of a broader international effort to monitor the Earth's climate and weather, contributing to global systems alongside satellites from other nations.
- **Development Status:** As of recent updates, the development of MetOp-SG has been progressing, with prototypes and testing models being delivered to facilities like ESA/ESTEC for full-scale tests.

https://www.eoportal.org/satellite-missions/metop#iasi-infrared-atmospheric-sounder-interferometer

EUMETSAT Polar System – Second Generation (EPS-SG) programme

Instrument	Wavelength Range	Function
Infrared Atmospheric Sounding Interferometer - Next Generation (IASI-NG)	3.62 µm to 15.5 µm (Infrared)	Provides advanced atmospheric temperature and humidity profiles, and measures trace gases with higher accuracy and resolution.
Visible/Infrared Imager (METimage)	0.443 µm to 13.345 µm (Visible to Infrared)	High-resolution imaging of clouds, land, and oceans, and measures sea surface temperature and cloud properties.
MicroWave Sounder (MWS)	23.8 GHz to 229 GHz (Microwave)	Measures atmospheric temperature and humidity profiles, crucial for weather prediction models.
Scatterometer (SCA)	5.255 GHz (C-band Microwave)	Measures wind speed and direction over the oceans, aiding in accurate weather forecasting.
UV/VIS/NIR Sounder (UVNS)	270 nm to 500 nm (Ultraviolet to Visible)	Advanced monitoring of ozone, nitrogen dioxide, and other trace gases, contributing to air quality and climate studies.
Multi-viewing, Multi-channel, Multi-polarization Imager (3MI)	Visible to Shortwave Infrared	Observes aerosol properties, including optical thickness, size distribution, and composition, important for climate and air quality monitoring.
Radio Occultation Sounder (RO)	L-band and S-band	Measures atmospheric temperature, humidity, and electron density by analyzing signals from GNSS satellites as they pass through the atmosphere.
Ice Cloud Imager (ICI)	183 GHz to 664 GHz (Microwave)	Specifically designed to measure ice clouds and snowfall, providing critical data for understanding cloud processes and precipitation.
Microwave Imager (MWI)	18.7 GHz to 183 GHz (Microwave)	Measures precipitation, cloud properties, and sea surface wind speeds, enhancing forecasts of extreme weather events.
GNSS Radio Occultation (GNSS-RO)	L-band	Provides precise atmospheric profiles by measuring the bending of GNSS signals as they pass through the Earth's atmosphere.

EUMETSAT Polar System – Second Generation (EPS-SG) programme (sun-synchronous polar orbit)

EPS-SG payload complement and targeted applications

EPS-SG Satellite-A missions	*Instrument (and provider)*	*Predecessor on Metop*	*Applications benefitting*
Infrared Atmospheric Sounding (IAS)	*IASI-NG (CNES)*	*IASI (CNES)*	Atmospheric Chemistry; Climate Monitoring; Nowcasting (NWC) at high latitudes; Numerical Weather Prediction (NWP); Oceanography
Microwave Sounding (MWS)	*MWS (ESA)*	*AMSU-A (NOAA)* *MHS (EUMETSAT)* *AVHRR (NOAA)*	Climate Monitoring; Nowcasting (NWC) at high latitudes; Numerical Weather Prediction (NWP)
Visible-Infrared Imaging (VII)	*METIMAGE (DLR)*		Climate Monitoring; Hydrology; Nowcasting (NWC) at high latitudes; Numerical Weather Prediction (NWP); Oceanography; Land
Radio Occultation (RO)	*RO (ESA)*	*GRAS (ESA)*	Climate Monitoring; Numerical Weather Prediction (NWP)
UV/VIS/NIR/SWIR Sounding (UVNS)	*SENTINEL-5 (COPERNICUS, ESA)*	*GOME-2 (ESA)*	Atmospheric Chemistry; Climate Monitoring; Numerical Weather Prediction (NWP)
Multi-viewing, -channel, -polarisation Imaging (3MI)	*3MI (ESA)*		Atmospheric Chemistry; Climate Monitoring; Nowcasting (NWC) at high latitudes; Land

EPS-SG Satellite-B missions	*Instrument (and provider)*	*Predecessor on Metop*	*Applications benefitting*
Scatterometer (SCA)	*SCA (ESA)*	*ASCAT (ESA)*	Climate Monitoring; Hydrology; Nowcasting (NWC) at high latitudes; Numerical Weather Prediction (NWP); Oceanography; Land
Radio Occultation (RO)	*RO #2 (ESA)*	*GRAS (ESA)*	Climate Monitoring; Numerical Weather Prediction (NWP)
Microwave Imaging for Precipitation (MWI)	*MWI (ESA)*		Climate Monitoring; Hydrology; Nowcasting (NWC) at high latitudes; Numerical Weather Prediction (NWP); Oceanography
Ice Cloud Imager (ICI)	*ICI (ESA)*		Climate Monitoring; Hydrology; Nowcasting (NWC) at high latitudes; Numerical Weather Prediction (NWP)
Advanced Data Collection System (ADCS)	*ARGOS-4 (CNES)*	*A-DCS (CNES)*	Climate Monitoring; Oceanography

Atmospheric Chemistry · *Climate Monitoring* · *Hydrology* · *Land* · *Nowcasting (NWC) at high latitudes* · *Numerical Weather Prediction (NWP)* · *Oceanography*

Sentinel series

Sentinel series

Polar orbit

- Sentinel-1, -2, -3 and -6 are dedicated satellites, while Sentinel-4 and -5 are instruments to be flown on board EUMETSAT's Meteosat Third Generation and Metop Second Generation satellites.

Satellite	Onboard Sensors	Year of Launch	Orbit
Sentinel-1A	C-band synthetic aperture radar (SAR)	April 3, 2014	Sun-synchronous, near-polar
Sentinel-1B	C-band synthetic aperture radar (SAR)	April 25, 2016	Sun-synchronous, near-polar
Sentinel-2A	Multispectral instrument (MSI)	June 23, 2015	Sun-synchronous, near-polar
Sentinel-2B	Multispectral instrument (MSI)	March 7, 2017	Sun-synchronous, near-polar
Sentinel-3A	Sea and Land Surface Temperature Radiometer (SLSTR), Ocean and Land Colour Instrument (OLCI), SAR Altimeter (SRAL)	February 16, 2016	Sun-synchronous, near-polar
Sentinel-3B	Sea and Land Surface Temperature Radiometer (SLSTR), Ocean and Land Colour Instrument (OLCI), SAR Altimeter (SRAL)	April 25, 2018	Sun-synchronous, near-polar
Sentinel-4	Total Ozone Parcel Instrument (TROPOMI) **(On-board MTG-S)**	October 21, 2017	Geostationary orbit
Sentinel-5P	Total Ozone Parcel Instrument (TROPOMI)	October 13, 2017	Sun-synchronous, near-polar
Sentinel-5A	Total Ozone Parcel Instrument (TROPOMI) **(Ob-board Metop-SG)**	August 22, 2020	Sun-synchronous, near-polar
Sentinel-6	Poseidon-3 radar altimeter, microwave radiometer (MWR), synthetic aperture radar (SAR)	November 21, 2020	Sun-synchronous, near-polar

- **Sentinel-1**: The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night performing **C-band** synthetic aperture
- **Sentinel-2:** The Copernicus Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other.
- **Sentinel-3:** The main objective of the Sentinel-3 mission is to measure sea surface topography, sea and land surface temperature.
- **Sentinel-4:** is a payload devoted to atmospheric monitoring that will be embarked upon a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit.
- **Sentinel-5P:** The Copernicus Sentinel-5 Precursor mission is the first Copernicus mission dedicated to monitoring our atmosphere.
- **Sentinel-5:** is a payload that will monitor the atmosphere from polar orbit aboard a MetOp Second Generation satellite.
- **Sentinel-6:** carries a radar altimeter to measure global sea-surface height, primarily for operational oceanography and for climate studies. The first satellite was launched into orbit on 21 November 2020 on a SpaceX Falcon 9 rocket from the Vandenberg Air Force Base in California, US.

Sentinel-3

- Each satellite of the Sentinel-3 constellation is equipped with 3 instruments working in synergy and measuring systematically the Earth's oceans, land, ice and atmosphere.
- **Instruments:** List of the instrument on board are:
  - OLCI
  - SLSTR
  - MWR
  - SRAL
  - POD
  - Altimetry
  - Synergy

Only Level-1b products are distributed. They are radiance for each pixel in instrument grid, each view and each OLCI channel, plus annotation data associated to OLCI pixels.

Products Description:

There are different OLCI data products associated with the three levels of processing:

- Level 0 product (OL_0_EFR) output by the Level-0 processing and not distributed to users. It consists of time sorted and annotated data from Instrument Source Packets (ISP).
- **The product types distributed to users:**
  - **Level-1B Product (OL_1_EFR, OL_1_ERR) output by the OLCI Level-1 processing:** the Level-1 Product provides radiances for each pixel in the instrument grid, each view and each OLCI channel, plus annotation data associated to OLCI pixels.
  - Level-2 Products output by the OLCI Level-2 processing:
    - Level-2 Land Products (OL_2_LFR, OL_2_LRR): the level-2 Land Product provides land and atmospheric geophysical parameters computed for full (OL_2_LFR) and Reduced Resolution (OL_2_LRR).
    - Level-2 Water Products (OL_2_WFR, OL_2_WRR): the Level-2 Water Product provides water and atmospheric geophysical parameters computed for Full and Reduced Resolution.

Example of filename:

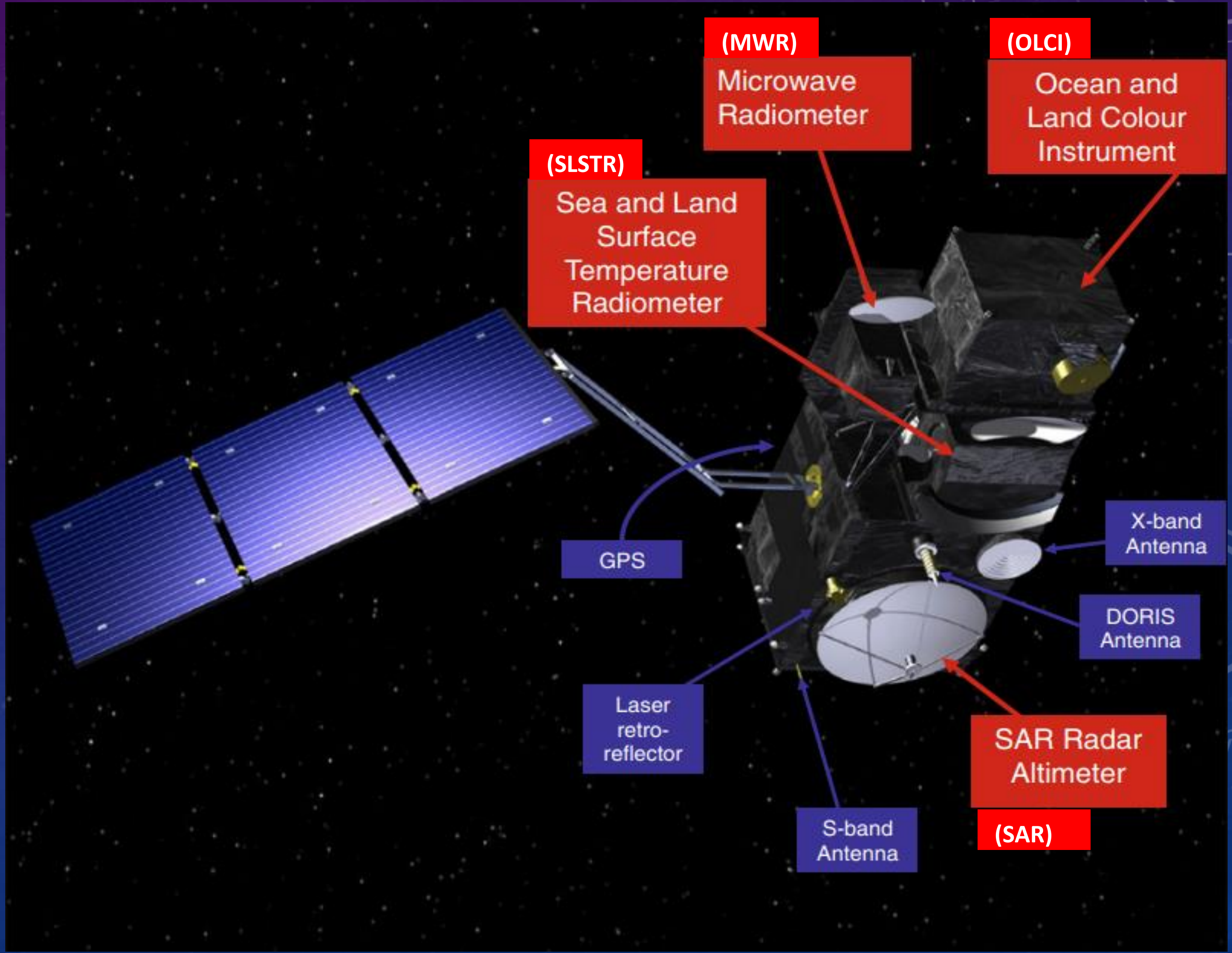
S3A_OL_1_EFR____20160614T101206_20160614T101506_20160614T120248_0180_005_179_2339_SVL_O_NR_001.SEN3

MMM_OL_L_TTTTTT_yyyymmddThhmmss_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_[instance ID]_GGG_[class ID].SEN3

Example of filename:

S3A_SL_2_AOD____20210803T215713_20210803T220308_20210804T002802_0355_055_229______MAR_O_NR_001.SEN3

MMM_OL_L_TTTTTT_yyyymmddThhmmss_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_[instance ID]_GGG_[class ID].SEN3



MMM_SS_L_TTTTTT_yyyymmddThhmmss_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_[instance ID]_GGG_[class ID].SEN3

SS - Data source/consumer

- OL is for OLCI
- SL is for SLSTR
- SR is for SRAL
- DO is for DORIS
- MW is for MWR
- GN is for GNSS
- AX is for multi-instrument auxiliary data

L is the processing level

- "0" for Level-0
- "1" for Level-1
- "2" for Level-2
- underscore "_" if processing level is not applicable.

yyyymmddThhmmss is the sensing start time

YYYYMMDDTHHMMSS is the sensing stop time

YYYYMMDDTHHMMSS is the product creation date

[class ID] identifies the class ID for instrument data products with conventional sequence "P_XX_NNN" where:

- P indicates the platform (O for operational, F for reference, D for development, R for reprocessing)
- XX indicates the timeliness of the processing workflow (NR for NRT, ST for STC, NT for NTC)
- NNN indicates the baseline collection or data usage.

GGG identifies the centre which generated the file

MMM is the mission ID:

- S3A = Sentinel-3A
- S3B = Sentinel-3B
- S3_ = for both Sentinel-3A and 3B

TTTTTT is the Data Type ID

- Level-0 OLCI data:
  - "EFR___" = full resolution ISPs
  - "CR1___" = calibration with spectral relaxation
  - "CR0___" = calibration with no spectral relaxation.
- Level-1 OLCI data:
  - "EFR___" = TOA radiances at full resolution
  - "ERR___" = TOA radiances at reduced resolution
  - "RAC___" = dark offset and gain coefficients from radiometric calibration
  - "SPC___" = wavelength characterisation from spectral calibration
  - "INS_AX" = instrument characterisation auxiliary data
- Level-2 OLCI data:
  - "WFR___" = full resolution ocean colour, water and atmosphere parameters
  - "WRR___" = reduced resolution ocean colour, water and atmosphere parameters
  - "LFR___" = full resolution land colour and atmosphere parameters
  - "LRR___" = reduced resolution land colour and atmosphere parameters

- **[instance ID]** The field consists of 17 characters, either uppercase letters or digits or underscores "_".

The instance id fields include the following cases, applicable as indicated:

1. Instance ID for the instrument data products disseminated in "stripes":
   Duration,"_", cycle number, "_", relative orbit number,"_", 4 underscores "_"
   DDDD_CCC_LLL____
2. Instance ID for the instrument data products disseminated in "frames":
   Duration, "_", cycle number, "_", relative orbit number, "_", frame along track coordinate
   DDDD_CCC_LLL_FFFF
3. Instance ID for the instrument data products disseminated in "tiles".
   Two sub-cases are applicable:
   a) tile covering the whole globe:
   "GLOBAL__________"
   b) tile cut according to specific geographical criteria:
   Tile Identifier
   tttttttttttttttt
4. Instance ID for auxiliary data:
   17 underscores "_"

.SEN3 is the filename extension.

- **NRT or NR:** Near Real Time (NRT) (i.e. delivered to users less than 3 hours after acquisition),
- **NTC or NT:** in Non-Time Critical (NTC) (i.e. within 1 month after acquisition) or in re-processed NTC. Comes with This additional delay allows consolidation of some auxiliary or ancillary data (e.g. precise orbit data).

Sentinel-3 OLCI Data Format:

- **OLCI (Ocean and Land Colour Instrument):** A sensor on the Sentinel-3 satellite.
- The data format follows the Sentinel-3 product specification and is based on **Sentinel-SAFE**.

Sentinel-SAFE:

- **SAFE (Standard Archive Format for Europe):** A data format used for storing and disseminating Earth Observation (EO) data.
- **XFDU (XML Formatted Data Units):** An XML-based standard developed by the Consultative Committee for Space Data Systems (CCSDS) to package data and metadata.
- Sentinel-SAFE is a specialized profile of XFDU tailored for EO data, ensuring interoperability between different ground segment facilities.

- Sentinel-3 user products are disseminated in Product Dissemination Units (PDU), in order to ease the online dissemination and data handling for the users. The PDU is a portion of data and is defined per product type.

XML file:
An XML (eXtensible Markup Language) file is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. Here's a simple example of an XML structure:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<manifest xmlns="http://www.esa.int/safe/sentinel-1.0">
    <metadataSection>
        <metadataObject ID="generalProductInformation">
            <metadataWrap>
                <xmlData>
                    <generalProductInformation>
                        <productType>OLCI_Level-1</productType>
                        <processingLevel>1</processingLevel>
                        <acquisitionTime>2024-06-08T12:34:56Z</acquisitionTime>
                        <satellite>Sentinel-3</satellite>
                        <sensor>OLCI</sensor>
                    </generalProductInformation>
                </xmlData>
            </metadataWrap>
        </metadataObject>
    </metadataSection>
    <dataObjectSection>
        <dataObject ID="measurementData">
            <byteStream fileLocation="measurement_data.dat"/>
        </dataObject>
        <dataObject ID="annotationData">
            <byteStream fileLocation="annotation_data.xml"/>
        </dataObject>
    </dataObjectSection>
</manifest>
```

Band Designation	*Frequency Range*	*Usage*
HF	3-30 MHz	OTH surveillance
VHF	30-300 MHz	Very-long-range surveillance
UHF	300-1,000 MHz	Very-long-range surveillance
L	1-2 GHz	Long-range surveillance En route traffic control
S	2-4 GHz	Moderate-range surveillance Terminal traffic control Long-range weather
C Band 10	4-8 GHz	Long-range Tracking Airborne weather detection
X	8-12 GHz	Short Range tracking Missile guidance Mapping, marine RADAR Airborne Intercept
K_a	12-18 GHz	High Resolution Mapping Satellite altimetry
K	18-24 GHz	Little use (water Vapour)
K_a	27-40 GHz	Very-High-Resolution Mapping Airport surveillance
Millimeter	40-100 + GHz	Experimental

Band name	Abbreviation	ITU band	Frequency	Wavelength
Extremely Low Frequency	ELF	1	3 – 30 Hz	100,000 – 10,000 km
Super Low Frequency	SLF	2	30 – 300 Hz	10,000 – 1,000 km
Ultra Low Frequency	ULF	3	300 – 3,000 Hz	1,000 – 100 km
Very Low Frequency	VLF	4	3 – 30 kHz	100 – 10 km
Low Frequency	LF	5	30 – 300 kHz	10 – 1 km
Medium Frequency	MF	6	300 – 3,000 kHz	1,000 – 100 m
High Frequency	HF	7	3 – 30 MHz	100 – 10 m
Very Figh Frequency	VHF	8	30 – 300 MHz	10 – 1 m
Ultra High Frequency	UHF	9	300 – 3,000 MHz	100 – 10 cm
Super High Frequency	SHF	10	3 – 30 GHz	10 – 1 cm
Extremely High Frequency	EHF	11	30 – 300 GHz	10 – 1 mm

Bottom of Atmosphere (BOA) reflectance, also known as surface reflectance, is the measurement of the reflectivity of the Earth's surface as it would be observed if there were no atmospheric effects like scattering and absorption. It represents the true reflectance of surface features, corrected for the influence of the atmosphere.

Key Concepts of BOA Reflectance

1. **Surface Reflectance**: This is the fraction of incoming solar radiation that is reflected by the surface. It provides crucial information about the properties of the surface materials, such as vegetation, soil, water bodies, and urban areas.
2. **Atmospheric Correction**: To derive BOA reflectance from satellite or airborne sensor data, the data must be corrected for atmospheric effects. This process involves removing the influence of gases (such as oxygen and water vapor), aerosols, and clouds that scatter and absorb the incoming solar radiation.

Importance of BOA Reflectance

- **Accuracy in Remote Sensing**: BOA reflectance provides a more accurate representation of the surface properties than Top of Atmosphere (TOA) reflectance, which includes atmospheric effects. This accuracy is crucial for various remote sensing applications.
- **Consistency in Multi-temporal Analysis**: When comparing images from different times, atmospheric conditions can vary. By correcting for these effects and using BOA reflectance, the comparisons become more reliable.
- **Improved Data for Analysis**: Many remote sensing applications, such as vegetation indices (e.g., NDVI), land cover classification, and surface property mapping, require accurate surface reflectance data.

Calculating BOA Reflectance from TOA:

To convert TOA reflectance to BOA reflectance, atmospheric correction algorithms and models are used. Some commonly used algorithms and tools include:

- **6S (Second Simulation of the Satellite Signal in the Solar Spectrum)**: A radiative transfer model used for atmospheric correction.
- **MODTRAN (MODerate resolution atmospheric TRANsmission)**: Another radiative transfer model often used in atmospheric correction.
- **NASA's Atmospheric Correction Parameter Calculator (ACPC)**: Provides parameters for correcting satellite data to BOA reflectance.
- **Sen2Cor**: A processor provided by ESA for Sentinel-2 data that corrects for atmospheric effects to produce BOA reflectance.

Copernicus Sentinel Expansion missions

Copernicus Hyperspectral Imaging Mission (CHIME)

- CHIME comprises of two satellites, namely CHIME-A and CHIME-B. These satellites are designed to provide systematic hyperspectral images that can be used to map changes in land cover and support sustainable agricultural practices.
- The two identical satellites flying will be separated by 180 degrees, in a sun-synchronous orbit at an average altitude of 632 km.

Measurement domain	Atmosphere, Ocean, Land
Measurement detailed	Ocean imagery and water leaving spectral radiance, Land surface imagery, Upwelling (Outgoing) spectral radiance at TOA
Instruments	HyperSpectral Imager (HSI)
Instrument type	Hyperspectral imagers

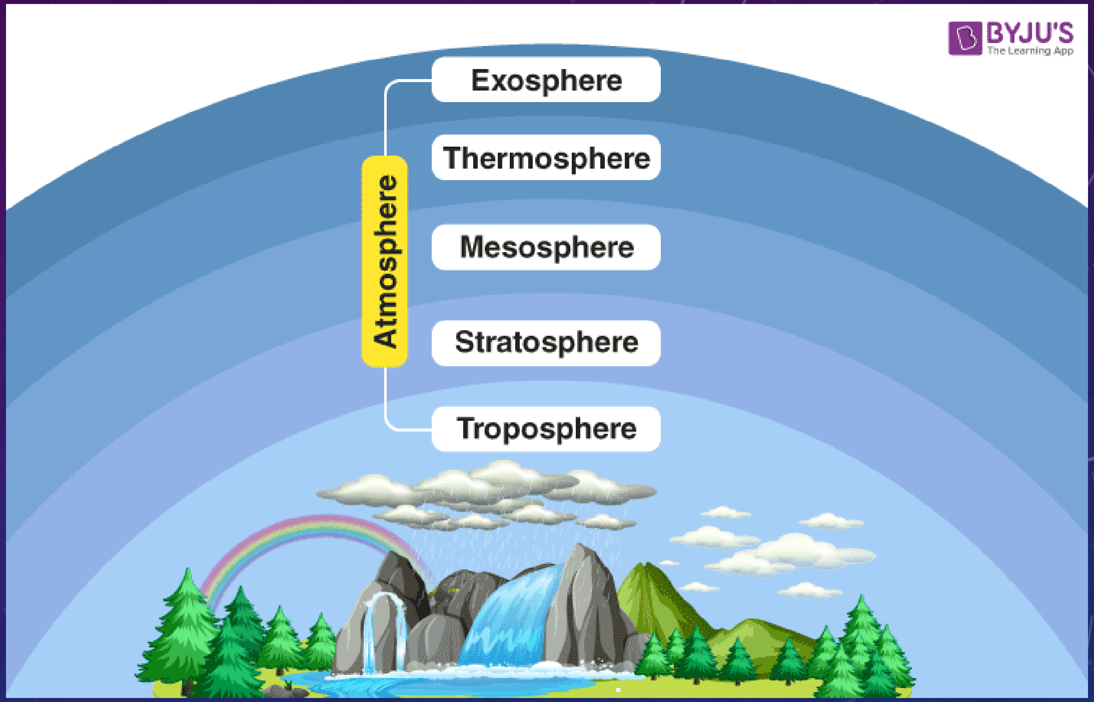
Copernicus Anthropogenic Carbon Dioxide Monitoring (CO2M)

- The mission is a part of the Copernicus Sentinel Expansion missions and consists of three satellites: CO2M-A, CO2M-B and CO2M-C (planned for launch in 2026).
- It is a European Space Agency (ESA) mission that will be the first to measure how much carbon dioxide is released into the atmosphere specifically through human activity.
- CO2M will be equipped with three instruments:
  - The Integrated **CO2 and NO2 Imaging Spectrometer (CO2I)** will provide CO2, CH4 and NO2 observation with a relatively high spatial resolution in support of estimating anthropogenic emissions, while
  - The **3-band CLoud IMager (CLIM)** will detect low and high clouds in the spatial sample of CO2I, allowing the removal of these data from the retrieval process.
  - The **Multi-Angular Multi-band Polarimeter (MAP)** will copper the CO2 and CH4 retrieval by accurately estimating the effective light path effects of the aerosols.

Measurement domain	Atmosphere
Measurement detailed	Cloud cover, Aerosol optical depth (column/profile), CH4 Mole Fraction, NO2 Mole Fraction, CO2 Mole Fraction
Instruments	CLIM, CO2I, MAP

Sentinel-4

- The main objective of the Sentinel-4 mission is to monitor key air quality trace gases and aerosols over Europe in support of the Copernicus Atmosphere Monitoring Service (CAMS) at high spatial resolution and with a fast revisit time.
- **Orbit:** Geostationary
- S4 mission will provide hourly data on tropospheric constituents over Europe mainly for air quality applications.
- The target species of the SENTINEL -4 mission include the key air quality parameters **NO2** (nitrogen dioxide), **O3** (ozone), **SO2** (sulfur dioxide), **HCHO** (formaldehyde), **CHOCHO** (glyoxal), and **aerosols**.
- Complementarily, the Low Earth Orbiting (LEO) missions S5 and S5p will deliver the S4 target species and additionally CO (carbon monoxide), CH4 (methane), and stratospheric O3 (ozone)with global daily coverage for climate, air quality, and ozone/surface UV applications.
- The Space Segment of the Sentinel-4 mission consists of an **Ultraviolet-Visible-Near-Infrared (UVN)** light imaging spectrometer instrument embarked on the Meteosat Third Generation Sounder (MTG-S) satellite.



UVN = 10nm – 2500 nm

Region	Wavelength Range	Frequency Range
Ultraviolet (UV)	10 nm to 400 nm	7.5 × 10^14 Hz to 3 × 10^16 Hz
- Far UV	10 nm to 200 nm	1.5 × 10^15 Hz to 3 × 10^16 Hz
- Near UV	200 nm to 400 nm	7.5 × 10^14 Hz to 1.5 × 10^15 Hz
Visible	400 nm to 700 nm	4.3 × 10^14 Hz to 7.5 × 10^14 Hz
Near-Infrared (NIR)	700 nm to 2500 nm	1.2 × 10^14 Hz to 4.3 × 10^14 Hz
- Short-Wave Infrared (SWIR)	1400 nm to 2500 nm	1.2 × 10^14 Hz to 2.1 × 10^14 Hz

- 'UVN' imaging spectrometer instrument, comprises three main units:
  - the Optical Instrument Module (OIM),
  - the Instrument Control Unit (ICU), and
  - the Scanner Driving Electronics (SDE).
- The Ground Segment of SENTINEL-4, part of the EUMETSAT MTG Core Ground Segment, comprises the following elements:
  - The SENTINEL-4 Level-1B and Level-2 processors;
  - The generic and multi-mission supporting functions of the EUMETSAT MTG Payload Data Ground Segment (PDGS) and the Flight Operations Segment (FOS);
  - The SENTINEL-4 ground segment system interfaces.

Instrument	Technical Concept	Spectral Range	Spatial resolution (km x km)	Earth Coverage	Revisit time	Operational
GOME	Whisk-broom (scanning)	UV-VIS-NIR (240-790 nm)	320 x 40	Global	1 ½ day	1995-2011
GOME-2	Whisk-broom (scanning)	UV-VIS-NIR (240-790 nm)	80 x 40	Global	1 ½ day	2006-present
SCIAMACHY	Whisk-broom (scanning)	UV to SWIR (240-2400 nm)	30 x 215	Global	6 days	2002-2012
OMI	Push-broom (staring)	UV-VIS (270-500 nm)	13 x 24	Global	1 day	2004-present
TROPOMI	Push-broom (staring)	UV-VIS-NIR-SWIR (270 – 2385 nm)	7 x 7	Global	1 day	Launch scheduled in 2016
Sentinel-4/UVN	Push-Broom (scanning)	UV-VIS-NIR (305- 775 nm)	8 x 8	Europe + parts of North Africa and the Atlantic	1 hour	Launch scheduled in 2021

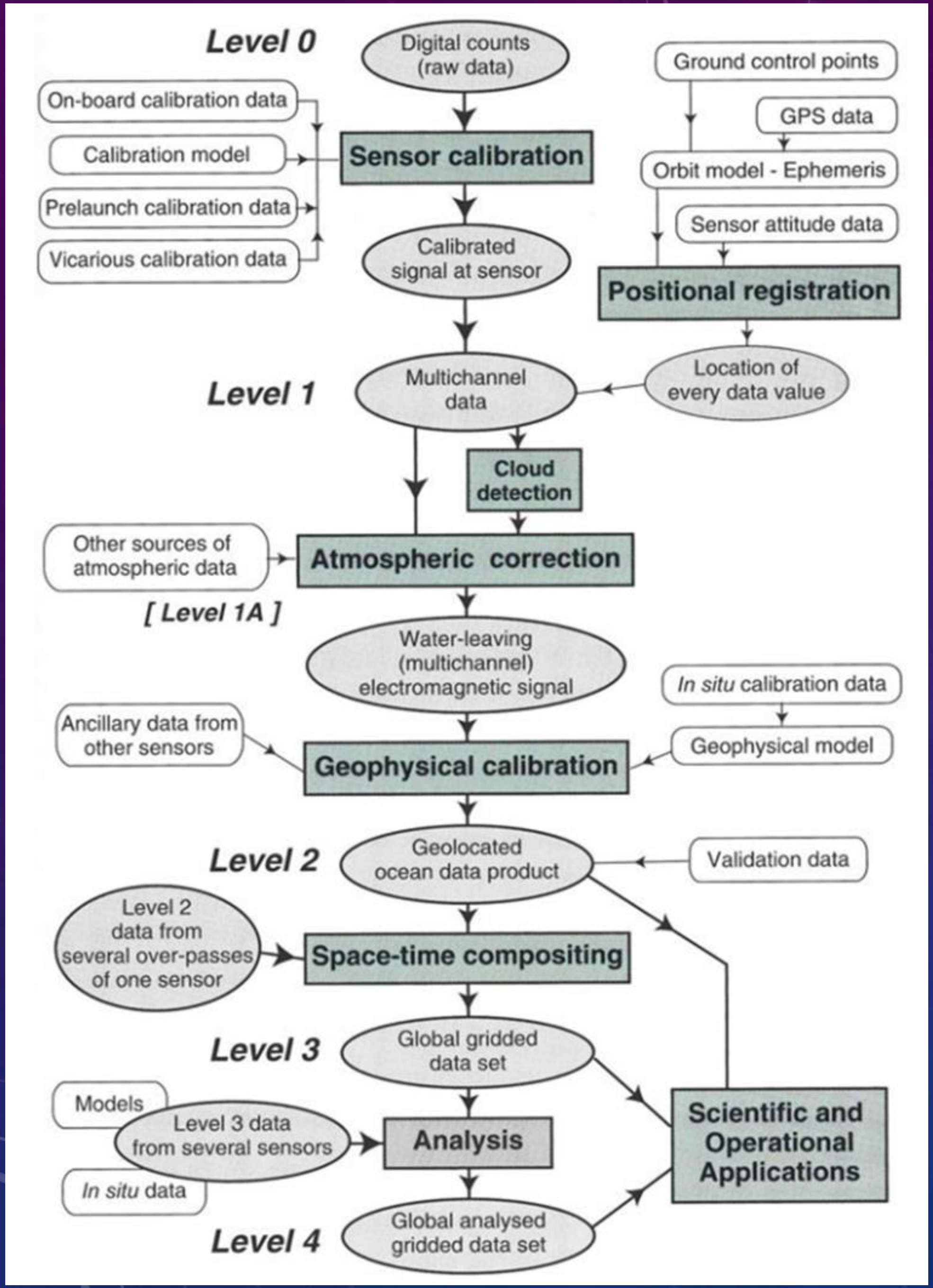
Sentinel 5

Sentinel4

Sentinel4 Calibration processors

The external data flow of the Sentinel-4/UVN L0 to L1 processor is defined as follows:

- L0 instrument data (reconstructed from the input data packets)
- L1b datasets including:
  Level 1b Earth spectral radiance dataset.
  Level 1b sun spectral irradiance dataset.
  Level 1b calibration datasets (several).
  Level 1b calibration star dataset, one of the Level 1b calibration datasets for star measurement data.
  Level 1b star dataset.
- L1b Data Processing Parameters File (DPPF) Data
  Level 1b data processing parameters file (DPPF) dataset.



Processing satellite data up to Level 1 (calibrated/geolocated radiances) and Level 2 (geophysical parameters) involves several steps, each with its own set of mathematical formulas and algorithms. Here's a general overview of the processes involved:

Level 2 Processing (Geophysical Parameters):

Level 2 processing involves retrieving geophysical parameters or derived products from the calibrated radiances. This often involves complex algorithms and radiative transfer models specific to the parameter being retrieved.

1. Atmospheric Correction: This step aims to remove atmospheric effects (e.g., scattering, absorption) from the calibrated radiances to obtain surface reflectance or brightness temperature values. It typically involves radiative transfer models that account for atmospheric composition, aerosol properties, and other environmental conditions.
2. Retrieval Algorithms: Geophysical parameters are retrieved from the atmospherically corrected data using various algorithms. These algorithms can be based on physical models, empirical relationships, or machine learning techniques. For example, the retrieval of chlorophyll-a concentration from ocean color data might involve algorithms based on the ratios or combinations of reflectance values in specific wavebands, such as: Chl-a = A * (R1 / R2)^B Where R1 and R2 are reflectance values in different wavebands, and A and B are empirically derived coefficients.
3. Quality Control and Flagging: This step involves applying quality control measures to the retrieved geophysical parameters, such as cloud masking, identifying invalid or unreliable values, and assigning quality flags based on various criteria.

Instrument grid processing (Level 1A) and image grid processing (Level 1B)

NETCDF (.nc)

NetCDF (Network Common Data Form) is a self-describing, machine-independent data format widely used for storing and sharing array-oriented scientific data, such as meteorological, oceanographic, and climate data.

Here are some key points about the NetCDF format:

1. Data Model:
   - NetCDF represents data as multi-dimensional arrays, allowing for efficient storage and manipulation of large datasets with multiple variables and dimensions.
   - It supports a hierarchical structure, with groups and subgroups for organizing related variables and metadata.
2. Self-Describing:
   - NetCDF files are self-describing, meaning they contain metadata that describes the data, such as variable names, units, dimensions, and data types.
   - This metadata makes NetCDF files easy to interpret and use across different systems and applications.
3. Platform Independence:
   - NetCDF is a platform-independent format, allowing data to be easily shared and used across different operating systems and computing environments.
   - It is supported by various programming languages and libraries, such as C, Fortran, Python, MATLAB, and R.
4. Data Types:
   - NetCDF supports a range of data types, including integers, floating-point numbers, characters, and user-defined types.
   - It can store both scalar and array-based variables, as well as coordinate variables for representing spatial and temporal dimensions.
5. Compression:
   - NetCDF supports various compression techniques, such as deflation and shuffling, which can significantly reduce file sizes while maintaining data integrity.
6. Metadata Conventions:
   - NetCDF files often follow specific conventions for metadata, such as the Climate and Forecast (CF) conventions, which provide a standardized way of describing geospatial and climate data.
7. Applications:
   - NetCDF is widely used in fields such as atmospheric science, oceanography, climate research, remote sensing, and earth system modeling.
   - It is the default data format for many scientific data products, including those from NASA, NOAA, and other international organizations.
8. Software Support:
   - Various software libraries and tools are available for reading, writing, and manipulating NetCDF files, such as netCDF-C, netCDF-Fortran, netCDF4-python, and NCO (NetCDF Operators).

Copy code

```
NetCDF File: example.nc
├── Metadata
│   ├── Conventions
│   ├── Title
│   ├── Source
│   ├── History
│   └── ...
├── Dimensions
│   ├── time (unlimited)
│   ├── lat (720)
│   └── lon (1440)
├── Variables
│   ├── Variable: time
│   │   ├── Type: double
│   │   ├── Dimensions: time
│   │   ├── Units: hours since 1970-01-01 00:00:00
│   │   └── Data: [0.0, 1.0, 2.0, ..., 23.0]
│   ├── Variable: lat
│   │   ├── Type: float
│   │   ├── Dimensions: lat
│   │   ├── Units: degrees_north
│   │   └── Data: [-90.0, -89.5, ..., 89.5, 90.0]
│   ├── Variable: lon
│   │   ├── Type: float
│   │   ├── Dimensions: lon
│   │   ├── Units: degrees_east
│   │   └── Data: [0.0, 0.25, ..., 359.75]
│   └── Variable: temperature
│       ├── Type: short
│       ├── Dimensions: time, lat, lon
│       ├── Units: K
│       ├── _FillValue: -32767
│       └── Data:
│           ├── [[:], [:], [0]]
│           │   ├── [293.2, 292.1, ..., 291.5]
│           │   ├── [293.4, 292.3, ..., 291.7]
│           │   └── ...
│           ├── [[:], [:], [1]]
│           │   ├── [293.1, 292.0, ..., 291.4]
│           │   ├── [293.3, 292.2, ..., 291.6]
│           │   └── ...
│           └── ...
└── Groups (optional)
    └── ... (Nested groups and variables)
```

HDF data file

HDF (Hierarchical Data Format) is a file format and data model designed for storing and managing large and complex scientific datasets. It supports hierarchical organization of data, similar to a file system, and allows for efficient storage of multi-dimensional arrays and metadata.

Copy code

```
HDF File: example.hdf
├── Root Group (/)
|   ├── Attributes
|   |   ├── Title: "Example HDF File"
|   |   ├── Creator: "John Doe"
|   |   └── ...
|   ├── Data Group: /temperature
|   |   ├── Dataset: /temperature/data
|   |   |   ├── Data Type: 32-bit float
|   |   |   ├── Dimensions: (time, lat, lon)
|   |   |   ├── Data: [[:], [:], [:]]
|   |   |   |   ├── [293.2, 292.1, ..., 291.5]
|   |   |   |   ├── [293.4, 292.3, ..., 291.7]
|   |   |   |   └── ...
|   |   ├── Dataset: /temperature/lat
|   |   |   ├── Data Type: 64-bit float
|   |   |   ├── Dimensions: (lat)
|   |   |   ├── Data: [-90.0, -89.5, ..., 89.5, 90.0]
|   |   └── Dataset: /temperature/lon
|   |       ├── Data Type: 64-bit float
|   |       ├── Dimensions: (lon)
|   |       ├── Data: [0.0, 0.25, ..., 359.75]
|   ├── Data Group: /humidity
|   |   ├── Dataset: /humidity/data
|   |   |   ├── Data Type: 16-bit integer
|   |   |   ├── Dimensions: (time, lat, lon)
|   |   |   ├── Data: [[:], [:], [:]]
|   |   |   |   ├── [75, 68, ..., 82]
|   |   |   |   ├── [77, 70, ..., 80]
|   |   |   |   └── ...
|   |   ├── ...
|   └── ...
└── Other Groups and Datasets
    └── ...
```

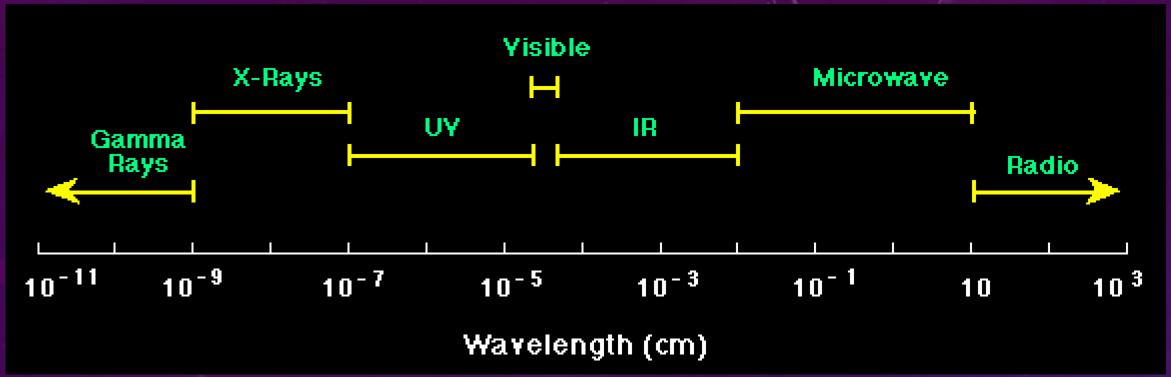
Difference between NETCDF and HDF data file

While both NetCDF (.nc) and HDF (.hdf) are file formats used for storing and managing scientific data, they differ in several ways:

Feature	NetCDF (.nc)	HDF (.hdf)
Data Model	Multidimensional arrays	Hierarchical, nested groups and datasets
Metadata Handling	Attributes associated with variables or file	Extensive metadata support, associated with groups, datasets, and elements
Data Types	Limited set of predefined data types (integers, floats, characters)	Wide range of data types, including user-defined and complex types
Compression	Built-in support for compression techniques like deflation and shuffling	Compression support may require additional tools or libraries
Portability	Self-describing and platform-independent	Aims for portability but may require more effort across platforms and software
Software Support	Widespread support in various programming languages (C, Fortran, Python, MATLAB, R)	Software support may be more limited or require additional libraries
Performance	Can handle large datasets, performance varies based on use case	Can handle large datasets, performance varies based on use case
Adoption	Widely adopted in atmospheric science, oceanography, climate research	Commonly used in remote sensing, astrophysics, high-energy physics
Data Model Simplicity	Simple data model based on multidimensional arrays	More flexible and complex hierarchical data model
Metadata Flexibility	Limited metadata flexibility	Extensive metadata flexibility

Difference between NETCDF and HDF data file

- **Data Model**:
  - NetCDF uses a simple data model based on multidimensional arrays, where data is organized into variables with dimensions.
  - HDF follows a more flexible and hierarchical data model, allowing for nested groups and datasets, similar to a file system structure.
- **Metadata Handling**:
  - In NetCDF, metadata (attributes) are associated with variables or the file itself.
  - HDF supports more extensive metadata handling, allowing metadata to be associated with groups, datasets, and even individual data elements.
- **Data Types**:
  - NetCDF supports a limited set of predefined data types, such as integers, floats, and characters.
  - HDF supports a wider range of data types, including user-defined and complex data types.
- **Compression**:
  - NetCDF has built-in support for data compression using techniques like deflation and shuffling.
  - HDF also supports compression, but it may require additional tools or libraries.
- **Portability**:
  - NetCDF is designed to be self-describing and platform-independent, making it easier to share data across different systems and software environments.
  - HDF also aims for portability, but it may require more effort to ensure compatibility across different platforms and software tools.
- **Software Support**:
  - NetCDF has widespread support from various programming languages and libraries, such as C, Fortran, Python, MATLAB, and R.
  - HDF also has software support, but it may be more limited or require additional libraries or tools.
- **Performance**:
  - Both NetCDF and HDF can handle large datasets, but their performance characteristics may vary depending on the specific use case and data access patterns.
- **Adoption**:
  - NetCDF is widely adopted in fields like atmospheric science, oceanography, and climate research, and is often the default format for many scientific data products.
  - HDF is more commonly used in fields like remote sensing, astrophysics, and high-energy physics, where complex data structures and user-defined data types are more prevalent.



Vegetation health monitoring, cloud properties, and surface temperature.

Cloud imaging, surface albedo, vegetation, and ocean color observations.

Monitoring ozone levels, solar irradiance, and upper atmospheric studies.

Region	Wavelength range (approx.)	Frequency range (approx.)	Comments
Long-wave radio	>10 m	<$3x10^{7}$ hz	Includes traditional AM radio region. These frequencies can travel long distances by multiple reflections between the surface of the earth and its ionosphere.
Short-wave radio	10 cm - 10 m	$3x10^{7}$ - $3x10^{9}$	Used for TV, FM, and other communication purposes. Generally travels only relatively short distances because the ionosphere is transparent to it.
Microwave	1 mm - 10 cm	$3x10^{9}$ - $3x10^{11}$	Present limit of radio technology for most purposes.
Far infrared	30 µm - 1 mm	$3x10^{11}$ - 10^{13}	3 K radiation fills universe.
Thermal infrared	3 µm - 30 µm	10^{13} - 10^{14}	Thermal emission of earth and planets.
Near infrared	700 nm - 3µm	10^{14} - $4x10^{14}$	Solar and stellar emission.
Visible	400 nm - 700nm (1.7 - 3 eV)	$4x10^{14}$ -$7x10^{14}$	Peak of solar radiation. Visible to human eye, standard photographic film and CCD video detectors.
Ultraviolet	200 nm - 400nm (3 - 6 eV)	$7x10^{14}$ - $1.5x10^{15}$	Divided at 300 nm by atmospheric (ozone) cutoff. Appreciable solar flux causes sunburn.
Vacuum UV (EUV)	10 nm - 200 nm (6 - 120 eV)	$1.5x10^{15}$ - $3x10^{16}$	Very strong absorption in matter, hence very difficult to observe.
X-rays	120 eV- 100keV	$3x10^{16}$ - $3x10^{19}$	Produced by electron beams in X-ray tubes, and by inner atomic transitions. Progressively more penetrating as E increases, up to many centimeters in water.
γ-rays	100 keV	$3x10^{19}$	Produced by nuclear and other high energy processes. Can penetrate up to meters in water.

https://web.pa.msu.edu/courses/2000fall/phy232/lectures/emwaves/spectrum.html