Meteorological Satellites (MetSat)

World Meteorological Organization WMO

International Telecommunication Union ITU

Meteorological Satellites, constellations, applications, development

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Definition of MetSat in the ITU Radio Regulations

- MetSat is defined in No. 1.52 of the Radio Regulations (RR) as "an Earth exploration-satellite service (RR No. 1.51) for meteorological purposes".
- It allows the radiocommunication operation between earth stations and one or more space stations, which may include links between space stations, with links to provide:
  - Information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, obtained from active or passive sensors on Earth satellites;
  - Information collected from airborne or Earth-based platforms;
  - Information distributed to earth stations;
  - Feeder links necessary for the operation of MetSat satellites and its applications.

The mission of a MetSat operator is…

- ...to deliver operational satellite data and products that satisfy the meteorological and climate data requirements of its user community - 24 hours a day, 365 days a year, through decades.

- … to provide the space-based component of the WMO Global Observing System (GOS) for the measurement of environmental and meteorological data with geostationary (GSO) and non-geostationary (NGSO) low Earth-orbiting, mostly polar-orbiting observation satellites.

MetSats are vital for …

Monitoring Weather

- The high-quality observations of MetSat satellites are vital for weather forecasting.

Monitoring Climate

- More and more climate data need to be delivered to meet the challenge of mitigating and adapting to climate change.

Monitoring Oceans

- Operational oceanography for the delivery of ocean data over decades to monitor the state of the oceans and sea level rise.

Atmospheric Composition

- Observations of MetSat satellites are also critical inputs to monitoring and forecasts of air quality, which are increasingly important for the health of the population.

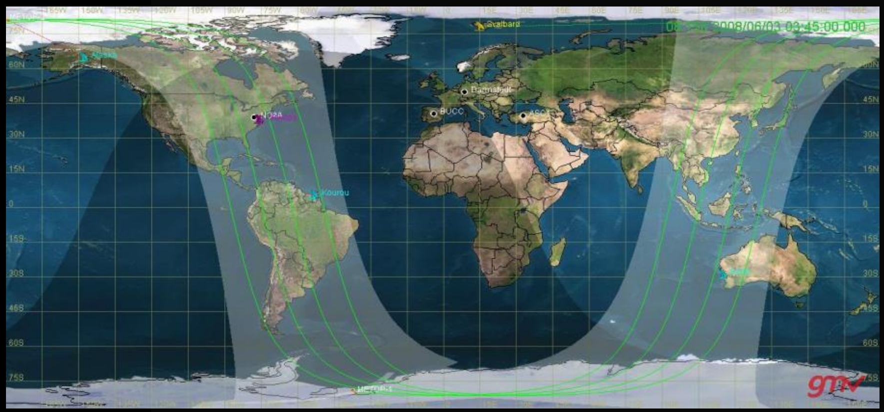
Distributing Data

- Delivery of satellite data and products in real-time to users worldwide.

Why are MetSats so important for all this?

Answer: Global coverage !

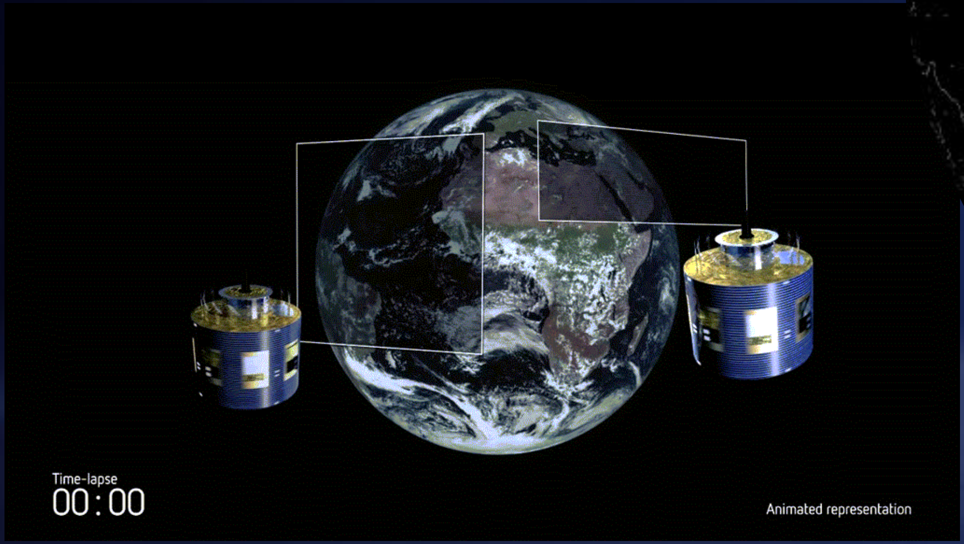
- NGSO Polar Orbit (example Metop):
- Primary source of global climate observations and forecasts up to 10 days, e.g. providing vertical profiles of temperature and humidity through the atmosphere on a global basis.

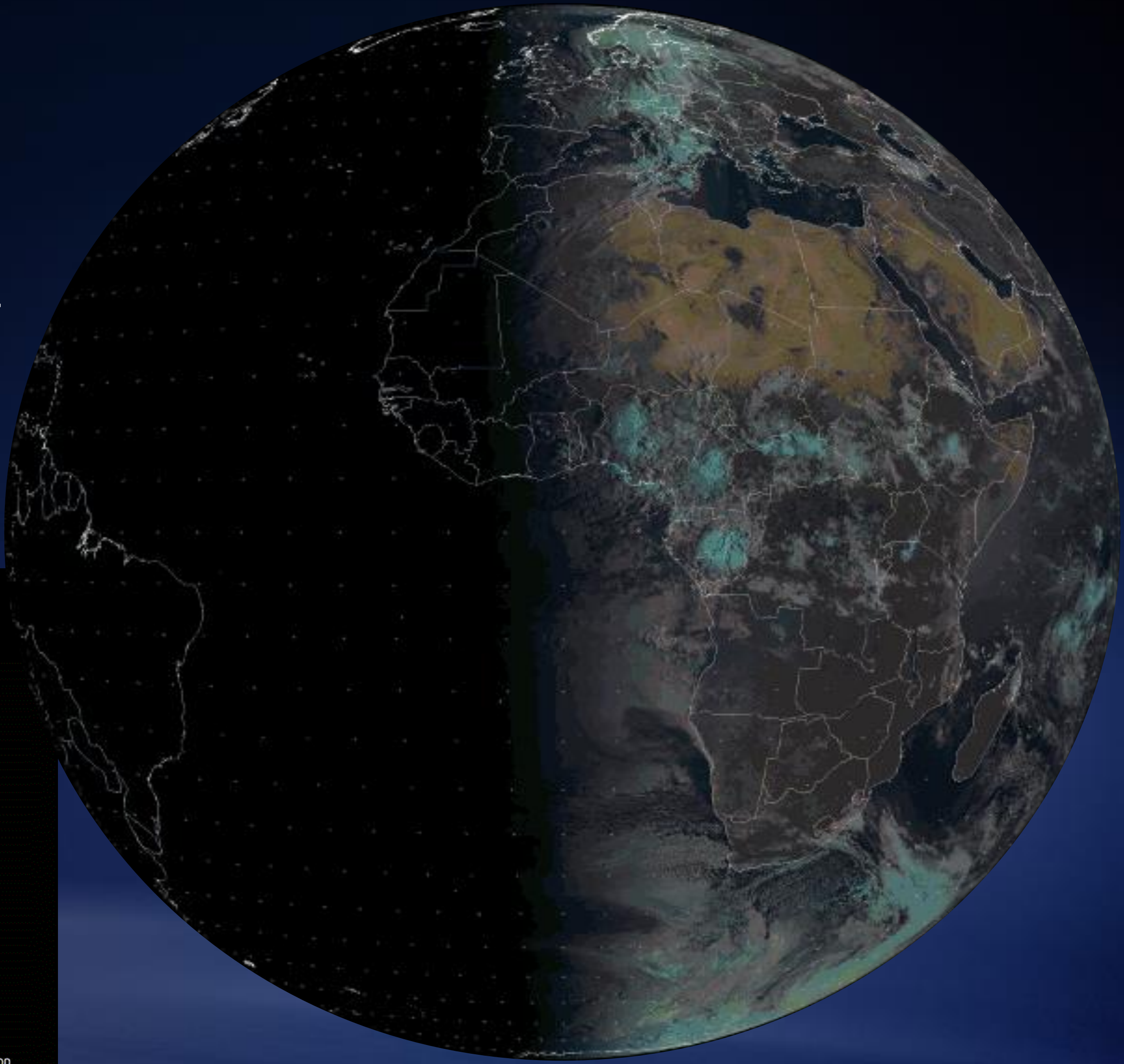


Metop: Orbit height 830 km, 14 orbits/day, measurements twice over the same are at a swath width of ~2000 km

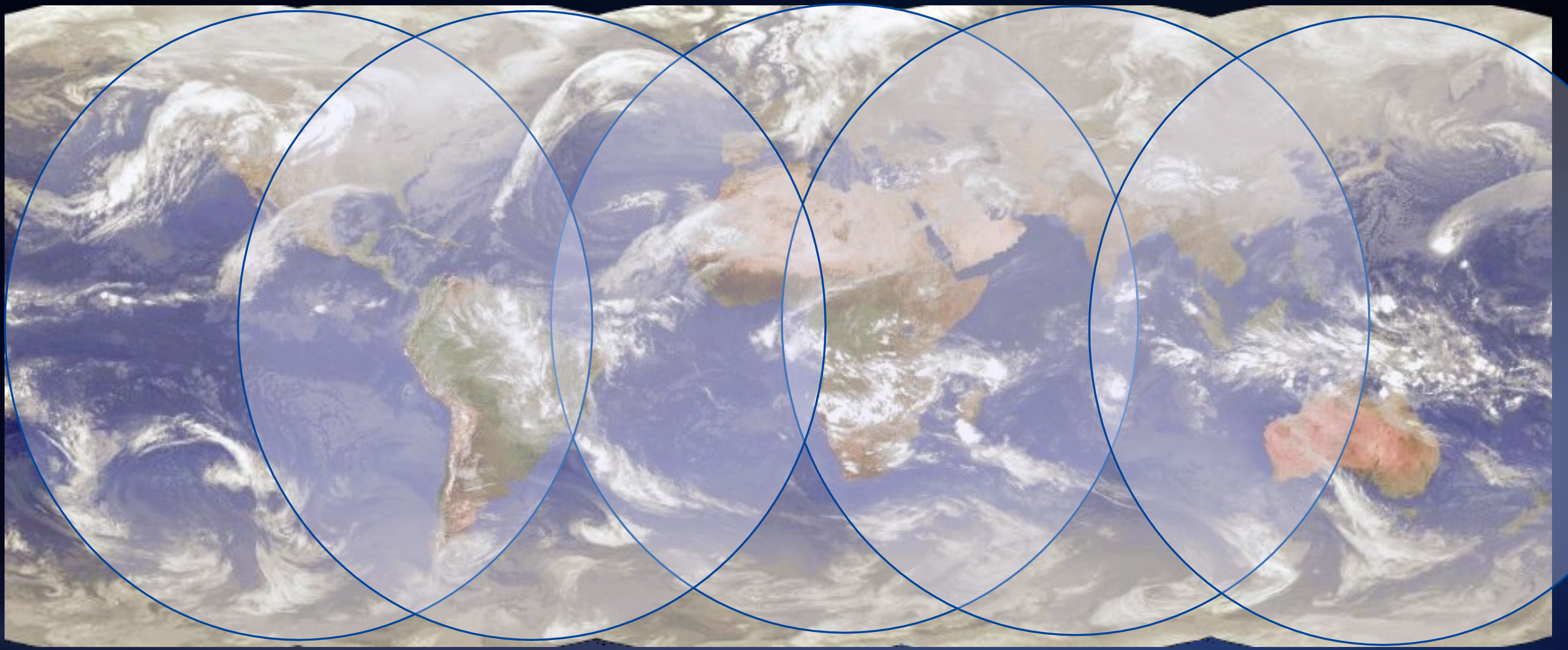
Example of a full disk visible image from a GSO MetSat

- This is the example of Meteosat Second Generation (MSG) satellites on GSO orbit.
- These satellites are particularly useful for detecting the development of weather and predicting their behaviour over the next few hours. They provide information on storms, clouds, winds, fog, rain, snow, incoming solar radiation, volcanic ash, dust, land and sea surface temperature and even fires.
- Data is also used for longer range weather forecasting and climate monitoring.





Global coverage with GSO MetSat through international cooperation

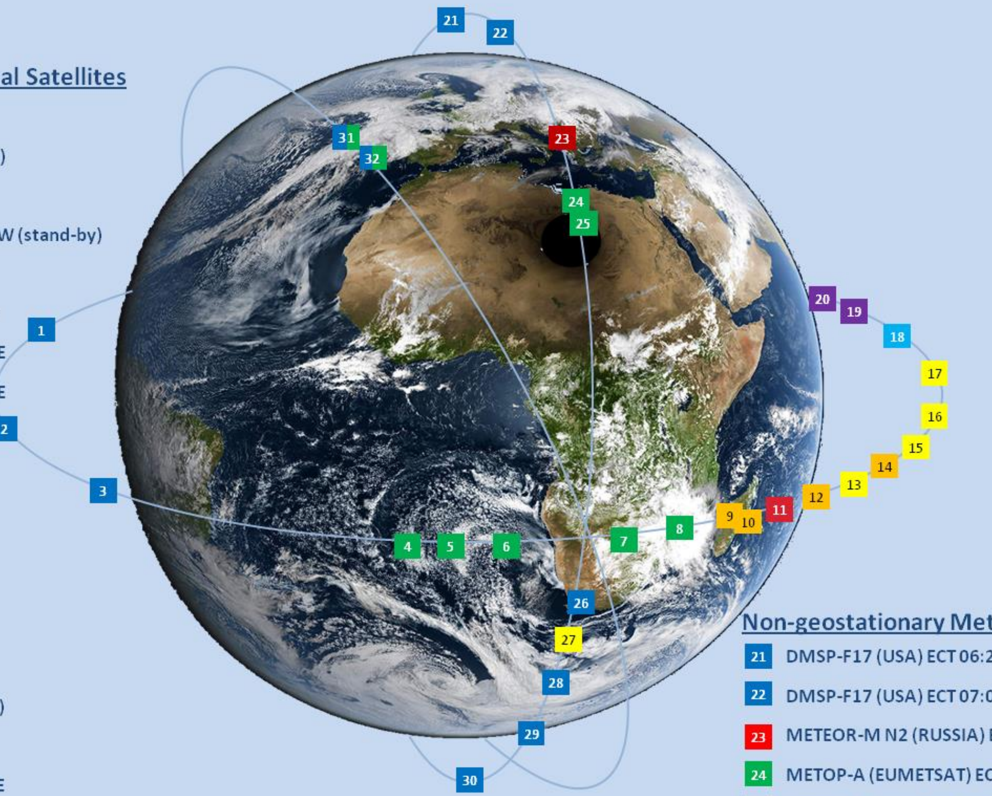


Current global network of MetSat in the WMO GOS

Currently operational Meteorological Satellites (Status: June 2016, Information Source: CGMS)

Geostationary Meteorological Satellites

- 1 GOES-15 (USA) 135°W
- 2 GOES-14 (USA) 105°W (stand-by)
- 3 GOES-13 (USA) 75°W
- 4 METEOSAT-11 (EUMETSAT) 3.4°W (stand-by)
- 5 METEOSAT-10 (EUMETSAT) 0°
- 6 METEOSAT-9 (EUMETSAT) 9.5°E
- 7 METEOSAT-8 (EUMETSAT) 41.5°E
- 8 METEOSAT-7 (EUMETSAT) 57.5°E
- 9 INSAT-3C (INDIA) 74°E
- 10 KALPANA-1 (INDIA) 74°E
- 11 ELECTRO-L N2 (RUSSIA) 77.8°E
- 12 INSAT-3C (INDIA) 82°E
- 13 FY-2E (CHINA) 86.5°E
- 14 INSAT-3A (INDIA) 93.5°E
- 15 FY-2G (CHINA) 105°E
- 16 FY-2F (CHINA) 112.5°E (stand-by)
- 17 FY-2D (CHINA) 123.5°E
- 18 COMS-1 (SOUTH KOREA) 128.2°E
- 19 HIMAWARI-8 (JAPAN) 140.7°E
- 20 HIMAWARI-7 (JAPAN) 145°E (stand-by)

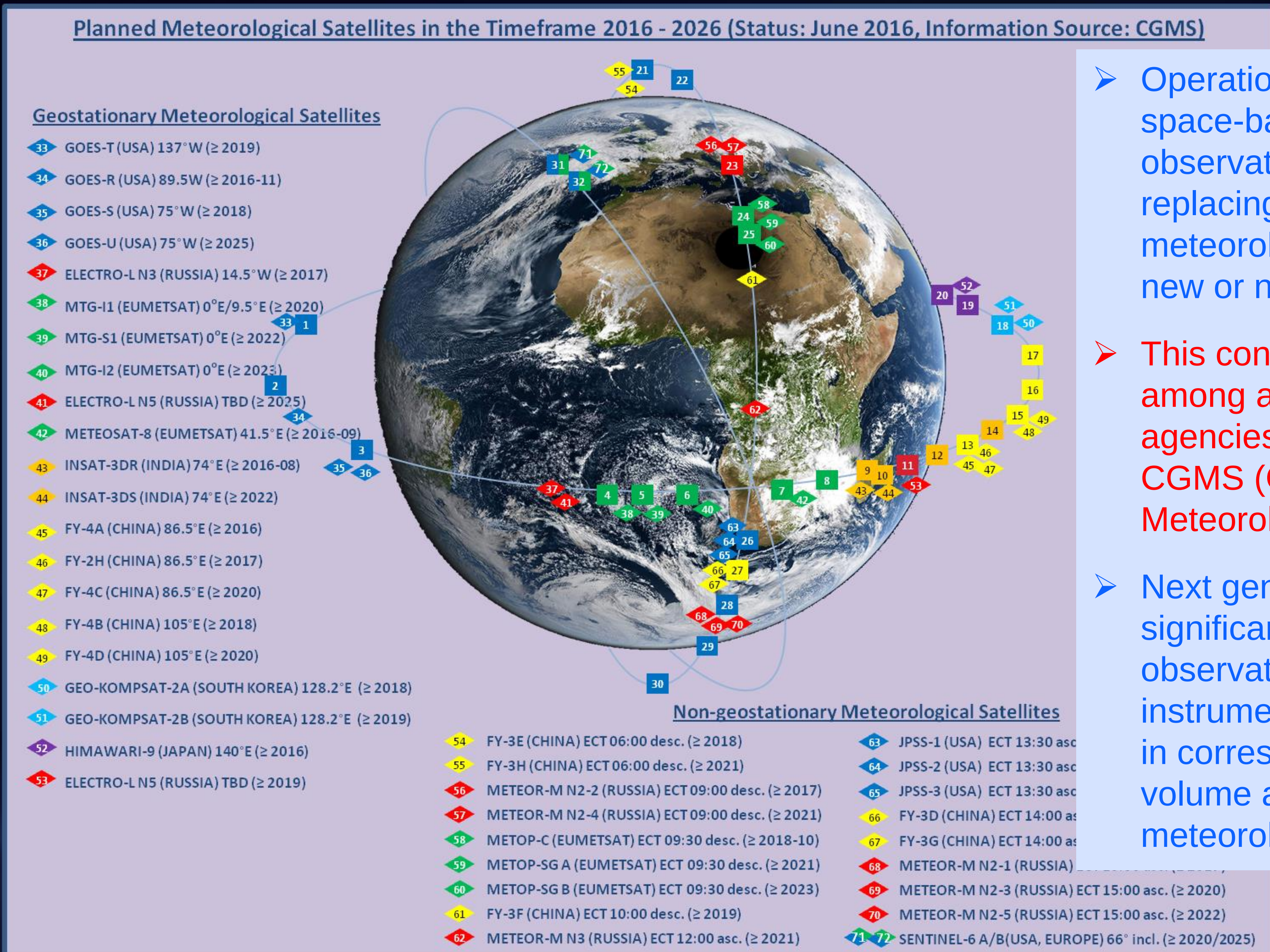


Non-geostationary Meteorological Satellites

- 21 DMSP-F17 (USA) ECT 06:20 descending
- 22 DMSP-F17 (USA) ECT 07:08 descending
- 23 METEOR-M N2 (RUSSIA) ECT 09:10 descending
- 24 METOP-A (EUMETSAT) ECT 09:30 descending
- 25 METOP-B (EUMETSAT) ECT 09:30 descending
- 26 SNPP (USA) ECT 13:29 ascending
- 27 FY-3B (CHINA) ECT 13:38 ascending
- 28 NOAA-19 (USA) ECT 14:36 ascending
- 29 DMSP-F16 (USA) ECT 16:12 ascending
- 30 NOAA-18 (USA) ECT 17:53 ascending
- 31 JASON-2 (USA, EUROPE) 66° inclination
- 32 JASON-3 (USA, EUROPE) 66° inclination

The actual list of currently operational MetSat and their parameters is available at: http://www.wmo.int/pages/prog/sat/GOSleo.html.

Constellation of planned MetSat for the WMO GOS



- Operational continuity in the space-based meteorological observations is ensured by replacing existing series of meteorological satellites with new or next generation MetSats.
- This continuity is coordinated among all MetSat operating agencies in the framework of CGMS (Coordination Group for Meteorological Satellites).
- Next generation MetSats have significantly increased observation capabilities and instrument resolution, resulting in corresponding higher data volume available to the meteorological user community.

Overview of instrument types and missions on MetSat systems

GSO MetSat:

- Visible imagers
- Infrared imagers
- Infrared sounders
- UV sounders

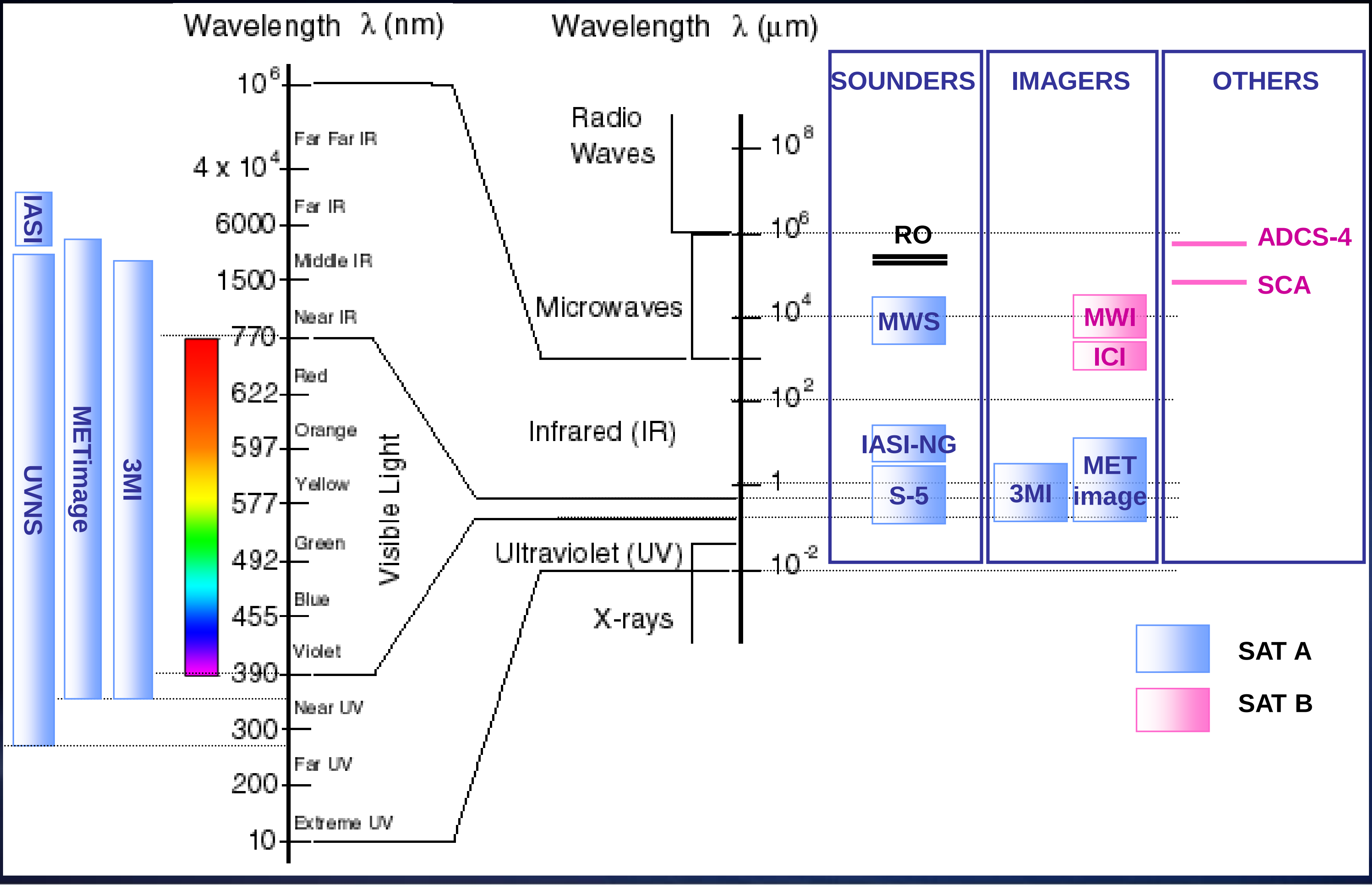
First microwave sensors are planned also for next generation GSO MetSats !

- Data Collection System
- Search and Rescue
- Further instruments (e.g. lightning imager)

NGSO MetSat:

- Visible imagers
- Infrared imagers
- Infrared sounders
- UV sounders
- Active microwave sensors
- Passive microwave sensors
- Data Collection System
- Search and Rescue
- Further instruments (individual to different NGSO MetSat systems)

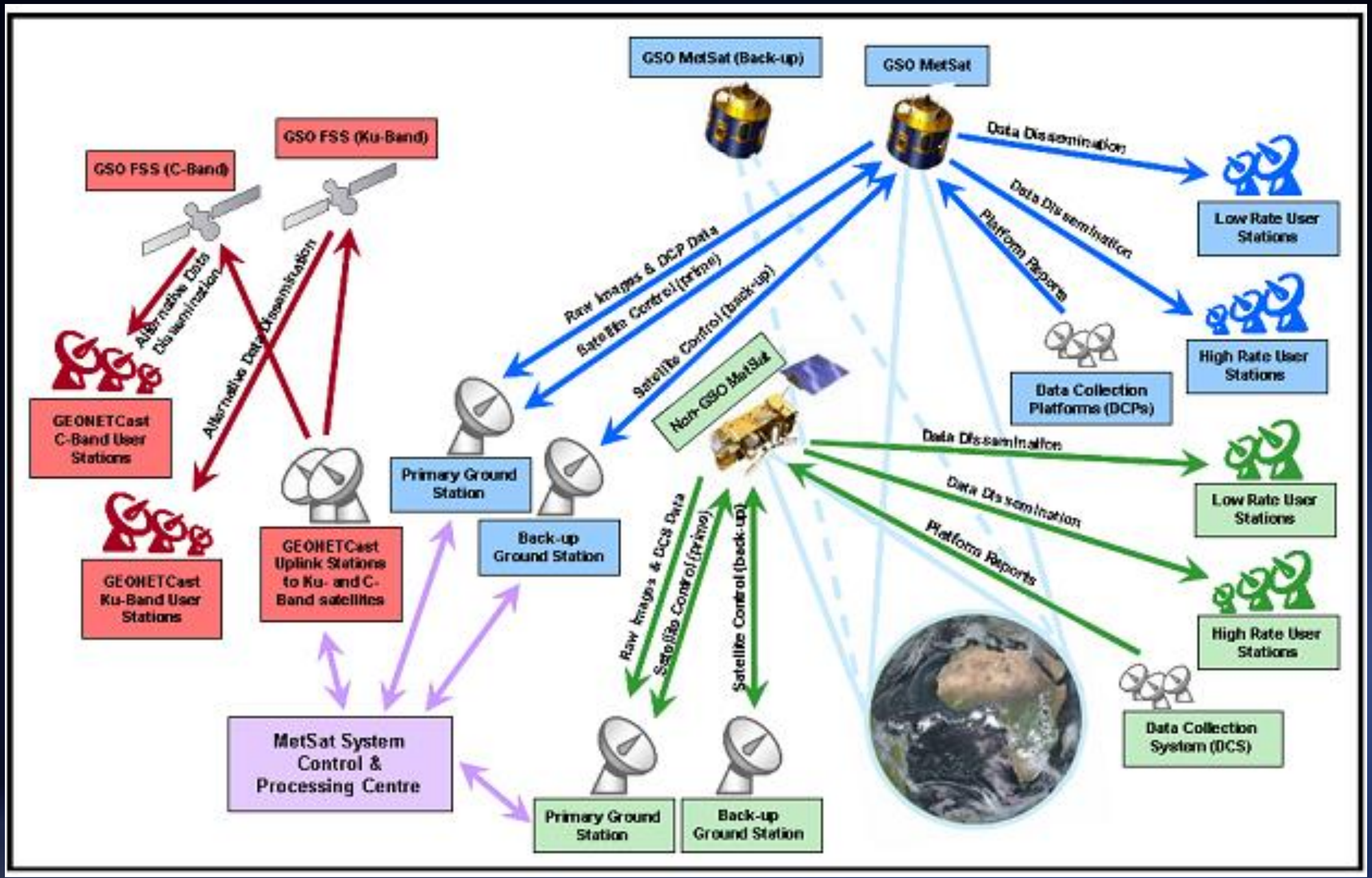
Typical NGSO MetSat instrument coverage in the electromagnetic spectrum (example: Metop-SG)



MetSat radio-frequency transmissions and sensing

- Radio-frequencies are used for the following MetSat/EESS applications:
  - telemetry, telecommand and ranging of the spacecraft
  - transmissions of observation data from MetSat satellites to main reception stations;
  - re-transmissions of pre-processed data to meteorological user stations through MetSat satellites;
  - direct broadcast transmissions to meteorological user stations from MetSat satellites;
  - alternative data dissemination to users (GEONETCast) via other satellite systems than MetSat (not in MetSat/EESS allocated frequency bands);
  - transmissions from Data Collection Platforms through MetSat satellites;
  - relay of Search and Rescue messages (COSPAS-SARSAT);
  - active and passive microwave sensing.

General concept of MetSat systems (graphical overview)



Data Transmission concepts of MetSat systems (in a bit more detail)

- The raw data gathered by the instruments on-board geostationary MetSats are permanently transmitted to a primary ground station of the operating agency, processed, and distributed to various national meteorological centres, to official archives, and other users.
- Processed data from geostationary MetSats are either sent back to the meteorological satellite for re-transmission as part of a direct broadcast to user stations via low and/or high rate digital signals.
- Different to geostationary MetSat satellites, where the satellite is permanently in visibility of its ground stations, the raw data acquired by instruments on non-geostationary MetSats have to be gathered and stored on-board the satellite until they can be transmitted to a primary ground station of the operating agency when the satellite passes over such a ground station.
- The raw instrument data are then processed by the operating agency and provided to the users by different data dissemination mechanisms. To improve the latency of the data, a subset of the data acquired by the instruments are "broadcasted" directly from the satellite and can be received by user stations when the satellite is in the visibility of such a user station which can be located anywhere. Such a service is called "direct read-out".
- In addition, the processed data are also distributed to users by using alternative means of data dissemination, e.g. GEONETCast.

Overview of bands and their applications most commonly used by current & planned MetSat systems

Communications	Passive Sensing		Active Sensing	Other Instruments
399.9 – 400.05 MHz	10.6 – 10.68 GHz	Shared	5150 – 5250 MHz	1164 – 1215 MHz
400.1 – 403 MHz	10.68 – 10.7 GHz	RR 5.340	5250 – 5350 MHz	1215 – 1240 MHz
406 – 406.1 MHz	18.6 – 18.8 GHz	RR 5.340	5350 – 5460 MHz	1559 – 1610 MHz
460 – 470 MHz	23.6 – 24 GHz	RR 5.340	5360 – 5470 MHz	
1544 – 1545 MHz	31.3 – 31.5 GHz	RR 5.340	5470 – 5570 MHz	
1675 – 1710 MHz	31.5 – 31.8 GHz	shared	13.4 – 13.75 GHz	
2025 – 2110 MHz	36 – 37 GHz	shared	35.5 – 36 GHz GHz	
2200 – 2290 MHz	50.2 – 50.4 GHz	RR 5.340		
7450 – 7550 MHz	52.6 – 54.25 GHz	RR 5.340		
7750 – 7900 MHz	54.25 – 59.3 GHz	shared		
8025 – 8400 MHz	86 – 92 GHz	RR 5.340		
25.5 – 27 GHz	114.25 – 116 GHz	RR 5.340		
	116 – 122.25 GHz	shared		
Data Distribution via	155.5 – 158.5 GHz	shared		
commercial sats:	164 – 167 GHz	RR 5.340		
3800 – 4200 MHz	174.8 – 182 GHz	shared		
10.7 – 12.5 GHz	182 – 185 GHz	RR 5.340		
	185 – 190 GHz	shared		
	190 – 191.8 GHz	RR 5.340		
	226 – 231.5 GHz	RR 5.340		
	235 – 238 GHz	RR 5.340		
	238 – 248 GHz	RR 4.4		
	313 – 356 GHz	RR 5.565		
	439 – 467 GHz	RR 5.565		
	657 – 692 GHz	RR 5.565		

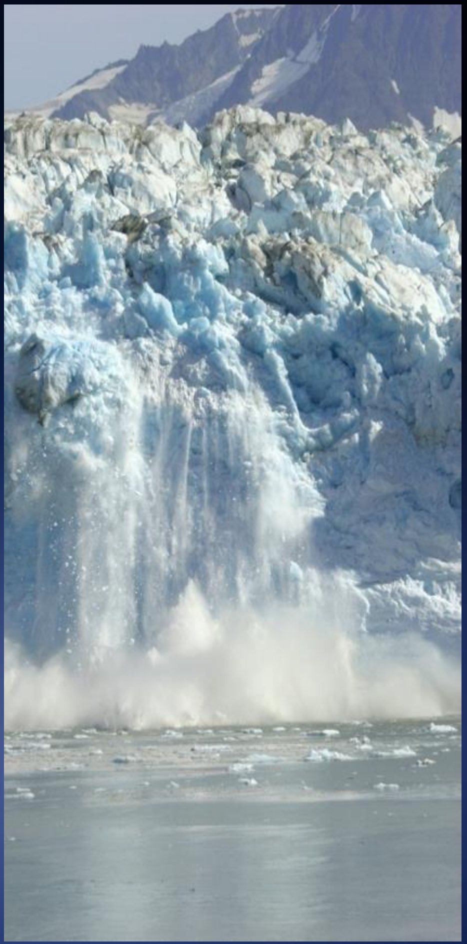
RR Footnote 5.340:
All emissions are prohibited in the following frequency bands…

Socio-economic benefits

Safety of life, property and infrastructure…

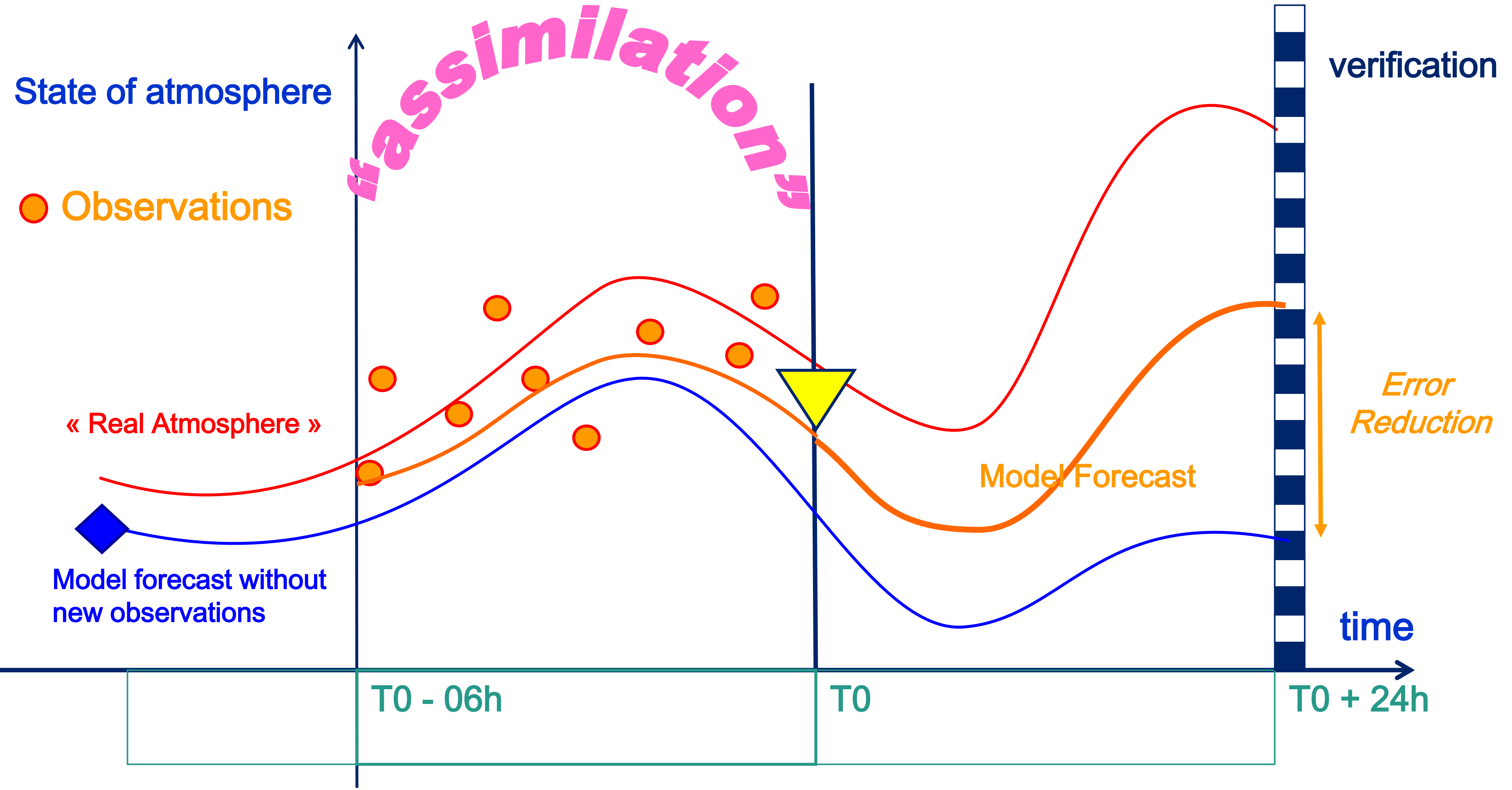
Transport …

....Energy, agriculture, tourism....

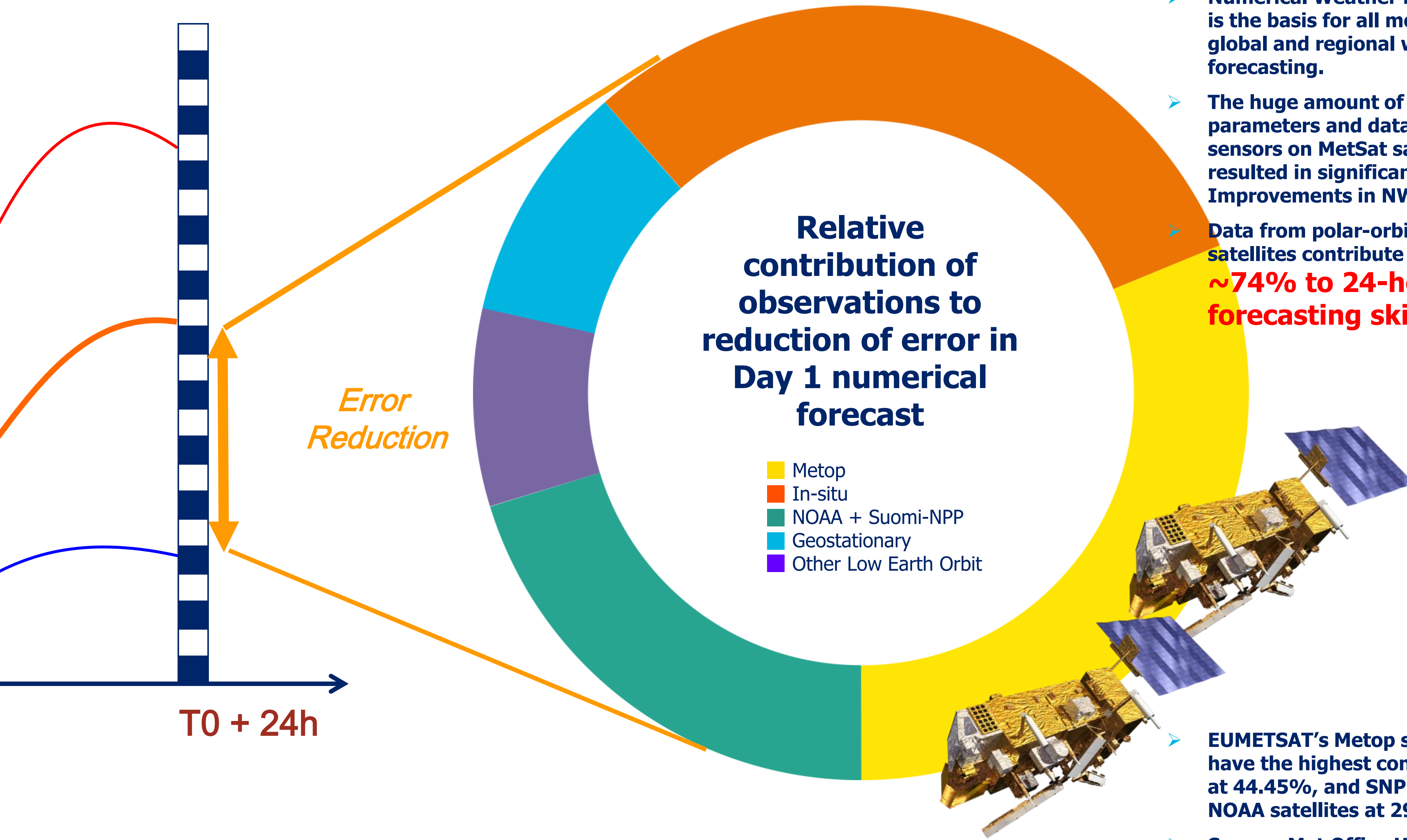


...Climate policy and environment protection

Impact of NGSO MetSat data on day-1 forecast (1)



Impact of NGSO MetSat data on day-1 forecast (2)

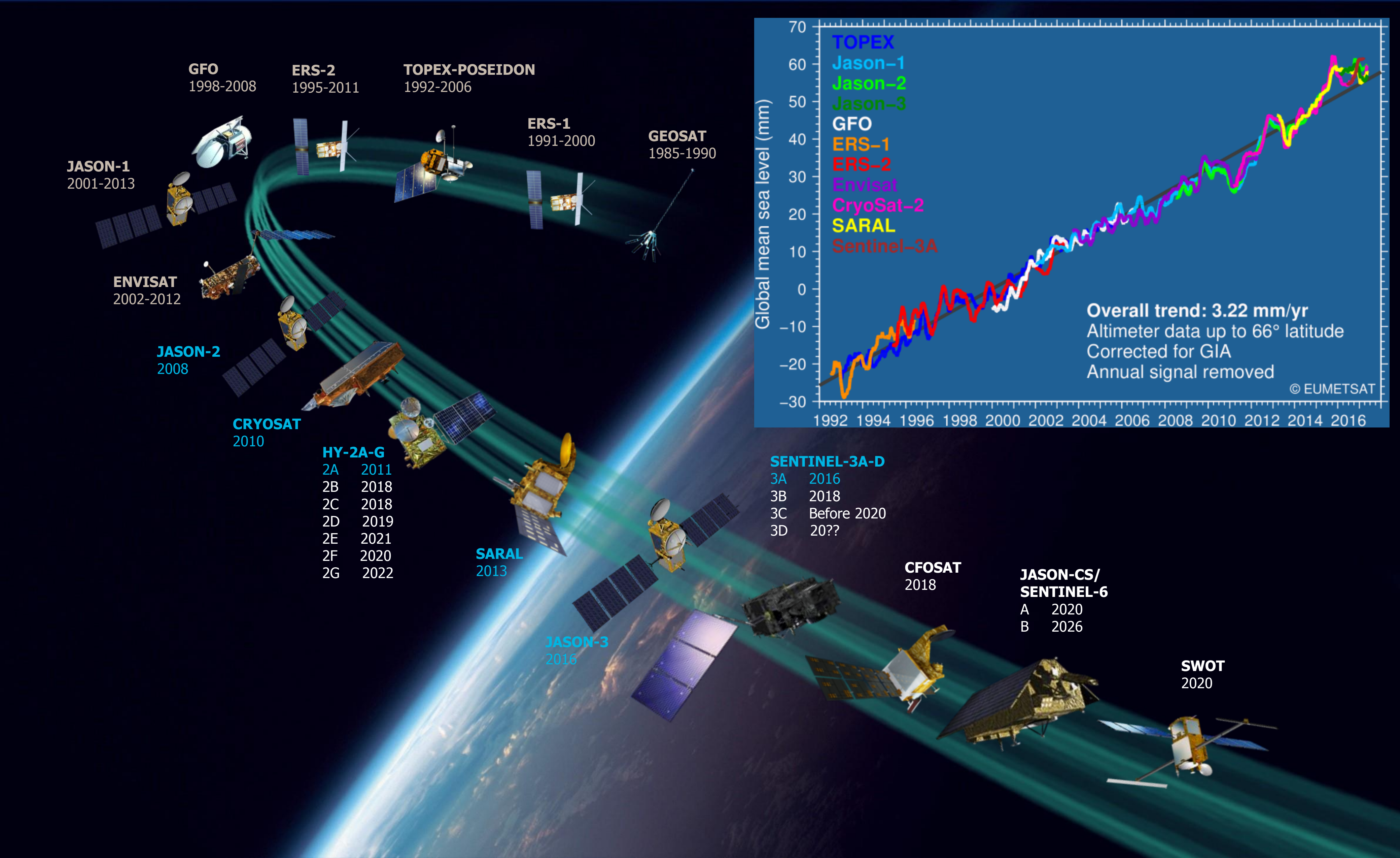


- **Numerical Weather Prediction is the basis for all modern global and regional weather forecasting.**
- **The huge amount of parameters and data from sensors on MetSat satellites resulted in significant Improvements in NWP.**
- **Data from polar-orbiting satellites contribute ~74% to 24-hour forecasting skill.**
- **EUMETSAT's Metop satellites have the highest contribution at 44.45%, and SNPP and NOAA satellites at 29.36%.**
- **Source: Met Office UK**

Data Archiving (example: EUMETSAT)

- Archive dating back to 1981
- 2.0 Petabytes stored
- 1.5 Petabytes retrieved annually
- Contains raw, processed and reprocessed data of EUMETSAT missions
- Transparent data discovery through a central catalogue of data and products (Product Navigator) across the data produced centrally at EUMETSAT HQ
- Access online via archive.eumetsat.int
- 2018: 1,900 users (+35%), 650 TB (+ 25%) delivered (one file every 2s)
- **Visualisation of 30 years worth of Data: http://pics.eumetsat.int/**

Altimetry - Example for the need of data records and continuity



Development and trends for next generation of MetSat satellite systems

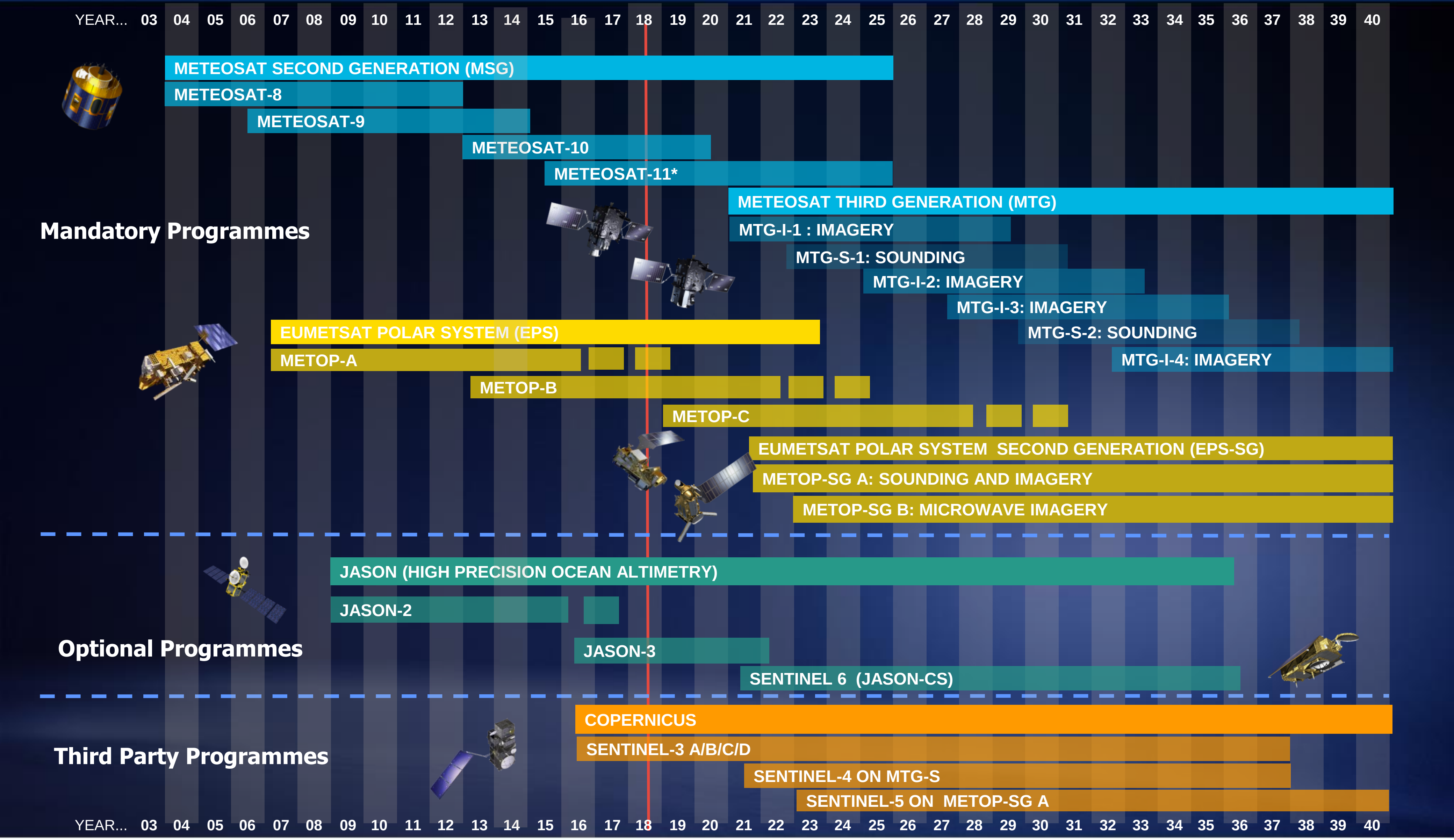
- Each operating agency of MetSat satellite systems has their next generation satellite systems under development to complement and finally gradually replace the existing satellites.
- Data continuity is ensured on instrument level, by providing successor instruments.
- Additional new instrument types cover the user requested additional/new observations of weather and climate variables (e.g. microwave sensing from GSO, lightning imager from GSO, ice cloud measurements from NGSO, exploiting frequency bands above 275 GHz).
- New instruments observe with increased measurement resolutions, higher instrument sensitivity, higher repetition rates, increased number of observation channel.
- Consequence from the evolution of the measurements is a significantly increased data volume which requires the use of higher frequency bands to handle the data volumes.
- The data volume to be downlinked and distributed to the users from the new generation of MetSat/EESS satellites that are currently deployed will (have to) use X-Band (7450-7550 MHz, 7750-7900 MHz, 8025-8400 MHz) and/or Ka-Band 25.5-27 GHz).
- EU Copernicus programme with the fleet of Sentinels underline the essential importance of satellite measurements for society.

Example for instrument heritage and evolution in next generation MetSat systems

Metop-SG A Optical Imagery and Sounding	Instrument	Predecessor on Metop
Infrared Atmospheric Sounding (IAS)	IASI-NG	IASI
Microwave Sounding (MWS)	MWS	AMSU-A, MHS
Visible-infrared Imaging (VII)	METimage	AVHRR
Radio Occultation (RO)	RO	GRAS
UV/VIS/NIR/SWIR Sounding (UVNS)	Sentinel-5	GOME-2
Multi-viewing, -channel, -polarisation Imaging (3MI)	3MI	-/-

Metop-SG B Microwave Imaging	Instrument	Predecessor on Metop
Scatterometer (SCA)	SCA	ASCAT
Radio Occultation (RO)	RO	GRAS
Microwave Imaging for Precipitation (MWI)	MWI	-/-
Ice Cloud Imager (ICI)	ICI	-/-
Advanced Data Collection System (ADCS)	Argos-4	A-DCS

Continuity: EUMETSAT satellite systems (timeline till 2040)



A little bit of history ! (1)

First weather satellite launched from Cape Canaveral, FL

- Satellite Weight: 122 kg
- Payload: Two TV cameras, two video recorders, and the power, communications, and other systems needed

First view of cloud formations as they developed and moved across the continent

A little bit of history ! (2)

- With the launch of the first Meteosat satellite on 23 November 1977, Europe gained the ability to gather weather data over its own territory with its own satellite.
- Meteosat began as a research programme for a single satellite by the European Space Research Organisation, a predecessor of the European Space Agency (ESA).
- Once the satellite was in orbit, the immense value of the images and data it provided led to the move from a research to an operational mission requiring a dedicated organisation to conduct it.
- In anticipation of the founding of EUMETSAT, ESA launched the Meteosat Operational Programme (MOP) in March 1983.