General/Common operational concepts of Meteorological Satellite Service (MetSat) and Earth Exploration Satellite Service (EESS) Systems

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Introduction: EESS & MetSat (1/2)

- Earth exploration-satellite service (EESS) systems are used to gather data about the Earth and its natural phenomena. These satellites use active and/or passive sensors onboard the spacecraft to obtain data on the Earth's land, sea, and atmosphere for the purpose of studying and monitoring the Earth's climate and environment, amongst many other related scientific applications.
  - Earth exploration-satellites used for weather-related purposes are known as meteorological-satellites (MetSats).
  - Active sensors are radar-like measuring instruments in the Earth exploration-satellite service (EESS (active)) which obtain information by transmitting radio waves and then receiving their reflected energy.
  - Passive sensors are very sensitive receivers in the Earth exploration-satellite service (EESS (passive)) which measure the electromagnetic energy emitted, absorbed or scattered by the Earth's surface or atmosphere. In practice, they are instruments which measure the natural noise floor at discrete resonance frequencies described by the laws of physics.
- In addition to the data collected by satellites, data may also be collected from airborne or ground-based platforms to supplement and calibrate the satellite data. All of this collected data must also be transmitted to Earth stations or to other platforms for additional processing and distribution.

Introduction: EESS & MetSat (2/2)

- The data from EESS and MetSat satellites enable a diverse set of scientific applications which provide countless societal benefits including those related to disaster management to all humans. As a rule, the scientific data and the associated data products are shared with all nations, regardless of which nation built, launched, or operates the satellite.
  - There are, however, a growing number of commercial remote sensing missions which sell their data; however, during a disaster situation, they share their data with disaster response agencies.
- It should be noted that while "Earth exploration-satellites" is the terminology used in the ITU, in the open literature it is often referred to such satellites as "remote sensing satellites" or "Earth observation satellites". These terms are used interchangeably when discussing such Earth science applications.
- The study of natural systems, including biology, geology, hydrology, meteorology, oceanography and climate change, benefit greatly from the truly global observing capability unique to EESS and MetSat satellites and the ability of such systems to repeat consistent observations over a long period of time.
- Many aspects of our societal life benefit from such Earth observations include, among many others, agriculture, planning and optimizing transportation systems, exploring for energy sources and other natural resources, mapping the Earth (cartography), planning and implementing communications systems, archaeology (human history), health (human condition), and population and urban studies (human distribution).

Definition of EESS & MetSat in the Radio Regulations

1.51 Earth exploration-satellite service: A radiocommunication service between earth stations and one or more space stations, which may include links between space stations, in which:

- information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active sensors or passive sensors on Earth satellites;
- similar information is collected from airborne or Earth-based platforms;
- such information may be distributed to earth stations within the system concerned;
- platform interrogation may be included.
- This service may also include feeder links necessary for its operation.

1.52 Meteorological-satellite service: An earth exploration-satellite service for meteorological purposes.

EESS and MetSats for weather and climate

- **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.

EESS & MetSat Radiocommunication Architecture

From RECOMMENDATION ITU-R SA.1020-0 (from 03/94):

recommends:

3.1 data collection: the process of retrieving data from a data collection platform (A → B);

3.2 data dissemination: the transmission of data from a central data processing facility to earth stations at remote sites (B → D);

3.3 data collection platform interrogation: the transmission of commands evoking a data collection platform to transmit data (may also include commands to change platform operating mode) (B → A);

3.4 passive sensing: measurement of natural emissions from the Earth or its atmosphere (B → C);

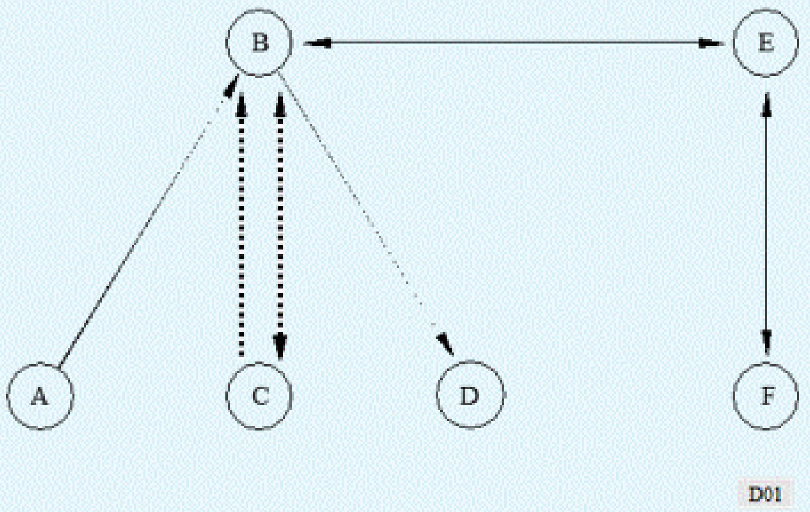
3.5 active sensing: reception of signals that have been transmitted and reflected, refracted or scattered by media under observation (B → C);

3.6 direct data readout: reception of data that is generated by instruments on the spacecraft and transmitted as it is collected (real-time transmission) (B → D);

3.7 recorded data acquisition: reception of data that has been collected and stored on the spacecraft and transmitted upon command (B → D) (B → E → F).

FIGURE 1

Hypothetical reference system



A: transmitting earth station (data collection, data dissemination, data collection platform interrogation, tracking or command)

B: satellite, including any active and passive sensors, transponders and data handling or processing sub-systems

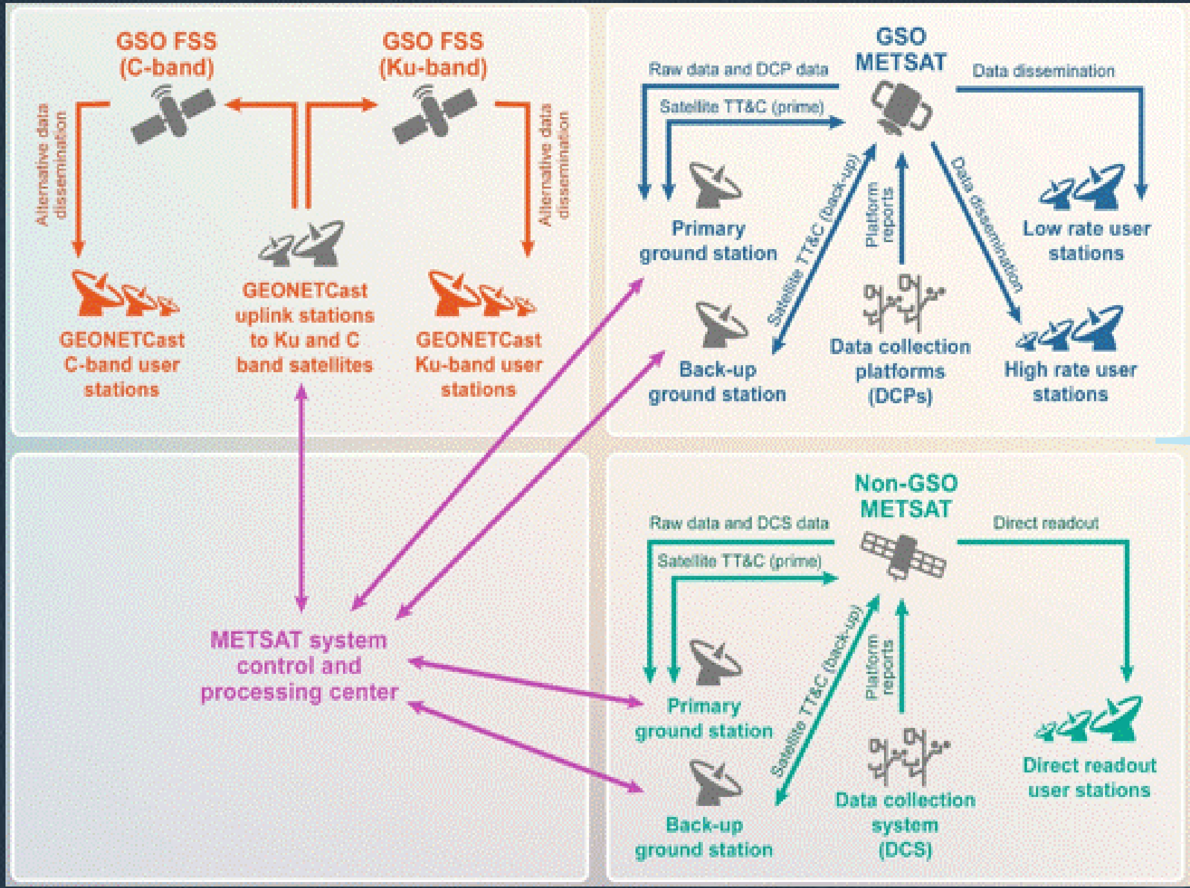
C: media being remotely observed

D: receiving earth station (interrogation received by a data collection platform, data collection, data dissemination, direct data readout, recorded data acquisition or tracking)

E: data relay satellite

F: earth station serving data relay satellite

General radiocommunication architecture of MetSat systems



- 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;
- active and passive microwave sensing;
- relay of Search and Rescue messages (COSPAS-SARSAT);
- orbit determination and radio occultation systems by exploitation of GPS signals.

Frequency allocations to SOS, EESS & MetSat in the RR

Space operation service	Earth Exploration-satellite service (not including active and passive sensor EESS allocations)	Meteorological-satellite service
137-138 MHz (s-E) (P)		137-138 MHz (s-E) (P)
400.15-401 MHz (s-E) (s)		400.15-401 MHz (s-E) (P)
401-402 MHz (s-E) (P)	401-402 MHz (E-s) (P)	401-402 MHz (E-s) (P)
	402-403 MHz (E-s) (P)	402-403 MHz (E-s) (P)
	460-470 MHz (s-E) (may be used under FN 5.289)	460-470 MHz (s-E) (s)
1525-1535 MHz (s-E) (P)	1525-1535 MHz (s)	
	1690-1710 MHz (s-E) (may be used under FN 5.289)	1675-1710 MHz (s-E) (P)
2025-2110 MHz (E-s) (s-s) (P)	2025-2110 MHz (E-s) (s-s) (P)	
2200-2290 MHz (s-E) (s-s) (P)	2200-2290 MHz (s-E) (s-s) (P)	
7125-7155 MHz (E-s)	7190-7250 MHz (E-s) (P)	
7190-7235 MHz (E-s)		7450-7550 MHz (s-E) (GSO) (P)
		7750-7900 MHz (s-E) (NGSO) (P)
	8025-8400 MHz (s-E) (P)	8175-8215 MHz (E-s) (P)
	13.75-14 GHz (s)	
	18-18.3 GHz (R2) / 18.1-18.4 GHz (R1&3) (s-E) (P)	
	25.5-27 GHz (s-E) (P)	
	28.5-30 GHz (E-s) (s)	
	37.5-40 GHz (s-E) (s)	
	40-40.5 GHz (E-s) (P) & (s-E) (s)	
	65-66 GHz (P)	

Summary table of allocations to SOS, EESS, MetSat and SRS vs. WRC-27 AIs

Space operation service		Earth Exploration-satellite service		MetSat service		Space research service	
Frequency band	WRC-27 AI	Frequency band	WRC-27 AI	Frequency band	WRC-27 AI	Frequency band	WRC-27 AI
		1690-1710 MHz (s-E) (5.289)		1675-1710 MHz (s-E)	1.11, 1.13		
2025-2110 MHz (E-s) (s-s)	1.12, 1.13, 1.14	2025-2110 MHz (E-s) (s-s)	1.12, 1.13, 1.14			2025-2110 MHz (E-s) (s-s)	1.12, 1.13, 1.14
						2110-2120 MHz (E-s) (deep space)	1.13, 1.14
2200-2290 MHz (s-E) (s-s)	1.13	2200-2290 MHz (s-E) (s-s)	1.13			2200-2290 MHz (s-E) (s-s)	1.13
						2290-2300 MHz (s-E) (deep space)	1.13
7125-7155 MHz (E-s)	1.7					7145-7190 MHz (deep space)	1.7
7190-7235 MHz (E-s)	1.7	7190-7250 MHz (E-s)	1.7			7190-7235 MHz both (E-s) (P)	1.7, 1.15
				7450-7550 MHz (s-E) (GSO)	1.7		
				7750-7900 MHz (s-E) (NGSO)	1.7		
		8025-8400 MHz (s-E)	1.7	8175-8215 MHz (E-s)	1.7		
						8400-8500 MHz (s-E)	1.7, 1.15

The mission of a MetSat system is…

- ...to deliver operational satellite data and products that satisfy the meteorological and climate data requirements of its user community (= all of us!) - 24 hours a day, 365 days a year, over decades.

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

Observing weather & climate from space – a global undertaking! (1/2)

- The development and operation of meteorological and environmental satellite systems and their instruments is usually based on public investments.

- In turn, the data from the instruments (to a significant extent from active and passive microwave sensors) go back (non-profit) to the benefit of society and are used to develop products for the global public, ranging from daily weather forecasts to environmental monitoring and warnings, coverage of disasters, and long-term studies of the Earth's climate.

- The global weather community is the heaviest user of passive microwave data.

- Computer weather models use passive sensor data and data from other sources to create Numerical Weather Prediction (NWP) products. These forecasts cover different sized geographic areas from the whole globe down to small areas.

Observing weather & climate from space – a global undertaking! (2/2)

- There is a global network of GSO and NGSO MetSat satellites in order to ensure global weather and climate monitoring at any time.

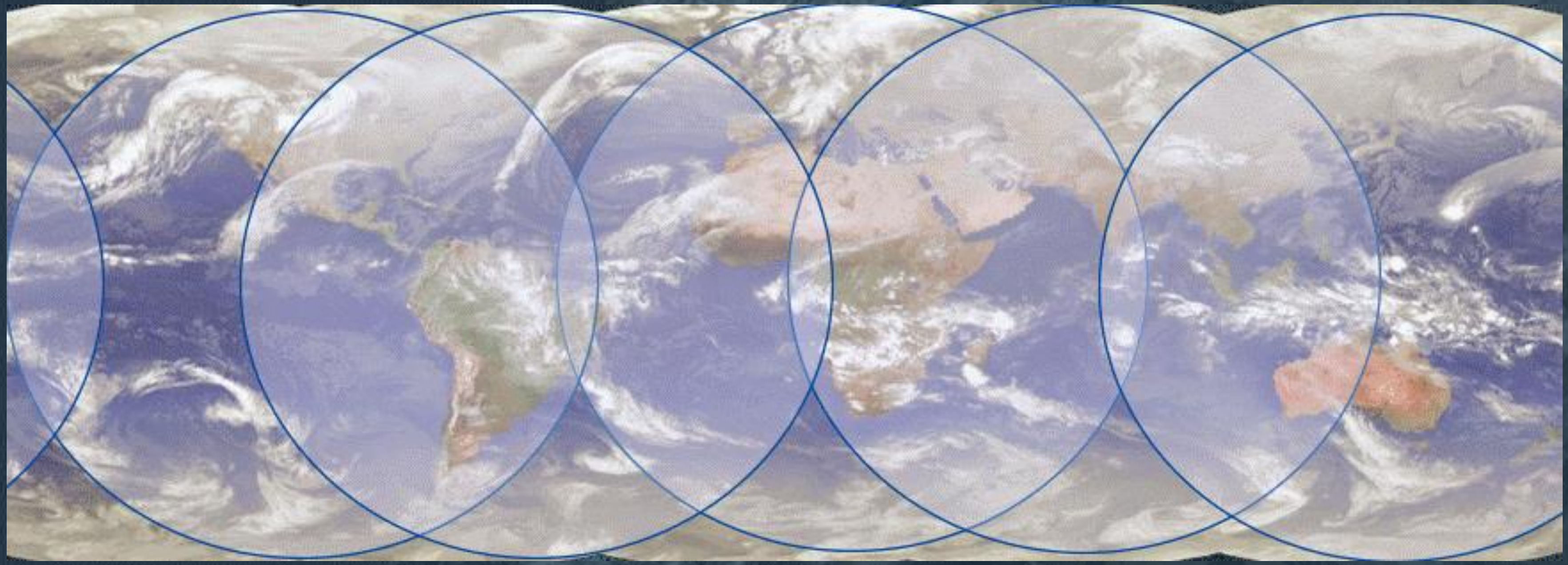
- Operational continuity in the space-based meteorological observations is ensured by replacing existing series of MetSat satellites with new or next generation MetSats.

- 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.

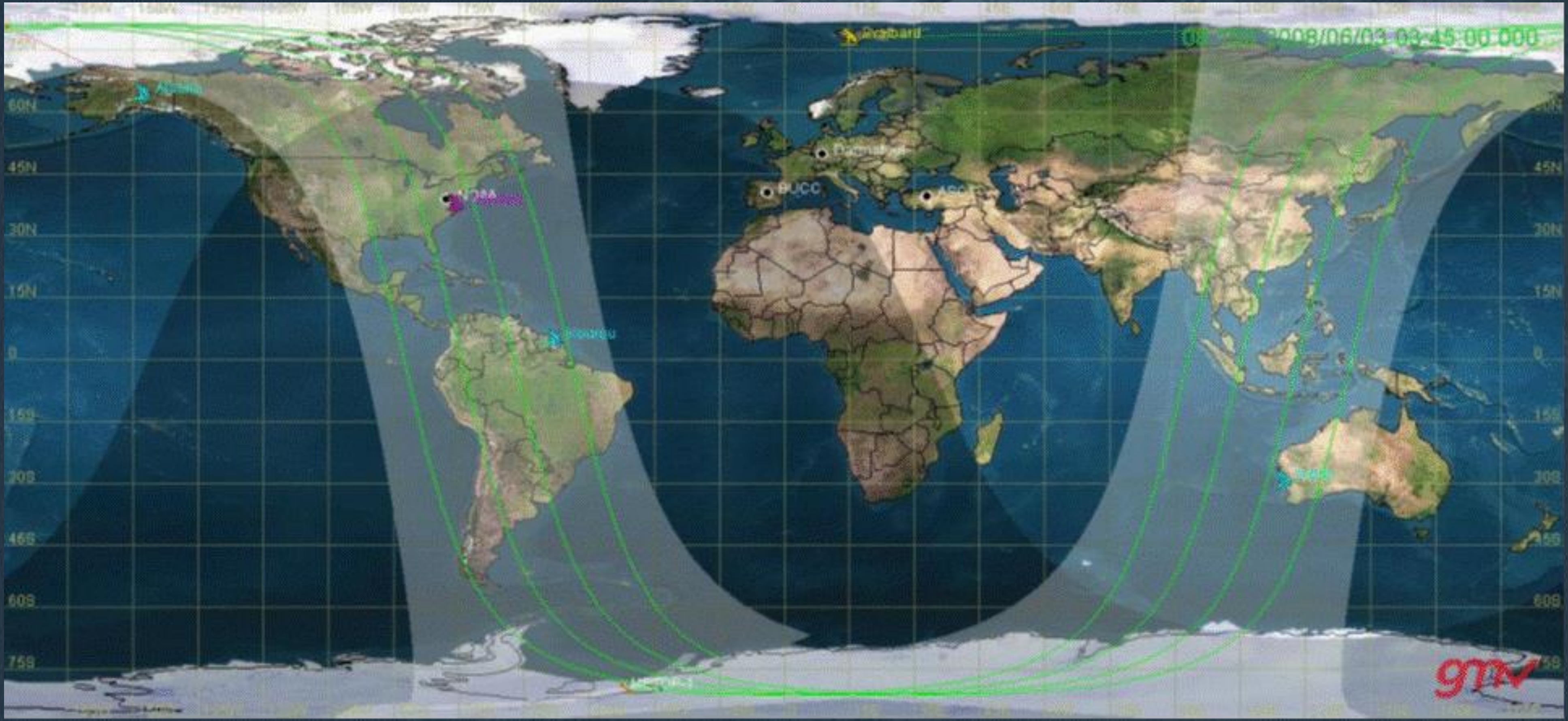
Global coverage with GSO MetSat through international cooperation

- Geostationary MetSat 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.



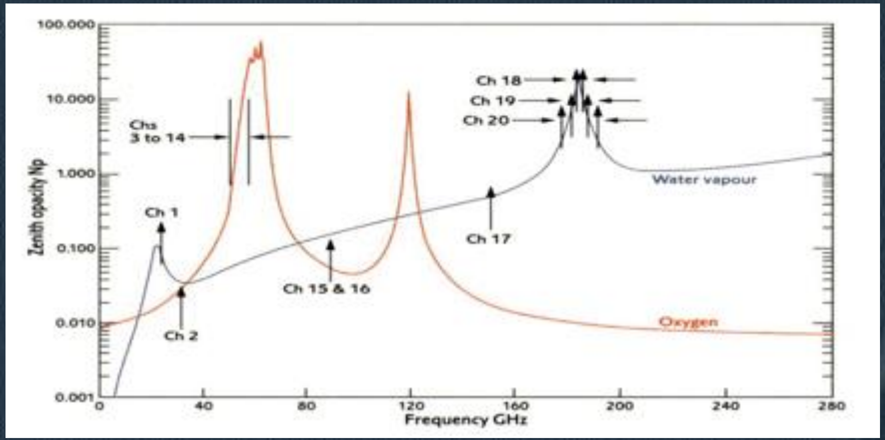
Global coverage by non-geostationary MetSat satellites

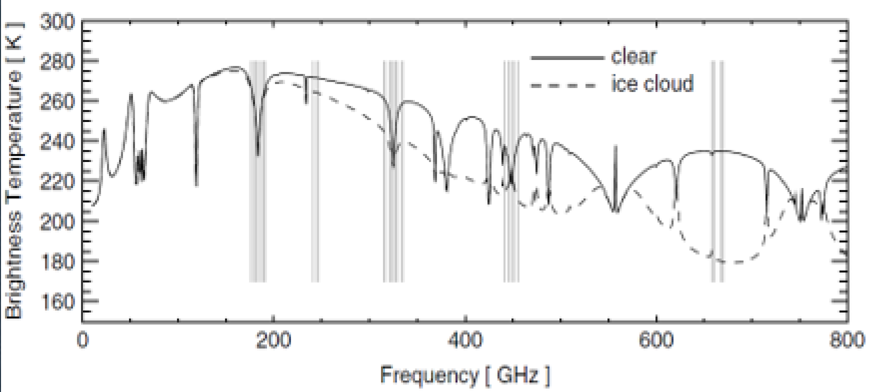
- Non-geostationary polar orbiting MetSat satellites (example Metop: Orbit height 830 km, 14 orbits/day, measurements twice over the same are at a swath width of ~2000 km)
  - Primary source of global climate observations and forecasts up to 10 days



Passive Microwave Sensing (EESS (passive)) (1/2)

- Frequency bands used for passive microwave sensing (Radio Regulations: EESS (passive)) are determined by the fundamental properties of the Earth and its atmosphere.

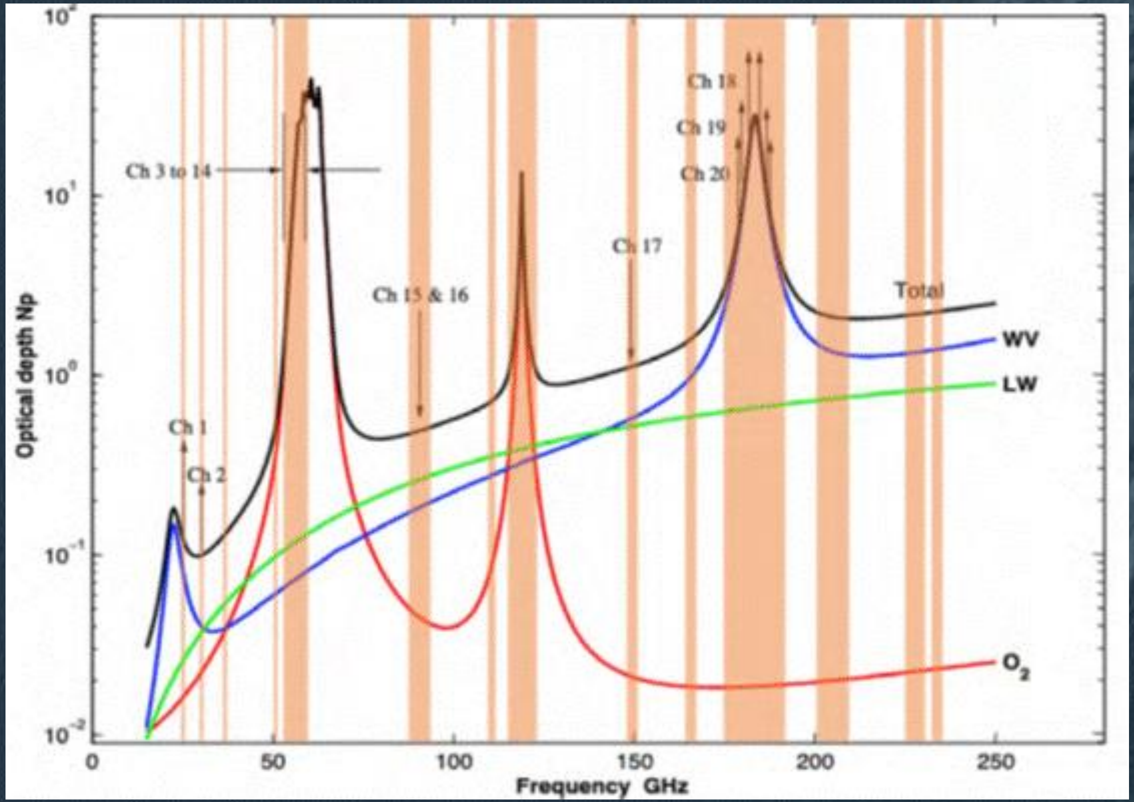




- Absorption peaks are fixed by molecular physics and are indispensable natural resources for passive sensing.
- No amount of engineering and/or funding can change these properties that are given by nature !!!.
- In the RR, due regard is given to this fact by footnote 5.340 ("…all emissions are prohibited.") and specific limitations to active services in Resolution 750.

Passive Microwave Sensing (EESS (passive)) (2/2)

- Passive sensors can determine vertical variation and horizontal distribution of temperature and water vapour in the atmosphere, which are two key atmospheric variables. Together with several other physical parameters (e.g. ice, liquid water, and sea state) they determine the condition of the planet.



- There are bands where absorption caused by different atmospheric gases is much higher, for example oxygen close to 60 GHz and 118 GHz and water vapour at 24 GHz and 183 GHz.
- Information for cloud and precipitation comes mostly from window channels.
- Analysis of an observation in a single window channel band, e.g. 89 GHz is not able to disentangle the contribution of different hydrometeor types.
- Therefore, complementary observations across multiple window channels are required.

What is measured in the different passive bands? (1/3)

- **Below 10 GHz,** the atmosphere is almost completely transparent, even in the presence of clouds. This allows sensors operating below 10 GHz to directly sense the planet's surface. For example, soil moisture and ocean salinity is measured at 1.4 GHz and sea surface temperature at 6/7 GHz.

- **At 10 GHz,** clouds and water vapour remain largely transparent, but heavy rain does attenuate, providing unique information about rainfall (other techniques are indirect).

- **At 18 GHz,** the dielectric properties of seawater are such that energy collected by the passive sensors becomes almost independent of the sea surface temperature, but the wind induced ripples and waves change the emissivity, so wind information can be determined.

- **Around 24 GHz,** there is a weak water absorption line and by measuring this line, the total column water vapour can be determined. The 24 GHz band is strongly sensitive to total column water vapour and weakly sensitive to cloud liquid water.

- **At 31 GHz,** liquid water attenuation provides liquid water content of clouds.
    - Although 24 GHz is referred to as a water vapour channel and 31 GHz as a cloud channel, in reality the loss of data from one channel also diminishes the value of both.

- Oxygen absorbs energy **between 50 and 60 GHz** in several individual narrow bands (lines). Passive sensors operating in these bands provide temperature vertical profile information, showing how temperature changes at different atmospheric heights (vertical temperature profile). A large number of channels is needed across this oxygen absorption spectral line complex to provide vertical profile information.

What is measured in the different passive bands? (2/3)

- There is also an important 118 GHz oxygen absorption line. The short wavelength allows for narrow sensor fields of view to detect small scale features of extreme weather events such as hurricanes/typhoons.

- At 183 GHz is the most important water vapour spectral line. This line is sampled progressively further from the centre frequency to gain profile information. The effects of clouds are even stronger at 183 GHz than at 50 GHz so additional channels are needed to provide cloud information, in particular at 89 GHz, 150/165 GHz and 229 GHz.

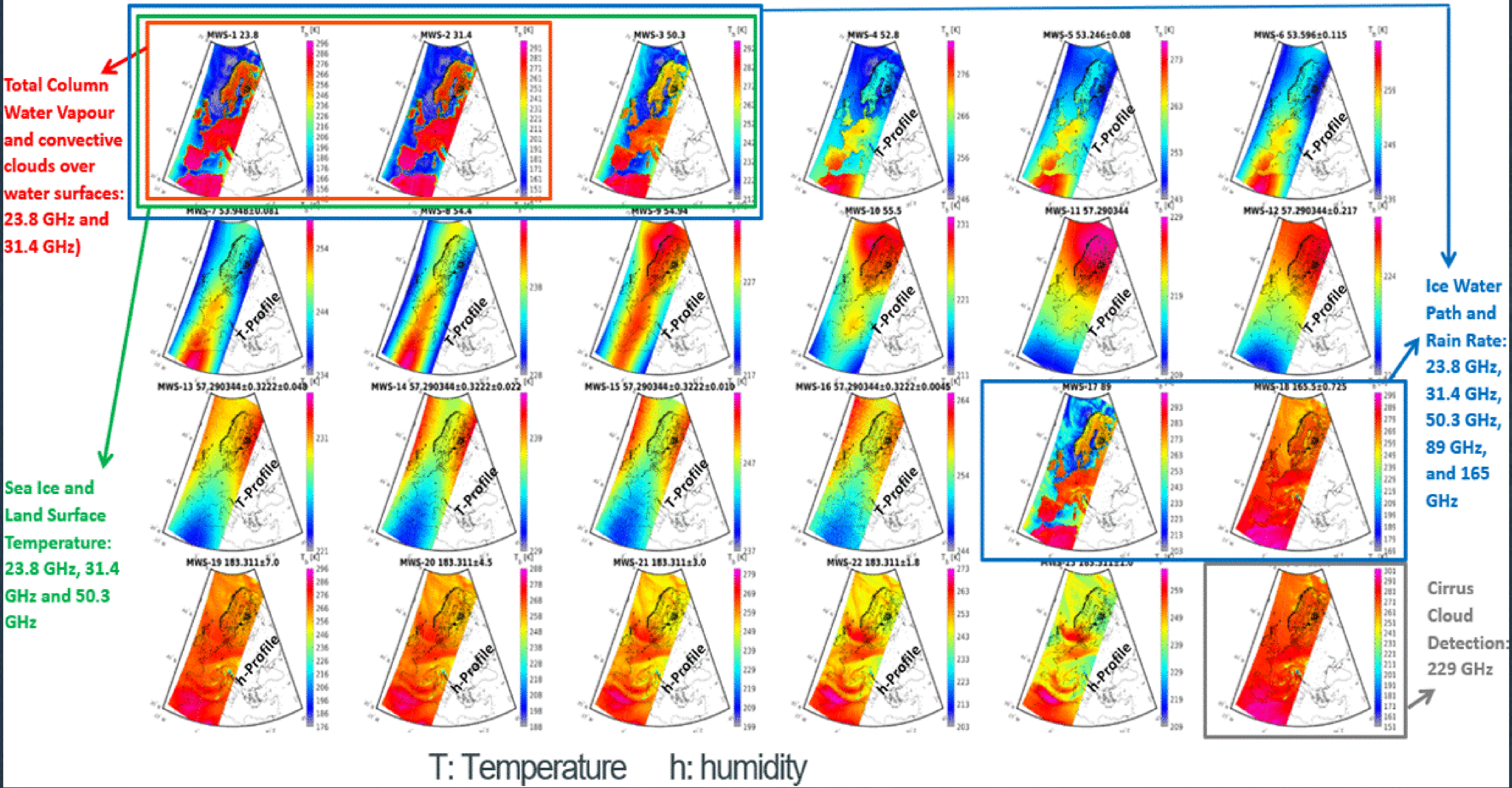
- For determining cloud-ice content, measurements in a set of frequency channels are needed, i.e. 183 GHz, 243 GHz, 325 GHz, 448 GHz and 664 GHz to retrieve all relevant atmospheric parameters.

Frequencies relevant for measurement of the long term trends in the atmosphere	
Frequency Bands (GHz)	**Main use**
10.65, 18.7, 23.8, 31.4, 36.5, 89, 118, 150, 166, 183	Precipitation
23.8	Humidity
50-59	Temperature
89/157	Low level humidity
118	Temperature
183	Humidity
204, 229, 243, 325, 448, 664	Ice cloud

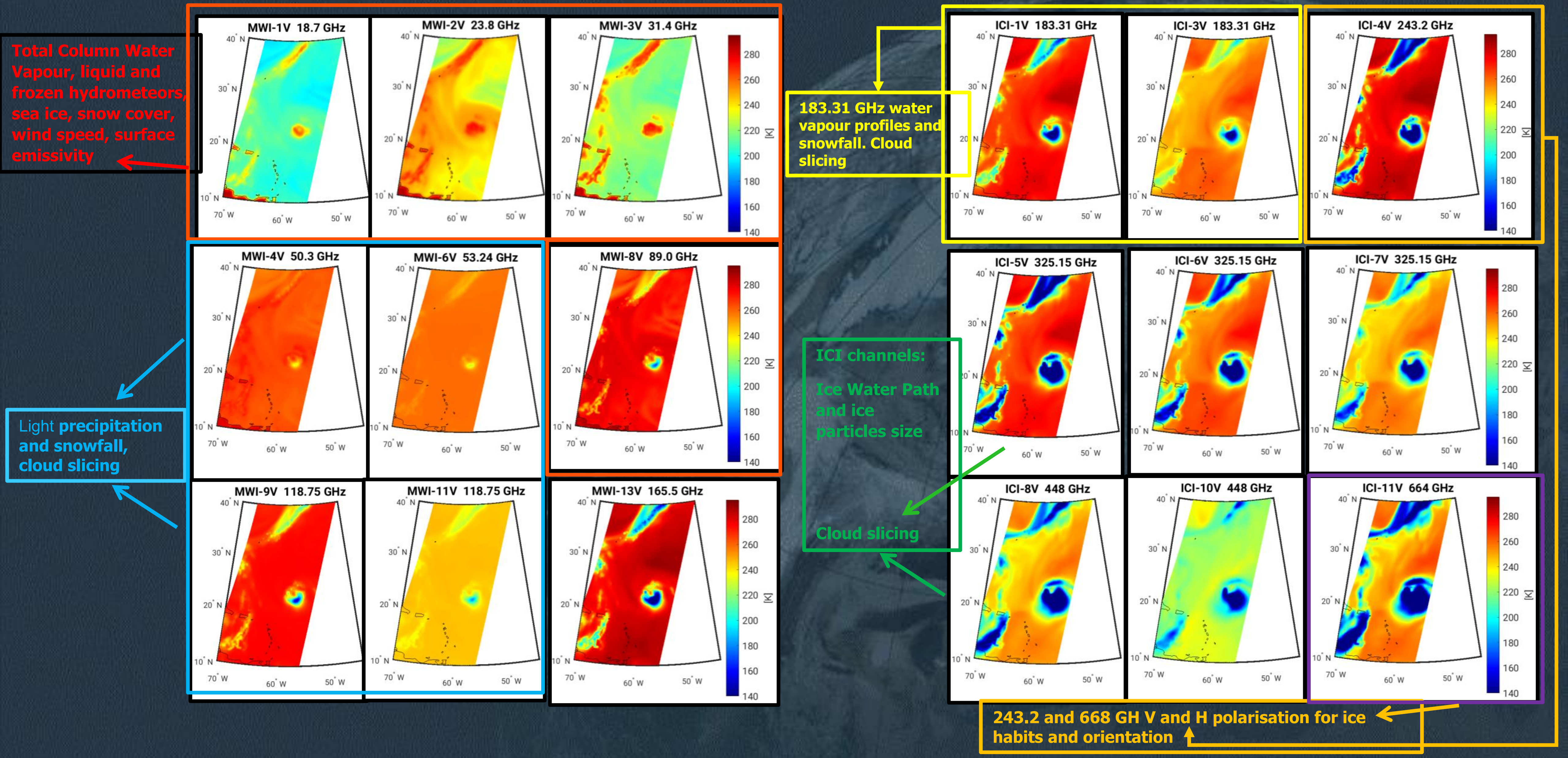
What is measured in the different passive bands? (3/3)

Bands being actively used or prepared for by NWP centres (Slide from ECMWF presentation)		
Frequency (GHz)	*Instruments*	*Application area*
1.4-1.427	SMOS (ESA), SMAP (NASA), Aquarius (NASA) , CIMR (ESA)	Soil moisture, salinity, thin sea ice
6.425-7.25	AMSR-2 (JAXA) , CIMR (ESA)	Sea surface Temperature (SST)
10.6-10.68, 10.68-10.7	AMSR-2 (JAXA), GMI (NASA), MWRI (CMA) , CIMR (ESA)	Heavy Precipitation
18.6-18.8	AMSR-2 (JAXA), GMI (NASA), AMR (NOAA), MWRI (CMA) , CIMR (ESA) , MWI (EUMETSAT)	Ocean near surface wind,
23.6-24	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), SSMIS (DOD), GMI (NASA), AMR (NOAA), MTVZA-GY (Roscosmos), MWRI (CMA), MWS (EUMETSAT), MWI (EUMETSAT), AMSR-2 (JAXA)	Total column water vapour
31.3-31.5, 31.5-31.8	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), GMI (NASA), MTVZA-GY (Roscosmos), MWS (EUMETSAT, MWI (EUMETSAT)	Total column cloud liquid
36-37	SSMIS (DOD), GMI (NASA), AMSR-2 (JAXA), MWRI (CMA), CIMR (ESA)	Liquid water path and cloud detection
50.2-50.4, 52.6-54.25, 54.25-59.3, 59.3-59.5, 60.40- 61.15, 63-63.5	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), SSMIS (DOD), MWTS-2 (CMA), MTVZA-GY (Roscosmos), MWS (EUMETSAT)	Temperature profile
86-92	AMSU-A (NOAA/EUMETSAT), ATMS (NOAA), SSMIS (DOD), MWHS-2 (CMA), MTVZA-GY (Roscosmos), MWRI (CMA), MWS (EUMETSAT), MWI (EUMETSAT), AMSR-2 (JAXA)	Precipitation
100-102, 109.5-111.8, 114.25-116, 116-122.25	MWHS-2 (CMA), TROPICS (NASA), MWI (EUMETSAT)	Temperature profile, cloud
148.5-151.5, 155.5-158.5, 164-167	ATMS (NOAA), GMI (NASA), MHS (EUMETSAT), MWHS-2 (CMA), MTVZA-GY (Roscosmos), SSMIS (DOD) , MWS (EUMETSAT), MWI (EUMETSAT)	Precipitation, water vapour
174.8-182.0, 182.0-185.0, 185.0-190.0, 190.0- 191.8	AMSU-B (NOAA), MHS (EUMETSAT), ATMS (NOAA), SSMIS (DOD), MWHS-2 (CMA), GMI (NASA), SAPHIR (CNES-ISRO), TROPICS (NASA), MTVZA-GY (Roscosmos), MWS (EUMETSAT, MWI (EUMETSAT)	Water vapour
200-209, 226-231.5, 239.2-242.2, 244.2-247.2, 313-356, 439-467, 657-692	TROPICS (NASA), MWS (EUMETSAT), ICI (EUMETSAT)	Ice cloud

Example for a passive sensor channel composition – MWS on Metop-SGA



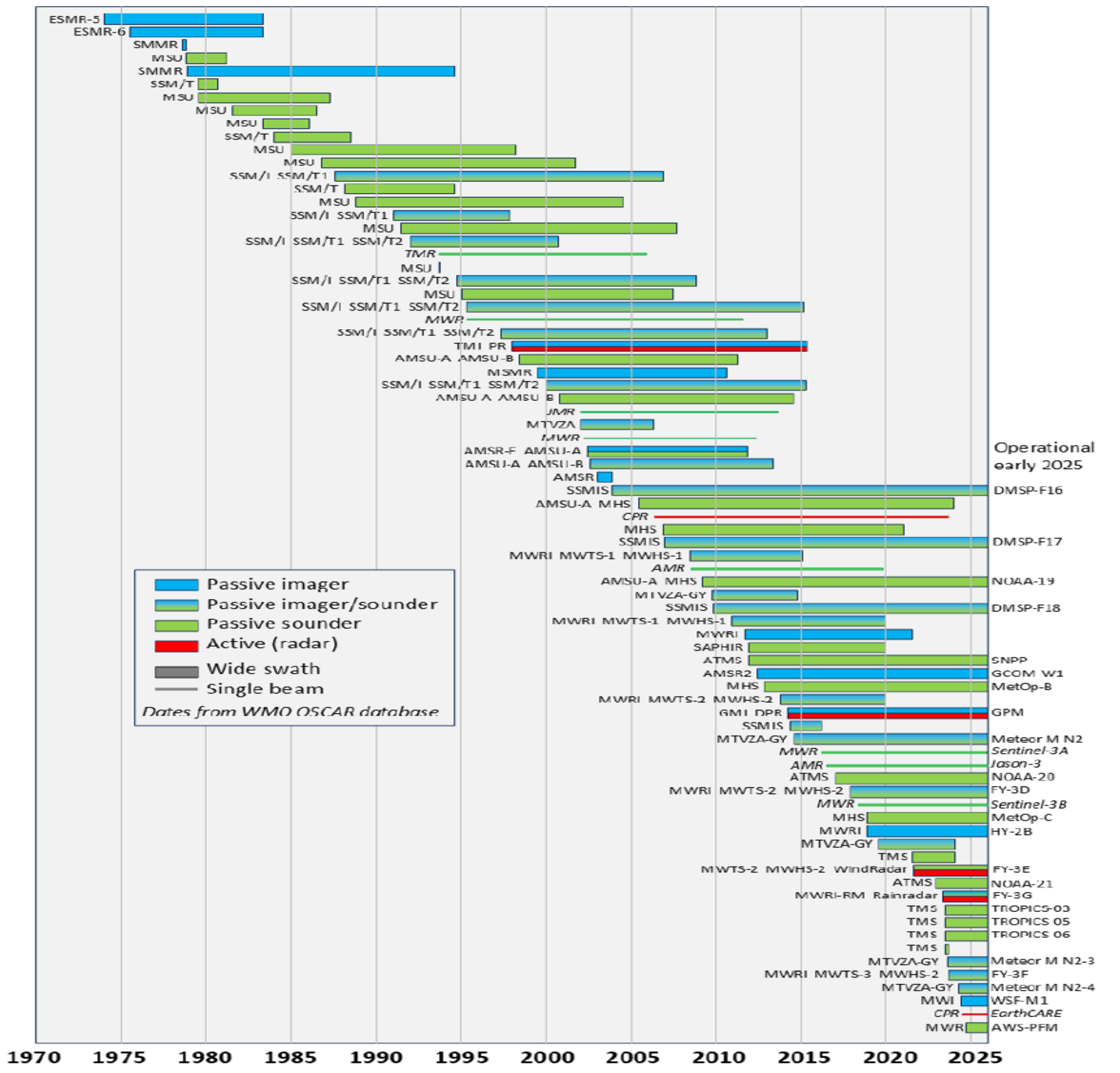
Example for a passive sensor channel composition – MWI & ICI on Metop-SGB

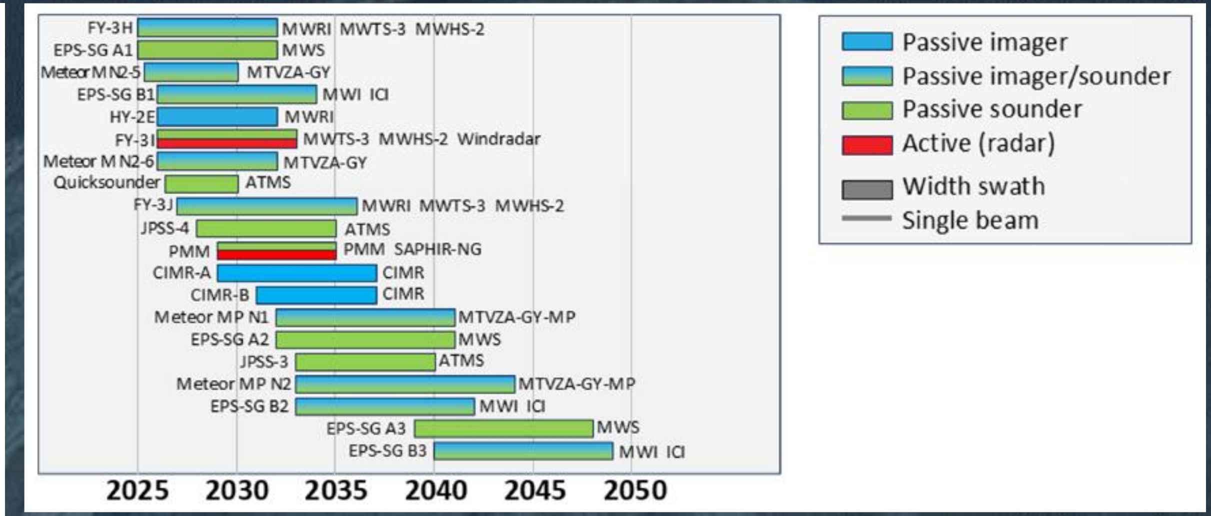


Summary table of EESS (passive) allocations & identifications vs. WRC-27/31 AIs

EESS (passive) primary allocations either RR FN. 5.340 or shared				EESS (passive) identifications above 275 GHz			
Frequency band	WRC AI	Frequency band	WRC AI	Frequency band	WRC AI	Frequency band	WRC AI
1400-1427 MHz (5.340)	1.12, 1.13	100-102 GHz (5.340)	2.6	275-286 GHz (shared 5.564A, 5.565)	1.8, 2.1	634-654 GHz (5.565)	1.8
2690-2700 MHz (5.340)		109.5-111.8 GHz (5.340)	2.6	296-306 GHz (5.565)	1.8, 2.1	657-692 GHz (5.565)	1.8
10.6-10.68 GHz (shared)		114.25-116 GHz (5.340)	1.18	313-318 GHz (5.565)	1.8, 2.1	713-718 GHz (5.565)	1.8
10.68-10.7 GHz (5.340)		116-122.25 GHz (shared)		318-333 GHz (shared 5.564A, 5.565)	1.8, 2.1	729-733 GHz (5.565)	1.8
15.35-15.4 GHz (5.340)	1.7	148.5-151.5 GHz (5.340)	2.6	313-356 GHz (5.565)	1.8, 2.1	750-754 GHz (5.565)	1.8
18.6-18.8 GHz (shared)		164-167 GHz (5.340)	1.18, 2.6	361-365 GHz (shared 5.564A, 5.565)	1.8	771-776 GHz (5.565)	1.8
21.2-21.4 GHz (shared)		174.8-182 GHz (shared)	2.6	369-392 GHz (shared 5.564A, 5.565)	1.8	823-846 GHz (5.565)	1.8
22.21-22.5 GHz (shared)		182-185 GHz (5.340)	2.6	397-399 GHz (shared 5.564A, 5.565)	1.8	850-854 GHz (5.565)	1.8
23.6-24 GHz (5.340)		185-190 GHz (shared)	2.6	409-411 GHz (shared 5.564A, 5.565)	1.8	857-862 GHz (5.565)	1.8
31.3-31.5 GHz (5.340)		190-191.8 GHz (5.340)	2.6	416-434 GHz (shared 5.564A, 5.565)	1.8	866-882 GHz (5.565)	1.8
31.5-31.8 GHz (5.340 R2) (shared R1,R3)		200-209 GHz (5.340)	1.18	439-450 GHz (shared 5.564A, 5.565)	1.8	905-928 GHz (5.565)	1.8
36-37 GHz (shared)		226-231.5 GHz (5.340)	1.8, 2.6	450-467 GHz (5.565)	1.8	951-956 GHz (5.565)	1.8
50.2-50.4 GHz (5.340)	1.1	235-238 GHz (shared)	1.8	477-502 GHz (5.565)	1.8	968-973 GHz (5.565)	1.8
52.6-54.25 GHz (5.340)	1.3	239.2-242.2 GHz (shared)	1.8	523-527 GHz (5.565)	1.8	985-990 GHz (5.565)	1.8
54.25-59.3 GHz (shared)		244.2-247.2 GHz (shared)	1.8	538-581 GHz (5.565)	1.8		
86-92 GHz (5.340)	1.18	250-252 GHz (5.340)	1.8, 2.6	611-630 GHz (5.565)	1.8		

Continuity in the measurements is key!

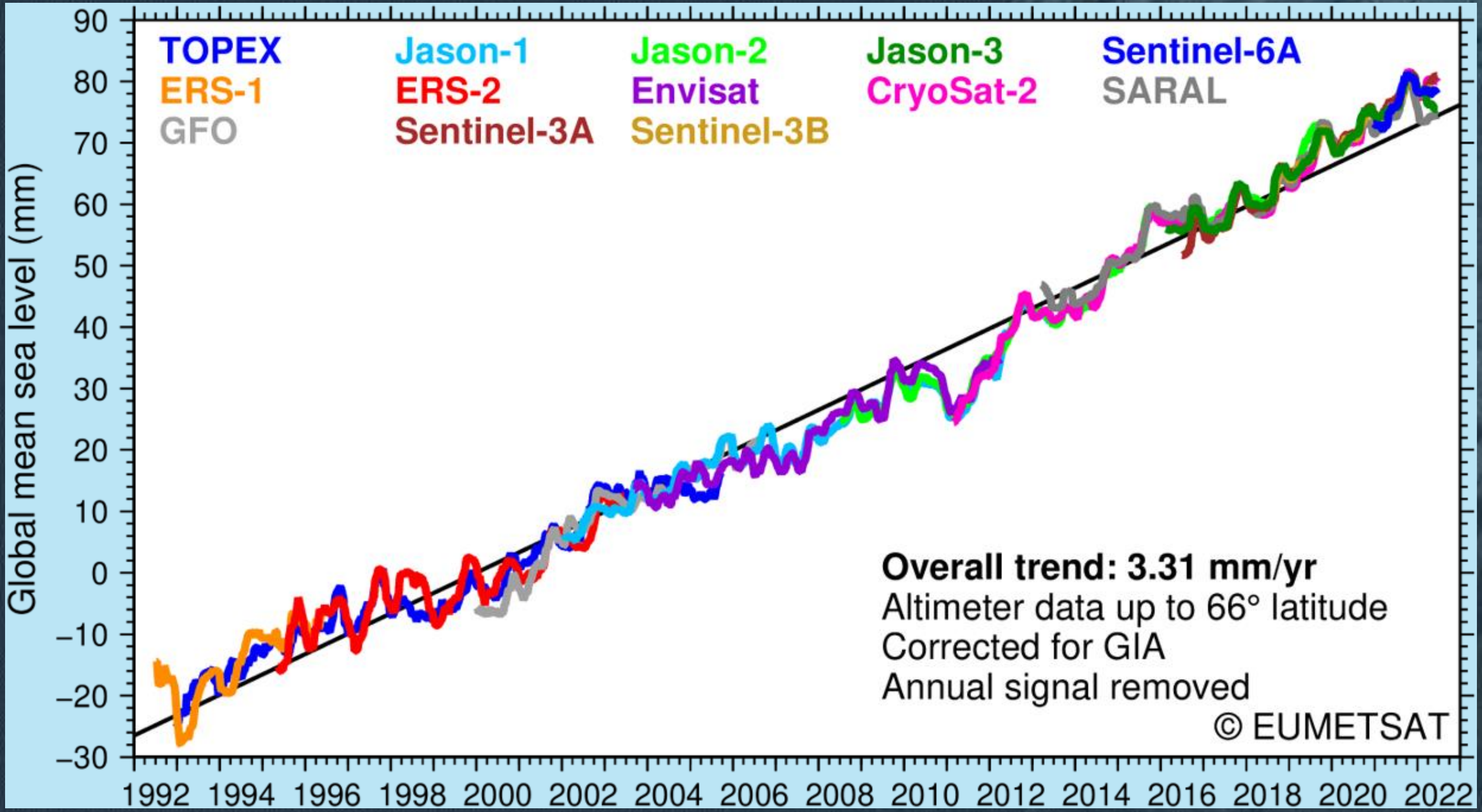




The two figures respectively show the timelines of past, current and future satellite missions carrying cross-track (sounding) and conically scanning (imaging) multi-channel microwave radiometers used for precipitation retrieval and providing analysis-ready data to the users on a global basis.

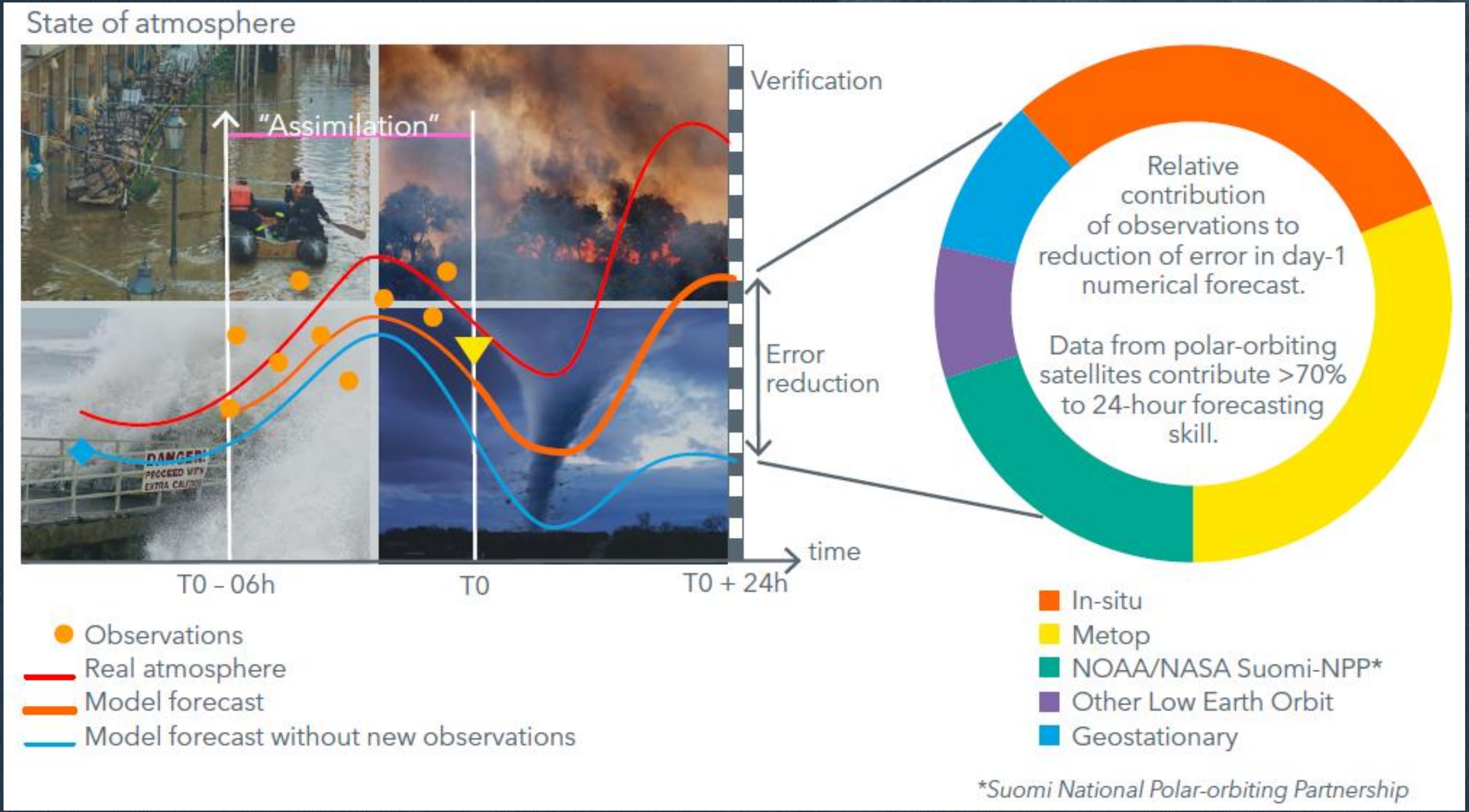
Sea level rise observed by 12 satellites over a period of 30 years

Monitoring of the oceans from space provides information about ocean currents, ocean surface winds, sea state, sea ice, sea surface temperature and ocean colour. Those data ingested into weather & ocean prediction models provide crucial information for safety at sea, operations of marine infrastructure, fisheries, sustainable use of marine resources and the protection of vital marine and coastal ecosystems.



- Mean sea level rise is a sensitive indicator of climate change.
- Thus, measuring continuously over decades the sea level rise with active and passive microwave sensors is essential.

Improvement of forecast skills due to MetSat (1/2)

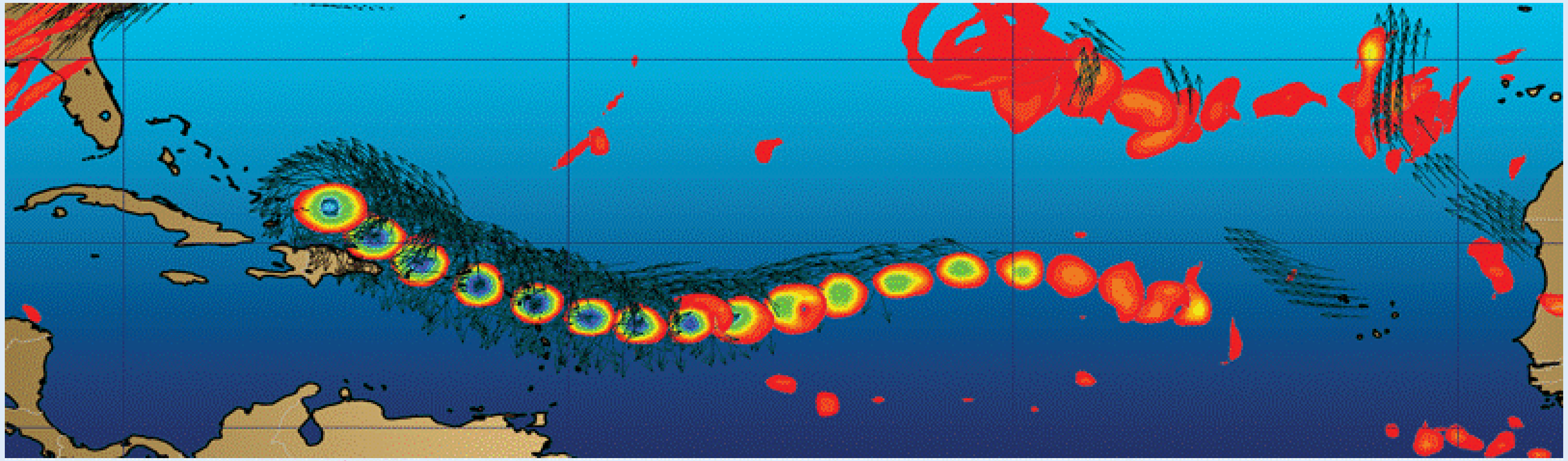


Improvement of forecast skills due to MetSat (2/2)

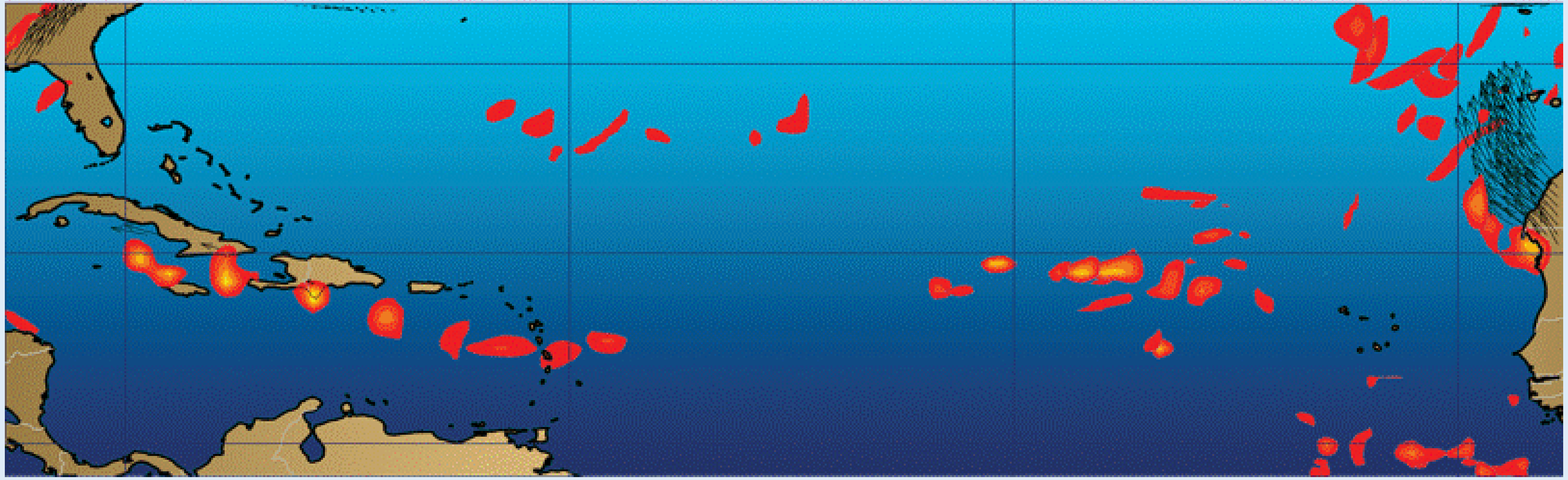
Contribution of meteorological satellites to forecasting

(Example: Initial Joint Polar System (IJPS) of NOAA and EUMETSAT polar-orbiting satellites)

The initial conditions, largely determined by satellite observations (top right, red), were essential for the ECMWF to forecast the development and trajectory of Hurricane Irma four days in advance (Source: ECMWF).



Without satellite observations the model would have missed the initial development of Irma (Source: ECMWF).



A little bit of history ! (1/2)

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 ! (2/2)

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.

Thank you very much
for your attention !!!