Future evolution of satellite observing systems

Stephen English

1. Recap on the current Satellite GOS
2. The WMO Integrated Global Observing System (WIGOS)
3. Future operational missions: EPS-SG, MTG, Sentinels
4. Future research missions: EarthCARE
5. Other: US, Asia, Other European efforts, commercial programmes

Stephen.English@ecmwf.int

ECMWF

Future evolution of satellite observing systems

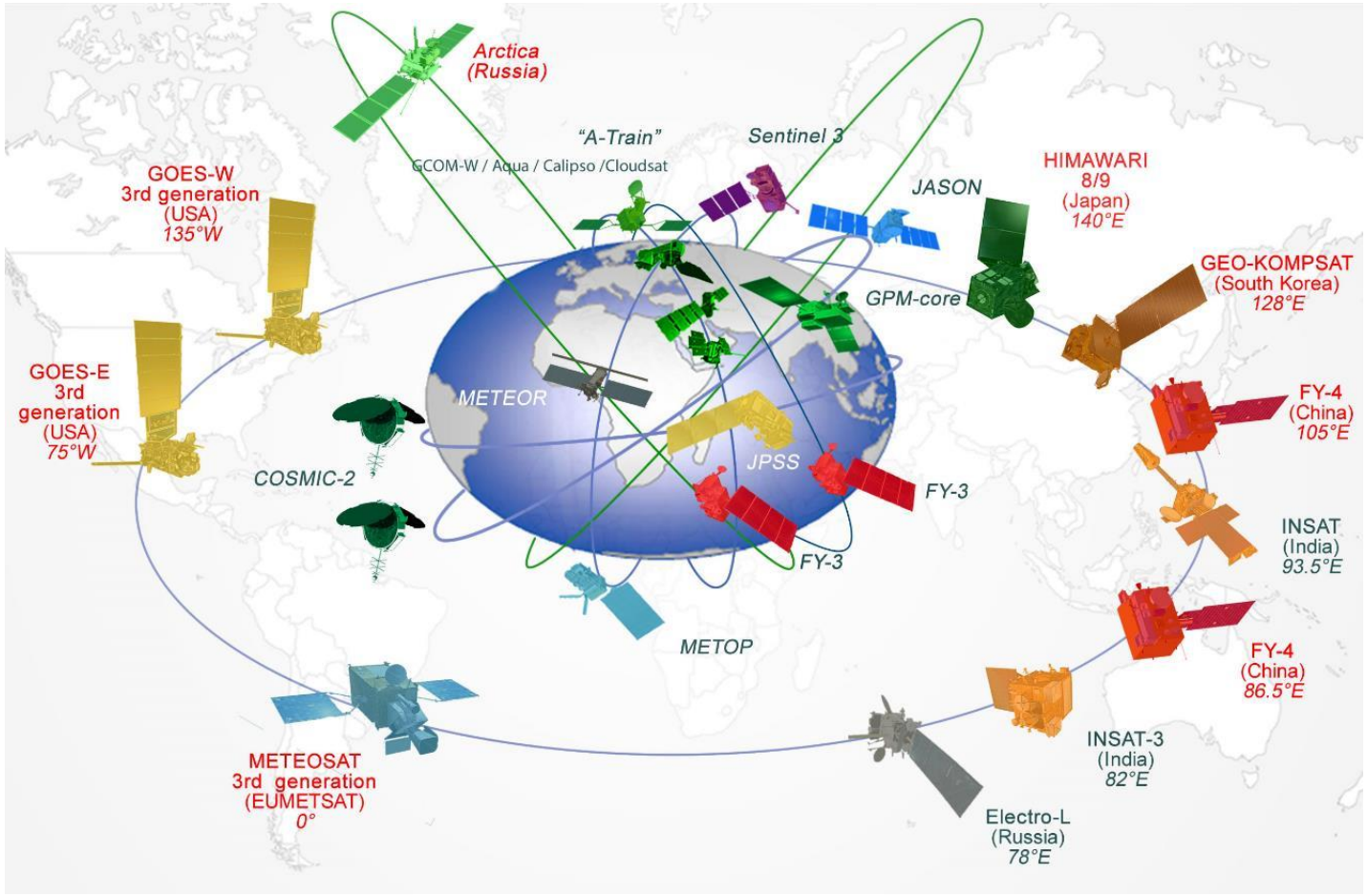
Stephen English

1. **Recap on the current Satellite GOS**
2. The WMO Integrated Global Observing System (WIGOS)
3. Future operational missions: EPS-SG, MTG, Sentinels
4. Future research missions: EarthCARE
5. Other: US, Asia, Other European efforts, commercial programmes

Stephen.English@ecmwf.int

ECMWF

WIGOS: WMO Integrated Global Observing System

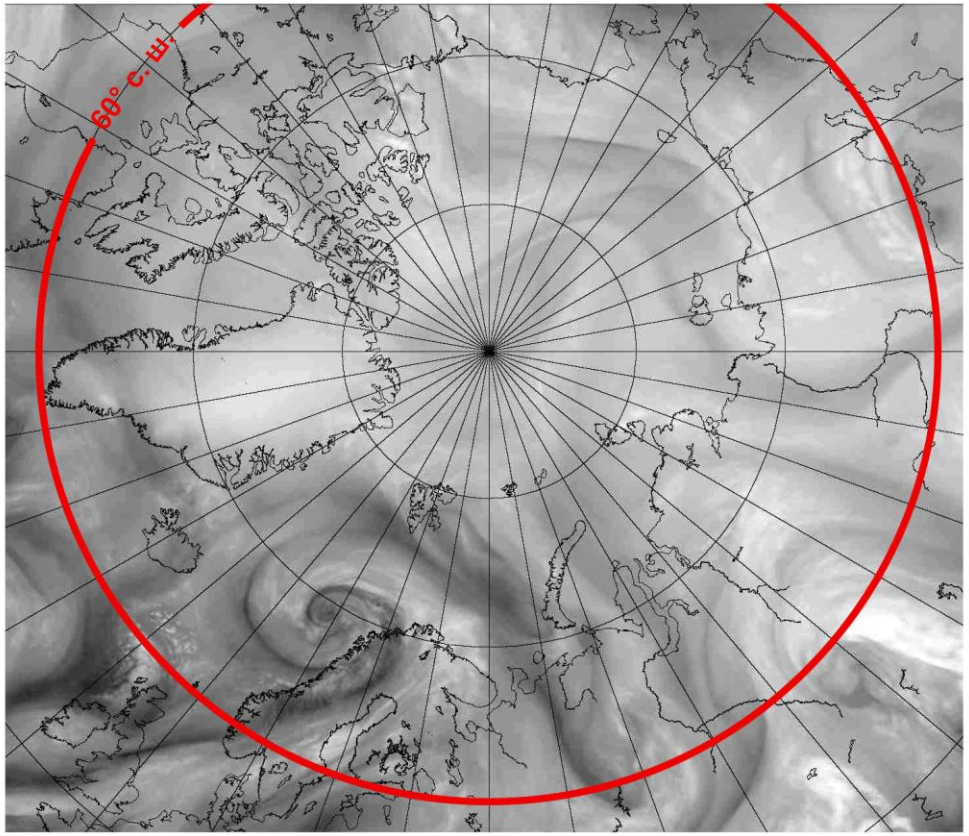


In 2024 there are ~200 active satellites supporting weather, climate, earth system and space weather and another ~100 doing relevant Earth Observation

ГИДРОМЕТ

РОСКОСМОС

НПО ЛАВОЧКИНА РКС



Анимация изображений с МСУ-ГС/ВЭ КА «Арктика-М» №1

5 канал (5,7 - 7,0 мкм)

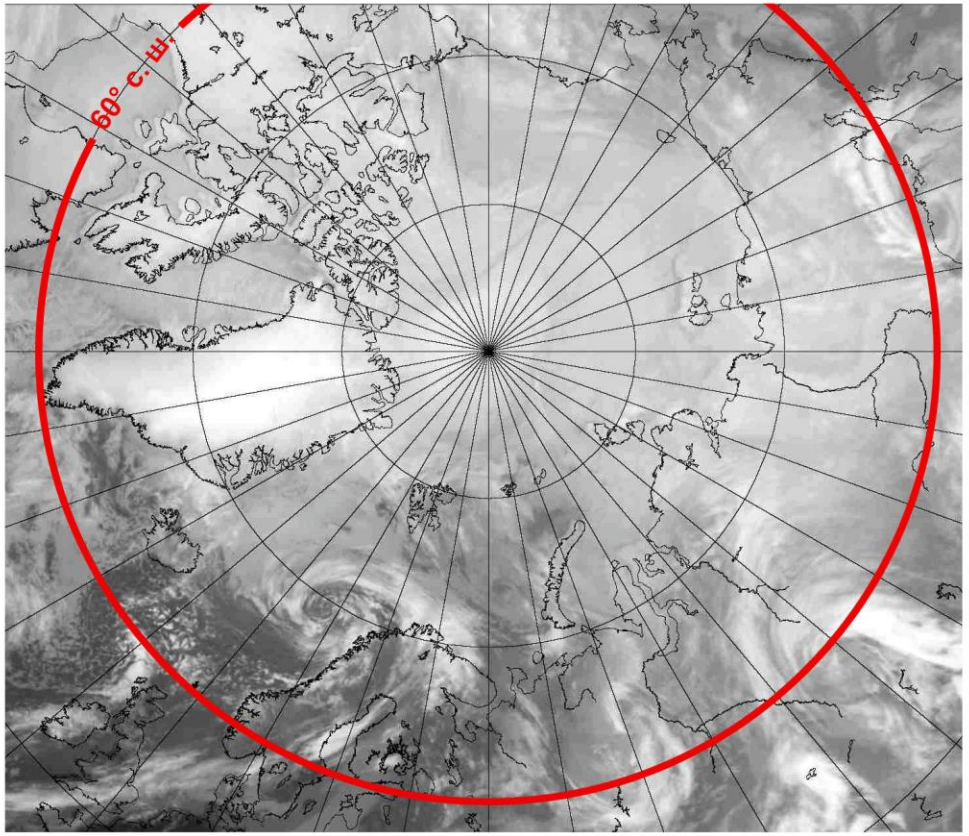
Рабочий участок орбиты - 6,5 часов, частота съёмки - 30 минут

ЕТА"
сква,
ер., 7
7
0
net.iitp.ru

ЕТ

РОСКОСМОС

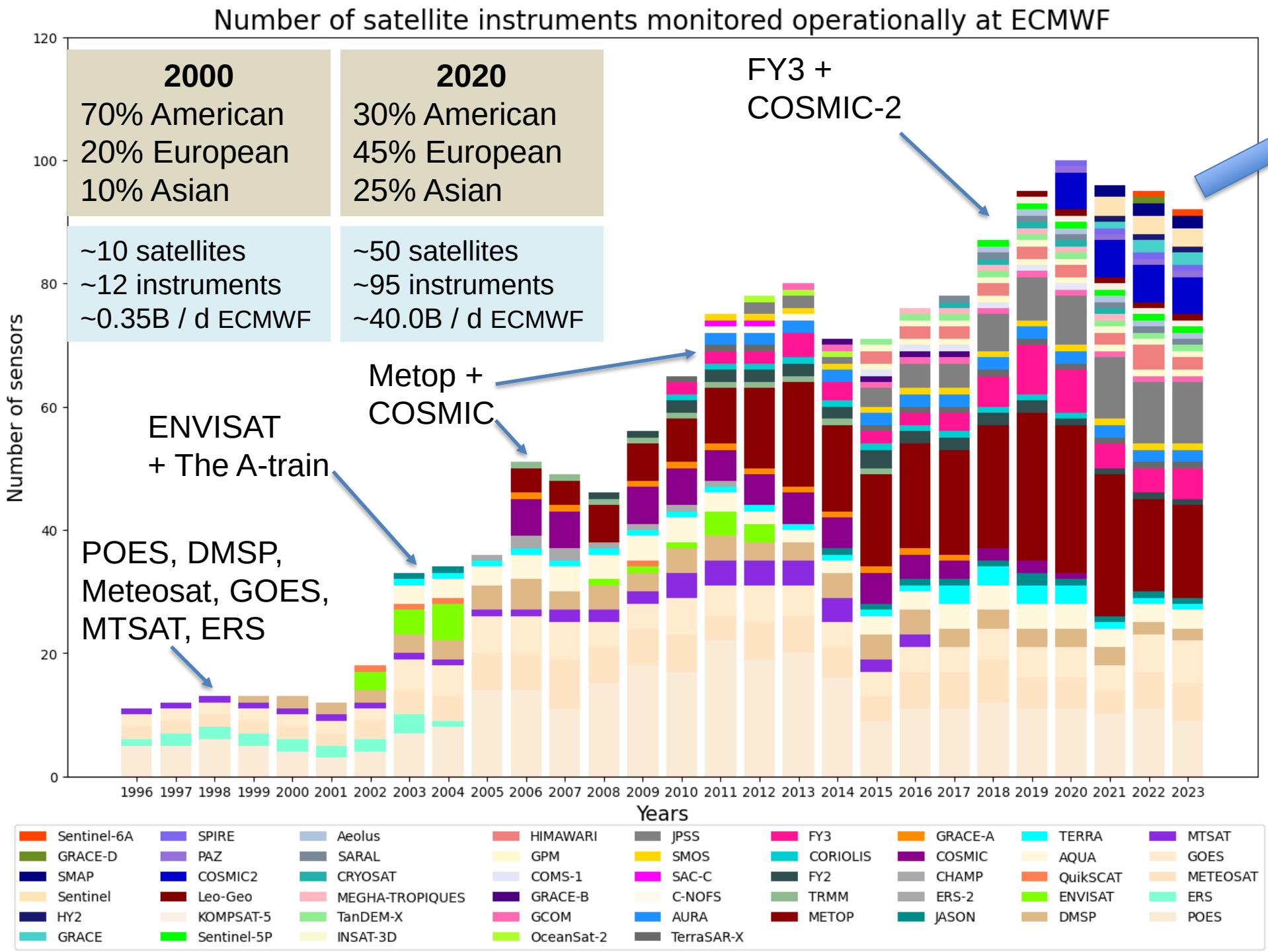
НПО ЛАВОЧКИНА РКС



Анимация изображений с МСУ-ГС/ВЭ КА «Арктика-М» №1

9 канал (10,2 - 11,2 мкм)

Рабочий участок орбиты - 6,5 часов, частота съёмки - 30 минут



Commercial e.g. Spire; EPS-SG; MTG; CEMs….

Constellations

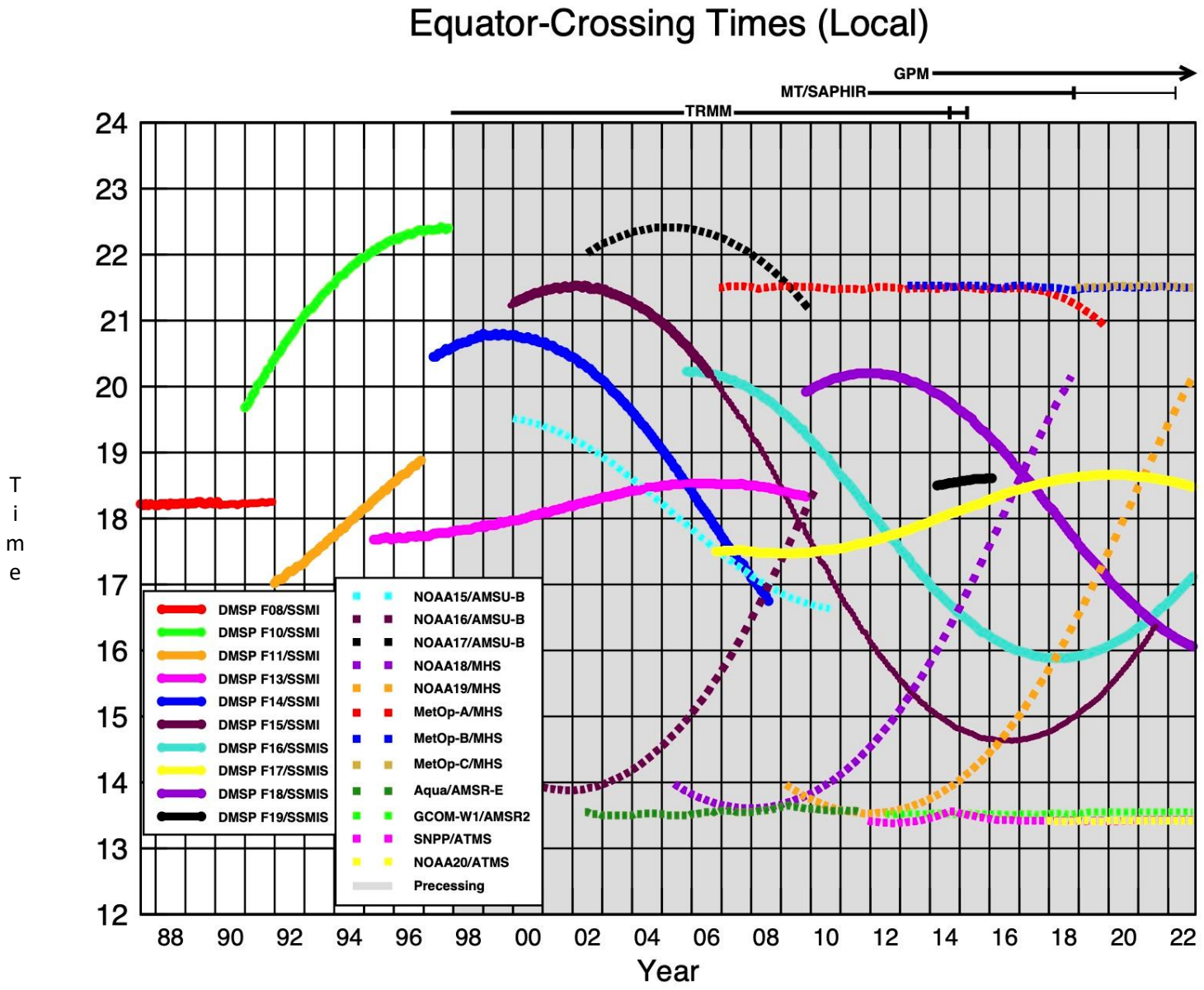
New Space Agencies

Growing Programmes

Long standing

Graph provided by Mohamed Dahoui

Satellite Equatorial Crossing Times (Courtesy of Eric Nelkin, NASA/GSFC)



AM
e.g. MetOp

Europe
China

Early AM
e.g. FY-3E

China
South Korea

Mid PM
e.g. Meteor-M N2

Russia?

PM
e.g. JPSS

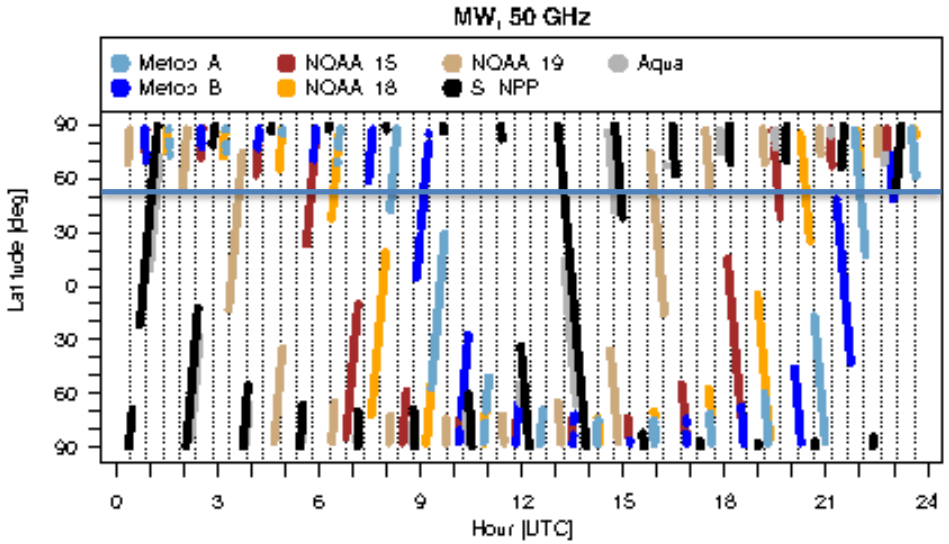
US
China

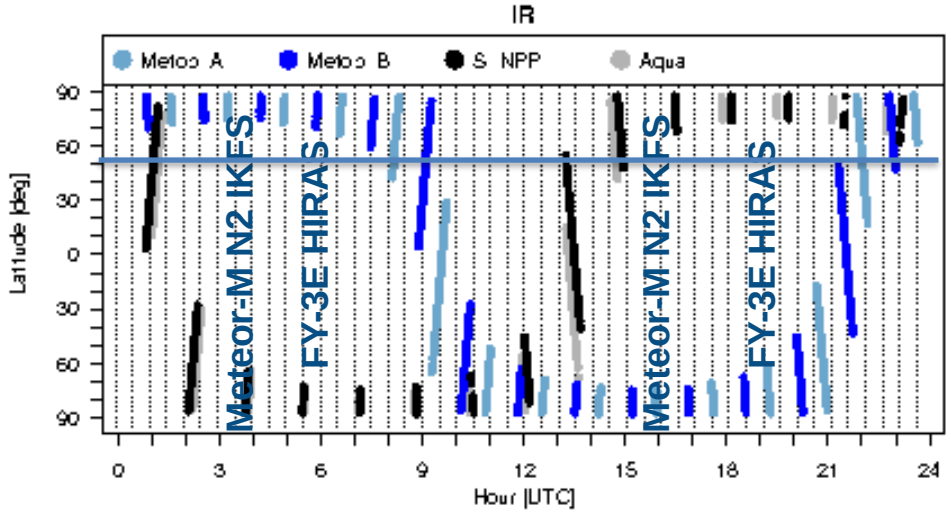
Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 29 November 2022, NASA/Goddard Space Flight Center, Greenbelt, MD.

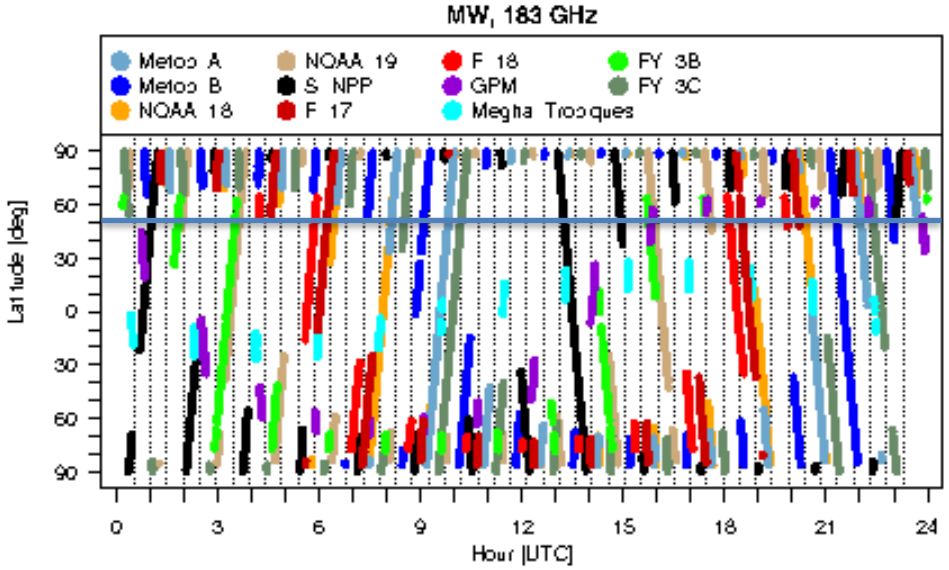
Temporal coverage of satellite data by type

Thanks to Tony McNally

In some bands e.g. 183 GHz excellent temporal coverage
In some bands e.g. 50 GHz gaps
In some bands e.g. IR major gaps in 2021







Future evolution of satellite observing systems

Stephen English

1. Recap on the current Satellite GOS
2. **The WMO Integrated Global Observing System (WIGOS)**
3. Future operational missions: EPS-SG, MTG, Sentinels
4. Future research missions: EarthCARE
5. Other: US, Asia, Other European efforts, commercial programmes

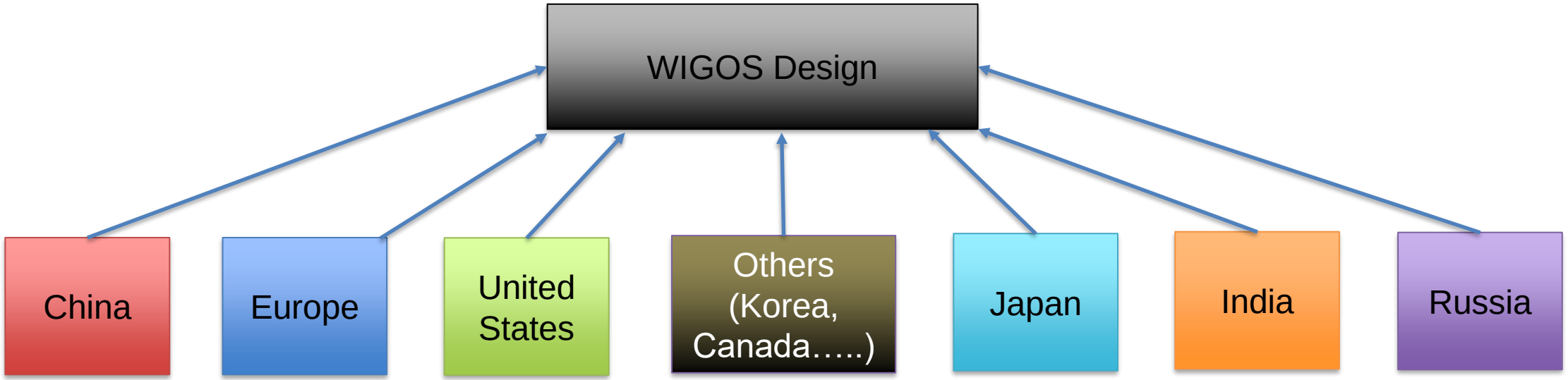
Stephen.English@ecmwf.int

ECMWF

WMO Coordination and WIGOS

WMO is striving towards a coordinated global observing system

(**WMO Integrated Global Observing System** – WIGOS)



Trying to make sure national efforts are complementary

Surface and space components

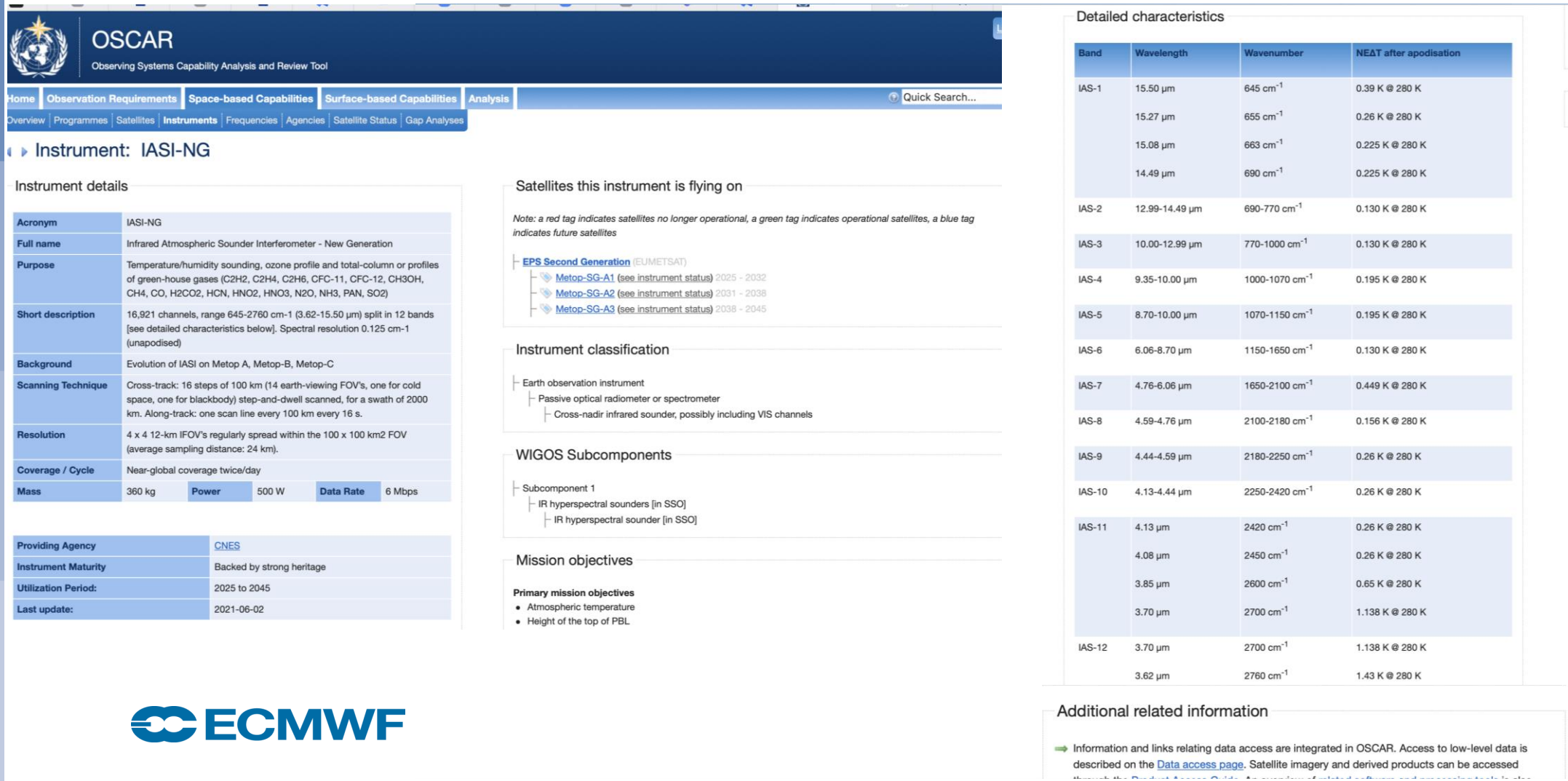
WIGOS – what is our/your role in this?

Monitoring performance of current WIGOS	→	WIGOS Data Quality Monitoring System Sharing monitoring at ECMWF etc.
Rolling Requirements Review WIGOS gap analysis	→	How will this be met? Vision 2040. https://community.wmo.int/vision2040
Preserving WIGOS Eg Spectrum Management	→	Responding to threats e.g. 5G Efforts by CGMS (Coordinating Group for Meteorological Satellites)

Tools to support WIGOS

WMO Space provide detailed support for satellite data from https://space.oscar.wmo.int

OSCAR lists what exists, what is planned, what it can do, how this compares to requirements



OSCAR
Observing Systems Capability Analysis and Review Tool

Home | Observation Requirements | Space-based Capabilities | Surface-based Capabilities | Analysis | Quick Search...

Overview | Programmes | Satellites | Instruments | Frequencies | Agencies | Satellite Status | Gap Analyses

Instrument: IASI-NG

Instrument details

Acronym	IASI-NG				
Full name	Infrared Atmospheric Sounder Interferometer - New Generation				
Purpose	Temperature/humidity sounding, ozone profile and total-column or profiles of green-house gases (C2H2, C2H4, C2H6, CFC-11, CFC-12, CH3OH, CH4, CO, H2CO2, HCN, HNO2, HNO3, N2O, NH3, PAN, SO2)				
Short description	16,921 channels, range 645-2760 cm-1 (3.62-15.50 µm) split in 12 bands [see detailed characteristics below]. Spectral resolution 0.125 cm-1 (unapodised)				
Background	Evolution of IASI on Metop A, Metop-B, Metop-C				
Scanning Technique	Cross-track: 16 steps of 100 km (14 earth-viewing FOV's, one for cold space, one for blackbody) step-and-dwell scanned, for a swath of 2000 km. Along-track: one scan line every 100 km every 16 s.				
Resolution	4 x 4 12-km IFOV's regularly spread within the 100 x 100 km2 FOV (average sampling distance: 24 km).				
Coverage / Cycle	Near-global coverage twice/day				
Mass	360 kg	Power	500 W	Data Rate	6 Mbps

Providing Agency	CNES
Instrument Maturity	Backed by strong heritage
Utilization Period:	2025 to 2045
Last update:	2021-06-02

Satellites this instrument is flying on

Note: a red tag indicates satellites no longer operational, a green tag indicates operational satellites, a blue tag indicates future satellites

- EPS Second Generation (EUMETSAT)
  - Metop-SG-A1 (see instrument status) 2025 - 2032
  - Metop-SG-A2 (see instrument status) 2031 - 2038
  - Metop-SG-A3 (see instrument status) 2038 - 2045

Instrument classification

- Earth observation instrument
  - Passive optical radiometer or spectrometer
    - Cross-nadir infrared sounder, possibly including VIS channels

WIGOS Subcomponents

- Subcomponent 1
  - IR hyperspectral sounders [in SSO]
    - IR hyperspectral sounder [in SSO]

Mission objectives

Primary mission objectives
- Atmospheric temperature
- Height of the top of PBL

Detailed characteristics

Band	Wavelength	Wavenumber	NEΔT after apodisation
IAS-1	15.50 µm	645 cm^{-1}	0.39 K @ 280 K
	15.27 µm	655 cm^{-1}	0.26 K @ 280 K
	15.08 µm	663 cm^{-1}	0.225 K @ 280 K
	14.49 µm	690 cm^{-1}	0.225 K @ 280 K
IAS-2	12.99-14.49 µm	690-770 cm^{-1}	0.130 K @ 280 K
IAS-3	10.00-12.99 µm	770-1000 cm^{-1}	0.130 K @ 280 K
IAS-4	9.35-10.00 µm	1000-1070 cm^{-1}	0.195 K @ 280 K
IAS-5	8.70-10.00 µm	1070-1150 cm^{-1}	0.195 K @ 280 K
IAS-6	6.06-8.70 µm	1150-1650 cm^{-1}	0.130 K @ 280 K
IAS-7	4.76-6.06 µm	1650-2100 cm^{-1}	0.449 K @ 280 K
IAS-8	4.59-4.76 µm	2100-2180 cm^{-1}	0.156 K @ 280 K
IAS-9	4.44-4.59 µm	2180-2250 cm^{-1}	0.26 K @ 280 K
IAS-10	4.13-4.44 µm	2250-2420 cm^{-1}	0.26 K @ 280 K
IAS-11	4.13 µm	2420 cm^{-1}	0.26 K @ 280 K
	4.08 µm	2450 cm^{-1}	0.26 K @ 280 K
	3.85 µm	2600 cm^{-1}	0.65 K @ 280 K
	3.70 µm	2700 cm^{-1}	1.138 K @ 280 K
IAS-12	3.70 µm	2700 cm^{-1}	1.138 K @ 280 K
	3.62 µm	2760 cm^{-1}	1.43 K @ 280 K

- Integrated Water Vapour (IWV)
- O3 Total Column
- Specific humidity
- Temperature of the tropopause

Evaluation of Measurements

Additional related information

Information and links relating data access are integrated in OSCAR. Access to low-level data is described on the Data access page. Satellite imagery and derived products can be accessed

ECMWF

The Guardian

5G signal could jam satellites that he
with weather forecasting

New mobile system to be launched this year 'will put lives

THE HILL

Mixing 5G and w
could skew forecas
storm

6 APRIL 2019

nature
International journal of science

Global 5G wireless networks
threaten weather forecasts

INION CONTRIBUTOR — 07/01/19 06:30 PM EDT
BY CONTRIBUTORS ARE THEIR OWN

PHYSICS TODAY

NOAA warns of threat to weather
forecasts from 5G spectrum

New mobile system to be launched this year 'will put lives at risk'

Why we need to protect weather prediction from radio frequency interference

15 Au
Step

Recent posts

Why we need to protect weather prediction from radio frequency interference

ECMWF over the Moon

THE Sun
NEWS WEBSITE OF THE YEAR

ITU News
MAGAZINE

Monitoring our changing planet

Critical spectrum for Earth observation from space

Le Point Tech & Net

Les prévisions météo menacées par l
de la 5G ?

FOGGY OUTLOOK UK weather forecasts
could get even WORSE as 5G 'risks
confusing satellite networks'

ccuracy of forecasts could dro

"For these numerical weather prediction applications, radio-frequency spectrum is crucial for satellite weather observations as well as communications."

Stephen English
Head of the Earth System Assimilation Section, European Centre for Medium-Range Weather Forecasts (ECMWF)

Frequency management and why this is critical to NWP

- Passive microwave contribute around 40% of the impact of all observations in NWP:
  - 50-60 GHz and 176-190 GHz provide largest direct impact
  - 18.7, 23.8, 31.4, 37, 89, 166 have lower direct impact but support use of 50-60 and 176-190 GHz
  - 1.4, 6.8, 10.7, 209, 229 important for emerging applications
  - Active bands, notably radar, also suffer interference.
- Satellite up + down link + control frequencies and data dissemination e.g. 400-406 MHz for radiosondes.
- Committee on Radio Frequencies (CORF), USA
- European Scientists on Spectrum for Earth Observation (ESSEO), Europe (Chair = S English so if you want to know more, ask me!)

ECMWF RFI Workshop, ECMWF, UK 13-14 September 2018

URSI-ECMWF RFI Workshop, Online 14-18 February 2022

URSI RFI Workshop, Argentina (TBC) August 2024

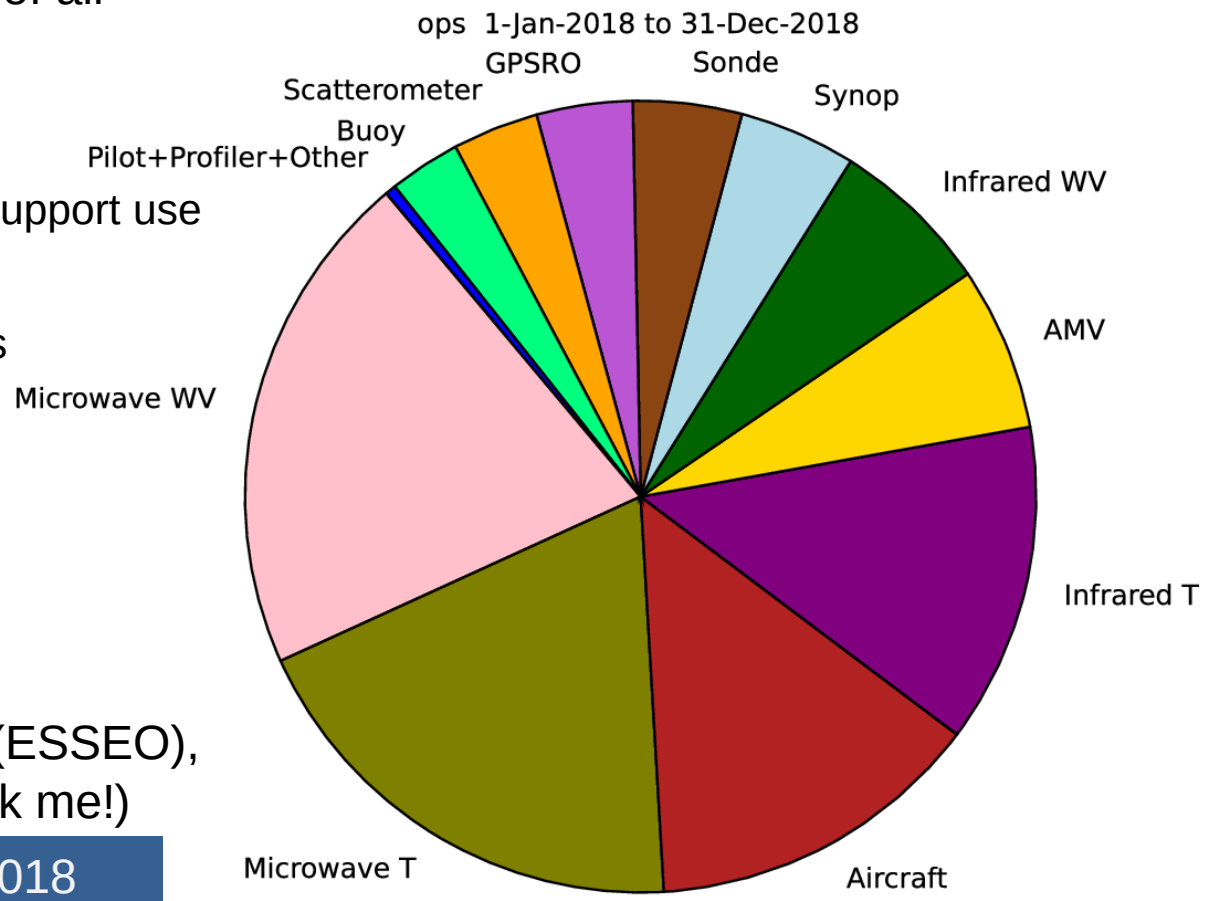
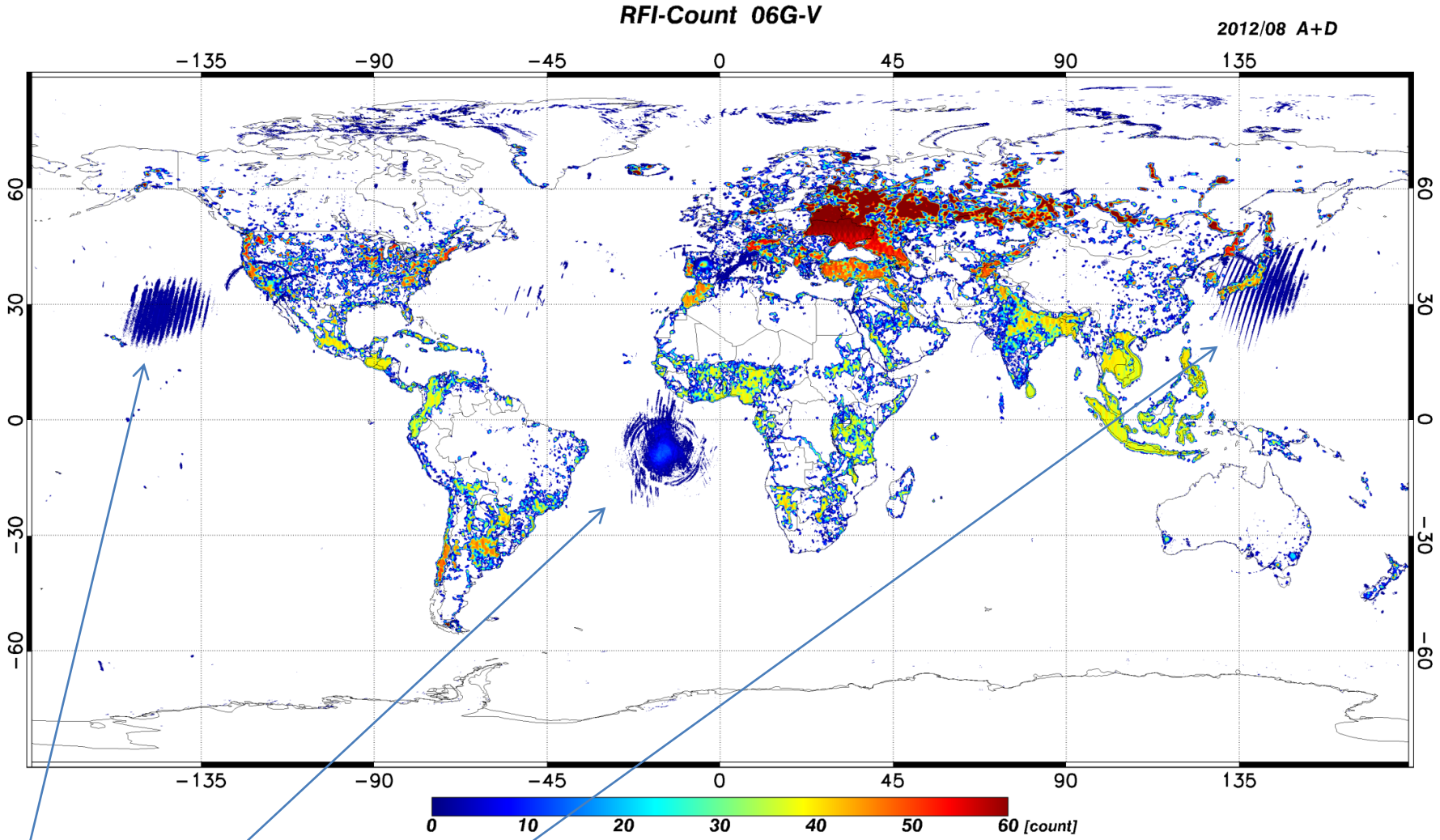


Figure from Alan Geer, ECMWF

Example of current RFI shown by JMA (Japan) in C band (unprotected)

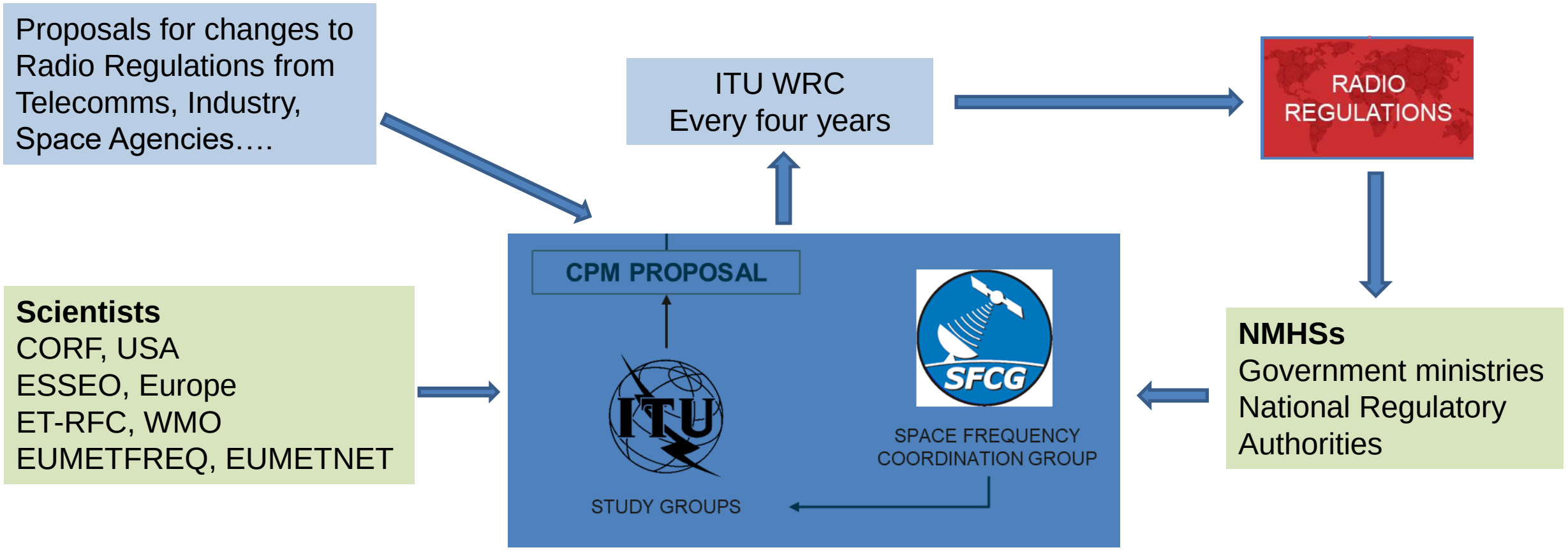


RFI sources:

1. Globalstar (satellite phone)
2. Ascension island(Ground-Satellite communication)
3. Japan, South-east Asia (ground-ground communication)

M. Seki, presented by M Kazumori at ECMWF RFI workshop, 2018

ITU WRCs


Proposals for changes to Radio Regulations from Telecomms, Industry, Space Agencies….
ITU WRC
Every four years
RADIO REGULATIONS
CPM PROPOSAL
ITU
STUDY GROUPS
SFCG
SPACE FREQUENCY COORDINATION GROUP
Scientists
CORF, USA
ESSEO, Europe
ET-RFC, WMO
EUMETFREQ, EUMETNET
NMHSs
Government ministries
National Regulatory Authorities

Future evolution of satellite observing systems

Stephen English

1. Recap on the current Satellite GOS
2. The WMO Integrated Global Observing System (WIGOS)
3. **Future operational missions: EPS-SG, MTG, Sentinels**
4. Future research missions: EarthCARE
5. US, Asia, commercial programmes

Stephen.English@ecmwf.int

ECMWF

Planned European EO Satellite Launches 2022 – 2032 (Indicative dates)

Science
Copernicus
Meteorology

SCOUT-2 HydroGNSS
SCOUT-1 ESP-MACCS
ALTIUS
TRUTHS
Aeolus-2

S-1C
S-2C
S-5A Instrument
S-3C
S-6B
CRISTAL A
CHIME A
CIMR A
CRISTAL B
CHIME B
S-5B Instrument
CIMR B

MetOp-SG A1
MetOp-SG B1
AWS
MetOp-SG A2
MetOp-SG B2

2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032

MTG I1 (Imagery)
MTG S1 (Sounding)
MTG I2 (Imagery)
MTG I3 (Imagery)

S-4A Instrument
CO2M A/B
CO2M C
ROSE-L A
LSTM A
ROSE-L B
LSTM B
S-6A NG
S-3A NG (TOPO)
S-1A NG

EE 6 EarthCARE
EE 7 Biomass
EE 8 Flex
EE 9 FORUM
EE 10 Harmony
EE 11

The history that led to EPS-SG

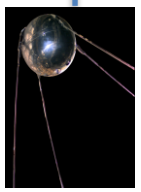
Europe

Rest of the World

US research satellites in 1960s and 1970s led to what we have now

We are approaching a new leap forward (EPS-SG, FY-5, Post-JPSS)

1957 1960 1970 1980 1990 2000 2010 2020 2030



1964
NIMBUS-1
HRIR
APT
ACVS

1968
NIMBUS-B
SIRS

1972
NIMBUS-5
ITPR
NEMS
ESMR

NOAA-2
VTPR
VHRR

1979
TOVS
HIRS/2
MSU
AVHRR

SSU

1998
ATOVS
HIRS/4
AMSU-A
AVHRR

AMSU-B

2003
A-train
AIRS
MODIS
MLS
CloudSat
Calipso

2007
Metop
MHS
IASI
ASCAT
GRAS
GOME-2

HIRS/4
AMSU-A
AVHRR

2011
JPSS
(S-NPP)
ATMS
CrIS
VIIRS
OMPS

2014
China
FY3-C
MWHS-2
MWTS-2
MWRI
IRAS
GNOS

2017
Russia
Meteor-M N2
MTVZA-GY
IKFS

2023/4
Metop-SG
MWS
MWI
ICI
IASI-NG
SCA
RO
MetImage
3MI
Sentinel-5

OR MEDIUM-RANGE WEATHER FORECASTS

EPS Second Generation

1. Updated counterparts to Metop 1st generation

ATOVS + AVHRR/MODIS → MWS + MetImage

IASI → IASI-NG

ASCAT → SCA (on EPS-SG-B)

GOME-2 → Sentinel-5 UVNS

GRAS → RO

2. New capability

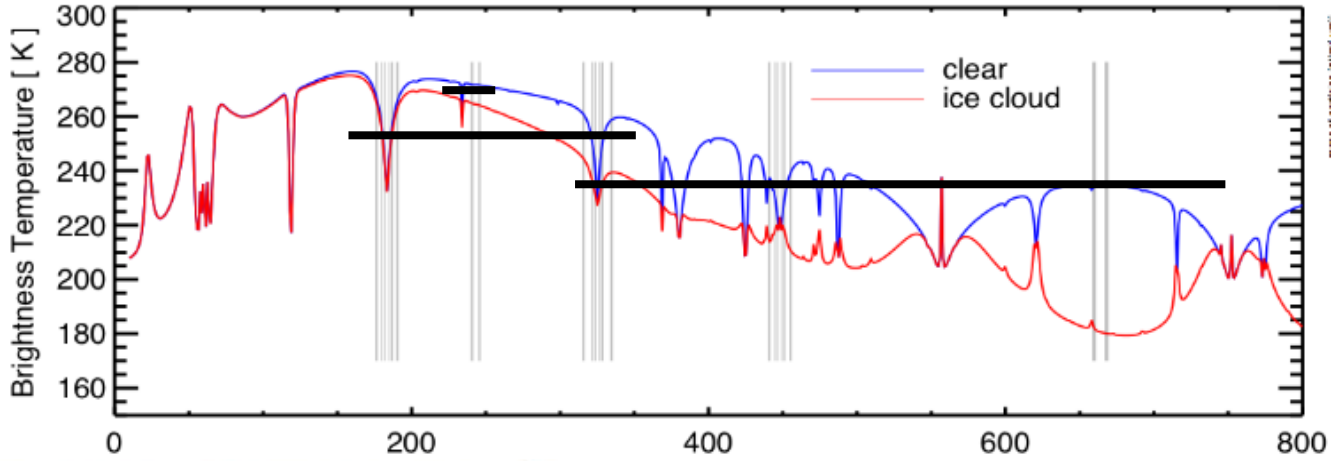
MWI: based on SSM/I

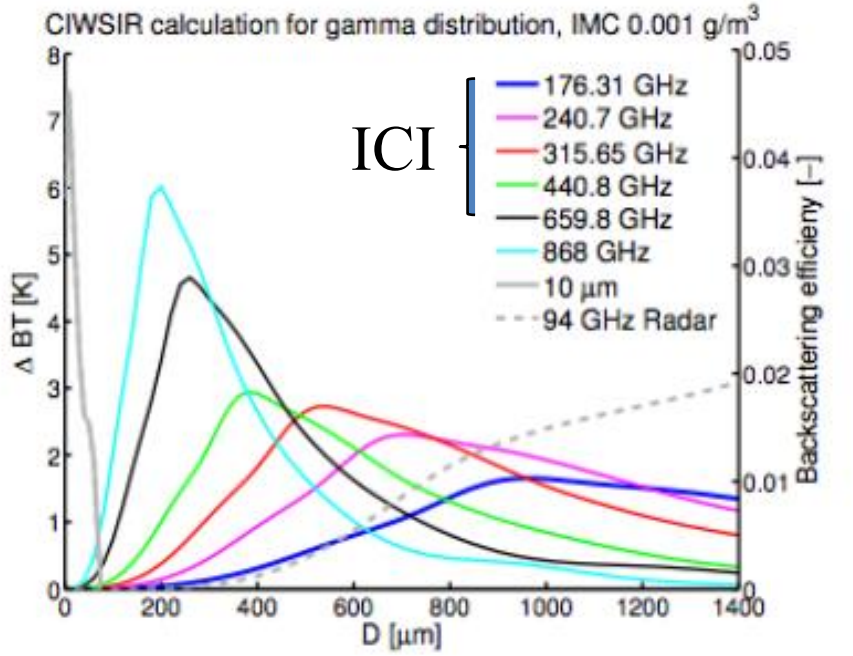
3MI: based on POLDER and PARASOL (VIS/NIR/SWIR)

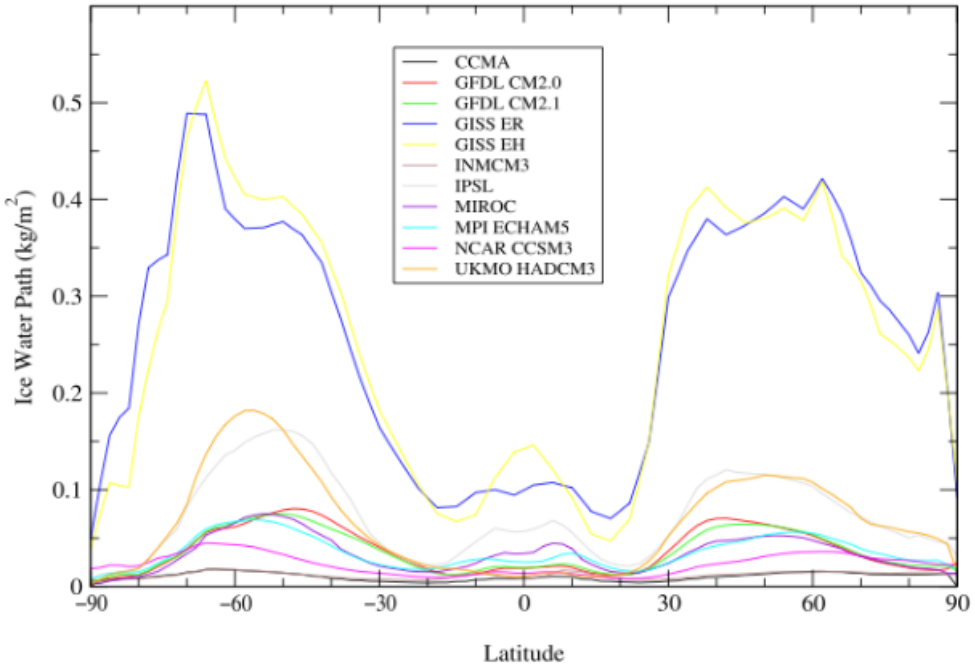
ICI: completely new! Sub-mm imager for cloud ice

EPS-SG: Ice Cloud Imager - ICI

From CloudIce proposal (Buehler et al.)







From John and Soden (2006)

Ice water path

+

Some information on particles (size, shape, orientation….)

The history that led to MTG

Europe

Rest of the World

1977
Meteosat-1
MVIRI = 3 channel imager
(research)

1989
Meteosat-4
MVIRI = 3 channel imager
(operational)

2005
MSG-1
SEVIRI
=12 channel imager

2023-4
MTG-I1
FCI
LI
MTG-S1
IRS
Sentinel-4

1957 1960 1970 1980 1990 2000 2010 2020 2030

1975
USA
GOES-1
VISSR

1994
USA
GOES-8
IMAGER
SOUNDER

2006
Japan
Himawari-6
IMAGER

2014
Japan
Himawari-8
AHI

2016
USA
GOES-16
ABI
GLM

2016
China
FY-4A
GIIRS
LMI
AGRI

India and South Korea have also developed similar programmes e.g. INSAT-3D 2013, GEOKOMPSAT 2018

Meteosat Third Generation

1. Updated counterparts to Meteosat second generation

SEVIRI → FCI 16 channel imager

European rapid scan 2.5 minutes, full disk 10 minutes.

2. New instruments

IRS: IR interferometer

LI: Lightning imager (777.4nm)

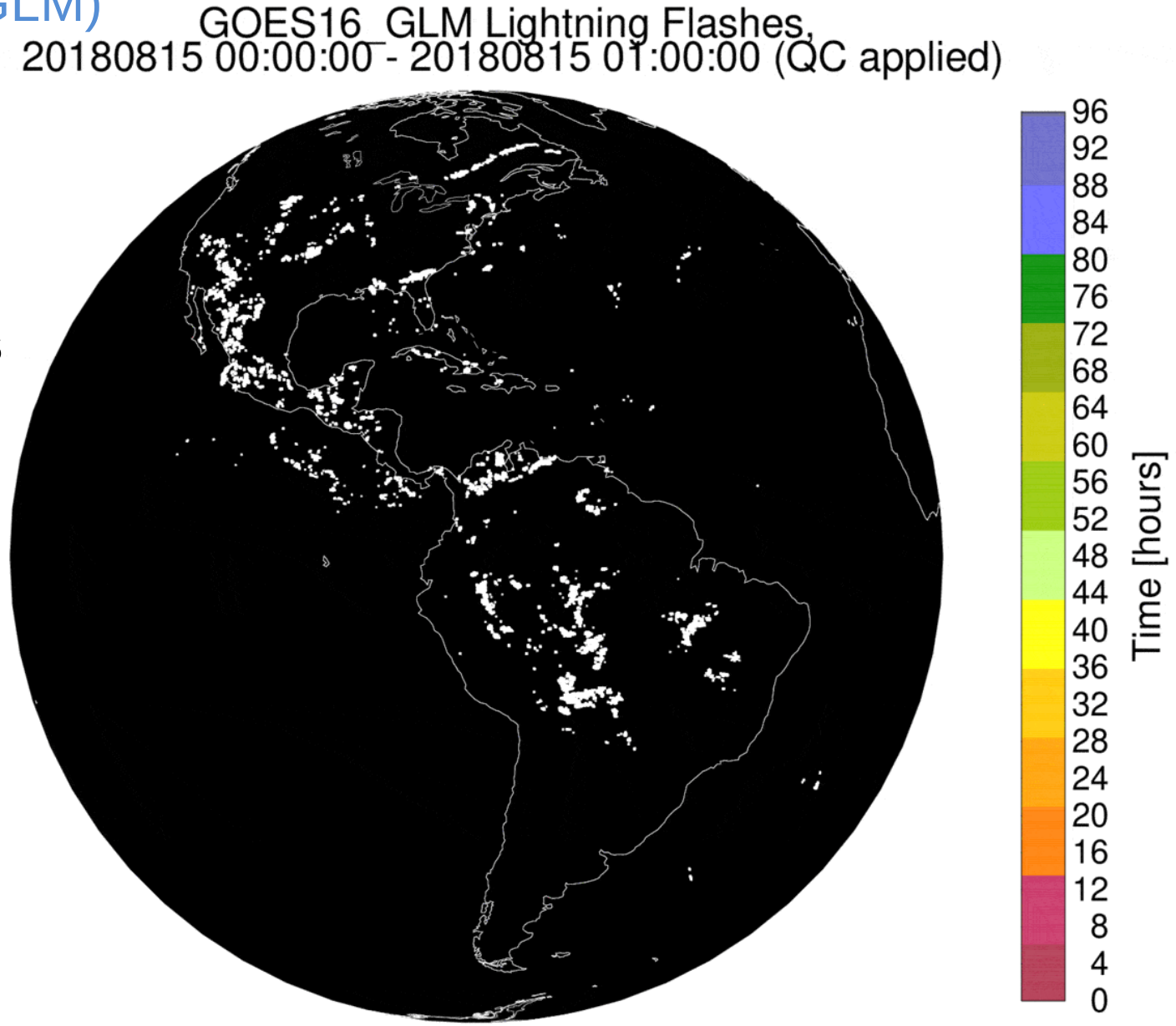
UVN: Ultraviolet, Visible and Near IR imager

First MTG Imager satellite launched
13 Dec 2022

GOES-16 GLM Lightning Mapper (GLM)

- **The Geostationary Lightning Mapper (GLM) on board the NOAA GOES-R series satellites provides continuous full-disk lightning observations at 8 km resolution (nadir) and in quasi-real-time.**

- **Lightning pulses are detected through their signature in the 777.4 nm oxygen band (lightning peak emission).**

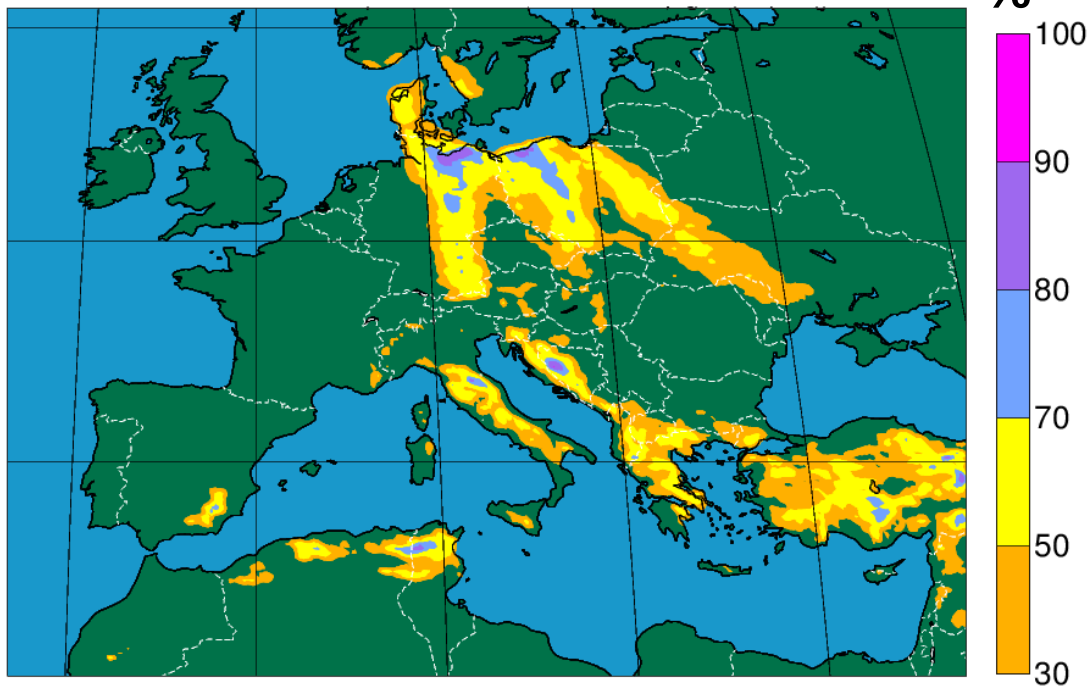


Animation of GOES-16 GLM lightning flashes over 4 days.

Thanks to Philippe Lopez for this slide

Towards lightning imager assimilation

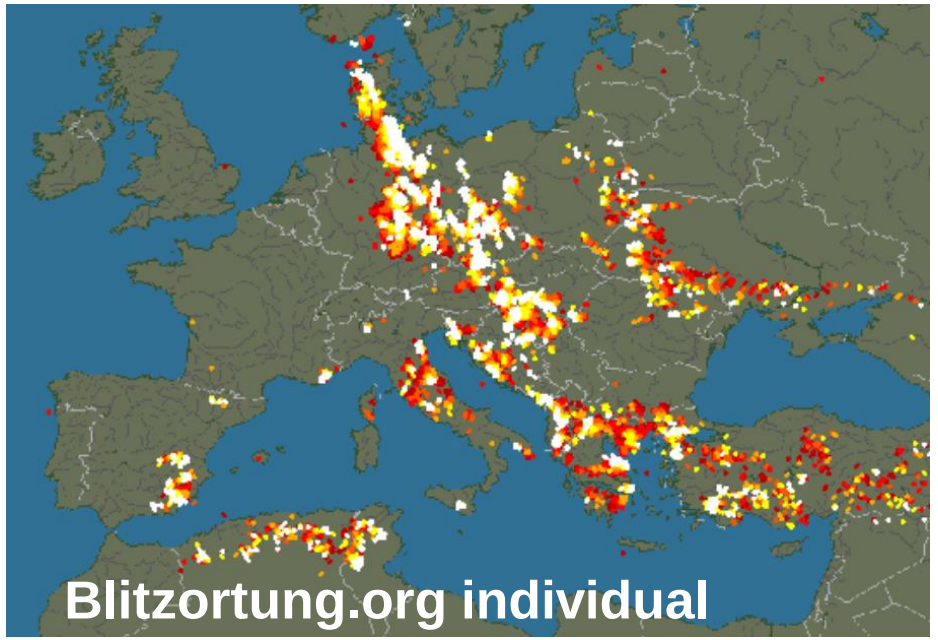
ECMWF ensemble forecast
Probability[flash density > 0.1 fl/100km^2/h]
FC Base: 10 May 2018 00Z, Range: +60 to +63h.

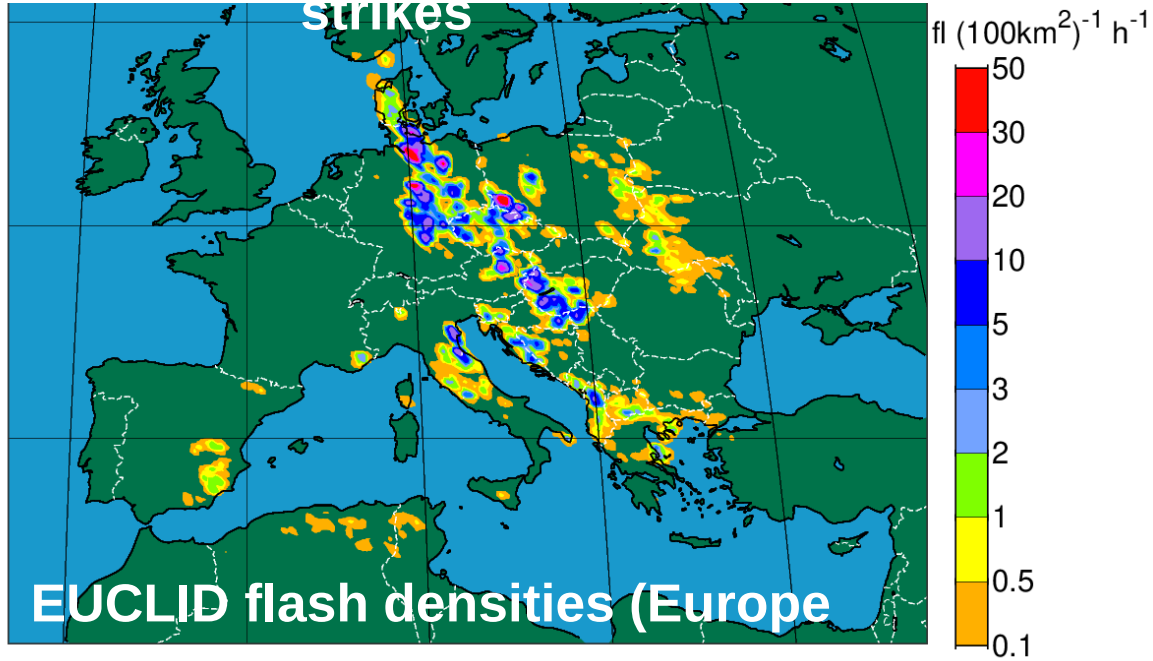


→ **Ensemble lightning forecasts can offer useful guidance to forecasters up to day 3 (in mid-latitude regions).**

Thanks to Philippe Lopez for this slide

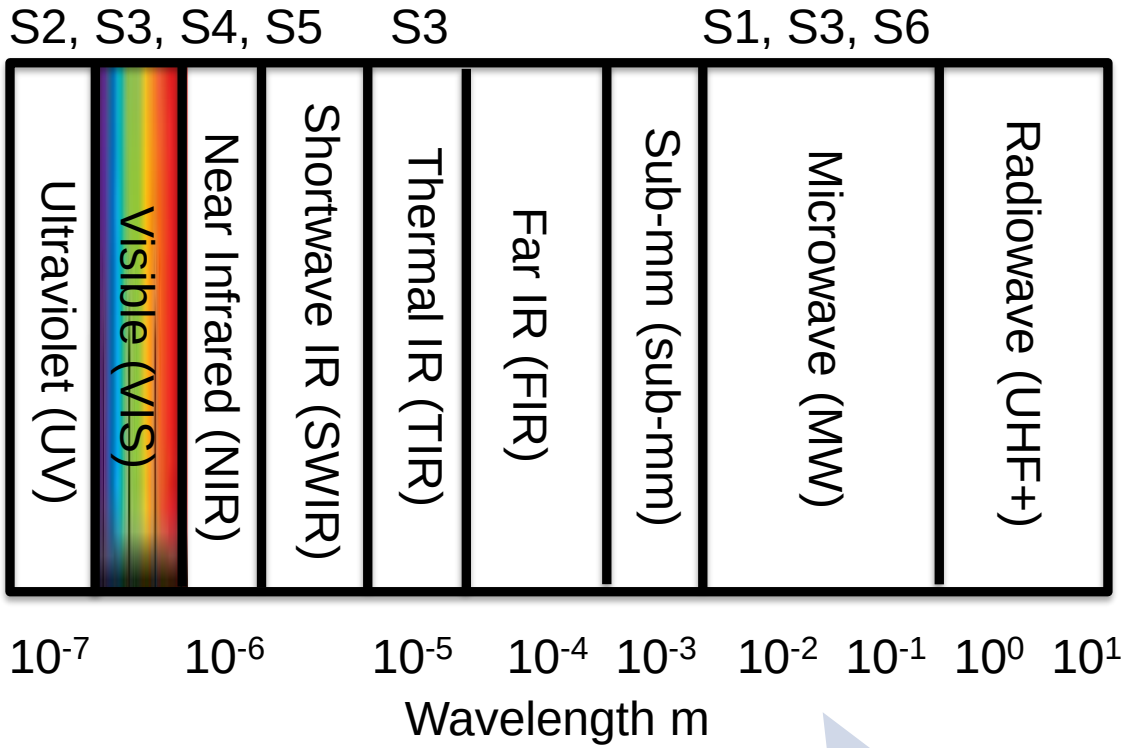
Ground-based obs., 10 May 2018 15Z

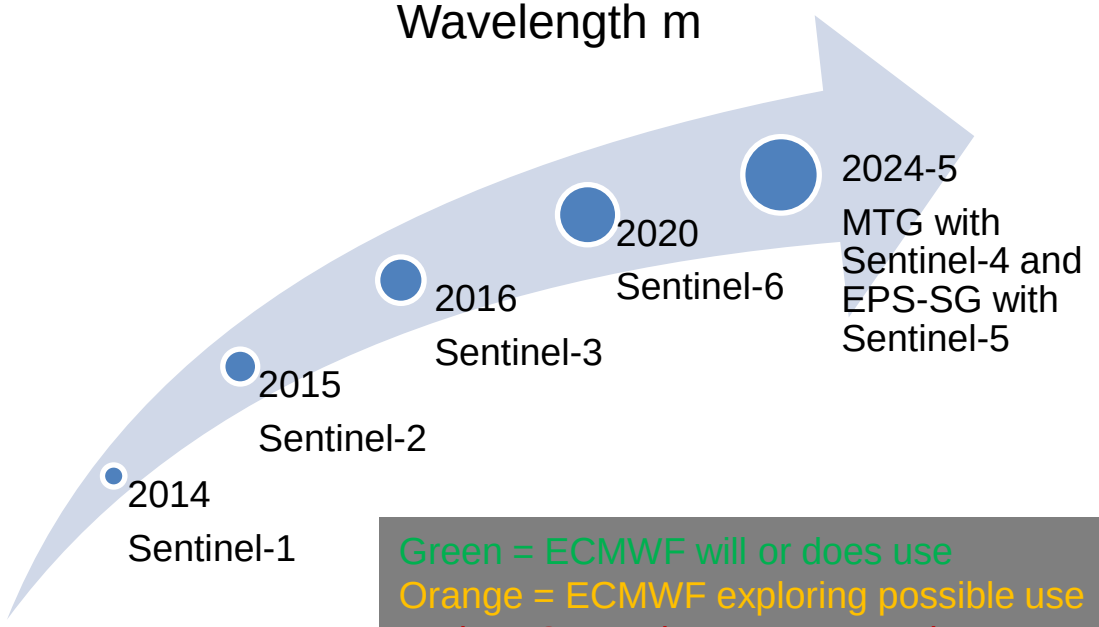




Copernicus Missions: Sentinel 1-6

- **Sentinel-1: 4-80m resolution C-band SAR (5.405 GHz): Discussion on possible new collaboration on wave spectrum assimilation**
- **Sentinel-2: 10-60m resolution NIR/VIS/UV imager 13 bands 443-2190nm**
- **Sentinel-3: Altimeter (SRAL), IR imager (SLSTR), Visible imager (OLCI), MW radiometer (MWR) and others.**
- **Sentinel-4: 8km resolution NIR/VIS/UV grating spectrometer for atmospheric chemistry flying on MTG**
- **Sentinel-5/UVNS (and Sentinel-5p/TROPOMI): 7km resolution NIR/VIS/UV grating spectrometer for atmospheric chemistry flying on EPS-SG**
- **Sentinel-6: Poseidon-4 altimeter 5.4 and 13.58 GHz**





Green = ECMWF will or does use
Orange = ECMWF exploring possible use
Red = ECMWF has no current plans to use

Sentinel-1

C-band Radar Mission

SAR imaging for All weather, day/night applications, interferometry

Launched S-1A/B 2014/2016

Sentinel-2

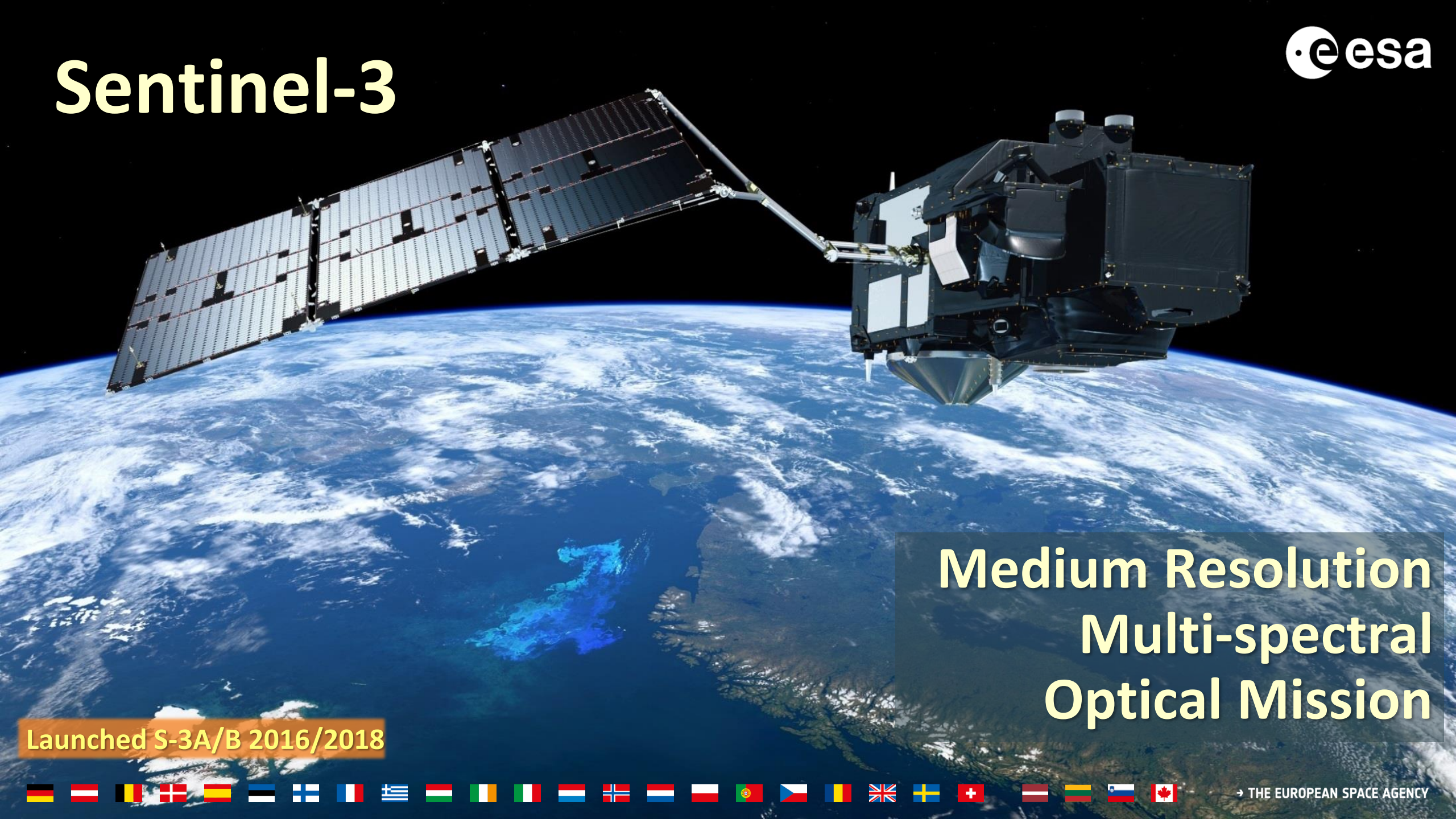
High Resolution Multi-spectral Optical Mission

Continuity of Landsat, SPOT for Land applications

Launched S-2A/B 2015/2017

→ THE EUROPEAN SPACE AGENCY

Sentinel-3

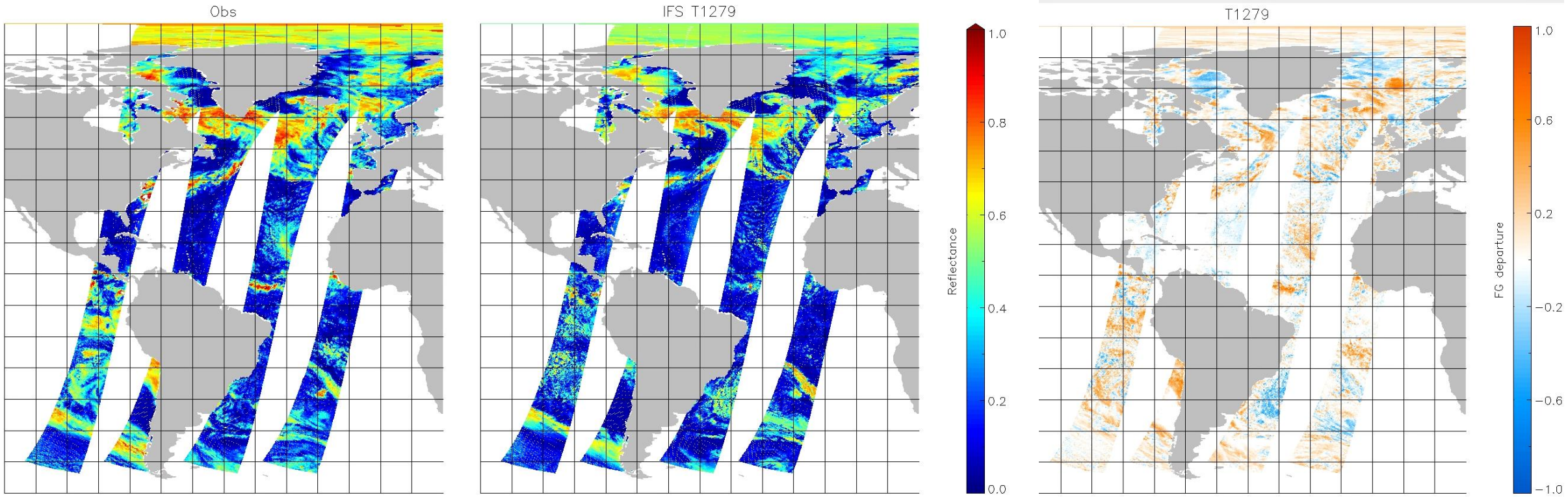


Medium Resolution Multi-spectral Optical Mission

Launched S-3A/B 2016/2018

→ THE EUROPEAN SPACE AGENCY

OLCI: Towards direct assimilation of visible observations



Observations

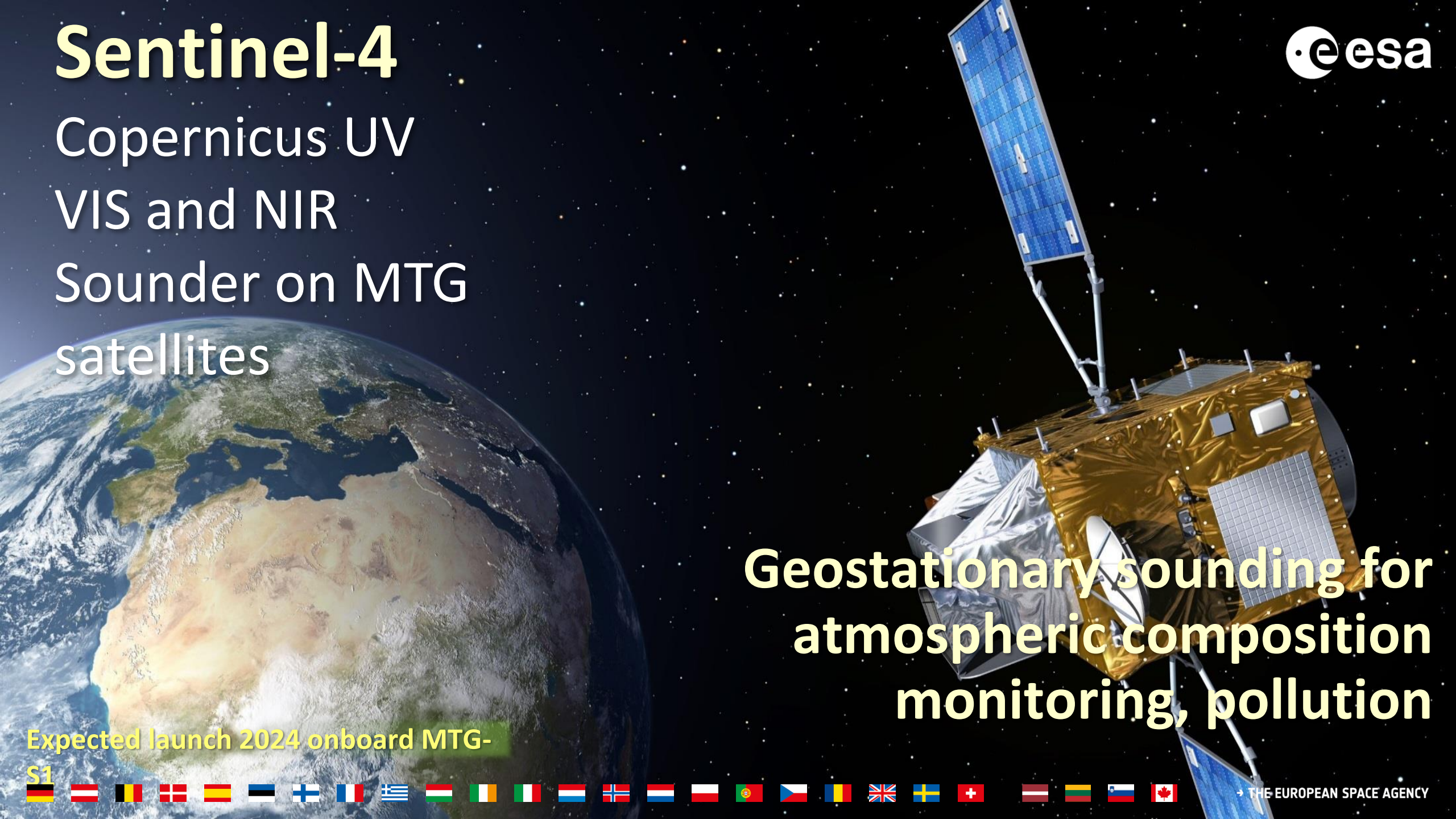
Model

Obs-Model

Thanks to Liam Steele and Angela Benedetti (CLOVIS project)

Sentinel-4

Copernicus UV VIS and NIR Sounder on MTG satellites



Geostationary sounding for atmospheric composition monitoring, pollution

Expected launch 2024 onboard MTG-S1

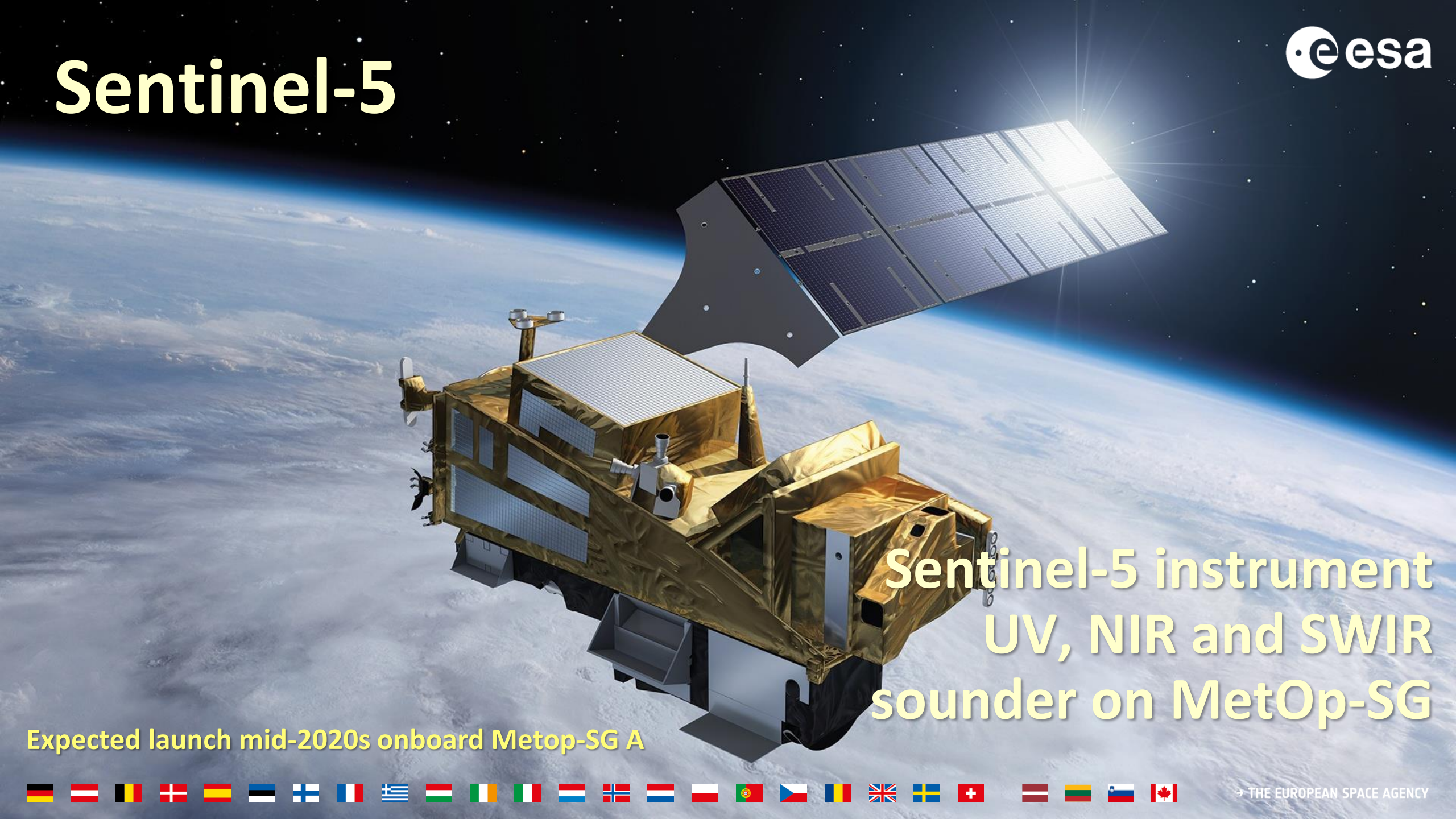
Sentinel-5p

Sentinel-5 precursor UV, NIR and SWIR sounder

Launched S-5p 2017

→ THE EUROPEAN SPACE AGENCY

Sentinel-5



Sentinel-5 instrument
UV, NIR and SWIR
sounder on MetOp-SG

Expected launch mid-2020s onboard Metop-SG A

→ THE EUROPEAN SPACE AGENCY

Sentinel-6 Michael Freilich

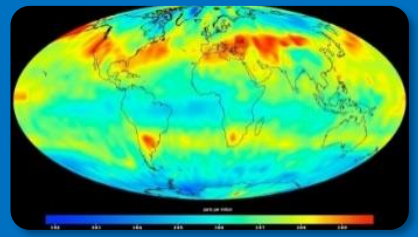
Altimetry reference mission

Launched S-6MF 2020

→ THE EUROPEAN SPACE AGENCY

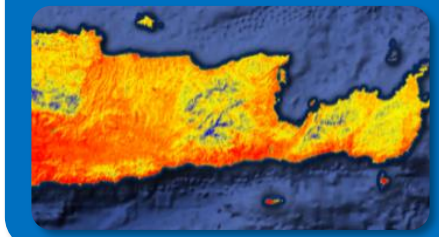
Sentinel Expansion Missions

CO2M - Anthropogenic CO_2 Monitoring



Causes of Climate Change

LST – Land Surface Temperature Mission

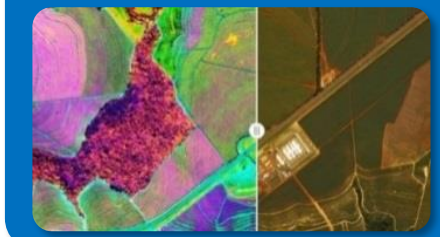


Agriculture & Urban Management

CRISTAL – Polar Ice & Snow Topography

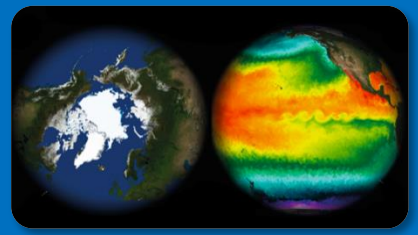
Effects of Climate Change

CHIME – Hyperspectral Imaging Mission



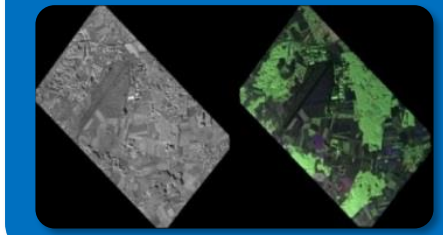
Food Security, Soil, Minerals, Biodiversity

CIMR – Passive Microwave Radiometer



Sea: Surface Temp. & Ice Concentration

ROSE-L – L-band SAR Mission



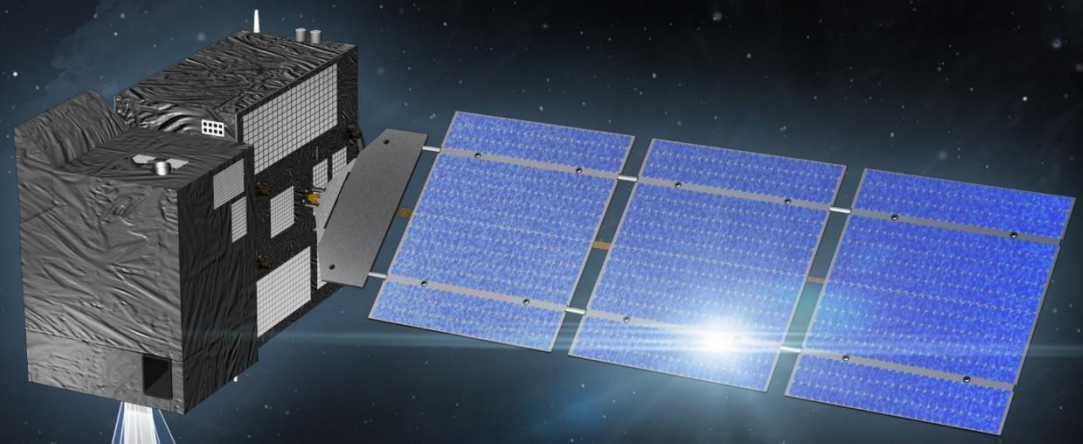
Vegetation & Ground Motion & Moisture

All contracts were signed in 2020

CO2M

0.8-1km VIS/NIR/SWIR

Anthropogenic CO_2 Monitoring Mission



Analyse CO2 emissions and overall budget at country and regional/megacity scales

Expected launch A/B 2025 – C 2026

→ THE EUROPEAN SPACE AGENCY

CRISTAL

10km dual frequency (Ku, Q-band) radar.
Heritage from Cryosat-2 SIRAL.

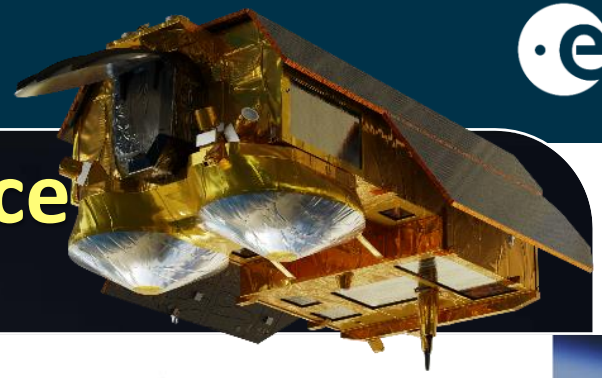
Polar Ice and Snow Topographic Mission

Mapping polar sea ice thickness and land ice elevation with overlaying snow depth

Expected launch A 2028 / B 2030

→ THE EUROPEAN SPACE AGENCY

Sentinel Expansion Missions: CRISTAL



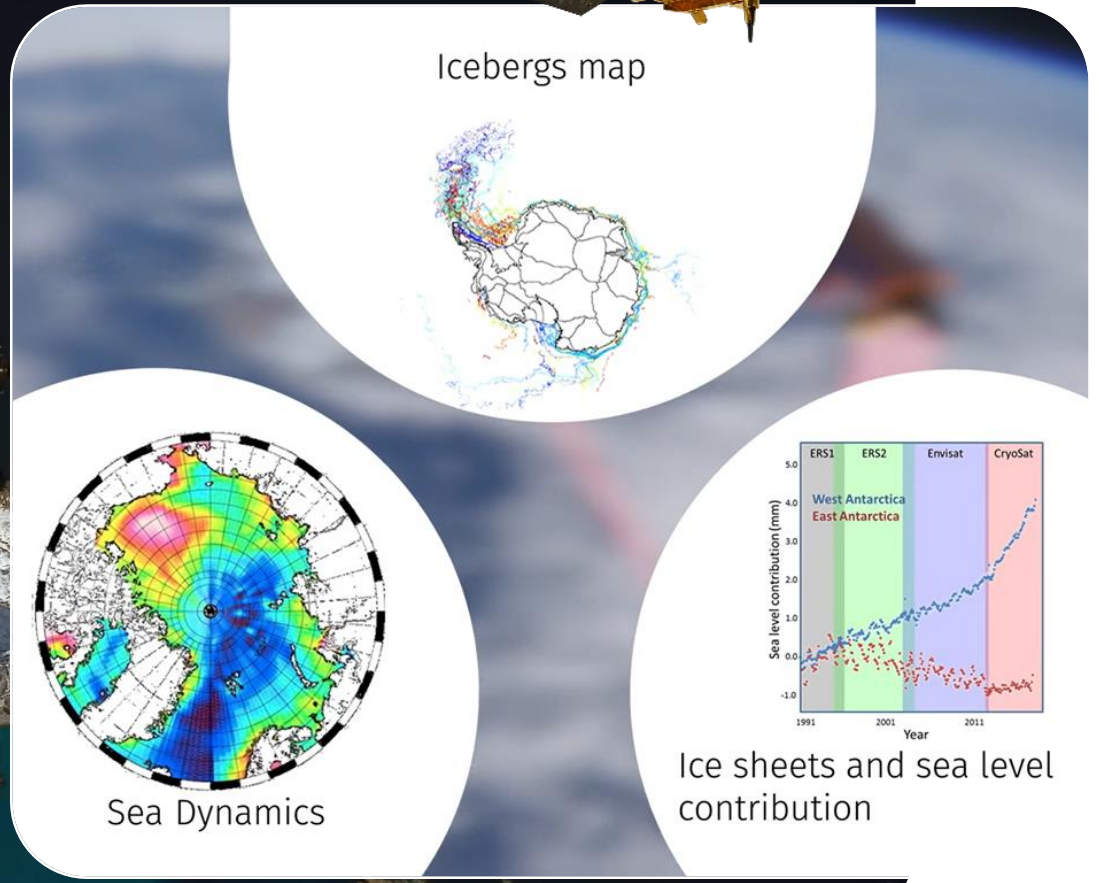
Mapping polar sea ice thickness and land ice elevation with overlaying snow depth

Polar Ice and Snow Topographic Mission

- Variability of Arctic and Southern Ocean sea-ice thickness and overlaying snow depth
- Observation of global ocean topography as a continuum up to the polar seas
- Surface elevation and (volume/mass) changes of glaciers, ice caps and the Antarctic and Greenland ice sheets

Dual-frequency InSAR altimeter

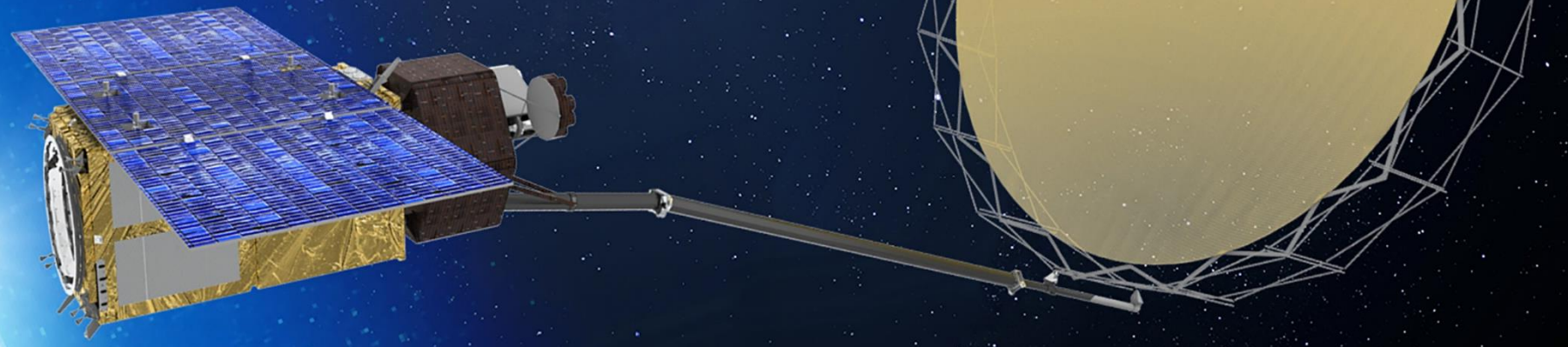
- Ku-band and Ka-band SAR altimetry
- Three modes of radar operation
  - *Sea-ice and iceberg (SII) mode*
  - *Land-ice and Glacier (LIG) mode*
  - *Open and coastal ocean mode (OCO) mode*



CIMR

3-64 km resolution L, C, X, K and Ka-band MW radiometer.
Heritage from SMOS, AMSR and the ”MIMR concept”

Daily imaging of polar oceans, sea ice and snow

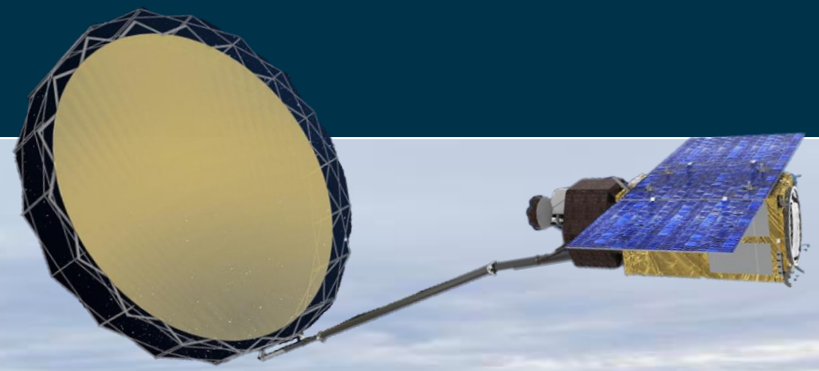


Understanding the polar oceans and their impact on our changing climate

Expected launch A 2029 / B 2031

Sentinel Expansion Missions: CIMR

Daily monitoring of polar oceans, sea ice and snow

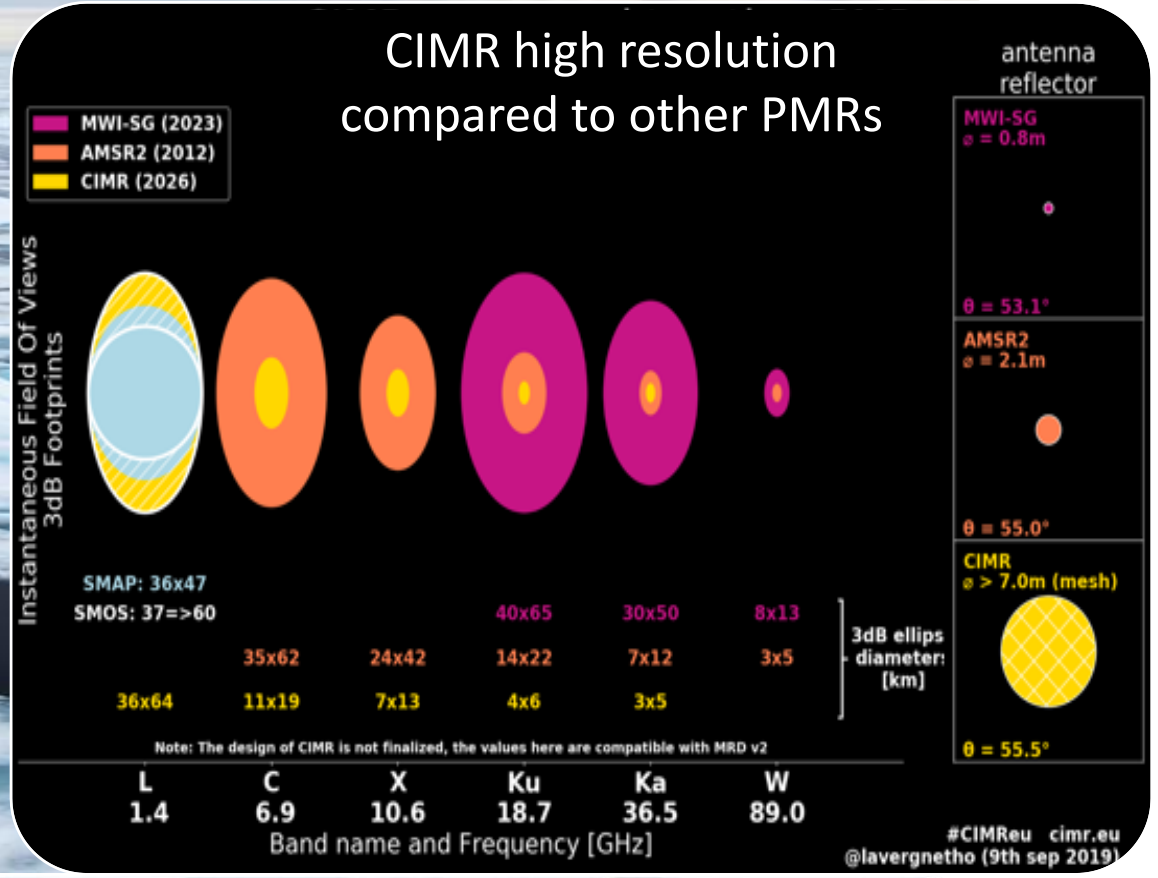


Mission for polar ocean parameters

- Measure the Polar regions every ~6 hours with 95% global daily coverage
- Support EU Arctic Policy & enhance Copernicus Services
- Ensure European continuity of an AMSR-type capability in synergy with other missions (eg. MetOp-SG(A/B)).
-

Wide-swath fully polarised conically-scanning multi-frequency microwave radiometer

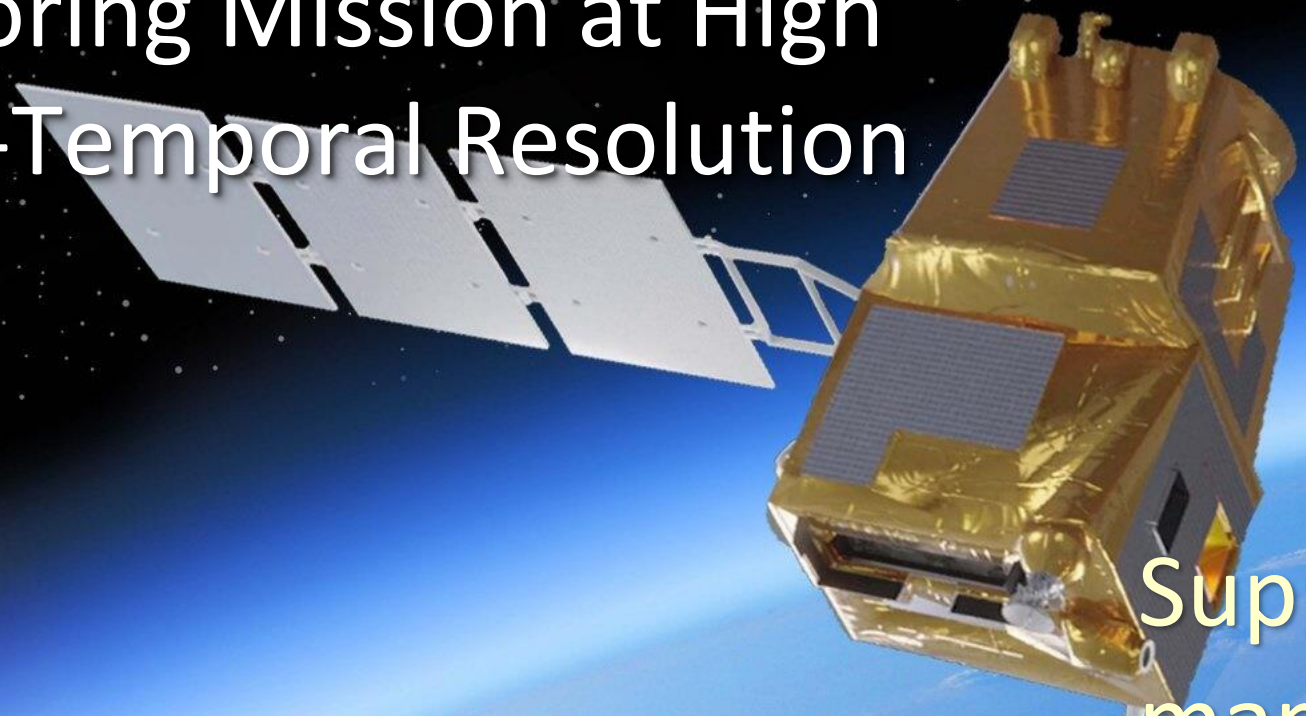
- Ka (36.5), Ku (18.7), X (10.6), C (6.9) and L (1.4) bands
- Information for Sea Ice Concentration, Sea Surface Temperature, thin Sea Ice Thickness, Sea Surface Salinity, Wind Speed, Snow Water Equivalent, Soil Moisture



LSTM

30-50m resolution VIS/NIR/SWIR/TIR 24 channel imager (follow on to Sentinel-3 SLSTR)

Land Surface Temperature Monitoring Mission at High Spatio-Temporal Resolution



Supporting agriculture management services, water and food security

Expected launch A 2028 / B 2030

Sentinel Expansion Missions: LSTM

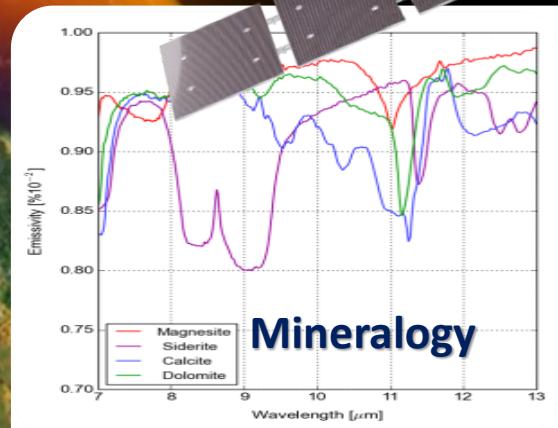
Land surface temperature observations supporting scientific research and applications for society

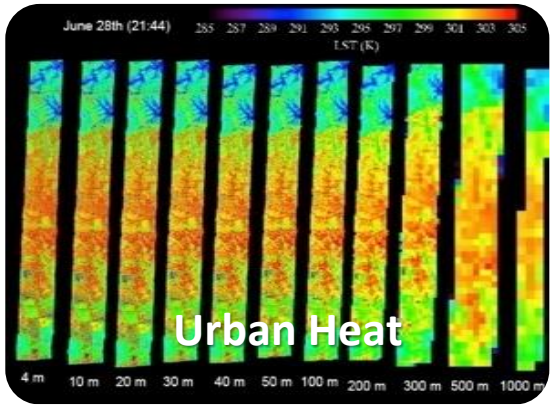
Land Surface Temperature Monitoring Mission

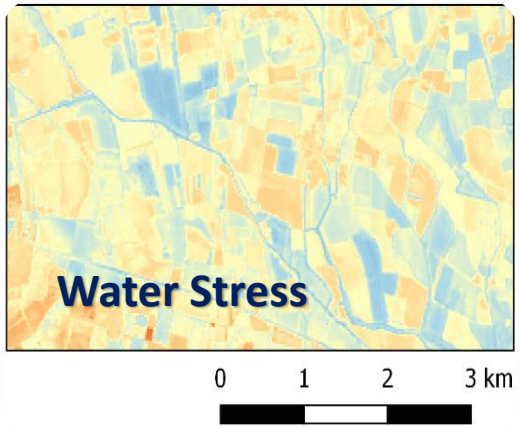
- TIR observations for monitoring evapotranspiration (ET) rate at European field scale
- Complement current S-2 and S-3 VIS and NIR data
- Further applications: soil composition, urban heat islands, coastal zone management, High-Temperature Events.

Optical imager with 3 bands in TIR

- Temperature observations over land & coastal regions , from approx. -20°C to +30°C, with high precision (0.3°C)
- Additional VNIR and SWIR narrow thermal bands for improved LST/emissivity separation
- 30-50m res., 600-700Km swath, 4day revisit.



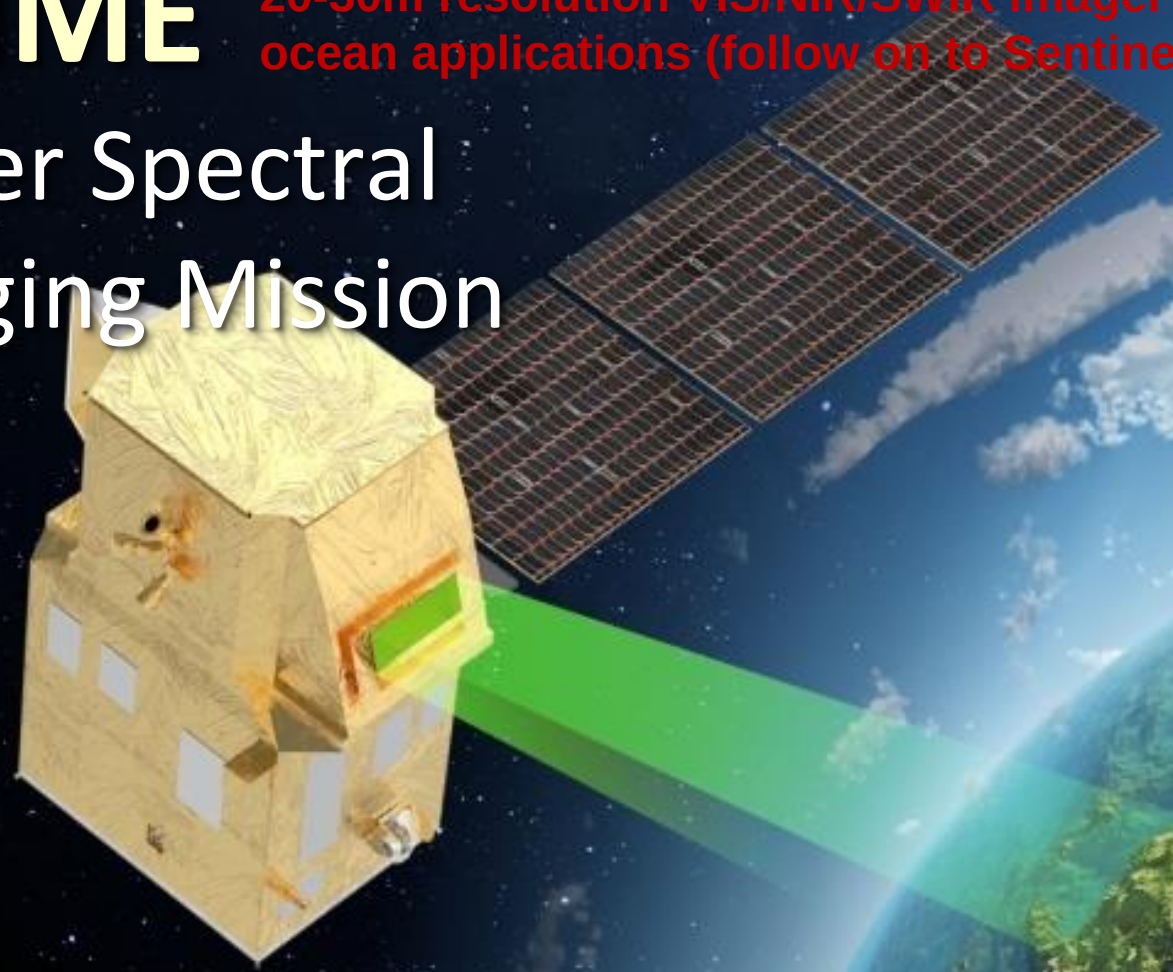




CHIME

20-30m resolution VIS/NIR/SWIR imager for land and ocean applications (follow on to Sentinel-2 MSI)

Hyper Spectral Imaging Mission



Support the European Green Deal and management of natural resources

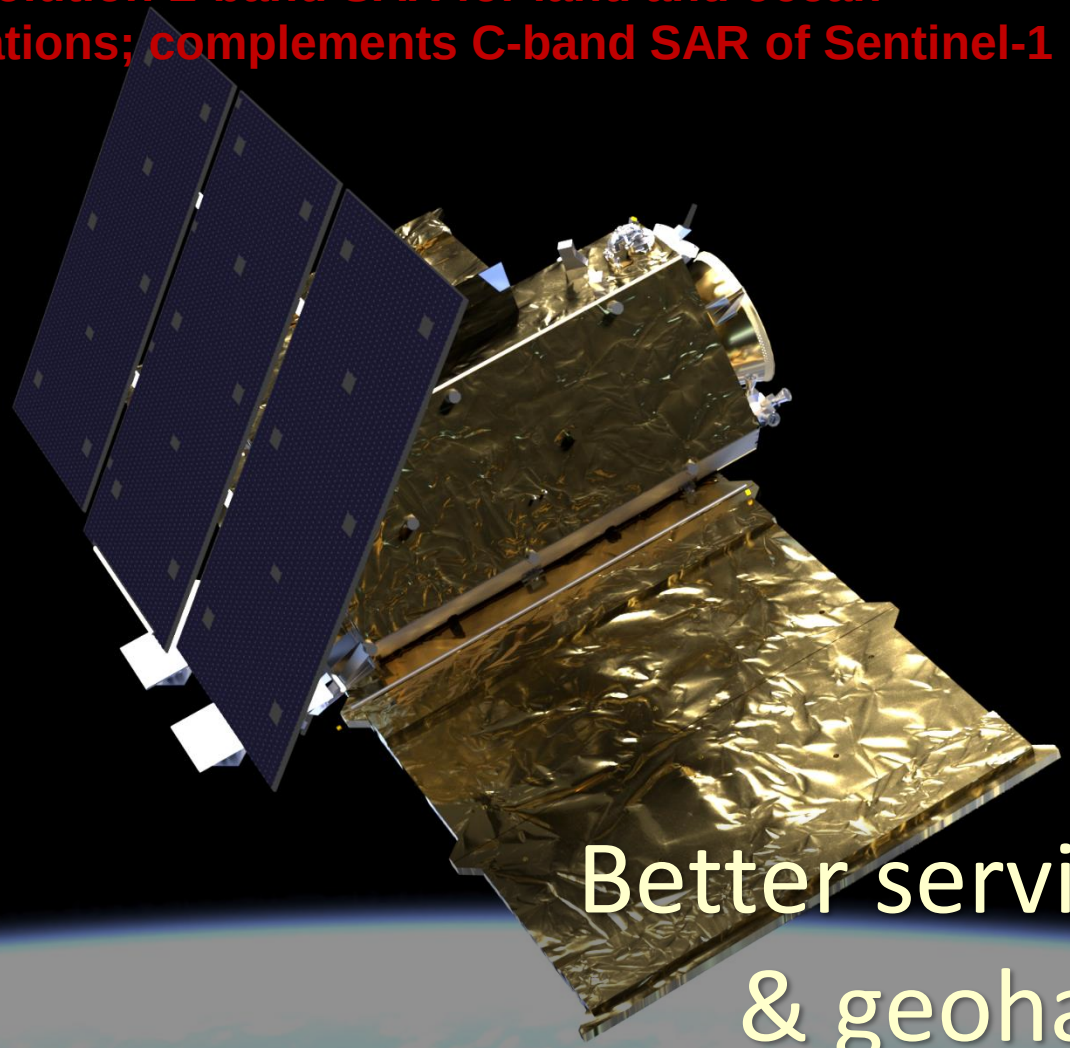
Expected launch A 2028 / B 2030

→ THE EUROPEAN SPACE AGENCY

ROSE-L

5m resolution L-band SAR for land and ocean applications; complements C-band SAR of Sentinel-1

L-band SAR system for Europe



Better services for disasters & geohazards, forests & agriculture management

Expected launch A 2028 / B 2030

Future evolution of satellite observing systems

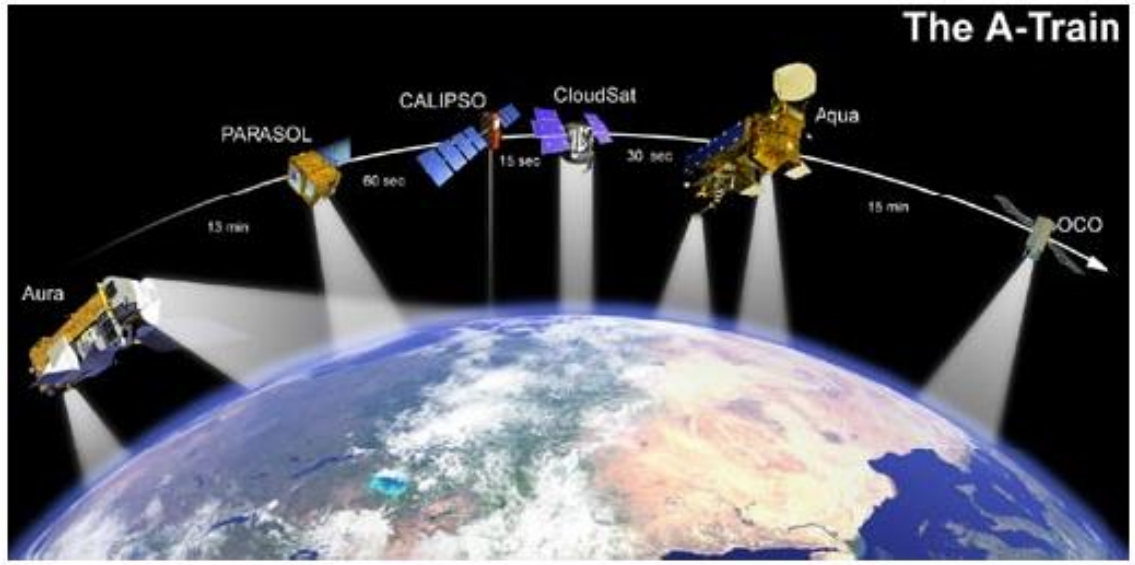
Stephen English

1. Recap on the current Satellite GOS
2. The WMO Integrated Global Observing System (WIGOS)
3. Future operational missions: EPS-SG, MTG, Sentinels
4. **Future research missions: EarthCARE, CubeSats**
5. Other: US, Asia, Other European efforts, commercial programmes

Stephen.English@ecmwf.int

ECMWF

EarthCARE: cloud radar and lidar



A-Train

Launched 2006

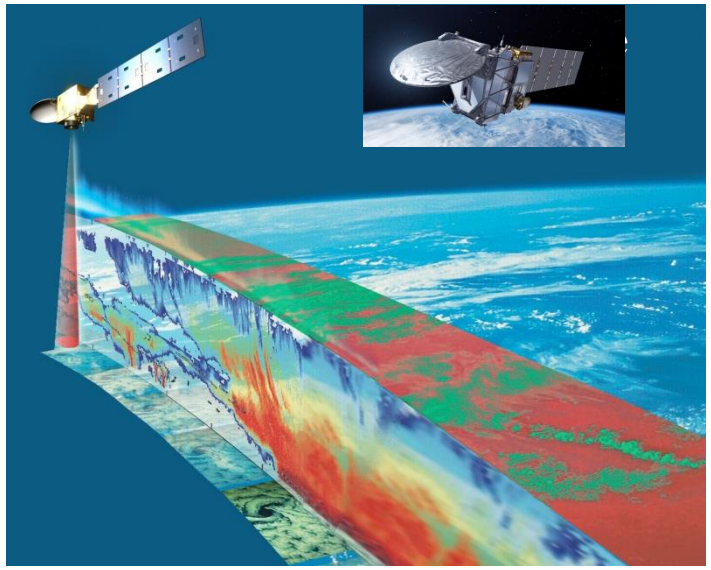
NASA

700-km orbit

CloudSat 94-GHz radar

CALIPSO 532/1064-nm lidar

MODIS, CERES and AMSR-E radiometers

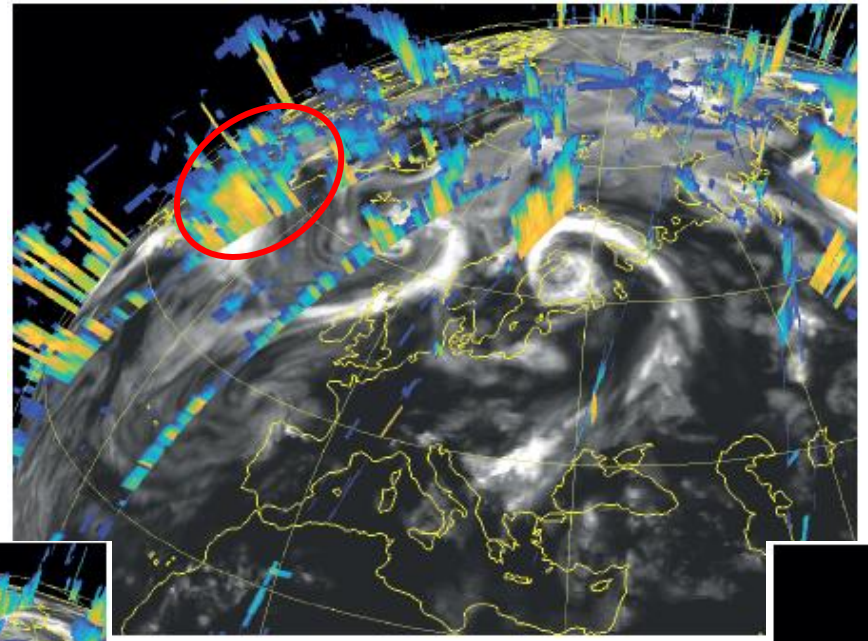


EarthCARE

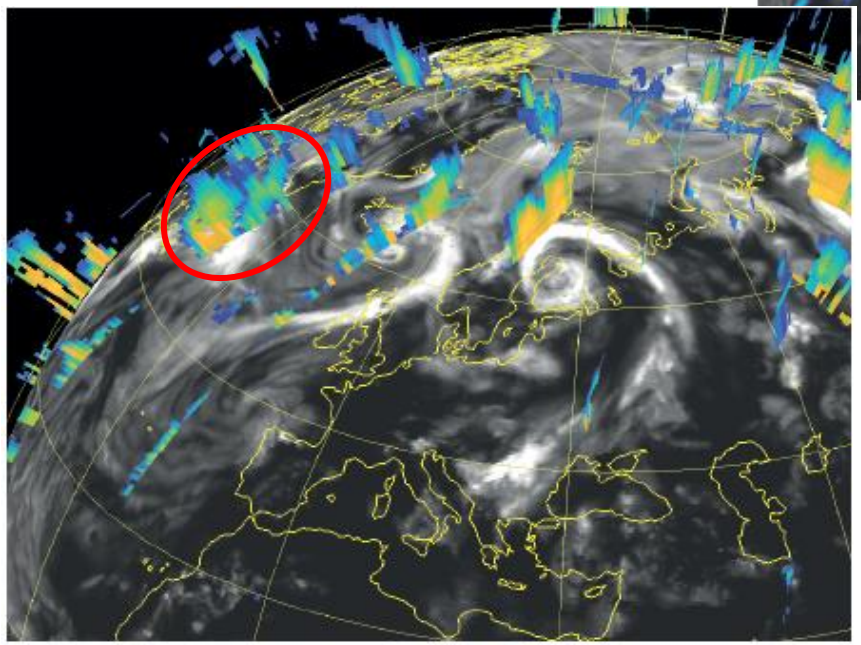
- **Expected launch May 2024**
- **ESA+JAXA**
- **400-km orbit (more sensitive)**
- **CPR: 94-GHz Doppler radar**
- **ATLID: 355-nm lidar**
- **MSI and BBR radiometers**

EarthCARE: 3D cloud structure from combined radar and lidar

CloudSat radar

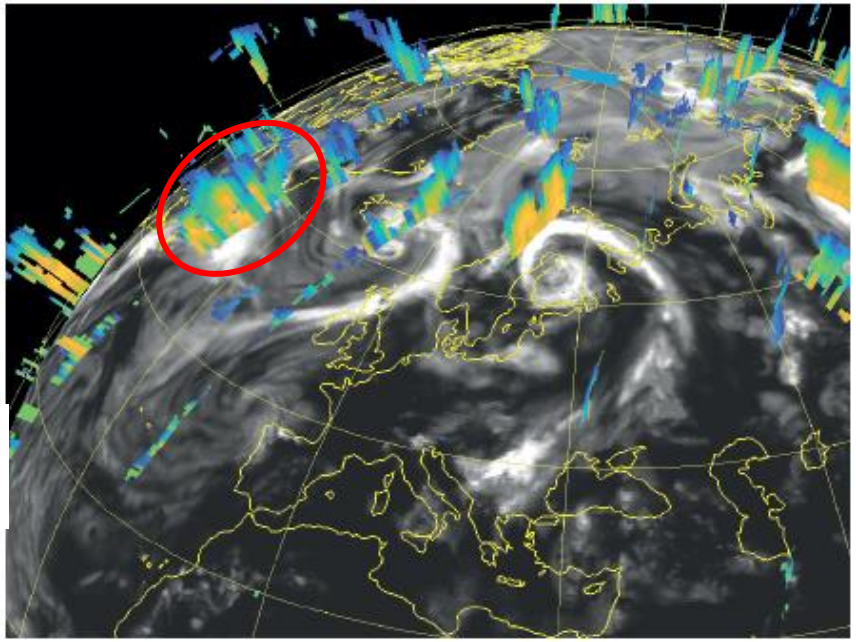


Experiments assimilating Cloudsat radar reflectivity (94 GHz) and CALIPSO lidar backscatter (532 nm)



First guess (FG)

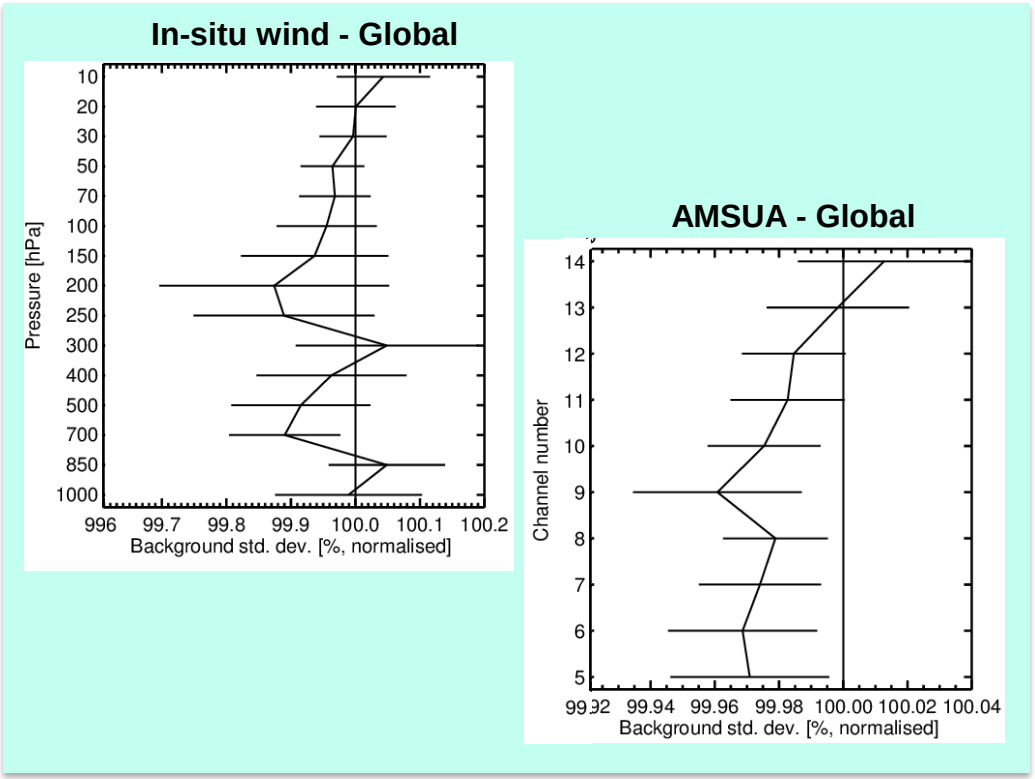
Analysis (AN)



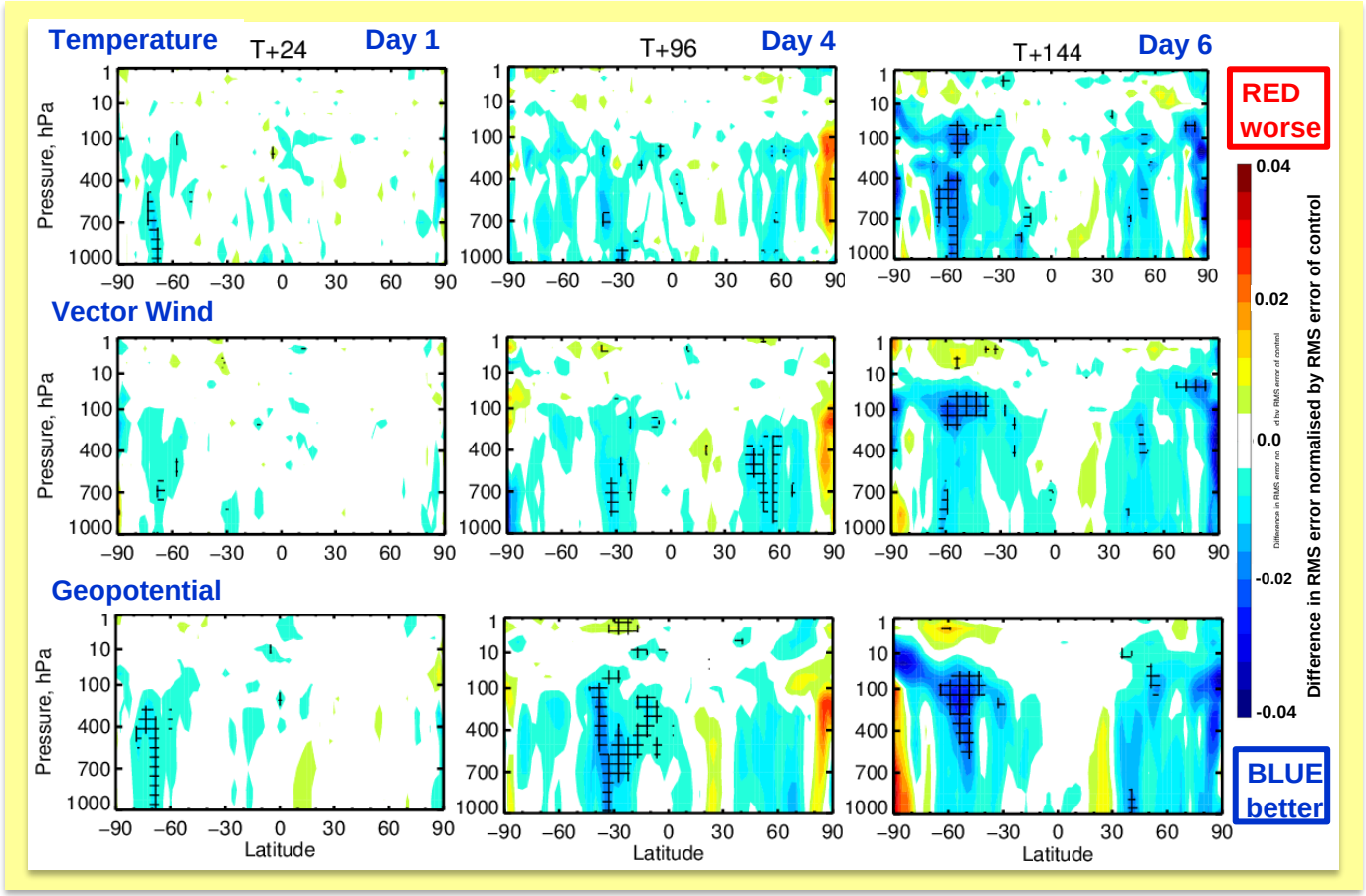
Situation: 20070731 21:00 UTC – 20070801 09:00 UTC

Courtesy of M. Janiskova

EarthCARE: Positive impact assimilating CloudSat and Calipso in all-sky framework



Improved fit to other assimilated observations



11-month period: 1 August 2007 – 31 October 2008

Thanks to Marta Janiskova and Mark Fielding (EarthCARE project)

Future evolution of satellite observing systems

Stephen English

1. Recap on the current Satellite GOS
2. The WMO Integrated Global Observing System (WIGOS)
3. Future operational missions: EPS-SG, MTG, Sentinels
4. Future research missions: EarthCARE
5. **Other: US, Asia, Other European efforts, commercial programmes**

Stephen.English@ecmwf.int

ECMWF

Satellite sizes

1U 10x10x10 cm Cubesat 1.3 kg

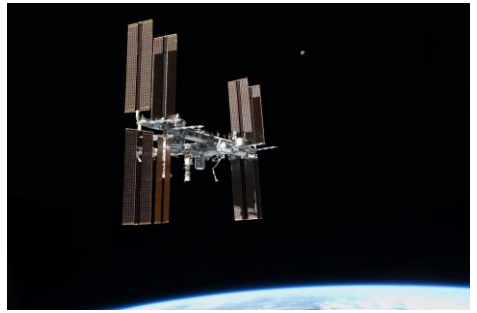
3U 3 x 10x10x10 cm Cubesat 4 kg
e.g. TROPICS

6U 6 x 10x10x10 cm Cubesat 12 kg
e.g. RainCube

Small satellite 3x2x2m 120 kg
e.g. ESA's AWS, ERS-1/2

Large satellite 17.6x6.5x5.2m 800 kg
e.g. Metop, ENVISAT, JPSS

The ISS 420,000 kg
= 500 Metop satellites!

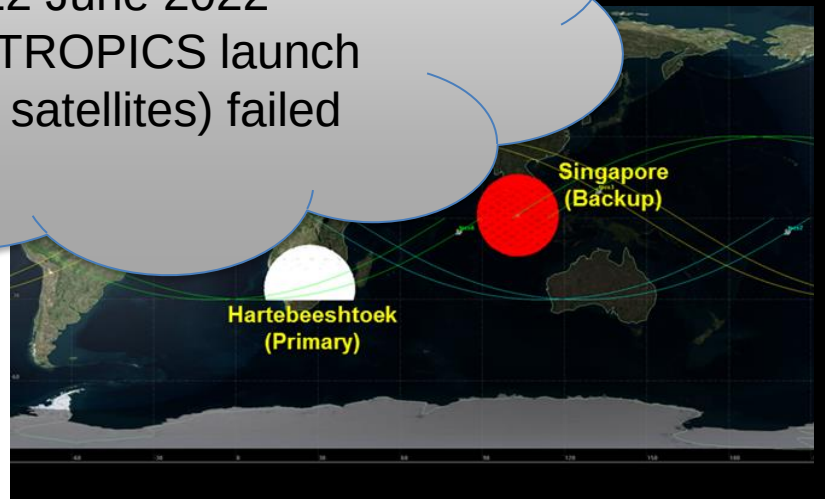


1 10 100 1,000 100,000 1,000,000

Car and bus indicate size not weight of these satellites!

TROPICS Mission Overview

12 June 2022
First TROPICS launch
(two satellites) failed

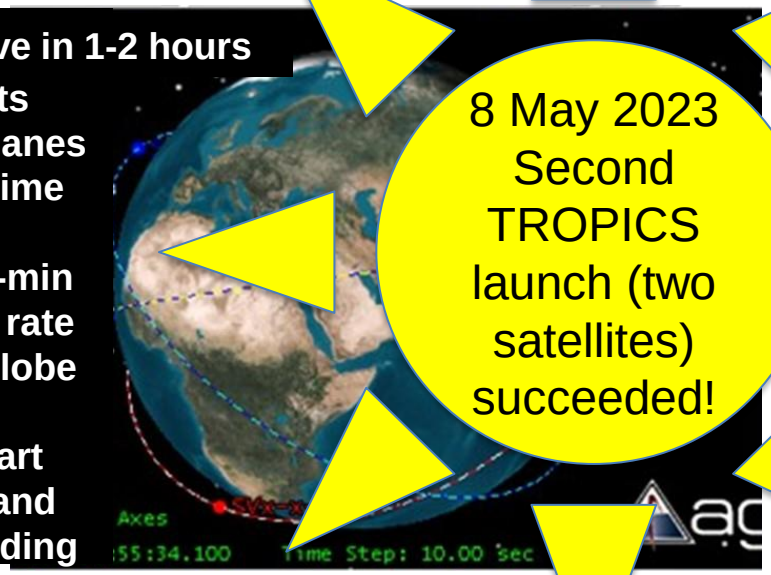


Significant % of data will arrive in 1-2 hours

Six CubeSats
Three orbital planes
15-month lifetime

Better than 60-min median revisit rate over most of globe

State-of-the-art temperature and moisture sounding



8 May 2023
Second
TROPICS
launch (two
satellites)
succeeded!

KSAT

Ground Station Network

BCT

Mission Operations Center

MIT LL

Science Operations Center

UW-SSEC

Data Processing Center

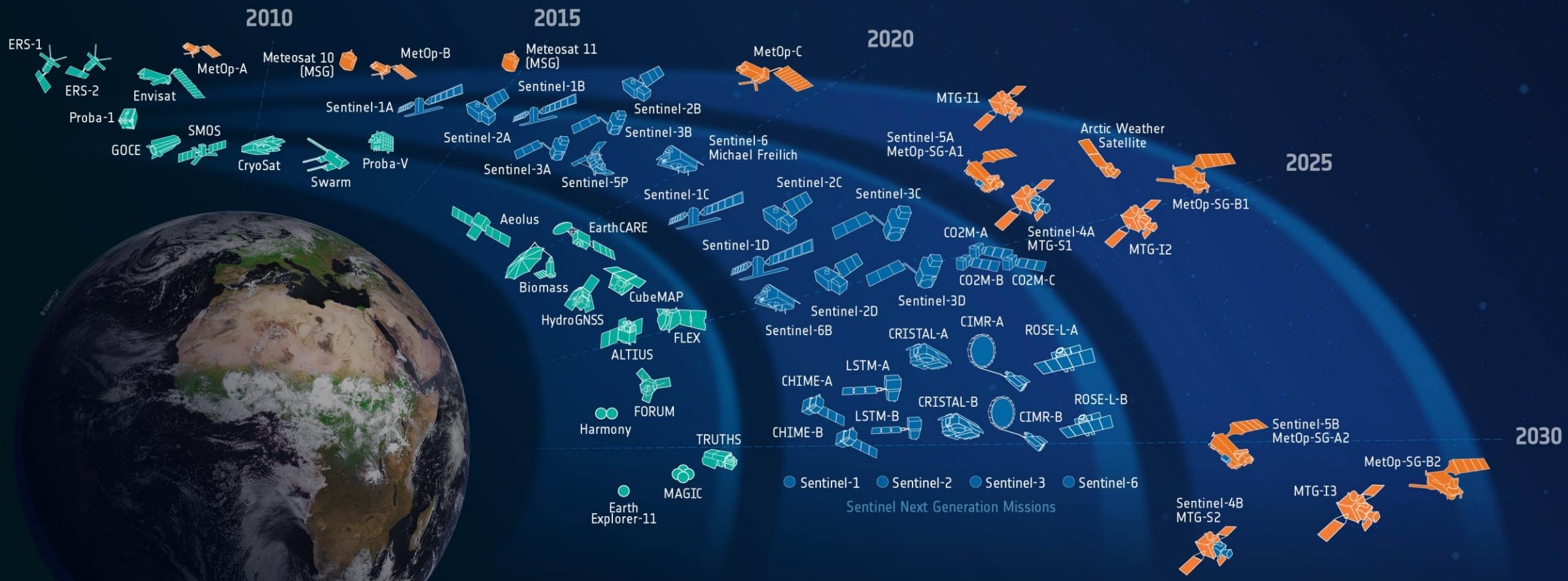
Courtesy of B.Blackwell TROPICS PI MIT

Other future programmes

- USA: LEO Post-JPSS mid 2030s - being planned
- China: LEO FY-5 late 2020s: likely to be mix of core satellite(s) plus free-flyers potentially making a constellation
- Commercial: constellations, MW and other ideas, especially from USA (Spire, Planetiq, Tomorrow.io etc)
- EPS-STERNA – potential European constellation of microwave small satellites
- EPS-Aeolus- (or Aeolus-2) – Follow on Doppler Wind Lidar to Aeolus
- ESA's Earth Explorer programme
  - EE11 on going (CAIRT, WIVERN, NITROSAT, SEASTAR) on-going
  - EE12 has some bids of interest to operational meteorology – reduction from 17 to 4 candidates to be announced soon

European Earth Observation Missions

We live in an incredible era for earth observation!!! Fantastic scope for research, innovation, impact.



Science esa Copernicus European Union Meteorology EUMETSAT