Future atmospheric observations: What might be important in the future, techniques to assess

Dorothee Coppens

Outline

- ✓ Overview of the EUMETSAT missions
- ✓ Focus on the current and future hyperspectral sounders
  - ✓ IASI experience
  - ✓ Future IASI-NG and MTG-IRS missions
  - ✓ Focus on the MTG-IRS challenges
- ✓ Atmospheric composition
- ✓ Overview of the other hyperspectral sounders missions

EUMETSAT

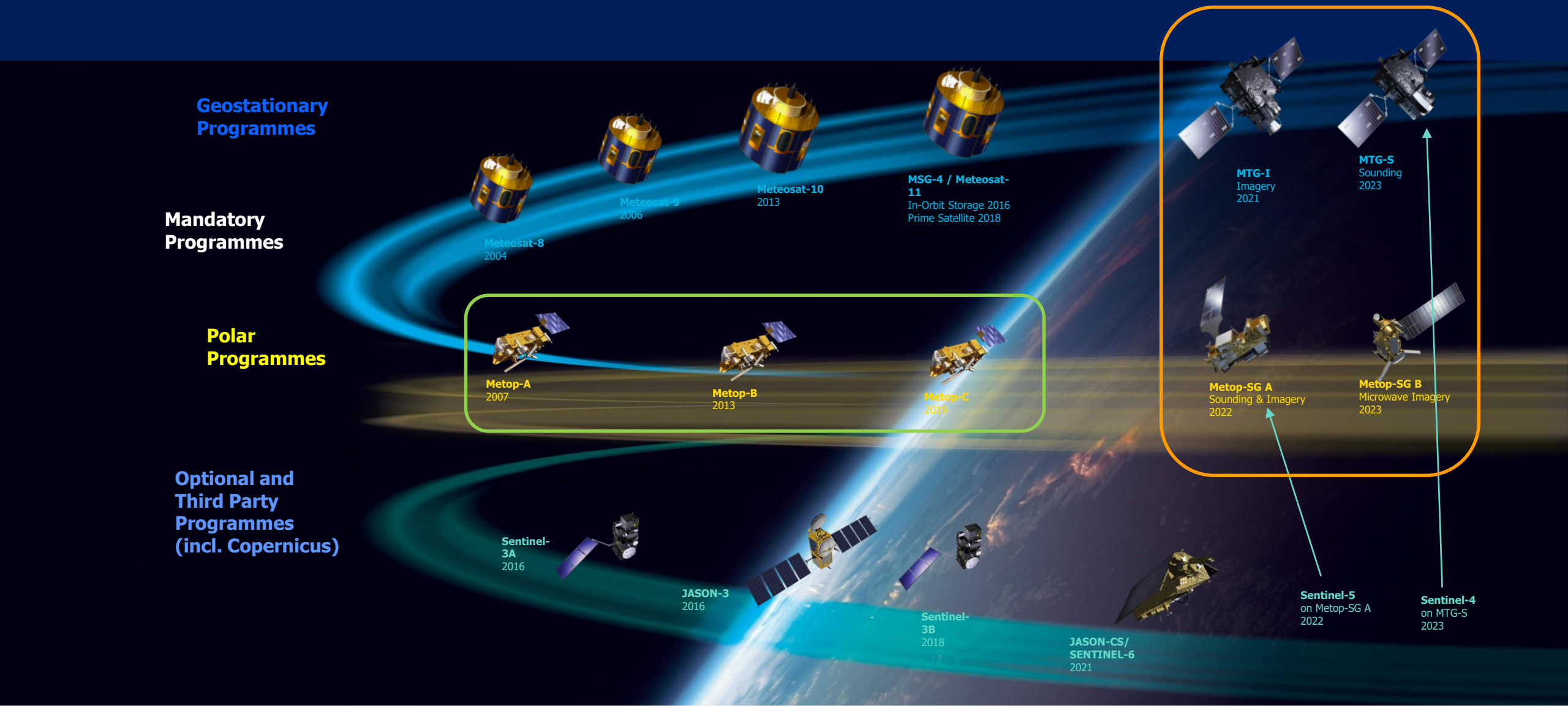
Who we are?

- ✓ EUMETSAT is the European operational satellite agency for monitoring weather, climate and the environment from space.
- ✓ We are an intergovernmental organisation based in Darmstadt, Germany, currently with 30 Member States.

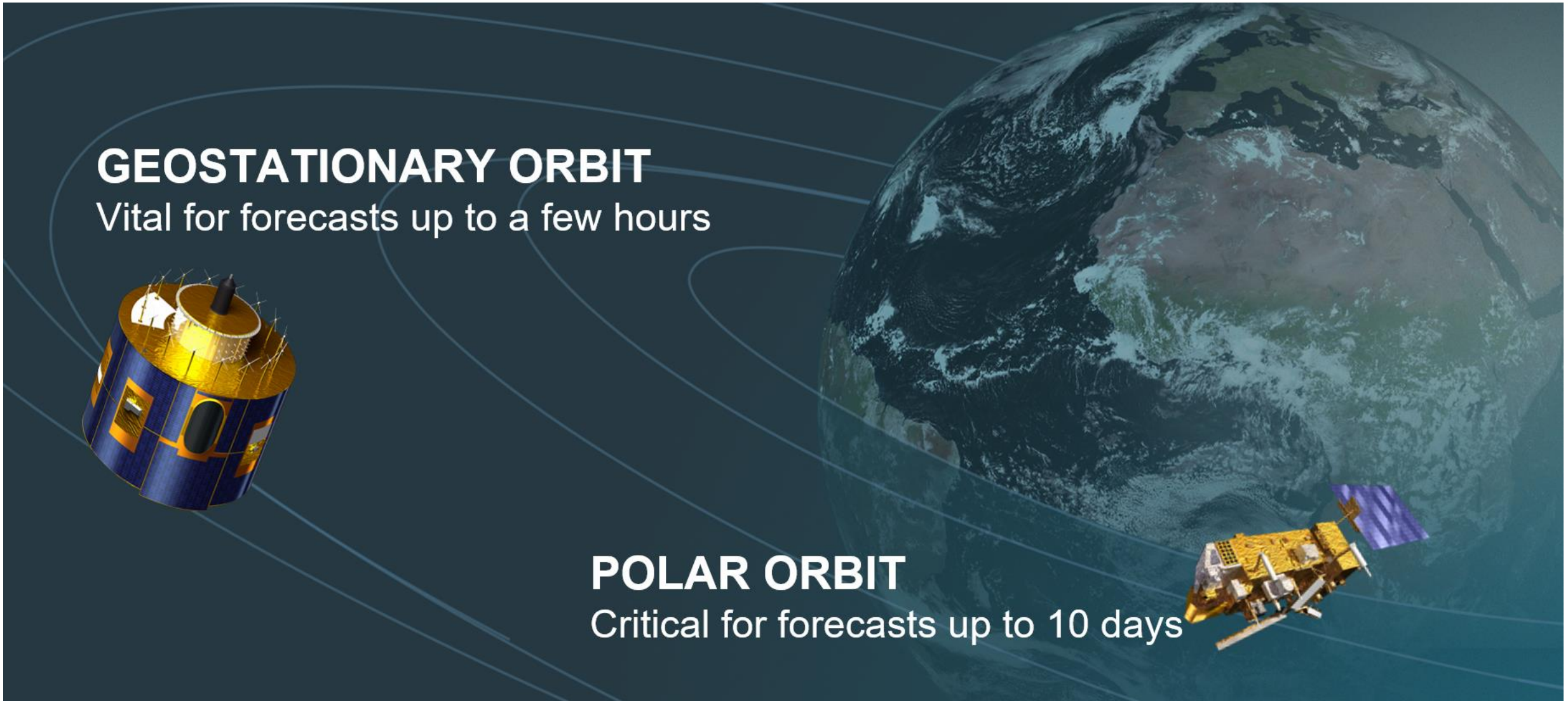
What do we do?

- ✓ We operate a system of meteorological satellites that observe the atmosphere and ocean and land surfaces – 24 hours a day, 365 days a year.
- ✓ This data is supplied to the National Meteorological Services of the organisation's Member and Cooperating States in Europe, as well as other users worldwide.

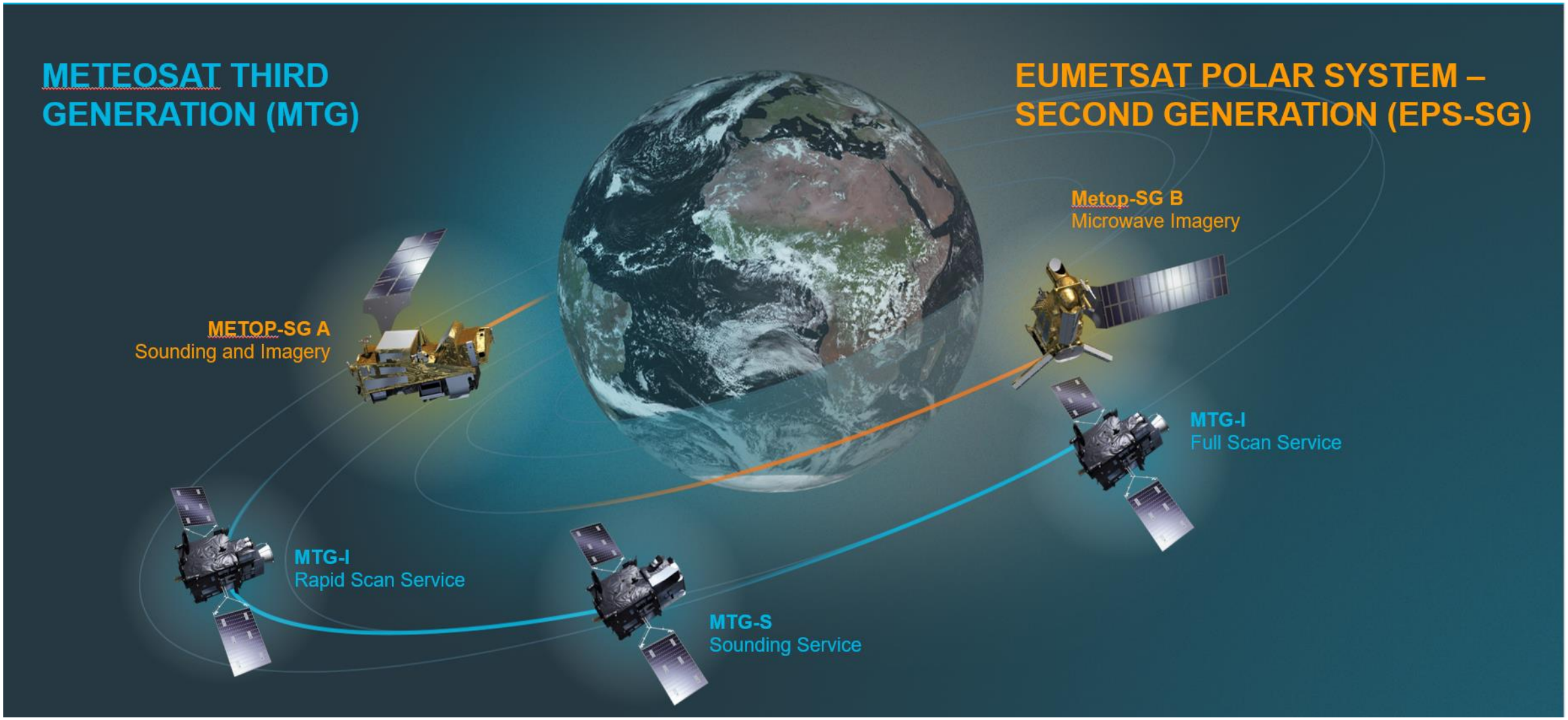
EUMETSAT missions – current and future



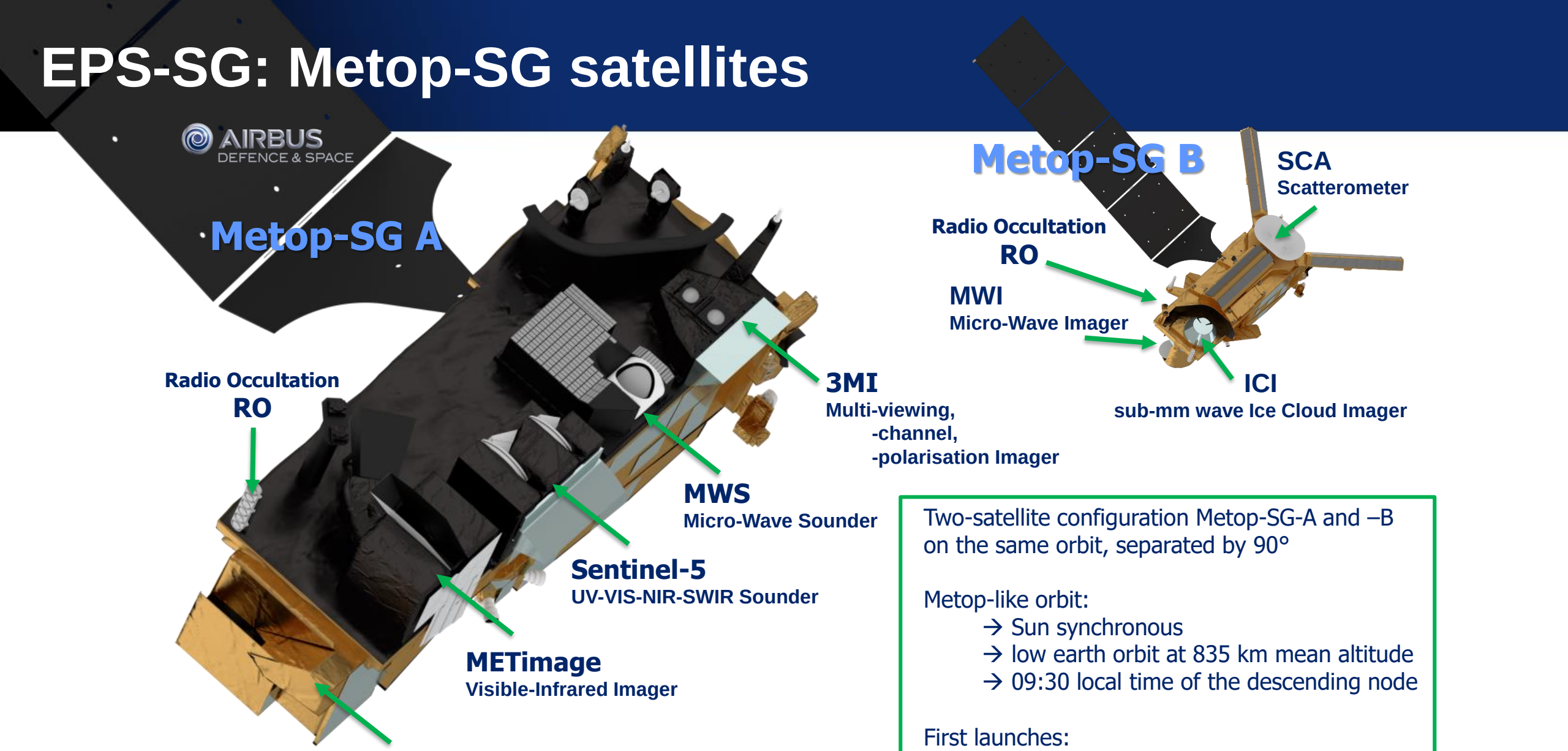
The need for two types of meteorological satellites



EUMETSAT Future focus: Two highly innovative programmes



EPS-SG: Metop-SG satellites



Two-satellite configuration Metop-SG-A and –B on the same orbit, separated by 90°

Metop-like orbit:
- → Sun synchronous
- → low earth orbit at 835 km mean altitude
- → 09:30 local time of the descending node

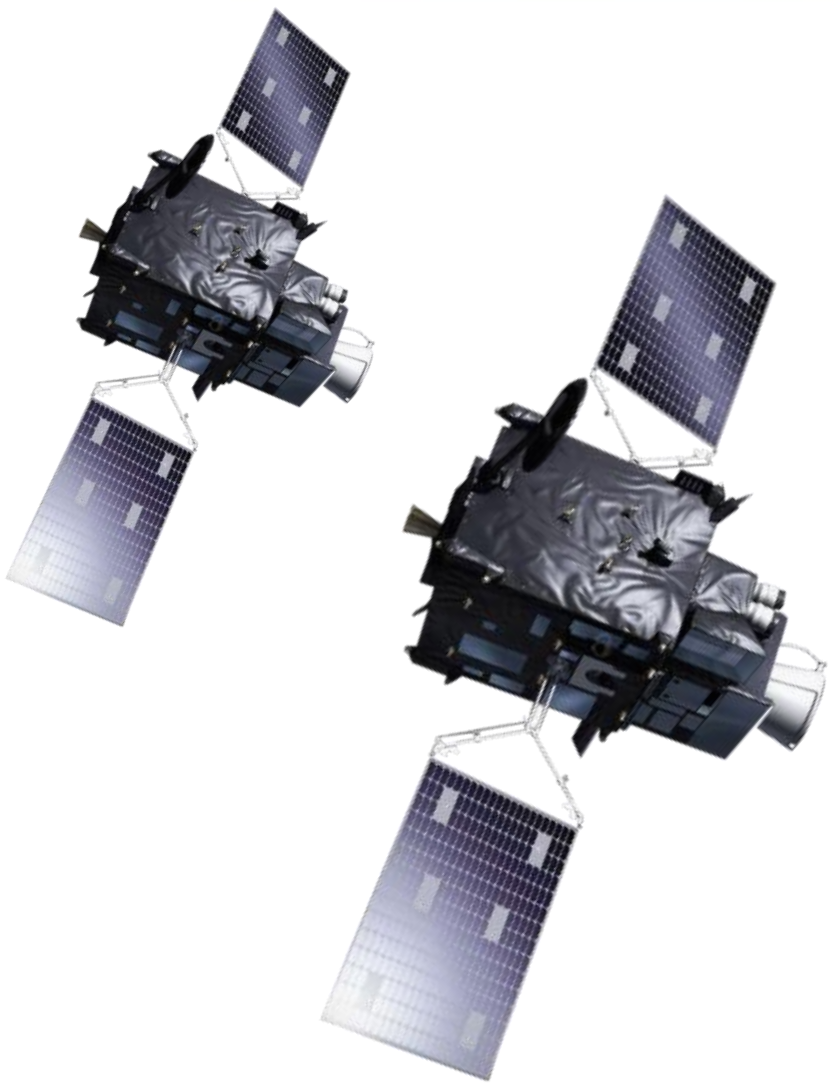
First launches:
- Metop-SG A1 → Early 2024
- Metop-SG B1 → Early 2025

EPS-SG benefits to activities of NMSs

Main Payload	Enhanced Capabilities	Innovative Capabilities	Applications Benefiting
High-Resolution Infrared Sounding **(IASI-NG)**	Higher spectral resolution (Twice better than IASI) + Better radiometric noise (half IASI)	More trace gases and their vertical profiles	NWP, NWC, AC, CM, Oceanography
Microwave Sounding **(MWS)**	Enhanced spatial over-sampling	Ice-cloud info in support of water-vapour profiling	NWP, NWC, CM, Hydrology
Radio Occultation Sounding **(RO)**	Large increase of number of radio-occultations	Tracking of Galileo, Beidou and QZSS signals	NWP, CM
Nadir viewing UV/VIS/NIR/SWIR Sounding **(Sentinel-5)**	Drastic increase of spatial resolution	Additional trace gas measurements; CO_2 being studied	Air Quality, CM, AC
VIS/IR Imaging **(METimage)**	Better radiometric and spatial resolution	Far more variables measured with higher accuracy	NWC, NWP, CM, Land-surface analysis, Oceanography, Hydrology
Scatterometry **(SCA)**	Higher spatial resolution and coverage	Cross polarisation for higher wind speeds	NWP, NWC, CM, Hydrology, Oceanography
Multi-viewing, -channel, -polarisation Imaging **(3MI)**	New mission	Aerosol parameters	Air quality, CM, NWC, Land surface analysis
Microwave Imaging **(MWI)**	New mission	Precipitation observations	NWP, NWC, Hydrology, CM, Oceanography
Ice Cloud Imaging **(ICI)**	New mission	Cloud microphysics parameters	NWP, NWC, Hydrology, CM

NWP: Numerical Weather Prediction; NWC: Nowcasting; CM: Climate Monitoring; AC: Atm. Composition

MTG-I imaging mission

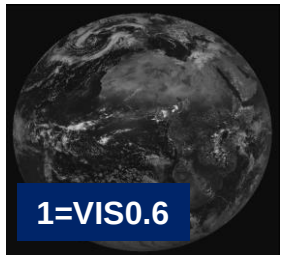


- Imagery mission implemented by two MTG-I satellites
- Full disc imagery every 10 minutes in 16 bands with the Flexible Combined Imager (FCI)
- Fast imagery of Europe every 2.5 minutes
- New Lightning Imager (LI)
- First launches:
  - MTG-I1 → Late 2022
  - MTG-I2 → 2025
- Start of operations in 2023
- Operational exploitation: ~2023-2043

MTG-S sounding mission

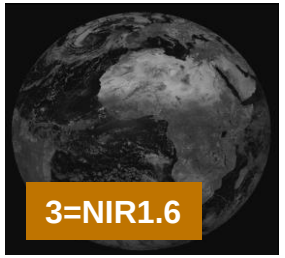
- Hyperspectral infrared sounding mission
- 3D weather cube: temperature, water vapour, O3, every 30 minutes over Europe
- Air quality monitoring and atmospheric chemistry in synergy with Copernicus Sentinel-4 instrument
- First launches:
  - MTG-S1 → Early 2024
- Start of operations in late 2024/early 2025
- Operational exploitation: ~2024-2044

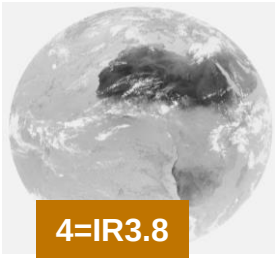
CURRENT AND FUTURE IMAGERS CHANNELS: MSG SEVIRI AND MTG FCI

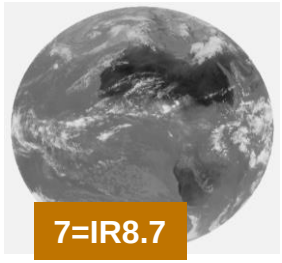


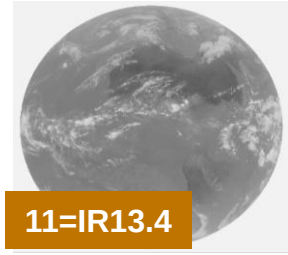
SSD: 1km

SSD: 3km



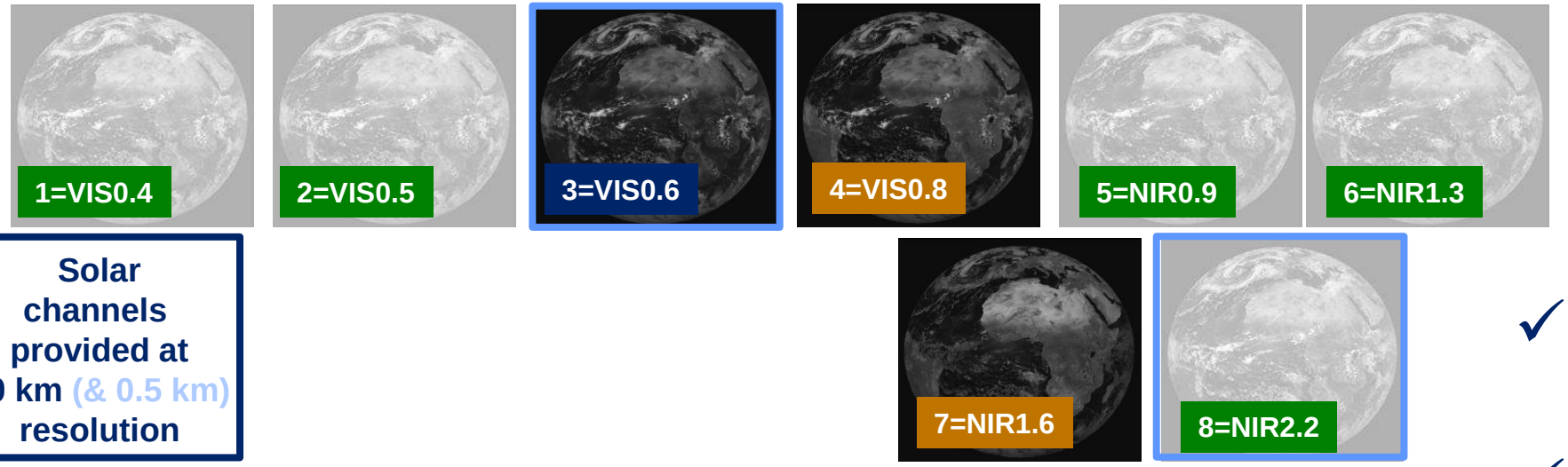




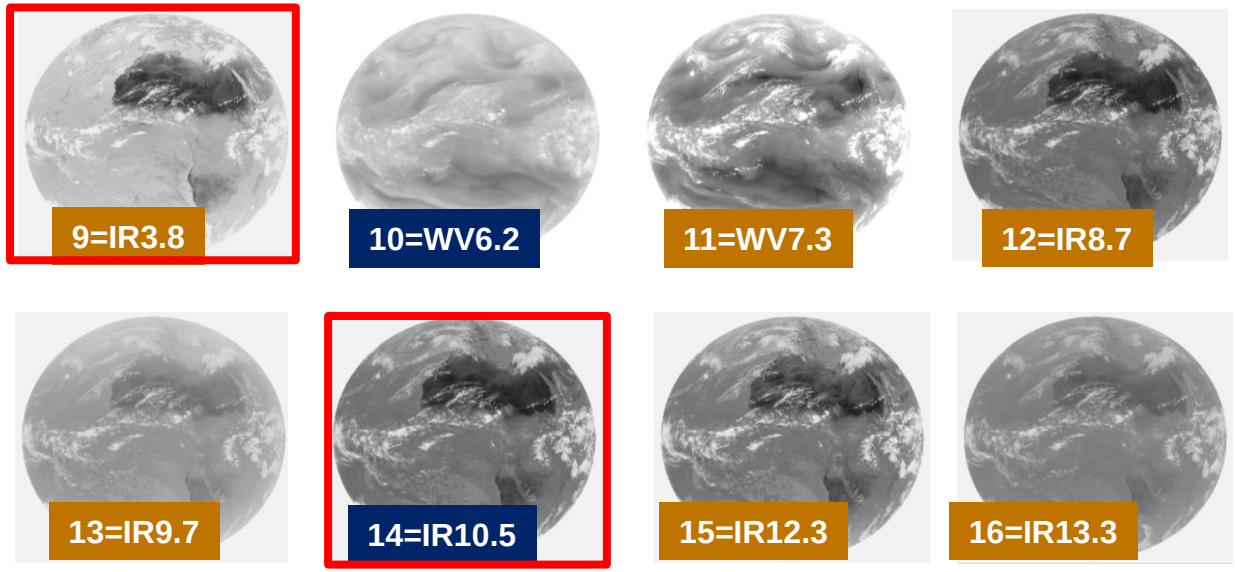


Current SEVIRI

CURRENT AND FUTURE IMAGERS CHANNELS: MSG SEVIRI AND MTG FCI



Solar channels provided at 1.0 km (& 0.5 km) resolution



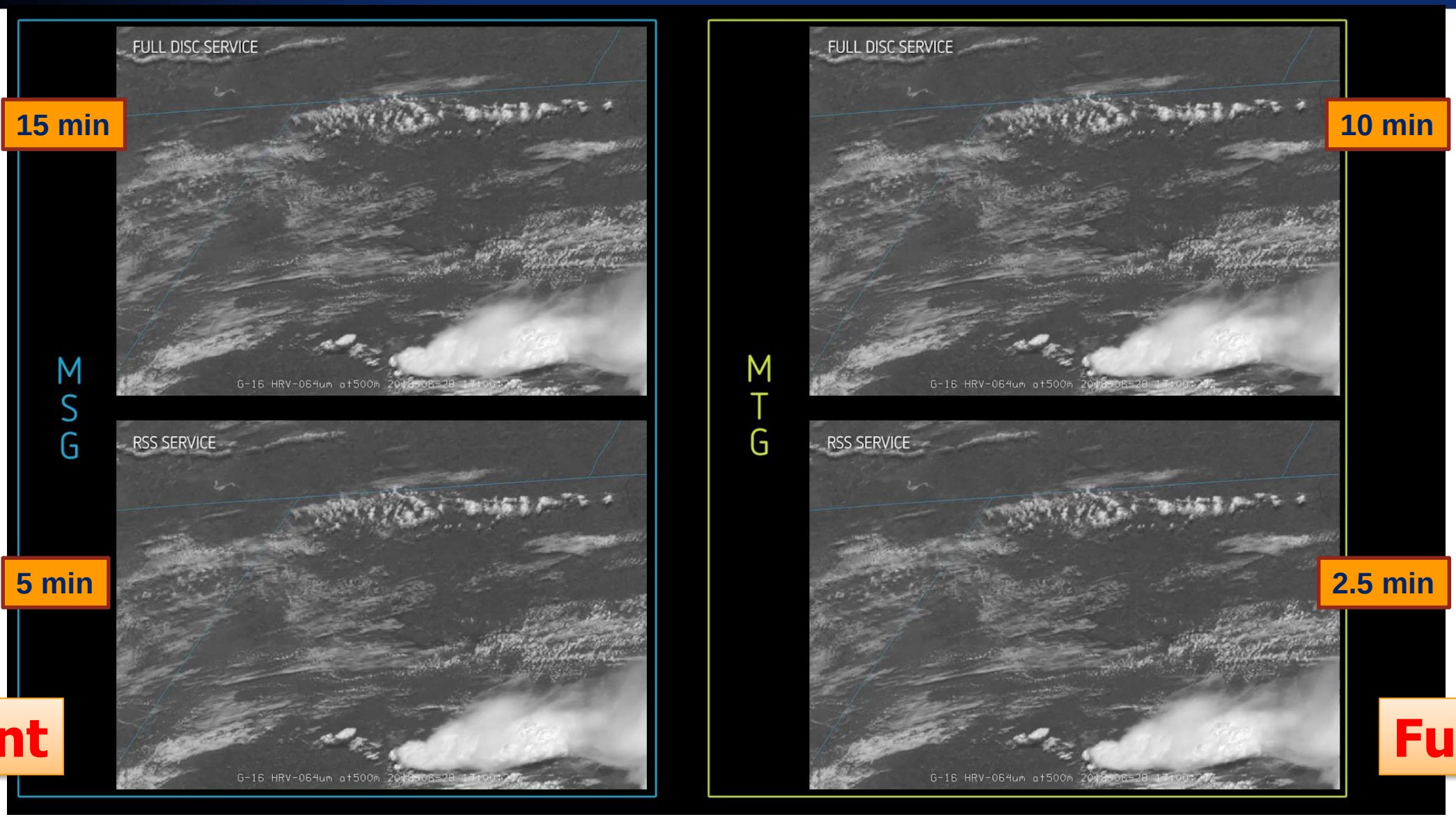
Thermal channels provided at 2 km (& 1 km) resolution

✓ **Continuity**

✓ **Innovation**

Future FCI

MTG Imager (FCI): New insights through higher temporal resolution



MTG Lightning imaging mission

- Lightning is a precursor of severe weather, with a lead time of tens of minutes
- Most ground-based lightning location systems are mainly sensitive to cloud-to-ground lightning (CG)
- Often, no increase in CG due to “weather intensification” observable → Total lightning is the parameter of interest

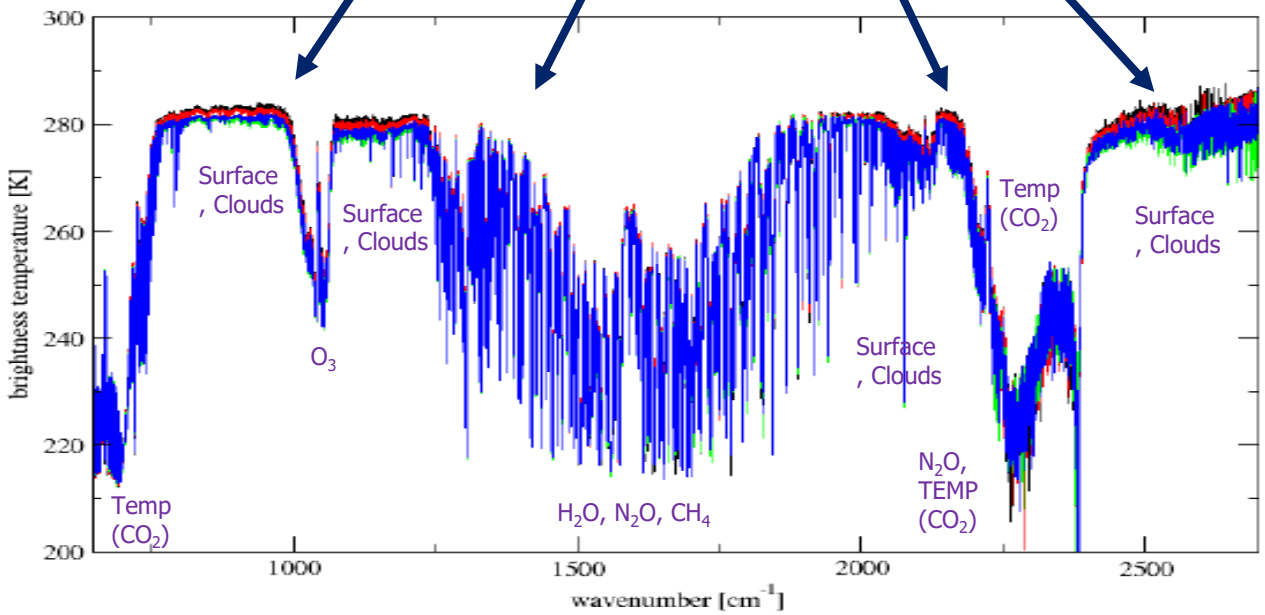
Total lightning =
cloud-to-ground
+ cloud-to-cloud lightning

Hyperspectral sounders

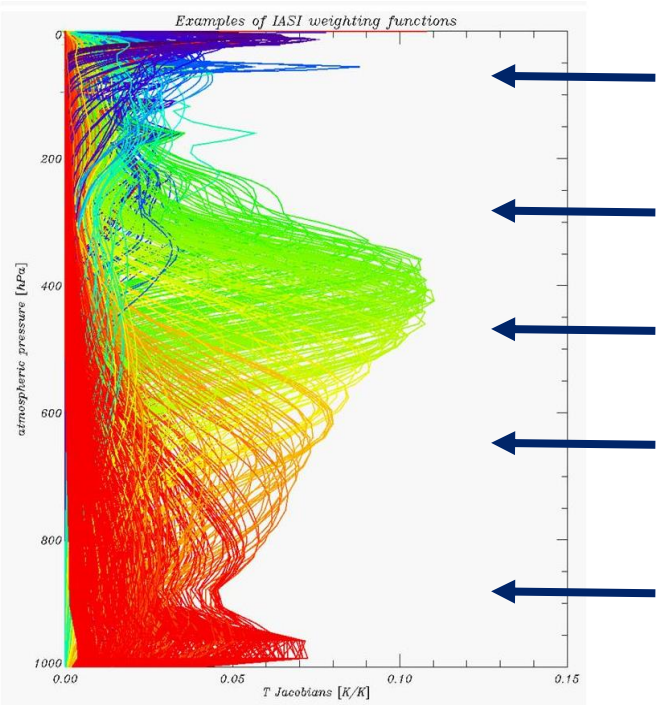
Both programmes will have an Hyperspectral sounder

- ✓ **The first hyperspectral sounder part of the EUMETSAT programme was launched on Metop-A in 2006**
- ✓ **It was a step forward in infrared sounding, as it was the first one providing continuous spectra with 8461 channels:**

➔ Many atmospheric variables…

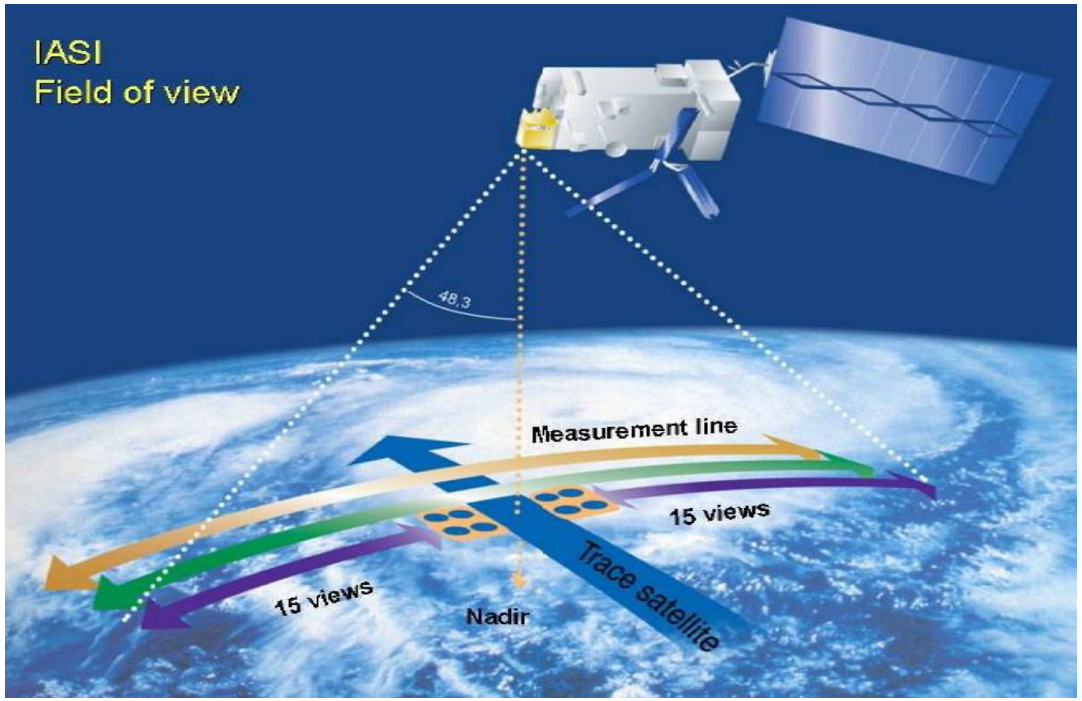


➔ More than 25 species can be observed



… located at different altitudes

Current hyperspectral infrared sounder: IASI



IASI	
Spectral characteristics	
Maximum OPD	2 cm
Spectral resolution	0.5 cm^{-1}
Spectral sampling	0.25 cm^{-1}
Spectral coverage	645-2760 cm^{-1} (3 bands are merged)
Spectral accuracy	< 2 ppm
Radiometric characteristics	
Radiometric noise	0.5 K
Geometric characteristics	
Field of view	12 km
Swath width	2100 km
Detector matrix	2x2 pixels covering 50x50 km^2

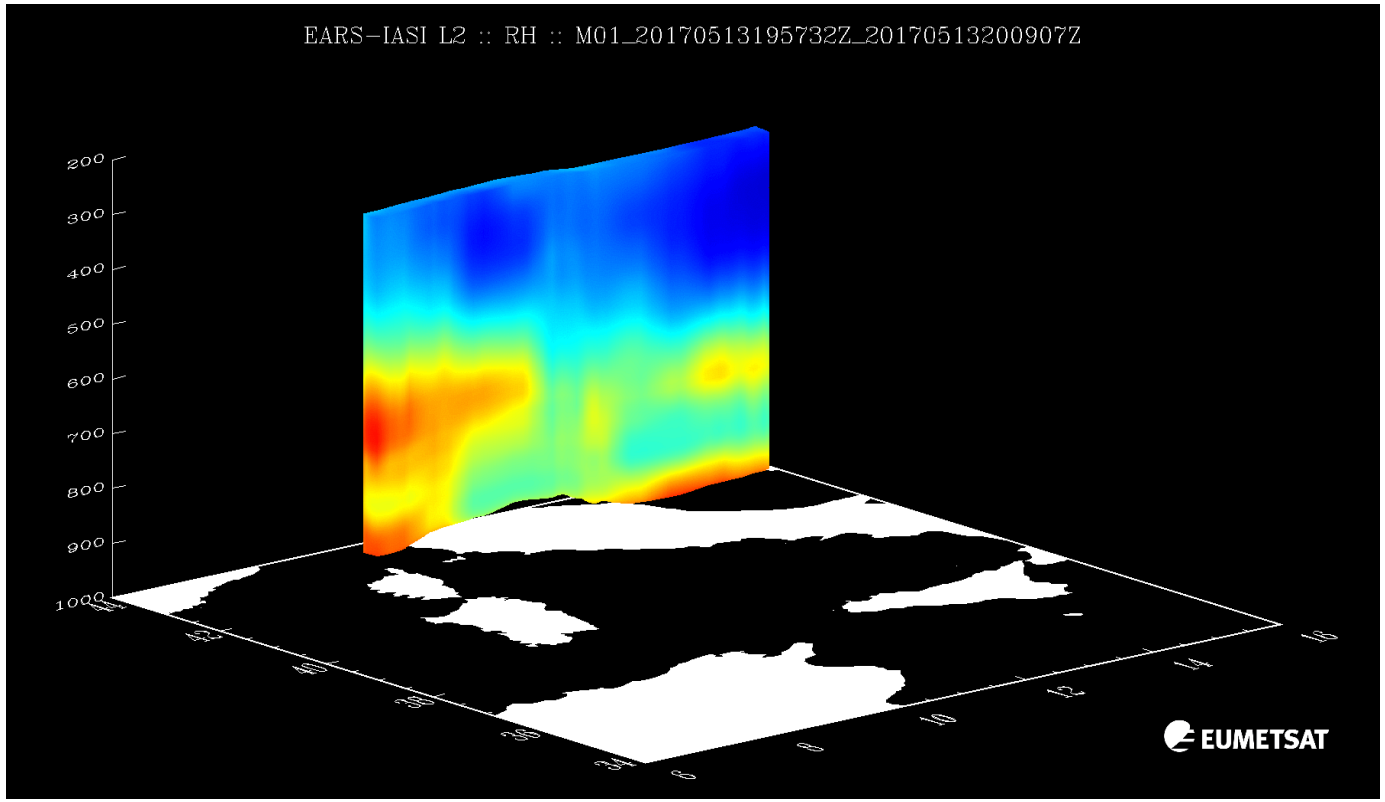
Normal Operation Mode

- ✓ Scanning the swath
- ✓ (30 Earth views + 2BB + 2CS) / 8 seconds

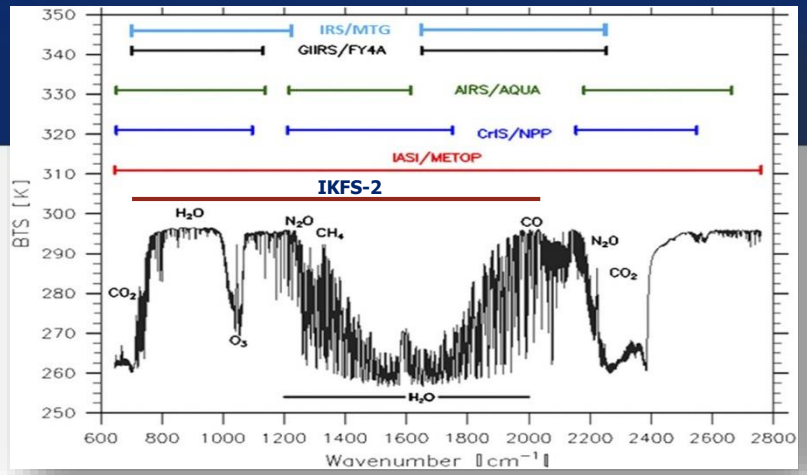
Flying IASI: 3 polar orbiting instruments on:

- ✓ Metop-A since October 19th, 2006
- ✓ Metop-B since September 17th, 2012
- ✓ Metop-C since November 7th, 2018

IASI Temperature and Humidity in 3D



IASI – Very well calibrated

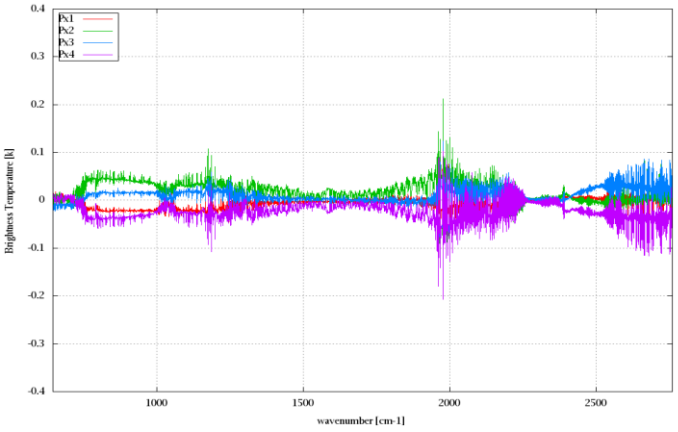


IASI:

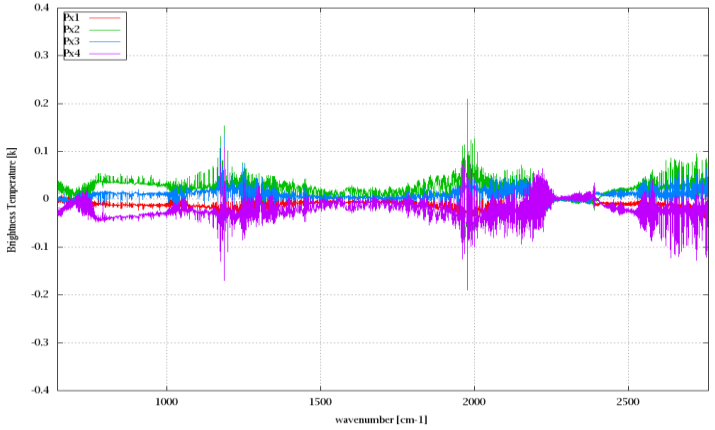
- ✓ **Provides continuous spectra from 3.62 to 15.5 µm**
- ✓ **Fine spectral sampling of 0.25 cm^{-1}**
- ✓ **Accurate radiometric and spectral calibration**

➔ **Very good stability and accuracy over the 3 Metops**

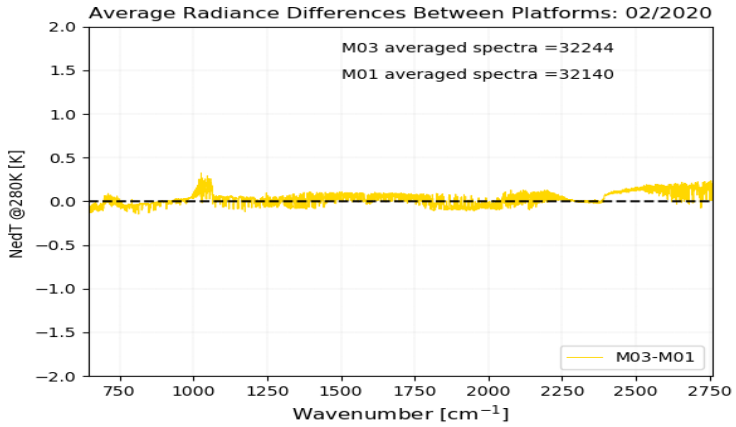
IASI-A annual inter-pixel stability



IASI-B annual inter-pixel stability



(IASI-C-IASI-B) for 1 month



➔ **IASI is a worldwide GSICS reference for all infrared sounders and imagers**

IASI used as a reference

Because of IASI very good stability and accuracy, it is taken as a reference for all any cross-calibration of the other hyperspectral instruments, but IASI (IASI-NG, IRS) does not provide an absolute calibration.

Only such instrument like Infrared Absolute Radiance Interferometer (ARI) for CLARREO (Climate Absolute Radiance and Refractivity Observatory) or TRUTH (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) mission would establish an SI-traceable space-based climate and calibration observing system to improve confidence in climate-change forecasts – a kind of 'standards laboratory in space'.

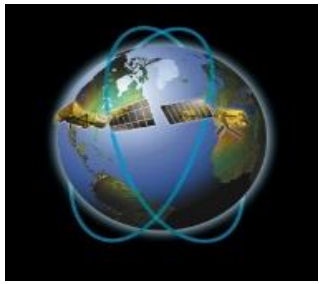
Moon calibration experiment with IASI is on-going at CNES to give IASI an absolute calibration target.

Programmes including hyperspectral IR sounders

Future Hyperspectral Infrared instruments operated by EUMETSAT will be flying on two kind of satellites:

Future Polar orbit Mission

The EPS-SG (EUMETSAT Polar System - Second Generation) program with the IASI-NG (IASI - New Generation) instruments, on three satellites from 2023 onwards, will be a continuation of the EPS program with three flying IASI instruments on the Metop satellites.



Future Geostationary mission

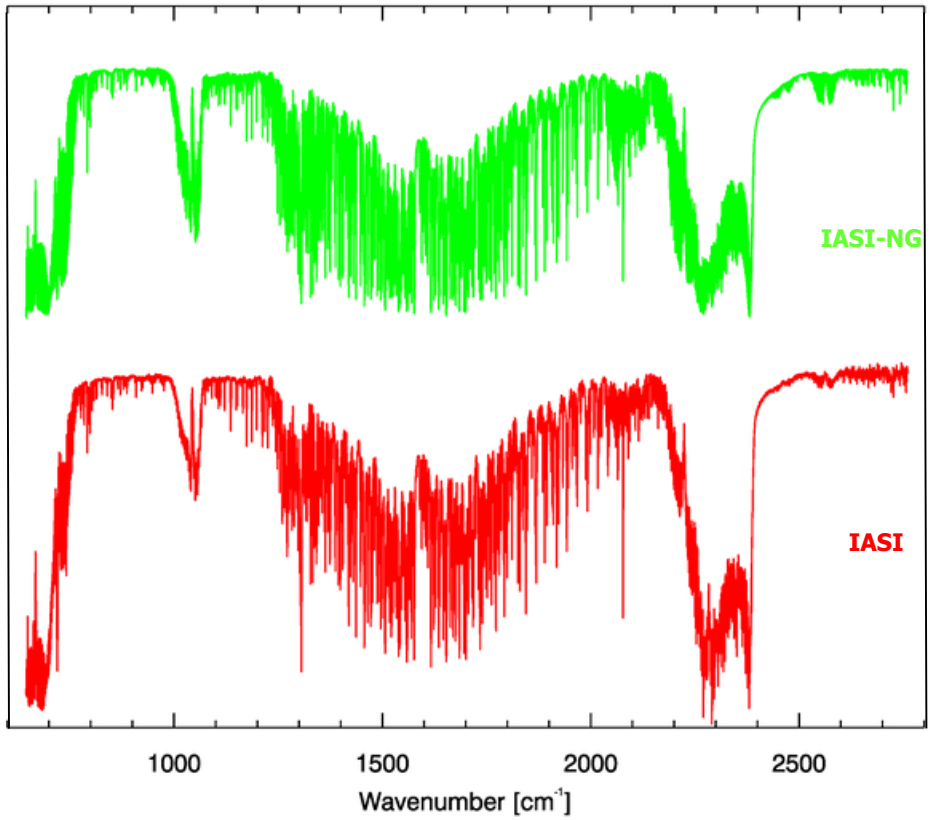
A step forward wrt IASI, with an hyperspectral sounder, the IRS (InfraRed Sounder), on-board the Meteosat Third Generation (MTG). MTG will see the launch of six new geostationary satellites from 2021 onwards. The satellite series will be based on 3-axis platforms and comprise:
Four Imaging Satellites (MTG-I) (20 years of operational services expected)
Two Sounding Satellites (MTG-S) (15.5 years of operational services expected)

The IRS (InfraRed Sounder) will be flying on MTG-S satellites.

IASI-NG mission on LEO orbit

IASI-NG is a continuation of the IASI mission: Michelson interferometer + Mertz compensation:

- ✓ **Same scanning mode than IASI**
- ✓ **Maximum OPD: 4 cm (on ground) i.e. a spectral sampling (0.125 cm^{-1}) and resolution of 0.25 cm^{-1} ➔ Better than IASI (0.25 cm^{-1} and 0.5 cm^{-1} respectively)**
- ✓ **Detector: 12 km resolution at nadir**
- ✓ **Spectral coverage: 645 - 2760 cm^{-1}**
- ✓ **Half of the IASI radiometric noise**



IASI-NG mission

Breakthrough

- **Doubling of spectral and increase of radiometric resolution of IASI for the benefit of weather forecast and atmospheric composition**
  - 75% more information in temperature profiling, particularly PBL
  - 30 % more information in water vapour profiling
  - Quantification of trace gases which are currently only detected
  - Vertical resolution of trace gases instead of columnar amounts only

Objectives / products

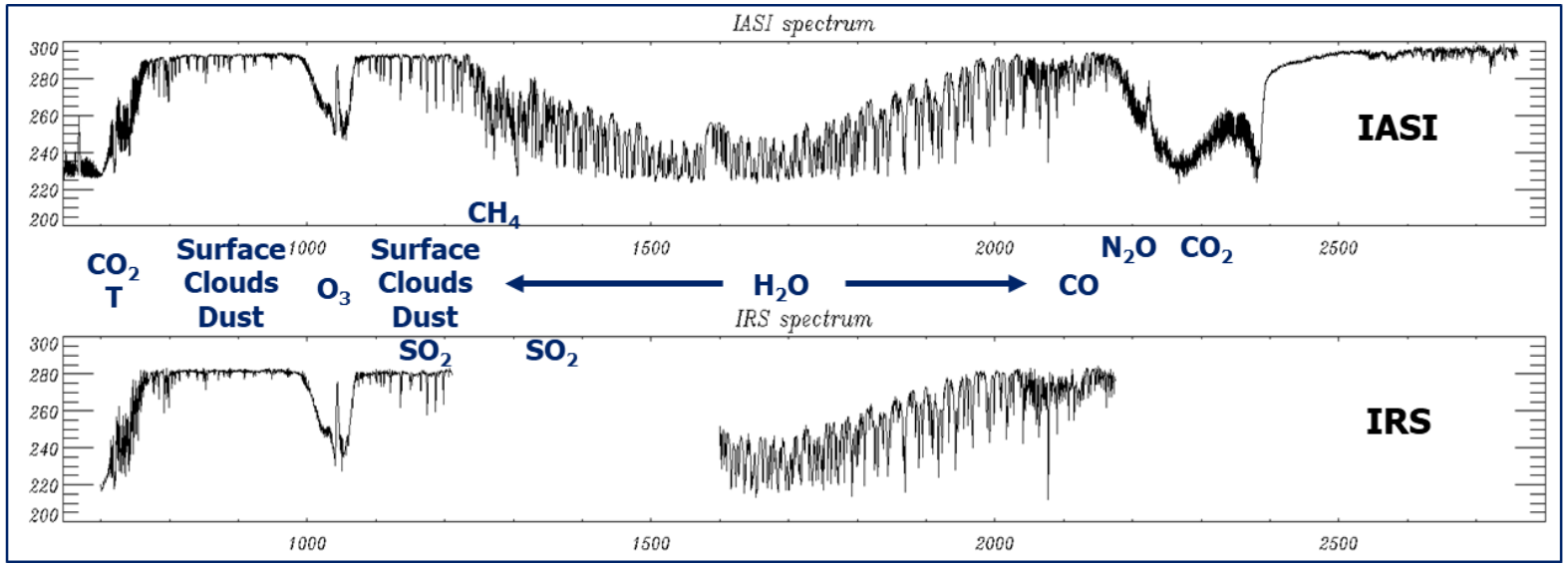
- ✓ Temperature/humidity profile at high vertical resolution in clear air
- ✓ Clouds, trace gases (O3, CO, CH4, CO2,...)
- ✓ Sea/land/ice surface temperature
- ✓ Aerosols, Volcanic Ash

Applications benefitting

- ✓ Numerical weather prediction
- ✓ Nowcasting
- ✓ Climate monitoring
- ✓ Oceanography
- ✓ Atmospheric composition

MTG Infra-Red Sounder (IRS) on GEO orbit

Operational spectro-imagery at high spectral, spatial & temporal resolution



Two spectral bands:

- ✓ **LWIR: 680 to 1210 cm^{-1} (8.26–14.70 µm)**
- ✓ **MWIR: 1600 to 2250 cm^{-1} (4.44–6.25 µm)**

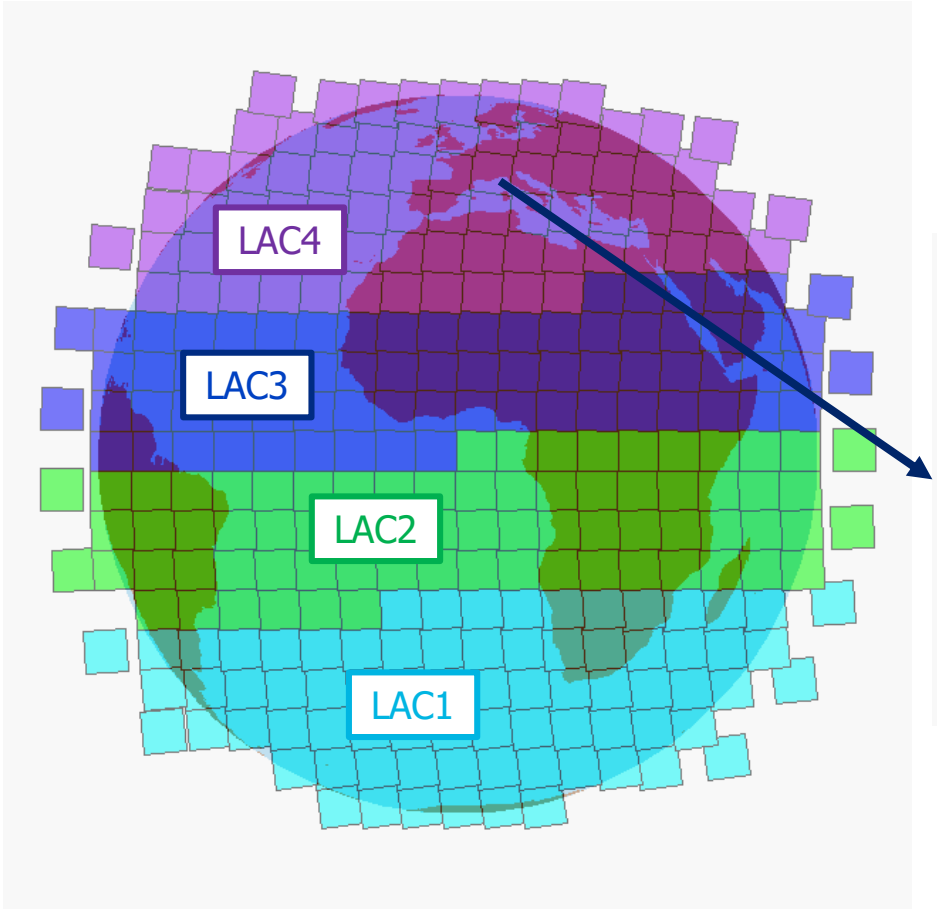
Spectral sampling: ~0.6 cm^{-1}
Spatial resolution :4 km at nadir spatial

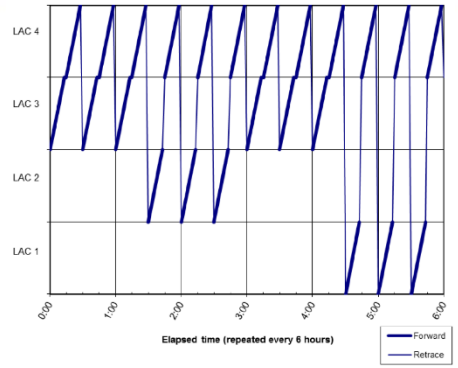
Applications benefitting

- ✓ Numerical weather prediction
- ✓ Nowcasting
- ✓ Climate monitoring
- ✓ Oceanography
- ✓ Atmospheric composition

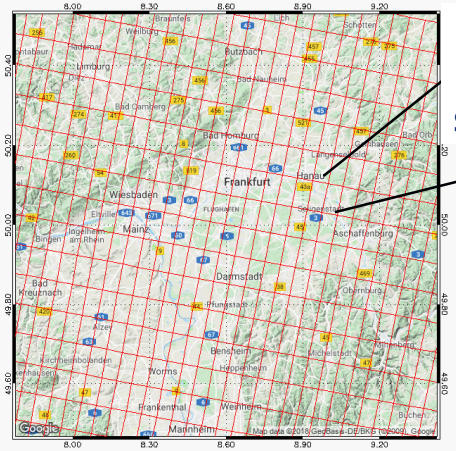
MTG Infra-Red Sounder (IRS) scanning sequence

- ✓ The Earth disk is split in 4 Local Area Coverage (LAC) zones, each of them covered in 15 min by a succession of “steps and stares” called dwells
- ✓ LAC4 (northern mid-latitudes) will be covered every 30 minutes
- ✓ LAC1, 2, 3 will be alternatively viewed in-between

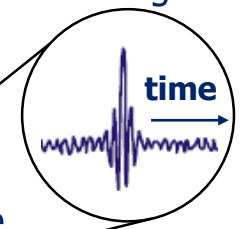




Each dwell consists of 160x160 pixels (4km resolution) yielding a high spatial sampling

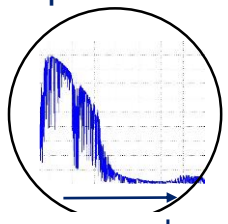


Single spatial sample



Interferogram

L0



Spectrum

L1

25600 spectra every 10 s

Dissemination

- ✓ **There are 12 LAC1, 12 LAC2, 24 LAC3 and 48 LAC4 /day**
- ✓ **Size of a LAC is ~ 1.1Go**

New technologies → New calibration processing

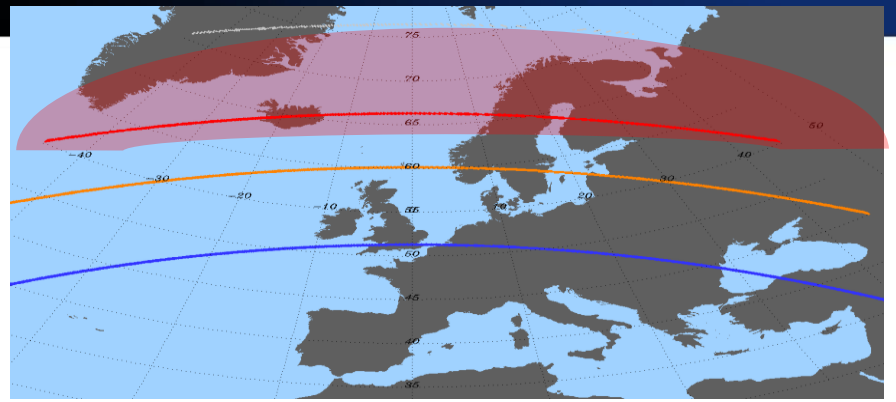
	IASI	IASI-NG	IRS
	Instrument Single laser	Instrument Multiple lasers Field compensation (hardware)	Instrument Multiple lasers
On-board	On-board processing Non-linearity correction Spike detection Radiometric calibration	On-board processing Non-linearity correction Spike detection	On-board processing Non-linearity correction Spike detection Field compensation (software)
On-ground	L1 processing Spectral calibration Spectral resampling Spectral shape removal and strong apodisation	L1 processing Spectral calibration and shape removal Strong apodisation Spectral resampling Radiometric calibration	L1 processing Light apodisation Radiometric calibration Spectral calibration Spectral resampling Spectral shape removal

- ✓ Different place to apply the radiometric calibration
- ✓ New: field compensation (software and hardware) leads to different spectral calibration
- ✓ Different apodisation function
- ✓ Different places to remove the instrument Spectral Response Function (Spectral unformisation)

Challenges of MTG-IRS mission

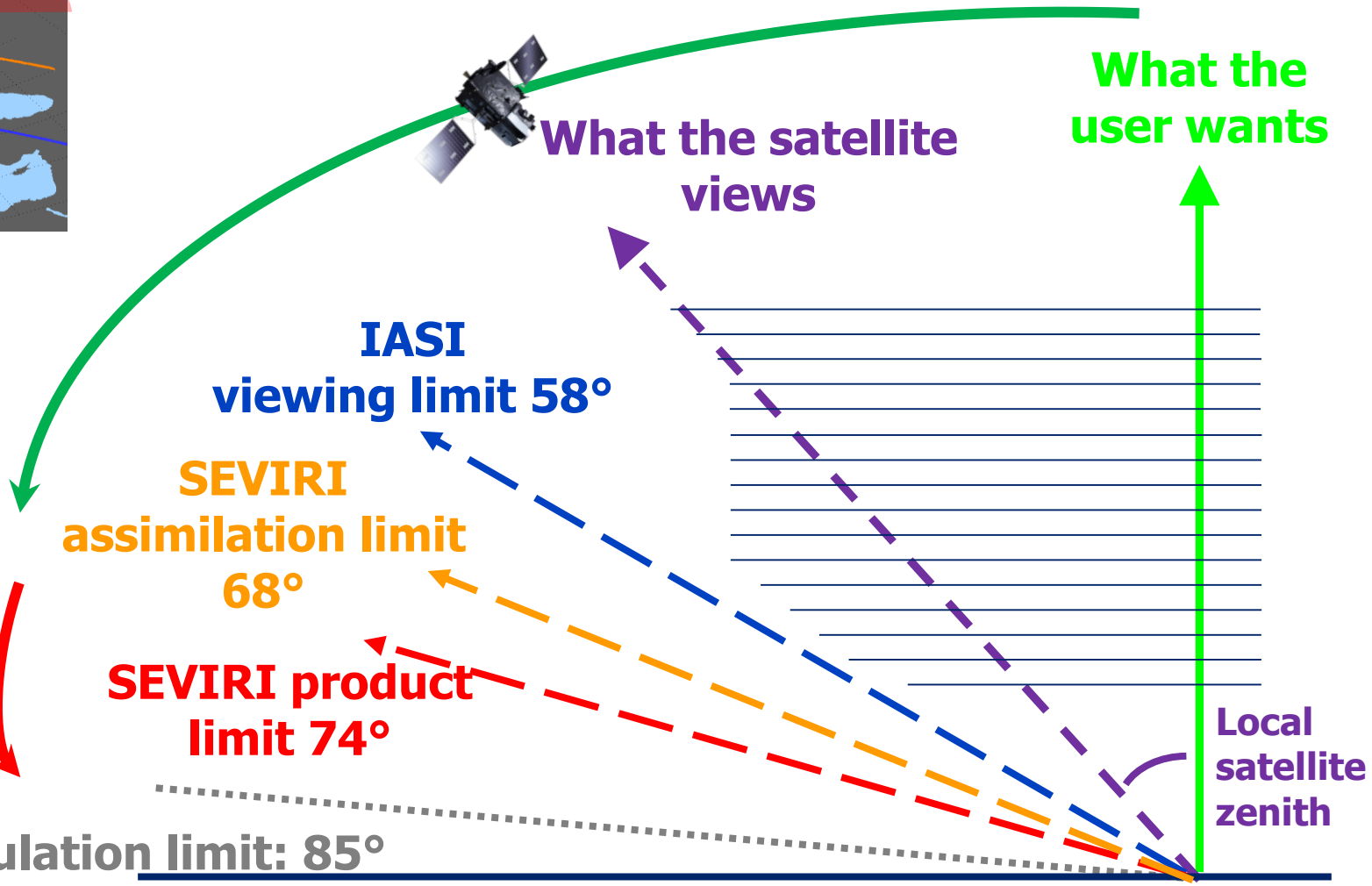
→ Slanted views
→ Huge amount of data → PC compression

To be ready for MTG-IRS ➔ Slanted views



Operational heritage

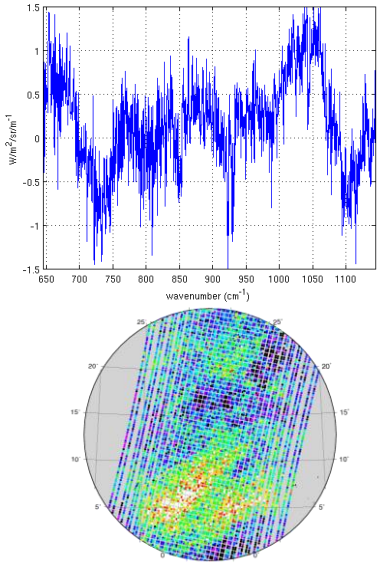
High slanted views, to study



Dissemination of the IRS radiances

IRS radiances dissemination baseline is only in Principal Component !!!

Original radiances



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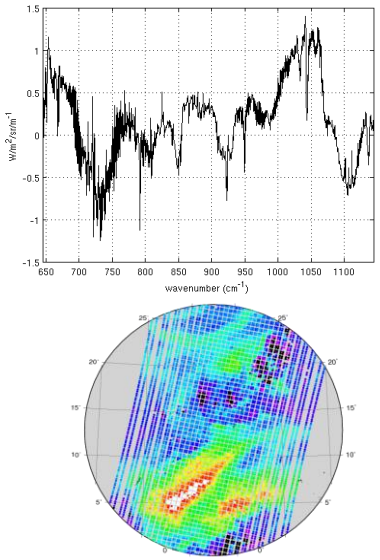
Reconstructed radiances



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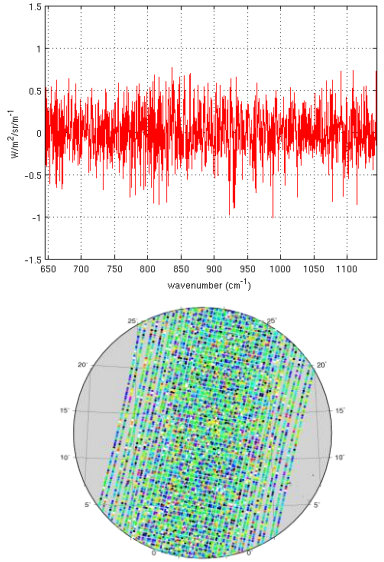
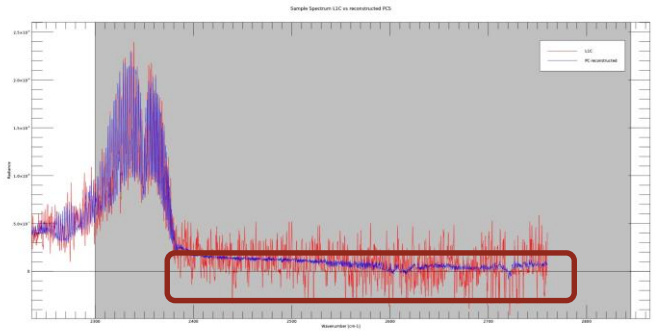
Residuals (noise)



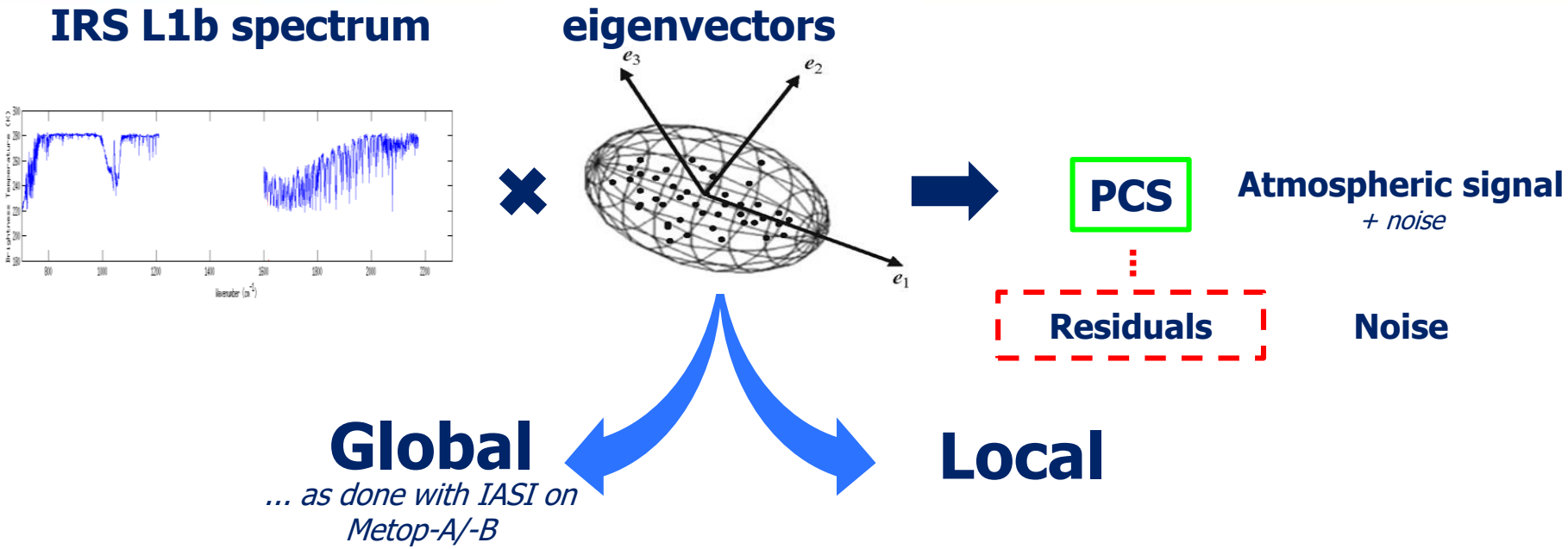
➔ **Less negative radiances with reconstucted radiances**



Different user communities - different needs & concerns:

- ✓ **AC/AQ fear information loss, *e.g. spectral signatures not present in the training base***
- ✓ **NWP concerned about DA configuration: *retuning obs. error, channels selection, bias correction…***
- ✓ **NWP required rare (to no) changes of eigenvector basis, with long notice and test data upfront**

2 options have been studied: Global & local PCs



	Global	Local
User	Static EV basis	New EV basis / dwell
	(PCS + quality indicators)/pix	(PCS + quality indicators)/pix + EV/dwell
	Less noise in leading PCs Weak signal distinguished from noise	More noise in leading PCs Less noise/signal separation
	New features not retained in PCS ➔ EV basis update may be required	All local "strong enough" signals retained in leading scores

New methodology: Hybrid approach

EUM new solution: compress with global (static) and local (granule-based) eigenvectors

1. A global (static) eigenvector basis is derived from an as exhaustive as possible training set
2. A local eigenvector basis is dynamically derived from the residuals in a data granule (i.e. what is left after PC compression with the static global eigenvectors).

The combined global+local is referred to as **PC-hybrid compression**

➔ Several uptake studies on-going

➔ **Operational roll-out planned end 2021**. User announcement + test data released on 03/06/2021 https://www.eumetsat.int/changes-pc-compressed-iasi-l1c-data

What about the atmospheric composition products?

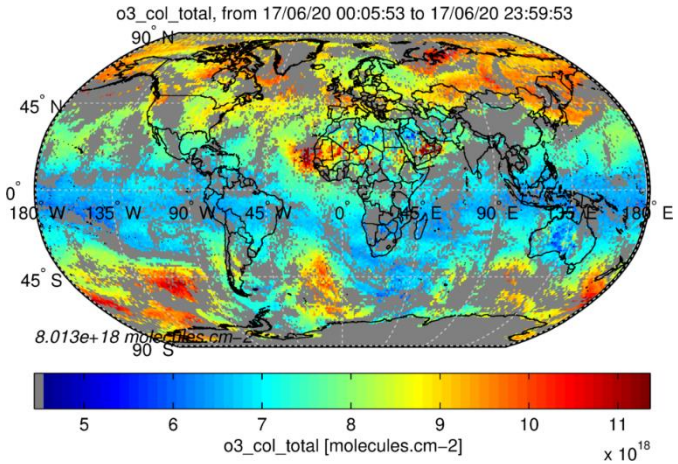
AC products with IASI-NG

AC Products	Developer	IASI heritage?
CO profile	AC SAF	Yes
CO partial column	AC SAF	Yes
Methane (CH_4) partial column	HQ	Yes
Nitric acid (HNO_3) partial column	AC SAF	Yes
Nitrous oxide (N_2O) total column	HQ	Yes
Ozone (O_3) profile	AC SAF	Yes
Ozone (O_3) total column	AC SAF	Yes
Sulphur dioxide (SO_2) total column	AC SAF	Yes

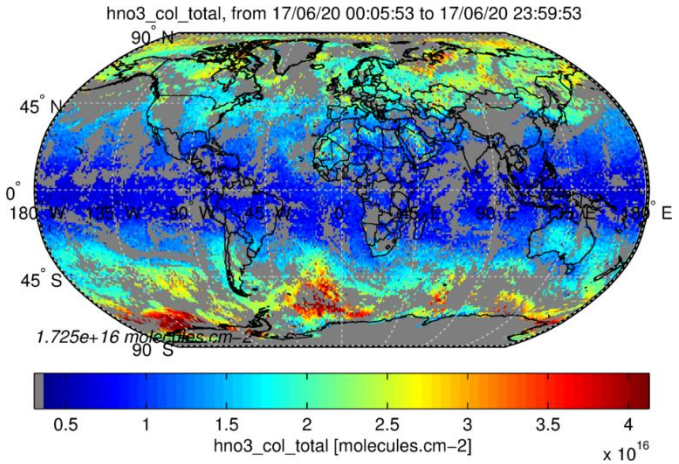
➔ **Few examples of current IASI AC products are provided in the next slides**

Some examples of AC products with IASI / IASI-NG

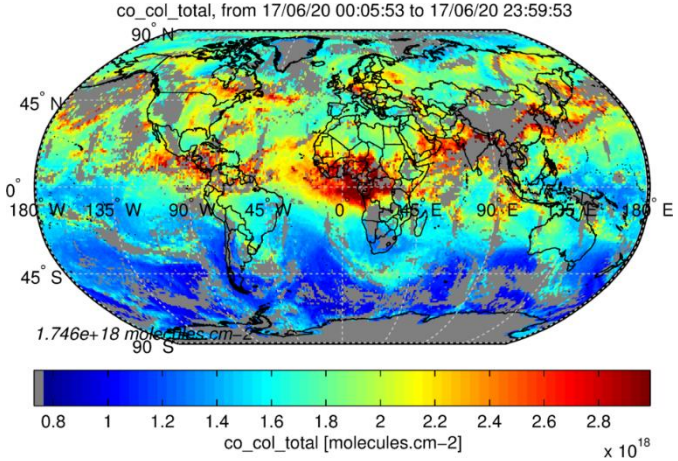
O_3 total column



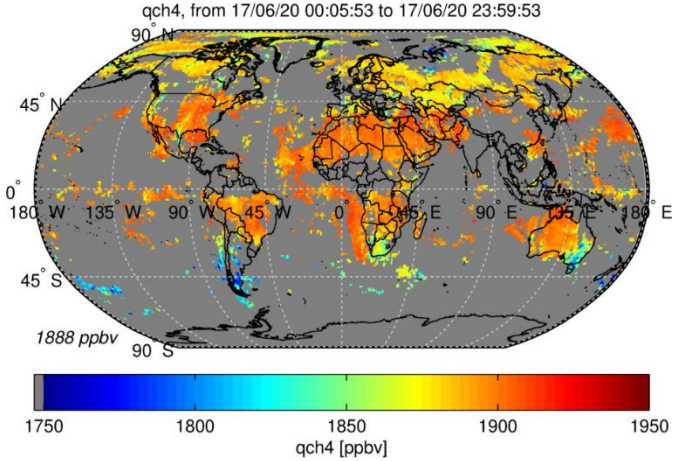
HNO_3 total column



CO total column



CH_4 partial column



Improvements expected with IASI-NG

AC Products	With IASI		With IASI-NG	
	Vertical res.	Accuracy	Vertical res.	Accuracy
CO profile	N/A	20%	3 km	LT: 30% MT: 25% HT, S: 20%
CO partial column	N/A	20%	3 km	20 %
Methane (CH_4) partial column	N/A	20%	LT: 3km S: 5km	LT: 12% S: 30%
Nitric acid (HNO_3) partial column	N/A	20%	T, S	20%
Nitrous oxide (N_2O) total column	N/A	20%	N/A	10%
Ozone (O_3) profile	7 km at pressures < 30 hPa 10 km at pressures > 30 hPa	15 % at pressures < 30 hPa 50 % at pressures > 30 hPa	3 km	LT,MT, UT: 20% S: 10%
Ozone (O_3) total column	N/A	5%	N/A	5%
Sulphur dioxide (SO_2) total column	N/A	N/A	N/A	50%

(LT: Lower Troposphere, MT: Middle Troposphere, UT: Upper Troposphere, S: Stratosphere, LS: lower Stratosphere)

What IRS would bring the Atmospheric Composition user community?

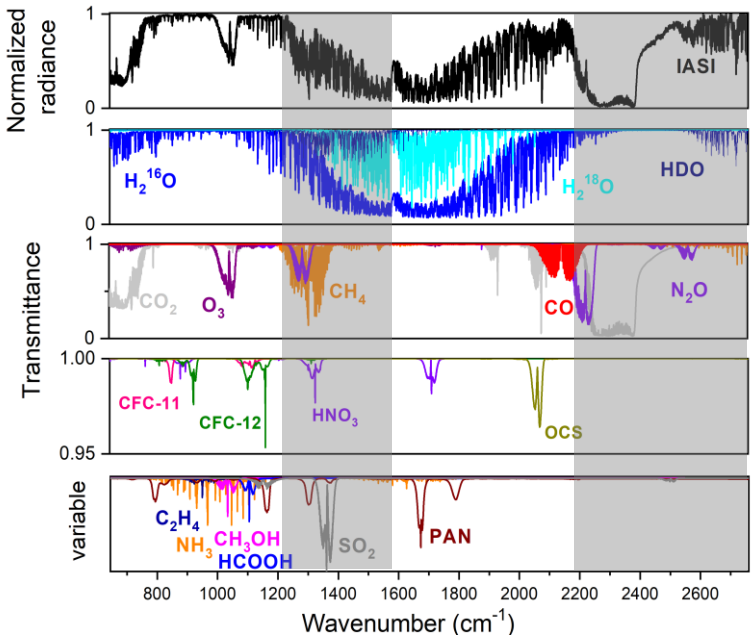
- ✓ **The situation for MTG-IRS is different**
- ✓ **There is no End-User requirements regarding the AC products**
- ✓ **Working with IRS Mission Advisory Group (MAG) members to define what could be done with MTG-IRS, what is possible and what needs to be studied or developed**
- ✓ **Next slides will show the outcome of the first discussion**

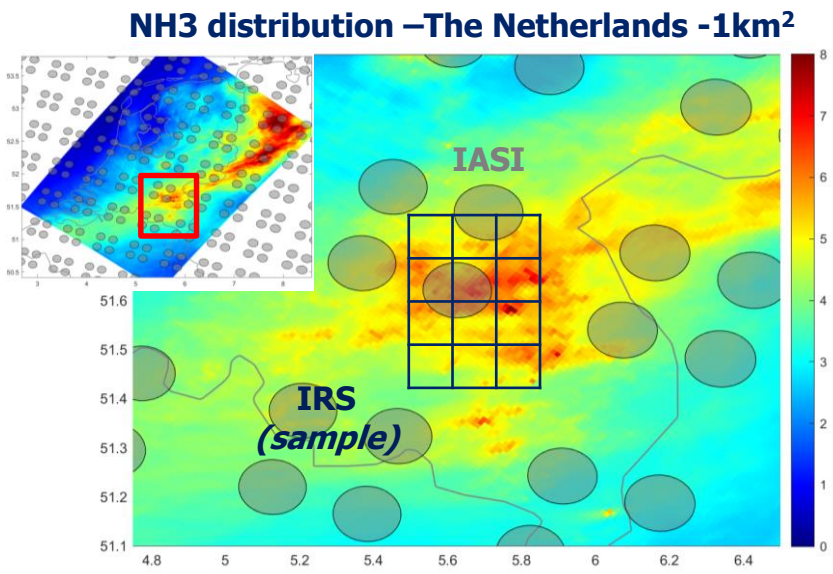
MTG-IRS possible contribution to AC

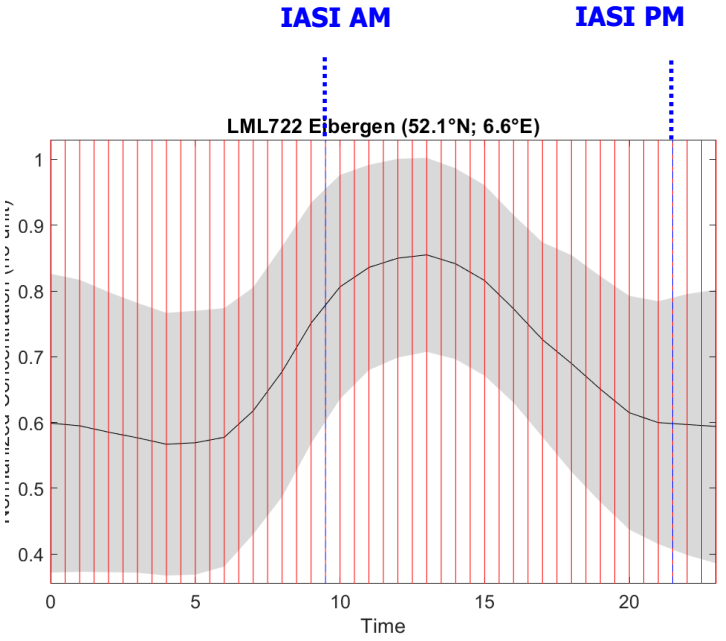
MTG-IRS vs. IASI and IASI-NG

- ✓**Reduced spectral coverage ➔ will miss CH_4, N_2O, SO_2 ν_3, HDO**
- ✓**Coarser spectral resolution and larger noise ➔ reduced vertical sensitivity + surface sensitivity**

- ✓**Continuous coverage ➔ Better mapping opportunities**
- ✓**Higher spatial resolution ➔ improved resolution of sources**
- ✓**High temporal sampling ➔ diurnal sampling; rapidly changing chemistry**







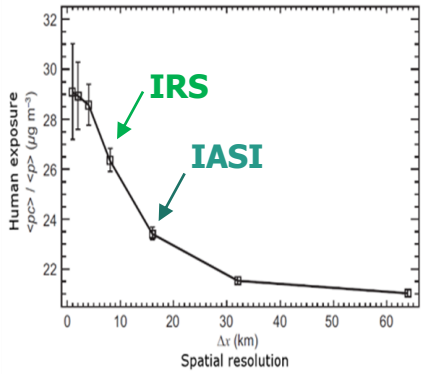
Credits: Pierre Coheur, IRS-MAG meeting

MTG-IRS possible contribution to AC

Air Quality

Limitations with polar sounders

- Spatial resolution: separating sources at city scale and improve exposure assessment



- Diurnal sampling

Opportunities for MTG-IRS

Time resolved measurements of CO, O_3, tropospheric/total columns, NH_3 columns at better spatial resolution over the Europe-Africa disc

but:

- Over polar sounders, IRS will have reduced vertical sensitivity in the troposphere for O_3 and CO
- Varying sensitivity to boundary layer as function of thermal contrast
- Anthropogenic SO_2 is unlikely to be measured (no coverage of ν_3 band) spectral range

Questions

- Will IRS allow resolving the diurnal cycle of pollution / emission?
- Is the reduced vertical sensitivity compromising AQ applications?
- Will operational assimilation system benefit from the diurnal measurements

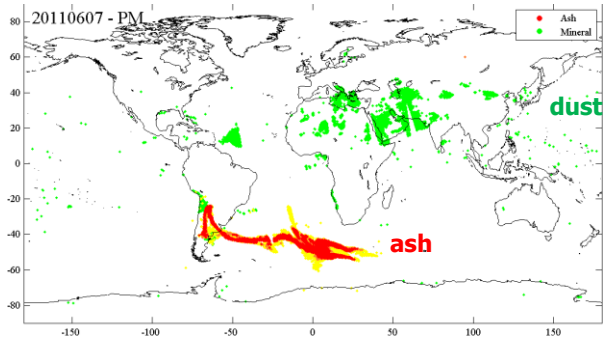
Credits: Pierre Coheur, IRS-MAG meeting

MTG-IRS possible contribution to AC

Events

Demonstrated with polar sounders

- Uses signature from SO_2, mainly in ν_3 band (ν_1 seen for large eruptions) or volcanic ash



- Fires with CO, NH_3 and VOCs

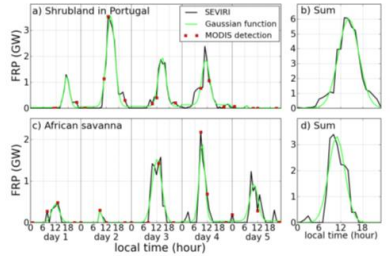
Opportunities for MTG-IRS

Volcanoes:

- SO_2 ν_3 band will not be accessible; alerts based on SO_2 will be possible using signal in ν_1, likely only for large eruptions
- Ash alerts will be possible and benefit from the improved spatial/temporal sampling

Fires:

- CO, NH_3 and VOCs at higher resolution with diurnal sampling



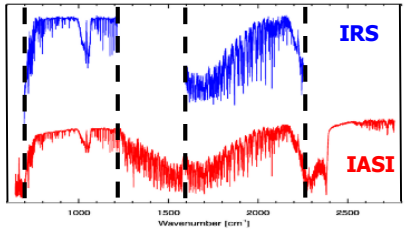
Questions

- Will IRS contribute to identifying/monitoring extreme events?
- Are there new operational applications to develop?
- Technical: Will these applications not be impacted by the use of PCs

Credits: Pierre Coheur, IRS-MAG meeting

Conclusion

EUMETSAT is preparing very complementary hyperspectral IR missions:



IASI-NG

is a continuation of the IASI mission: Michelson interferometer + Mertz compensation:

- ✓ Polar orbit at 817 km
- ✓ Better spectral sampling of 0.125 cm^{-1} and resolution of 0.25 cm^{-1} ➔ Twice better than IASI
- ✓ Detector: 12 km resolution at nadir
- ✓ Spectral coverage: 645 - 2760 cm^{-1}
- ✓ Half of the IASI radiometric noise

High spectral resolution and sampling
+
High radiometric accuracy

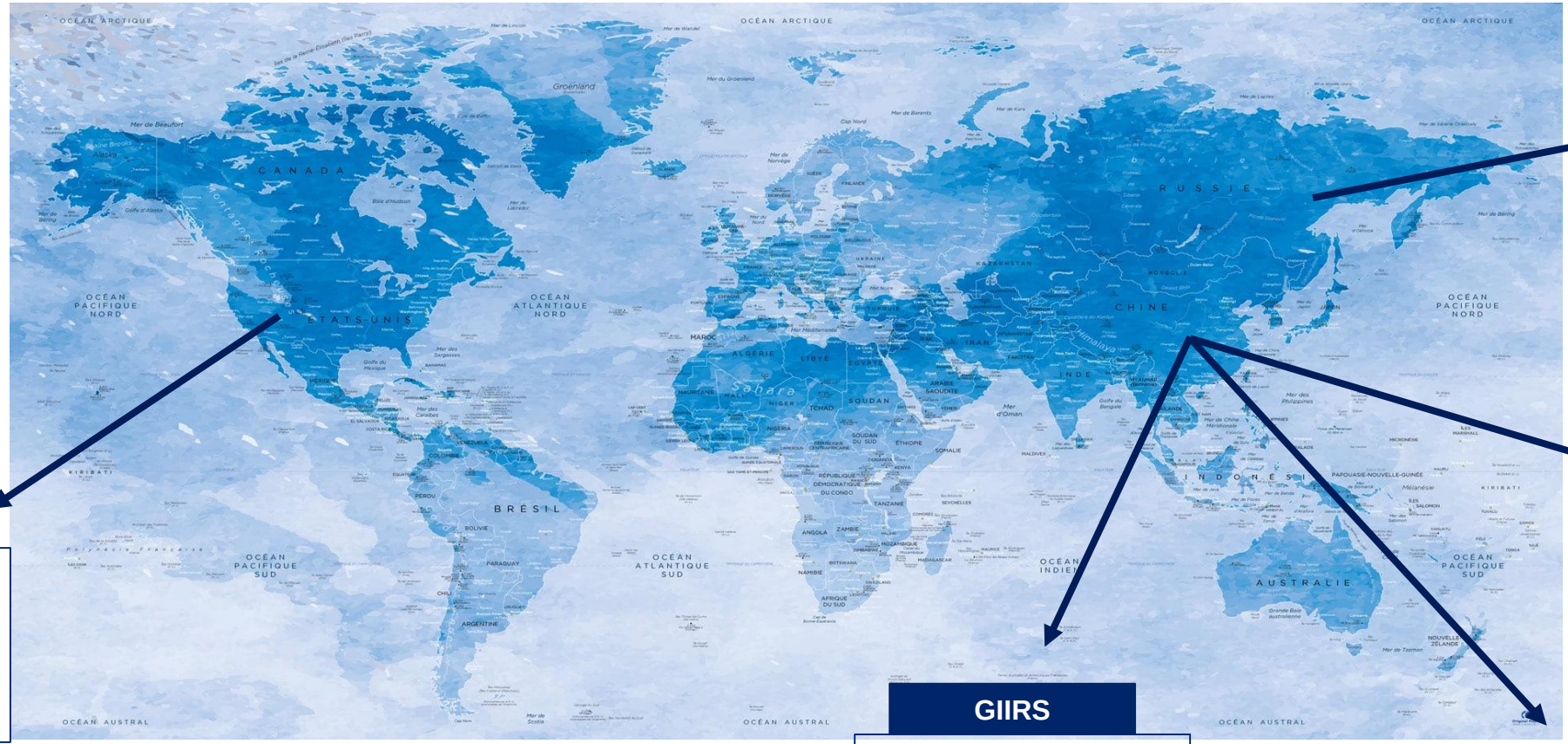
MTG-IRS

is an imaging FTS, based on a Michelson interferometer + on-board field compensation:

- ✓ Geostationary orbit
- ✓ Spectral sampling of ~0.6 cm^{-1} and resolution of ~0.754 cm^{-1}
- ✓ Detector: 4 km resolution at nadir
- ✓ Two spectral bands: 700-1210 and 1600-2175 cm^{-1} within IASI spectra

High spatial resolution and sampling
+
High temporal repetition

Current other hyperspectral sounders used at EUMETSAT



LTAN=13:30

Cross-track Infrared Sounder (CrIS)

Suomi-NPP (launched 2011)
JPSS-1 (launched 2017)
Next: JPSS-2 (2022), JPSS-3 (~2026), JPSS-4 (~2031)
+
GeoXO (Hyperspectral sounder in GEO orbit)

LTAN=09:30

IKFS-2

Meteor-M-N2 (launched 2014)
Next: Meteor-M-N2-3 (2021), Meteor-M-N2-4 (2022), Meteor-M-N2-5 (2024), Meteor-M-N2-6 (2025)
+
IKFS-3 (next generation in 2025/2026)

LTDN=14:00

HIRAS

FY-3D (launched 2018)

GIIRS

FY-4A (research, launched 2018), FY-4B (launched in 2021)
Next: FY-4C (2025), FY-4D (2026)

LTDN=10:00

HIRAS-2

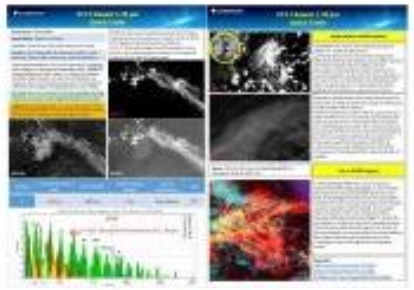
FY-3E (launched in 2021)
Next: FY-3F (2023). FY-3H (2024), FY-3I (2025)

Thanks for your attention!

Spare slides

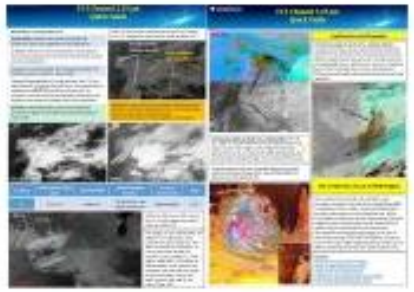
Guidance on FCI channels

Quick Guide - 1.37 µm Channel



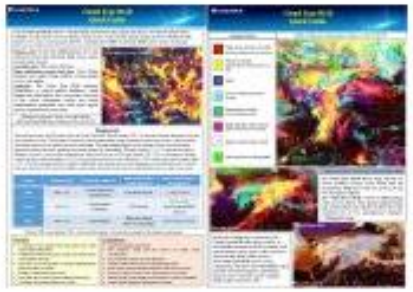
Download Quick Guide

Quick Guide - 2.25 µm Channel



Download Quick Guide

RGB Quick Guide - Cloud Type



Download Quick Guide

RGB Quick Guide - Cloud Phase

Download Quick Guide

RGB Quick Guide - True Colour

Download Quick Guide

RGB Quick Guide - Fire Temperature

Download Quick Guide

http://eumetrain.org/rgb_quick_guides/index.html

MTG-IRS possible contribution to AC

Global stratos.

Global tropos.

Climate

Opportunities for MTG-IRS

The relevant species (O_3, CO, HNO_3, VOCs) for monitoring the global troposphere and stratosphere will be accessible with IRS. However,

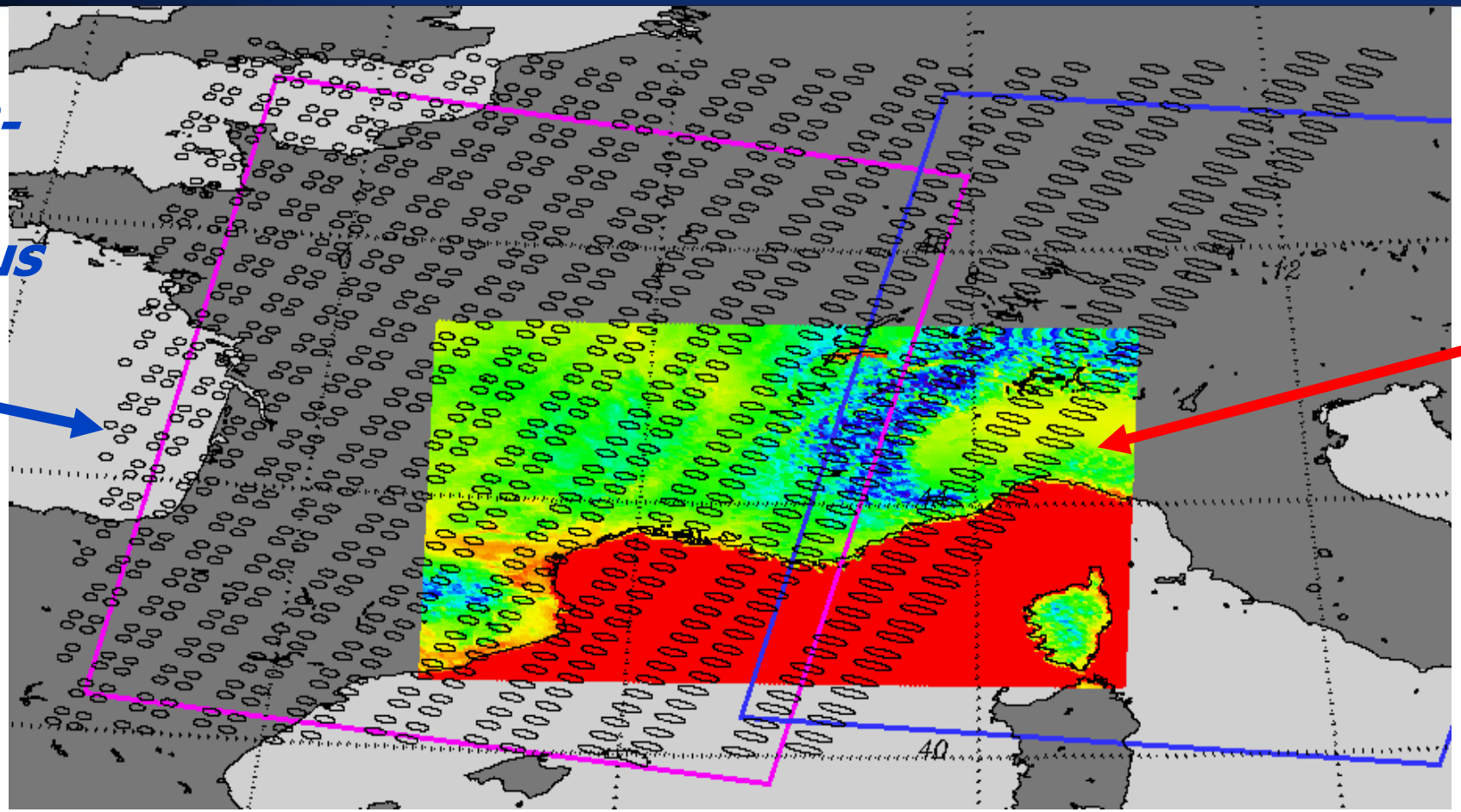
- ✓ **With less vertical sensitivity**
- ✓ **On temporal/spatial scales that are smaller than the processes currently looked at (most applications use averages, in time and space)**

Among the main long-lived greenhouse gases, only CO_2 will be measurable (not CH_4 and N_2O). Several short-lived or indirect climate forcers will be accessible but –as above- with less vertical sensitivity and accuracy.

Credits: Pierre Coheur, IRS-MAG meeting

IASI/IASI-NG and MTG-IRS are very complementary

IASI-NG footprints 12-40km Not-contiguous 2x per day



IRS pixels ~7km Contiguous Every 30'