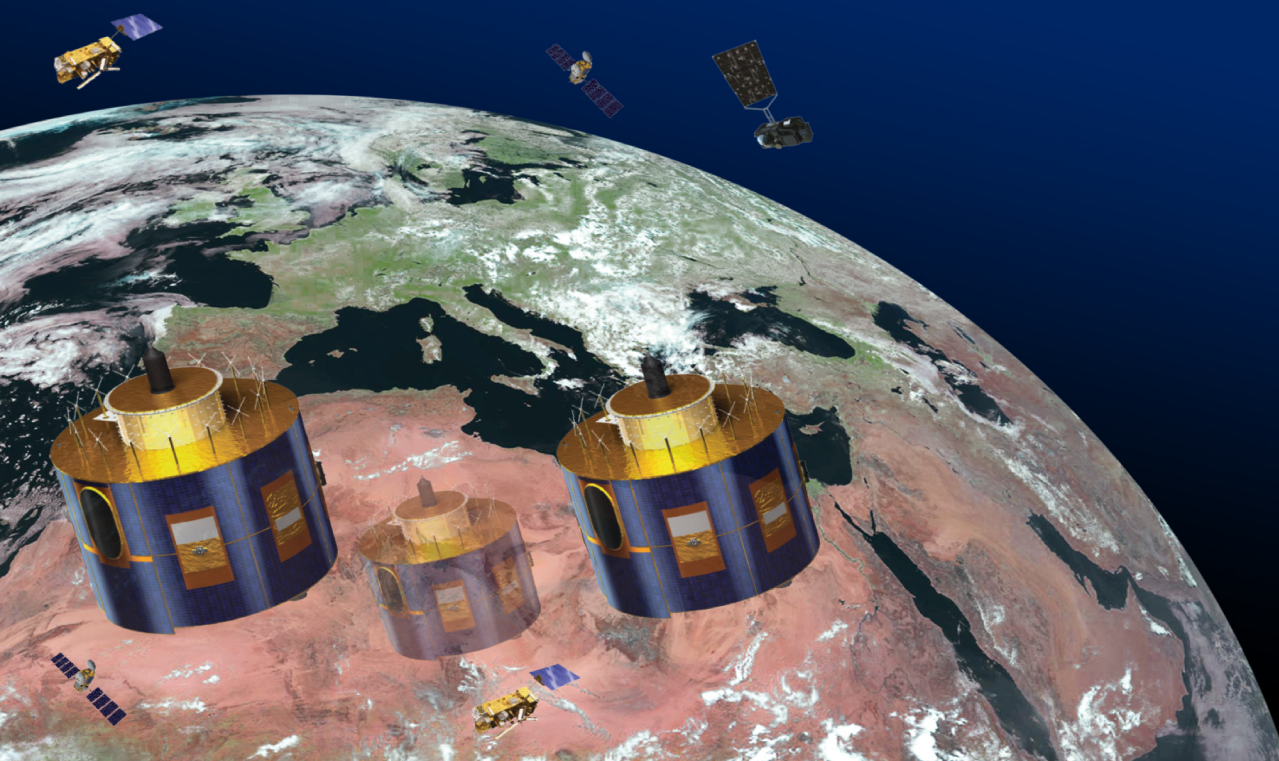
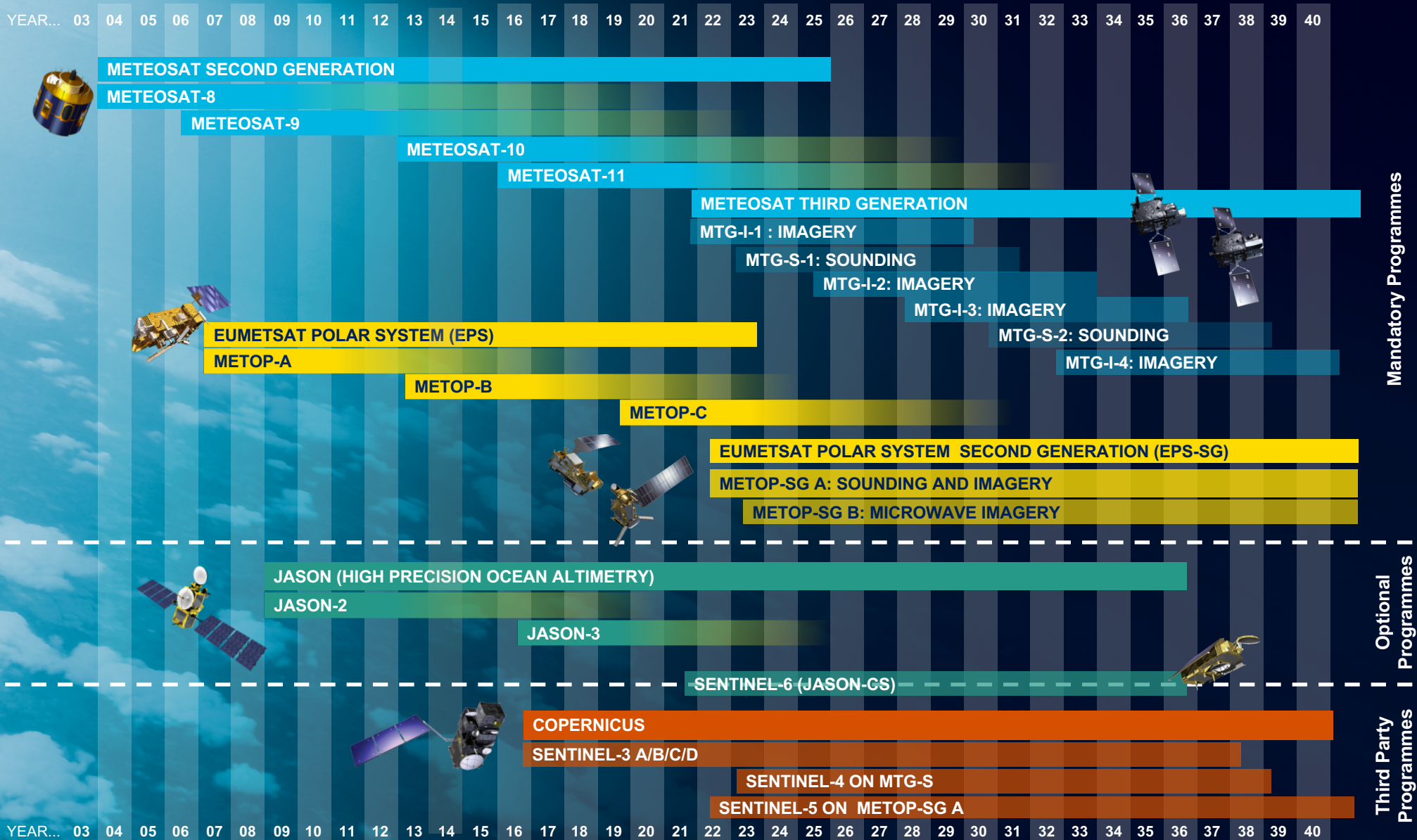


# EUMETSAT Contribution to the Sentinel Missions

Rosemary Munro



# EUMETSAT Mission Planning



# Motivation – Operational AC User Communities

- The Copernicus Atmosphere Monitoring Service (CAMS)
- The Numerical Weather Prediction Community and the Meteorological Services
- National Environment Agencies & Regulatory Bodies for Air Quality
- Intergovernmental Organisations
- WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)
- Volcanic Ash Advisory Centers (VAACs)
- The Copernicus Climate Change Service and the Climate Community

# Instruments and Products – Trace Gases & GHG

Metop GOME-2 (Radiance, Irradiance, O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, HCHO, BrO, UV Index, H<sub>2</sub>O, surface reflectance, SIF)

Metop IASI (Radiance, CO, SO<sub>2</sub>, O<sub>3</sub>, HNO<sub>3</sub>, NH<sub>3</sub>, CH<sub>4</sub>)

MTG UVN (S4) (Radiance, Irradiance, O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, HCHO, CHOCHO, surface reflectance)

MTG IRS (Radiance, CO, O<sub>3</sub>)

EPS-SG UVNS (S5) (Radiance, Irradiance, O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, HCHO, CHOCHO, surface reflectance, surface UV, CH<sub>4</sub>, CO)

EPS-SG IASI-NG (Radiance, CO, SO<sub>2</sub>, O<sub>3</sub>, HNO<sub>3</sub>, NH<sub>3</sub>, CH<sub>4</sub>)

*Copernicus-CO<sub>2</sub> (Radiance, Irradiance, CO<sub>2</sub>, CH<sub>4</sub>, SIF, NO<sub>2</sub>)*

# MTG-S UVN Sentinel-4

## UV-NIR Hyper Spectral Instrument from Geostationary Orbit

- Sentinel-4 has heritage from the GOME/SCIAMACHY/GOME-2/OMI series of instruments
- Primary focus is the monitoring of air quality in the European domain with high spatial and temporal resolution
- The spatial resolution will be  $\sim 8 \times 8$  km with hourly temporal resolution
- Sentinel-4 level 1 and 2 products will be produced operationally by EUMETSAT
- Products: O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, HCHO, (CHOCHO), UV, AAI, AOD, ALH, FCI support, CLD, HSC, SUR

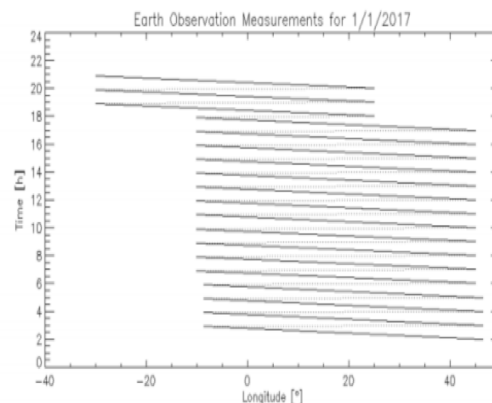
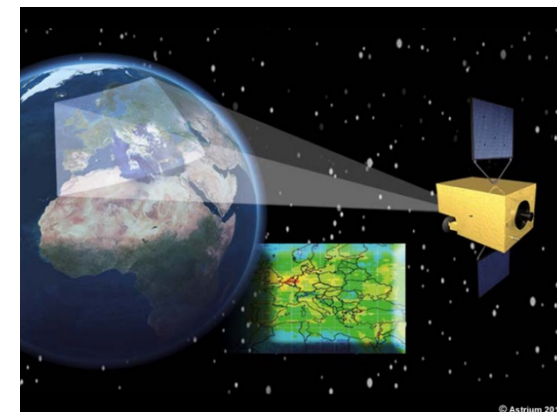


Figure 9-2: Possible UVN scanning scheme



An example of a single scan line is provided in Figure 4-13.

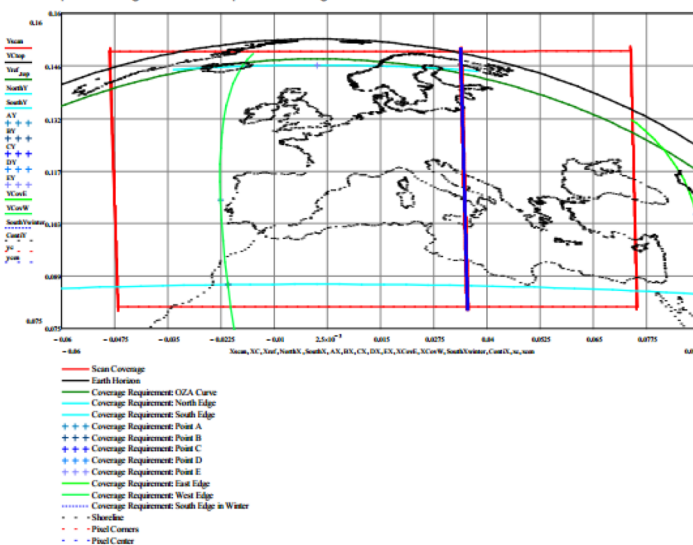


Figure 4-13: Scan coverage (red) and a single scan line (at an x-coordinate of about 0.035, corners: red, center: blue) in normalized GEOS projection.

# MTG-I Imaging Mission



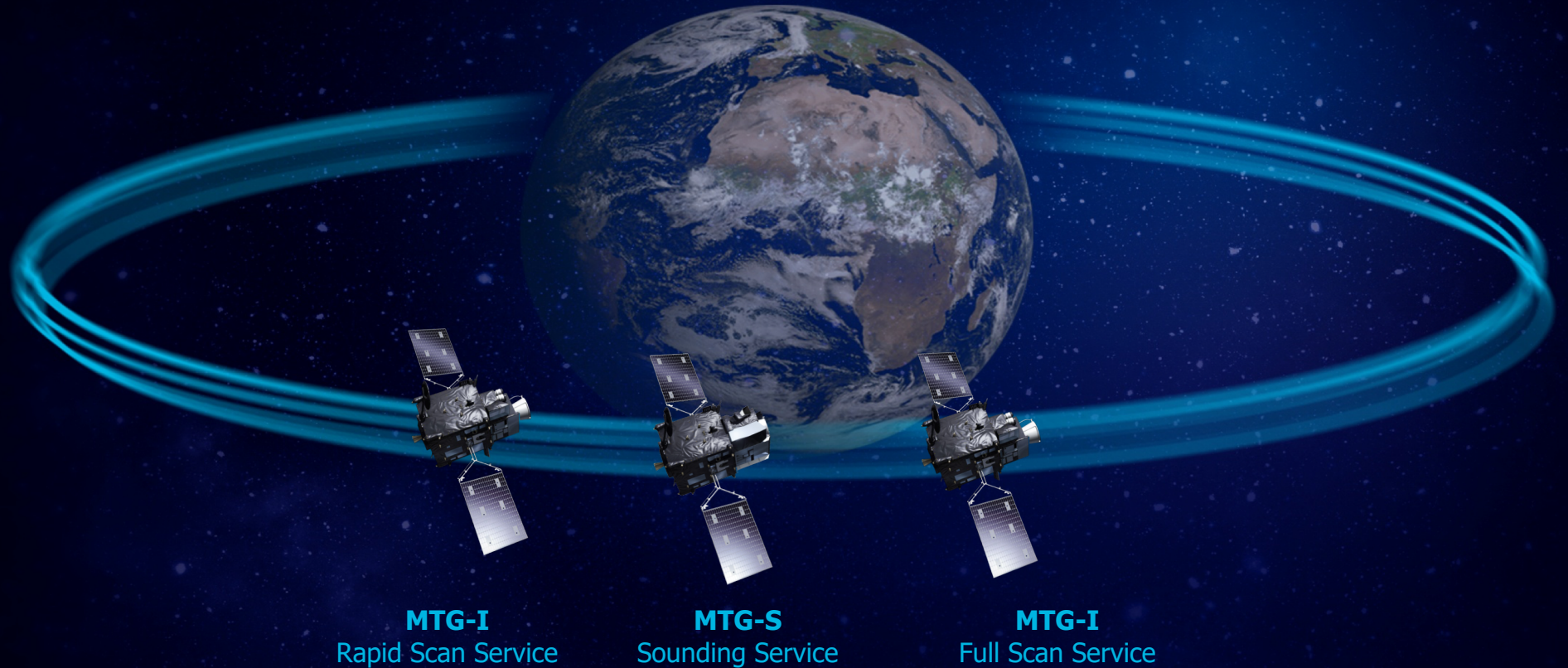
- Imagery mission implemented by two MTG-I satellites
- Full disc imagery every 10 minutes in 16 bands
- Fast imagery of Europe every 2.5 minutes
- New Lightning Imager (LI)
- Start of operations in 2021
- Operational exploitation: 2021-2042

# MTG-S Sounding Mission



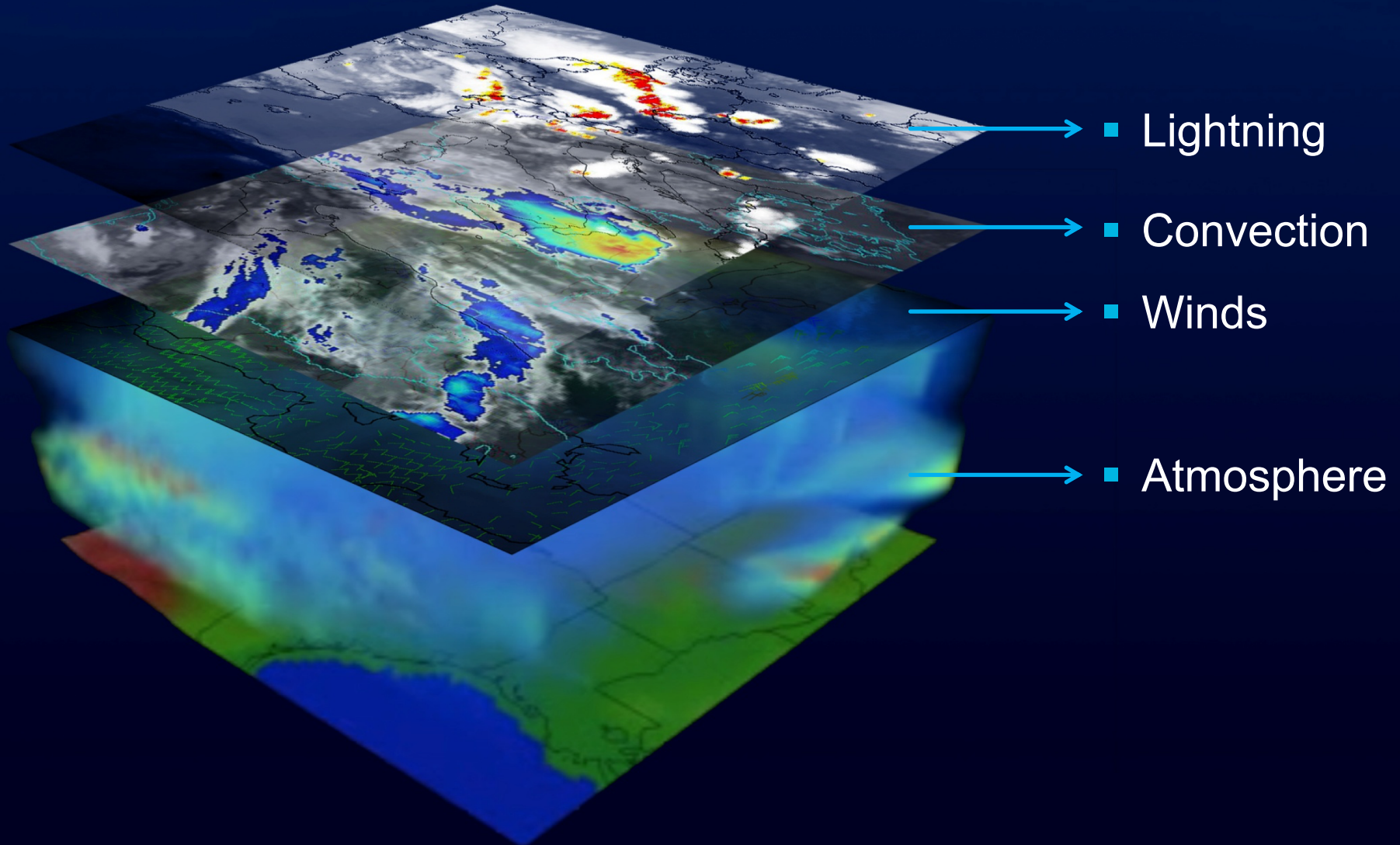
- Hyperspectral infrared sounding mission
- 3D weather cube: temperature, water vapour, O<sub>3</sub>, every 30 minutes over Europe
- Air quality monitoring and atmospheric chemistry in synergy with Copernicus Sentinel-4 instrument
- Start of operations in 2023
- Operational exploitation: 2023-2042

# Meteosat Third Generation (MTG) Full Operational Configuration

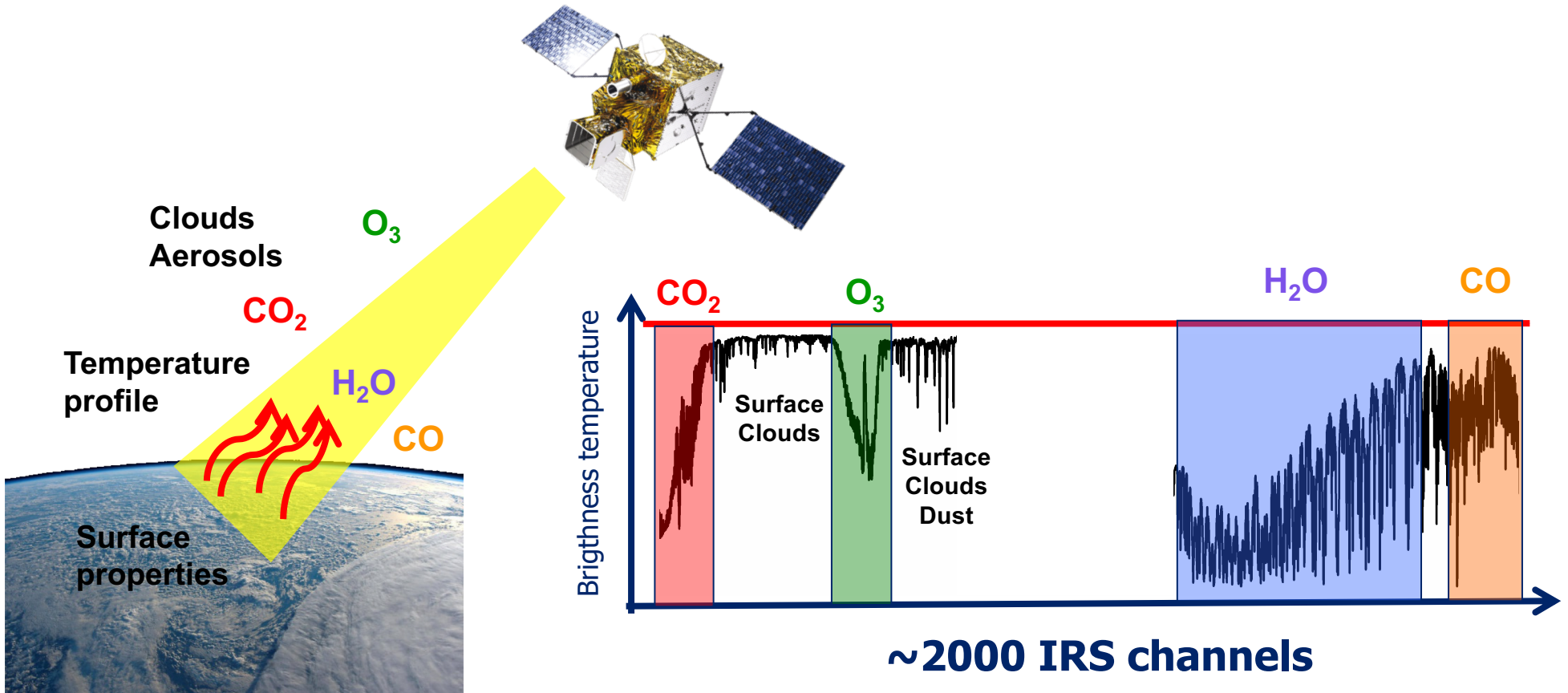




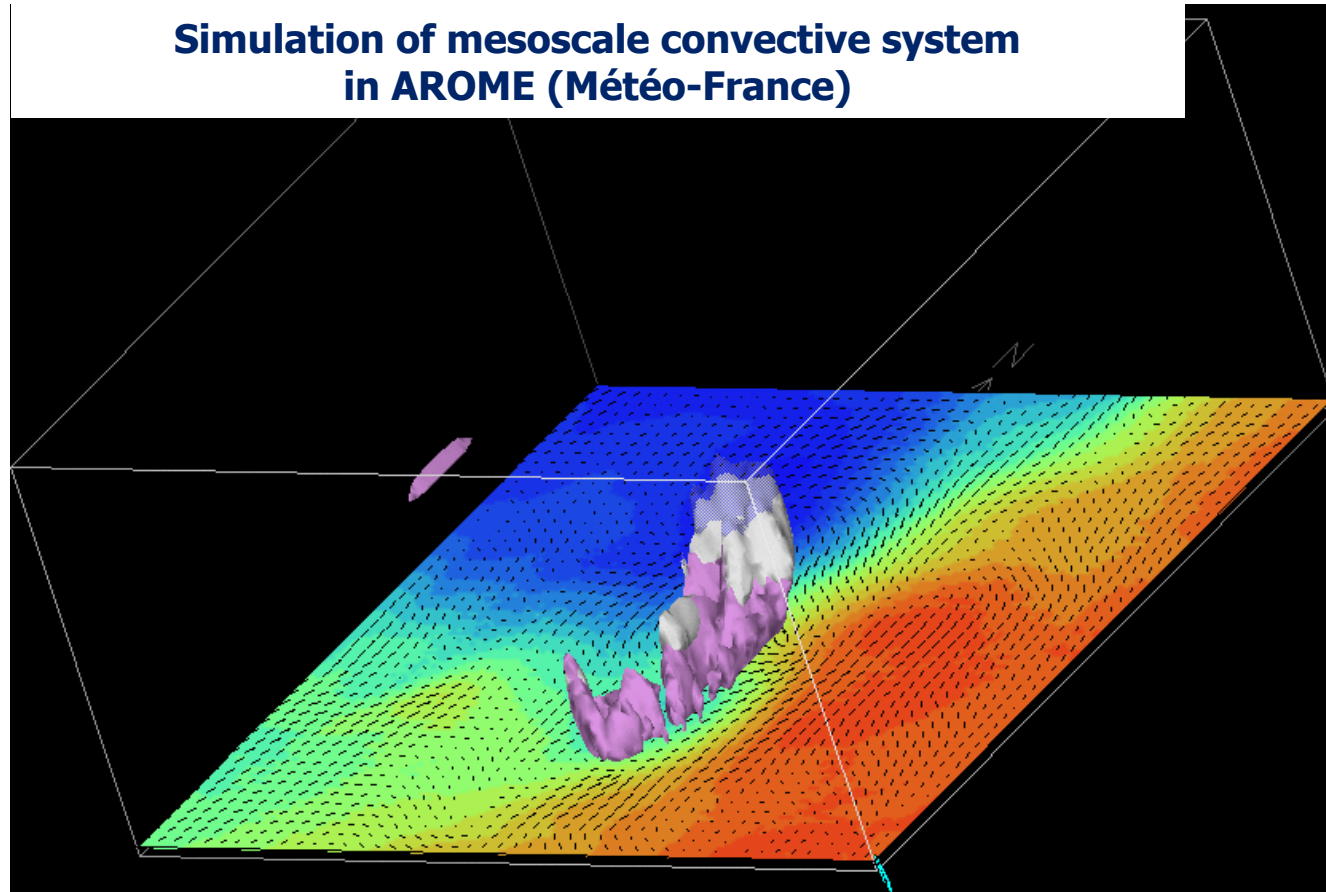
# 4D Weather Cube with MTG-I and MTG-S



# Information Content of the IRS Spectrum

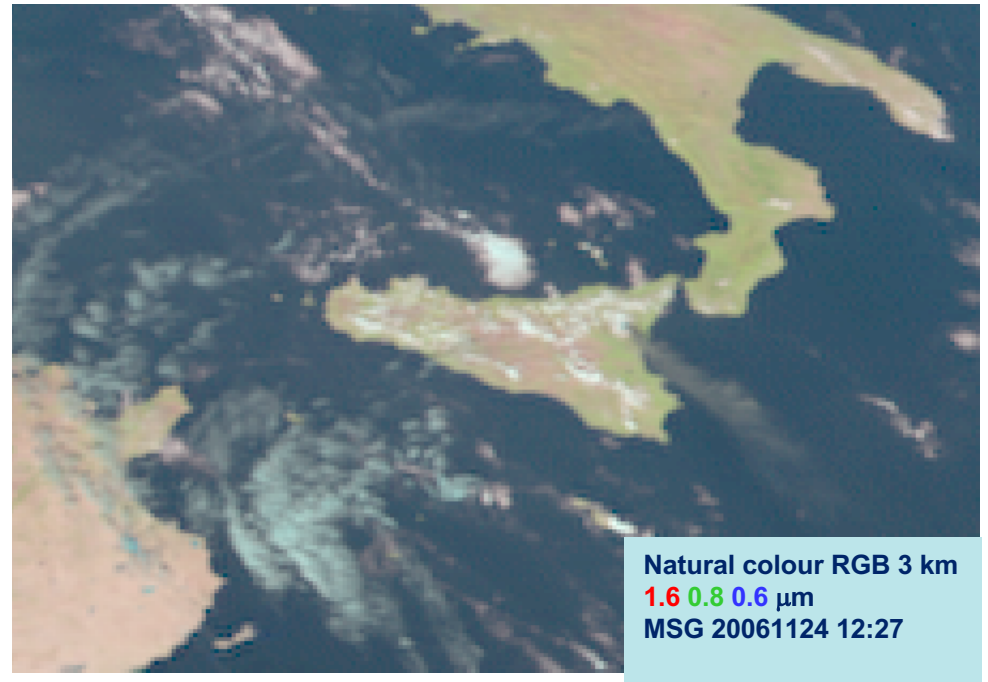
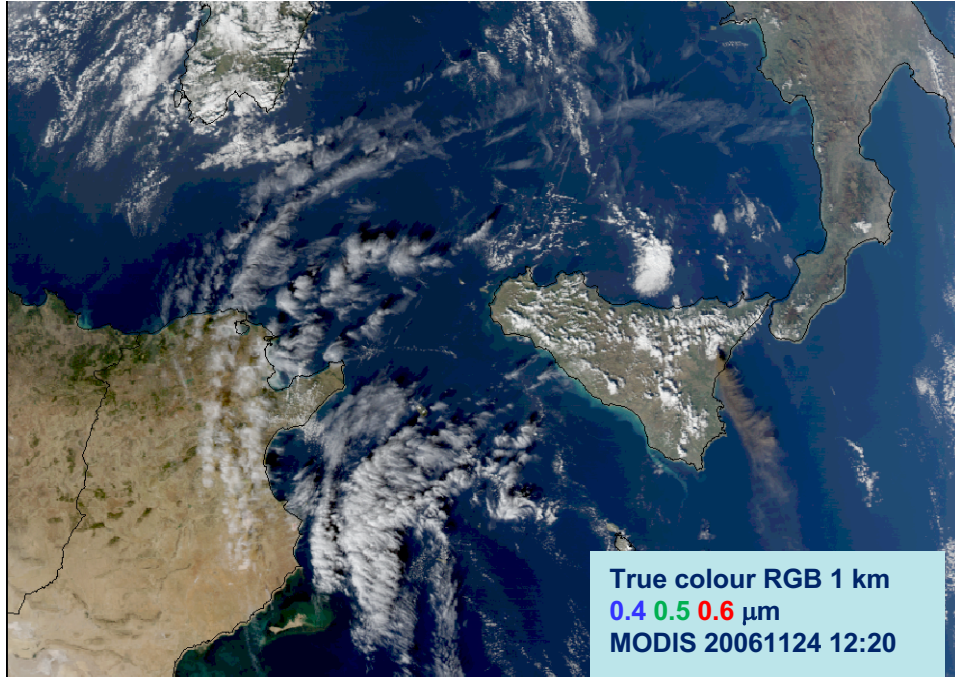


# Predict and Follow Rapid Events at Fine Resolution



**Importance of spatial and temporal resolution  
and accuracy of geolocation of observations**

# Spatial resolution and True Colour RGB

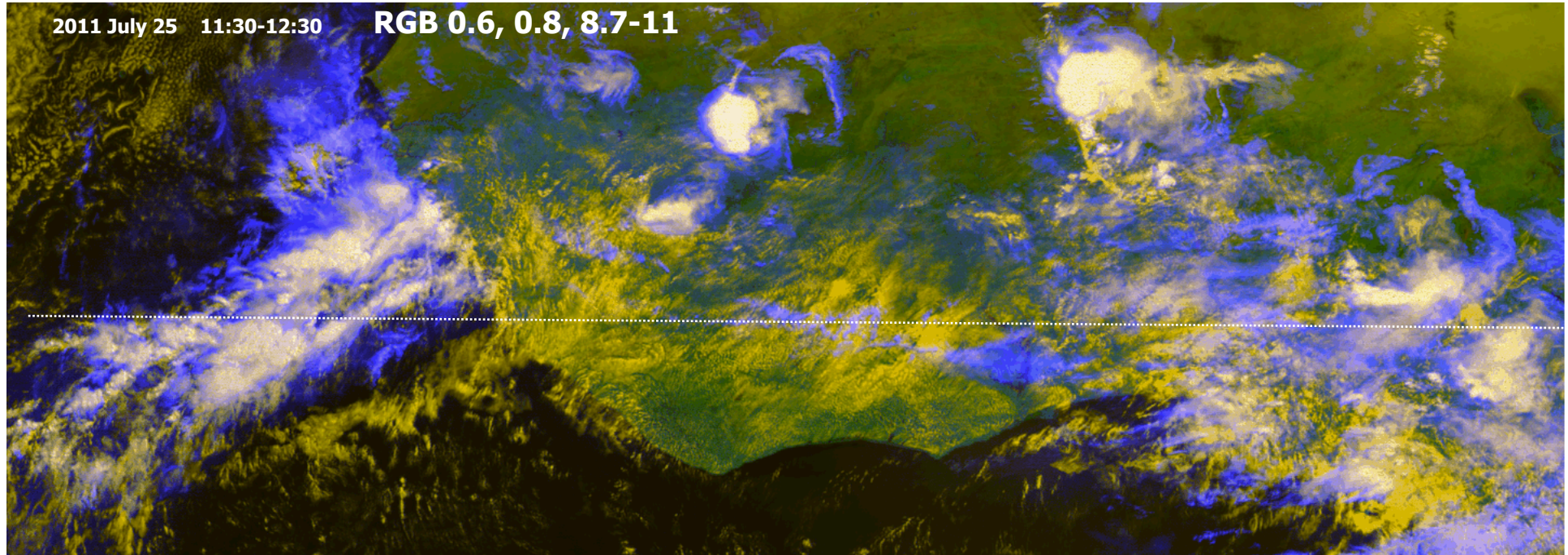


Application:

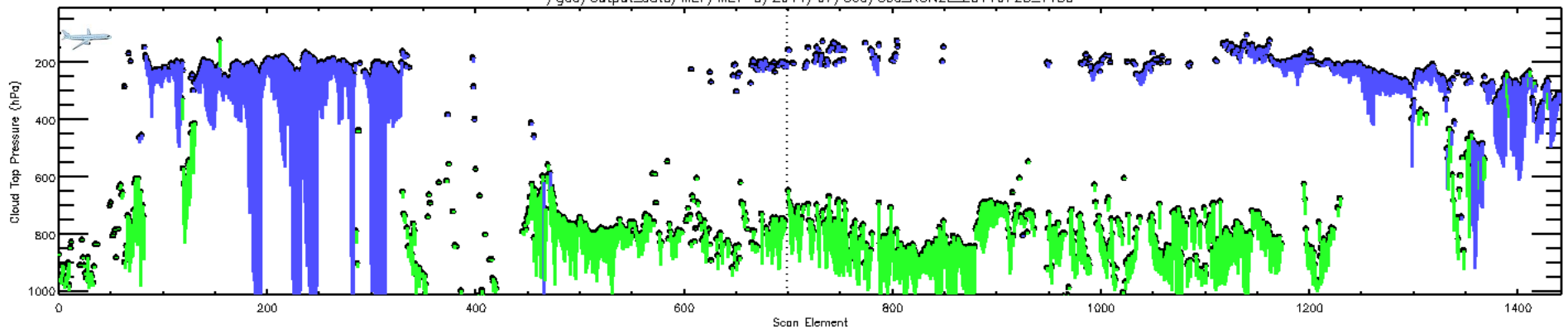
Weather forecasts for public  
Quicklooks for forecasters

courtesy D. Rosenfeld, Univ. Jerusalem

# EUMETSAT retrieval product: Optimal Cloud Analysis (OCA)

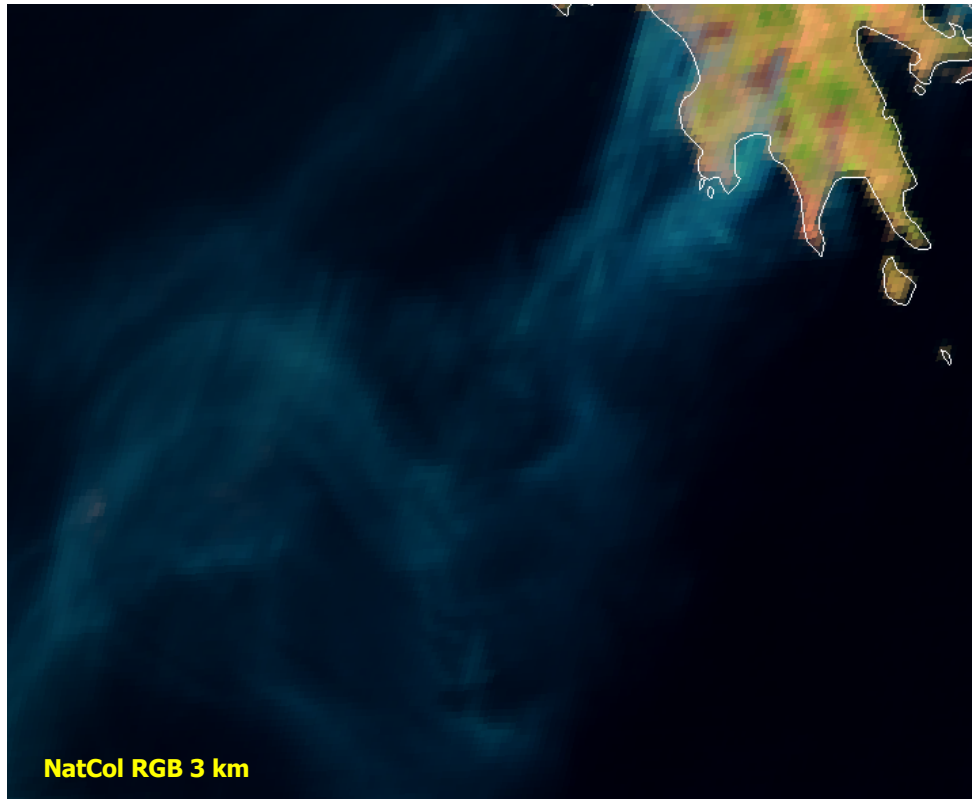


/geo/output\_data/MEF/MET-9/2011/07/oca/oca\_RUN2L\_20110725\_1130

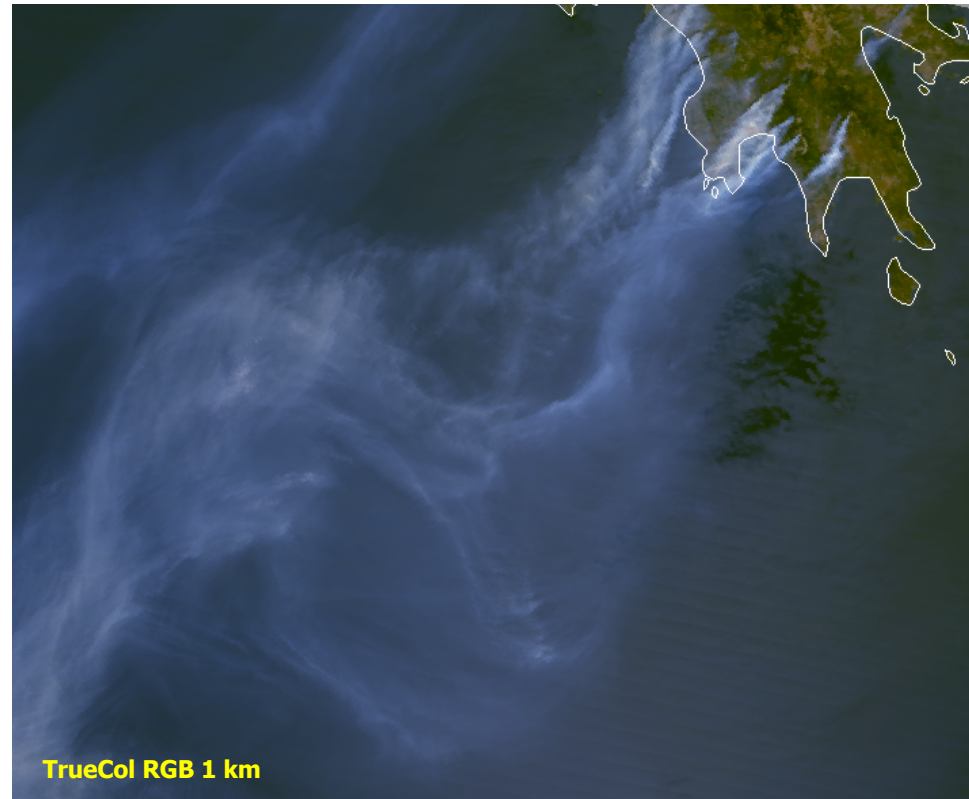


# MTG Improvements: smoke detection

**SEVERI (11:00 UTC)**



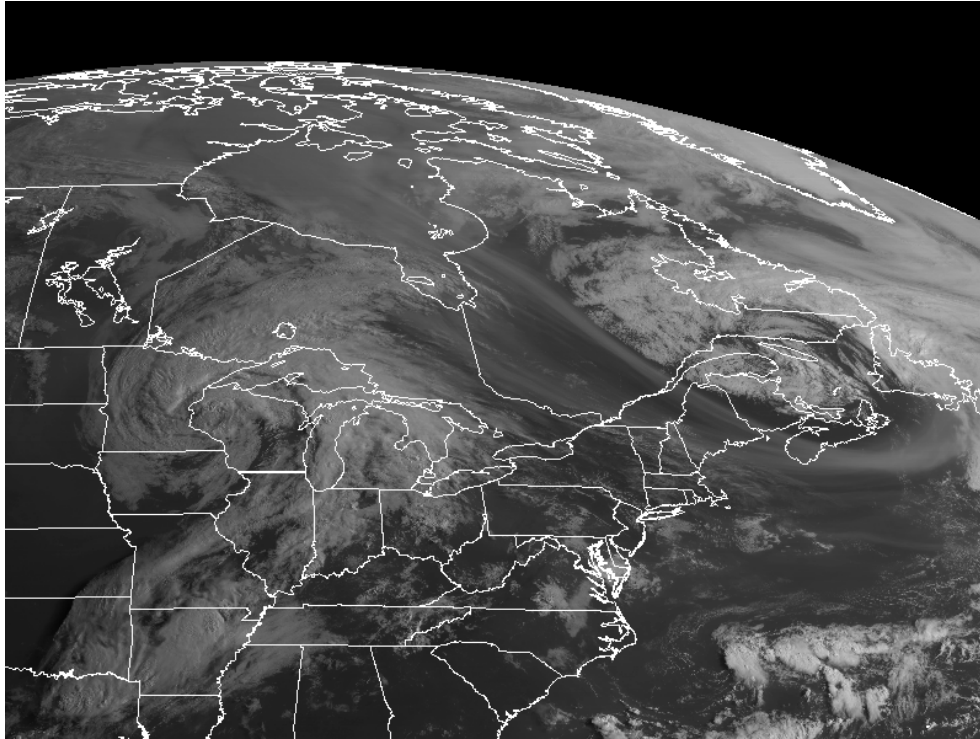
**MODIS (09:35 UTC)**



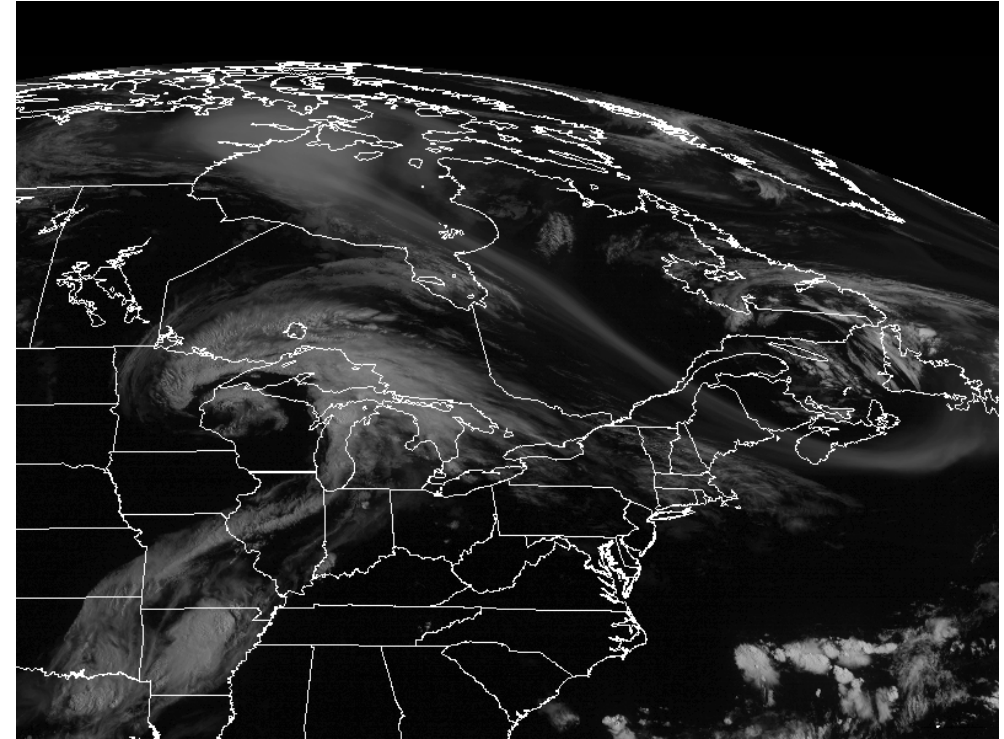
26 August 2007

**Smoke is transparent in IR !  
More solar channels needed !**

# Smoke from Canadian Fires

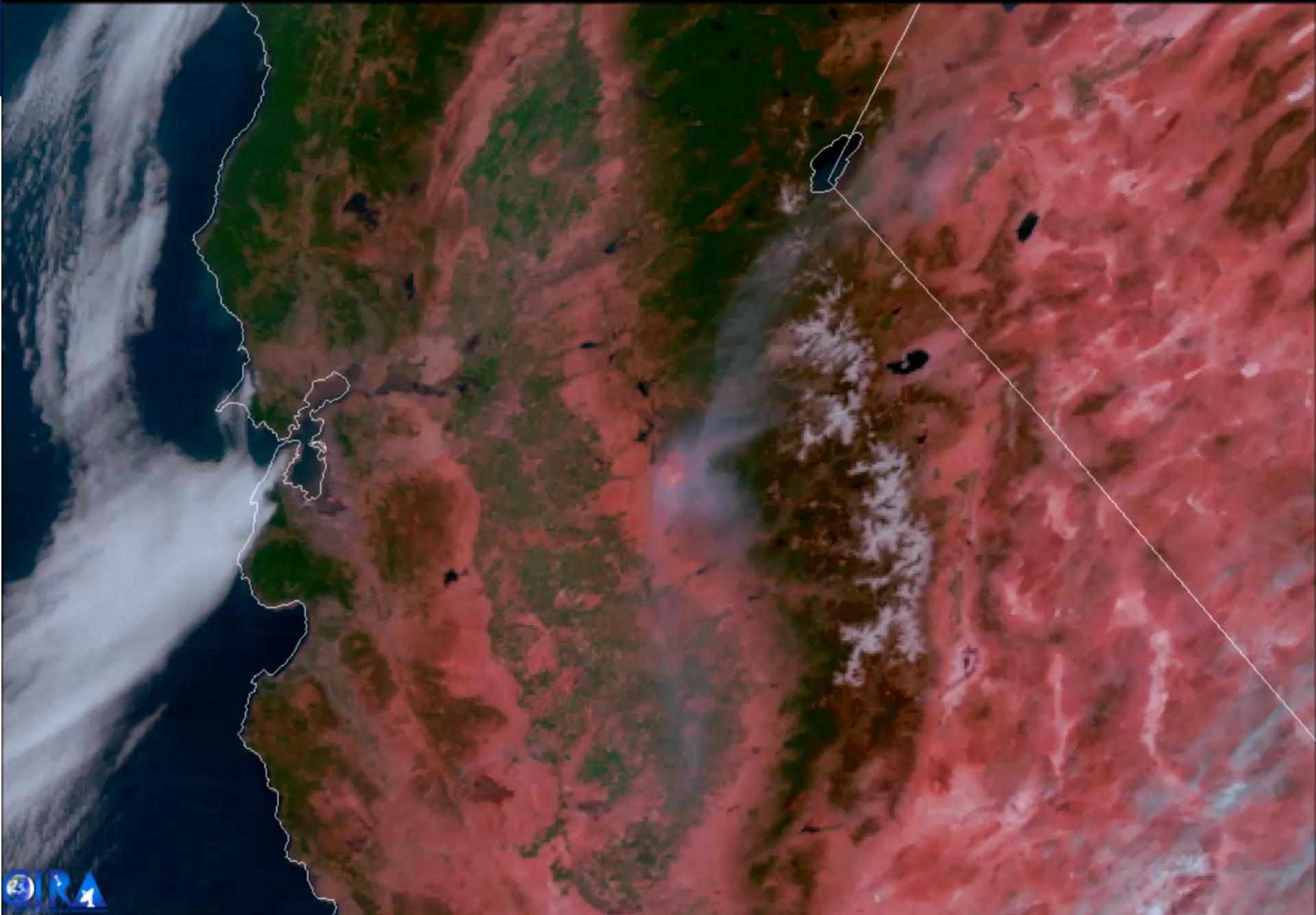


ABI Band 01 (VIS0.4)



ABI Band 04 (NIR1.3)

**New NIR1.3 band useful for high level Ash / Dust / Smoke**



2 0002 G-16 PRD 2 18 JUL 17199 200200 00701 00001 00.50

CIRRA/RAMMB



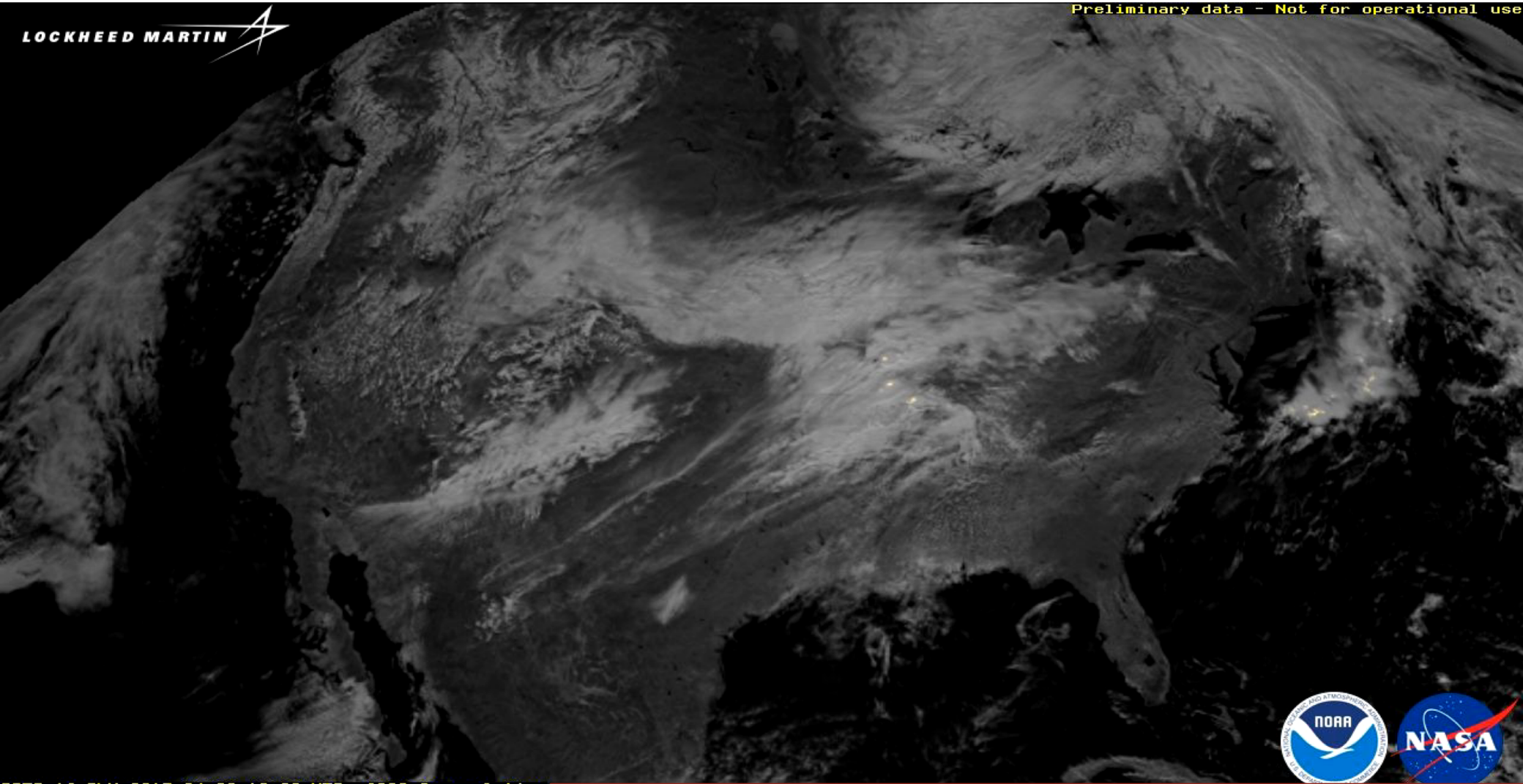
# Lightning as Seen from Space



# Lightning Monitoring for NWC / VSRF: GOES-R example

LOCKHEED MARTIN 

Preliminary data - Not for operational use



GOES-16 GLM 2017-04-28 18:00 UTC 6000.0x real time



**April 28-30, 2017**

**GOES-16 GLM lightning superimposed on GLM background: PRE-OPERATIONAL DATA**

- **Continuity of the EUMETSAT Polar System Services beyond 2020**
  - Provision of continuous long-term datasets in support of operational meteorological and environmental forecasting and global climate monitoring
- **EPS-SG will be part of the NOAA/EUMETSAT Joint Polar System**
  - Service in the mid-morning orbit
- **EPS-SG will fulfil the European contribution to the WMO Global Observing System (GOS) as concerns the space-based observations from polar orbits**
- **EPS-SG will rely on international cooperation for the development and on national contributions for key instruments**
  - ESA: development of the space segment
  - CNES: development of IASI-NG and Argos-4
  - DLR: development of METimage

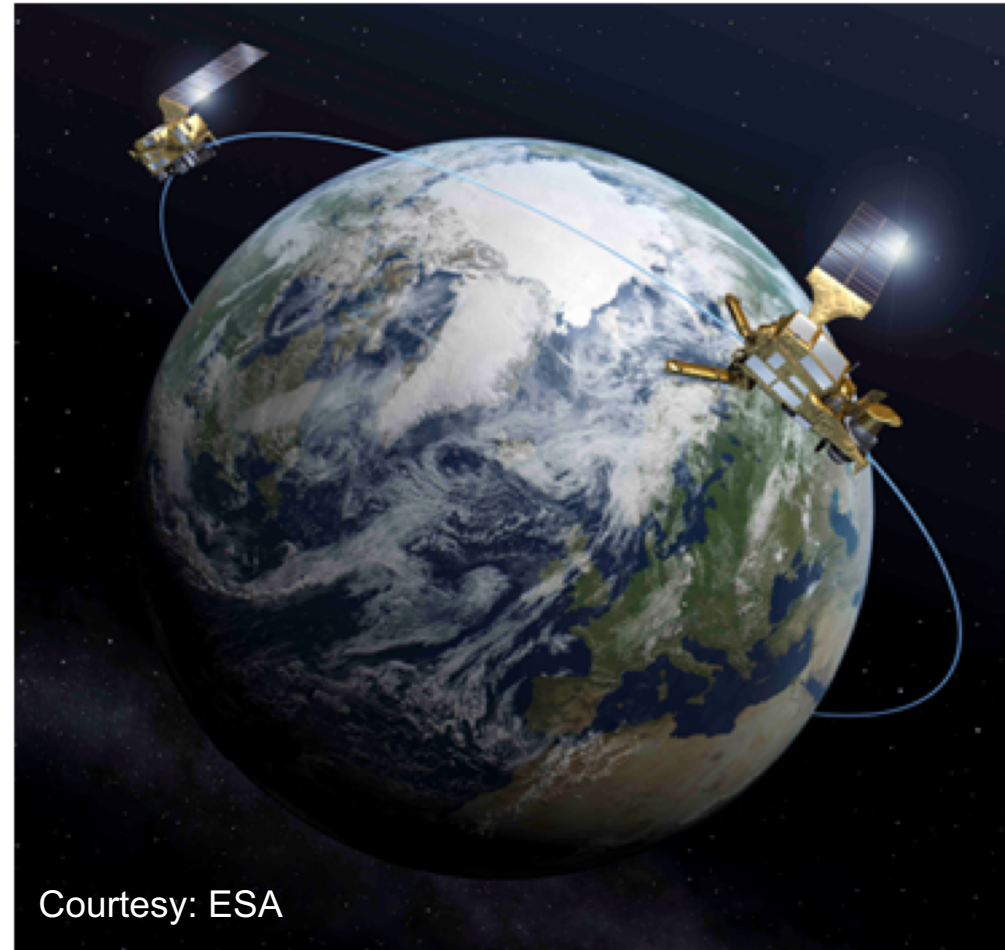
# EPS-SG benefits to activities of NMSs

Main Payload	Enhanced Capabilities	Innovative Capabilities	Applications Benfitting
High-Resolution Infrared Sounding ( <b>IASI-NG</b> )	+75% information in T-profiles +30% in WP-profiles	More trace gases and their vertical profiles	NWP, NWC, AC, CM
Microwave Sounding ( <b>MWS</b> )	Enhanced spatial over-sampling	Ice-cloud info in support of water-vapour profiling	NWP, NWC
Radio Occultation Sounding ( <b>RO</b> )	Large increase of number of radio-occultations	Tracking of Galileo signals	NWP, CM
Nadir viewing UV/VIS/NIR/SWIR Sounding ( <b>Sentinel-5</b> )	Significant increase of spatial resolution	Additional trace gas measurements; CO <sub>2</sub> being studied	Air Quality, CM, AC
VIS/IR Imaging ( <b>METimage</b> )	Better radiometric and spatial resolution	Far more variables measured with higher accuracy	NWC, NWP, CM
Multi-viewing, -channel, -polarisation Imaging ( <b>3MI</b> )	New mission	Aerosol parameters	Air Quality, CM, NWC
Scatterometry ( <b>SCA</b> )	Higher spatial resolution and coverage	Cross polarisation for higher wind speeds	NWP, NWC
Microwave Imaging ( <b>MWI</b> )	New mission	Precipitation observations	NWP, NWC, Hydrology, CM
Ice Cloud Imaging ( <b>ICI</b> )	New mission	Cloud microphysics parameters	NWP, NWC, Hydrology, CM

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

# Space Segment: Two Satellite System

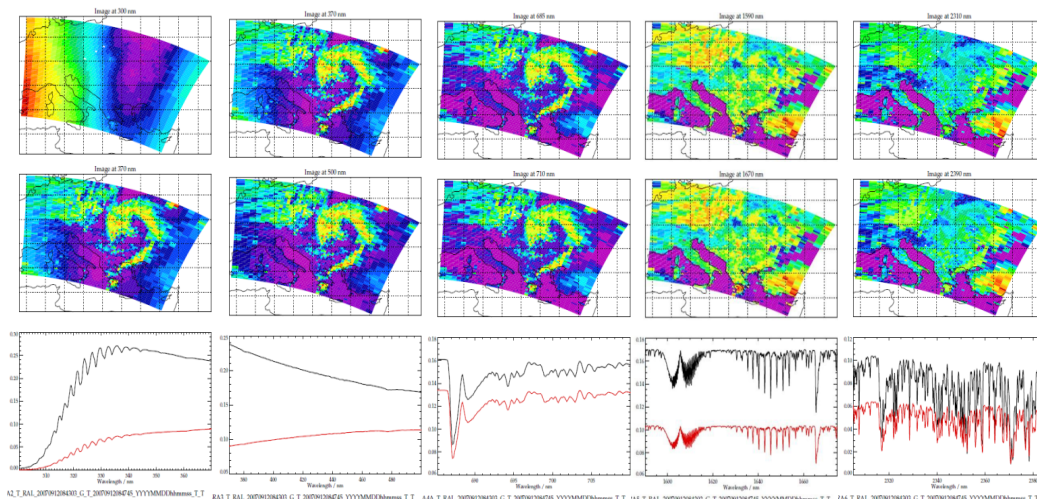
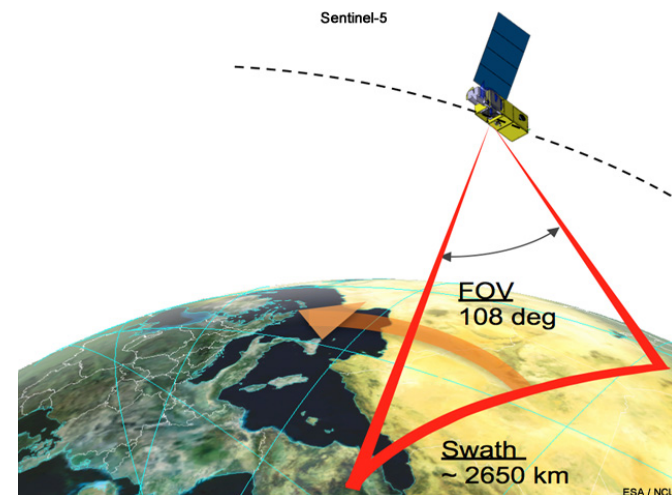
- Satellite-A payload:
  - IASI-NG
  - METimage
  - Sentinel-5
  - 3MI
  - MWS
  - RO
- Satellite-B payload:
  - SCA
  - MWI
  - ICI
  - RO
- Both satellites share the same orbit
  - Local time of descending node:  
09:30



# EPS-SG UVNS Sentinel-5

## UV-NIR-SWIR Hyper Spectral Instrument from Low-Earth Polar Orbit

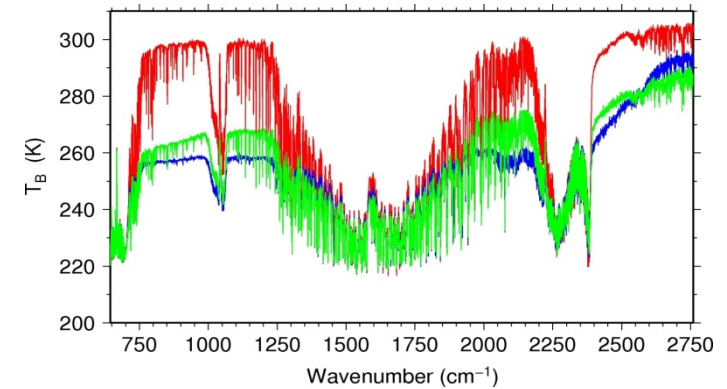
- Sentinel-5 will build on the heritage from the GOME/SCIAMACHY/GOME-2/OMI series of instruments and will provide continuity with these instruments
- The spatial resolution will be significantly improved compared to previous missions (~ 7 x 7 km at SSP), which is important to support development of air quality applications
- Sentinel-5 level 1 and 2 products will be produced operationally by EUMETSAT
- Products: O3, NO2, SO2, HCHO, CH4, CO, CHOCHO, UV, AAI, AOD, ALH, CLD, HSC, SUR



# Hyperspectral Infrared Sounding: IASI-NG

## Objectives

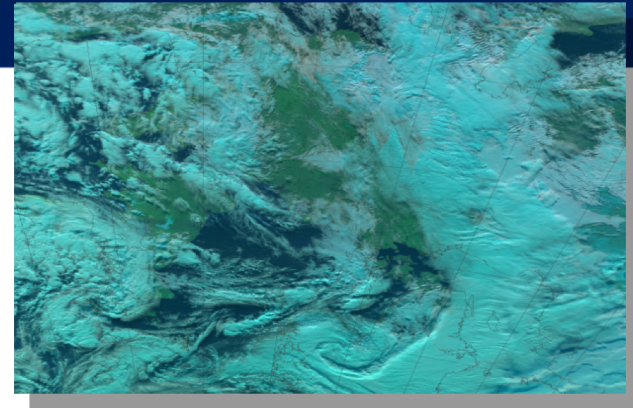
- Temperature/humidity profile at high vertical resolution
- Clouds, trace gases ( $O_3$ ,  $CO$ ,  $CH_4$ ,  $CO_2$ ,...)
- Sea/land/ice surface temperature
- Aerosols, Volcanic Ash



## Breakthrough

- **Doubling of radiometric and spectral 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

# Optical Imaging: METimage



## Objectives

- Hi-res cloud products, incl. microphysics
- Aerosols
- Polar AMVs
- Vegetation, snow, fire
- Sea/ice/land surface temperature
- Support to sounding missions

## Implementation

- Development of *METimage* by DLR

## Key performances

- 20 channels: 0.443 – 13.345  $\mu\text{m}$
- absolute calibration: 5% (short-wave)  
0.5 K (long-wave)
- radiometric sensitivity: SNR 60 – 500  
(short-wave) 0.05 – 0.2 K (long-wave)
- spatial sampling: 500 m cross-track scan

## Breakthrough

- **Far more spectral channels than AVHRR for the benefit of measuring more variables**
- **Higher spatial resolution (500 m):**
  - more complete coverage through greater likelihood to measure surface variables in partly cloud conditions
- **Better radiometric resolution for more accurate quantification of many variables**



# Multi-viewing Multi-channel Multi-polarisation Imaging (3MI)

## Objectives of a new mission

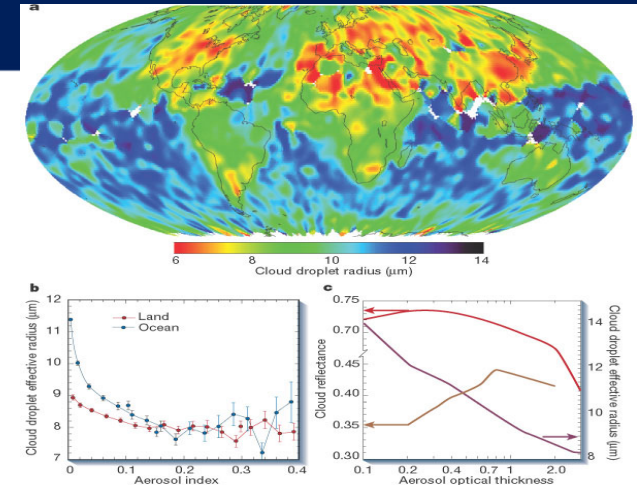
- Aerosol – optical thickness, particle size, type, height, absorption
- Volcanic Ash
- Cloud phase, height, optical depth
- Surface albedo

## Implementation

- ESA development

## Key performances

- 12 channels: 0.41 – 2.13  $\mu\text{m}$
- 3 polarisations: 0°, 60°, -60°
- 14 views
- radiometric bias: 3%
- SNR: 200
- spatial sampling: 4 km
- push-broom scan (2200 km swath)



Kaufman et al. (2002)

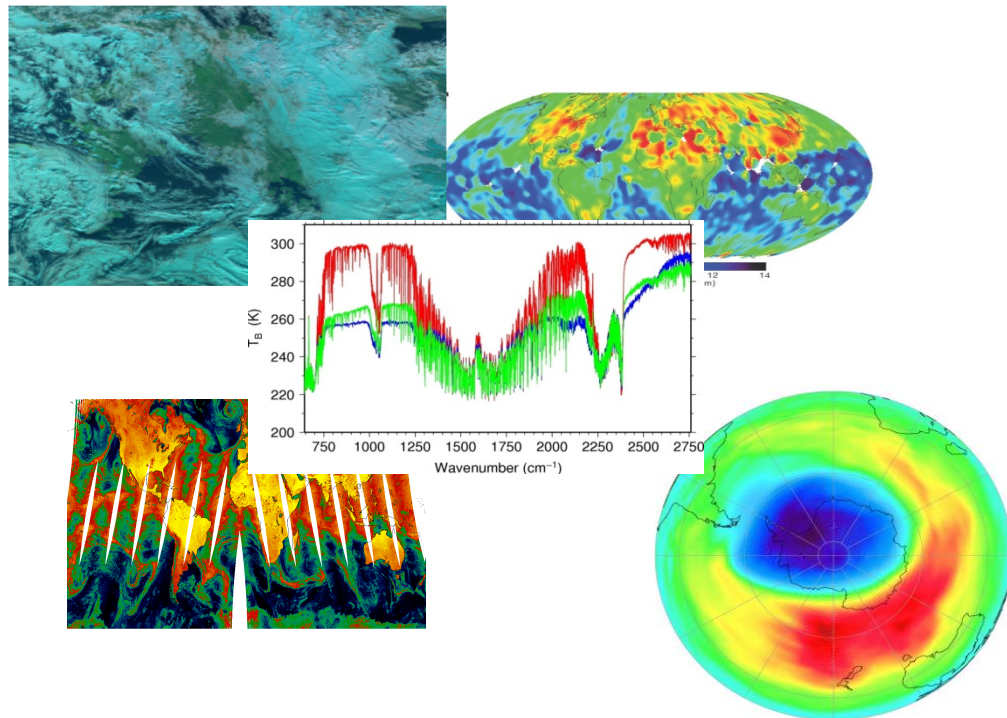
## Breakthrough:

- **Enhanced spatial sampling (4 km)**
  - Improves separation of cloudy areas
- **12 spectral channels (9 polarised), extending into the UV and SWIR**
  - Better aerosol characterisation
- **Higher angular resolution (14 views)**
  - Better phase function characterisation

# Synergy of Observation Missions

## Observation missions are highly complementary

- Co-registration of measurements will allow to optimise the information extraction
- Synergy to be considered in payload distribution of a dual satellite configuration

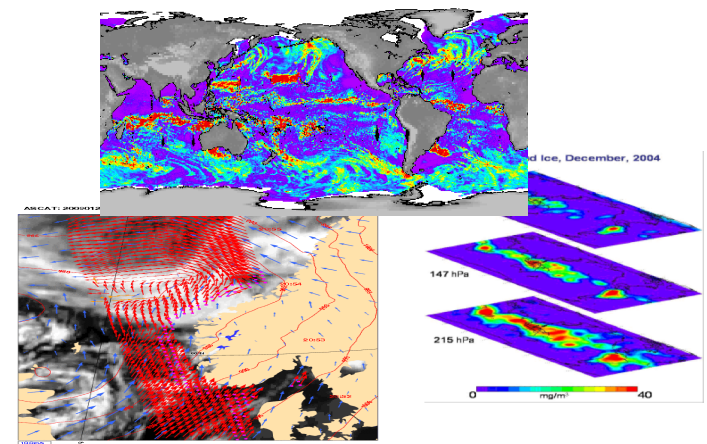


## Essential co-registrations

- IASI-NG – METImage – UVNS/S5
- MWI - ICI

## Desired co-registrations

- IASI-NG – MWS
- METImage – 3MI
- IASI-NG – UVNS/S5 – 3MI
- MWI – SCA – METImage



# Aerosol Product Commitments

Metop PMAp (GOME2/AVHRR/IASI) (AOD, Volcanic Ash Flag)

Metop GOME-2 (AAI, Absorbing Aerosol Layer Height)

Metop IASI (Dust, Volcanic Ash)

MSG SEVIRI (AOD, Volcanic Ash Flag & Layer Height)

Sentinel-3 SLSTR (AOD, Angstrom coefficient)

Sentinel-3 SLSTR & OLCI (AOD, Angstrom component)

MTG UVN (S4) (AAI, Absorbing Aerosol Height)

MTG IRS (Volcanic Ash, Dust)

MTG FCI (AOD, Volcanic Ash Flag & Layer Height)

EPS-SG 3MI & MAP (AOD, Single Scattering Albedo, Refractive Index, Effective Radius, Aerosol Layer Height, Aerosol Type)

EPS-SG UVNS (S5) (AAI, Absorbing Aerosol Layer Height)

*EPS-SG IASI-NG (Volcanic Ash, Dust)*

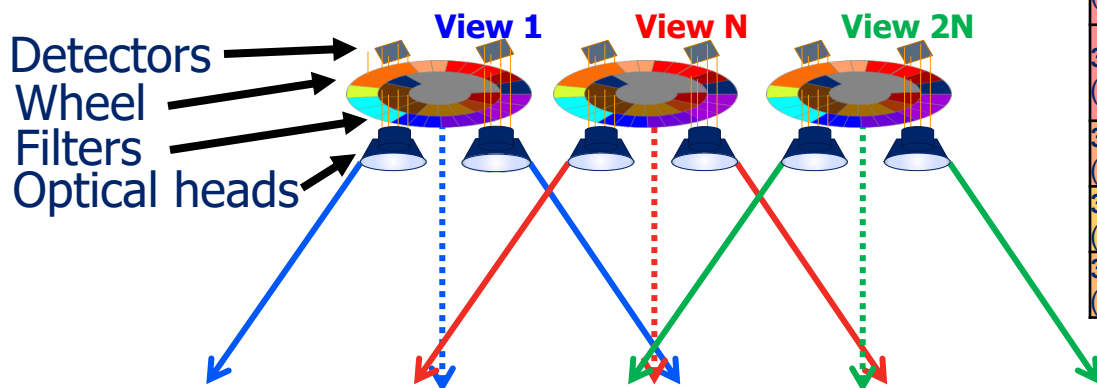
EPS-SG METimage (AOD, Volcanic Ash Flag & Layer Height)

# 3MI Observation Concept

## 3MI Multi Viewing Angle Acquisition



Channel (Polarisation)	Channel centre (channel width)	Channel index k	Optical head	Applications
3MI-2b (Yes)	410 nm (20 nm)	1	VNIR Optical head (h=1)	Absorbing aerosol and ash cloud monitoring
3MI-3 (Yes)	443 nm (20 nm)	2		Aerosol absorption and height indicators
3MI-4 (Yes)	490 nm (20 nm)	3		Aerosol, surface albedo, cloud reflectance, cloud optical depth
3MI-5 (Yes)	555 nm (20 nm)	4		Surface albedo
3MI-6 (Yes)	670 nm (20 nm)	5		Aerosol properties
3MI-7 (No)	763 nm (10 nm)	6		Cloud and aerosol height
3MI-8 (No)	765 nm (40 nm)	7		Cloud and aerosol height
3MI-9 (Yes)	865 nm (40 nm)	8		Vegetation, aerosol, clouds, surface features
3MI-9a (No)	910 nm VNIR (20 nm)	9		Water vapour, atmospheric correction
3MI-9a (No)	910 nm SWIR (20 nm)	10	SWIR Optical head (h=2)	Water vapour, atmospheric correction
3MI-10 (Yes)	1370 nm (40 nm)	11		Cirrus clouds, water vapour imagery
3MI-11 (Yes)	1650 nm (40 nm)	12		Ground characterisation for aerosol inversion
3MI-12 (Yes)	2130 nm (40 nm)	13		3MI-11 + Cloud microphysics at cloud top, Vegetation, fire (effects)



# Towards an EPS-SG Hyper-Instrument

3MI/S5/IASI-NG/VII - MAP

Combining co-locations of VII/Sentinel5/IASI-NG observations with co-registered multi-viewing observations (3MI) on 3MI multi-viewing fixed grid.



Sentinel-5  
UV-Vis-SWIR hyper spectral sounder

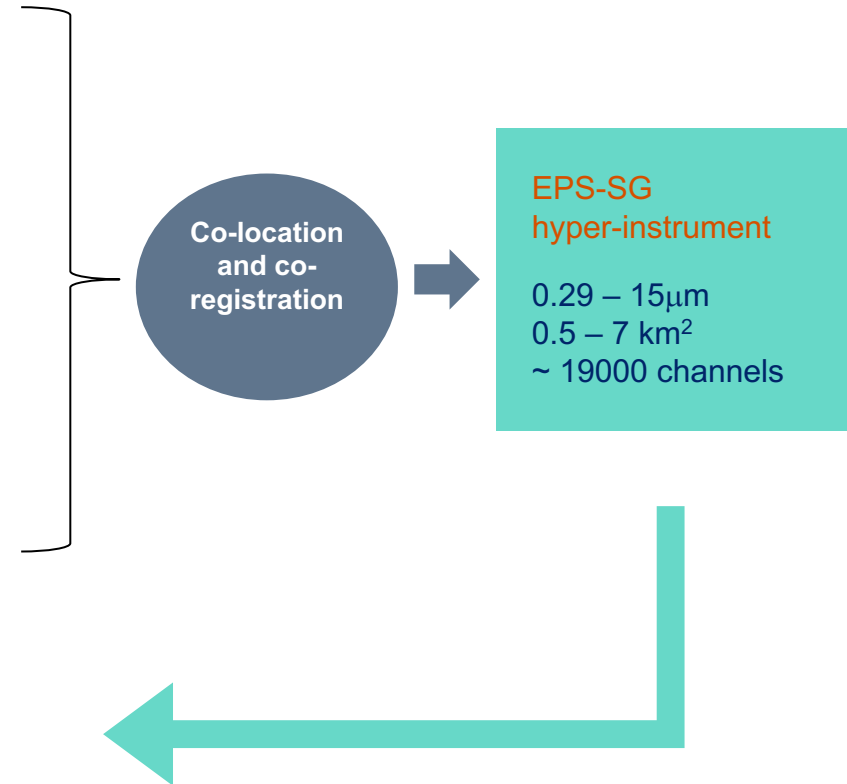
IASI-NG  
IR hyper spectral sounder

VII  
Very high spatial resolution,  
multi channel imager

3MI  
Multi-viewing,  
Multi-polarisation,  
Multi-channel imager

EPS-SG Platform

Initial product: Multi-sensor Aerosol product (MAP)



# Summary

- EUMETSAT will **Operate** a number of Sentinel missions
- EUMETSAT will **Monitor and Evolve** these products during the operational phase
- The Sentinels will benefit from a **Wealth of Data** available from operational EUMETSAT missions