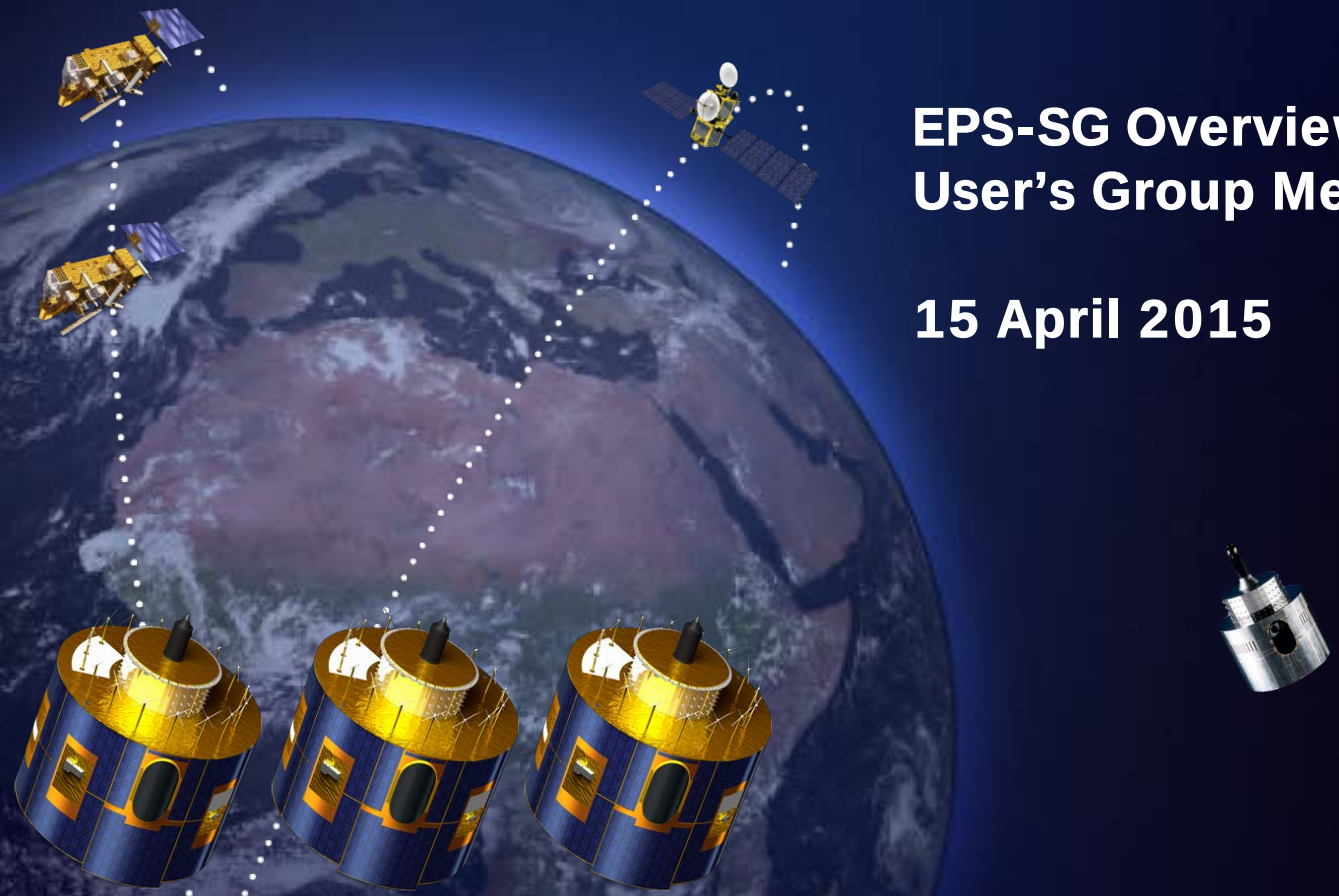
MONITORING WEATHER AND CLIMATE FROM SPACE

EUMETSAT



EPS-SG Overview for CSPP / IMAPP User's Group Meeting

15 April 2015

EPS-SG Programme Overview

- Achieved approval of the scope and contents of the EPS-SG Programme Proposal which includes the draft cooperation agreements with ESA, CNES, DLR and NOAA. Full funding to be confirmed by June 2015.
  - EUMETSAT responsible for the system, operations, ground segment development, LEOP and launch services and recurrent elements
  - ESA responsible for development of the Metop-SG satellites and certain instruments (MWS, 3MI, RO, SCA, MWI and ICI), as well as the Copernicus S-5 instrument
  - CNES responsible for the development of the IASI-NG instrument and delivery of the A-DCS4 instrument
  - DLR responsible for the development of the METimage instrument
  - NOAA and EUMETSAT will share responsibilities for the polar ground stations in Svalbard and McMurdo

EPS-SG Phase B – Summary Status

- System Preliminary Design Review (PDR) started in March 2015
- ESA: Prime contractors for the Metop-SG A and B satellites selected and Phase B2 kicked off in June 2014. PDR planned for September 2015.
- CNES: IASI-NG PDR started in March 2015.
- CNES: The first flight model of A-DCS4 for EPS-SG is under assembly.
- DLR: METimage instrument PDR started in March 2015.
- EUM: Overall Ground Segment PDR planned for September 2015

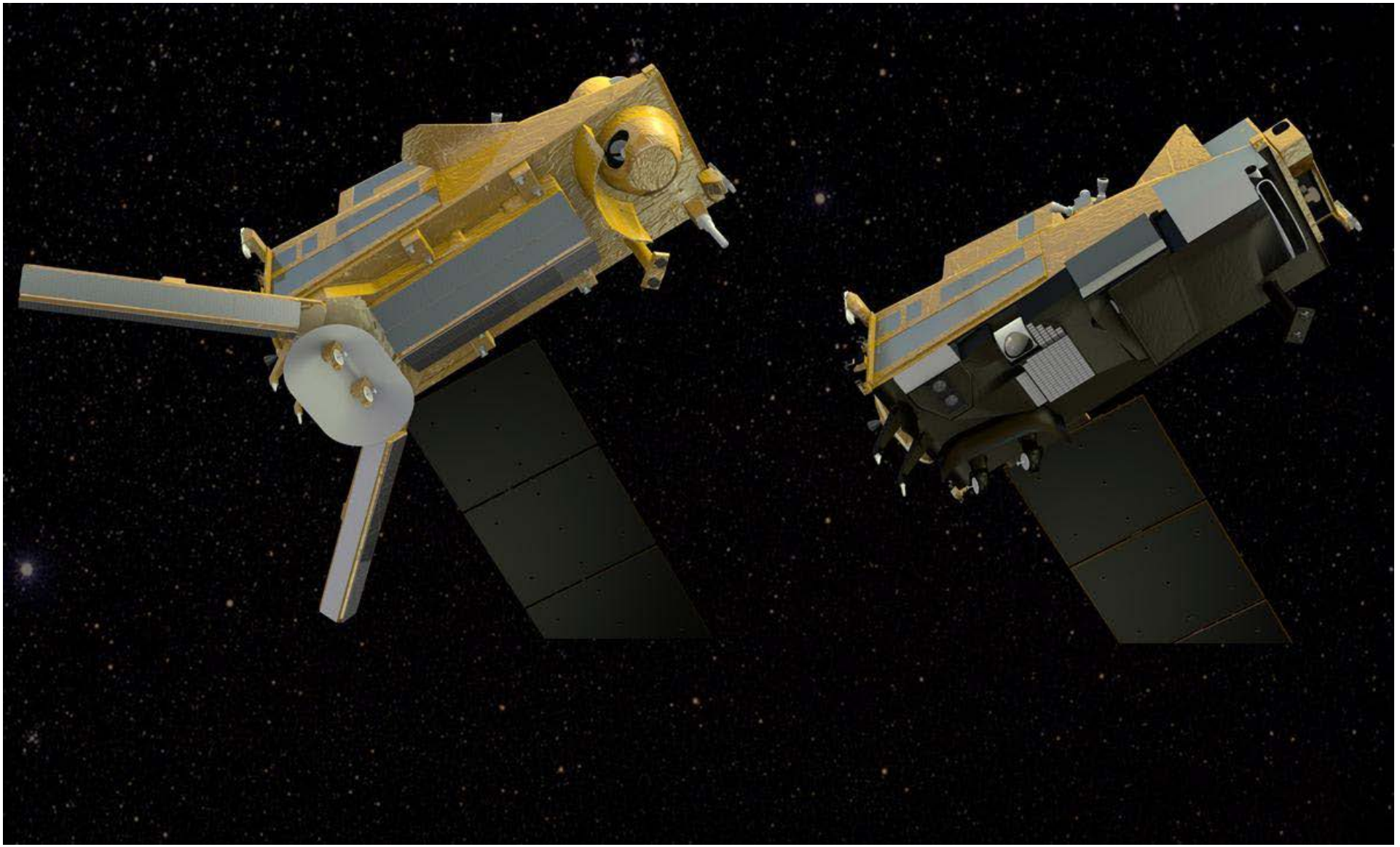
Launches and Orbits

- Nominal launches:
  - 2021 Metop-SG A1
  - 2022 Metop-SG B1
  - 2028 Metop-SG A2
  - 2029 Metop-SG B2
  - 2035 Metop-SG A3
  - 2036 Metop-SG B3

- Sun Synchronous Orbit at 835 km mean altitude, 09:30 LTDN
- Identical orbit as for EPS => shared orbit between Metop and Metop-SG satellites

- Controlled re-entry of the satellites into the South Pacific Ocean Uninhabited Area at the end of operational life

Metop-SG Dual Satellite Configuration



Metop-SG Satellite Key Parameters

Satellites Key Parameters	Satellite A	Satellite B
Payload Complement	METimage, IASI-NG, MWS, S-5, 3MI, RO	SCA, MWI, ICI, RO, Argos-4
Mass (kg)	4,017 (+135 adaptor)	3,818 (+135 adaptor)
Fuel (kg)	654	618
Total ΔV (m/s)	325.8 m/s (of which 68% is for controlled re-entry)	
Stowed Dimensions (m)	6.5 (+0.55) x 2.97 x 3.46	6.1 (+0.55) x 2.91 x 3.43
Power Consumption (kW)	3.60	2.53
Nominal Mode	Yaw steering – gyroless	
Safe Mode	Earth pointing – 3 axes stabilised	
Data Storage (Gbit)	600 (sized for 1.5 orbits of Satellite A)	
Average Data Rate (Mbps)	65 (day) & 25 (night)	19 (day & night)
Ka-band Downlink (Mbps)	781 (2 channels)	390.5 (1 channel)
X-band Downlink (Mbps)	80	
Lifetime	Nominal = 7.5 years, Extended = 9.5 years	

EPS-SG Direct Broadcast

- Roughly 20-fold increase of sensing data rates from EPS to EPS-SG, with a corresponding increase in global and direct broadcast data rates
- Direct broadcast data rates will be 80 Mb/s, making it impossible to remain in L-band as per EPS. X-band has been chosen instead; L-band will not be supported on the Metop-SG satellites
- Satellite A has a much higher peak data rate than Satellite B, but both satellites will have exactly the same direct broadcast data rates (filler data to be inserted on Satellite B)
- In routine operations, Satellite B will be flying about 90° / 25 minutes ahead of Satellite A. Metop satellites will also be flying in the same orbit, with Metop-C nominally at 90° after Metop-SG A1 until its de-orbiting

EPS-SG Direct Broadcast Key Parameters

Characteristic	NPP / JPSS-1	EPS-SG
Reception Station Performance Requirement, G/T	22.7 dB/K	22.7 dB/K
Typical Resulting Antenna Size	2.4 m	2.4 m
Data Rate (Instrument Data)	16 Mb/s	80 Mb/s
Radio Frequency	7.8 GHz	7.8 GHz
Modulation Scheme	QPSK	Offset QPSK
Polarisation	RHCP	RHCP

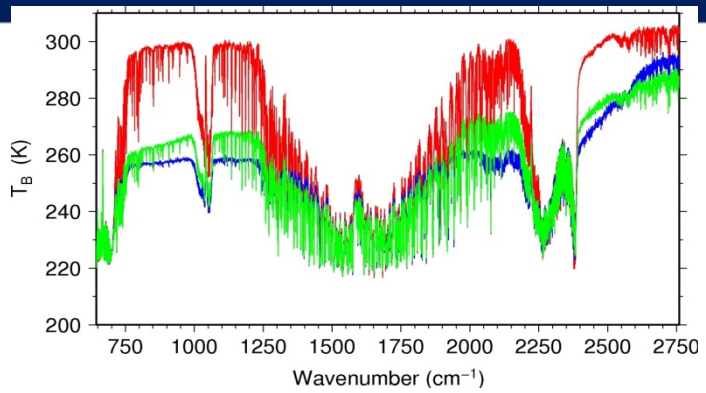
- The parameter G/T is the main driver for the Reception Station Performance Requirements. For EPS-SG, the plan is to match the NPP requirement;
- The G/T depends on the full chain of equipment including antenna dish quality and size, antenna tracking performance, feed, LNA, cabling, etc;
- With good quality equipment, the required G/T can be achieved with a 2.4m antenna dish. To add additional margins for severe weather conditions and to mitigate potential local RF interference, a larger dish size may be chosen.

Observation missions

Mission	Instrument	Applications Benefitting
Hyper-spectral Infrared Sounding	IASI-NG	NWP, NWC, Air Quality, CM
Visible/Infra-red Imaging	METimage	NWC, NWP, CM, Hydrology, Oceanography
Microwave Sounding	MWS	NWP, NWC, CM
Radio Occultation Sounding	RO	NWP, CM
Nadir viewing UV/VIS/NIR/SWIR Sounding	Sentinel-5	Ozone-UV, Air Quality, CM, Composition-Climate interactions
Multi-viewing, -channel, -polarisation Imaging	3MI	Air Quality, CM, NWC
Scatterometry	SCA	NWP, NWC, Oceanography, Hydrology
Microwave Imaging	MWI	NWP, NWC, Hydrology, CM, Oceanography
Ice Cloud Imaging	ICI	NWP, NWC, Hydrology, CM

NWP: Numerical Weather Prediction; NWC: Nowcasting; CM: Climate Monitoring

Hyper-spectral 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

Implementation

- Development of Fourier Transform Spectrometer IASI-NG by CNES

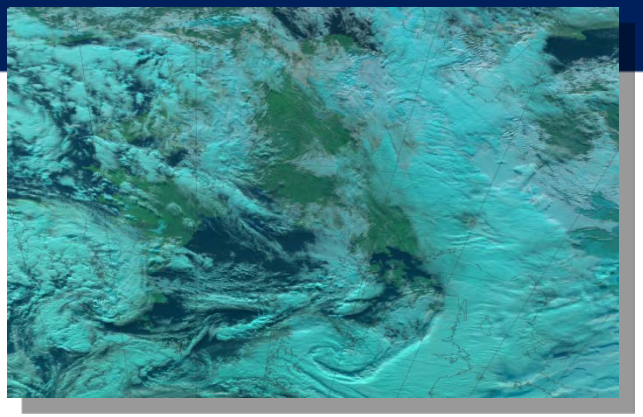
Key performances

- spectral range: 645 – 2760 cm^{-1}
- spectral resolution: 0.25 cm^{-1}
- radiometric calibration: 0.25 K
- stability: 0.1 K
- radiometric noise: 0.045 – 1.1 K
- pixel size: 12 km
- spatial sampling: 25 km
- cross-track scan

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

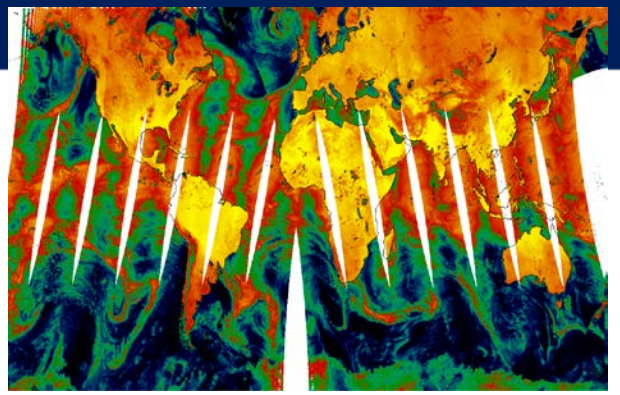
Key performances

- 20 channels: 0.443 – 13.345 µm
- 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 sampling (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**

Microwave sounding: MWS



Objectives

- Temperature/humidity profiles in clear and cloudy air
- Cloud liquid water total column
- Imagery: precipitation

Implementation

- ESA development

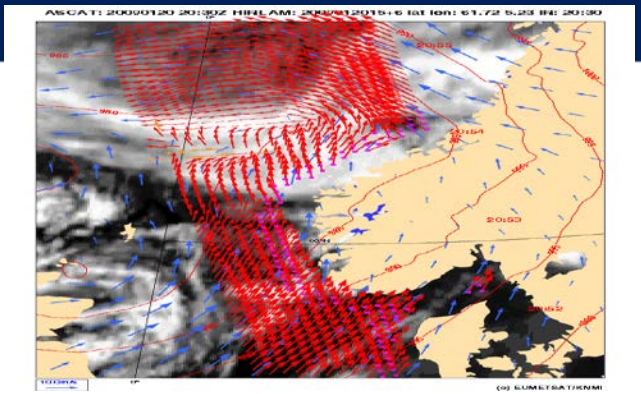
Key performances

- 24 channels: 23.8 – 229 GHz
- absolute calibration: 0.5 K
- radiometric noise: 0.2 – 1.6 K
- footprint size: 17 – 40 km
- cross-track scan

Breakthrough

- **Addition of a quasi-window channel at 229 GHz (recommended by ITSC-11)**
  - Cirrus cloud information giving a better humidity retrieval performance
- **Addition of sounding channels**
  - **+ 2 channels at 53-54 GHz**
  - **+ 2 channels at 183.31 GHz**
  - More information on temperature and water vapour profiles

Scatterometry: SCA



Objectives

- ocean surface wind vectors
- soil moisture
- snow equivalent water
- sea-ice type

Implementation

- ESA development

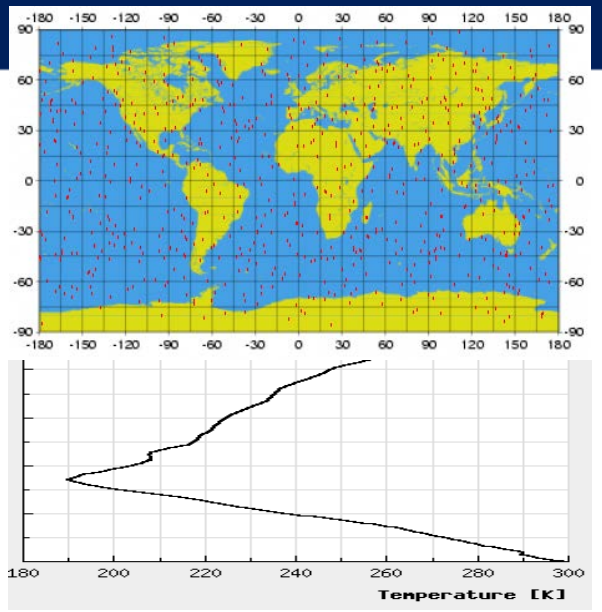
Key performances

- C-band carrier frequency
- VV + VH polarisation
- measurement range: 4 – 40 m/s
- Radiometric resolution: 3%
- spatial resolution: 25 km
- dual swath: 550 km each

Breakthrough

- **Increase of spatial resolution to 25 km**
  - Better approach of coast lines
- **Increase of swath width to >1100 km**
  - Enhanced coverage
- **Addition of VH polarisation**
  - Covers higher wind speeds without saturation, will benefit observation of tropical and extra-tropical storms

Radio occultation sounding: RO



Objectives

- Refractivity profiles at high vert. resolution
- Temperature / humidity profiles
- PBL top and tropopause height
- Ionospheric electron content

Implementation

- ESA development

Key performances

- tracking of GPS and Galileo satellites
- optional: GLONASS and COMPASS
- RO on two satellites: > 2600 occultations per day
- bending angle accuracy: 0.5 µrad or 0.2%

Breakthrough

- **Tracking of GPS and Galileo satellites to double the number of occultation measurements, optionally also GLONASS and Beidou**
- **Equipment of both Metop-SG satellites with RO**

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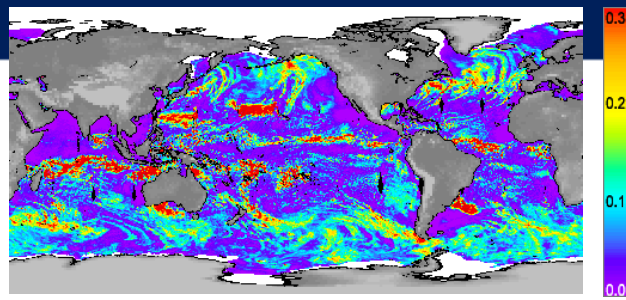
Microwave imaging: MWI



RSS (2011)

Cloud Liquid Column mm

Objectives of a new mission

- precipitation and cloud products
- water vapour profiles and imagery
- sea-ice, snow, sea surface wind

Implementation

- ESA development

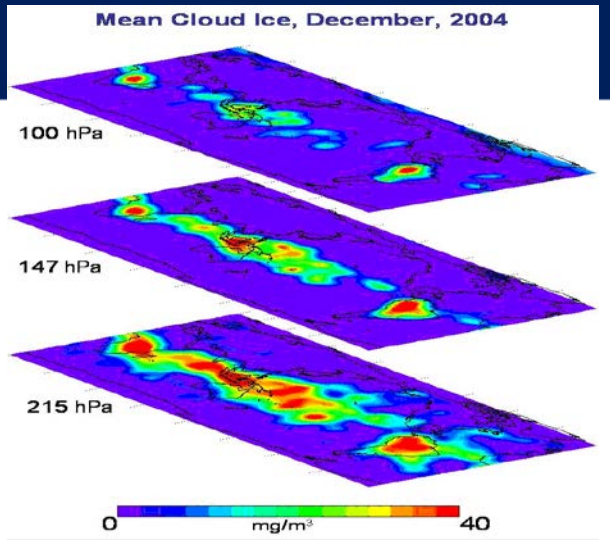
Key performances

- 18 channels: 18.7 – 183 GHz
- dual polarisation (V, H) up to 89 GHz
- V polarisation at higher frequencies
- radiometric accuracy: 1 K
- radiometric sensitivity: 0.6 – 1.2 K
- Footprint size: 10 – 50 km
- spatial sampling: 7 km
- conical scan

Breakthrough: 18 channels

- **Continuity of key microwave imager channels for weather forecast**
- **Inclusion of dedicated sounding channels (118.75 GHz)**
  - Enhanced precipitation measurements through inclusion of dedicated sounding channels
- **Extended suite of 183.31 GHz channels**
  - water-vapour and cloud profiling

Ice cloud imaging: ICI



NASA: Aura/MLS

Objectives of a new mission

- Cloud products, in particular ice clouds
- Snowfall detection and quantification
- Water-vapour profiles and imagery

Implementation

- ESA development

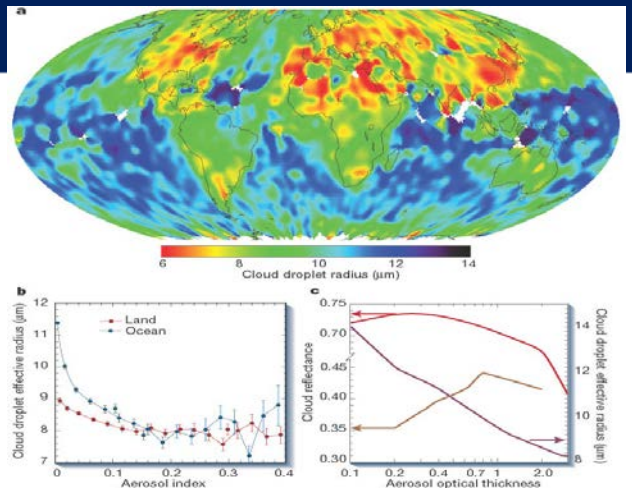
Key performances

- 11 channels: 183 – 664 GHz
- single polarisation (V) for all channels
- dual polarisation (V, H) at 243 and 664 GHz
- radiometric accuracy: 1 – 1.5 K
- radiometric sensitivity: 0.6 – 1.9 K
- Footprint size: 15-16 km
- spatial sampling: 7.5 km
- conical scan

Breakthrough: 11 channels

- **Establishes operational ice-cloud imaging mission**
- **Support of weather forecast, hydrology, and climate monitoring**

Multi-viewing Multi-channel Multi-polarisation Imaging: 3MI



Kaufman et al. (2002)

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

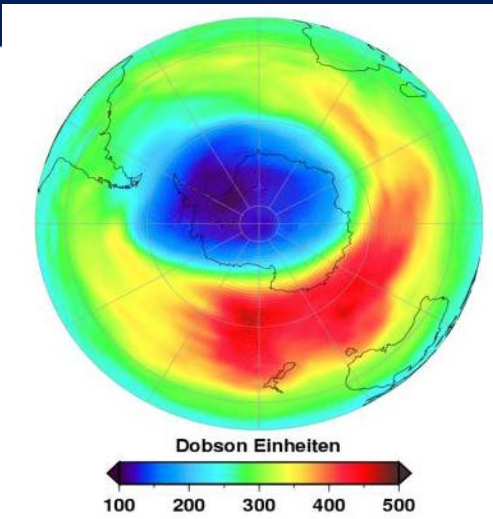
Key performances

- 12 channels: 0.41 – 2.13 µm
- 3 polarisations: 0°, 60°, -60°
- up to 14 views
- radiometric bias: 3%
- SNR: 200
- spatial sampling: 4 km
- push-broom scan (2200 km swath)

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

Nadir-viewing UVNS sounding: Sentinel-5



Objectives

- Ozone profile and column
- Columns of CO_2,SO_2, NO_2, H_2O, CO, CH_4
- Aerosol optical depth
- Columns of BrO, HCHO, OCHCHO
- Volcanic Plumes

Implementation

- Copernicus Sentinel-5 to be embarked on Metop-SG
- ESA development

Key performances

- spectral range: 0.27 – 2.385 µm
- spectral resolution: 0.25 – 1 nm
- radiometric calibration: 1 – 2%
- SNR: 120 - 1500
- spatial sampling: 7 km
- Cross-track scan

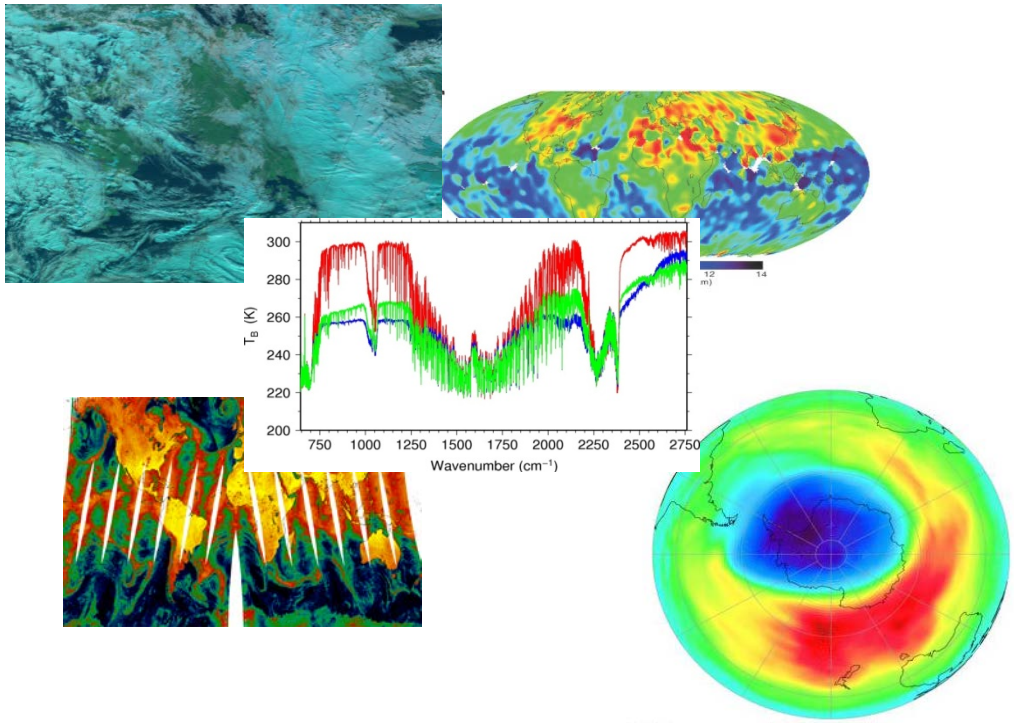
Breakthrough

- **Drastically increased spatial sampling (7 km)**
  - for the benefit of air quality monitoring
- **Extended spectral range into the near and shortwave infrared regions**
  - to measure aerosols as well as methane and carbon monoxide in the PBL

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

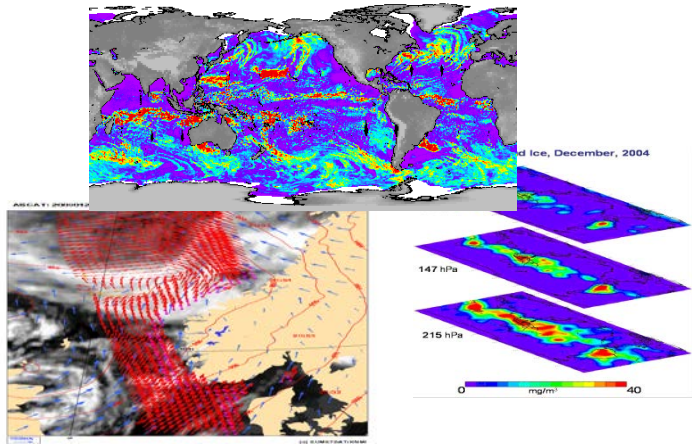


Essential co-registrations

- IASI-NG – METimage – Sentinel-5
- MWI - ICI

Desired co-registrations

- IASI-NG – MWS
- METimage – 3MI
- IASI-NG – Sentinel-5 – 3MI
- MWI – SCA



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Direct Broadcast Data Content

- EPS-SG Direct Broadcast data will include:
  - Data for each EPS-SG instrument (i.e. source packets)
  - HKTM, inc. satellite ancillary data (NAVATT)
  - Admin messages (as for Metop satellites)
- Dedicated Virtual Channels used for different data types, multiplexed in the X-band data stream.
- Dedicated APIDs to distinguish packets for different instruments, NAVATT, HKTM, ADMIN messages.
- Format and structure of all packets compliant with **CCSDS and ECSS** standards with appropriate tailoring.

Direct Broadcast Data Content - NAVATT

- Metop-SG satellites will provide in X-band **NAVigation and ATTitude (NAVATT) packets** including satellite ancillary data:
    - Orbit state vectors
    - Attitude quaternions
    - Flags indicating platform state (e.g. manoeuvres, pointing modes, on-board time synchronisation, etc.)
- Platform state at the time of instrument data acquisition available in real-time, high frequency and accuracy (e.g. ~10m for orbit)
- Flags (e.g. on-going manoeuvres) useful to identify and handle non-nominal conditions impacting products quality.

Direct Broadcast Data Content – ADMIN messages

- In continuity with Metop, Metop-SG satellites will also broadcast **ADMIN messages** including planned satellites/instrument activities e.g. manoeuvres, instrument decontamination, anomalies, etc.

- ADMIN messages will provide information on future/planned events, complementing real-time events and orbit/attitude parameters provided in NAVATT packets.

- ADMIN messages will be formatted according to the Multi-Mission Administrative Message (MMAM) format in continuity with EPS. http://oiswww.eumetsat.int/UMS/webapps/mmams/generated/index

Direct Broadcast Data Content – Timing information

- Metop-SG satellites will embark GNSS receivers for on-board orbit determination and time synchronisation.
- On-board time will be kept synchronised to GPS time.
- All Direct Broadcast data will be time-stamped with GPS time.
- On-ground data correlation to UTC will be simplified – no need for coefficients-based conversion between OBT/UTC. Only correction of leap seconds (available from IERS).
- NAVATT data will include flags indicating the status of on-board time synchronisation – it can indicate anomalies with potential impact on products quality

EPS-SG Products Processing Software

- EUMETSAT and partners responsible for implementation of **L1/L2 processing software** used at EUMETSAT Headquarters in Darmstadt to generate EPS-SG mission products in NRT.

- L1 software for selected EPS-SG instruments later on adapted by the EUMETSAT **SAFs** (including NWP SAF) for execution in local mission context / provision to local user.

- To support future use in local mission context, design drivers for L1 software development:

  - Highly modular design
  - Clear separation between common libraries, COTS and algorithms
  - Portability to multiple computing platforms (HW/OS)
  - Testing on commonly available platform (x86/64bits Linux kernel)

EPS-SG Products Formats

- **NetCDF** used as native format for EPS-SG products generated at EUMETSAT – but different or additional formats (e.g. BUFR) may be disseminated to the users for selected products and/or instruments.

- Pros of NetCDF are well known - open standard, self-describing, portable, APIs available, widely used in the EO satellites users community.

- Benefits for L1/L2 processing software – with an outlook to its future use in local mission context:

  - Simplified handling, reading/writing of input/output products
  - Increased SW portability to multiple platforms (HW/OS)
  - Simplified conversions from/to other product formats.
  - Use of standard APIs - improved SW modularity and maintainability

Auxiliary Data for local processing

- Ground-computed, static or quasi static **auxiliary data** will be also needed for local processing e.g. instrument calibration parameters, look-up tables, etc.

- In addition some EPS-SG instruments will routinely generate calibration data at pre-defined orbital positions which may not be in visibility of the local stations – this data will be only available at EUMETSAT.

- Auxiliary data generated or used at EUMETSAT and needed for local processing will be regularly made available to local users – unless already distributed by other entities (e.g. ECMWF).

- Goal is to ensure maximum consistency between locally generated and centrally generated products.