Securing the low earth orbit system for the future

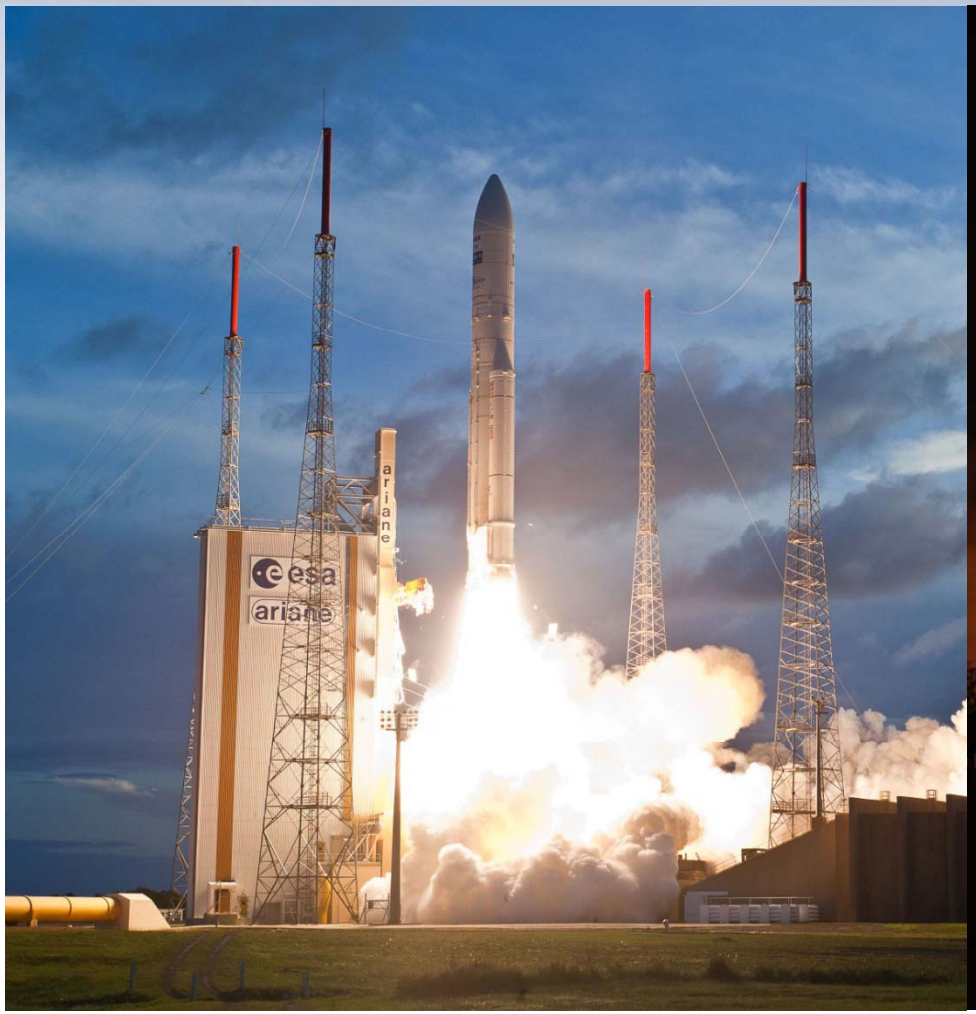
Mikael Rattenborg

Director of Operations and Services to Users

NOAA Satellite Conference, April 2013

EUMETSAT

2012
A year with two launches, MSG-3 and Metop-B



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Metop: European contribution to a unique cooperation with the US: the Joint Polar System

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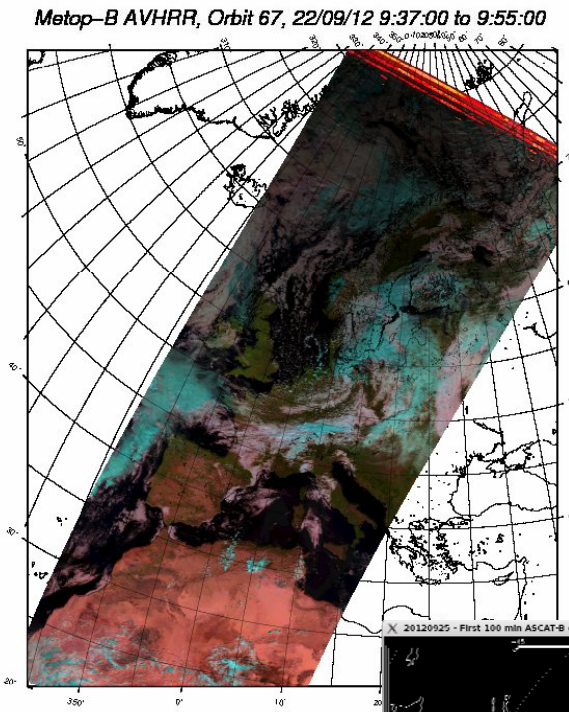
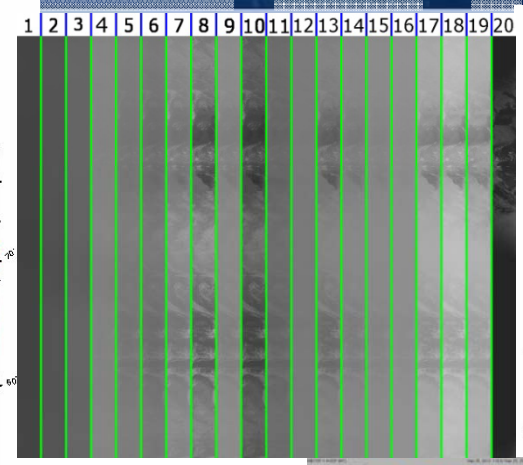
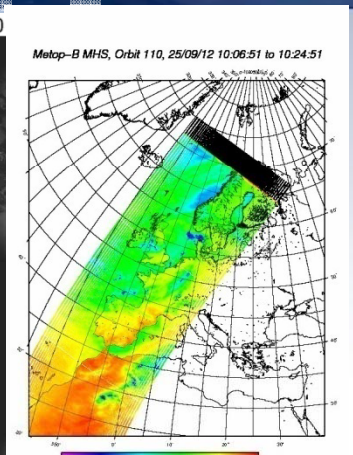
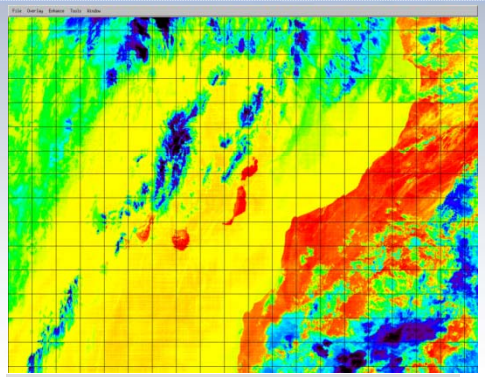
First Images and Early Data from Metop-B

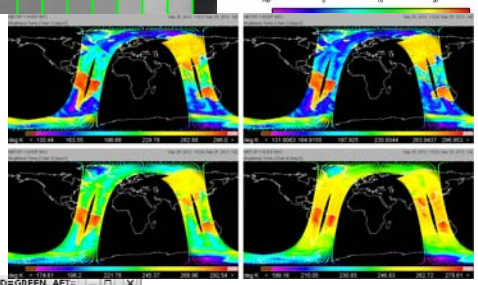
First Metop-B Image

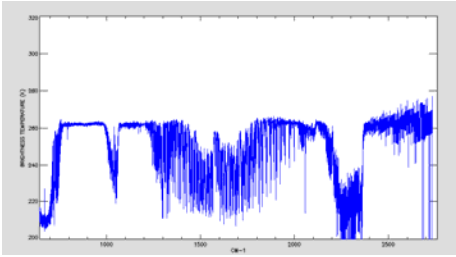


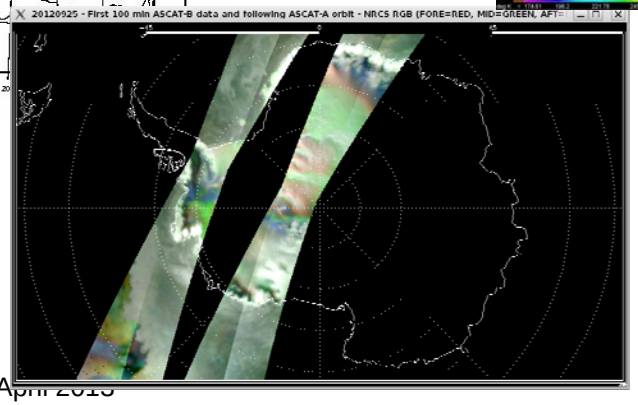


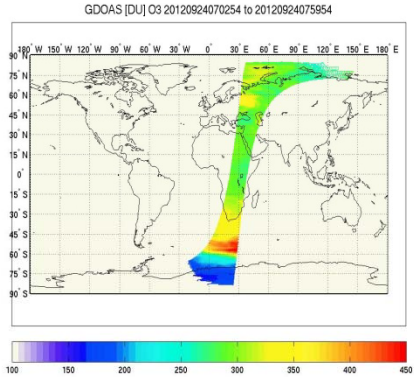


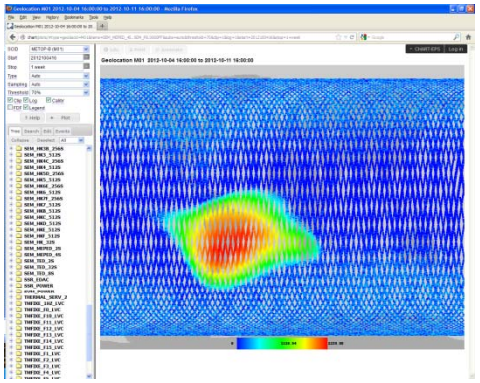












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Metop-B status

- Spacecraft is 100% healthy
- All instrument units are healthy except:
  - ADCS/SARR/SARP – message loss of ca. 35% for ARGOS / 15% for Search & Rescue due to CRA antenna cable problem;
  - GOME-2 throughput degrading in UV (as for Metop-A);
  - HIRS NEDT increase identified. Trend worsens and is thought to be due to filter wheel “wobble”;
  - Some minor MHS problem – but no data impact.

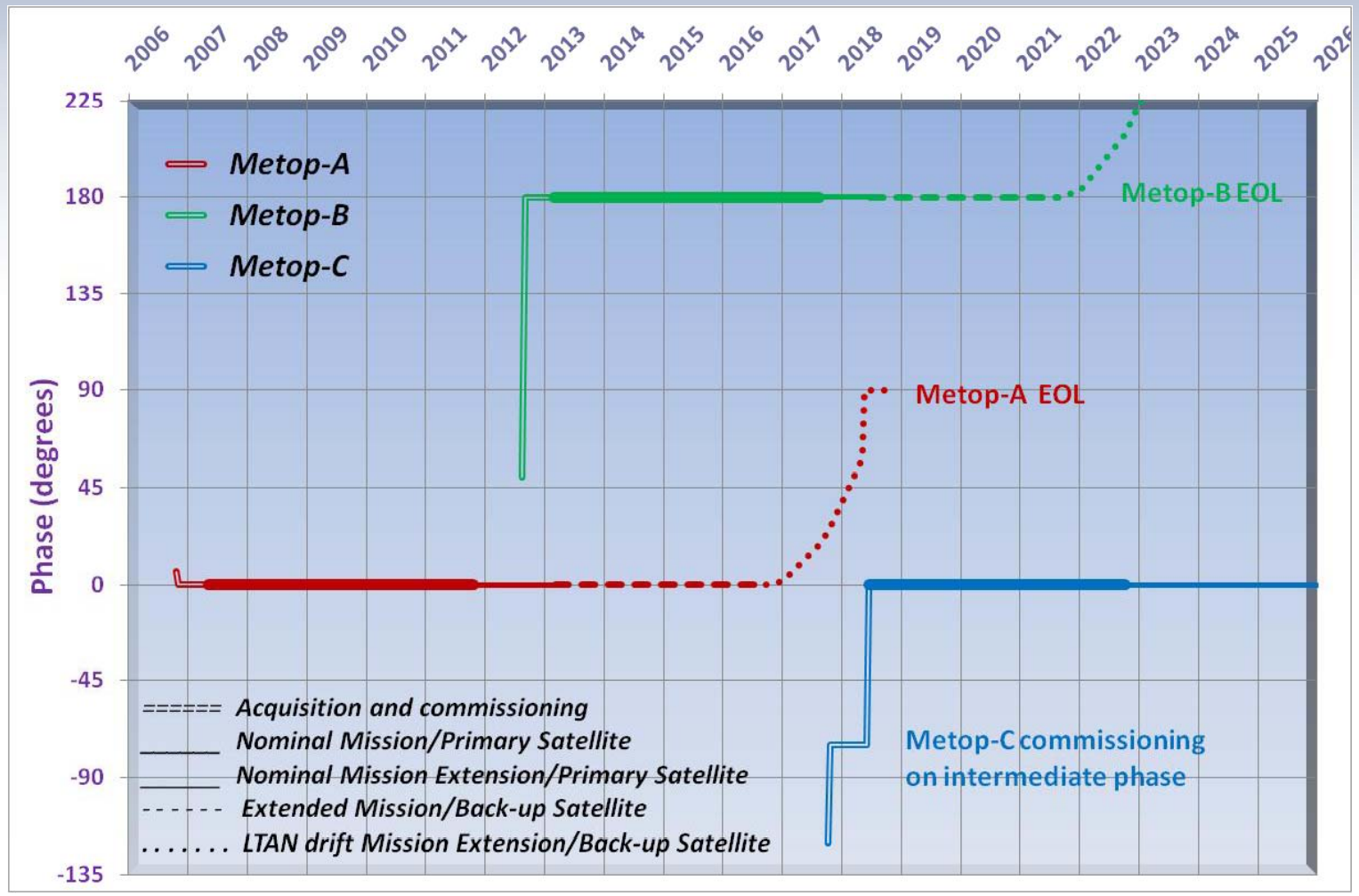
- Metop-B will become prime satellite 24 April

Metop-A/B dual operations

- Objective is to maintain the two-satellite mid-AM configuration up to the commissioning of Metop-C in 2018
- As long as the dual-Metop configuration is available:
  - Metop service as a whole will be more robust against failures;
  - Service will offers opportunities for additional benefits to users.
- The availability of Metop-A for dual operations is driven by
  - Spacecraft health (Metop-A is now beyond its design lifetime)
  - Instrument performance
  - Space Debris Mitigation, that require enough fuel available for final manouevre and spacecraft reentry within 25-30 years.

Metop-A/B dual Operations Feasibility: Orbit Position Planning

Phase drift corresponds to a drift in LTAN (Local Time of Acending Node) and ground track



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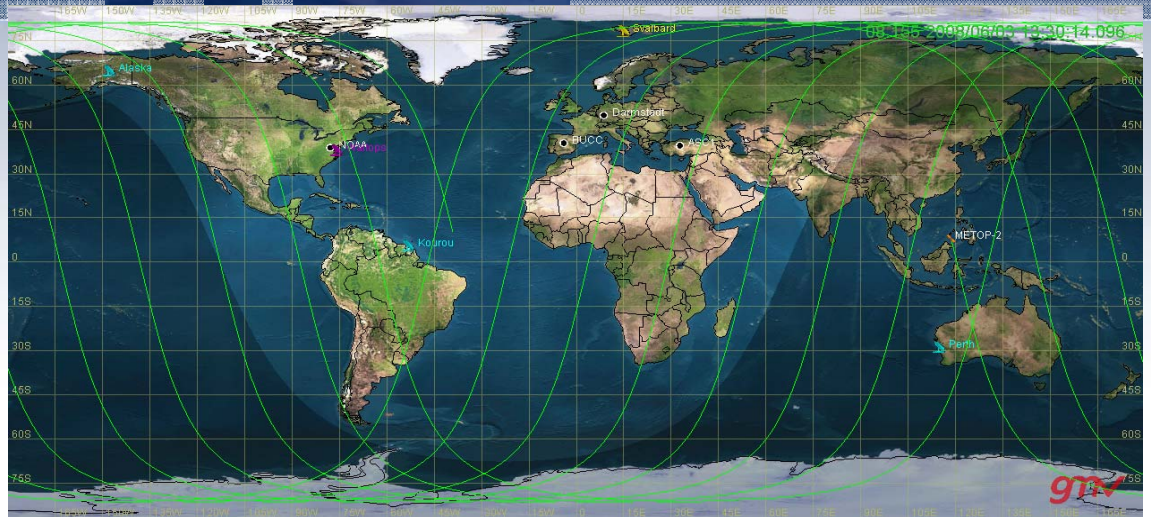
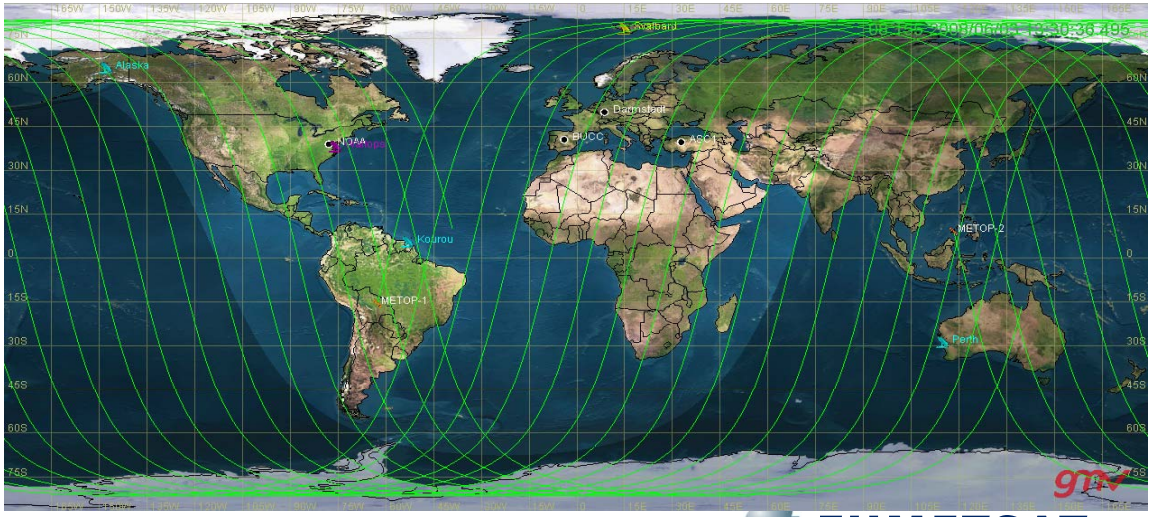
Dual Operations Scenario Overview
Orbital Configuration

- Same orbital plane, with Metop-B over ANX 48.93m ahead of Metop-A. Same viewing geometry over whole 29 day repeat cycle.

- Due to the Earth's rotation, the ground track and instrument swathes will be different.





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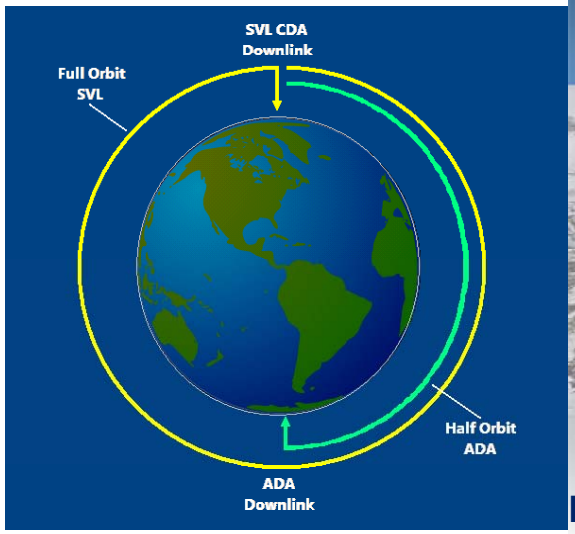
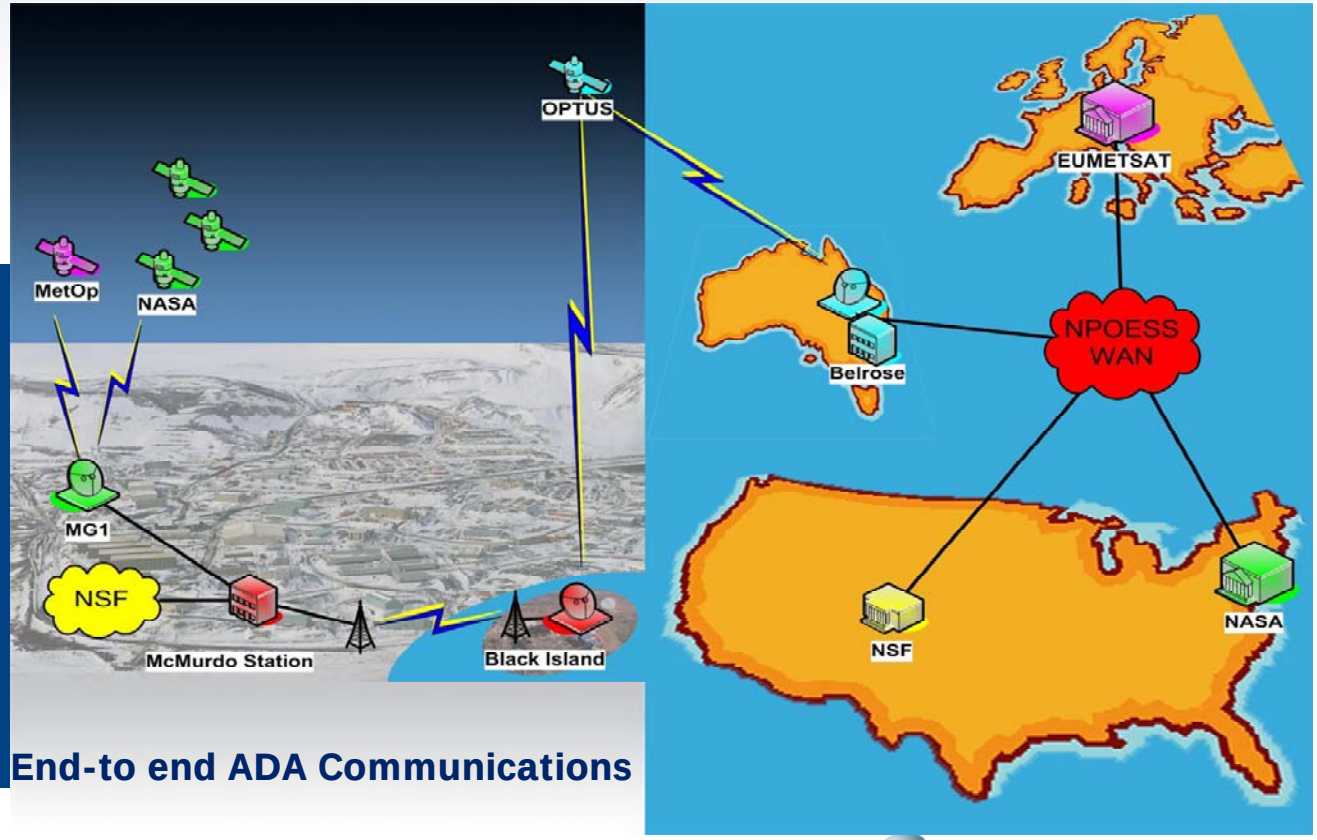
Dual Operations Scenario Overview
Global Data Mission Operations

Antarctic Data Acquisition (ADA) Service, using McMurdo Ground Station :

- ADA in Demonstration Phase since mid-2011 (9 orbits specified, 12-13 received on average), only for prime satellite;
- McMurdo Antenna will acquire all orbits from early 2014 (Operational Phase);
- With ADA, global L1 timeliness is around 65 minutes from sensing





End-to end ADA Communications

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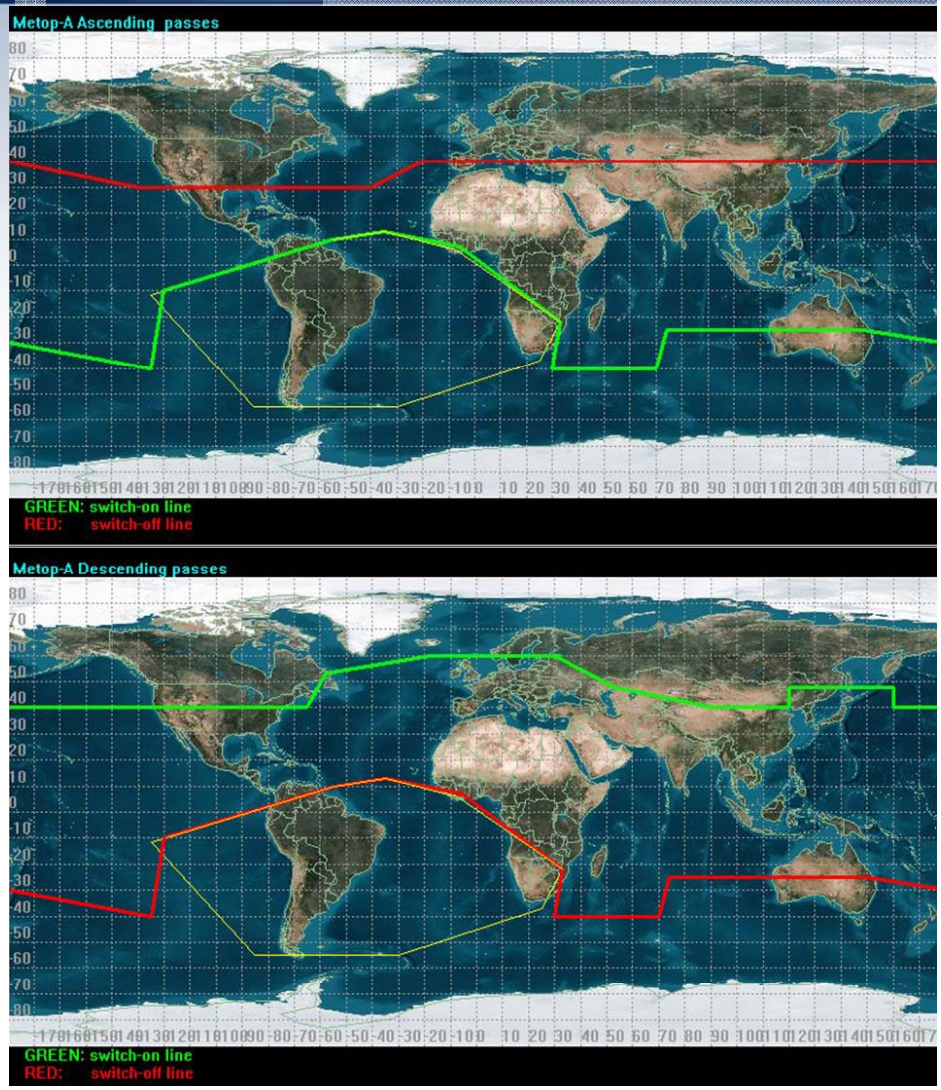
Dual Operations Scenario Overview
Local and Regional Data Mission Operations (1)

Local Mission Direct Readout Service:

- Parallel Metop-A / B AHRPT operation;
- Metop-A continues zone based operation *(see illustration right);*
- Metop-B AHRPT reengineered – operated permanently;
- Particular benefit to the ARGOS user community due to Metop-B antenna defect resulting in most of the weaker signals from ground being lost (about 35% of all messages);
- Note that LRPT operational mission has been discontinued for the Metop satellites.



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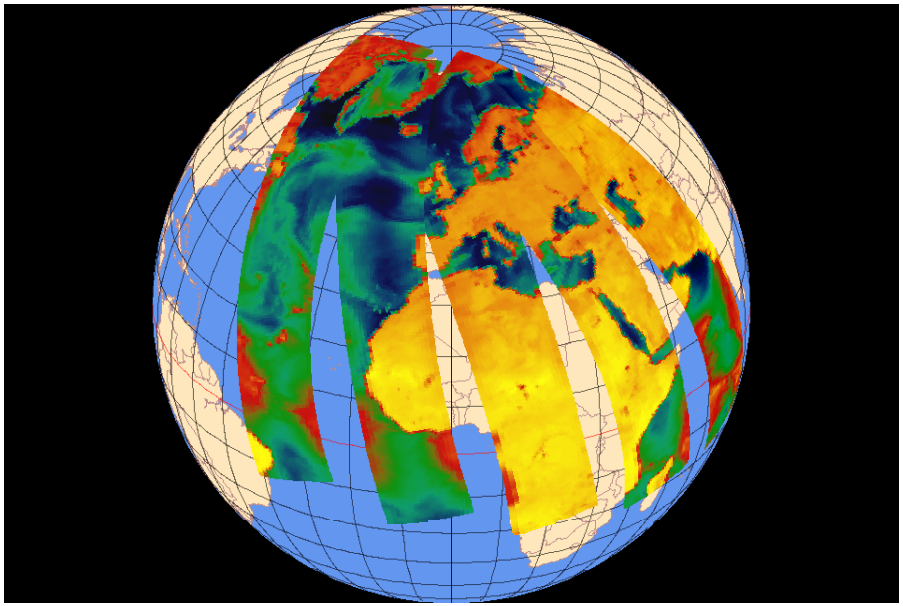
Dual Operations Scenario Overview
Local and Regional Data Mission Operations (2)

Regional Mission Service using the EARS retransmission system:

- To include data from both Metop satellites;
- The Metop-B related services under validation - expected to commence dissemination from a subset of the EARS ground stations from the March/April timeframe;
- Fast Dump Extract System (FDES) mitigates impact of Metop-A AHRPT service degradation: extracts recent (30 minutes) regional data from the global (X-band) data dump and make it available on the EARS services;
- Metop-B has no restrictions operating at polar latitudes, it is not intended to perform this X-band extraction for Metop-B data;
- Svalbard L-band data received from AHRPT will however contribute to the overall EARS regional mission service.



Benefits of Dual Metop Operations
Additional Benefits to Users (1)

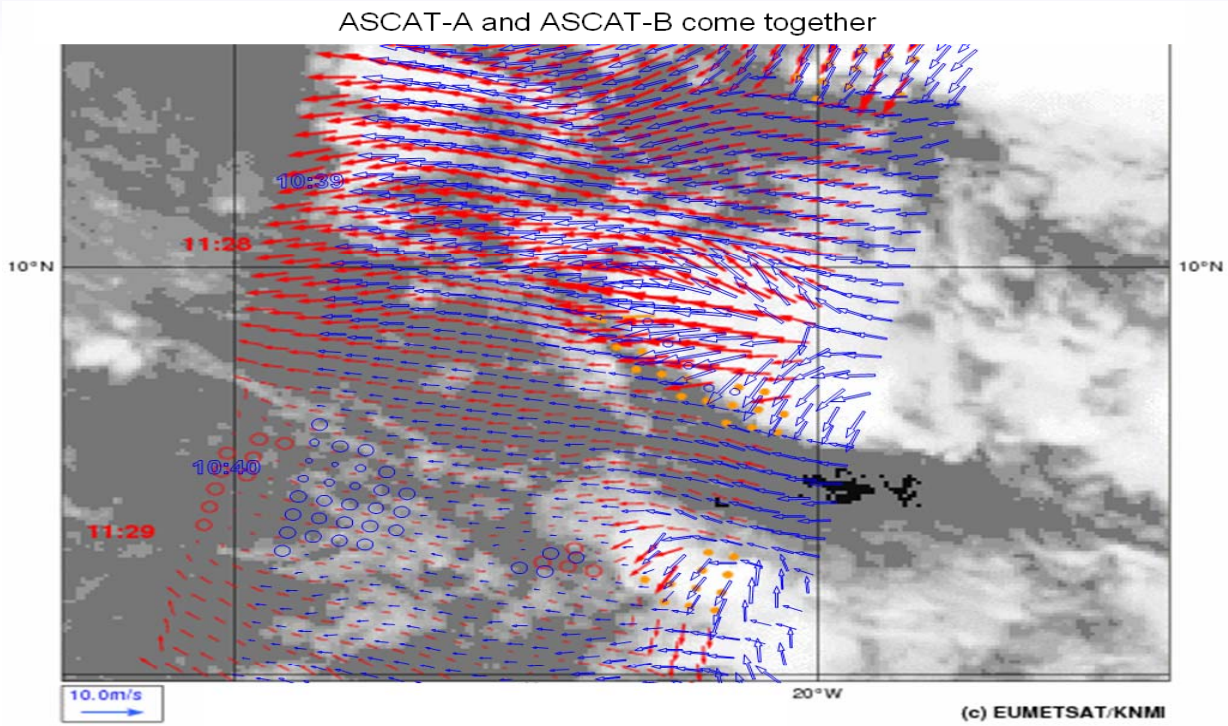
Benefits from dual-Metop data assimilation:

- DWD reported improvements in forecast model performance during trial runs assimilating GRAS-A and -B products;
- Global NWP models already assimilate ATOVS radiances from Metop-B, and the UK Met Office started assimilating IASI-B radiances in February 2013;
- SAF products are expected to improve with the use of data from two Metop satellites.

Benefits of Dual Metop Operations
Additional Benefits to Users (2)

Benefits from successive observations of the same event:

- ASCAT-A and ASCAT-B observations of Hurricane Sandy on 29/10/2012, showing short-term evolution of the wind field.



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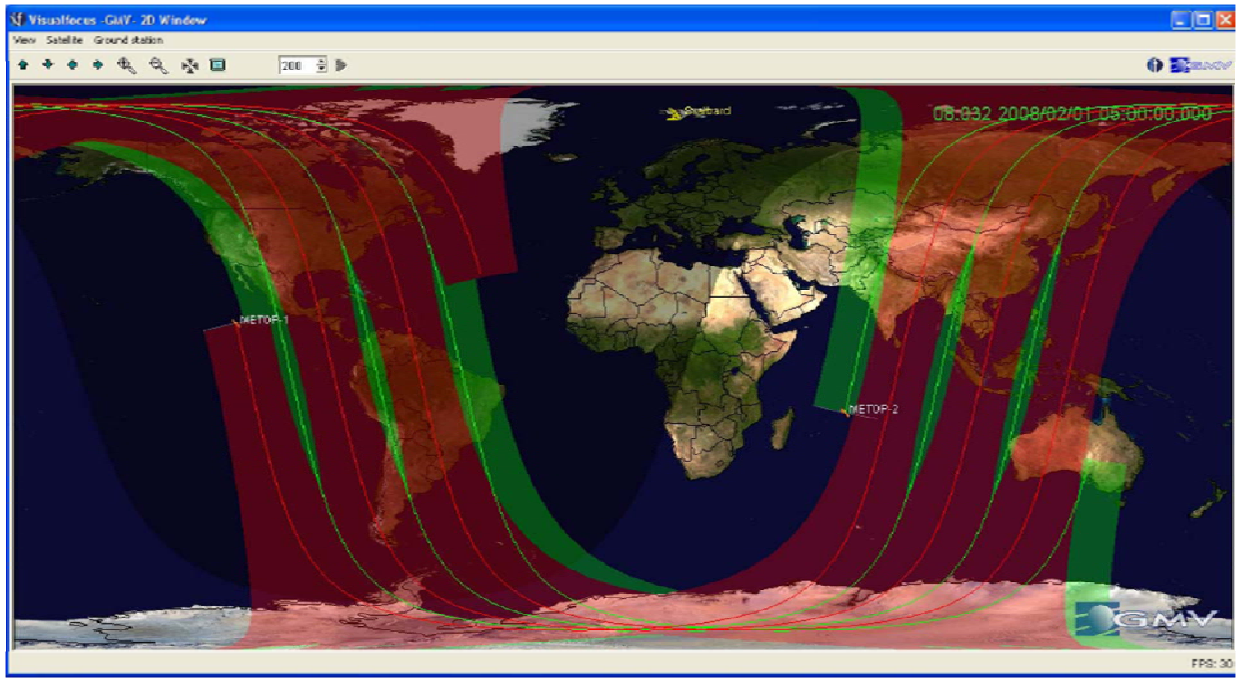
Benefits of Dual Metop Operations
Additional Benefits to Users (3)

Benefits from changes to instrument operation:

- GOME spatial resolution doubling possible by halving the swath width;
- Final configuration under test



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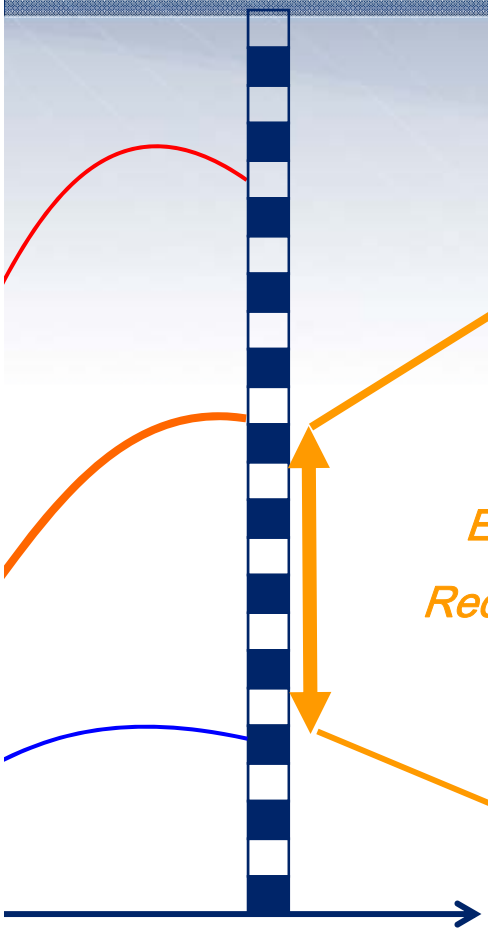
Benefits of Dual Metop Operations
Additional Benefits to Users (4)

Benefits through combing data from both satellites on ground:

Example: Dual AVHRR polar winds

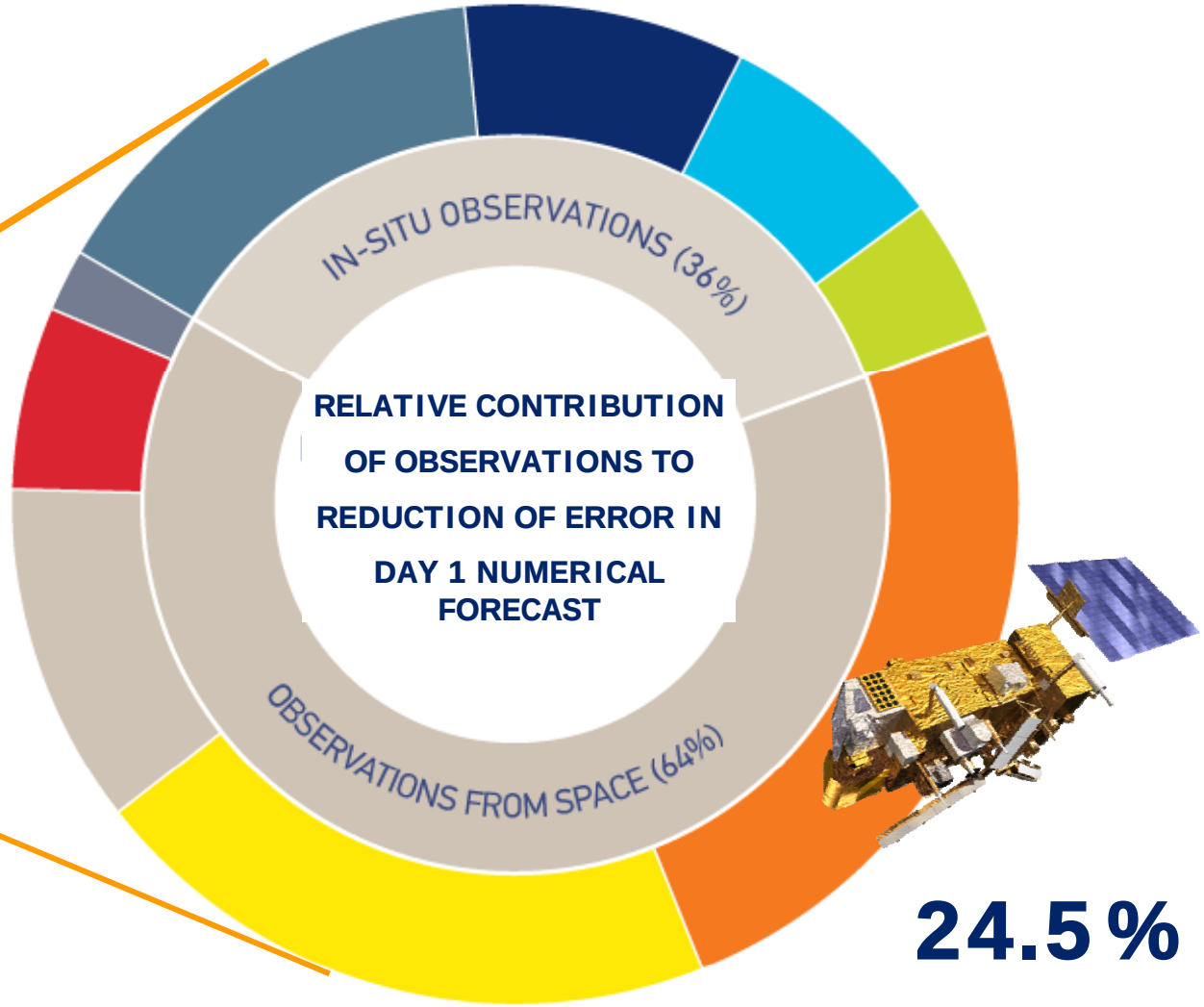
- Improvements to the Level-2 Polar Wind product are made possible using AVHRR data from both satellites;
- Since the interval between two successive passes over the same area is now in the order of every 50 minutes, rather than every 100 minutes, the accuracy of the product will be increased;

Major impact of Metop-A on Day 1 forecast



Error Reduction

T0 + 24h



24.5 %

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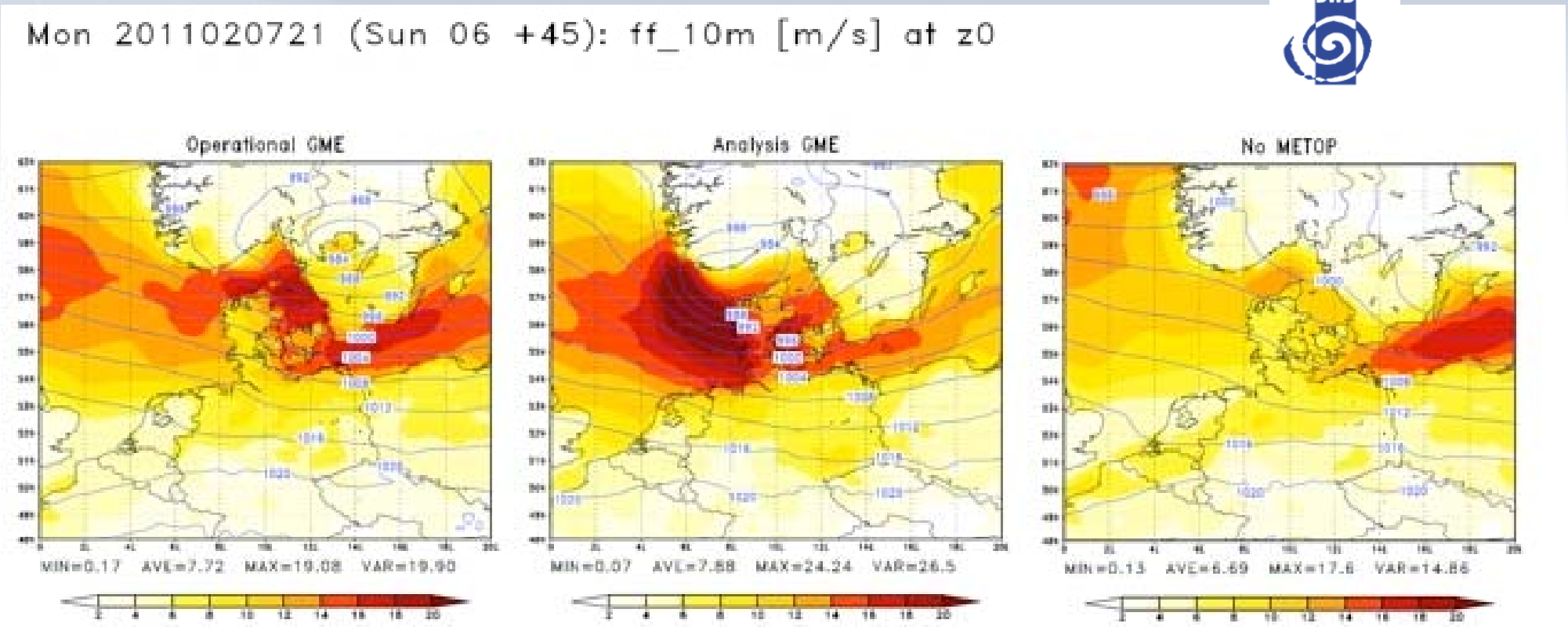
Estimated benefits of EPS-SG in the period 2020-40

- Estimated benefits of EPS-SG programme based of very conservative assumptions (8% contribution instead of 25%)

BENEFIT AREAS	SOCIO-ECONOMIC BENEFIT[29] (over 20 years of EPS/Metop-SG)	
	MINIMUM	LIKELY
Protection of property and infrastructure	€1.45 billion	€6.0 billion
Added value to the European economy	€11.3 billion	€45.2 billion
Private use by European citizens[30]	€3.0 billion	€11.45 billion
TOTAL	**€15.7 billion**	**€62.6 billion**

- Benefit to cost ratio of the EPS-SG programme is between 5 and 20
- Could be 3 times more with less conservative assumptions

Beyond statistics, some cases matter more than others: failing to forecast major storms without Metop



- Winter storm “Nicolas”: 45 hour forecasts and operational analysis (best approximation of ground truth) of surface pressure (contour lines) and 10m wind speed (shaded areas – units M/S) for 7 February 2011

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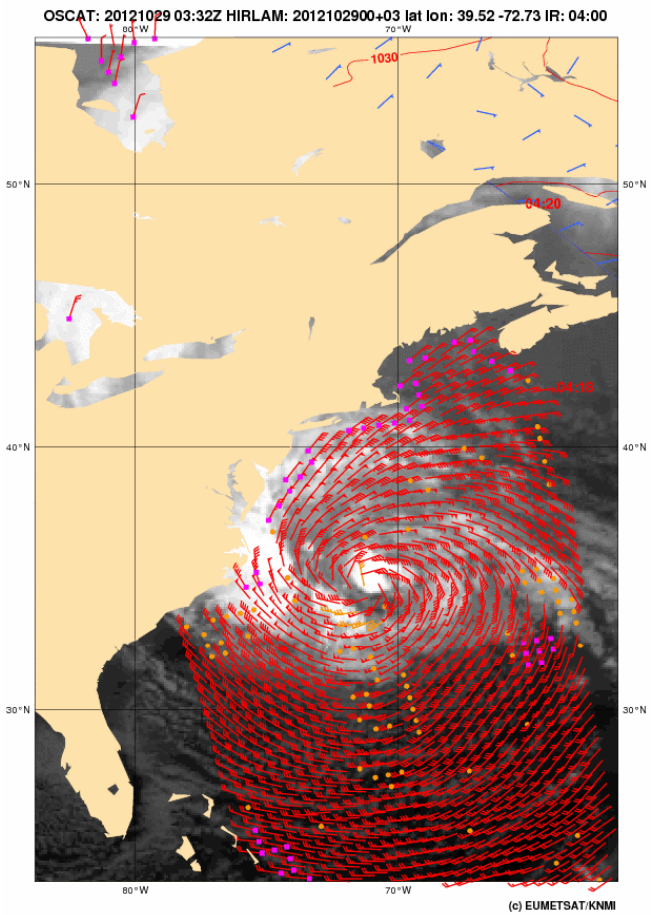
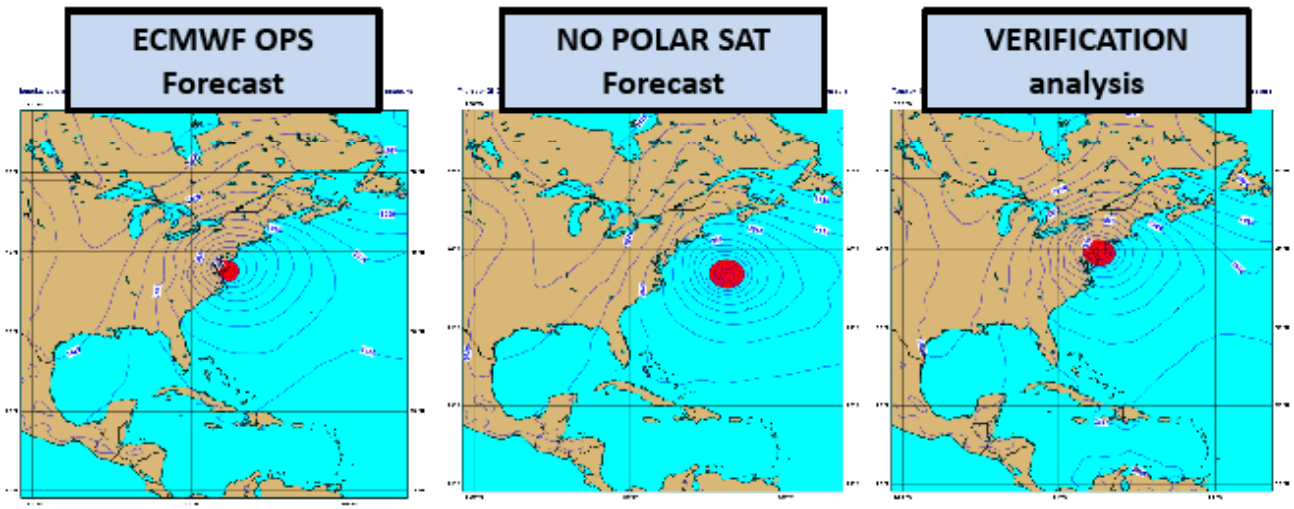
No preparedness for Sandy without NOAA-EUMETSAT Joint Polar System



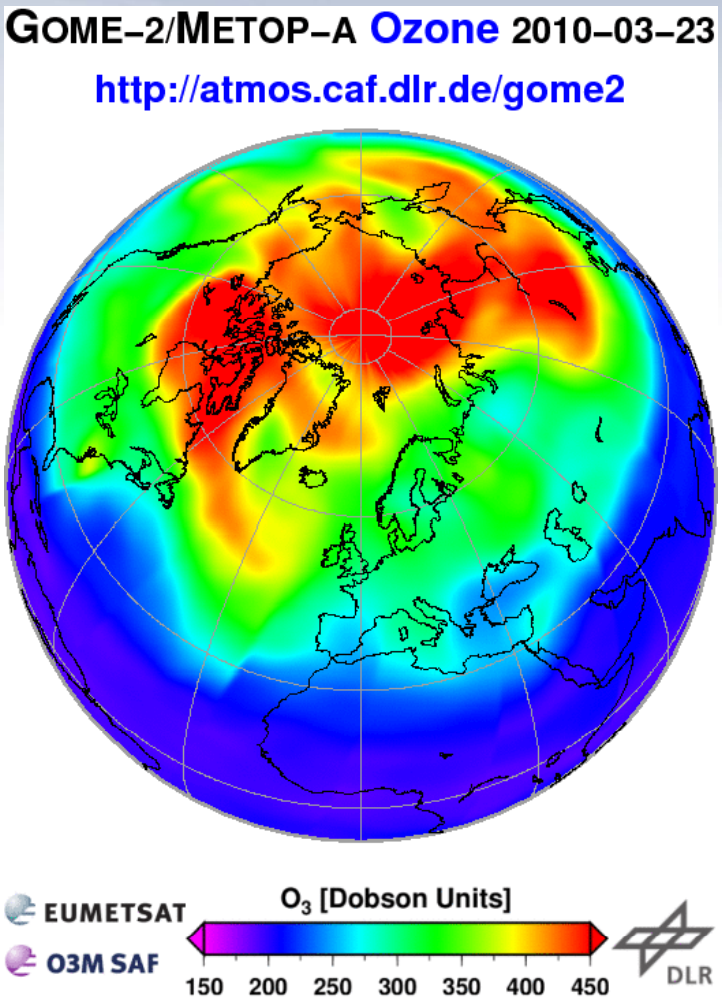
Forecasts of Hurricane Sandy without polar satellites

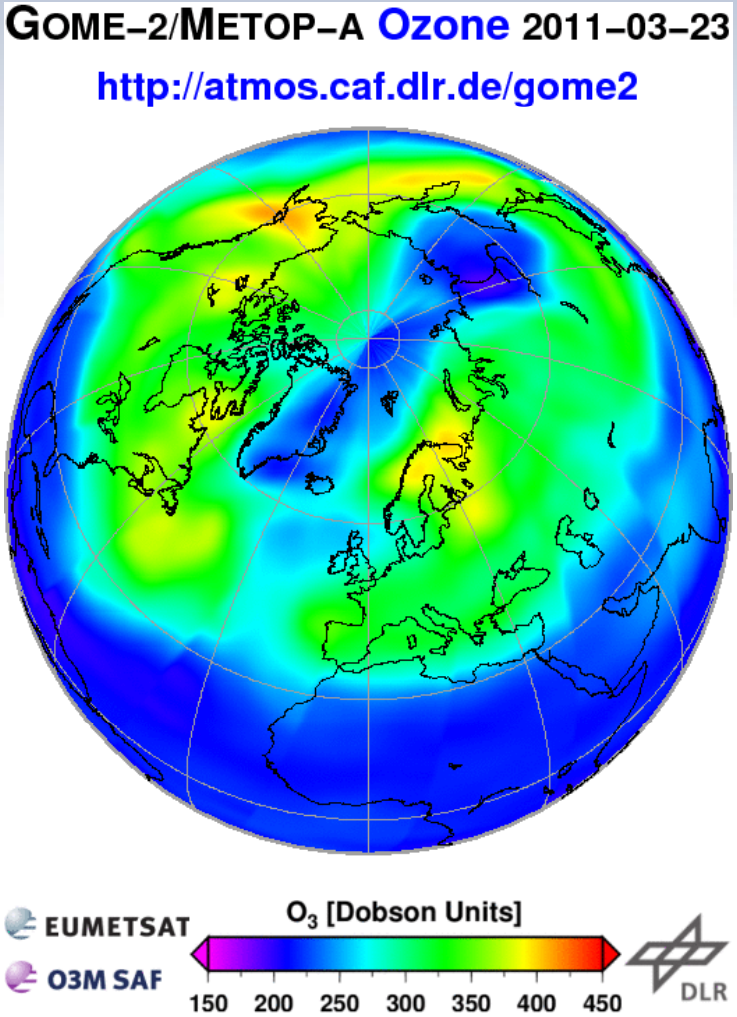
ECMWF forecasts of Mean Sea Level Pressure, **5 days in advance** of the 30th October 2012 for the landfall of Hurricane Sandy. Forecasts from an assimilation system with no polar satellites fail to predict the landfall of the storm on the US east coast.



5 day forecast: Base time 2012-10-25-00z **Valid Time: 2012-10-30-00z**

Atmospheric composition: Arctic circulation, O3, UV





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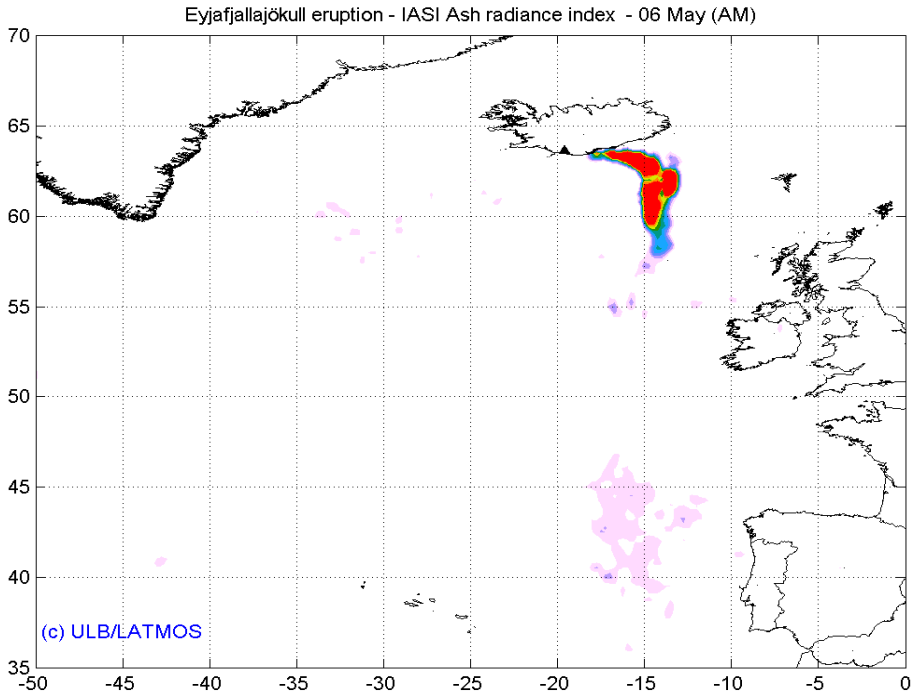
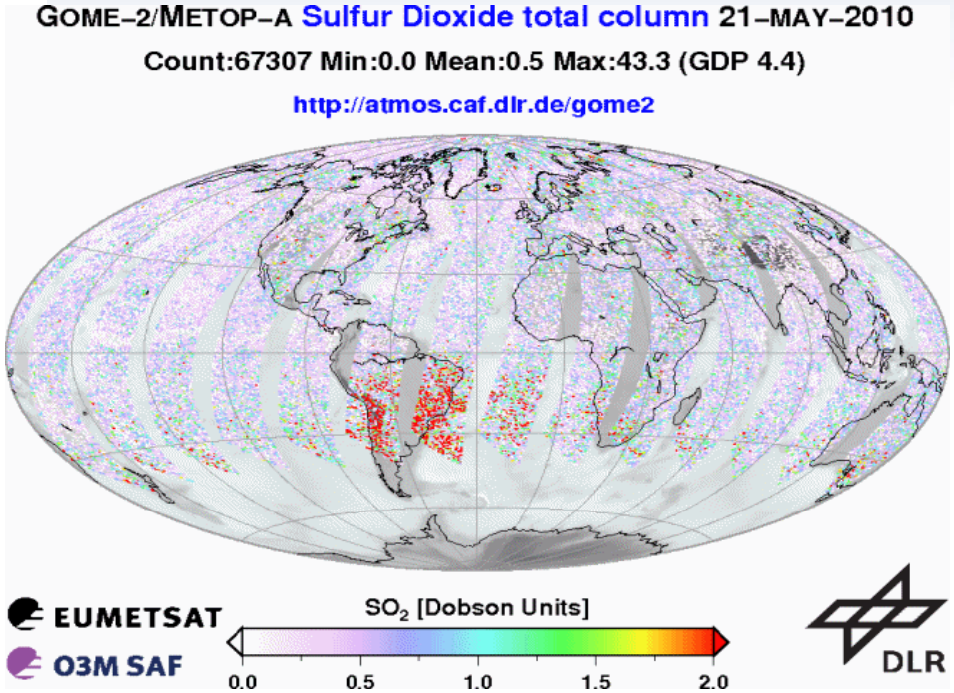
Atmospheric composition: volcanic ash and SO2

GOME-2 SO2 Total Column (Ozone Monitoring SAF, 2010)

IASI

Ash Radiance Index (ULB/LATMOS 2010)





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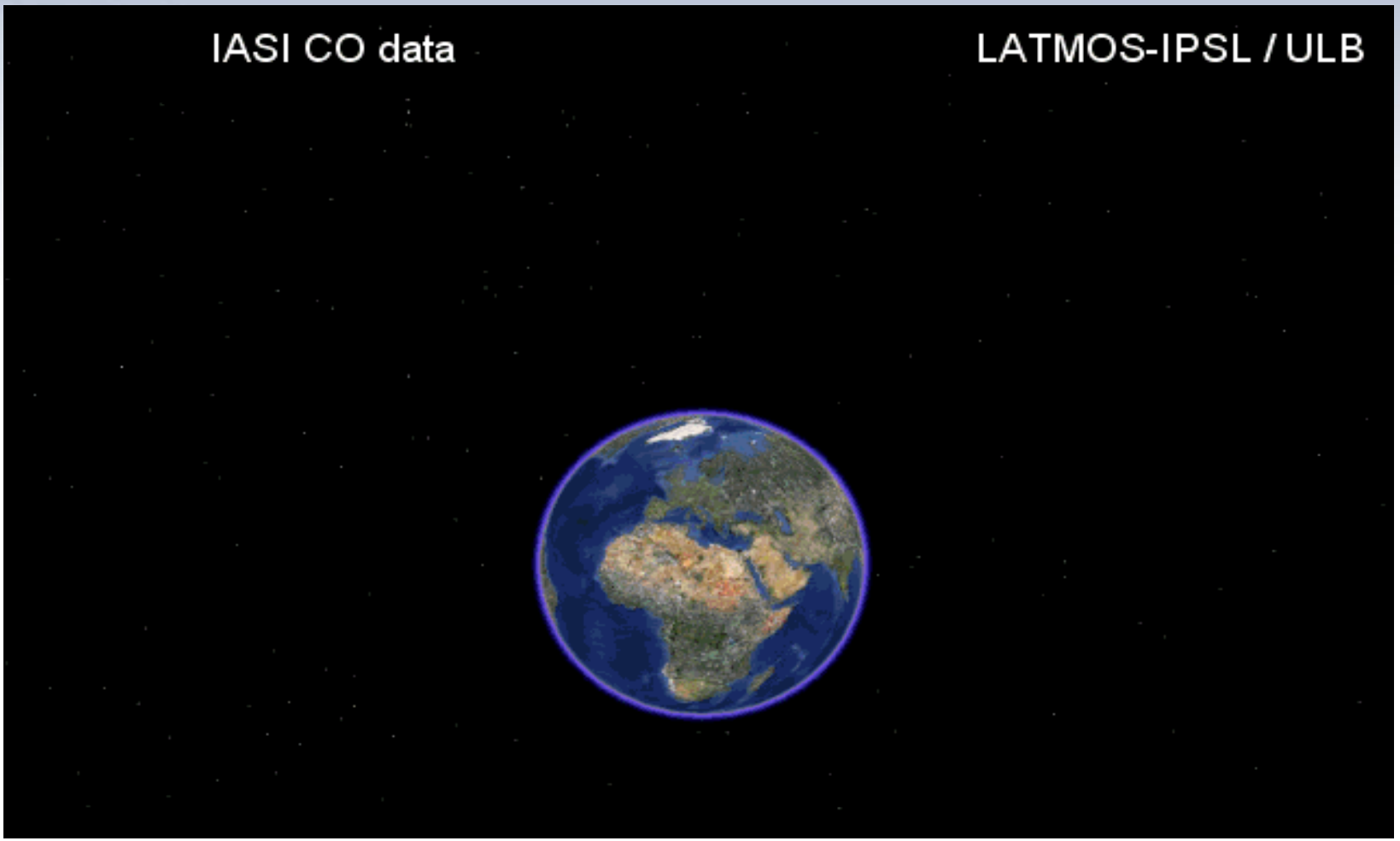
Monitoring large scale fires & pollution: Russia, summer 2010



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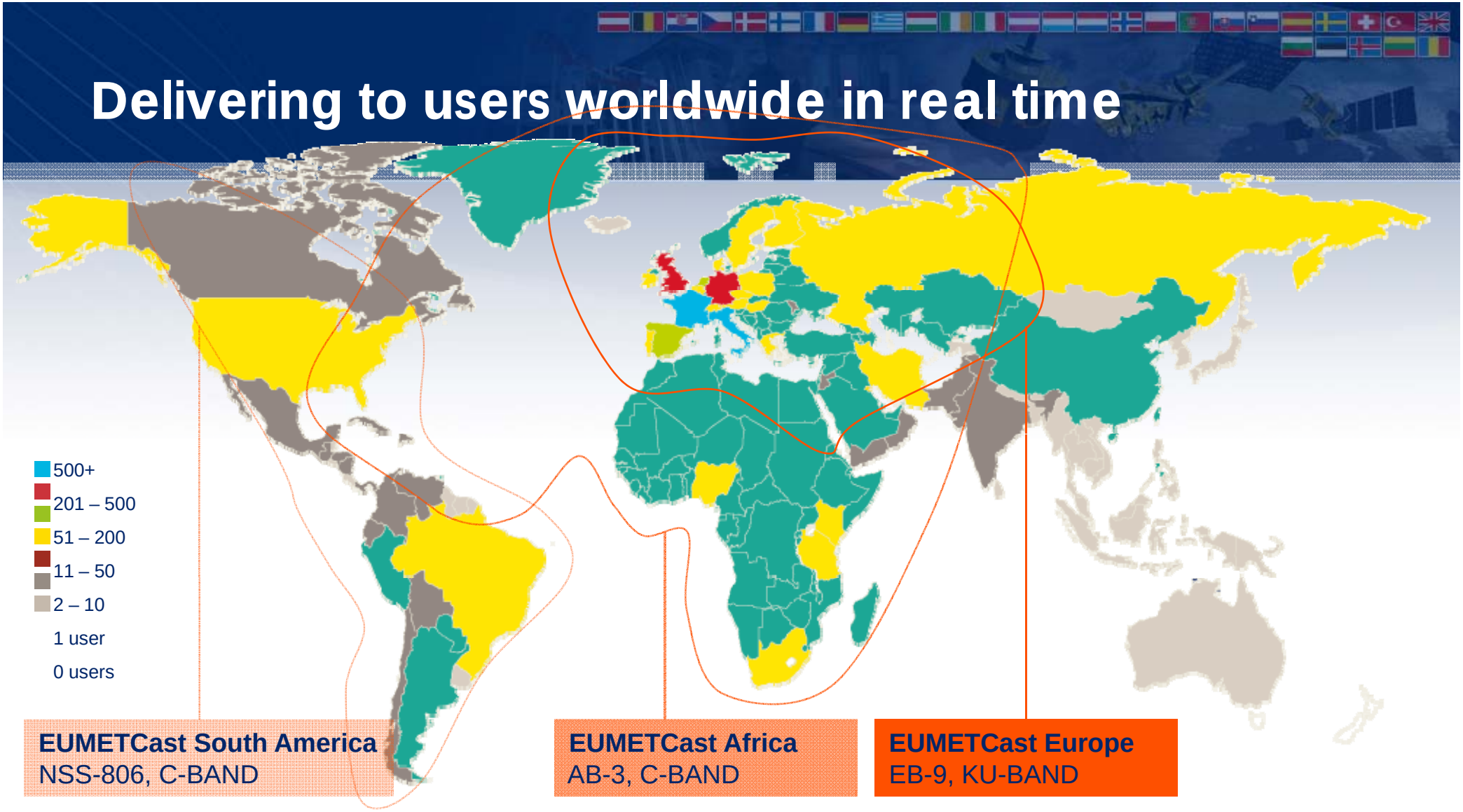
Delivering to users worldwide in real time



3,248 users worldwide (end 2012)

incl. 148 users of global S-NPP data

EUMETSAT

Capacity building: MESA / AMESD project

Participants at the MESA Workshop which was held at EUMETSAT HQ, 9-12 May 2011

Mosaic of Africa made up of the images of the 111 EUMETCast stations in Africa [courtesy of Telespazio]

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Training users to use satellite technology

Local training in Montenegro

Local training in Yerevan, Armenia

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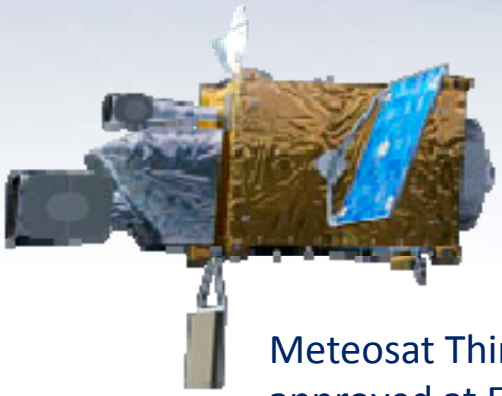
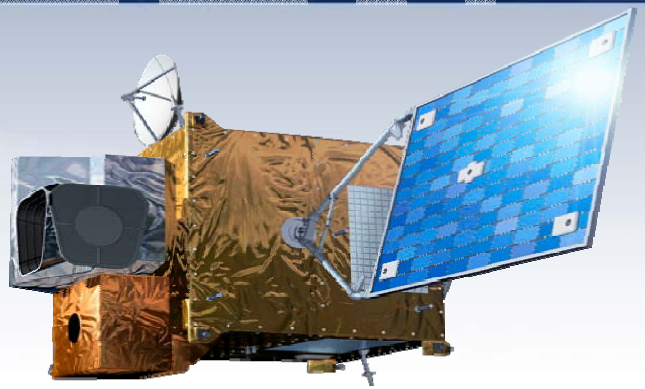
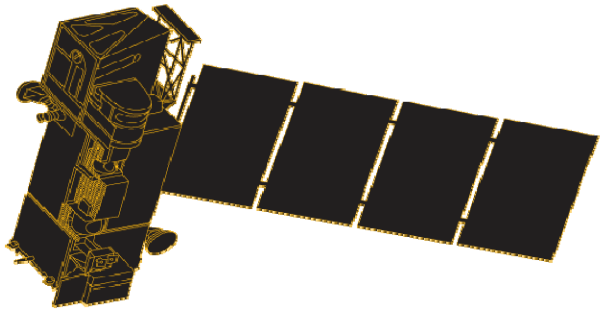
Future : 2018 – 2040, meteorology and GMES





Meteosat Third Generation (MTG): Fully approved at ESA and EUMETSAT, development in progress, first satellite to be ready for launch 2018.

Jason-CS : Planned, phase B2 approved at ESA in 2012.



EPS-SG : Planned, Metop-SG development programme approved at ESA in 2012.

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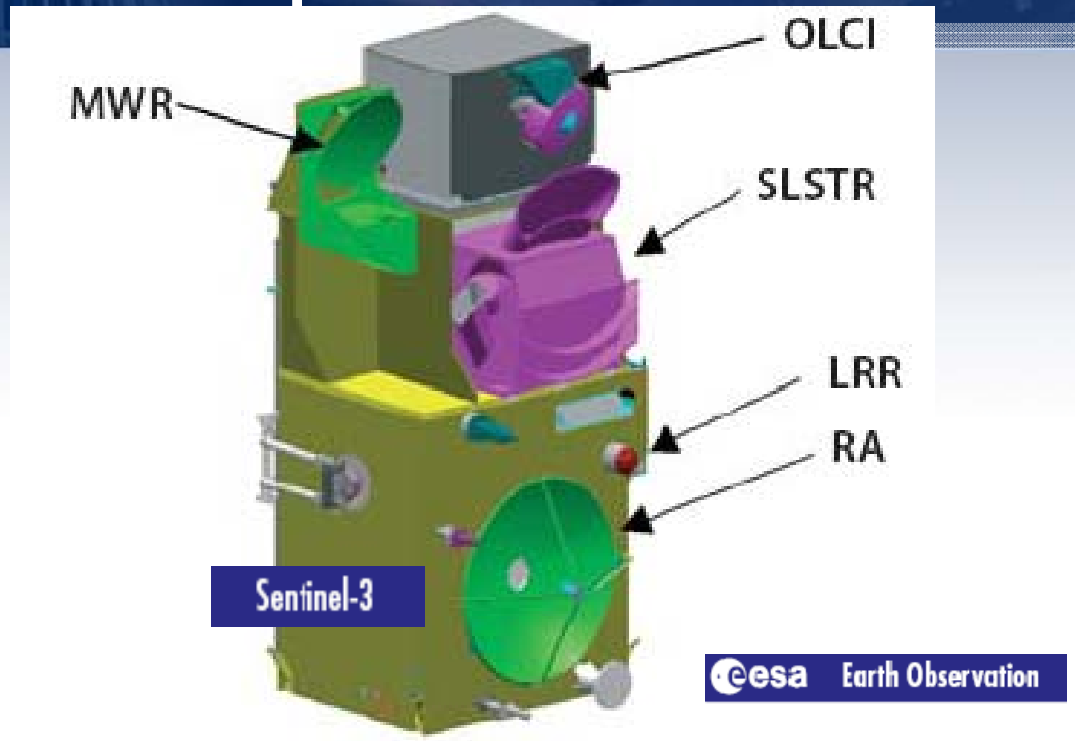
Oceanography: from 2015 onwards EUMETSAT will operate the marine mission of Copernicus Sentinel-3



- SLSTR: Sea and Land Surface Temperature Radiometer
- SRAL: Synthetic Aperture Radar Altimeter
- OLCI: Ocean (and Land) Colour Instrument
- MWR: MicroWave Radiometer
- LRR: Laser Retro-Reflector

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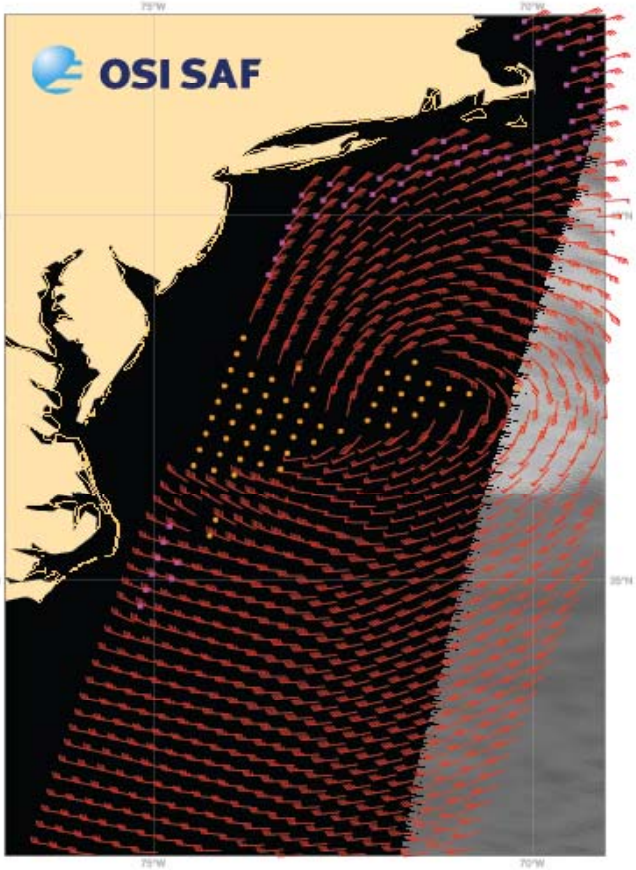
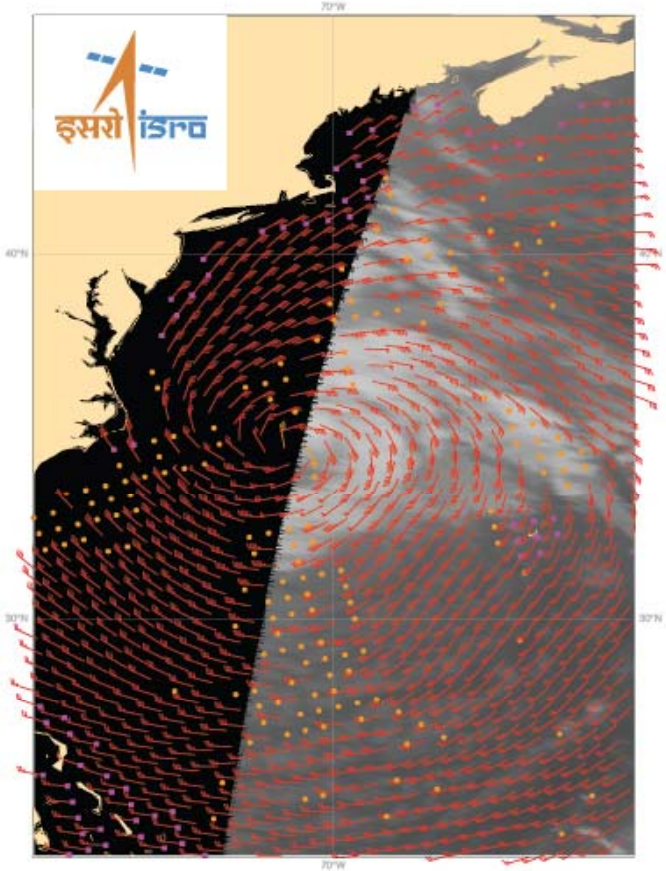
Exchange of data: third party data services





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EPS -Second Generation- Satellites

- **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 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 IASI-NG
  - DLR: development of METimage

EPS -Second Generation- Satellites

- Primary mission: further improvement of observational inputs to Numerical Weather Prediction models
- Significant improvements for other applications :
  - Nowcasting at high latitudes
  - Marine meteorology and operational oceanography
  - Operational hydrology
  - Atmospheric composition and air quality monitoring
  - Climate monitoring
- Two satellites in orbit configuration:
  - Metop-SG A : optical imagery and sounding mission
  - Metop-SG B : microwave imaging mission

EPS-Second Generation Evolutions in 2012

Council-75 approved the EPS-SG payload complement as the baseline for the preparation of the full programme:

Satellite-A Missions	Instrument (and Provider)	Predecessor on Metop
Infrared Atmospheric Sounding (IAS)	IASI-NG (CNES)	IASI (CNES)
Microwave Sounding (MWS)	MWS (ESA)	AMSU-A (NOAA) MHS (EUM)
Visible-infrared Imaging (VII)	METImage (DLR)	AVHRR (NOAA)
Radio Occultation (RO)	RO (ESA)	GRAS (ESA)
UV/VIS/NIR/SWIR Sounding (UVNS)	Sentinel-5 (GMES, ESA)	GOME-2 (ESA)
Multi-viewing, -channel, -polarisation Imaging (3MI)	3MI (ESA)	-/-

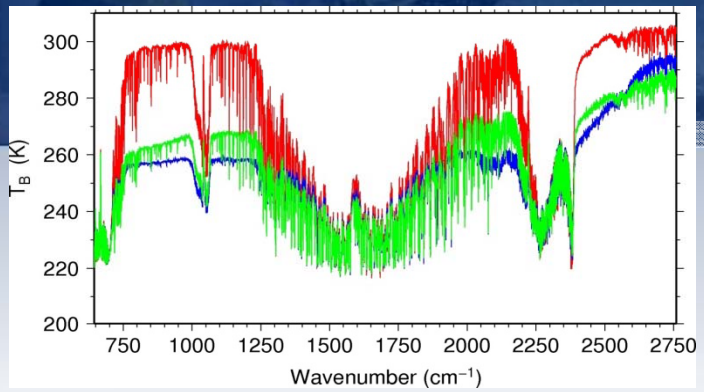
Satellite-B Missions	Instrument (and Provider)	Predecessor on Metop
Scatterometer (SCA)	SCA (ESA)	ASCAT
Radio Occultation (RO)	RO #2 (ESA)	GRAS (ESA)
Microwave Imaging for Precipitation (MWI)	MWI (ESA)	-/-
Ice Cloud Imager (decided at 76th EUM Council)	ICI (ESA)	-/-
Advanced Data Collection System (ADCS)	Argos-4 (CNES)	A-DCS

Observation missions and application areas

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 (New Generation), IAS



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

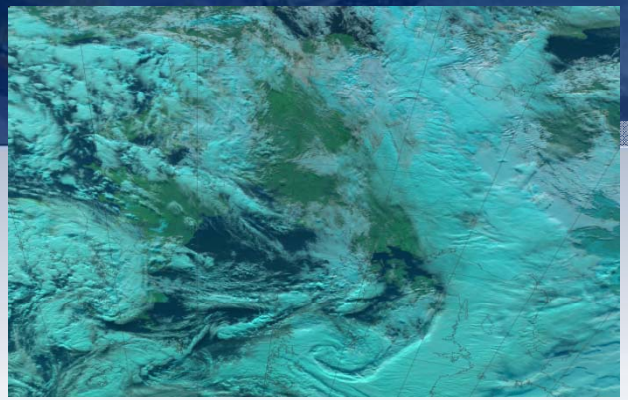
Key performances

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

Optical imaging, VII 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

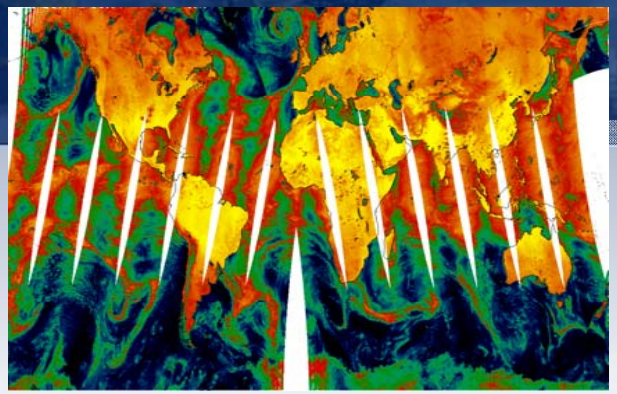
Key performances

- 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
  250 m at 0.67 and 0.865 µm
- cross-track scan

Breakthrough

- **Far more spectral channels than AVHRR for the benefit of measuring more variables**
- **Higher spatial resolution (250 - 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

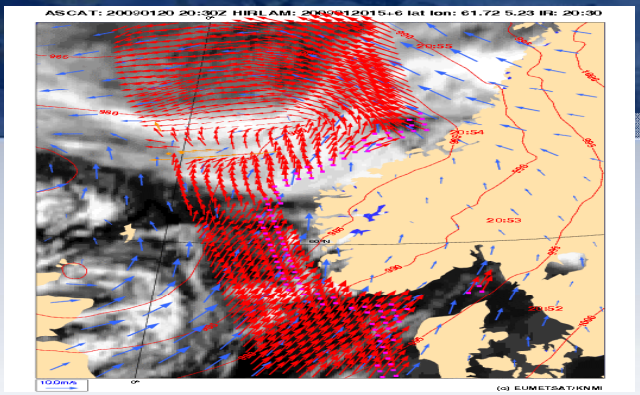
Key performances

- 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**
  - **+ 3 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

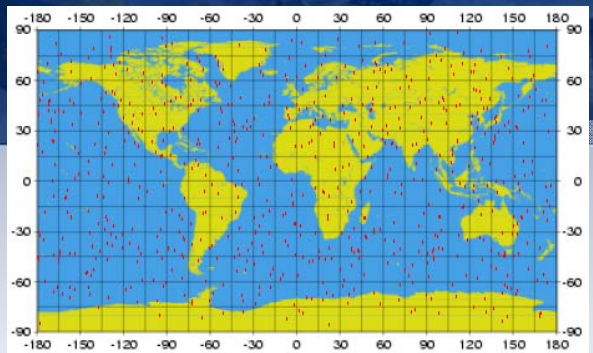
Key performances

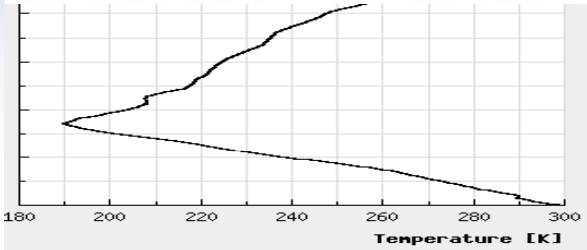
- C-band carrier frequency
- VV + VH polarisation
- measurement range: 4 – 40 m/s
- Radiometric resolution: 3%
- spatial resolution: 25 km
- dual swath: 550 km each

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

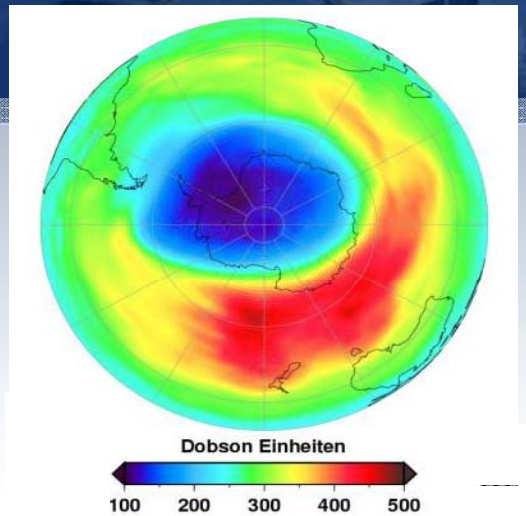
Key performances

- 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**
- **Equipment of both Metop-SG satellites with RO in case of a dual satellite configuration**

UVNS
Nadir viewing UV/VIS/NIR/SWIR sounding



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

GMES Sentinel-5 to be embarked on Metop-SG, ESA development

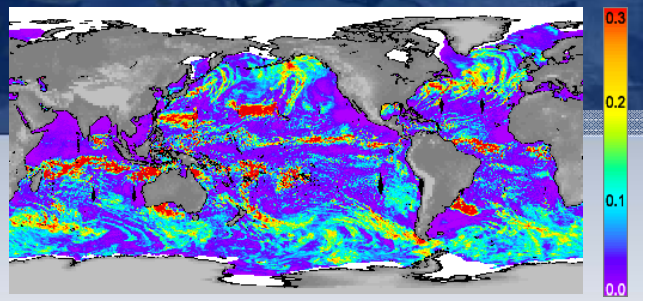
Key performances

- 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

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

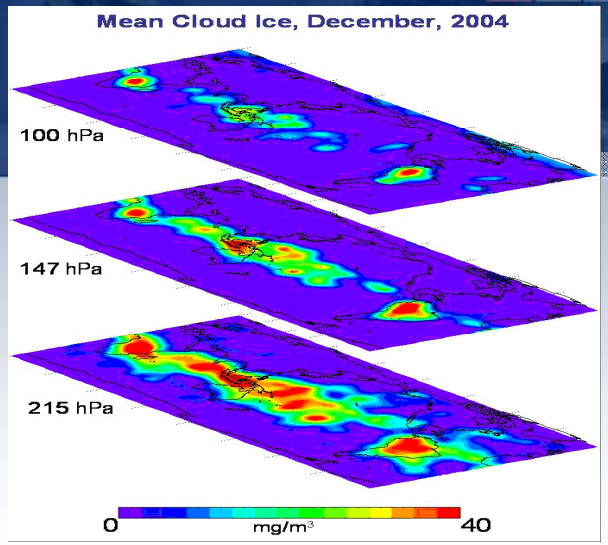
Key performances

- 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 km
- spatial sampling: 7.5 km
- conical scan

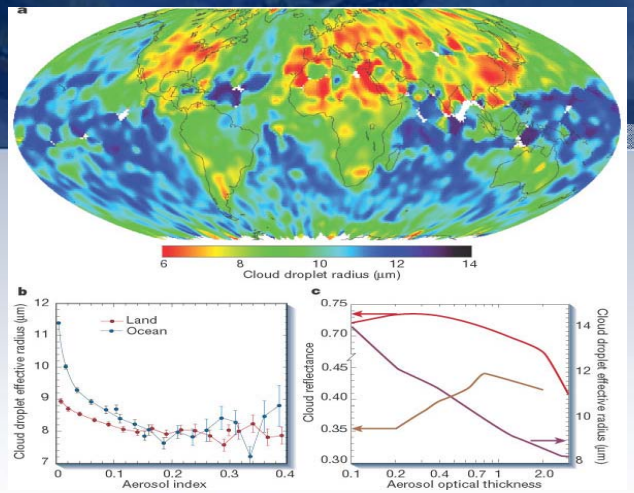
Breakthrough: 11 channels

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

Multi-viewing multi-channel multi-polarisation Imaging, 3MI

Objectives of a new mission

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



Kaufman et al. (2002)

Implementation

ESA development

Key performances

- 12 channels: 0.41 – 2.13 µm
- 3 polarisations: 0°, 60°, -60°
- 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

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EPS-SG Direct Readout - Based on X-Band Only

- EPS-SG instruments offer a much higher performance than on EPS – but this leads to peak data rates almost 20 times higher than on EPS, for global data and direct readout downlinks;
- Transmitting this amount of direct readout data in L-band, within the allocated frequency band, is not technically feasible. The meteorological X-band (7.75 – 7.90 GHz) has been selected for EPS-SG direct broadcast;
- Transmitting a (very) reduced amount of data in L-band in parallel has been excluded, for cost reduction and performance reasons;
- This baseline has been established in coordination with NOAA.

EPS-SG Direct Readout – High Level Characteristics

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	70 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 the 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.

Case 1: Upgrade from NPP to EPS-SG Direct Readout Reception

- Assuming an existing Direct Readout Reception Station that is fully compatible with the requirements for NPP, there are two upgrade scenarios to EPS-SG reception that are likely to be technically feasible:
  - For systems that can already handle the increased EPS-SG data rate of 70 Mb/s and that have a reprogrammable demodulator:
    - a) Firmware upgrade of Demodulator;
    - b) Software upgrades to handle EPS-SG instrument data and other EPS-SG specific aspects.
  - Other systems that don't meet those requirements:
    - a) Replacement of Demodulator and potentially other components;
    - b) Software upgrades to handle EPS-SG instrument data and other EPS-SG specific aspects.

Case 2: Upgrade from Existing L-Band to EPS-SG Direct Readout Reception

- In most cases it will not be possible to upgrade an Existing L-Band Direct Readout Reception Station for use with EPS-SG Direct Readout:
  - The shorter wave length of the X-band signal compared to the L-Band signal (a factor of 4) requires more accurate and stable shape of the antenna dish as well as more accurate tracking of the satellite;
  - The higher radio frequency (a factor of 4) and the higher data rates (a factor of 20) means that the feed, demodulator and other parts of the system are incompatible with EPS-SG Direct Readout.

Registration of X-Band Direct Readout Reception Stations

Please note:

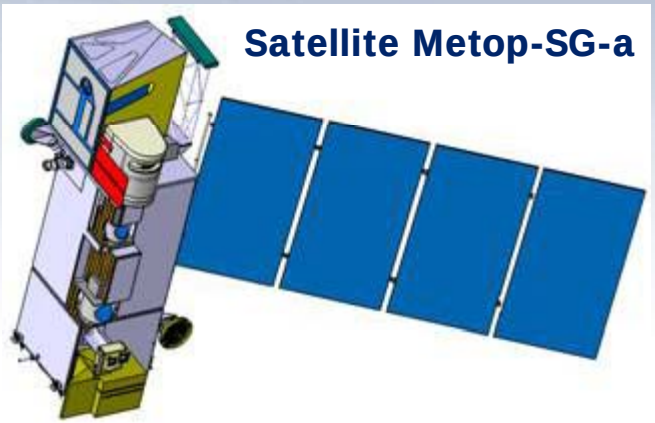
- The X-band range (7.75 – 7.90 GHz) is shared between Meteorological Satellites and Point-to-Point Radio Links on ground.
- To protect against Potential Interference from Point-to-Point Radio Links it is strongly recommended to register X-band Direct Readout Reception Stations with the national Radio Frequency Authorities;
- Before selecting a location for a new X-band Direct Readout Reception Station it is advisable to carry out a Radio Frequency Survey to identify any existing sources of interference.

EPS-SG Direct Readout

Conclusion:

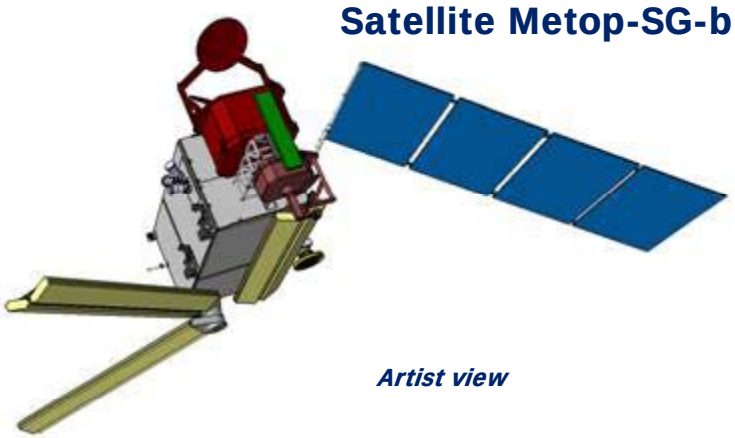
- The direct readout service from EPS-SG will be in X-band (7.75 – 7.90 GHz)
- The Reception Station Performance Requirements for EPS-SG will match the NPP requirements
- Therefore re-use of an NPP-compatible X- or L/X- band antenna is possible, but may require an upgrade to other parts of the system
- Reuse of a pure L-band system (including antenna) is generally not possible
- Note: it is strongly recommended to register X-band Direct Readout Reception Stations with the national Radio Frequency Authorities;.

EPS-SG in-orbit configuration



Artist view

Satellite-a Payload	METimage IASI-NG MWS 3MI Sentinel-5 RO
Dry mass	~ 3250 kg
Launch mass	~ 3661 kg
Power	~ 2.3 kW
P/L data rate	~ 54 Mb/s



Artist view

Satellite-b Payload	SCA MWI ICI ARGOS-4 RO
Dry mass	~ 2928 kg
Launch mass	~ 3339 kg
Power	~ 2.0 kW
P/L data rate	~ 6.3 Mb/s

EPS-SG space segment

Two-Satellite Configuration

Overall lifetime

21 years

Earliest launch date (first satellite)

end 2020

Orbit

Metop orbit @ 09:30 LTDN

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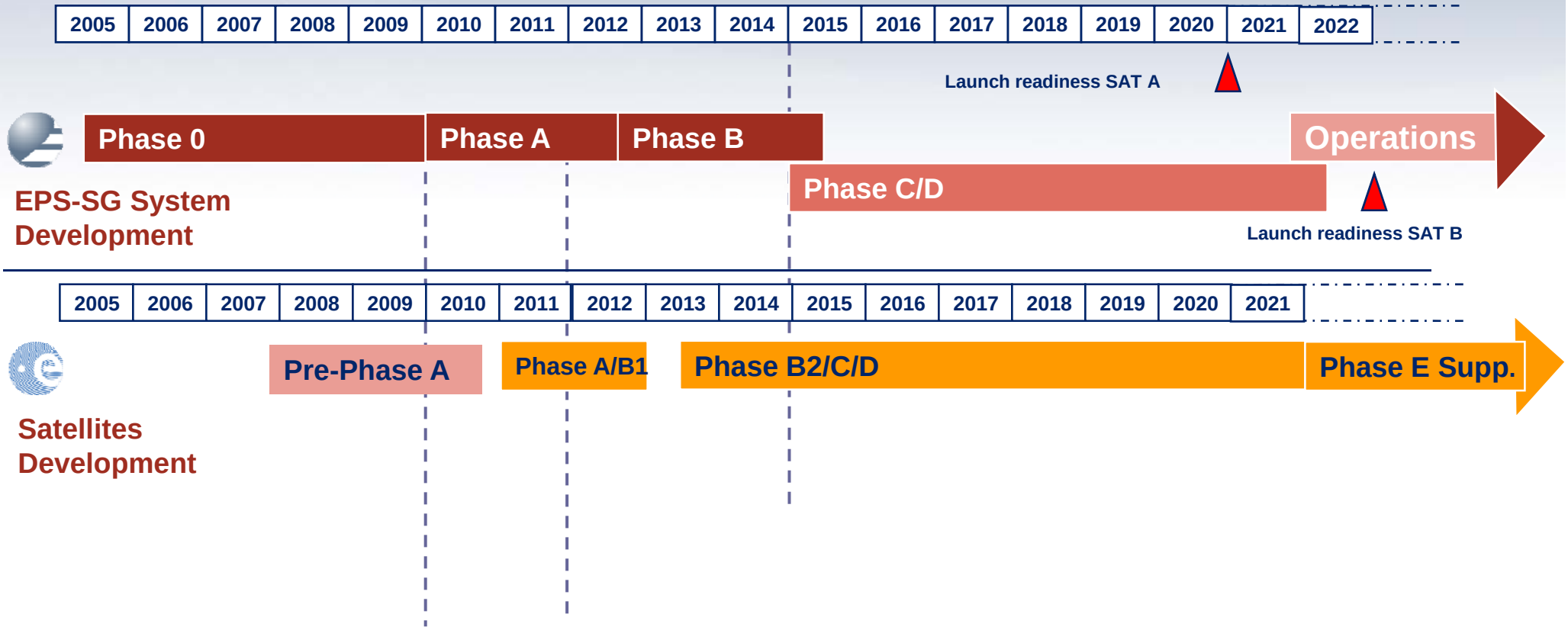
EPS-SG Overall Planning



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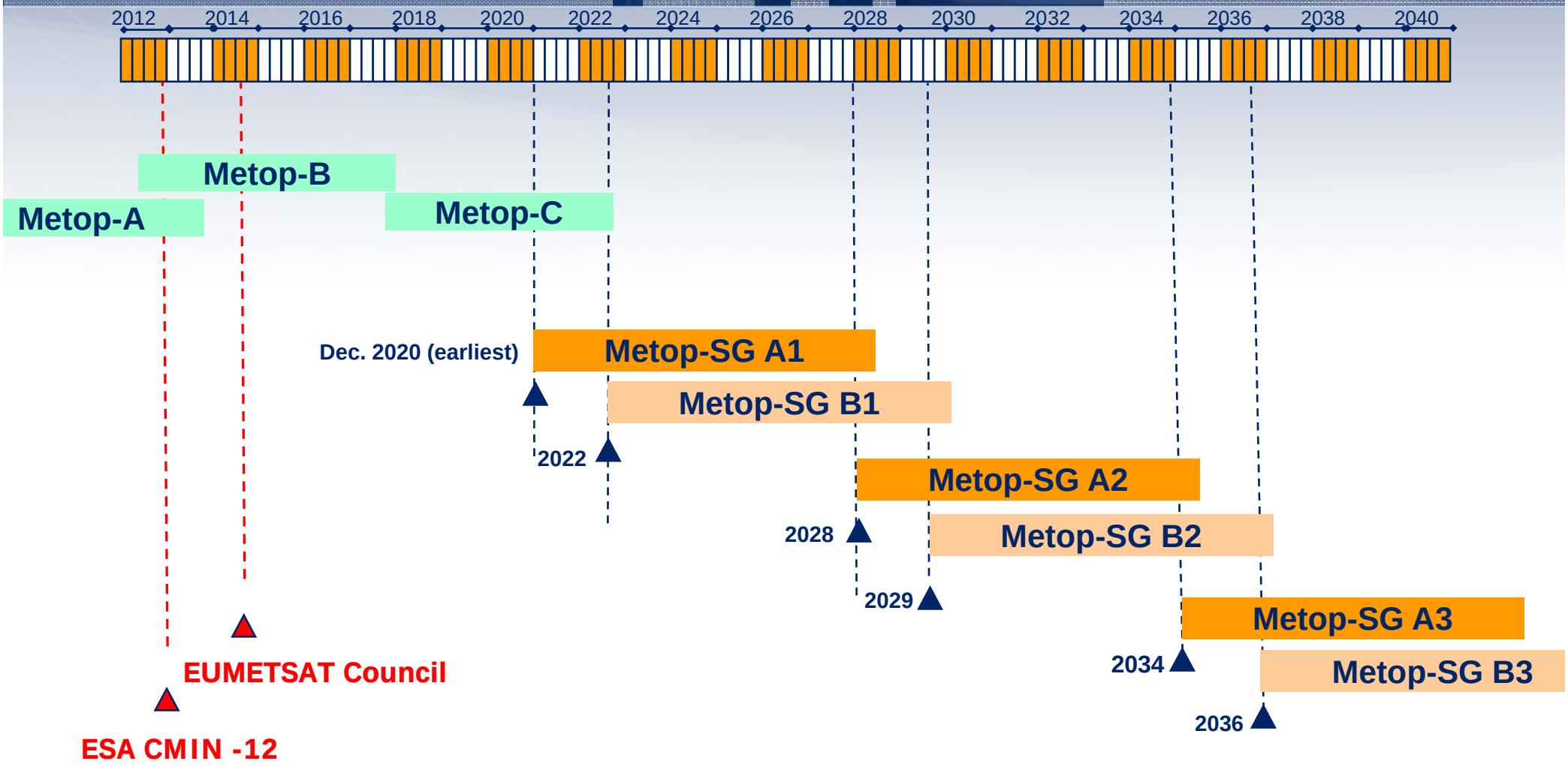
Deployment Schedule of EPS-SG



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Thank you for your attention