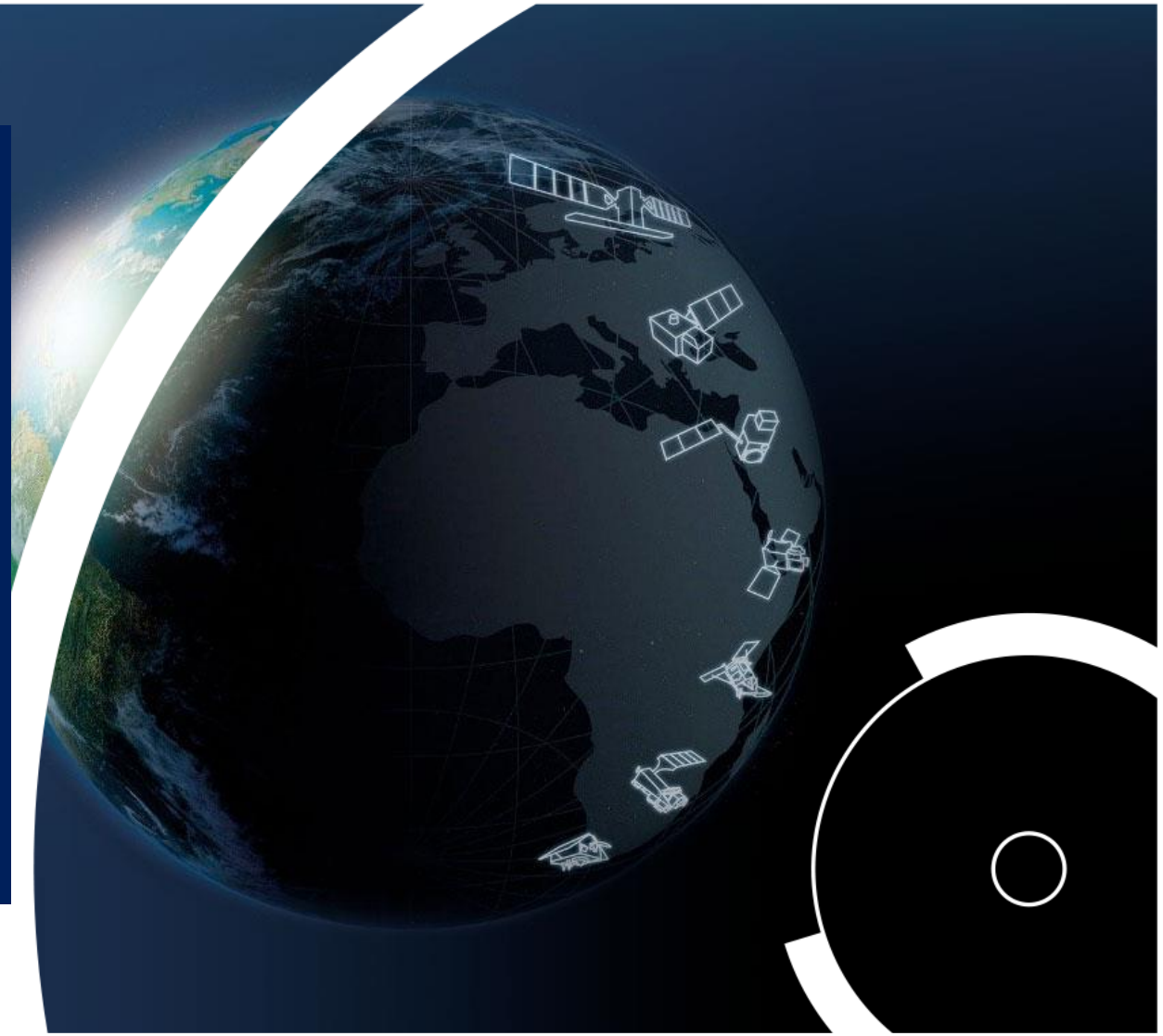
EUMETSAT plans for cloud and aerosol products from the next generation geostationary and polar orbiting satellites.

A. Bozzo, C. Accadia, A. Belo do Couto, H. Bauch, B. Bojkov, J. Chimot, F. De Angelis, B. Fougnie, J. Jackson, S. Jafariserajehlou, H.J. Lutz, T. Marbach , V. Mattioli, L. Spezzi, M. Vazquez Navarro, P. Watts
Remote Sensing and Products division

EMS conference, Bonn 4-9 September 2022



Summary



Upcoming missions

Challenges and opportunities.

Cloud products development

Development and validation plans.

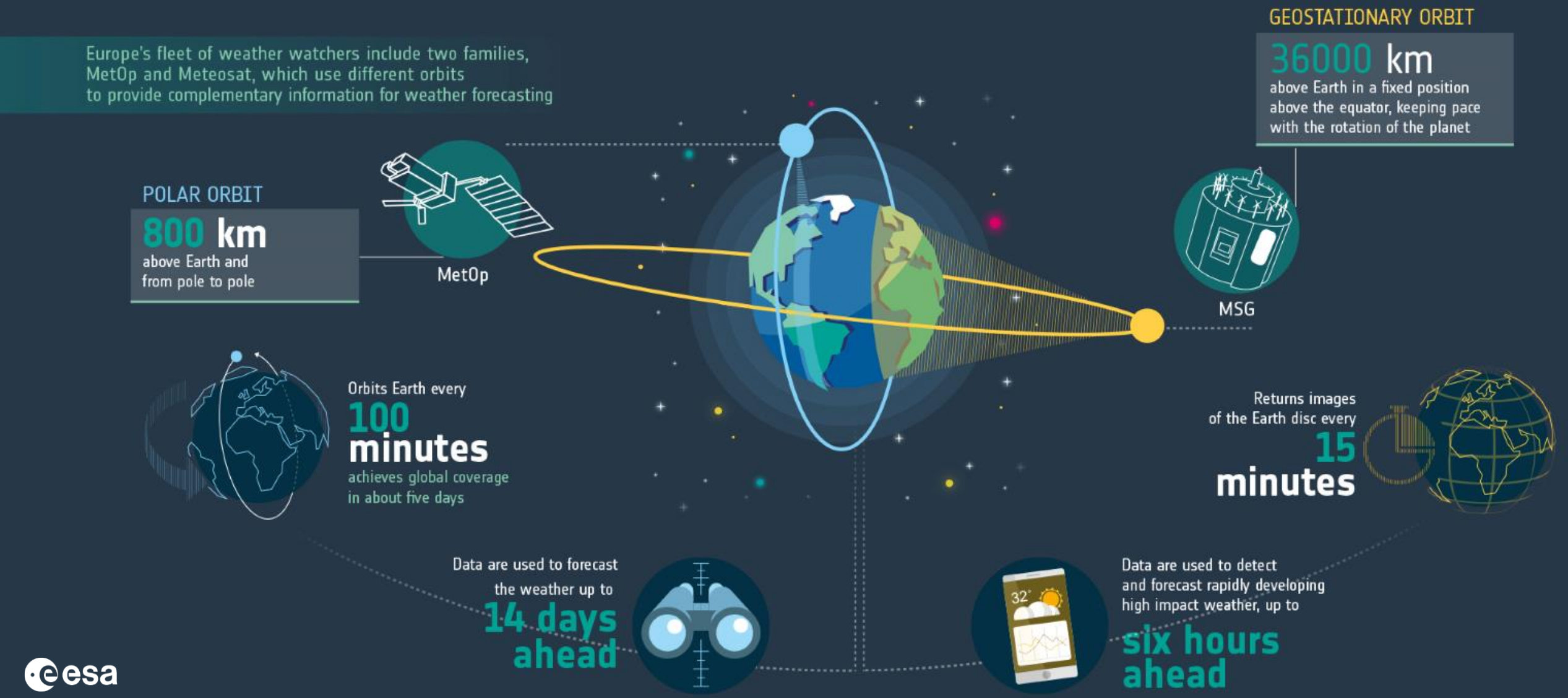
Aerosol products development

Development and validation plans.

Conclusions

Watching the Earth System

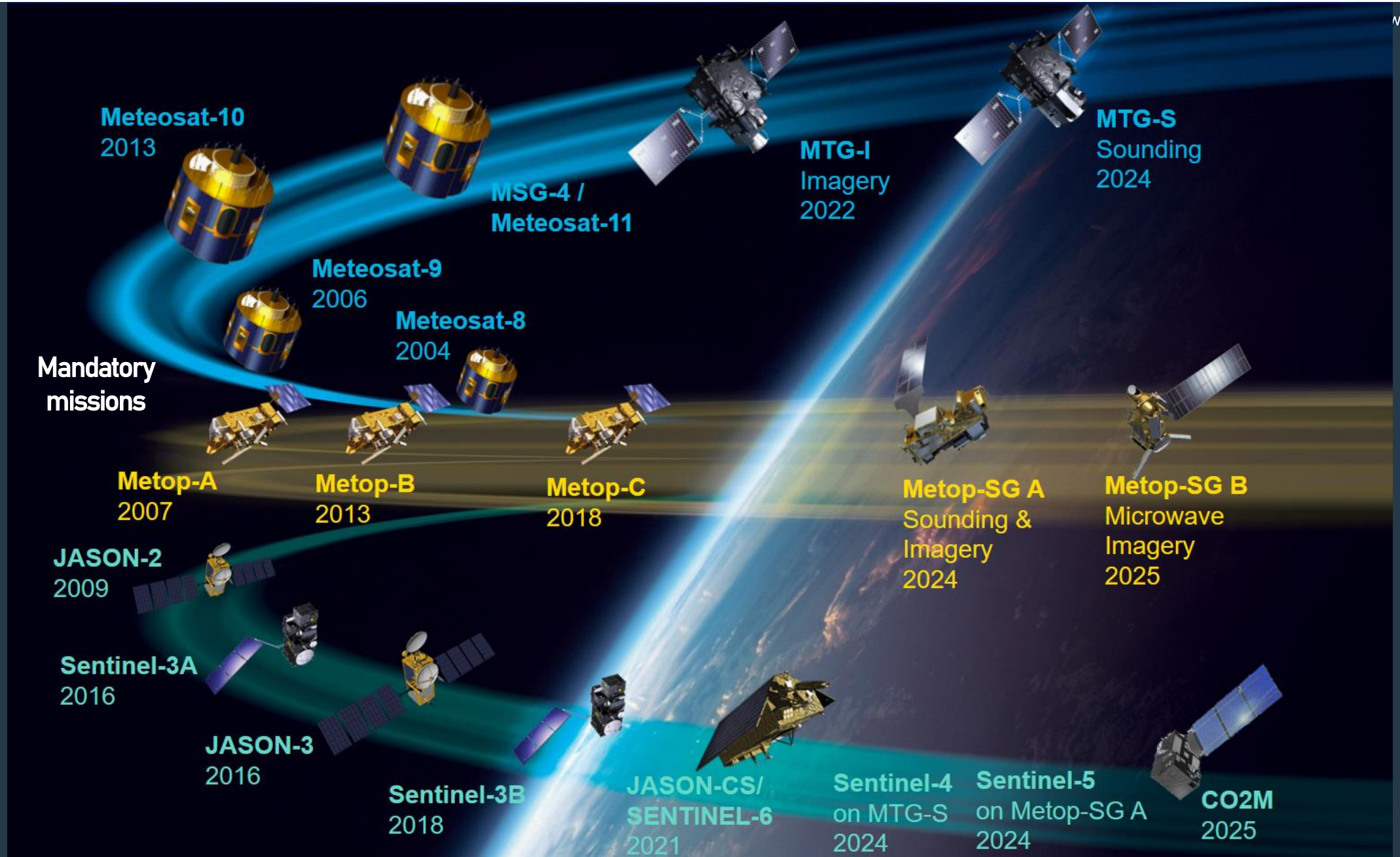
www.eumetsat.int



esa

Source: ESA

Current and future EUMETSAT satellites



Imagers for clouds and aerosol characterisation



FCI: 16 channels, 1km (VIS/NIR) 2km (IR) nadir
10 minute repeat cycle (2.5 Europe in rapid scan)
Heritage: SEVIRI



METimage(VII): 20 channels (VIS/NIR/IR), 500 m nadir
Heritage: AVHRR, VIIRS



3MI: 14 views -50° backward to 50° forward, 12 spectral bands (VIS-NIR), 3 polarisations. 6 km at nadir
Heritage: POLDER





ICI,MWI: microwave imagers 18-664 GHz 10-50km conical scanner
Heritage: SSMI/S, TRMM-TMI, AMSR

EUMETSAT Operational products development

- Operational products have constraints
  - Dissemination to operational users
  - Near real time (<3 h)
  - Robustness and documented performance
  - Stability (constant monitoring) and continuity
  - Tailored to users needs
- Development needs to fulfil these requirements, hence:
  - New products need to guarantee continuity from past to current and future platforms (e.g. EPS to EPS-SG and MSG to MTG)
  - Scientific development -> conversion/adaptation to operational codes according to user needs and requirements

Summary



Upcoming missions

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Aerosol products development

Development and validation plans.

Conclusions

Cloud products users, applications, requirements

- Support to downstream L2 products
  - Cloud top height for AMV height assignment
  - Cloud detection and decontamination for ocean colour, surface parameters, aerosol and trace gases retrievals, IR temperature and humidity soundings
  - Parallax correction for Lightning Imager

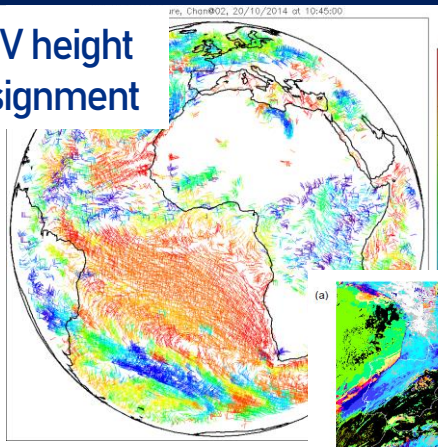
- NRT Cloud products in combination with RGB imagery to support forecasting and nowcasting (in collaboration with NWC-SAF)
  - Fog detection, aviation meteorology, severe convection forecasting
  - PV energy forecasting

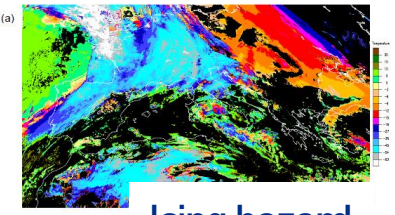
- Evaluation of physical parameterizations in models and support to science studies towards the assimilation of all-sky radiances (in collaboration with NWC-SAF and CM-SAF)
  - Requirement for more frequent/higher resolution observations and products

- Climate data records for climate monitoring (in collaboration with CM-SAF).

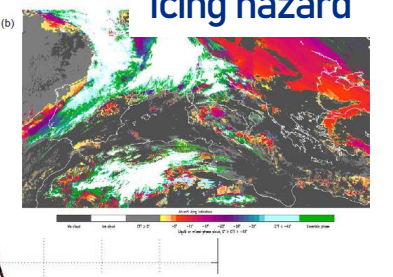
www.eumetsat.int

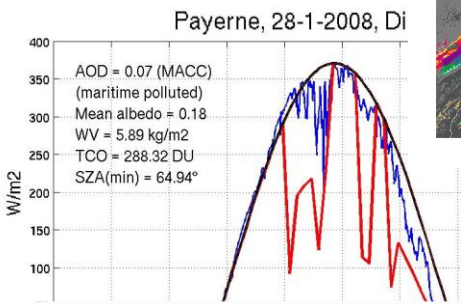
AMV height assignment



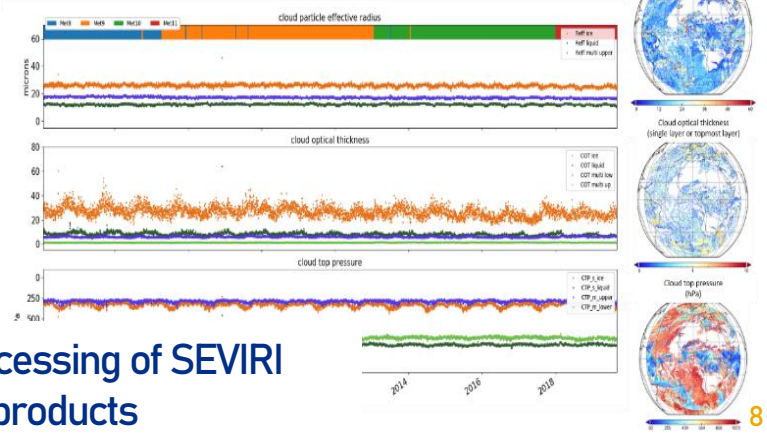


Icing hazard





Downwelling SW flux estima

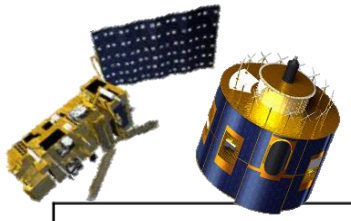


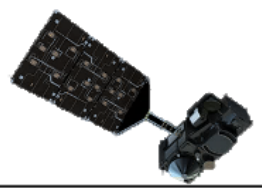
Reprocessing of SEVIRI cloud products

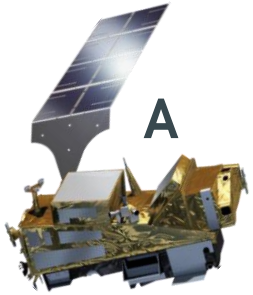
Operational cloud products at EUMETSAT – current and planned

d = daytime only
d+n = daytime and night time

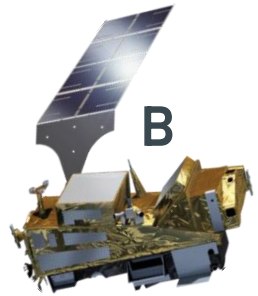
	Existing operational product
	Under implementation
	Under development
	Feasibility study











ICI, MWI

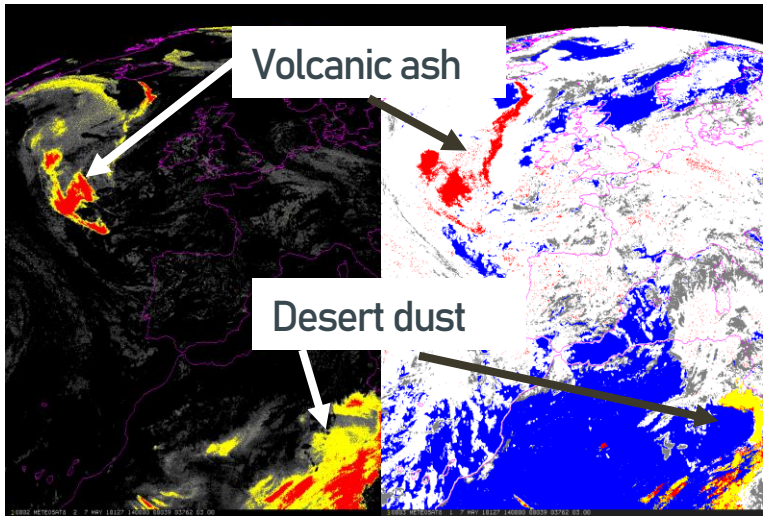
		In-orbit					In preparation			
		EPS	MSG	S3			EPS-SG			MTG
Parameter	**Acronym**	**AVHRR**	**SEVIRI**	**OLCI**	**SLSTR**	**SYN**	**3MI**	**VII**	**SYN**	**FCI**
Cloud Mask	CM	d+n	d+n	d	d+n	d	d	d+n		d+n
Cloud Albedo	CA						d			
Cloud Optical Thickness	COT		d+n	d			d	d+n		d+n
Cloud Microphysics and Phase	CRE, LWP, IWP, CPH		d+n		d+n		d	d+n	d	d+n
Cloud Top Pressure, Temperature & Height	CTP,CTT, CTH		d+n	d	d+n		d	d+n		d+n
Multi-layer flag	MLF		d+n				d	d+n		d+n
Multi-layer (2) products / Vertical structure	CRE, COT, CTP		d+n				d	d+n	d	d+n

+

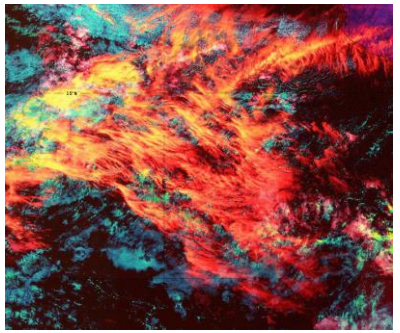
- Precipitation
- IWC
- Ice particles size distribution
- Ice crystals habit
- Cloud top height

Cloud screening and decontamination

- Cloud screening and detection in MTG/EPS-SG
  - higher spatial resolution, faster repeat cycle (MTG)
  - new dust and ash detection
  - narrower SW bands and extra channels: 1.38 μm for high cirrus detection

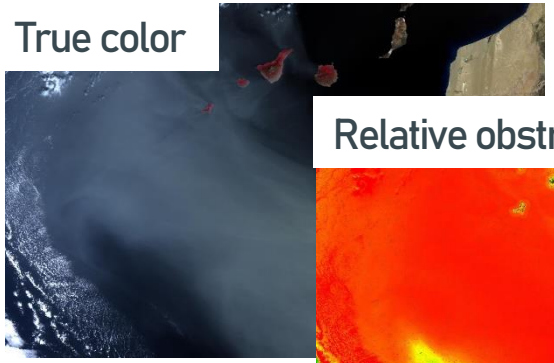


RGB including channel 1.38 μm (red)

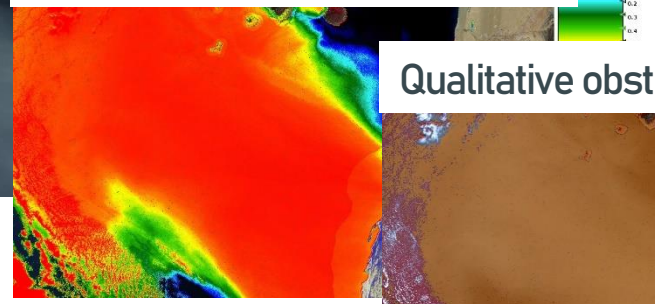


- Improved cloud masking techniques for polar orbiting satellites:
  - S3 synergy between SLSTR (dual view) and OLCI (O_2 bands) (https://www.eumetsat.int/S3-synergy-cloud-mask)
  - synergy between METimage cloud detection and 3MI products (in development)

True color



Relative obstruction at 554 nm

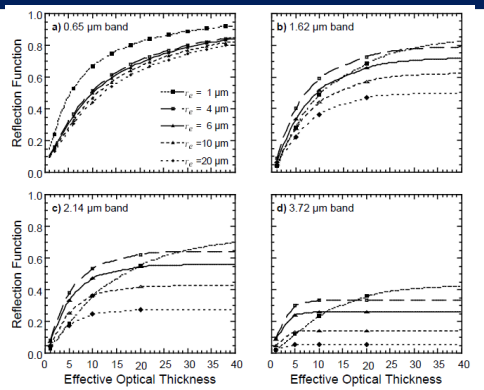


Qualitative obstruction mask

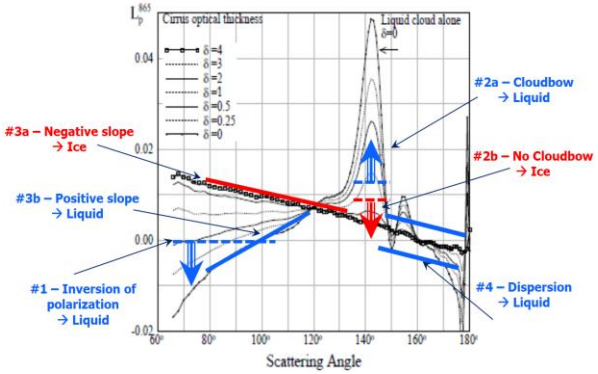


Improvements in Cloud Properties Retrieval

- FCI/METimage new channels:
  - 1.38 μm : better constraint on high cirrus cloud top.
  - 2.2 μm+ 1.6 μm+ 3.8 μm: more complete microphysics characterization, (some) more information on vertical structure. Needs appropriate cloud model



- Use of directional and polarised measurements (3MI) https://www.eumetsat.int/3MI-cloud



- Improved retrieval of multi-layer cloud situations (OCA algorithm, Watts et al. 2011)
  - Detection and forward modelling
  - aerosol over clouds (e.g. volcanic ash plume)

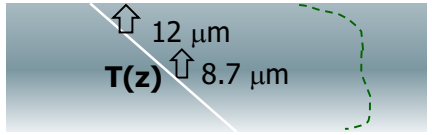
- Vertical IH cloud model
  - Removes CTP bias against lidars
  - Allows better use of new channels (e.g. 2.2 μm or O_2 band)
  - Possibly controversial for AMV height assignment – buyer beware!

Clean Solar: Little effect

IR/SWIR: Absorption / Scattering depth

"Industry Standard"
COT
CGT=0
CRE
CTP

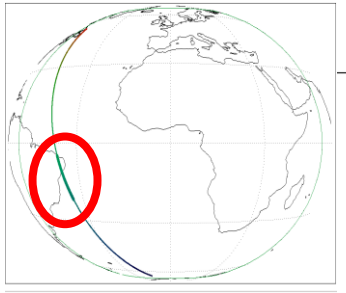
+Vertical Inhomogeneity VI
COT
CGT!=0
EXT(z)=Func(COT,CTP)
CRE(z)=Func(CRE_{top},z)
CTP

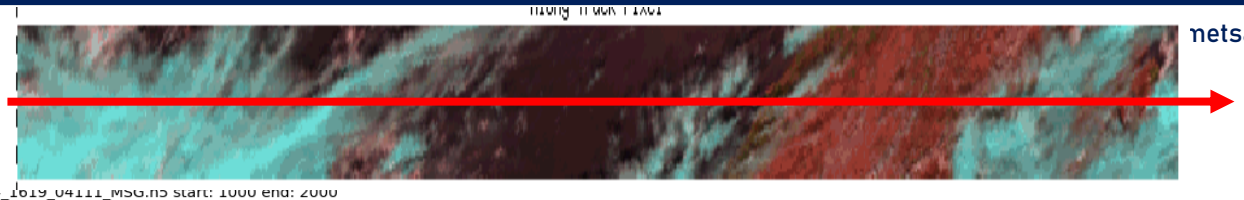


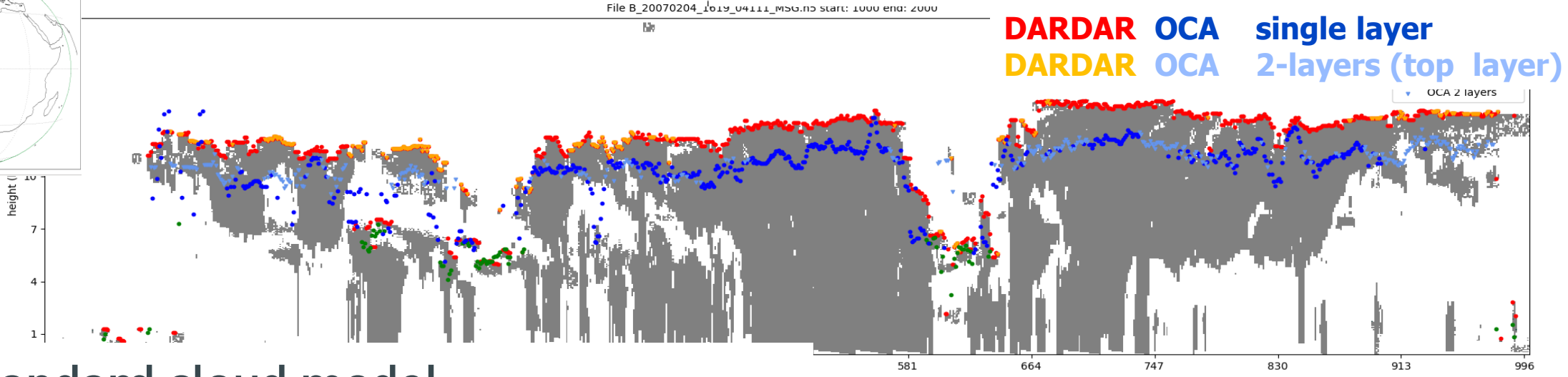
In collab. with HYGEOS

Current development: accounting for vertical cloud inhomogeneity

Results for a single scene

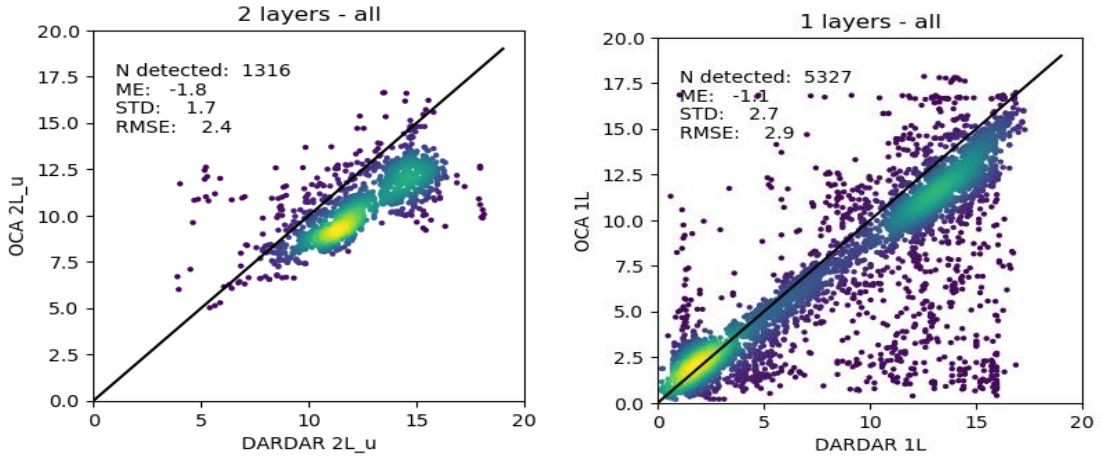






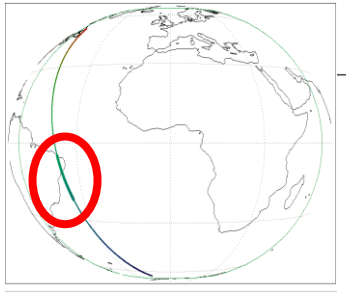
Standard cloud model

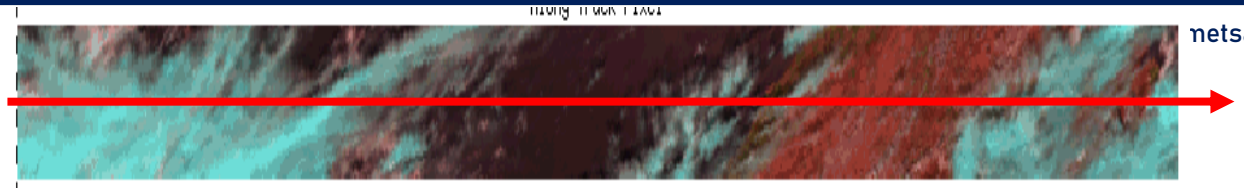
Results using 6 co-located orbits

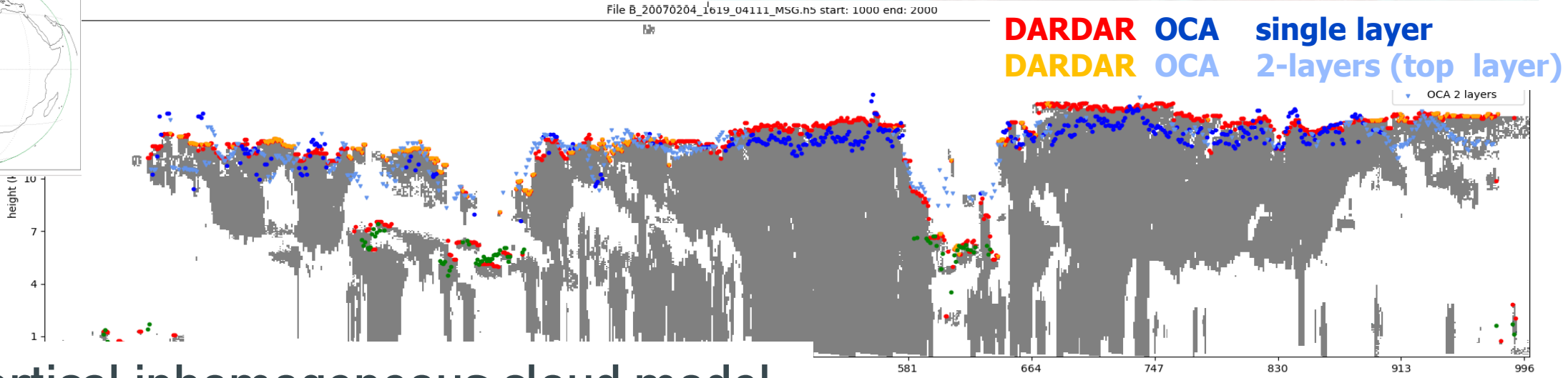


Current development: accounting for vertical cloud inhomogeneity

Results for a single scene

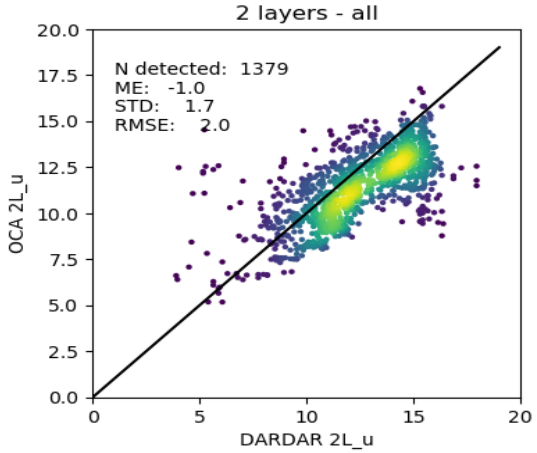


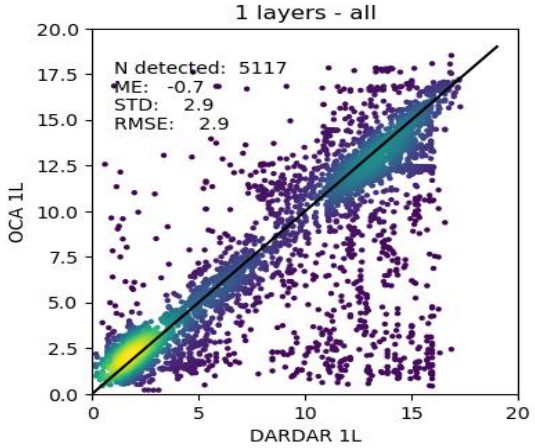




Vertical inhomogeneous cloud model

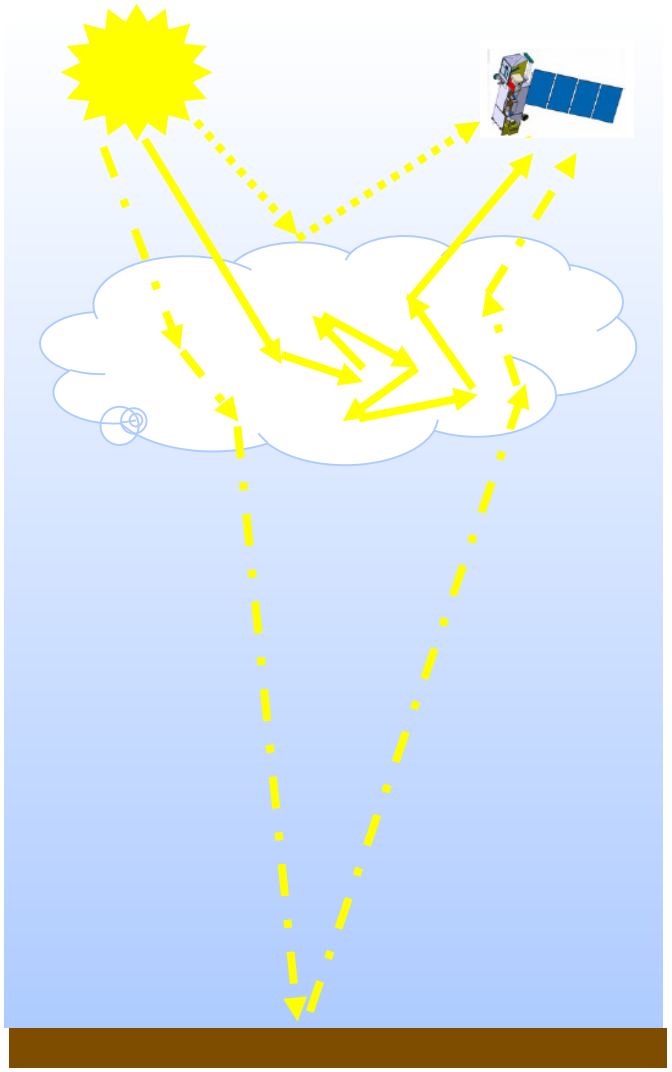
Results using 6 co-located orbits

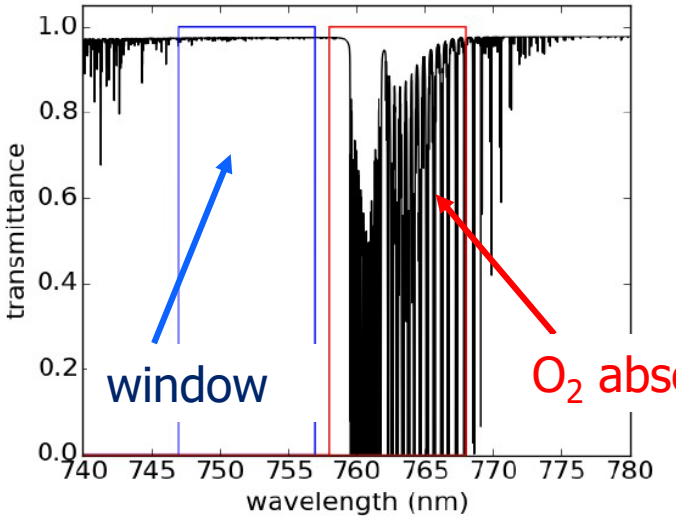


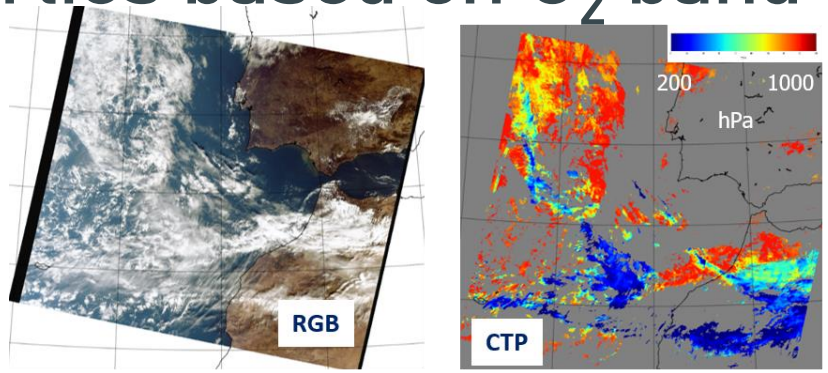


Oxygen band cloud properties retrieval

- OLCI, METimage retrievals of cloud properties based on O_2 band

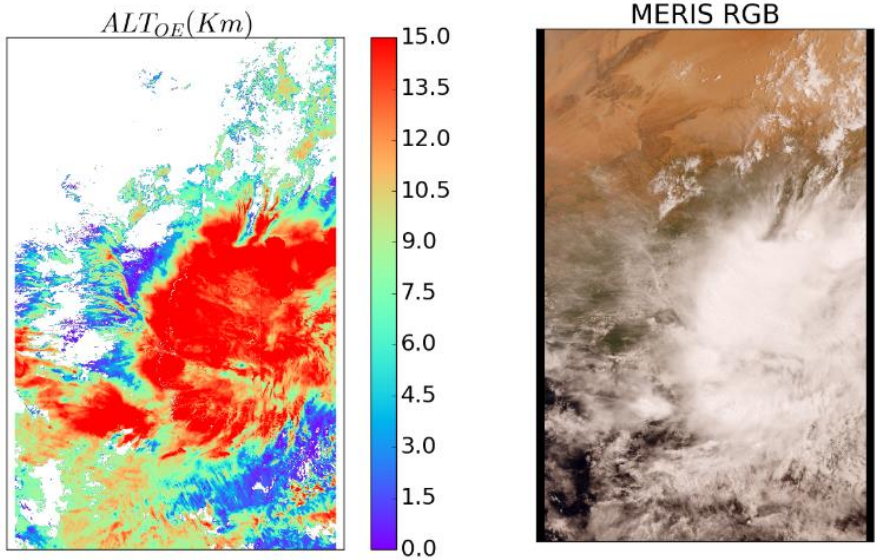






S3 OLCI https://www.eumetsat.int/S3-OLCI-CTP
(courtesy R. Preusker, J. Fischer)

- 1D-var scheme comparing signals from O_2 absorption band and nearby window.
- Photons travel into cloud layers requiring extra constraints:
  - Surface reflection
  - Cloud model with vertical structure
  - Cloud optical properties



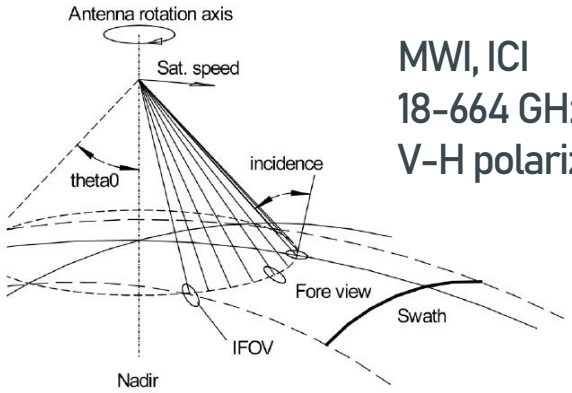
Cloud top height retrieved for deep convective clouds with MERIS
(courtesy M. Compiegne https://www.eumetsat.int/O2-band-CTP)

MW to Sub-mm channels for cloud observation

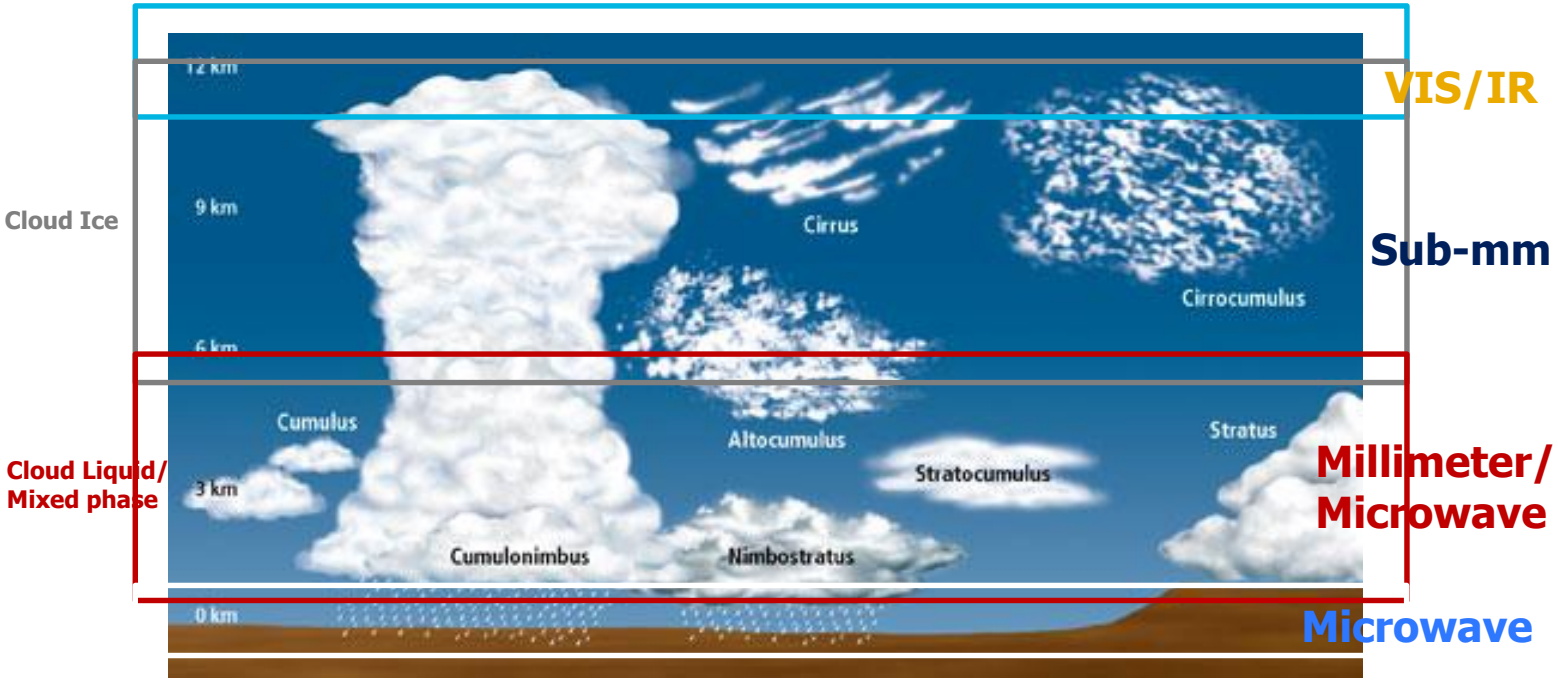
MWI and ICI on the same platform is unprecedented. Synergy between MWI and ICI will need to be exploited for many applications.

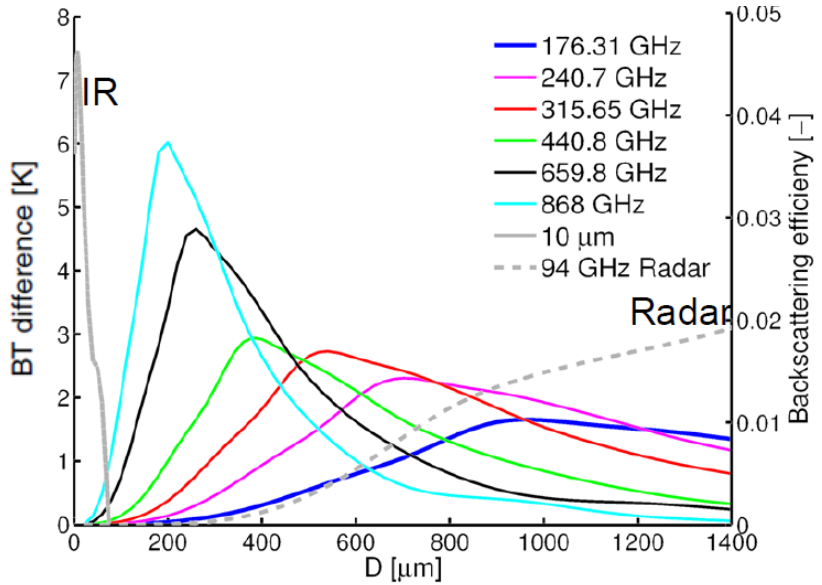
Challenges:

- WV absorption
- Particle phase/size/shape/orientation
- Surface properties at sub-mm
- Validation facilities
- Synergy with other EPS-SG instruments



MWI, ICI
18-664 GHz
V-H polarization



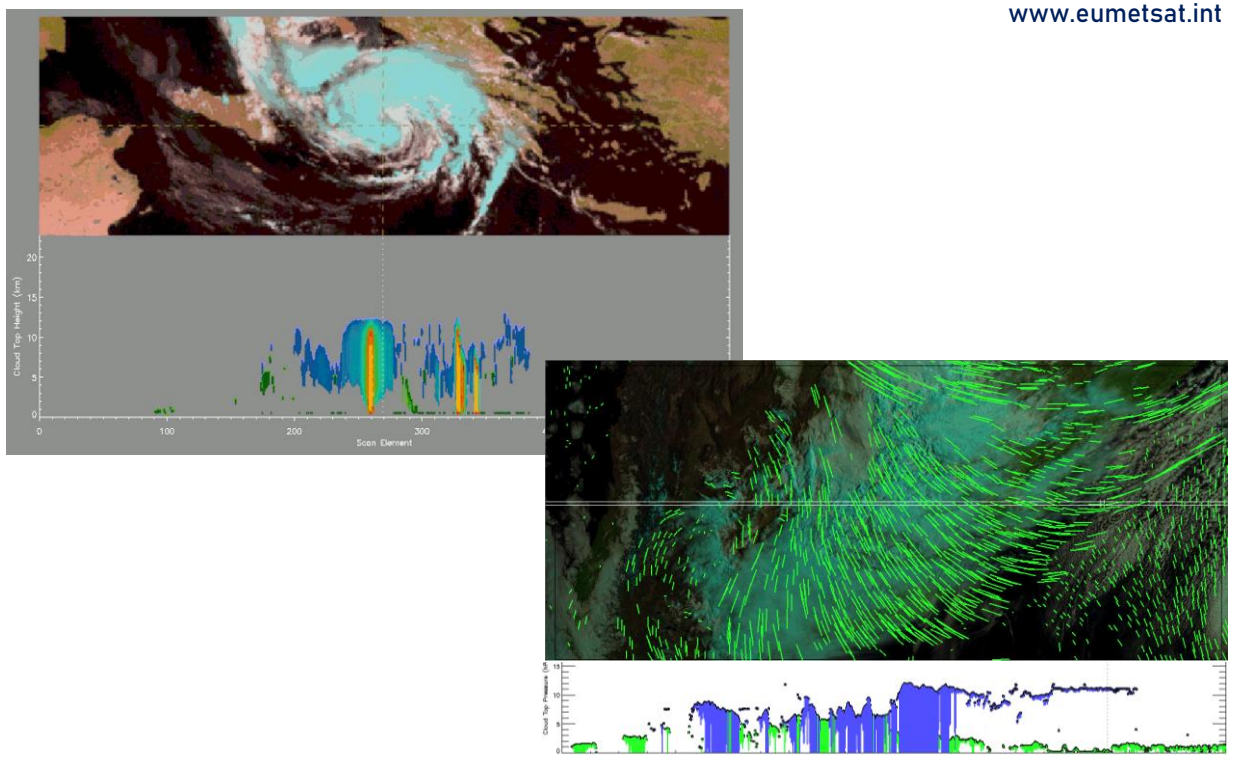


Buehler et al., 2007

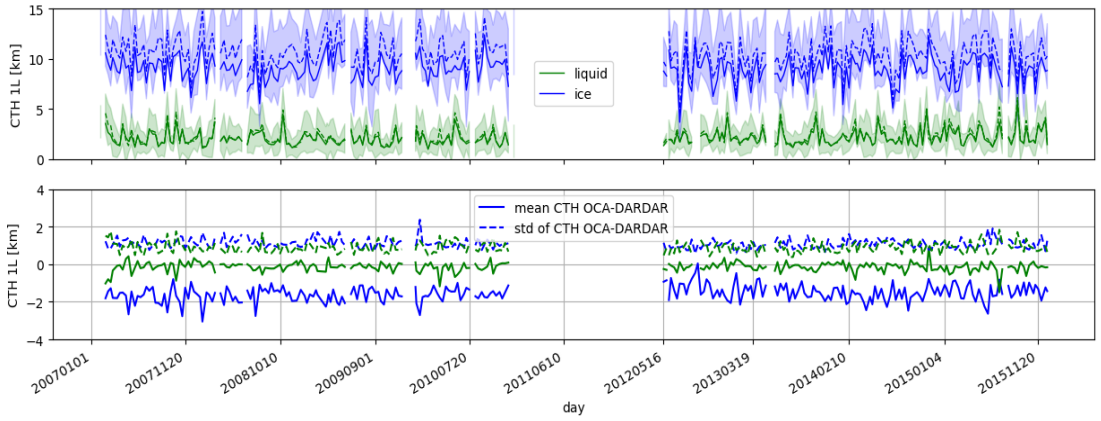
Buehler, et al. 2007: A concept for a satellite mission to measure cloud ice water path, ice particle size, and cloud altitude", *Q. J. Roy. Meteorol. Soc.*, 133, 109–128

Developments for applications

- Product visualization
  - Improving the visualization of cloud products for now casting applications
- Height assignment for AMV
  - Exploring how to provide the best height assignment including quality indicators and layering
- CDR
  - Improve the quality of the reprocessing of long time series of cloud products. New OCA CDR https://www.eumetsat.int/release-oca-climate-data-record

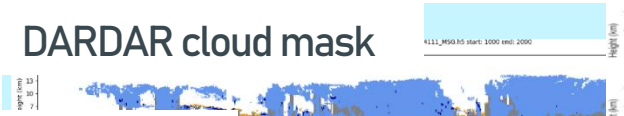


OCA vs Combined Lidar/Radar CTH 2007-2015

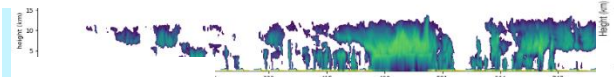


Cloud products validation – from above and from the surface

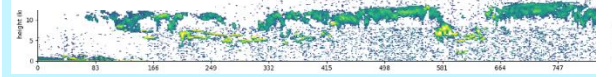
DARDAR cloud mask

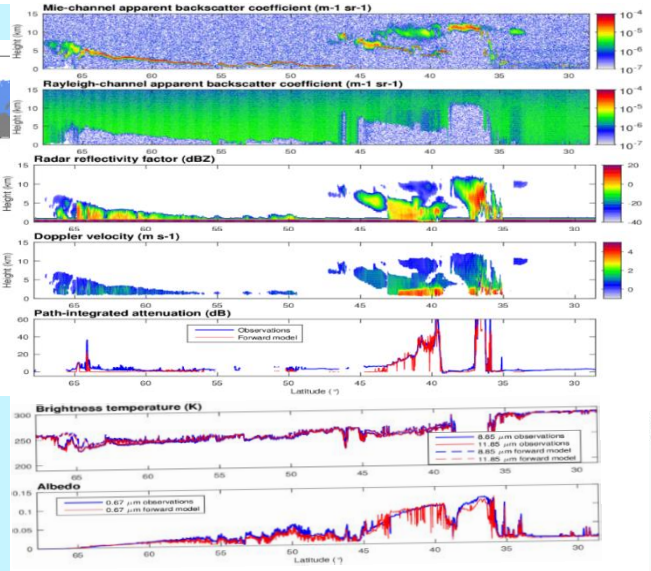


Cloudast

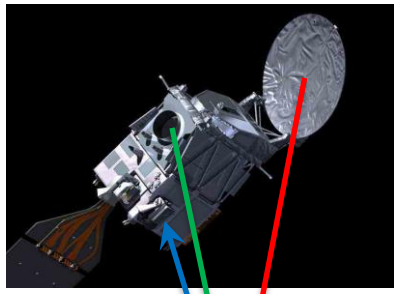


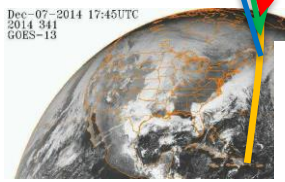
CALIPSO

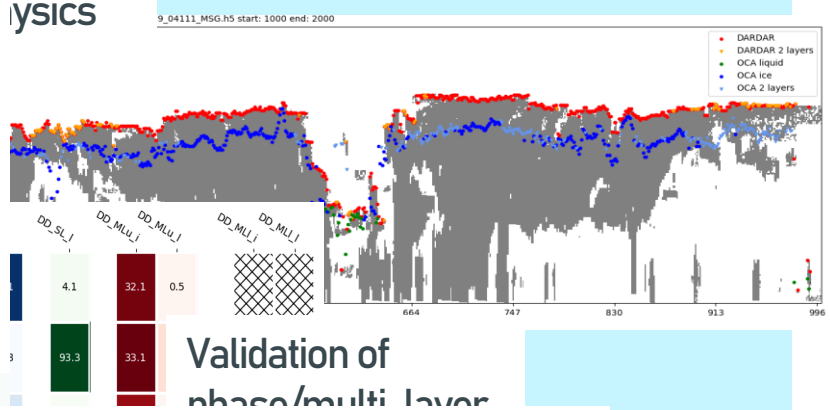




A(C)-Train has provided most of the needed independent validation of cloud products





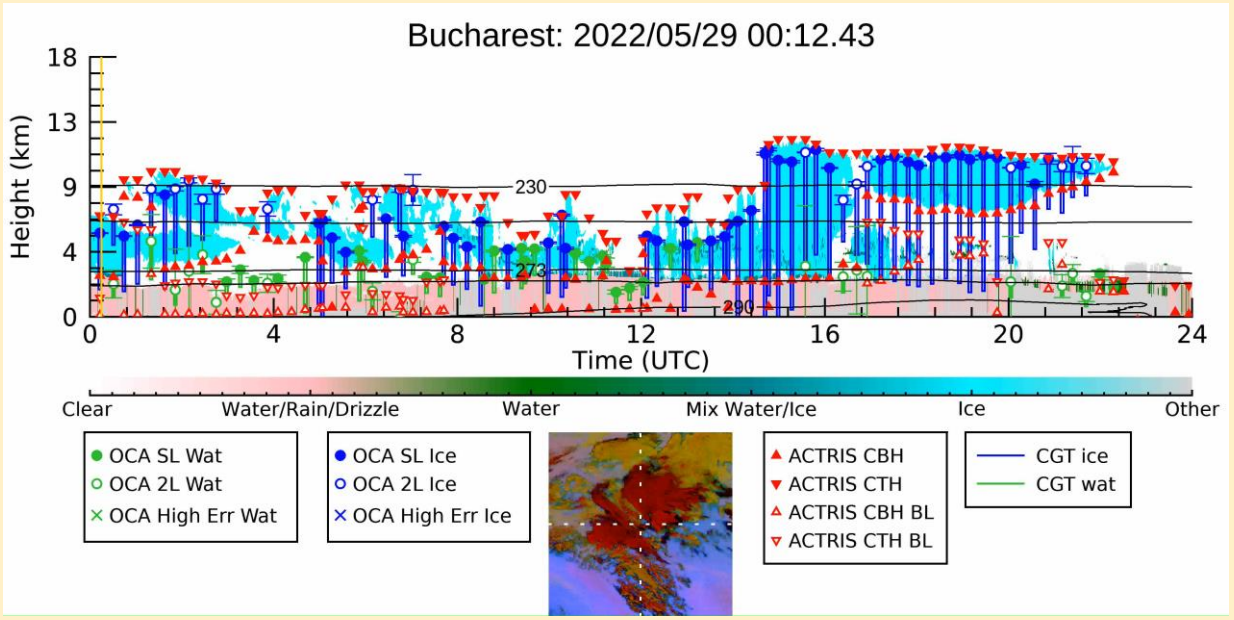


Validation of phase/multi-layer

Preparation for EarthCARE (not available for FCI commissioning)

Cloudnet ACTRiS

- Surface observations from ACTRIS/Cloudnet sites co-located with SEVIRI/FCI/METimage pixels
  - Multi layer/microphysics available
  - Cloud geometrical thickness and base height estimate
  - Integrated LWC/IWC



Summary



Upcoming missions

Challenges and opportunities.

Cloud products development

Development and validation plans.

Aerosol products development

Development and validation plans.

Conclusions

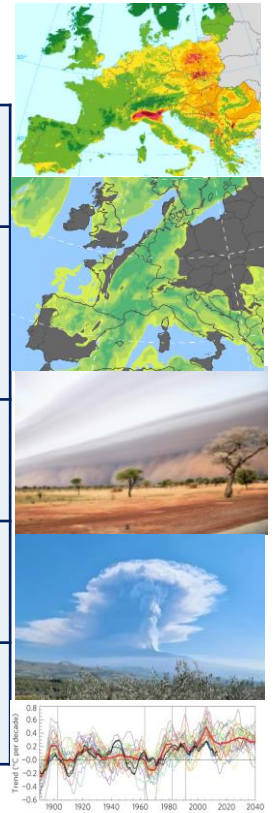
Aerosols and Users

- EUMETSAT provides 2 NRT AOD operational products
- Importance of aerosol
  - NWP and National Weather Prediction
    - radiative effect and interaction with cloud (nucleation)
  - Air quality, Warning and Advisory
    - Visibility, health and security issues
  - Climate change

- Diversity of type and situation:

Main users for EUMETSAT

Copernicus Atmosphere Monitoring Service (CAMS)
Numerical Weather Prediction (NWP) and National Meteorological Services (NMS)
Sand & Dust Storm Warning (SDS-WMO)
Volcanic Ash Advisory Centre (VAAC)
Copernicus Climate Change Service (C3S)





Dust



Volatile organic compounds (vegetation)



Smoke (fire & industrial)



Volcanic ash



Sea salt





Anthropogenic activities trace gas precursors

All current and future satellite aerosol products by EUMETSAT

Current & next generation of sensors (Member states, Copernicus)

Beyond AOD: e.g. aerosol layer height, fine mode, etc…

Synergy: EPS-SG/MAP

		Current platforms						Future platforms						
		EPS	EPS	EPS	MSG	S3	S3	EPSSG	EPSSG	EPSSG	EPSSG	MTG	MTG	CO2M
Parameter	**Acronym**	***GOME2***	***IASI***	***PMAp***	***SEVIRI***	***OLCI***	***SLSTR***	***3MI***	***MAP***	***S5***	***IASI-NG***	***FCI***	***S4***	***MAP***
Total Optical Thickness	AOD			550nm	550nm	spectral	spectral	spectral	spectral	550nm		550nm	550nm	spectral
Model or Type				class								type		
Fine mode fraction	FMF													
Single Scattering Albedo	SSA						spectral							
Refractive index														
Effective radius	AER													
Angstrom coefficient														
Absorbing index	AAI													
Layer Height	ALH	absorb.	ash/dust		ash					absorb.	ash/dust	ash	absorb.	
Volcanic Ash			AOD	flag	AOD				AOD		AOD	flag		
Desert dust			AOD	flag					AOD		AOD			

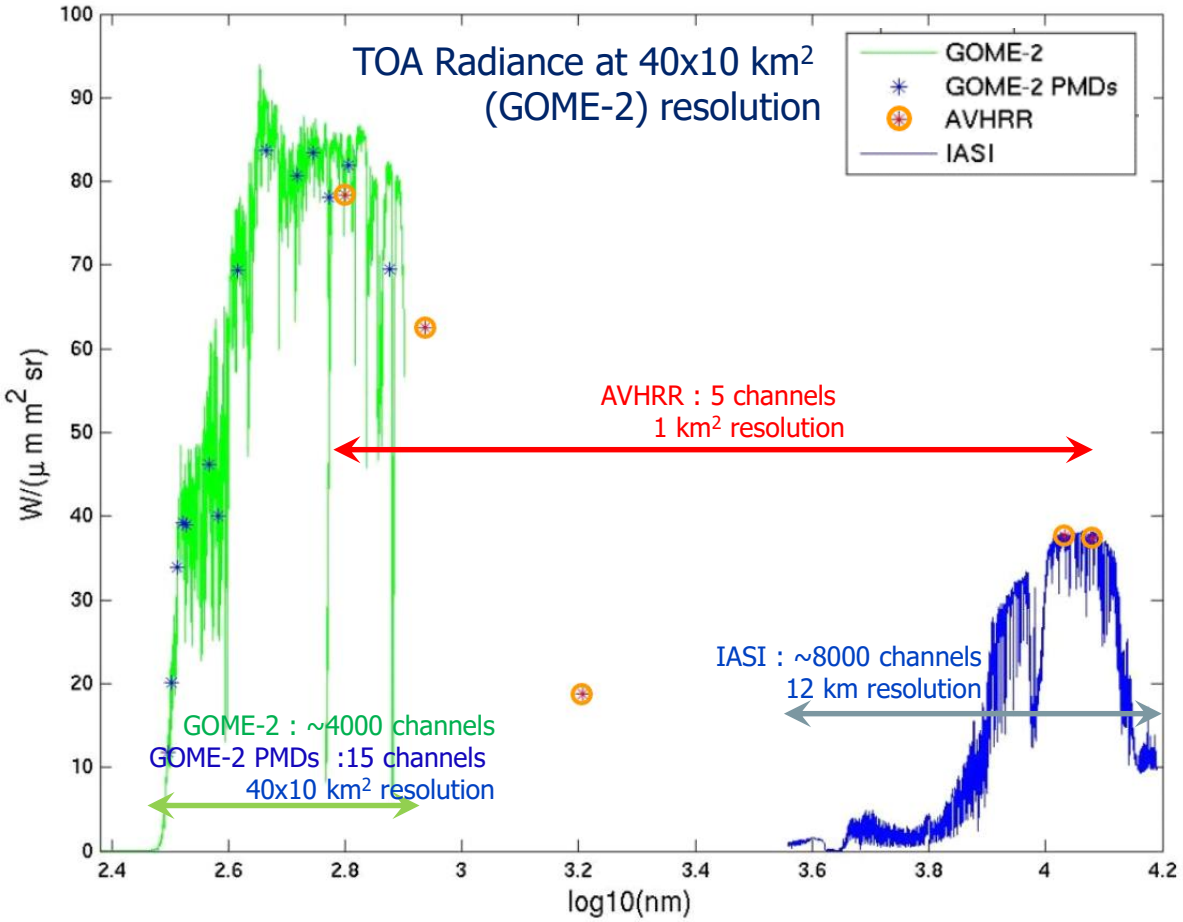
	Existing operational product
	Under implementation
	Under development
	Feasibility study

Operational – EPS/PMAp: Polar Multi-sensor Aerosol Product

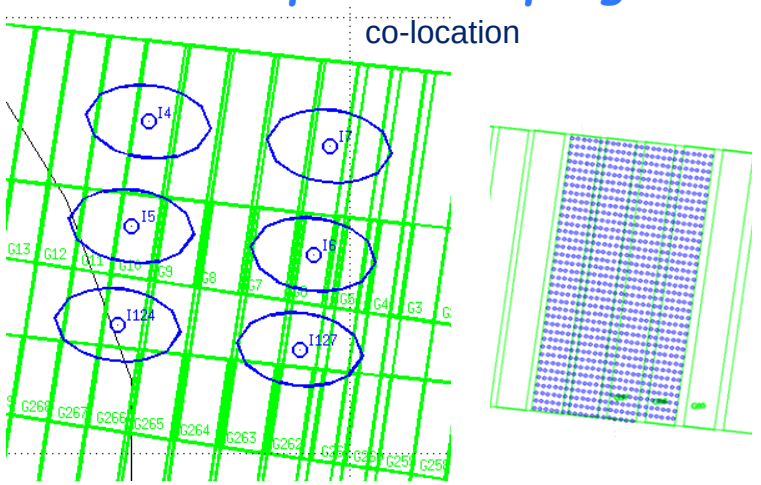
PMAp: Polar Multi-sensor Aerosol product from GOME-2, AVHRR and IASI

- EPS : Polar orbit at 09:30 ECT – A/2006, B/2012, C/2018
- 3 redundant platform/instrument → 25 y. of operation
- GOME-2, AVHRR, IASI

Combined Spectral information



Spatial sampling



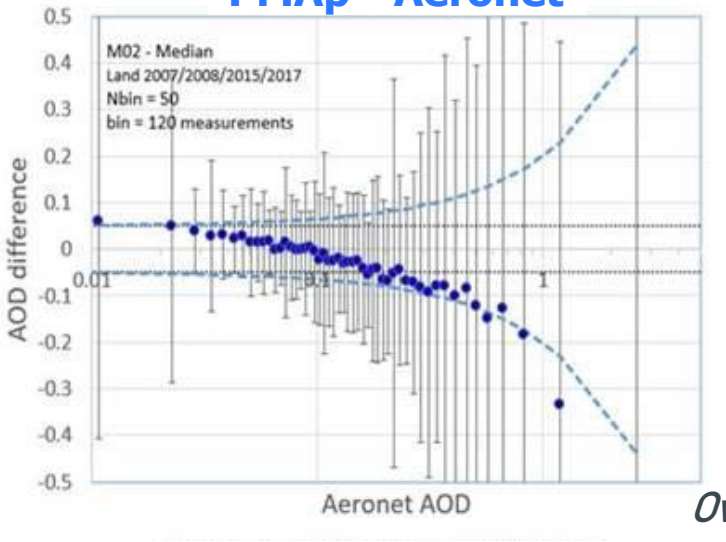
- Product = AOD @550nm + aerosol type classification
- Fully operational product since Oct'14 (over ocean)
- Version 2 since Feb'17 (ocean & land)
- Version 2.2.4 released May'21
- Version 2.2.5 released soon

detailed in Grzegorski et al., Remote Sensing, 2022

PMAp validation

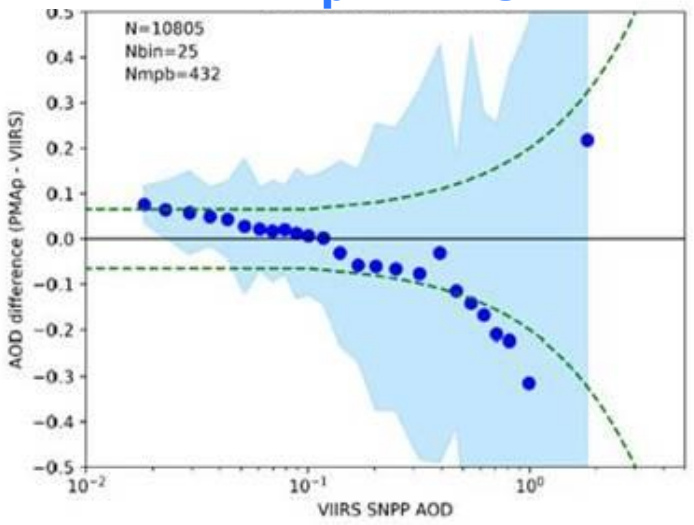
- Qualitative evaluation, Matchup with Aeronet, Comparison with other sensors
  - Analysed for many parameters: pixel inhomogeneity, surface type (igbp), aerosol type, viewing geometry

PMAp - Aeronet



Over land

PMAp - VIIRS

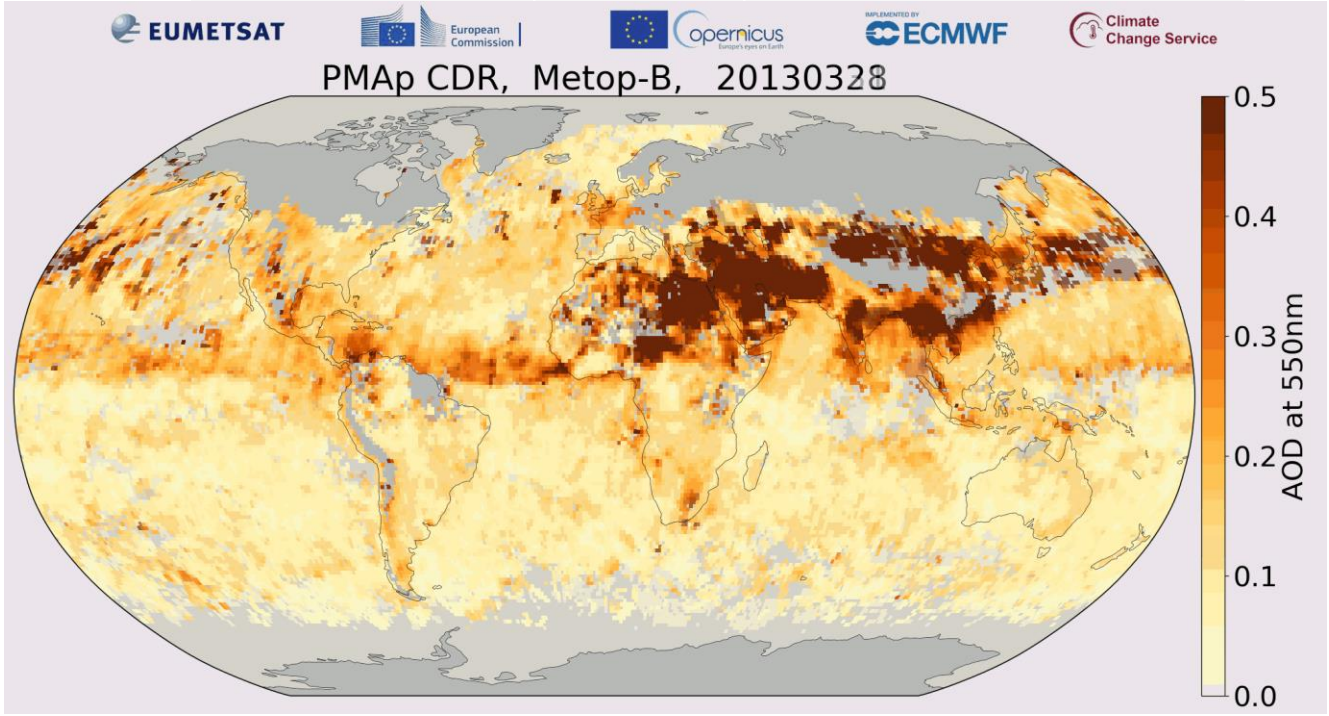


Reprocessing PMAp to create a climate data record (CDR)

in the context of Copernicus Climate Change Service (C3S)

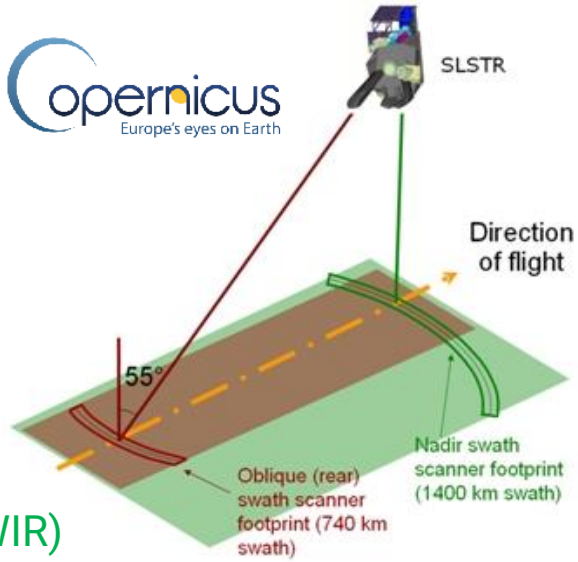
- Create a homogeneous, consistent, and well-calibrated, long-term AOD dataset
- Instrumental for an extensive validation

Satellite	Coverage	Reprocessing period
Metop-A	global	01/07/2007 – 29/01/2018
Metop-B	global	20/02/2013 – 31/08/2019



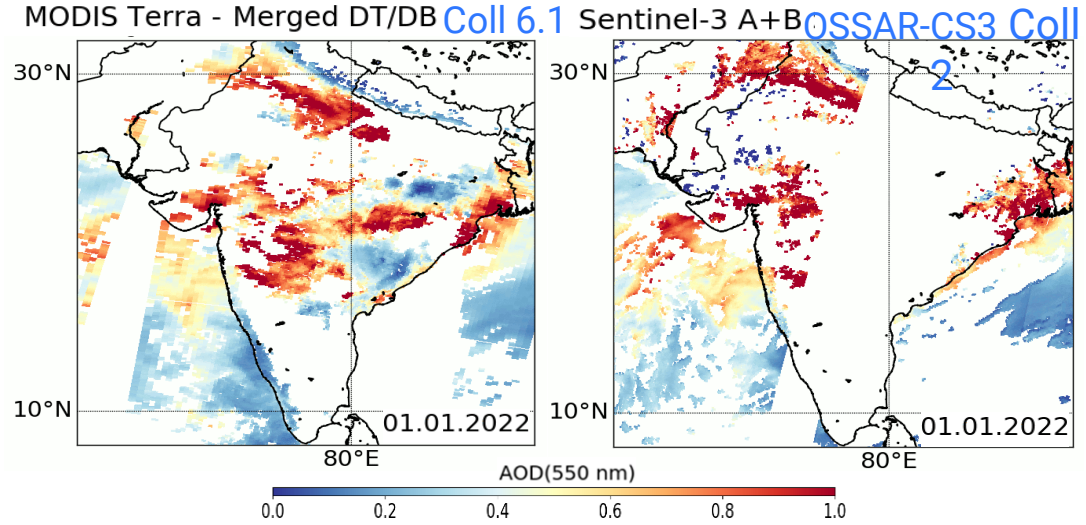
NRT Operational – from Sentinel-3/SLSTR – EUMETSAT entrusted by the EC

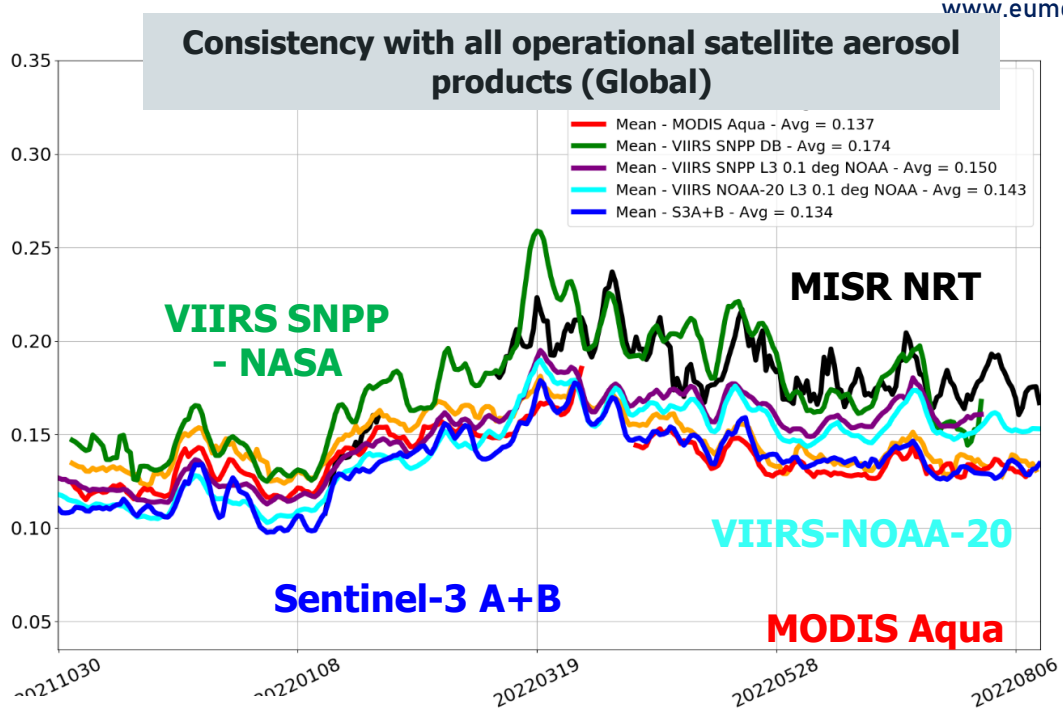
- **OSSAR-CS3 = joint algorithm baseline between EUMETSAT scientific experts + Swansea University**
- Dynamic L1 radiance correction (e.g. mis-calibration)
- Naïve probabilistic Cloud & Aerosol identification
- **Ocean:**
  - Dual-view retrieval
  - Ocean surface pre-computed (not retrieved) based on ECMWF forecast + Ocean Colour
- **Land:**
  - Aerosol fit with land surface constraints, depending on dual-view information content
  - Land surface = weighted between dual-angular model (SU) & spectral 1st guess (AFRI Red-SWIR)
- Aerosol types: 35 mixtures interpolated between dust, sea salt, weakly & strongly absorbing (Kinne et al., 2006)
- Log(AOD)
- Quality Indicator: 0 (Not retrieved), 1 (Poor), 2 (Good), 3 (Very Good)
- History of a recent development
  - Collection 1 – Demonstrational – 2020
  - Collection 2 – October 2021 – Preliminary operational
    - Collection 3 – Scheduled October 2022 – Major improvements (enhanced coverage, Land bias reduction)



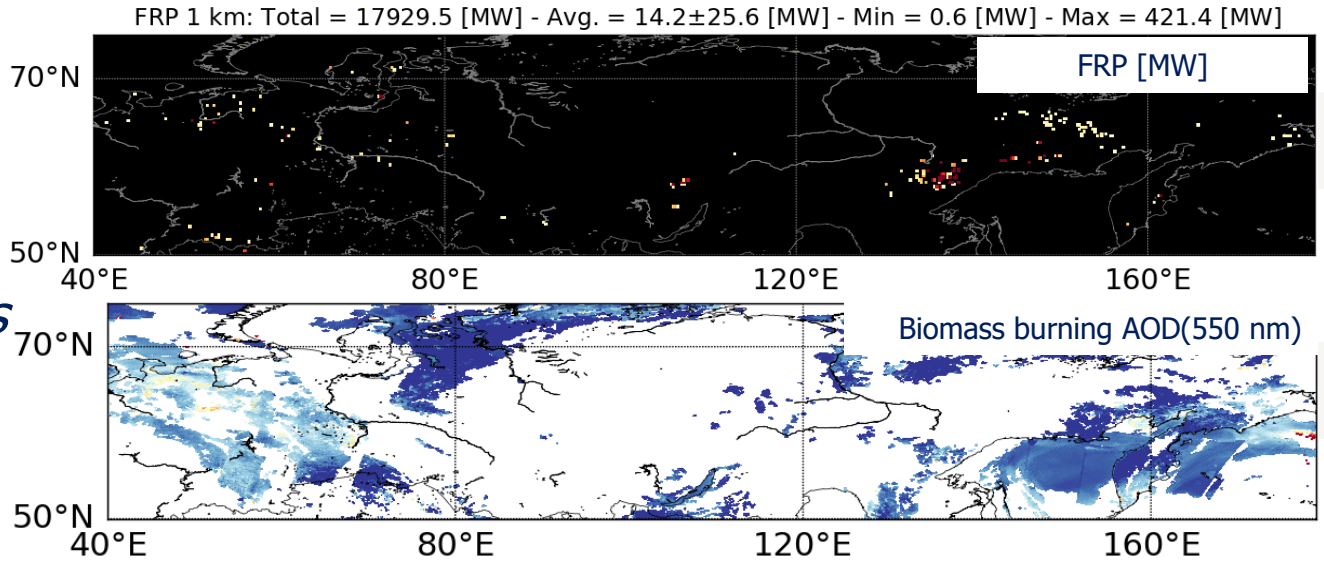
OSSAR-CS3: comparison to satellite AOD products

Sentinel-3 A+B SLSTR - AOD(550 nm) Land & Ocean





Summer 2022
Siberia Wildfires



OFRaP-CS3 - NRT S3
Coll 2.0

OSSAR-CS3 - NRT S3
Coll 3.0 (New)

EPS-SG/3MI - polarimetry

- Large information content:
  - 14 views : from -50° backward to 50° forward
  - 12 spectral bands: from 410 to 2130nm
  - 3 polarisations providing I, Q, and U (except for absorption bands)
- The aerosol retrieval is based on an optimal simultaneous retrieval of the surface and aerosol (GRASP)
- Phase function measured in spectral, angular and polarised space

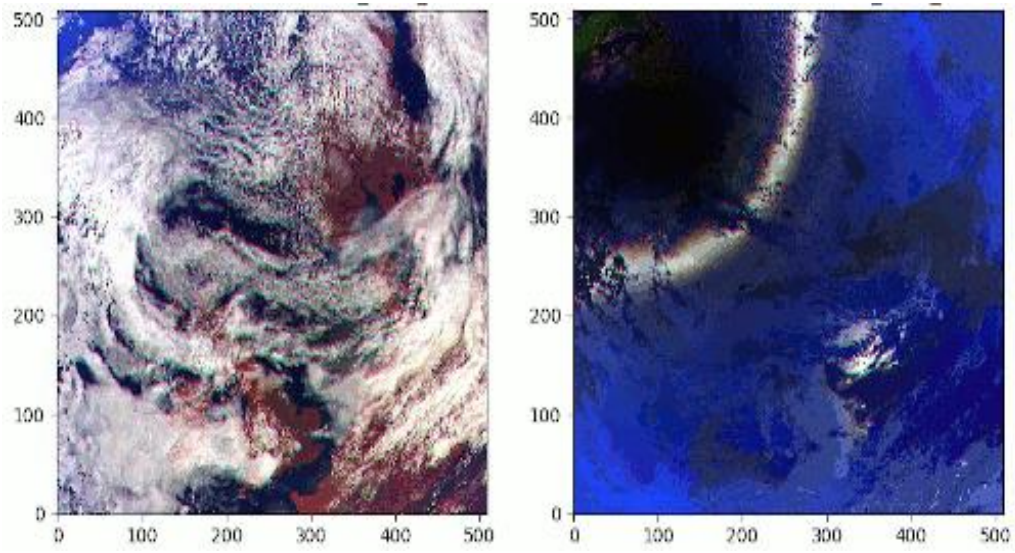


- **Aerosol model (type f/c, microphysics, size distribution, shape, absorption…)**
- **Aerosol load (optical thickness)**

- But it is unrealistic to retrieve all of them and everywhere
  - Geometry of acquisition and/or the surface type strongly influence the performance of the retrieval
  - Wrt our user needs, the retrieval will be optimised to derive properly for AOD and Aerosol model
  - Other parameters will be retrieved when/if possible

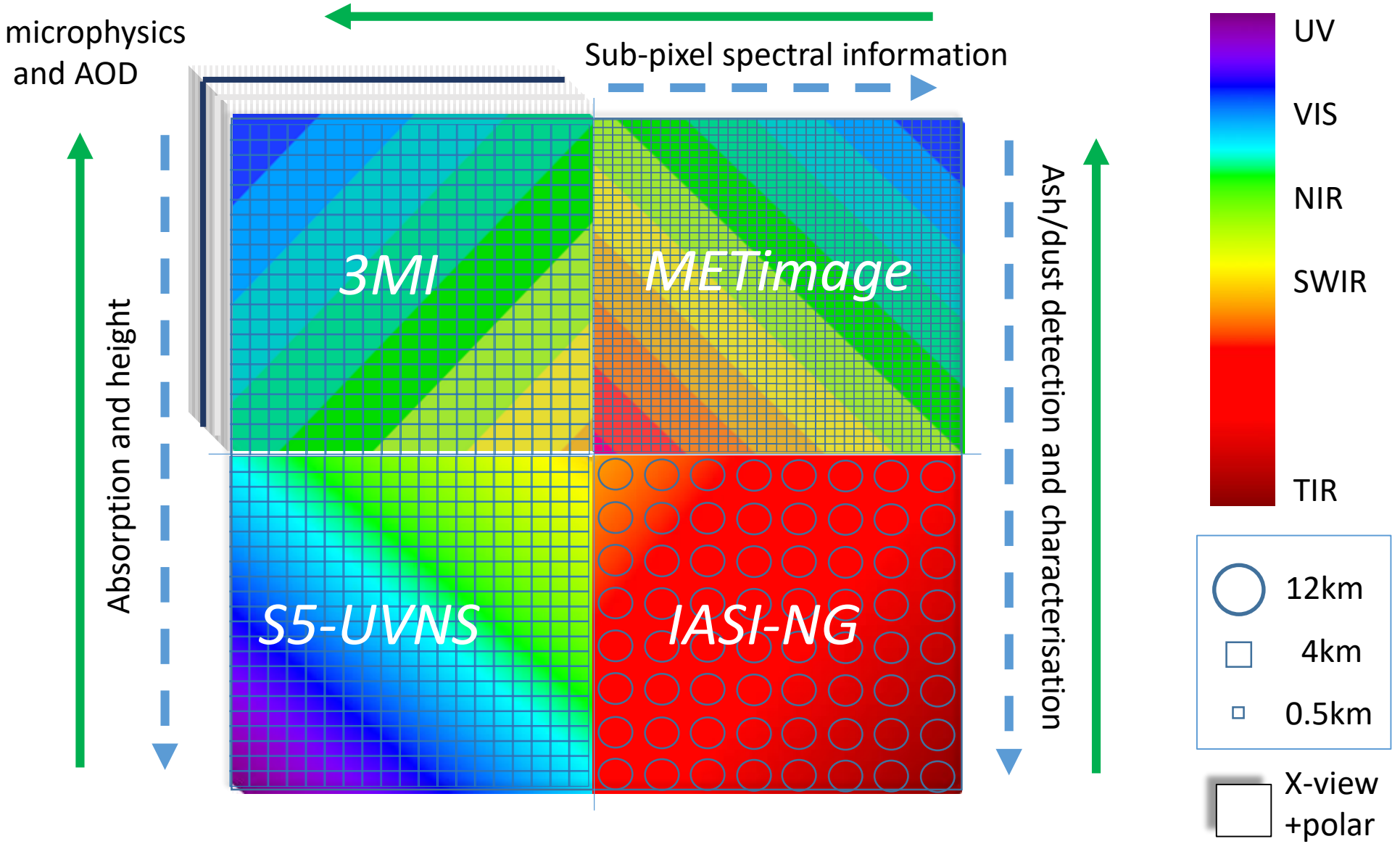
Standard RGB

Polarisation



detailed in Fougnie et al., JQSRT, 2020

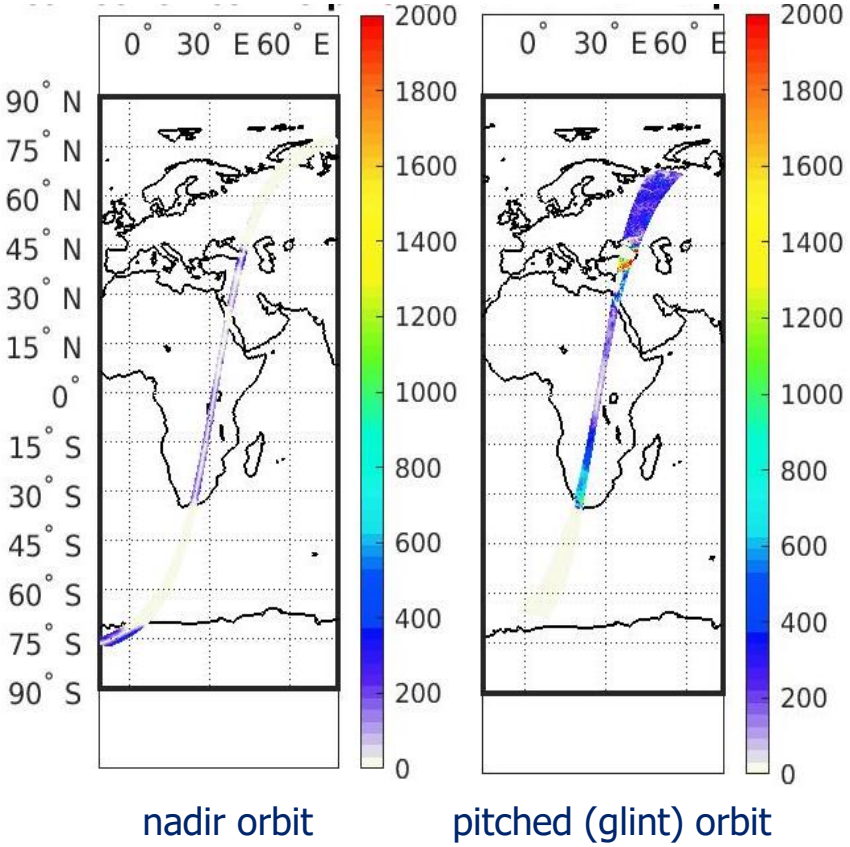
The Aerosol Observatory from EPS-SG sensors



CO2M project

- MAP Multi-Angle Polarimeter in VIS-NIR
  → 45 views, I/Q/U in 7 bands (410-865nm)

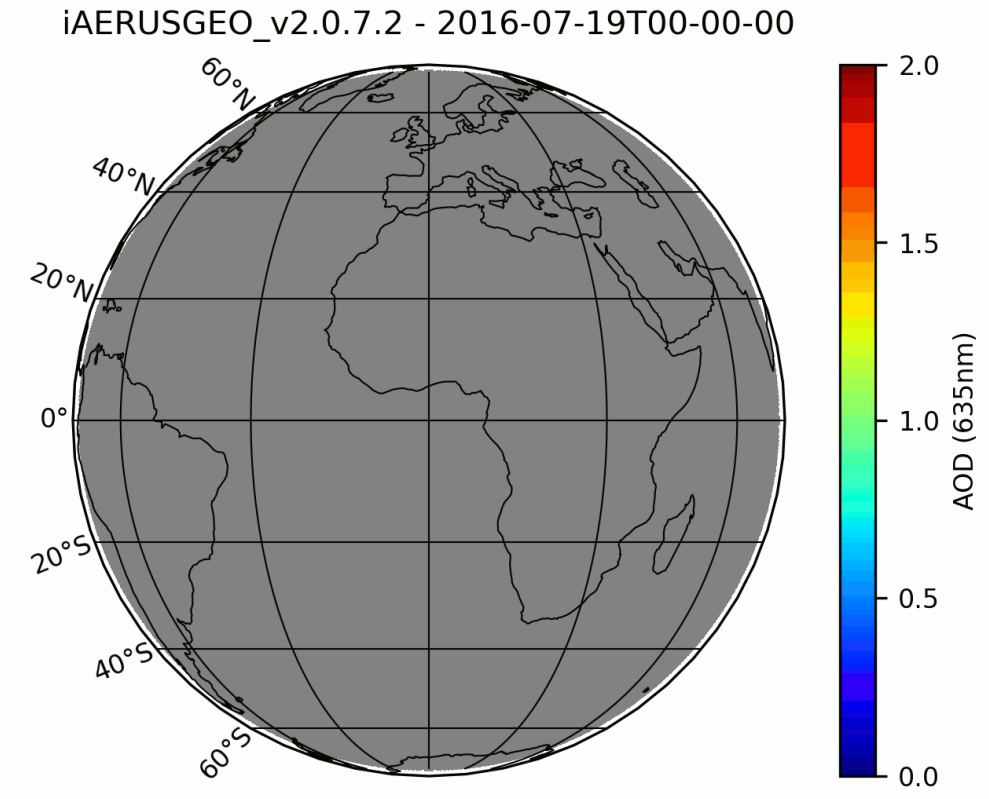
- Aerosol correction is needed to reach the performance for CO2 & CH4
- Challenge: aerosol contribution is needed in SWIR
- Similarly as for 3MI, GRASP to be optimised for MAP
- Influence of the geometry
- Synergy with CLIM and CO2IS



nadir orbit pitched (glint) orbit

On-going development with GEO

- GEO – for a given lat/lon:
  - Very high number of observation per day
  - fix viewing geometry, but wide range of solar geometry
- i-AERUS based on MSG/SEVIRI observations
  - Previous EUMETSAT study, continued by MeteoFrance
  - Operated in ICARE
- Demonstrate the potential for i-AERUS with MTG/FCI
  - More spectral bands → better assessment of the aerosol model
- https://www.eumetsat.int/I-AERUS-GEO

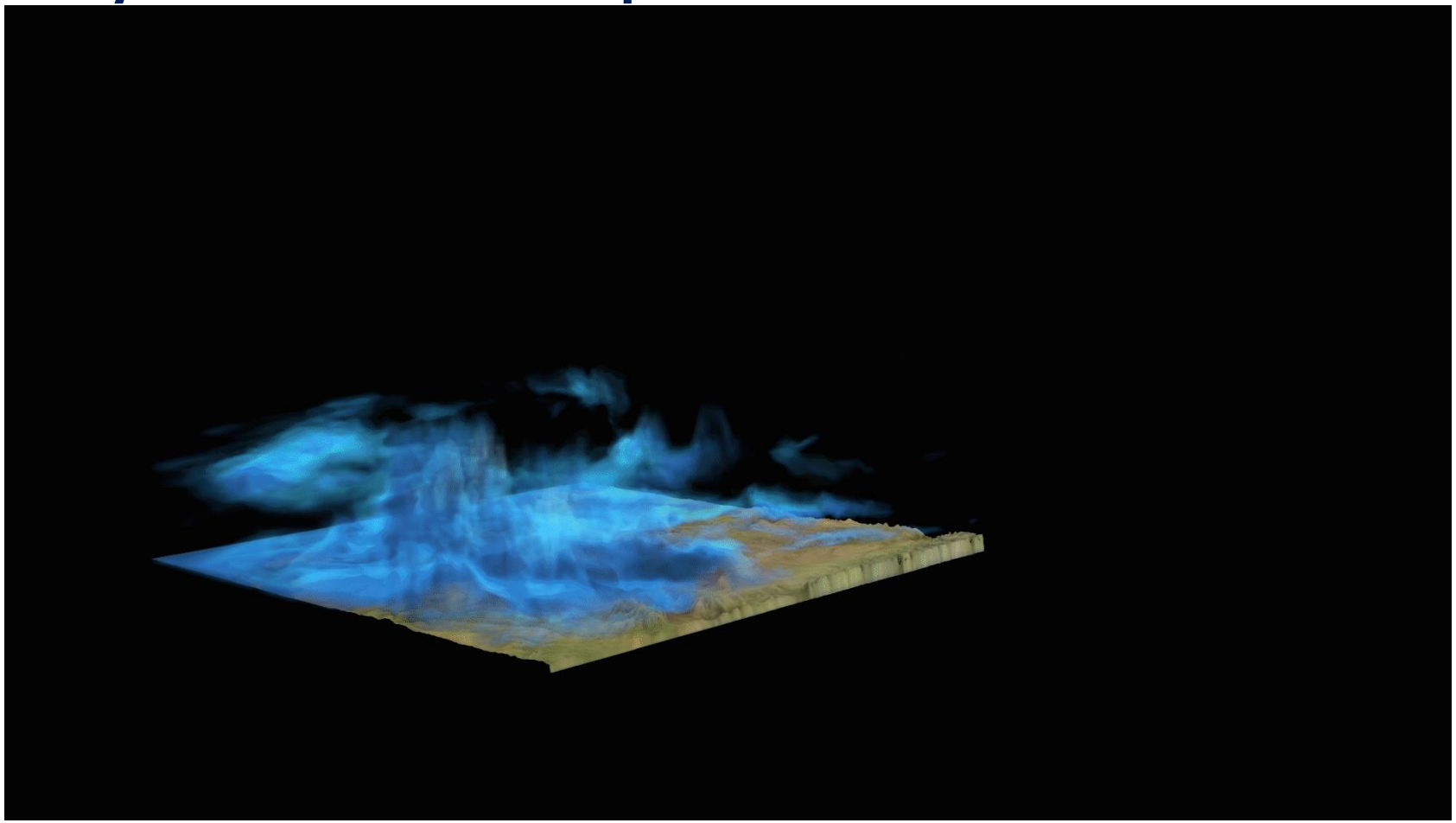


Conclusions

New opportunities and challenges:

- a rich array of different spectral/spatial/angular/ polarization observations of clouds/aerosols from geostationary and lower polar orbits
- algorithms consistency and new approaches to retrieval
- need for independent validation data

Synergy example: 4D weather cube with MTG-I and MTG-S Every 30 minute over Europe



Science studies can be accessed at https://www.eumetsat.int/science-studies



Thank you!

Questions are welcome.