

# ESA Update for ICAP

23 July 2019

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*with help from some ESA colleagues:*

*Anne Grete Straum, Michael Eisinger, Christian Retscher, Claus Zehner*

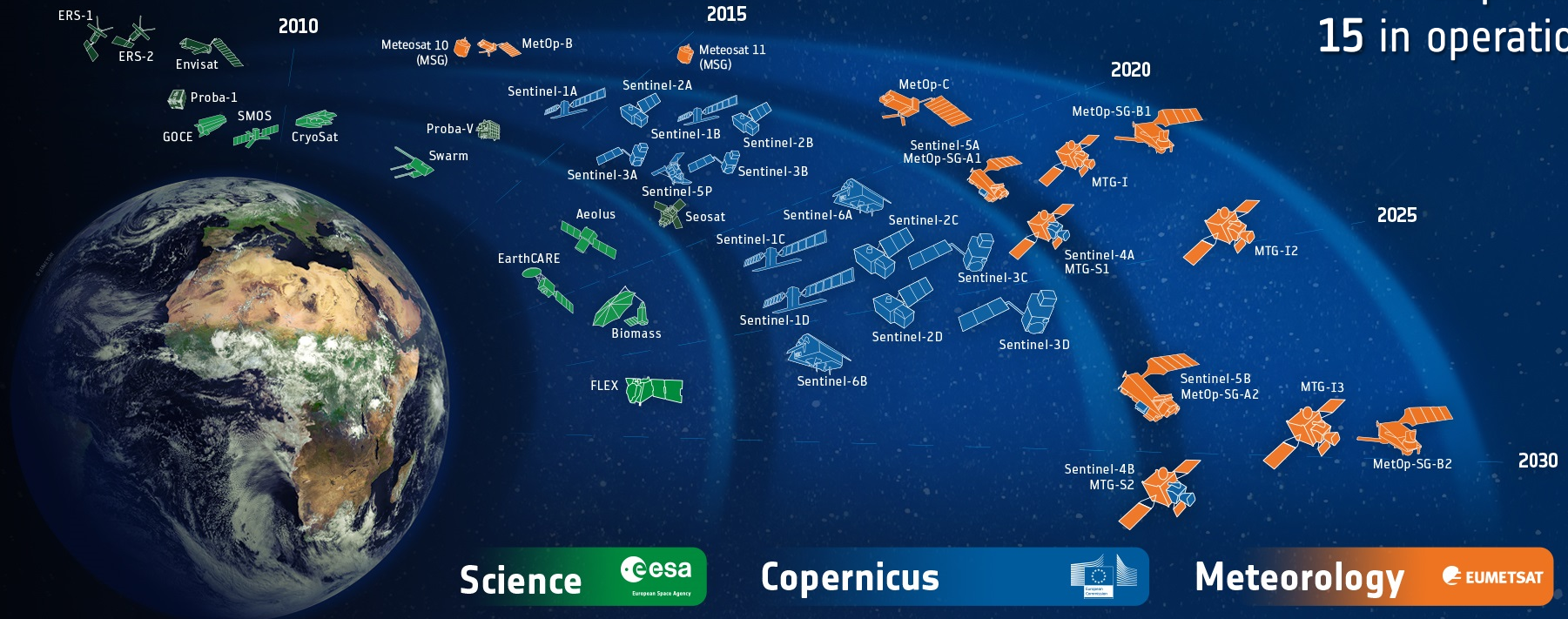
# ESA-Developed Earth Observation Missions



Satellites

25 under development

15 in operation



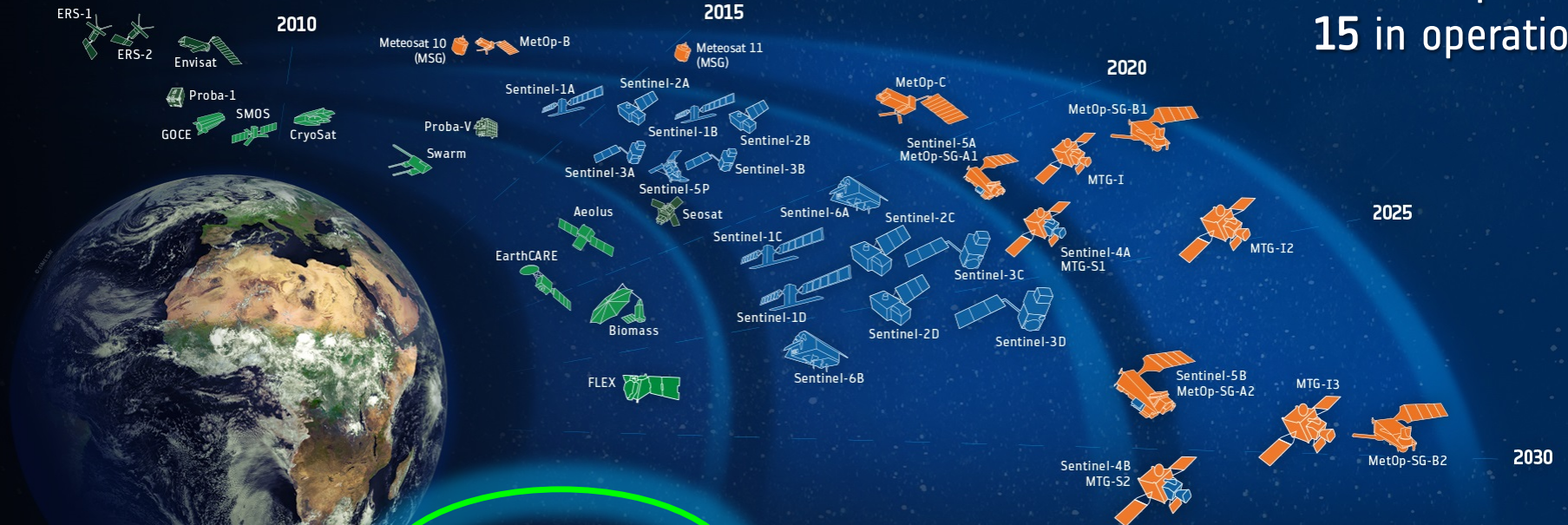
# ESA-Developed Earth Observation Missions



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Science  European Space Agency

Copernicus 

Meteorology 



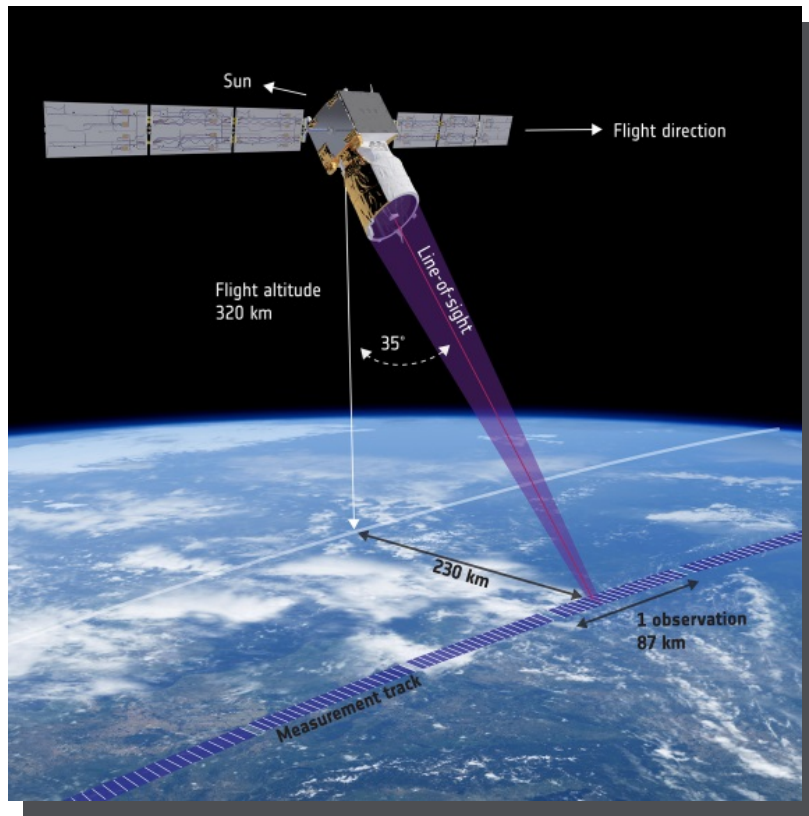
# Science: Earth Explorers



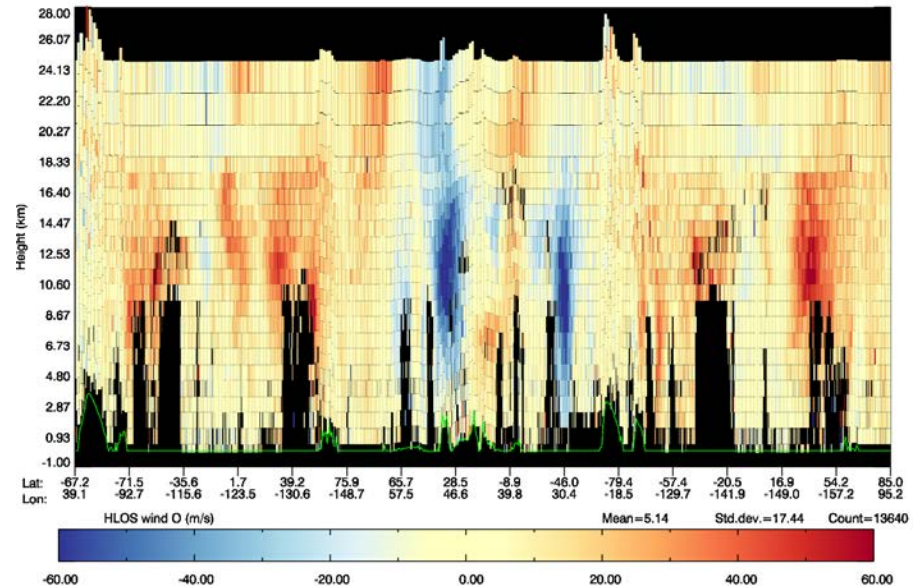
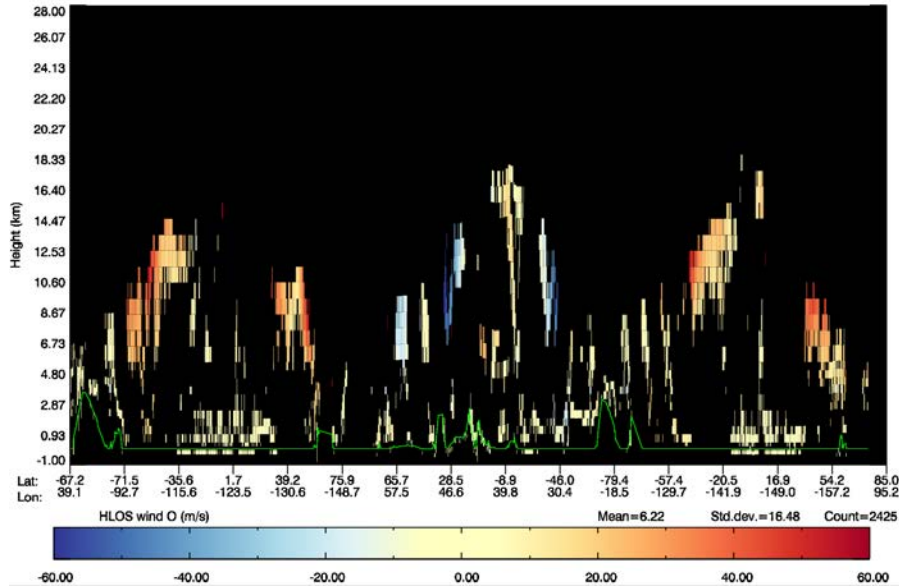
GOCE, SMOS, CRYOSAT, SWARM, AEOLUS, EARTH CARE, FLEX, BIOMASS, CLOUD, AEROSOL & RADIATION MISSION, FLEX, CRYOSAT, SWARM



# Aeolus – ESA's Wind mission



- Direct detection UV Doppler Wind Lidar (355 nm), **80mJ laser output**, 50 Hz PRF, 2 receiver channels
- Mie receiver to determine winds from aerosol & cloud backscatter (Fizeau)
- Rayleigh receiver to determine winds from molecular backscatter (Double edge Fabry-Perrot)
- The line-of-sight (LOS) points 35° from nadir to capture profiles of single component horizontal wind (LOS wind is projected to HLOS)
- Pointing orthogonal to the ground track to remove contribution from satellite velocity
- Ground return used for attitude correction and instrument calibration



Courtesy Michael Rennie, ECMWF

# Aeolus data products and requirements



## 1. Level 1B:

- a. Preliminary horizontally projected LOS winds (HLOS), not p and T corrected and not scene classified
- b. Input to Level 2B processor (no direct scientific use in its own)

## 2. Level 2B:

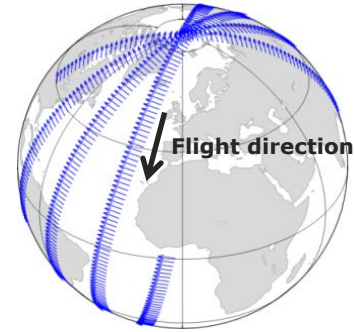
- a. **Scene classified, temperature and pressure corrected HLOS winds**
  - Four products: **Rayleigh clear/cloudy**, **Mie cloudy/clear**
- b. **Random errors** < PBL: 1 m/s, FT: 2.5 m/s, Stratosphere: 3-5 m/s
- c. **Bias** < 0.7 m/s
- d. **NRT**, ESA EE format, BUFR data via EUMETCAST (BUFR convertor available)

## 3. Level 2C:

- a. Assimilated winds from ECMWF model at location of Aeolus Level 2B observations

## 4. Level 2A:

- a. Atmospheric backscatter and extinction coefficient profiles (**NRT**)
- b. Circularly polarized emitted light
- c. Cross-polarized part of backscattered light not measured, **cloud and aerosol separation not yet fully implemented!**



Dusk/dawn orbit  
Courtesy  
N. Žagar

The Aeolus aerosol product is still under development. For the product on 87 km scale, the backscatter and extinction is given for aerosol+cloud scenes together, hence not useable for ICAP. On smaller scale a cloud and aerosol separation is attempted, but not yet working. There will be some substantial work done to improve on this during the coming 6-12 months. I.e. we hope to give aerosol and cloud backscatter and extinction separately in the product around the middle of next year. What will be in the next release, however, is cross-talk corrected signals which can be used by the users.

We have now switched to laser-B, and the laser is very stable so far. This means that we are expecting not to lose energy with time as we experienced with laser A, and if it occurs we expect to be able to correct for it by optimization of the instrument settings. We expect the instrument to be working well for the coming few years.

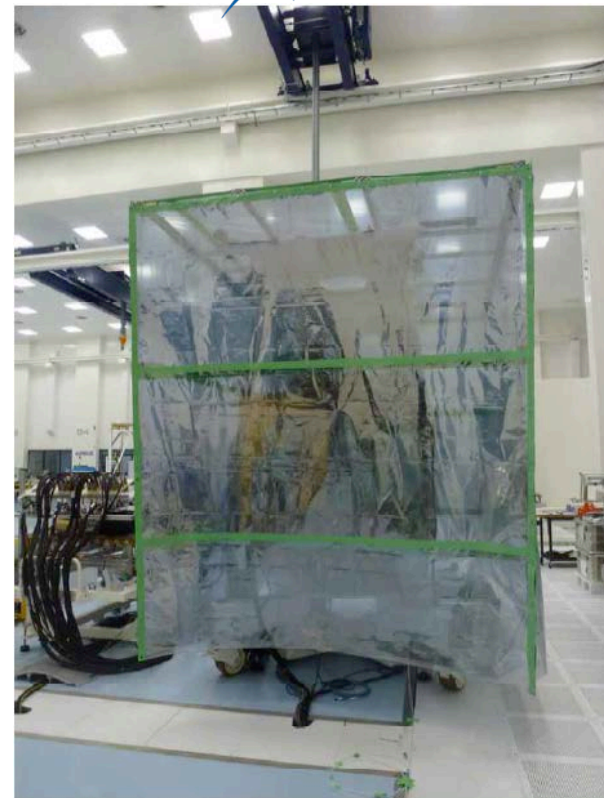


# EarthCARE: Status

- Platform fully integrated. BBR delivered and integrated on platform. Platform/BBR assembly currently in storage due to EarthCARE Payload Bridging Phase
- MSI fully calibrated, now undergoing final testing on instrument level. Expected delivery Oct 2019.
- ATLID instrument integration completed. Ambient performance tests ongoing, to be followed by tests in thermal vacuum. Expected delivery end 2019
- CPR pre-delivered for pre-integration. Now back at provider. Anomalies in High Power Transmitters under investigation. Expected delivery Nov 2020.
- Launch date: June 2022

## Ground Segment development status

- L1 and L2 processors and end-to-end simulator E3SIM available, further tunings and adaptations and full scientific verification ongoing
- Ground segment facilities available, system integration ongoing



## Level 2 Developments

- clouds profiles from radar, lidar, imager
- aerosol profiles from lidar, imager
- calculated radiation from retrieved profiles and measured SW, LW
- closure assessment

## Science Preparation

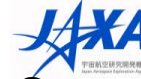
Building on CloudSat, Calipso, CERES/GERB, MODIS, ground-/air-based radar/lidar, modelling, campaigns ...

## Preparation of NWP Assimilation

ECMWF: preparation of radar and lidar assimilation

## Campaigns

2016: NAWDEX  
incl 355HSRL, 95GHz (F)  
532HSRL, 35GHz (D)



## Joint Mission Advisory Group

Members: Europe, Japan, Canada  
Observers: USA

## Preparation GCM evaluation

Dedicated data processor (CFMIP-type) development

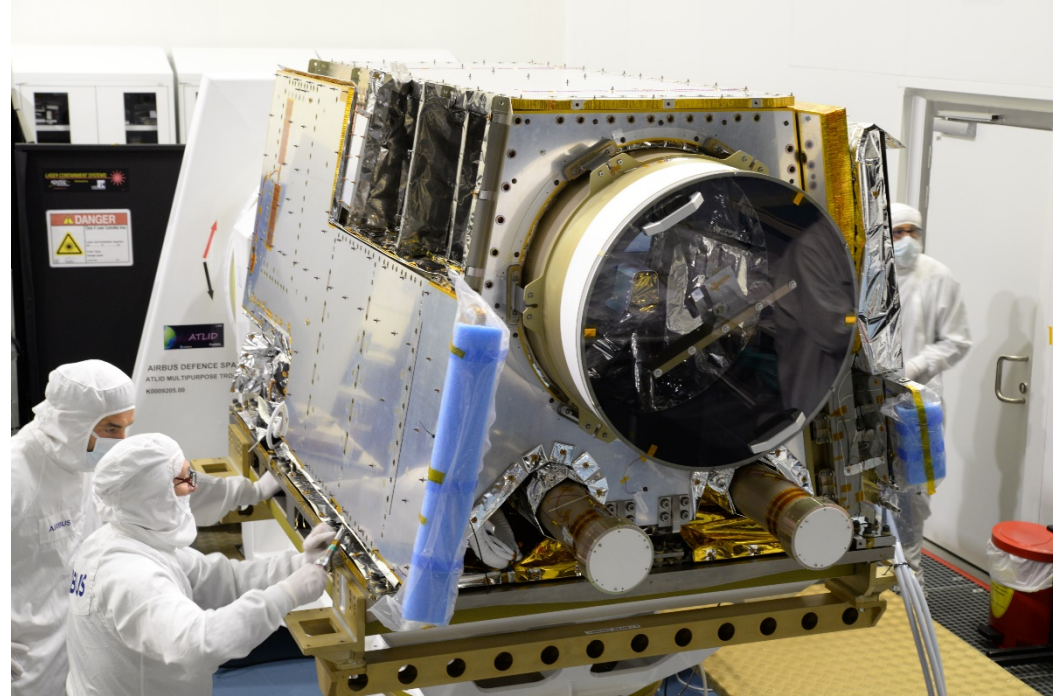
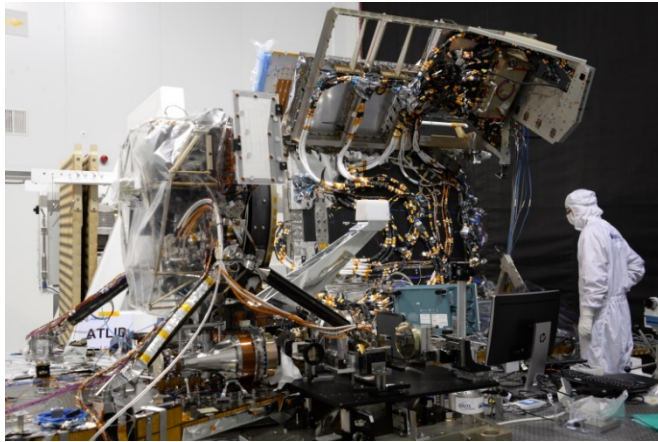
## Validation preparation

- ESA announcement of opportunity (AO) 2017 (EarthCARE only, closed, 32 AO proposals accepted)
- JAXA 2<sup>nd</sup> research announcement (RA) 2018 (multi-mission including EarthCARE, closed 30 Nov)
- Joint validation workshop before launch

## Scientific Workshops

- Kyoto 2009
- Paris 2012, jointly with CloudSat and CALIPSO
- Tokyo 2014
- Bonn 2018: science and validation  
*Proceedings and validation workshop report available online*

# ATLID



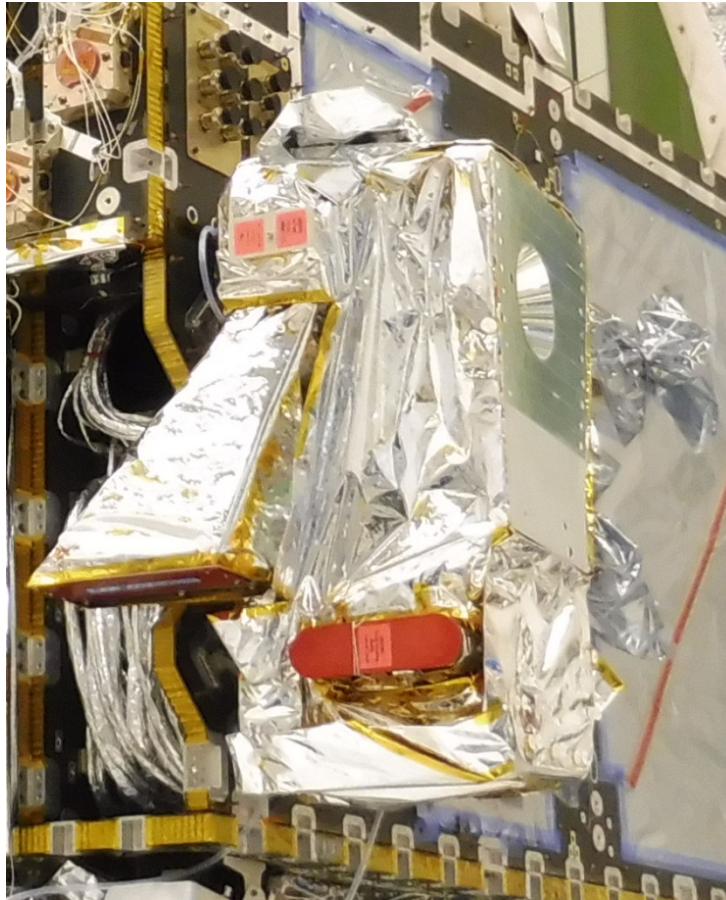
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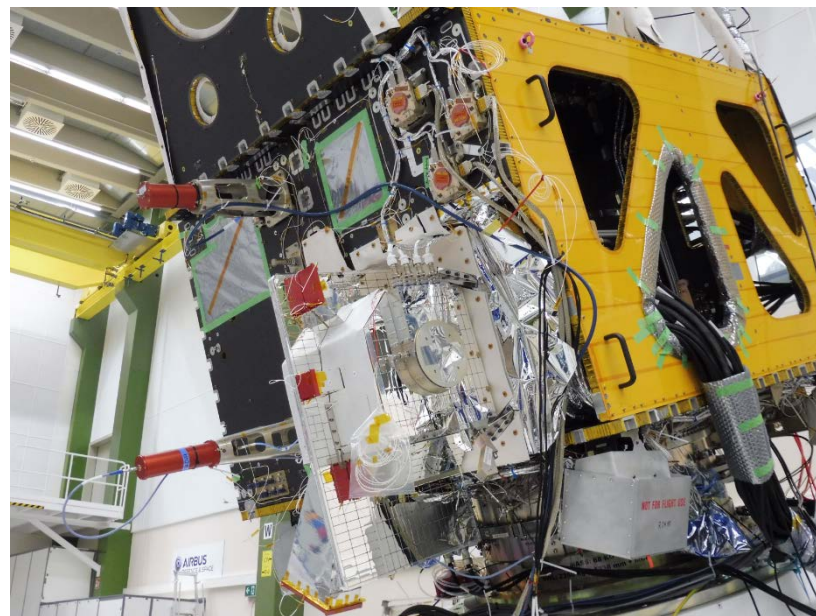
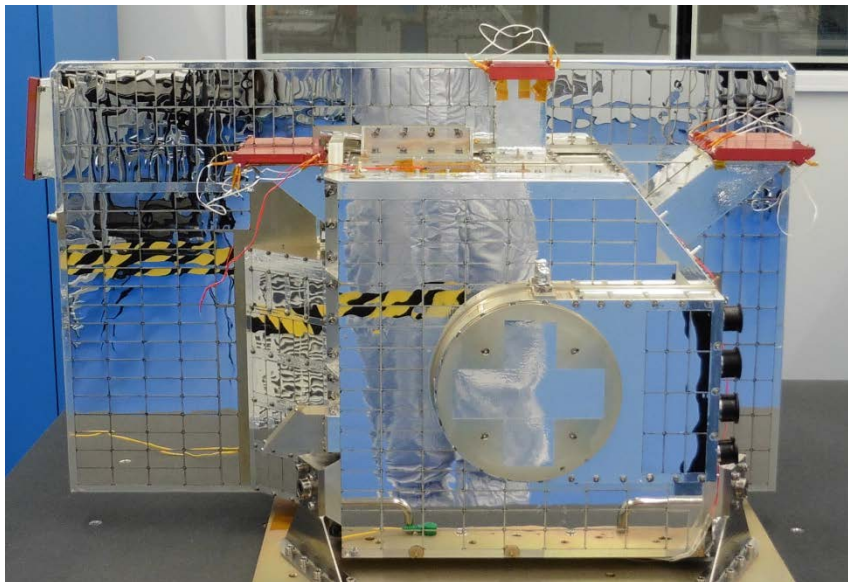


European Space Agency

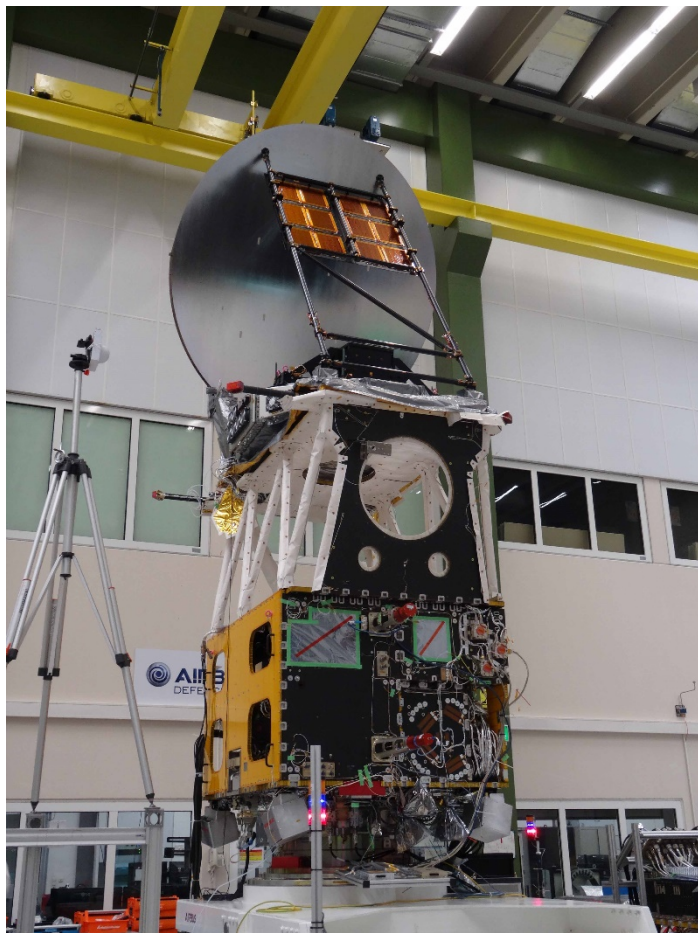
# MSI



# BBR



# CPR



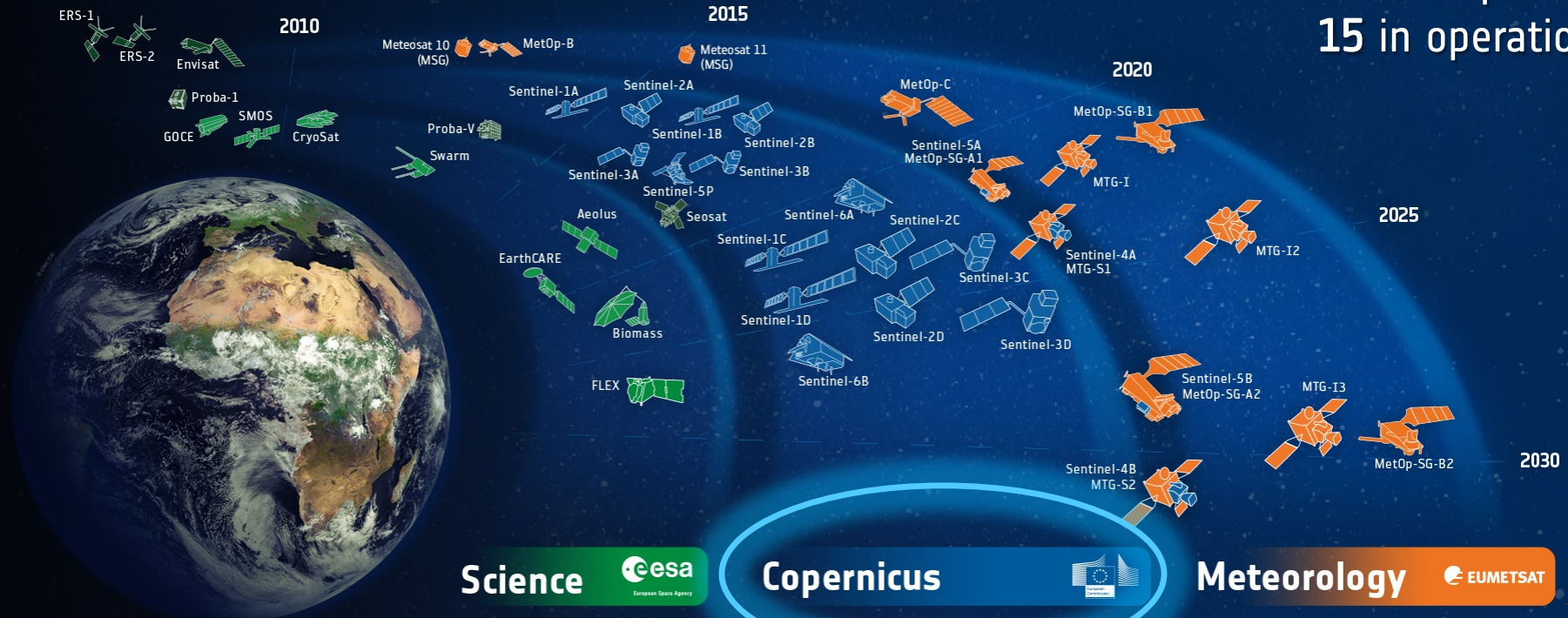
# ESA-Developed Earth Observation Missions



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# Copernicus – Sentinel Status

**S-1**



Radar

**A**

3 Apr. 2014

**B**

25 Apr. 2016

**C**

2022/23

**D**

> 2022/23

**S-2**



High Res.  
Optical

**A**

23 Jun. 2015

**B**

6 Mar. 2017

**C**

2022/23

**D**

> 2022/23

**S-3**



Medium Res.  
Optical &  
Altimetry

**A**

16 Feb. 2016

**B**

25 Apr. 2018

**C**

2023

**D**

> 2023

**S-4**



Atmospheric  
Chemistry  
(GEO)

**A**

2022

**B**

2027

**S-5P**



Atmospheric  
Chemistry  
(LEO)

**A**

13 Oct. 2017

**S-5**



Atmospheric  
Chemistry  
(LEO)

**A**

2021

**B**

2027

**C**

> 2027

**S-6**



Altimetry

**A**

2020

**B**

2025



# Overview Sentinel-3 Atmospheric Products



	Atm dedicated EUMETSAT	Atm dedicated ESA	Others (e.g. Research, Atm correction parameters etc...)
Aerosol Optical Depth (AOD)	<b>SLSTR NRT</b> Under evolution & evaluation Global	<b>SYN OLCI+SLSTR NTC</b> Under development & evaluation Global	<b>OLCI – NRT – Existing</b> <b>EUMETSAT</b> In L2 OC (AC standard NIR correction), water surfaces  <b>ESA/CCI</b> ATSR/SLSTR: <b>Swansea, FMI, Oxford/RAL, Rayference</b> MERIS/OLCI: <b>Bremen, DLR</b>
Fire Radiative Product (FRP)	<b>SLSTR NRT - Under development &amp; evaluation</b> Global, day & night	<b>SLSTR NTC - Under development &amp; evaluation</b> Global, day & night	
Total Column Water Vapour (TCWV)	<b>OLCI - Existing, under improvement</b> In OC L2 product, evolution Global  <b>SLSTR - To be initiated</b> Water surfaces, day & night	<b>OLCI - Existing</b> In Land L2 product	<b>MWR – NRT - Under preparation - EUMETSAT</b> For altimetry correction, water surfaces  <b>ESA/CCI</b> <b>OLCI/MODIS/MERIS:</b> FUB/SE (land and coast)
Cloud Top Pressure (CTP)	<b>OLCI NRT - Under Preparation</b> Global		
Cloud mask	<b>OLCI - Existing in L2</b> Global  <b>SLSTR Existing in L1 (basic) and L2 (Bayes. / Prob.)</b> Global  <b>SYN OLCI+SLSTR - To be initiated</b> Global		<b>ESA/CCI</b> <b>Cloud mask, CTT/CTP, optical depth, eff. radius, LWP, IWP, Phase</b> AVHRR/MODIS/ATSR/SLSTR: DWD/Oxford/RAL OLCI/SLSTR: FUB



# Sentinel-3 Aerosol NRT – SLSTR AOD



## Initial Algorithm & Processor

- Developments in the framework of S3 Mission Performance Centre (MPC) under ESA contract.
- Final Delivery to EUMETSAT in October 2018.
- EUMETSAT fully in charge of maintenance, long-term evaluation, validation monitoring, evolution, deployment.

## Scientific approach

University of Swansea (P. North, *et al.*, S3 AOD NRT ATBD, 2016)

- ✓ Historically applied to dual-view instruments ATSR 1&2, AATSR (ref. ESA CCI\_aerosol project)
- ✓ 5 spectral channels at 554 nm, 659 nm, 868 nm, 1.613  $\mu\text{m}$ , 2.255  $\mu\text{m}$
- ✓ Viewing constraints: multi-angular – dual-view over land, nadir view over ocean
- ✓ Physical based surface model - Iterative optimization of AOD, aerosol model & surface reflectance
- ✓ Spatial resolution 4.5 km

North, *et al.*,  
1999

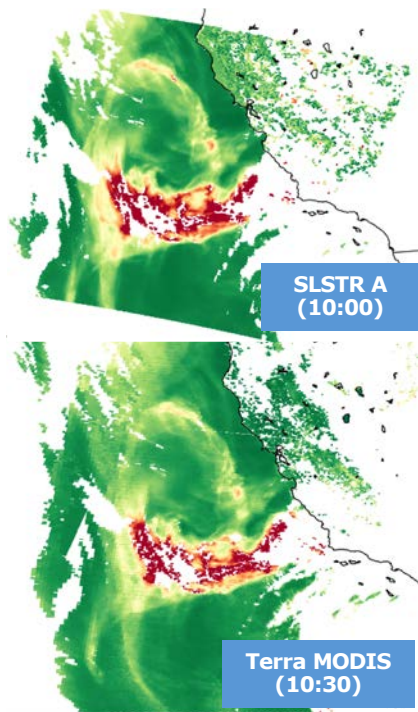
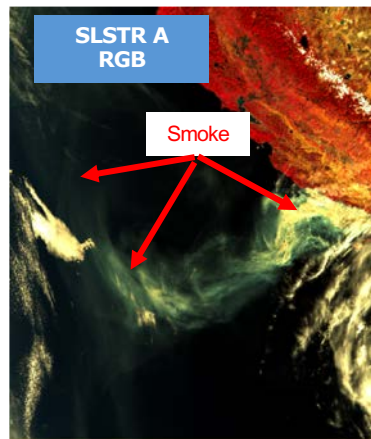
## On-going analyses / validation performed by EUMETSAT for necessary evolutions before operational release:

- ✓ Optimal adaptation to be achieved thanks to up-to-date acquired knowledge on SLSTR sensor specificities (e.g. geometry, radiometry calibration, etc..)

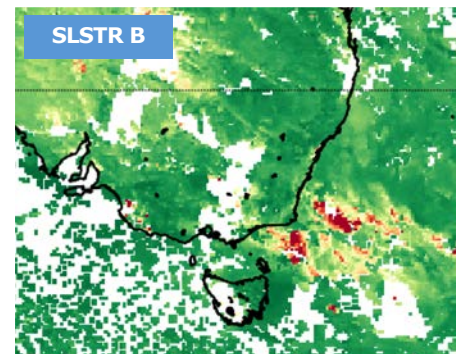
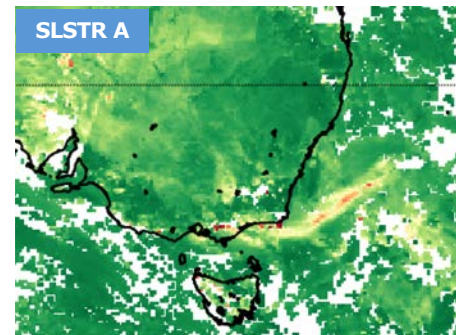
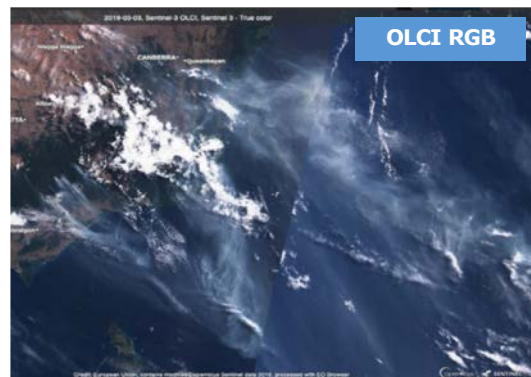


# SLSTR AOD NRT – Expected potential (some examples)

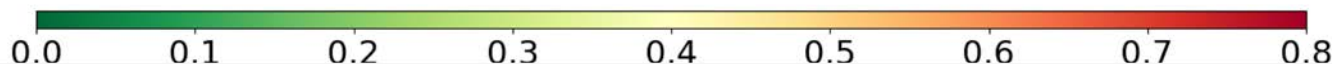
**Massive Thomas fire, California, 2017.12.10**



**Victoria hills wildfire, Australia, 2019.03 (~10 days)**



AOD(550 nm)



## Algorithm:

- Synergy approach combining information from both SLSTR and OLCI
- Originally developed by P. North *et al.* under ESA contract for MERIS/AATSR synergy algorithms for cloud screening, aerosol, atm. corr. and surface reflectance.

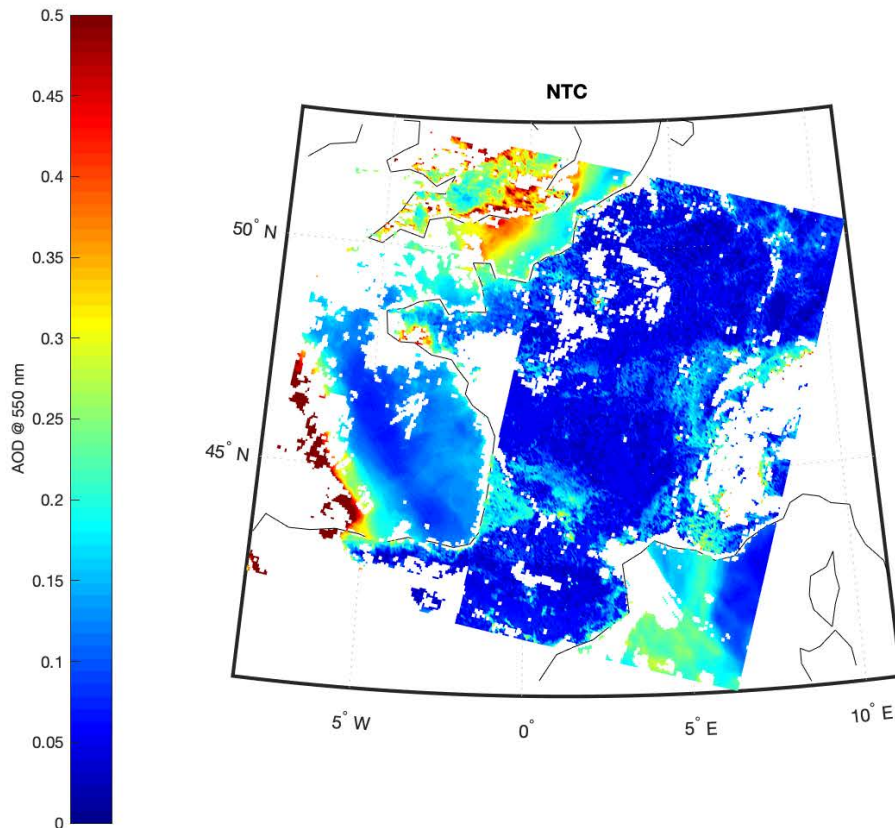
## Main differences from NRT algorithm:

- Addition of extra OLCI spectral bands and a spectral constraint for land surface reflectance
- Use of OLCI for improved cloud screening
- More detailed atmos. model with variable ozone and w.v. concentrations

## Products:

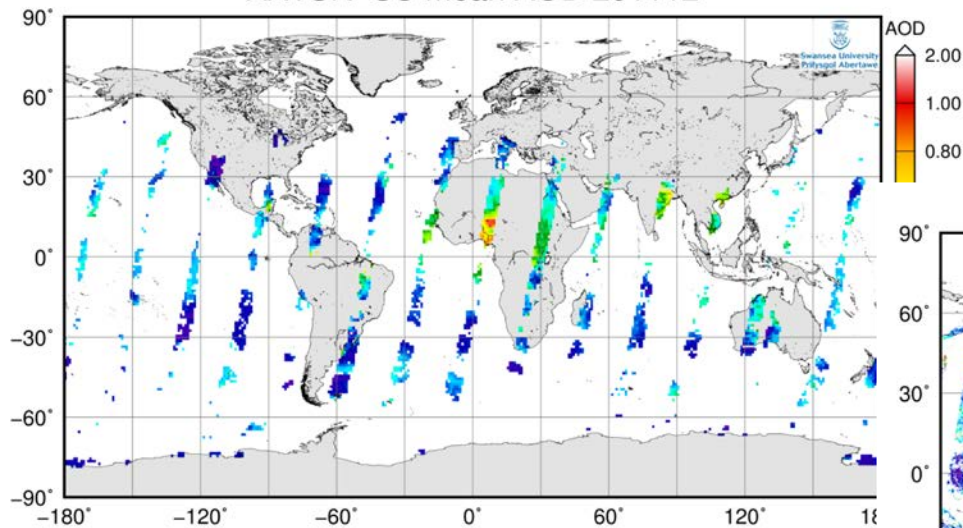
- ✓ AOD (550nm and FMF, plus other derived parameters, e.g. dust) at spatial resolution of 4.5 km
- ✓ Coverage:
  - ✓ Ocean: 1420 km SLSTR swath (nadir and dual-view)
  - ✓ Land: 720 km SLSTR dual-view + SLSTR-nadir over the 1270 km OLCI swath
  - ✓ No retrieval over cloud/sun-glint/snow/ice

# Example results – Sentinel-3 NTC aerosol (OLCI/SLSTR synergy)

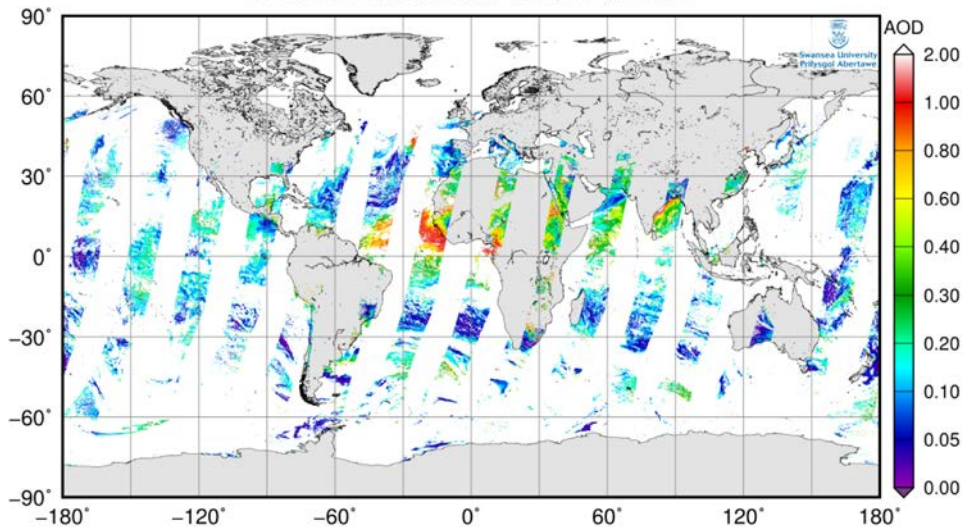


# Example results – Sentinel-3 NTC aerosol (OLCI/SLSTR synergy)

AATSR–SU mean AOD 201112



SLSTR–SU mean AOD 201612



# Sentinel-5 Precursor

## COPERNICUS ATMOSPHERE MISSION IN POLAR ORBIT



The Sentinel-5 Precursor (S5p) is the first **atmospheric Sentinel** mission focusing on global observations of the atmospheric composition for **air quality** and **climate monitoring**. Launched on **Oct. 13 2017** with a **7 years** design lifetime.



The TROPOspheric Monitoring Instrument (**TROPOMI**) is the payload of the S5P mission and was jointly developed by **The Netherlands and ESA**. Polar synchronous orbit at a height of about 820 km. Global coverage within 1 day (swath of 2600 km). Ground-pixel spatial resolution of 7 x 3.5 km. Open data access following the Copernicus Data Policy.

Sentinel-5 Precursor mission operations → in operations since April 2018 and in routine operations since March 2019

Methane (CH<sub>4</sub>) – 01 March 2019

Tropospheric Ozone Column (trop. O<sub>3</sub>)

Sulfur Dioxide (SO<sub>2</sub>)

Formaldehyde (OCHO)

Total Columns of Ozone (O<sub>3</sub>)

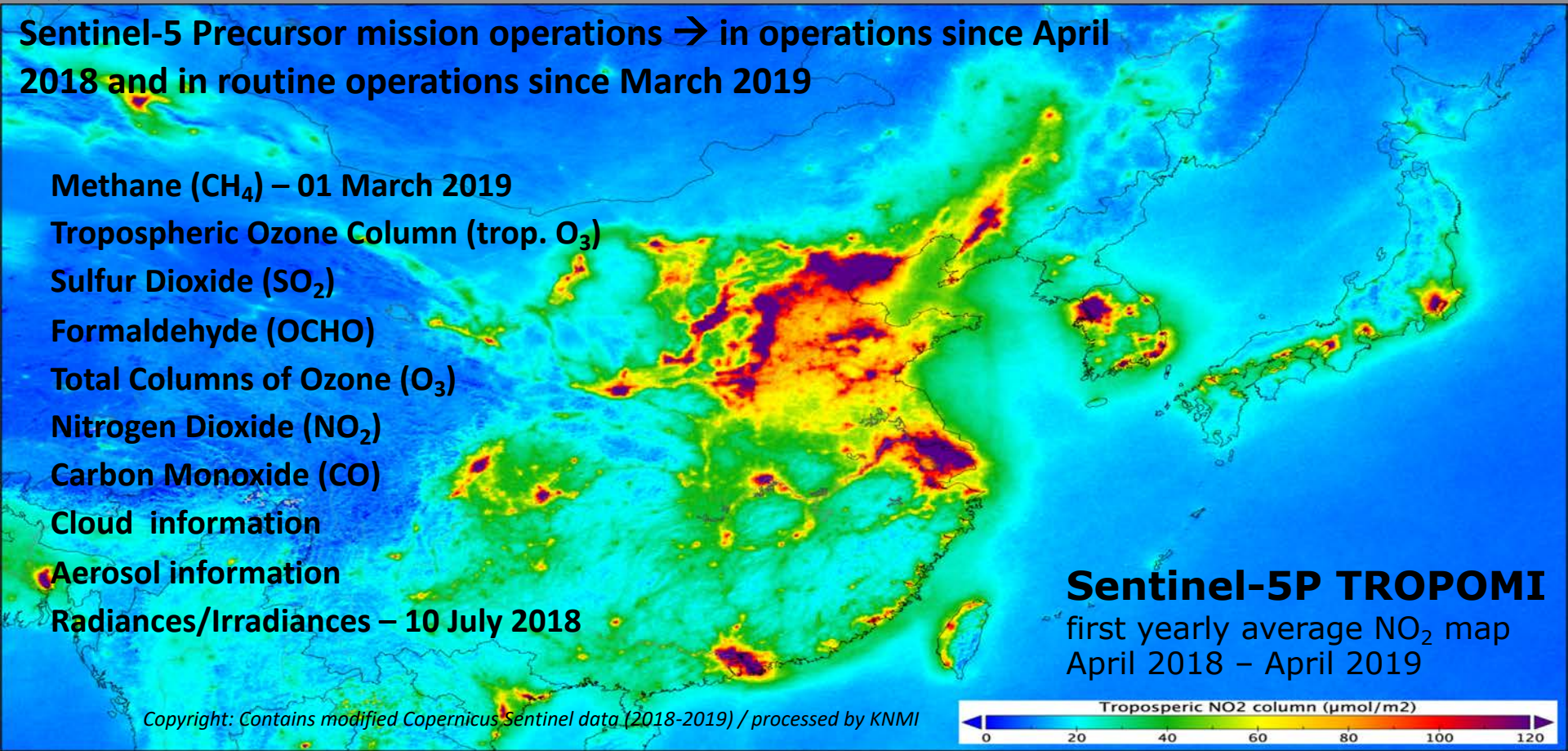
Nitrogen Dioxide (NO<sub>2</sub>)

Carbon Monoxide (CO)

Cloud information

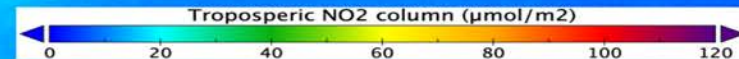
Aerosol information

Radiances/Irradiances – 10 July 2018



**Sentinel-5P TROPOMI**

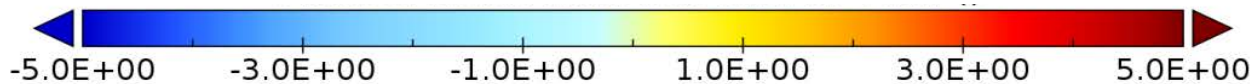
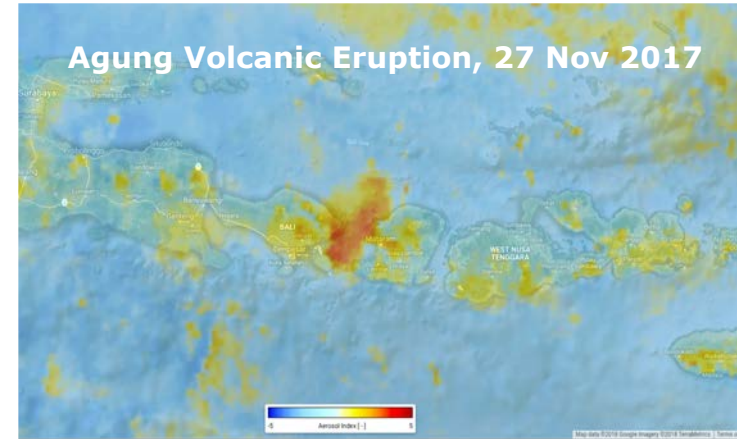
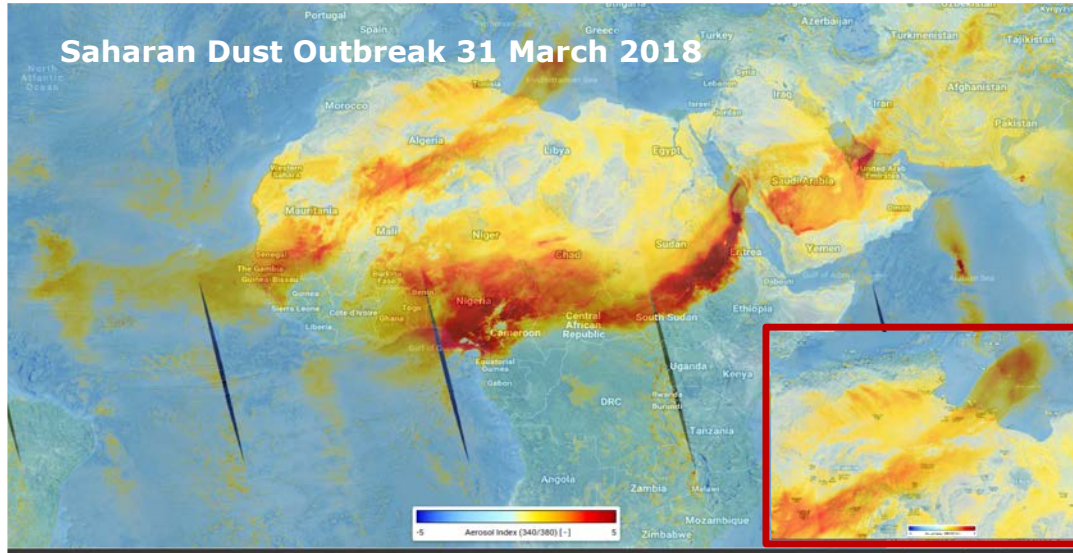
first yearly average NO<sub>2</sub> map  
April 2018 – April 2019





# S5p Aerosol Index Examples

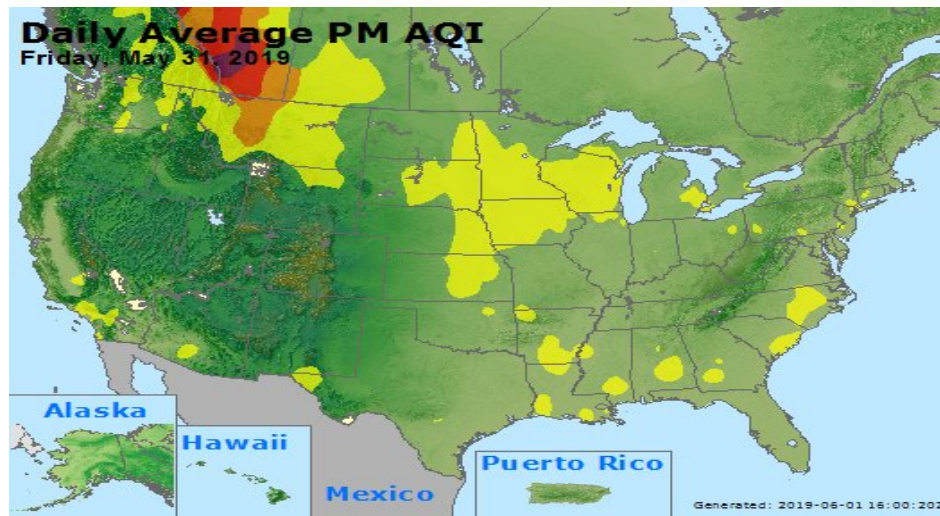
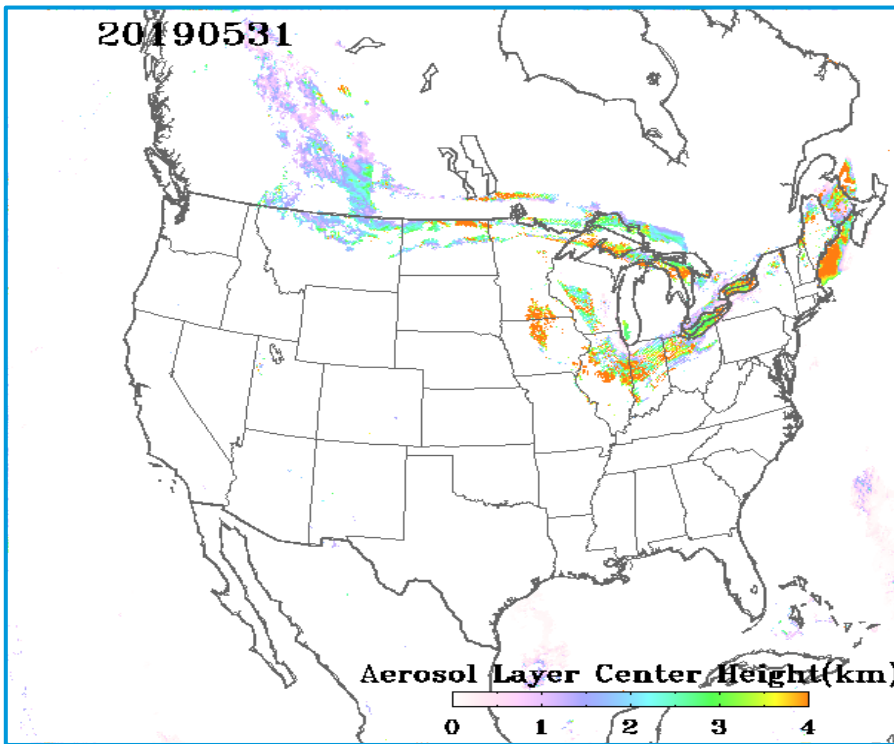
Copyright: Contains modified Copernicus Sentinel data (2017-2019) / processed by KNMI



# S5p Aerosol Layer Height

(already validated and to be released to the public early autumn 2019)

Copyright: Contains modified Copernicus Sentinel data (2017-2019) / processed by NOAA and KNMI



- Near the source region in Alberta, surface PM<sub>2.5</sub> concentrations moderate (code yellow) indicating some smoke near the ground but mostly aloft if present. TROPOMI plume height > 2km.
- Away from source region in the US smoke spread far and wide and surface PM<sub>2.5</sub> concentrations moderate (code yellow) indicating some smoke near the ground but mostly aloft if present. TROPOMI plume height > 2 km

# Sentinel-5p+ Innovation Project

## Theme 5: AOD/BRDF – DARIUS (just started!)



### DARIUS

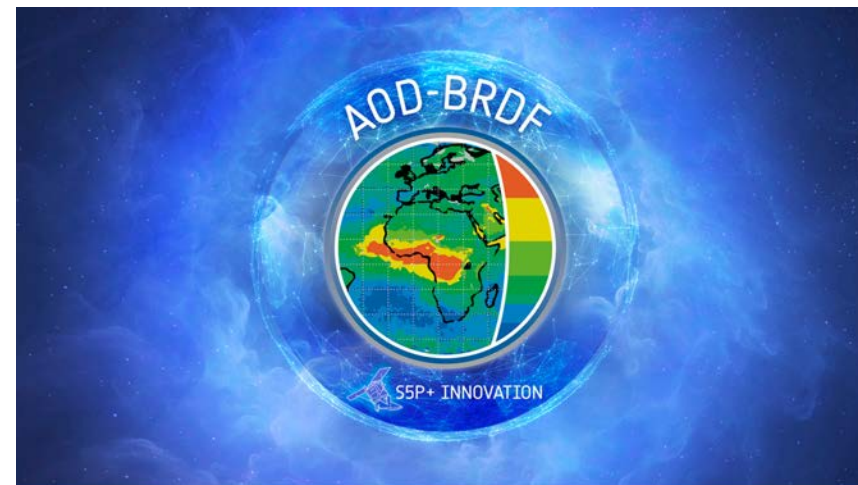
Development of advanced retrieval of aerosol and surface properties from Sentinel-5P observations.

### Main objectives

- Aerosol Optical Depth (AOD)
- Absorption and type of the aerosol
- Surface reflectance, BRDF

### Partners

- GRASP SAS
- Catalysts
- KNMI



# Sentinel-5p+ Innovation Project

## Theme 5: AOD/BRDF – DARIUS



### Approach

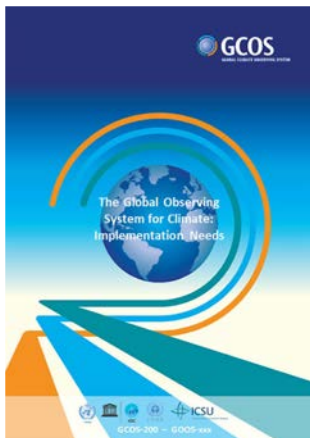
- Evaluation of OMI heritage AOD and BRDF algorithms for S5P;
- Integration of OMI heritage best practices and the GRASP algorithm;
- Performing GRASP algorithm adaptations for S5P;
- Provision of a consolidated S5P AOD and BRDF algorithm;
- Intercomparison
  - AOD: OMI, MODIS, and AERONET;
  - BRDF: use existing LER products, MODIS, GRASP/PARASOL BRDF



# Essential Climate Variables (ECVs)



**United Nations**  
Framework Convention on  
Climate Change



Measurement domain	Essential Climate Variables
Atmospheric	<p>Surface: air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget</p> <p>Upper-air: temperature, wind speed and direction, water vapour, cloud properties, Earth radiation budget, lightning</p> <p>Composition: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), other long-lived greenhouse gases, ozone, aerosol, precursors for aerosol and ozone</p>
Oceanic	<p>Physics: temperature: sea surface and subsurface; salinity: sea surface and subsurface; currents, surface currents, sea level, sea state, sea ice, ocean surface stress, ocean surface heat flux</p> <p>Biogeochemistry: inorganic carbon, oxygen, nutrients, transient tracers, nitrous oxide (N<sub>2</sub>O), ocean colour</p> <p>Biology/ecosystems: plankton, marine habitat properties</p>
Terrestrial	<p>Hydrology: river discharge, groundwater, lakes, soil moisture</p> <p>Cryosphere: snow, glaciers, Ice sheets and Ice shelves, permafrost</p> <p>Biosphere: albedo, land cover, fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, soil carbon, fire, land surface temperature</p> <p>Human use of natural resources: water use, greenhouse gas fluxes</p>

- Established 2010
- €160M
- 450 scientists
- 21 ECVs in total
- 13 ECVs transferred to C3S



## climate change initiative

Oceanic

Terrestrial

Atmospheric



Sea Level Budget



RESCAP-2 CCI

# ESA Aerosol\_cci project ([cci.esa.int/aerosol](http://cci.esa.int/aerosol))



## CCI Phases 1 & 2 (2010–2018) – 23 partners

German Aerospace Center	DLR	Main contract	Oberpfaffenhofen	D
Finnish Meteorological Institut	FMI	Sub contract	Helsinki	FI
Barcelona Supercomputing Center	BSC	Sub contract	Barcelona	ES
Belgium Institute for Space Aeronomie	BIRA	Sub contract	Uccle	B
Centre National de la Recherche Scientifique	ICARE	Sub contract	Lille	F
Eidgenössische Technische Hochschule Zürich	ETHZ	Sub contract	Zürich	CH
Freie Universität Berlin	FUB	Sub contract	Berlin	D
Laboratoire de Meteorologie Dynamique	LMD	Sub contract	Paris	F
Lille Observatoire Atmospherique	LOA	Sub contract	Lille	F
London Metropolitan university	LonMet	Sub contract	London	UK
Max Planck Institut	MPI	Sub contract	Hamburg / Mainz	D
Meteorological Institute of Norway	MetNo	Sub contract	Oslo	NO
Norwegian Institut for Air Research	NILU	Sub contract	Oslo	NO
Oxford university	UOx	Sub contract	Oxford	UK
Rayference	RF	Sub contract	Brusseles	B
Royal Meteorological Institute	KNMI	Sub contract	De Bilt	NL
Rutherford Appleton Laboratory	RAL	Sub contract	Harwell	UK
Swansea university	SU	Sub contract	Swansea	UK
Universität Bremen	UB	Sub contract	Bremen	D
Universite Libre de Bruxelles	ULB	Sub contract	Brusseles	B
University of Derby	UD	Sub contract	Derby	UK
Technical University Delft	TUD	Sub-sub contract	Delft	NL
University of Saskatchewan	US	Sub-sub contract	Saskatoon	CAN

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## CCI Phases 1 & 2 (2010–2018) – Aerosol data sets

- **ATSR-2 / AATSR** AOD, FMAOD, Angstrom (1995–2012) – 3 algorithms
  - U. Swansea, FMI, Oxford/RAL
- **IASI** Dust AOD (2007–2015) – 4 algorithms
  - ULB, LMD, BIRA, DLR
- **PARASOL** AOD, Angstrom, SSA, non-spherical – LOA/GRASP
  - Selected regions (2006–2013) plus all Africa for one year (~2008)
- **Multi-mission UV AAI** (1978–2013) – KNMI
  - TOMS/GOME/SCIAMACHY/GOME-2/OMI
- **GOMOS** Stratospheric extinction vertical profiles – AERGOM
  - BIRA



## CCI Phases 1 & 2 (2010–2018) - Investigations

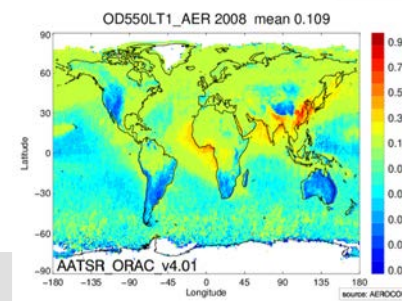
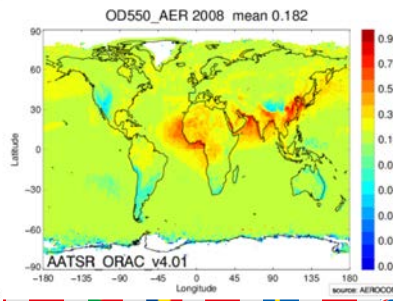
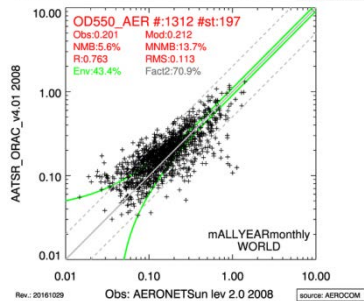
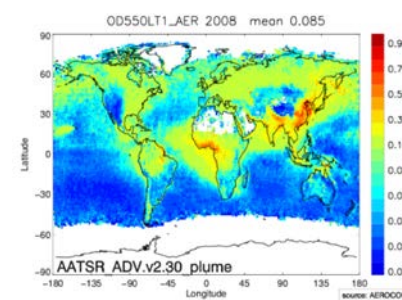
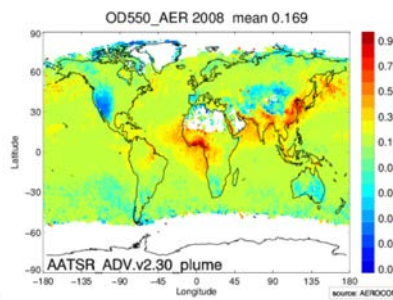
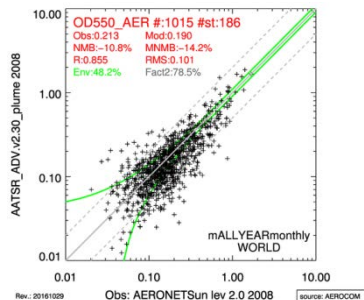
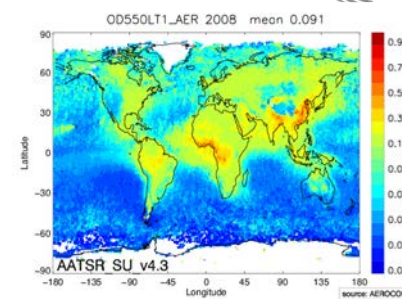
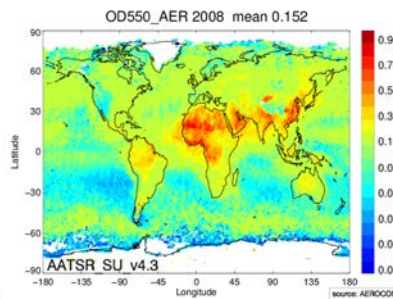
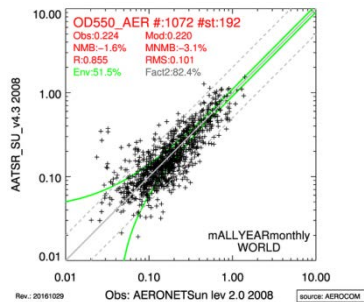
- **MERIS/OLCI** AOD (2008) – 2 algorithms
  - XBAER (U.Bremen), SeaWiFS-4-MERIS (DLR)
- **SEVIRI** Hourly-AOD (2008) – for aerosol-cloud interactions
  - CISAR (Rayference)
- Experimental algorithm intercomparisons:
  - Aerosol layer height (IASI, UV-VIS)
  - Aerosol absorption (MERIS, AATSR, PARASOL)
- Case Studies into the use of satellite AOD:
  - Trends, AOD assimilation, model verification, radiative forcing, aerosol-cloud interactions, volcano emission inventories, ...

# ESA Aerosol\_cci project – ATSR AOD



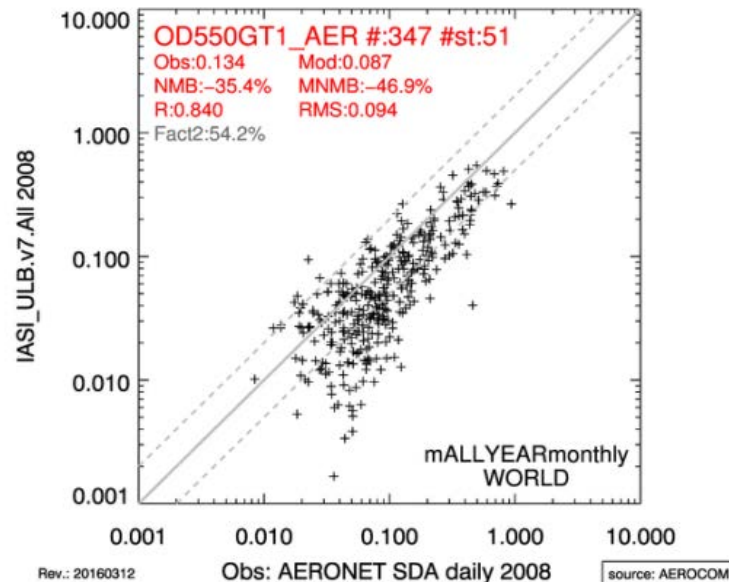
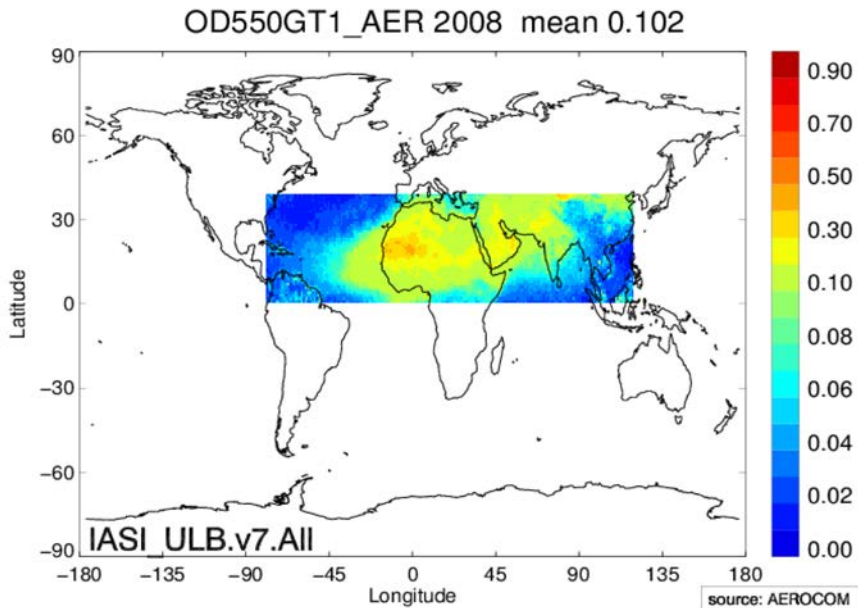
Left: AOD error statistics  
 Middle: annual AOD  
 Right: FM-AOD

Top: U. Swansea  
 Middle: FMI  
 Bottom: Oxford/RAL



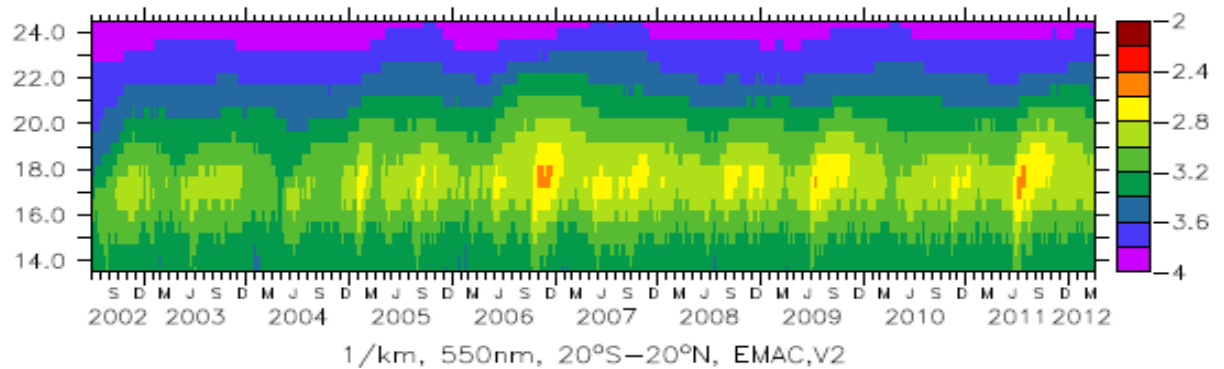
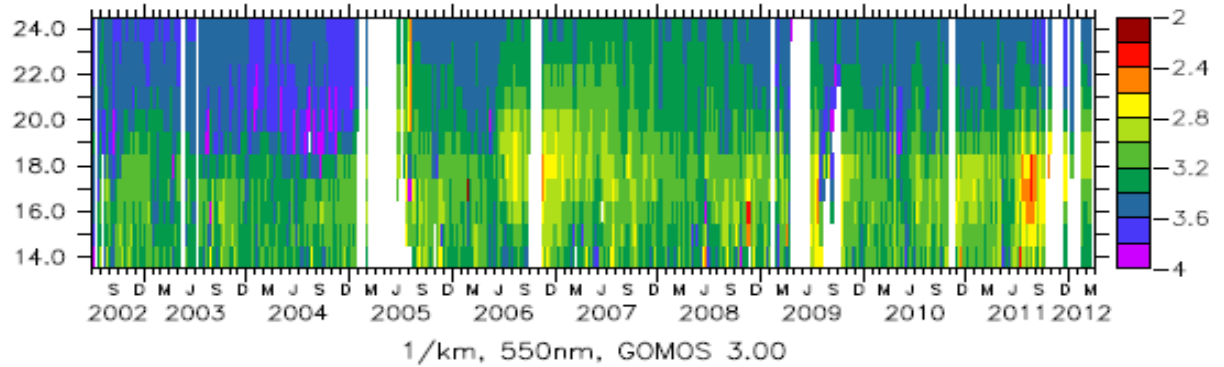
ESA UNCLASSIFIED - For Official Use





Example dust AOD from ULB (L. Clarisse)

Comparison of stratospheric aerosol extinctions (in  $\log_{10}$  scale) based on GOMOS retrievals (top) and EMAC model simulations (bottom) at 550nm wavelength (C. Bruhl, MPI-Chem)



# New ESA Aerosol\_cci+ project (2019–2022)



- Led by **DLR**, but now focus on just the ATSR-2 – AATSR – SLSTR series
- Develop and qualify two algorithms with different maturity :
  - **U. Swansea**: mature algorithm from Aerosol\_cci which provided best combination of quality, uncertainty characterisation and size information (Ångström exponent)
  - **Rayference**: innovative optimal estimation algorithm based on the continuous variation of the state variables (AOD, SSA, phase function) in the solution space, and using temporal accumulation to provide a multi-angular obs vector.
- Conduct two specific user case studies to demonstrate the value of the datasets for different application domains:
  - **MPI**: aerosol modelling / radiative forcing
  - **ECMWF**: data assimilation for reanalysis and forecasting



# Thanks for your attention

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