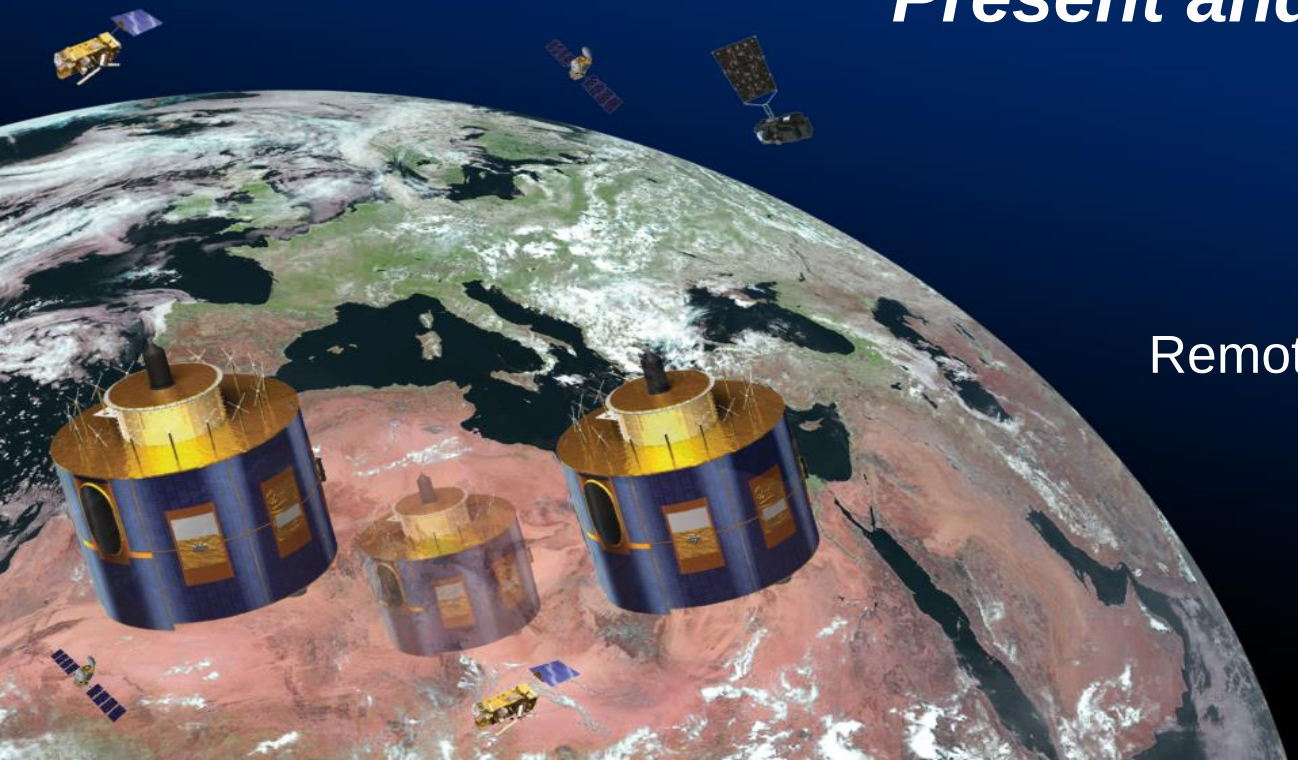
Scientific Development for Operational Aerosol Products

Present and Future



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for the Cloud & Aerosol Team

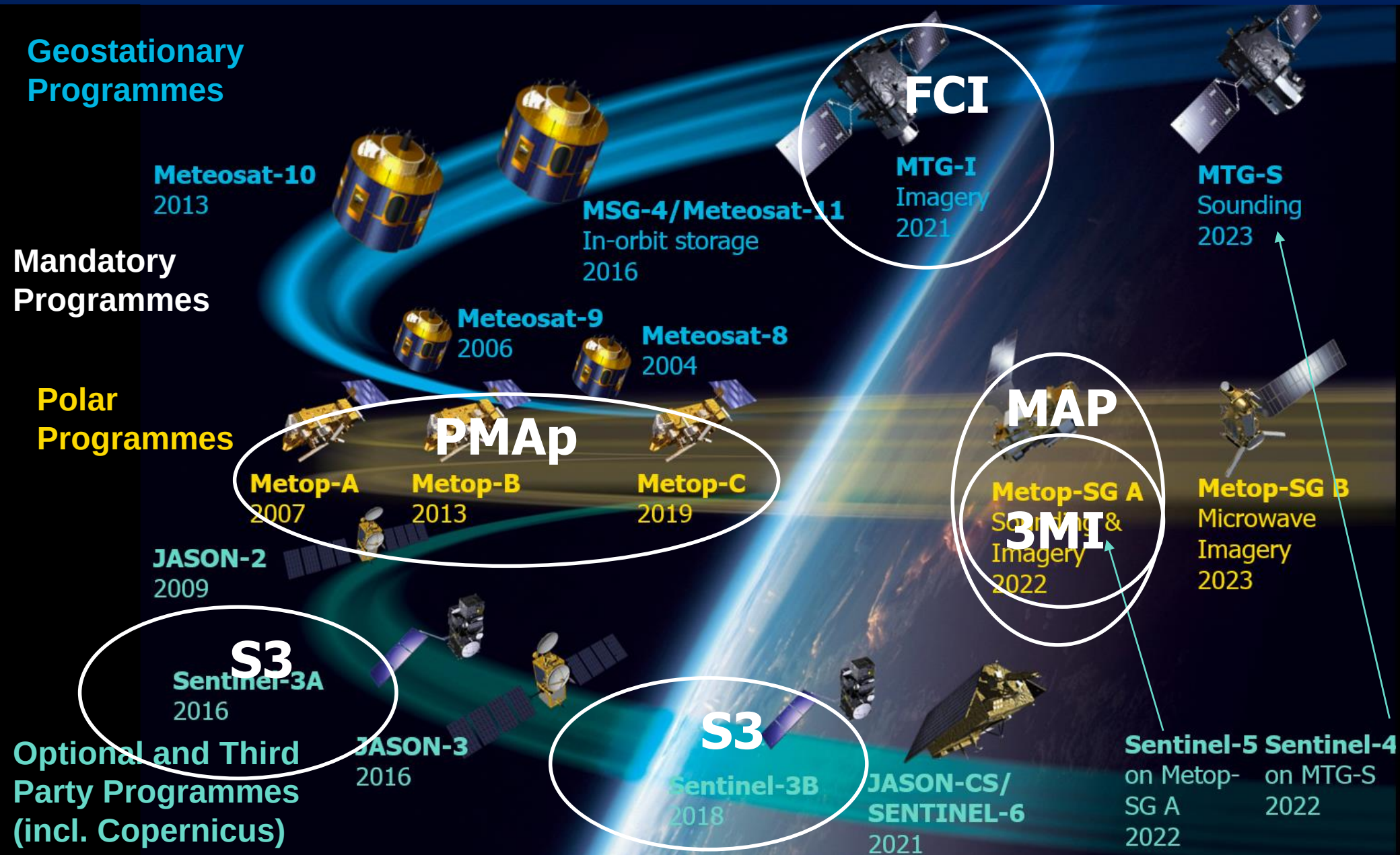
Remote Sensing & Products Division

EUM/RSP/VWG/20/1181654, v1 Draft, 22 June 2020

Summary

- The general picture
- Aerosol characterisation: What's the challenge ?
- The aerosol product currently available
- The future aerosol products: What's coming ?
- Conclusion remarks

EUMETSAT missions: *current and future*



Most relevant sensors for the Aerosol characterisation

Indicative list (non exhaustive) **Different maturity levels (dev/ope)**

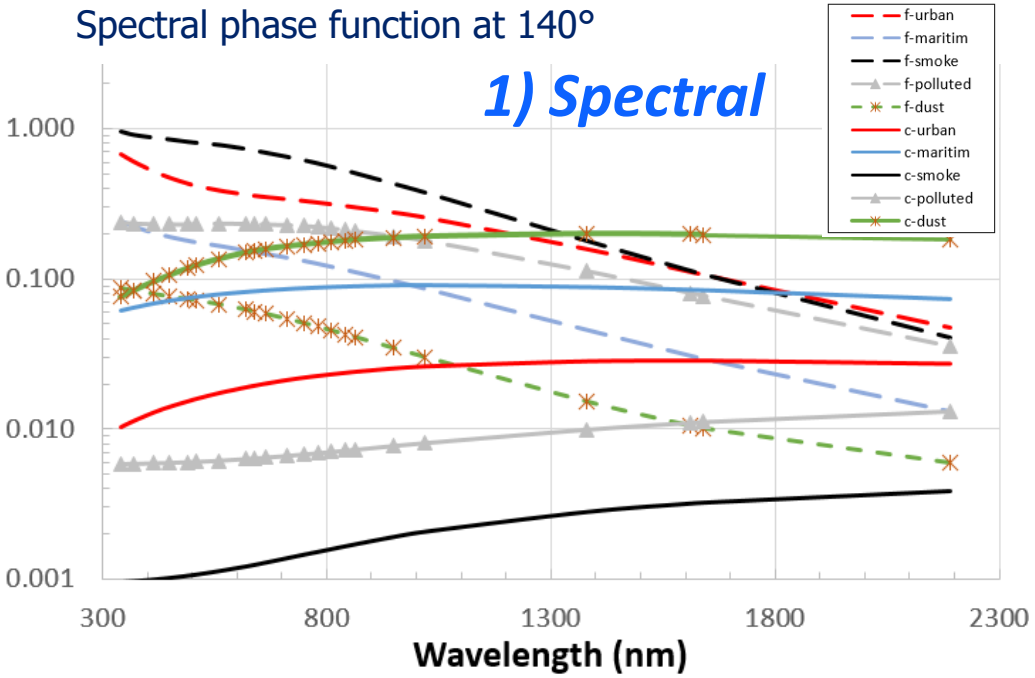
Satellite	Instrument*	Type	Aerosol parameters
EPS	GOME-2	UV-VIS spectrometer	Absorbing index, aerosol height
EPS	PMAp	Hyper-instrument	AOD, model type
EPS	IASI	TIR spectrometer	Ash/dust detection, thickness & height
Sentinel-3	SLSTR	Dual-view scanner	AOD, fine mode
Sentinel-3	OLCI	X-spectral imager	AOD, model type
MSG	SEVIRI	GEO imager	d-AOD, Ash detection & height
MTG	FCI	GEO image	i-AOD, model, Ash detection & height
MTG	S4-UVN	UV-VIS spectrometer	Absorbing index, aerosol height
EPS-SG	S5-UVNS	UV-VIS spectrometer	Absorbing index, aerosol height
EPS-SG	IASI-NG	TIR spectrometer	Ash/dust detection, thickness & height
EPS-SG	3MI	Polarimeter	AOD, model, fine mode, abs…
EPS-SG	MAP	Hyper-instrument	Full characterisation
…	…	…	…

What's the challenge ?

The aerosol optical properties

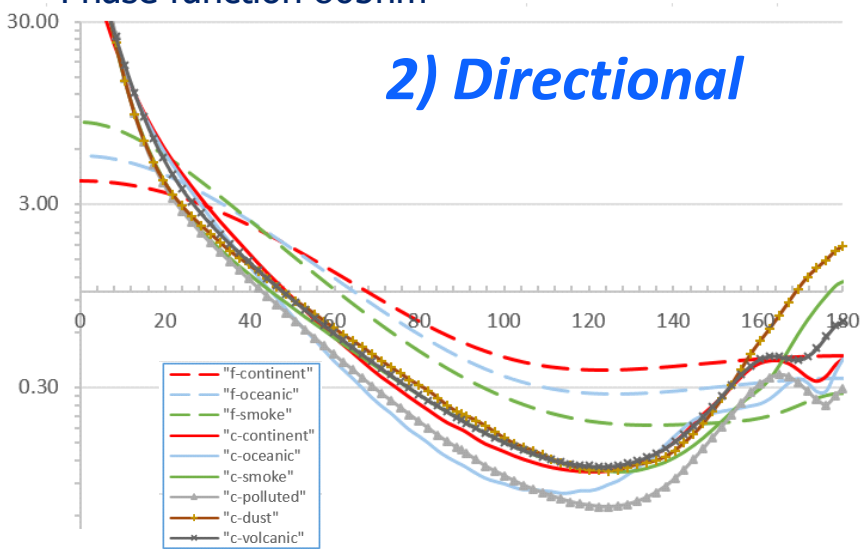
Spectral phase function at 140°

1) Spectral



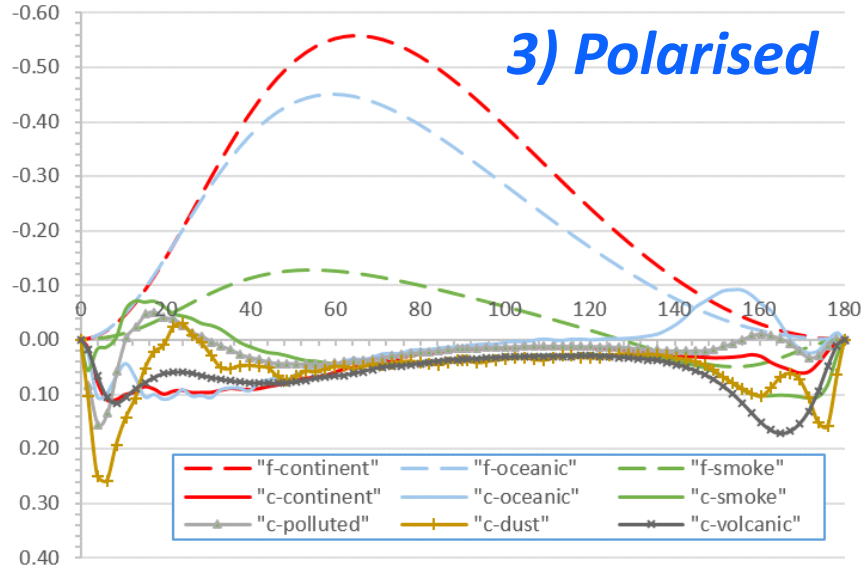
Phase function 865nm

2) Directional



Polarized phase function 865nm

3) Polarised



→ **all depend on :**

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

What's the challenge ?

The measurement

→ **all signatures are mixed in the observed signal**

At first order (for the scattered part):

$$R_{aerosol}(\lambda, view) \sim \boxed{\omega_o(\lambda).\tau(\lambda).P_{aerosol}(\lambda, view)}$$

where

ω_o	Single scattering albedo
τ	Optical thickness
$P_{aerosol}$	Phase function

Challenge = disentangle the contributors to retrieve aerosol parameters

→ **The analysis of the information content is a prerequisite**
→ **This includes how the sensor/system is able to sample the spectral, the geometrical, and polarisation information**
→ **The larger, the better… but not only !**

What's the challenge when using various sensors

- Provide aerosol products retrieved from different sensors
  - Aerosols are observed from different geometries
  - Aerosols are observed for different spectral ranges

  → Aerosol are not seen similarly

  → In general, the same aerosol characterisation cannot be extracted

  → The aerosol products (at least some of the parameters) may/will differ

- Provide aerosol products retrieved from the synergistic use of different sensors
  - Aerosols are observed through complementary geometries
  - Aerosols are observed for more spectral ranges

  → The conditions of observation are extended

  → The aerosol characterisation can be consolidated (performance) and/or extended (number of parameters)

  → The aerosol products are better:

  - more parameters can be provided
  - parameters can be retrieved more accurately

Products from sensors currently in-orbit

- **EPS (EUMETSAT Polar System)**
  - 3 LEO satellites : Metop-A (2007), Metop-B (2013), Metop-C (2019)
  - 3 instruments for aerosol retrieval

    GOME-2, AVHRR, IASI → hyper-instrument

Operational over ocean (provisional over land)

- **Sentinel-3 (Copernicus)**
  - 2 LEO satellites : S3-A (2016) and S3-B (2018)
  - 2 instruments for aerosol retrieval

    SLSTR, and OLCI

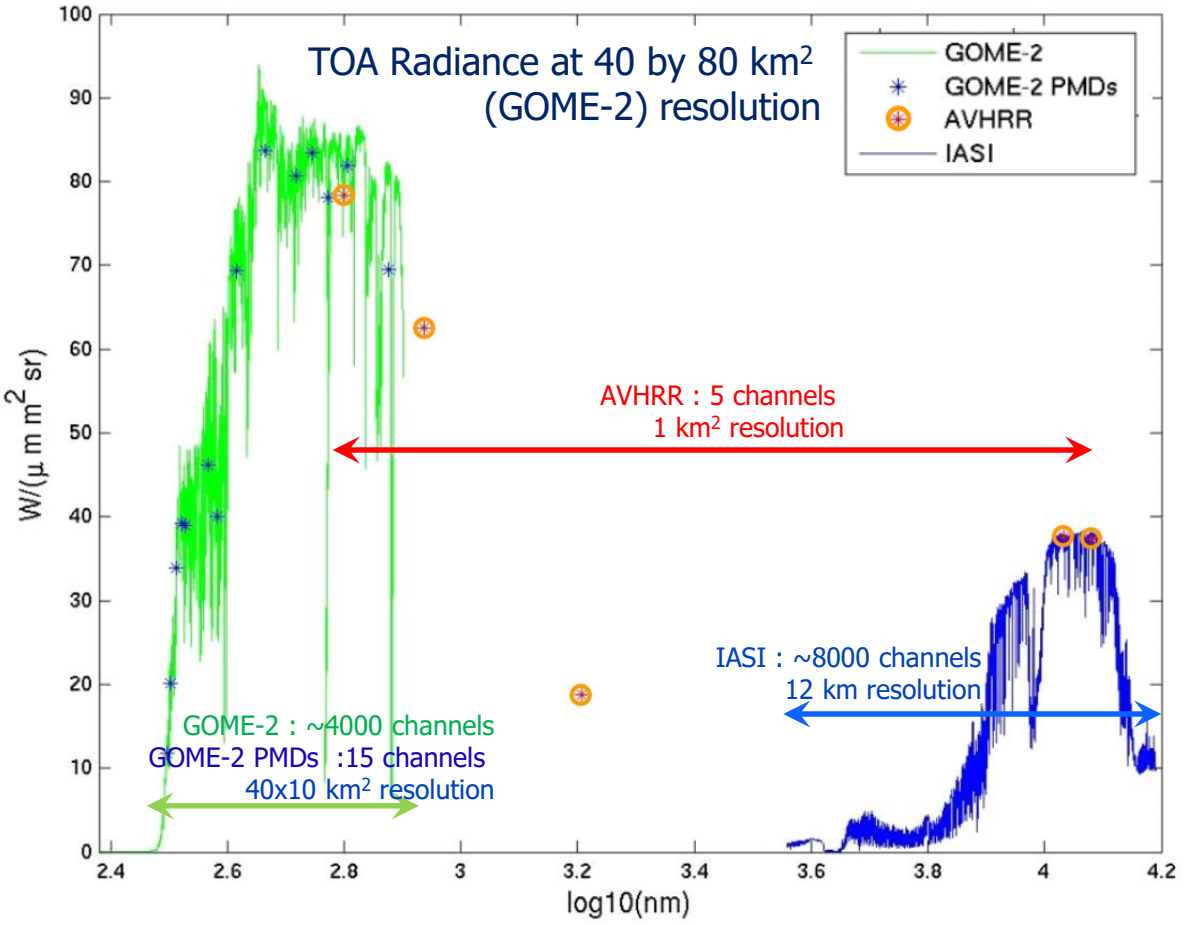
Very soon operational over ocean (provisional over land)

The hyper-instrument from EPS - on a nutshell

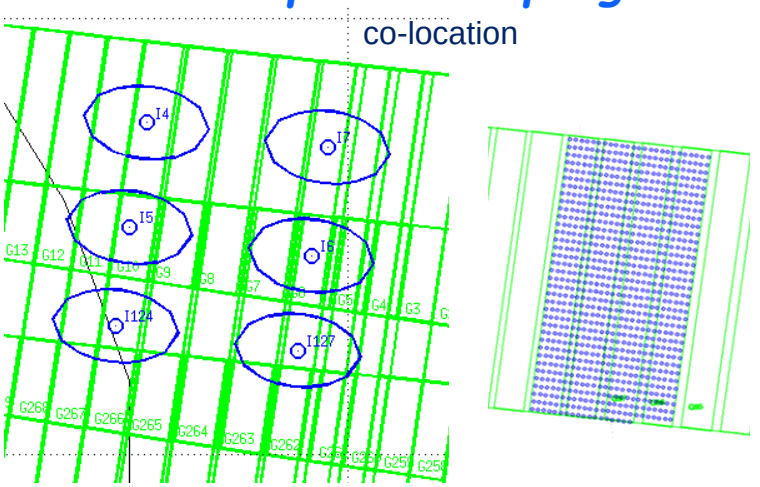
PMAp : Polar Multi-sensor Aerosol product from GOME-2, AVHRR and IASI

- 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 released very soon

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PMAp Main Updates

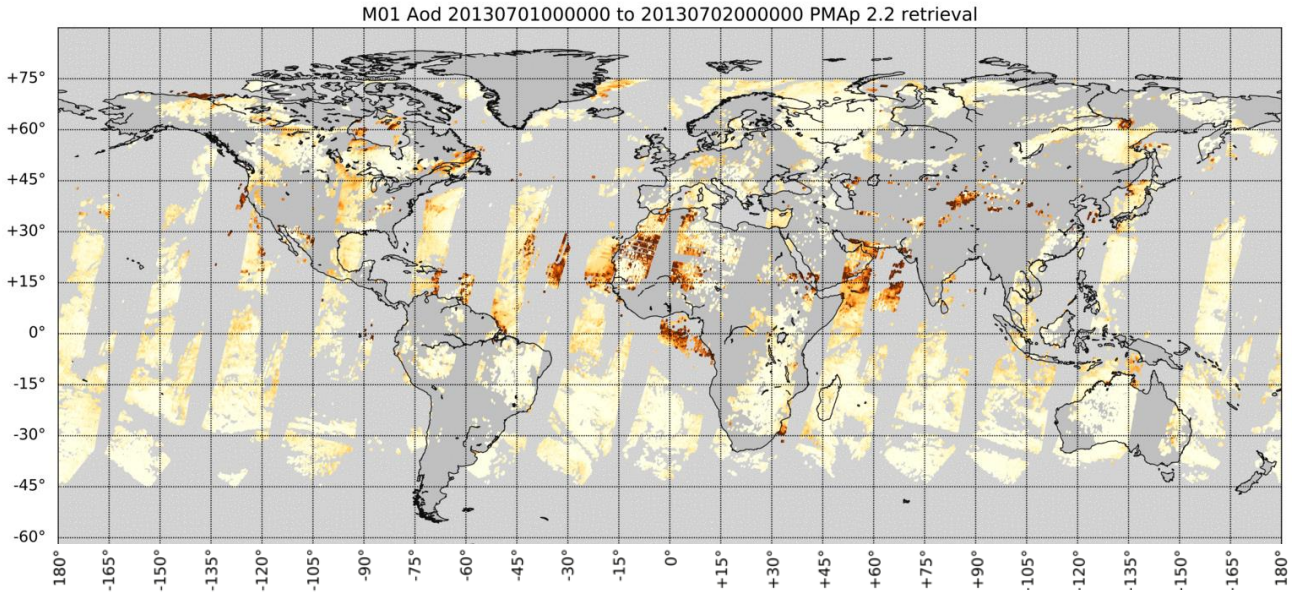
- **Operational product, Currently Version 2.1.0 (Feb 2017)**
  - Surface homogeneity test
  - Surface elevation correction function for Rayleigh scattering calculation
  - Surface reflectance database (LER v1.6) statically masked for more accurate land/water areas partition
  - Volcanic Ash/SO_2 class using thermal IR IASI measurement

- **Next Release 2.2 - coming very soon**
  - GOME-2 PMDs L1 radiance correction for degradation (degradation + offset)
  - Surface reflectance database (LER) now based on MetopA & B
  - Improved detection and AOD quality for thick desert dust -in particular over bright surfaces and discrimination w.r.t. to water clouds (IASI spectrum)
  - Very good consistency between Metop-A, -B, and -C

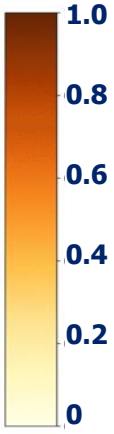
The Polar Multi-sensor Aerosol Product

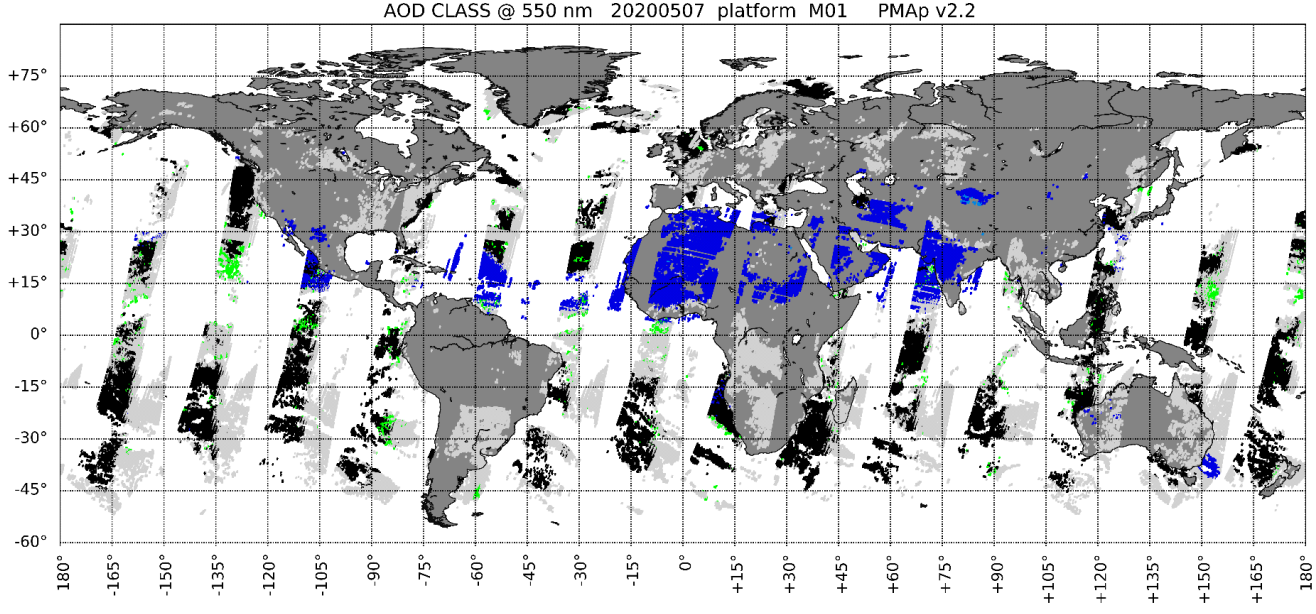
Operational near-real time products from EPS/Metop

Parameters



AOD @ 550 nm





Aerosol Class

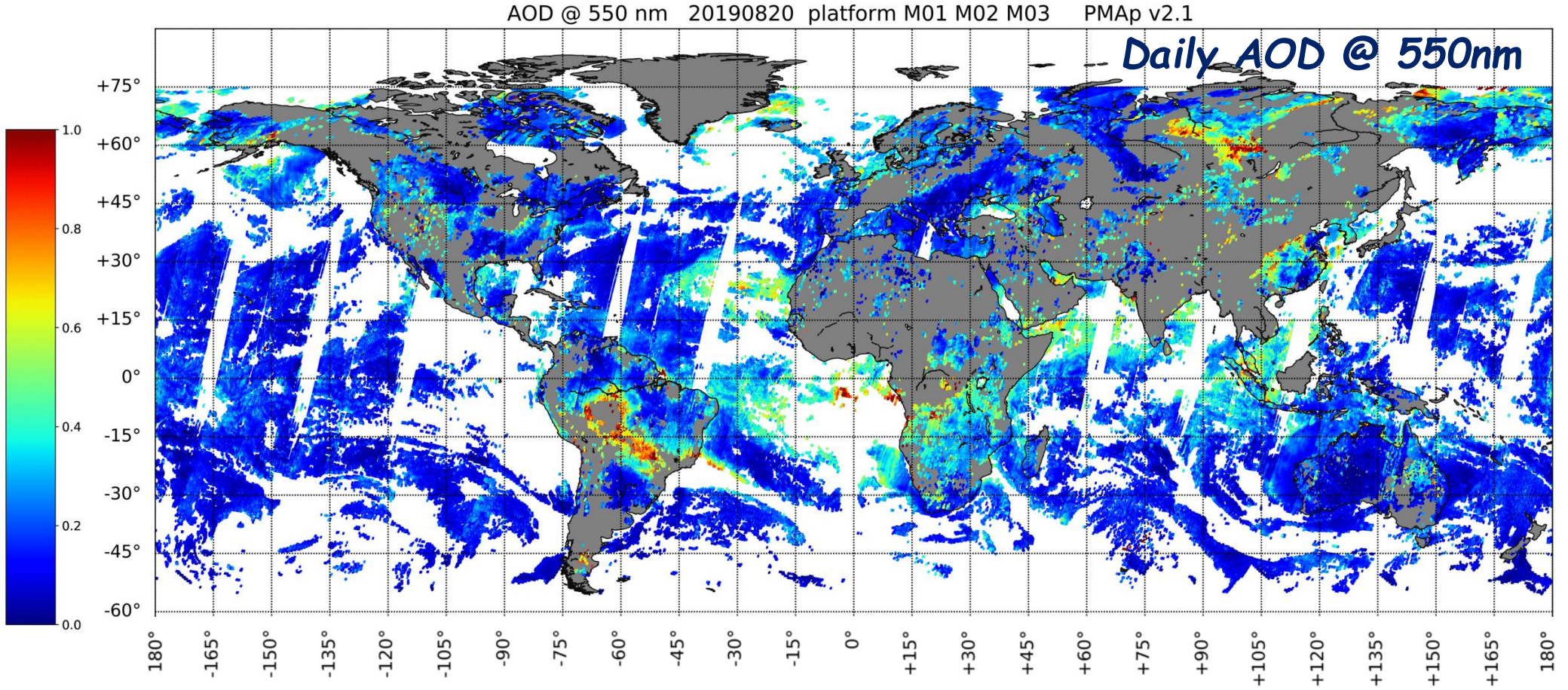
- fine mode
- coarse mode
- volcanic ash / thick dust
- volcanic ash with SO_2
- undetermined

The Polar Multi-sensor Aerosol Product

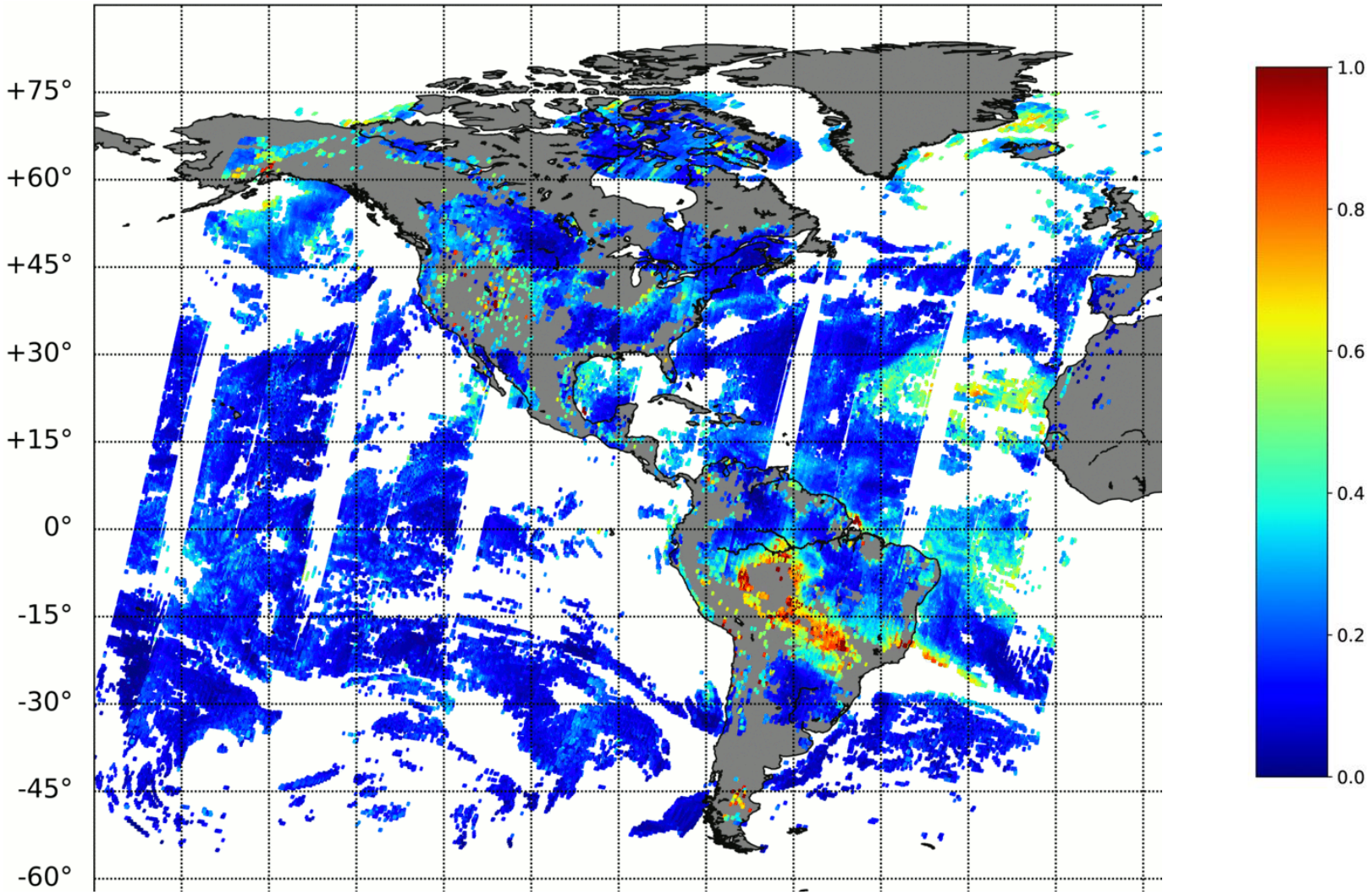
Operational near-real time products from EPS/Metop

PMAp-A/B/C = PMAp-D

- **Tristar MetOp configuration → very good complementarity of PMAp A/B/C products**
  - Remarkable global daily coverage : complementarity of the ground tracks (low loss due to sunglint)
  - Efficiency of the cloud decontamination, especially over ocean
  - Good consistency over dust events & Better identification of the inter-track residues



August 2019 AOD @ 550 nm from PMAp



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Very soon operational over ocean (provisional over land)

Sentinel-3 sensors - on a nutshell

Sentinel-3 : Copernicus Mission

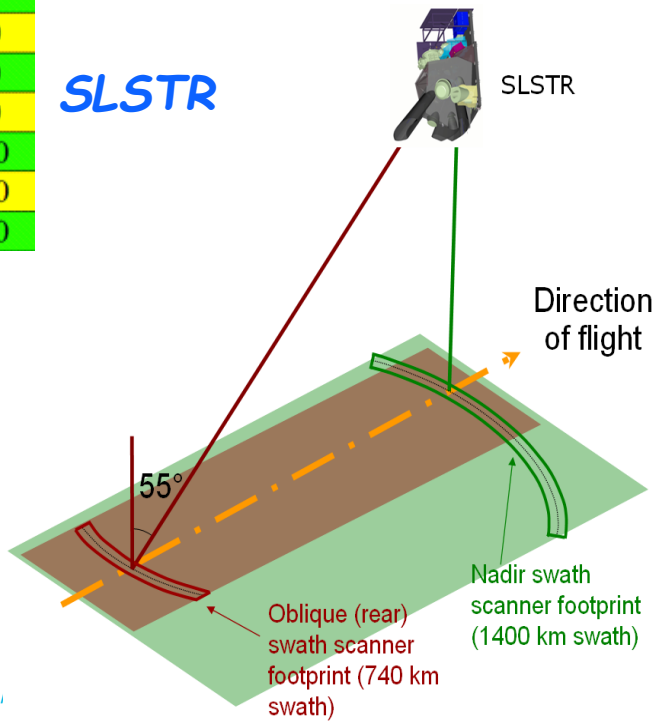
- Polar orbit at 10:00 ECT – A in Feb. 2016, B in Apr. 2018
- 2 complementary instruments : OLCI and SLSTR

	λ center (μm)
Band 1	0.555
Band 2	0.659
Band 3	0.865
Band 4	1.375
Band 5	1.610
Band 6	2.250
Band 7	3.740
Band F1	3.740
Band 8	10.850
Band F2	10.850
Band 9	12.000

Sea Land Surface Temperature Radiometer

dual view conic scanner, 500m @nadir
(1km @nadir for TIR)
9 spectral bands

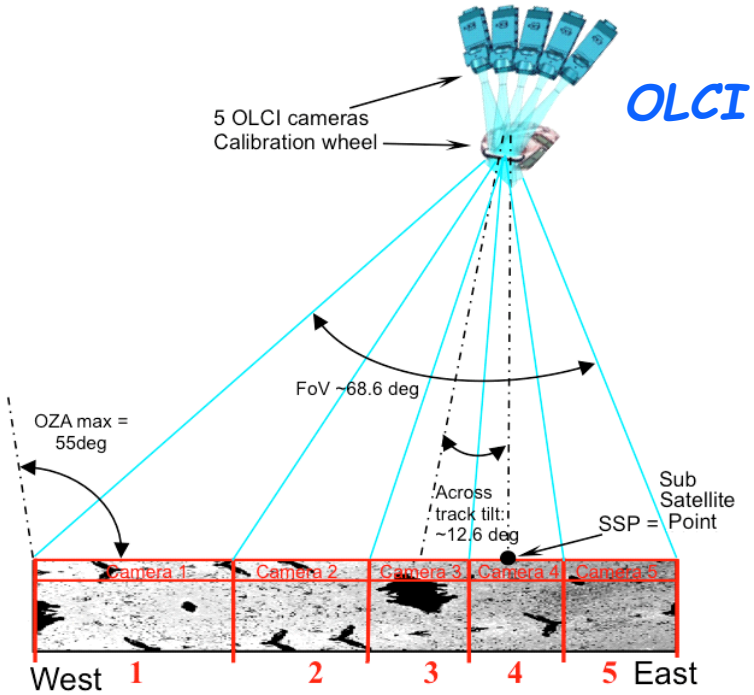
SLSTR



Ocean Land Colour Imager

pushbroom,
Fine resolution 300m@nadir
Reduced Resolution 1.2 km@nadir
21 spectral bands

OLCI



λ center nm	Width nm
400	15
412.5	10
442.5	10
490	10
510	10
560	10
620	10
665	10
673.75	7.5
681.25	7.5
708.75	10
753.75	7.5
761.25	2.5
764.375	3.75
767.5	2.5
778.75	15
865	20
885	10
900	10
940	20
1020	40

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Aerosol Product from Sentinel-3 : SLSTR

- Sentinel-3 / SLSTR
  - 5 spectral channels at 554, 659, and 868 nm, and 1.613, 2.255 um – 4.5km resolution
  - dual-view instruments nadir + 50° oblique (ATSR 1&2, AATSR)

  → Very relevant for retrieval of AOD + model

- Baseline for the scientific approach (Univ. Swansea; North. et al. 1999)
  - Historically applied to dual-view instruments ATSR 1&2, AATSR (ESA CCI_aerosol project)
  - Aerosol retrieval with a physical based surface model - Iterative optimization of AOD, aerosol model & surface reflectance
  - Over Land, the constraint is mostly based on the difference between dual-views

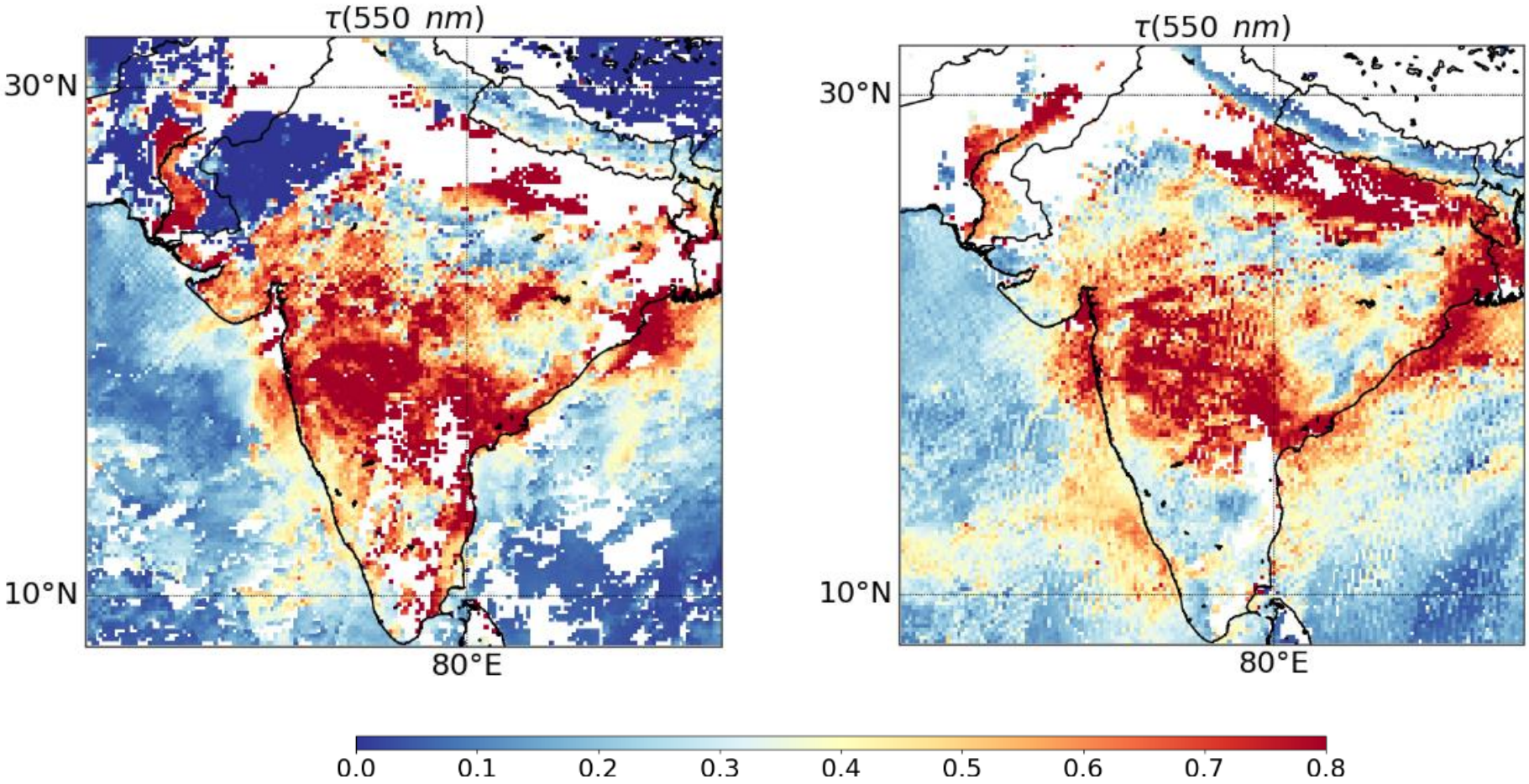
- Initial algorithm & Processor
  - Developed in the framework of S3 Mission Performance Centre (ESA contract)

- Additional developments by EUMETSAT:
  - Correction of the SLSTR mis-calibration for SWIR and oblique view
  - Addition of a spectral constraint (considering indexes like AFRI, NDVI)
  - Various refinement of the algorithm (dir/spec weigthing, improved filtering, tuning)

- First release of the product (version 2.0): coming mid-2020

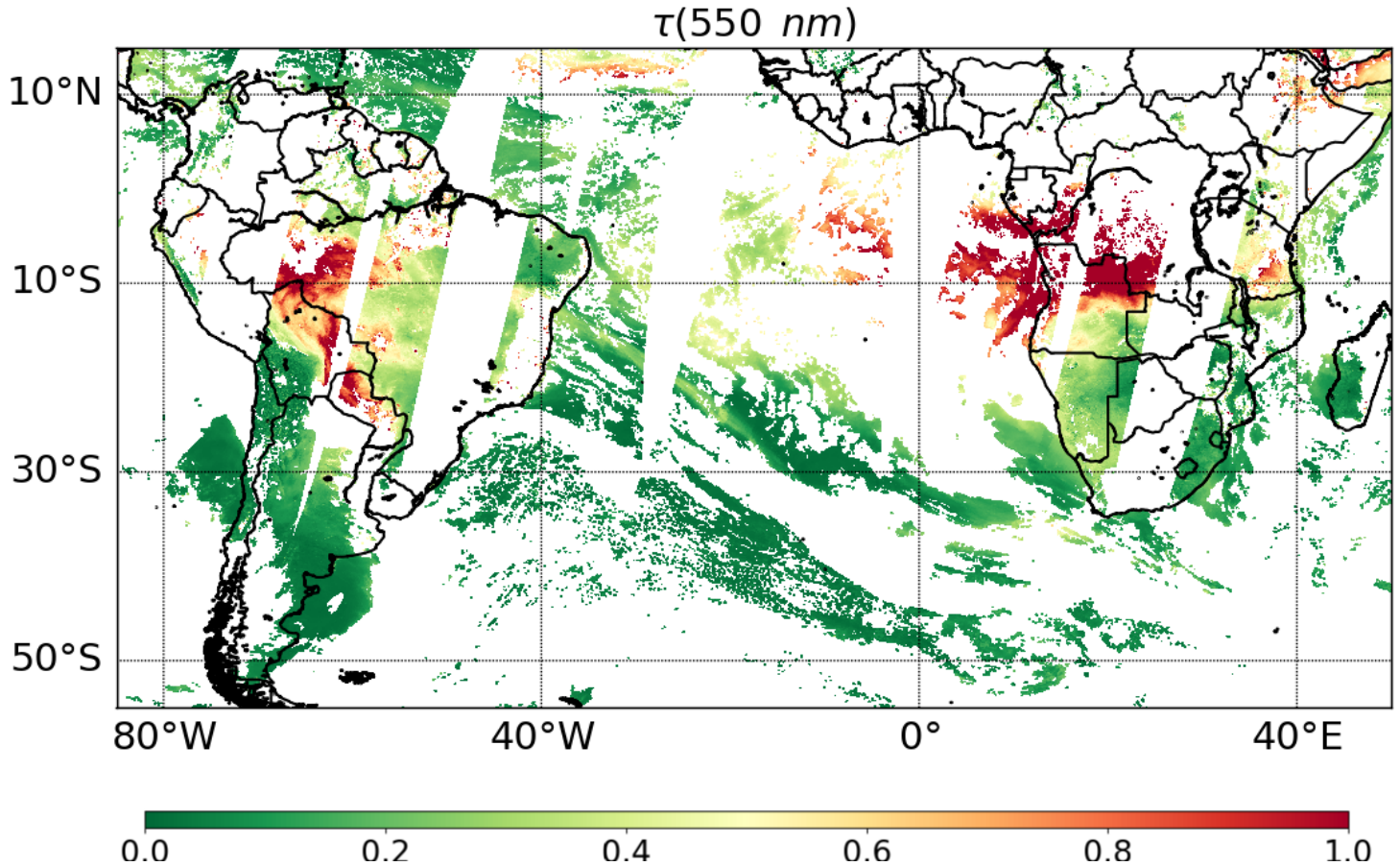
Aerosol Product from Sentinel-3 : SLSTR

SLSTR 20-31 May 2020 **MODIS**



Aerosol Product from Sentinel-3 : SLSTR

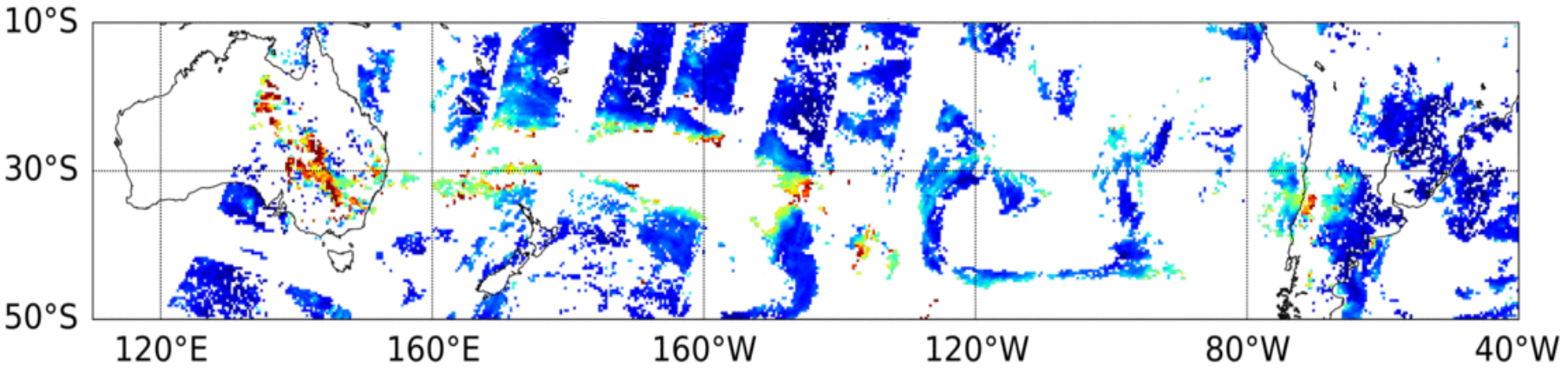
22 August 2019
Sentinel-3A and -3B



AOD @ 550 nm from 5 Satellites!

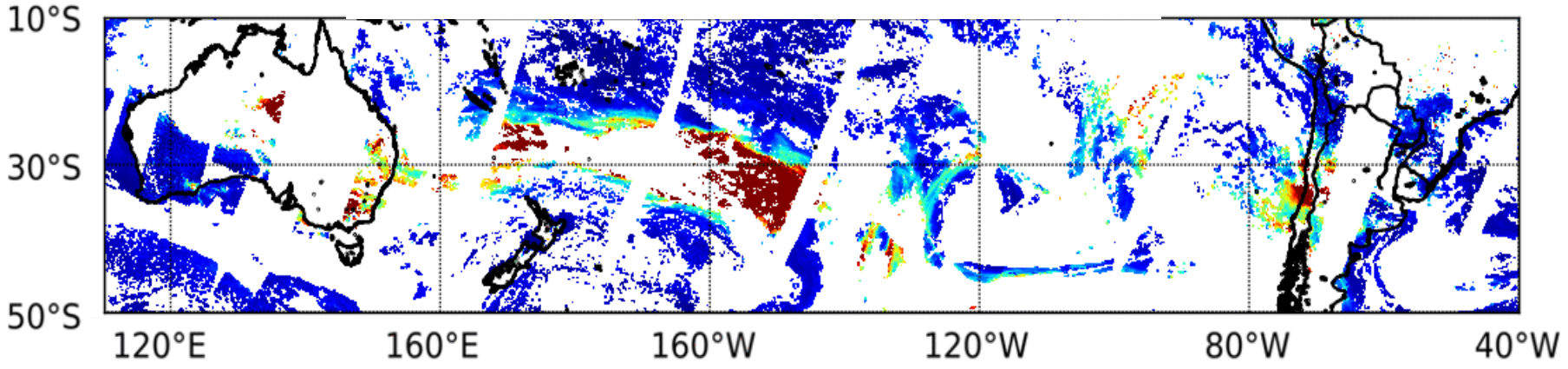
PMAp- Metop-A/B/C

Australia Bushfires – Smoke over South-Pacific



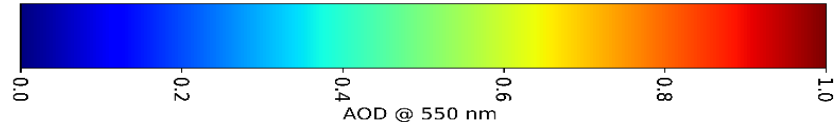
SLTR-A/B

AOD @ 550nm

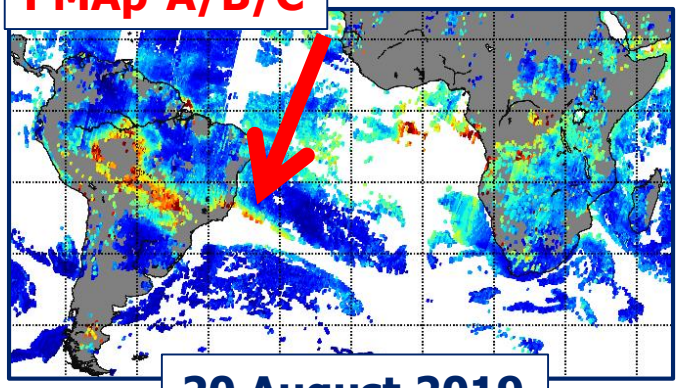


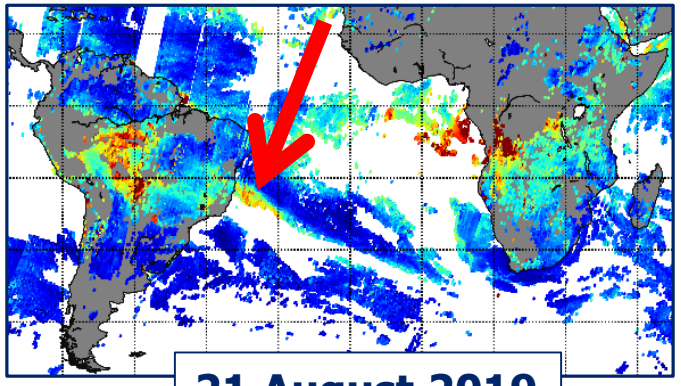
All 5 satellites: - Detect Dust gust over Australian desert on 11-12.01.2020
- Observe smoke transport across Pacific, with variable cloud-screening performance

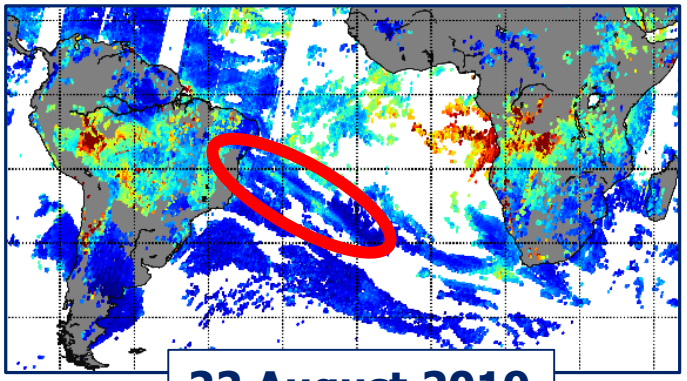
AOD @ 550 nm from 5 Satellites!



PMAp-A/B/C



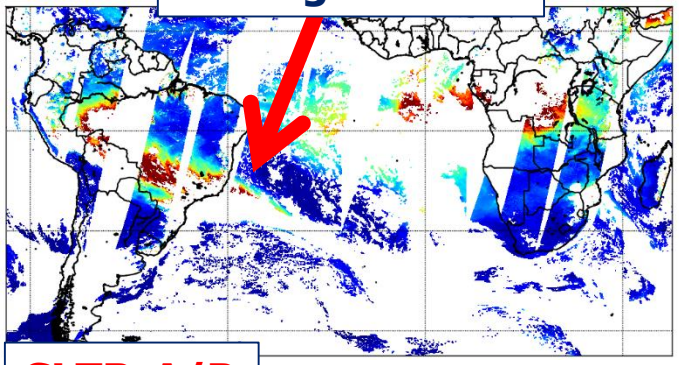


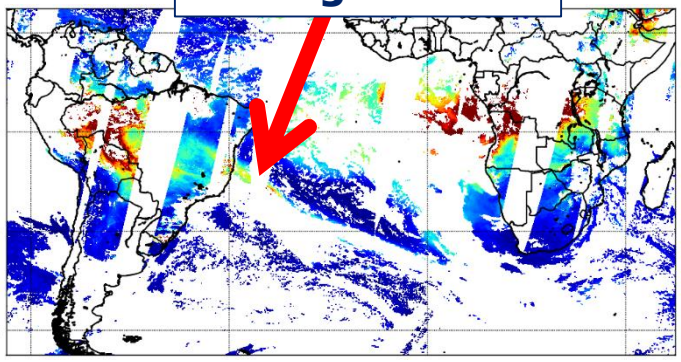


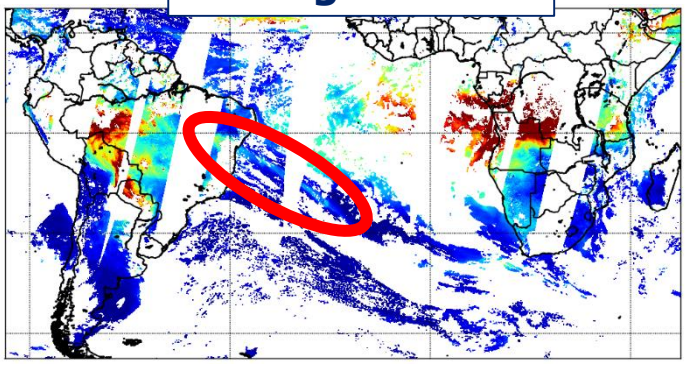
20 August 2019

21 August 2019

22 August 2019







SLTR-A/B

Clouds located in the same spot
AOD of the area ~1 (or higher)
Cloud filtering is similar

Plume edge is observed
AOD around 0.6-0.7 in both retrievals
Cloud filtering is similar
Also same AOD patterns in Brazil and west of Africa

AOD of the plume ~0.4 in both retrievals

Products from future sensors

- **MTG (Meteosat Third Generation)**
  - 3 GEO satellites
  - 1 instrument for aerosol retrieval

    FCI imager

- **EPS-SG (EPS Second Generation)**
  - 3 LEO satellites : Metop-SG on LEO at 9:30
  - core instrument for aerosol : 3MI polarimeter
  - 4 instruments for aerosol retrieval

    3MI, Metimage, S5, IASI-NG → hyper-instrument MAP

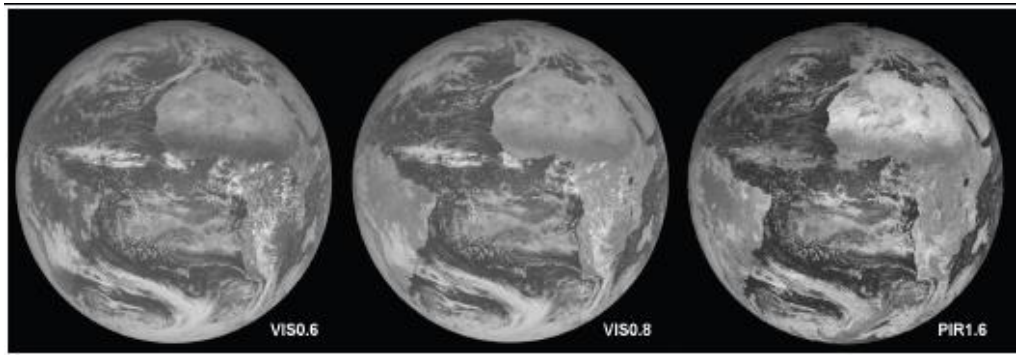
GEO sensors SEVIRI and FCI – on a nutshell

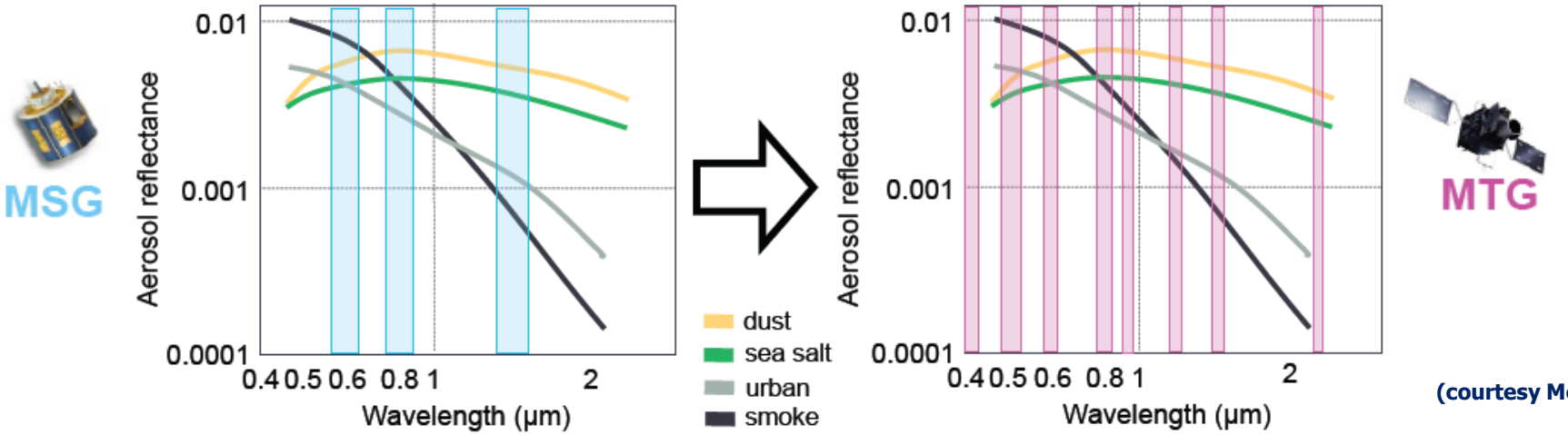
MSG/SEVIRI :

- full disk every 15’
- 3 reflective solar bands
- 3km@nadir

MTG/FCI :

- full disk every 10’
- Rapid scan service (1/4th of full disk every 2.5’)
- 8 reflective solar bands
- 1km@nadir



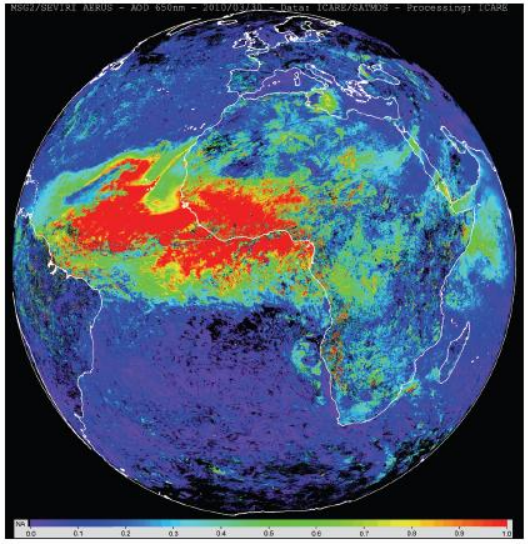


(courtesy Météo-France/CNRM)

Aerosol Product from MSG : SEVIRI

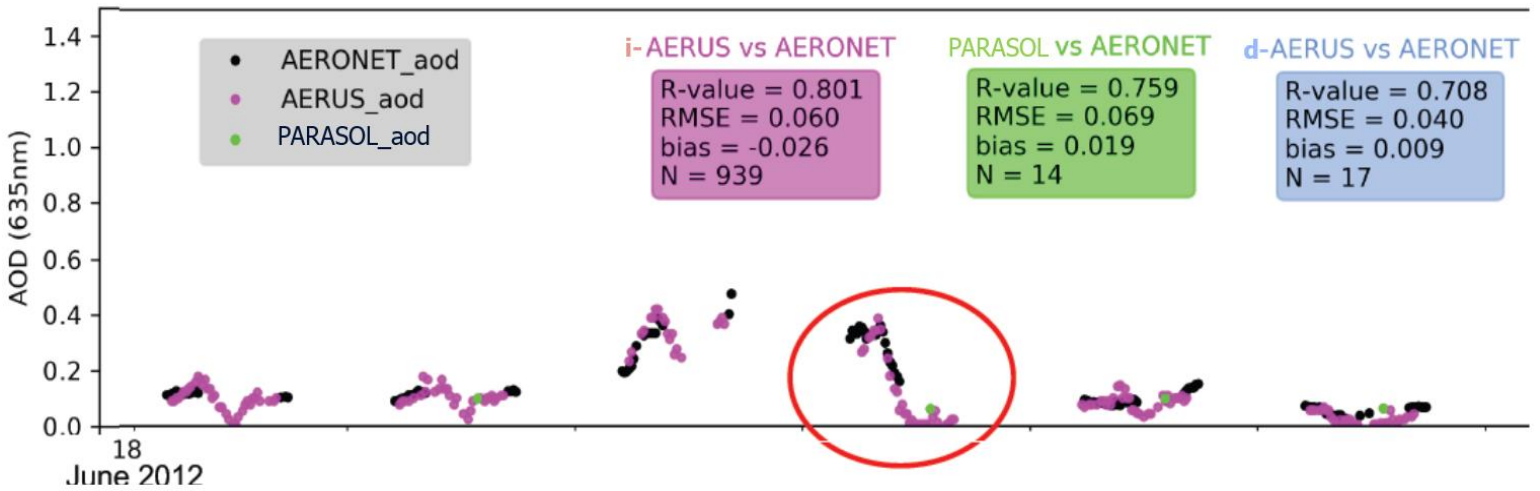
- Simultaneous aerosol-surface retrieval with AERUS-GEO (Carrer et al., 2010; 2014)
- Daily retrieval for MSG/SEVIRI available in ICARE
- Instantaneous retrieval (up to 96/day) under development → i-AERUS
- good estimation of the AOD + reveal the diurnal variation that may be large
  - Difficulties for some geometries (backscattering) due to the aerosol model identification
- Operationally implementation foreseen in EUMETSAT for MTG/FCI
  - Spectral extension will allow the model identification

Daily AOD



Daily AOD at 0.64µm on March 30th, 2010

Instantaneous AOD

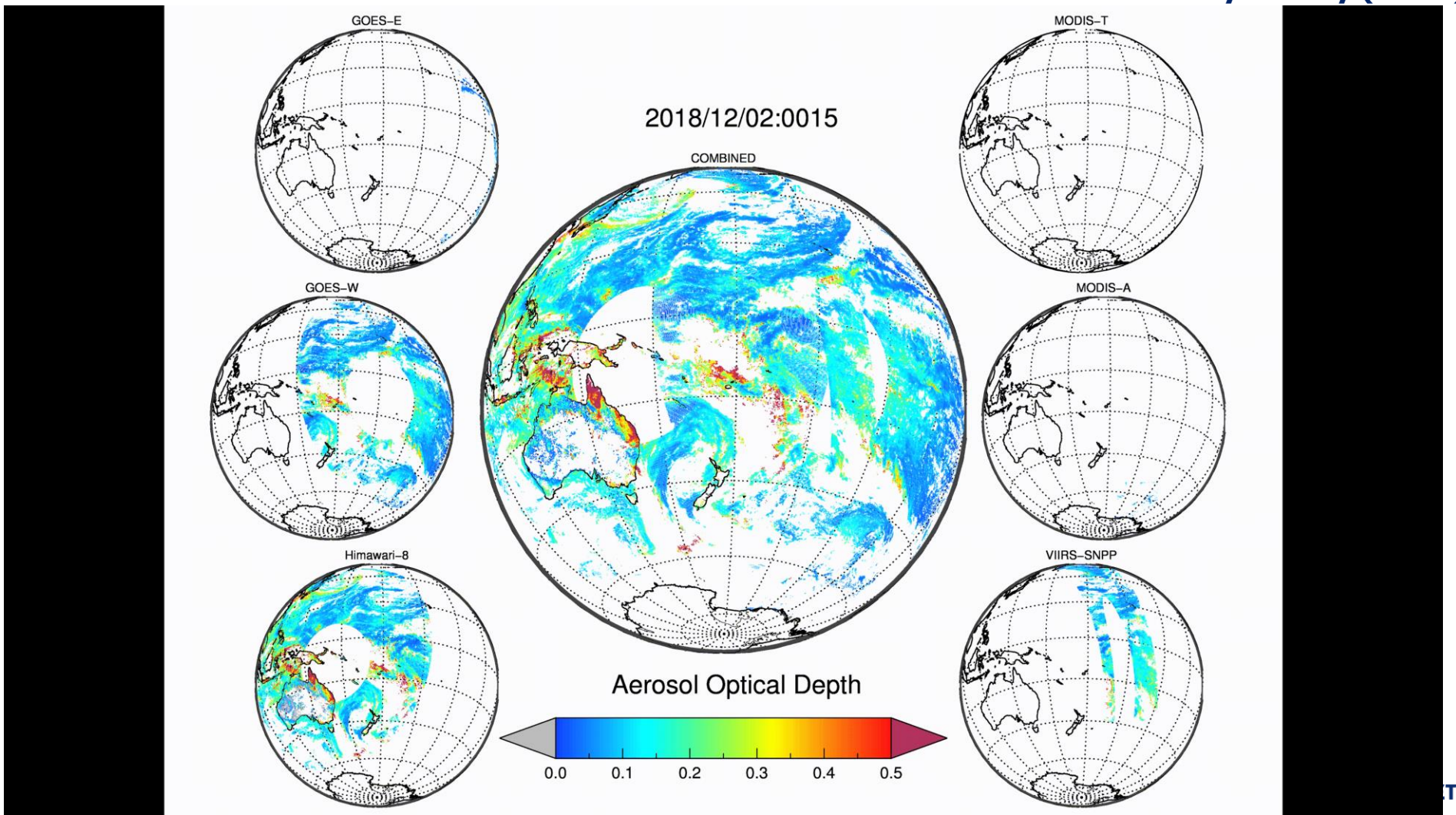


(Ceamanos et al. 2018)

Aerosol Product from MTG : toward FCI

- Expectation: similar products as those already available (AHI, ABI)
  - Complementarity with other GEO, Synergy with LEO to be explored

Courtesy R. Levy (NASA)



Products from future sensors

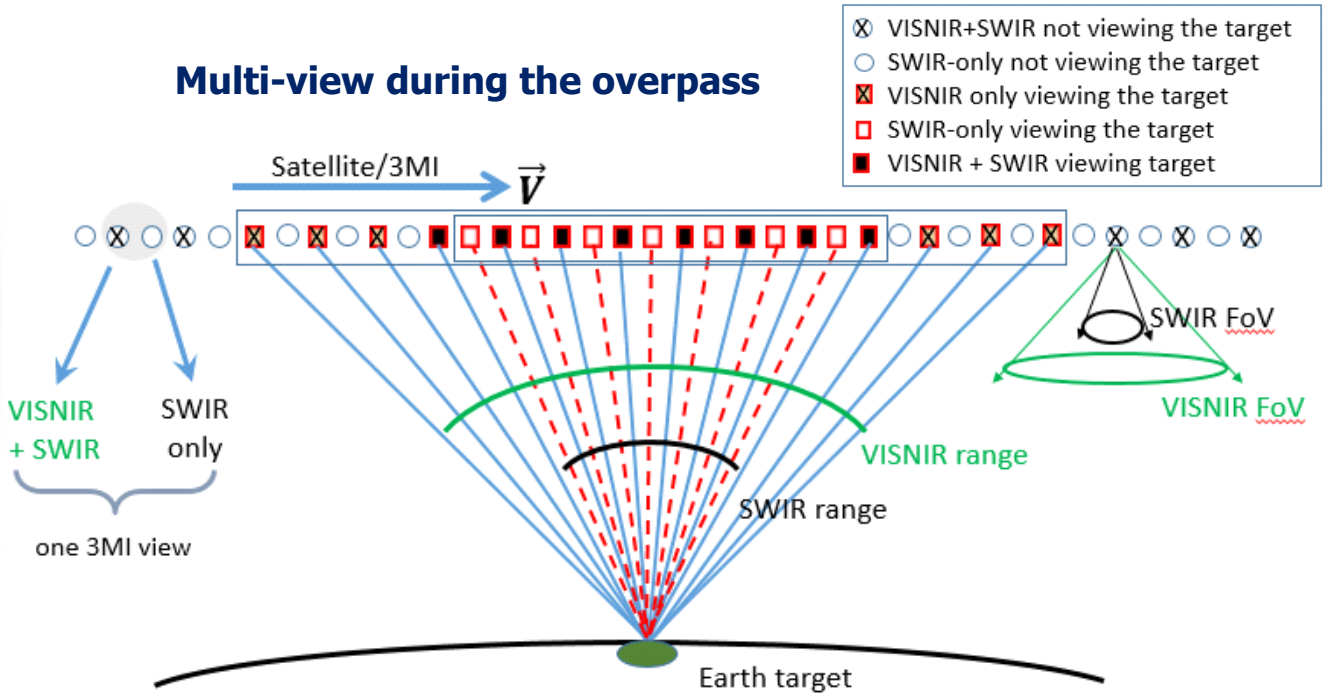
- **MTG (Meteosat Third Generation)**
  - 3 GEO satellites
  - 1 instrument for aerosol retrieval
- FCI imager

- **EPS-SG (EPS Second Generation)**
  - 3 LEO satellites : Metop-SG on LEO at 9:30
  - A core instrument for aerosol : the 3MI polarimeter
  - 3 additional instruments to support the aerosol retrieval

3MI + Metimage, S5, IASI-NG → hyper-instrument MAP

EPS-SG 3MI - on an nutshell

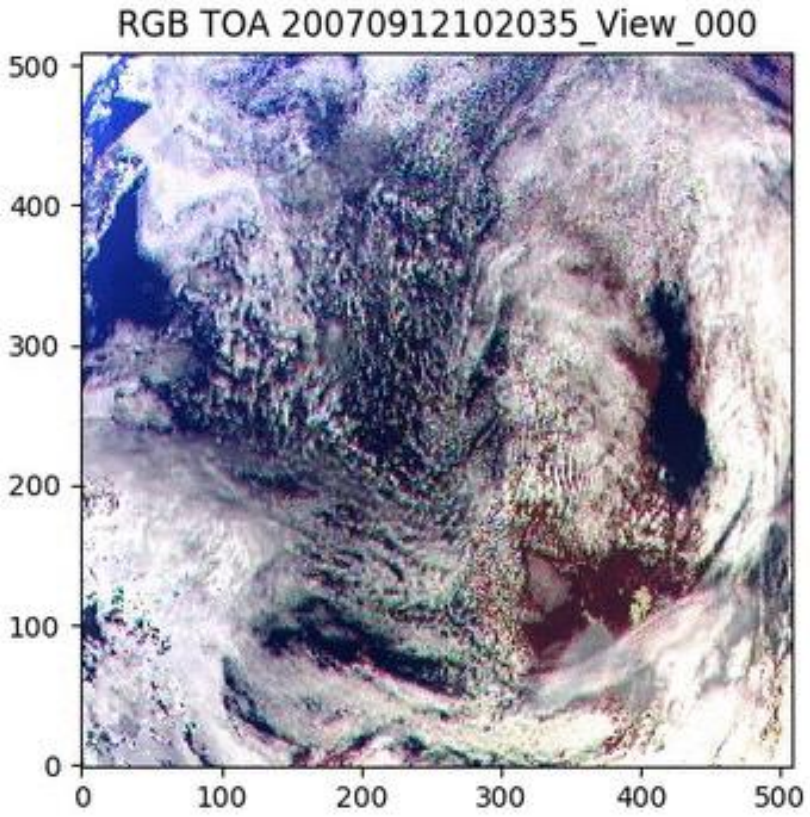
- The instrument relies on a very simple concept
  - 2 wide field-of-view optics (VISNIR + SWIR, 2200km swath)
  - 2D detectors at focal planes (CCD for VISNIR, CMOS for SWIR, 4km nadir pixel)
  - 1 filter wheel inc. polarizer (12 bands from 410 to 2130nm with I/Q/U)



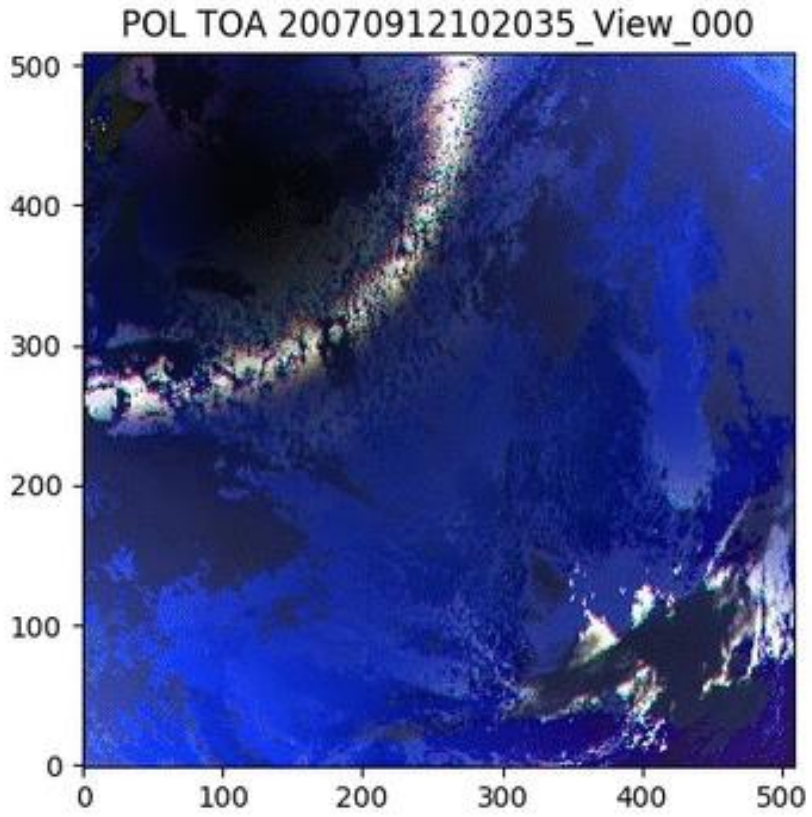
See Fougnie et al., 2018 in JQSRT APOLO'17

Why polarisation is a key-element for the observation of atmospheric scatterers ?

Level 1 TOA reflectance



Natural light



Polarized light

First overflight (simulated 3MI data)

Aerosol retrieval from 3MI

- 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)

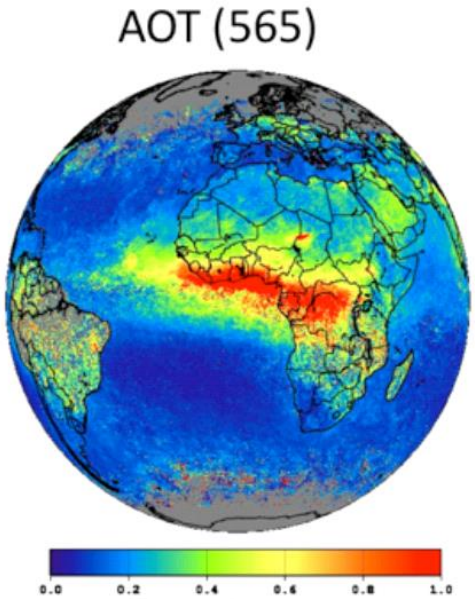
  → Potentially 420 information per pixel to feed the retrieval

- The aerosol retrieval will be based on an optimal simultaneous retrieval of the surface and aerosol
  - GRASP was adopted to be the best solver for this specific information
    - From Dubovik et al. 2014
    - Already tested on many sensors (POLDER, PARASOL, MISR, MODIS…)
  - Configured to an Operational processor (product available 1:30 after sensing)
  - The simultaneous retrieval will be adjusted to optimise the performance of the aerosol retrieval

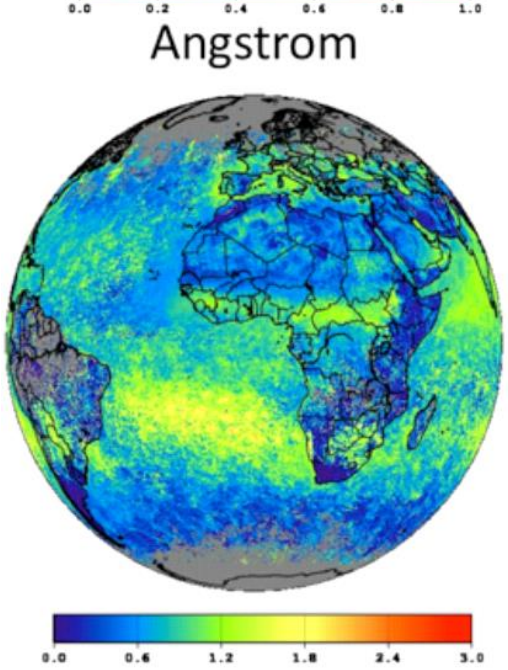
Aerosol retrieval from 3MI

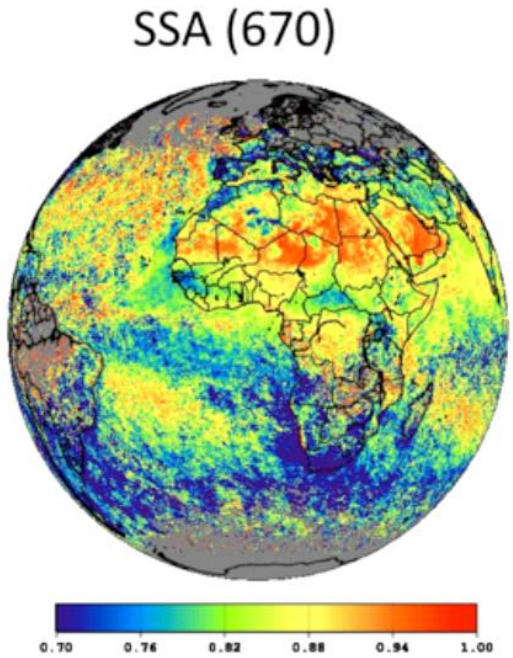
- It is potentially possible to address the following aerosol properties:
  - Aerosol optical thickness
  - Angstrom coefficient
  - Fine/coarse fraction
  - Single scattering albedo
  - Absorbing aerosol optical thickness
  - Refractive indexes
  - Sphericity index
  - Aerosol height
- But it is unrealistic to retrieve all of them and everywhere
  - The geometry of acquisition and/or the surface type strongly influence the performance of the retrieval
- With respect to our user needs, the retrieval will be optimised to derive properly
  - AOD
  - Aerosol model (angstrom coefficient)
- Other parameters will be retrieved when/if possible

Aerosol Product from EPS-SG : 3MI

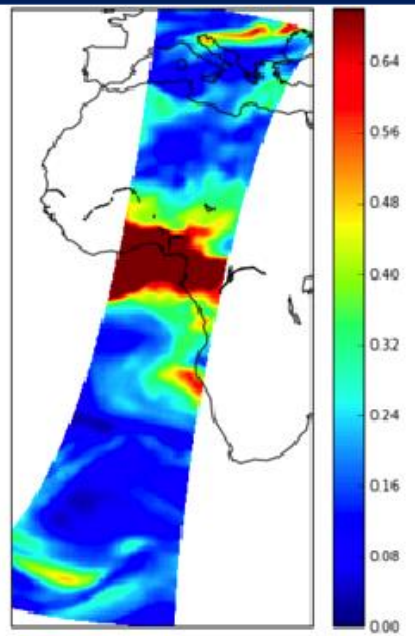


PARASOL
(2004-2013)



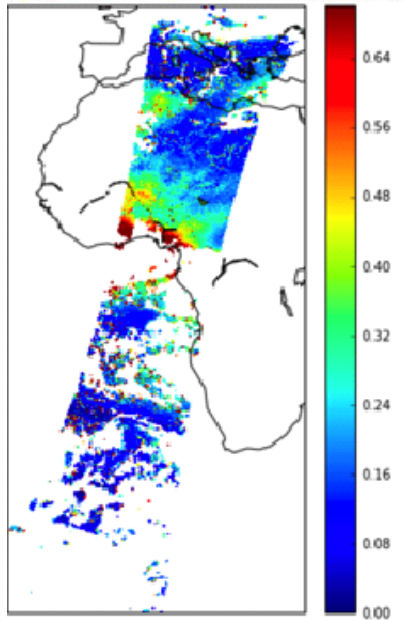


"ideal" input



AOD retrieved
with 3MI

Based on
simulated dataset



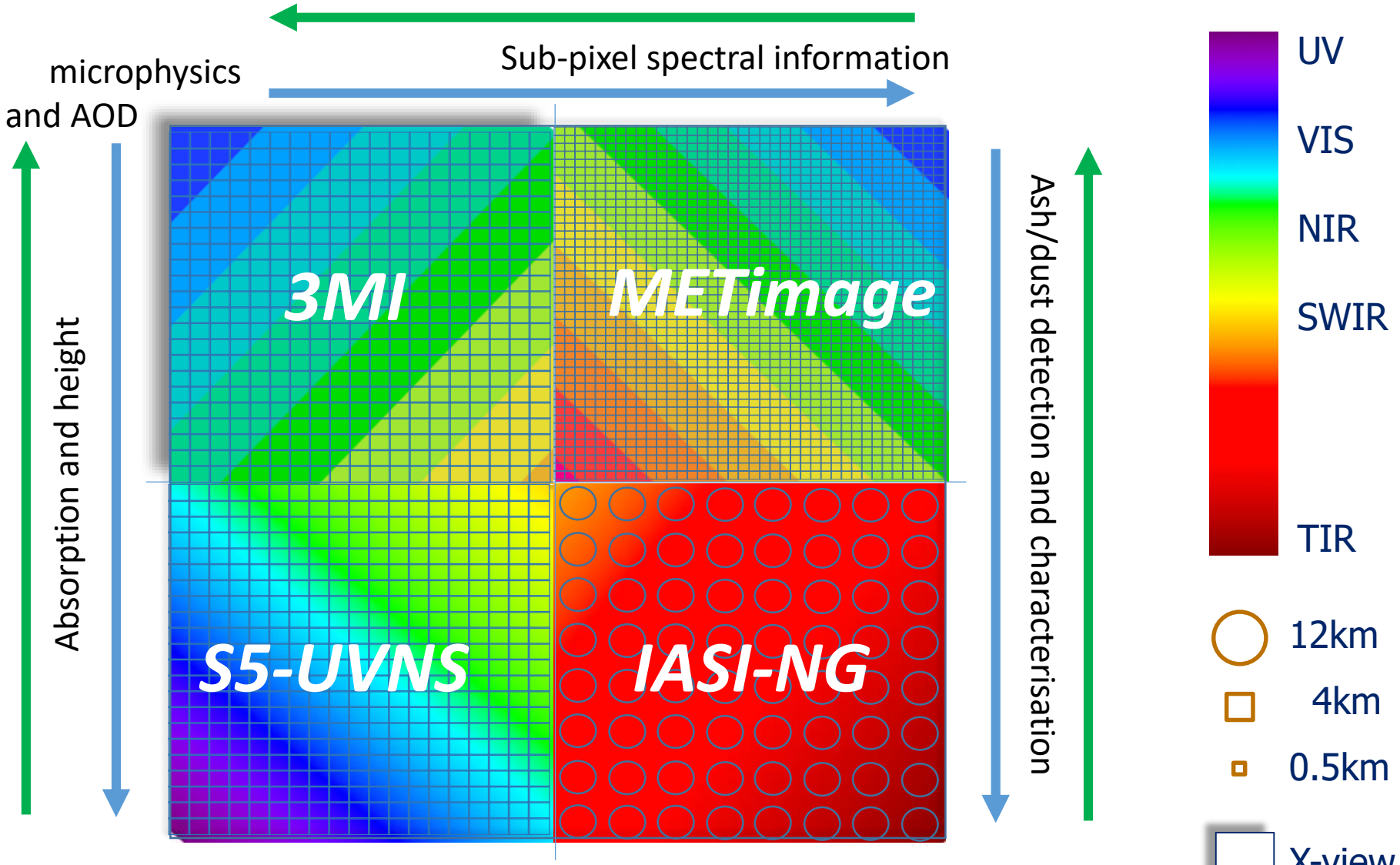
Retrieved AOD

The hyper-instrument from EPS-SG – on a nutshell

- Information content = incredible collection of measurements from the same single platform
- Creating an hyper-instrument with many key-elements for a 4-km aerosol product: MAP (Multi-sensor Aerosol Product)
  - Extended spectral content: UV/VIS/NIR/SWIR/TIR
  - Improved spectral content: highly resolved in absorption lines
  - Sub-pixel radiometric characterisation
  - Multi-view and polarisation

Sensor	Spatial resolution	Swath	Spectral type	Spectral bands	Spectral range	Additional capabilities
3MI	4x4 km²	2200 x 2200 km²	VIS/NIR/SWIR	12 bands	410 to 2130nm	14 views Polarisation (I/Q/U)
METimage	0.5x0.5 km²	2670 km	VIS/NIR/SWIR TIR	11 bands 9 bands	443 to 2250nm 3.3 to 13.3µm	
S5-UVN	7.5x7.5 km² 50x50 km² (<300nm)	2670 km	UV/VIS/NIR/SWIR	1669 bands (0.25nm in SWIR to 1nm in UV)	270-300nm 300-370-500nm 685-710nm 755-773nm 1590-1675nm 2305-2385nm	
IASI-NG	12km spot	2000 km	TIR	16921 bands (0.25cm-1)	645 to 2760cm-1	

The hyper-instrument from EPS-SG sensors



EUMETSAT

Aerosol characterisation from EPS-SG sensors

- The MAP measurements will allow
  - More aerosol parameters to be retrieved
  - A consolidation and improvement of the 3MI retrieval (the core aerosol mission)

Characterisation		3MI	METimage	S5-UVN	IASI-NG
Cloud identification	CM	X	O		
Cloud decontamination			O		
Ash/Dust detection		X	O		O
Aerosol height	ALH	O	X	O	X
Aerosol over clouds		O	X		O
Aerosol model		O	X	X	
Aerosol fine fraction	FMF	O			
Aerosol Optical Depth	AOD	O	X	X	
Aerosol absorption	AAI/SSA	O		O	

  - Potentialities for air quality : PM2.5 (function of AOD-fine, height…)
- The development will consider feedbacks from POLDER/PARASOL, MODIS, and EPS/PMAp (GOME, AVHRR, IASI)
  - The activity is only starting

End-users requirements for EPS-SG

- EPS-SG (from EPS-SG EURD):
  - Timeline: 100min after sensing - NRT
  - Parameters to be retrieved [expected performance]:
    - Total and fine mode aerosol optical thickness [0.05]
    - Aerosol type (Angström exponent) [4 classes]
    - Non-sphericity index
    - Effective radius and refractive index (fine and coarse) [0.6µm]
    - Altitude range & aerosol layer height [1km]
    - Aerosol UV absorbing index, single scattering albedo [0.2]
    - Volcanic ash [detection]

Use cases and scenario

- Currently assimilated Level-2 into NWP and CAMS:
  - Aerosol Optical Thickness
- Needs:
  - Aerosol model, Aerosol height
  - PM (particulate matter) is needed for Air Quality

- Level-2 are more generally used to validate the model

- Aerosol-cloud interaction
  - Difficult to retrieve aerosol when clouds
  - But aerosol important for the cloud modelling (nucleation)
  - Aerosol parameters assimilated → output of assimilation = input for cloud modelling (spatial & temporal interpolator)

Concluding remarks - The strengths

- **EPS/PMAp** → Synergistic use
- **Sentinel-3/SLSTR and OLCI** → Dual-view and spectral
- **MTG/FCI** → Diurnal variation
- **EPS-SG/3MI and MAP** → The aerosol observatory (synergistic use of multi-view, spectral, polarisation, and spatial resolution)

Concluding remarks – The performance

- Coming systems MTG & EPS-SG are significant steps in term of:
  - Additional information = more measurements, more parameters can be retrieved for the same scene: diurnal cycle, aerosol microphysics, aerosol types, height…
  - Performance: for the already existing parameters

- The performance depends on:
  - The information content available on the measurements: spectral range (UV to TIR), resolution, directional, polarisation…
    - This includes the precision of the measurements: calibration, noise, geometry…
  - The performance of the retrieval approach (should be optimised wrt the information content)

- In general, efforts have to be done on the description of the performance associated to each parameters

- The performance of the aerosol parameter is a parameter by itself and should be properly described in the products

Thank you for your attention