Potential of EarthCARE active observation synergy with novel passive multi-platform satellite observations

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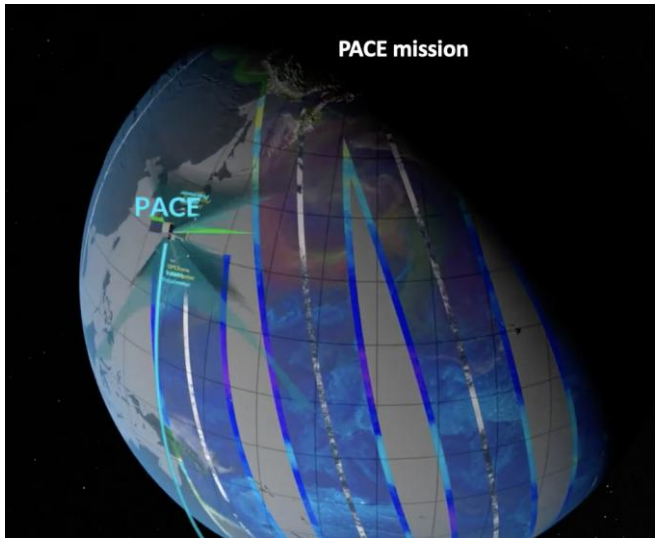
1- LOA, CNRS/Univ. of Lille, France
2- GRASP SAS, Lille, France,
3- World-wide team

EarthCARE Science and Validation Workshop 2025
1-5 December 2025 | The University of Tokyo | Tokyo, Japan

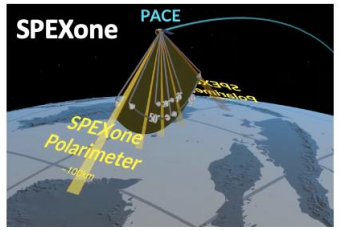
Era of Multi-Angular Polarimetry

PACE mission



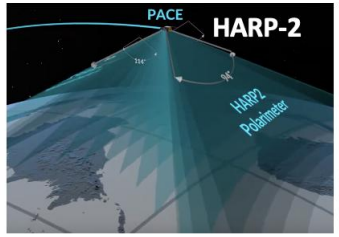
- 385-770 nm continues
- 5 viewing angles
- 30+ day global coverage
- 2.5 km spatial resolution

high information content;
high meas. precision;



- 440, 550, 670, 870 nm
- viewing angles:
- 10 for 440, 550, 870 nm
- 60 viewing angles for 670
- 2 days global coverage
- 3 km spatial resolution

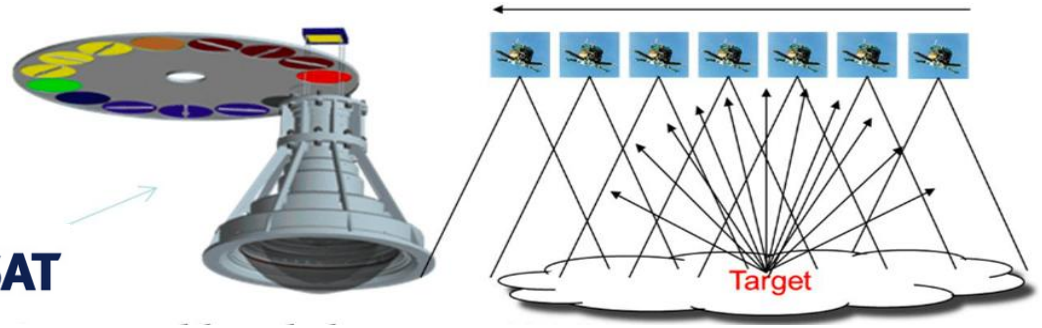
high information content;
wide coverage;



3MI/METOP-SG

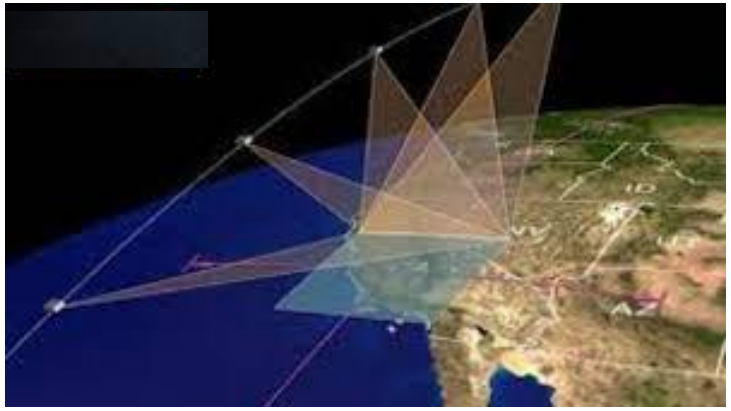
esa

EUMETSAT



MAP/CO2M

MAIA



Multi-Angular Polarimetry

HAPR-2, SPEXone/PACE, 3MI/METOP-SG, MAP/CO2M, etc.

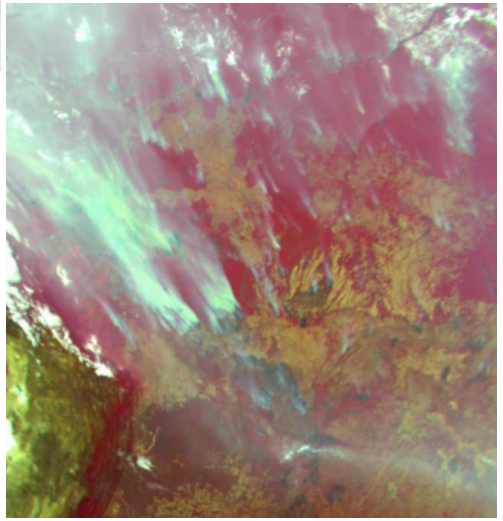
Intensity

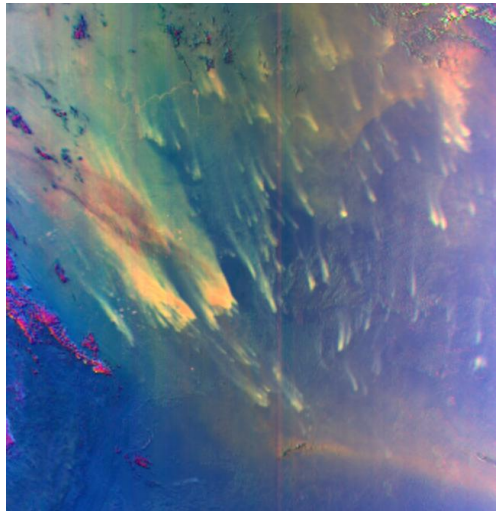
Polarised Intensity

Polarised Intensity

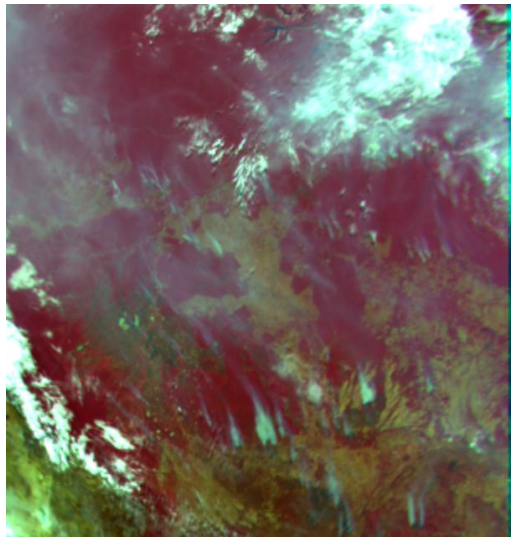
Amazonia

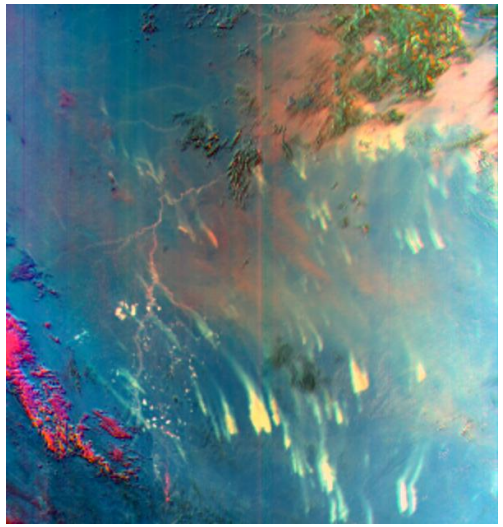
26th August 2024





12th August 2024

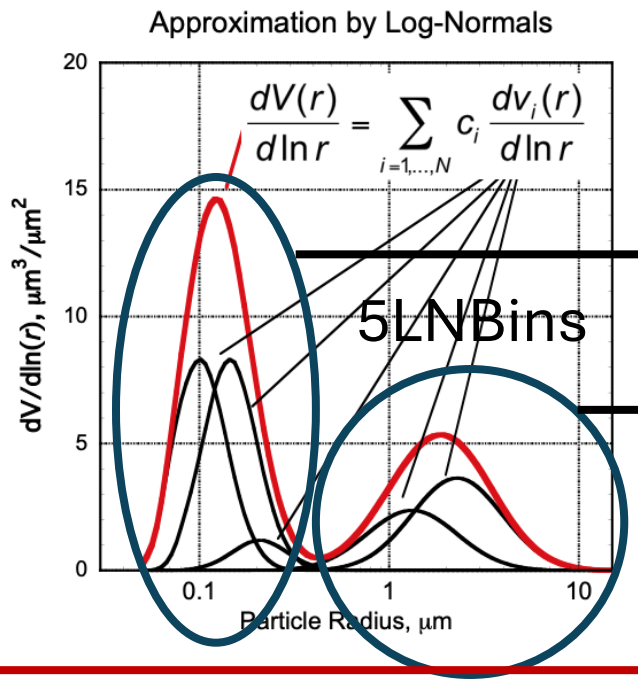




RGB = 865/670/440nm

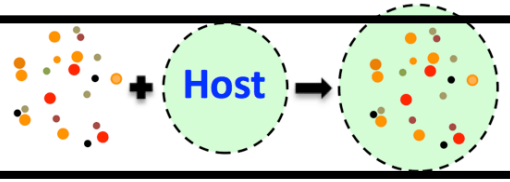
Curtesy of Bertrand Fougnie, EUMETSAT

GRASP approach – 5LNBins + Chemical Component



(L. Li et al., ACP, 2019)

Fine mode



Maxwell Garnett
effective medium approximation

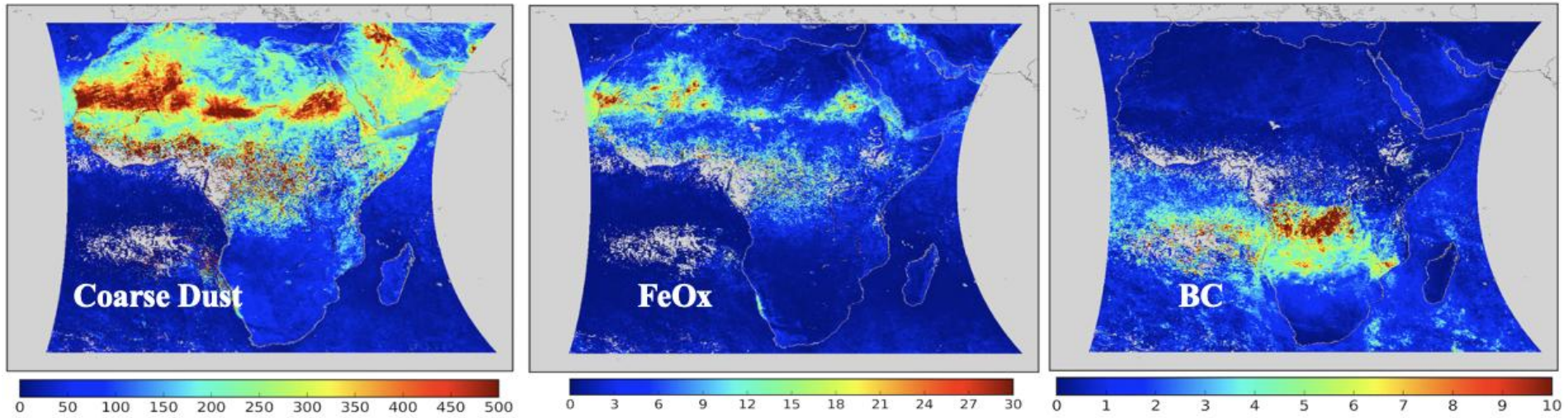
Coarse mode

or
Volume weighted

GRASP/Component Validation (2008)

BC
BrC
Non-absorbing soluble
Non-absorbing insoluble
Water
Fine mode

Absorbing insoluble (Iron oxides)
Non-absorbing insoluble (Dust)
Non-absorbing soluble (SS, etc)
Water
Coarse mode



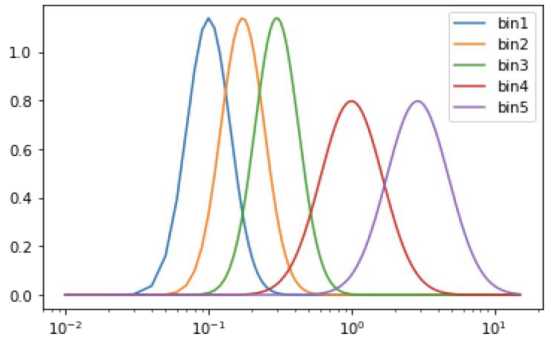
By using ***prescribed spectral refractive index*** of components,

GRASP/Component approach provides consistent and stable results for AOD as well as detailed properties.

3MI NRT Processor – New era of L2 Aerosol Product

- Aerosol components external mixture in 2 modes (internal mixture by Maxwell-Garnett
- Refractive index from literature review (publications 1979-2007)
- Vertical profiling is accounted with aerosol concentration per mode (exponential one).

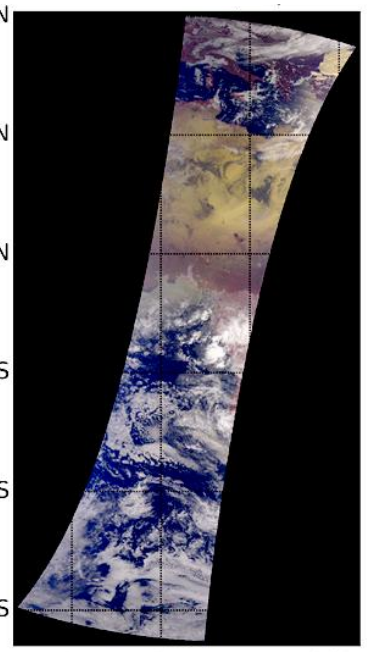
	Size distribution	Volume Concentration	BC	BrC	Quartz	Iron Oxide	Water/ Sulphate
Fine mode	3 LN bins	✓	✓	✓	✓	✗	✓
Coarse mode	2 LN bins	✓	✗	✗	✓	✓	✓



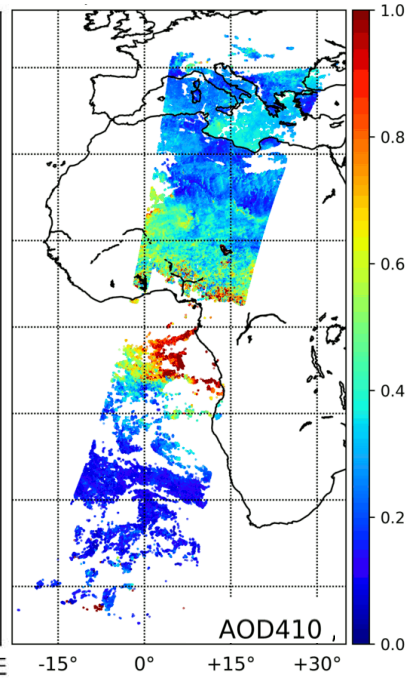
Size
Radius:
mode 1:
bins: 0.1, 0.1732, 0.3 µm
mode 2:
bins: 1., 2.9 µm

More parameters

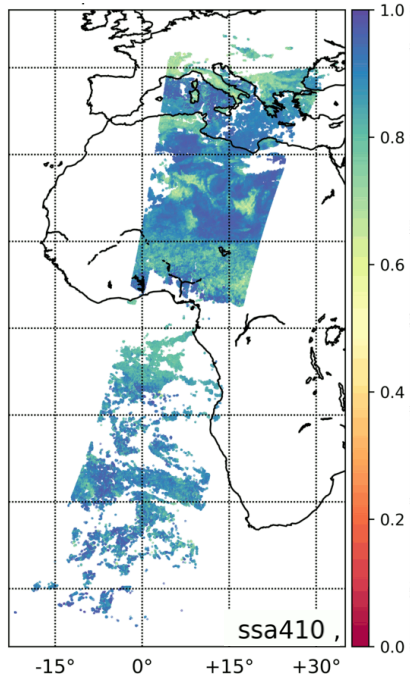
TOA RGB



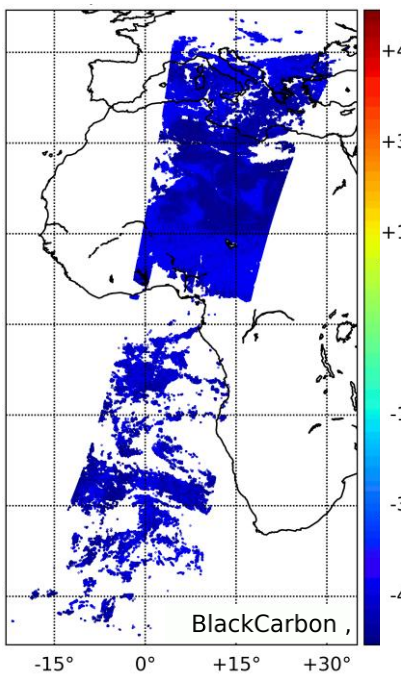
Aerosol Optical Depth (Fine and Coarse AOD)



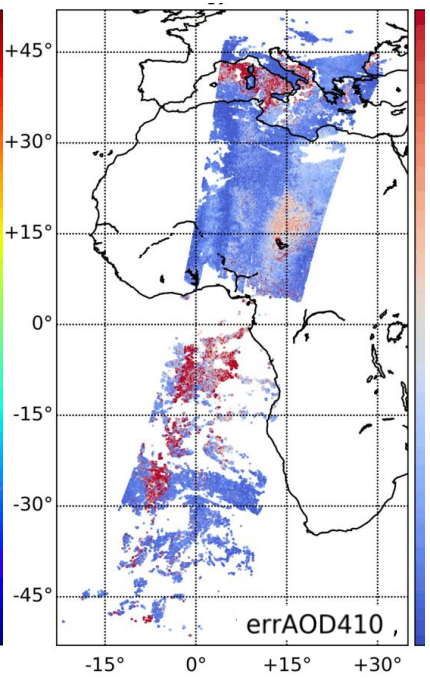
Single Scattering Albedo



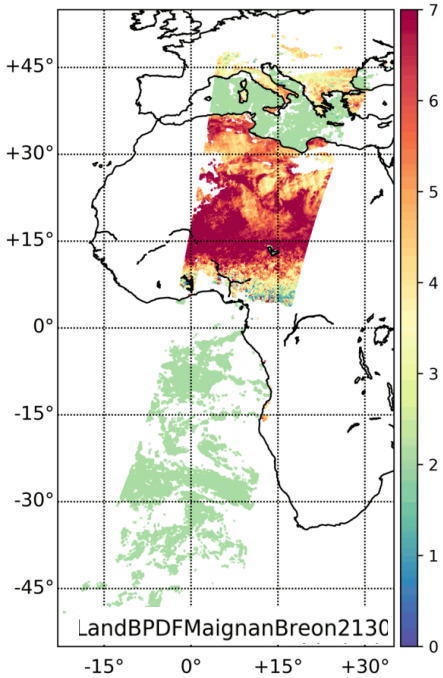
Chemical Components



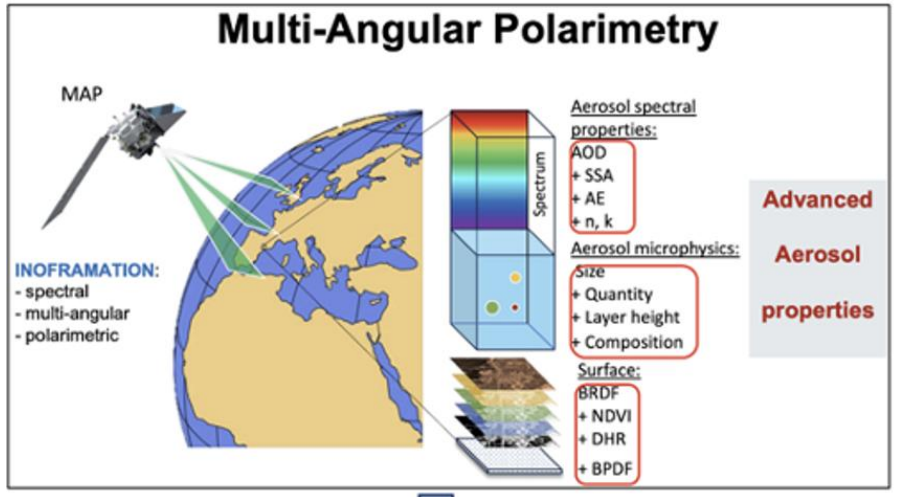
AOD Error

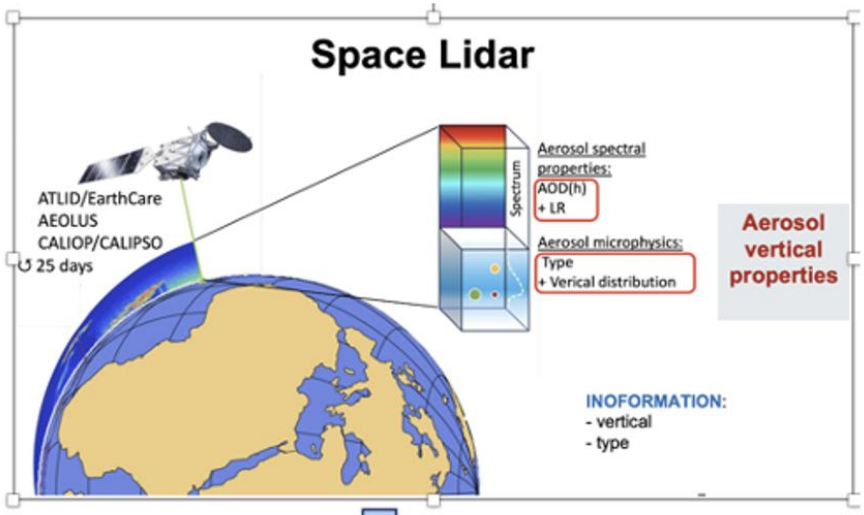


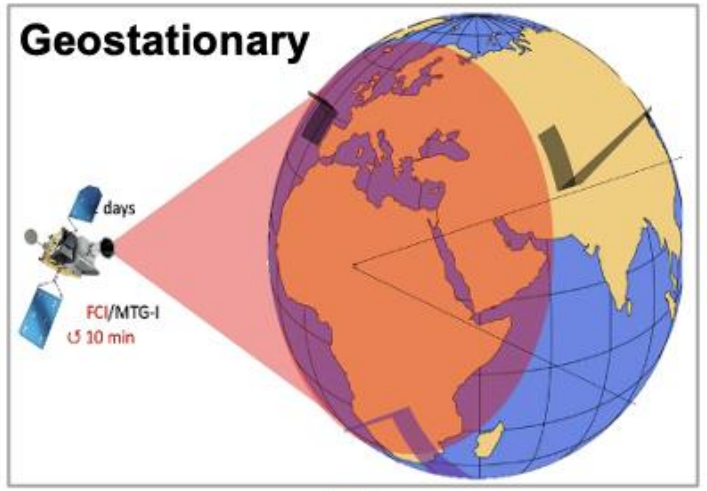
Surface Polarized Reflectance



Curtesy of Bertrand Fougnie, EUMETSAT







columnar aerosol properties

vertical aerosol properties

temporal and spatial variations of aerosol properties

Advantage:
high information content regarding columnar properties

Limitations:
- limited sensitivity to vertical variability of aerosol;
- limited temporal and spatial coverage

Advantage:
high sensitivity to vertical variability of aerosol

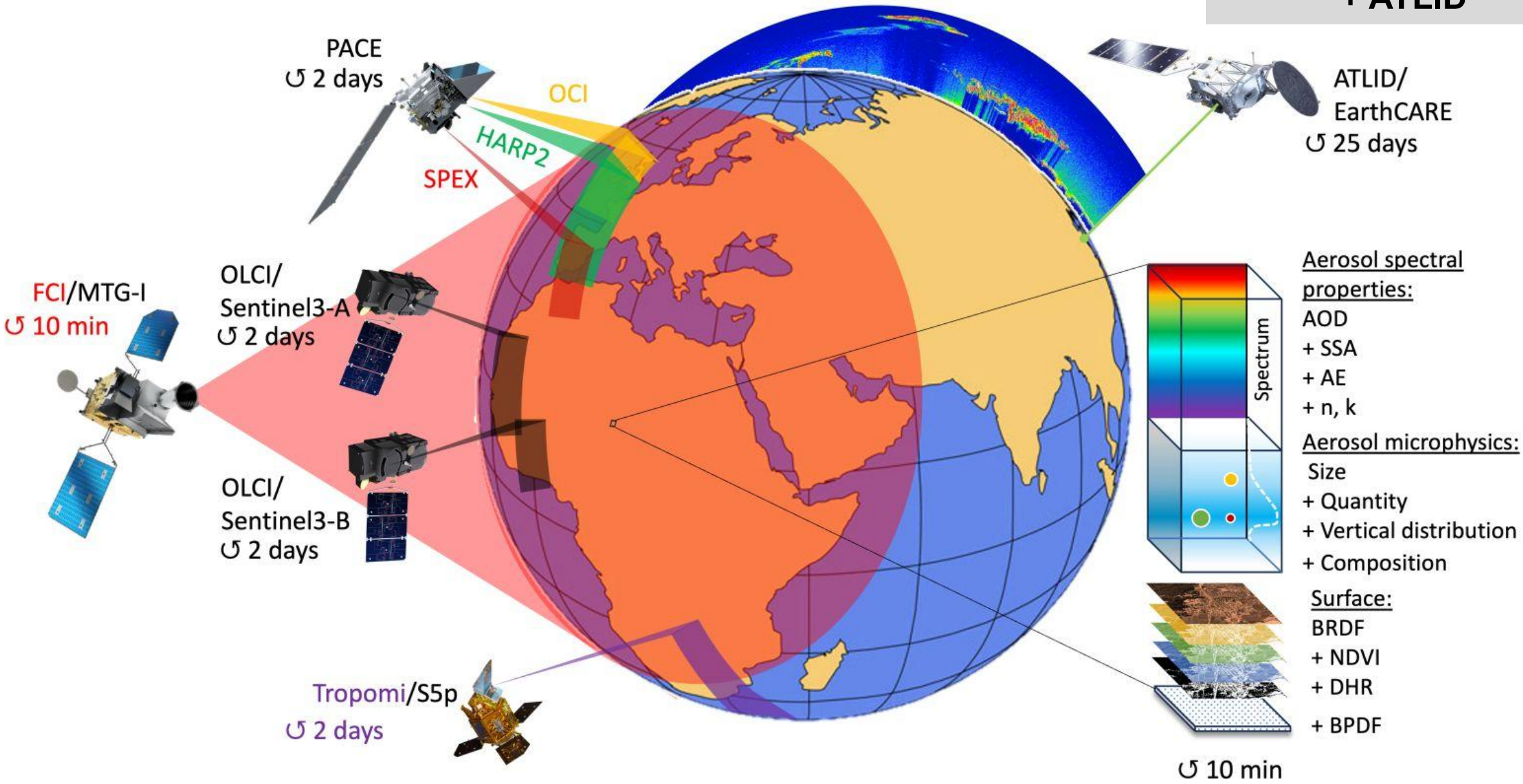
Limitations:
- dependence on assumed aerosol type;
- very limited spatial and temporal coverage

Advantage:
detailed spatial and temporal coverage

Limitations:
- limited sensitivity to vertical variability of aerosol;
- dependence on assumed aerosol type;

SYNERGY: LEO + GEO + EarthCARE

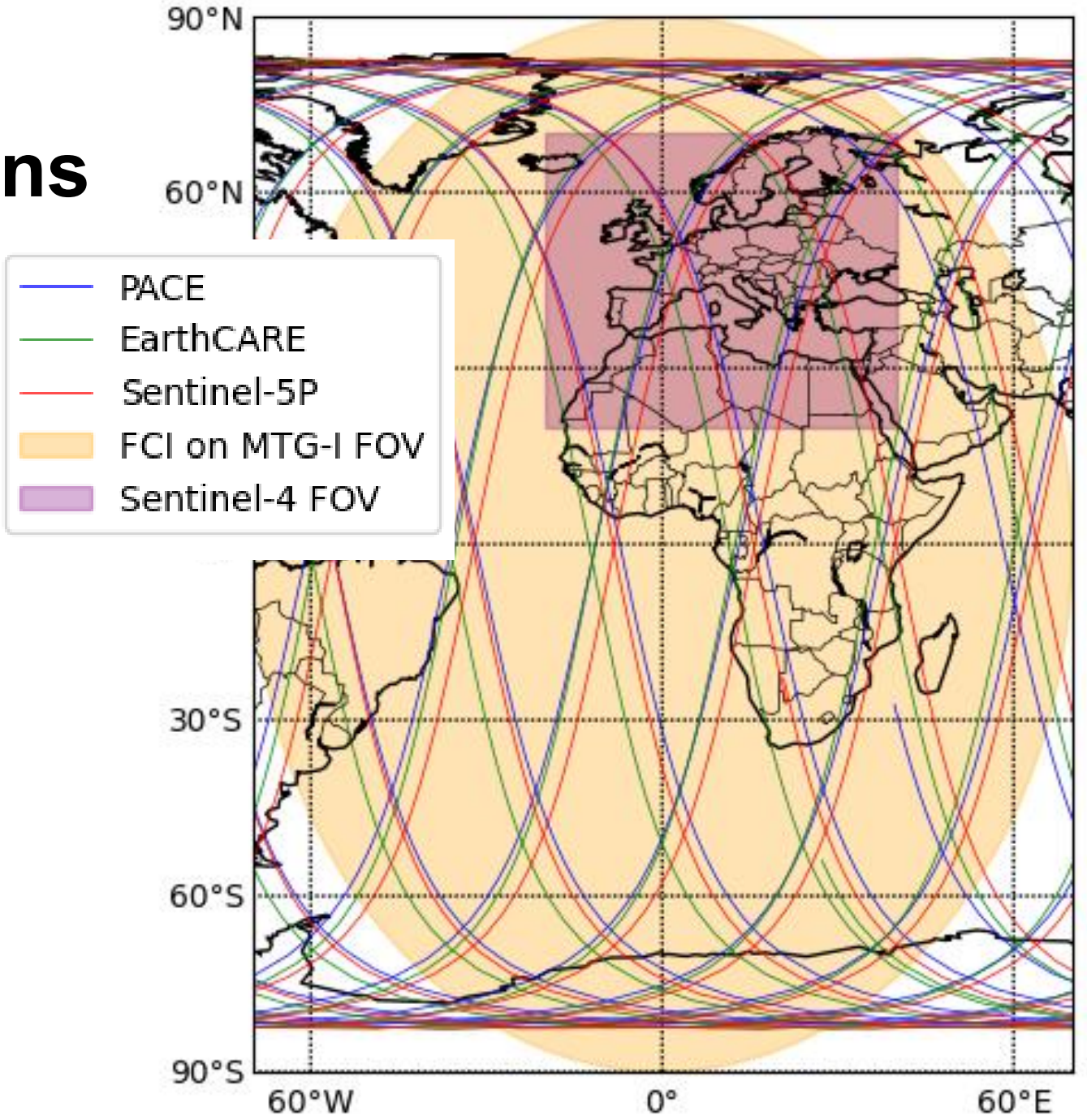
PACE + S-5P + S3A-B
+ FCI/MTG
+ ATLID



Overlap of EarthCARE with passive observations

ISSUE: There is no fully co-incident and co-located passive Multi-Angular- Polarimetric observations

Nonetheless: There are often co-incident and co-located GEO observations.



Methodology of combining

12 hours

OLCI-A/ Sentinel3 ↺ 2 days

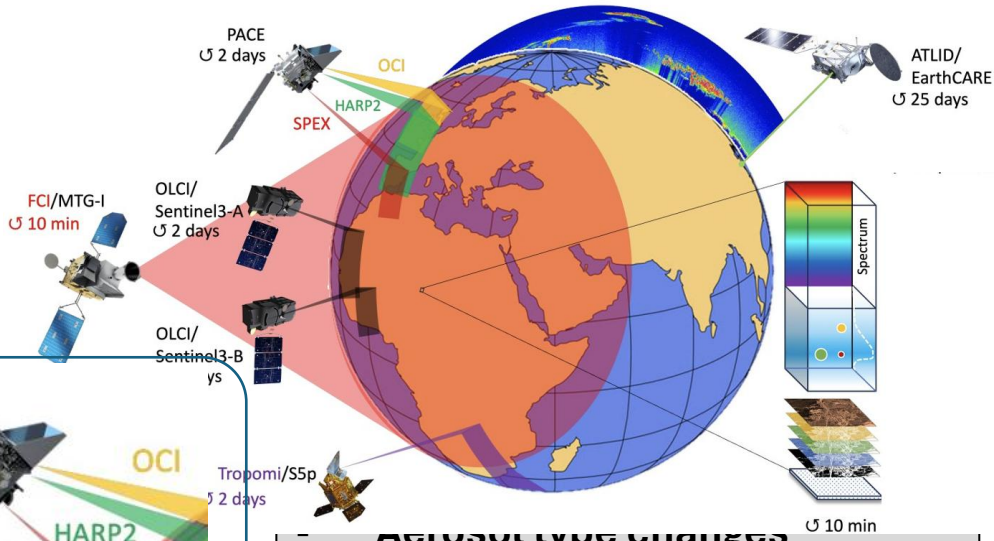
OLCI-B/ Sentinel3 ↺ 2 days

FCI/MTG-I ↺ 10 min

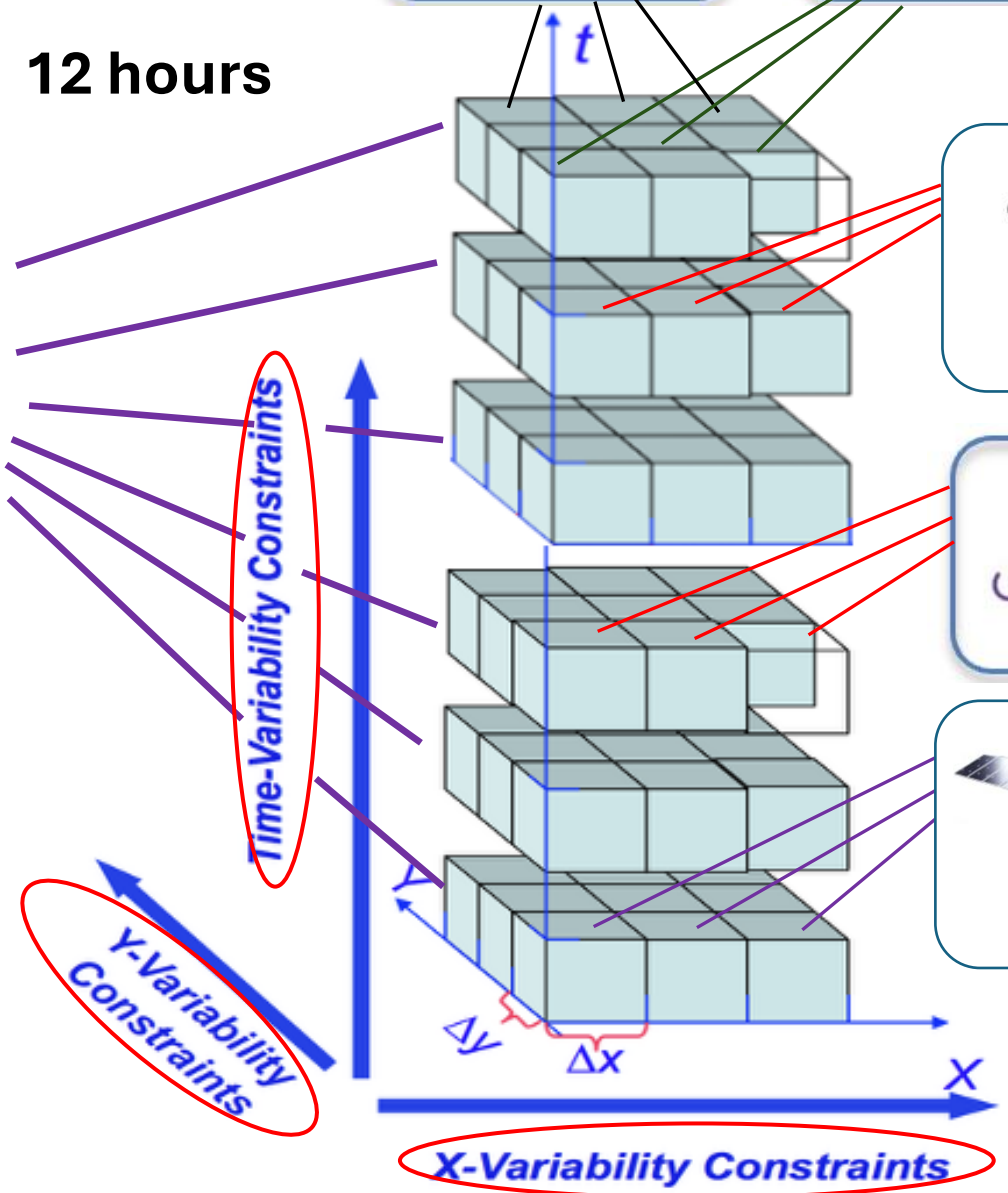
PACE ↺ 2 days

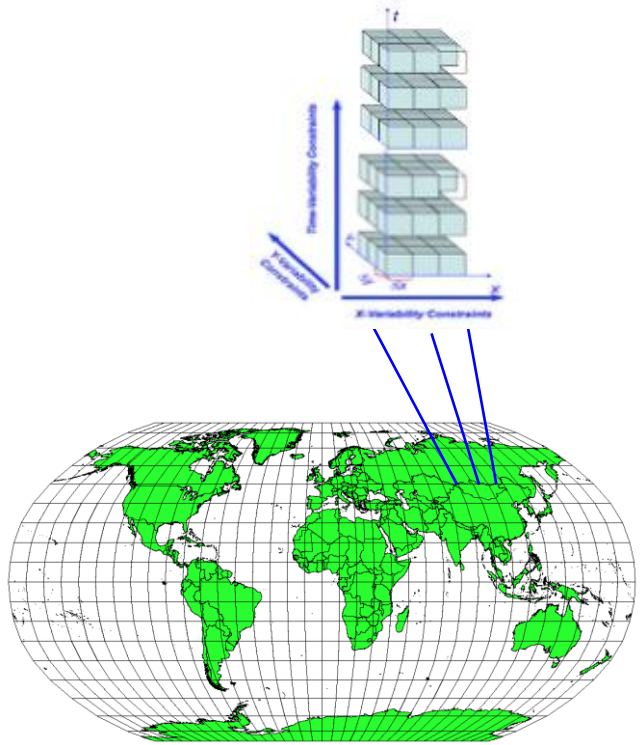
Tropomi/S5p ↺ 2 days

ATLID/ EarthCARE ↺ 25 days



Aerosol type changes horizontally rather slowly;





LEO + GEO

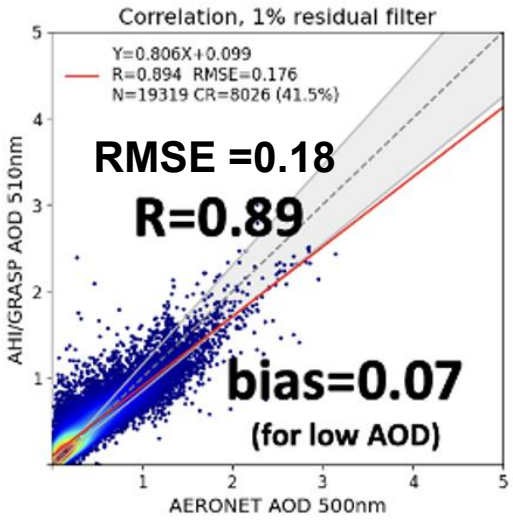
TROPOMI/S-5P + OLCI/S3-A + OLCI/S3-B + AHI/HIMAWARI

Practical advantages of SYNERGY

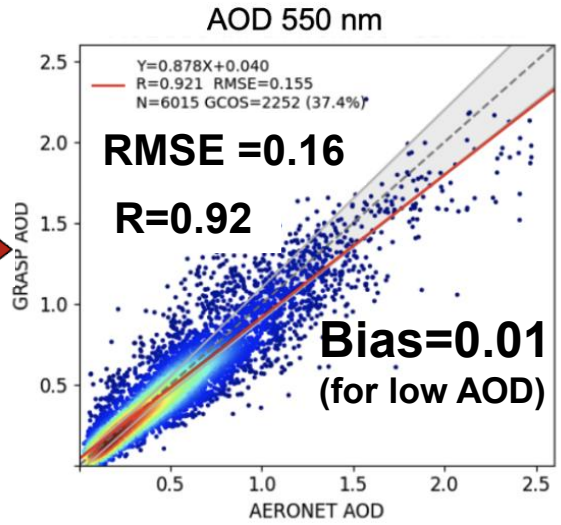
March – May, 2019

Litvinov et al., AMT, 2025

AOD from AHI/GRASP (alone, NO SYNERGY)

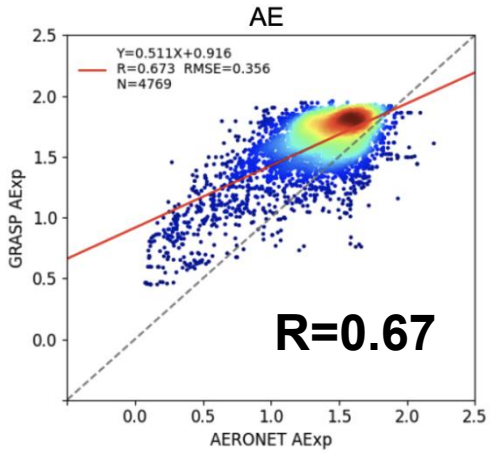


AOD from AHI/GRASP (SYNERGY)

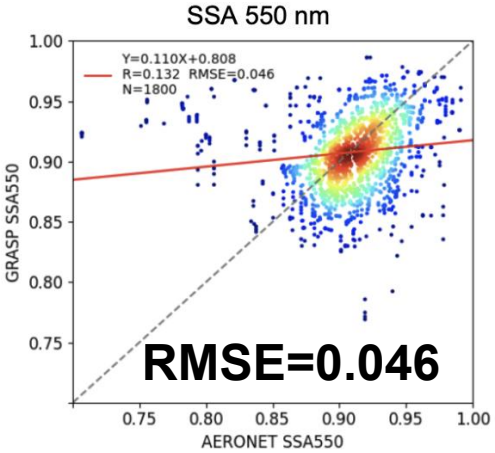


+

AE from AHI/GRASP (SYNERGY)



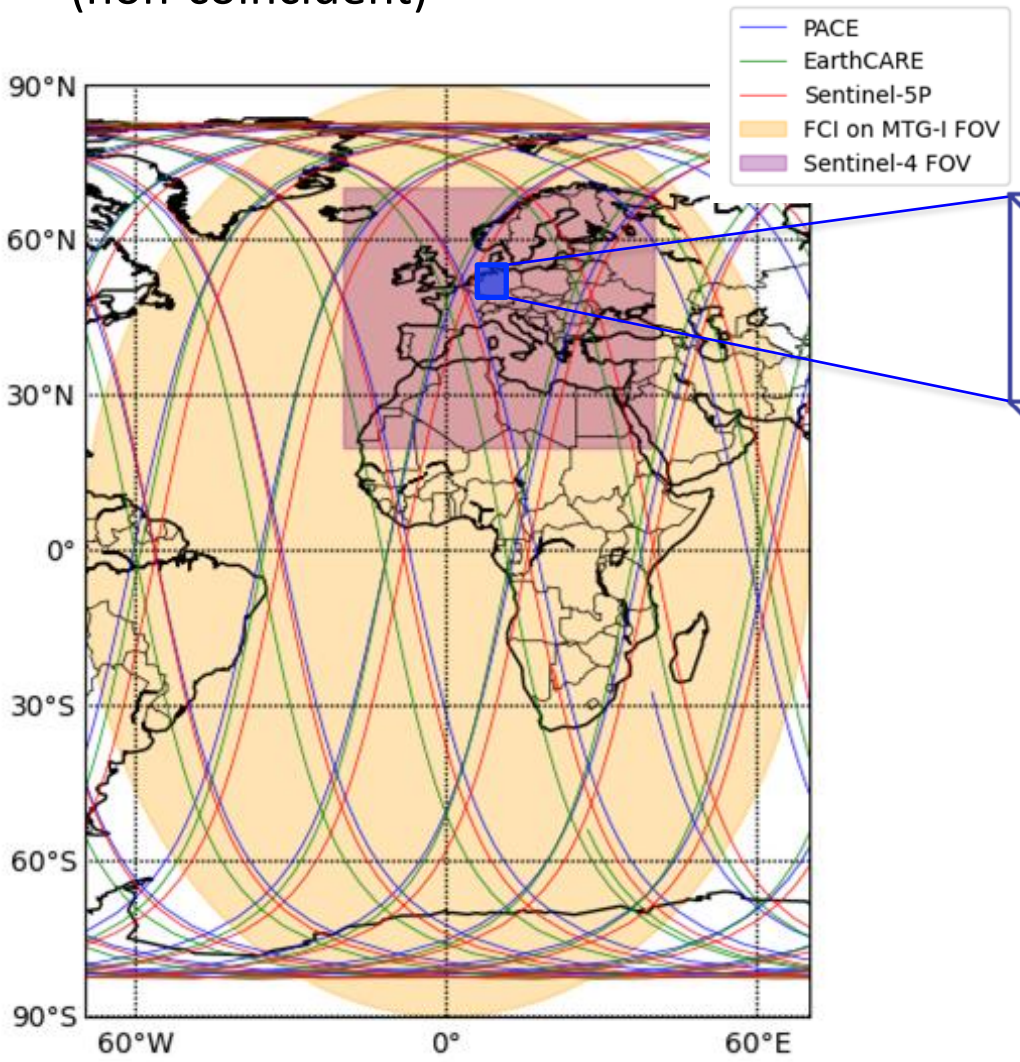
SSA from AHI/GRASP (SYNERGY)

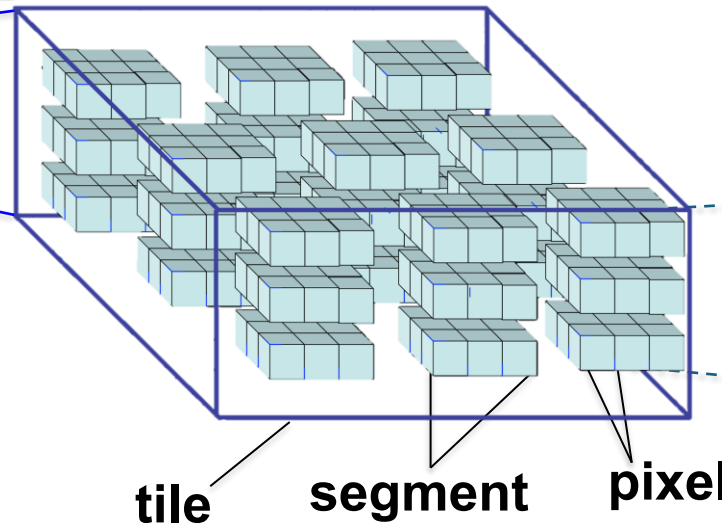


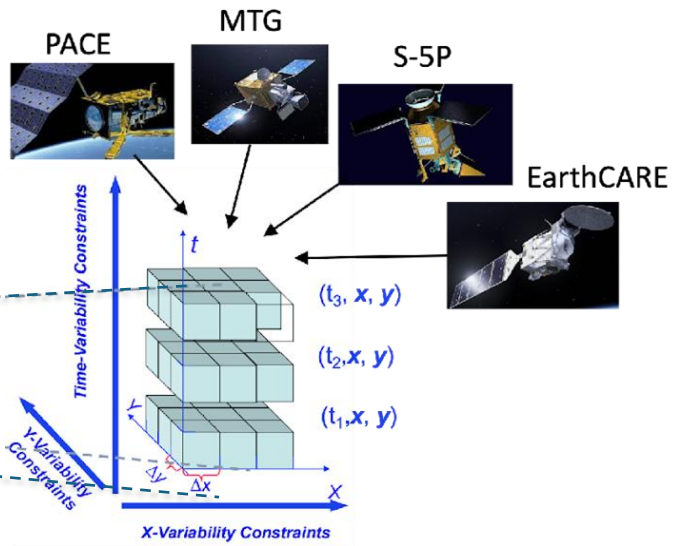
AE and **SSA** normally are not available from GEO

GLADIS: next level of passive & active synergy

- Extend AIRSENSE approach to vertical profiling to maximise ATLID/EarthCARE and passive synergy (non-coincident)







GLADIS

esa EarthCARE +

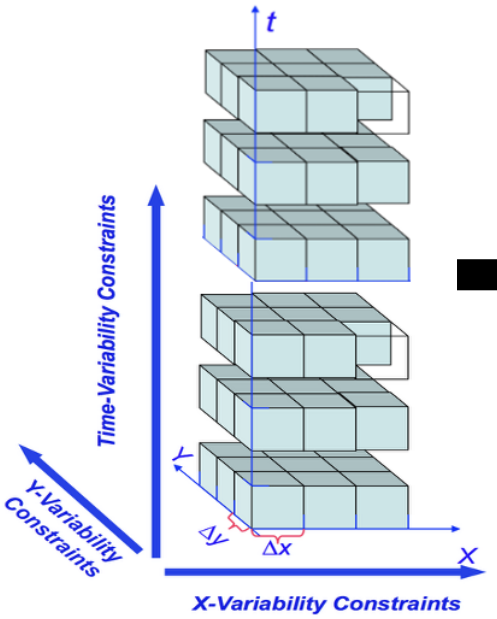
Time constraints to be used:

- Surface changes very slowly
- Columnar aerosol type changes moderately in time
- Aerosol vertical distribution changes in time are limited

THANK YOU FOR YOUR ATTENTION!

Formalism of Multi - Pixel Retrieval:

Dubovik et al.. 2011, 2021



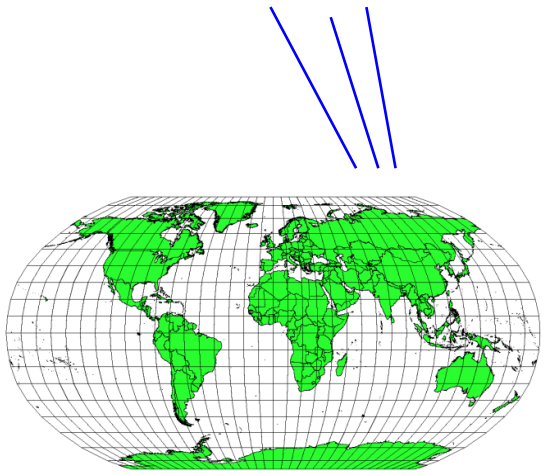
$$\begin{pmatrix} f_1^* \\ o_1^* \\ f_2^* \\ o_2^* \\ f_3^* \\ o_3^* \\ \dots \\ O_t^* \\ O_x^* \\ O_y^* \end{pmatrix} = \begin{pmatrix} F_1 & 0 & 0 \\ S_1 & 0 & 0 \\ 0 & F_2 & 0 \\ 0 & S_2 & 0 \\ 0 & 0 & F_3 \\ 0 & 0 & S_3 \\ \dots & \dots & \dots \\ S_{t,1} & S_{t,2} & S_{t,2} \\ S_{x,1} & S_{x,2} & S_{x,3} \\ S_{y,1} & S_{y,2} & S_{y,3} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} + \begin{pmatrix} \begin{pmatrix} \Delta_1^m \\ \Delta_1^a \end{pmatrix} \\ \begin{pmatrix} \Delta_2^m \\ \Delta_2^a \end{pmatrix} \\ \begin{pmatrix} \Delta_3^m \\ \Delta_3^a \end{pmatrix} \\ \Delta_t^a \\ \Delta_x^a \\ \Delta_y^a \end{pmatrix}$$

Single-Pixel Data (PARASOL measurements and physical a priori constraints) ***are used by the same way as in Single-Pixel retrieval.***

Multi-Pixel a priori constraints (*e.g.Dubovik et al. 2008):*

- limited ***spatial*** variability of each aerosol /surface parameter
- limited ***temporal*** variability of each aerosol /surface parameter

NOTE: *degree of variability constraints (smoothness) can be different and adequately chosen for each parameter*



Multi-term LSM ***Multi-Pixel Solution:***

$$\begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \left[\begin{pmatrix} \mathbf{F}_1^T\mathbf{W}_1^{-1}\mathbf{F}_1 & 0 & 0 \\ 0 & \mathbf{F}_2^T\mathbf{W}_2^{-1}\mathbf{F}_2 & 0 \\ 0 & 0 & \mathbf{F}_3^T\mathbf{W}_3^{-1}\mathbf{F}_3 \end{pmatrix} + \begin{pmatrix} \gamma_1\Omega_1 & 0 & 0 \\ 0 & \gamma_2\Omega_2 & 0 \\ 0 & 0 & \gamma_3\Omega_3 \end{pmatrix} + \gamma_x\Omega_x + \gamma_y\Omega_y + \gamma_t\Omega_t \right]^{-1} \begin{pmatrix} \mathbf{F}_1^T\mathbf{W}_1^{-1}\Delta\mathbf{f}_1^p \\ \mathbf{F}_2^T\mathbf{W}_2^{-1}\Delta\mathbf{f}_2^p \\ \mathbf{F}_3^T\mathbf{W}_3^{-1}\Delta\mathbf{f}_3^p \end{pmatrix}$$

$$\Omega_x = \mathbf{S}_x^T\mathbf{S}_x;\ \Omega_y = \mathbf{S}_y^T\mathbf{S}_y;\ \Omega_t = \mathbf{S}_t^T\mathbf{S}_t;\ \gamma_x = \frac{\varepsilon_f^2}{\varepsilon_x^2};\ \gamma_y = \frac{\varepsilon_f^2}{\varepsilon_y^2};\ \gamma_t = \frac{\varepsilon_f^2}{\varepsilon_t^2}$$

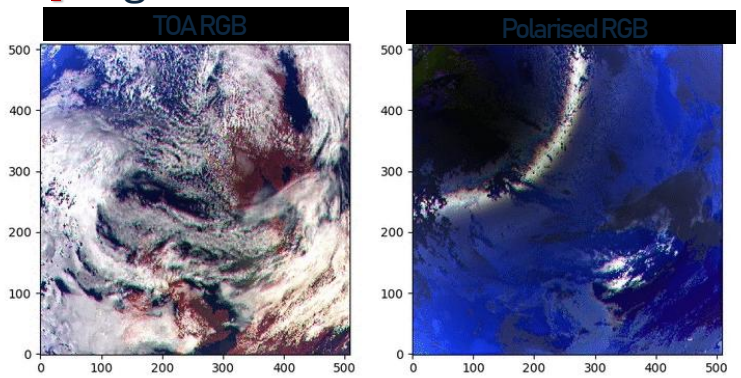
3MI NRT Aerosol Processor and Product

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

L1 product

- Radiances and polarization (8 bands)
- 10-14 viewing directions

240 – 336 measurements



3MI L2 Aerosol Processor:
GRASP: Generalized Retrieval of Aerosol and Surface Properties

GRASP
In principle, yes!

L2 Aerosol product

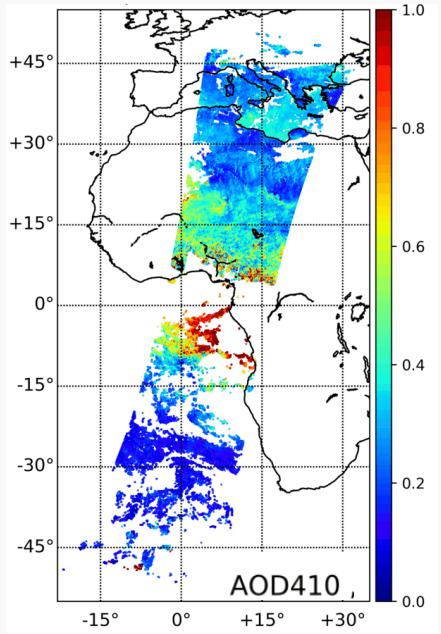
Retrieved parameters
(more linked to GRASP optimisation)
&
Derived parameters
(more linked to user needs)

AEROSOL
- Size distribution
- Fraction of chemical components
- Sphericity fraction
- Aerosol layer height

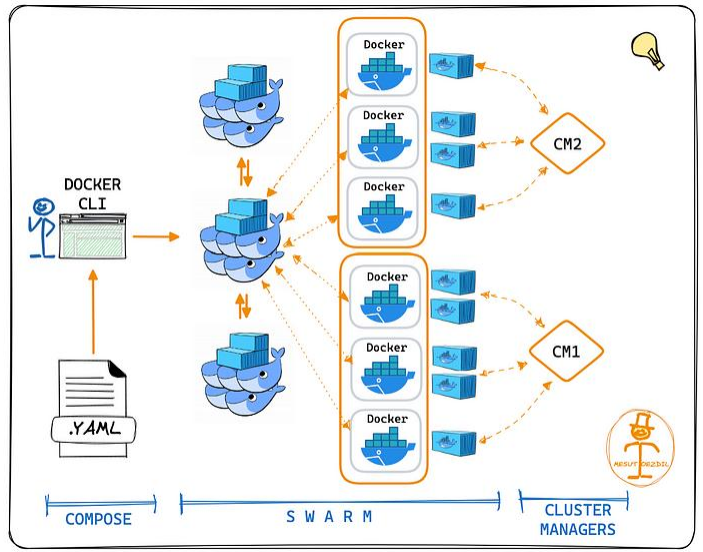
spectral properties (8 wavelengths):
- AOD (fine and coarse)
- Absorbing AOD
- Angstrom Exponent
- SSA
- Index of refraction

Error Estimation

Surface
- BRDF (3 Spectrally dependent parameters) and BPDF



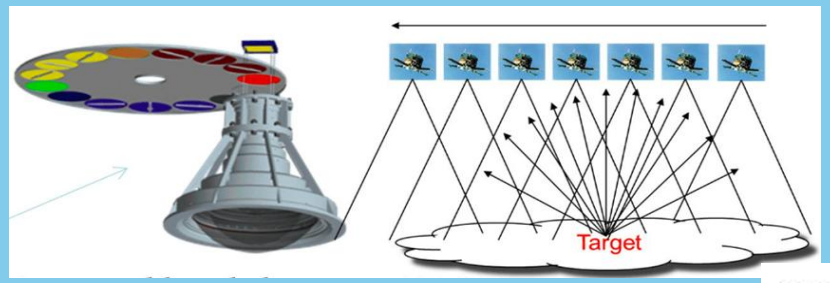
Proposed Architecture for the NRT GRASP



- Product to be tailored to better meet the user's requirement in term of product content and accuracy;
- Regular interaction with users and collection of feedback needed.

Curtesy of Bertrand Fougnie, EUMETSAT

Multi-Angular Polarimeters



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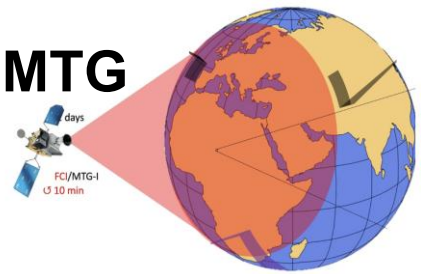
GEO Imagers



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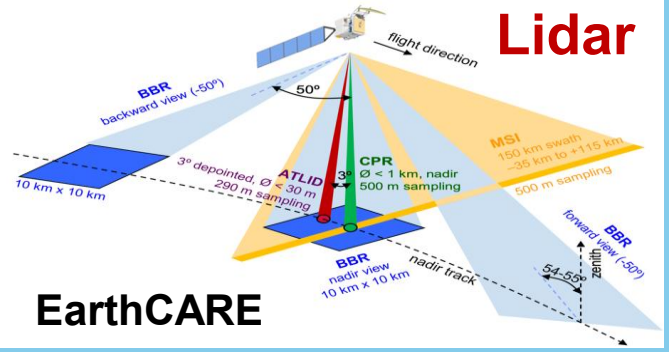
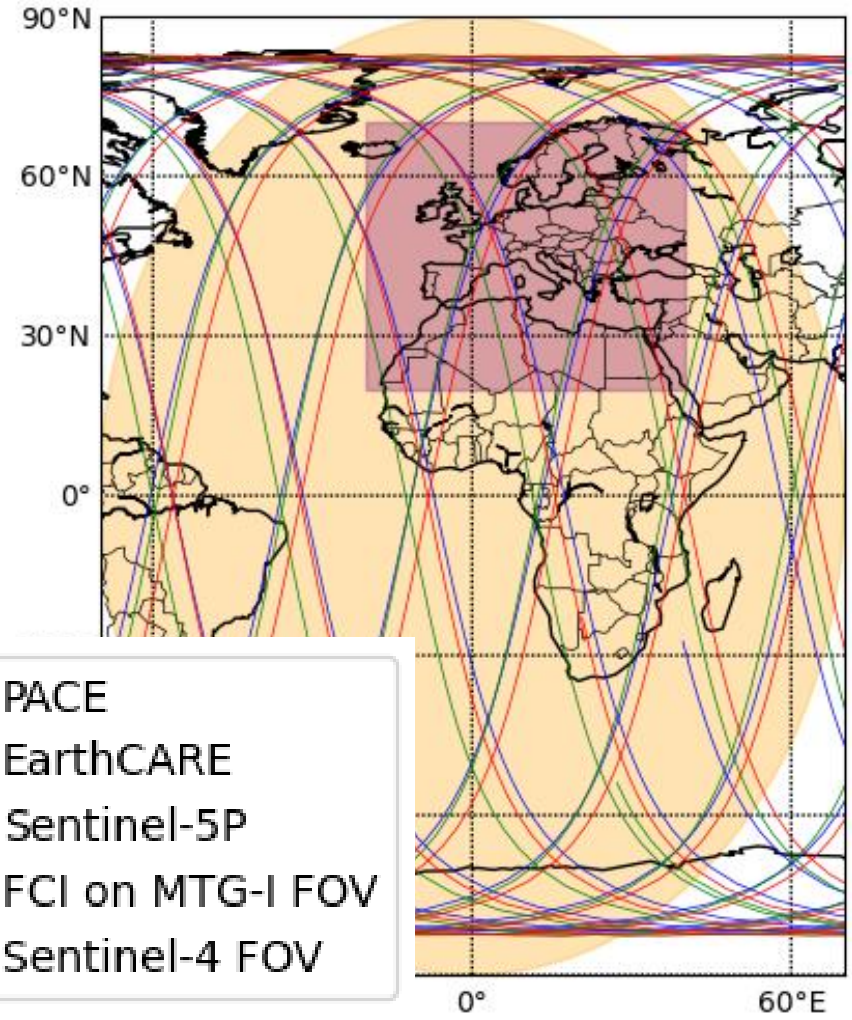
Lidar



GLADIS

esa

EarthCARE +



ECAMS

AIRSENSE

<u>ISSUE:</u> There is no fully co-incident and co-located passive Multi-Angular- Polarimetric observations

<u>Nonetheless:</u> There are often co-incident and co-located GEO observations.