Multi-Mission Synergetic Retrieval for Enhanced Aerosol and Surface Characterization

Pavel Lytvynov[a], Oleg Dubovik[a,b], Siyao Zhai[a] , Cheng Chen[c], Christian Matar[a], Smita Panda[a], Goyo Cancio[a], Juan Lopez[a], Xinyue Wang[a], Chong Li[a], Anton Lopatin[a], David Fuertes[a], Tatyana Lapyonok[b], Daniele Gasbarra[c], Cristian Retscher[d], Silvia Scifoni[d], and Philippe Goryl[d]

a: GRASP b: Laboratoire d'Optique Atmosphérique c: AIOFM d: esa

Aerosol and its characterization in remote sensing

Dust outburst

Aerosol from volcano eruptions

Anthropogenic pollution

Biomass burning

Full aerosol characterization

1. Size
2. Aerosol chemistry: absorption and hygroscopic properties
3. Particle structure: morphology, homogeneity, shape etc
4. Vertical distribution
5. Spatial and temporal variability

Aerosol remote sensing is based on the models of aerosol and atmosphere

Physical/chemical aerosol characterization

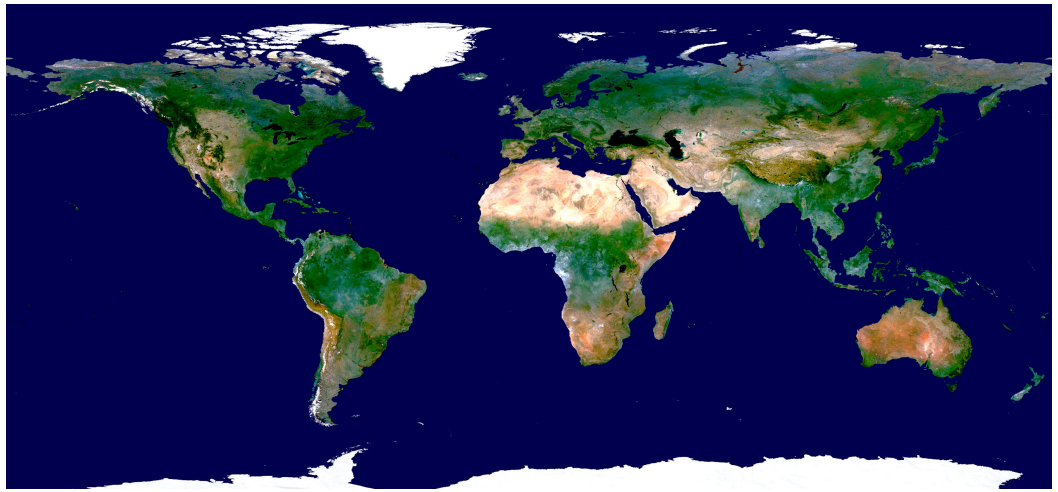
1. Size distribution
2. Aerosol chemistry (complex refractive index)
3. Nonsphericity
4. Concentration vertical profile
5. Atmosphere temperature vertical profile (for TIR)

Aerosol optical characterization

1. **AOD**: aerosol concentration
2. **AE**, Angstrom Exponent (spectral dependence of AOD): aerosol size
3. **SSA**: aerosol absorption
4. **dSSA** (spectral dependence of SSA): size and absorption

Surface and its characterization in remote sensing

Surface reflectance



Full Surface characterization

1. Topology
2. Surface structure : morphology, heterogeneity, scatterers distribution etc
3. Surface scatterers chemistry
4. Temperature (TIR)

Too complex!

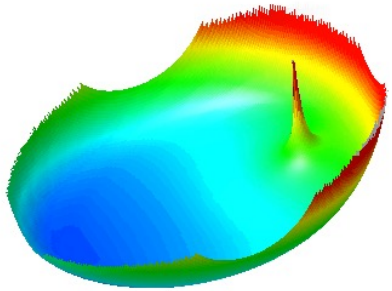
Surface Remote sensing for atmospheric studies is based on

BRDF models: Bi-Directional Reflectance Distribution Function

Land use & Deforestation

Ocean color: sediments and chlorophyll

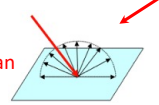
BRDF derived from dessert surface (Banizoumbou)



BRDF parameters to be derived: a_{iso}, a_{vol} , a_{geom}

$$BRDF_{Ross-Li} = a_{iso}(\lambda)\cdot(1 + a_{vol} f_{vol} + a_{geom} f_{geom})$$

Isotropic Lambertian term:



Volumetric turbid medium term (RTT):

Geometric optics shadow driven term term (GO):

A soybean field

backscattering forward scattering

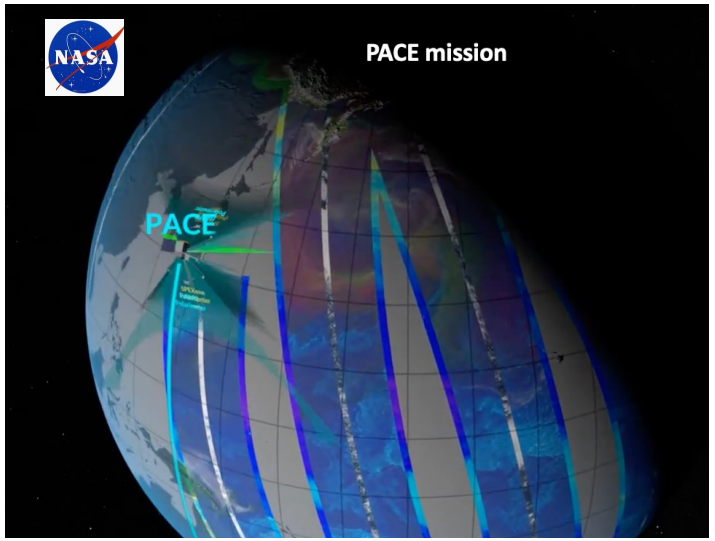
https://www.umb.edu/spectralmass/terra_aqua_modis/modis

Atmospheric studies and applications	Advanced aerosol characterization						
	1. AOD	2. Extended properties			3. Vertical profile	4. Spatial Resolution/ Coverage	5. Temporal resolution
		Absorp-tion (i.e. SSA)	Size (AExp)	Microphysics, Chemistry, Hygroscopicity			
Aerosol ECVs (GCOS-245)	X	X	X	-	X	A few km or more Global	Daily or monthly
Air quality monitoring and forecasting	X	X	X	X	X	The finer is better (a few meters)	Hourly or better
Aerosol dynamic, aerosol-cloud interaction etc	X	X	X	X	X	Fine and moderate	Hourly or better
Global and regional climate models	X	X	X	X	X	From a few meters to hundred km Global	Hourly, Daily
Aerosol as auxiliary product for Atmospheric and surface studies	X	X	X	-	X		From Hourly, to Monthly

Aerosol characterization from space: current status		Advanced aerosol characterization				
		1. AOD	2. Extended properties	3. Vertical profile	4. Spatial resol.	5. Temporal resolution
1. Single angle observation: - moderate or coarse spatial resolution - wide swath	MODIS-, Sentinel-3-like	+	Rather not	Rather not	Moderate	Daily
	TROPOMI-like: - Wide spectra range - Hyperspectral	+	- Absorption (SSA) - Size (Angstrom Exponent)	Possible with O2A band	Rather coarse	
2. Single angle obs. (Sentinal-2 like): - high spatial resolution - narrow swath (~ 200 km or less)		+	Rather not	Rather not	High Spatial	A few days per week
3. Geostationary (Sentinel-4, FCI etc)		+	Limited	Rather not	Rather coarse	High temporal
4. Multi-angular polarimeters (PARASOL, SPEX, HARP-2, 3MI etc)		+	High accuracy	Limited	Rather coarse	Daily
5. Active	Space LIDAR	+	Size, Aerosol type	+	-	-
	TIR sensors	Dust AOD	Dust chemistry	Rather not	Coarse	Daily

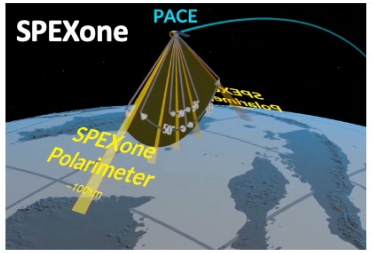
Multi-angular Polarimeters for aerosol studies

PACE mission



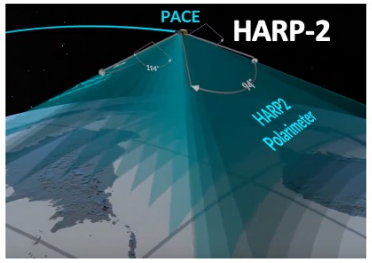
- 385-770 nm continues
- 5 viewing angles
- 30+ day global coverage
- 2.5 km spatial resolution

high information content;
high meas. precision;

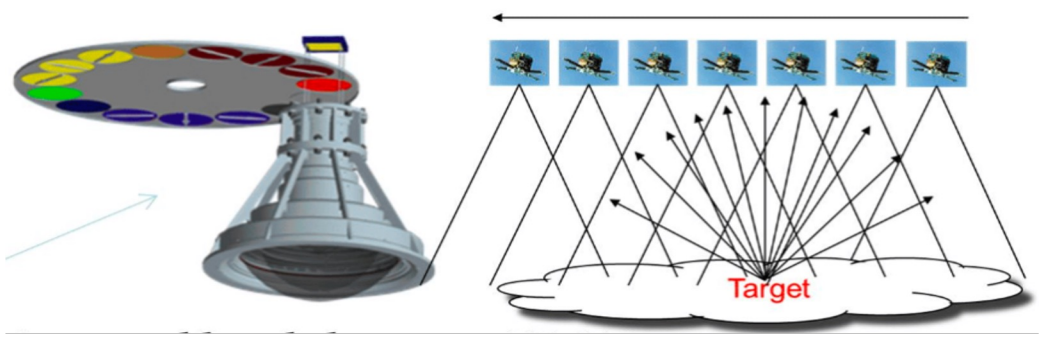


- 440, 550, 670, 870 nm
- viewing angles:
  - 10 for 440, 550, 870 nm
  - 60 viewing angles for 670
- 2 days global coverage
- 3 km spatial resolution

high information content;
wide coverage;



3MI/METOP-SG



EUMETSAT esa

MAP/CO2M

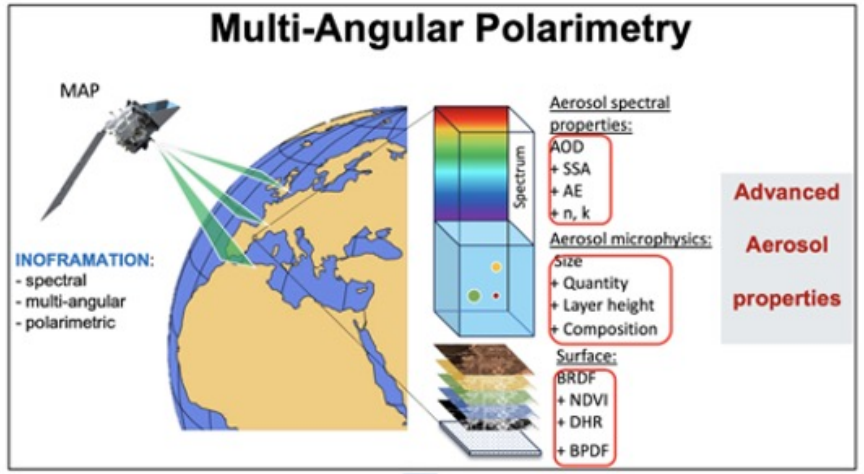
Polarimeters greatly advance aerosol characterization

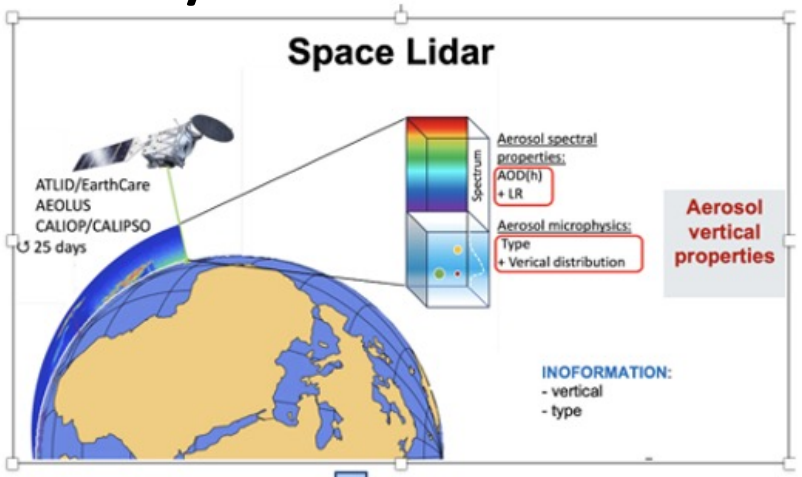
but

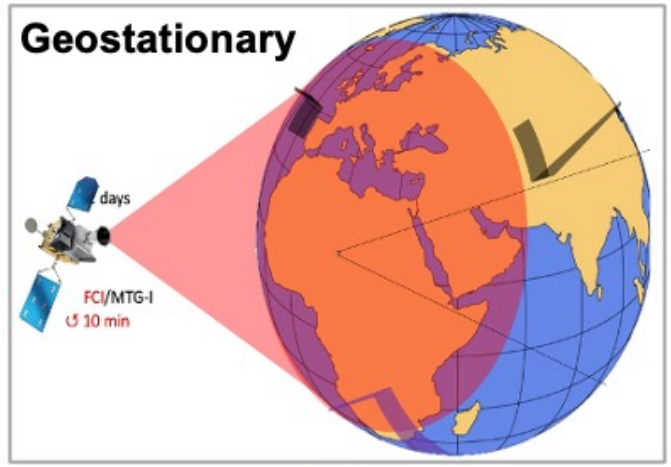
still have number of limitations:

- Temporal coverage
- Vertical profiling

2. Solution: Multi-mission synergetic constellations and aerosol/surface retrieval







columnar aerosol properties

Advantage:
high information content regarding columnar prosperities

vertical aerosol properties

Advantage:
high sensitivity to vertical variability of aerosol

temporal and spatial variations of aerosol properties

Advantage:
detailed spatial and temporal coverage

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

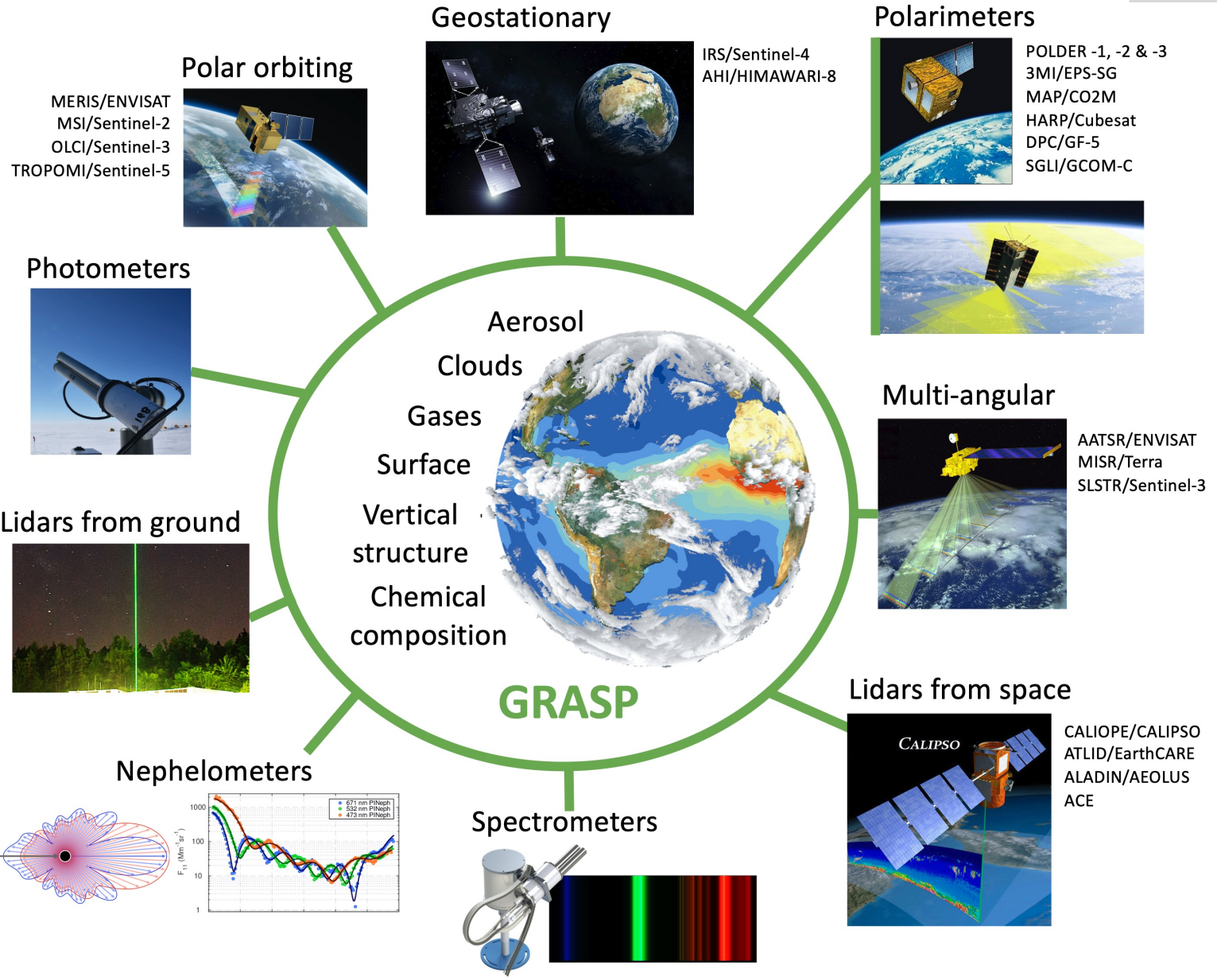
➢ Transfer of information from one instrument to another!

➢ Filling gaps in information content: several instruments as a single one!

GRASP for Multi-mission, Multi-instrument synergy

Requirements on the retrieval algorithms for synergy:

1. Algorithm should be based on advanced inversion approach and adaptable flexible forward models.
2. Algorithm should be able to account for diverse measurements from different instruments.
3. Algorithm should be able account for multi-temporal and multi-spatial measurements (**not collocated measurements**).



Dubovik et al. *"A Comprehensive Description of Multi-Term LSM for Applying Multiple a Priori Constraints in Problems of Atmospheric Remote Sensing: GRASP Algorithm, Concept, and Applications", Front. Remote Sens., 2021*

Litvinov et al. *"Synergetic Retrieval from Multi-Mission Spaceborne Measurements for Enhancement of Aerosol and Surface Characterization, AMT, 2025*

Multi-mission synergetic constellations and aerosol/surface retrieval

Synergy	Instrument/ Platform	Spectral Range	Resolution		Specific sensitivity to dedicated products and added value
			Spatial	Timporal	
LEO+LEO **Solar** Spectrum	TROPOMI, S5, 3MI (HARP-2, SPEX), Sentinel-3A/B/C etc	UV + VIS + NIR + SWIR	4-10 km	a few hours	Aerosol: AOD, AODF, AODC, AE, SSA, Aerosol microphysics and chemistry etc. Surface: BRDF, BPDF, Surface albedo etc.
		UV + VIS + NIR + SWIR + Hyperspectral (S5)			+ Aerosol layer hight
LEO+LEO **Solar + TIR** Spectrum	LEO+LEO (Solar) + IASI-NG (TIR)	UV + VIS + NIR + SWIR + TIR	12 km		+ DLH + Dust Chemistry + Surface TIR emissivity + Surface Temperature
LEO + GEO	LEO+LEO+FCI (HIMAWARI) LEO+LEO+TIR+ FCI	UV + VIS + NIR + SWIR UV + VIS + NIR + SWIR + TIR	1-12 km	10 min	LEO + LEO + + high temporal resolution of the product

GRASP multi-mission synergetic retrieval: SYREMIS

GRASP cloudflight esa

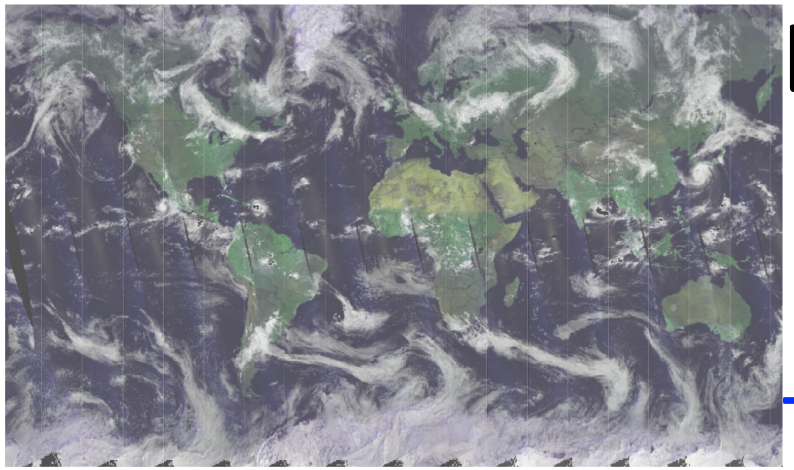
Satellites	Description
Sentinel-3A /OLCI and Sentinel-3B/OLCI	- Polar-orbiting, global coverage - One observation per pixel - Moderate spatial resolution - Radiance measurements in VIS and NIR spectral range
Sentinel-5p/TROPOMI	- Polar-orbiting, global coverage, from 1 to a few observations per day - Hyperspectral measurements in UV, VIS, NIR, SWIR spectral range
Himawari/AHI	- Geostationary. Coverage area: Asia - Every 15 min daily measurements - Radiance measurements in VIS, NIR and SWIR spectral range

Litvinov et al., AMT 2025

SYREMIS Synergy	i. Multi-spectral			ii. Multi-angular	iii. Multi-Polarization	iv. Multi - Temporal
	UV	VIS - NIR	SWIR			
S3A/OLCI + S3B/OLCI + TROPOMI + HIMAWARI	+	+	+	+ Quasi multi-angular	-	+

LEO+LEO and LEO+GEO synergy

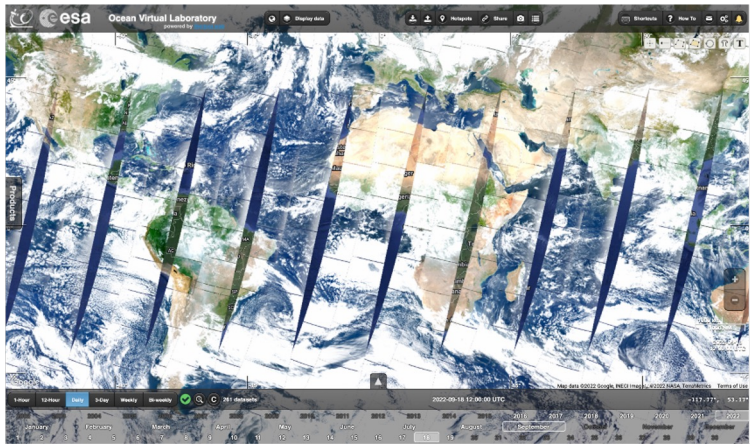
Litvinov et al., AMT 2025



TROPOMI

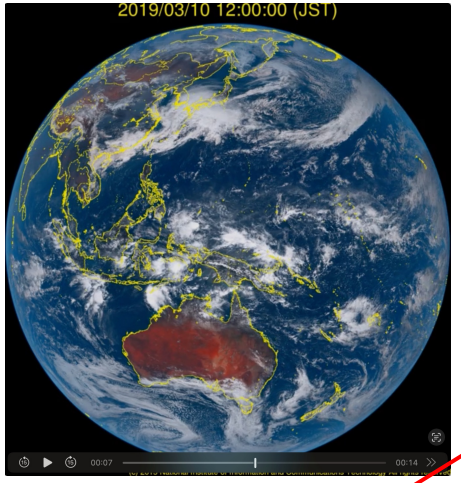
+

OLCI-A + OLCI-B



+

HIMAWARI



OLCI-A

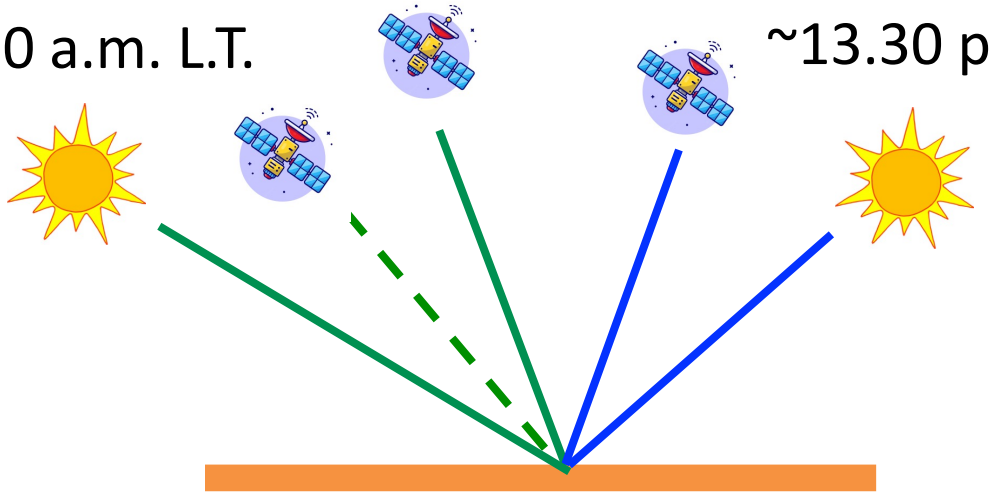
~10 a.m. L.T.

OLCI-B

~10.20 a.m. L.T.

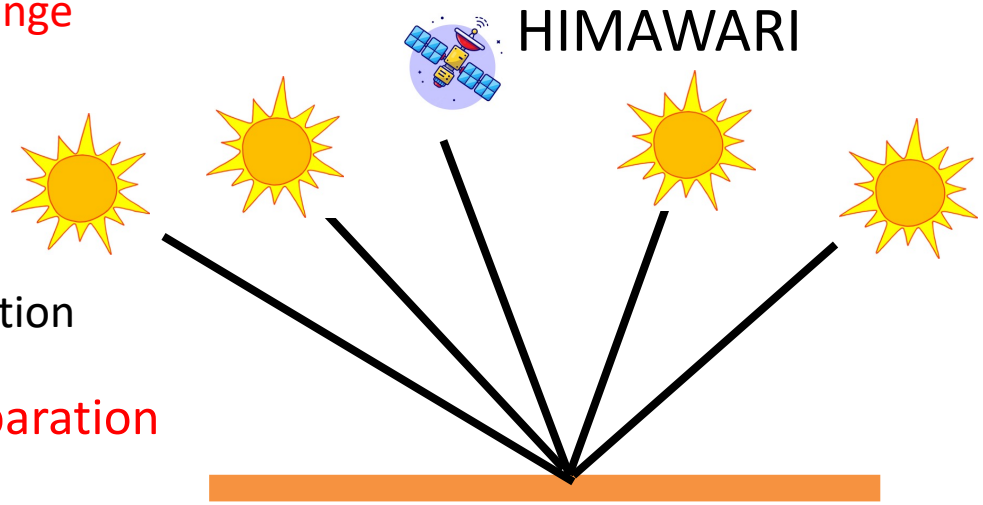
TROPOMI

~13.30 p.m.



+

HIMAWARI



➢ Extended spectral range

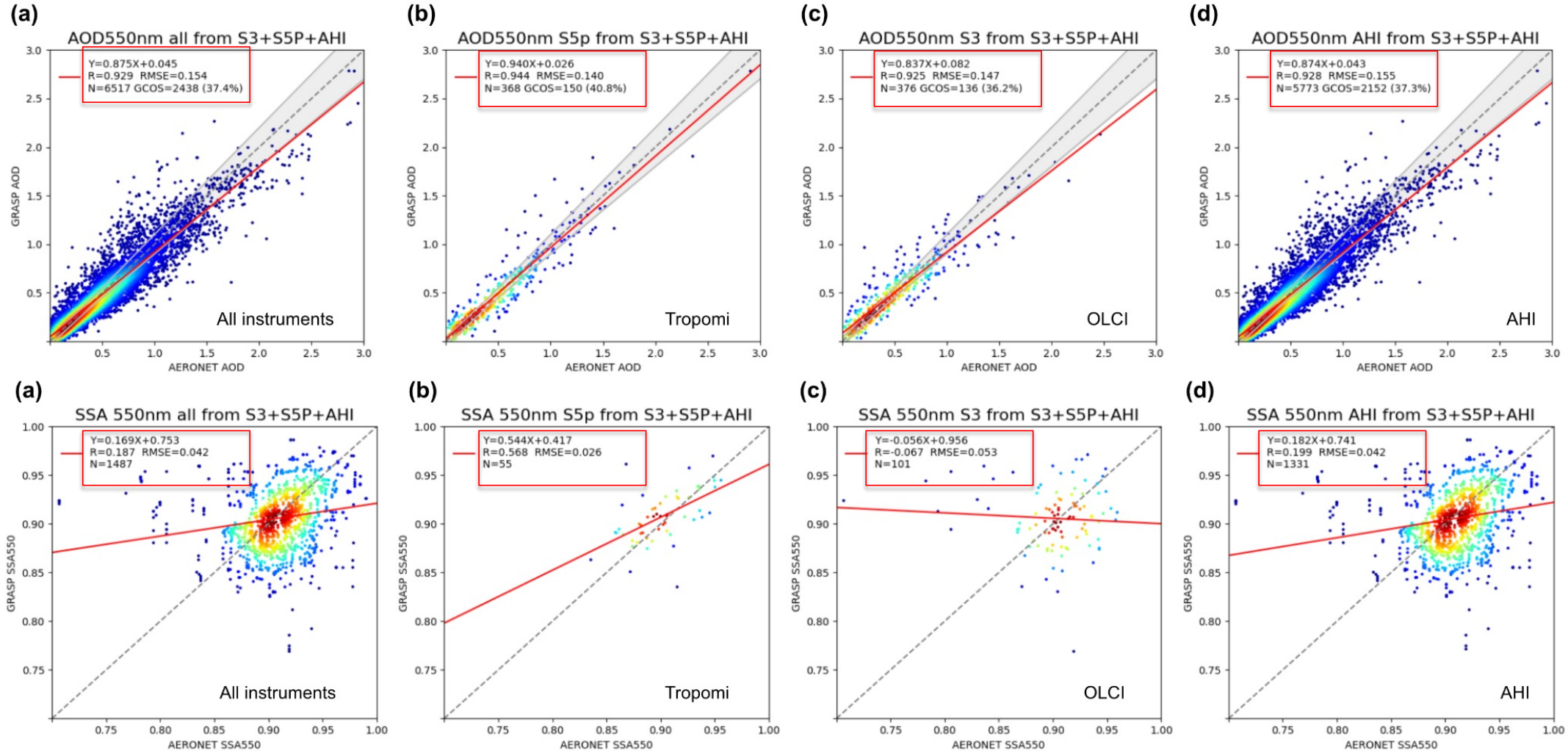
$$I_{SYN}(\theta_{1sol}, \ldots, \theta_{Nsol}; \theta_{1sat}, \ldots, \theta_{Nsat}; \Delta\varphi_1, \ldots, \Delta\varphi_N; t_1, \ldots, t_N; \lambda):$$

➢ Quasi multi-angular measurements

➢ Hight temporal resolution measurements!

1. Better surface BRDF sampling and surface/atmosphere signal separation
2. **Hourly (or better) extended** aerosol properties variability!

YREMIS/GRASP **LEO+GEO** synergy and extended aerosol characterization



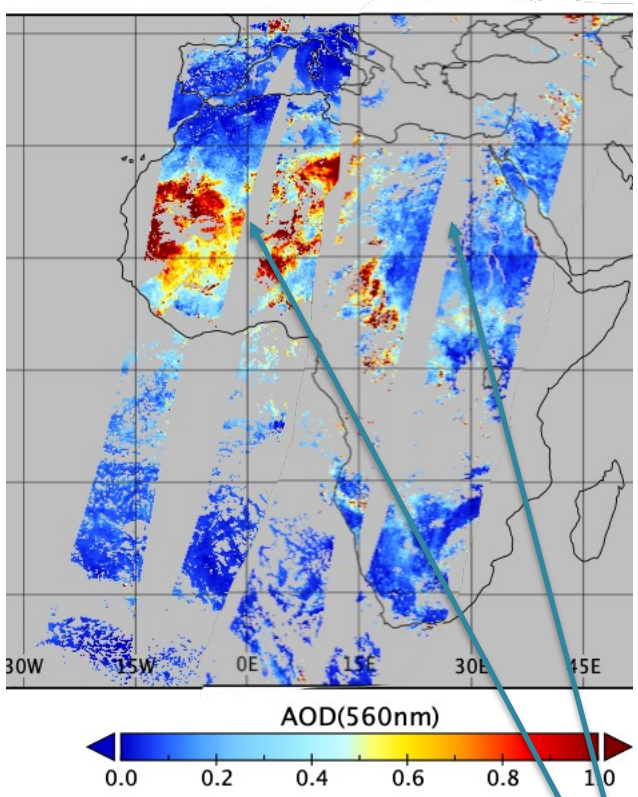
1. Extended aerosol properties (AOD, AExp, SSA etc) are improved for all instruments
2. The biggest improvements are for the instruments with smaller information content (OLCI, AHI)
3. TROPOMI is a driver of the considered synergy
4. Consistent retrieval for all instruments in the synergy!

SYREMIS/GRASP synergetic retrieval

- **Consistent retrieval from OLCI A, B and TROPOMI**

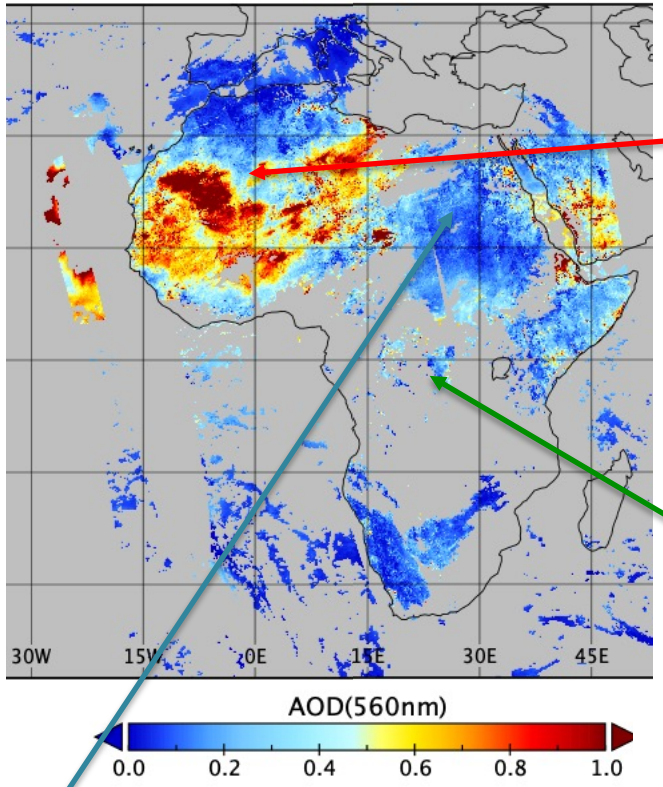
- **Several measurement per day (aerosol transport):**
  OLCI A/B (~10 a.m.),
  TROPOMI (~13.00 p.m.).

Aerosol Optical Depth for 560 nm



OLCI A/B (~10 a.m.)

Aerosol Optical Depth for 560 nm

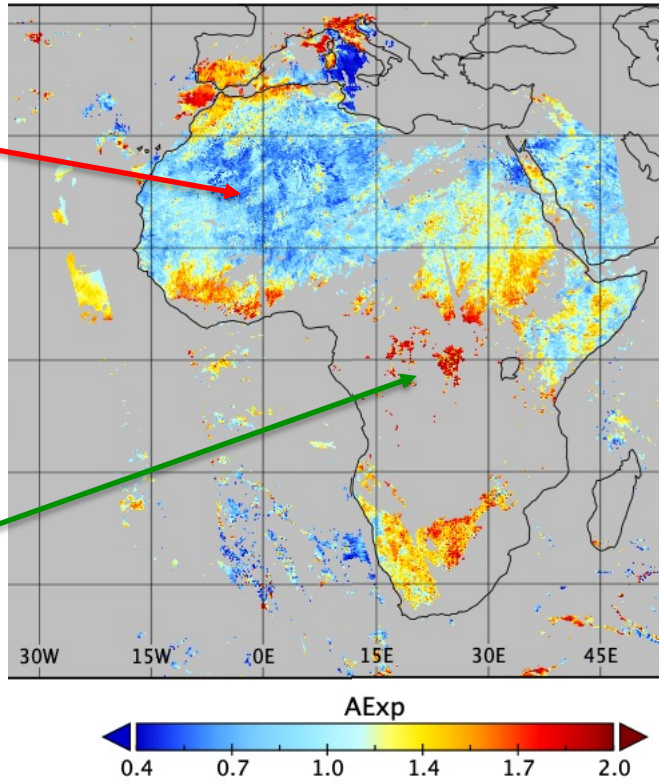


TROPOMI (~13.00 p.m.)

Dust

Biomass Burning

Angstrom Exponent



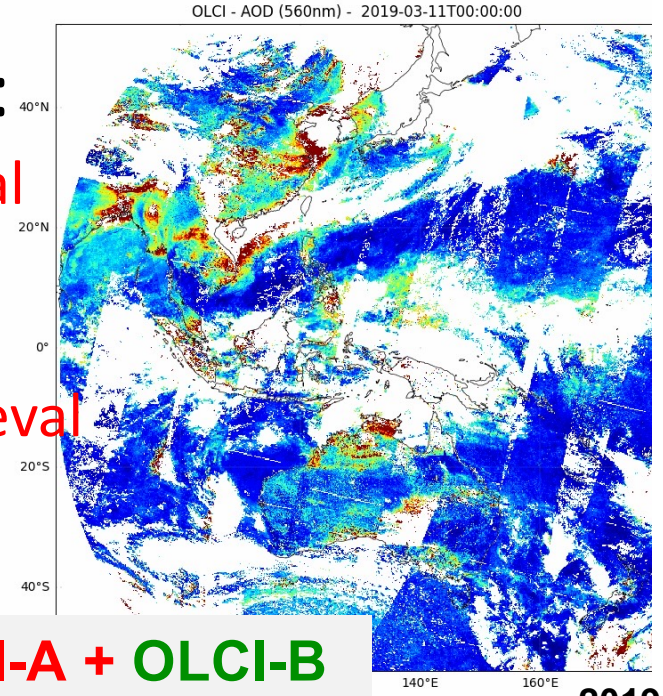
TROPOMI (~13.00 p.m.).

- **Better spatial coverage**

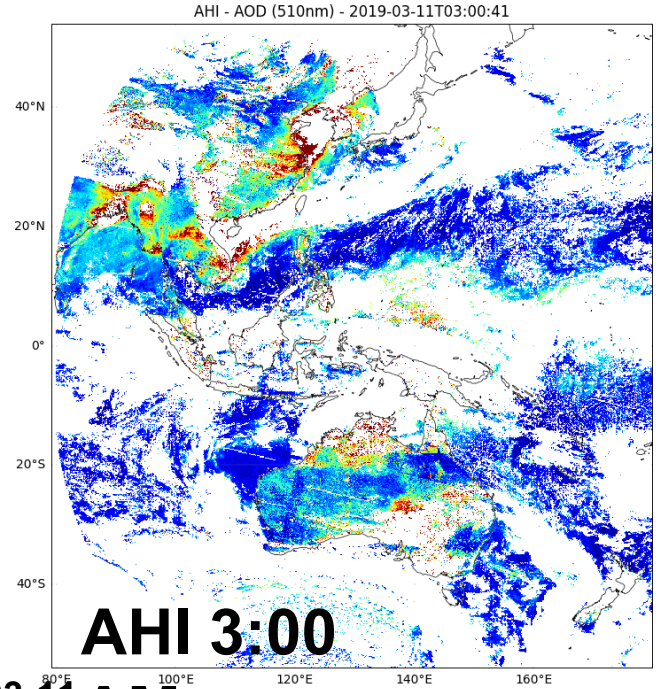
✓ **Extended aerosol properties: AOD, AExp, SSA etc.**

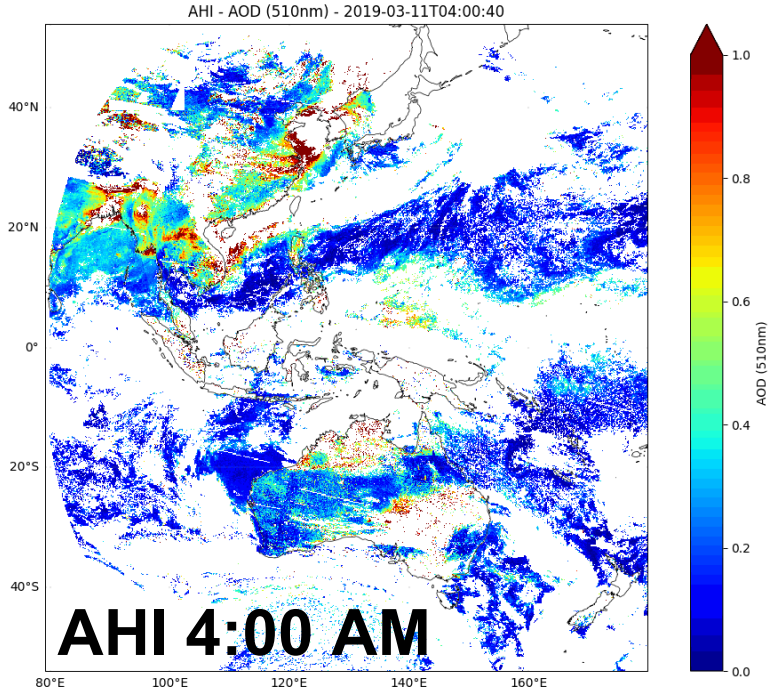
LEO+GEO:

high temporal (diurnal) resolution aerosol retrieval



OLCI-A + OLCI-B

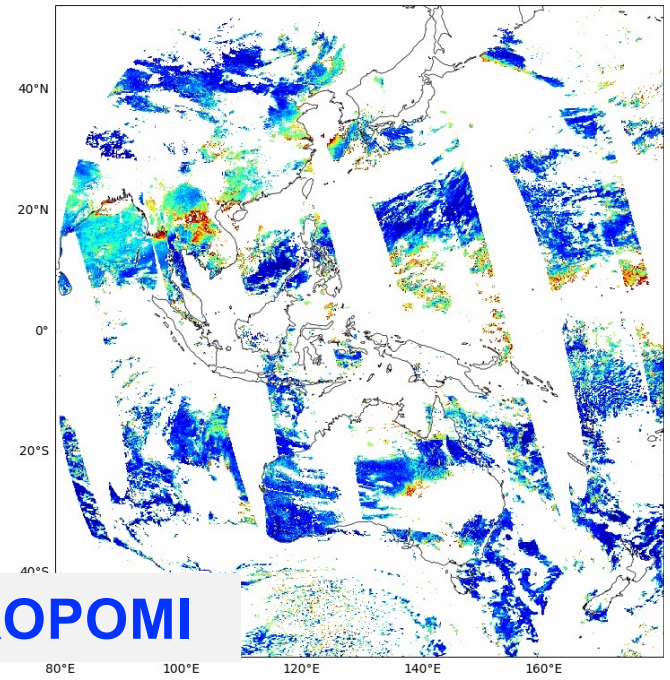




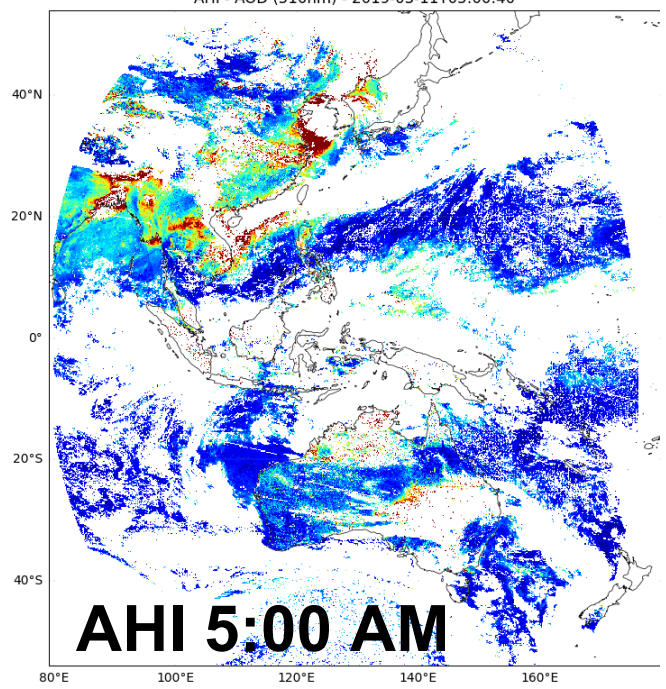
2019-03-11 - -

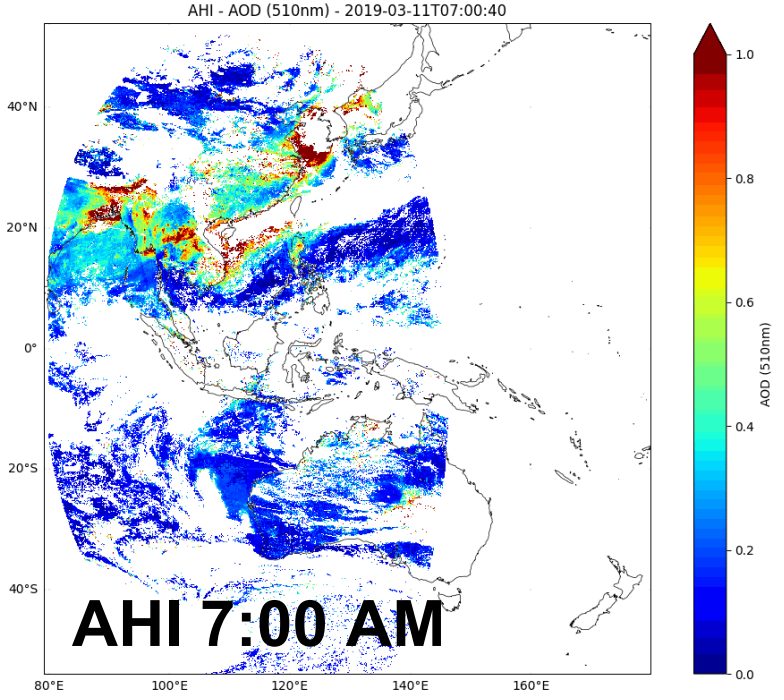
Consistent retrieval from all instruments in the synergy:

- OLCI-A
- OLCI-B
- AHI
- TROPOMI

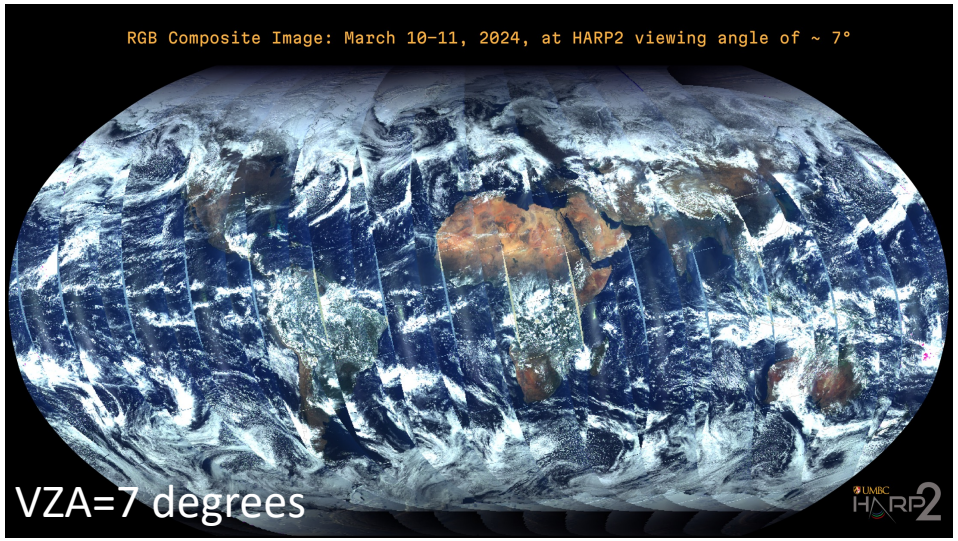


TROPOMI





LEO+LEO synergy with polarimeter



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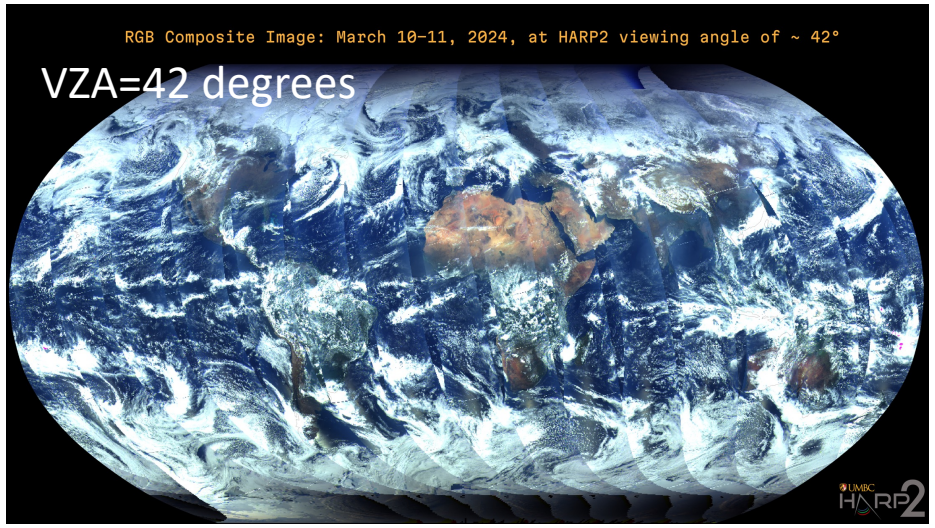
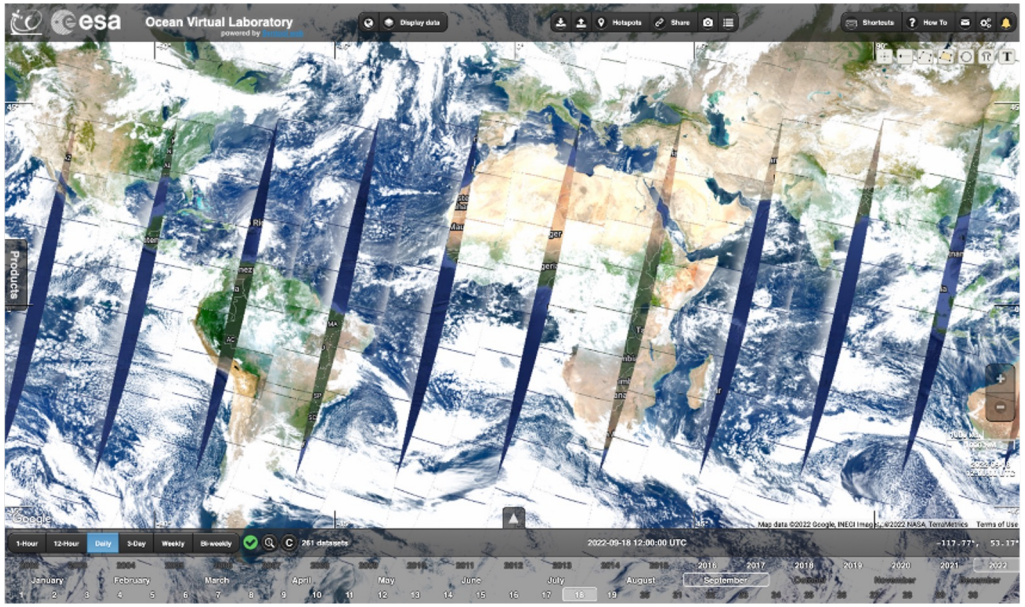
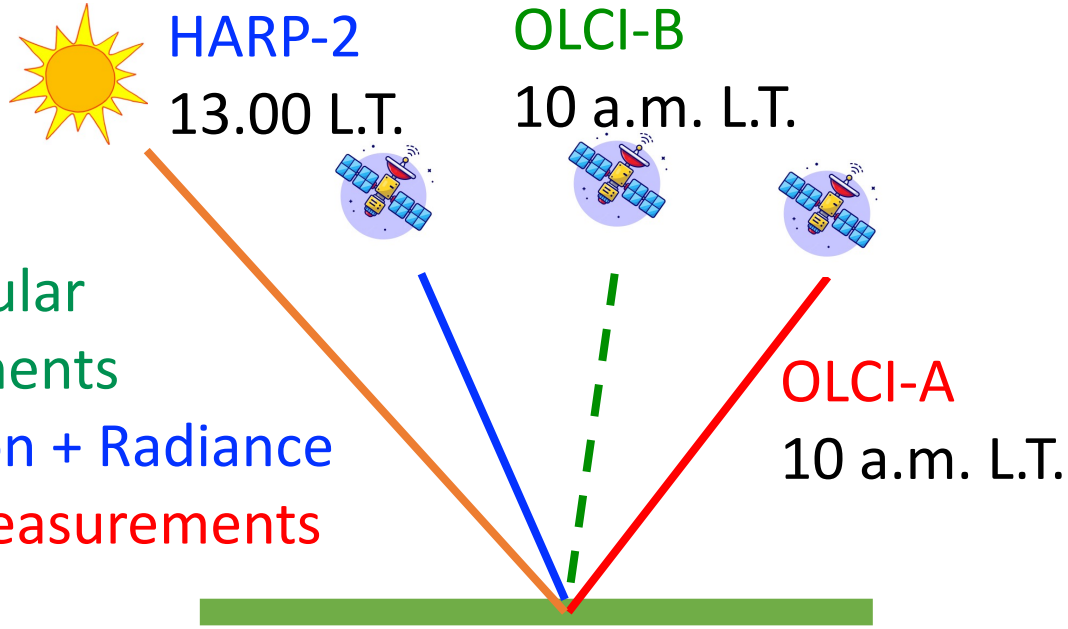


+ **PACE/HARP-2 multi-angular, polarimetric**



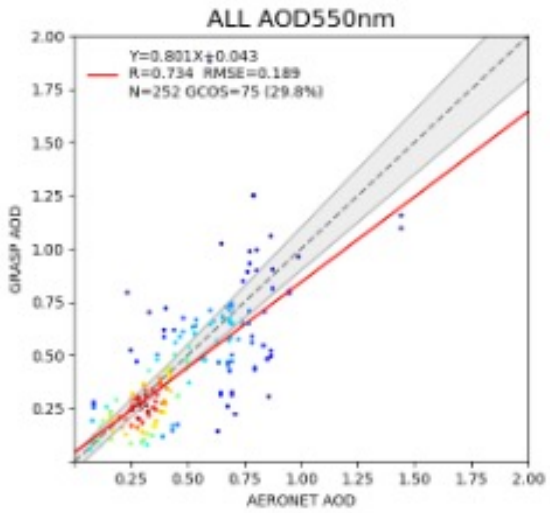
OLCI-A + OLCI-B

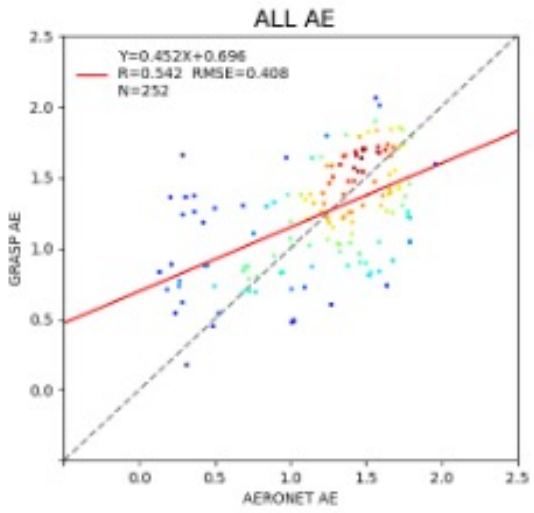
- Multi-angular measurements
- Polarization + Radiance
- Several measurements per day!

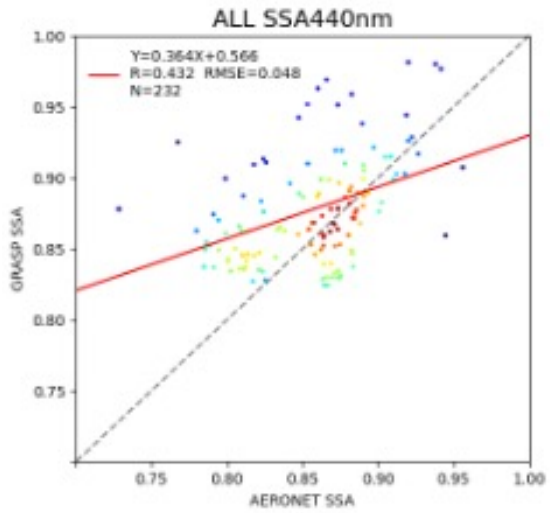


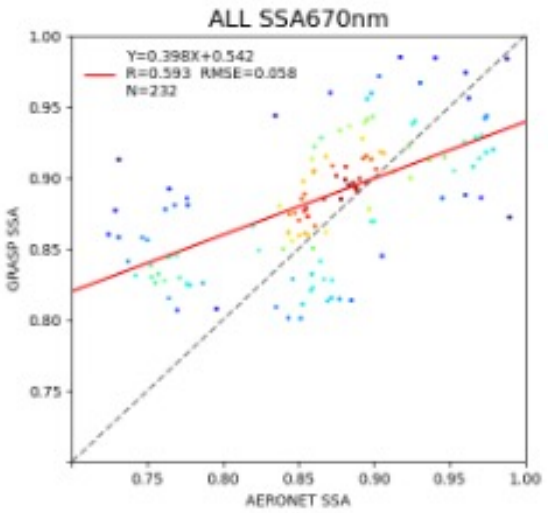
SYREMIS/GRASP HARP-2 and OLCI synergy: added value of HARP-2

HARP-2
+
OLCI-A
+
OLCI-B



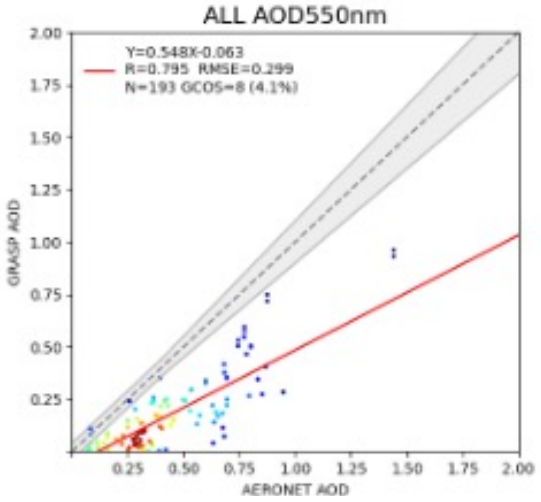


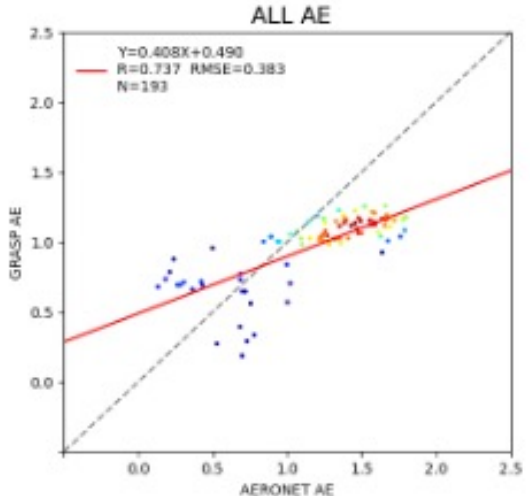


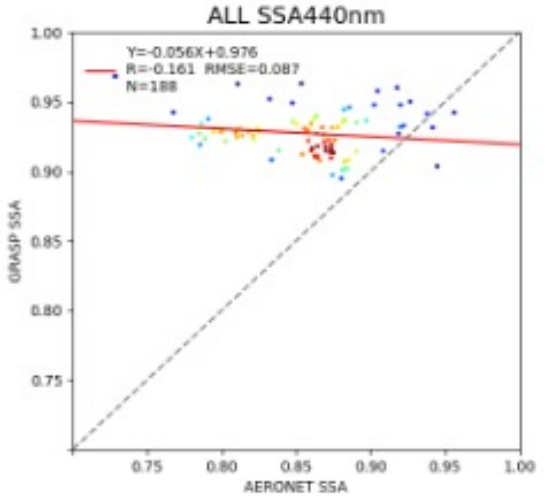


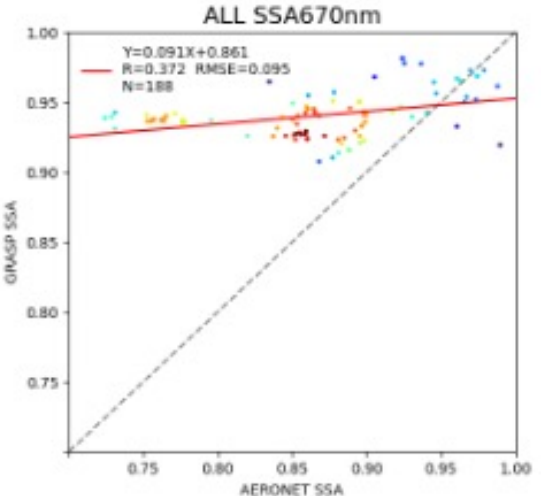
HARP-2 is a driver of synergy with OLCI!

OLCI-A
+
OLCI-B









Multi-mission synergy with GRASP: status and future perspectives

Synergy constellation	Instrument/ Platform	Synergy Driver	Aerosol characterization				
			1. AOD	2. Extended properties		3. Vertical profile	4. Temporal resolution
				AExp, SSA	Microphysics, Chemistry, Hygroscopicity		
LEO+LEO Single-viewing Intensity-only measurements instrument	TROPOMI + OLCI-A + OLCI-B	**TROPOMI**: 1. UV-SWIR 2. Wide swath	Improved	Improved	Basic aerosol typing	Should be improved! ➢ Hyperspectral measurements ➢ Synergy with Space LIDAR ➢ Synergy with ground-based LIDAR	Improved (several measurements per day)
LEO+LEO Single-viewing Intensity-only + **multi-angular polarimeter**	OLCI-A + OLCI-B + HARP-2	**HARP-2**: - Multi-angular - Polarimetry	Improved	Improved	**Improved** Can be further improved by **synergy with ground-based!**		Improved (several measure-ments per day)
LEO + GEO	TROPOMI + OLCI-A + OLCI-B + HIMAWARI (FCI)	**TROPOMI**: - UV-SWIR - wide swath	Improved	Improved	Basic aerosol typing		Improved (hourly or better)

New instruments in the synergy

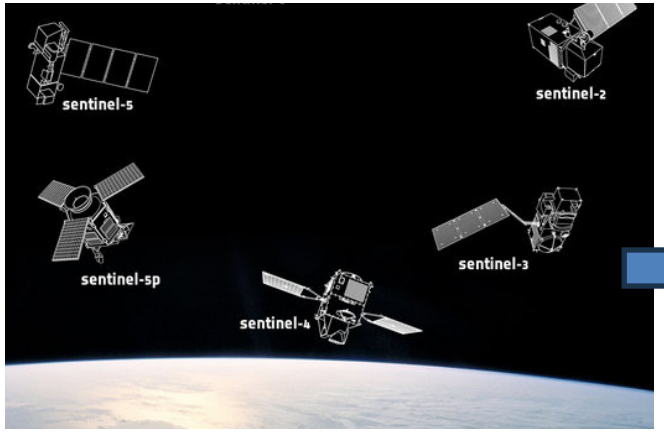
Instrument/ Platform	Orbit	Spectral Range	Resolution		Specific sensitivity to dedicated products
			Spatial	Timporal	
S5/EPS-SG	LEO	UV,VIS, NIR, SWIR	7 km	~1-2 days	AOD, ALH, Surface albedo
3MI/EPS-SG		VIS, NIR, SWIR	4 km		AOD, AODF, AODC, AE, SSA, ALH, Aerosol type and composition, BRDF, BPDF, Surface albedo
IASI-NG/ EPS-SG		TIR	12 km		DOD, DLH, Surface TIR emissivity, Surface temperature
Sentinel-3A/B/C		VIS, NIR	300 m	~1 day	AOD, Surface albedo
FCI/MTG-I Sentinel-4 etc	GEO	VIS,NIR, SWIR	1 km	10 min	AOD, Surface albedo

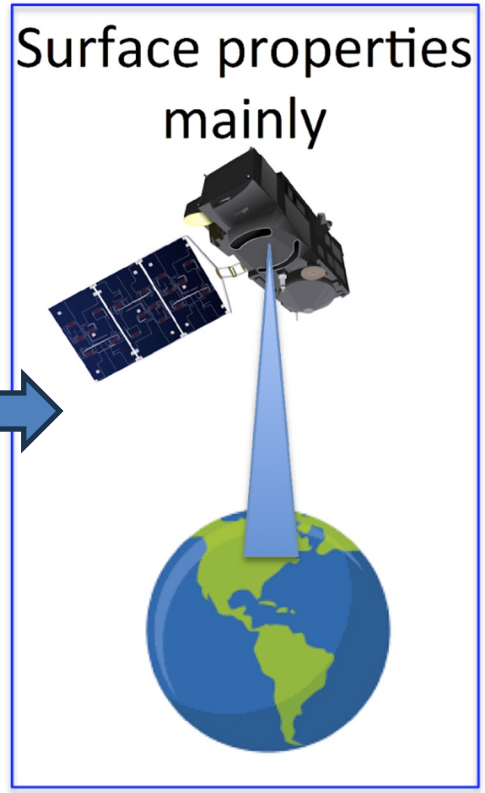
GROSAT synergy
(Optional slides)

GRASP esa

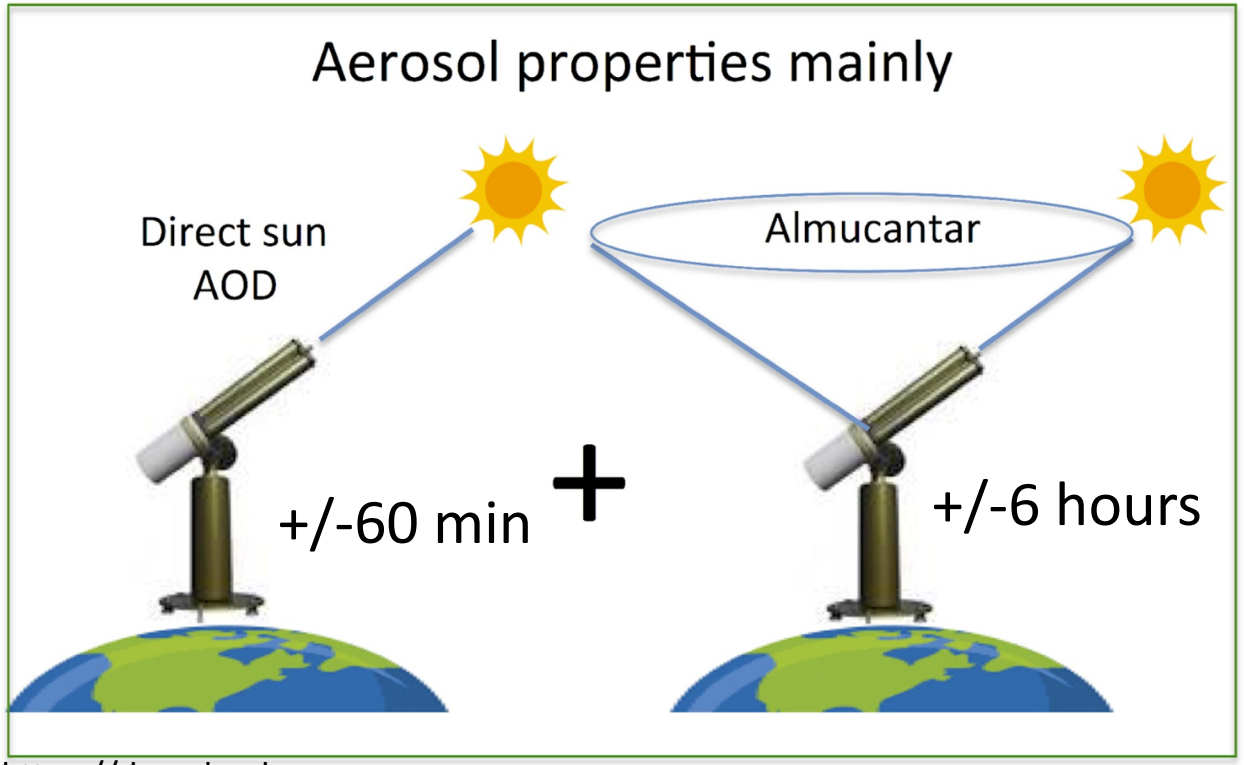
GROSAT: Synergetic GROund-based and SATellite retrieval with GRASP algorithm

Input: Satellite + Nearest AERONET TOD + Almucantar (and/or Principal plane) measurements





+



https://download.grasp-open.com/download/grosat/surface_reference/v02.0/

Output:

1. **Surface** reference dataset for remote sensing studies
2. **Aerosol** retrieved properties

Conditions:

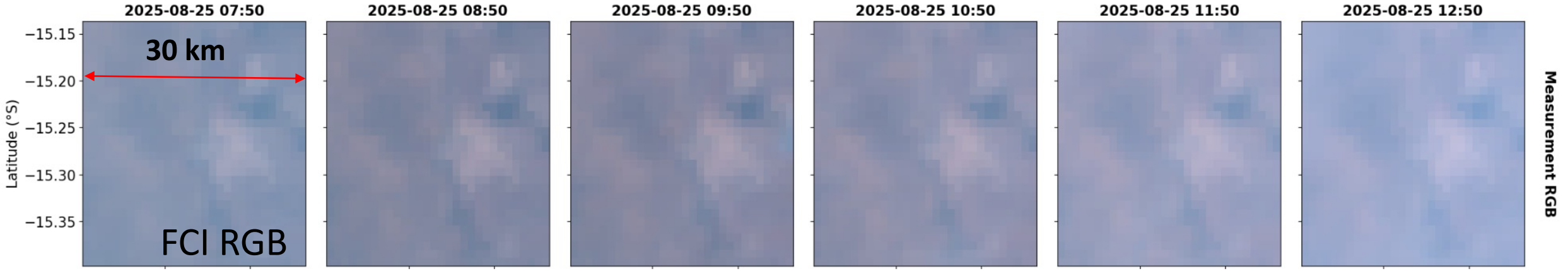
1. Good fit of measurements (better than radiometric error)
2. Good correspondence of the retrieved aerosol properties with AERONET
3. Space-borne instrument is well-calibrated

GROund-based and **SAT**ellite synergy for local aerosol **monitoring**

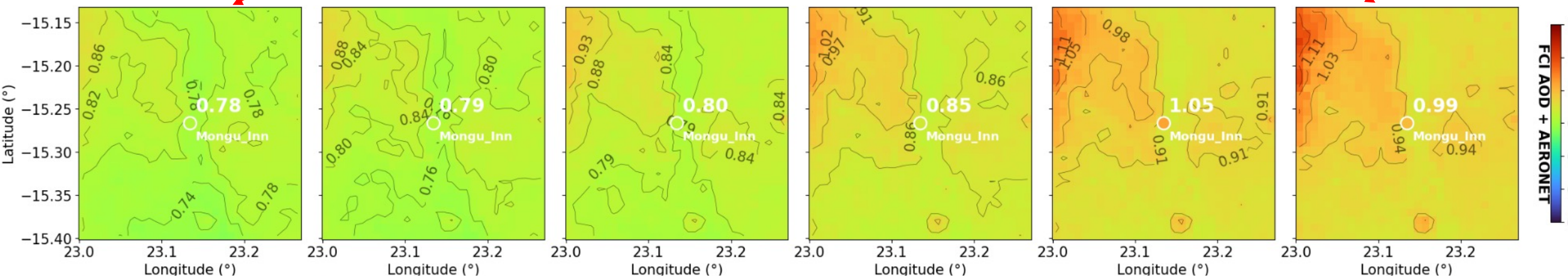
Geostationary satellite:

FCI: measurements every 10 min!

30 km area around **Mongu_Inn** AERONET station (1 km pixel resolution)



Diurnal variability of aerosol properties in local scale around AERONET!



LEO+GEO synergy: FCI and AHI