Aerosol retrieval products retrieved from different satellite observations using GRASP platform

O. Dubovik[1], P. Litvinov[2], D. Fuertes[2], C. Chen[1,2], A. Lopatin[2], T. Lapyonok[1], M. Herreras-Giralda[2], M. Herrera[2], C. Matar[2], S. Zhai[2], F. Ducos[1], and Y. Karol[2],

1 - Univ. Lille, CNRS, UMR 8518 - LOA - Laboratoire d'Optique Atmosphérique, Lille, France

2 – GRASP SAS, Remote sensing developments, Lezennes, France

ICAP, 13th Technical Working Group Meeting, Darmstadt, Germany, November 8-10, 2023

GRASP: Generalized Retrieval of Atmosphere and Surface Properties

GRASP is advanced algorithm for retrieval of aerosol, gas and surface properties from diverse remote sensing observations and any combination of them based on:

Forward Model for rigorous simulation of atm. radiation.

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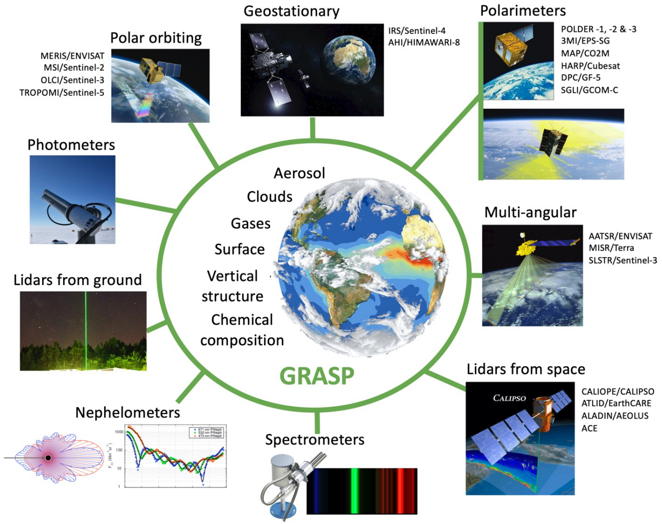
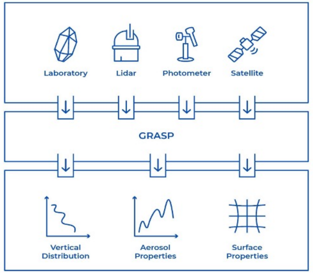
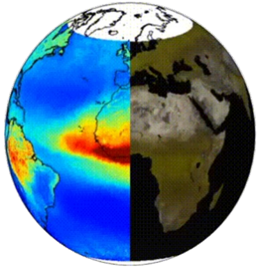
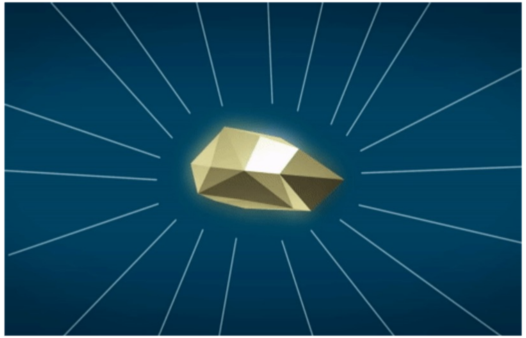
Inversion with *ap*plying multiple *a priori* constraints



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

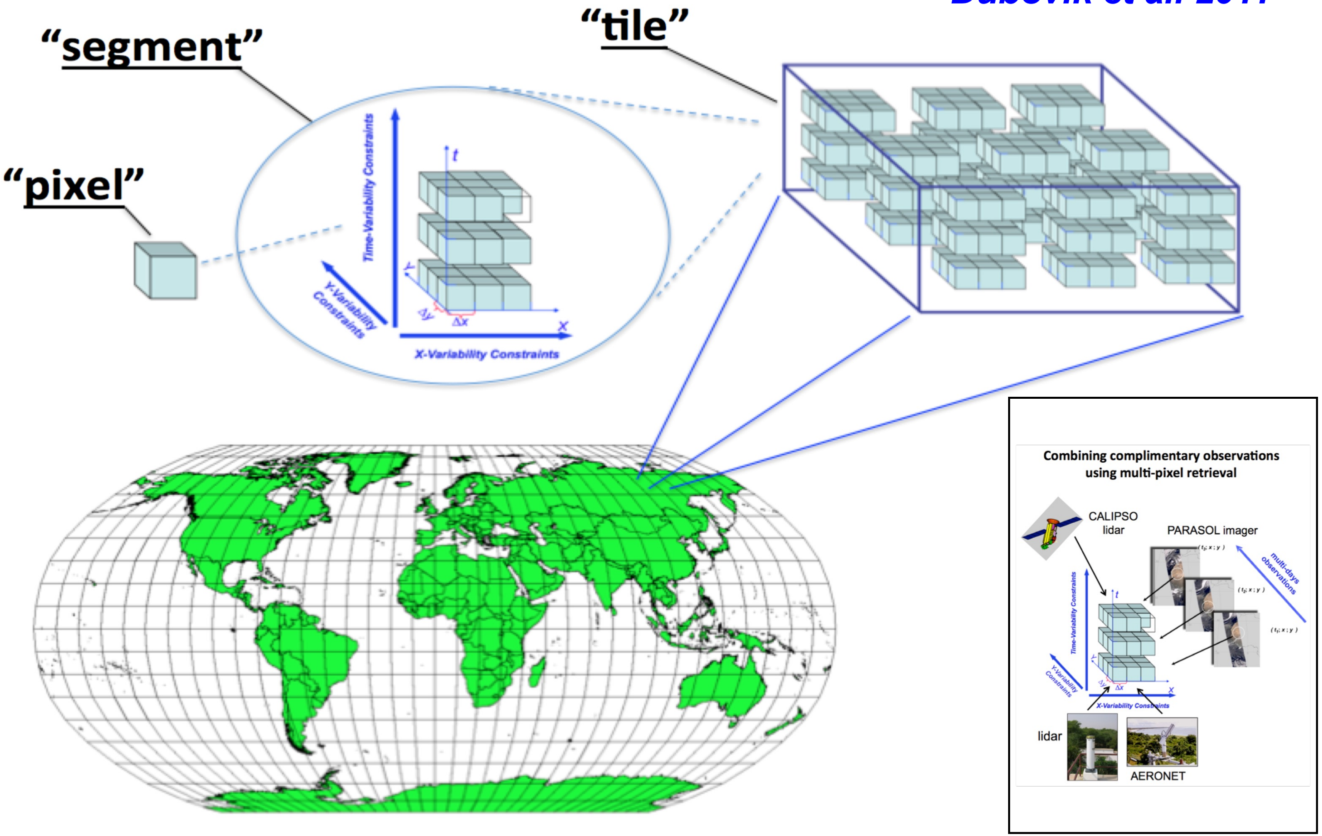






The concept of multi-pixel retrieval

Dubovik et al. 2011



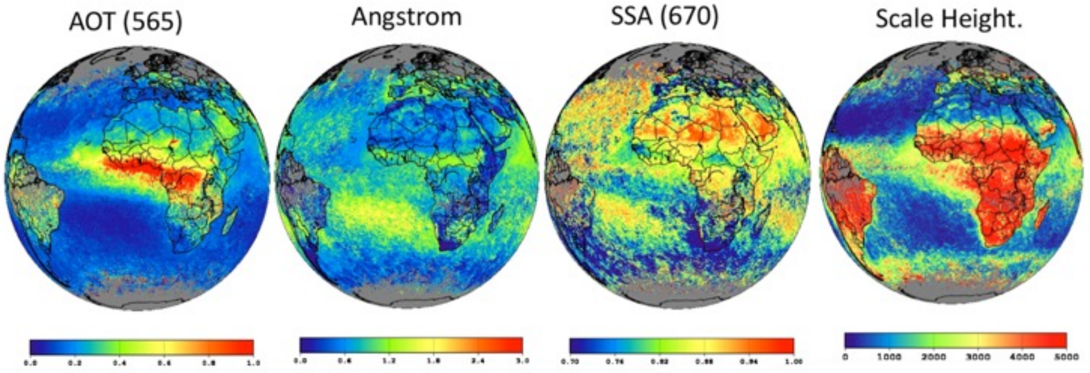
GRASP aerosol and surface product developments
AHI/Himawari
2019/03/10 12:00:00 (JST)
GAPMAP-0
2023-
DPC/GF-5
2022-
DPC Hardware Construction
MAP – Multi – Angular Polarimeters
OLCI/S-3A 2016-
OLCI/S-3B 2018-
TROPOMI/S-5P
2017-
S-4 2024
MAP/CO2M 2026 -
3MI/MetOP-SG
2025 ?
-
2037
Past mission
ENVISAT 2012-2012
MERIS
AATSR
MERIS + AATSR
Copernicus Sentinel missions
esa
atmospheric missions
S-1
Radar
A 3 Apr. 2014
B 25 Apr. 2016
S-2
High Resolution Optical
A 23 Jun. 2015
B 6 Mar. 2017
S-3
Medium Resolution Optical & Altimetry
A 16 Feb. 2016
B 25 Apr. 2018
S-4
Atmospheric Chemistry (GEO)
A 2021
B 2027
S-5P
Atmospheric Chemistry (LEO)
A 13 Oct. 2017
S-5
Atmospheric Chemistry (LEO)
A 2021
B 2027
S-6
Altimetry
A 2020
B 2025
S-7
Candidate
CO2 Monitoring Mission
envisaged 2025
Past mission
POLDER-1, -2, -3
08/1996- 06/1997
12/2003-09/2004
2004-2013
EUMETSAT
esa
European Space Agency
cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES
NASA

POLDER/PARASOL
2004-2013
4 products

Chen et al., 2020
Li et al., 2019
Zhang et al. 2021
Dubovik et al. 2021

Winter 2009

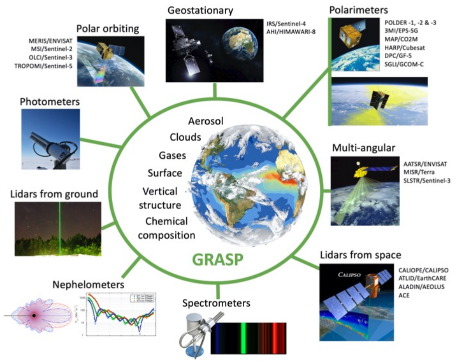
Ocean and land



AEROSOL: **AOD spectral**, **AOD fine/coarse**, **Angstrom**, **SSA**, **AAOD**, aerosol height, spectral complex index of refraction, sphericity fraction.

SURFACE: **land** BRDF spectral, BPDF spectral;
ocean wind speed and water leaving radiances, etc.

GRASP

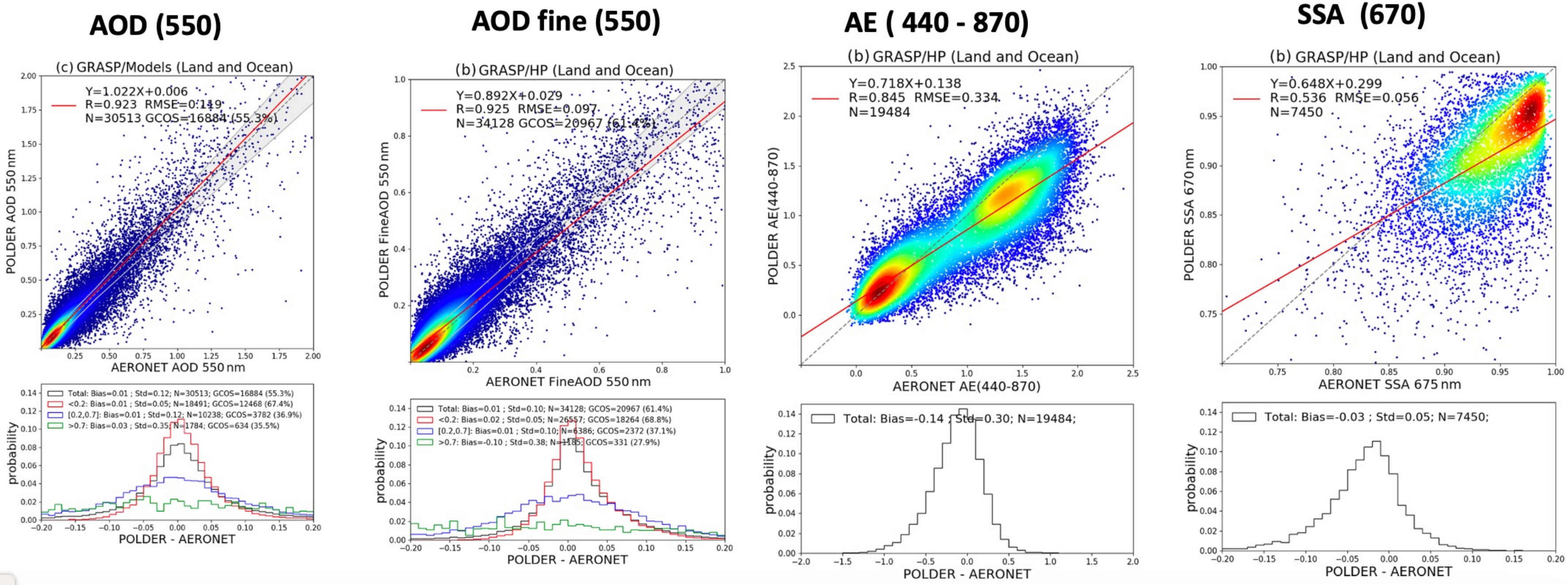


Important features of GRASP retrieval:

- Globally the same initial guess for aerosol;
- Globally the same set of a priori constraints;
- No location specific assumptions;
- Retrieval on 6 km resolution, no averaging;
- Surface retrieved simultaneously

GRASP results validation against AERONET

Globally over Land and Ocean for 2004 – 2013 years (Chen et al., 2020)



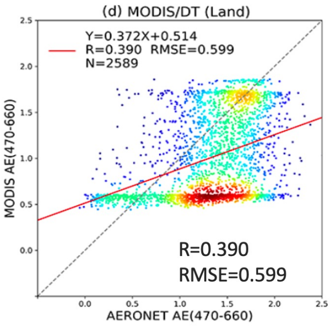
CONSLUSIONS from POLDER aerosol product analysis :

Detailed properties - **AE, fine /coarse AOD** (ocean), from MAP generally notably more accurate than from MODIS like instruments;

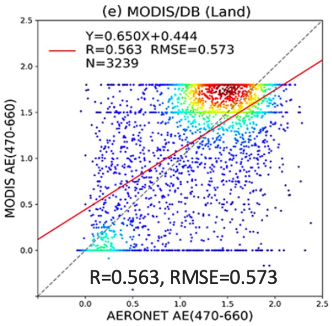
Angstrom Exponent, 2008 (LAND) Validation against AERONET

AE , 2008 (LAND)

MODIS/DT



MODIS/DB



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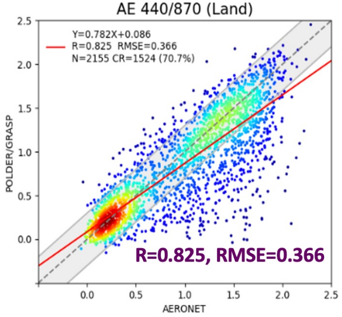
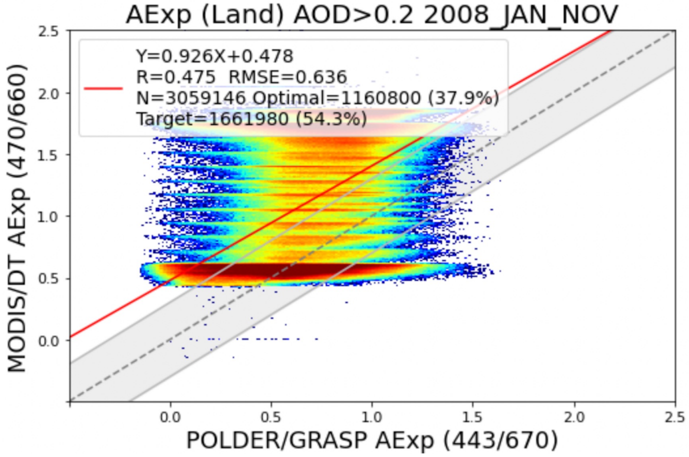
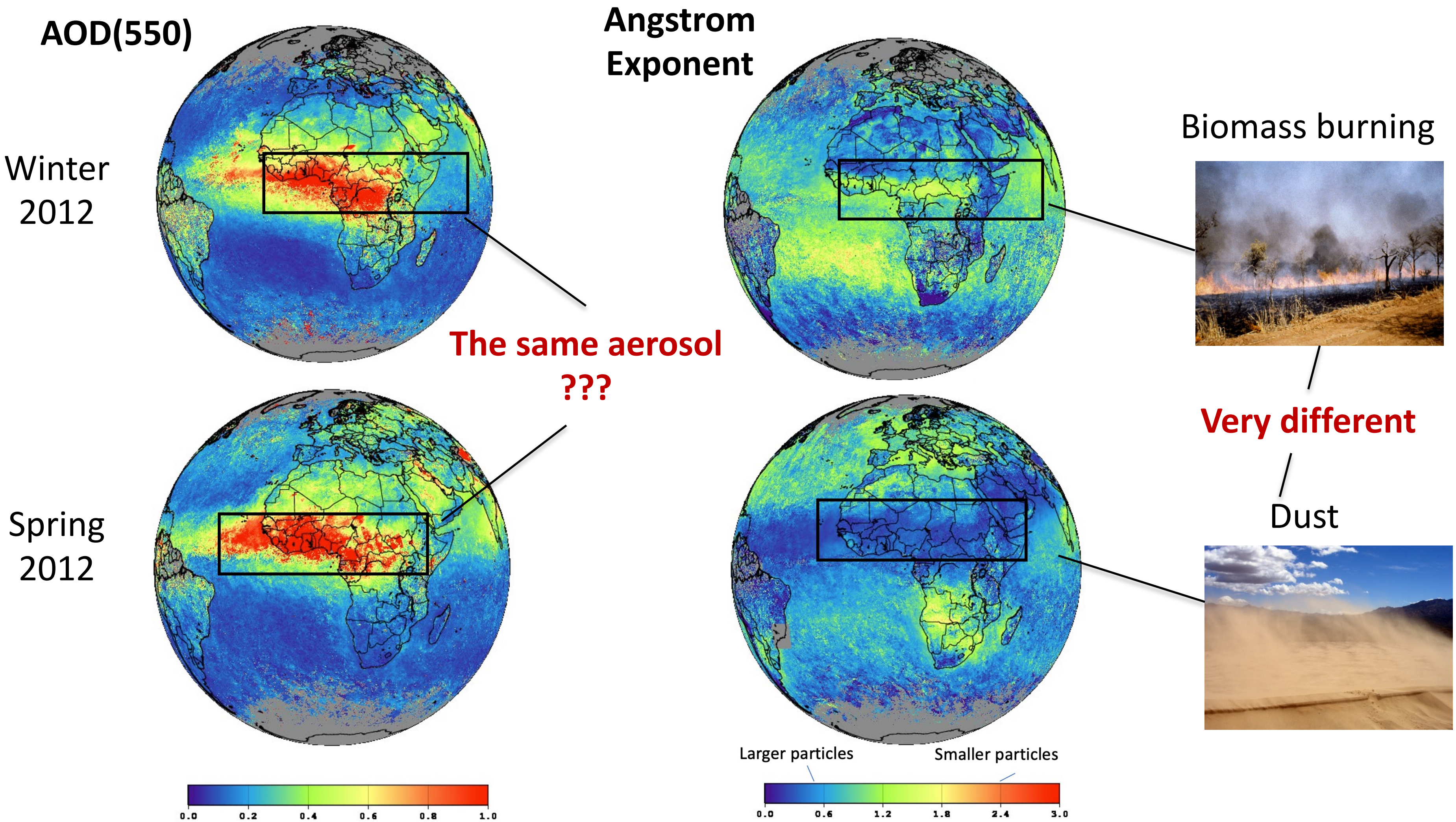
POLDER/ GRASP

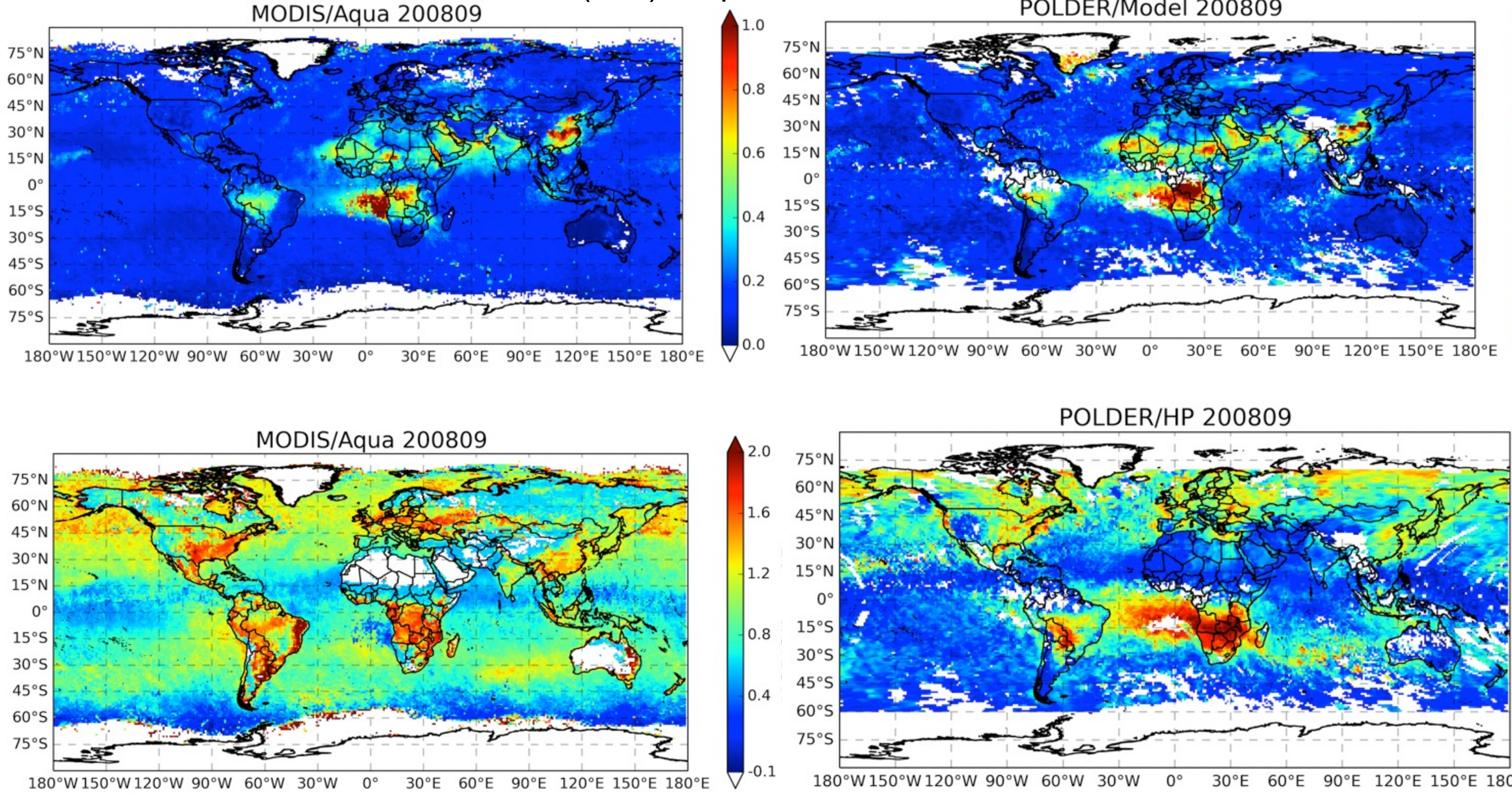


MODIS

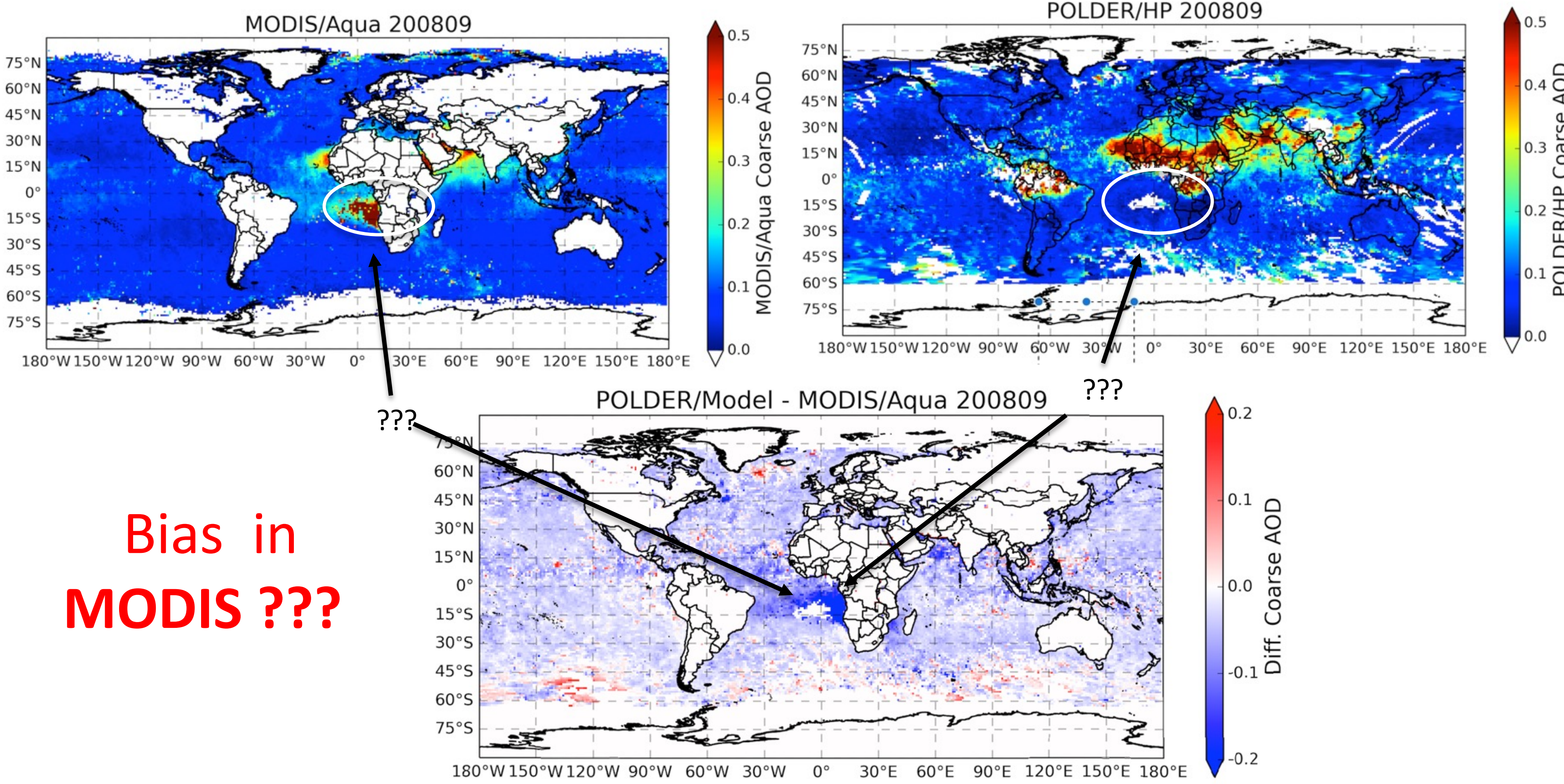



AOD(550)
Angstrom Exponent
Winter 2012
Spring 2012
The same aerosol ???
Biomass burning
Very different
Dust
Larger particles
Smaller particles
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.6
1.2
1.8
2.4
3.0

AOD(560), September 2008



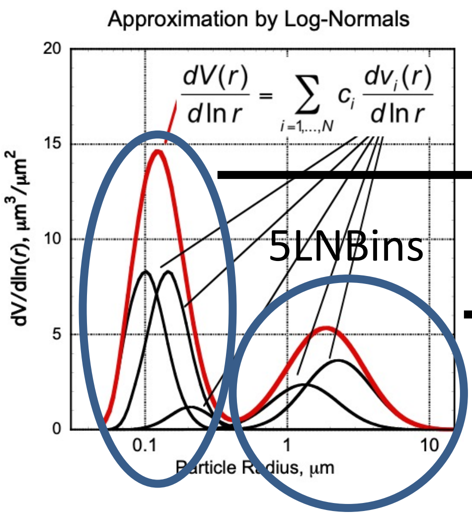
AOD Coarse (560) , September 2008



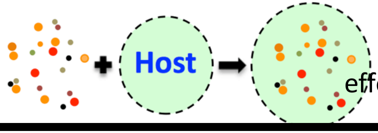
Bias in
MODIS ???

Evolution: GRASP Component approach

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



Fine mode

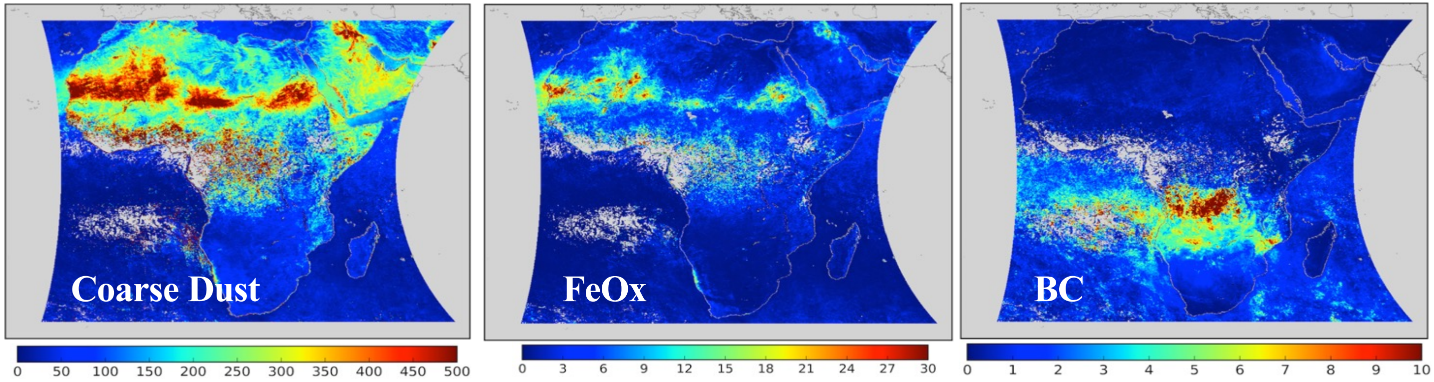


Maxwell Garnett
effective medium approximation

Coarse mode

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

Absorbing insoluble (FeOx)
Non-absorbing insoluble (Dust)
Non-absorbing soluble (SS, etc.)
Water
Coarse mode

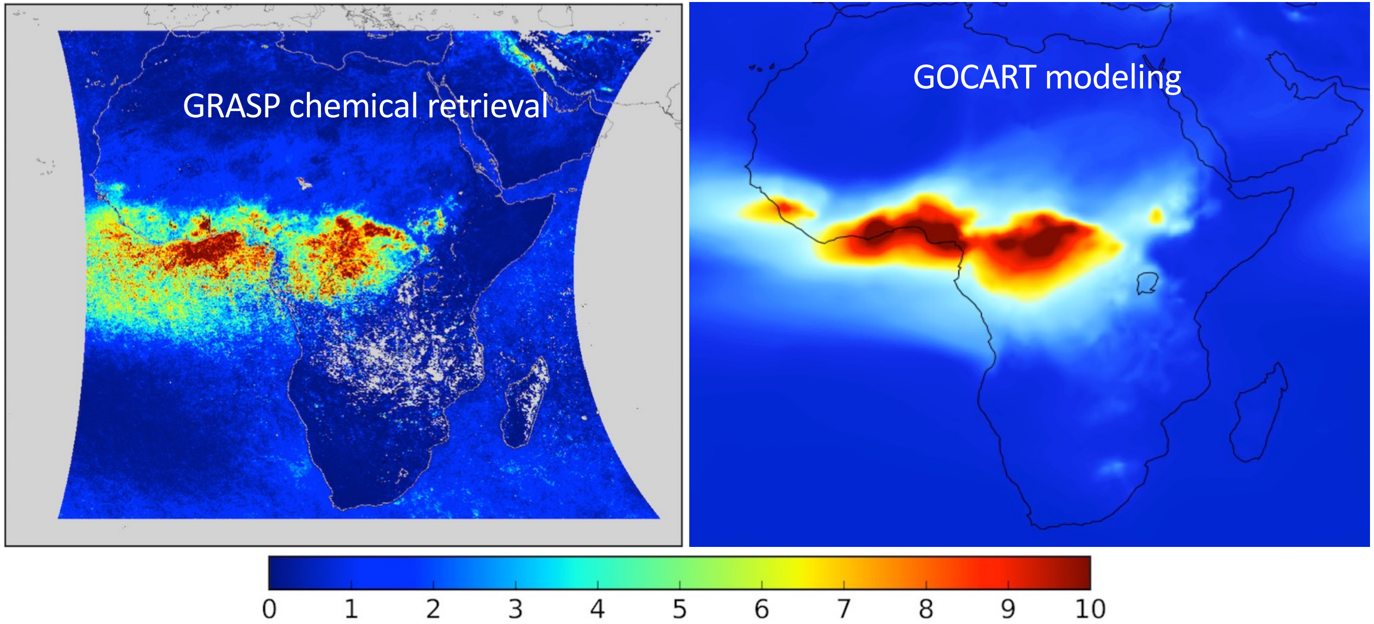


Concentrations volumiques (mg/m²) **Automne 2008**

By using ***prescribed spectral refractive index*** of components, *GRASP/Component approach provides consistent and stable results for AOD as well as detailed properties*.

Example of chemical composition retrieval

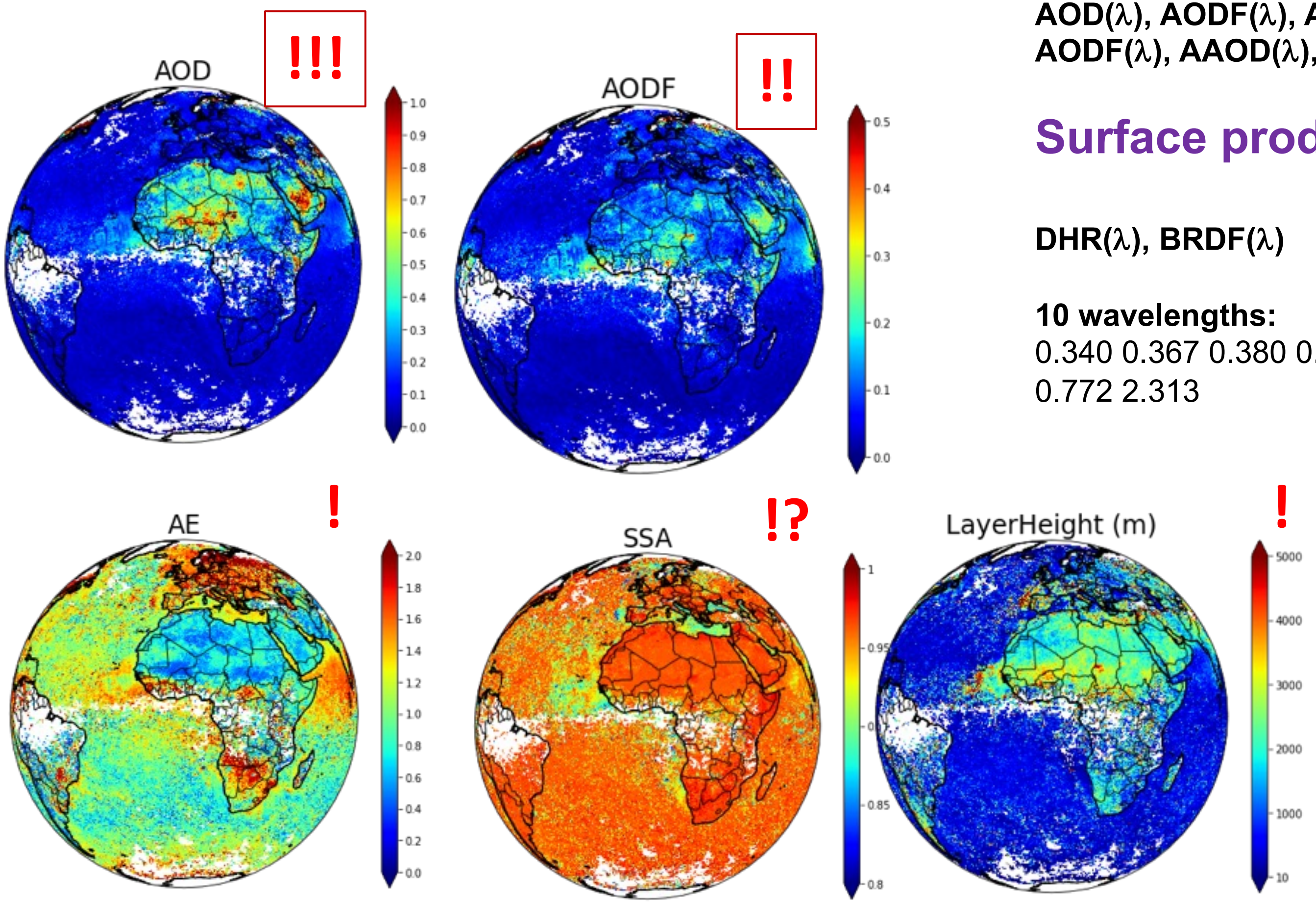
Black Carbon mass concentration(mg/m²) in January 2008



Details are in Li et al. (2019)

Emission retrievals –Chen et al. (2018, 2019, 2022)

TROPOMI/GRASP (2019-2020, …)



Aerosol products:

AOD(λ), AODF(λ), AODC(λ), SSA(λ), AODF(λ), AAOD(λ), AE, Aerosol Height

Surface products:

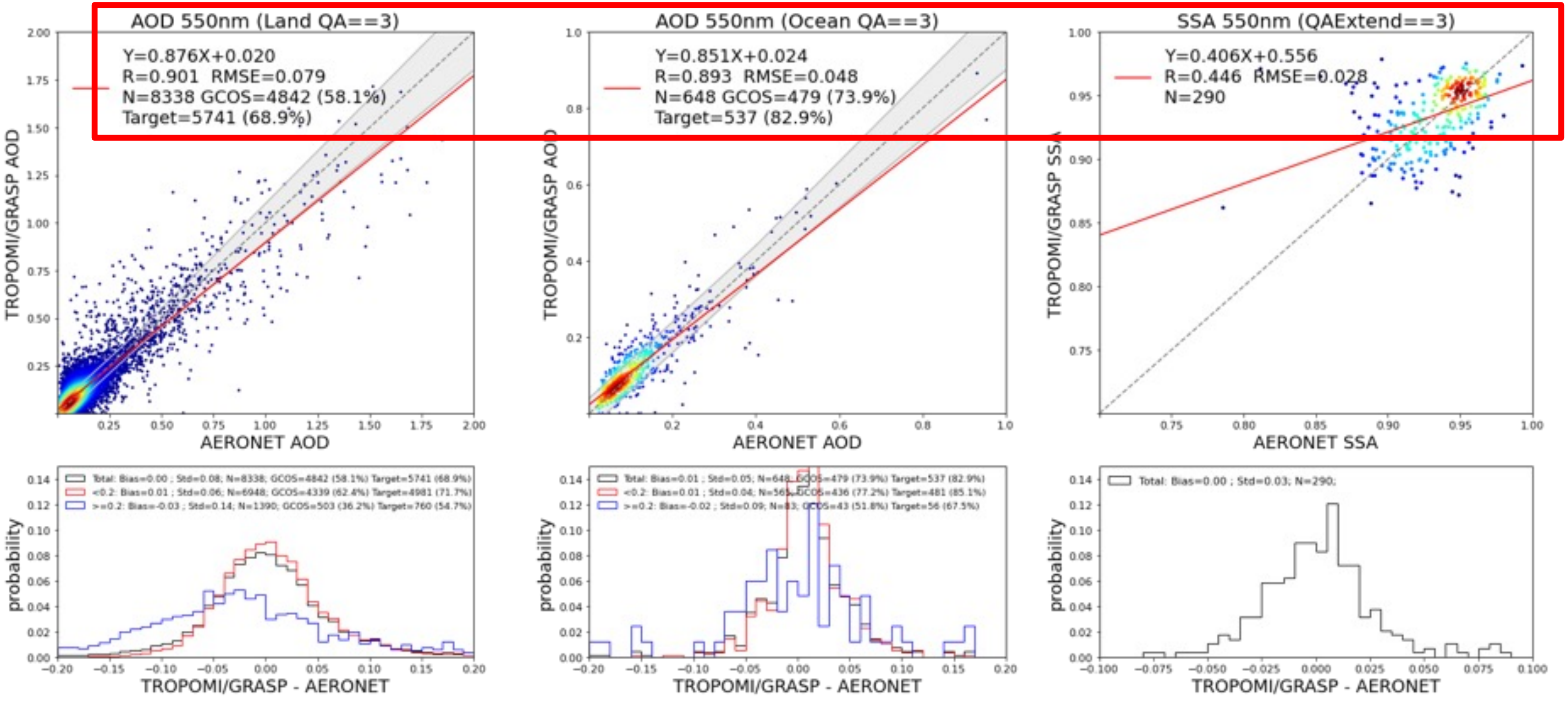
DHR(λ), BRDF(λ)

10 wavelengths:
0.340 0.367 0.380 0.416, 0.440 0.494 0.670 0.747 0.772 2.313

Litvinov et al.
Chen et al.
To be submtted

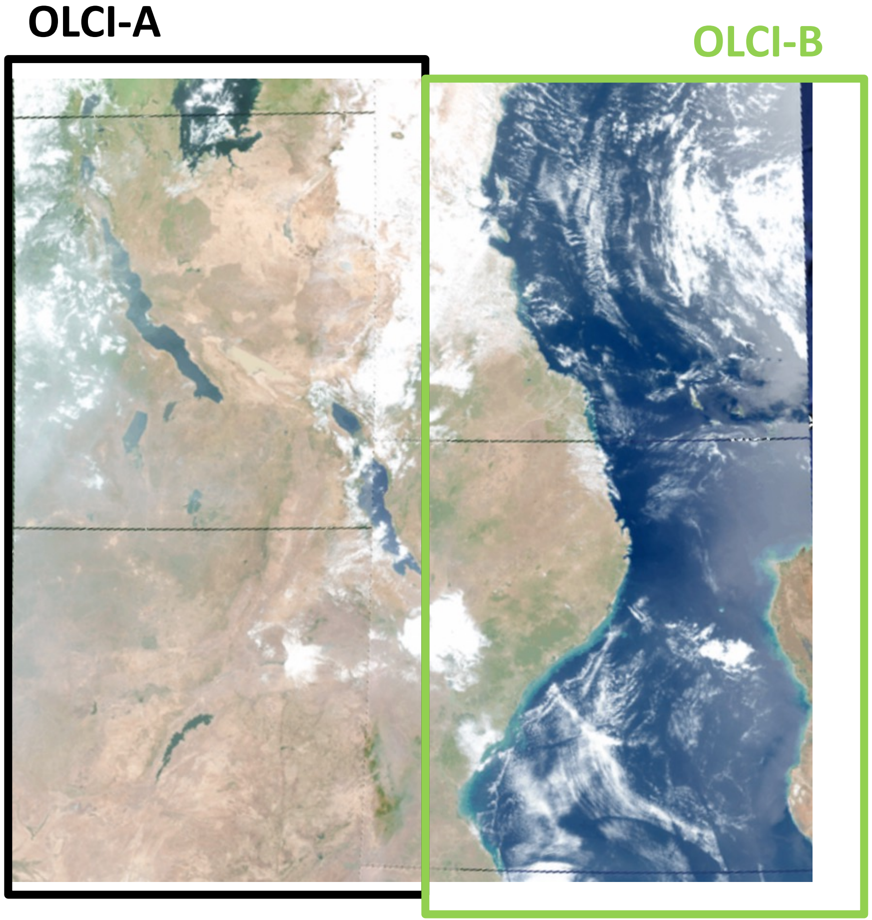
GRASP

S-5P/GRASP aerosol product validation

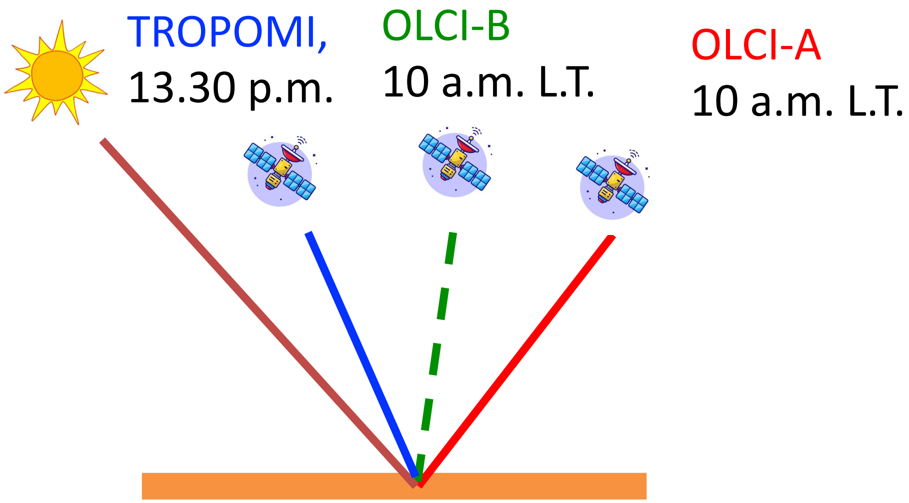


S-5P/GRASP products show to:

- be of comparable accuracy of those of MODIS;
- provide Some information about SSA and aerosol height-



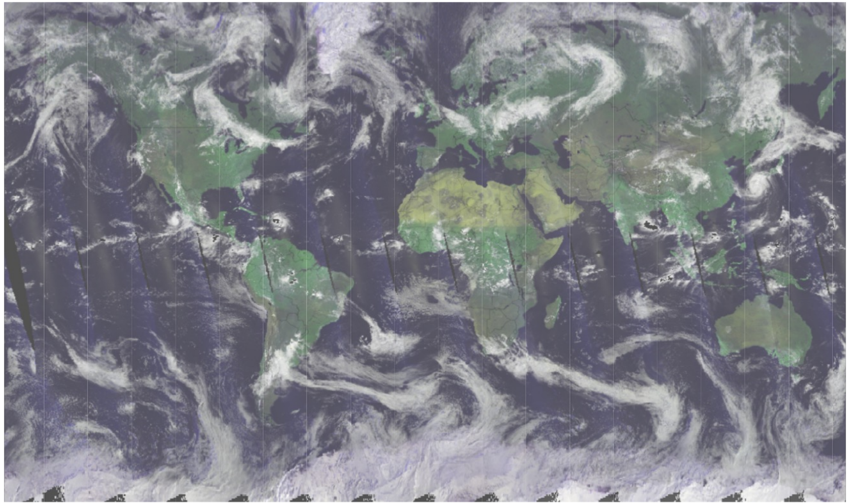
Pseudo “multi-angle”



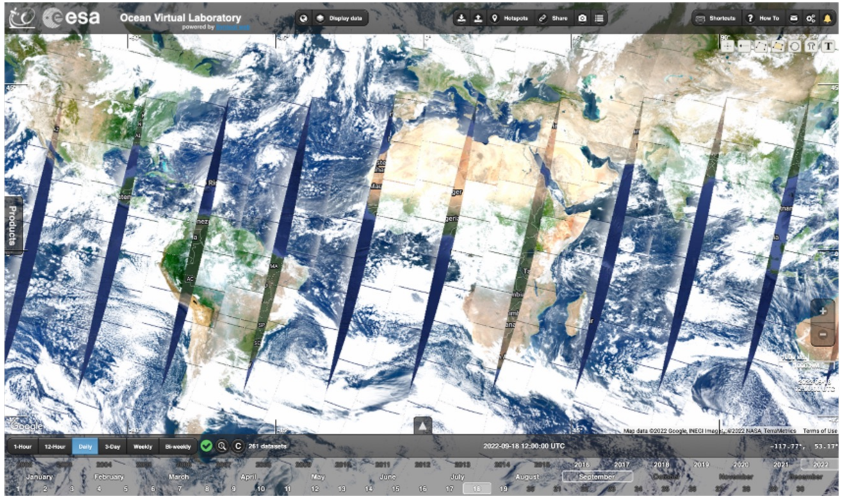
Better surface BRDF sampling and atmosphere signal separation!

Global Processing Results
S5P+S3A+S3B, March, 2019

SYREMIS Synergy: TROPOMI + OLCI-A + OLCI-B + HIMAWARI



+



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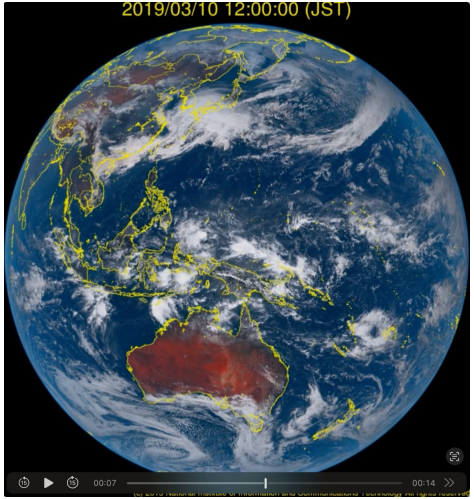
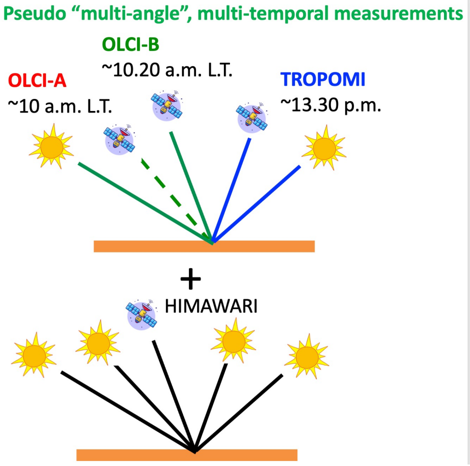


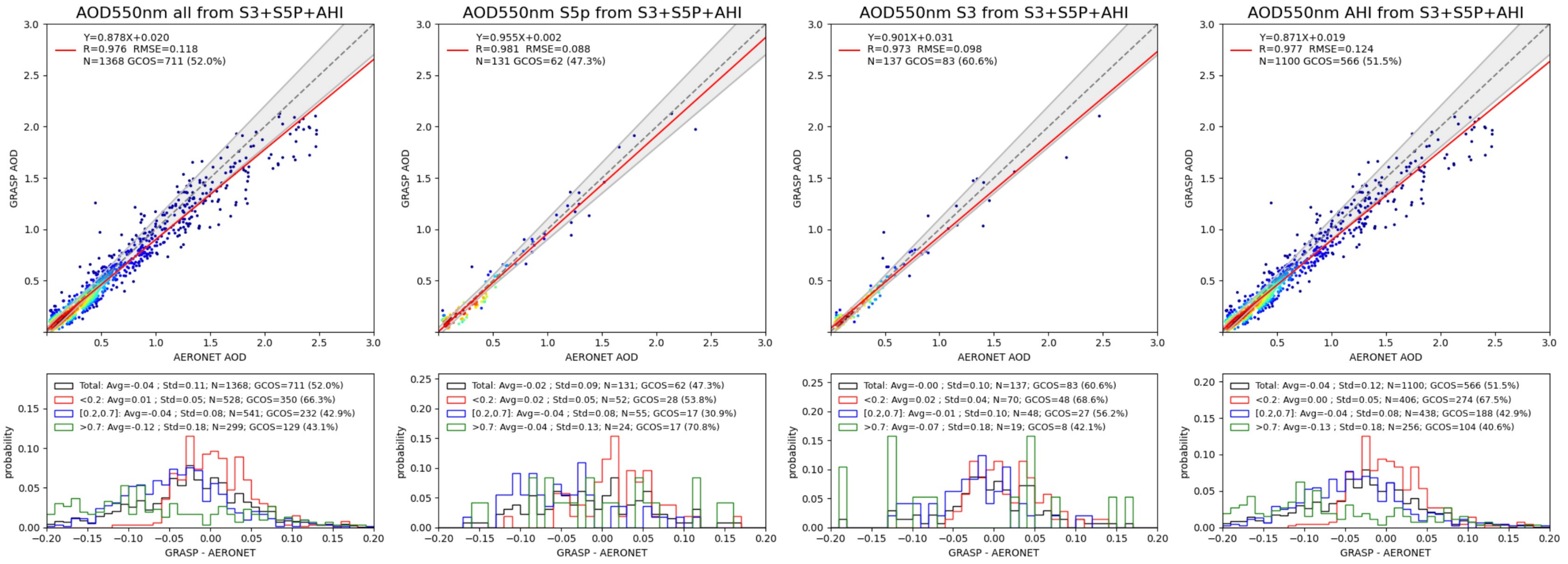


Better surface BRDF and <u>aerosol</u> sampling and atmosphere signal separation!

Synergy of geostationary and polar orbiting

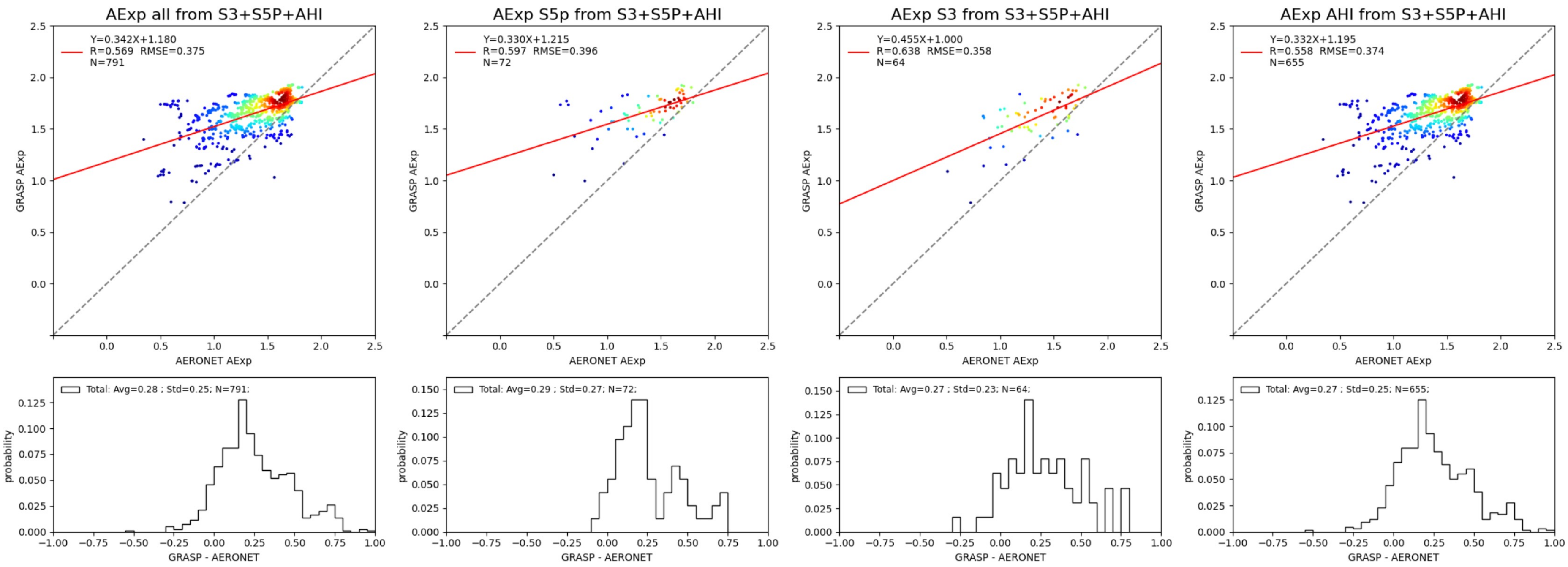
	Geostationary HIMAWARI	Synergy Polar-Orbiting	Synergy Geostationary + Polar orbitting
Swath	Japan, East Asia, and Western Pacific region	> ~ 2600 km	Japan, East Asia, and Western Pacific region
Temporal overpassing/ measurements	15 min	GLOBAL, Every day	**To be defined:** **15 min, 1 h, a few hours?**
Equator crossing time	Geostationary	~10:00h, ~13:40h (few times per day)	Geostationary + ~10:00h (2 times), ~13:40h
Spatial Resolution	Japan, East Asia, and Western Pacific region	~10km	Japan, East Asia, and Western Pacific region
Spectral bands	470.6, **510**, 639.1, 856.7, 1610.1, 2256.8	19 spectral bands: 340, 367, 380, 412.5, 416, 440, 442.5, 490, 494, **510**, 560, 665, 670, 747, 753,772, 865, 1020, 2313 nm	19+6

Polar + Geostationary synergy. AOD



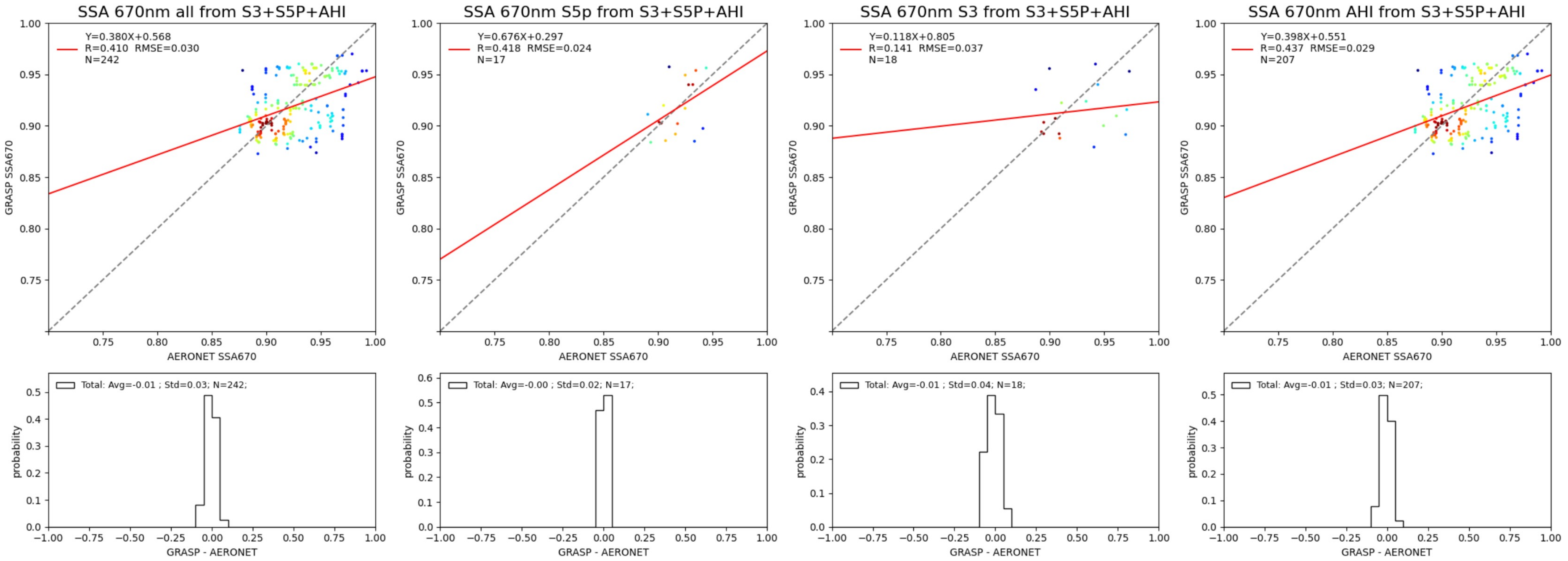
Over 15 AERONET site over Asia, March 2019

Polar + Geostationary synergy. AE



Over 15 AERONET site over Asia, March 2019

Polar + Geostationary synergy. SSA



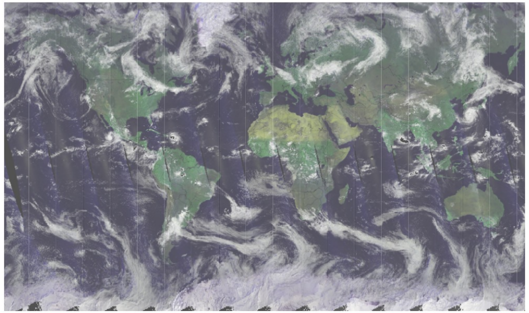
Over 15 AERONET site over Asia, March 2019

Synergy effects:

- Enhanced number of observations from HIMAWARI observations improves aerosol characterization from all satellites;

- The synergy retrievals for OLCI and HIMAWARI approach in the content S5p/TROPOMI retrieval for all parameters including AE and SSA;

SYREMIS Synergy: TROPOMI + OLCI-A + OLCI-B + HIMAWARI



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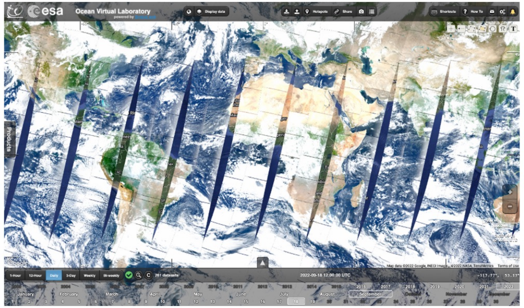
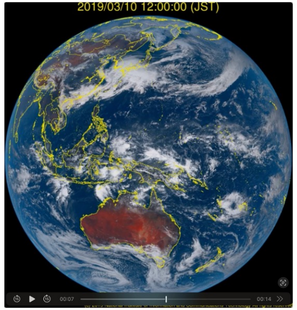
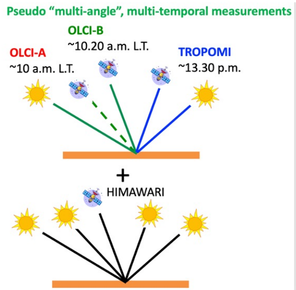
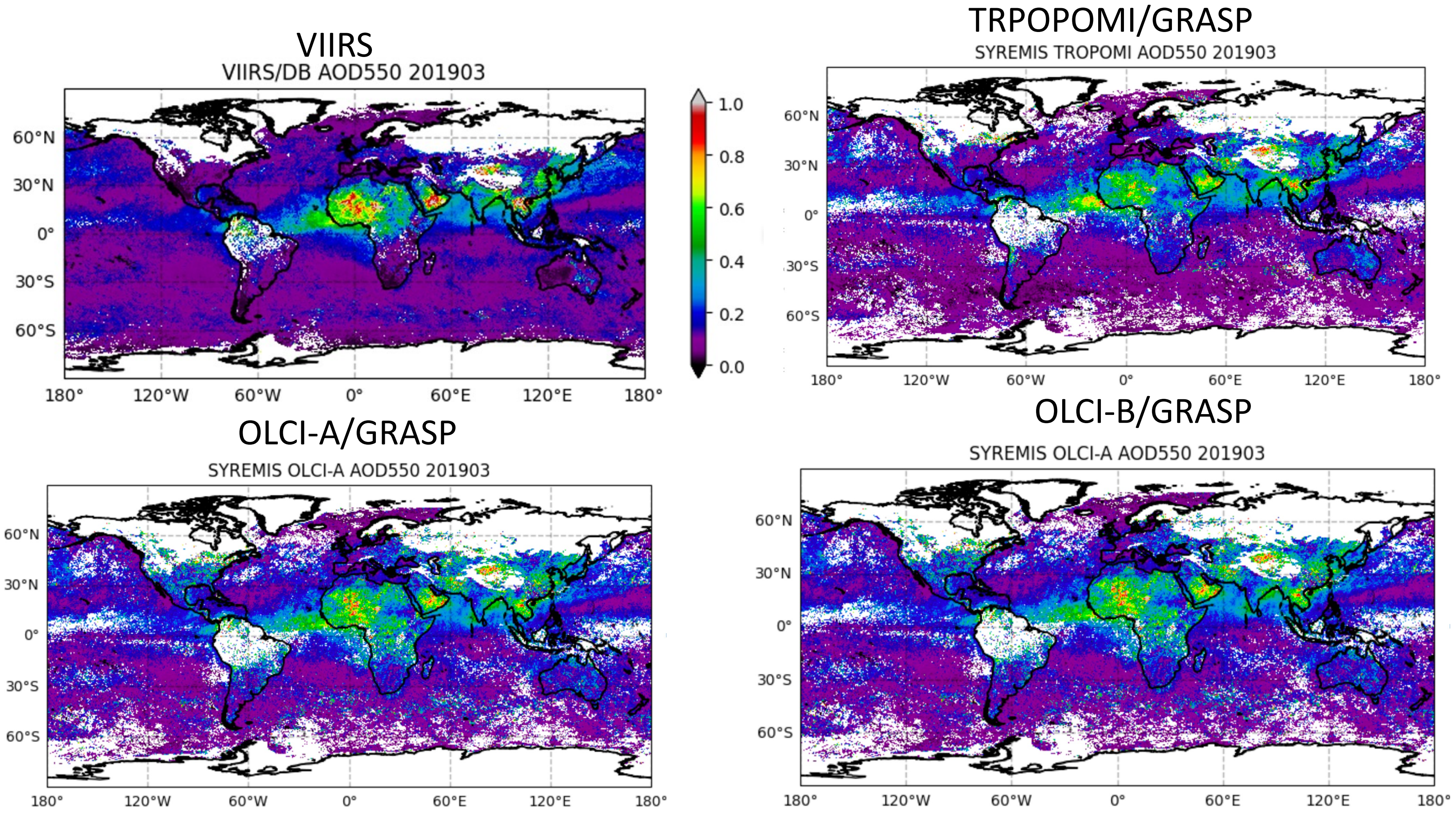


+

Better surface BRDF and aerosol sampling and atmosphere signal separation!





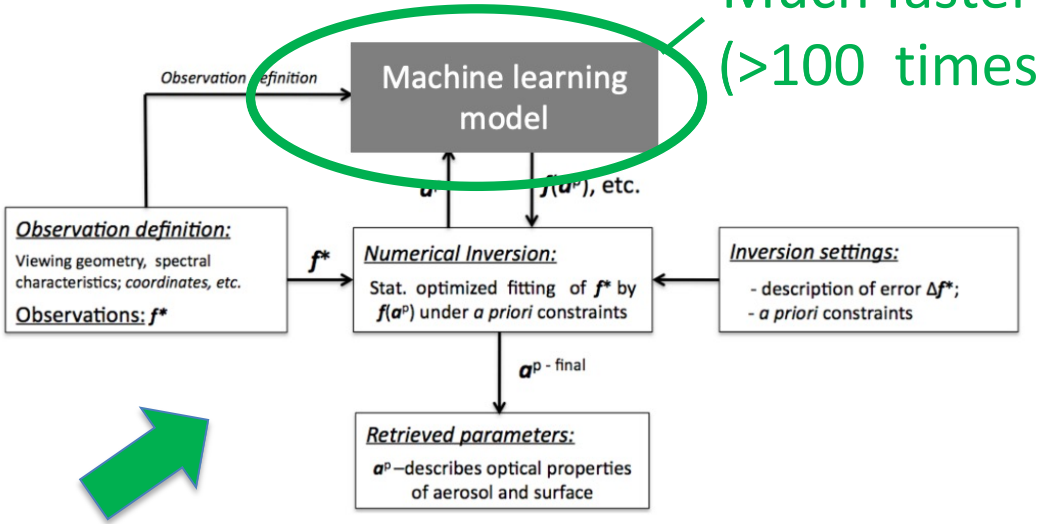

VIIRS
VIIRS/DB AOD550 201903
TRPOPOMI/GRASP
SYREMIS TROPOMI AOD550 201903
OLCI-A/GRASP
SYREMIS OLCI-A AOD550 201903
OLCI-B/GRASP
SYREMIS OLCI-A AOD550 201903
1.0
0.8
0.6
0.4
0.2
0.0
60°N
30°N
0°
30°S
60°S
180°
120°W
60°W
0°
60°E
120°E
180°

GRASP

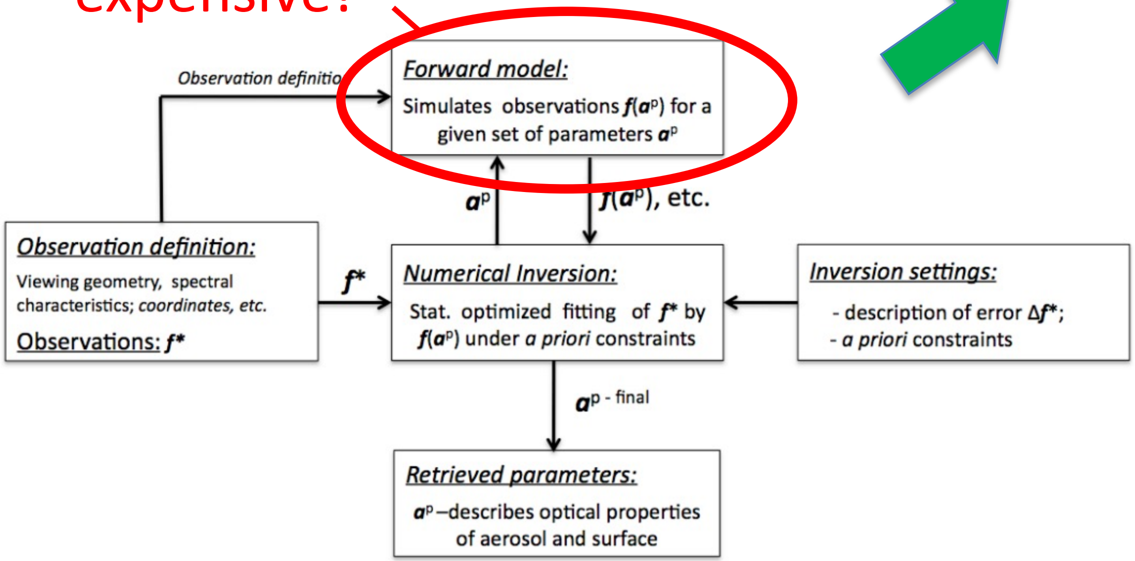
In principle, yes!

& AI

Much faster! (>100 times)



Computationally expensive!

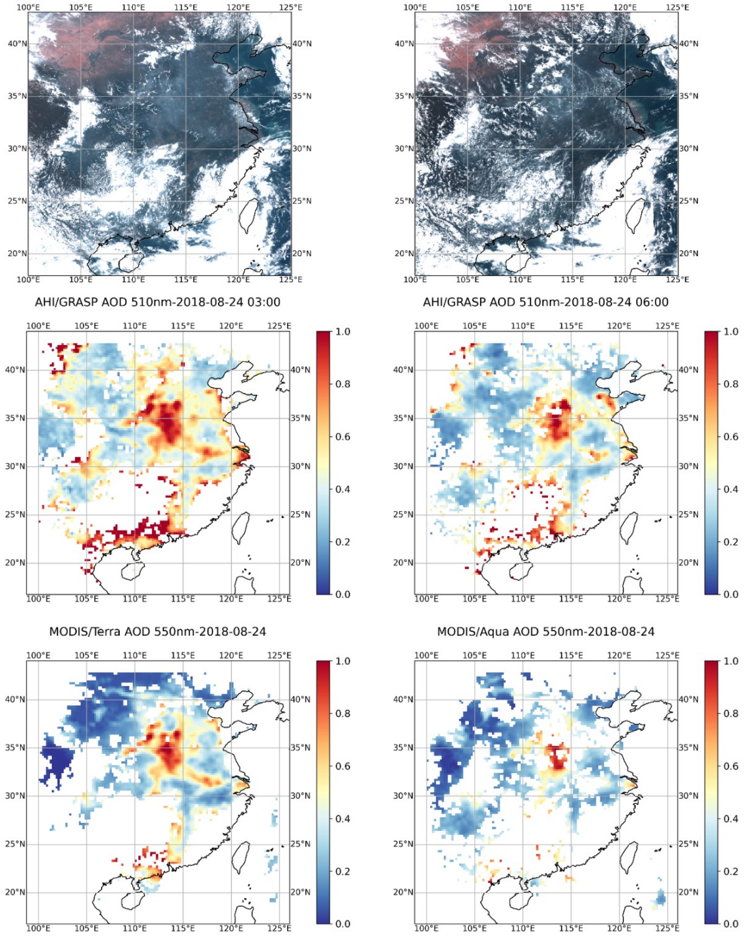


Measured radiation

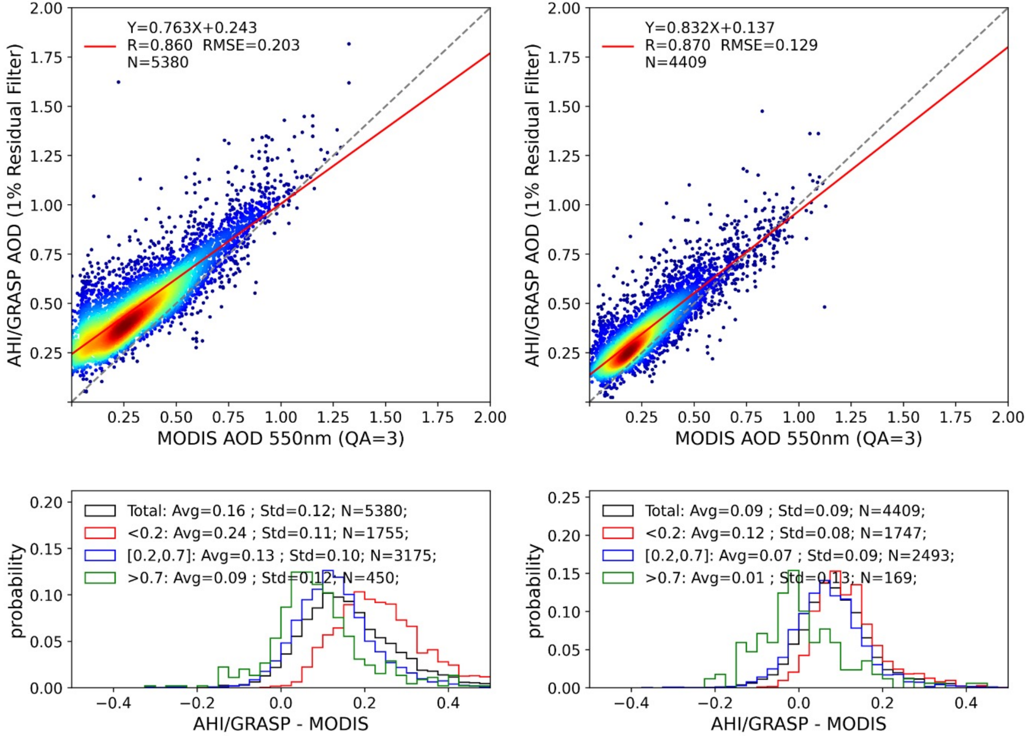
Atmosphere & surface parameters

Takenaka et al. 2011

AHI/GRASP vs MODIS AOD Comparison

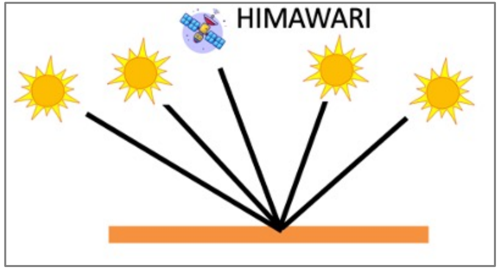


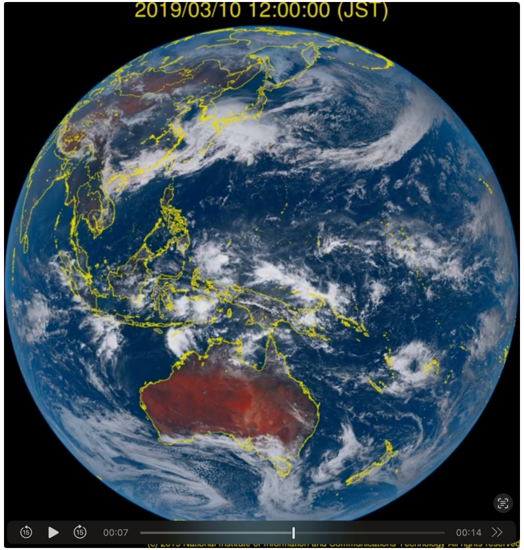
2018.08.24 11:00 LST **2018.08.24 14:00 LST**



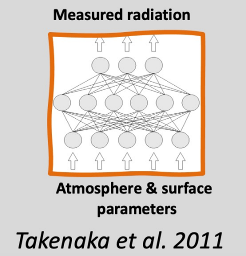
Data: 2018.08.24 11:00 14:00LST RGB Image; AHI/GRASP AOD; MODIS C6.1 Aqua/Terra AOD

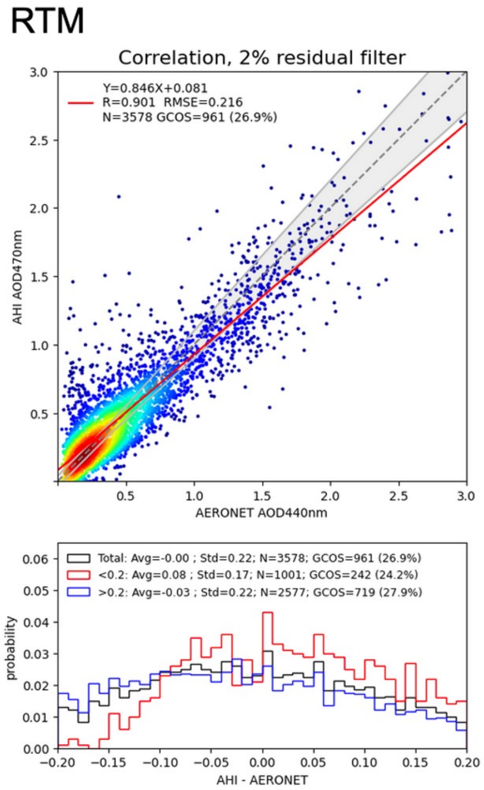
Full disk 2018 AERONET validation

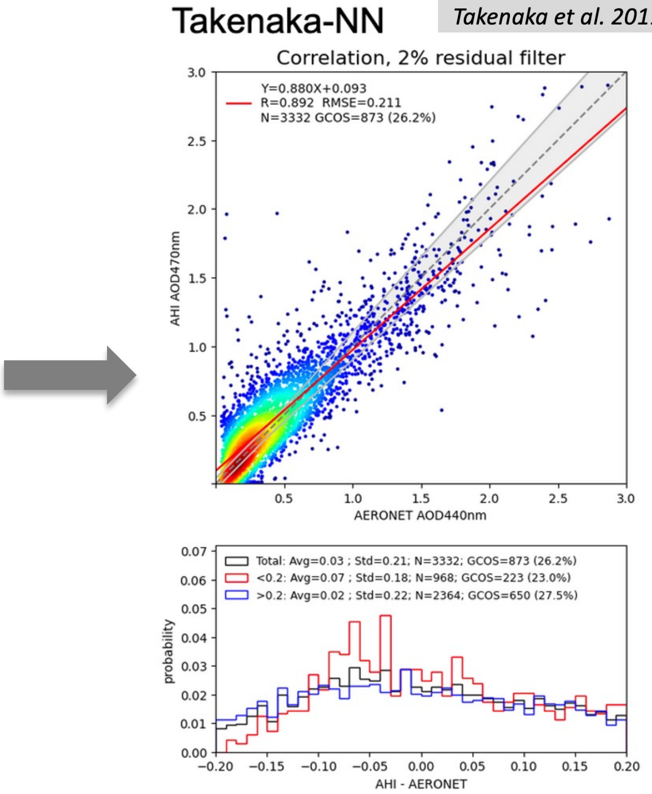




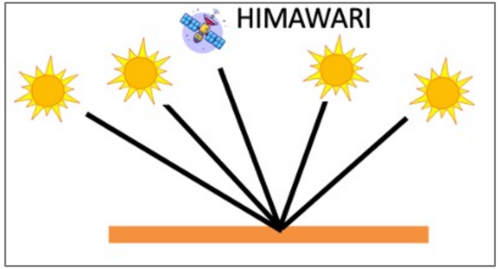
4 times faster

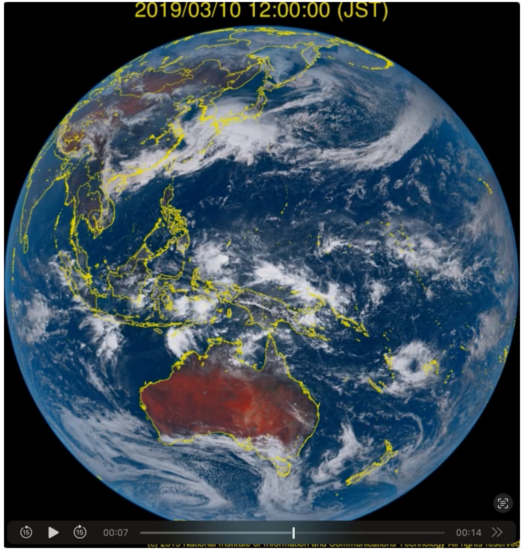


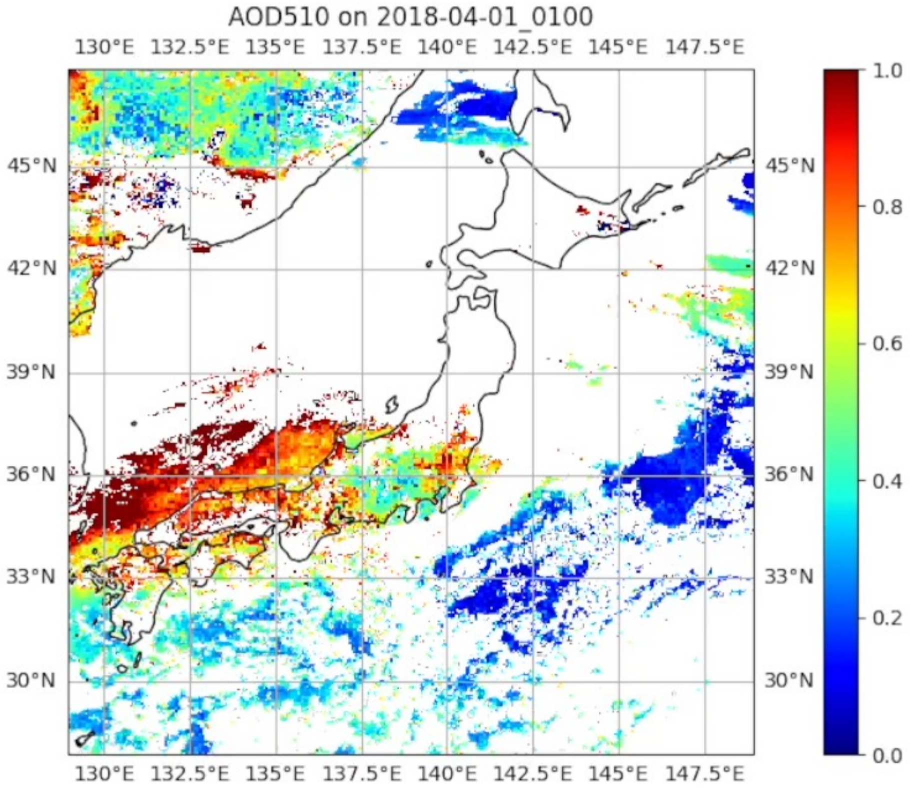




HIMAWARI/ GRASP-NN 4 times faster







Asian dust storm

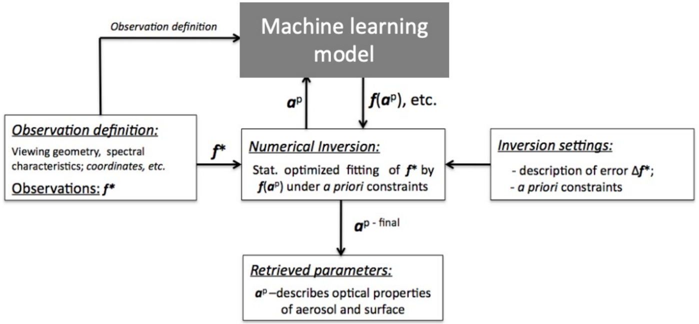
GRASP

In principle, yes!

&

Takenaka et al. 2011

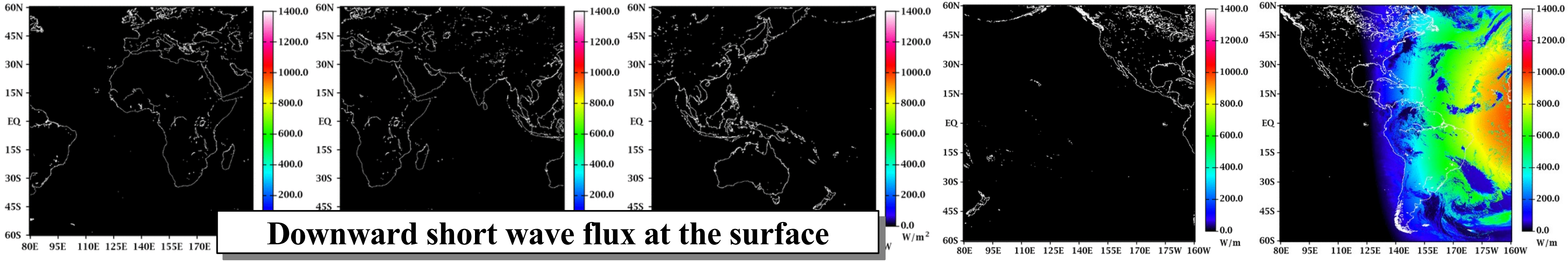
Measured radiation



Atmosphere & surface parameters

Goal: GEO/GRASP 100-1000 times faster

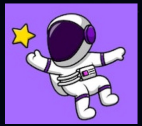
2002/09/02 - 03



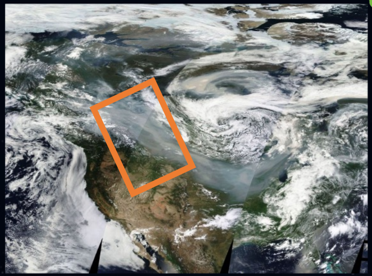
Downward short wave flux at the surface

METEOSAT-7	**METEOSAT-5**	**GMS-5**	**GOES-10**	**GOES-8**
0 deg.	**63 deg.**	**140 deg.**	**225 deg.**	**285 deg.**

The first look from outer space



MODIS Terra



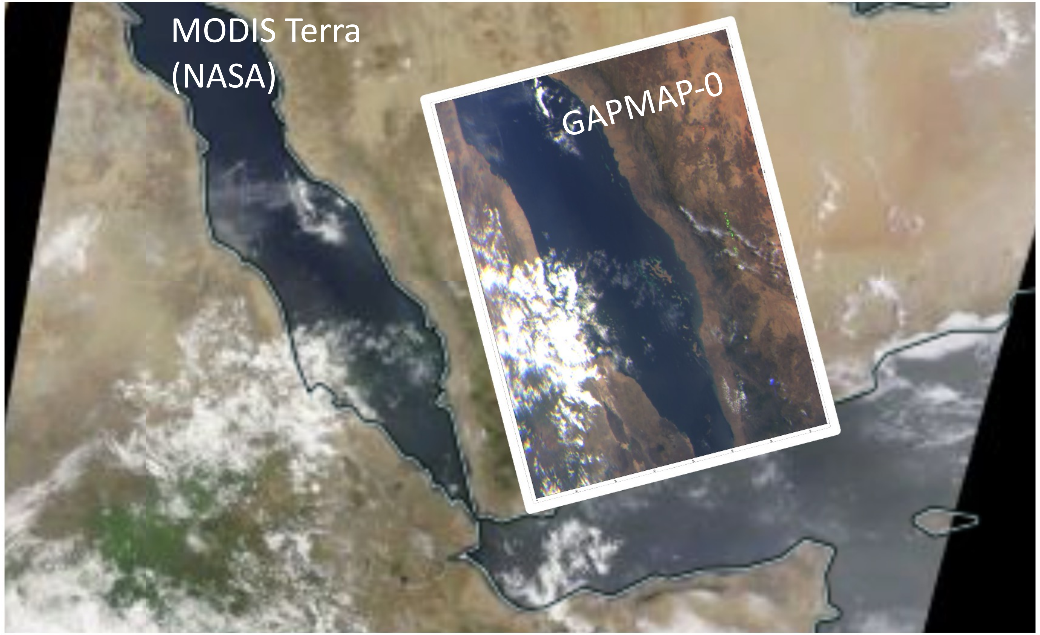
GRASP

In principle, yes!

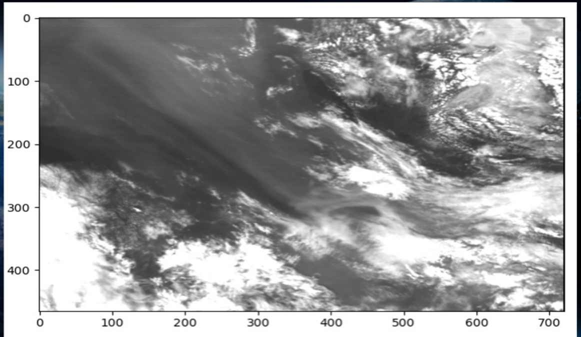
GAPMAP-0

launched 15 April 23

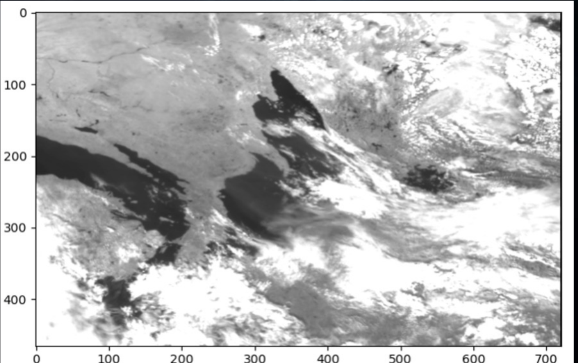
GAPMAP-0 and MODIS Terra



440nm (Blue) Emphasizes the Smoke

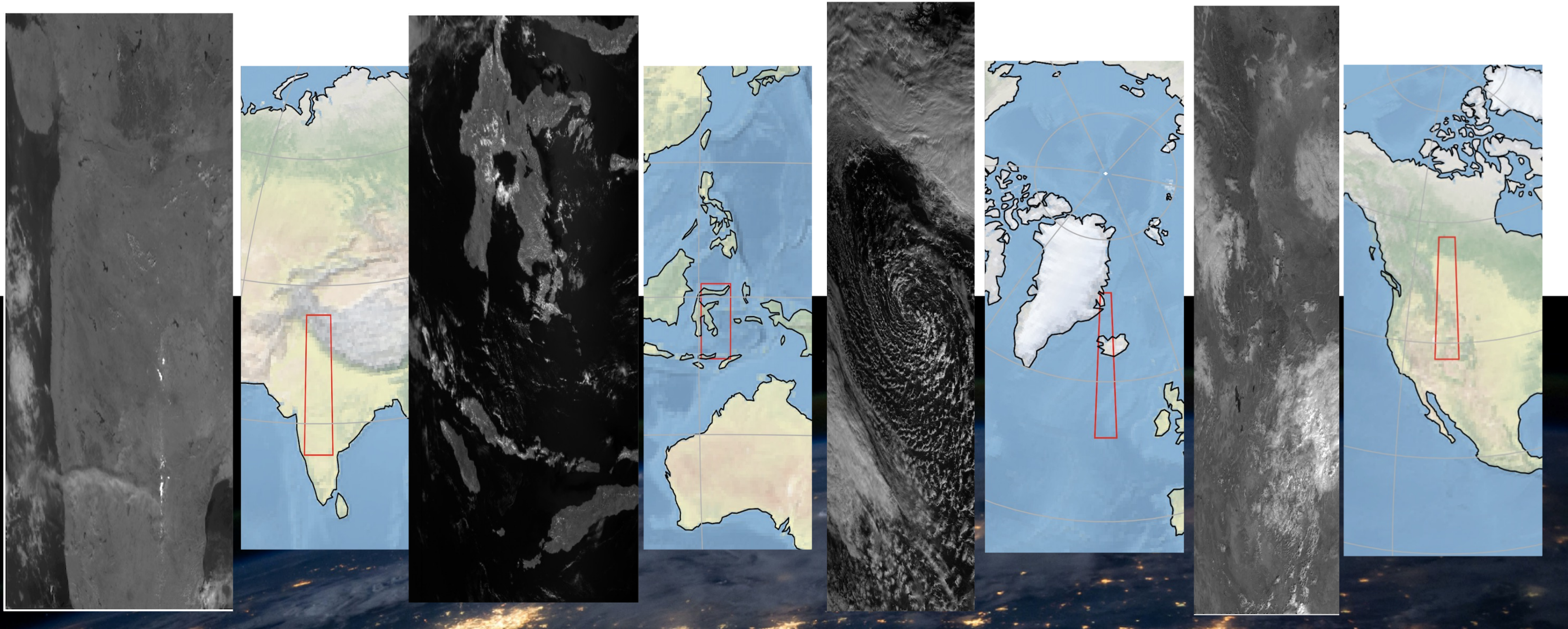


870nm (NIR) Can see through the smoke



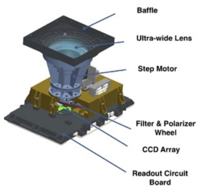
GAPMAP-0 has collected over 300 multi-angle, polarized images since successful commissioning in August 2023

Captures include newsworthy aerosol events around the globe



GF-5(02) vs MODIS

Shikuan Jin, et al.



DPC Hardware Construction

Parameters	GF-5(01)	GF-5(02)
Bands	443, 490P, 565, 670P, 763, 765, 865P, 910	443, 490P, 565, 670P, 763, 765, 865P, 910
Spatial Resolution	3.3km (nadir)	3.3km (nadir)
Angle Number	~9	~17
Uncertainties	~5%(I); ~0.02(DOLP)	~5%(I); ~0.02(DOLP)
Field of View	~1850km	~1850km
Transit Time	~13:30 Local Time	~10:30 Local Time

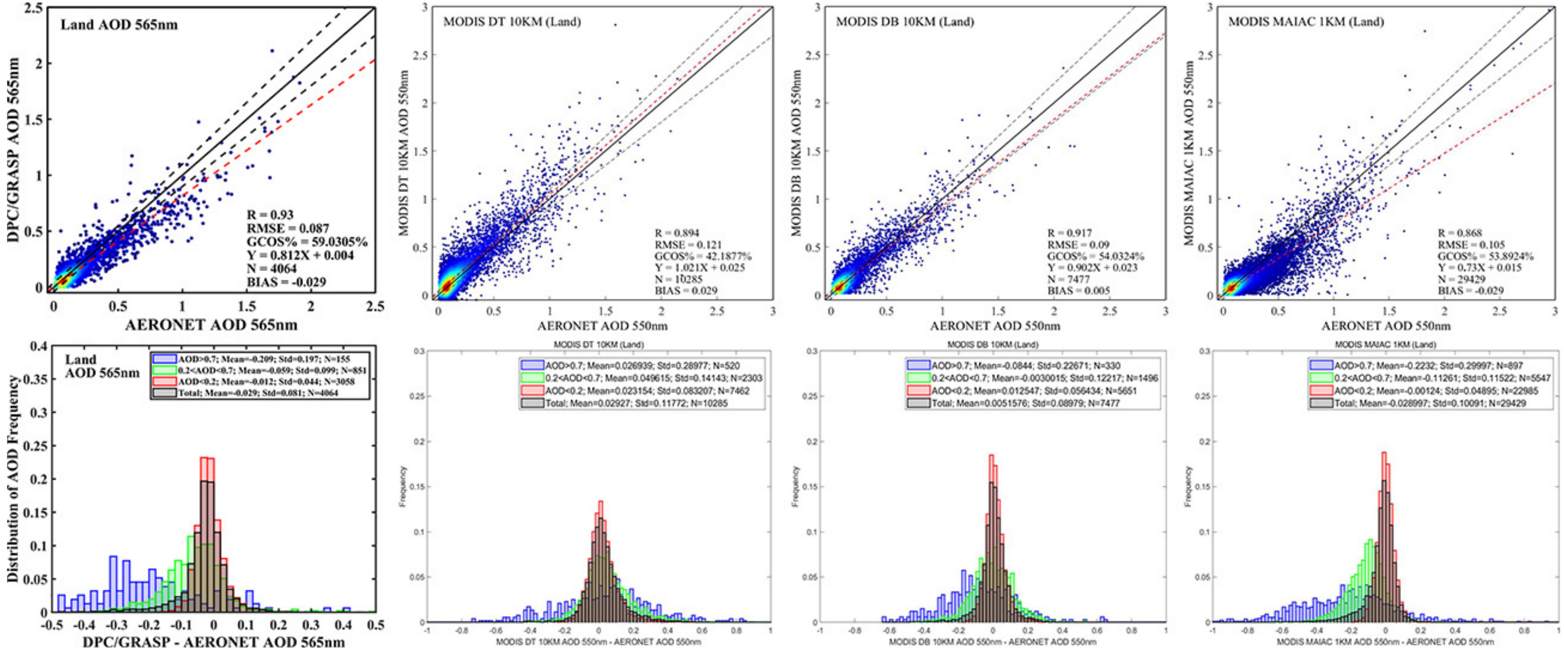
Various aerosol properties **for DPC/GF-5(02): AOD**

- Validation by AERONET and Comparison with MODIS DT, DB, and MAIAC

DPC/GRASP R = 0.93 | MODIS/DT R = 0.894 | MODIS/DB R = 0.917 | MODIS/MAIAC R = 0.868

Land scattering plot

Land frequency plot

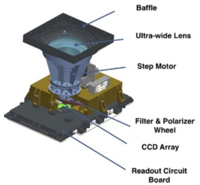


- DPC GF-5(02), 01/01/2022 to 30/06/2022 (6 months dataset)

➢ DPC GF-5(02) and GRASP get the best results in AOD over Lan

Shikuan Jin, et al.

GF-5(02) vs MODIS

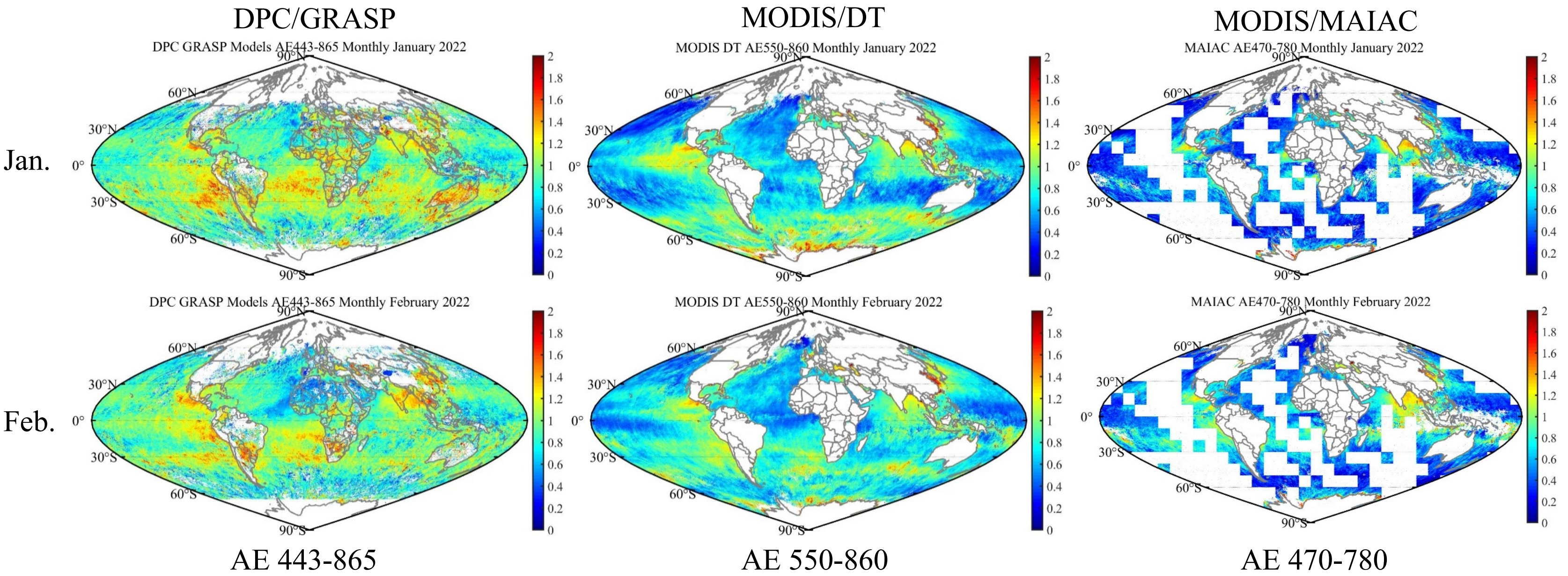


DPC Hardware Construction

Parameters	GF-5(01)	GF-5(02)
Bands	443, 490P, 565, 670P, 763, 765, 865P, 910	443, 490P, 565, 670P, 763, 765, 865P, 910
Spatial Resolution	3.3km (nadir)	3.3km (nadir)
Angle Number	~9	~17
Uncertainties	~5%(I); ~0.02(DOLP)	~5%(I); ~0.02(DOLP)
Field of View	~1850km	~1850km
Transit Time	~13:30 Local Time	~10:30 Local Time

Various aerosol properties **for DPC/GF-5(02):** AE

- ☐ Preliminary comparison of global aerosol properties retrievals from DPC GF-5(02) and GRASP/Models with MODIS, from January to February 2022 (2 months as an example)



- ➢ DPC/GRASP can obtain AE over land and different wavelength can also impact the AE.

GRASP OPEN

Home Products Publications Documentation Register Contact

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

Thank you for you attention !

GRASP

POLDER past polarimetric missions:

3MI/EPS-SG and MAP/CO2 polarimeters are to come in near future”

POLDER-1, -2, -3

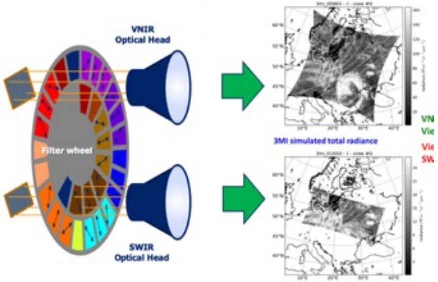
08/1996- 06/1997

12/2003-09/2004

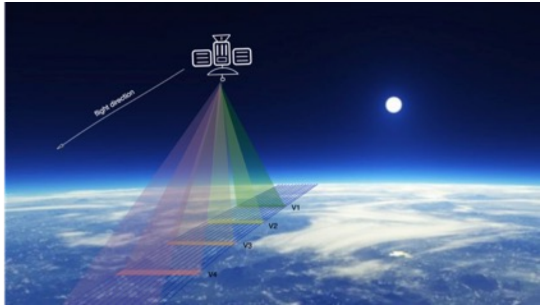
2004 - 2013

3MI/MetOP-SG

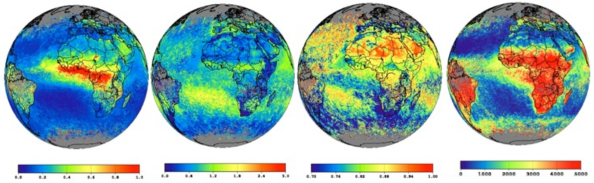
2026 - 2035



MAP/CO2M 2025

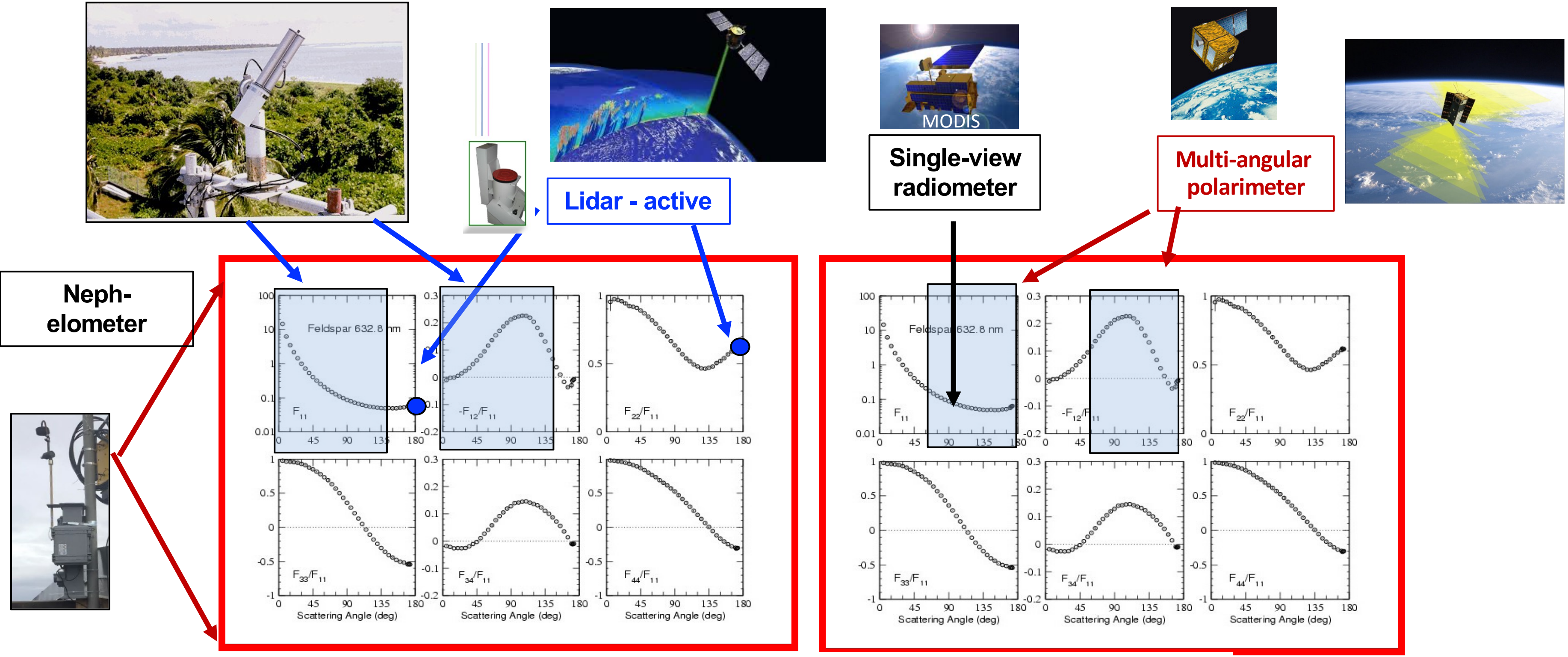


processed by GRASP



Aerosol L2 operational products of EUMETSAT to be based on GRASP algorithm

Angular aspects of different observations



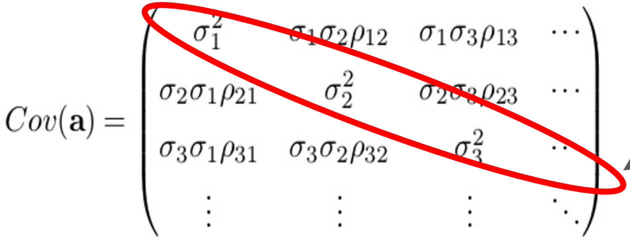
P_{11} – intensity, P_{12} , P_{22} - state of polarization

size, shape, absorption, refraction

$$\begin{pmatrix} I_s\\ Q_s\\ U_s\\ V_s\end{pmatrix} \propto \begin{pmatrix} P_{11}(\Theta) & P_{12}(\Theta) & 0 & 0\\ P_{12}(\Theta) & P_{22}(\Theta) & 0 & 0 \\ 0 & 0 & P_{33}(\Theta) & P_{34}(\Theta)\\ 0 & 0 & -P_{34}(\Theta) & P_{44}(\Theta)\end{pmatrix}\begin{pmatrix} I_i\\ Q_i\\ U_i\\ V_i\end{pmatrix}$$

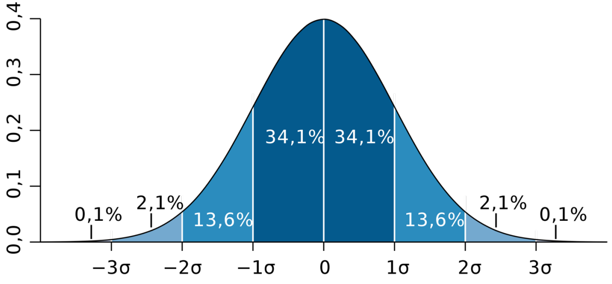
GRASP provides **dynamic error estimations** :

$$Cov(\mathbf{a}) = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho_{12} & \sigma_1\sigma_3\rho_{13} & \cdots \\ \sigma_2\sigma_1\rho_{21} & \sigma_2^2 & \sigma_2\sigma_3\rho_{23} & \cdots \\ \sigma_3\sigma_1\rho_{31} & \sigma_3\sigma_2\rho_{32} & \sigma_3^2 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$



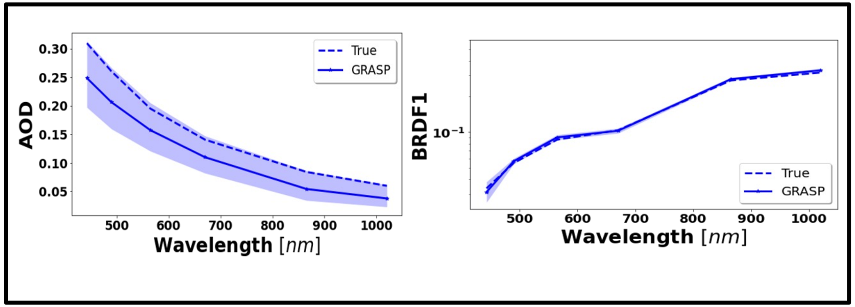
Error variances

$\pm$ σ, 2σ, 3σ



- Aerosol and surface from the I, Q and U of POLDER/PARASOL simulations over Mongu

Example: PARASOL-like retrieval



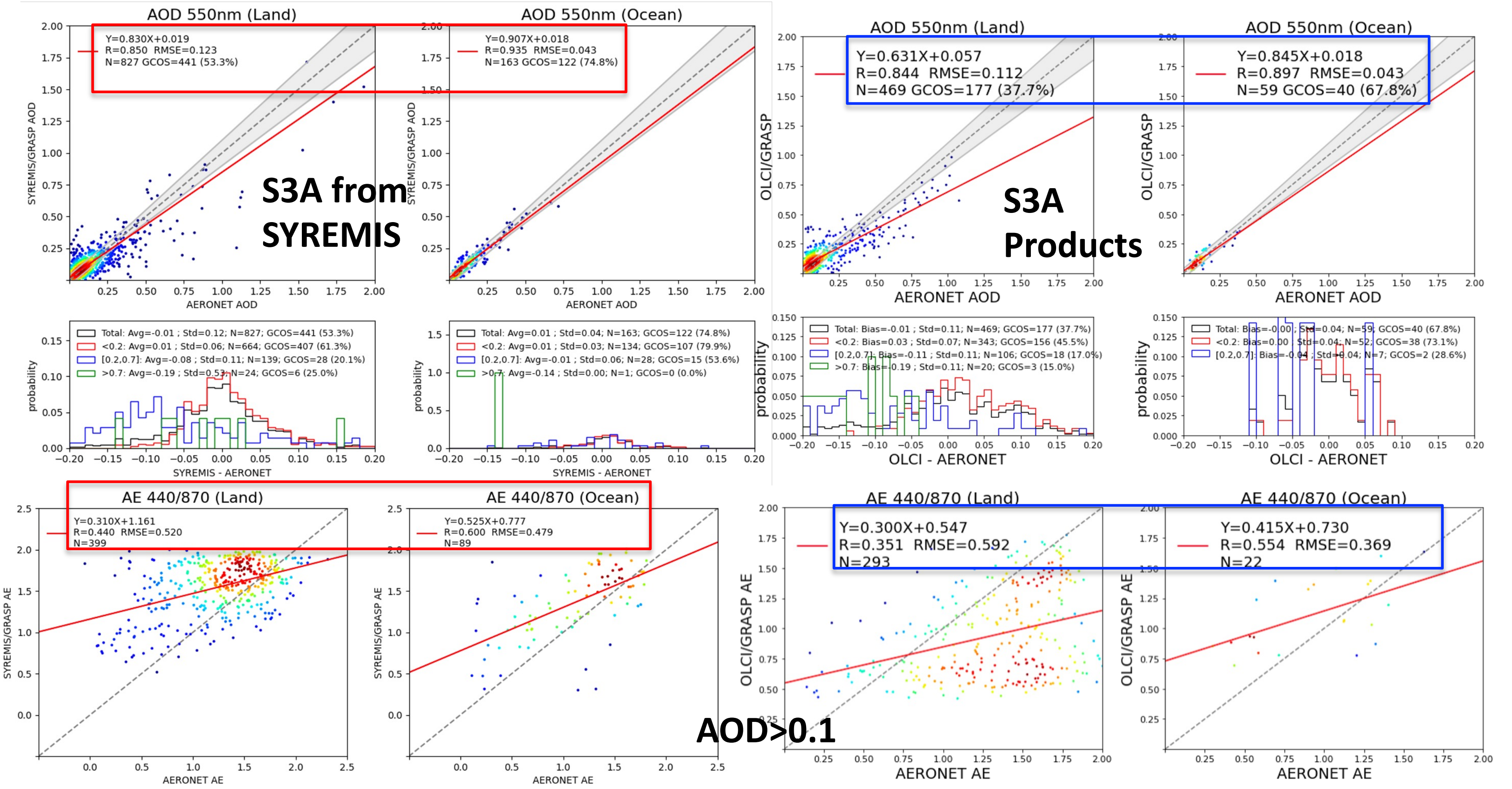
GRASP/HP (size distribution as 5 bins simplification) simulated data: 2x2x30 pixels

$C_i,\ n(\lambda_i),\ k(\lambda_i),\ C_{sph},\ h,\ BRDF_{iso},\ BRDF_{vol},\ BRDF_{geom}$ and $BPDF$

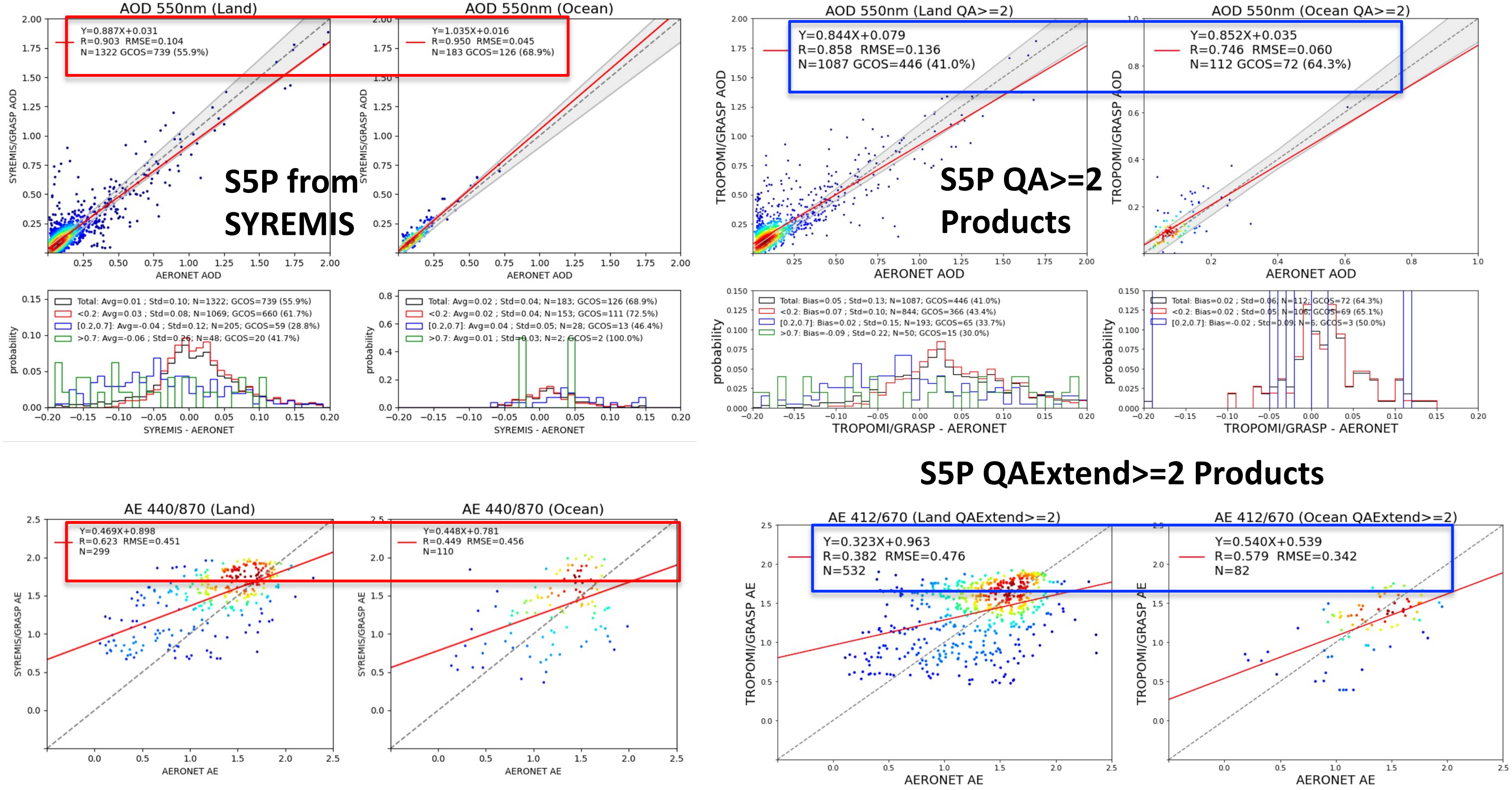
Synergy of polar orbiting satellites

	OLCI/ Sentinel-3A and Sentinel-3B	Sentinel-5p/ TROPOMI	Synergy
Orbit		Polar-Orbiting	
Swath	~1270 km	~2600 km	> ~ 2600 km
Temporal overpassing/ measurements	GLOBAL, Every 2 days	GLOBAL, Every day	GLOBAL, Every day
Equator crossing time	~10:00h	~13:40h	~10:00h, ~13:40h (few times per day)
Spatial Resolution	~300 m	~3.5 x 5.5 Km, SWIR: ~7 x 7 km	~10km
Spectral bands	9 spectral bans: 412.5, 442.5, 490, 510, 560, 665, 753, 865, 1020 nm	10 spectral bands: 340, 367, 380, 416, 440, 494, 670, 747, 772, 2313 nm	19 spectral bands: 340, 367, 380, **412.5**, **416**, **440**, **442.5**, **490**, **494**, 510, 560, **665**, **670**, 747, 753, 772, 865, 1020, 2313 nm

OLCI SYREMIS vs OLCI GRASP product



TROPOMI SYREMIS vs TROPOMI GRASP product



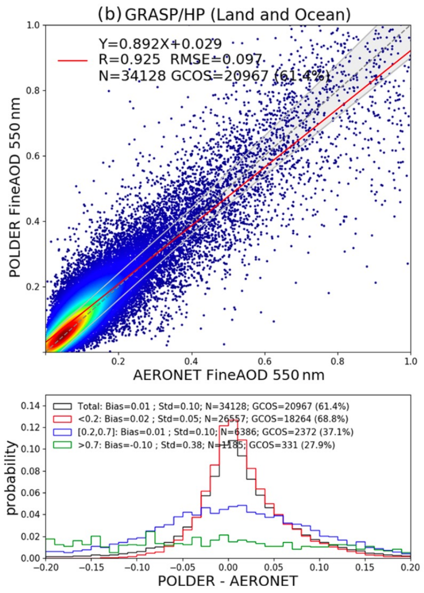
CONSLUSIONS from POLDER aerosol product analysis :

2. Detailed properties - **AE**, **fine /coarse AOD** (land), **SSA**, **AAOD** are available from MAP and generally not from MODIS like single- or bi- viewing images;

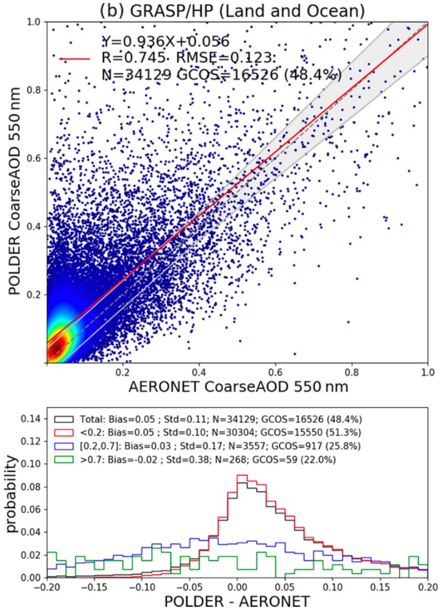
POLDER/ GRASP

over Land and Ocean for 2004 – 2013 years (Chen et al., 2020)

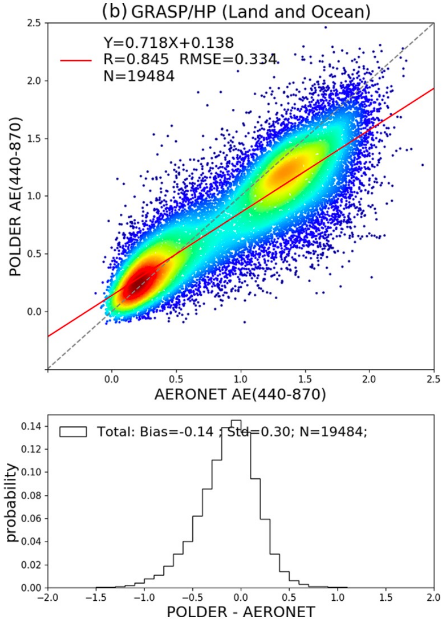
AOD fine (550)



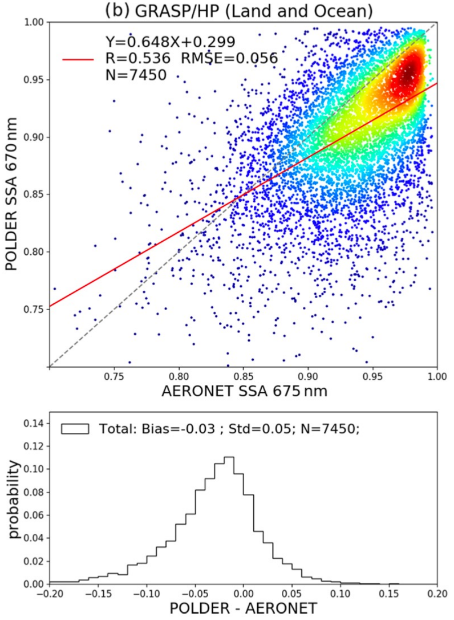
AOD coarse (550)



AE (440 - 870)

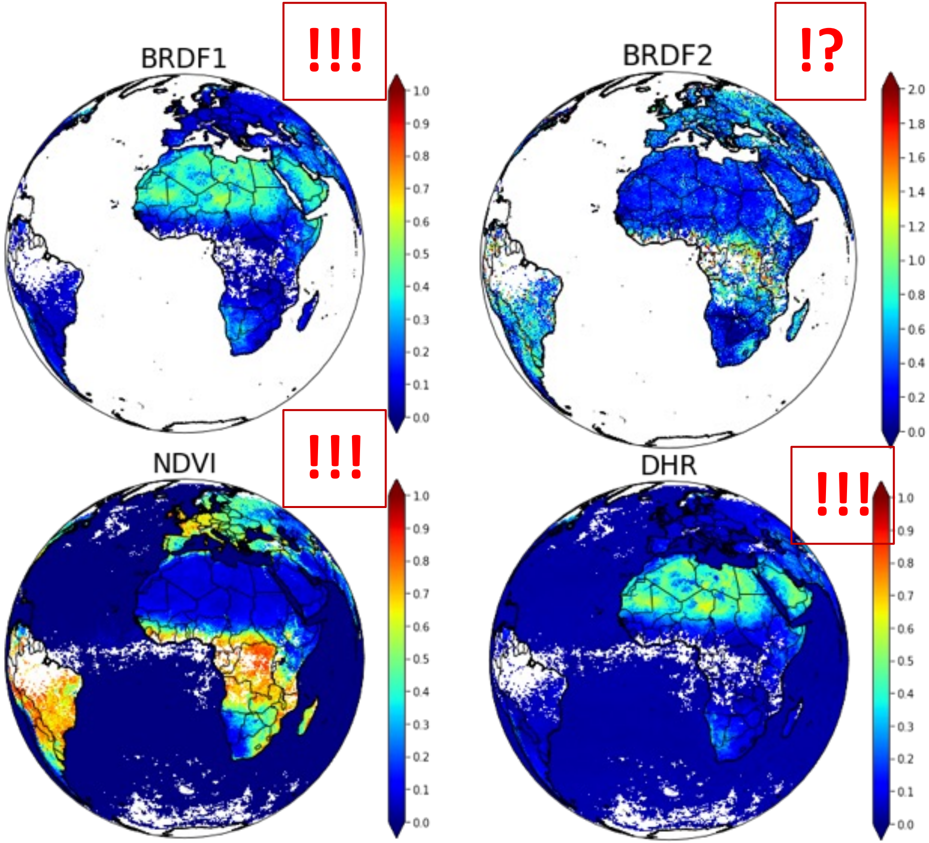


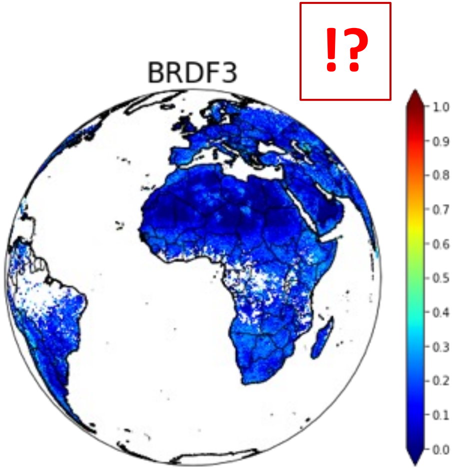
SSA (670)



TROPOMI/GRASP

GRASP





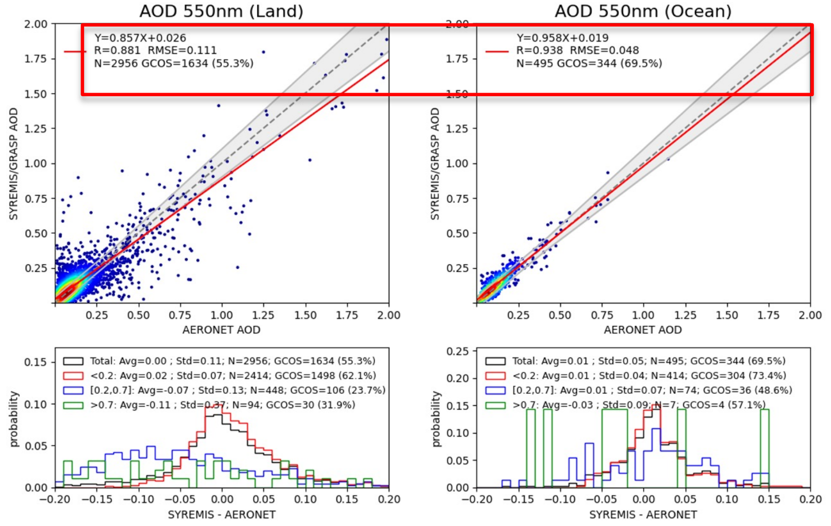
Surface products

10 wavelengths:
0.340 0.367 0.380 0.416 0.440
0.494 0.670 0.747 0.772 2.313

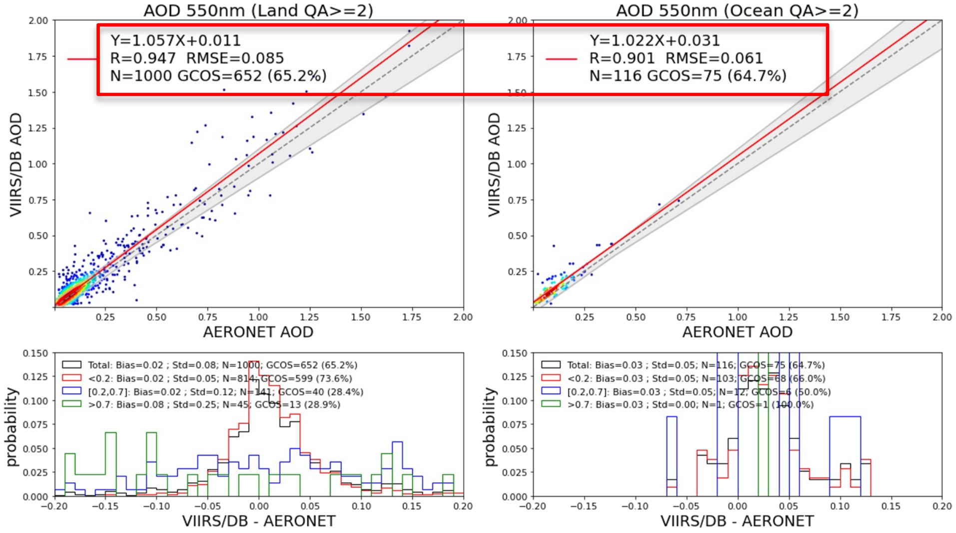
1. Spectral BRDF1 (land)
2. BRDF 2nd and 3rd parameters (land)
3. NDVI
4. Spectral water body albedo (sea/ocean)
5. Spectral DHR, BHR_iso

AERONET Validation - AOD

SYREMIS
S5P+S3A+S3B



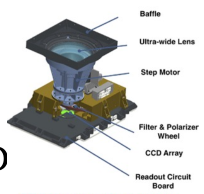
VIIRS



Shikuan Jin, et al.

GF-5(02) vs MODIS

Various aerosol properties **for DPC/GF-5(02):** Differences in AOD



DPC Hardware Construction

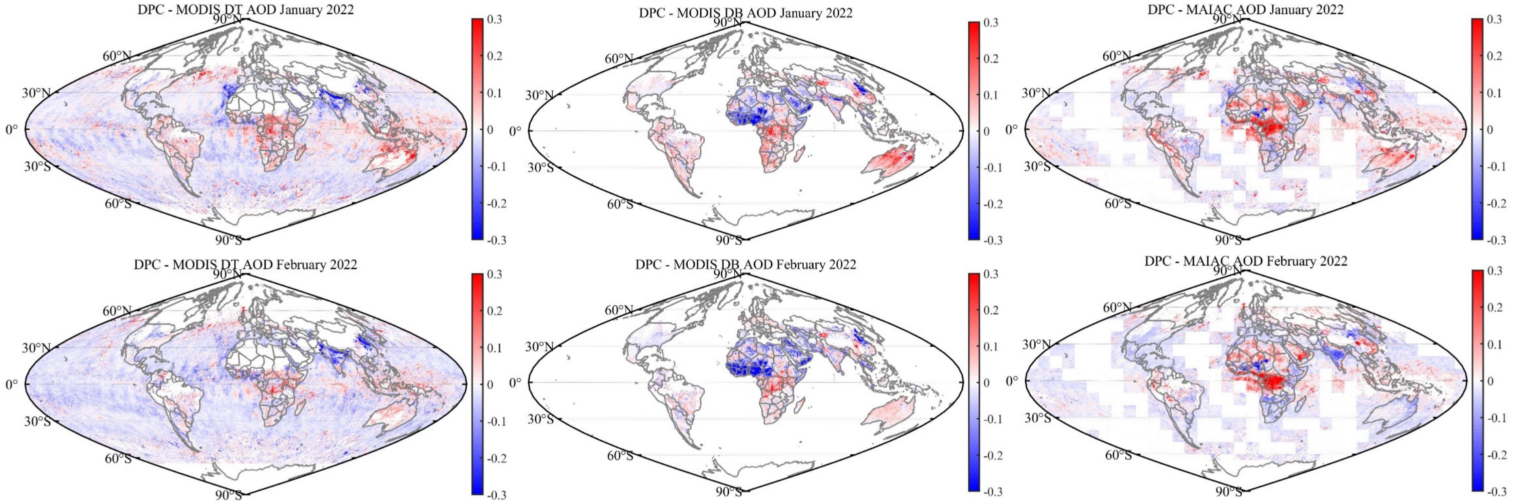
Parameters	GF-5(01)	GF-5(02)
Bands	443, 490P, 565, 670P, 763, 765, 865P, 910	443, 490P, 565, 670P, 763, 765, 865P, 910
Spatial Resolution	3.3km (nadir)	3.3km (nadir)
Angle Number	~9	~17
Uncertainties	~5%(I); ~0.02(DOLP)	~5%(I); ~0.02(DOLP)
Field of View	~1850km	~1850km
Transit Time	~13:30 Local Time	~10:30 Local Time

- Preliminary comparison of global aerosol properties retrievals from DPC GF-5(02) and GRASP/Models with MODIS, from January to February 2022 (2 months as an example)

DPC-DT | DPC-DB | DPC-MAIAC

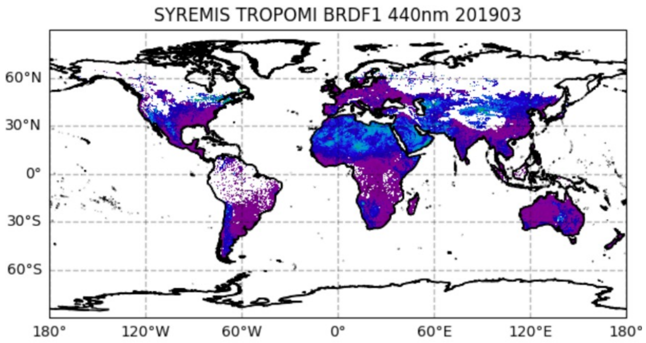
Jan.

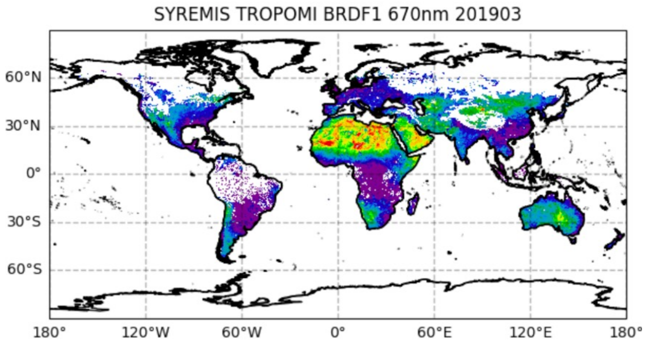
Feb.

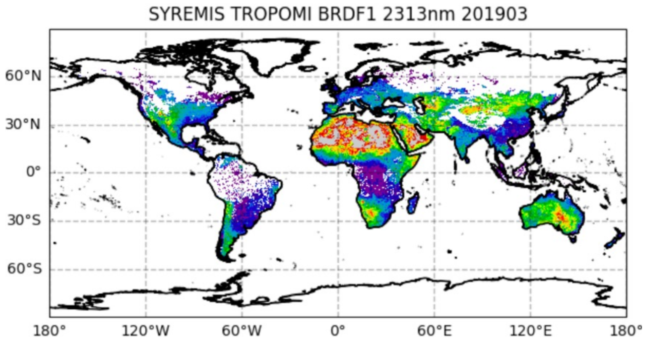


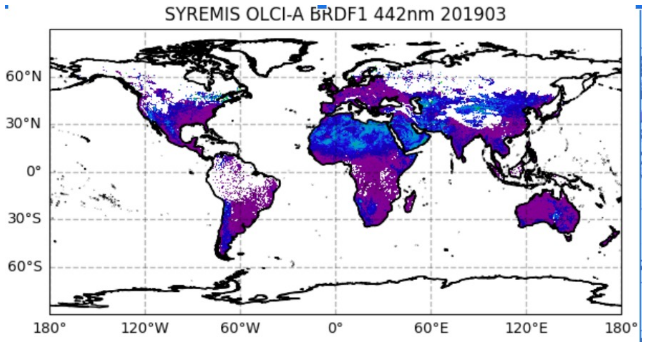
- The monthly AODs still show difference between different satellite aerosol products.

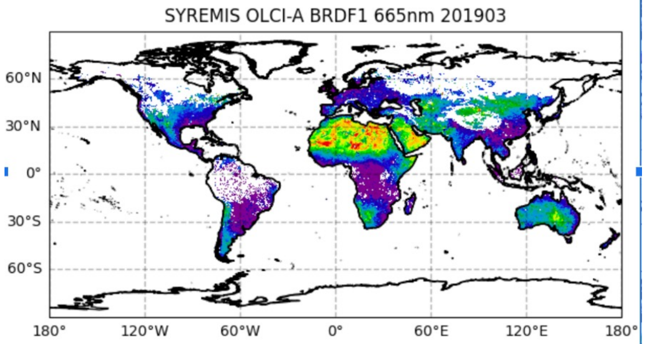
Extended BRDF properties

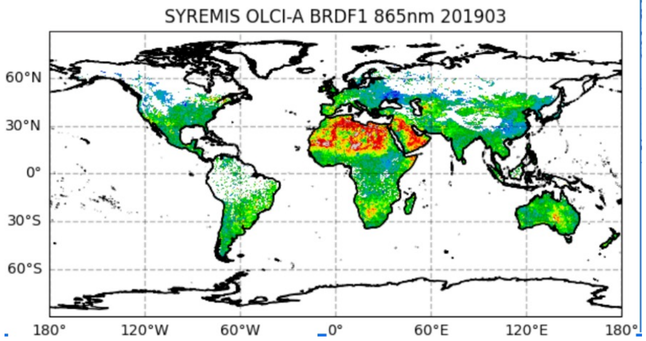






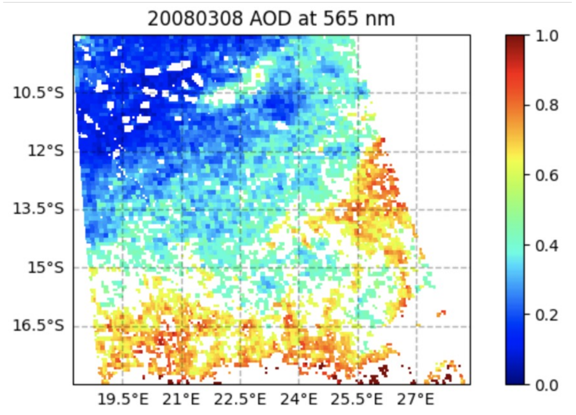


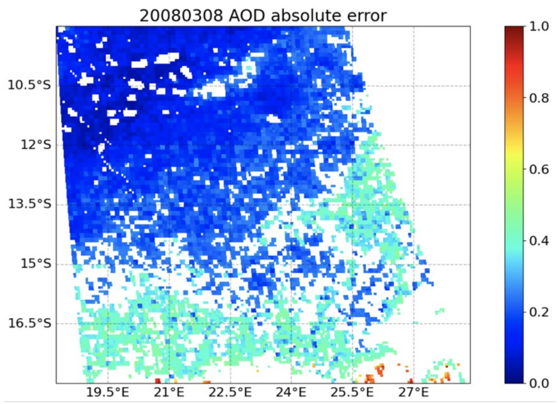




Error images for POLDER data: Banizoumbou 1000x1000km

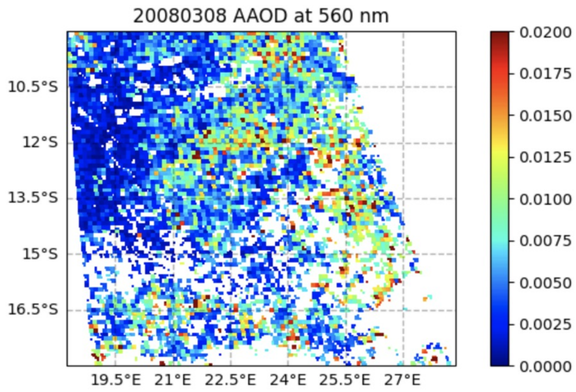
AOD(550)

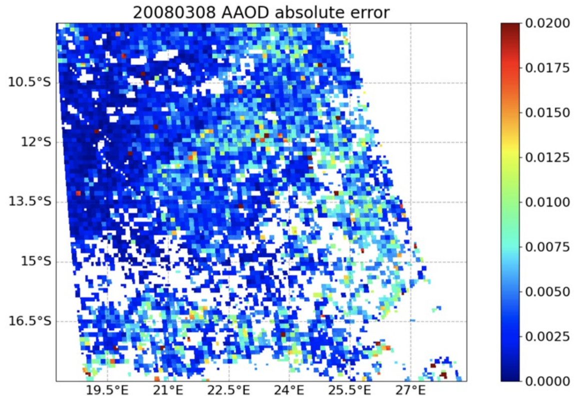




AOD(550) absolut error

AAOD(550)





AAOD(550) absolut error

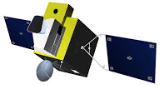
GRASP processing developments for agencies
EUMETSAT, ESA, CNRS, etc.

Single-, Bi-View Imagers

OLCI/S-3A 2016-
OLCI/S-3B 2018-

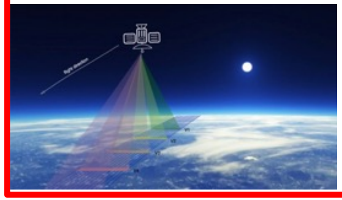
TROPOMI/S-5P
2017-

S-4 2024

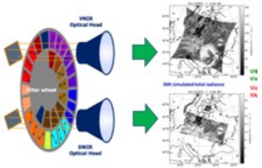


MAP – Multi – Angular Polarimeters

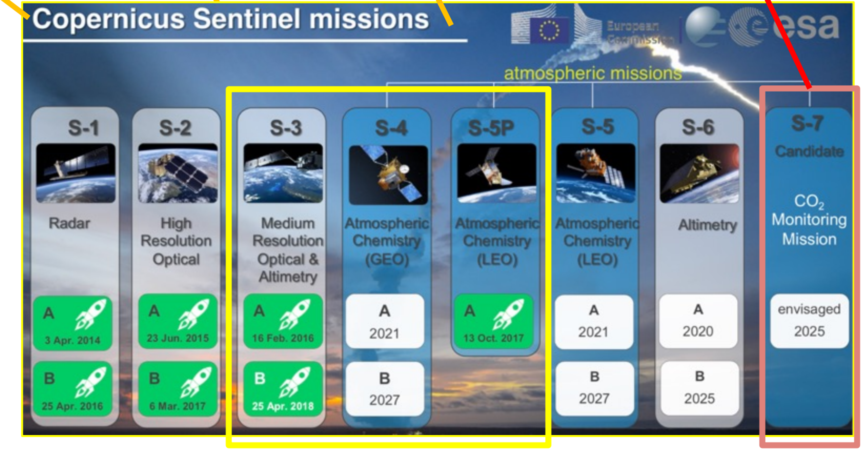
MAP/CO2M 2026 -



3MI/MetOP-SG



2025 ? - 2037



Past mission

ENVISAT 2012-2012

- MERIS
- AATSR
- MERIS + AATSR

Past mission

POLDER-1, -2, -3

08/1996- 06/1997
12/2003-09/2004
2004-2013

GRASP

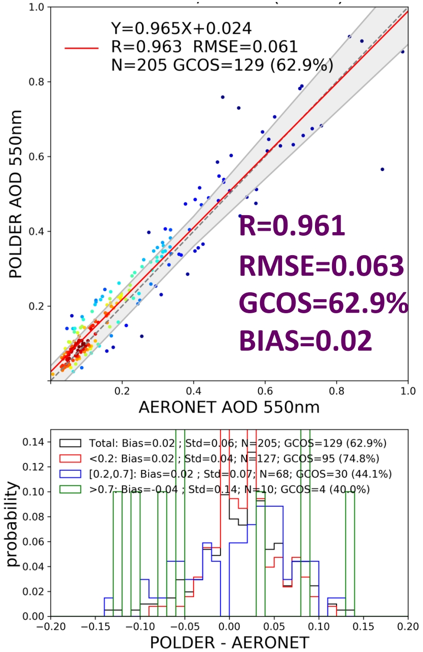
CONSLUSIONS from POLDER aerosol product analysis :

1. The baseline **AOD products from MAP** overall have higher, or at least, of similar accuracy as AOD from MODIS – like instruments;

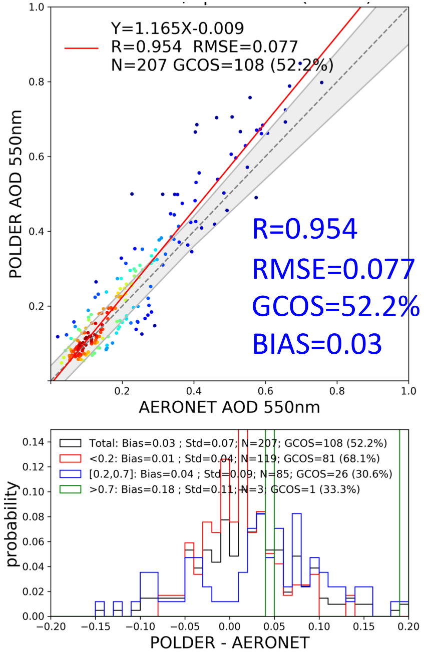
AOD(550)] or 2008 year (Chen et al., 2020)

Ocean

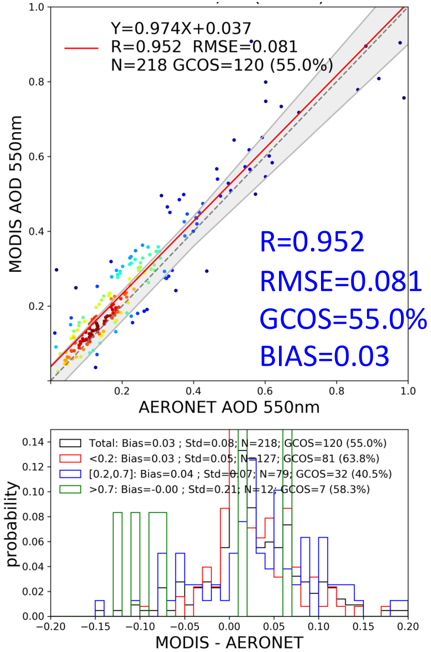
POLDER/GRASP-Models

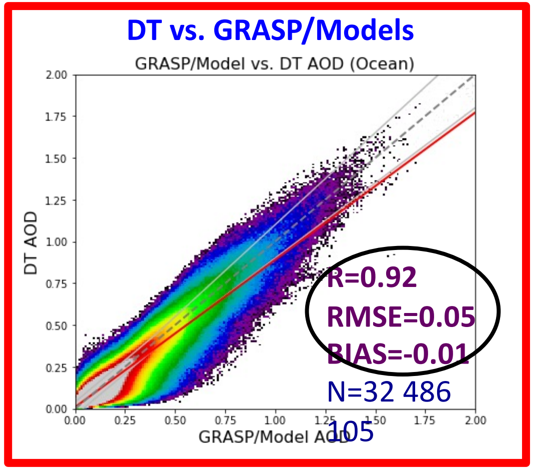


POLDER/Operational



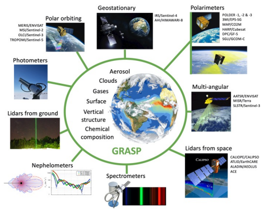
MODIS-Aqua/DT

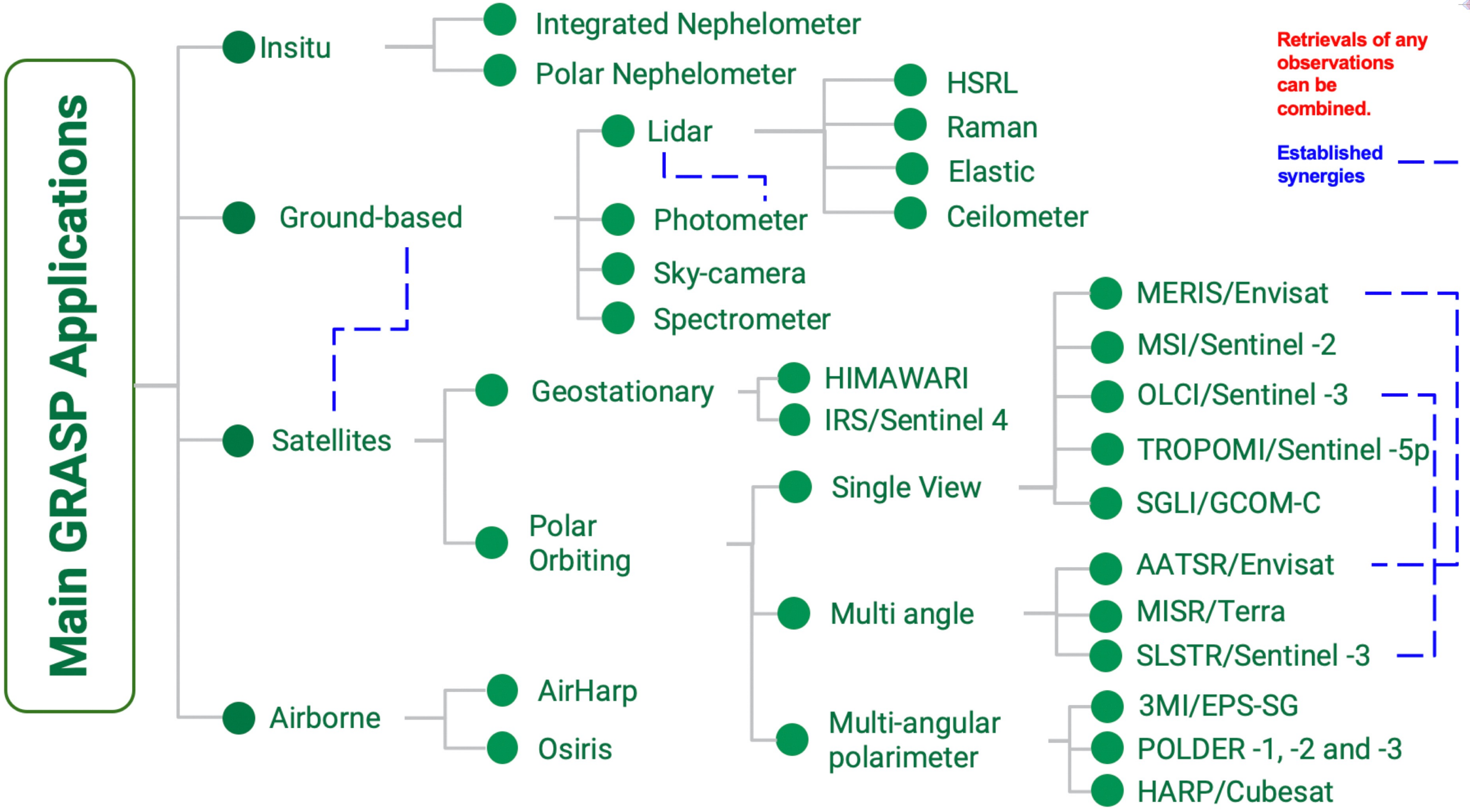




GRASP remote sensing developments

Dubovik et al. (2021)

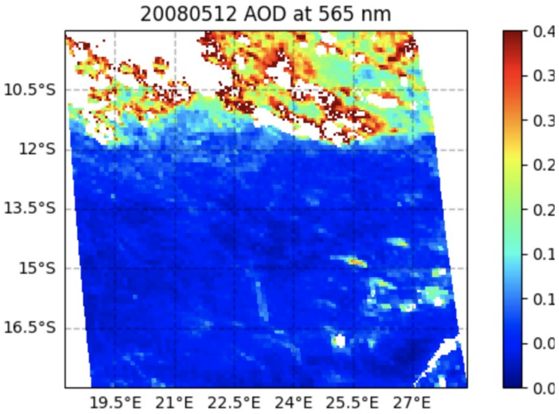


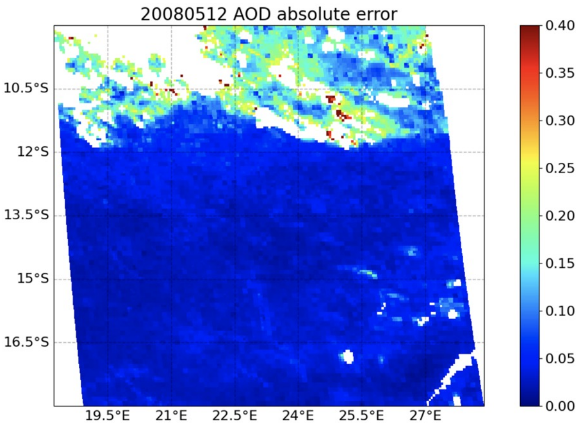


Error images for POLDER data: Mongu

1000x1000km

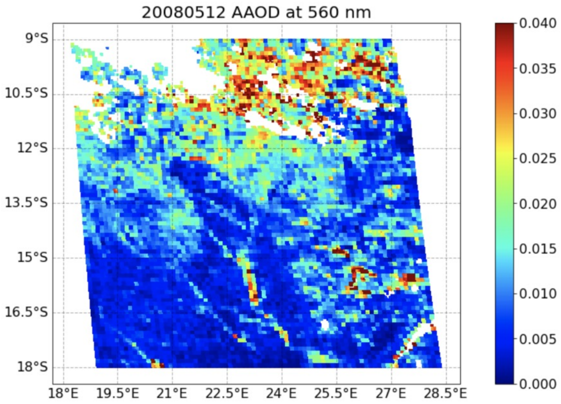
AOD(550)

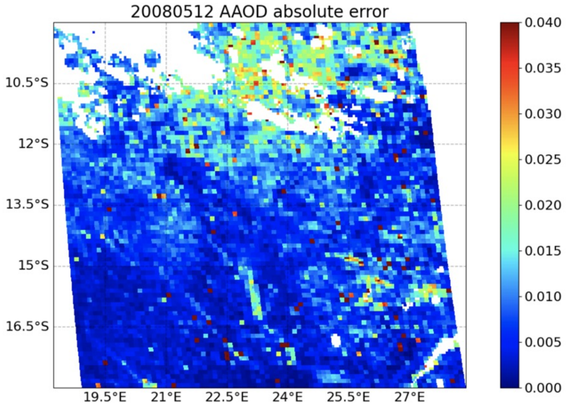




AOD(550) absolute error

AAOD(550)





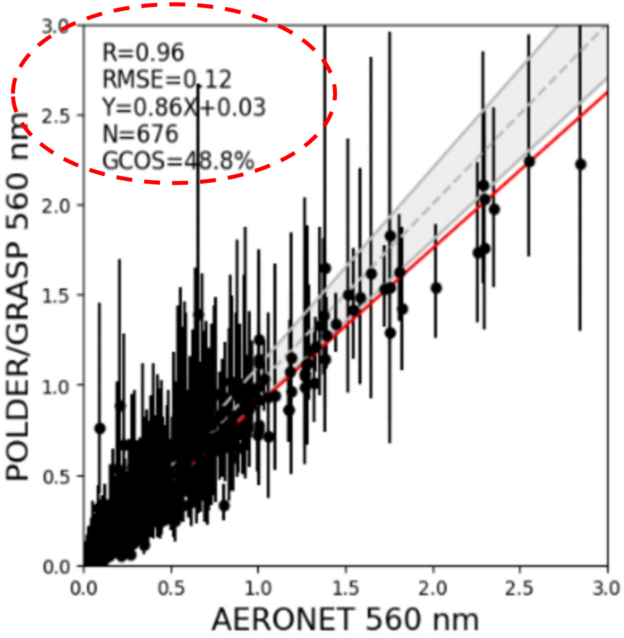
AAOD(550) absolute error

POLDER/GRASP retrievals over 19 AERONET sites (2008 year)

$$\sigma_{tot} = \sqrt{\sigma_{ran}^2 + \sigma_{bias}^2}$$

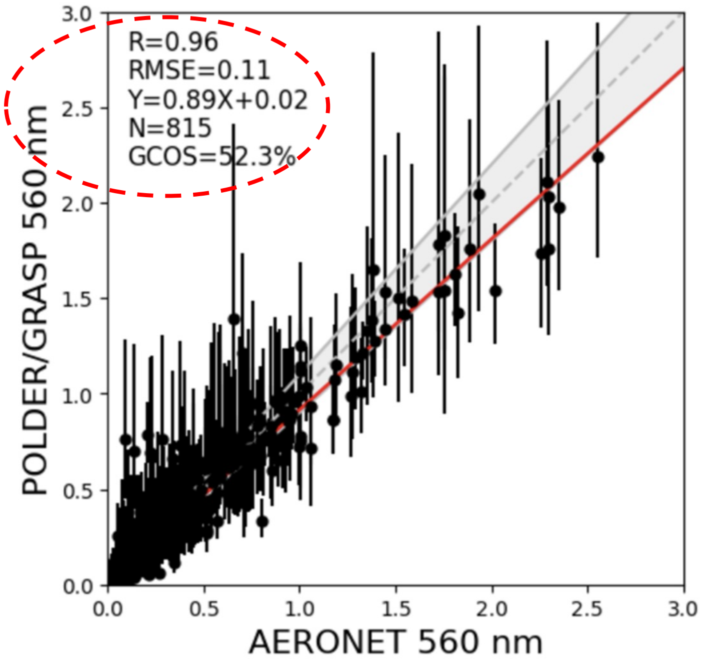
$$\sigma_{bias}^2 = \sigma_{lm}^2 + \sigma_{misfit}^2 + \frac{1}{N}\sum_{k=1}^{N}\sigma_k^2$$

Empiricaly quality assured results
(using residual , etc.)



AOD(550)

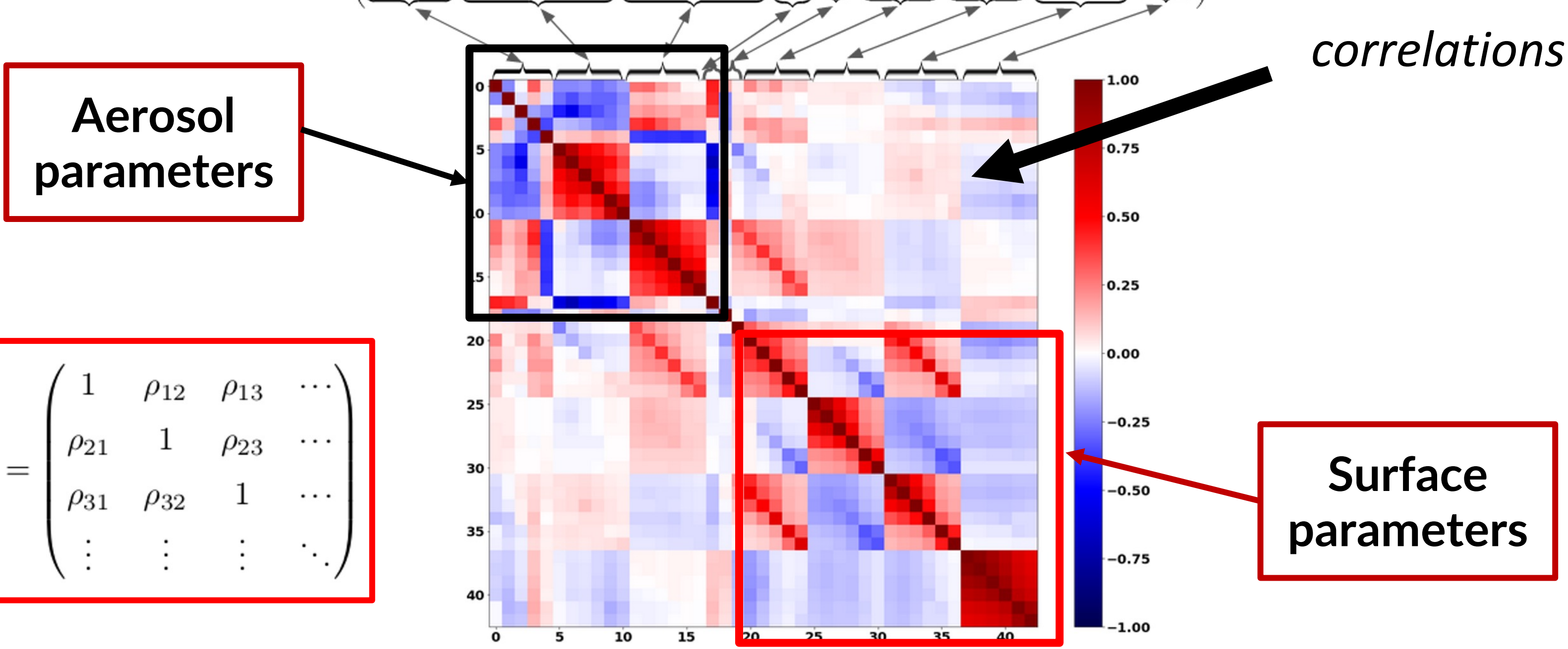
Quality assured using olny values of estimated dynamic errors



Correlation matrix:

- Example for POLDER/PARASOL-like retrievals

$$\mathbf{a}^T = \left(\underbrace{C_1,\cdots,C_5}; \underbrace{RRI_{\lambda_1},\cdots,RRI_{\lambda_6}}; \underbrace{IRI_{\lambda_1},\cdots,IRI_{\lambda_6}}; \underbrace{C_{sph}}; \underbrace{h}; \underbrace{BRDF_{iso}}; \underbrace{BRDF_{vol}}; \underbrace{BRDF_{geom}}; \underbrace{BPDF}\right)$$



$$Corr(\mathbf{a}) = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \cdots \\ \rho_{21} & 1 & \rho_{23} & \cdots \\ \rho_{31} & \rho_{32} & 1 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

Synergy of polar orbiting satellites

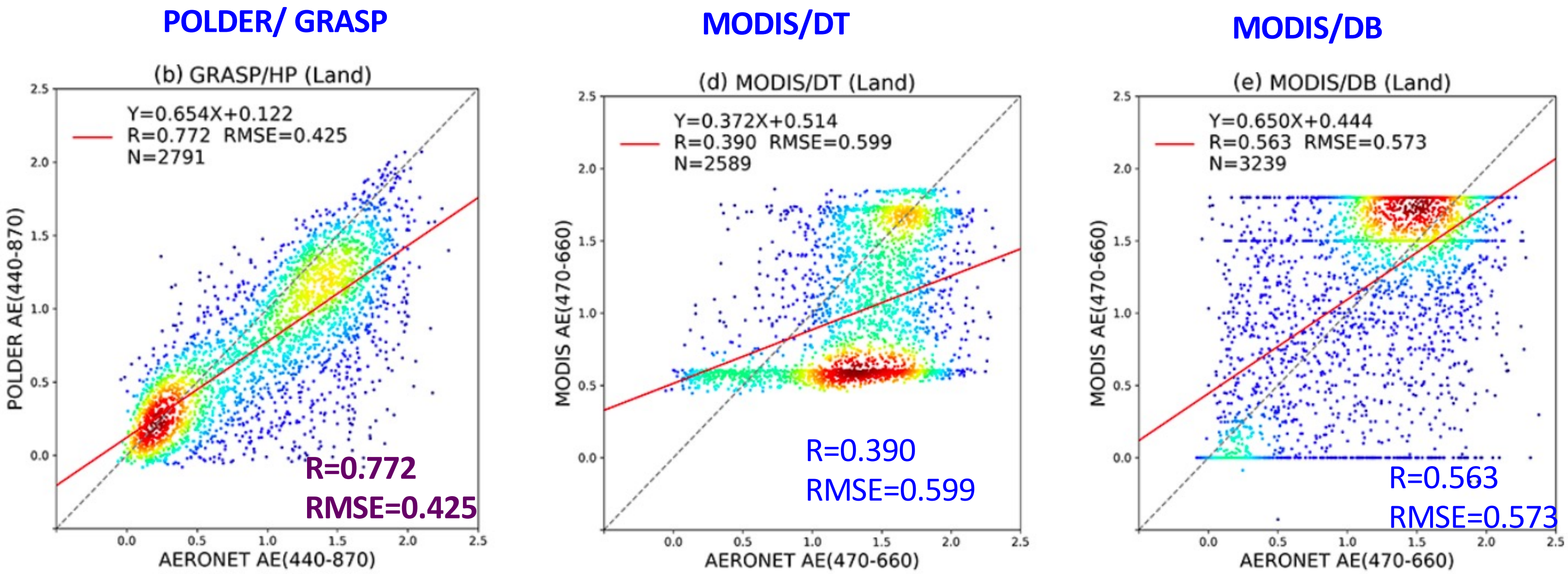
	OLCI/ Sentinel-3A and Sentinel-3B	Sentinel-5p/ TROPOMI	Synergy
Orbit		Polar-Orbiting	
Swath	~1270 km	~2600 km	> ~ 2600 km
Temporal overpassing/ measurements	GLOBAL, Every 2 days	GLOBAL, Every day	GLOBAL, Every day
Equator crossing time	~10:00h	~13:40h	~10:00h, ~13:40h (few times per day)
Spatial Resolution	~300 m	~3.5 x 5.5 Km, SWIR: ~7 x 7 km	~10km
Spectral bands	9 spectral bans: 412.5, 442.5, 490, 510, 560, 665, 753, 865, 1020 nm	10 spectral bands: 340, 367, 380, 416, 440, 494, 670, 747, 772, 2313 nm	19 spectral bands: 340, 367, 380, **412.5**, **416**, **440**, **442.5**, **490**, **494**, 510, 560, **665**, **670**, 747, 753, 772, 865, 1020, 2313 nm

CONSLUSIONS from POLDER aerosol product analysis :

3. Detailed properties - **AE, fine /coarse AOD** (ocean), from MAP generally notably more accurate than from MODIS like instruments;

AE – Angstrom Exponent (440 – 870) for 2008 year (Chen et al., 2020)

Land



CONSLUSIONS from POLDER product analysis :

1. The baseline **AOD, AE**, **fine /coarse AOD** (ocean), **products from MAP** overall have higher, or at least, of similar accuracy as AOD from MODIS – like instruments;

!

2. Detailed properties - **AE**, **fine /coarse AOD** (land), **SSA**, **AAOD** are available from MAP and generally not from MODIS like single- or bi- viewing images;

!!

3. MAP algorithms are complex, and need **specific tuning for different products:**

- e.g., **MAP** algorithms provide - **AE, fine /coarse AOD** (land), **SSA**, **AAOD** but **struggle with** issues in **baseline AOD products.**

!?

Overall, once retrieval fully optimized all parameters including– **AOD**(land), **AE**, **fine /coarse AOD** (land), **SSA**, **AAOD** can be of retrieved with unprecedented accuracy from **MAP**;

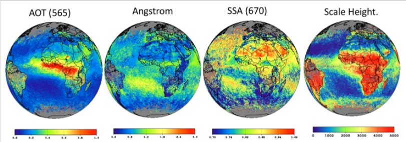
MAP Algorithm studies:

GRASP

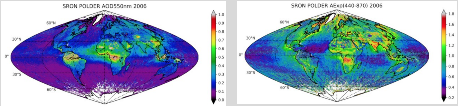
SRON Netherlands Institute for Space Research — Remo- TAP

cnes

GRASP: POLDER-1, -2, -3

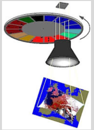


SRON Remo-TAP: POLDER -3

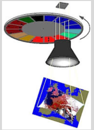


EUMETSAT, esa European Space Agency

GRASP: 3MI/EPS-SG, MAP/CO2M

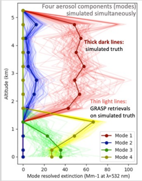


SRON Remo-TAP: 3MI/EPS-SG, MAP/CO2M



NASA, UMBC

GRASP: Air HARP, HARP/CubeSat, HARP-2/PACE, AOS



SRON Remo-TAP: SPEX Airborne, SPEX/PACE

CNSA, Chinese Academy of Sciences, AMS

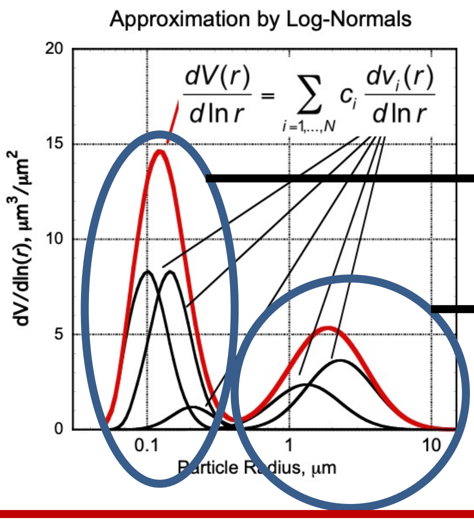
GRASP: DPC/GF-5

SRON Remo-TAP: DPC/GF-5

JAXA, Government of Dubai, GRASP

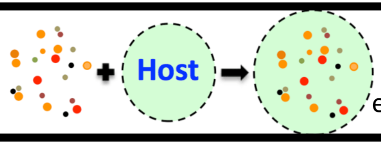
GRASP: SGLI/GCOM-C, DMSAT, GAPMAP

GRASP Chemical Component approach



(Li et al., 2019, 2020, 2022)

Fine mode

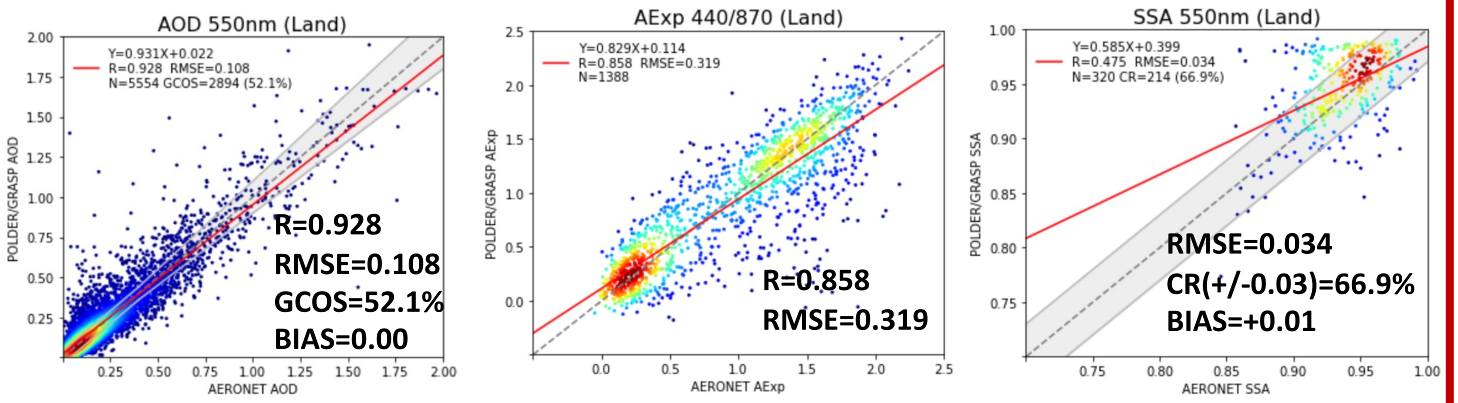


Maxwell Garnett
effective medium approximation

Coarse mode

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

Absorbing insoluble (FeOx)
Non-absorbing insoluble (Coarce 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*.

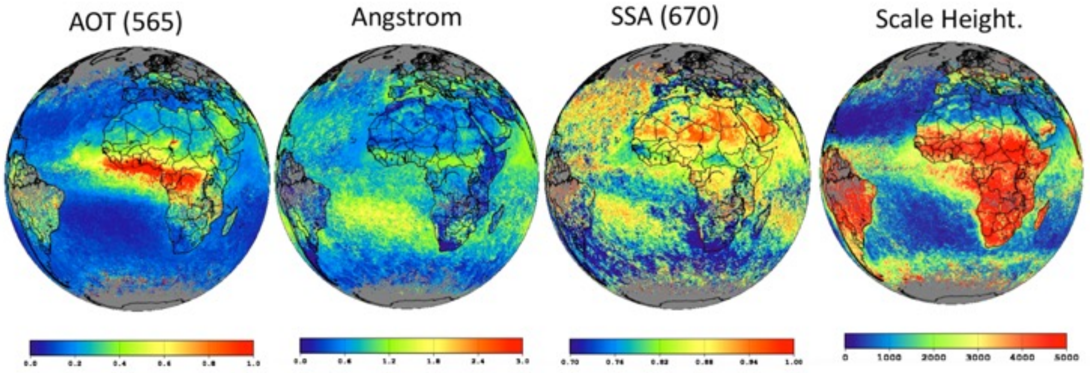
POLDER-3/GRASP products

2004-2013
4 products

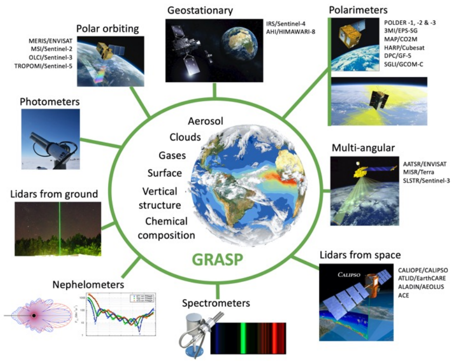
Chen et al., 2020
Li et al., 2019, 2021, 2022
Zhang et al. 2021
Dubovik et al. 2021

Winter 2009

Ocean and land



GRASP



AEROSOL: **AOD(λ), AOD fine/coarse, Angstrom, SSA (λ), AAOD (λ)**
aerosol height, spectral complex index of refraction, sphericity fraction.

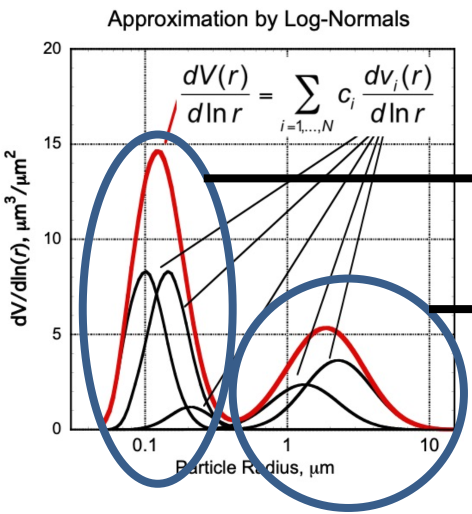
SURFACE: **land BRDF(λ), BPDF(λ)**
ocean wind speed and water leaving radiances, etc.

Important features of GRASP retrieval:

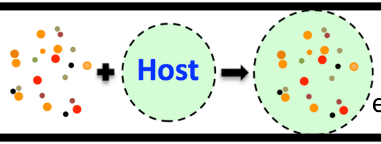
- Globally the same initial guess for aerosol;
- Globally the same set of a priori constraints;
- No location specific assumptions;
- Retrieval on 6 km resolution, no averaging;
- Surface retrieved simultaneously

GRASP Chemical Component approach

(Li et al., 2019, 2020, 2022)



Fine mode

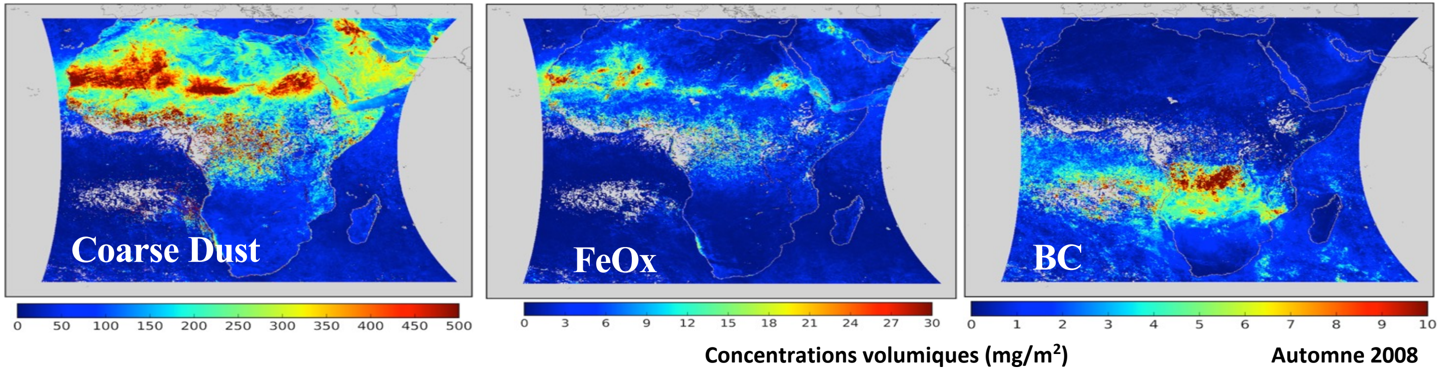


Maxwell Garnett
effective medium approximation

Coarse mode

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

Absorbing insoluble (FeOx)
Non-absorbing insoluble (Coarce 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*.

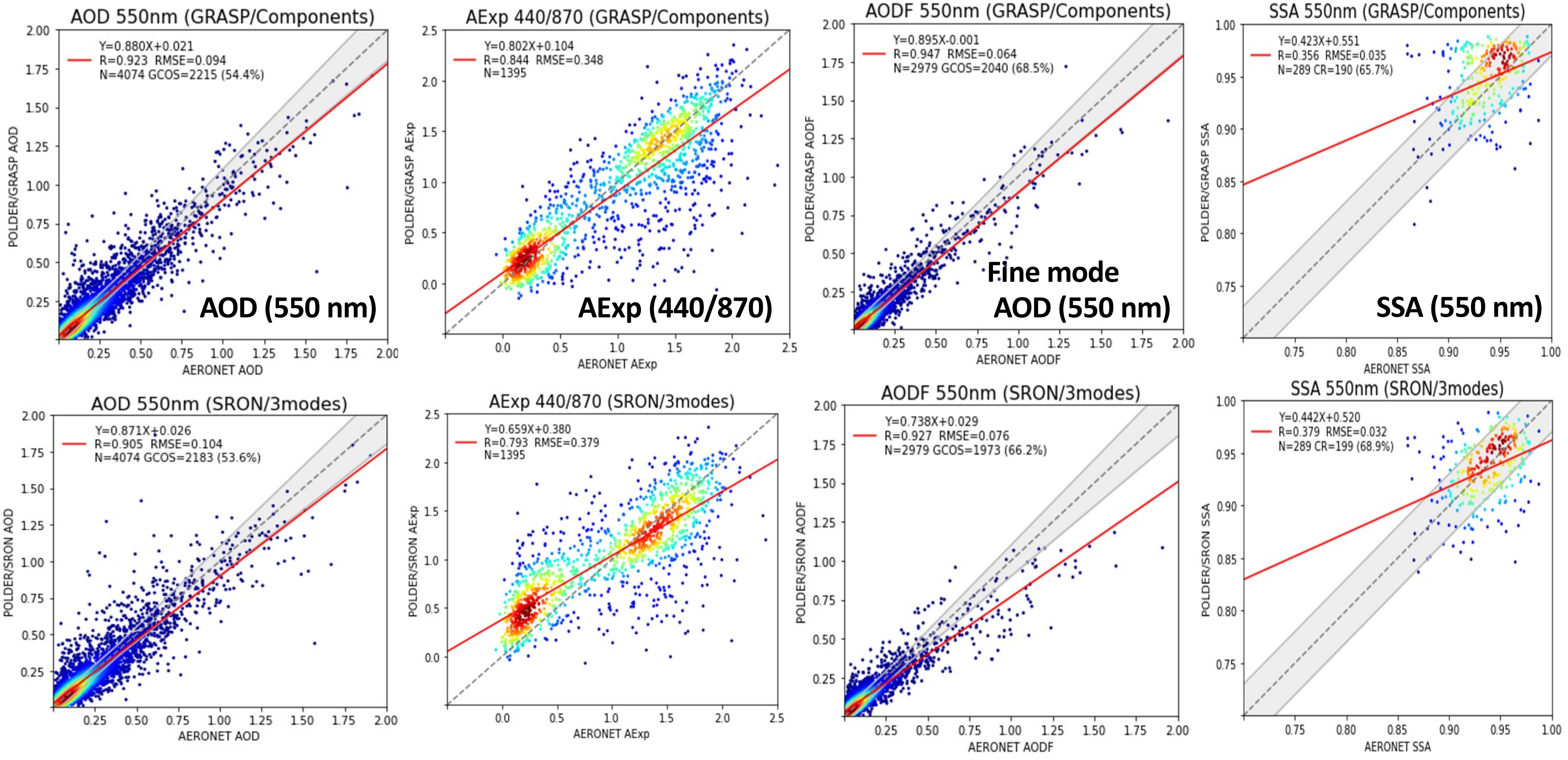
Harmonizing GRASP and SRON-RemoTAP GRASP approaches *(similar performance)*

G. Fu, ..., O. Hasekamp presentation on ESA HARPOL project

Process the same amount PARASOL data

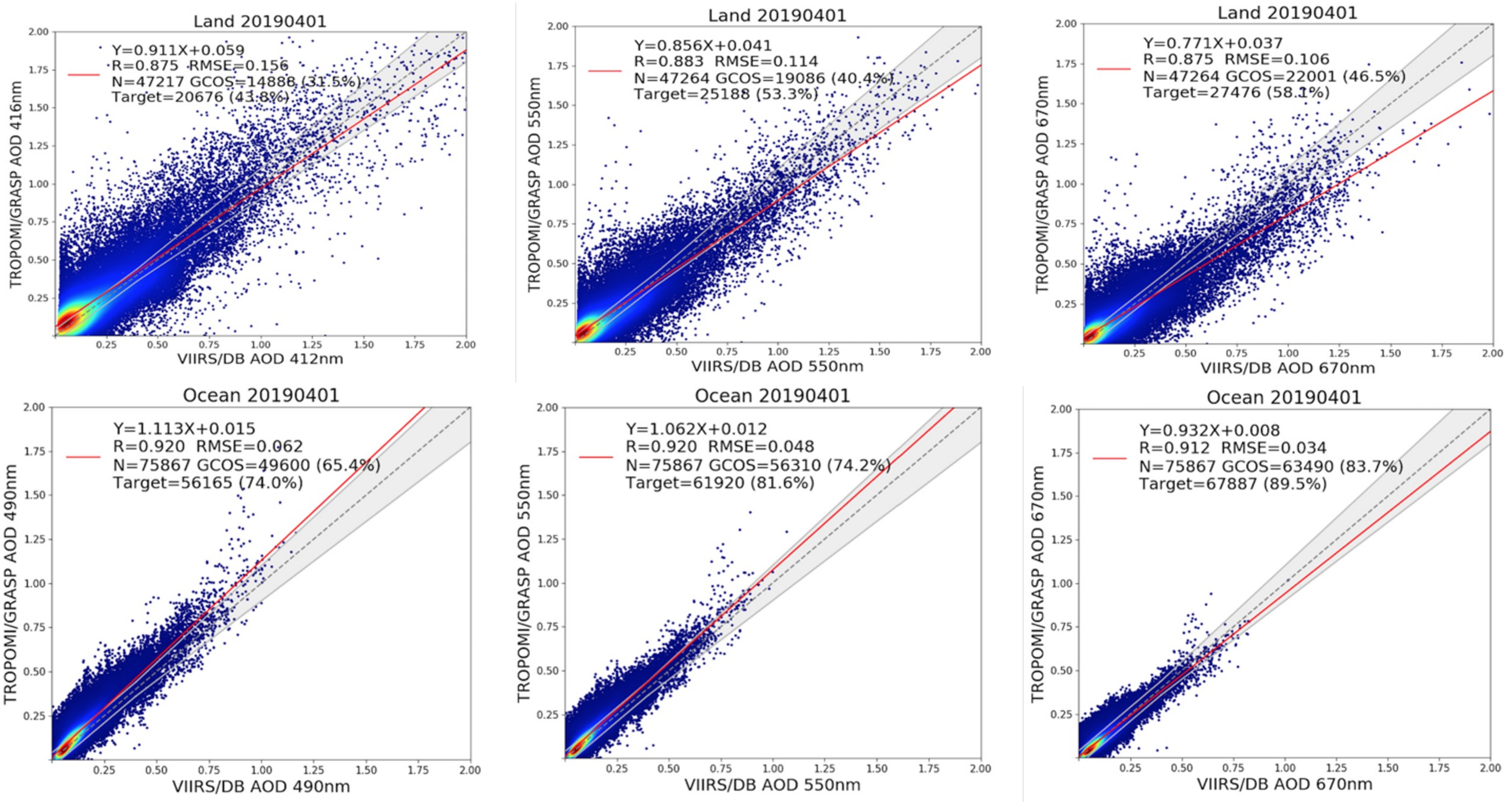
GRASP/Component

RemoTAP 3modes Component



Aerosol intercomparison. Daily

S-5P/GRASP vs VIIRS



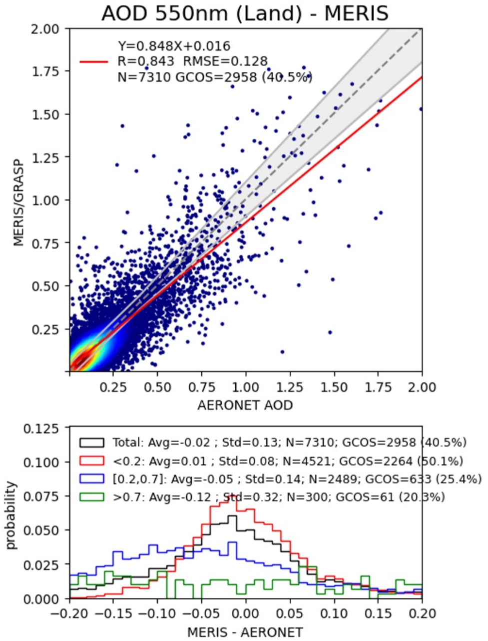
ENVISAT/GRASP (2002-2012)

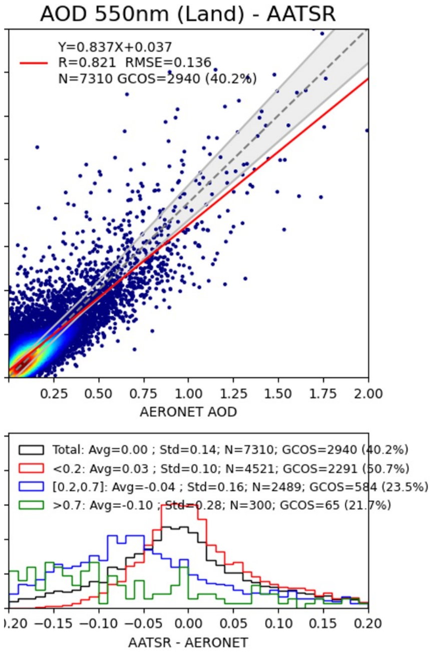
MERIS

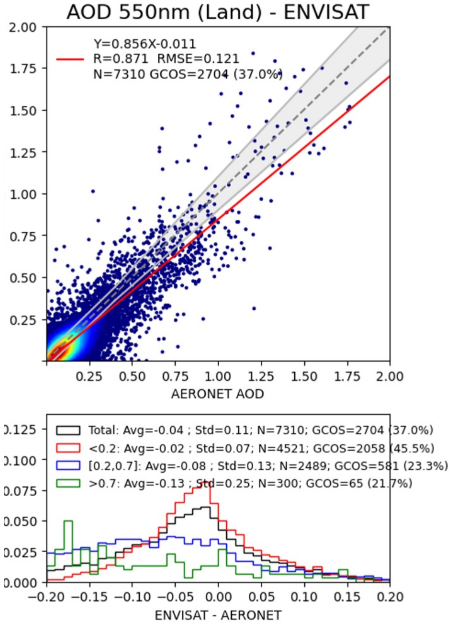
AATSR

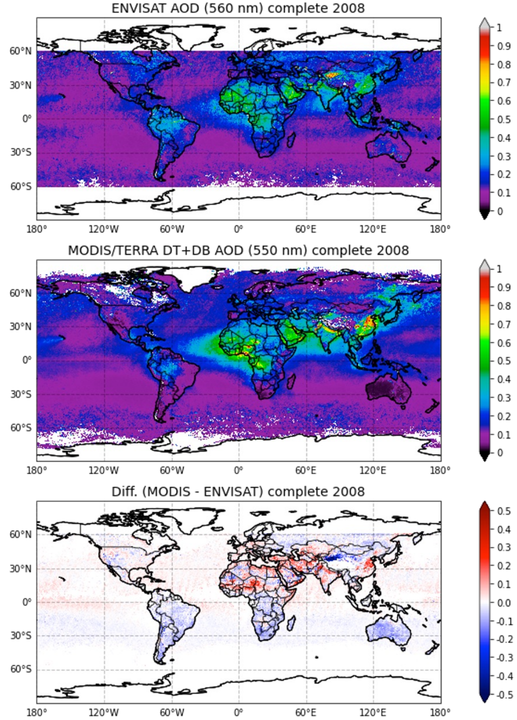
MERIS + AATSR

ENVISAT vs MODIS









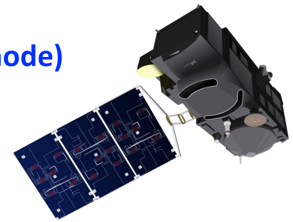
AOD(550)

Sentinel-3A/OLCI

Chen et al., 2022, Rem. Sens. Environ

Ocean and Land Color Instrument (OLCI)

Onboard Sentinel-3A Single-viewing
Overpass: ~10 a.m. L.T. (descending node)
Bands: 412 – 1020 nm

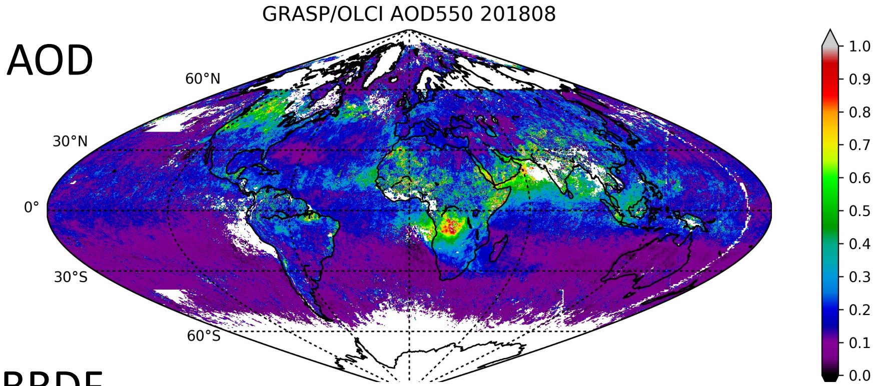


L1B RR -> Target 10km pixel aerosol and surface retrieval

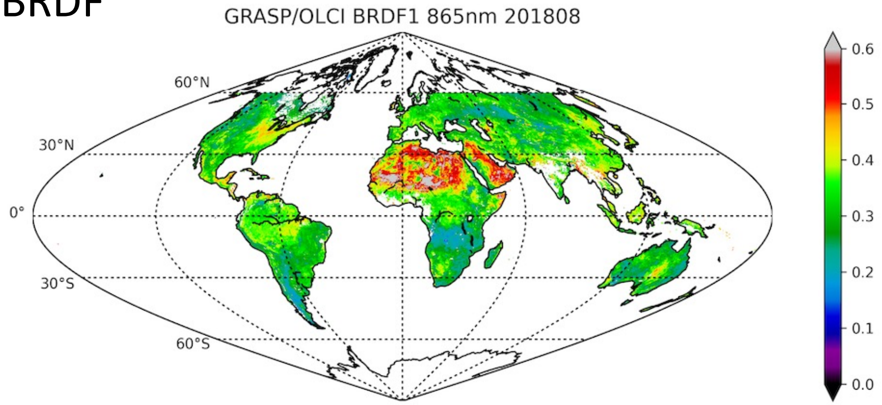
OLCI-A Band	Central Wavelength (nm)	Band Width (nm)	Radiance Bias Correction
Oa02	412.5	10	-2%
Oa03	442.5	10	-2%
Oa04	490	10	-2%
Oa05	510	10	-2%
Oa06	560	10	-2%
Oa08	665	10	-2%
Oa12	753	7.5	-2%
Oa17	865	20	-2%
Oa21	1020	40	-6%

OLCI/GRASP – product. (2018-2019)

AOD



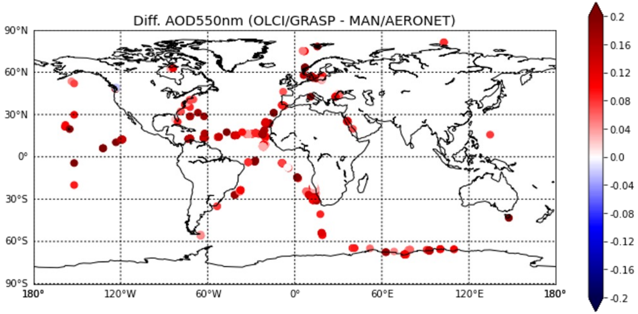
BRDF



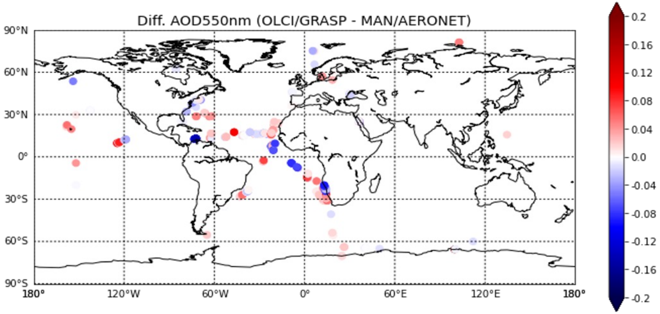
✓ *AOD retrieval over ocean*

1 yr validation with **MAN**/AERONET

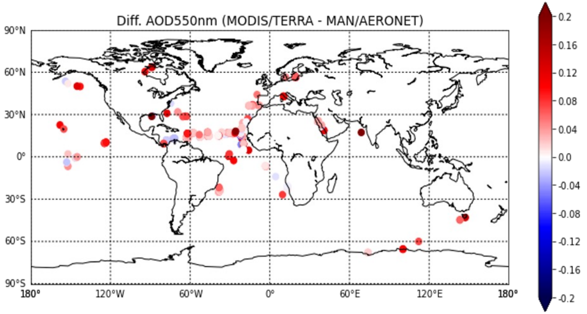
OLCI/GRASP (Initial) - MAN



OLCI/GRASP (Optimized) - MAN



MODIS/TERRA - MAN

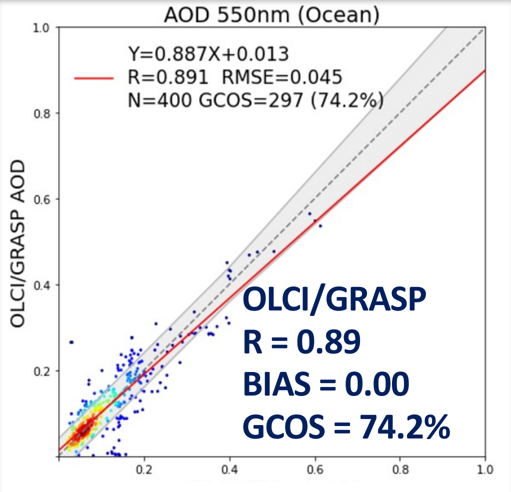


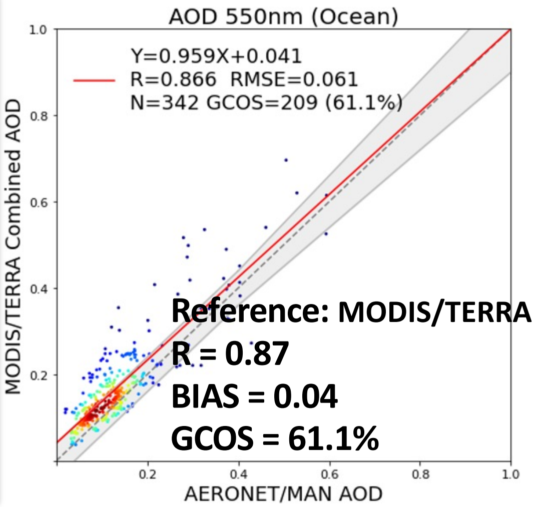
Observed improvements:

a. Clear evolution from Initial to Optimized OLCI/GRASP retrieval over ocean

b. The AOD BIAS decrease from +0.11 to +0.01 with AERONET coastal sites and ~0.00 with MAN deep ocean measurements.

c. Comparable quality of AOD product with MODIS/TERRA. The OLCI/GRASP bias is even smaller than MODIS/TERRA over ocean.



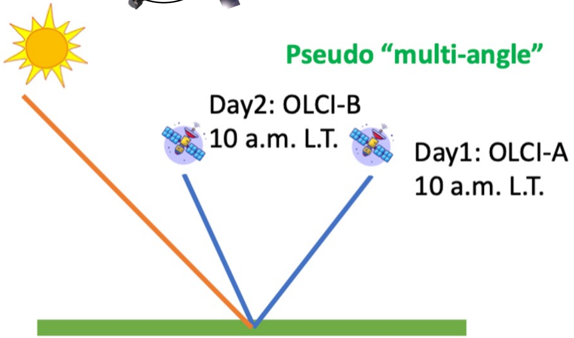


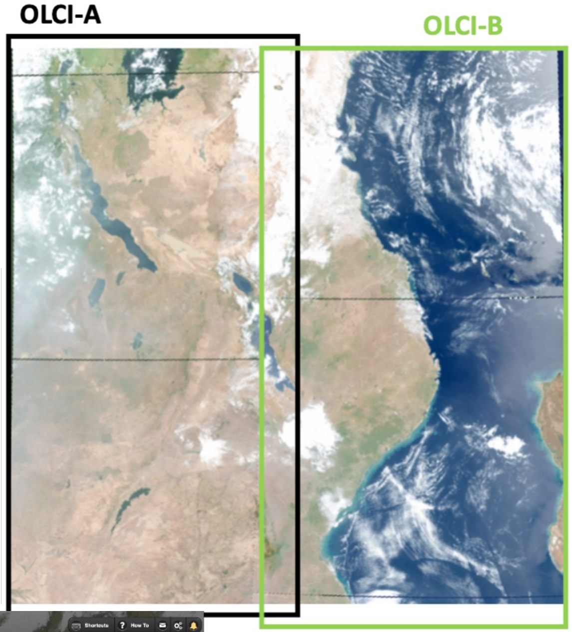
ΣYREMIS

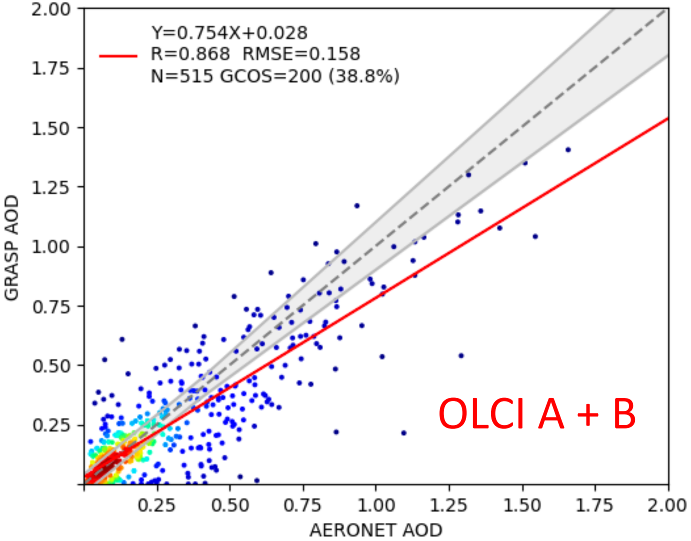
GRASP

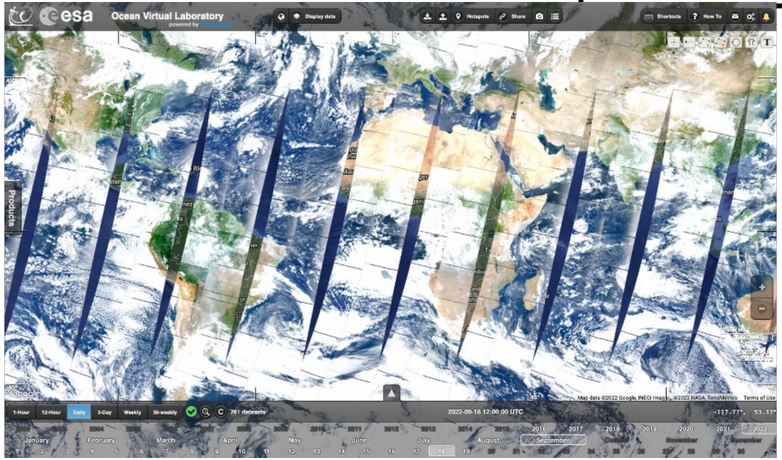
cloudflight

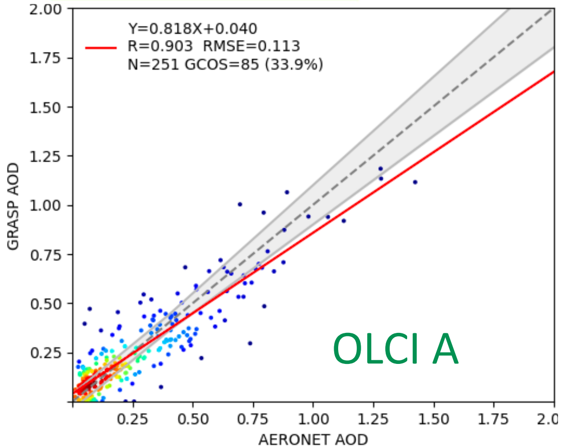
esa

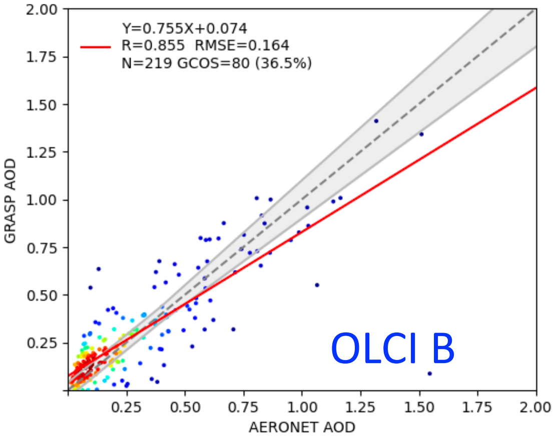












GRASP synergetic retrieval: ESA SYREMIS project

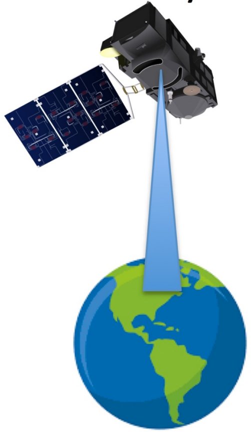
Satellites	Description
OLCI/Sentinel-3A and OLCI/Sentinel-3B	- Polar-orbiting, global coverage - One observation per pixel - Moderate spatial resolution - Radiance measurements in VIS and NIR spectral range
TROPOMI/ Sentinel-5p	- Polar-orbiting, global coverage - Hyperspectral measurements in UV, VIS,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

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	-	+

Synergetic Satellite + AERONET retrieval with GRASP

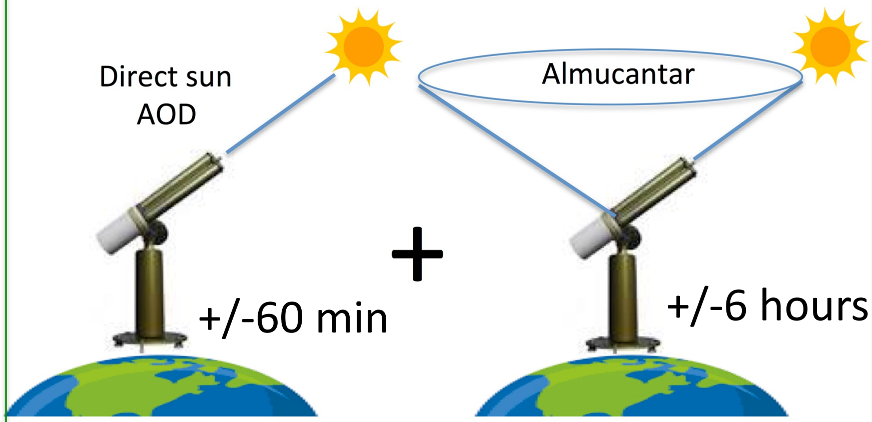
Satellite + Nearest AERONET TOD + Almucantar (or Combined Almucantar and Principal plane) measurements

Surface properties mainly



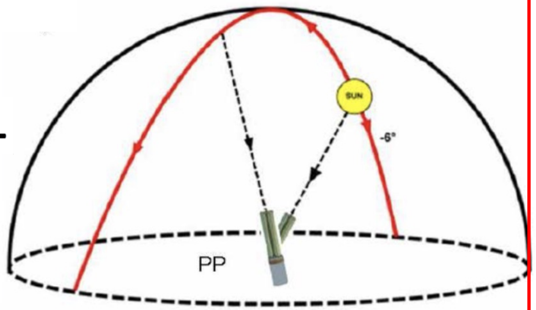
+

Aerosol properties mainly



+

Principal Plane



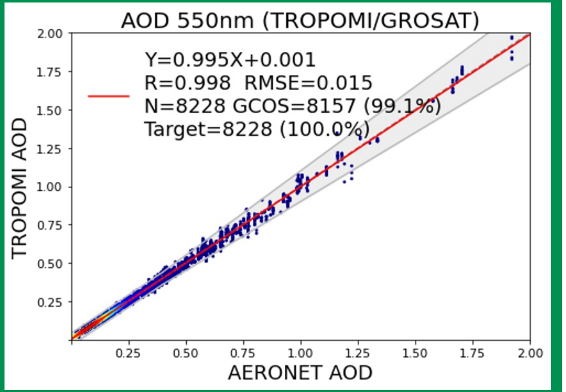
Conditions:

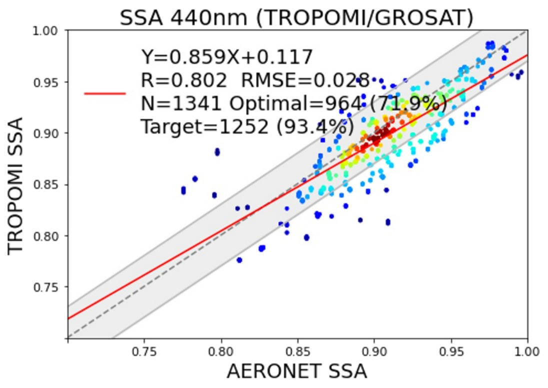
1. Reasonable fit of measurements (less than radiometric error).
2. Good correspondence of the retrieved aerosol properties with AERONET.
3. Instrument is well calibrated.

New Possibilities:

1. Validation tool for forward models of aerosol and surface
2. Surface Reference Database for surface validation
3. Instrument inter-calibration.

Synergetic satellite + AERONET retrieval: validation of aerosol models





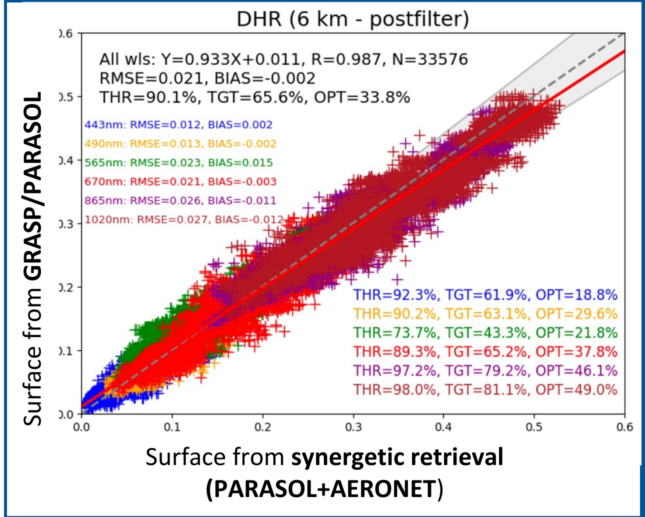
ESA GROSAT project:

Surface reference dataset Selected satellites

Satellite	Resolution	Product
S2/MSI	20 m	BRDF, albedos
S3/OLCI	700 m; 10 km	BRDF, albedos
PARASOL/ POLDER	6 km	BRDF, BPDF, albedos
S5p/ TROPOMI	0.1 deg (~10 km)	BRDF, albedos

Surface BRDF/albedos	Uncertainties
Threshold	Max (0.02 or 20%)
Target	Max (0.01 or 10%)
GCOS (Optimal)	Max (0.0025 or 5%)

Synergetic satellite + AERONET retrieval: surface reference dataset



www.grasp-sas.com/projects/grosat/
eo4society.esa.int/projects/grosat

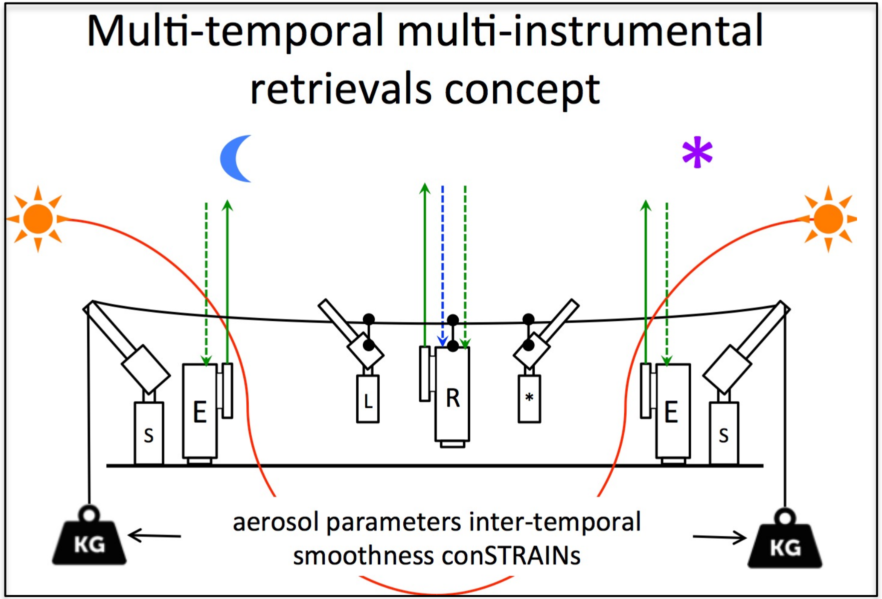
Advanced processing of ground-based observations using GRASP

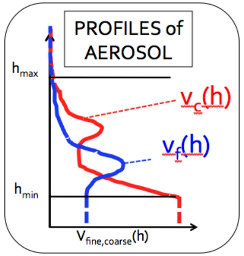
Lopatin et al., 2013, 2021

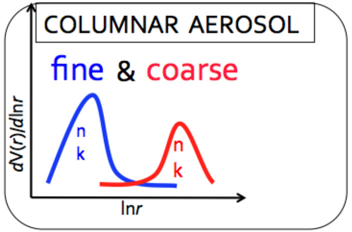
- combining observation during **several days**;
- combining **day and night** observations;
- combining **passive** (photometric) **and active** (lidar);
- combining **ground-based and satellite** observations;
- retrieving as many parameters as possible;

Expectations: more accurate and more complete validation data set

Aerosols, Clouds and Trace gases Research Infrastructure



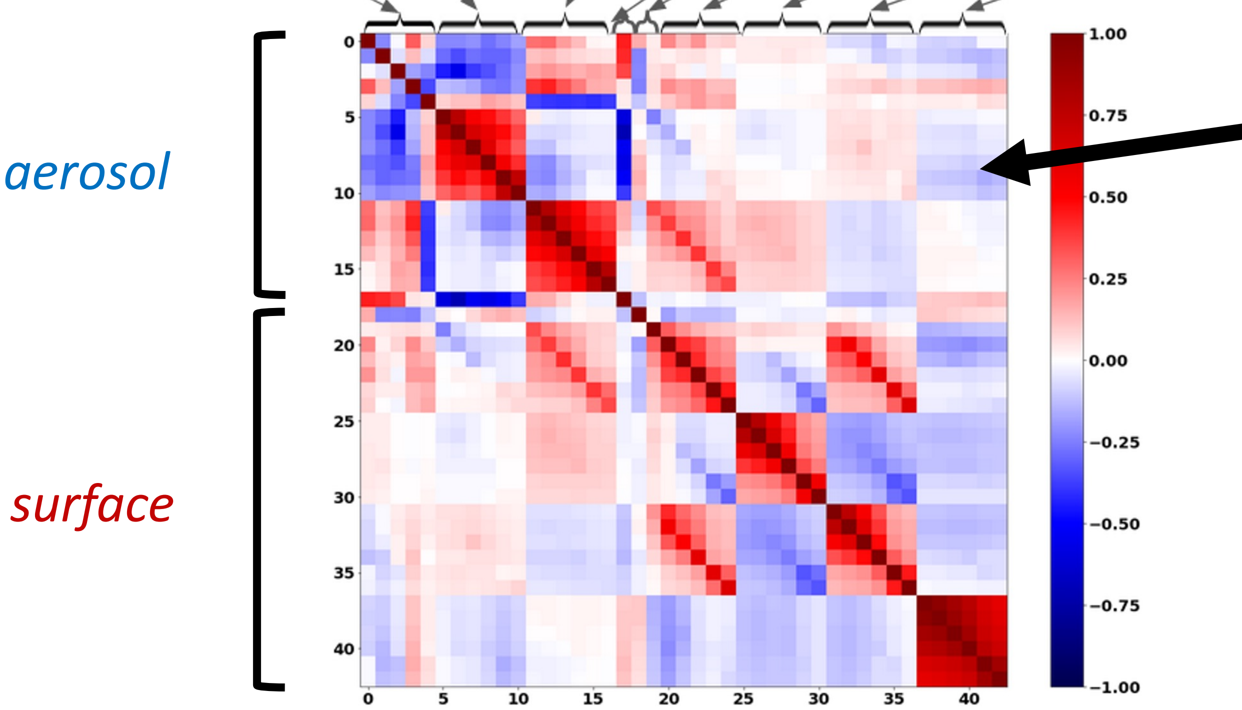




Correlation matrix for satellite retrieval :

(POLDER illustration)

$$\mathbf{a}^T = \left(C_1, \cdots, C_5; RRI_{\lambda_1}, \cdots, RRI_{\lambda_6}; IRI_{\lambda_1}, \cdots, IRI_{\lambda_6}; C_{sph}; h; BRDF_{iso}; BRDF_{vol}; BRDF_{geom}; BPDF\right)$$



e.g., correlations between surface and aerosol parameters