GRASP production lines:
current and in perspective

O. Dubovik[1], P. Litvinov[2], D. Fuertes[2], C. Chen[1,2], A. Lopatin[2], T. Lapyonok[1], C. Matar[2], F. Ducos[1], Y. Karol[2], L. Bindreiter[3], A. Hangler[3] and M. Aspetsberger[3]

1 - Univ. Lille, CNRS, UMR 8518 - LOA - Laboratoire d'Optique Atmosphérique, Lille, France
2 – GRASP SAS, Remote sensing developments, Lezennes, France
3 - Cloudflight Austria GmbH, High Performance Computing, Linz, Austria

ICAP, 12th Technical Working Group Meeting, Monterey, California, USA, October 18-21, 2022

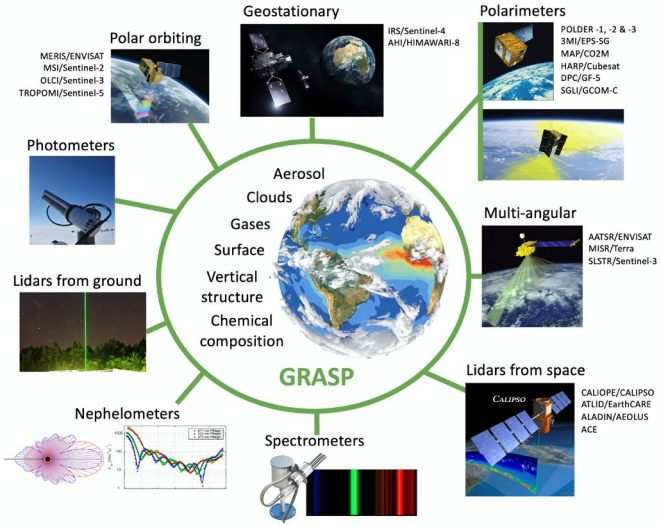
GRASP: Generalized Retrieval of Atmosphere and Surface Properties

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

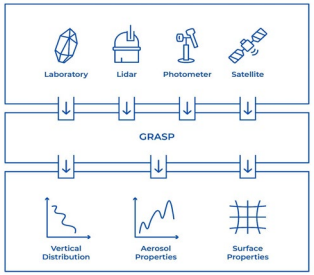
Forward Model for rigorous simulation of atm. radiation.

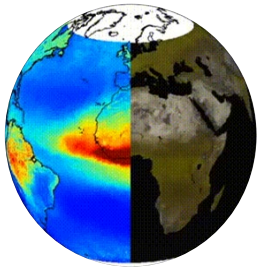
+

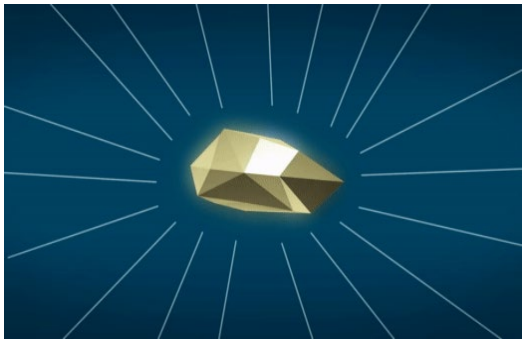
Inversion with *ap*plying multiple *a priori* constraints



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

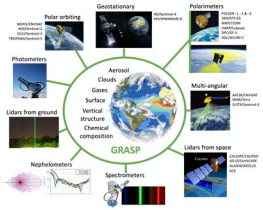






GRASP remote sensing developments

Dubovik et al. (2021)



Main GRASP Applications

- Insitu
  - Integrated Nephelometer
  - Polar Nephelometer
- Ground-based
  - Lidar
    - HSRL
    - Raman
    - Elastic
    - Ceilometer
  - Photometer
  - Sky-camera
  - Spectrometer
- Satellites
  - Geostationary
    - HIMAWARI
    - IRS/Sentinel 4
  - Polar Orbiting
    - Single View
      - MERIS/Envisat
      - MSI/Sentinel -2
      - OLCI/Sentinel -3
      - TROPOMI/Sentinel -5p
      - SGLI/GCOM-C
    - Multi angle
      - AATSR/Envisat
      - MISR/Terra
      - SLSTR/Sentinel -3
    - Multi-angular polarimeter
      - 3MI/EPS-SG
      - POLDER -1, -2 and -3
      - HARP/Cubesat
- Airborne
  - AirHarp
  - Osiris

Retrievals of any observations can be combined.

Established synergies

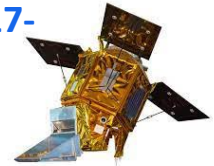
GRASP processing developments for agencies EUMETSAT, ESA, CNRS, etc.

Single-, Bi-View Imagers

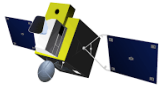
MAP – Multi – Angular Polarimeters

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

TROPOMI/S-5P 2017-

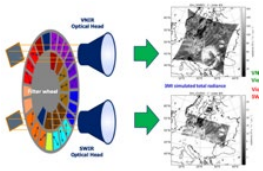


S-4 2024



MAP/CO2M 2026 -

3MI/MetOP-SG

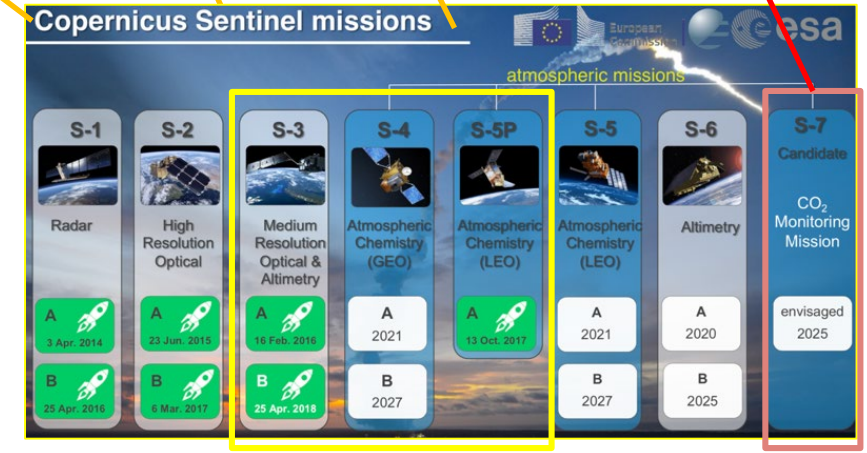


2025 ? - 2037

Past mission

ENVISAT 2012-2012

MERIS
AATSR
MERIS + AATSR



Past mission

POLDER-1, -2, -3

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

GRASP

POLDER-3/GRASP products

2004-2013

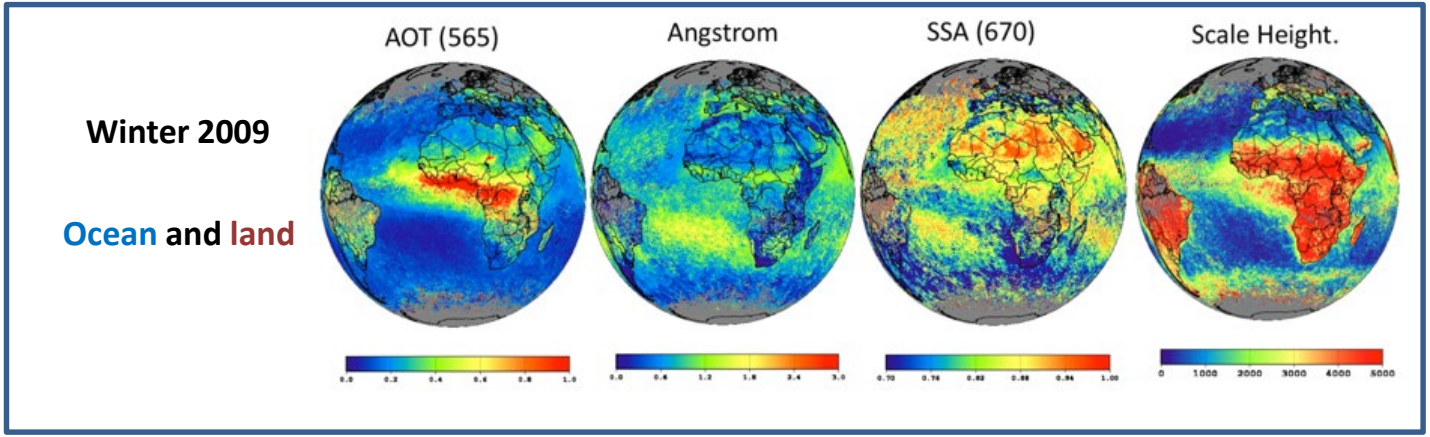
4 products

Chen et al., 2020

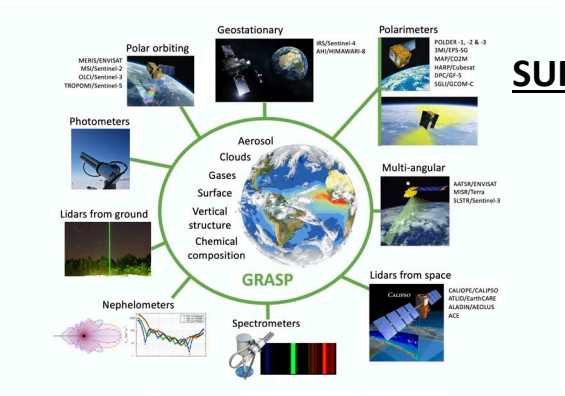
Li et al., 2019, 2021, 2022

Zhang et al. 2021

Dubovik et al. 2021



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

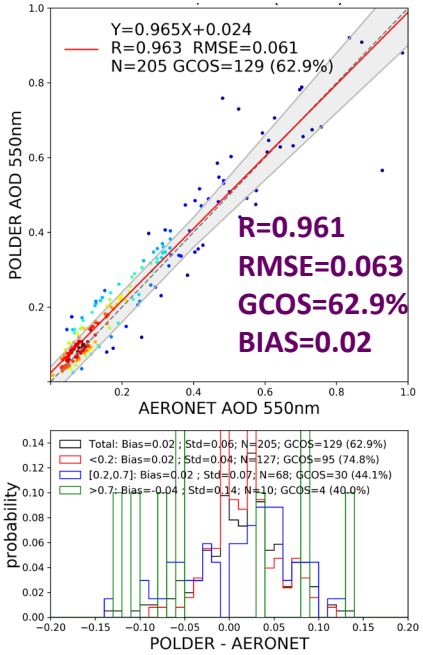
CONSLUSIONS from POLDER aerosol product analysis :

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

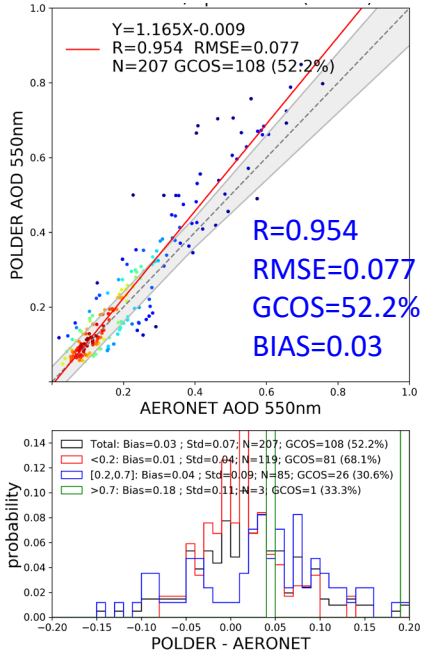
AOD(550)] or 2008 year (Chen et al., 2020)

Ocean

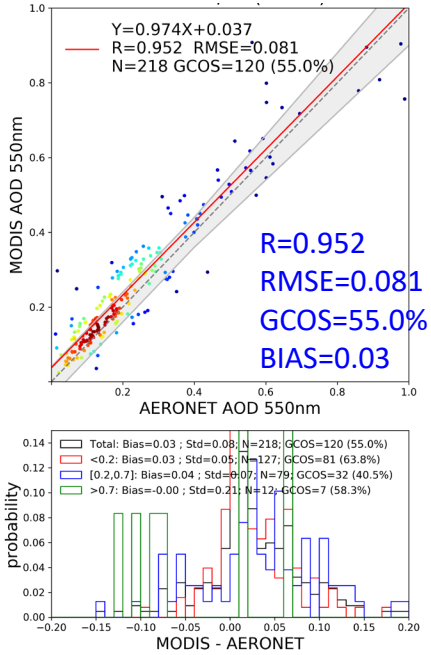
POLDER/GRASP-Models



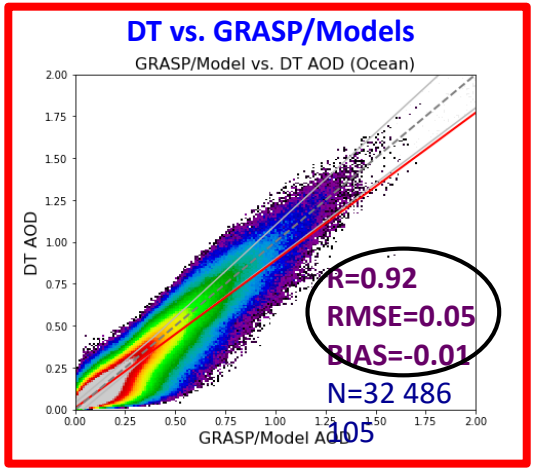
POLDER/Operational



MODIS-Aqua/DT



DT vs. GRASP/Models



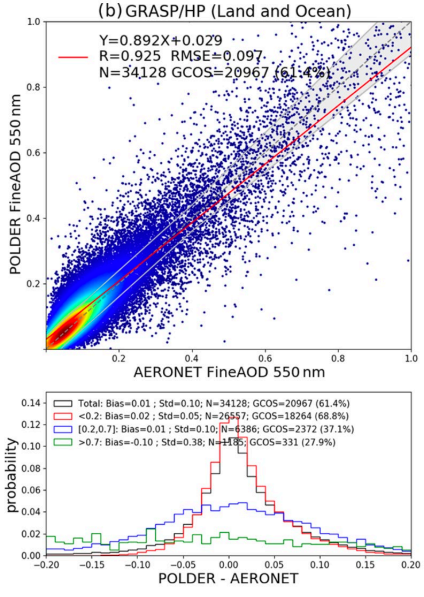
CONSLUSIONS from POLDER aerosol product analysis :

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;

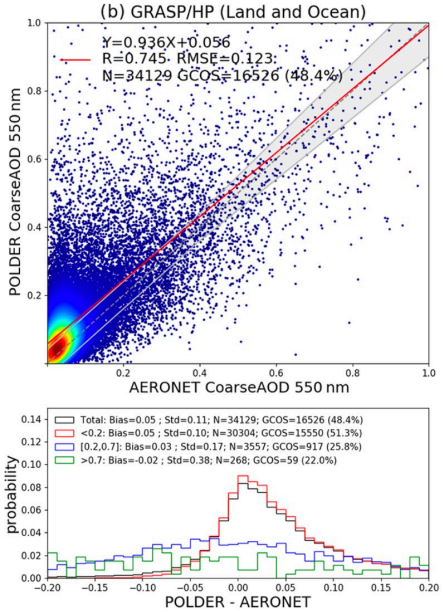
POLDER/ GRASP

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

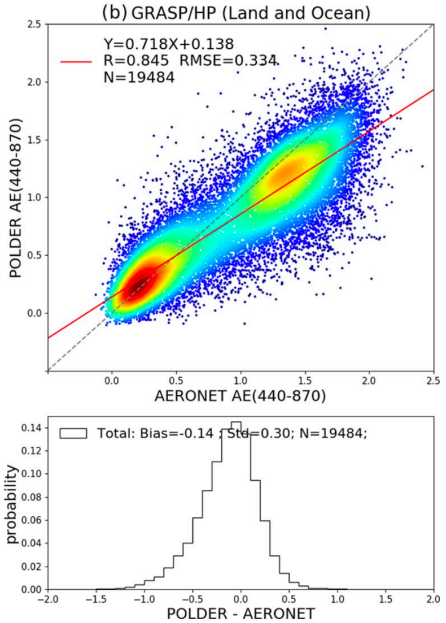
AOD fine (550)



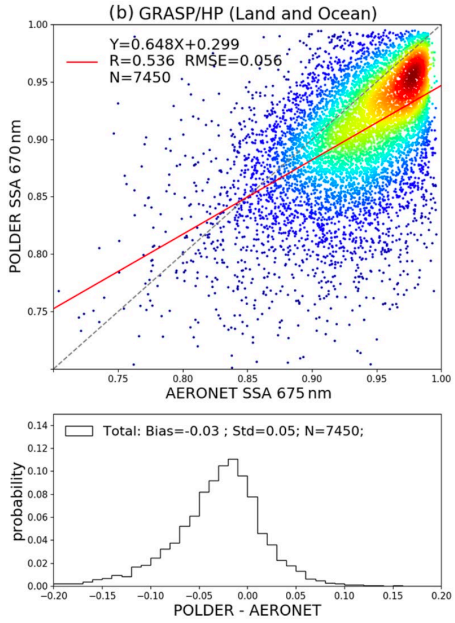
AOD coarse (550)



AE (440 - 870)



SSA (670)



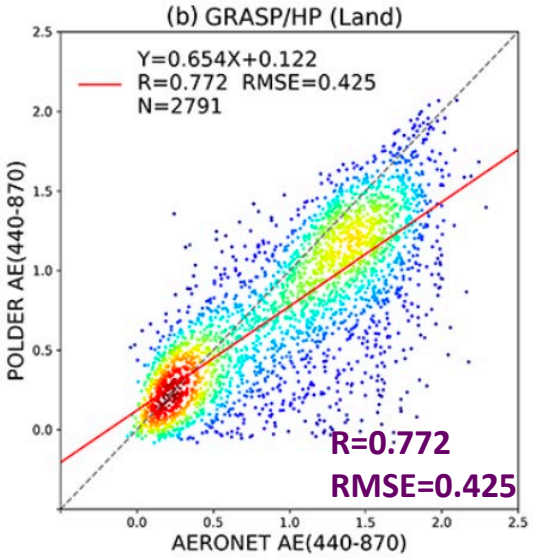
CONSLUSIONS from POLDER aerosol product analysis :

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

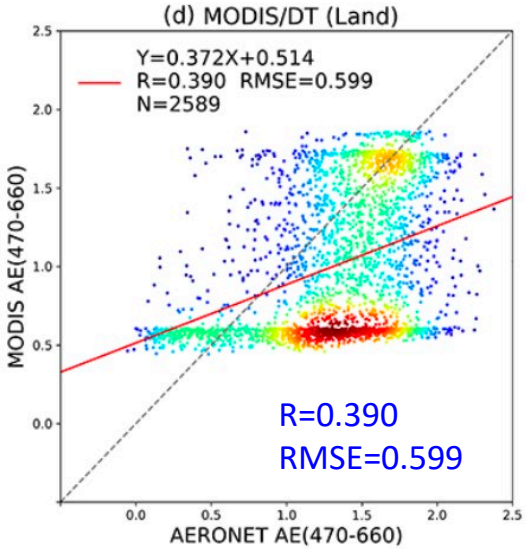
AE – Angstrom Exponent (440 – 870) for 2008 year (Chen et al., 2020)

Land

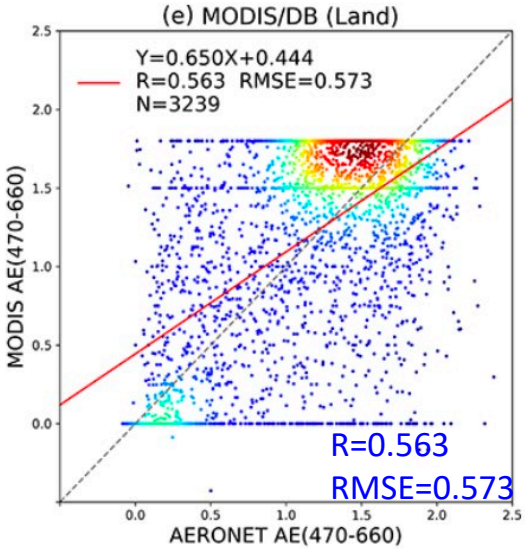
POLDER/ GRASP



MODIS/DT



MODIS/DB



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**;

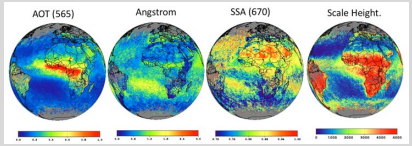
MAP Algorithm studies:

GRASP

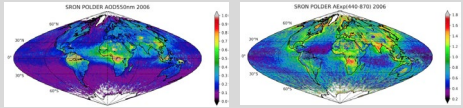
SRON Netherlands Institute for Space Research — Remo- TAP

cnes

POLDER-1, -2, -3



POLDER -3



EUMETSAT esa European Space Agency

3MI/EPS-SG

MAP/CO2M

3MI/EPS-SG

MAP/CO2M

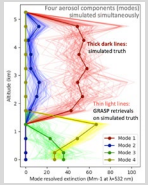
NASA UMBC

Air HARP

HARP/CubeSat,

HARP-2/PACE

AOS



SPEX Airborne

SPEX/PACE

CNSA AMS

DPC/GF-5

DPC/GF-5

JAXA GOVERNMENT OF DUBAI

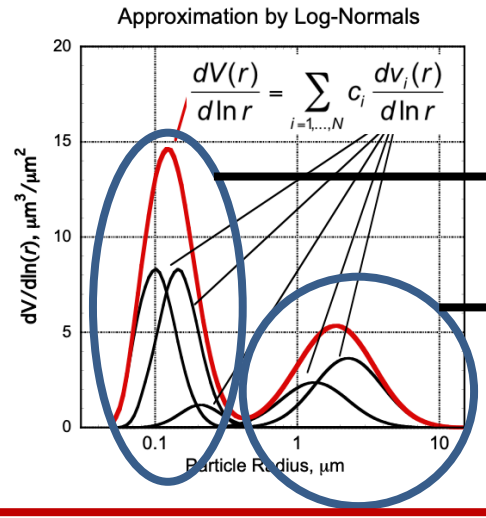
SGLI/GCOM-C

DMSAT

GAPMAP

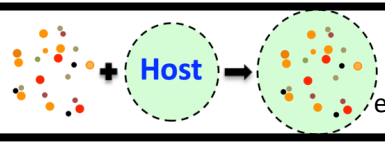
GRASP

GRASP Chemical Component approach



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

Fine mode



Maxwell Garnett effective medium approximation

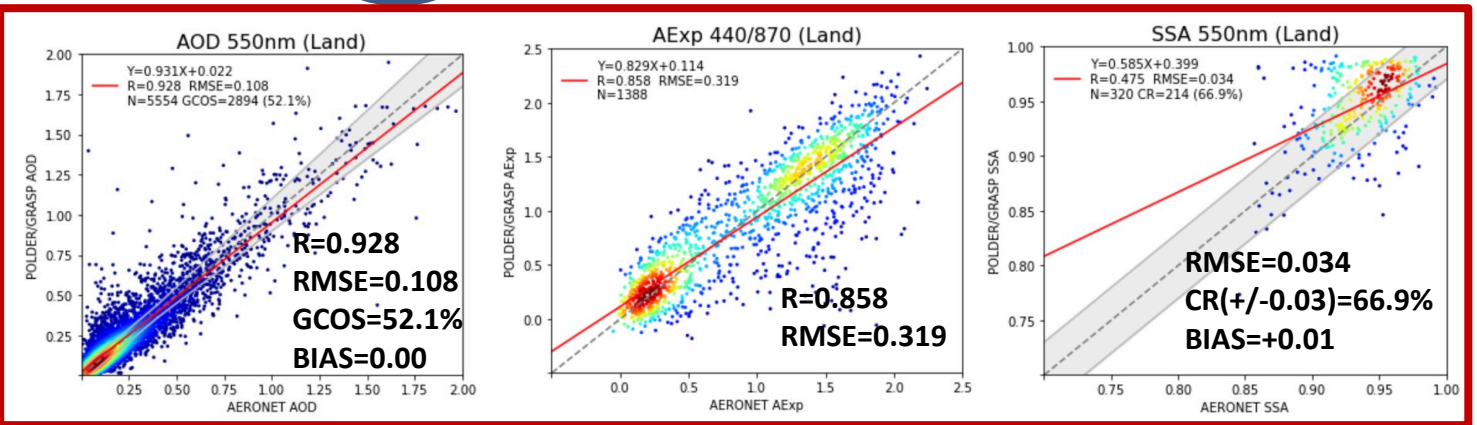
Coarse mode

BC
BrC
Non-absorbing soluble
Non-absorbing insoluble
Water

Fine mode

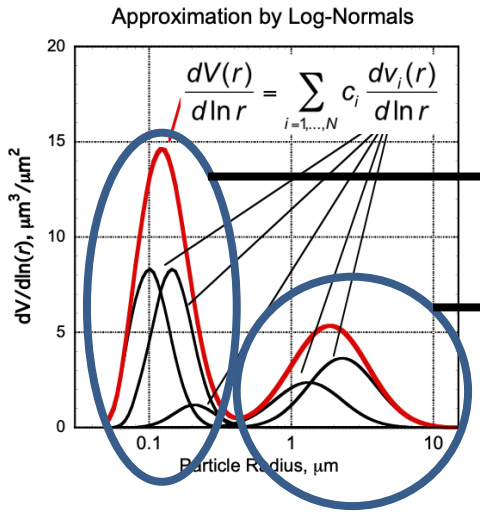
Absorbing insoluble (FeOx)
Non-absorbing insoluble (Coarce Dust)
Non-absorbing soluble (SS, etc)
Water

Coarse mode



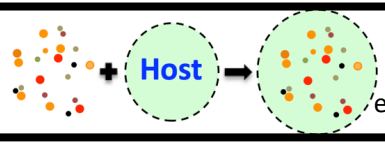
By using ***prescribed spectral refractive index*** of components, *GRASP/Component approach provides consistent and stable results for AOD as well as detailed properties*.

GRASP Chemical Component approach



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

Fine mode

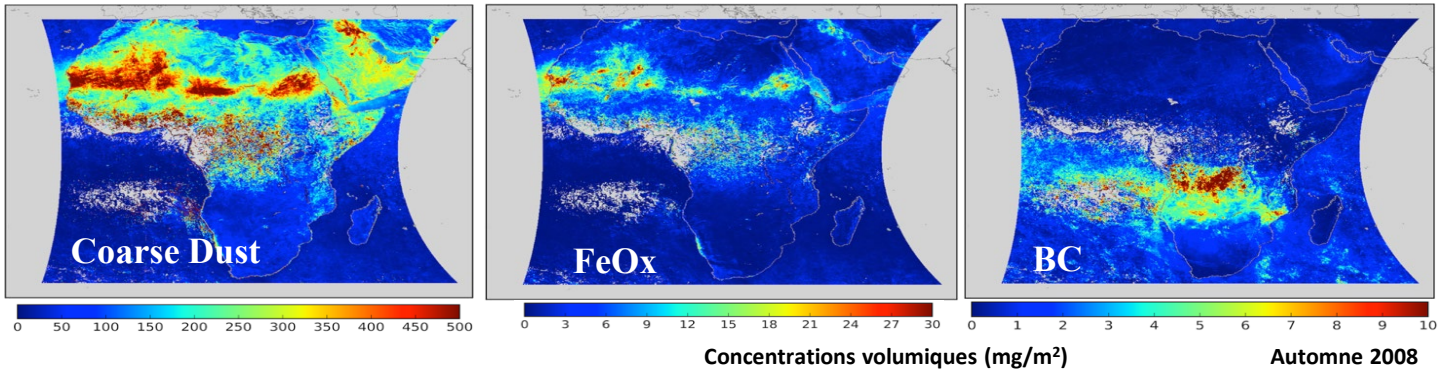


Maxwell Garnett effective medium approximation

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*.

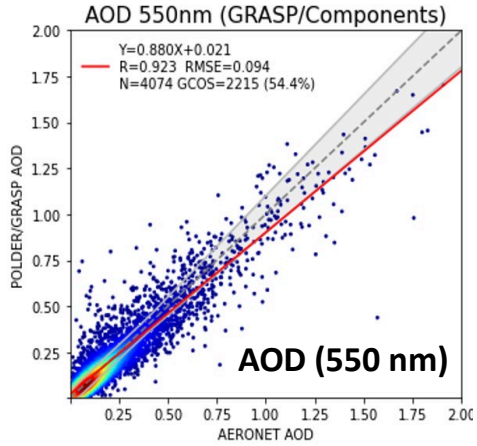
Harmonizing GRASP and SRON-RemoTAP GRASP approaches *(similar performance)*

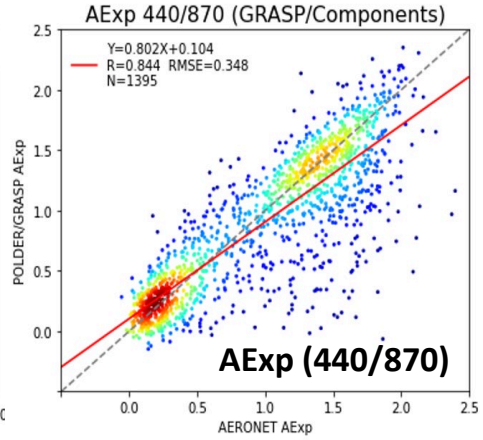
G. Fu, …, O. Hasekamp presentation on ESA HARPOL project

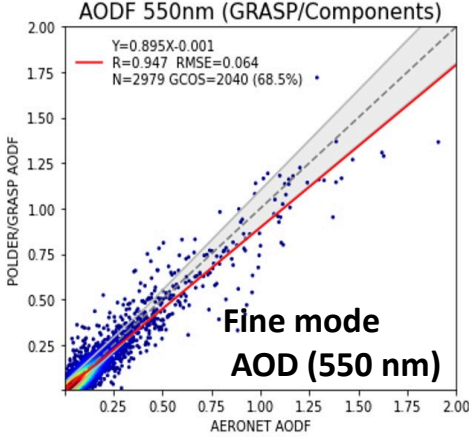
Process the same amount PARASOL data

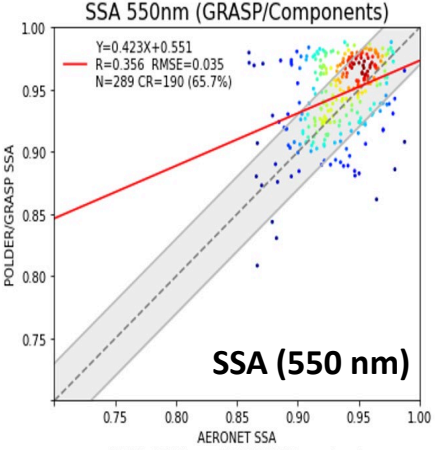
GRASP/Component

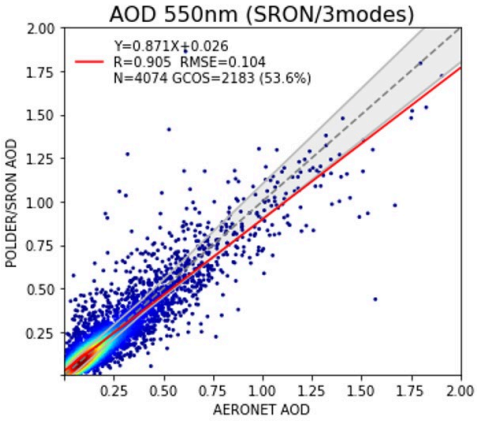
RemoTAP 3modes Component

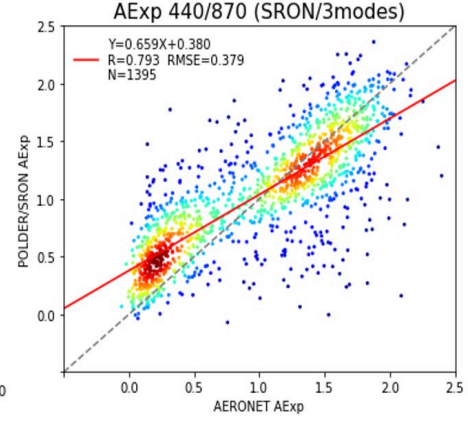


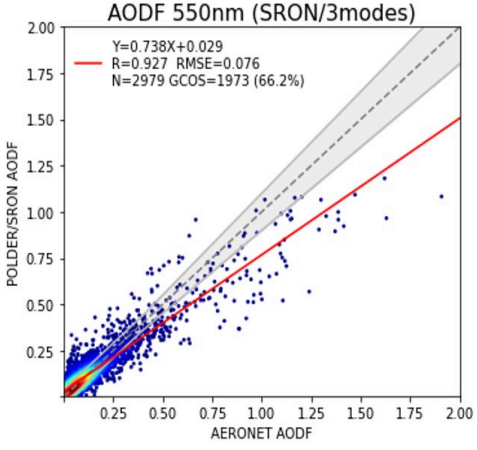


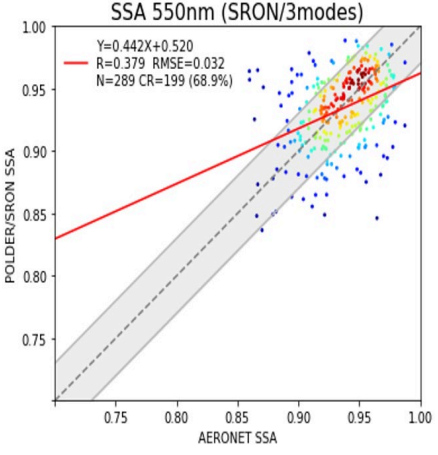




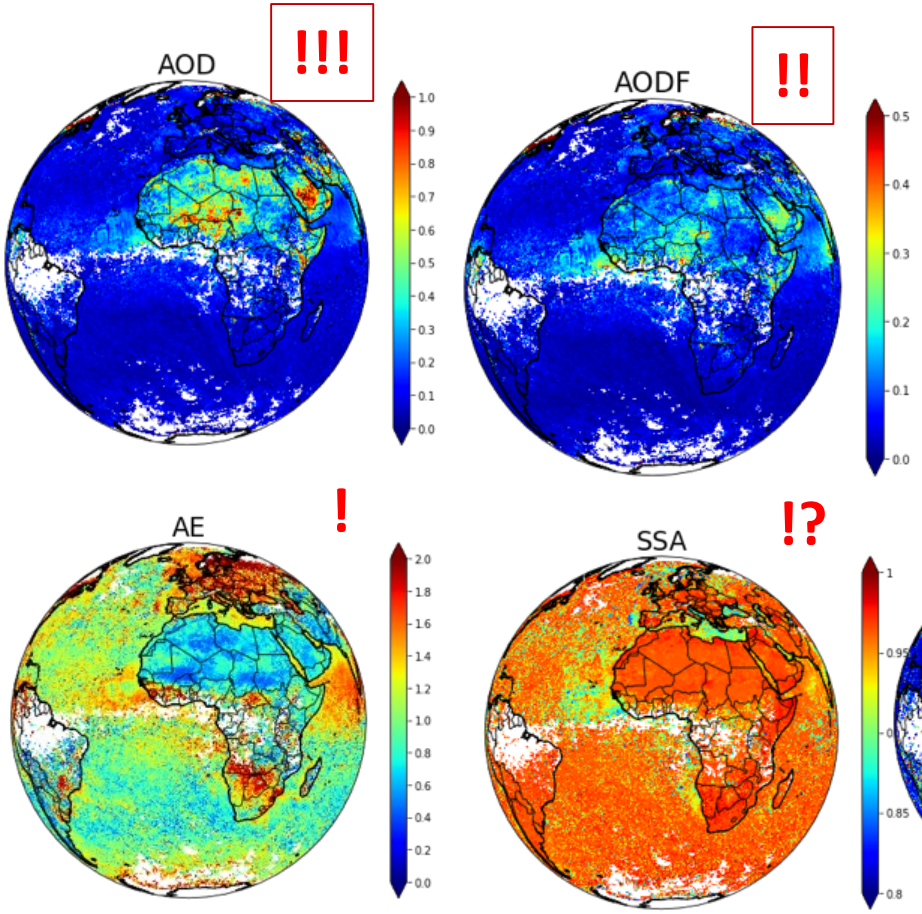








TROPOMI/GRASP (2019-2020, …)



Aerosol products:

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

Surface products:

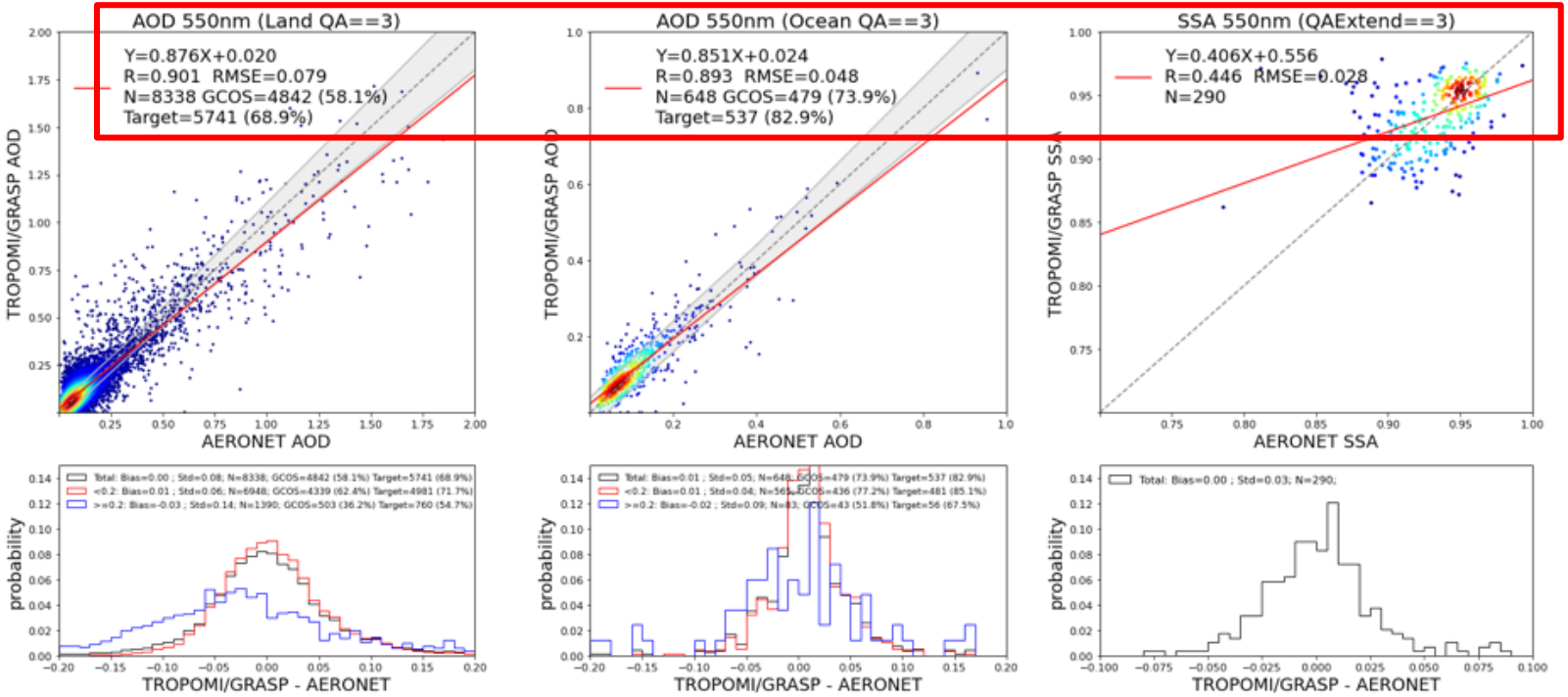
DHR(λ), BRDF(λ)

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



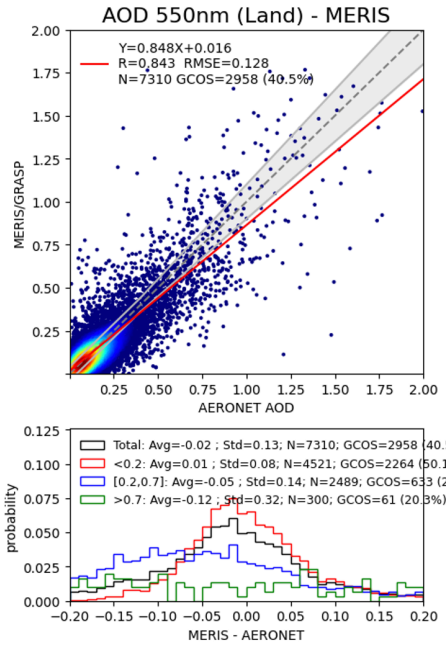
S-5P/GRASP products show to:

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

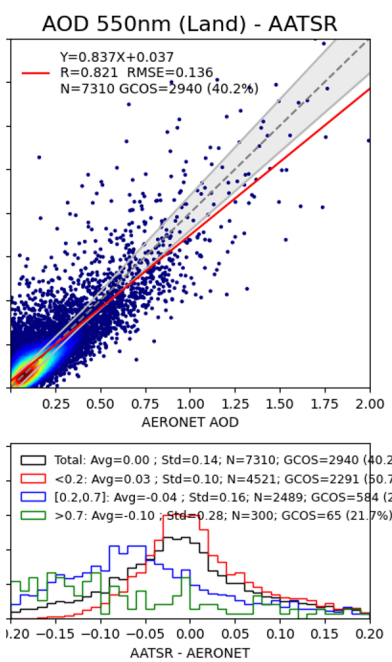
ENVISAT/GRASP (2002-2012)

GRASP

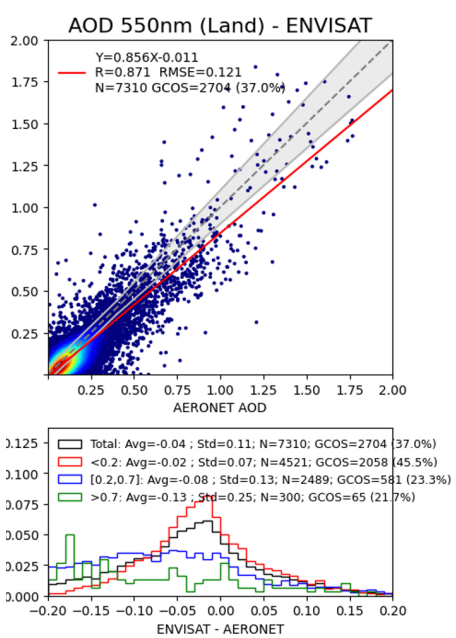
MERIS



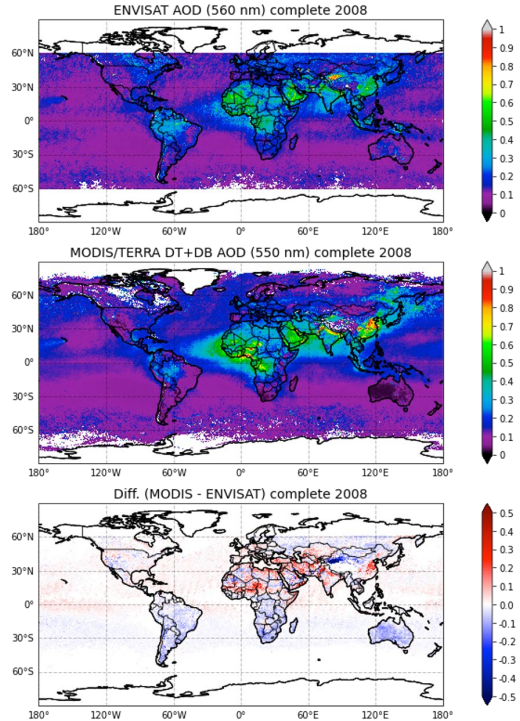
AATSR



MERIS + AATSR



ENVISAT vs MODIS



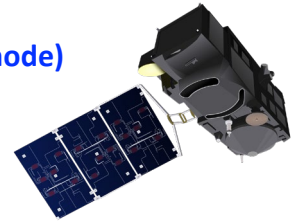
AOD(550)

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

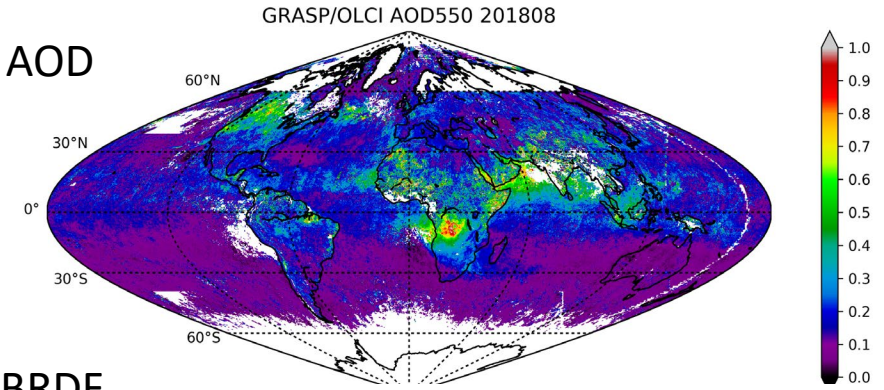


L1B RR -> Target 10km pixel aerosol and surface retrieval

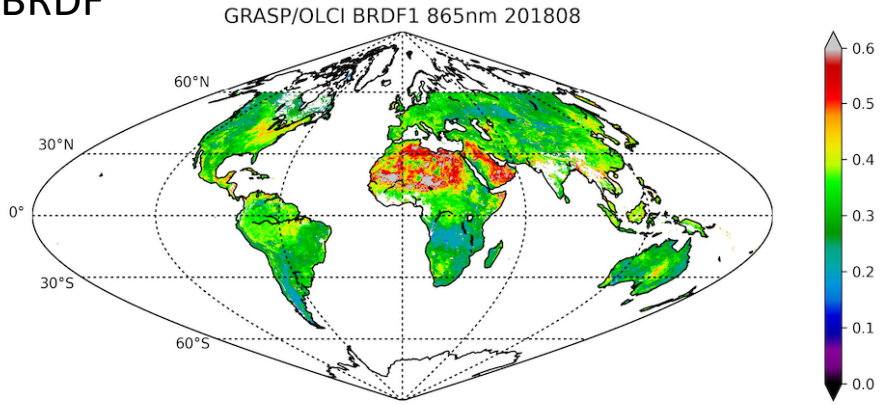
OLCI-A Band	Central Wavelength (nm)	Band Width (nm)	Radiance Bias Correction
Oa02	412.5	10	-2%
Oa03	442.5	10	-2%
Oa04	490	10	-2%
Oa05	510	10	-2%
Oa06	560	10	-2%
Oa08	665	10	-2%
Oa12	753	7.5	-2%
Oa17	865	20	-2%
Oa21	1020	40	-6%

OLCI/GRASP – product. (2018-2019)

AOD



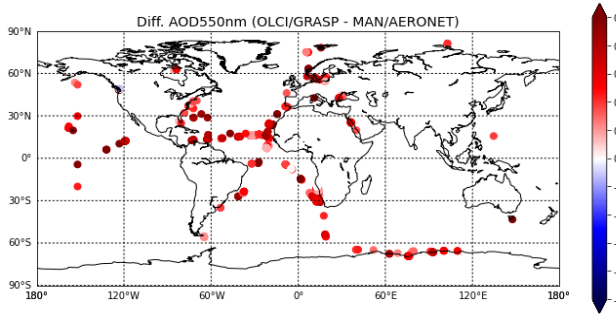
BRDF



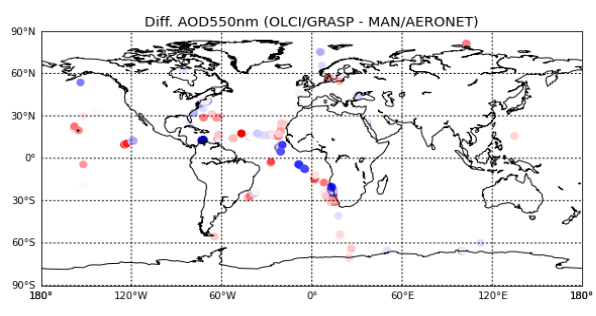
✓ *AOD retrieval over ocean*

1 yr validation with **MAN**/AERONET

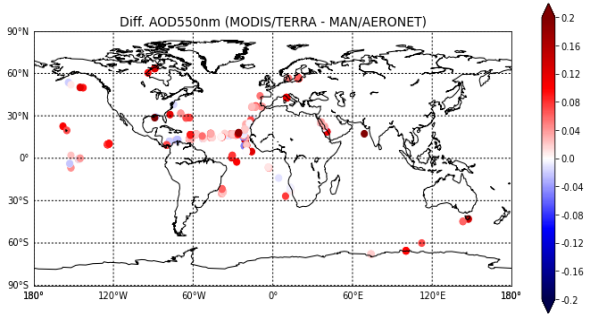
OLCI/GRASP (Initial) - MAN



OLCI/GRASP (Optimized) - MAN



MODIS/TERRA - MAN

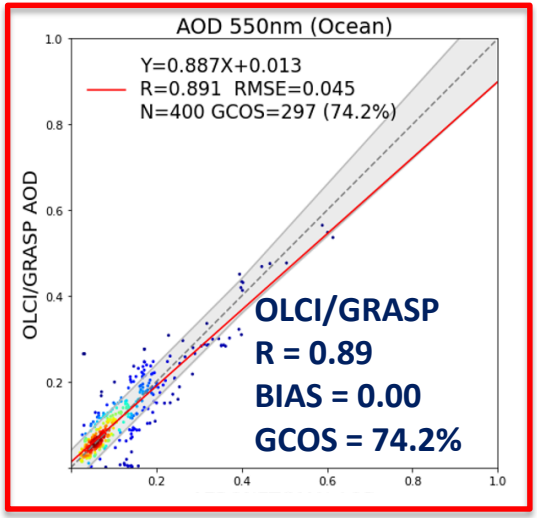


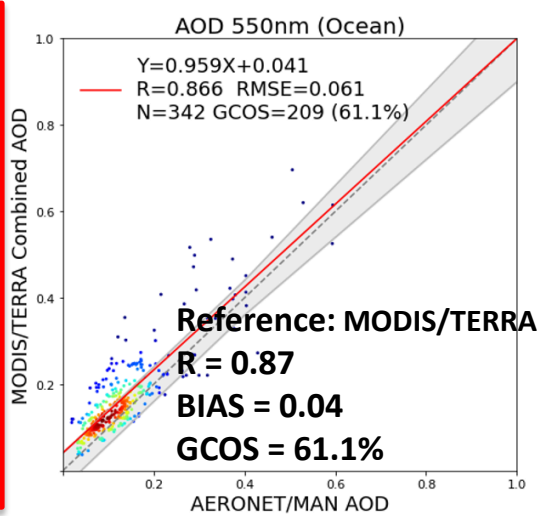
Observed improvements:

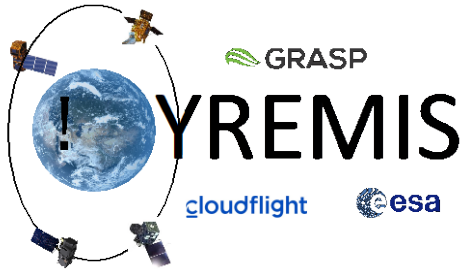
a. Clear evolution from Initial to Optimized OLCI/GRASP retrieval over ocean

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.





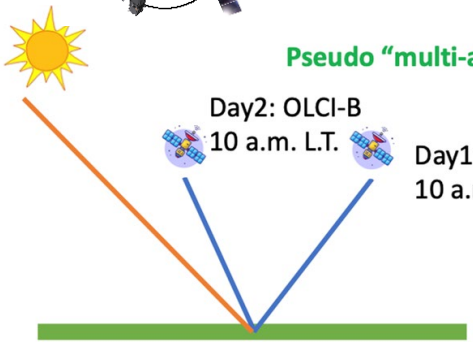


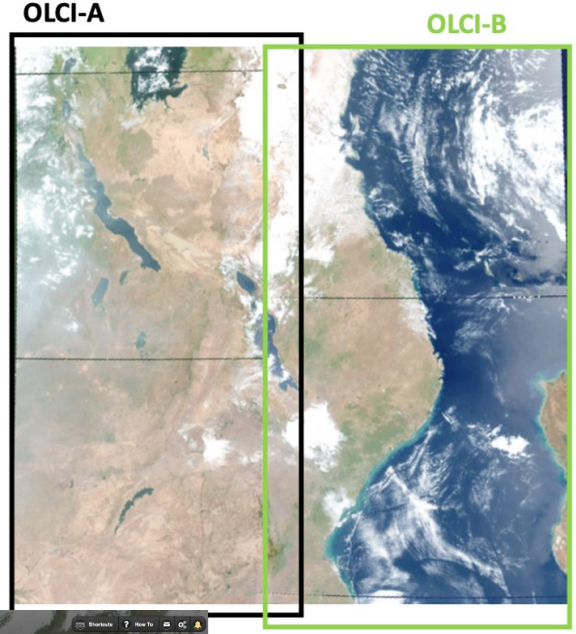
GRASP

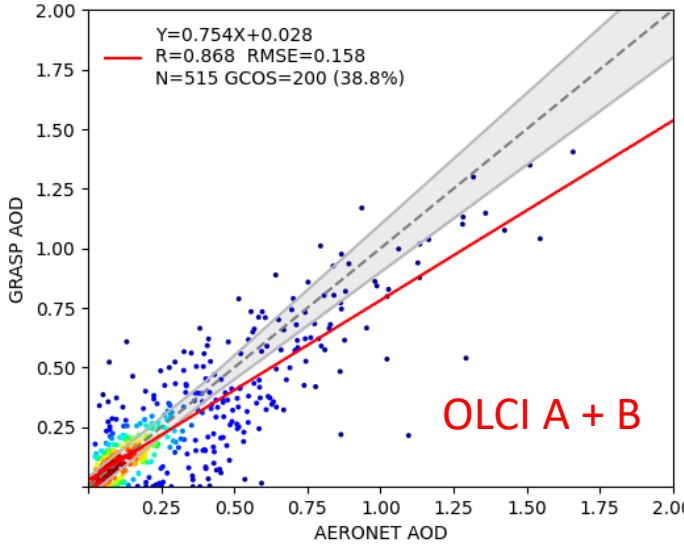
YREMIS

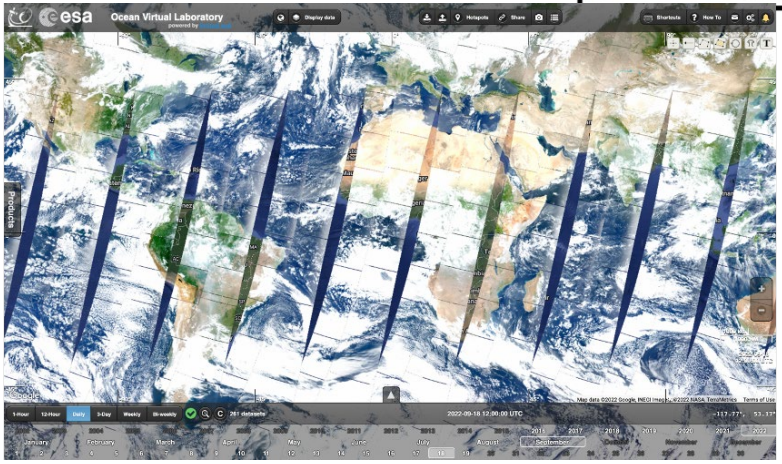
cloudflight

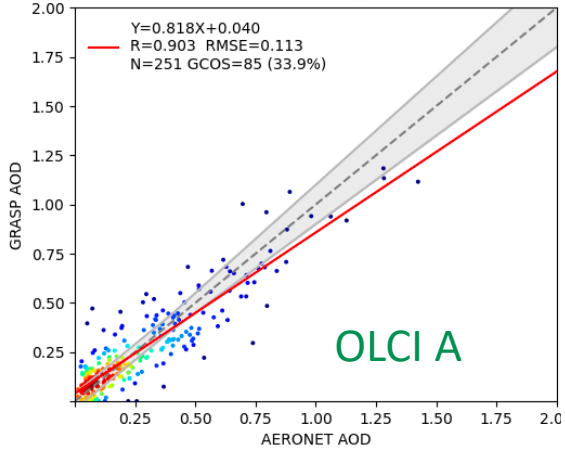
esa

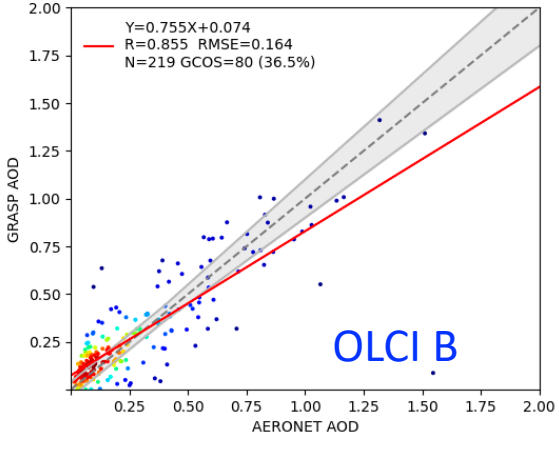




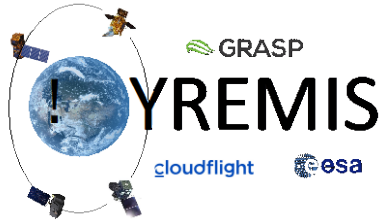








GRASP synergetic retrieval: ESA SYREMIS project



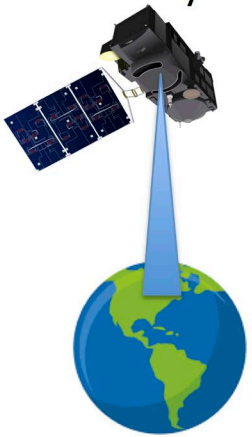
Satellites	Description
OLCI/Sentinel-3A and OLCI/Sentinel-3B	- Polar-orbiting, global coverage - One observation per pixel - Moderate spatial resolution - Radiance measurements in VIS and NIR spectral range
TROPOMI/ Sentinel-5p	- Polar-orbiting, global coverage - Hyperspectral measurements in UV, VIS, 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

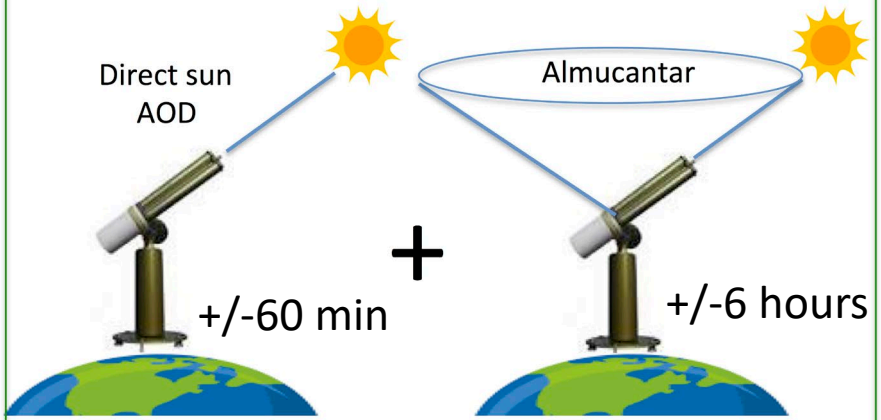
Satellite + Nearest AERONET TOD + Almucantar (or Combined Almucantar and Principal plane) measurements

Surface properties mainly



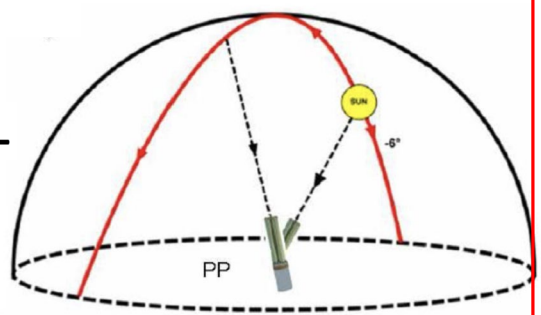
+

Aerosol properties mainly



+

Principal Plane



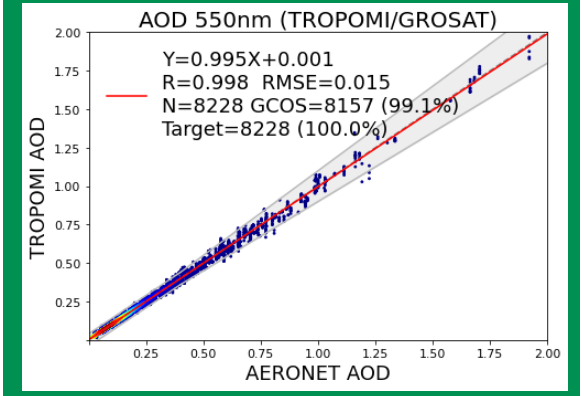
Conditions:

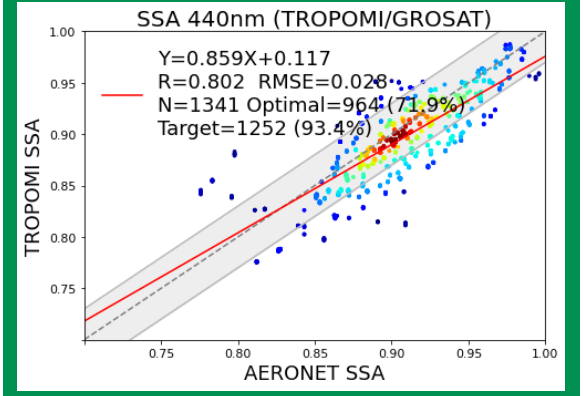
1. Reasonable fit of measurements (less than radiometric error).
2. Good correspondence of the retrieved aerosol properties with AERONET.
3. Instrument is well calibrated.

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:

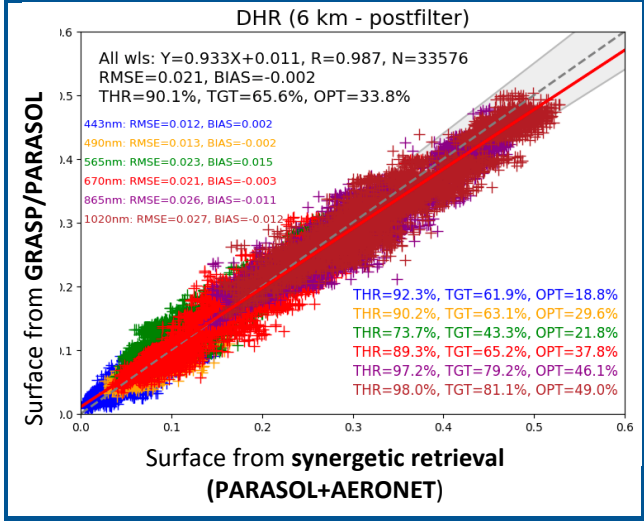
GRASP + SAT

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

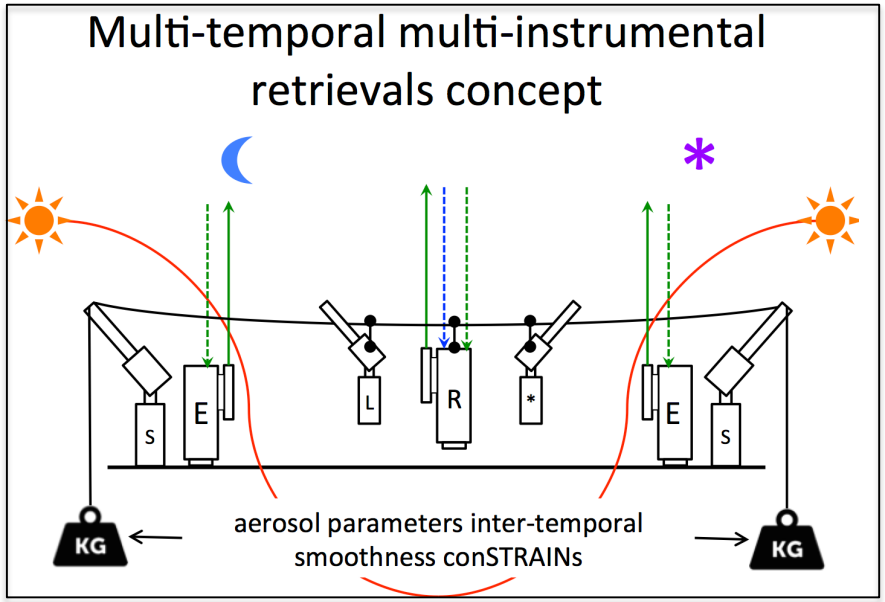
Advanced processing of ground-based observations using GRASP

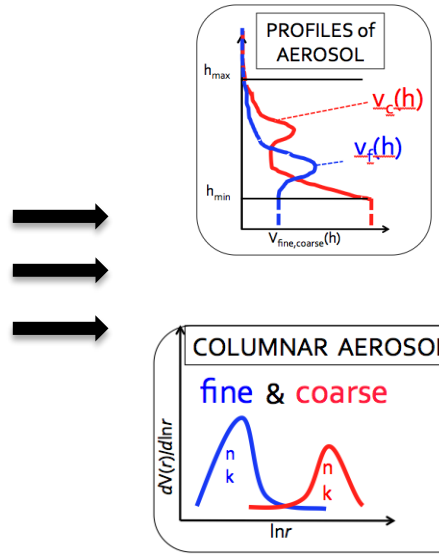
Lopatin et al., 2013, 2021

- 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;

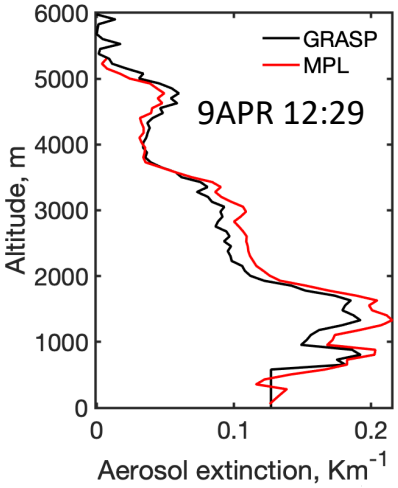
Expectations: more accurate and more complete validation data set

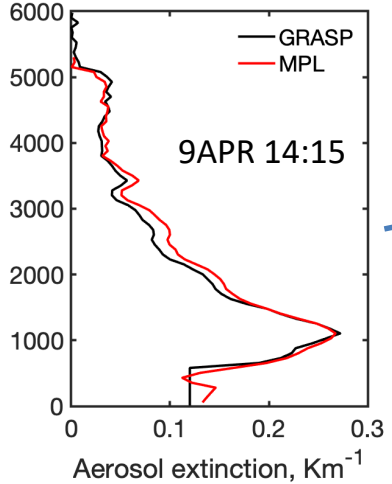
ACTRiS
Aerosols, Clouds and Trace gases Research Infrastructure

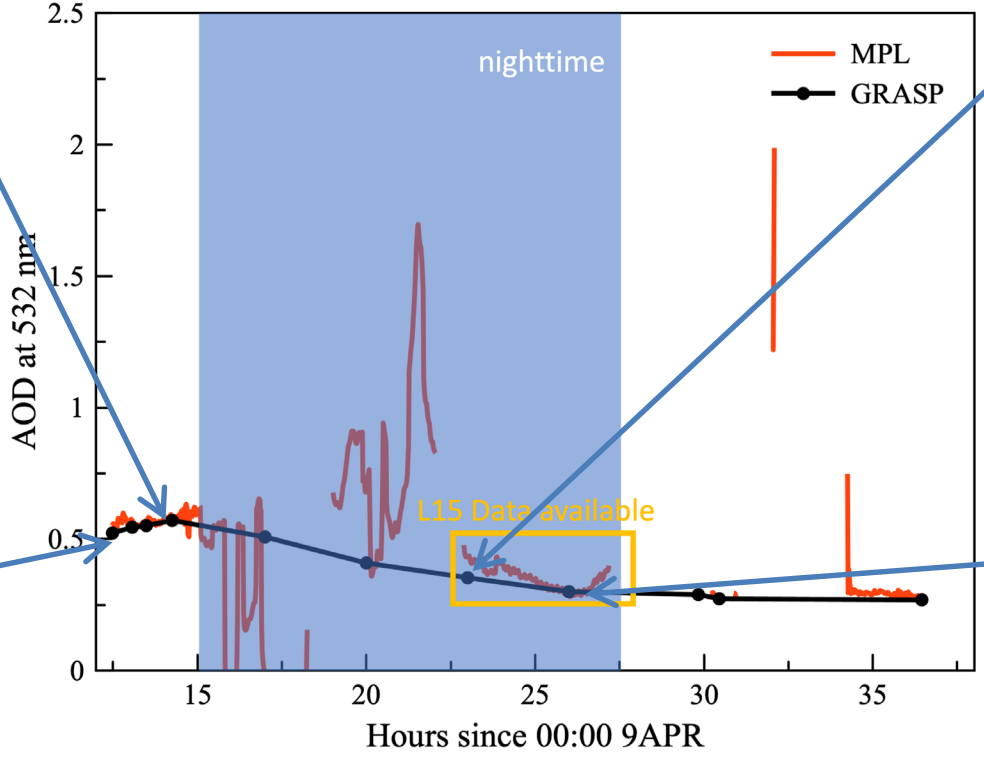


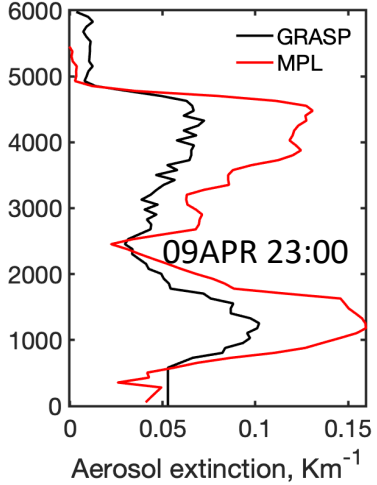


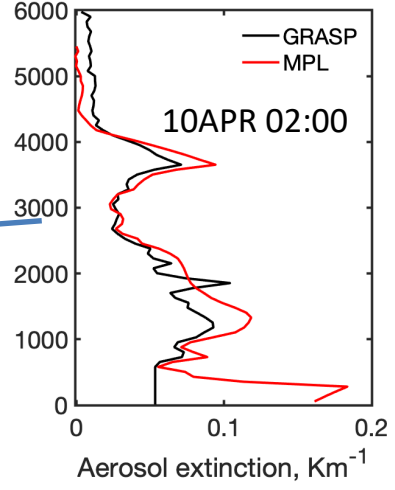
Aerosol extinction & AOD



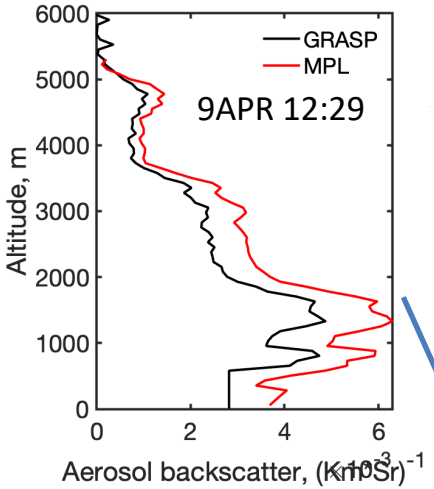


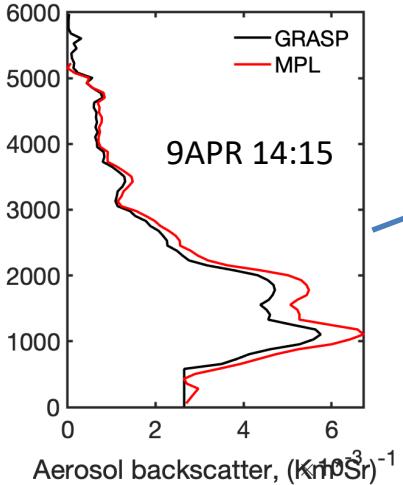


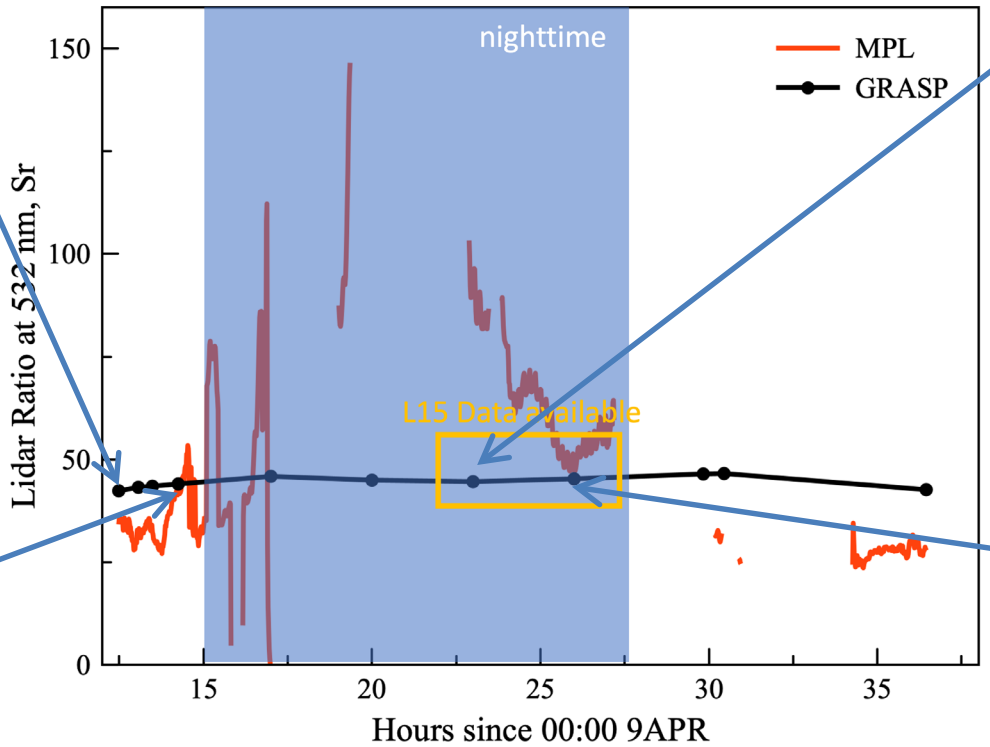


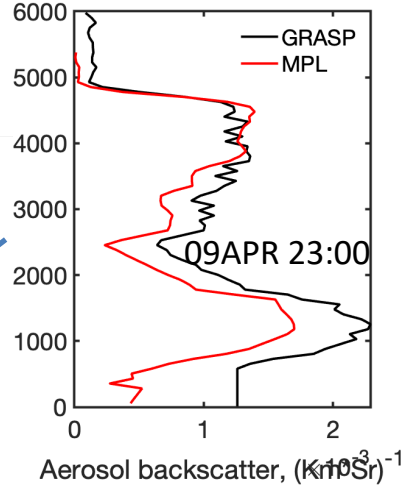


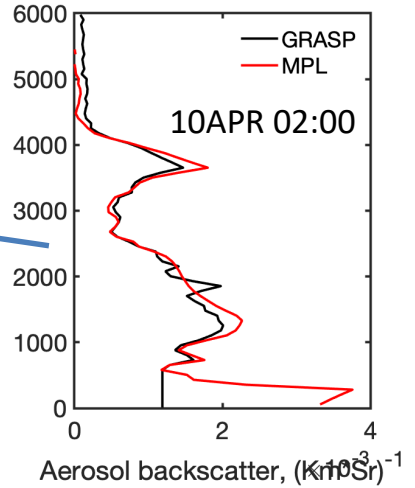
Aerosol backscatter & LR











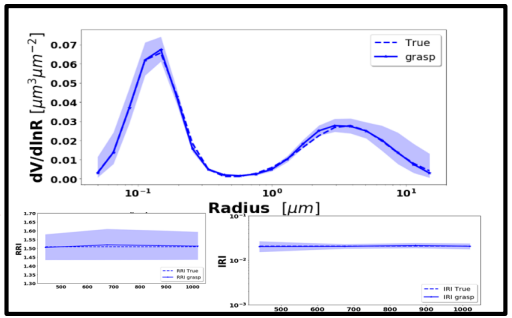
GRASP approach for providing dynamic error estimates for retrievals

Herrera, et al. AMT, 2022

- Retrieval of columnar properties of aerosol from the measurements by ground-based sun/sky-scanning radiometer alone;

AOD at 440, 675, 870 and 1020 nm and Sky radiances in solar almucantar from ±3.5 degrees to ±180 degrees

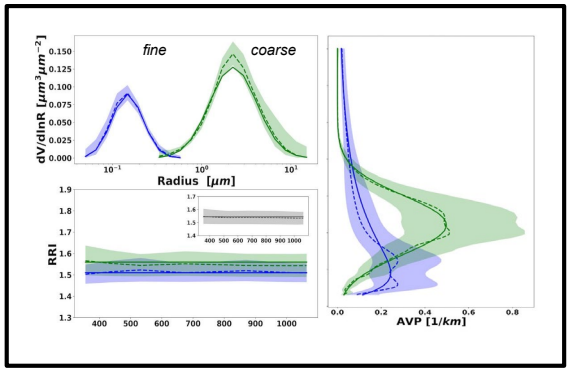
Example: AERONET-like retrieval



- Simultaneous retrieval of both columnar aerosol properties and their vertical distribution from the combined observations by Sun/sky-scanning radiometer and multi-wavelength lidar.

RCS at 355, 532 and 1064 nm, normalized at 60 log-spaced bins at different heights

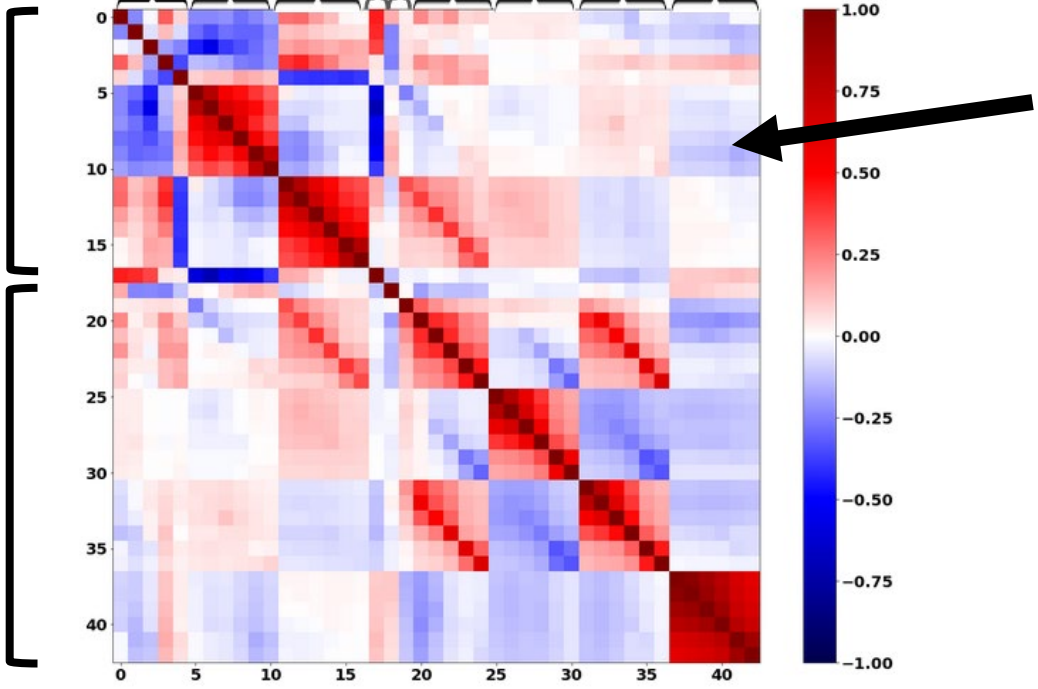
Example: synergy with lidar



Correlation matrix for satellite retrieval :

(POLDER illustration)

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



aerosol

surface

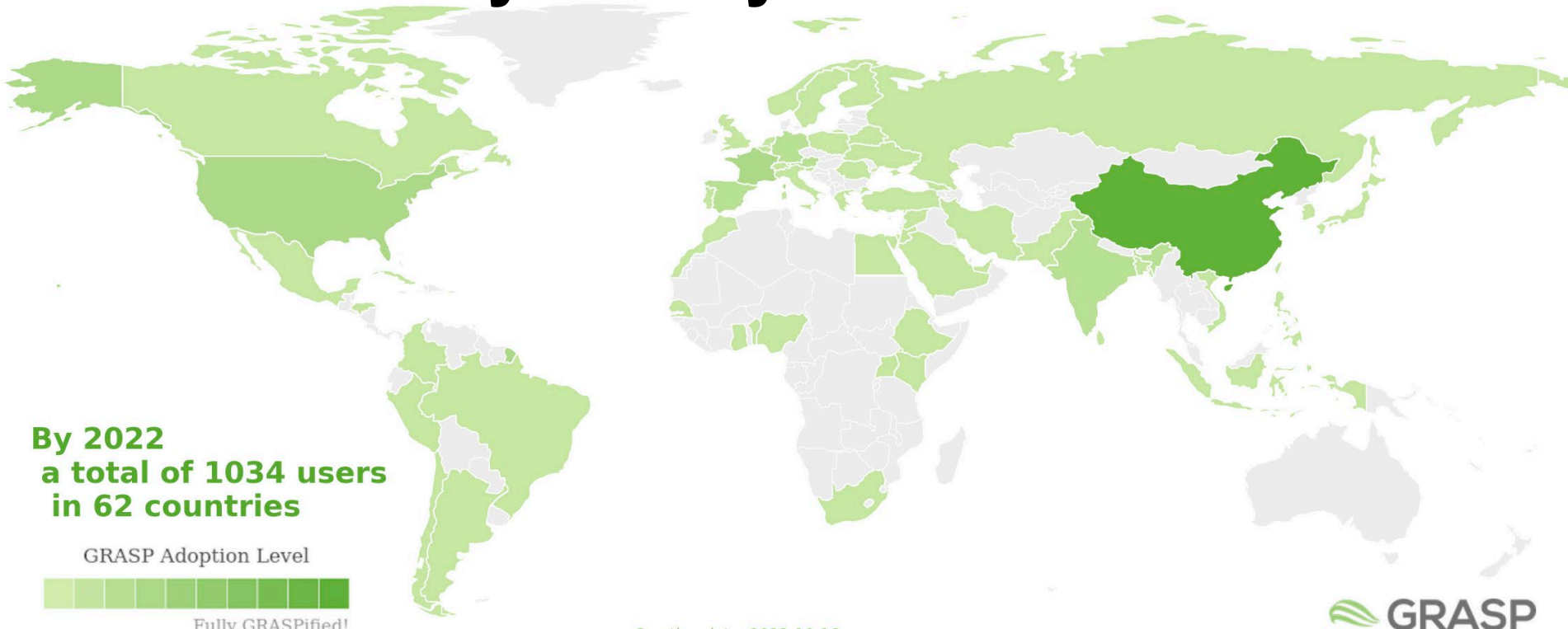
e.g., correlations between surface and aerosol parameters

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

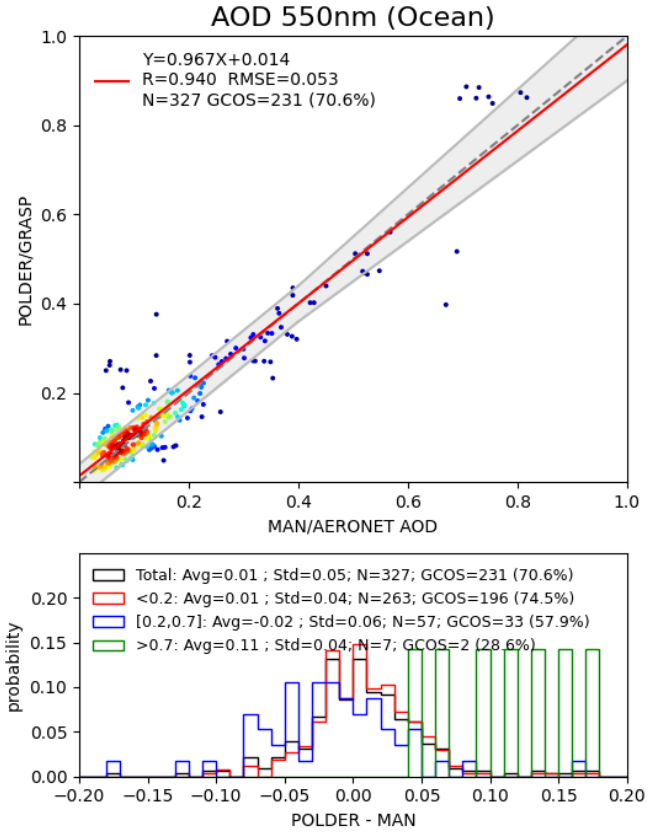
Thank you for you attention !



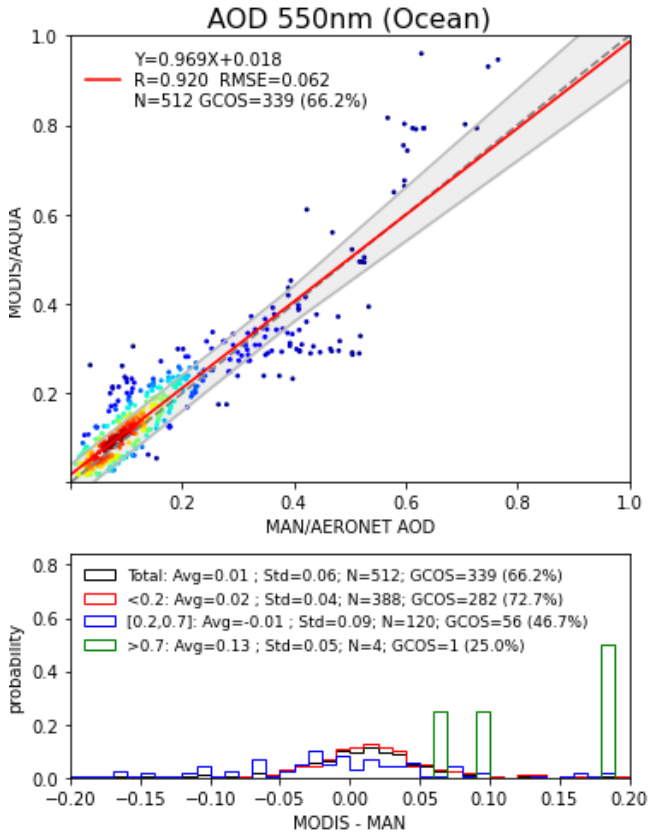
Back – up slides

AOD Validation over AERONET/MAN - 2008

POLDER/GRASP

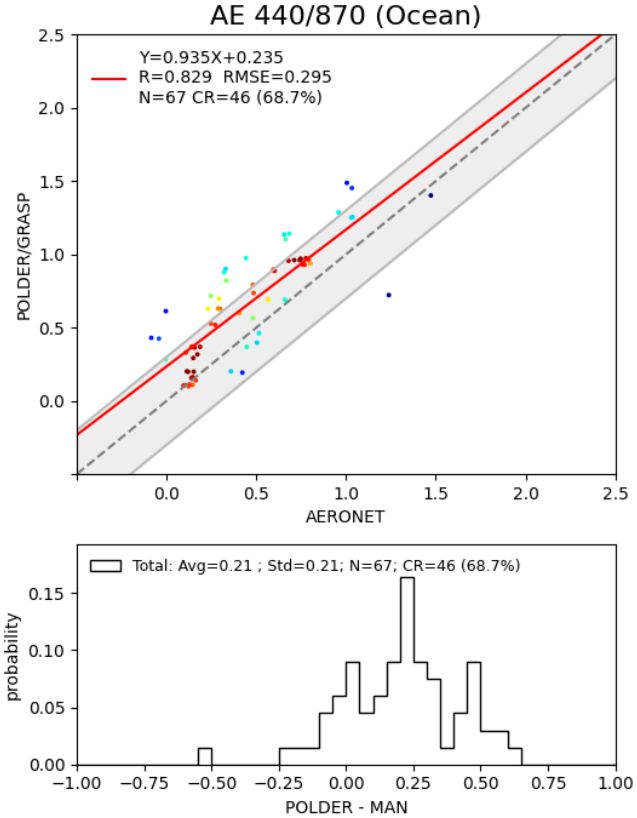


MODIS/AQUA DT

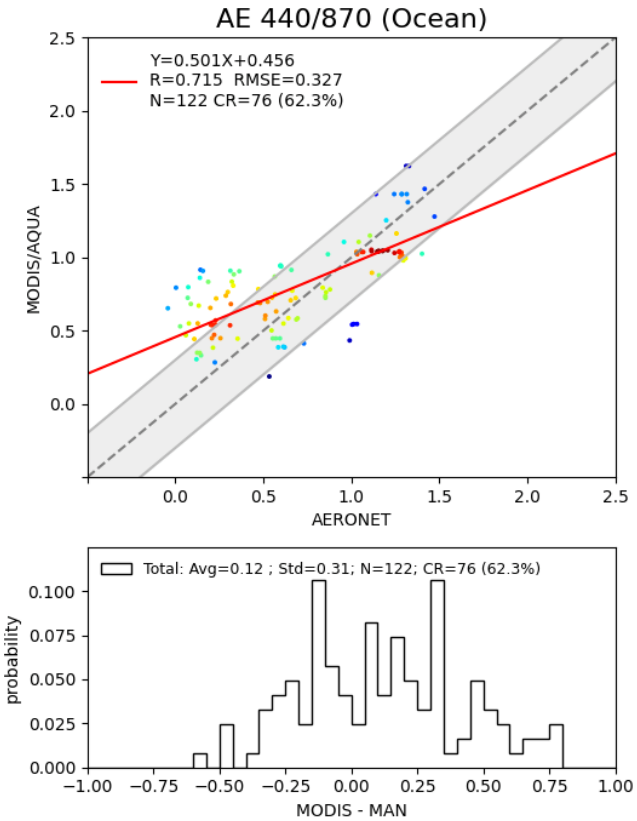


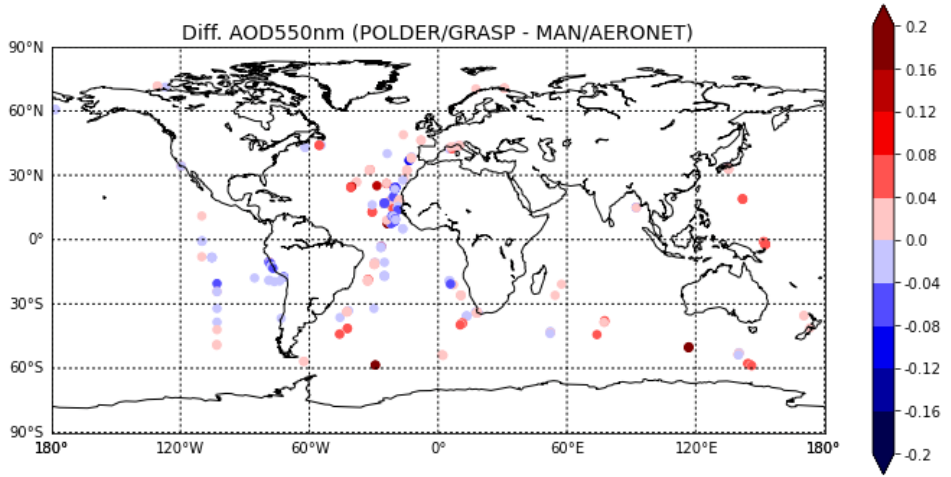
AExp Validation over AERONET/MAN

POLDER/GRASP

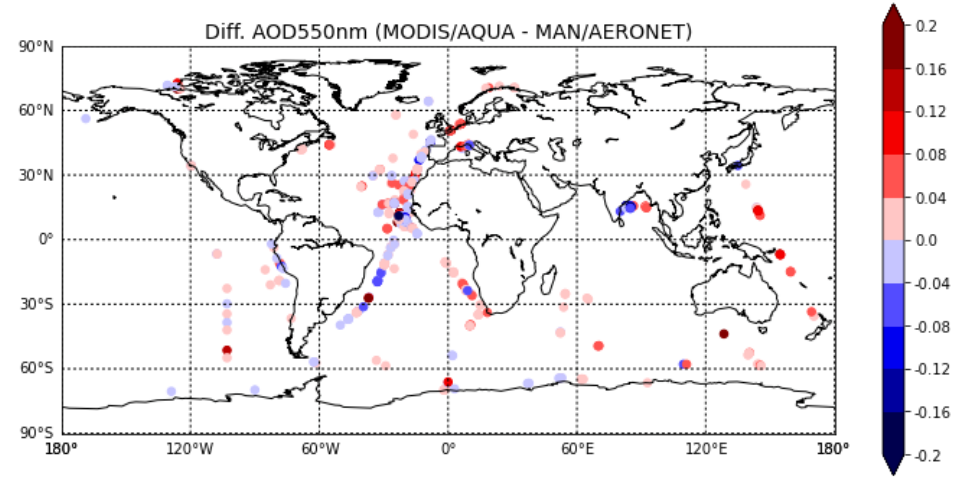


MODIS/AQUA DT





POLDER/GRASP - MAN

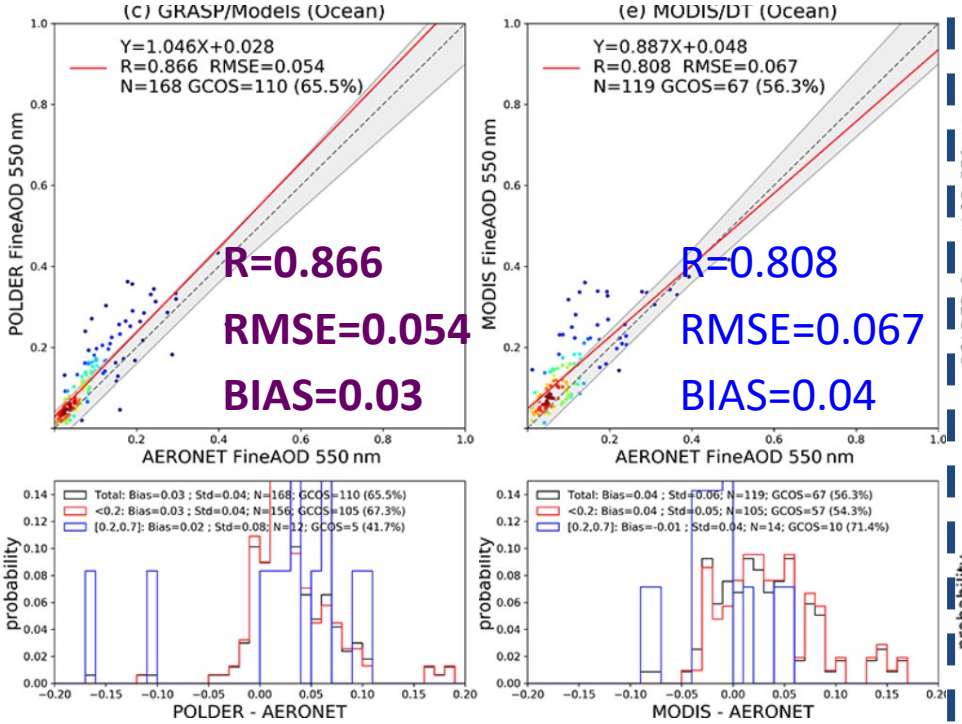


MODIS/AQUA - MAN

AODF and AODC validation over AERONET coastal sites

AODF

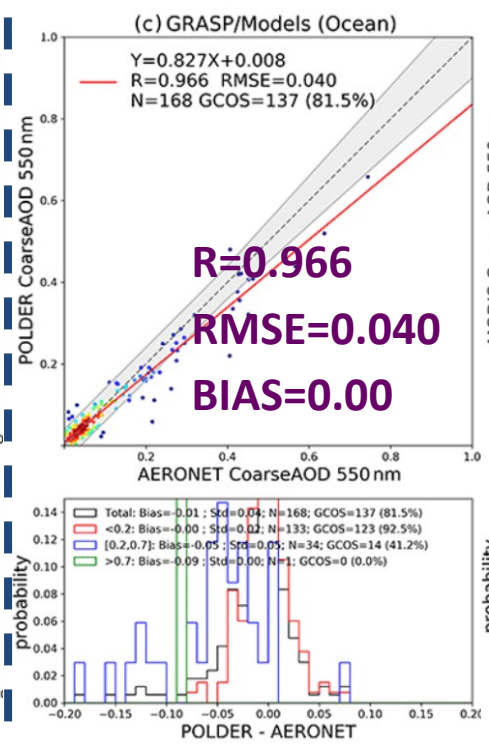
POLDER/GRASP



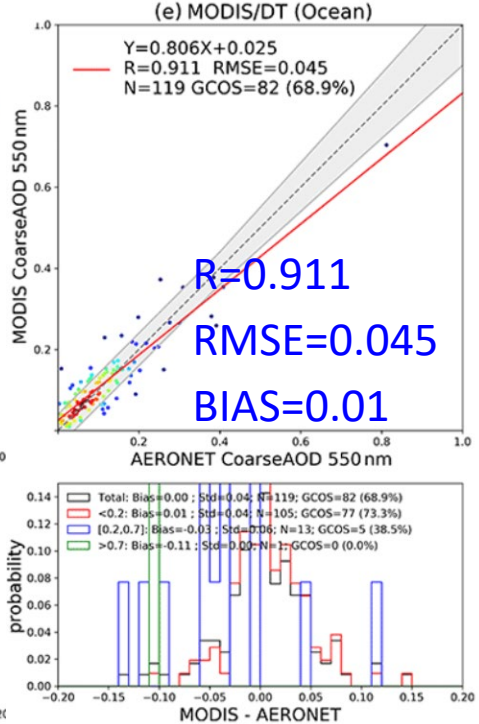
MODIS/AQUA DT

AODC

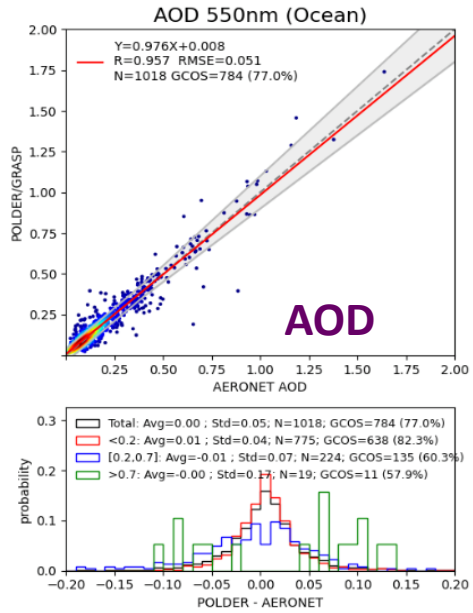
POLDER/GRASP

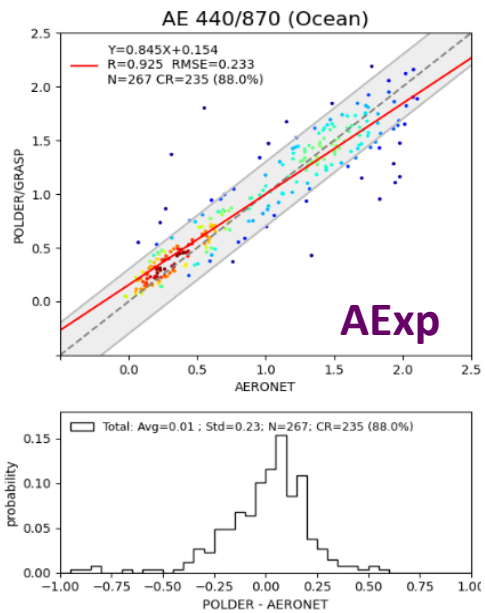


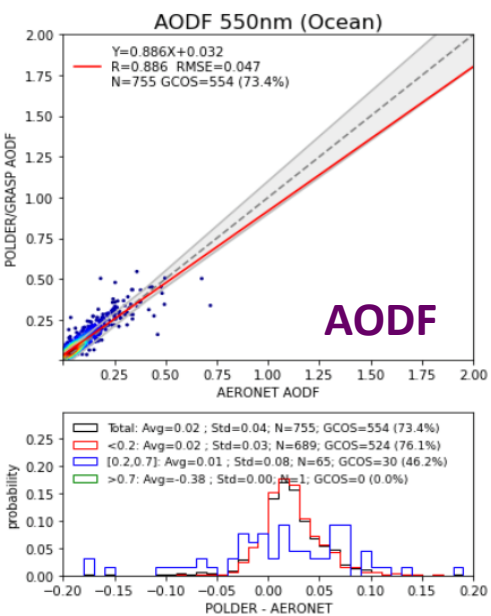
MODIS/AQUA DT

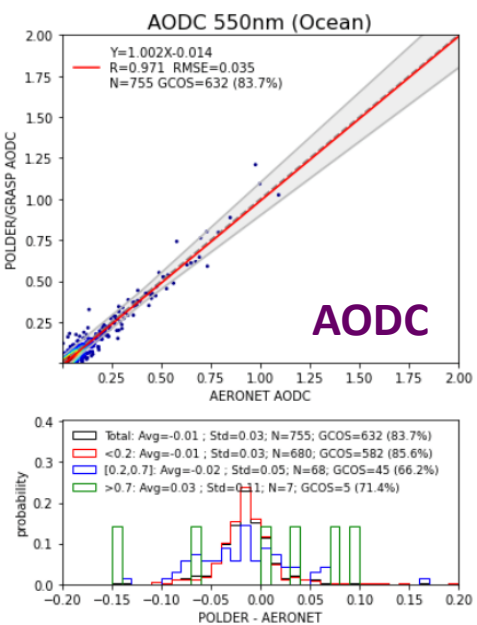


Latest GRASP/Components HARPOL Processing (Ocean)









Latest GRASP/Components HARPOL Processing (Land)