

ICAP 2026 Meeting

Observing Aerosols: New perspectives and implications for global modelling



Harmonizing aerosol remote sensing with transport models: achievements and perspectives

Oleg Dubovik^a, **Mian Chin^b**, **Pavel Litvinov^c**, Yevgeny Derimian^a, Lei Li^d, Xindan Zhang^d, Huizheng Ched, Abhinna Behera^b, Milagros Herrera^b, Tatyana Lapyonok^a, Huisheng Bian^b, Dongchul Kim^b, Hongbin Yu^b, Tom Eck^b, Pawan Gupta^b, Elena Lind^b, Bertrand Fougnie^e, and Johannes Flemming^f



^a Université de Lille, CNRS, Lille, France

^c GRASP SAS, Lille, France

^e EUMETSAT, DLR, Darmstadt, Germany

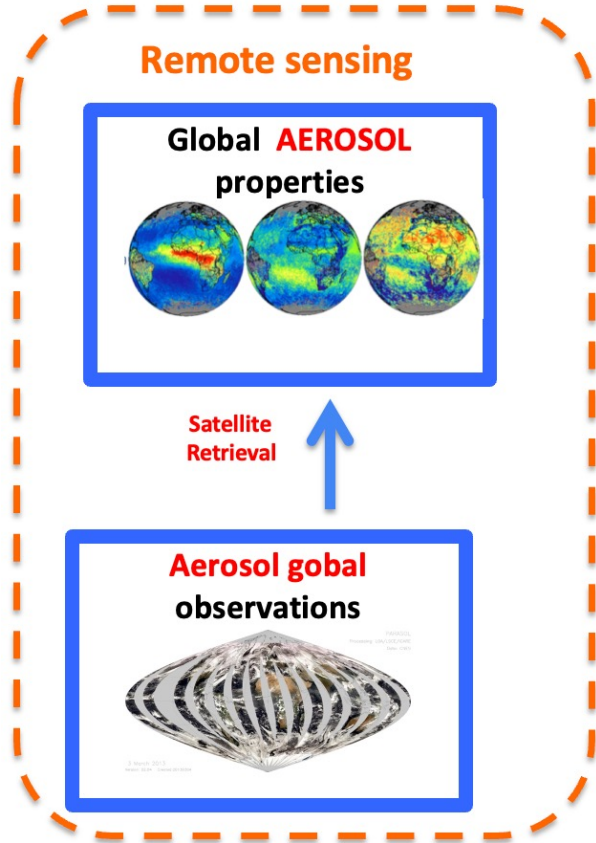
^b NASA/GSFC, Maryland, USA

^d CAMS, Beijing, China

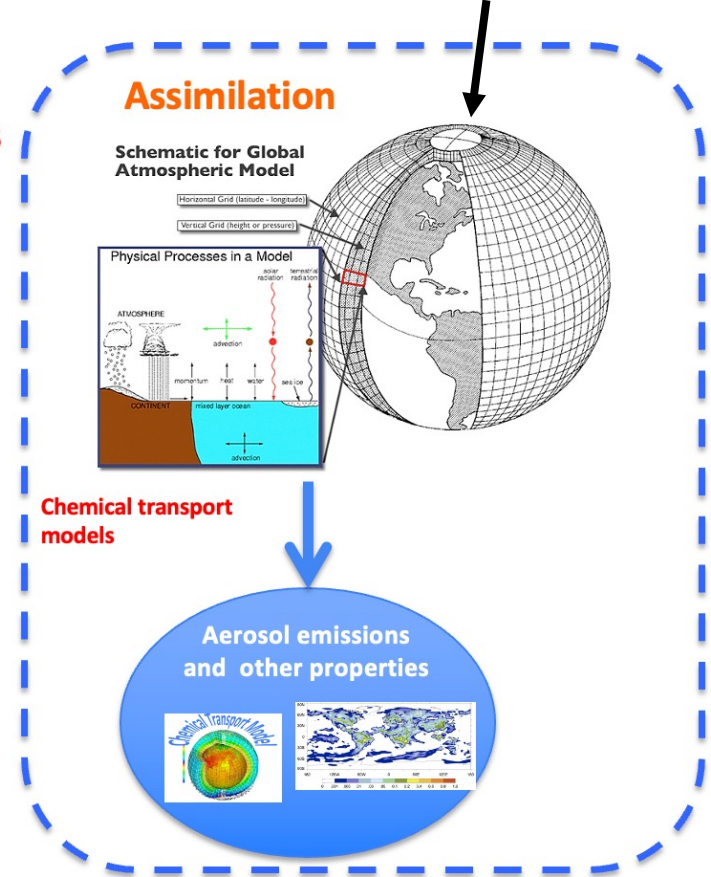
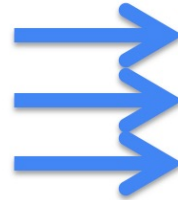
^f ECMWF, Bonn, Germany



Chemical transport information



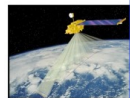
Reanalysis of observations



Motivation:

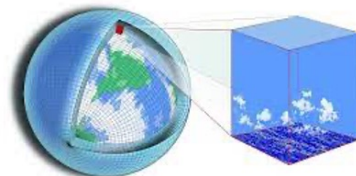
Remote sensing:

- passive
- active
- satellite
- ground-based
- airborne
- etc.



Transport Modeling / Reanalysis:

Spatial and temporal distributions of aerosol microphysical properties



aerosol assumptions are

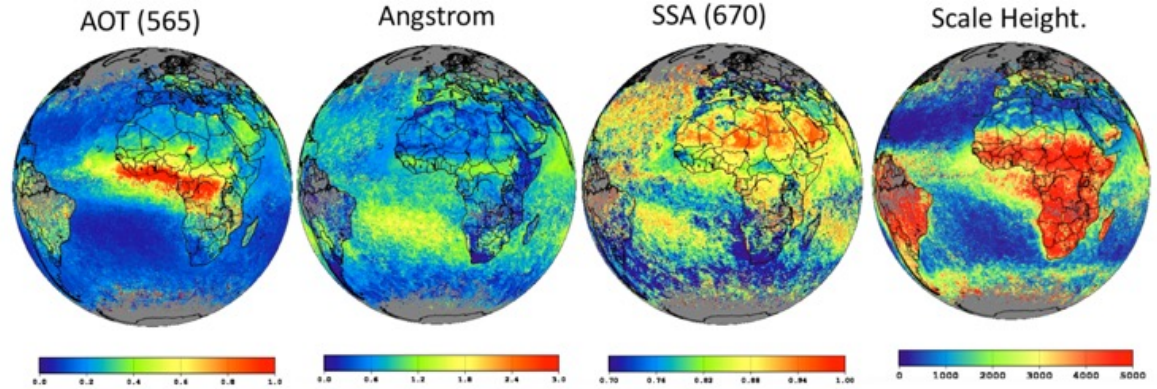
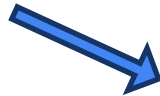
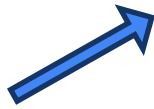
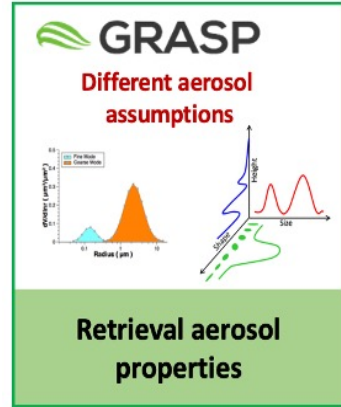
= or \neq



- **Gap** between aerosol modelling approaches used in different remote sensing algorithms and in the global climate models.

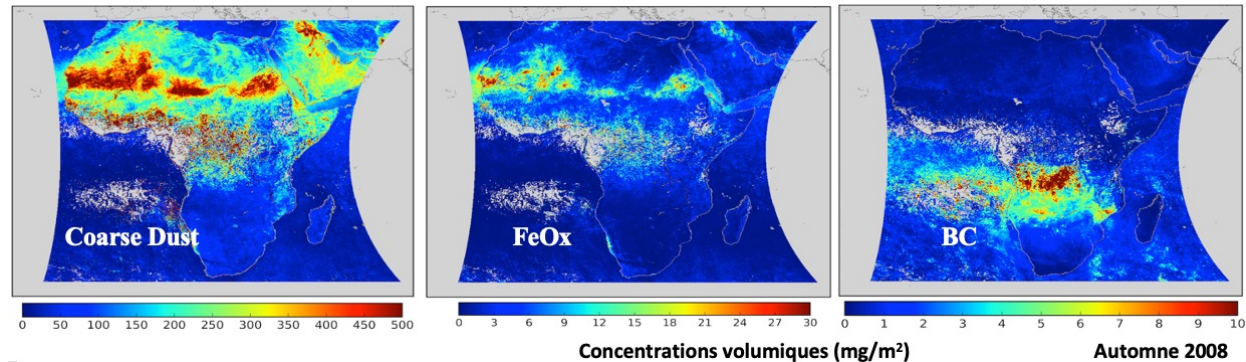
Component approach
directly infer
composition information

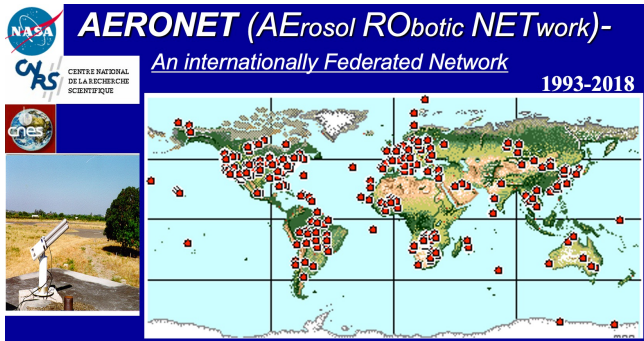
Optical properties



Aerosol components:

BC, BrC, SOL (fine, coarse), Iron, INSOL/DU (fine, coarse)





AERONET and NASA/GSFC (1997 – 2006)



GRASP is highly versatile and very suitable for **multi-instrument synergy** retrieval

AERONET retrieval

<http://aeronet.gsfc.nasa.gov>

Holben et al.
RSE, 1998
Holben et al.
JGR, 2001

Flux measurements
Direct - $\lambda=340, 380, 440, 500, 670, 870, 940, 1020$ nm
Diffuse - $\lambda=440, 670, 870, 1020$ nm (alm, pp, pol)

Smirnov et al.
RSE, 2000

Calibration and processing information

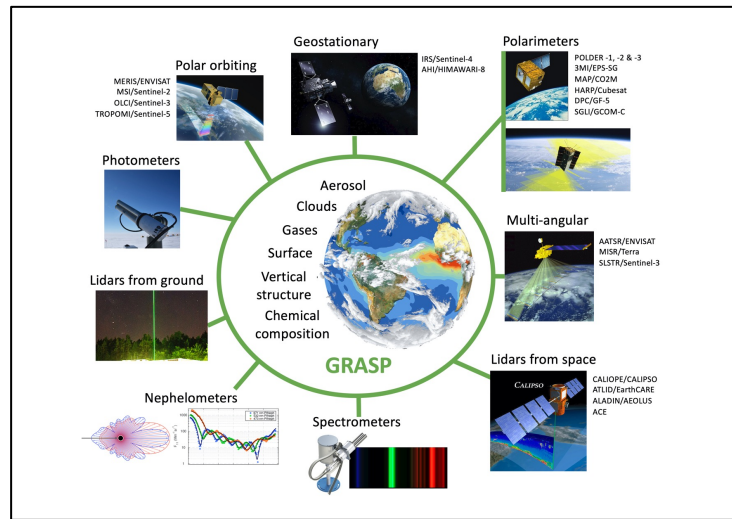
Cloud screening and quality control

Eck et al.
JGR, 1999

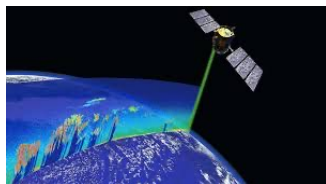
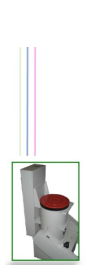
Aerosol optical depth and perceptible water computations

Dubovik and King
JGR, 2000
Dubovik et al.
JGR, 2000
GRL, 2002, JGR 2006

Inversion products
Volume size distribution ($0.05 < R < 15 \mu\text{m}$),
refractive index, single scattering albedo
($\lambda=440, 670, 870, 1020$ nm), fraction of
spherical particles



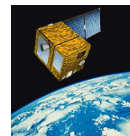
Angular aspects of different observations



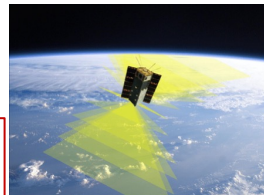
Lidar - active



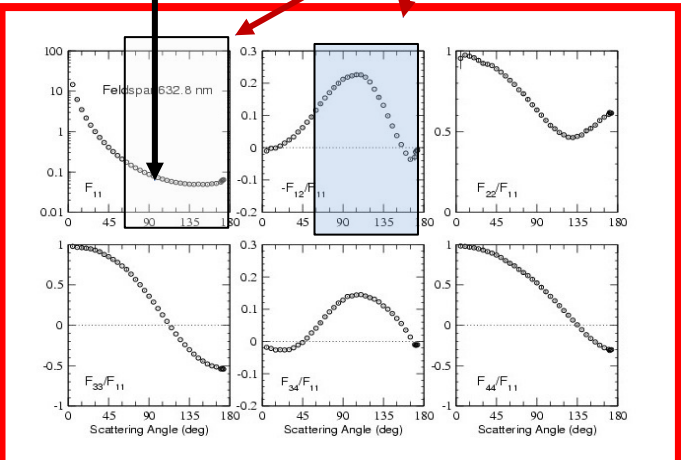
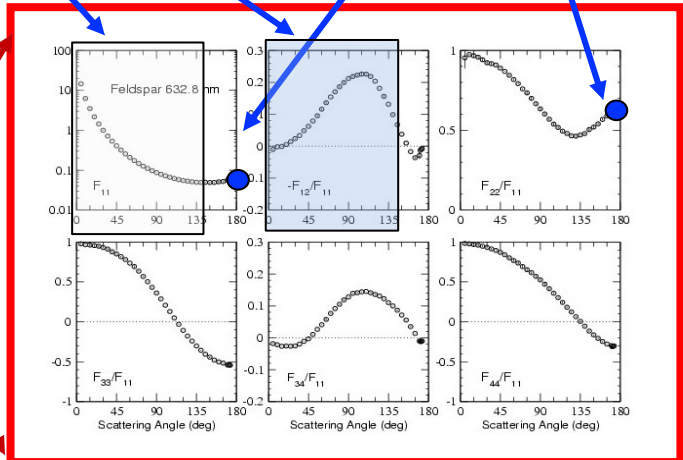
Single-view radiometer



Multi-angular polarimeter



Nephelometer



P_{11} – intensity, P_{12}, P_{22} – state of polarization
 size, shape, absorption, refractive index

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

Model Evolution:

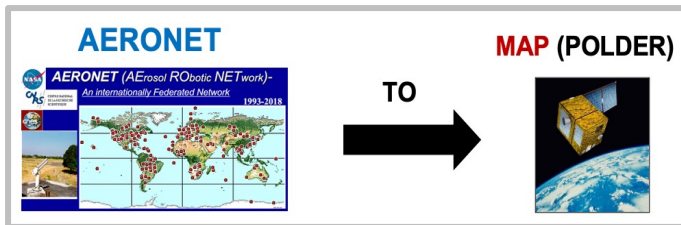
Statistically optimized inversion algorithm for enhanced retrieval of aerosol properties from spectral multi-angle polarimetric satellite observations

O. Dubovik¹, M. Herman¹, A. Holdak¹, T. Lapyonok¹, D. Tanré¹, J. L. Deuzé¹, F. Ducos¹, A. Sinyuk³, and A. Lopatin^{1,2}

¹Laboratoire d'Optique Atmosphérique, UMR8518, CNRS – Université de Lille 1, Villeneuve d'Ascq, France

²Institute of Physics, Laboratory of Scattering Media, 68 Nezavisimosti avenue, Minsk, 220072, Belarus

³NASA/GSFC, Greenbelt, MD, USA



22 size bins r_i

16 size bins r_i

or

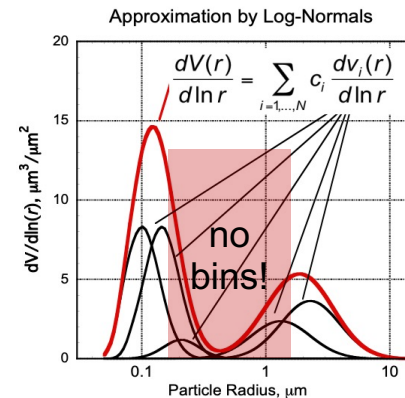
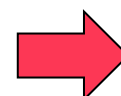
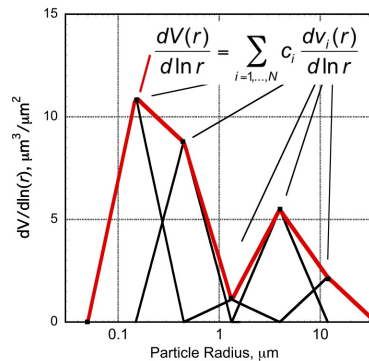
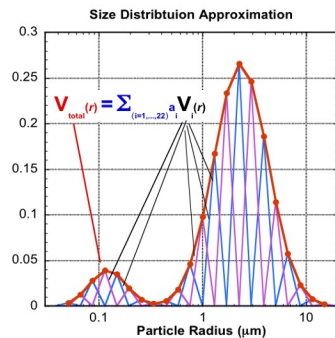
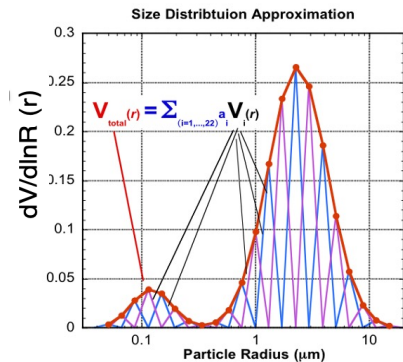
9 size bins r_i

5 size bins r_i

equidistant

5 size bins r_i

Log-normal



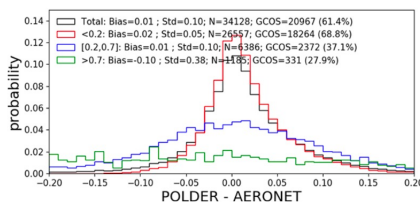
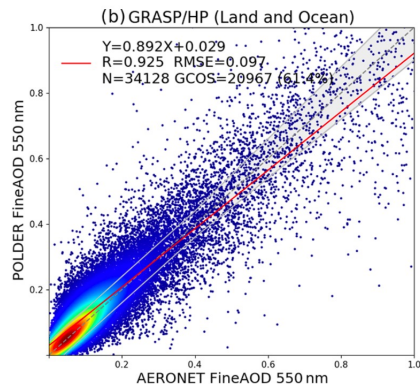
CONCLUSIONS from POLDER aerosol product analysis :

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

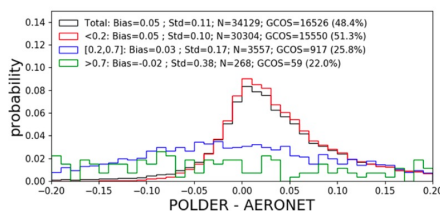
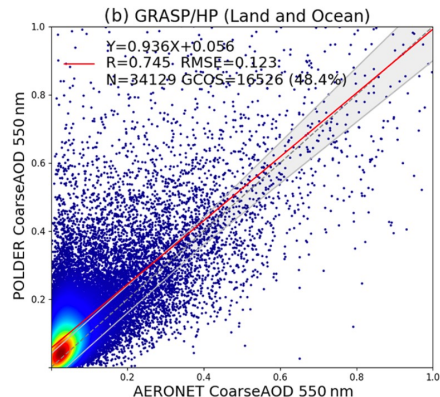
POLDER/ GRASP

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

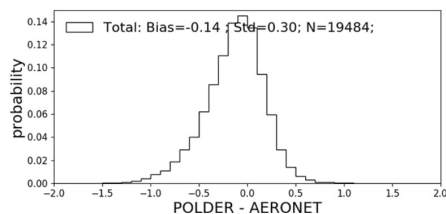
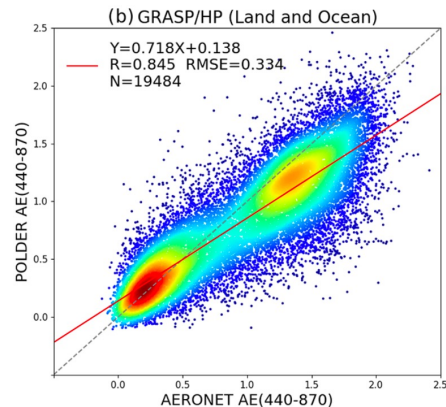
AOD fine (550)



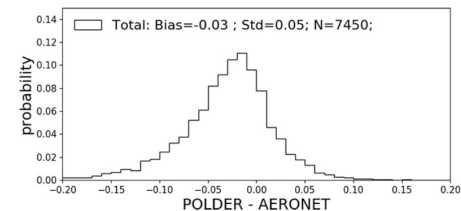
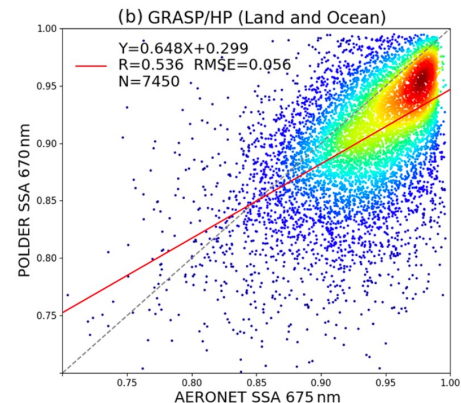
AOD coarse (550)



AE (440 - 870)



SSA (670)

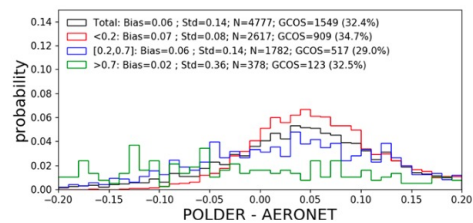
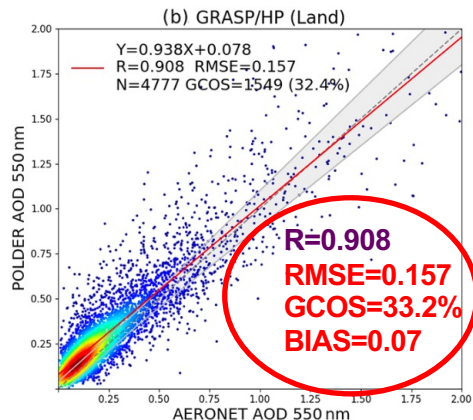


CONCLUSIONS from POLDER aerosol product analysis :

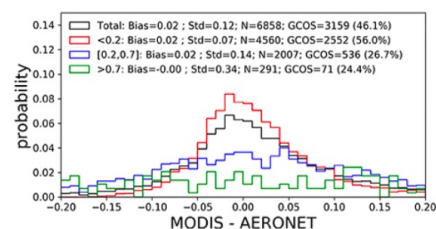
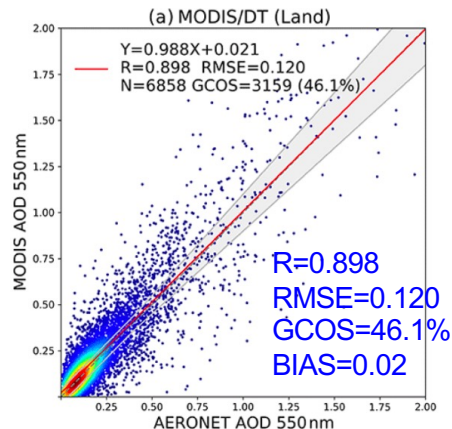
ISSUE of baseline AOD products from first POLDER/GRASP processing;

AOD(550) over Land for 2008 year (Chen et al., 2020)

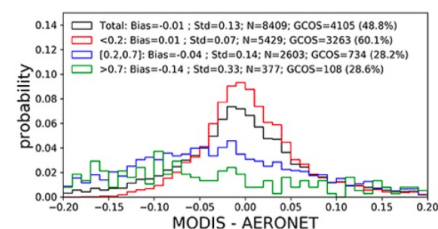
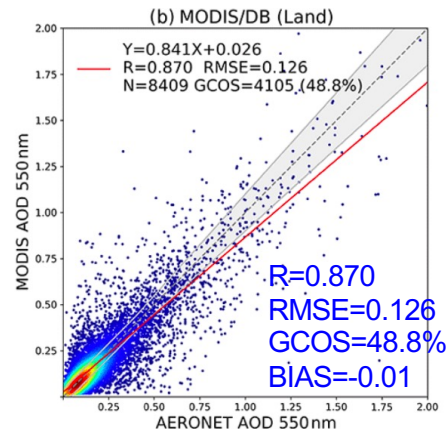
POLDER/ GRASP-HP



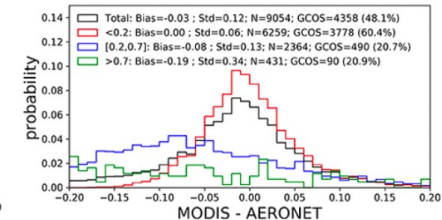
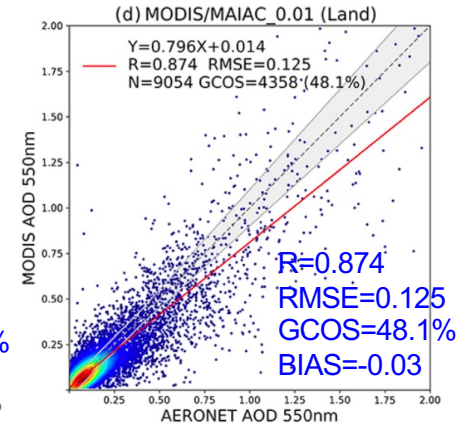
MODIS/DT



MODIS/DB



MODIS/MAIAC_0.1



Model Evolution

Open Access
Earth System
Science
Data

Validation of GRASP algorithm product from POLDER/PARASOL data and assessment of multi-angular polarimetry potential for aerosol monitoring

Cheng Chen^{1,2}, Oleg Dubovik¹, David Fuentes², Pavel Litvinov², Tatjana Lapyonok¹, Anton Lopatin², Fabrice Ducos¹, Yevgeny Derimian¹, Maurice Herman¹, Didi Taubert¹, Christophe A. Reuter¹, Alexei Lyapustin⁴, Andrew M. Sayer^{4,5}, Robert C. Levy⁴, N. Christian Hsu⁶, Jacques Deschamps⁶, Lei Li^{1,7}, Benjamin Torres¹, Yana Karol², Milagros Herrera¹, Marcos Herrera¹, Michael Aspetsberger⁸, Moritz Wanzanboeck³, Lukas Bindreiter⁸, Daniel Marth³, Andreas Hanel⁸, and Christian Federspiel⁸

Based on Dubovik et al 2002 and evaluated by Chen et al., 2020 and Lopatin et al., 2021

Desert Dust	Bahrain/ Persian Gulf (1998–2000)	Solar-Vil/ Saudi Arabia(1998-2000)	Cape Verde (1993–2000)
Number of meas. (total)	1800	1500	1500
Number of meas. (for α_s, n, A)	100	250	300
Range of optical thickness τ_{550}	$0.1 \leq \tau(1020) \leq 1.2, \langle \tau(1020) \rangle = 0.22$	$0.1 \leq \tau(1020) \leq 1.5, \langle \tau(1020) \rangle = 0.17$	$0.1 \leq \tau(1020) \leq 2.0, \langle \tau(1020) \rangle = 0.39$
Range of Angstrom parameter α	$0.5 \leq \alpha \leq 1.6$	$0.1 \leq \alpha \leq 0.9$	$-0.1 \leq \alpha \leq 0.7$
σ_g (440/670/870/1020)	0.68/0.66/0.66/0.66 ± 0.04	0.69/0.66/0.65/0.65 ± 0.04	0.71/0.71/0.71/0.71 ± 0.04
n	1.55 ± 0.03	1.56 ± 0.03	1.48 ± 0.05
(440/670/870/1020)	0.00225 ± 0.0014 / 0.0011/0.001 ± 0.001	0.00229 ± 0.0013 / 0.0011/0.001 ± 0.001	0.00225 ± 0.0007 / 0.00065/0.0006 ± 0.001
τ_{550} (440/670/870/1020)	0.92/0.95/0.96/0.97 ± 0.03	0.92/0.96/0.97/0.97 ± 0.02	0.93/0.98/0.99/0.99 ± 0.01
τ_{550} (μm), α_s	0.15 ± 0.04, 0.42 ± 0.04	0.12 ± 0.05, 0.40 ± 0.05	0.12 ± 0.03, 0.49 ± 0.10 ± 0.04
τ_{550} (μm), α_s	2.54 ± 0.04, 0.61 ± 0.02	2.32 ± 0.03, 0.60 ± 0.03	1.90 ± 0.03, 0.63 ± 0.10 ± 0.03
C_m ($\mu\text{m}^2/\mu\text{m}^2$)	0.02 ± 0.1 $\tau(1020) = 0.05$	0.02 ± 0.02 $\tau(1020) = 0.03$	0.02 ± 0.02 $\tau(1020) = 0.03$
C_m ($\mu\text{m}^2/\mu\text{m}^2$)	-0.02 ± 0.92 $\tau(1020) = 0.04$	-0.02 ± 0.98 $\tau(1020) = 0.04$	0.9 $\tau(1020) \leq 0.09$

5 size bins r_i
Log-normal

Models approach

5 log-normal bins:
Full Microphysics approach

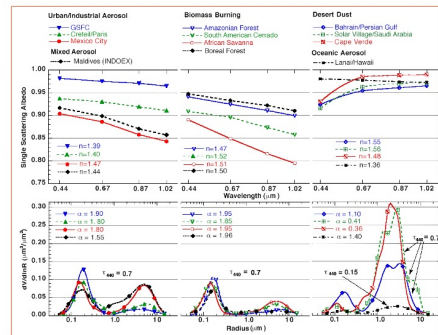
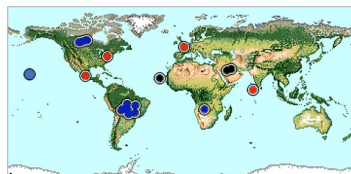
1. 5 LN Bins
2. Total Concentration
3. Non-spherisity
4. Spectral CRI

GRASP: aerosol models approach

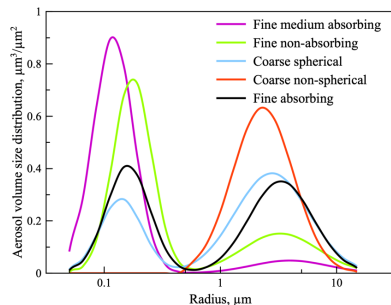
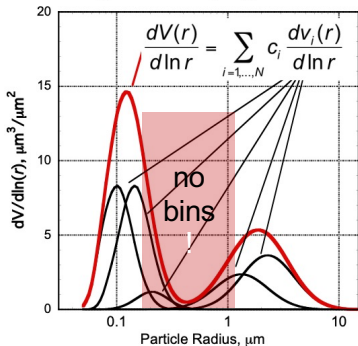
1. Aerosol component concentrations
2. Total concentration

Dubovik et al. 2002

- Urban/Industrial (GSFC, Paris, Mexico-City, INDOEX)
- Biomass Burning (Savanna, Cerrado, Forest)
- Desert Dust (Cape Verde, Saudi Arabia, Persian Gulf)
- Oceanic Aerosol (Hawaii)



Approximation by Log-Normals



Aerosol type	Fine mode			Coarse mode			Refractive index at 500nm
	C_v^f	τ_m^f	σ_g^f	C_v^c	τ_m^c	σ_g^c	
Fine non-absorbing	0.72	0.175	0.38	0.28	3.27	0.7	1.395–0.003i
Fine moderately absorbing	0.91	0.1200	0.40	0.09	3.95	0.7	1.51–0.05i
Fine strongly absorbing	0.52	0.16	0.43	0.48	3.32	0.63	1.47–0.15i
Coarse spherical	0.30	0.140	0.42	0.70	2.78	0.7	1.37–0.0001i
Coarse non-spherical	0.05	0.12	0.4	0.95	2.32	0.6	1.56–k(λ)i

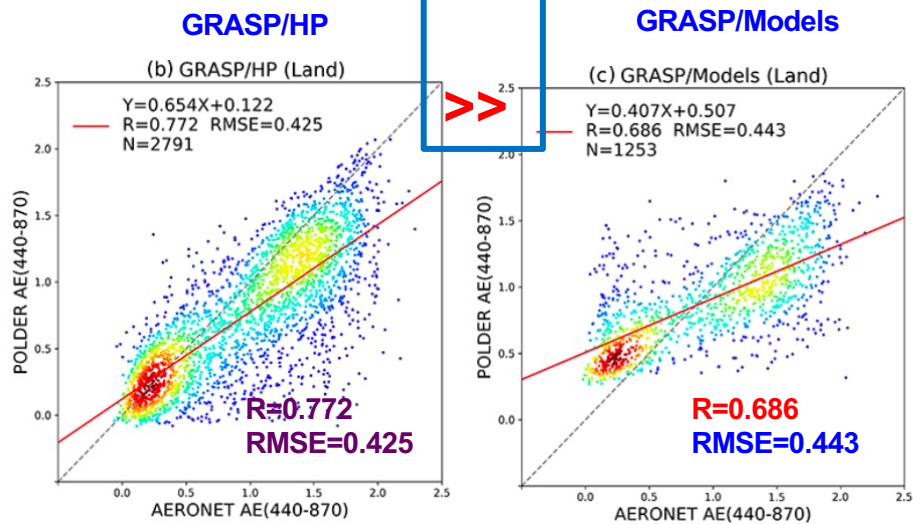
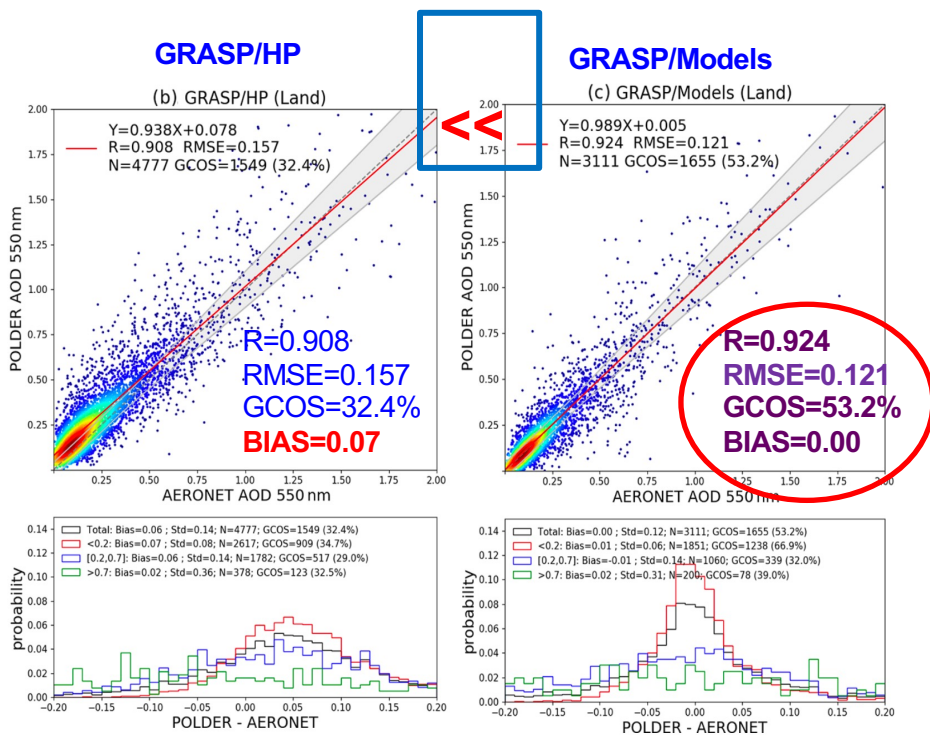
CONSLUSIONS from POLDER aerosol product analysis :

MAP algorithms are complex, and need **specific tuning** for different products:
 - e.g., most general algorithms provide - **AE, fine /coarse AOD (land), SSA, AOD**
 but **struggle** with issues in **baseline AOD products**.

Over **Land** for 2008 year (Chen et al., 2020)

GRASP/HP – **complex retrieval** (size, complex ref. index, etc.)

GRASP/Models – **simpler retrieval** (mixture of components)



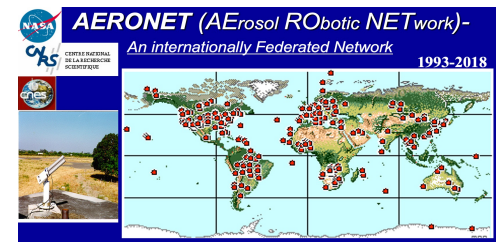
AERONET like

(Dubovik and King, 2000)



GRASP/Components

(Li et al., 2011)

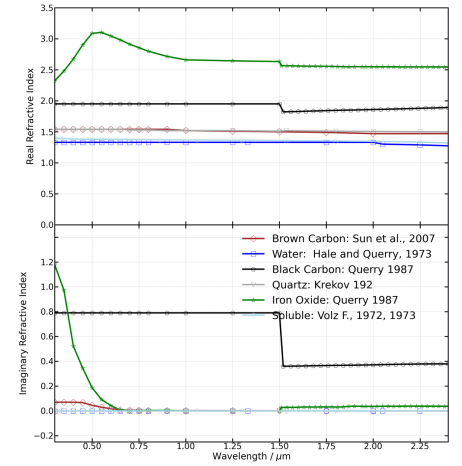
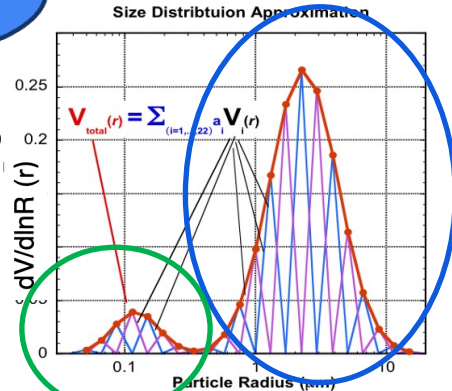
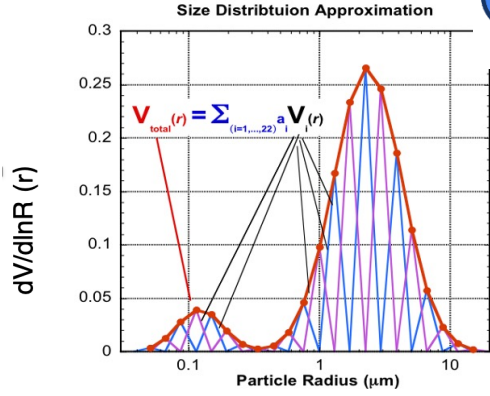


Inspiration of Greg Schuster work

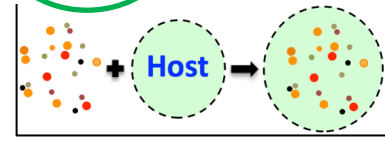
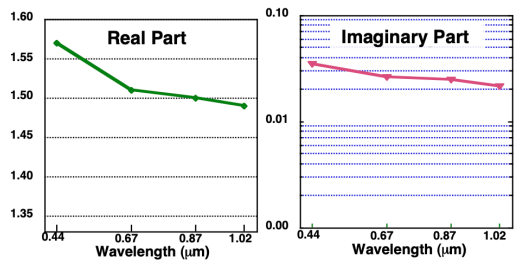
22 size bins r_i

22 size bins r_i

Schuster et al. 2005



Complex Refractive Index at $\lambda = 0.44; 0.67; 0.87; 1.02 \mu\text{m}$



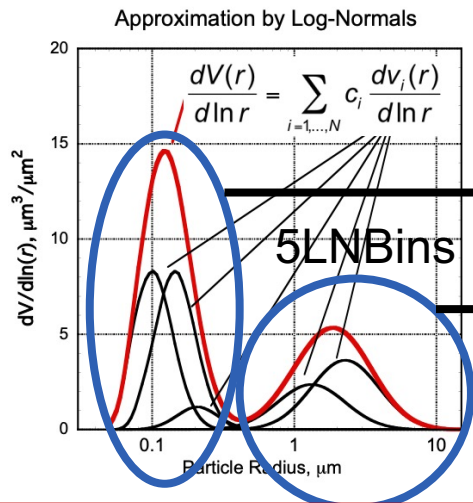
Fine mode :

$$\hat{m}_{eff}^{fine} = \hat{m}_{BC} \delta_{BC}^{phil} + \hat{m}_{Brc} \delta_{Brc} + \hat{m}_{Quartz} \delta_{Quartz}^{fine} + \hat{m}_{Sol} \delta_{Sol} + \hat{m}_{Water} \delta_{Water}^{fine}$$

Coarse mode:

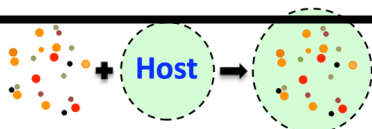
$$\hat{m}_{eff}^{coarse} = \hat{m}_{Quartz} \delta_{Quartz}^{coarse} + \hat{m}_{Iron} \delta_{FeOx} + \hat{m}_{Sol} \delta_{Sol} + \hat{m}_{Water} \delta_{Water}^{coarse}$$

GRASP approach – 5LNBins + Chemical Component



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

Fine mode



Maxwell Garnett
effective medium approximation

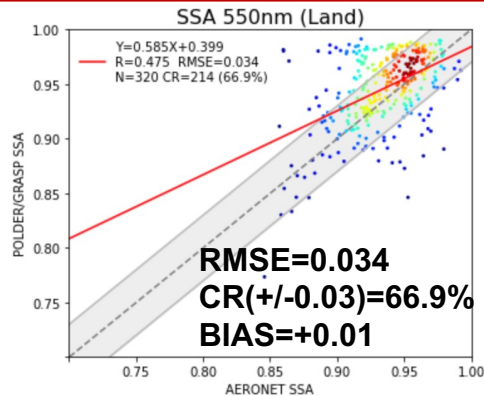
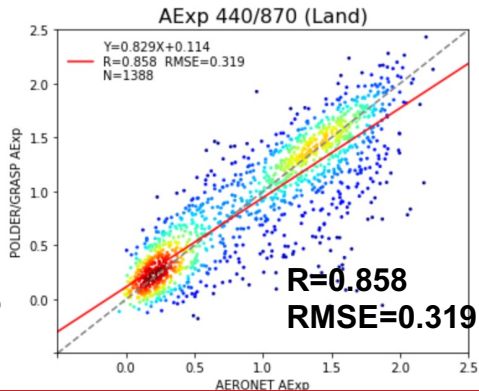
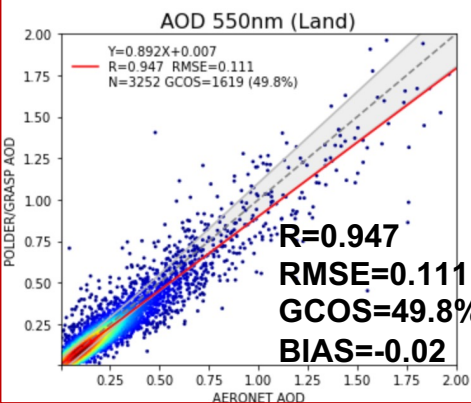
Coarse mode

or
Volume weighted

GRASP/Component Validation (2008)

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

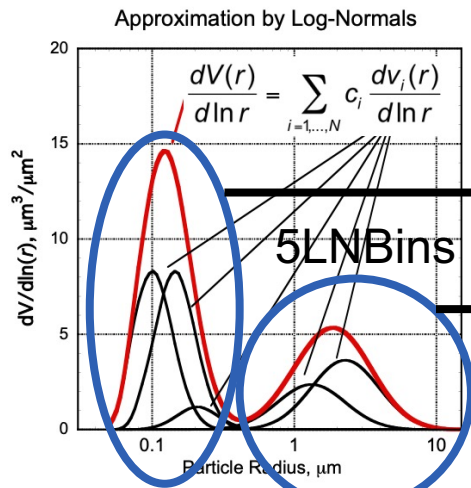
Absorbing insoluble (Iron oxides)
Non-absorbing insoluble (Dust)
Non-absorbing soluble (SS, etc)
Water
Coarse mode



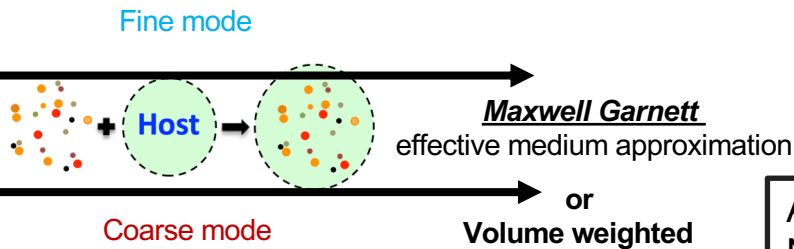
By using prescribed spectral refractive index of components,

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

GRASP approach – 5LNBins + Chemical Component



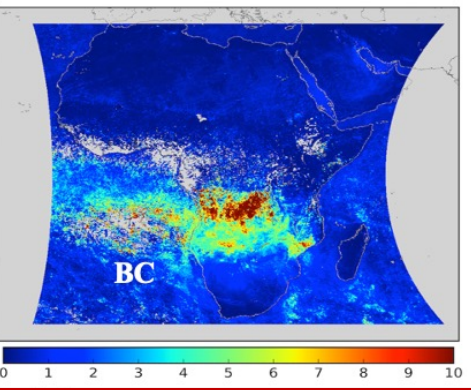
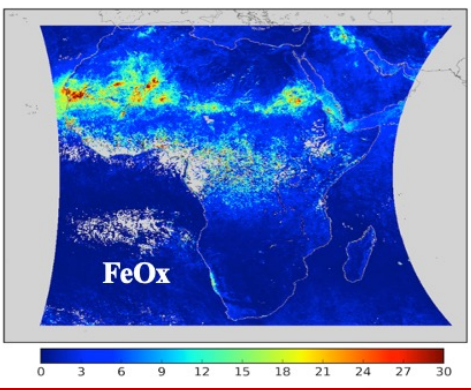
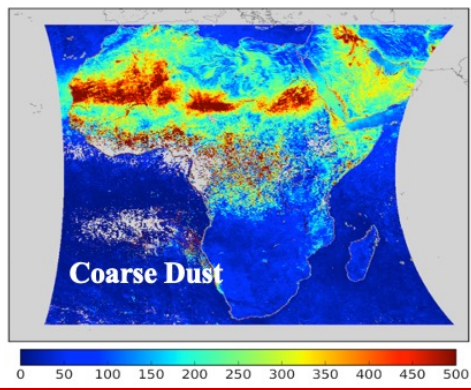
(L. Li et al., ACP, 2019)



GRASP/Component Validation (2008)

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

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

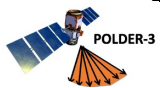


Concentrations volumiques (mg/m³) Automne 2008

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

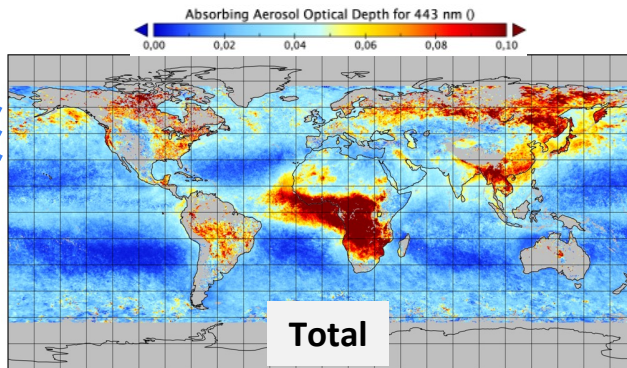
GRASP/Component approach provides consistent and stable results for AOD as well as detailed properties.

Example of the aerosol composition retrieval from satellite remote sensing observations: POLDER-3/GRASP (Li et al., 2019)



EXAMPLE of aerosol absorption from polarimeter

RESULT: The aligned retrieval allows direct retrieval of different aerosol components from satellite observations



Coarse mode

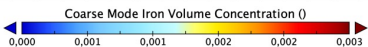
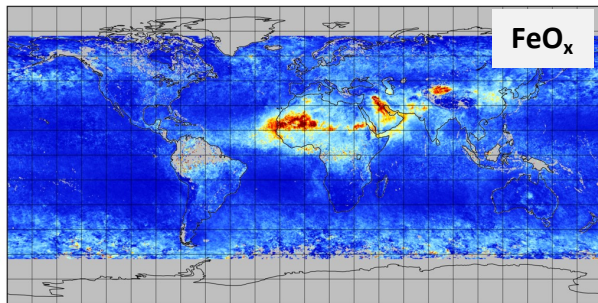
Fine mode

September 2008

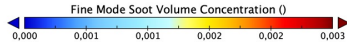
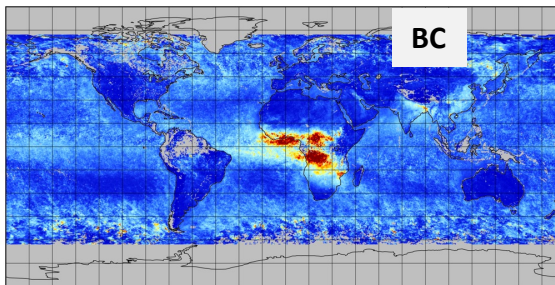
Aerosol Absorption Optical Thickness AAOD(440)

contributions of different components can be identified

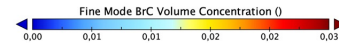
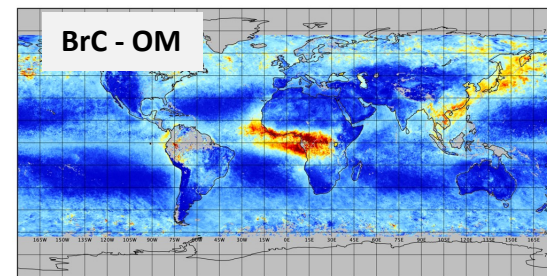
Coarse Mode Iron Volume Concentration



Fine Mode Soot Volume Concentration



Fine Mode BrC Volume Concentration



Comparison:

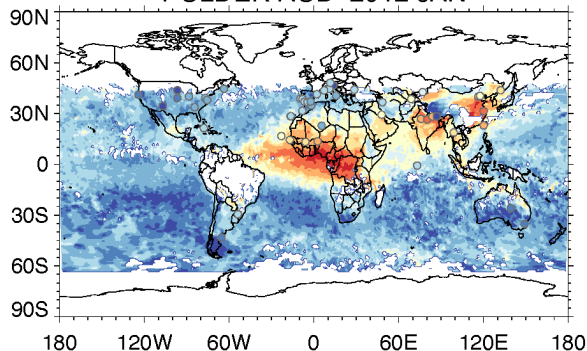
AERONET/GRASP and POLDER/GRASP Components with GEOS/GOCART model simulation

AERONET	POLDER	Definition (AERONET & POLDER)	Model output
AOD_440nm	AOD443 (565)	AOD	AOD at 550 nm
AAOD_440nm	AAOD443 (565)	AAOD	AAOD at 550 nm
BC	Soot	Fine mode λ -independent strong absorbing	BC column dry mass loading
BrC	BrC	Fine mode λ -dependent absorbing	BrC column mass dry loading (BB only)
CAI	Iron	Coarse mode λ -dependent absorbing (FeOx) insoluble	Hematite + goethite column dry mass loading
CNAI	Insoluble_C	Coarse mode non-absorbing insoluble (non-abs dust+aged OA)	DU column dry mass loading (compared with CNAI+FNAI)
FNAI	Insoluble_F	Fine mode non-absorbing insoluble	
CNAS	Soluble_C	Coarse-mode non-absorbing soluble	NH ₄ ⁺ + NO ₃ ⁻ + SO ₄ ⁼ + SS + OC column dry mass loading
FNAS	Soluble F	Fine-mode non-absorbing soluble	

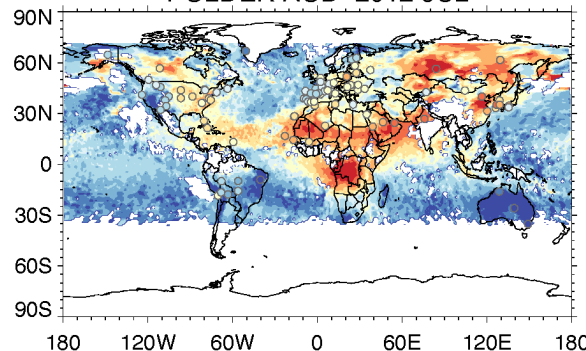
AOD monthly mean

POLDER and AERONET: AOD ~440nm GEOS: AOD 550nm

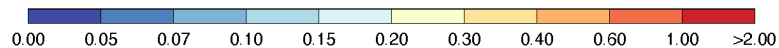
POLDER AOD 2012 JAN



POLDER AOD 2012 JUL

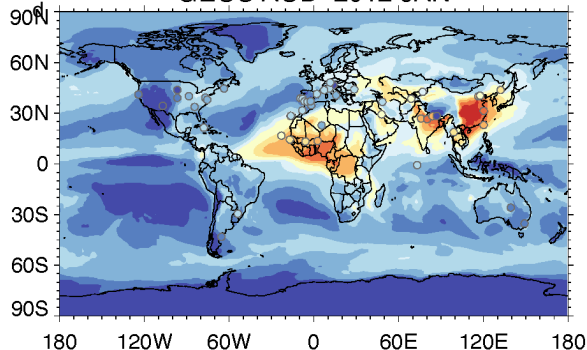


AERONET
data

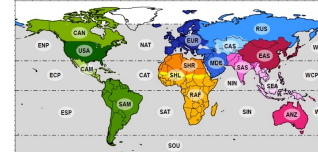
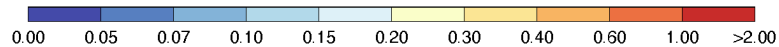
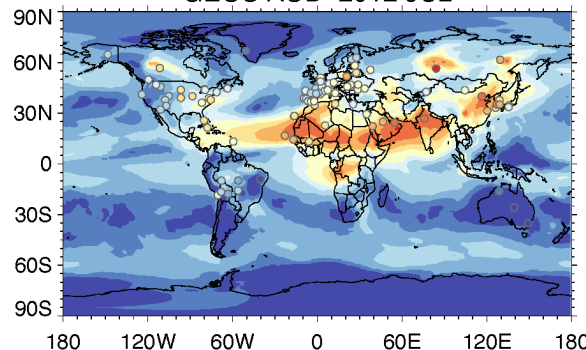


superimpose

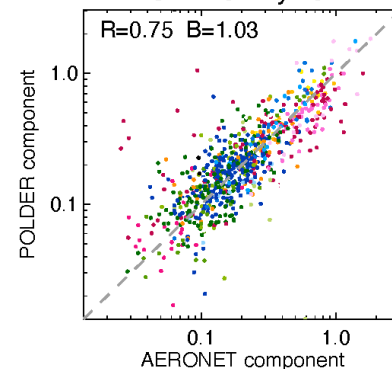
GEOS AOD 2012 JAN



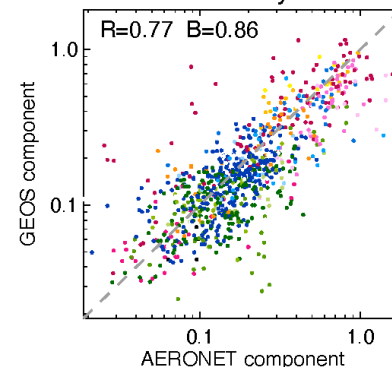
GEOS AOD 2012 JUL



AOD monthly 2012



AOD monthly 2012

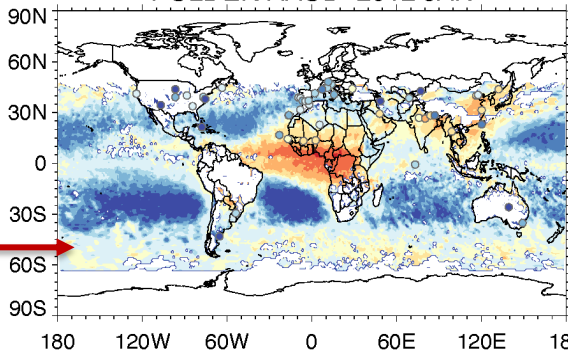


Colors representing land regions (domains on top)

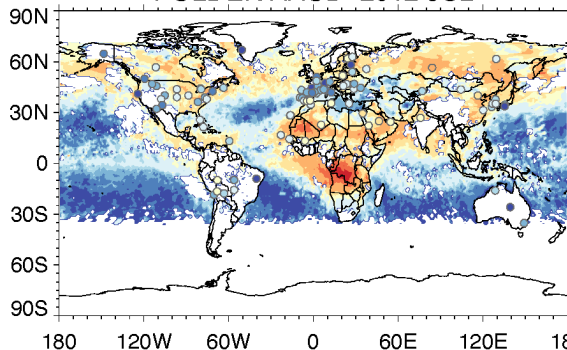
AAOD monthly mean

POLDER and AERONET: AAOD ~440nm GEOS: AAOD 550nm

POLDER AAOD 2012 JAN



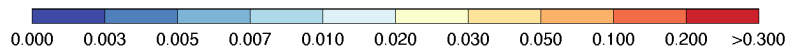
POLDER AAOD 2012 JUL



High
AAOD in
Southern
Ocean?

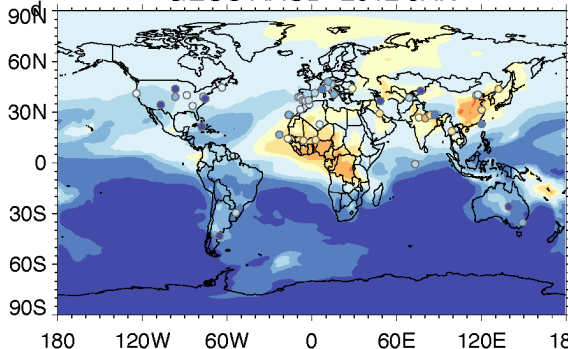


AERONET
data

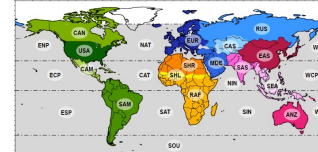
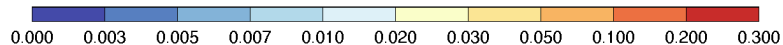
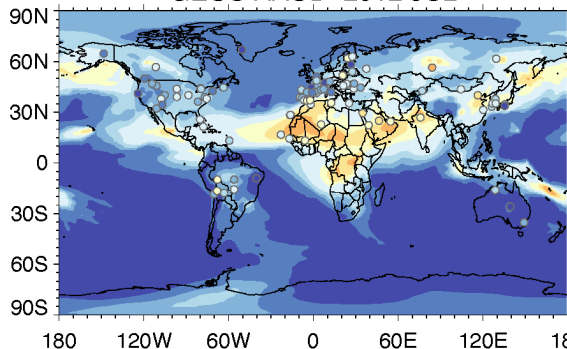


superimpose

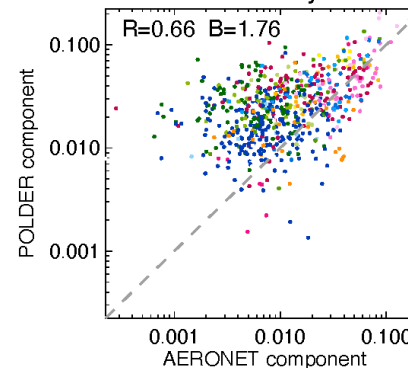
GEOS AAOD 2012 JAN



GEOS AAOD 2012 JUL

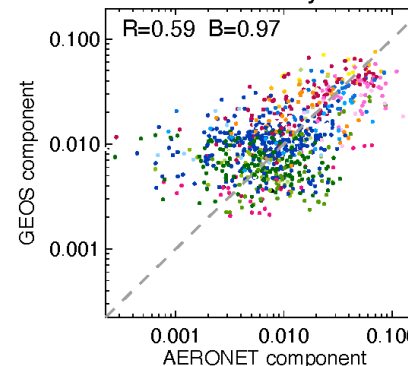


AAOD monthly 2012



All months

AAOD monthly 2012

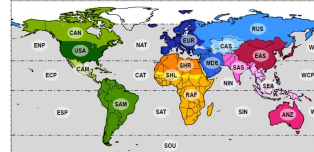


All months

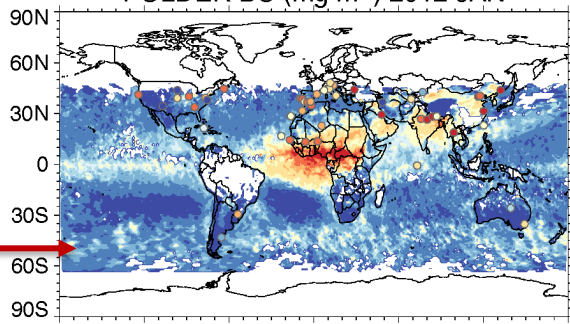
Colors representing land regions (domains on top)

BC monthly mean

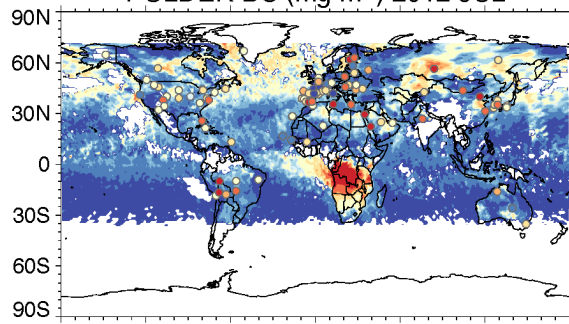
POLDER and AERONET: Ambient GEOS: Dry



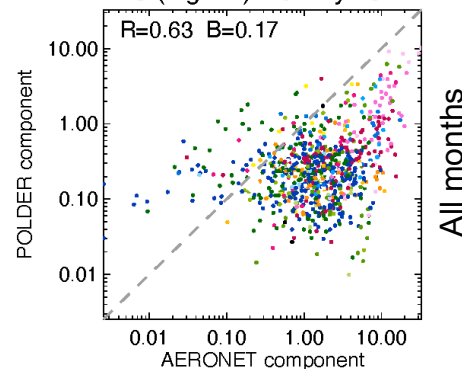
POLDER BC (mg m^{-2}) 2012 JAN



POLDER BC (mg m^{-2}) 2012 JUL



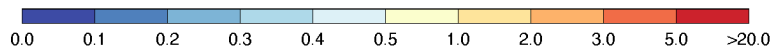
BC (mg m^{-2}) monthly 2012



High BC
in
Southern
Ocean?

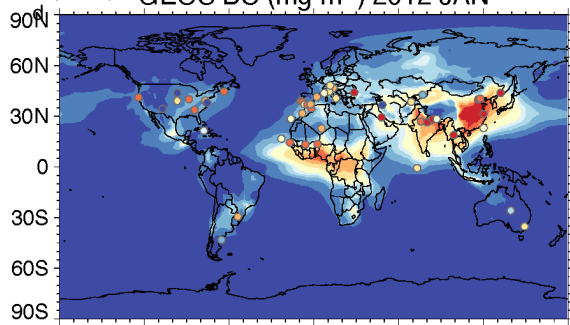
All months

AERONET
data

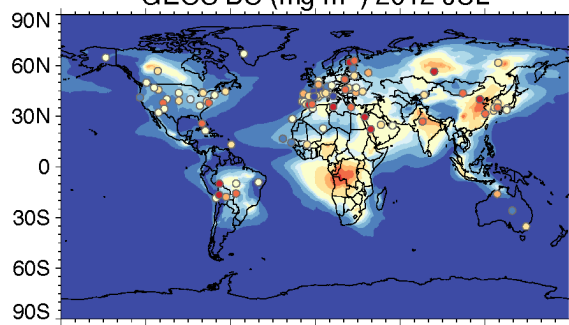


superimpose

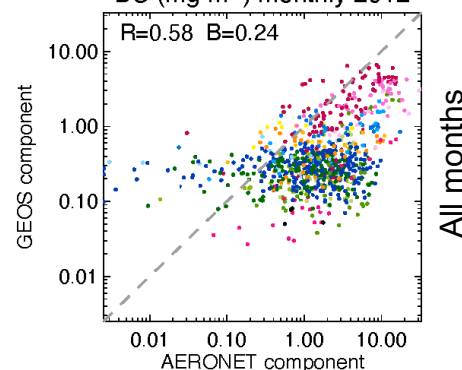
GEOS BC (mg m^{-2}) 2012 JAN



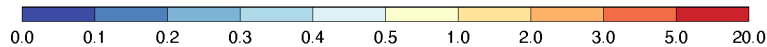
GEOS BC (mg m^{-2}) 2012 JUL



BC (mg m^{-2}) monthly 2012



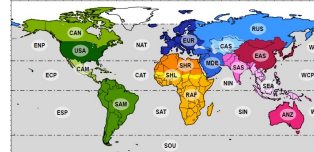
All months



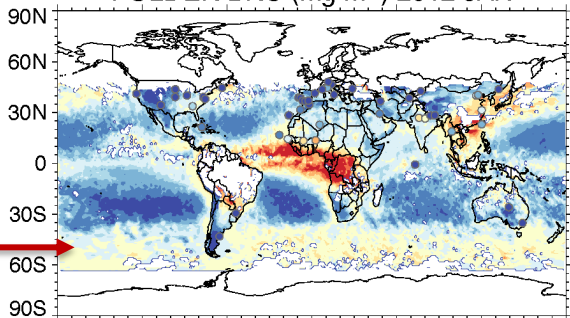
Colors representing land regions (domains on top)

BrC monthly mean

POLDER and AERONET: Ambient GEOS: Dry

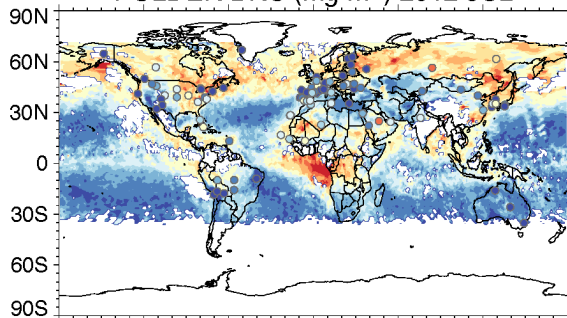


POLDER BRC (mg m^{-2}) 2012 JAN

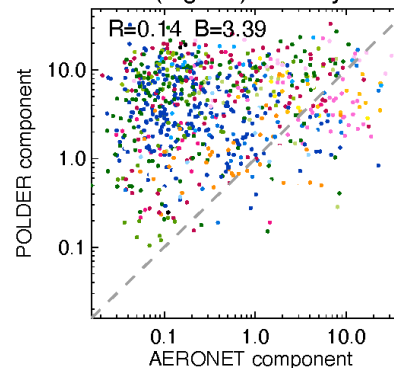


High BrC
in
Southern
Ocean?

POLDER BRC (mg m^{-2}) 2012 JUL

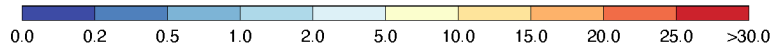


BRC (mg m^{-2}) monthly 2012



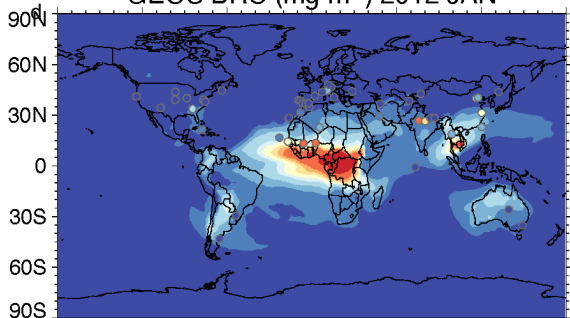
All months

AERONET
data



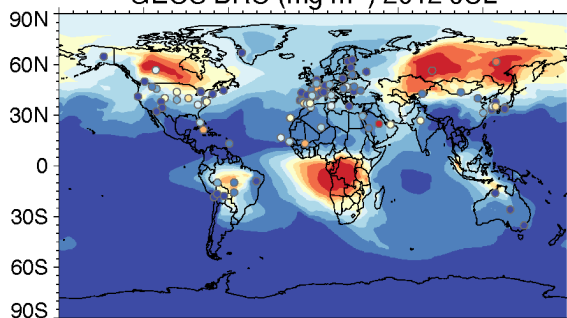
superimposed

GEOS BRC (mg m^{-2}) 2012 JAN

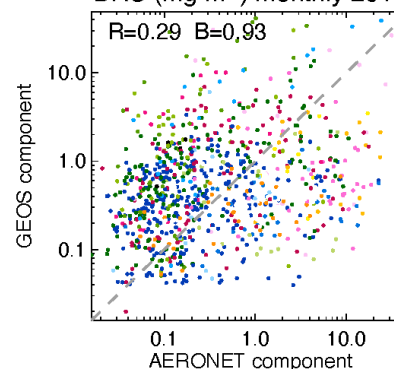


Model
puts BrC
only in
smoke
aerosols

GEOS BRC (mg m^{-2}) 2012 JUL



BRC (mg m^{-2}) monthly 2012

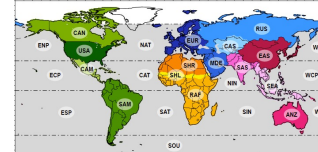


All months

Colors representing land regions (domains on top)

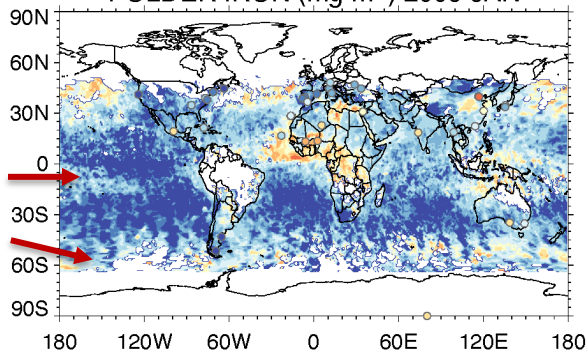
Iron monthly mean

POLDER: Iron AERONET: CAI GEOS: Hematite + Goethite

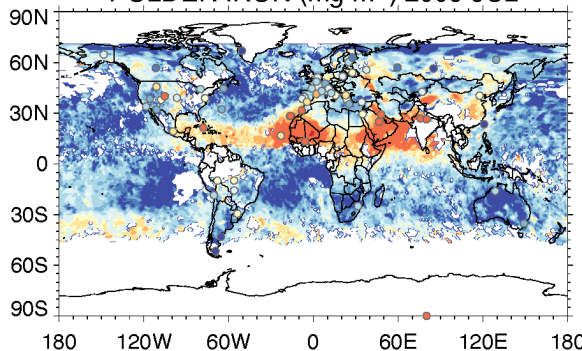


Iron contents over ocean seems high

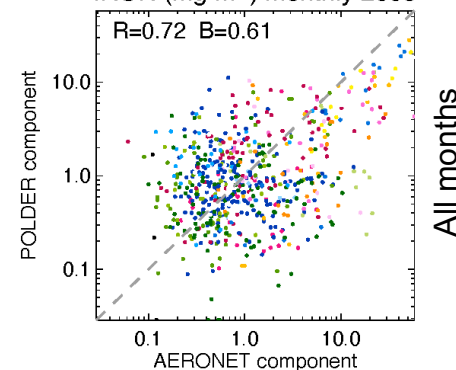
POLDER IRON (mg m^{-2}) 2009 JAN



POLDER IRON (mg m^{-2}) 2009 JUL

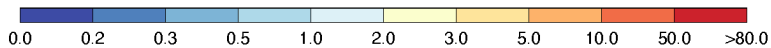


IRON (mg m^{-2}) monthly 2009

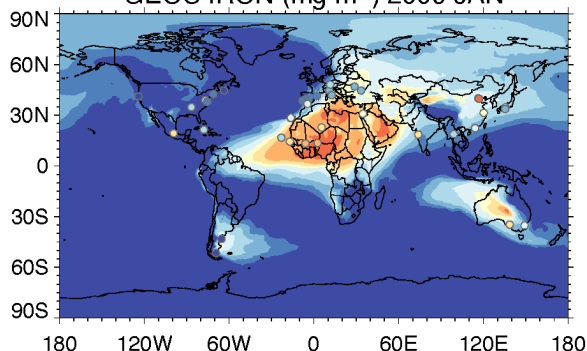


All months

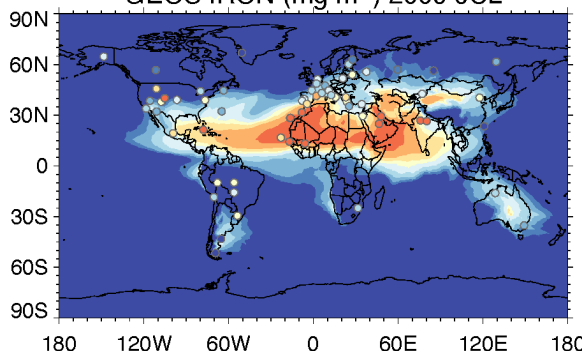
AERONET data superimposed



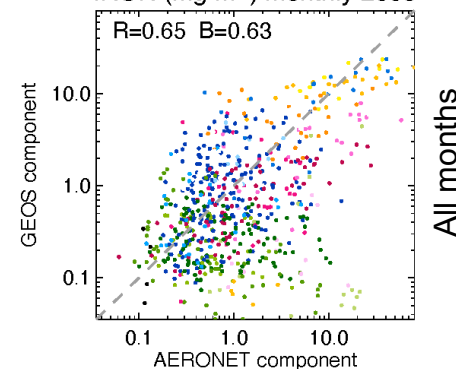
GEOS IRON (mg m^{-2}) 2009 JAN



GEOS IRON (mg m^{-2}) 2009 JUL

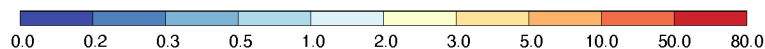


IRON (mg m^{-2}) monthly 2009



All months

(Note: GEOS iron simulation only tested for 2009)



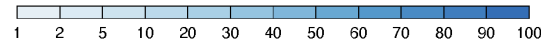
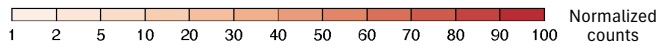
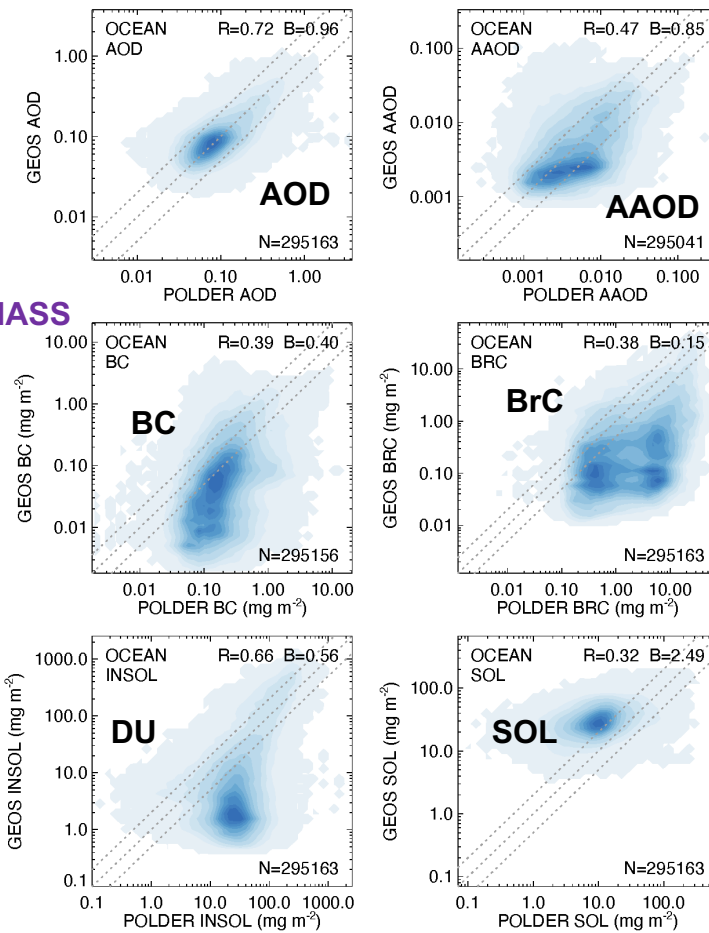
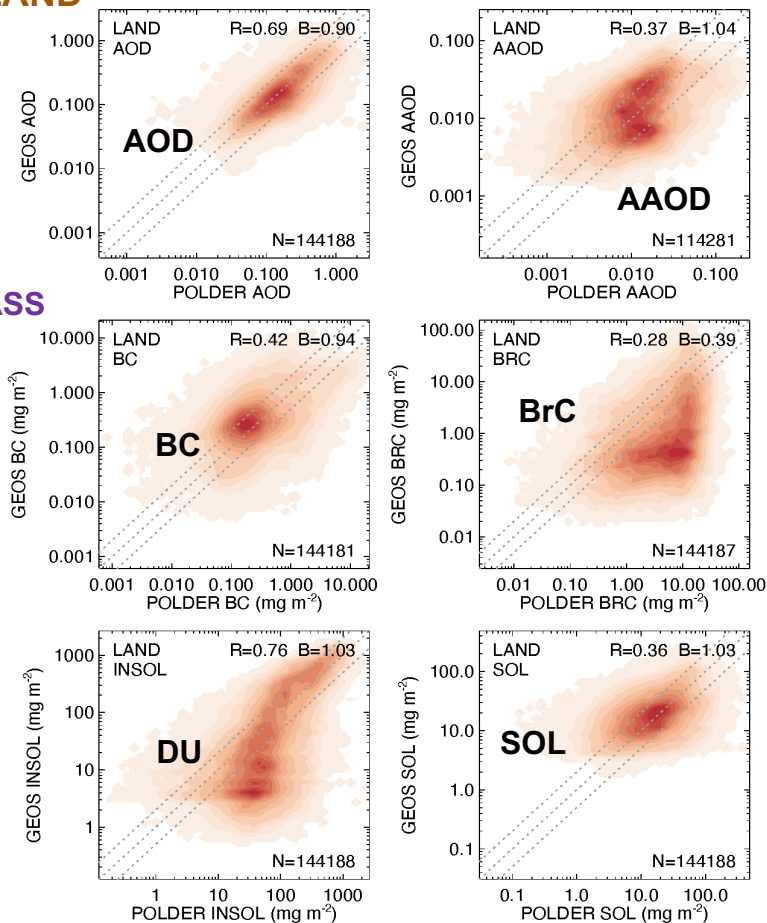
Colors representing land regions (domains on top)

POLDER/GRASP vs GEOS/GOCART

OCEAN

LAND

2012 year



Observations and thoughts from components comparisons

- **AERONET-POLDER and AERONET-GEOS comparisons (over land and ocean):**
 - Orders of agreement (best to worst): AOD, AAOD, BC, SOL, INSOL, BrC
 - For most of components more than half of data points **agree within a factor of 2 (100%)** in every regions
 - **Initial comparisons of components mass loading is very encouraging**
- **Main differences between remote-sensing products and GEOS can be explained by differences in the assumptions:**
 - BrC: GEOS assigns all BrC to biomass burning and none to anthropogenic OA. GRASP could also have included some fine mode absorbing dust in BrC
 - GEOS INSOL (dust) is different from the optical signature in INSOL (non-absorbing, low water vapor) by GRASP. It is also likely that GRASP overestimated INSOL over ocean.
 - etc.

Aerosol properties in CAMS and GRASP/PARASOL

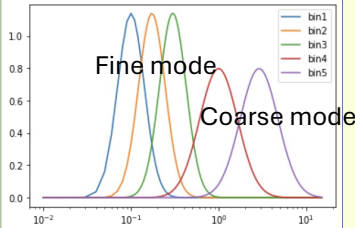
CAMS

Cycles: CAMS	CAMS C42R1 Reanalysis		CAMS C49R2 Forecast	
	Fine	Coarse	Fine	Coarse
Modes	Fine	Coarse	Fine	Coarse
Species	BC OM SU	DU SS	BC OM SOA SU	DU SS

GRASP/PARASOL

2. GRASP 5LN Chemical Component approach (L. Li et al., ACP, 2019)

- 5 LN bins
- Non-spherisity
- Chemical Components mixture



CRI: Maxwell Garnett effective medium approximation



	Size distribution	Volume Concentration	BC	BrC	Quartz	Iron Oxide	Soluble
Fine mode	3 LN bins	✓	✓	✓	✓	X	✓
Coarse mode	2 LN bins	✓	X	X	✓	✓	✓

Effective refractive index:

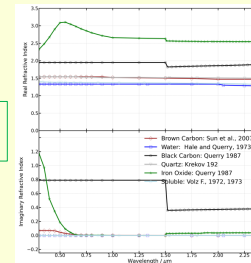
- Maxwell-Garnett
- Linear volume mixture

Fine mode:

$$\hat{m}_{eff}^{fine} = \hat{m}_{BC} \delta_{BC}^{sph} + \hat{m}_{BrC} \delta_{BrC} + \hat{m}_{Quartz} \delta_{Quartz}^{fine} + \hat{m}_{Sol} \delta_{Sol} + \hat{m}_{Water} \delta_{Water}^{fine}$$

Coarse mode:

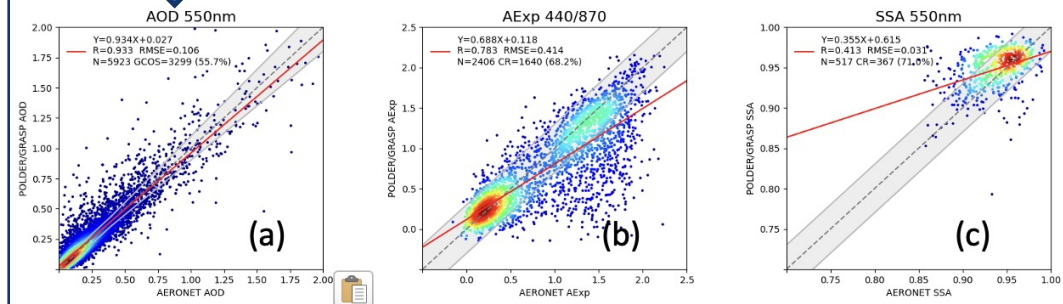
$$\hat{m}_{eff}^{coarse} = \hat{m}_{Quartz} \delta_{Quartz}^{coarse} + \hat{m}_{Iron} \delta_{FeOx} + \hat{m}_{Sol} \delta_{Sol} + \hat{m}_{Water} \delta_{Water}^{coarse}$$



Year: 2008

Months:

February, May,
August, November



GRASP/PARASOL vs CAMS

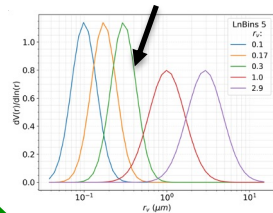
C42R1 and C49R2

2. Underestimated fine mode in C42R1 and C49R1 vs GRASP/PARASOL

SD for BC, OM, SU should be adjusted

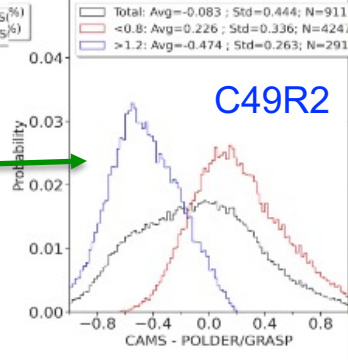
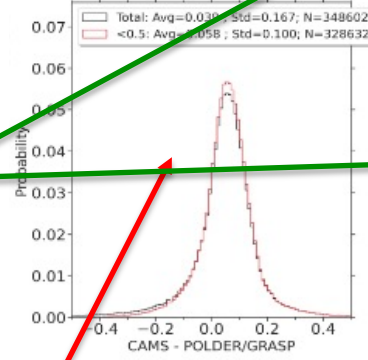
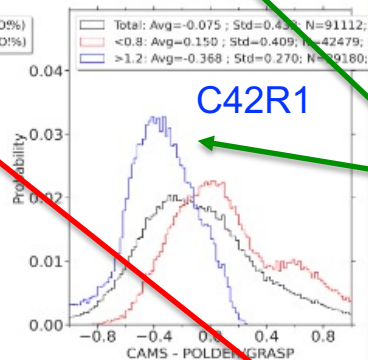
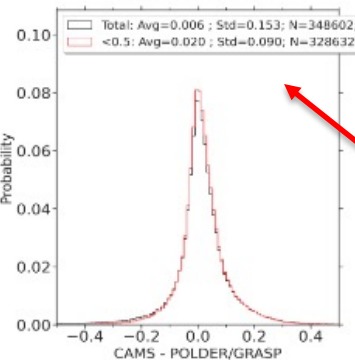
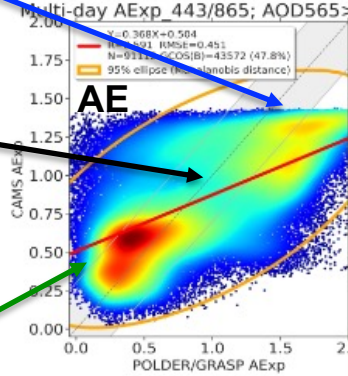
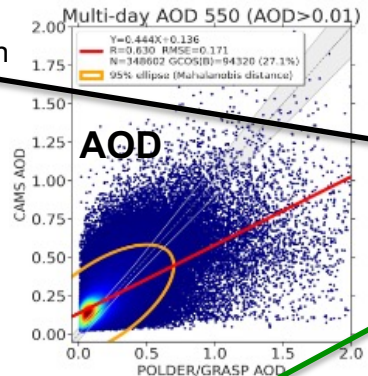
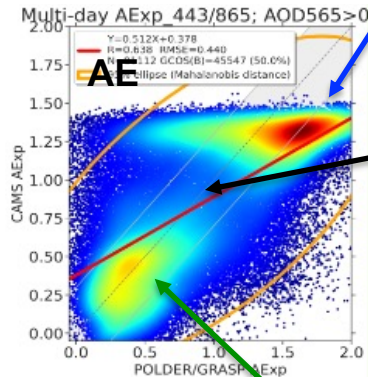
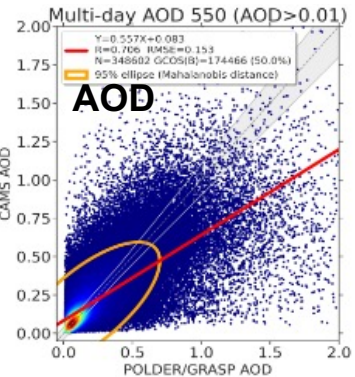
3. Gaps in CAMS AE between fine and coarse particles

Intermediate SD bins in CAMS?



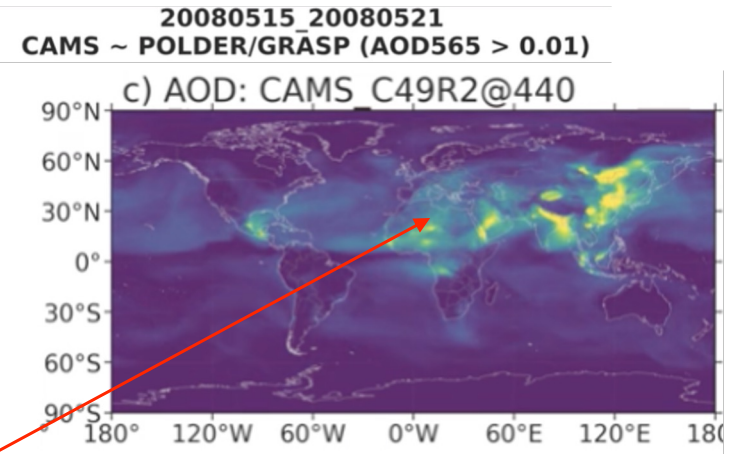
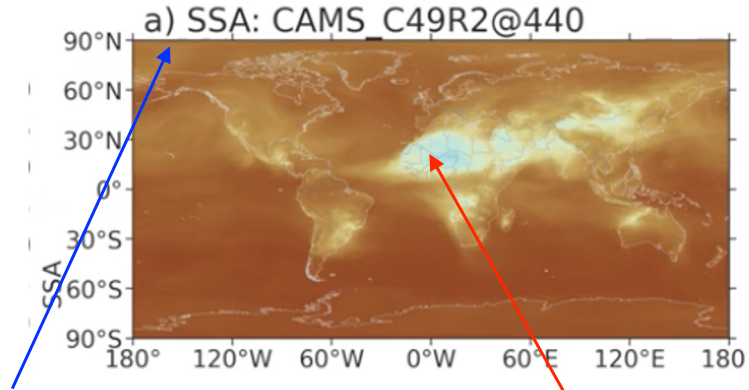
4. Coarse mode is biased in CAMS at high AOD

Assimilation of FAOD and CAOD



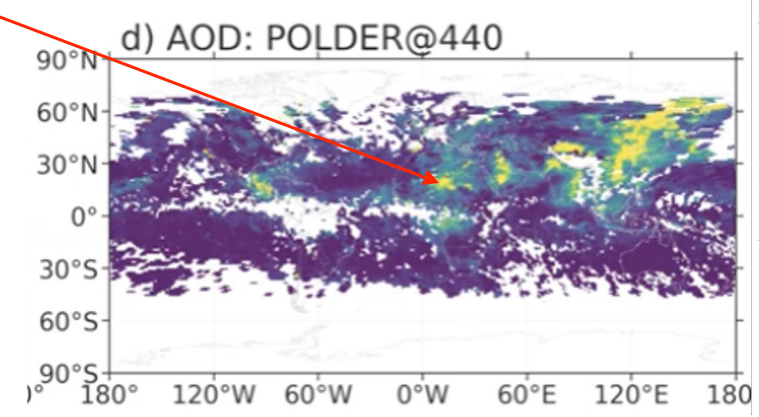
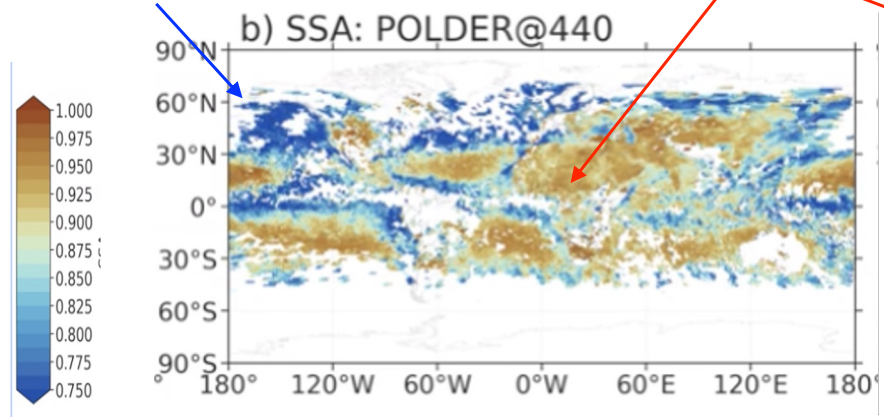
1. AOD from CAMS reanalysis C42R1 corresponds better to GRASP/PARASOL \rightarrow Spectral AOD assimilation is crucial

CAMS vs GRASP/PARASOL: SSA



Underestimated global absorption in CAMS or overestimation in GRASP?

Too absorbing Dust in CAMS?



Feedback of the comparisons:

1. Refractive index

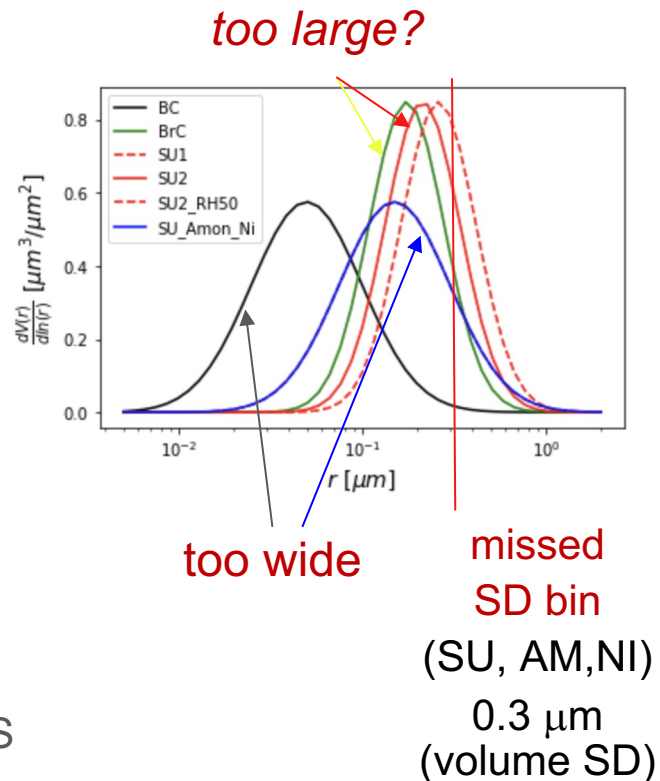
- BC:** Bond-2006
- BrC:** Brown-2018
- Dust:** mineralogy flexibility and non-sphericity?
(in GRASP: 1-2% FeOx and 99-98% Quartz)

2. Size distribution:

- Underestimated fine particles in CAMS ?:
 - SD for **BC**, **OM**, **SU** should be adjusted
- Gap in CAMS AE between fine and coarse mode:
 - An intermediate SD bin (around 0.3 μm , volume SD)) is recommended for SU (soluble component) in CAMS

3. Big **difference in SSA** between remote sensing and CAMS - **lack of flexibility in modeling absorption** in CAMS

4. **No absorbing coarse** particles (BB) in CAMS – is it real?



Harmonization platform

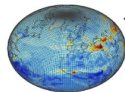
Modeling consistency?

OM Desert Dust
BC Sea Salt SU



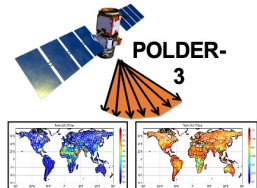
TEST-1: Nature run retrieval

MERA-2/CAMS Global chemistry-transport model

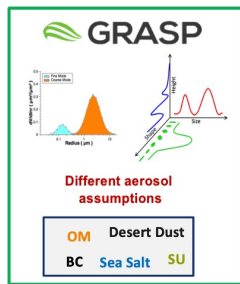


NATURE RUN
or pseudo-reality
BC, OM, SU, Sea Salt,
Dust

4-D - mixing ratios;
Variability: time, vertical,
horizontal



Simulation of
POLDER-3
measurements



Aerosol columnar
properties
AOD, AE, SSA, etc.

« reality »

retrieval

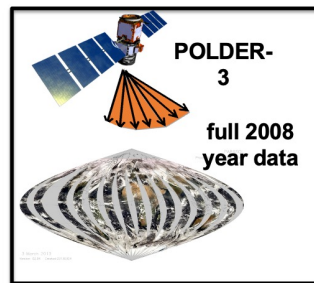
Comparison
« reality » vs retrieval

Agreement with reality?

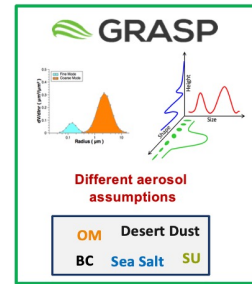
OM Desert Dust
BC Sea Salt SU



TEST-2: reality test



retrieval from
REAL data



« reality »

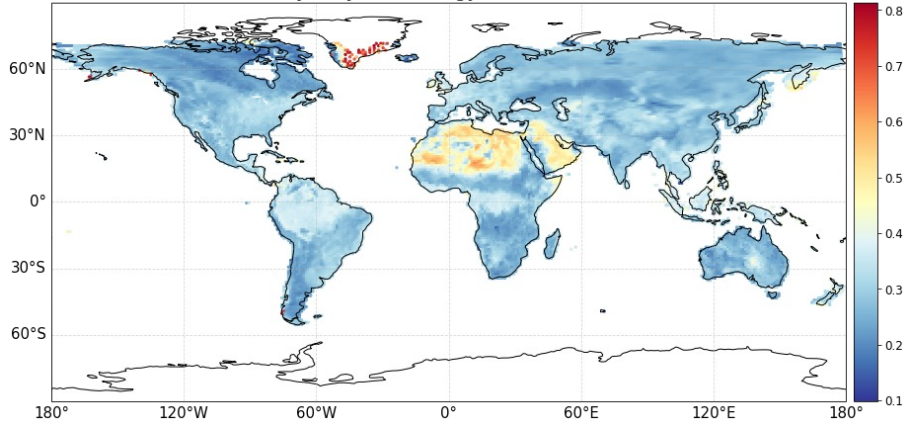
Aerosol columnar
properties
AOD, AE, SSA, etc.

retrieval

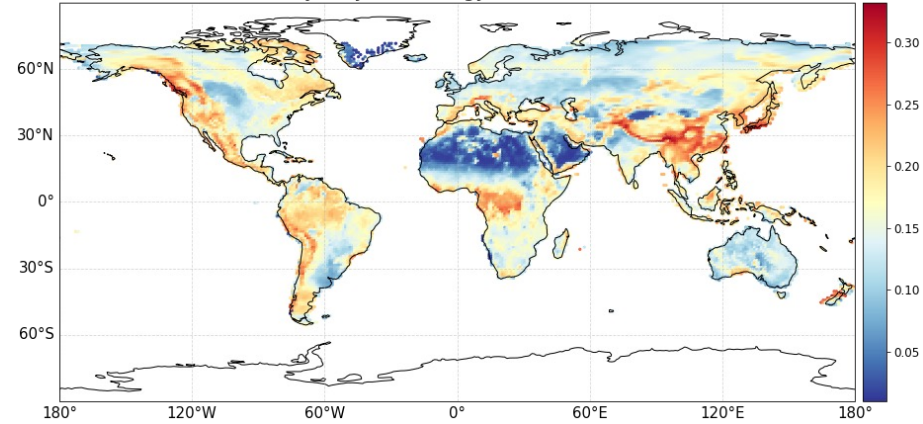
Comparison
« reality » vs retrieval

Surface simulation: BRDF and BPDF

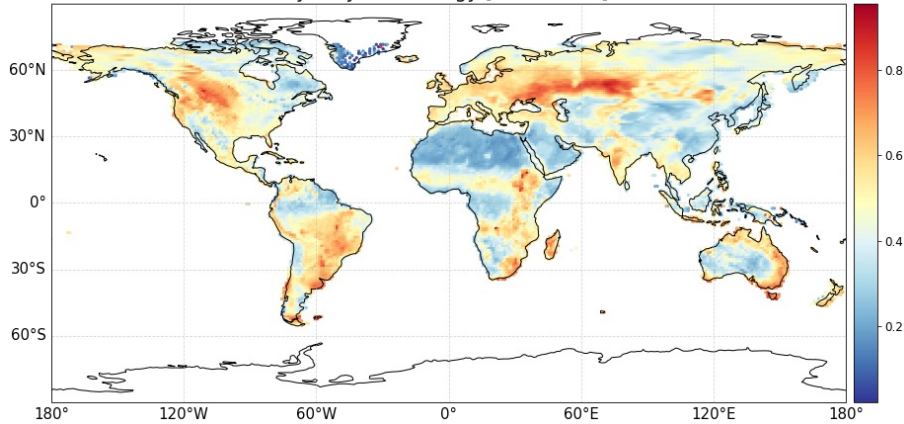
GRASP/PARASOL yearly climatology [2005-2013] - BRDF1 865nm



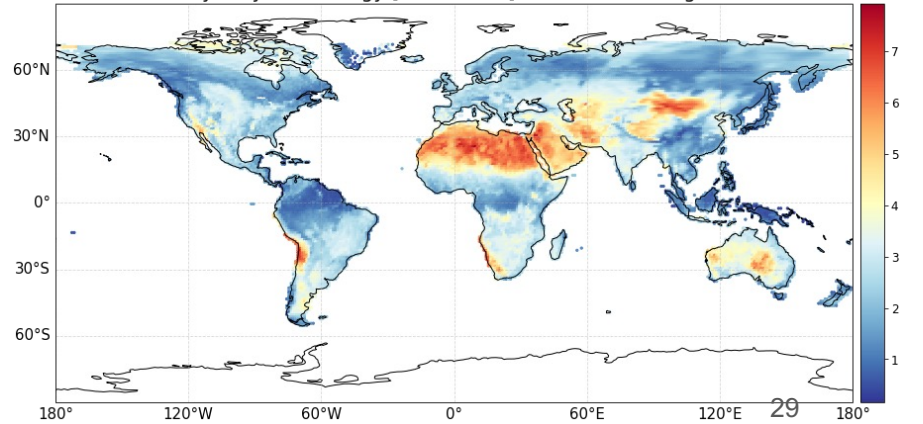
GRASP/PARASOL yearly climatology [2005-2013] - BRDF3 865nm



GRASP/PARASOL yearly climatology [2005-2013] - BRDF2 865nm



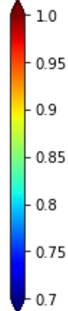
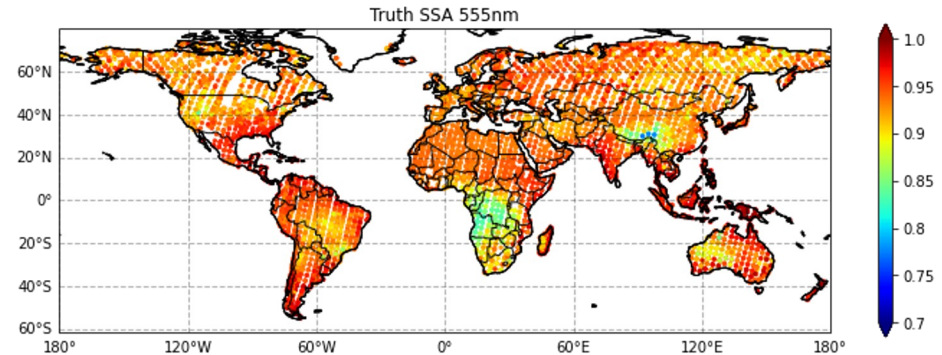
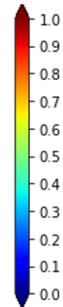
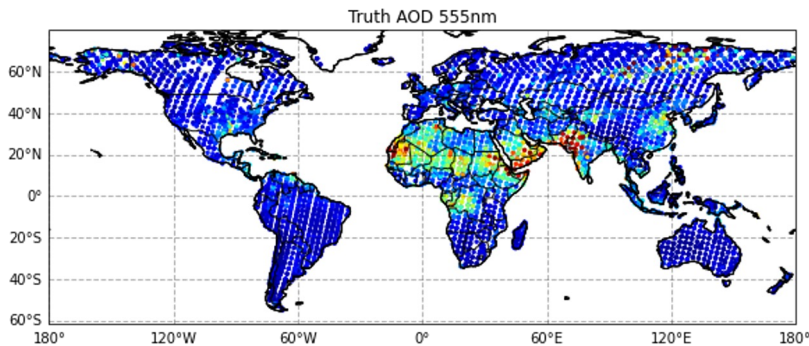
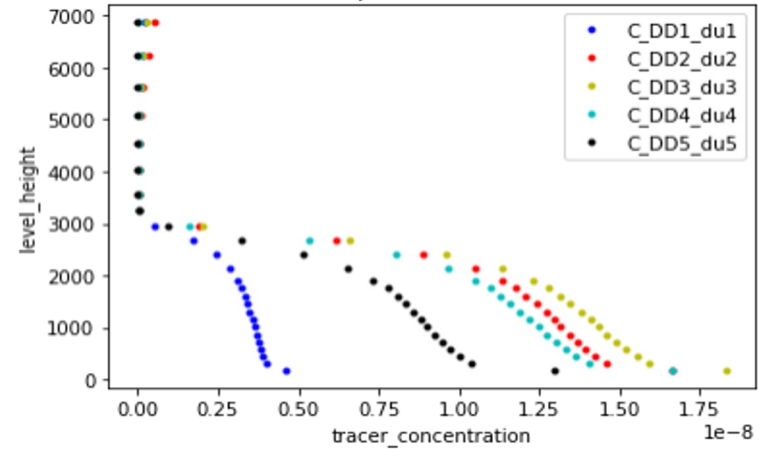
GRASP/PARASOL yearly climatology [2005-2013] - Land BPDF Maignan Breon 670nm



Synthetic dataset

Based on CAMS aerosol model

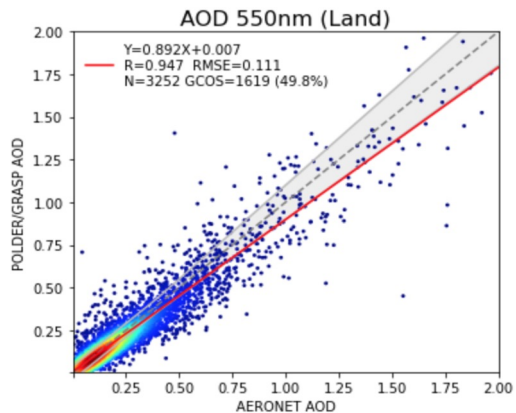
- Pressure, Relative, humidity profiles
- Mass mixing ratio
- 11 aerosol tracers and level concentration for 5 aerosol species : Sulphate (SU), Desert dust (DU), Sea Salt (SS), Organic (OC) and Black Carbon (BC)



GRASP/Component approach performance

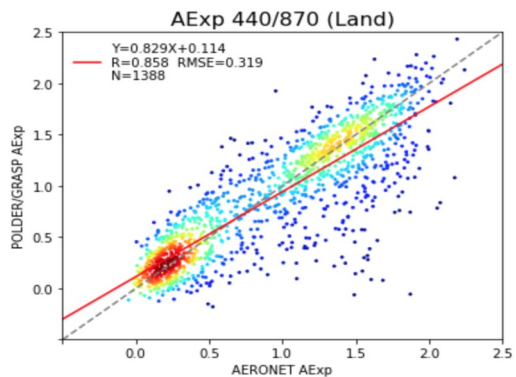
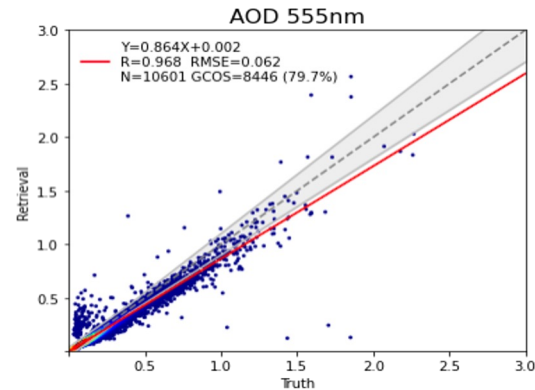
POLDER-3 retrieval (2008)

MERA-2 synthetic data inversion



Over land

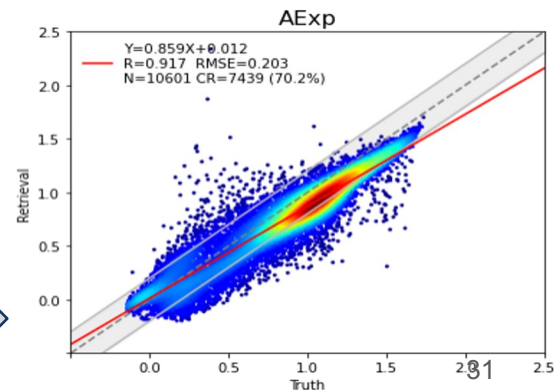
Remote sensing
approach
works well
both on



real data

and on

synthetic data



Conclusions, Questions and Actions:



Conclusions:

- **Models (for remote sensing):**
 - help satellite teams improve their classification of aerosol components and types;
 - provide insightful physics-based information on aerosol composition,
 - help assessing the confidence level of remote-sensing component products, suggest improvements;
- **Remote sensing (for models):**
 - help to improve quantitative agreement with observations – “real world”;

Challenges and Questions:

- Comparisons provide **meaningful suggestions**, e.g., BrC/OC partitioning, dust iron fraction, etc., but quantitative comparison remains difficult and **no “ground truth” to verify?**
- **How hard should we try** to “match” the components and “harmonize” remote sensing and models?

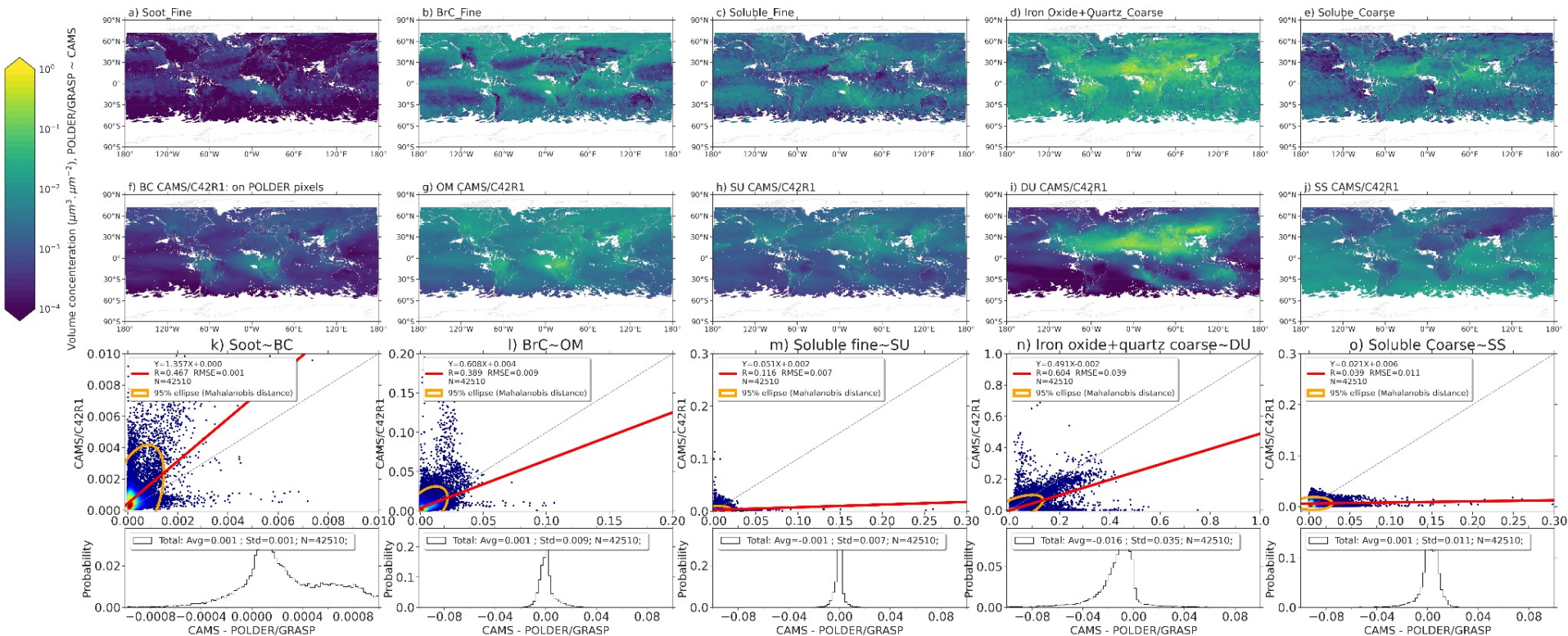
Actions:

- Should we make efforts to understand the differences, find common grounds, assess the values of the products the way, and decide the next move?

BACK-UP SLIDES

CAMS C42R1 vs GRASP/PARASOL: Volume concentrations (unharmonized)

Total volume concentration (AOD565>0.01): Reanalysis: C42R1
20080801_20080831



Overestimated in CAMS

Globally Similar

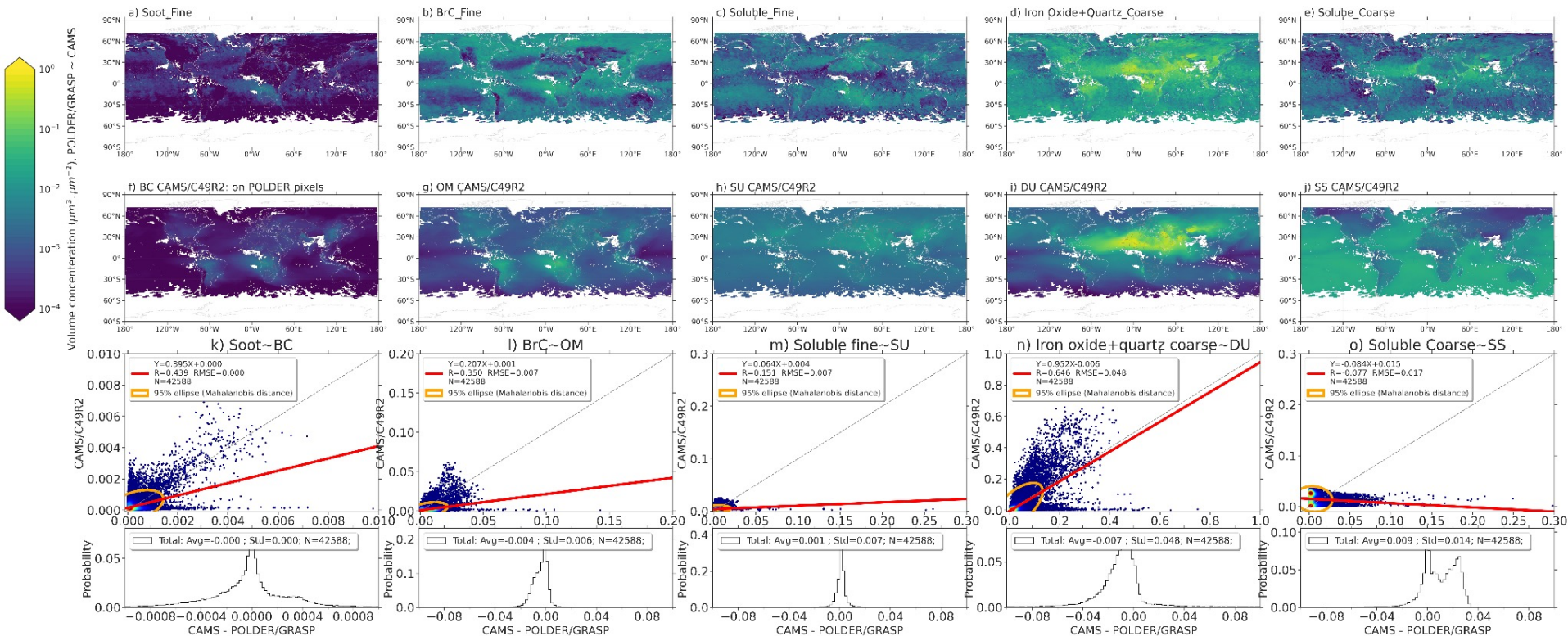
Globally Similar

Underestimated in CAMS

Underestimated in GRASP?

CAMS C49R2 vs GRASP/PARASOL: Volume concentrations (unharmonized)

Total volume concentration (AOD565>0.01): Reanalysis: C49R2
20080801_20080831



Globally Similar?

Underestimated in CAMS?

Globally Similar?

Underestimated in CAMS?

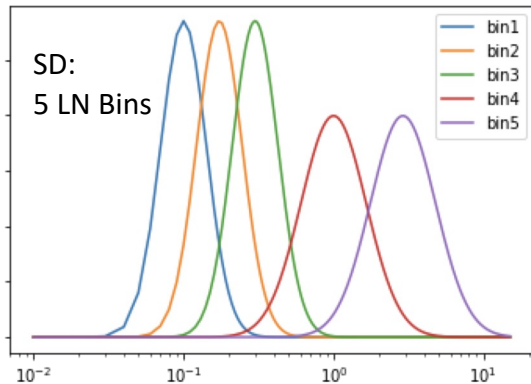
Underestimated in GRASP?

Aerosol model harmonization summary

	Harmonization	CAMS/MERRA-2	Remote sensing: multi-angular polarimeter
1	Aerosol species Harmonization is necessary	Several aerosol species: BC, OM, SU, SS, Dust, Nitrates, SOA etc	Several aerosol species similar to CAMS Limitations: some soluble components may be indistinguishable: SeaSalt, Nitrate, SU, etc
2	Refractive index Harmonization is necessary	Defined for each species Refractive indices can be adapted from remote sensing (Dust)	Defined for each species
3	Size distribution Harmonization is necessary	SD for each aerosol bin Should be adjusted according to feedback from remote sensing	Retrieved size distribution parameters or few bins for each of 1-3 modes (usually for fine and coarse modes)
4	Aerosol mixing Can be improved	External mixture Internal mixture in CAMS? (OM, Dust)	External, Internal or hybrid mixture
5	Aerosol profile Can be improved	<ul style="list-style-type: none"> Mass Mixing ratio for each tracer at each level Vertical dependence of aerosol characteristics with RH 	1-3 concentration profiles 1: the same for all components 2: different for each modes
6	Non-sphericity/ Inhomogeneity Can be improved	Not accounted yet Effects the aerosol optics and atmospheric radiance calculations	Accounted with different models

1.2 3 aerosol modes: Dust and Sea Salt in separate modes

	Size distribution	Volume Concentration							
			BC Hydrophilic	BrC Hydrophilic	SU	Water	Sea Salt	Dust	
								Iron Oxide	Quartz
Fine mode	Bin1, Bin2	✓	✓	✓	✓	✓			
Coarse mode 1	Bin2, Bin3	✓				✓	✓		
Coarse mode 2	Bin4, Bin5	✓						✓	✓



Effective refractive index:

Fine mode:

$$\hat{m}_{eff}^{fine} = \hat{m}_{BC} \delta_{BC}^{phil} + \hat{m}_{BrC} \delta_{BrC} + \hat{m}_{SU} \delta_{SU} + \hat{m}_{Water} \delta_{Water}^{fine}$$

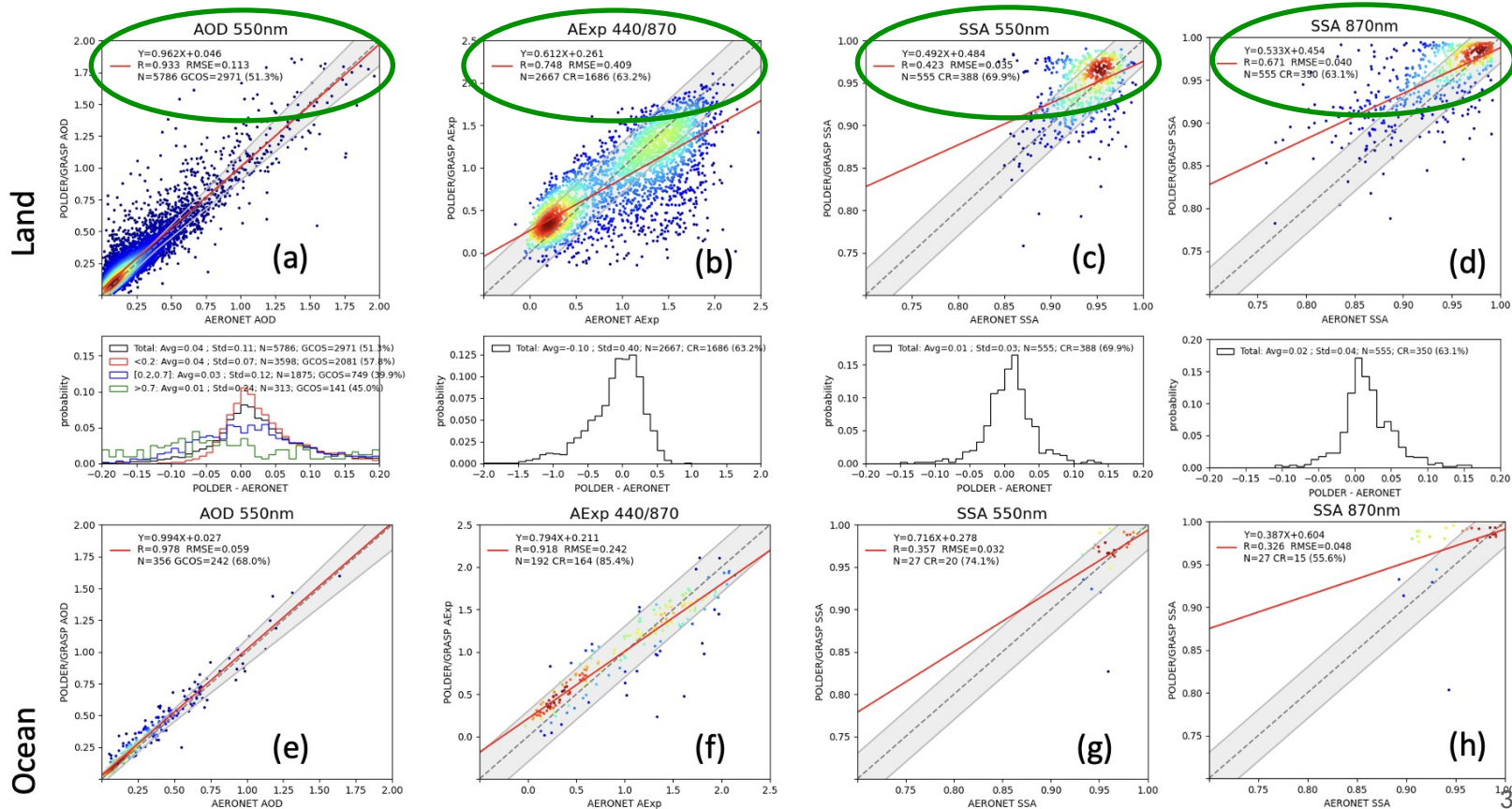
Fine mode 2:

$$\hat{m}_{eff}^{coarse_1} = \hat{m}_{SeaS} \delta_{SeaS} + \hat{m}_{Water} \delta_{Water}^{coarse}$$

Coarse mode:

$$\hat{m}_{eff}^{coarse_2} = \hat{m}_{Quartz} \delta_{Quartz}^{coarse} + \hat{m}_{Iron} \delta_{FeOx}$$

Dust and Sea Salt in different modes: (performance on PARASOL measurements) **Improved performance**



POLDER/PARASOL

2004-2013

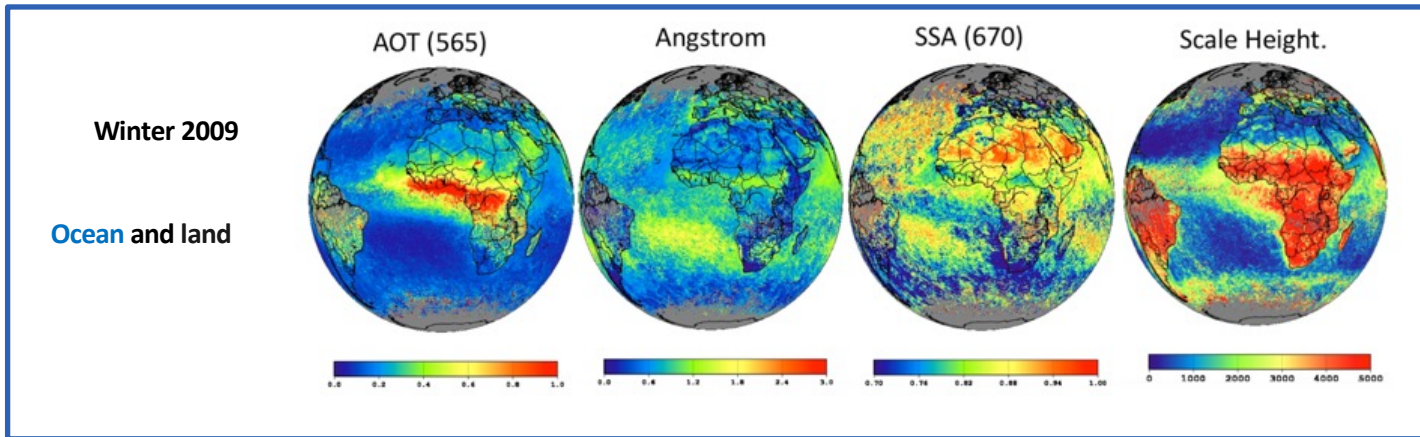
4 products

Chen et al., 2020

Li et al., 2019

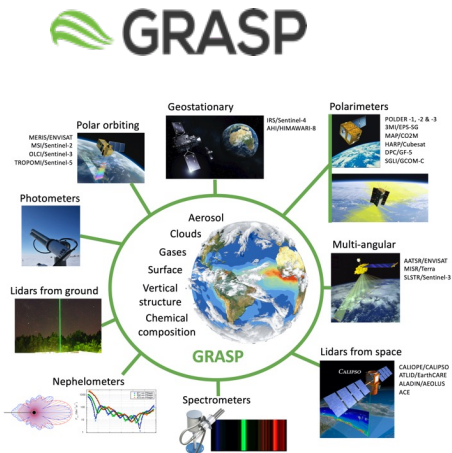
Zhang et al. 2021

Dubovik et al. 2021



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

SURFACE: land BRDF spectral, BPDF spectral;
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

POLDER/PARASOL

2004-2013

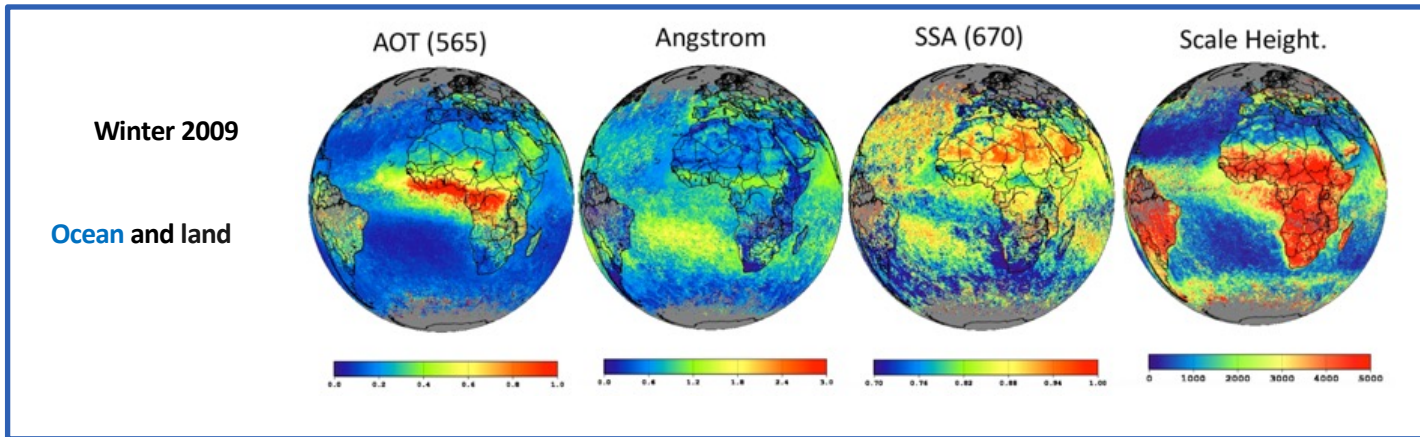
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Chen et al., 2020

Li et al., 2019

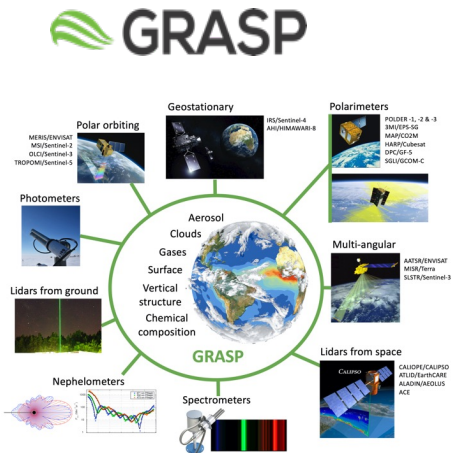
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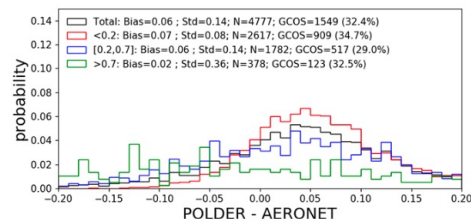
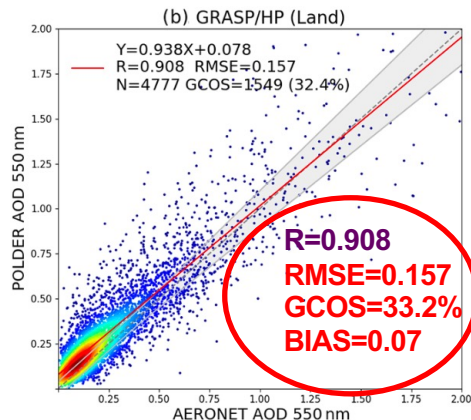
- Globally the same initial guess for aerosol;
- Globally the same set of a priori constraints;
- No location specific assumptions;
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CONCLUSIONS from POLDER aerosol product analysis :

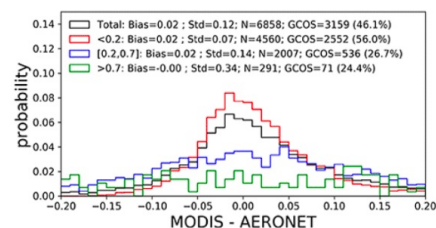
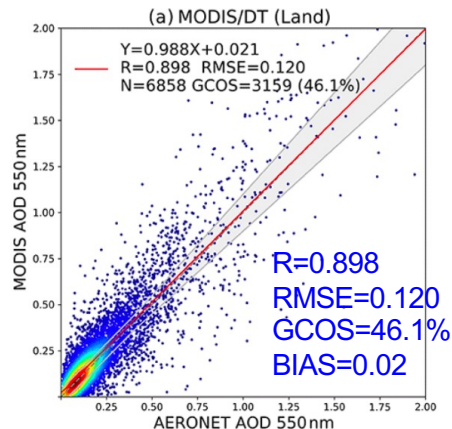
ISSUE of baseline AOD products from first POLDER/GRASP processing;

AOD(550) over Land for 2008 year (Chen et al., 2020)

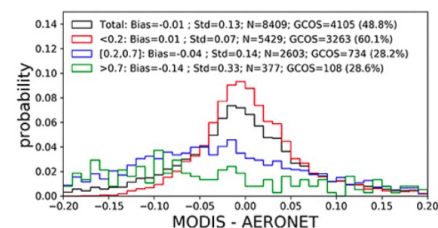
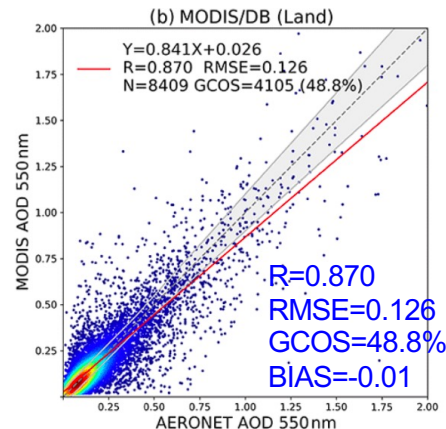
POLDER/ GRASP-HP



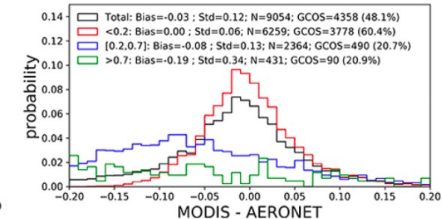
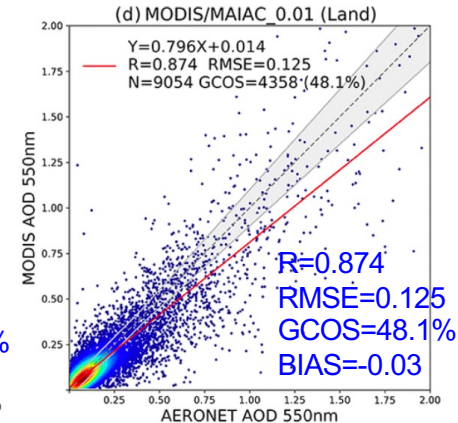
MODIS/DT



MODIS/DB



MODIS/MAIAC_0.1



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)

