GRASP aerosol from POLDER, 3MI, etc. polarimeters: towards estimation PM2.5

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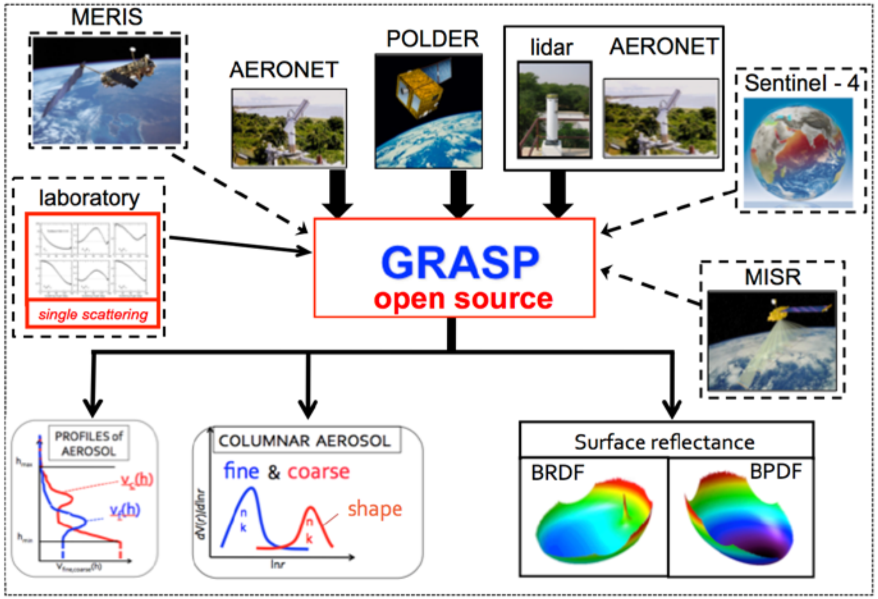
AC-VC-13, Satellite aerosol for AQ, CNES, Paris, France, 29 June, 2017

GRASP: Generalized Retrieval of Aerosol and Surface Properties



Strength of GRASP algorithm concept:

- ✓ Based on accurate rigorous physics and math;
- ✓ Versatile (applicable to different sensors and retrieval of different parameters);
- ✓ Designed for multi-sensor retrieval (satellite, ground-based, airborne; polar and geostationary,);
- ✓ Not-stagnant (different concept can be tested and compared within algorithm);
- ✓ Flexible:
  - generalizable (to IR, hypo spectral, to retrieval of gases and clouds, etc.);
  - or degradable (to less accurate but fast solution, LUT,…);
- ✓ Practical (rather fast and easy to use for given level fundamental complexity);

Current and potential applications:

Satellite instruments:

polar: POLDER/PARASOL, 3MI/MetOp-SG, MERIS/Envisat, Sentinel-3 (OLCI, SLSTR), etc.
geostationary: Sentinel-4, FCI, GOCO, Himawari-8, etc.

Ground-based, airborne and laboratory instruments:

passive: AERONET radiometers, sun/luna/star-photometers, etc.
active: multi-wavelength elastic and non-elastic lidars; *airborne and laboratory*: *polar nephelometers*,

Multi-instrument synergy:

ground-based: lidar + radiometers + photometers , sun/luna/star-photometers, etc.
satellite: OLCI + SLSTR, polarimeter + lidar (e.g. PARASOL + CALIPSO)

Support: **CNES** (TOSCA, RD), **ANR** (CaPPA), **ESA** (S-4, MERIS/S-3, GPGPU, CCI, CCI-2,CC+); **EUMETSAT** (3MI NRT), **FP6-7** (ACTRIS 1-2), Catalysts GmbH, etc.

Collaborations: NASA/JPL, NASA/GSFC, NASA/GISS, NASA/Langley KNMI, JAXA, Catalysts GmbH (Austria), Chinese Academy of Science and Space Agency, Belarus, Ukraine, etc.

Multi-Source LSM approach:

$$P_{1,2,3}=P_1P_2P_3... \sim \exp\left(-\frac{1}{2\sigma_1^2}\sum_i \frac{\sigma_1^2}{\sigma_i^2}\left(\Delta f_i^T \Delta f_i\right)\right) = max \longrightarrow \sum_i \frac{\sigma_1^2}{\sigma_i^2}\left(\Delta f_i^T \Delta f_i\right) = min$$

where $\Delta_i = f_i^* - f_i(a)$ and f_i^* - measurements or *a priori data*

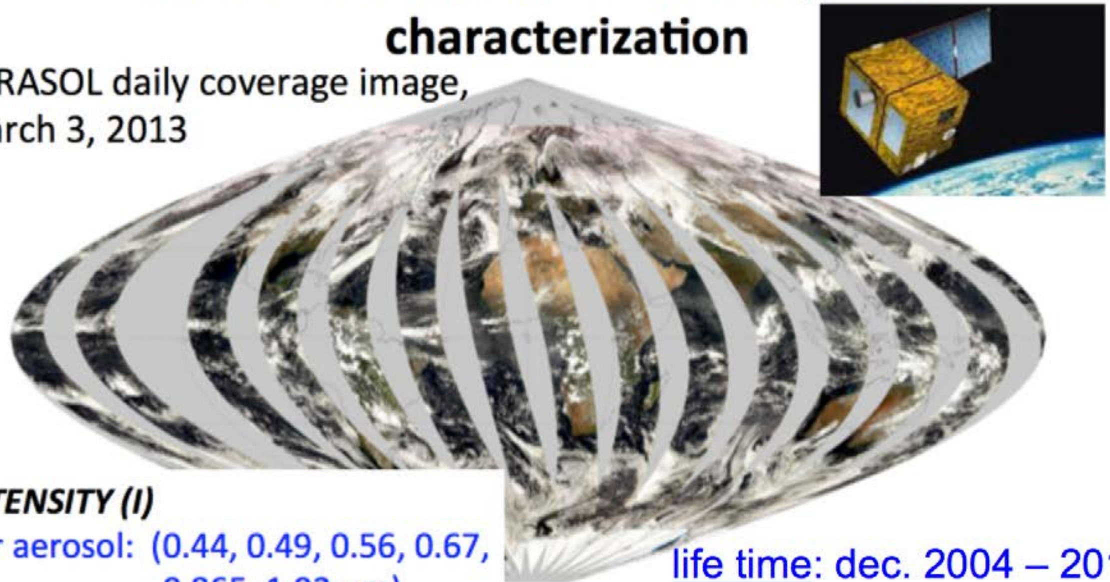
P (...) - *Probability Density Function* (***Likelihood***)

- ***Optimum data combination***
- ***Optimum use of a priori information***
- ***Continuous solution space***
- ***Rigorous error estimations***
- ***Large number of retrieved parameters with less assumption***

- ***More "sophisticated"***
- ***Generally more time consuming (Jacobean calculations)***

PARASOL: the space–borne instrument most suitable for enhanced aerosol/surface characterization

PARASOL daily coverage image, March 3, 2013



INTENSITY (I)

for aerosol: (0.44, 0.49, 0.56, 0.67, 0.865, 1.02 μm)

for gas absorption): (0.763, 0.765, 0.910 μm)

POLARIZATION (Q, U): (0.49, 0.67, 0.865 μm)

life time: dec. 2004 – 2013

Swath: about 1600 km cross-track

Global coverage: every 2 days

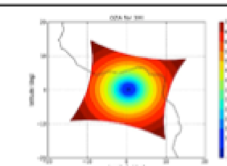
1 pixel spatial resolution: 5.3km × 6.2km

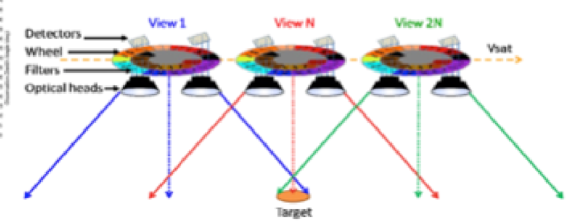
Viewing directions: 16: (80^0 – 180^0)

Multi- Angular Polarimetric imagery:

What is a real value?

3MI:





Swath: ~ 2200 km

Global coverage: every :

Pixel spatial resolution: ~ 4 km

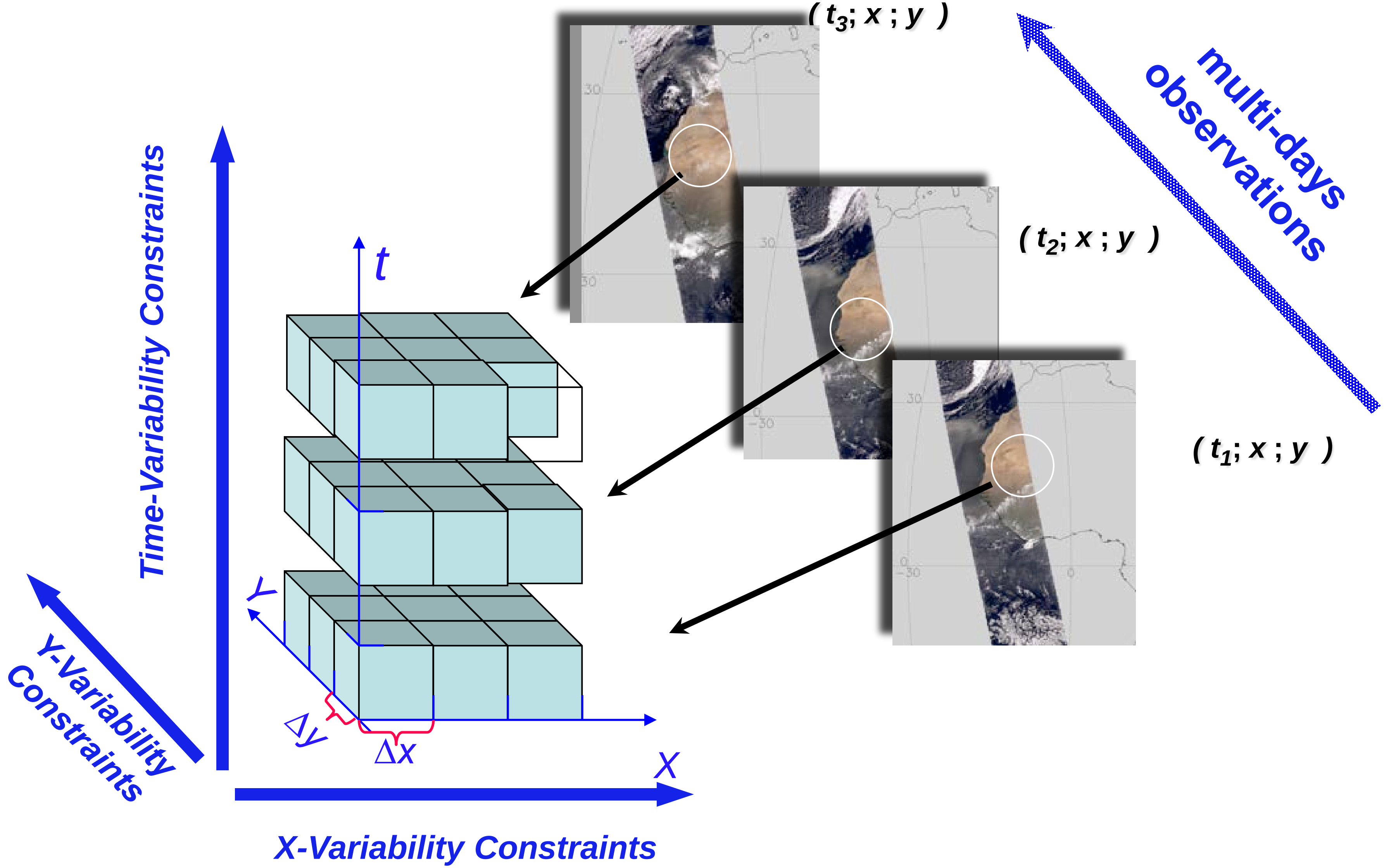
Viewing direction: 10 – 14 (80^0 – 180^0);

for aerosol (0.41, 0.44, 0.49, 0.56, 0.67, 0.87, 1.37, 1,65, 2,13);

for gas absorption (0.763, 0.765, 910);

polarization (0.41, 0.44, 0.49, 0.56, 0.67, 0.87, 1.37, 1,65, 2,13);

The concept of multi-pixel retrieval



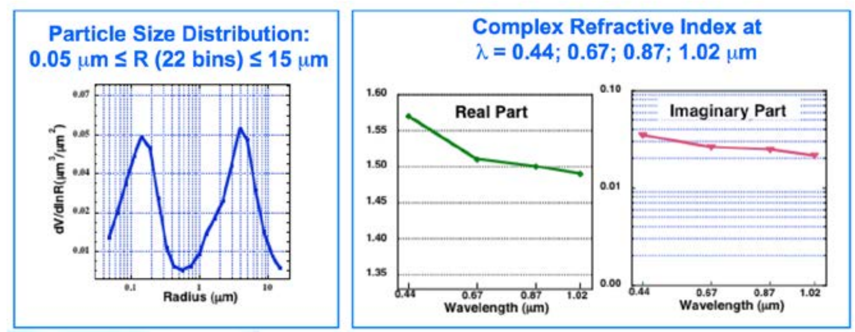
PARASOL:

- radiances: *(443, 490, 560, 670, 870, 1020 nm)*
- polarization: *(490, 670, and, 870 nm)*
- up to 16 viewing directions

144 measurements

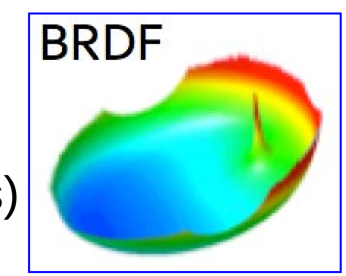
AEROSOL:

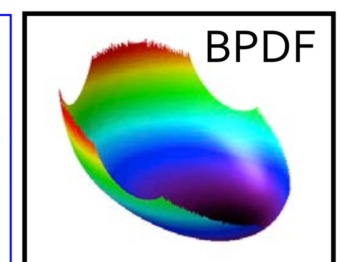
- size distribution (5 or more bins)
- spectral index of refraction (8 λ)
- sphericity fraction;
- aerosol height



SURFACE:

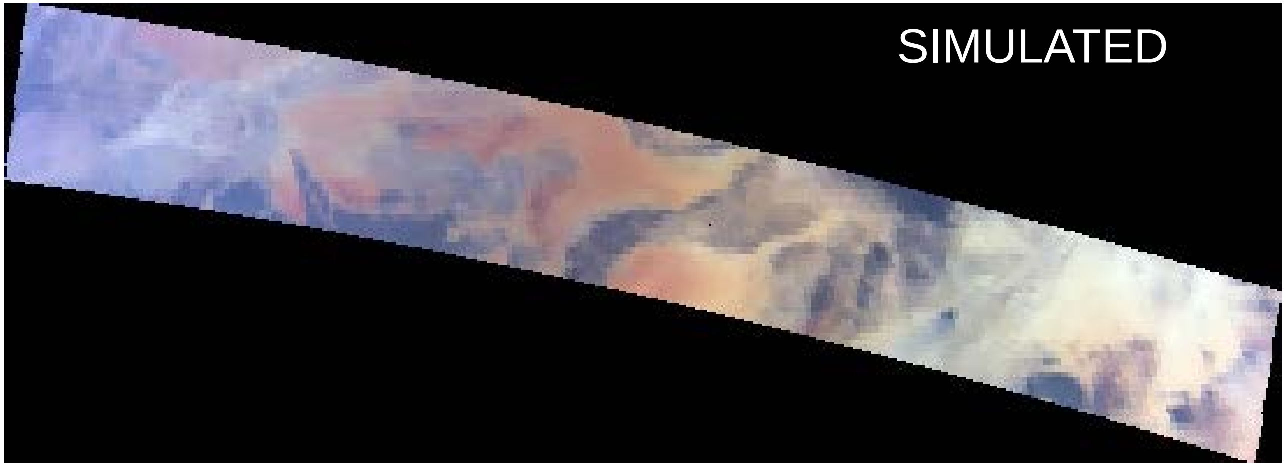
- BRDF (3 spectrally dependent parameters)
- BPDF (1 or 2 spectrally dependent parameters)

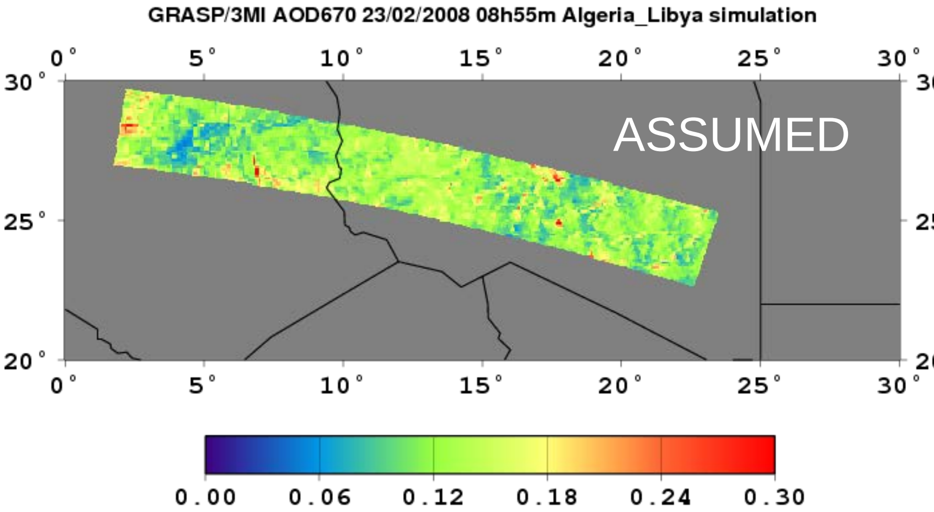


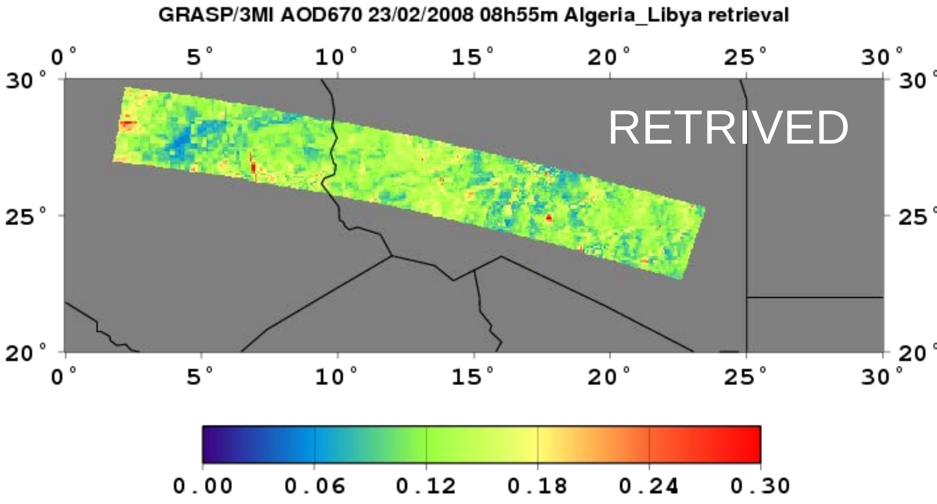


43 = (5 (SD) +12 (ref. ind.) + 1 (nonsp.) + 18 (BRDF) +6 (BPDF) + 1 (height)

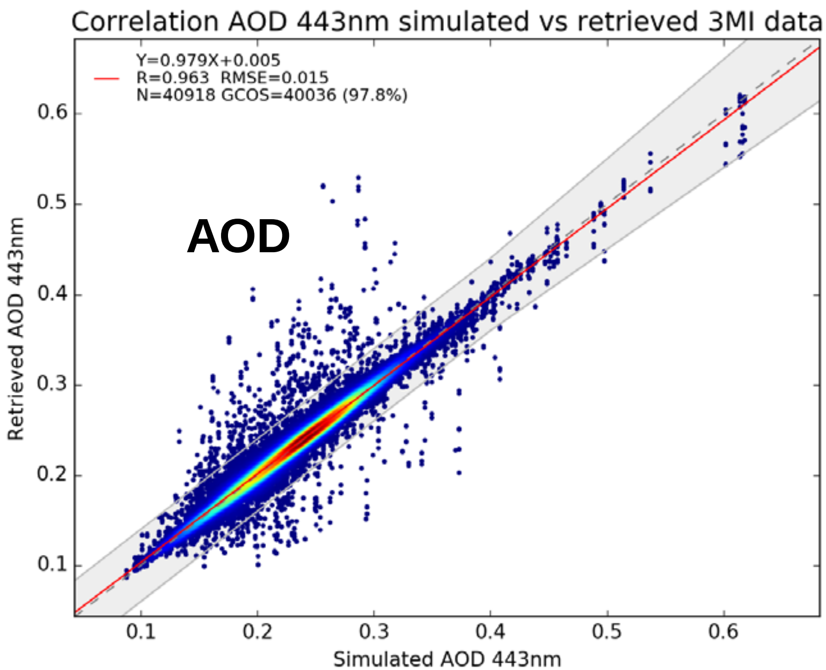
3MI / Metop


SIMULATED

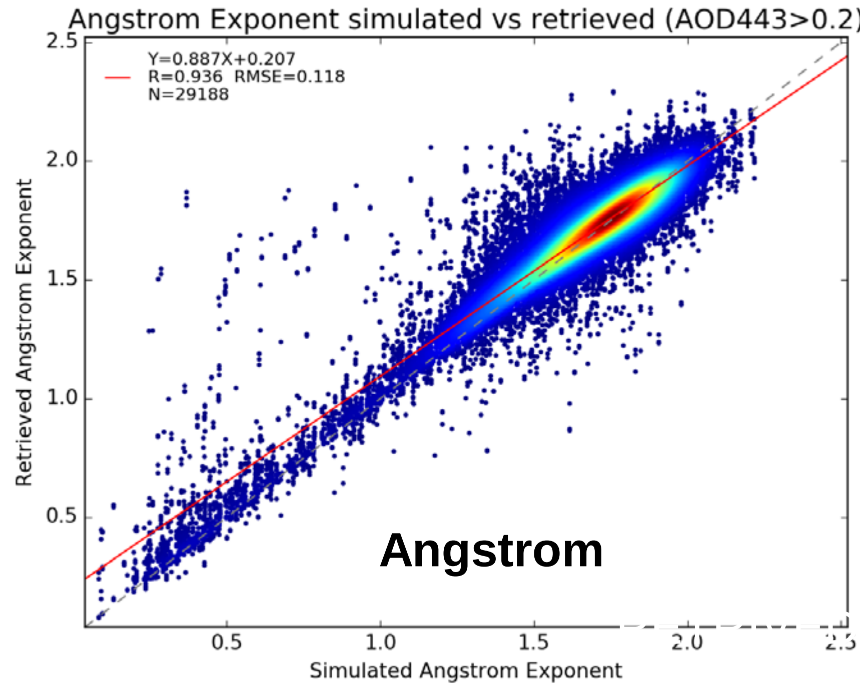

GRASP/3MI AOD670 23/02/2008 08h55m Algeria_Libya simulation
ASSUMED
0° 5° 10° 15° 20° 25° 30°
30° 25° 20°
0.00 0.06 0.12 0.18 0.24 0.30


GRASP/3MI AOD670 23/02/2008 08h55m Algeria_Libya retrieval
RETRIVED
0° 5° 10° 15° 20° 25° 30°
30° 25° 20°
0.00 0.06 0.12 0.18 0.24 0.30

3MI / Metop

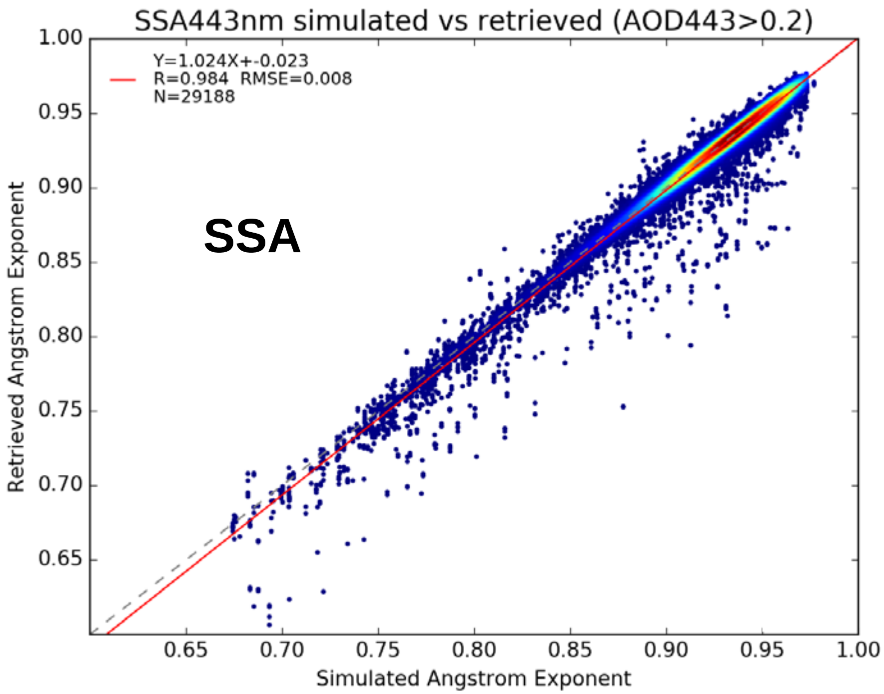


Correlation AOD 443nm simulated vs retrieved 3MI data
Y=0.979X+0.005
R=0.963 RMSE=0.015
N=40918 GCOS=40036 (97.8%)
AOD
Retrieved AOD 443nm
Simulated AOD 443nm
0.1
0.2
0.3
0.4
0.5
0.6

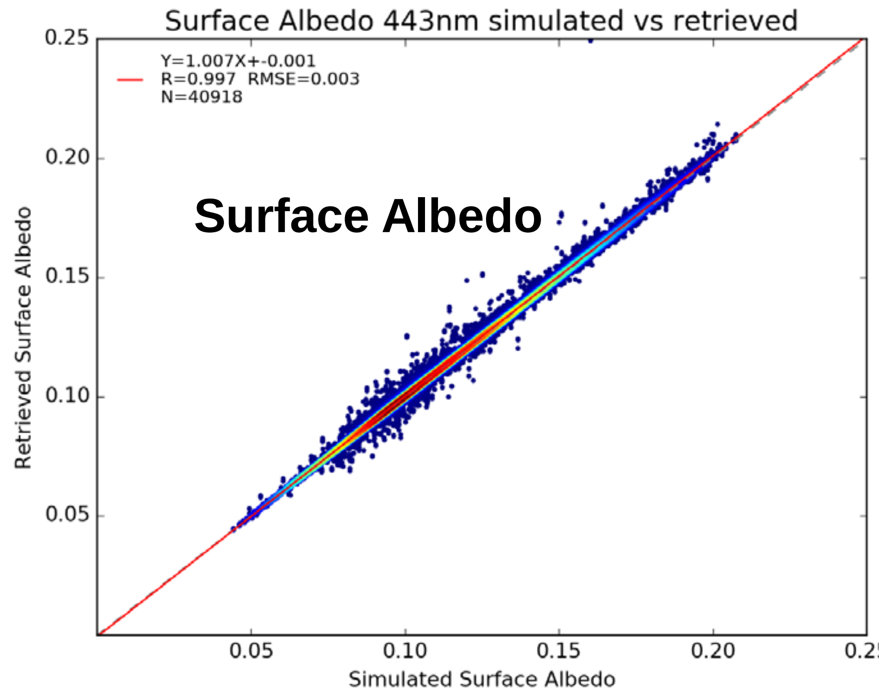


Angstrom Exponent simulated vs retrieved (AOD443>0.2)
Y=0.887X+0.207
R=0.936 RMSE=0.118
N=29188
Angstrom
Retrieved Angstrom Exponent
Simulated Angstrom Exponent
0.5
1.0
1.5
2.0
2.5

3MI / Metop

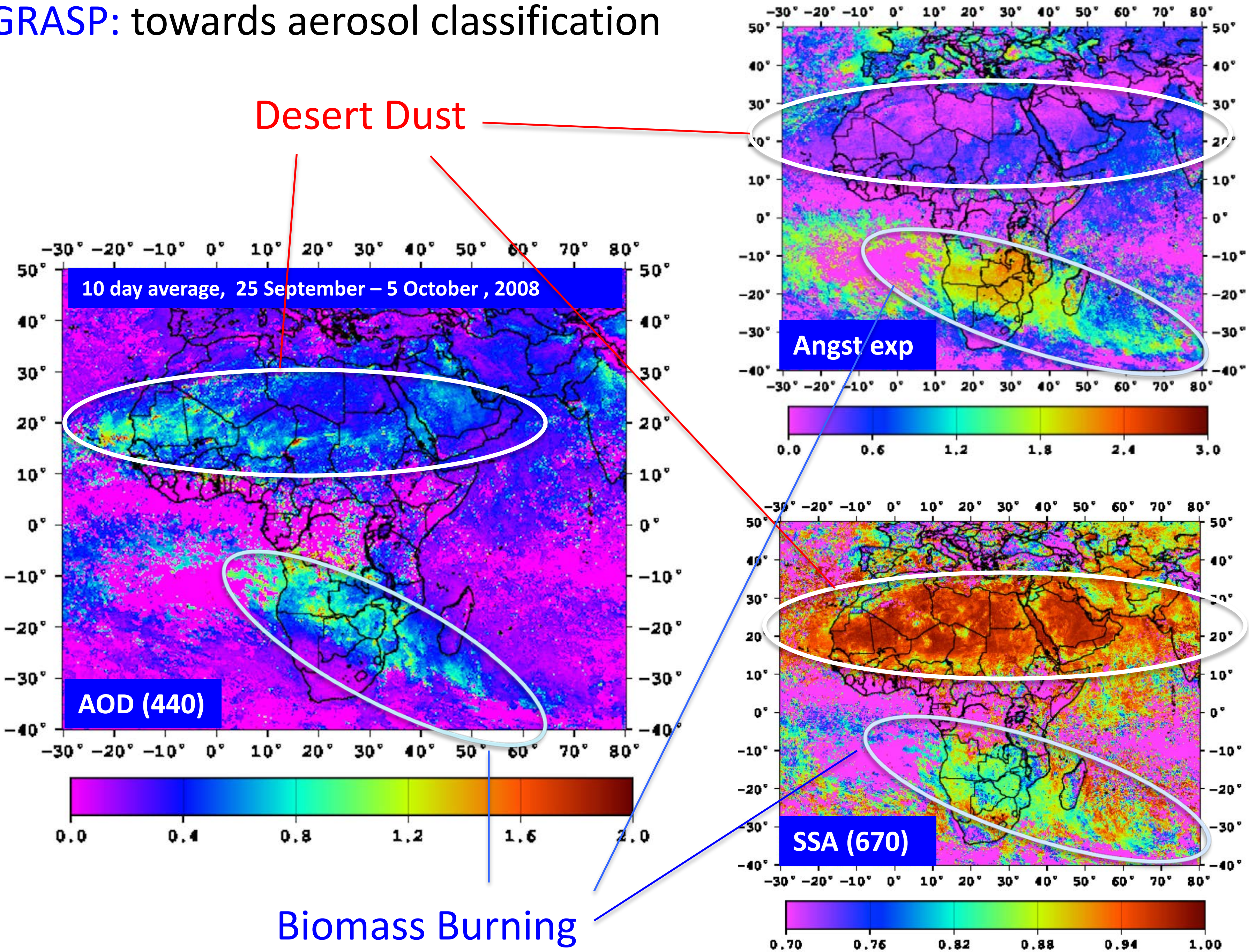


SSA443nm simulated vs retrieved (AOD443>0.2)
Y=1.024X+-0.023
R=0.984 RMSE=0.008
N=29188
SSA
Retrieved Angstrom Exponent
Simulated Angstrom Exponent
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00

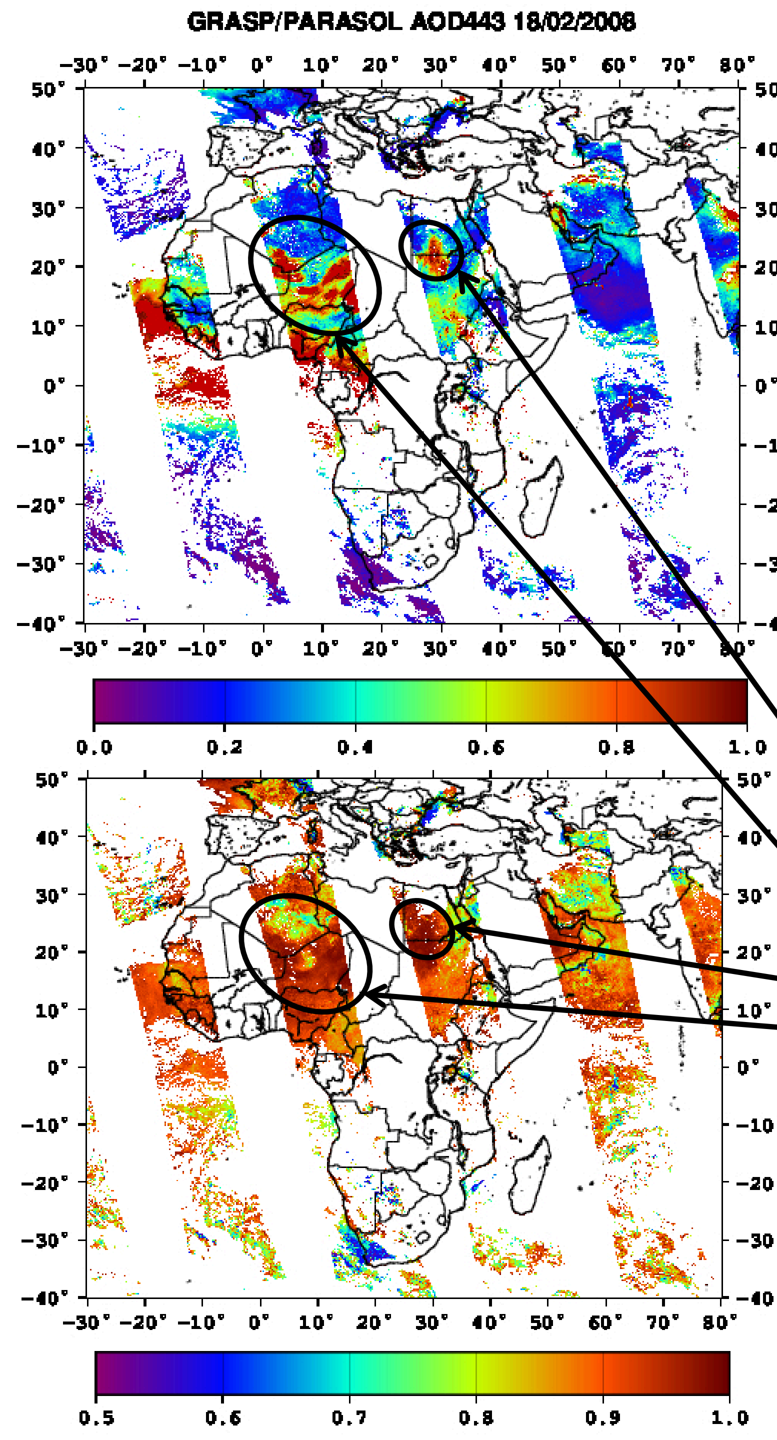


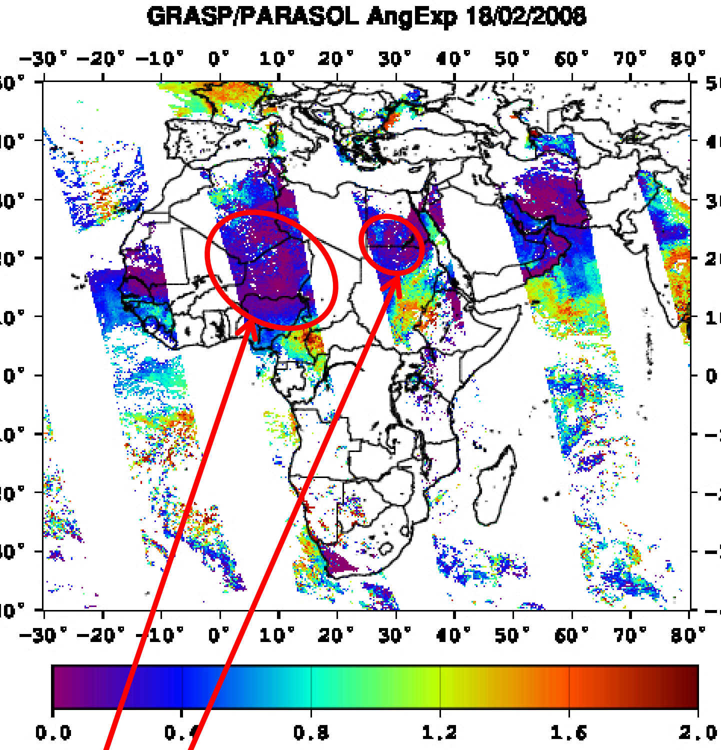
Surface Albedo 443nm simulated vs retrieved
Y=1.007X+-0.001
R=0.997 RMSE=0.003
N=40918
Surface Albedo
Retrieved Surface Albedo
Simulated Surface Albedo
0.25
0.20
0.15
0.10
0.05
0.05
0.10
0.15
0.20
0.25

GRASP: towards aerosol classification



Dust detection with GRASP





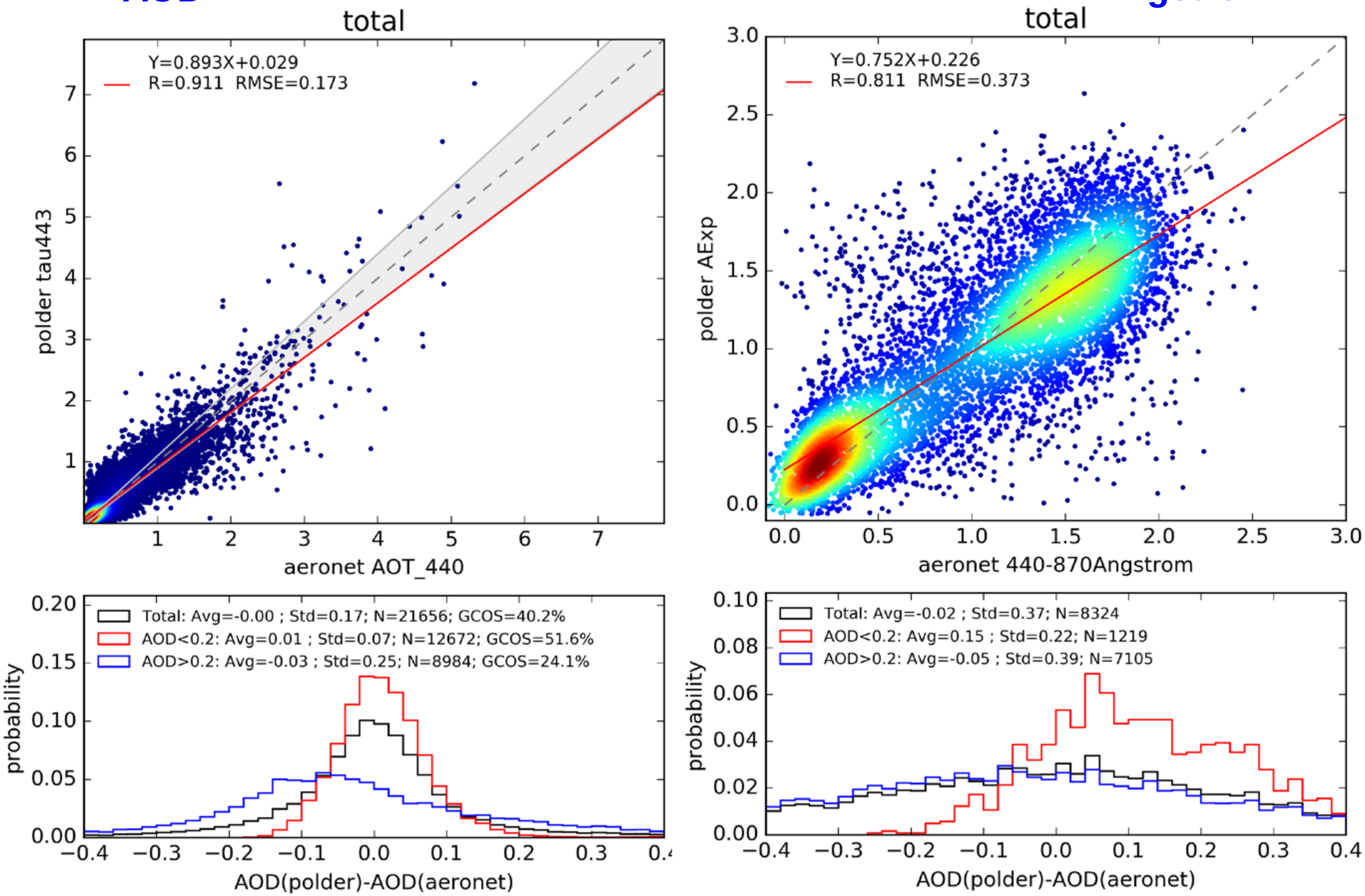
Dust events:

- ✓High AOD
- ✓Angstrom Exponent < 0.5
- ✓SSA (440 - 1020) > 0.9

Validation vs AERONET 2004 - 2013

Land

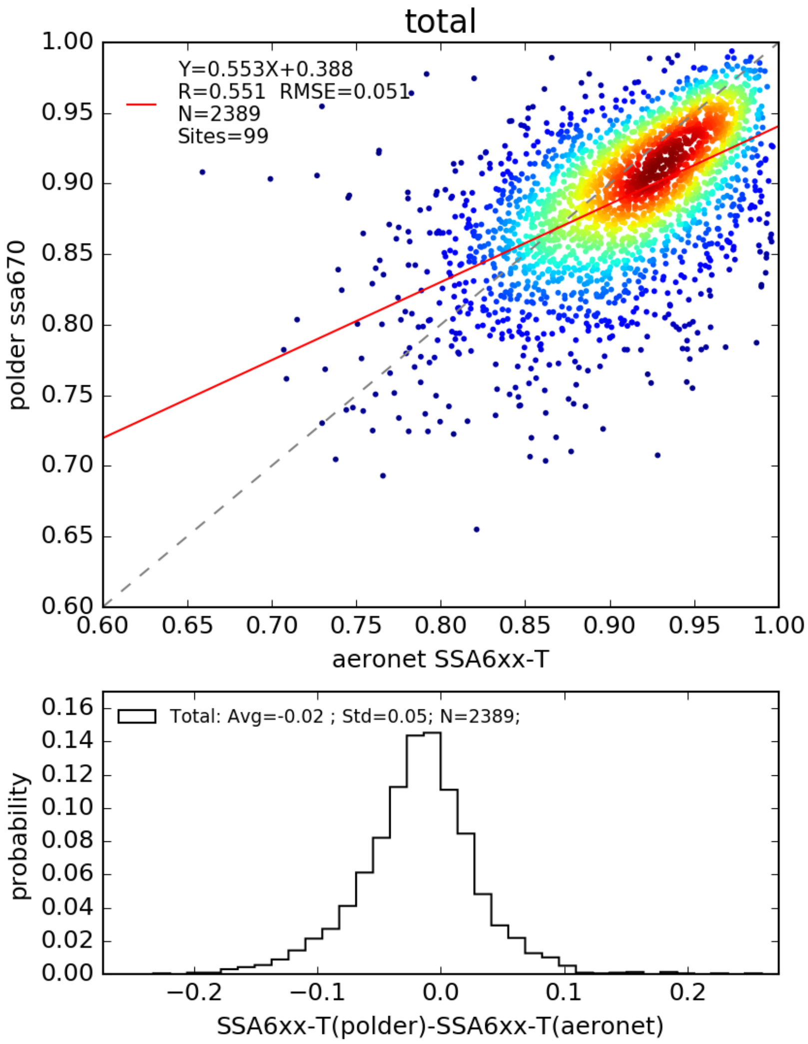
AOD **Angstrom**



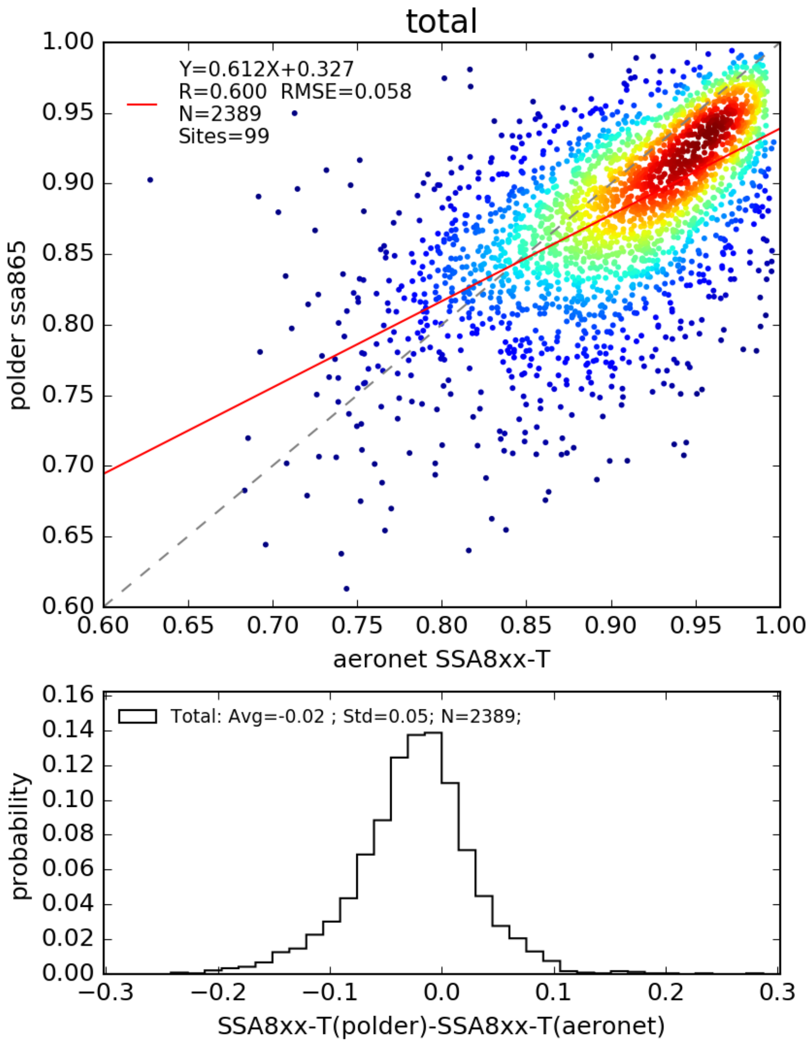
PARASOL Validation vs AERONET 2004 - 2013

Land + Ocean

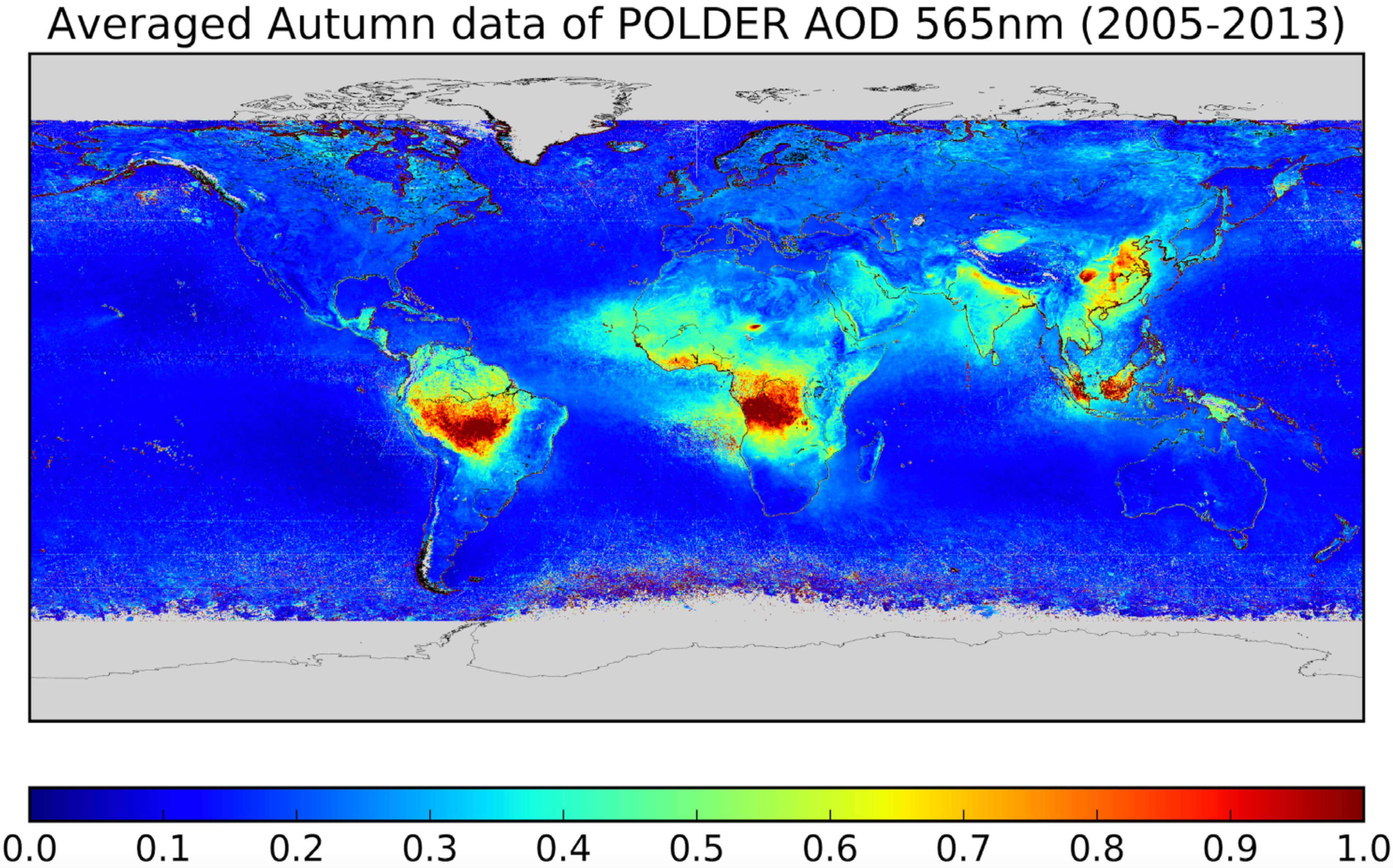
SSA(670) R=0.55



SSA(870) R=0.6

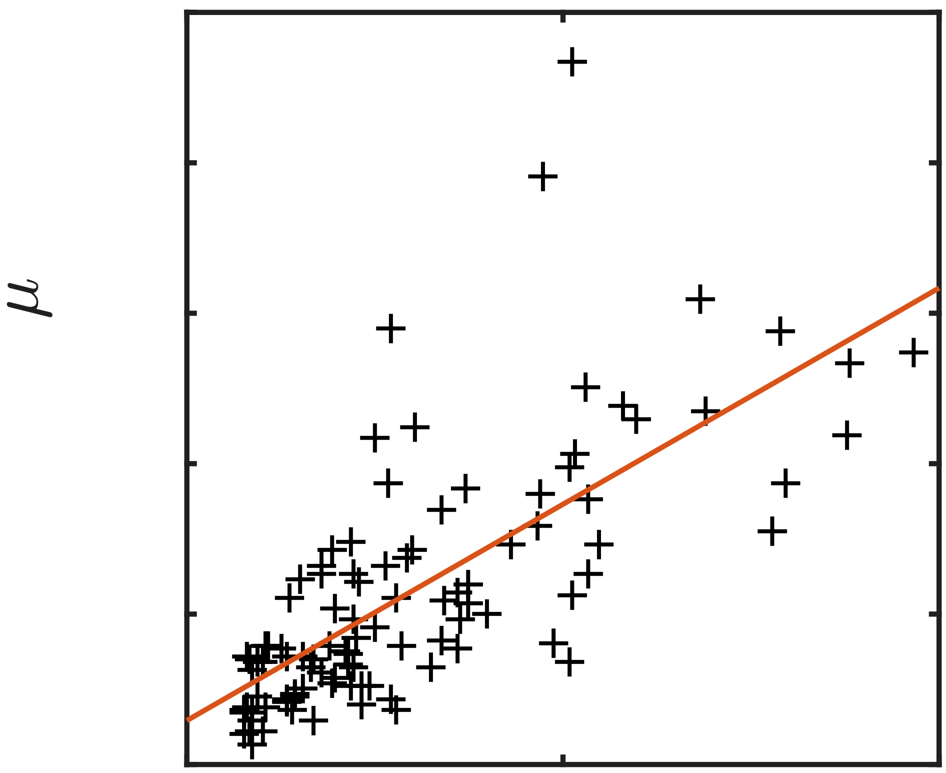


AOD (565), Autumn (PARASOL archive average)



Amount of aerosol

PM2.5 over Beijing versus AOT
2009–2012



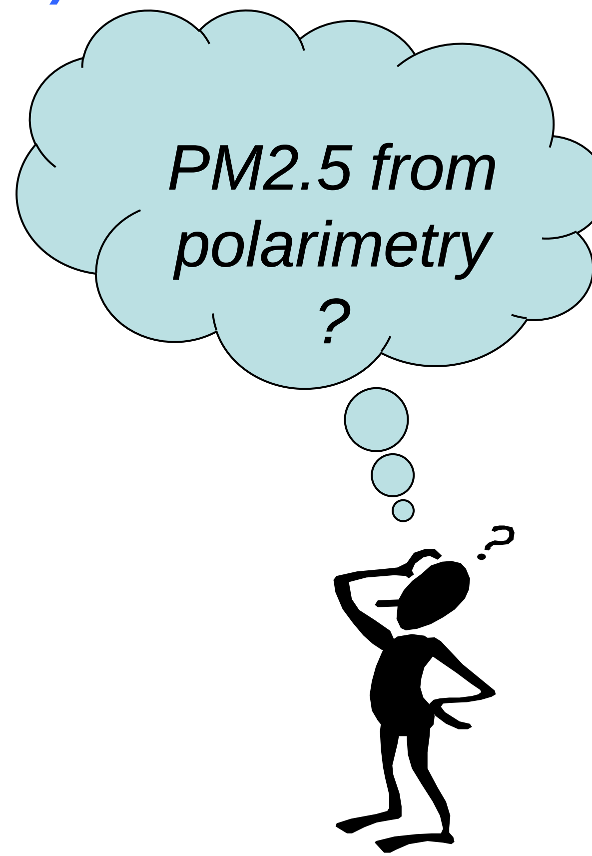
GRASP
In principle, yes!

size distribution (spectral AOD)

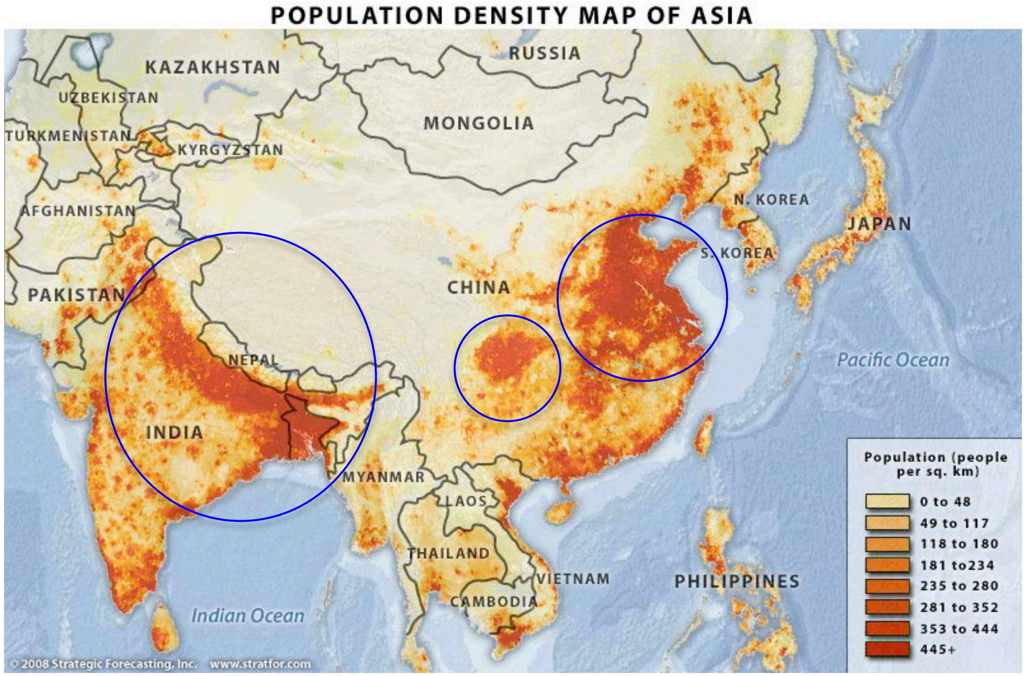
refractive index (~ water fraction)

scale height

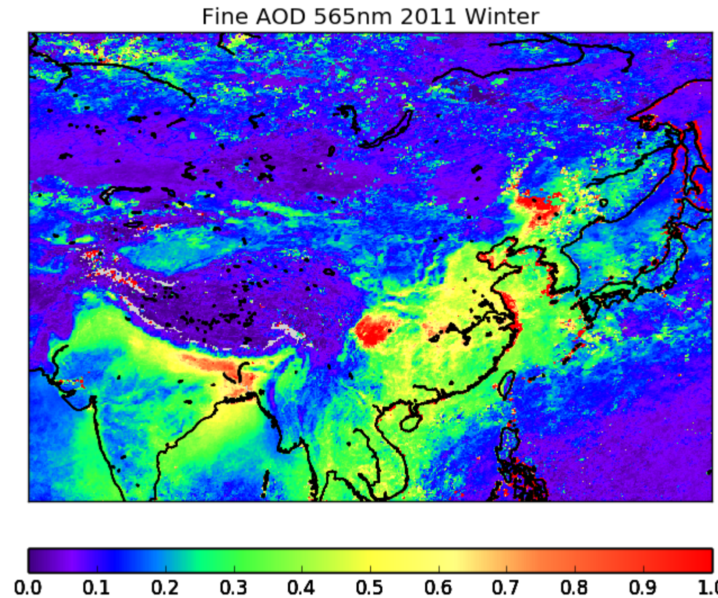
PM2.5 ?

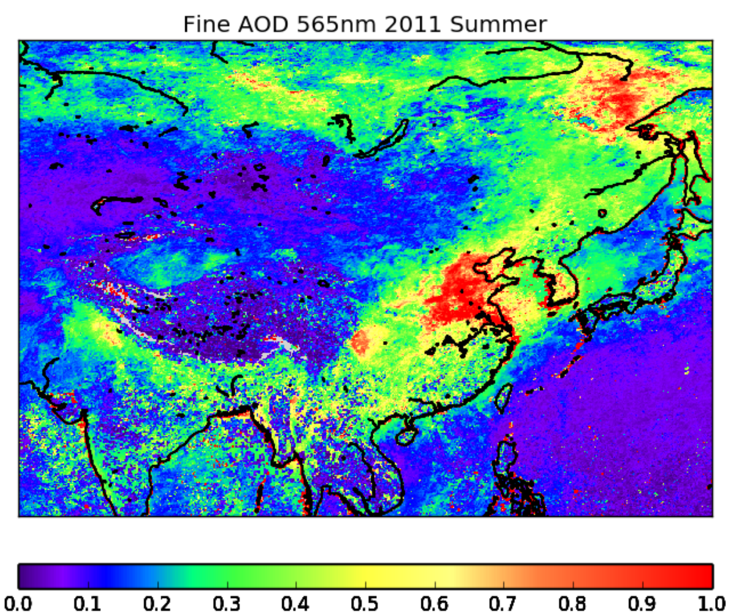


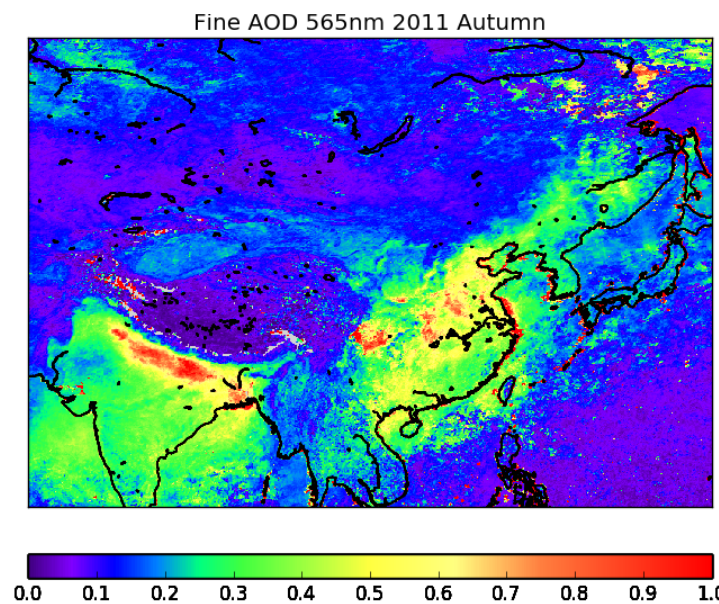
Correlation of population density and pollution



AOD_{fine}(565)

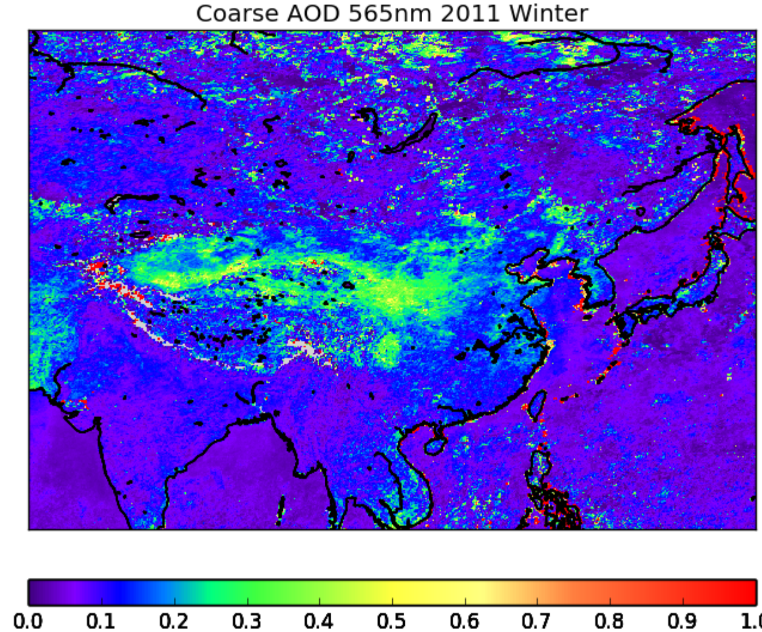


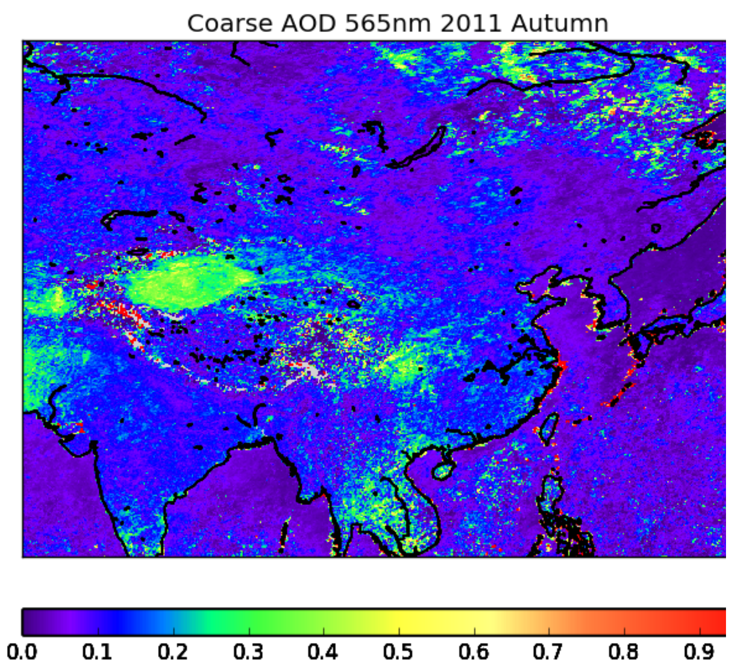


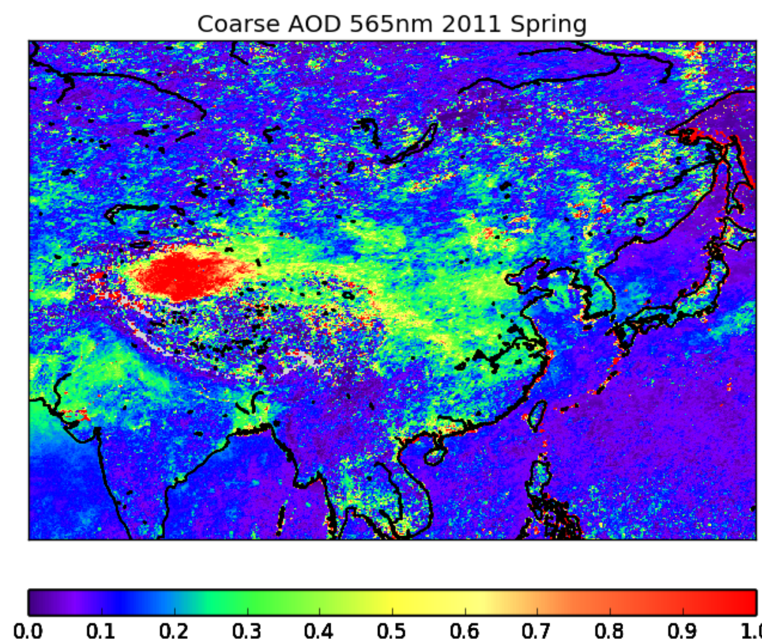


Distribution of coarse mode aerosol Asia

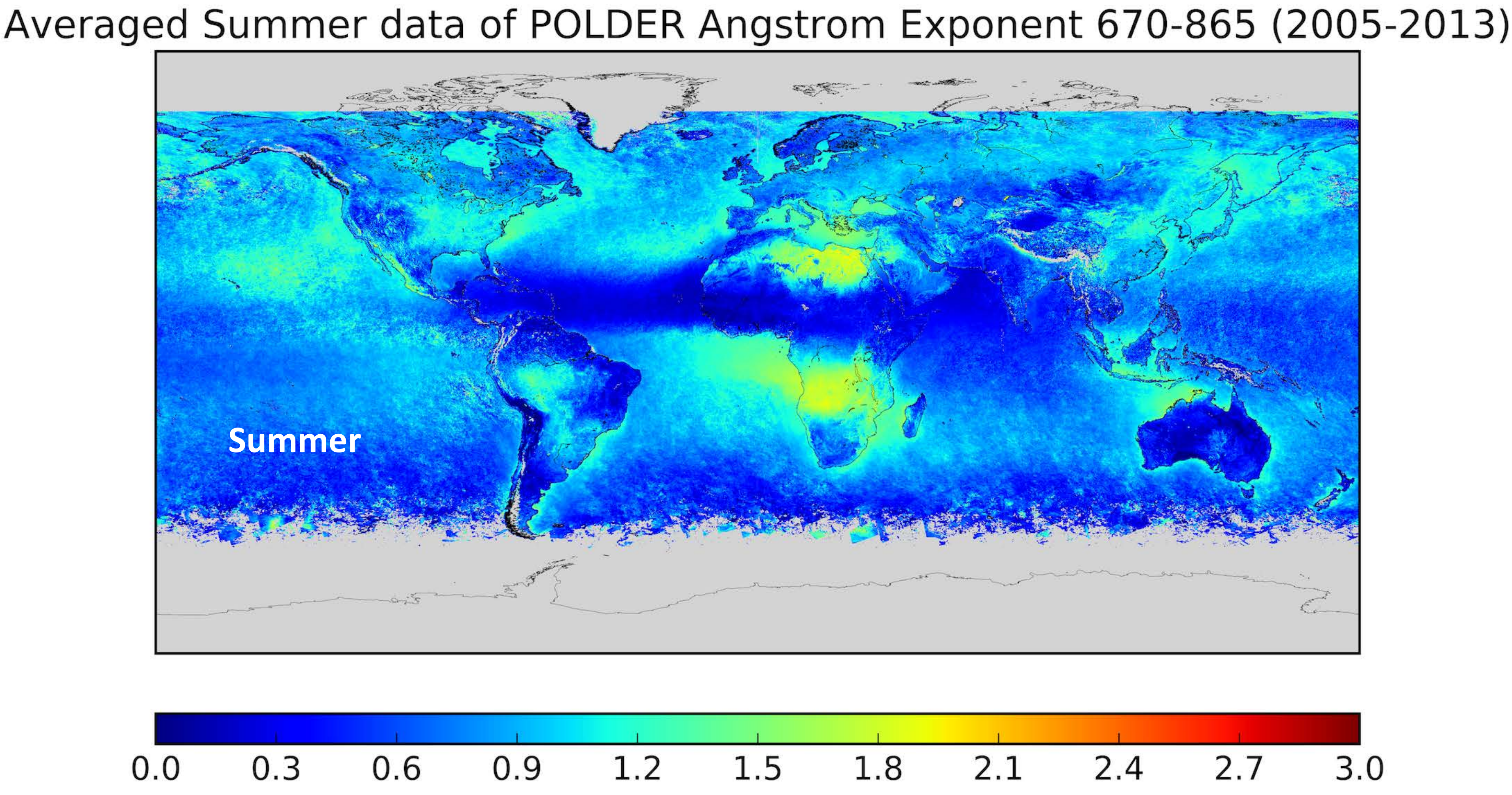
$AOD_{coarse}(565)$







Angstrom exponent, Summer (PARASOL archive average)



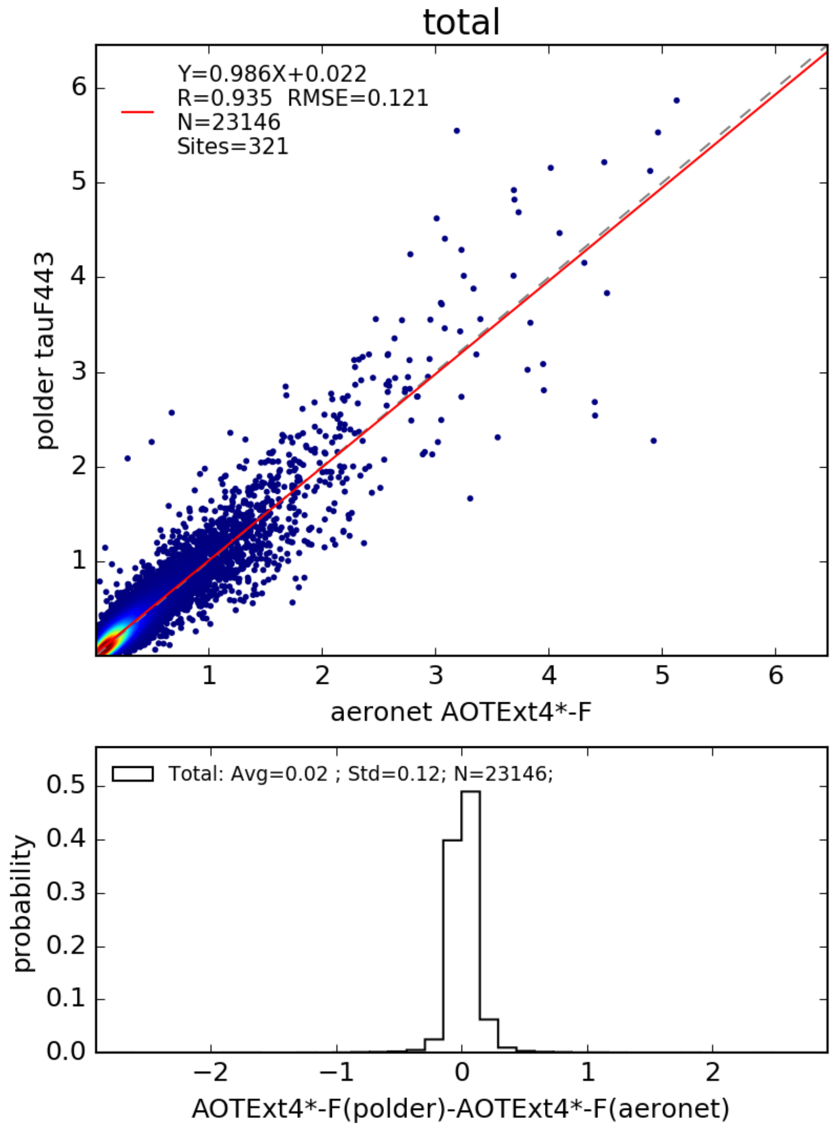
Large particles

Small particles

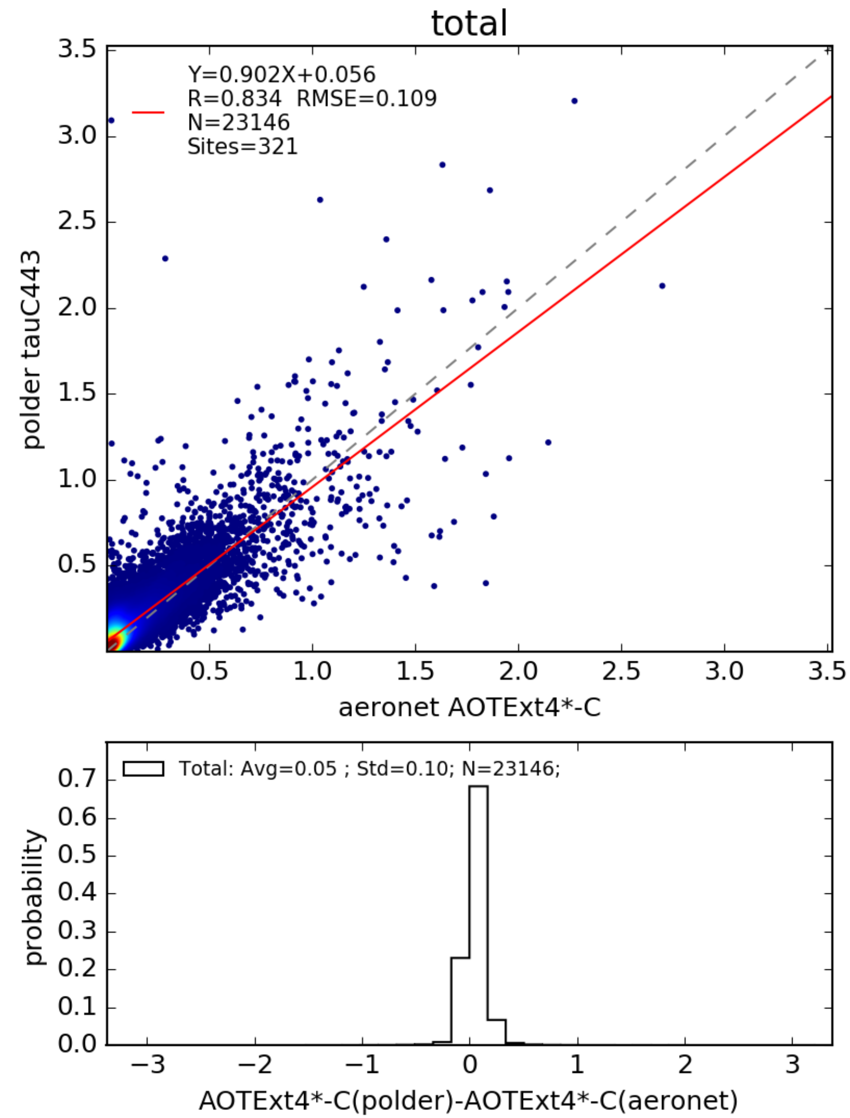
PARASOL Validation vs AERONET 2004 - 2013

Land + Ocean

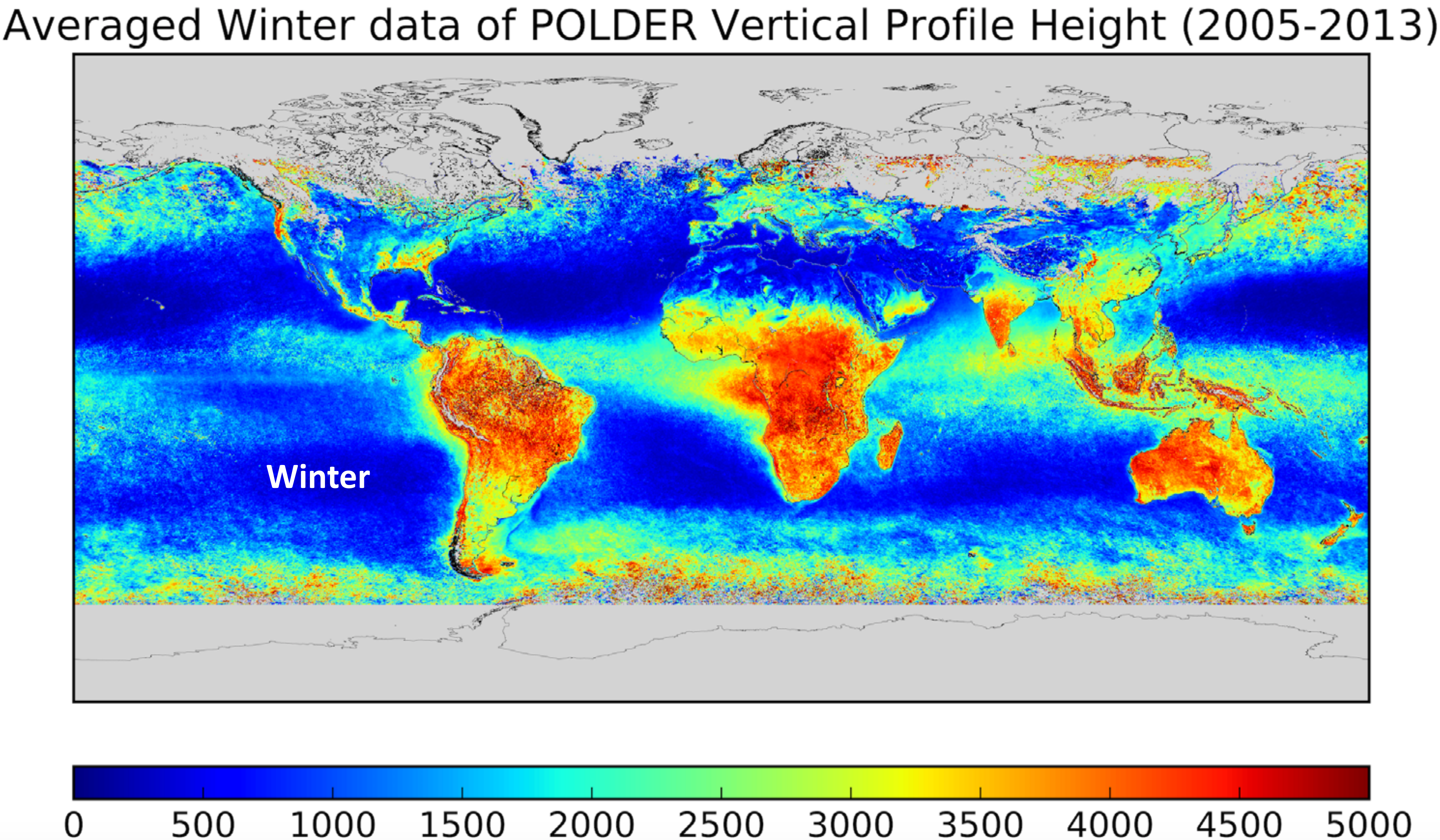
AOD Fine mode



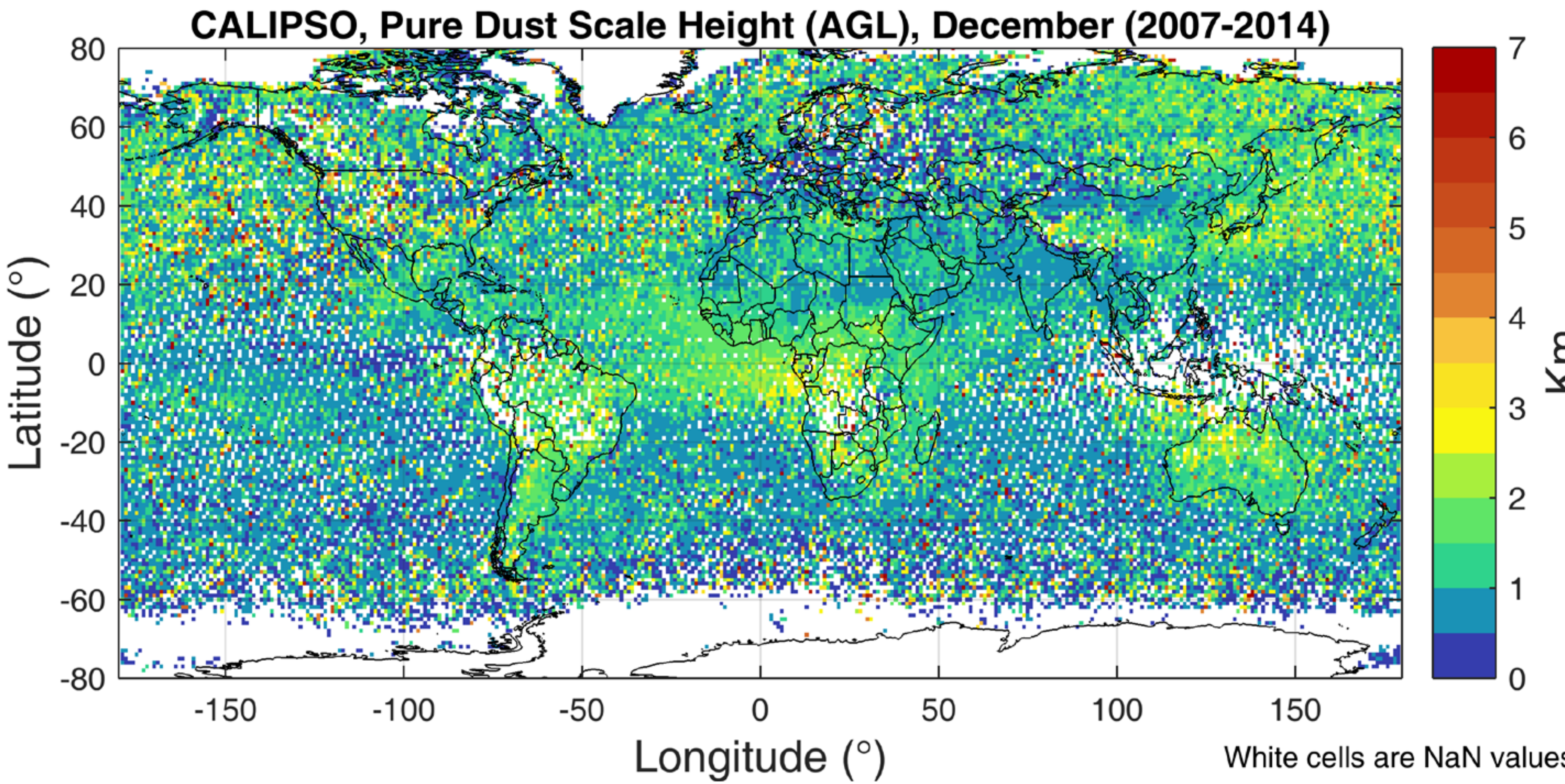
AOD Coarse mode



Scale height (m), Winter (PARASOL archive average)



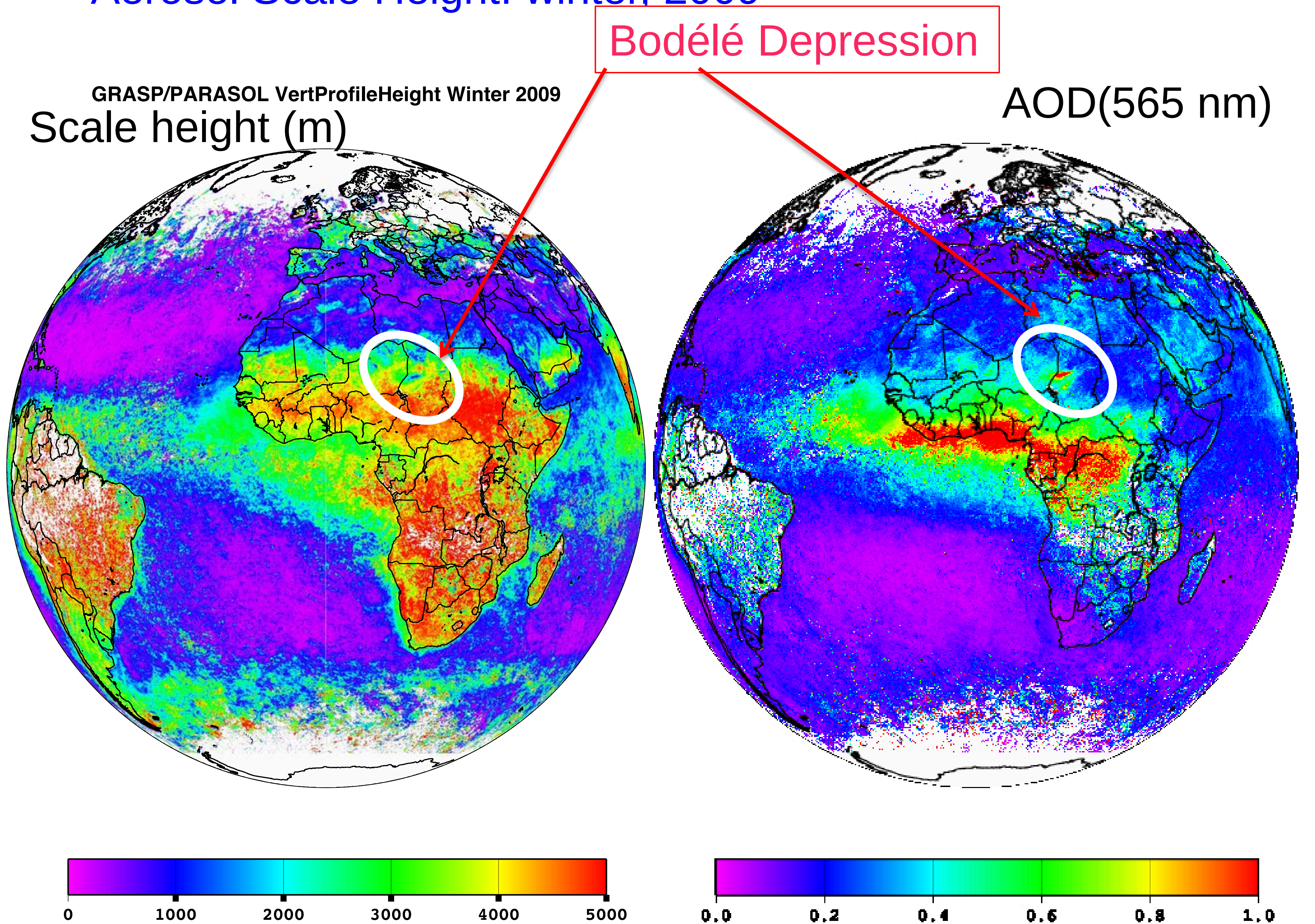
CALIPSO climatology



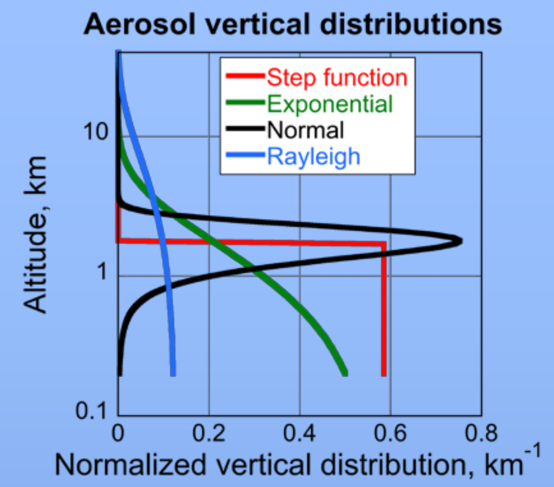
Courtecy of Vassilis Ameridis

Aerosol Scale Height: winter, 2009

PARASOL/GRASP



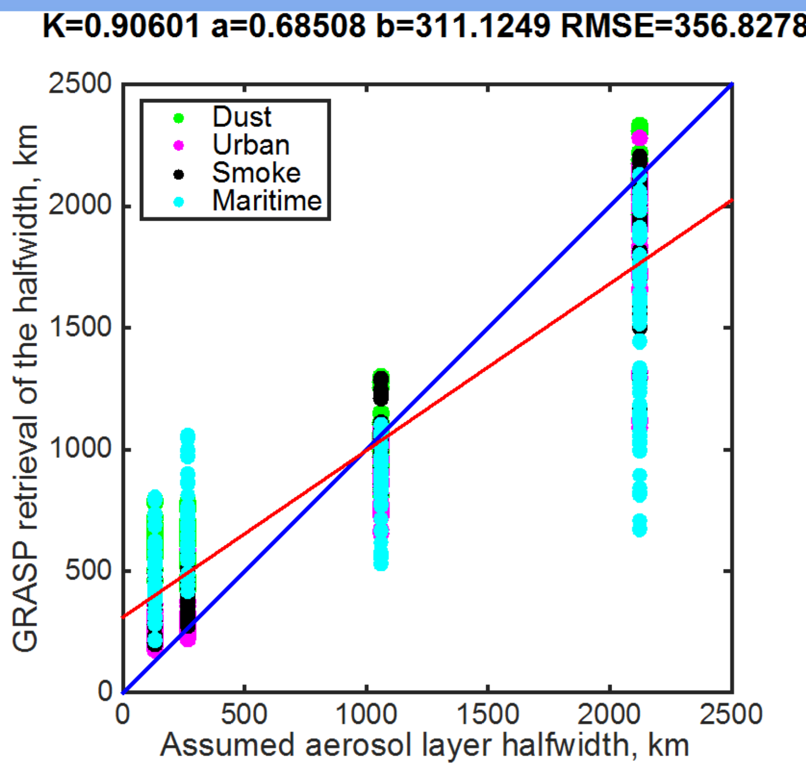
Sensitivity test for aerosol vertical information retrieval

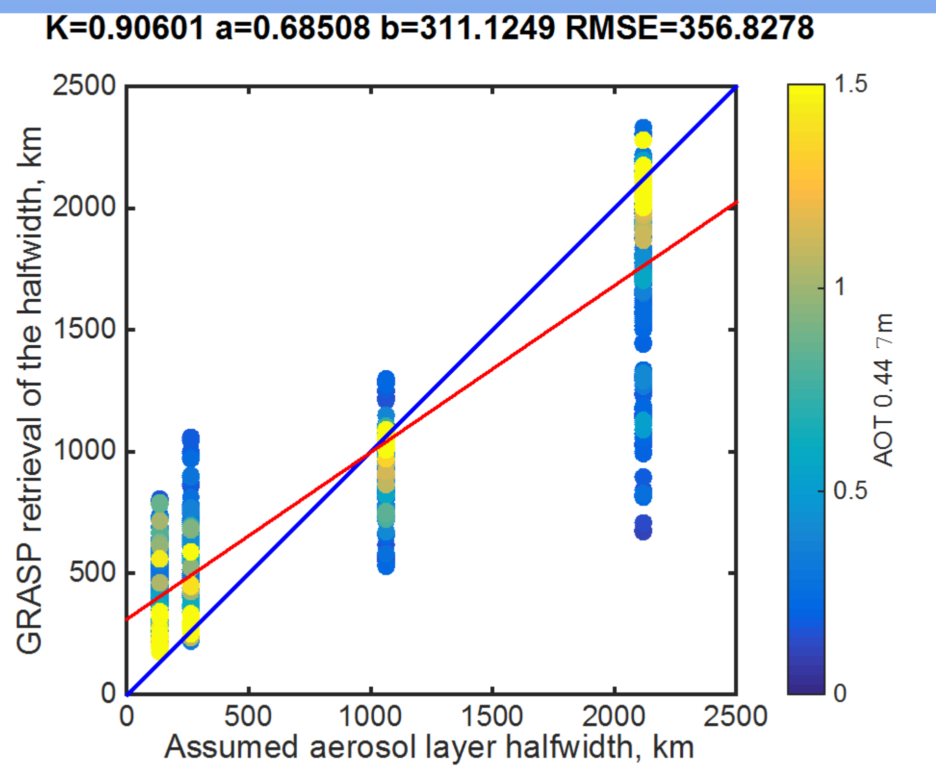


Dependence on aerosol type

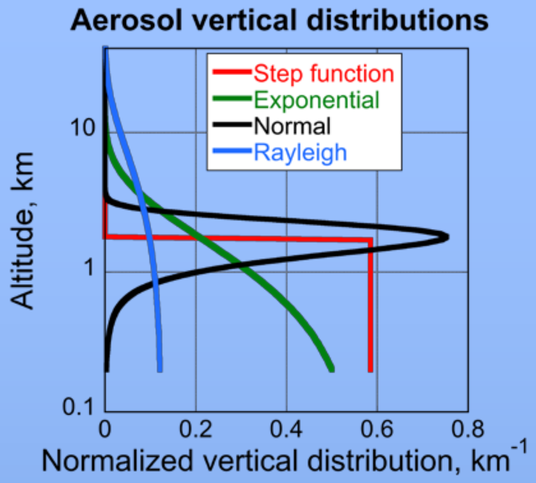
St. deviation

Dependence on Aerosol AOD





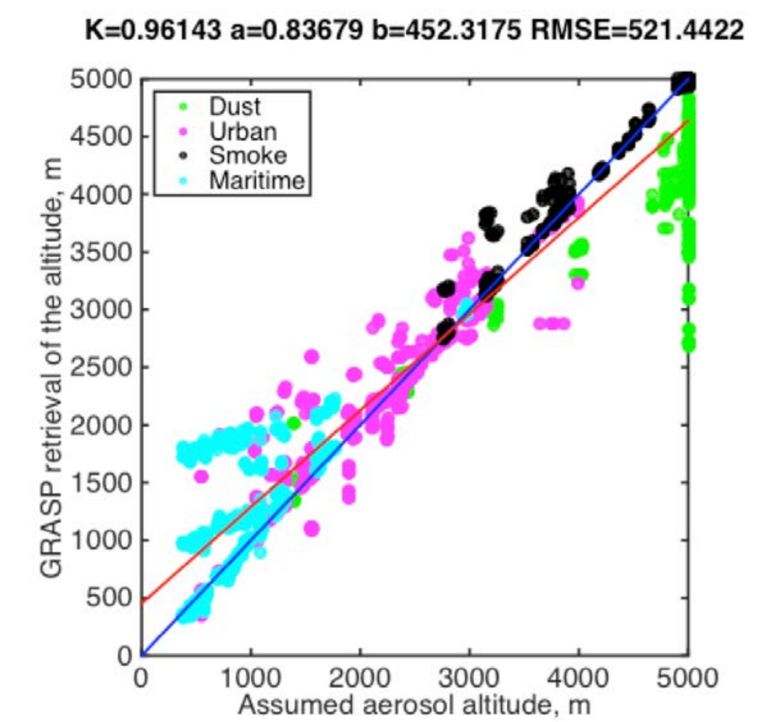
Sensitivity test for aerosol vertical information retrieval

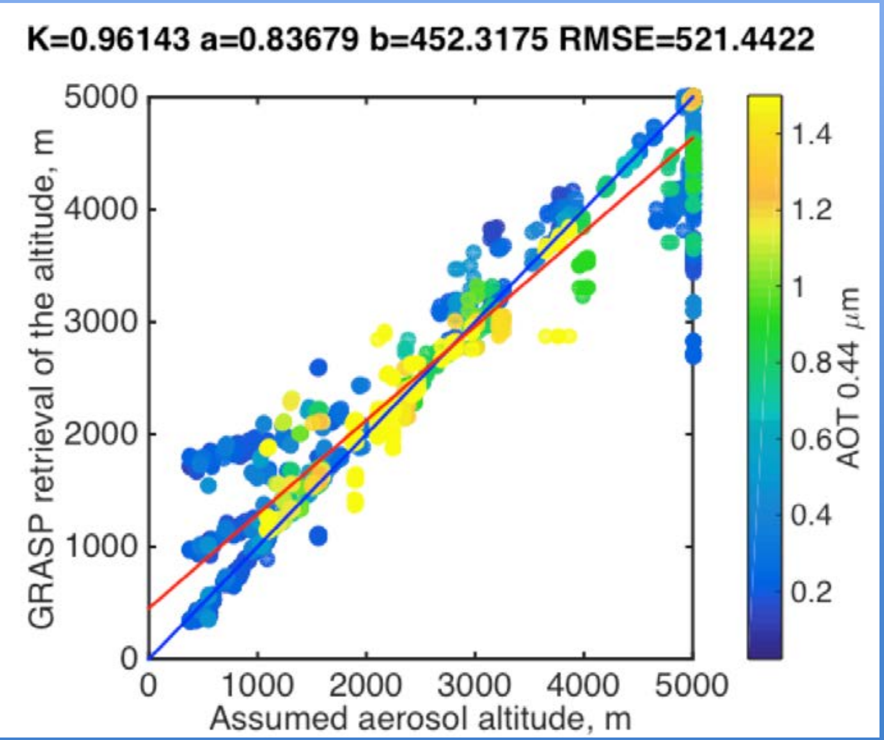


Dependence on aerosol type

Mean height

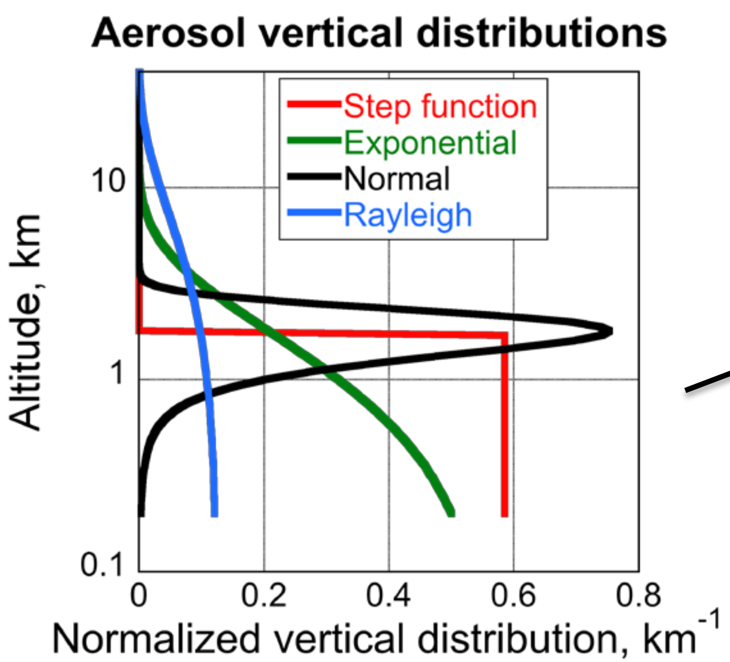
Dependence on Aerosol AOD





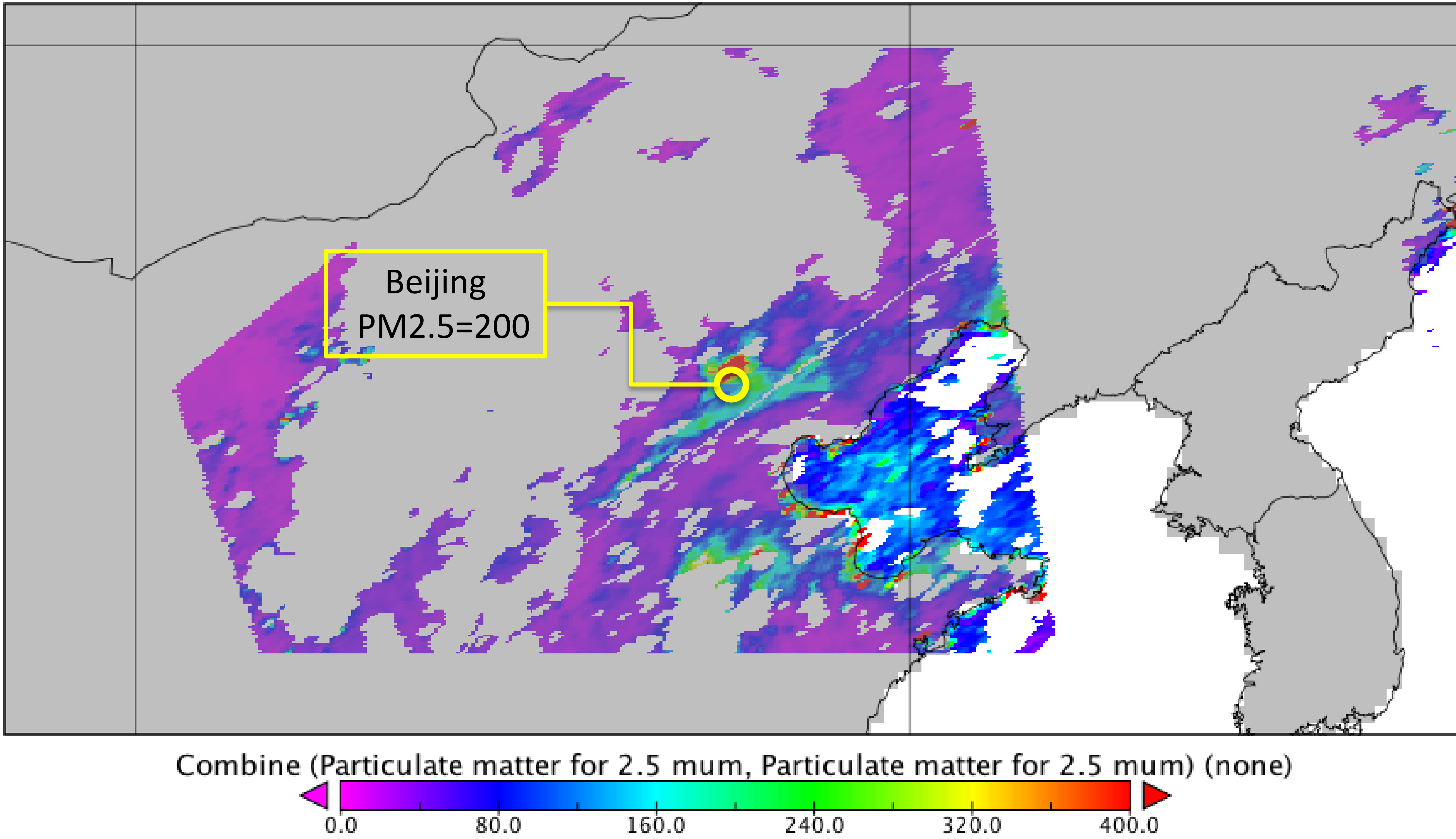
Conclusion of sensitivity tests:

- ✓ *PARASOL data have solid sensitivity to aerosol height;*
- ✓ *Sensitivity is higher to fine mode aerosol and less to large non-spherical dust;*
- ✓ *There is dependence on assumption about atmospheric aerosol vertical profile.*

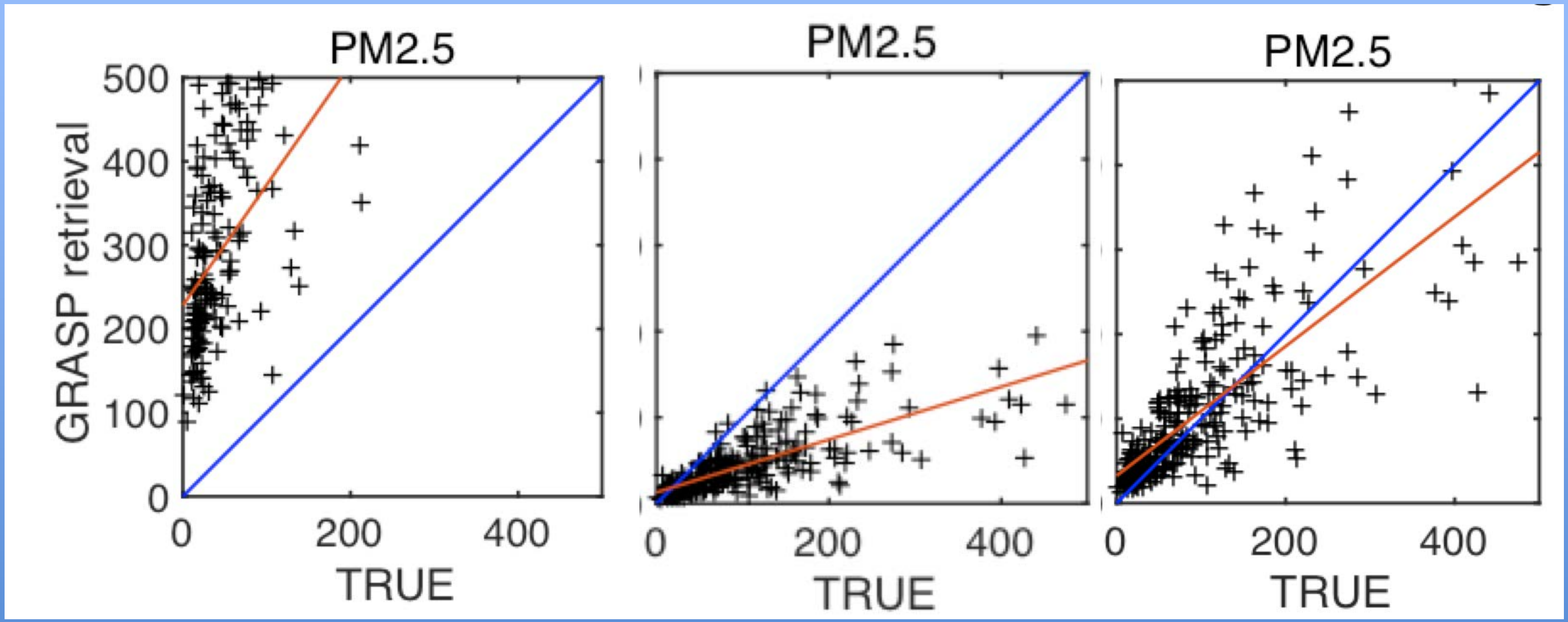


Which profile to use?

Particulate matter for 2.5 mum



Importance of knowledge of height



Too low

~ 500 m

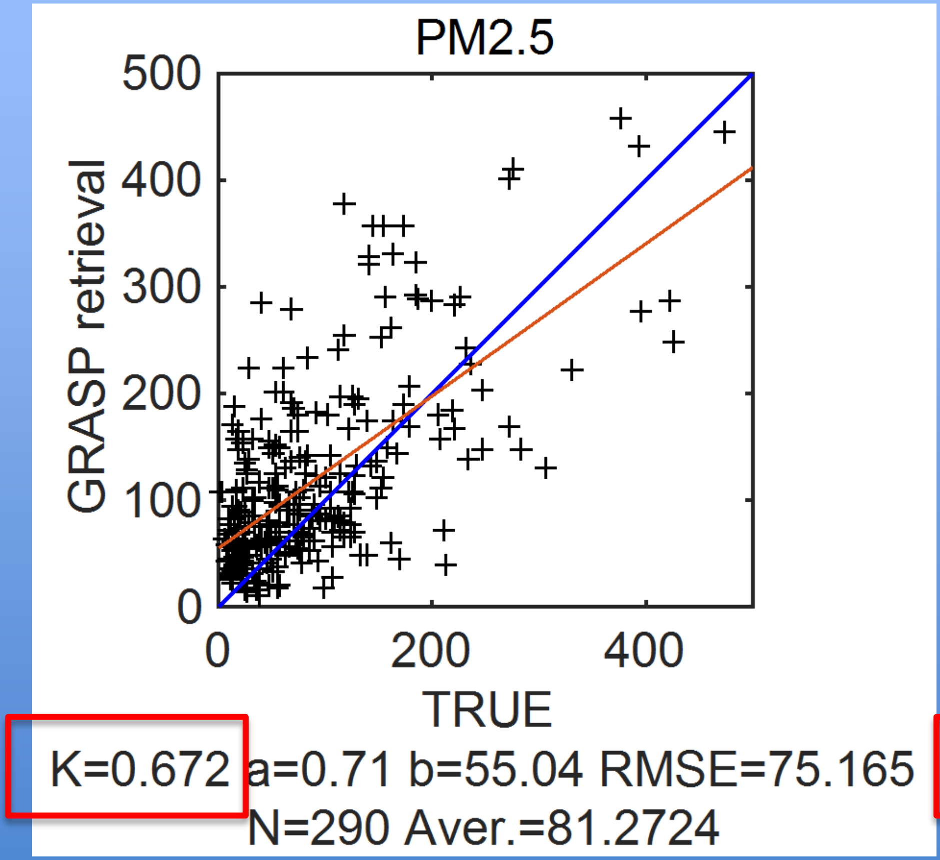
Too high

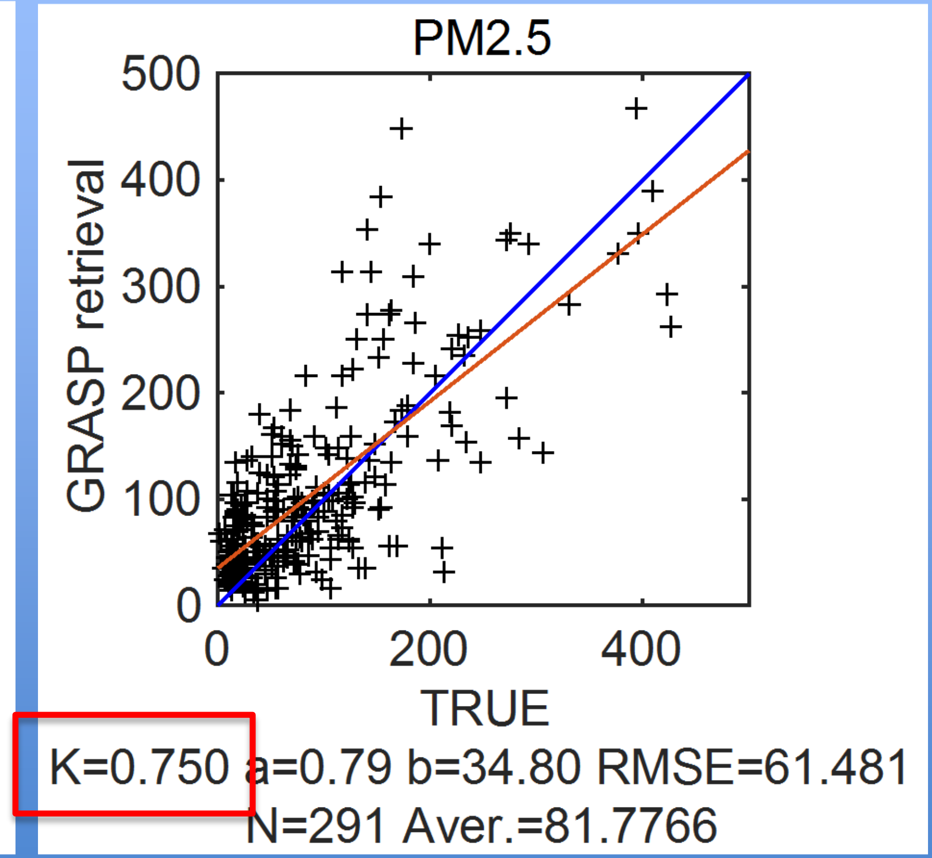
~ 3000 m

Retrieved

~2500 m

Sensitivity to particle drying

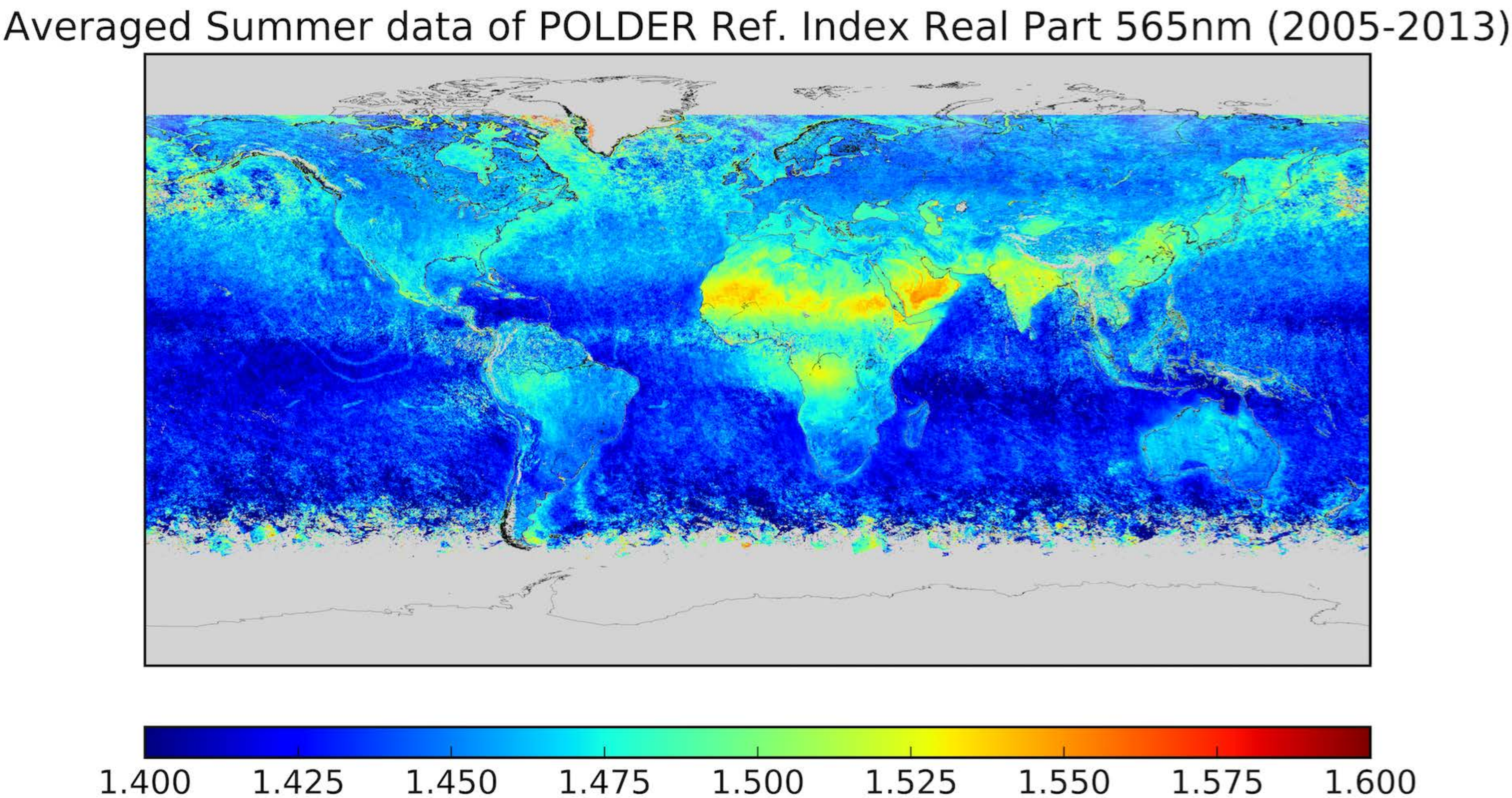




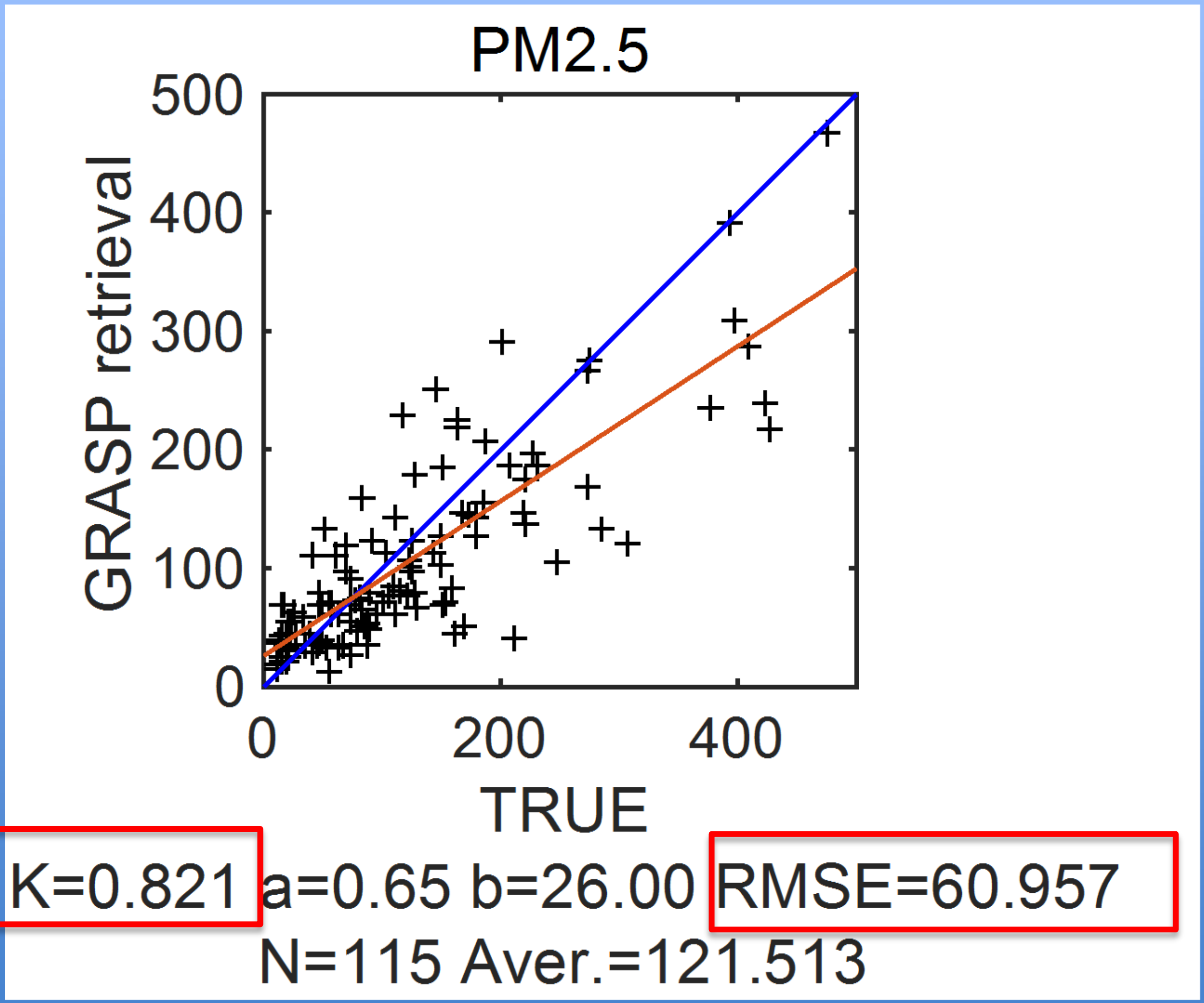
Fixed particle density, wet

Varied particle density, wet

Real Part of Ref. Index (565), Summer (PARASOL archive average)



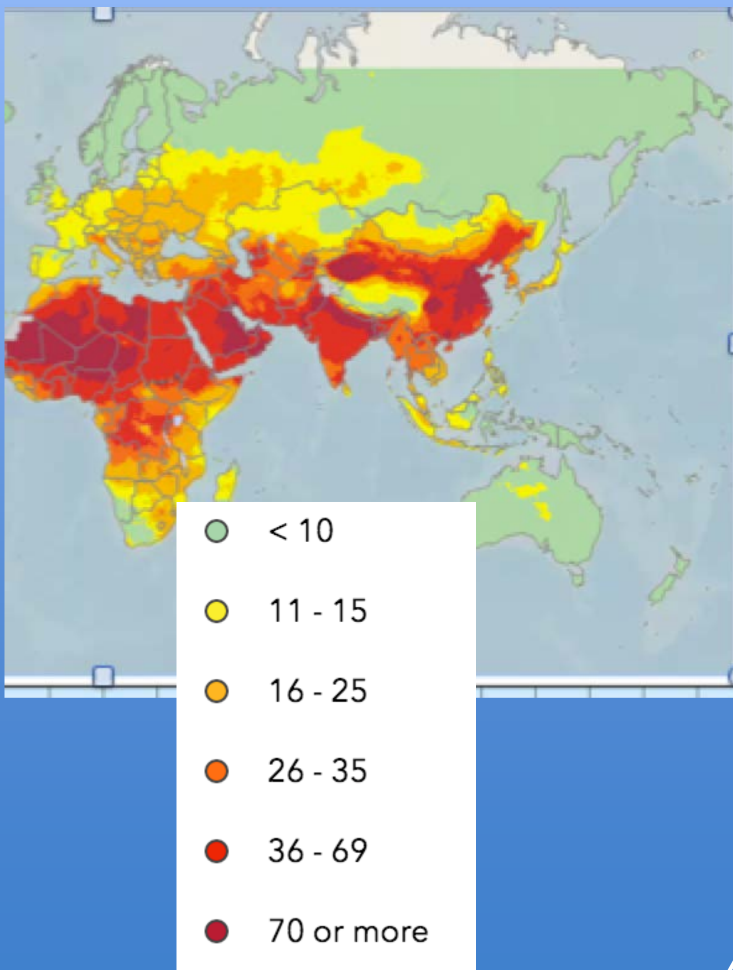
PARASOL/GRASP PM2.5 over Beijing 2009–2012



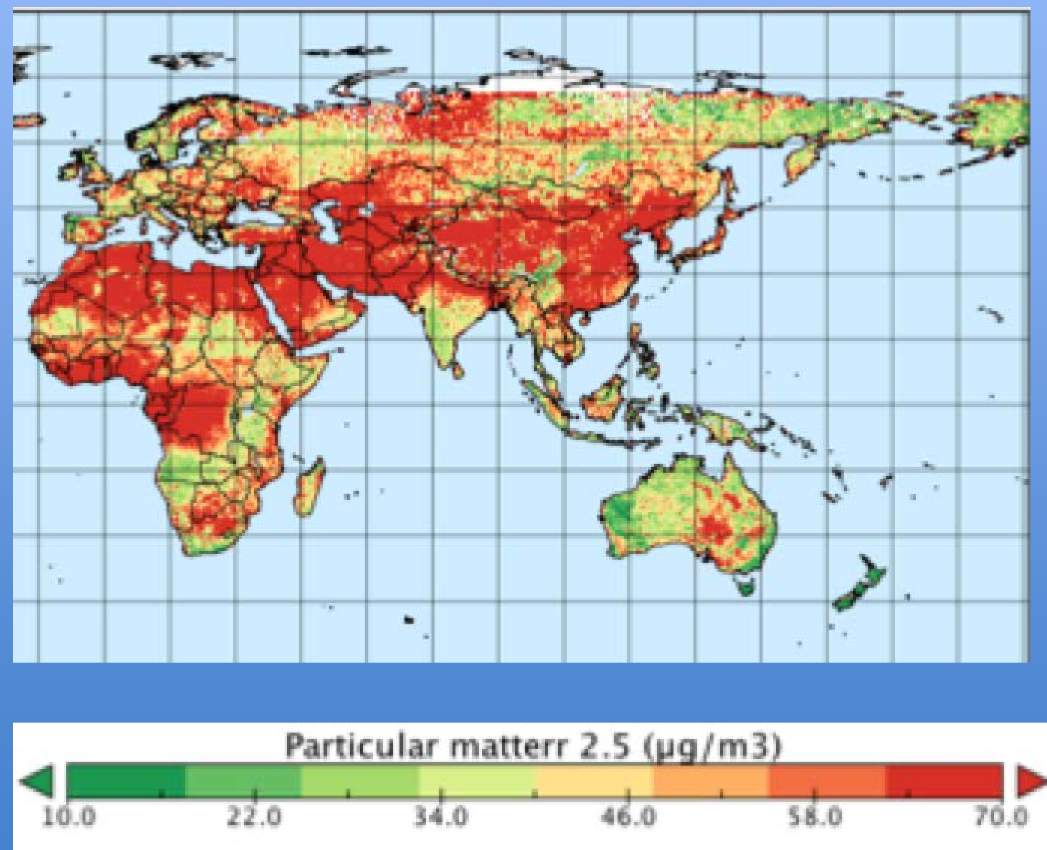
AOT>0.3, residual<3%

PM2.5 climatology

WHO Global Urban Ambient Air Pollution Database

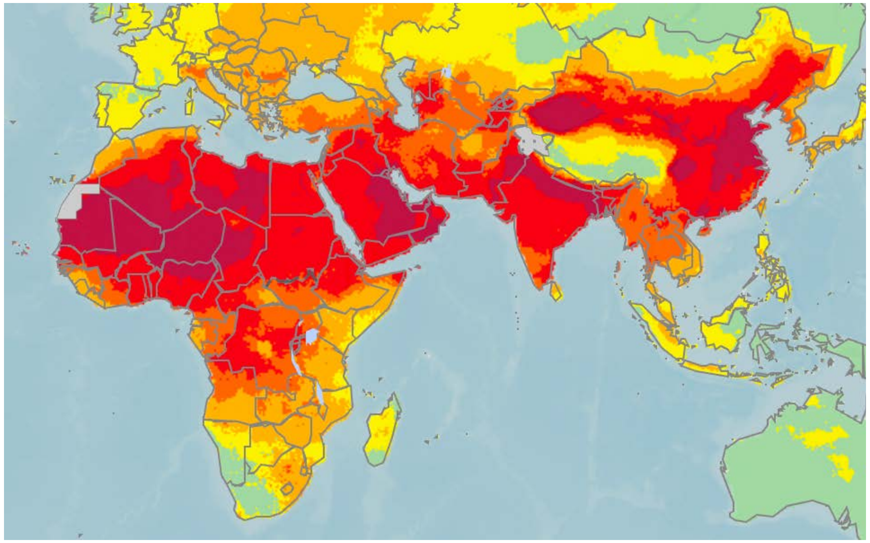


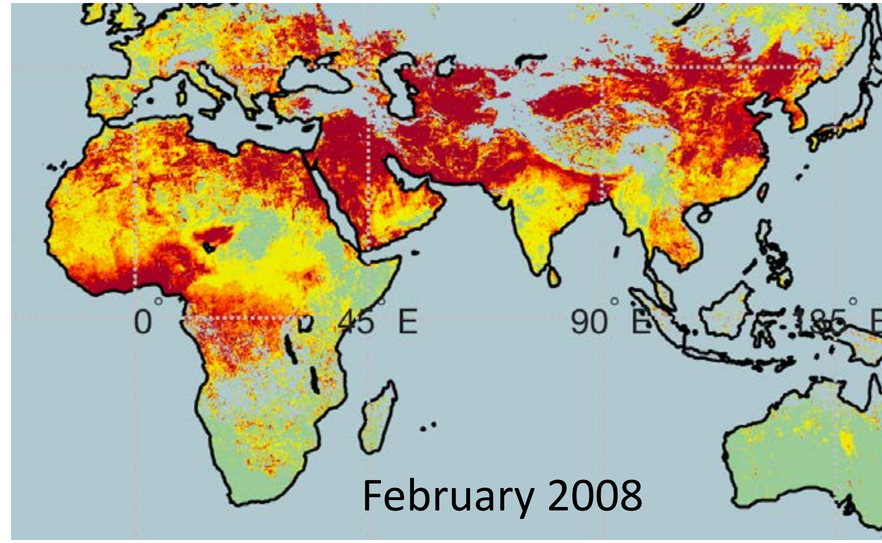
PARASOL/GRASP 2008

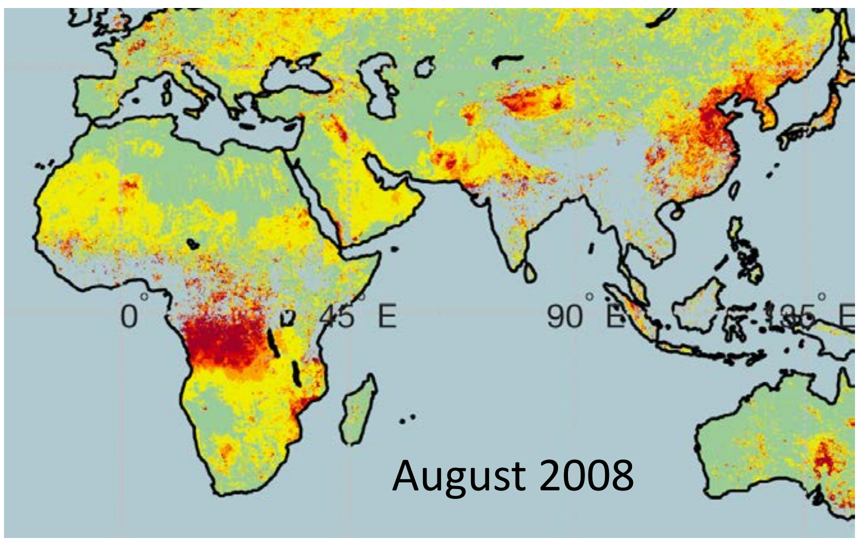


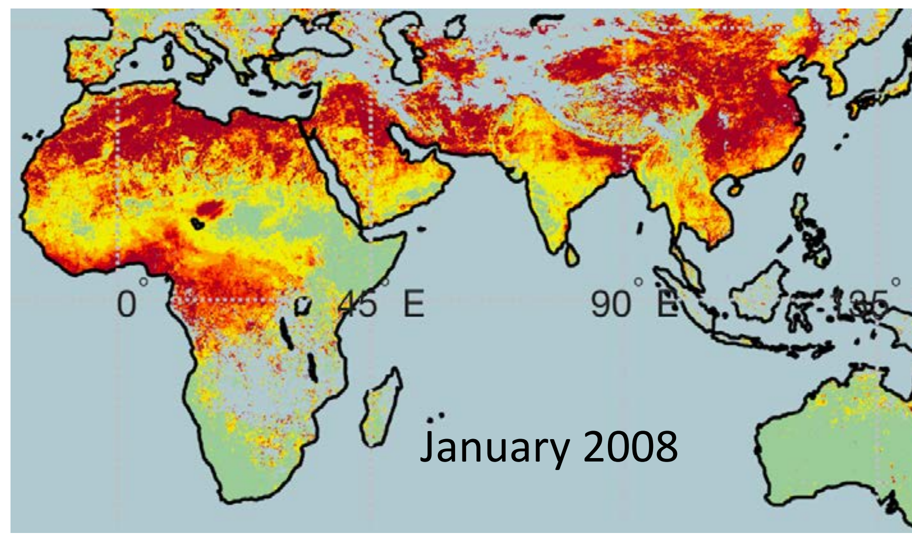
WHO Global Urban Ambient Air Pollution Database

PARASOL/GRASP 2008



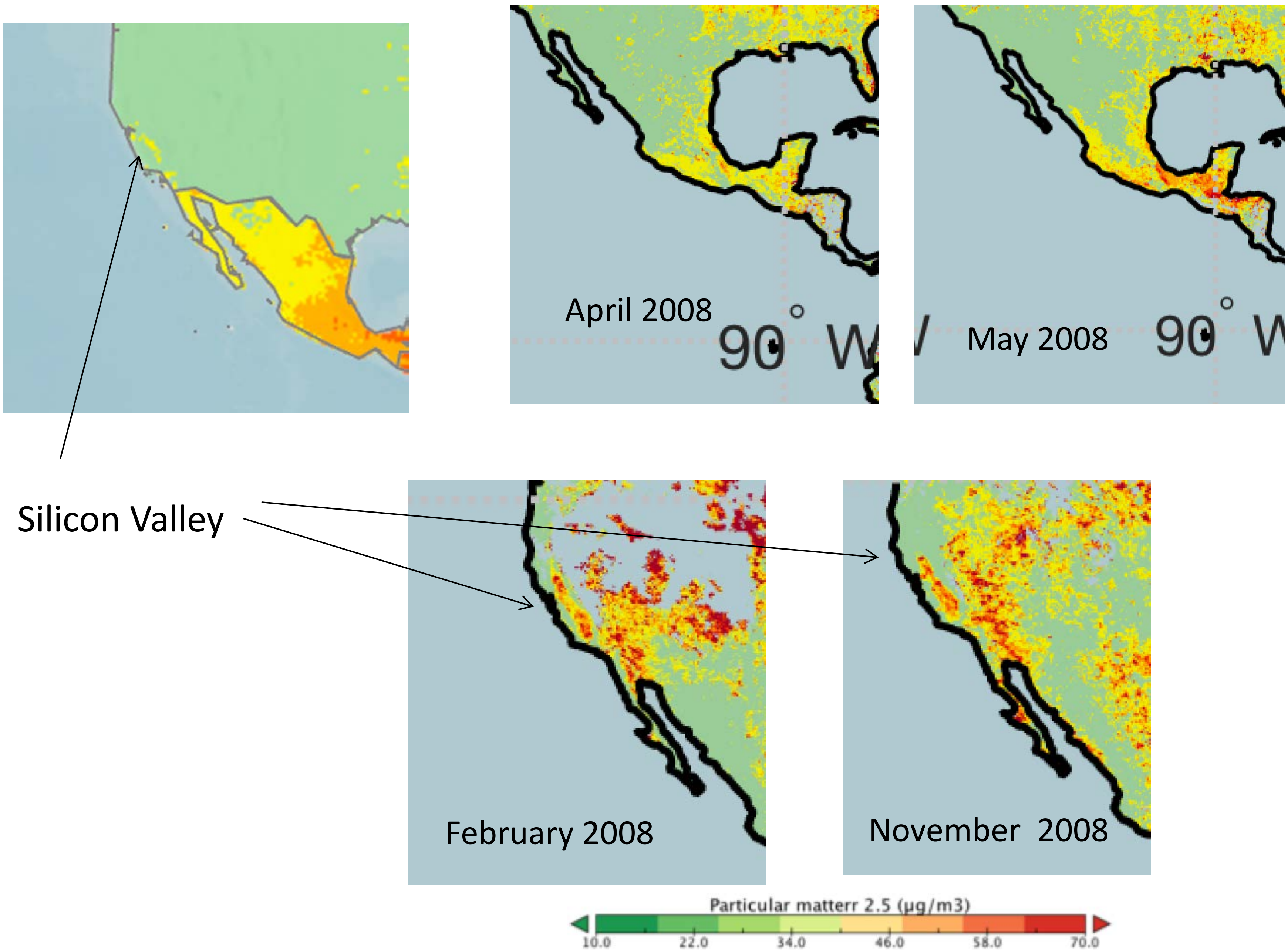






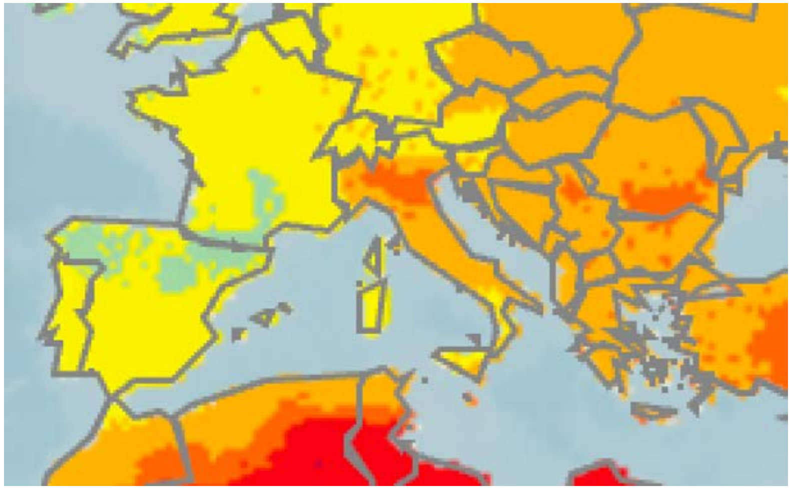
WHO Global Urban Ambient Air Pollution Database 2016

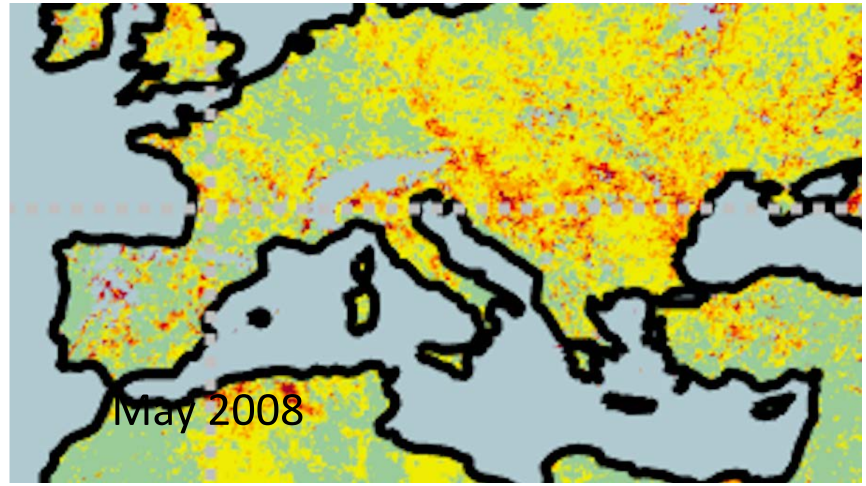
PARASOL/GRASP 2008

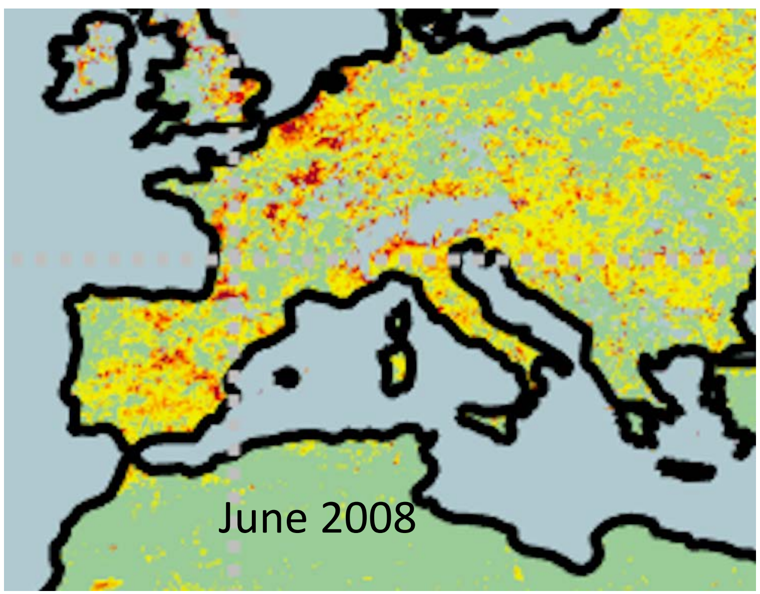


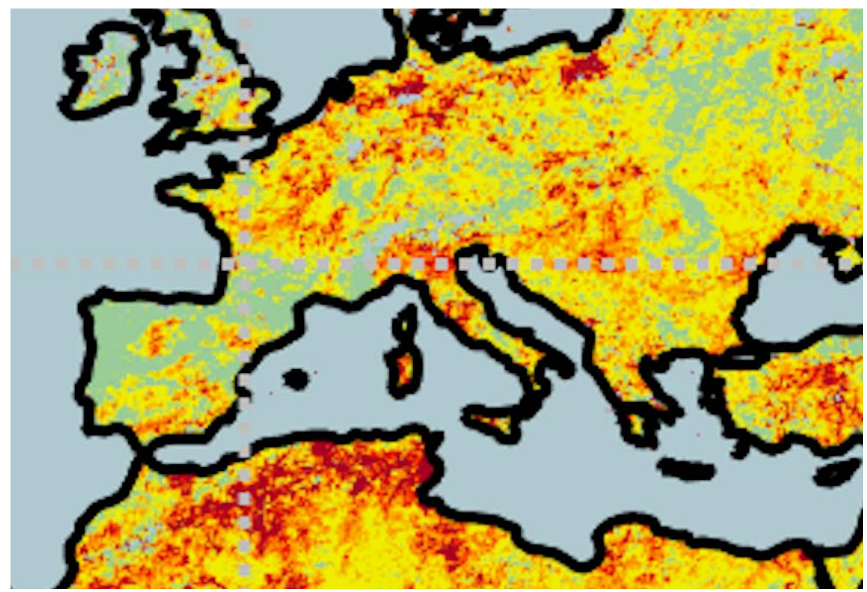
WHO Global Urban Ambient Air Pollution Database 2016

PARASOL/GRASP 2008

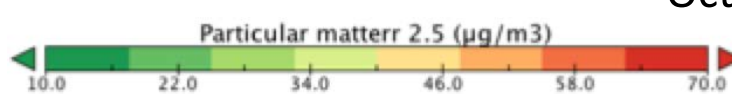








October 2008



1st International Workshop on

Advancement of POLarimetric Observations

Calibration and improved aerosol retrieval

APOLO 2017

October 24-27, 2017 Hefei · China

- Welcome Letter
- Important Dates
- Organizing Committee
- Agenda
- Invited Speakers
- Registration
- Abstract Submission
- Venue
- Booking Hotel
- Sponsorship
- Tours Information
- Useful Information
- Contact Us

NASA cnes EUMETSAT

Welcome Letter

Dear colleagues,

We are glad to announce that the 1st International Workshop on "Advancement of polarimetric observations: calibration and improved aerosol retrievals" (APOLO2017) will be held in Hefei, China from October 24 to 27, 2017. This is the first workshop of a series of polarimetry workshops (http://www-loa.univ-lille1.fr/workshops/APOLO-2017).

Several polarimetric missions are scheduled for launch in the coming years by international and national space agencies. Satellite polarimetry is one of the most promising and, at the same time, largely underexploited fields of aerosol remote sensing. This is the 1st meeting of the planned series of workshops on satellite polarimetry. These scientific workshops aim to promote international collaboration as well as in-depth exchange of ideas and experiences on diverse aspects of polarimetric remote sensing, in particular: advances in the theory of polarimetric remote sensing, optimisation of strategies of polarimetric Earth observations, improvement of polarimetric observation quality and information content, advancement of retrieval algorithms and data processing, and long-term Cal/Val.

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

$$\begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \left[\begin{pmatrix} \mathbf{F}_1^T \mathbf{W}_1^{-1} \mathbf{F}_1 & 0 & 0 \\ 0 & \mathbf{F}_2^T \mathbf{W}_2^{-1} \mathbf{F}_2 & 0 \\ 0 & 0 & \mathbf{F}_3^T \mathbf{W}_3^{-1} \mathbf{F}_3 \end{pmatrix} + \begin{pmatrix} \gamma_1 \Omega_1 & 0 & 0 \\ 0 & \gamma_2 \Omega_2 & 0 \\ 0 & 0 & \gamma_3 \Omega_3 \end{pmatrix} + \gamma_x \Omega_x + \gamma_y \Omega_y + \gamma_t \Omega_t \right]^{-1} \begin{pmatrix} \mathbf{F}_1^T \mathbf{W}_1^{-1} \Delta f_1^p \\ \mathbf{F}_2^T \mathbf{W}_2^{-1} \Delta f_2^p \\ \mathbf{F}_3^T \mathbf{W}_3^{-1} \Delta f_3^p \end{pmatrix}$$

$$\Omega_x = \mathbf{S}_x^T \mathbf{S}_x; \quad \Omega_y = \mathbf{S}_y^T \mathbf{S}_y; \quad \Omega_t = \mathbf{S}_t^T \mathbf{S}_t;$$

$$\begin{pmatrix} a_v \\ a_n \\ a_n \\ a_h \\ a_{sph} \\ a_{Vc} \\ a_{brdf,1} \\ a_{brdf,2} \\ a_{brdf,3} \\ a_{bpdf} \end{pmatrix}$$

43 parameters

$$\gamma_\Delta \Omega = \begin{pmatrix} \gamma_{\Delta,1}\Omega_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma_{\Delta,2}\Omega_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma_{\Delta,3}\Omega_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{\Delta,4}\Omega_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{\Delta,5}\Omega_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{\Delta,6}\Omega_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{\Delta,7}\Omega_7 \end{pmatrix}$$

$$\mathbf{S}_y^T \mathbf{S}_y = \begin{pmatrix} \begin{pmatrix} \mathbf{I}_{d_{11}} & \mathbf{I}_{d_{12}} & \mathbf{I}_{d_{13}} \\ \mathbf{I}_{d_{21}} & \mathbf{I}_{d_{22}} & \mathbf{I}_{d_{23}} \\ \mathbf{I}_{d_{31}} & \mathbf{I}_{d_{32}} & \mathbf{I}_{d_{33}} \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{11}} & \mathbf{I}_{d_{12}} & \mathbf{I}_{d_{13}} \\ \mathbf{I}_{d_{21}} & \mathbf{I}_{d_{22}} & \mathbf{I}_{d_{23}} \\ \mathbf{I}_{d_{31}} & \mathbf{I}_{d_{32}} & \mathbf{I}_{d_{33}} \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{11}} & \mathbf{I}_{d_{12}} & \mathbf{I}_{d_{13}} \\ \mathbf{I}_{d_{21}} & \mathbf{I}_{d_{22}} & \mathbf{I}_{d_{23}} \\ \mathbf{I}_{d_{31}} & \mathbf{I}_{d_{32}} & \mathbf{I}_{d_{33}} \end{pmatrix} \end{pmatrix};$$

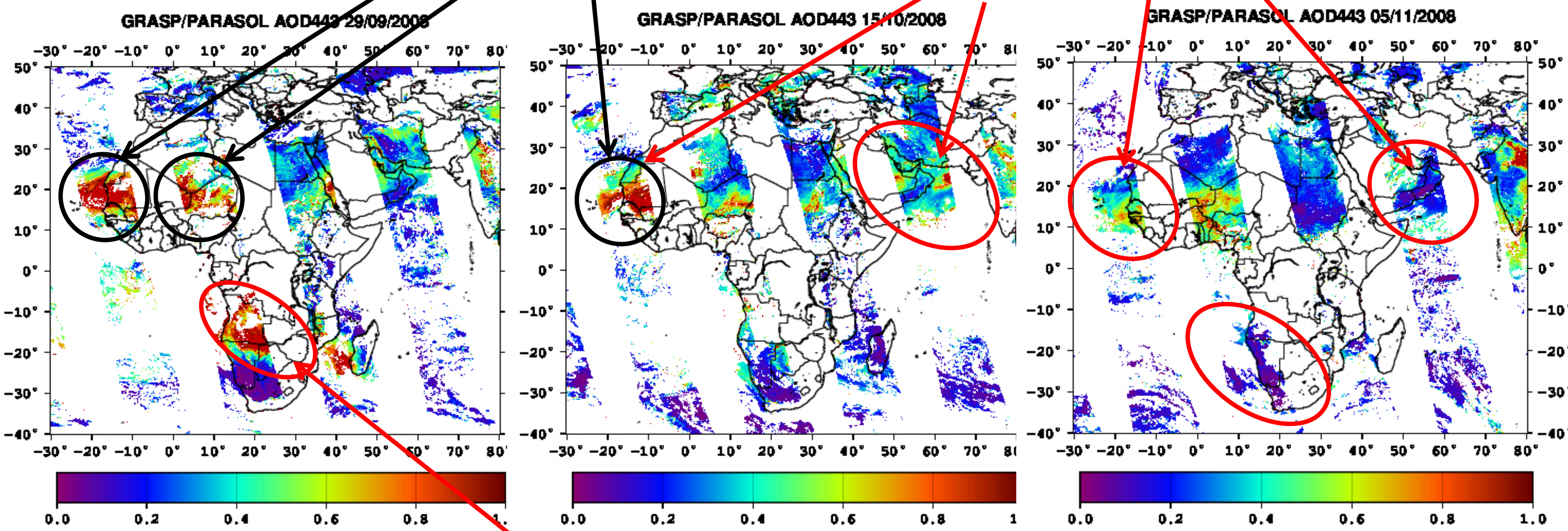
$$\mathbf{S}_y^T \mathbf{S}_y = \begin{pmatrix} \begin{pmatrix} \mathbf{I}_{d_{11}} & \mathbf{I}_{d_{12}} & \mathbf{I}_{d_{13}} \\ \mathbf{I}_{d_{21}} & \mathbf{I}_{d_{22}} & \mathbf{I}_{d_{23}} \\ \mathbf{I}_{d_{31}} & \mathbf{I}_{d_{32}} & \mathbf{I}_{d_{33}} \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{11}} & \mathbf{I}_{d_{12}} & \mathbf{I}_{d_{13}} \\ \mathbf{I}_{d_{21}} & \mathbf{I}_{d_{22}} & \mathbf{I}_{d_{23}} \\ \mathbf{I}_{d_{31}} & \mathbf{I}_{d_{32}} & \mathbf{I}_{d_{33}} \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{11}} & \mathbf{I}_{d_{12}} & \mathbf{I}_{d_{13}} \\ \mathbf{I}_{d_{21}} & \mathbf{I}_{d_{22}} & \mathbf{I}_{d_{23}} \\ \mathbf{I}_{d_{31}} & \mathbf{I}_{d_{32}} & \mathbf{I}_{d_{33}} \end{pmatrix} \end{pmatrix};$$

$$\mathbf{S}_t^T \mathbf{S}_t = \begin{pmatrix} \begin{pmatrix} \mathbf{I}_{d_{11}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{11}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{11}} \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{12}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{12}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{12}} \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{13}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{13}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{13}} \end{pmatrix} \\ \begin{pmatrix} \mathbf{I}_{d_{21}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{21}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{21}} \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{22}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{22}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{22}} \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{23}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{23}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{23}} \end{pmatrix} \\ \begin{pmatrix} \mathbf{I}_{d_{31}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{31}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{31}} \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{32}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{32}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{32}} \end{pmatrix} & \begin{pmatrix} \mathbf{I}_{d_{33}} & 0 & 0 \\ 0 & \mathbf{I}_{d_{33}} & 0 \\ 0 & 0 & \mathbf{I}_{d_{33}} \end{pmatrix} \end{pmatrix}.$$

GRASP over land and ocean

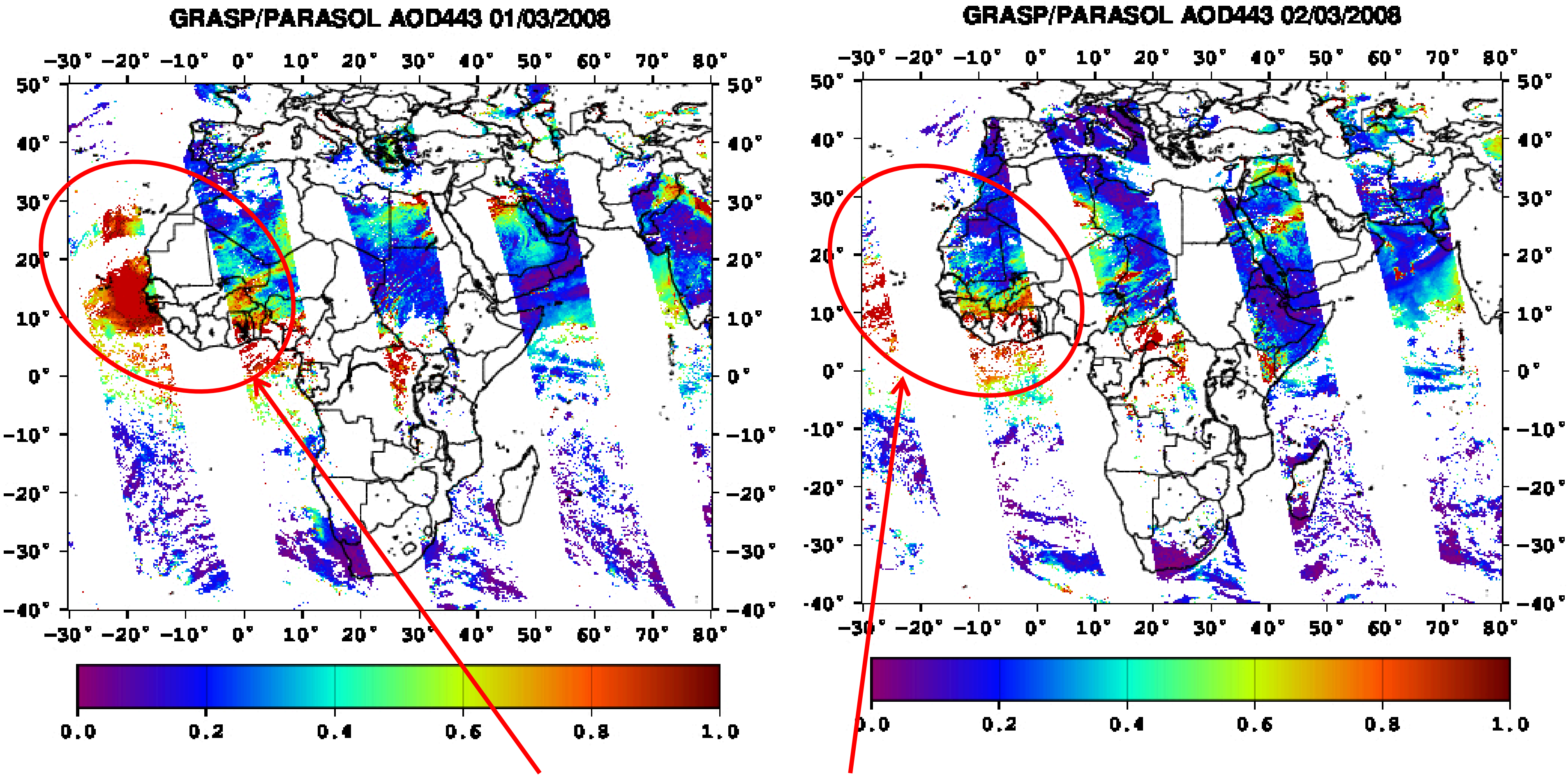
Dust events

There are no discontinuity over ocean and land

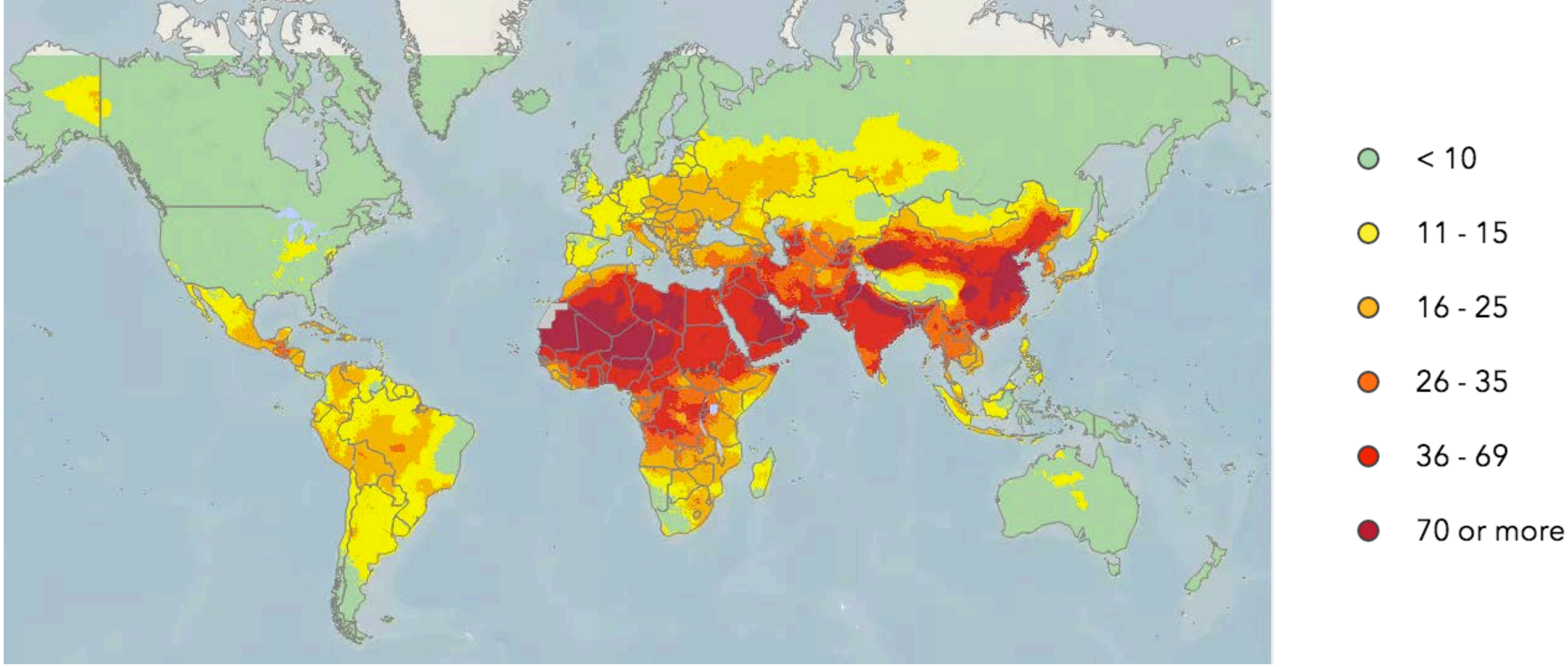


Biomass burning

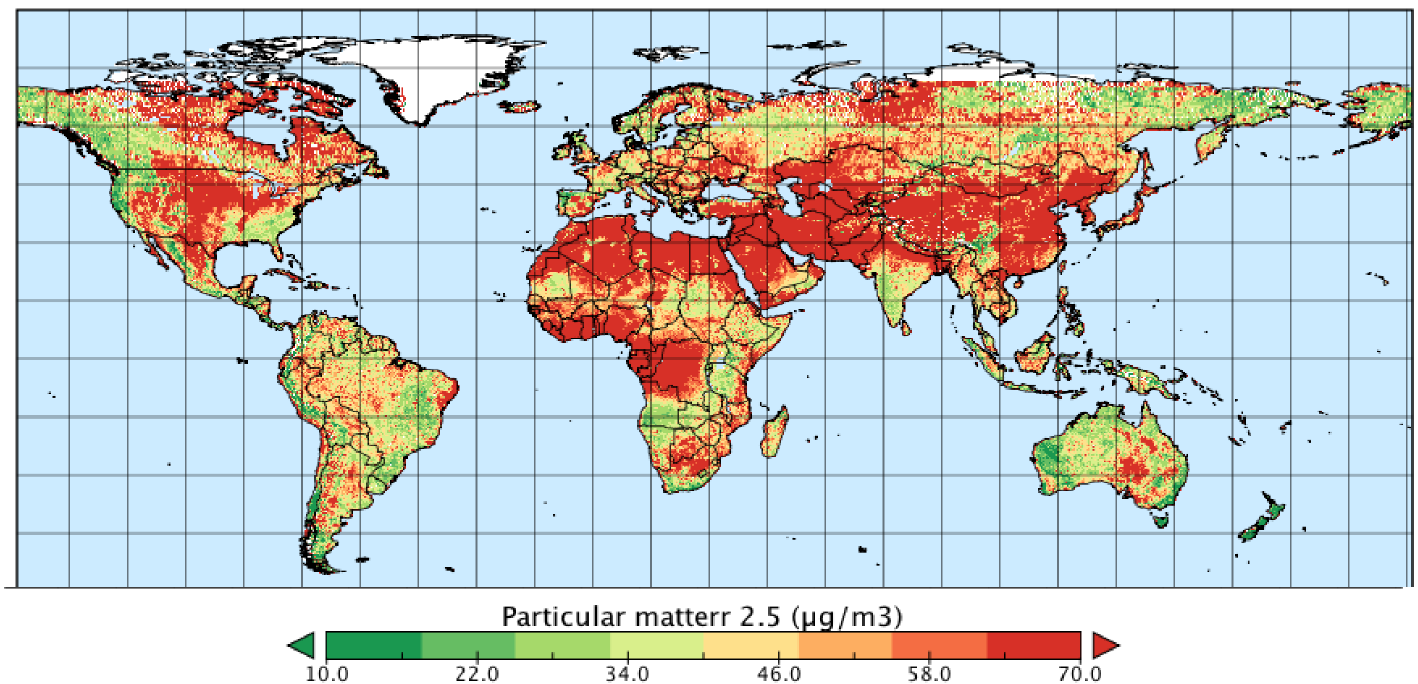
Ocean/ land discontinuity as averaging artifact



Gaps in spatial coverage (due to cloud mask or PARASOL swath) can be source of ocean/land discontinuity.

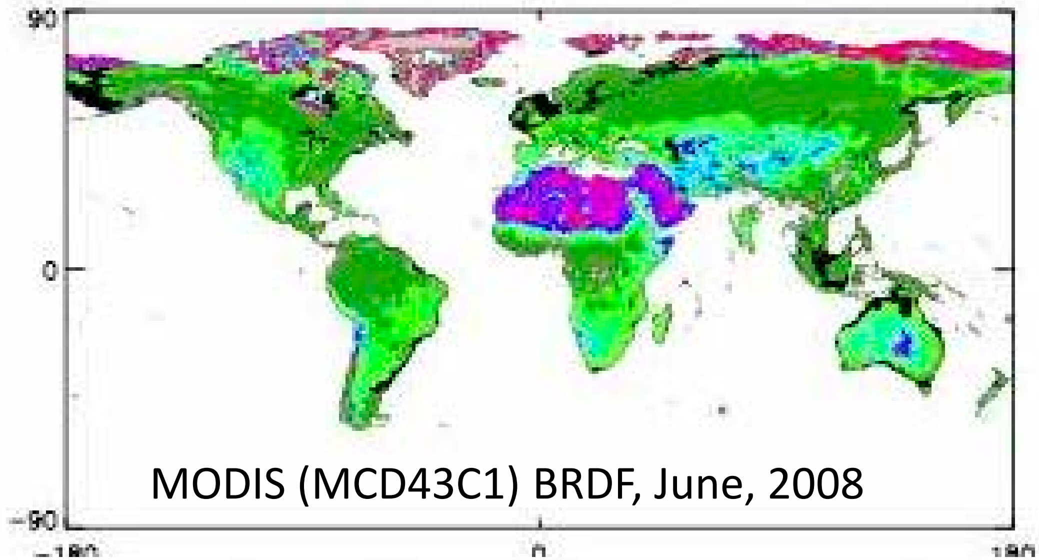


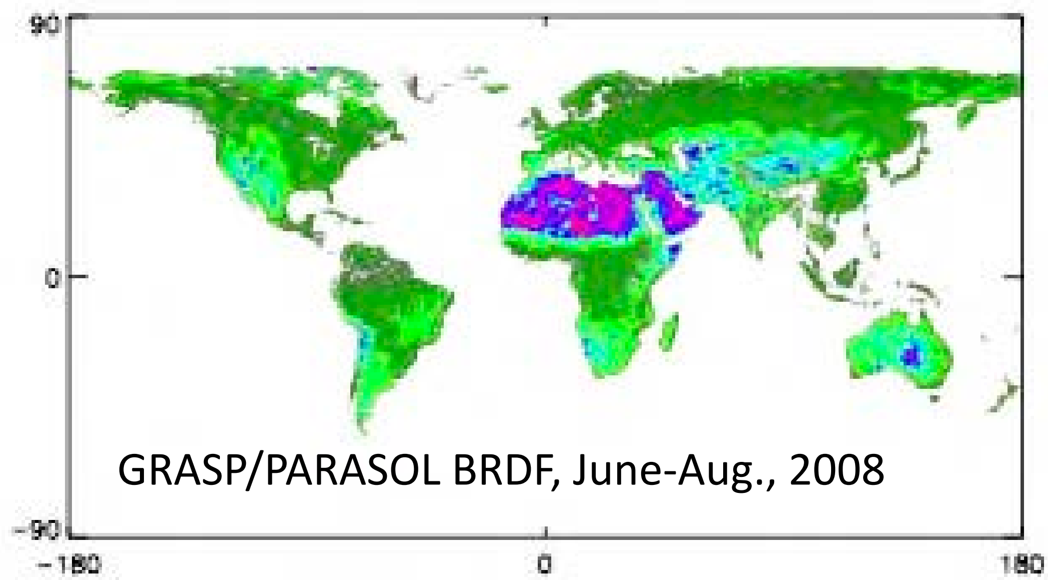
< 10
11 - 15
16 - 25
26 - 35
36 - 69
70 or more

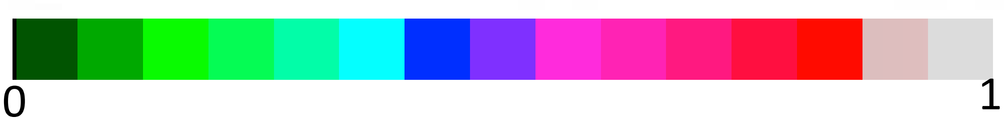


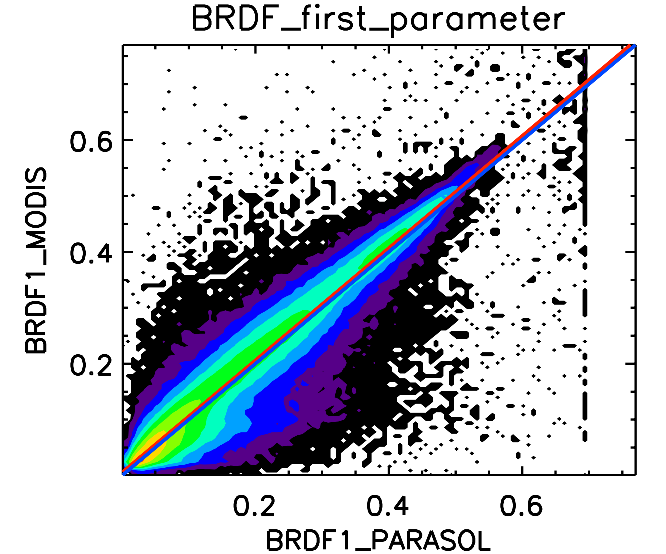
Particular matterr 2.5 (µg/m3)
10.0
22.0
34.0
46.0
58.0
70.0

First parameter (670 nm) of Ross-Li BRDF, 2008

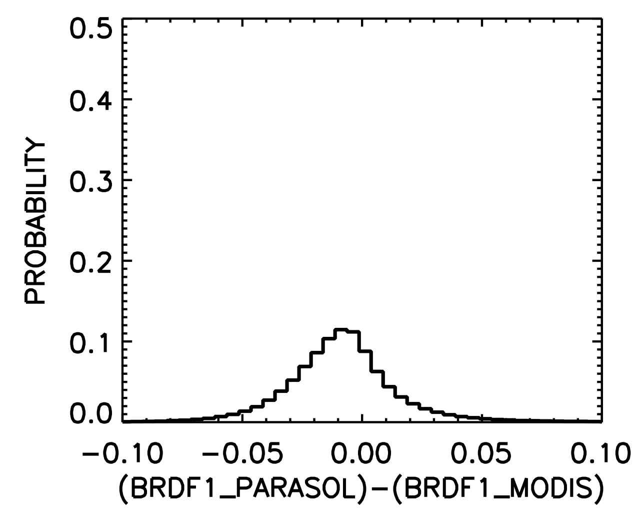






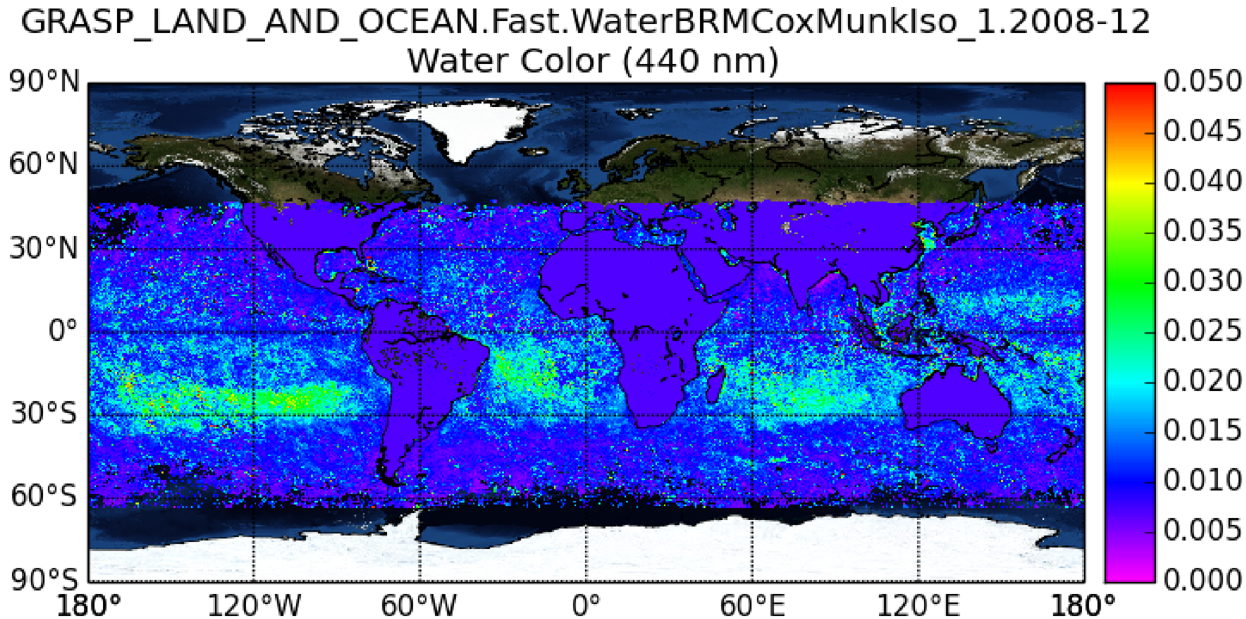


K=0.965 a= 1.00 b= 0.01 RMSE= 0.030



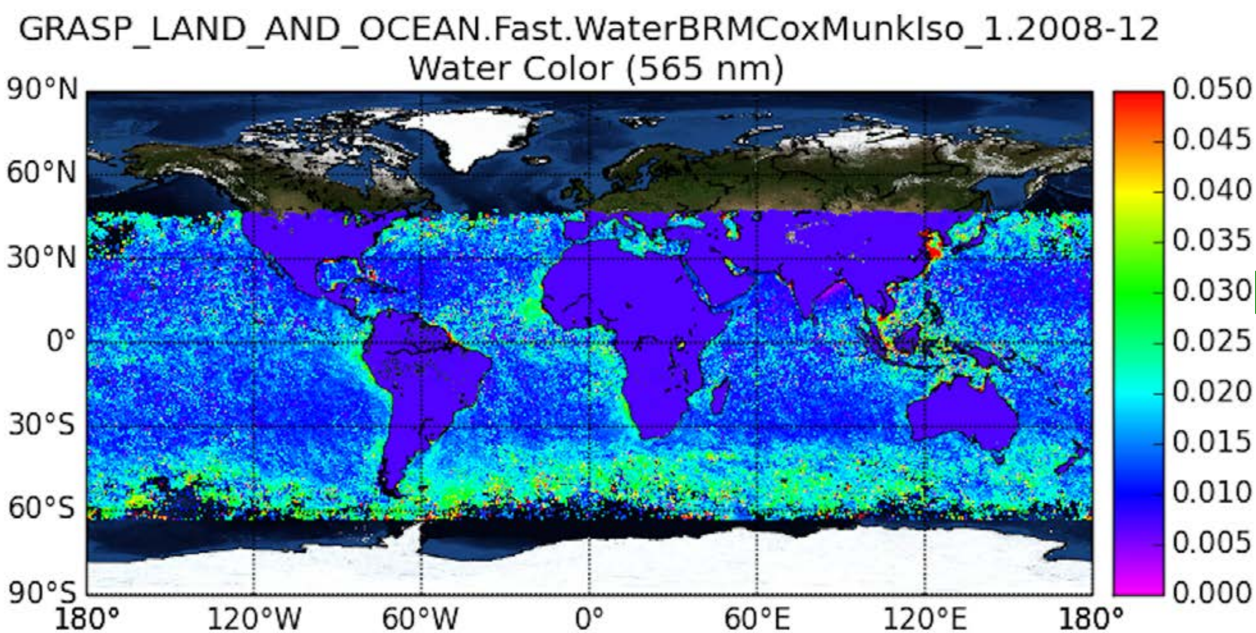
Aver. Value=−0.006 St.D.= 0.030 N=1222958

PARASOL water living radiance **December 2008,**



« Blue » water

« clean »



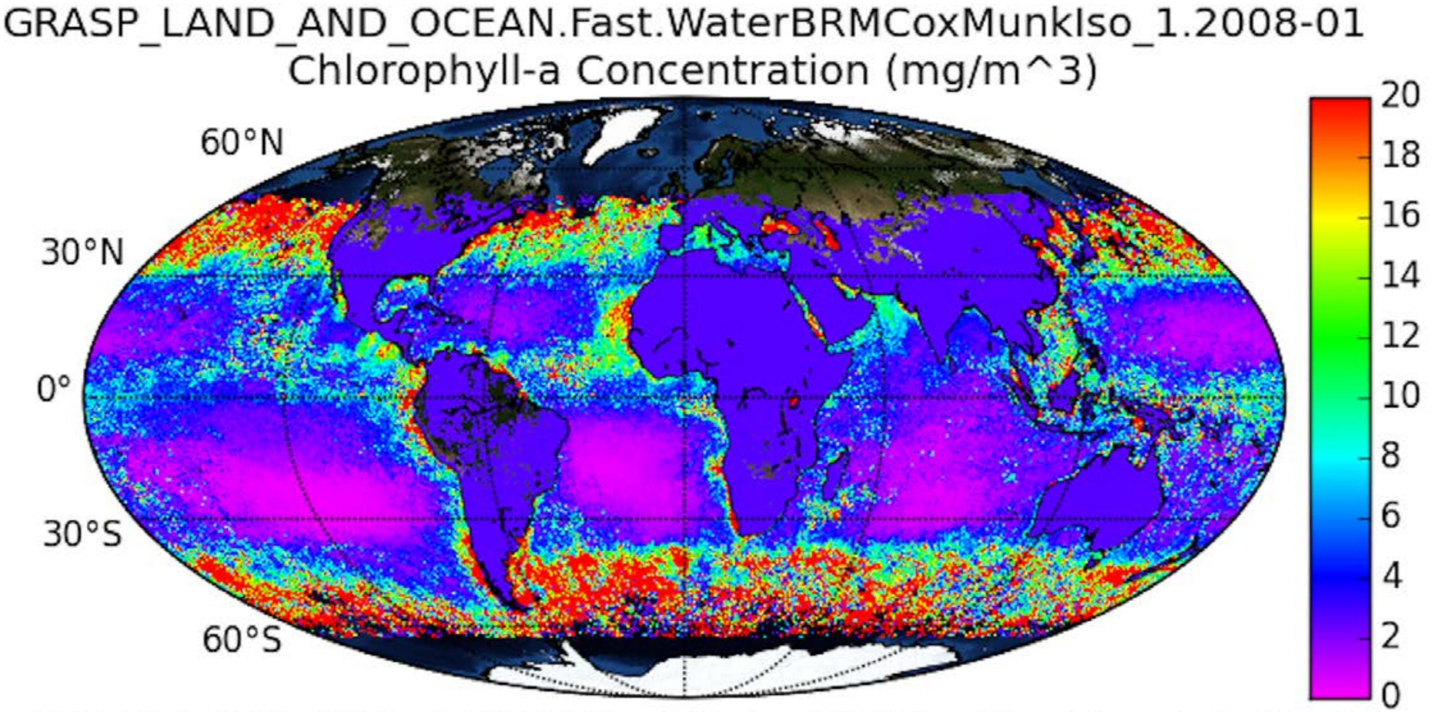
« Green » water

« bio active »,
bio-active (phytoplankton), etc.

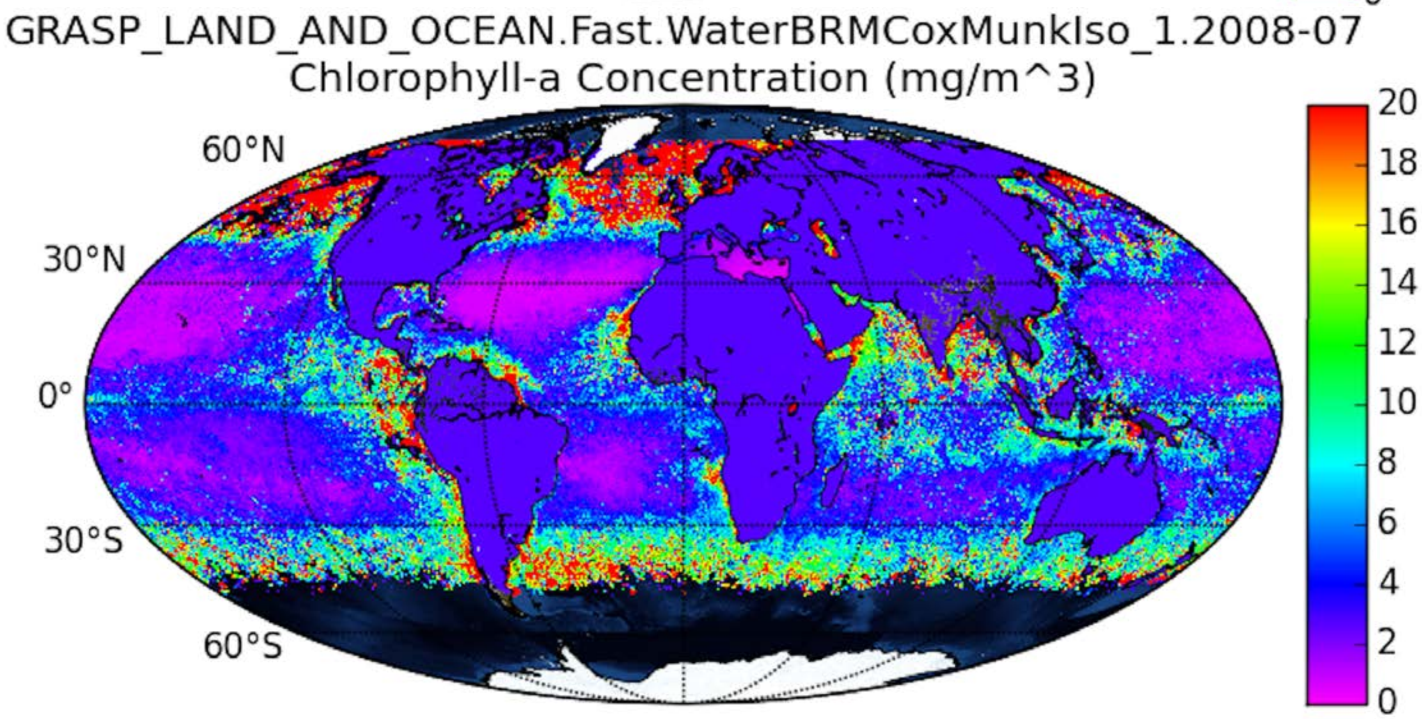
PARASOL 2008
Chlorophyll

Preliminary result…

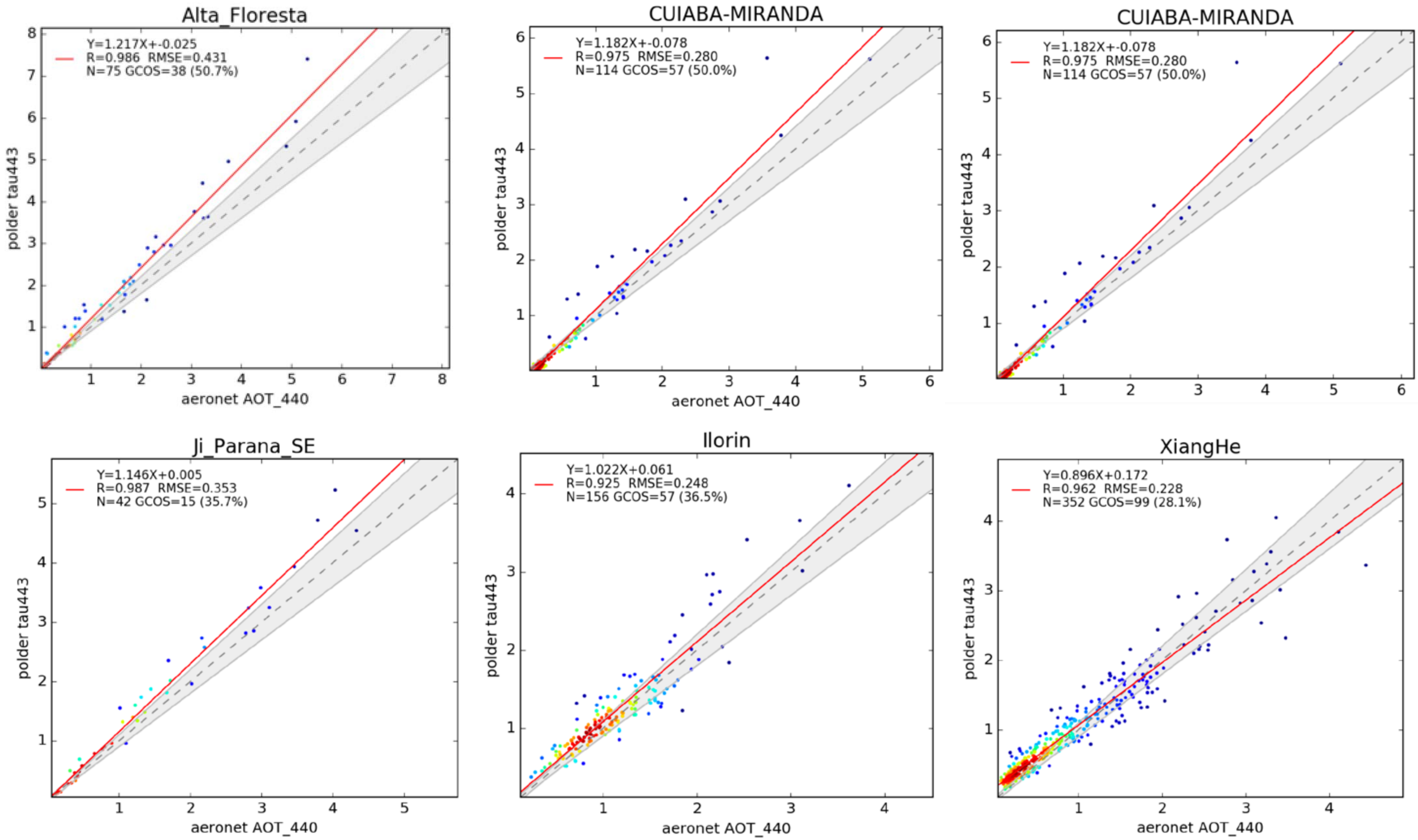
January



July



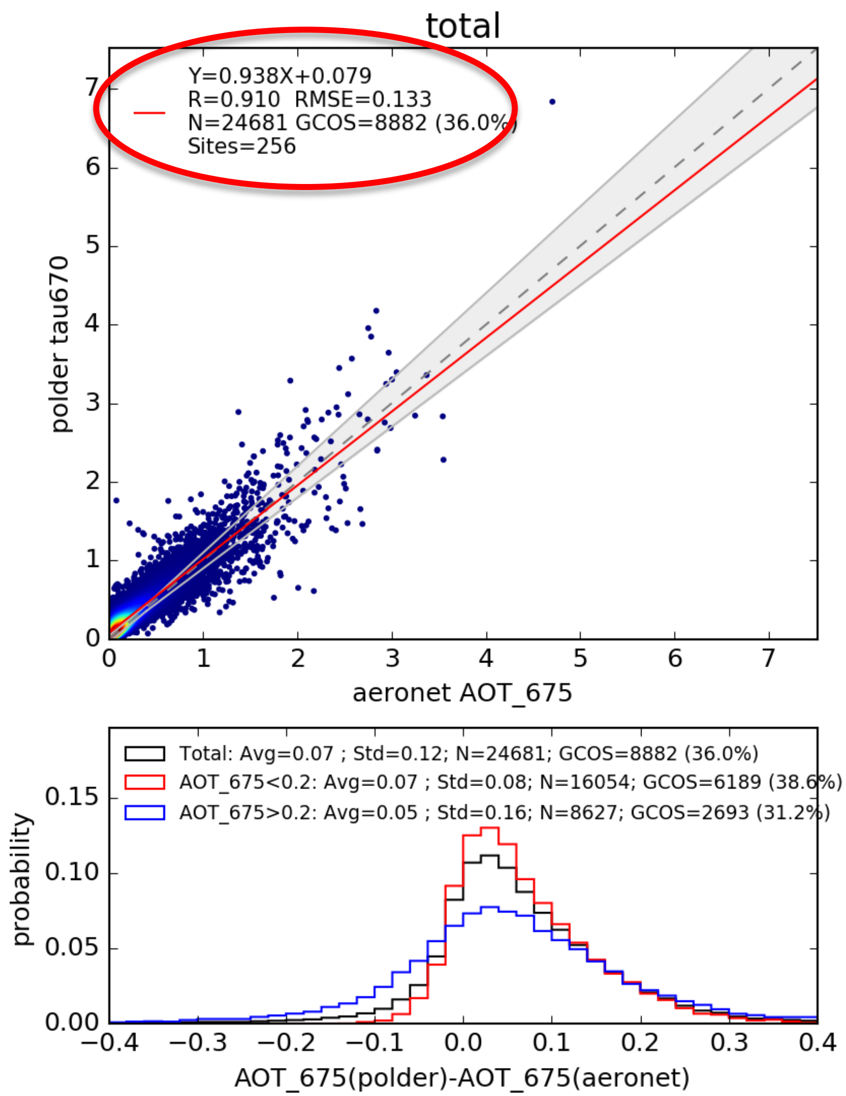
Validation against AERONET for high AOD biomass cases



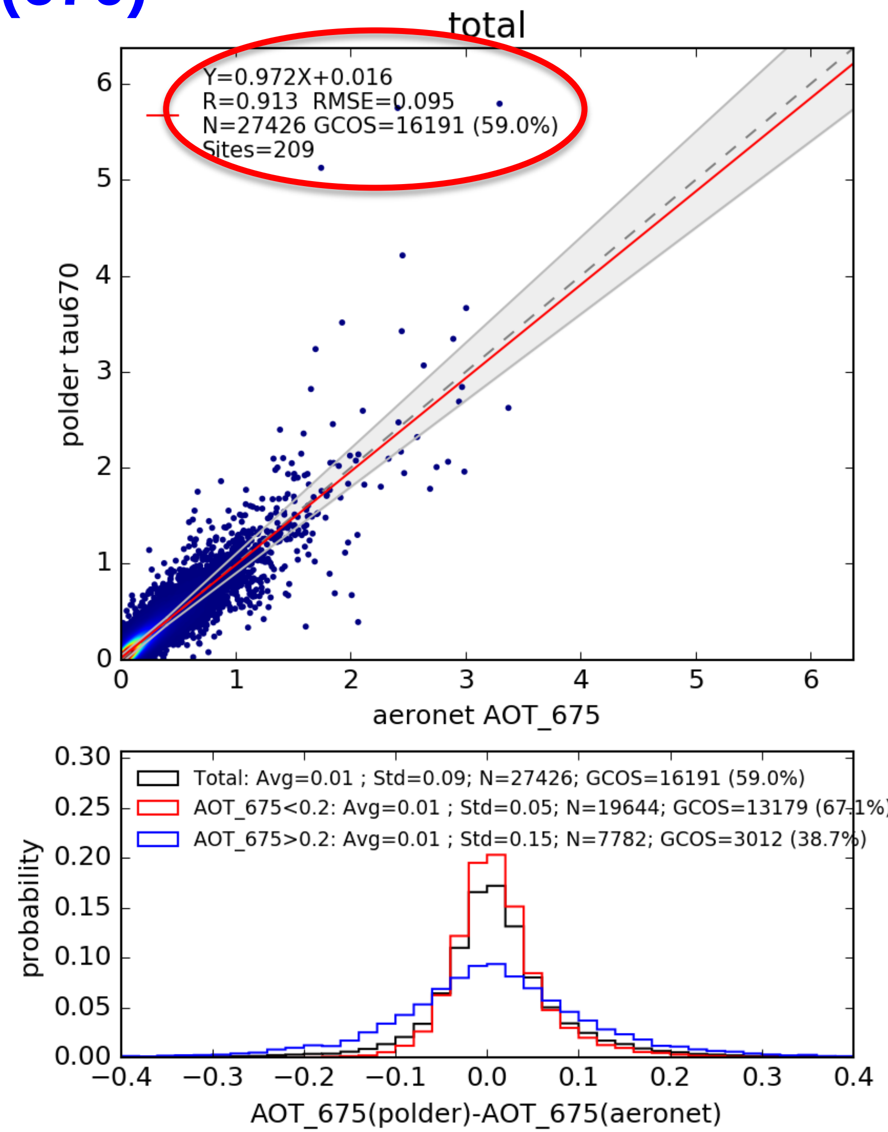
Validation vs AERONET 2004 - 2013

AOD(670)

Reference version



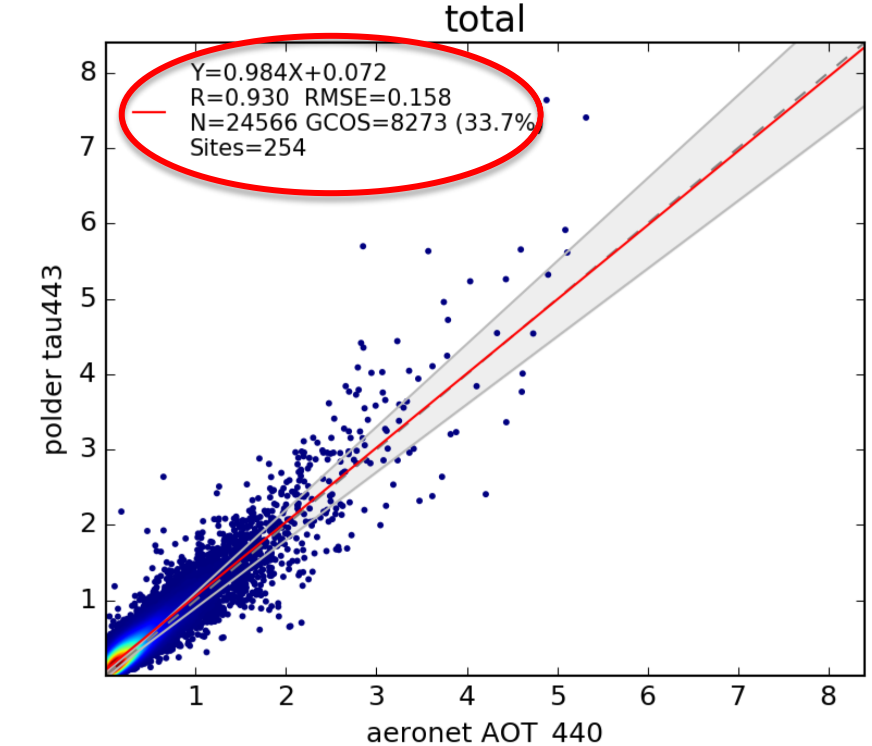
Component mixture

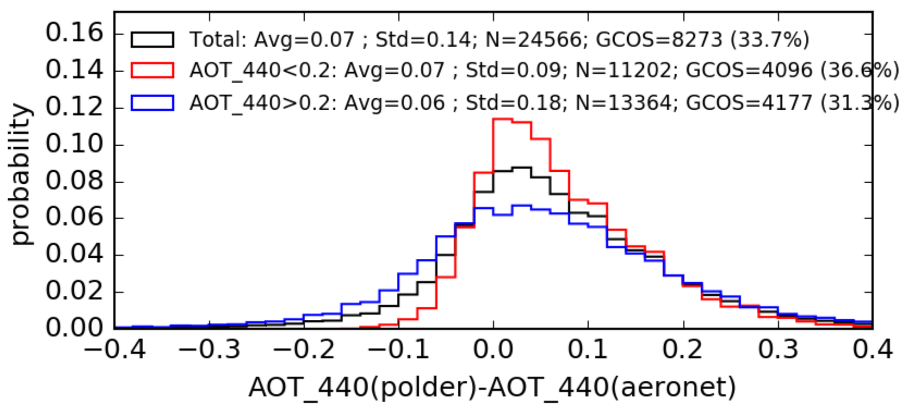


Validation vs AERONET 2004 - 2013

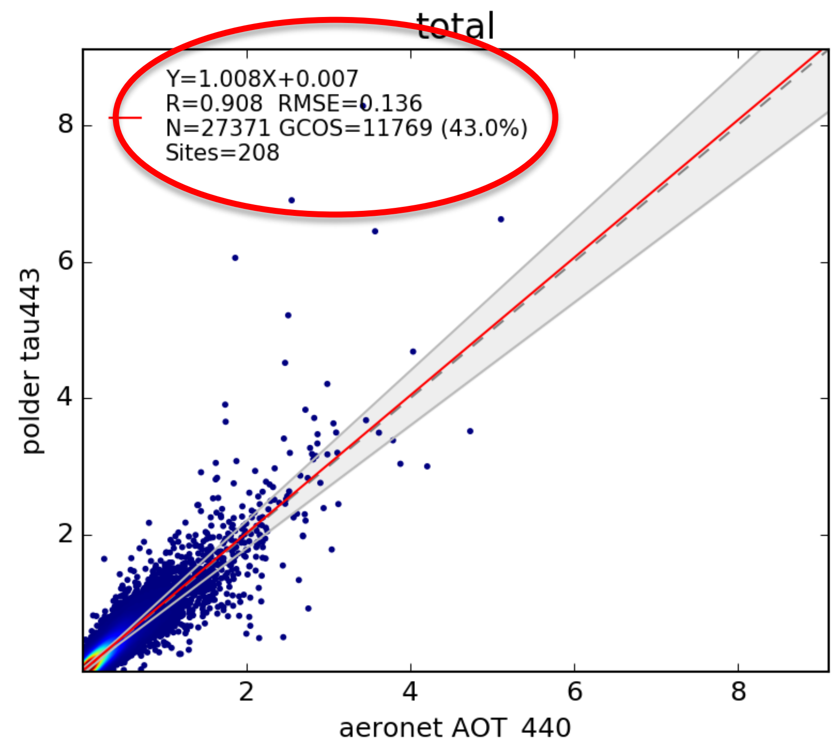
AOD(440)

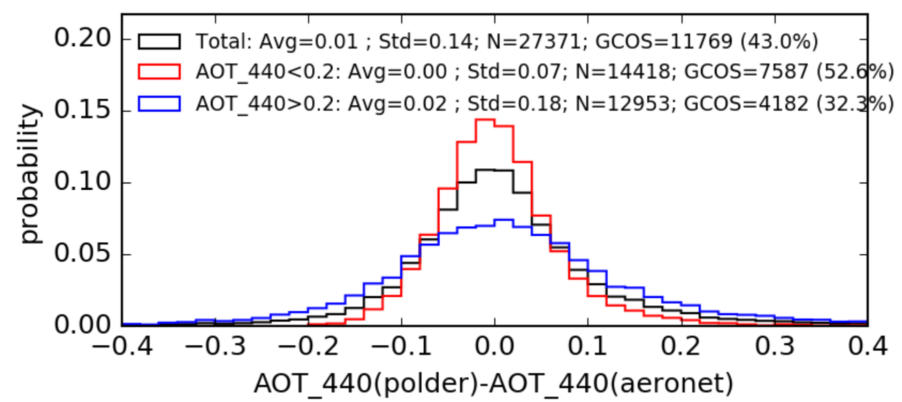
Reference version



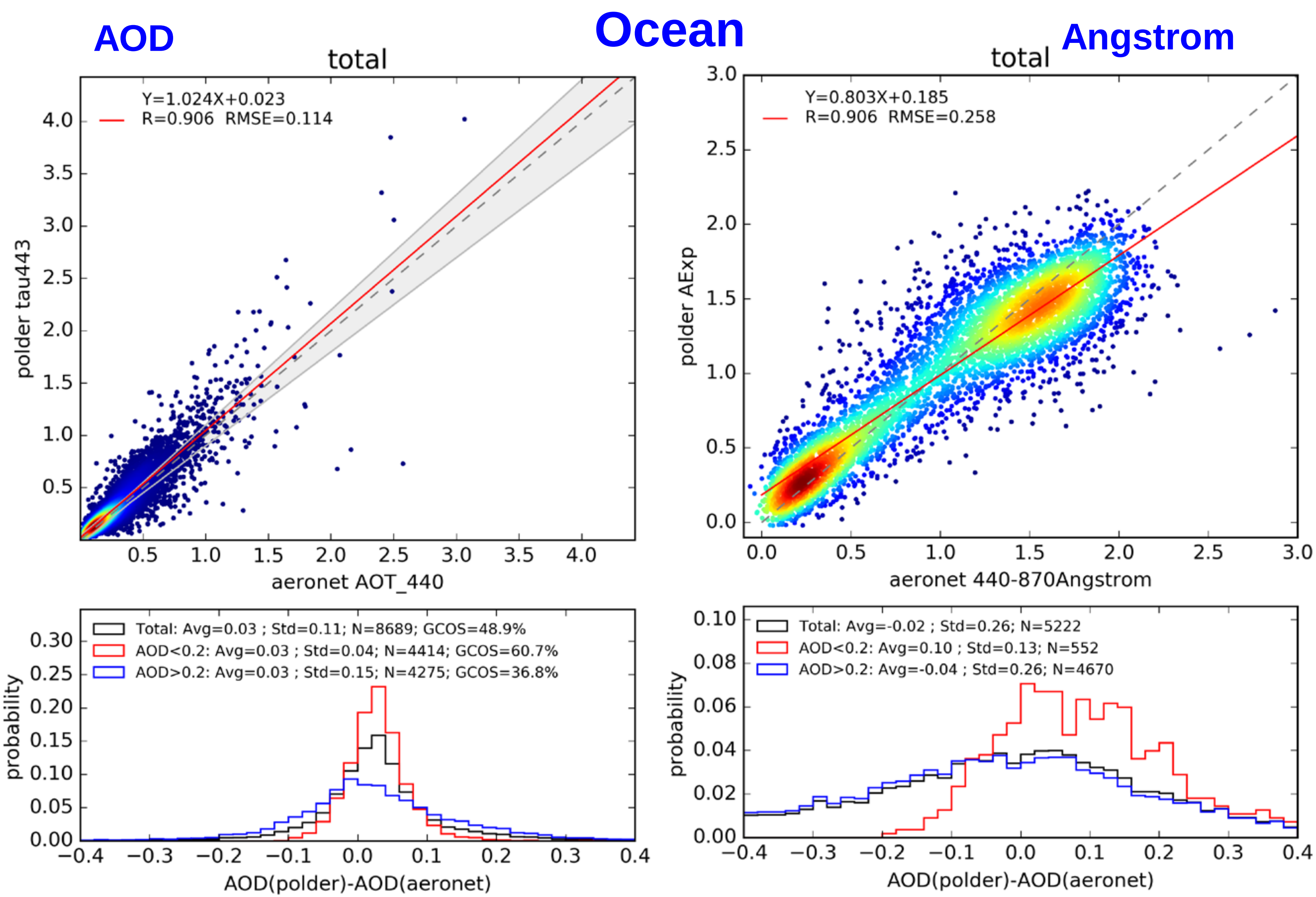


Component mixture

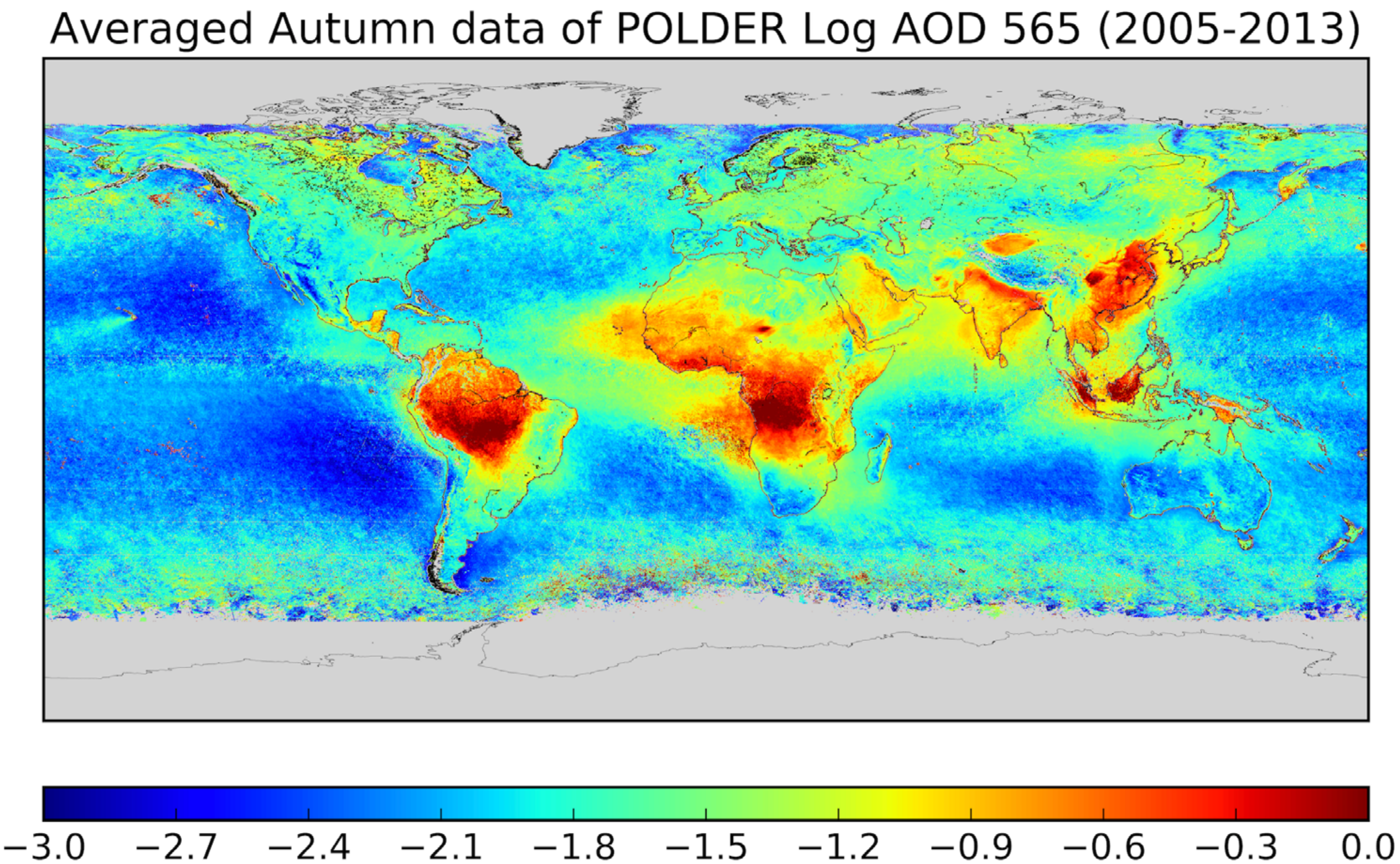




PARASOL Validation vs AERONET 2004 - 2013



AOD (565), Autumn (PARASOL archive average)



Amount of aerosol

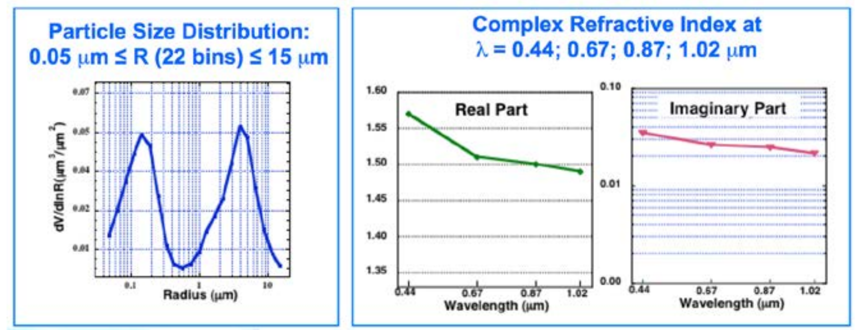
PARASOL:

- radiances: *(443, 490, 560, 670, 870, 1020 nm)*
- polarization: *(490, 670, and, 870 nm)*
- up to 16 viewing directions

↓ 144 measurements

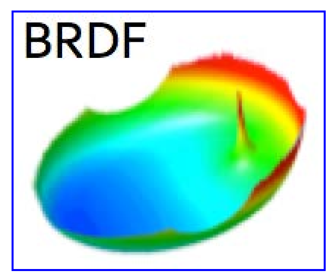
AEROSOL:

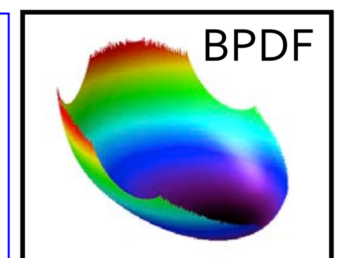
- size distribution (5 or more bins)
- spectral index of refraction (8 λ)
- sphericity fraction;
- aerosol height



SURFACE:

- BRDF (3 spectrally dependent parameters)
- BPDF (1 or 2 spectrally dependent parameters)





43 = (5 (SD) +12 (ref. ind.) + 1 (nonsp.) + 18 (BRDF) +6 (BPDF) + 1 (height)