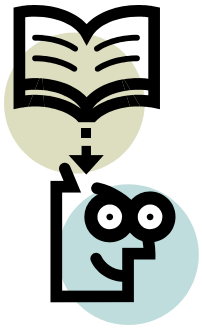
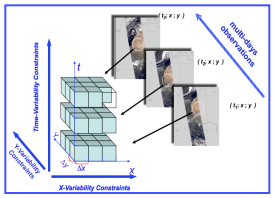


Results from GRASP: A Versatile Retrieval Algorithm for Multiple Platforms



GRASP Team:

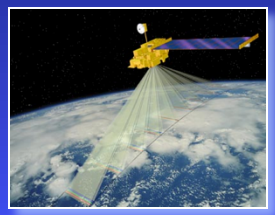
Oleg Dubovik[1], Pavel Litvinov[2], Tatyana Lapyonok[1], Fabrice Ducos[1], Xin Huang[1], Anton Lopatin[1], David Fuertes[2], Benjamin Torres[2], Yevgeny Derimian[1] and Cheng Chen[1]

1- University of Lille-1, CNRS, France

2- GRASP-SAS, Lille, France

M. Aspetsberger[2], G. Ogris[2], C. Federspiel[2], etc.

2- Catalysts GmbH, High Performance Computing, Linz, Austria



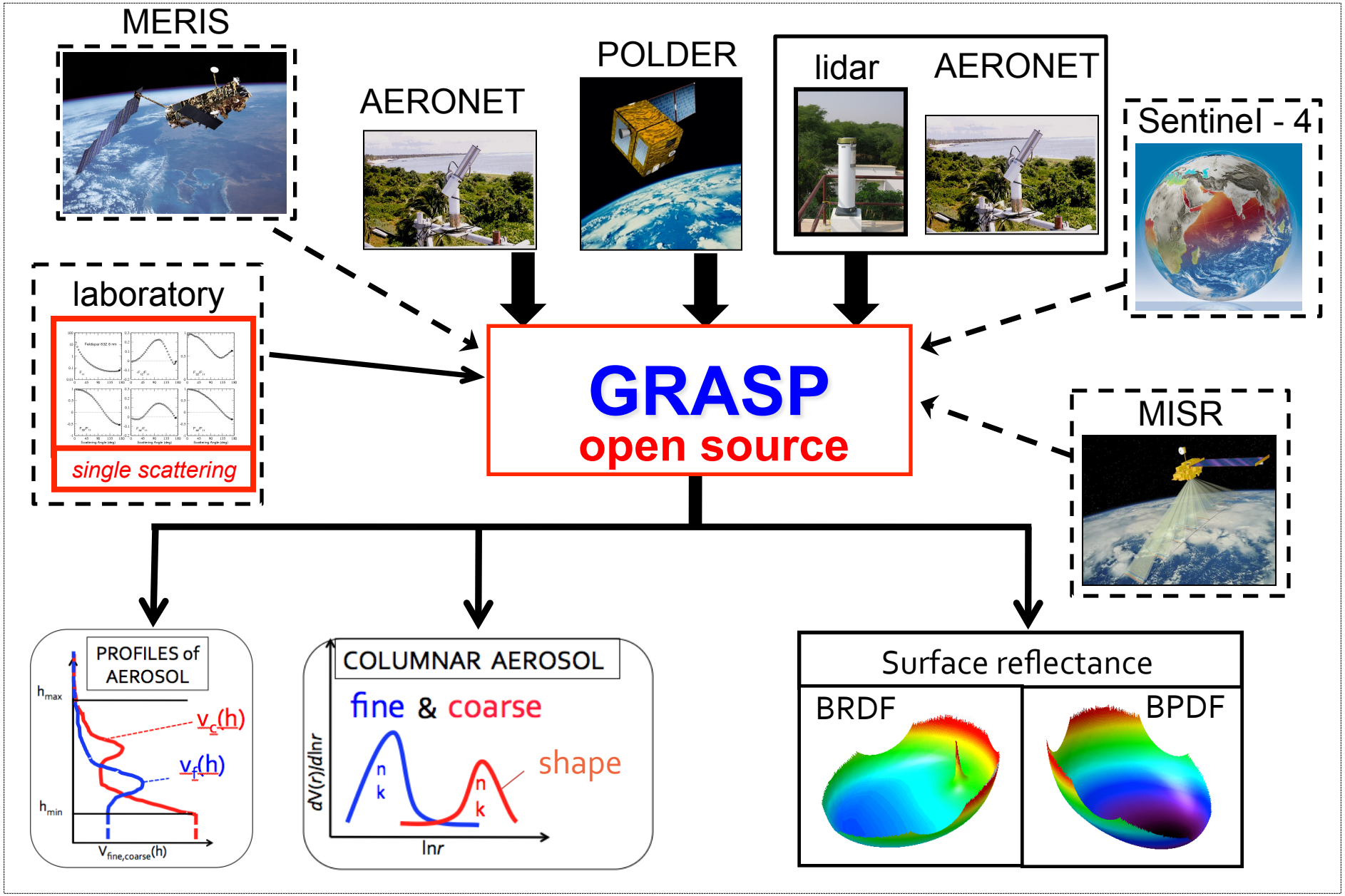
Yoram Kaufman Memorial Symposium , June 21-23, 2016 NASA/GSFC, USA

Principles learned:

✧ scientific and life optimism;

✧ positive ambition;

GRASP: Generalized Retrieval of Aerosol and Surface Properties



http://www.grasp-open.com

+337 868 051 80 office@grasp-sas.com

GRASP OPEN

Home Code Documentation Products Contact

Platform for GRASP open source code

Get public access to the code, documentation and user assistance

GET STARTED WITH DOCUMENTATION

GRASP is a highly accurate aerosol retrieval algorithm that processes properties of aerosol- and land-surface-reflectance. It infers nearly 50 aerosol and surface parameters including particle size distribution, the spectral index of refraction, the degree of sphericity and absorption. The algorithm is designed for the enhanced characterization of aerosol properties from spectral, multiangular polarimetric remote sensing observations. GRASP works under different conditions, including bright surfaces such as deserts, where the reflectance overwhelms the signal of aerosols. GRASP is highly versatile and allows input from a wide variety of satellite and surface measurements.

GET STARTED

GRASP Code

Download the GRASP-code, install it and run it for a large number of different aerosol measurements. Signup for the latest version of GRASP-code: stable, fast and easy to use.

Code Documentation

Complete documentation about the code, API and features of GRASP.

GRASP specifics:

Inversion scheme:

- ✓ search in continues space of solution for many parameters (aerosol + surface) ;
- ✓optimization as Multi-term LSM;
- ✓adapted for synergy of observations: multi-pixel retrieval;
- ✓single fitting procedure ;

$$2\Psi(\mathbf{x}) = \sum_{i=1}^{N}\left[\Delta\mathbf{y}_i^{\mathrm{T}}\mathbf{W}_{\mathrm{f},i}^{-1}\Delta\mathbf{y}_i + \gamma_{\mathrm{s}}\mathbf{x}_i^{\mathrm{T}}\boldsymbol{\Omega}_{\mathrm{s},i}\mathbf{x}_i + \gamma_{\mathrm{a}}(\mathbf{x}_i - \mathbf{x}_i^*)^{\mathrm{T}}\mathbf{W}_{\mathrm{a},i}^{-1}(\mathbf{x}_i - \mathbf{x}_i^*)\right] + \mathbf{x}^{\mathrm{T}}\boldsymbol{\Omega}_{\text{inter-pixel}}\mathbf{x}$$

- ✓no solution modifications (no averaging, etc.)
- ✓all parameters (43) are retrieved simultaneously at original resolution of (~6 km) ;
- ✓no location specific assumptions (except land/water/snow);
- ✓all a priori constraints general for all pixels (~6 km);
- ✓singe initial guess;

Promising aspects of GRASP development:

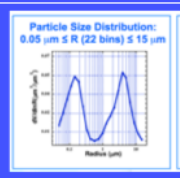
✓Improvements in retrieval accuracy;

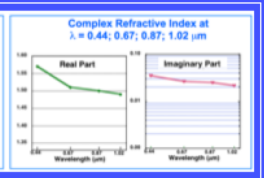
✓Deriving new information;

✓Straightforward applications to: - to diverse observations;
- to different characteristics;

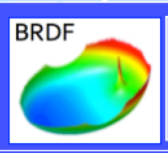
PARASOL:
- radiances: *(443, 490, 560, 670, 870, 1020 nm)*;
- polarization: *(490, 670, and, 870 nm)*;
- up to 16 viewing directions

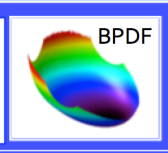
AEROSOL:
- size distribution (5 or more bins);
- spectral index of refraction (8 λ);
- sphericity fraction;
- aerosol height





SRFACE:
- BRDF
(3 spectrally dependent parameters);
(1 or 2 spectrally dependent parameters);

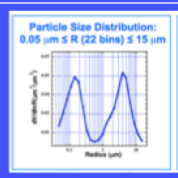


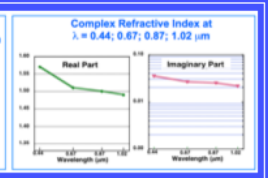


43 = (5 (SD) +12 (ref. ind.) + 1 (nonsp.) + 18 (BRDF) +6 (BPDF) + 1 (height)

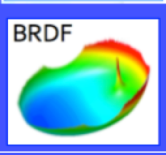
MERIS:
- radiances at seven wavelengths:
(413, 443, 490, 510, 560, 665, and 870 nm);
- single view

AEROSOL:
- size distribution (5 or more bins);
- spectral index of refraction (7 λ);
- sphericity;



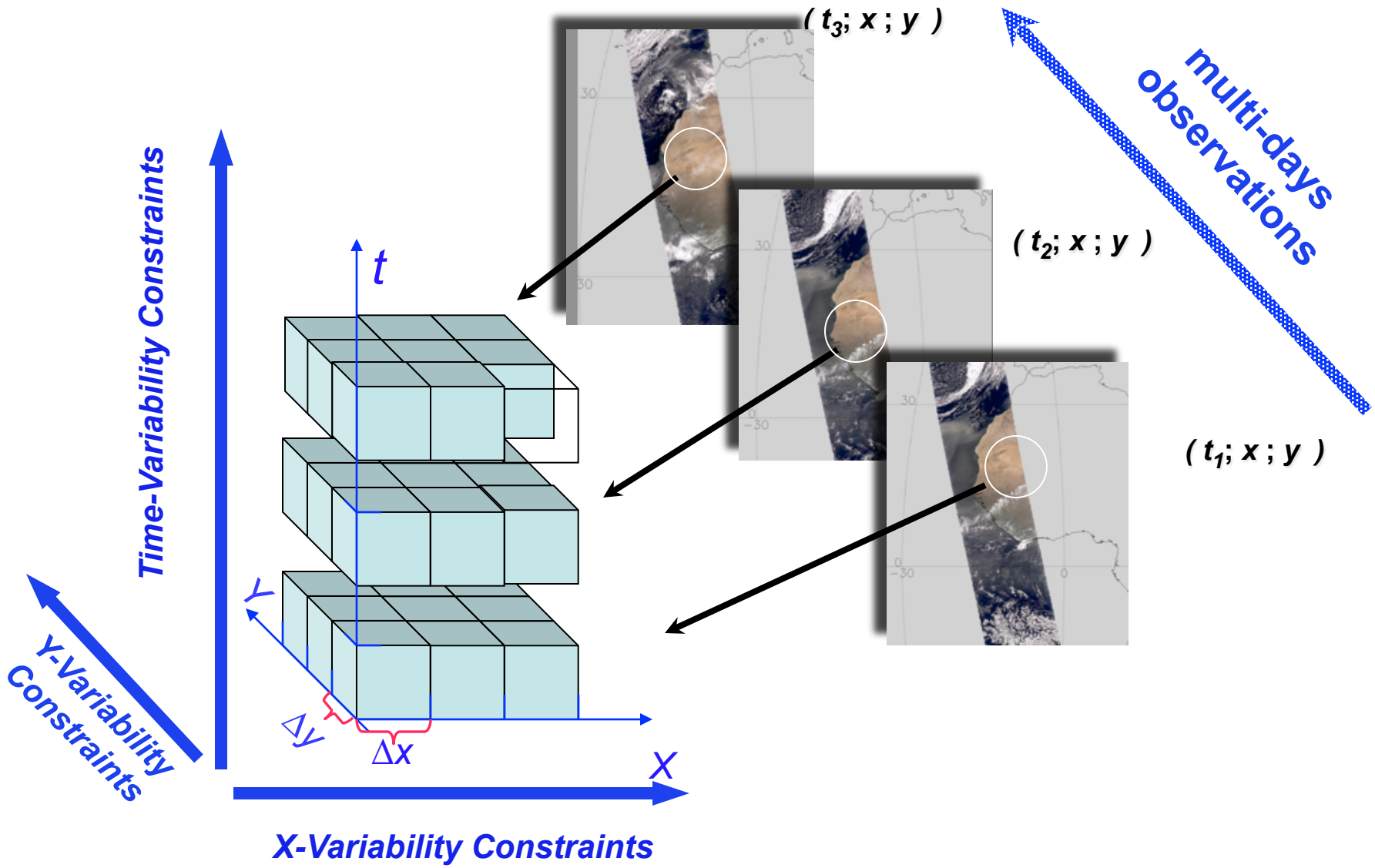


SRFACE:
- BRDF
(3 spectrally dependent parameters);



41 = (5 (SD) +14 (ref. ind.) + 1 (nonsp.) + 21 (BRDF))

The concept of multi-pixel retrieval



Multi - Pixel Retrieval:

$$\begin{cases} \begin{pmatrix} \boldsymbol{f}_1^* \\ O_1^* \end{pmatrix} \\ \begin{pmatrix} \boldsymbol{f}_2^* \\ O_2^* \end{pmatrix} \\ \begin{pmatrix} \boldsymbol{f}_3^* \\ O_3^* \end{pmatrix} \\ \cdots \\ O_t^* \\ O_x^* \\ O_y^* \end{cases} = \begin{pmatrix} \begin{pmatrix} \mathbf{F}_1 \\ \mathbf{S}_1 \end{pmatrix} & 0 & 0 \\ 0 & \begin{pmatrix} \mathbf{F}_2 \\ \mathbf{S}_2 \end{pmatrix} & 0 \\ 0 & 0 & \begin{pmatrix} \mathbf{F}_3 \\ \mathbf{S}_3 \end{pmatrix} \\ \cdots & \cdots & \cdots \\ \mathbf{S}_{t,1} & \mathbf{S}_{t,2} & \mathbf{S}_{t,2} \\ \mathbf{S}_{x,1} & \mathbf{S}_{x,2} & \mathbf{S}_{x,3} \\ \mathbf{S}_{y,1} & \mathbf{S}_{y,2} & \mathbf{S}_{y,3} \end{pmatrix} \begin{pmatrix} \boldsymbol{a}_1 \\ \boldsymbol{a}_2 \\ \boldsymbol{a}_3 \end{pmatrix} + \begin{pmatrix} \begin{pmatrix} \Delta_1^m \\ \Delta_1^a \end{pmatrix} \\ \begin{pmatrix} \Delta_2^m \\ \Delta_2^a \end{pmatrix} \\ \begin{pmatrix} \Delta_3^m \\ \Delta_3^a \end{pmatrix} \\ \cdots \\ \Delta_t^a \\ \Delta_x^a \\ \Delta_y^a \end{pmatrix}$$

Single-Pixel Data (PARASOL measurements and physical a priori constraints) ***are used by the same way as in Single-Pixel retrieval.***

Multi-Pixel a priori constraints *(e.g.Dubovik et al. 2008):*

- limited ***spatial*** variability of each aerosol /surface parameter
- limited ***temporal*** variability of each aerosol /surface parameter

NOTE: *degree of variability constraints (smoothnes) can be different and adequately chosen for each parameter*

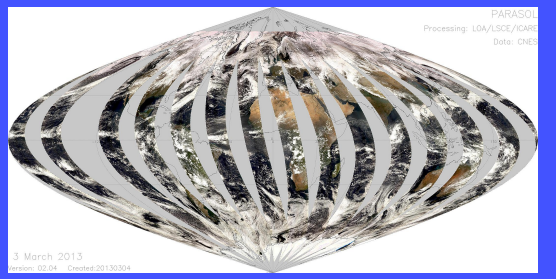
Multi-term LSM ***Multi-Pixel Solution:***

$$\begin{pmatrix} \boldsymbol{a}_1 \\ \boldsymbol{a}_2 \\ \boldsymbol{a}_3 \end{pmatrix} = \left[\begin{pmatrix} \mathbf{F}_1^T \mathbf{W}_1^{-1} \mathbf{F}_1 & 0 & 0 \\ 0 & \mathbf{F}_2^T \mathbf{W}_2^{-1} \mathbf{F}_2 & 0 \\ 0 & 0 & \mathbf{F}_3^T \mathbf{W}_3^{-1} \mathbf{F}_3 \end{pmatrix} + \begin{pmatrix} \gamma_1 \boldsymbol{\Omega}_1 & 0 & 0 \\ 0 & \gamma_2 \boldsymbol{\Omega}_2 & 0 \\ 0 & 0 & \gamma_3 \boldsymbol{\Omega}_3 \end{pmatrix} + \gamma_x \boldsymbol{\Omega}_x + \gamma_y \boldsymbol{\Omega}_y + \gamma_t \boldsymbol{\Omega}_t \right]^{-1} \begin{pmatrix} \mathbf{F}_1^T \mathbf{W}_1^{-1} \Delta \boldsymbol{f}_1^p \\ \mathbf{F}_2^T \mathbf{W}_2^{-1} \Delta \boldsymbol{f}_2^p \\ \mathbf{F}_3^T \mathbf{W}_3^{-1} \Delta \boldsymbol{f}_3^p \end{pmatrix}$$

,where $\boldsymbol{\Omega}_x = \mathbf{S}_x^T \mathbf{S}_x;\ \boldsymbol{\Omega}_y = \mathbf{S}_y^T \mathbf{S}_y;\ \boldsymbol{\Omega}_t = \mathbf{S}_t^T \mathbf{S}_t;\ \gamma_x = \frac{\varepsilon_f^2}{\varepsilon_x^2};\ \gamma_y = \frac{\varepsilon_f^2}{\varepsilon_y^2};\ \gamma_t = \frac{\varepsilon_f^2}{\varepsilon_t^2}$

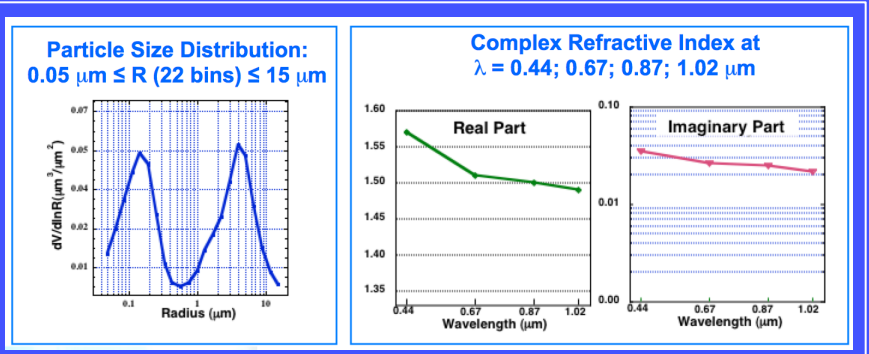
PARASOL:

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



AEROSOL:

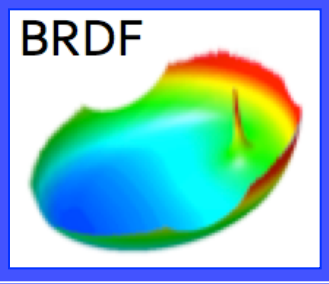
- size distribution (5 or more bins);
- spectral index of refraction (8 λ);
- sphericity fraction;
- aerosol height

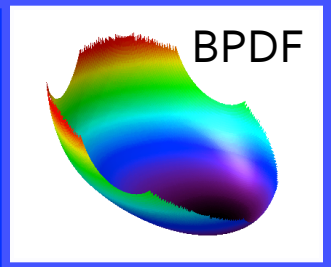


SRFACE:

- BRDF

(3 spectrally dependent parameters);
(1 or 2 spectrally dependent parameters);



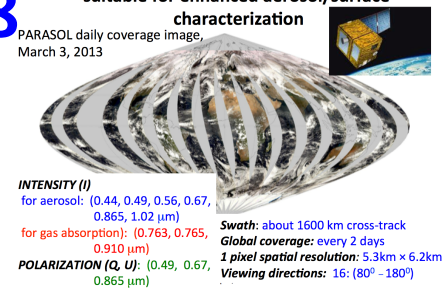


43 = (5 (SD) +12 (ref. ind.) + 1 (nonsp.) + 18 (BRDF) +6 (BPDF) + 1 (height)

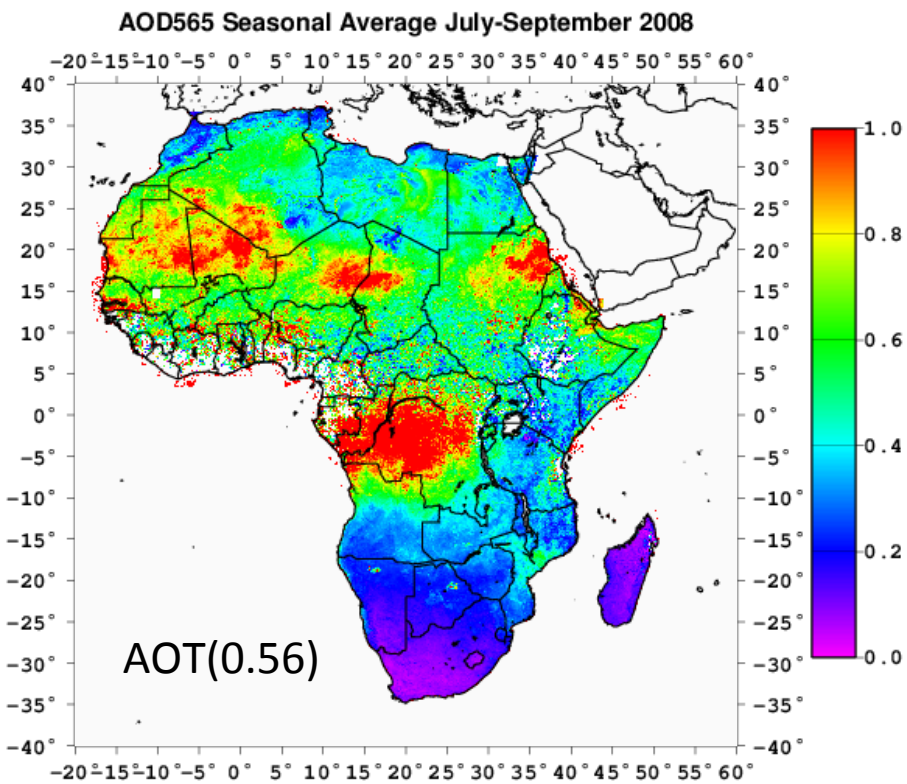
EXAMPLES of PARASOL/GRASP retrievals - 2008

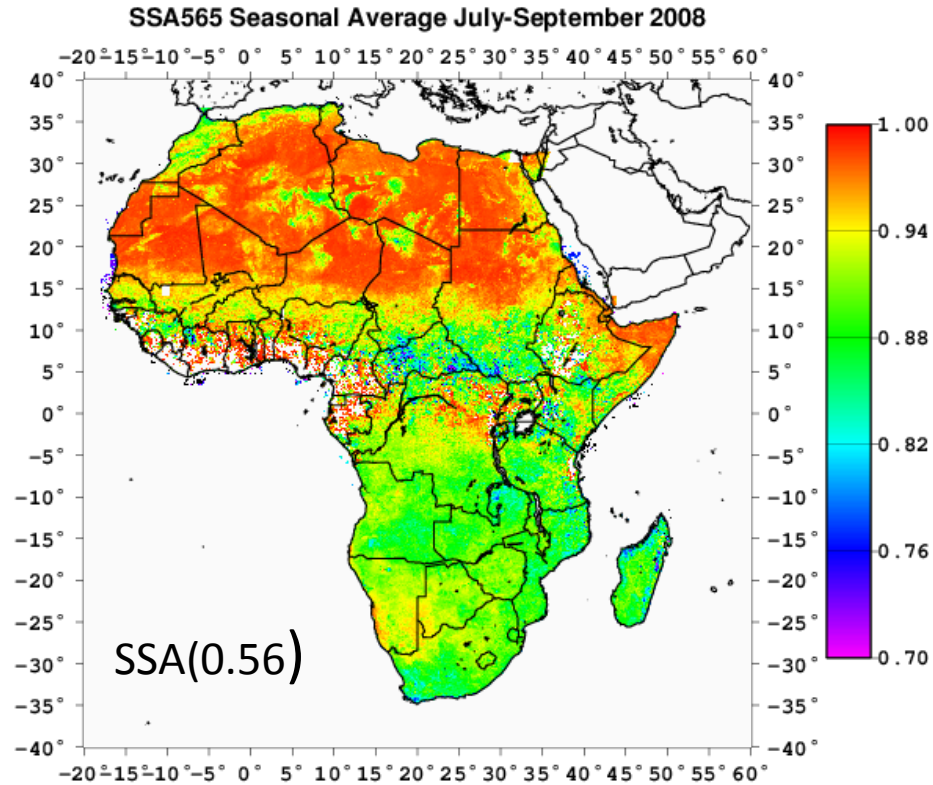
NO location specific ASSUMPTIONS on aerosol and surface

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



All calculation on the fly





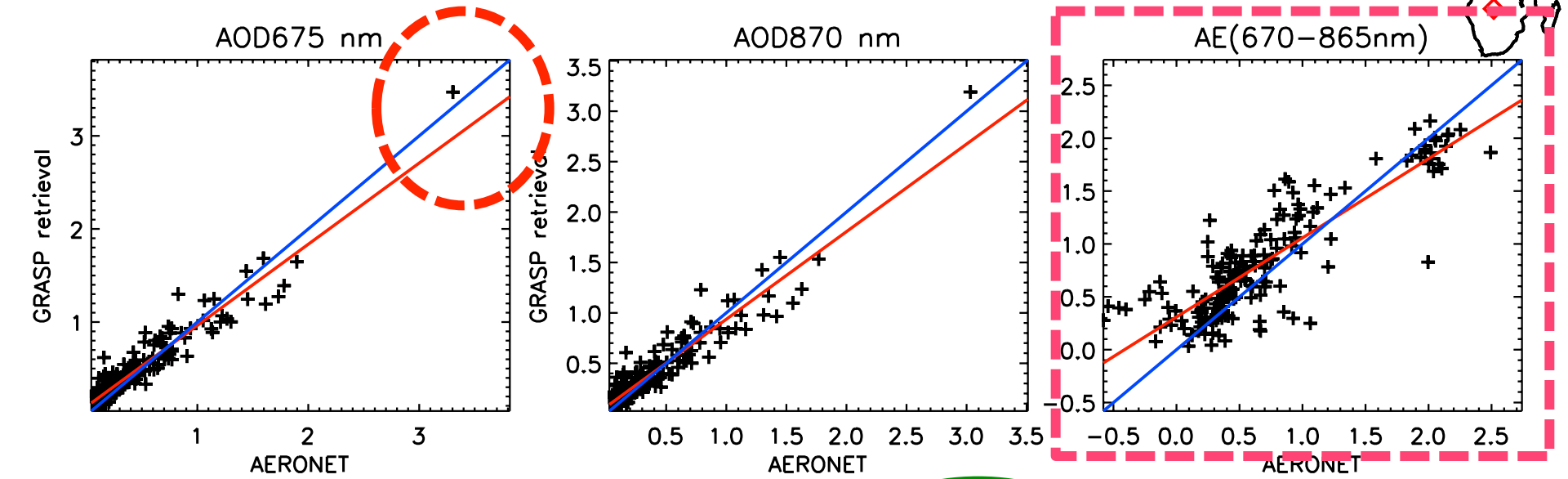
AOT(0.56) - **loading**

SSA(0.56) - **absorption**

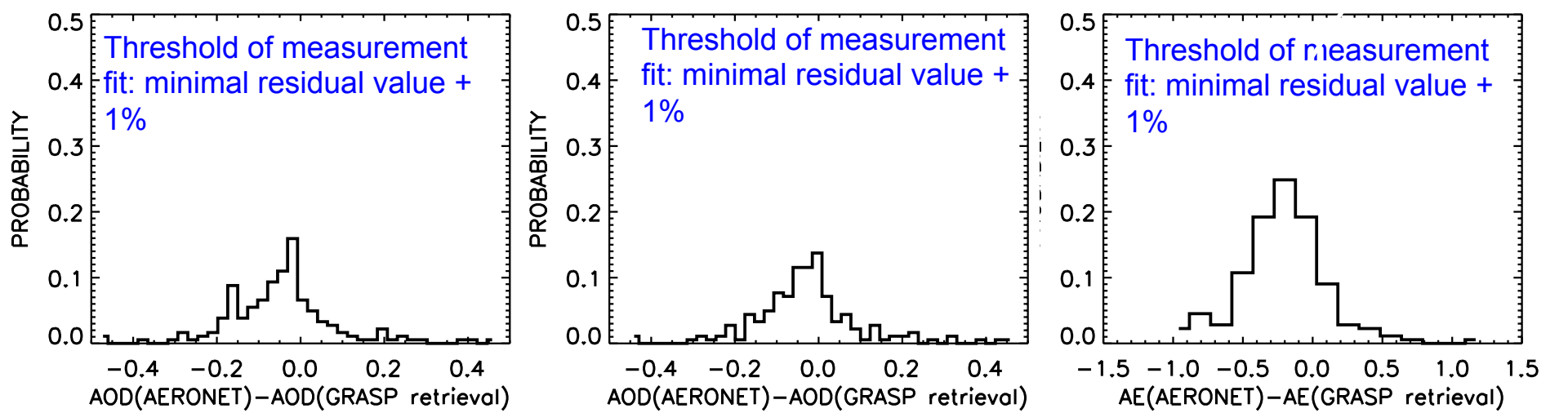
Processed at ICARE

PARASOL/GRASP vs. AERONET (Africa, 2008).

Mongu, Banizoumbou, IER_Cinzana, Agoufou, Ilorin, DMN_Maine_Soroa



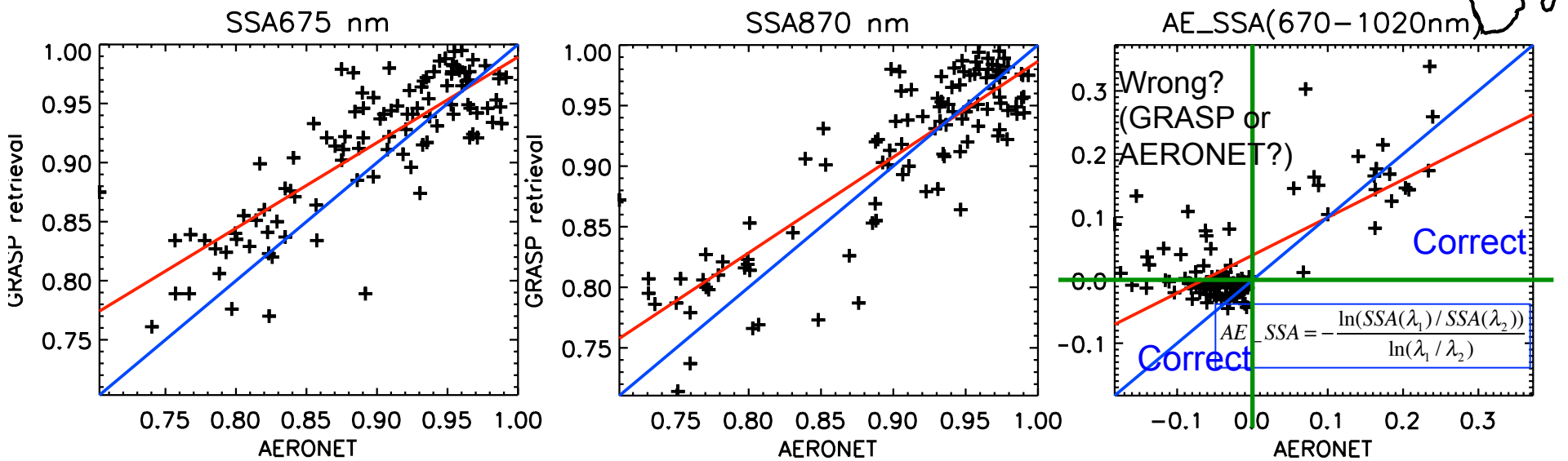
K=0.951 a= 0.87 b= 0.09 RMSE= 0.135 K=0.945 a= 0.87 b= 0.07 RMSE= 0.129 K=0.866 a= 0.75 b= 0.31 RMSE= 0.346



Aver. Value=−0.034 St.D.= 0.130 N=182 Aver. Value=−0.016 St.D.= 0.128 N=182 Aver. Value=−0.141 St.D.= 0.316 N=177

PARASOL/GRASP vs. AERONET (Africa, 2008).

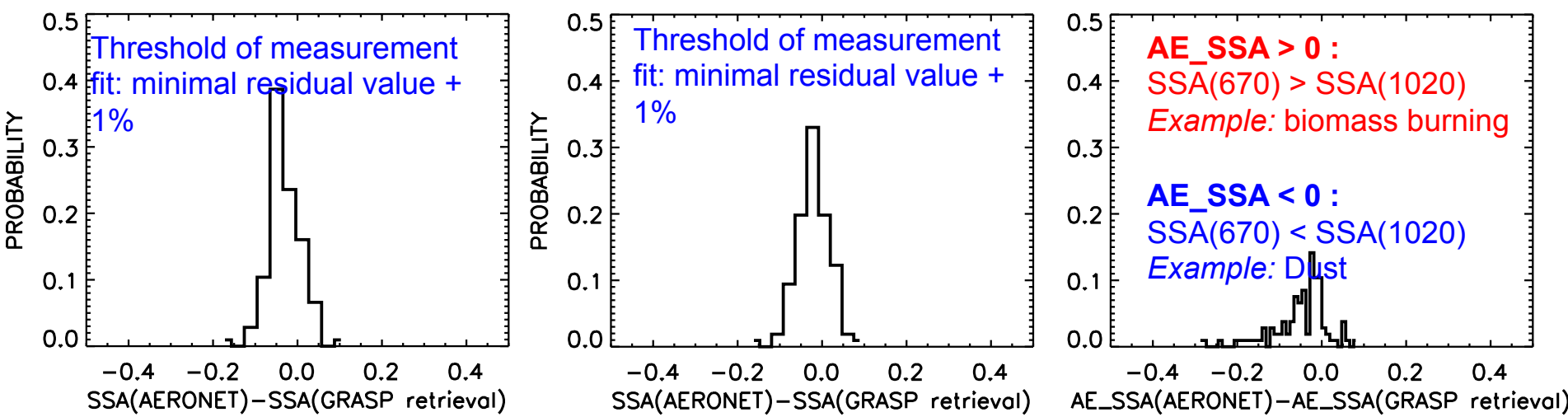
Mongu, Banizoumbou, IER_Cinzana, Agoufou, Ilorin, DMN_Maine_Soroa



K=0.827 a= 0.73 b= 0.26 RMSE= 0.042

K=0.869 a= 0.79 b= 0.20 RMSE= 0.039

K=0.703 a= 0.60 b= 0.04 RMSE= 0.080



Aver. Value=−0.018 St.D.= 0.038 N=106

Aver. Value=−0.007 St.D.= 0.038 N=106

Aver. Value=−0.046 St.D.= 0.066 N=106

GRASP specifics:

- more time consuming than LUT

✓ Software implementation:

- advance programing:

✓ highly parallelized (currently runs at LOA at ~100 CPU)

✓ uses CPI / GPU;

✓ Current inversion is 0.1-0.3 sec per sec

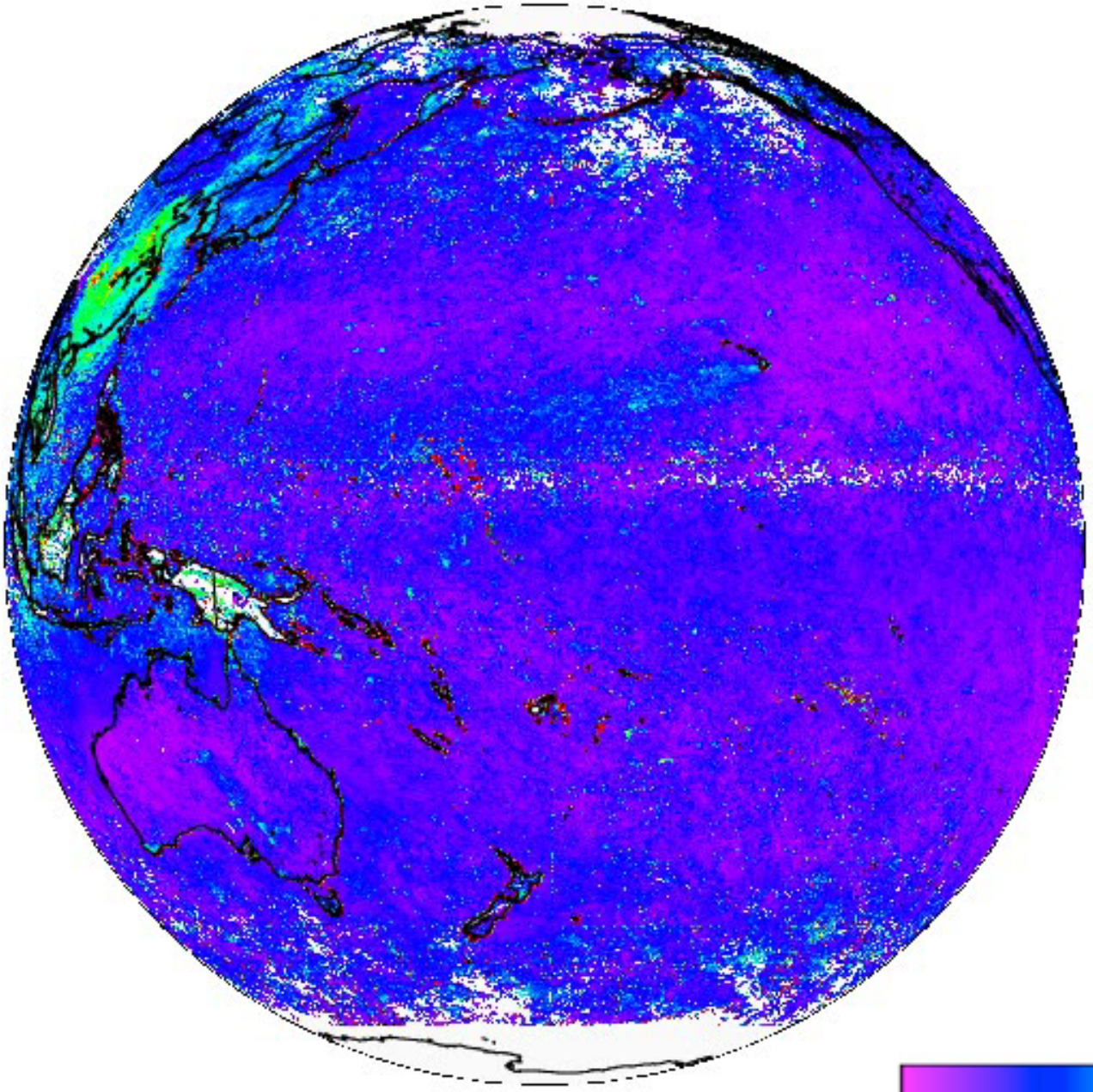
Currently processed **9 years (2006 – 2013)** with "fast" version

✓ to be available as OPEN SOURCE code;

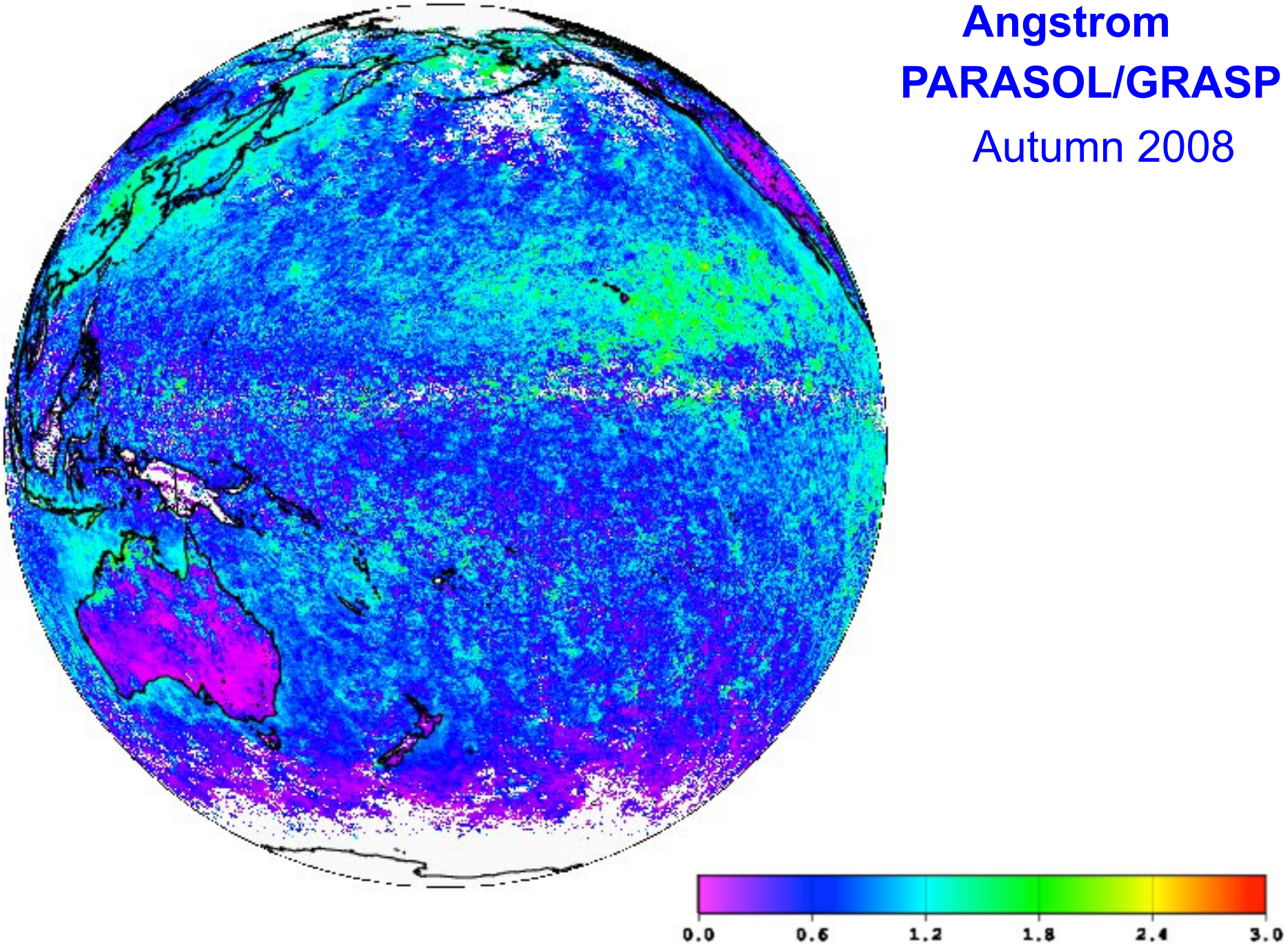
AOT(440 nm)

PARASOL/GRASP

Autumn 2008



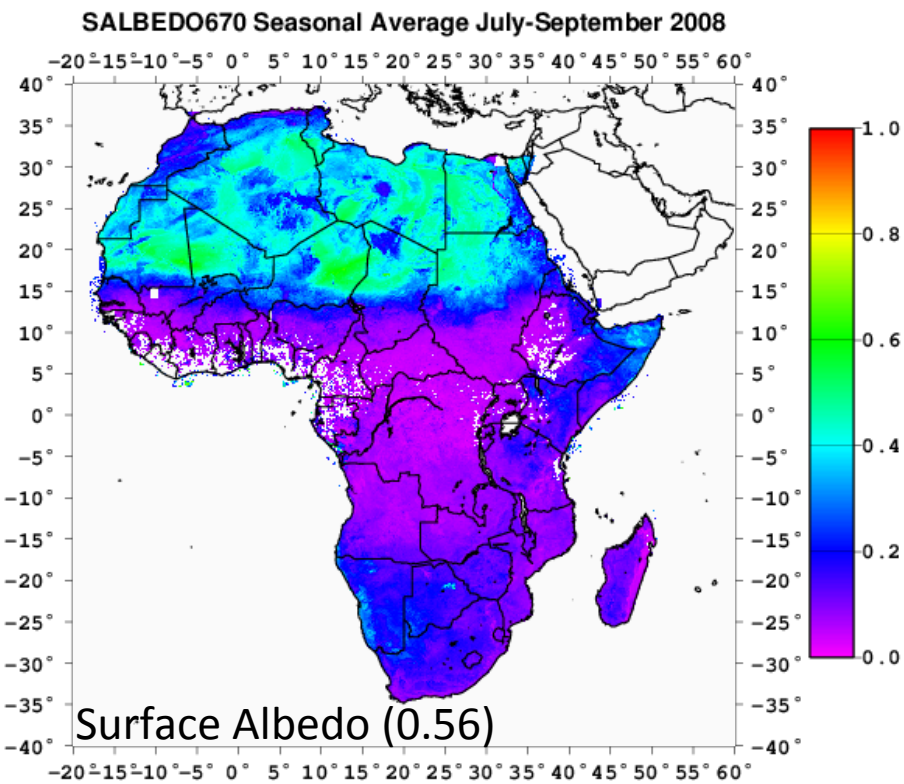
Angstrom
PARASOL/GRASP
Autumn 2008

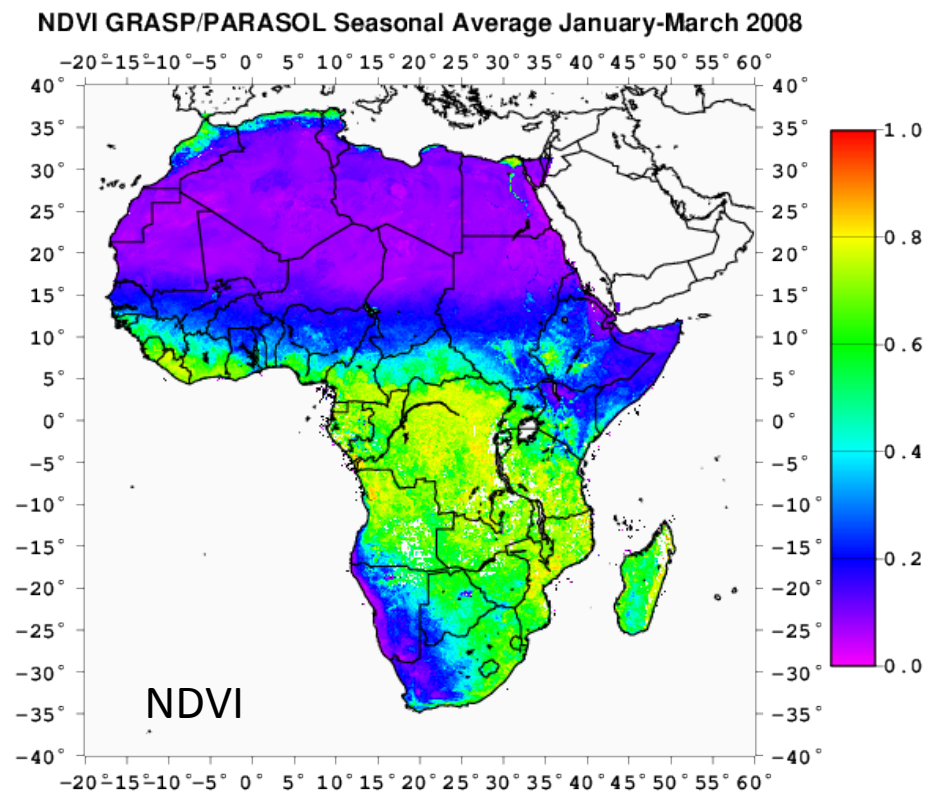


EXAMPLES of PARASOL/GRASP retrievals - 2008

NO location specific ASSUMPTIONS on aerosol and surface

All calculation on the fly





Albego(0.56) - **surface**

NDVI

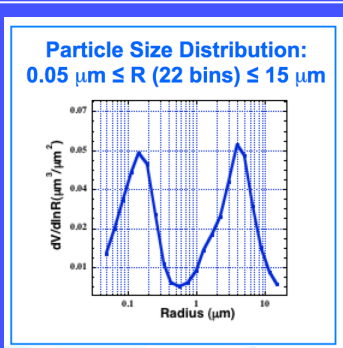
Processed at ICARE

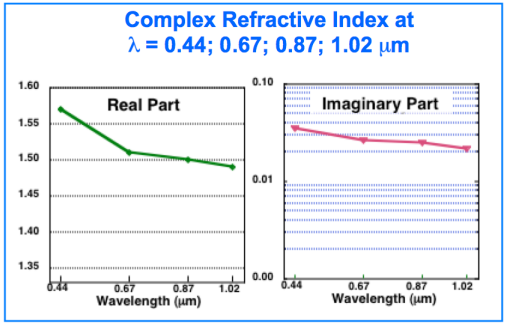
MERIS:

- radiances at seven wavelengths:
(413, 443, 490, 510, 560, 665, and 870 nm);
- single view

AEROSOL:

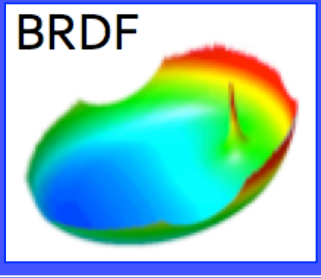
- size distribution (5 or more bins);
- spectral index of refraction (7 λ);
- sphericity;





SRFACE:

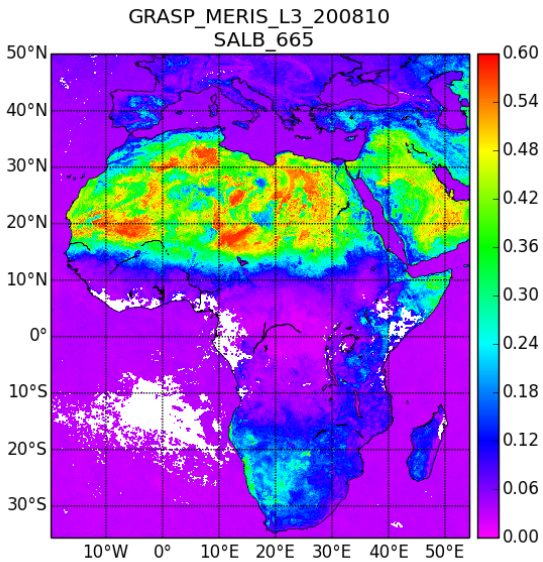
- BRDF
(3 spectrally dependent parameters);



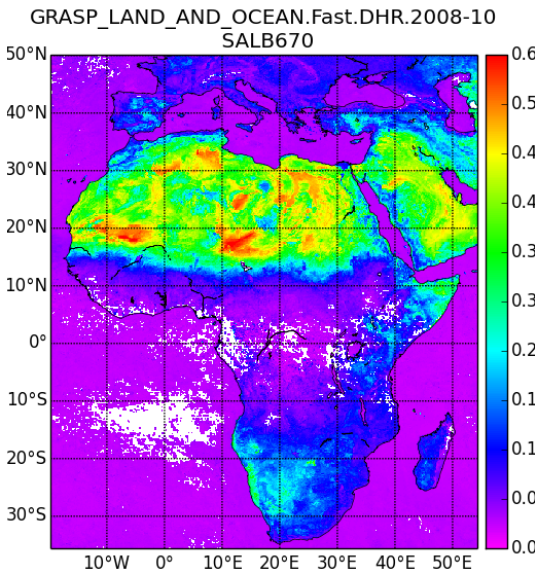
41 = (5 (SD) +14 (ref. ind.) + 1 (nonsp.) + 21 (BRDF))

Surface Albedo (670 nm) – Africa, October 2008

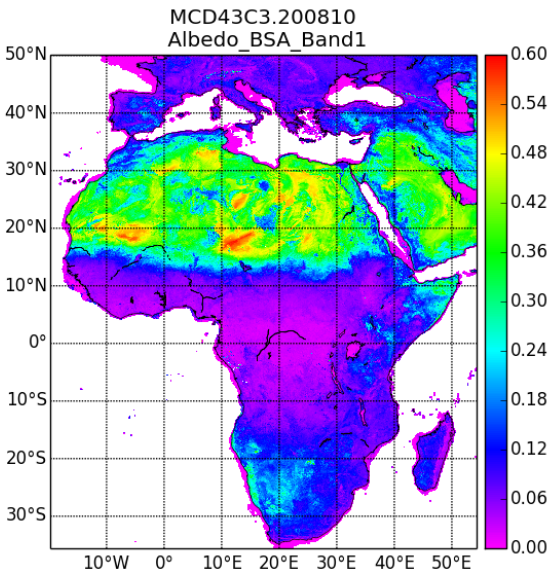
MERIS



PARASOL

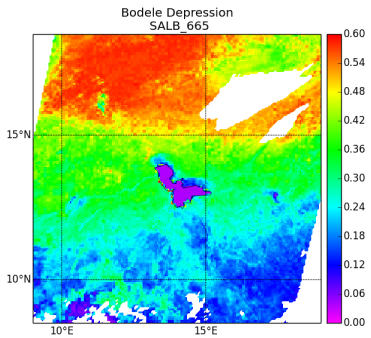


MODIS-TERRA

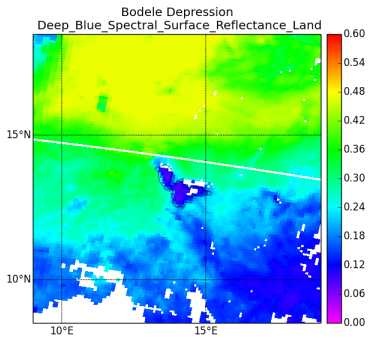


Surface Reflectance (660 nm) – Bodélé Depression 30/03/2008

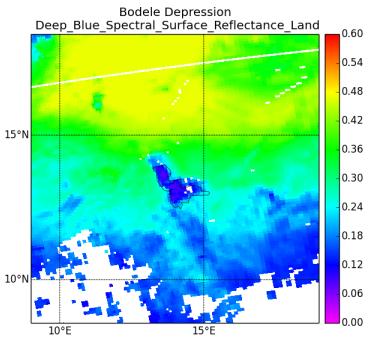
MERIS



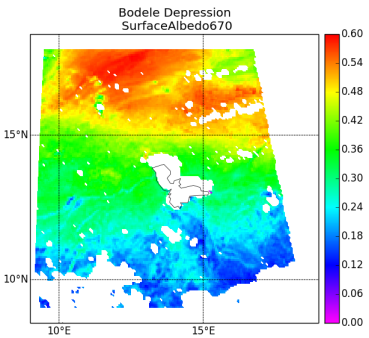
MODIS/Terra



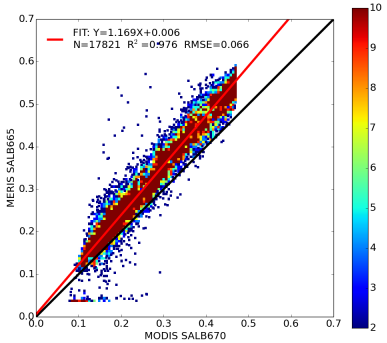
MODIS/Aqua



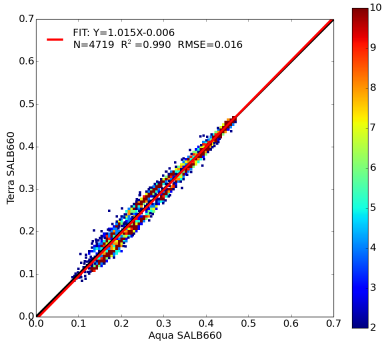
PARASOL



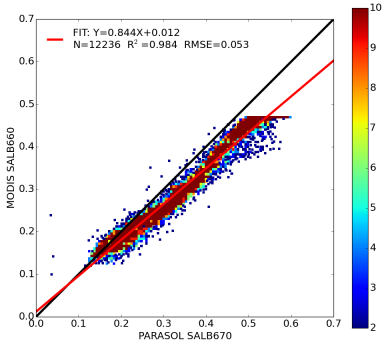
MERIS vs. Terra



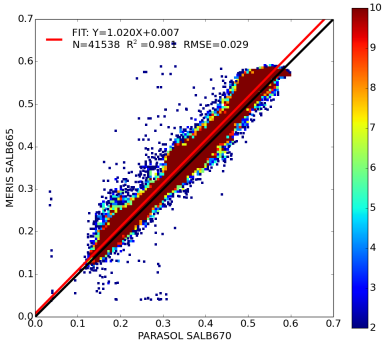
Terra vs. Aqua



Aqua vs. PARASOL



MERIS vs. PARASOL



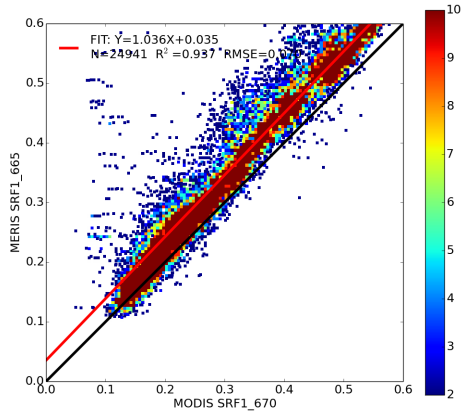
Surface Parameters – Bodélé Depression 30/03/2008

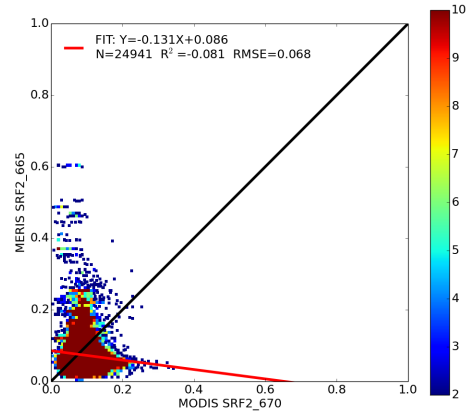
Lambertian Component

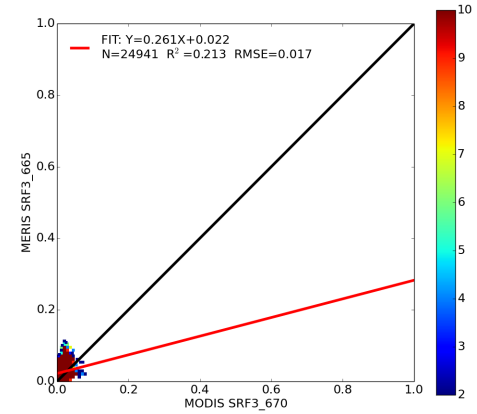
Volumetric Component

Geometric Component

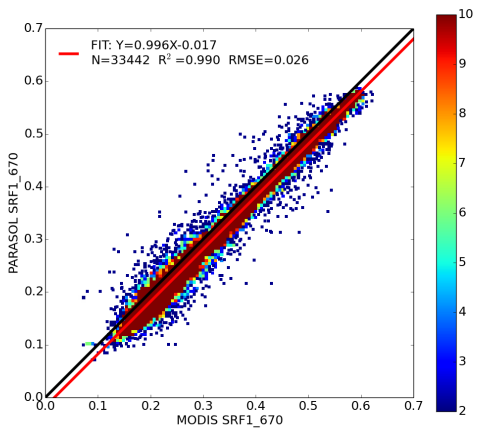
MODIS - MERIS

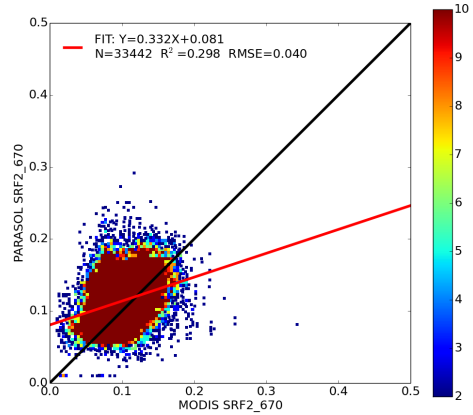


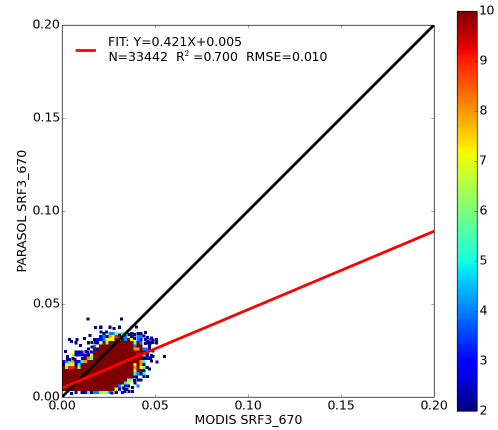




MODIS - PARASOL



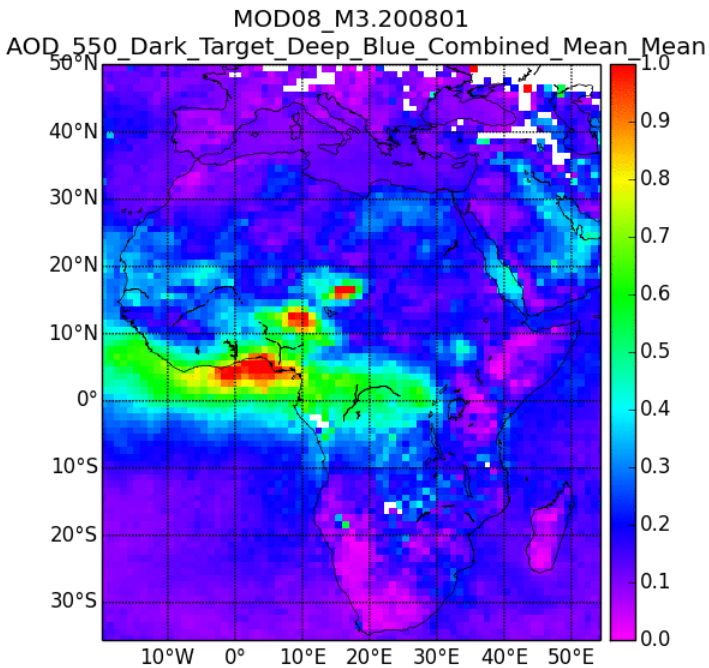




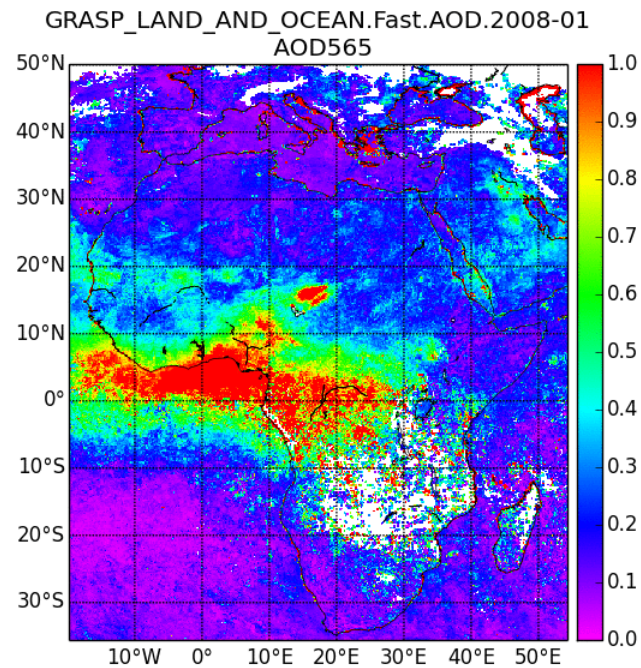
Animation of AOT retrieval from PARASOL over Africa and Mediterranean Region in 2008

Monthly averages

MODIS



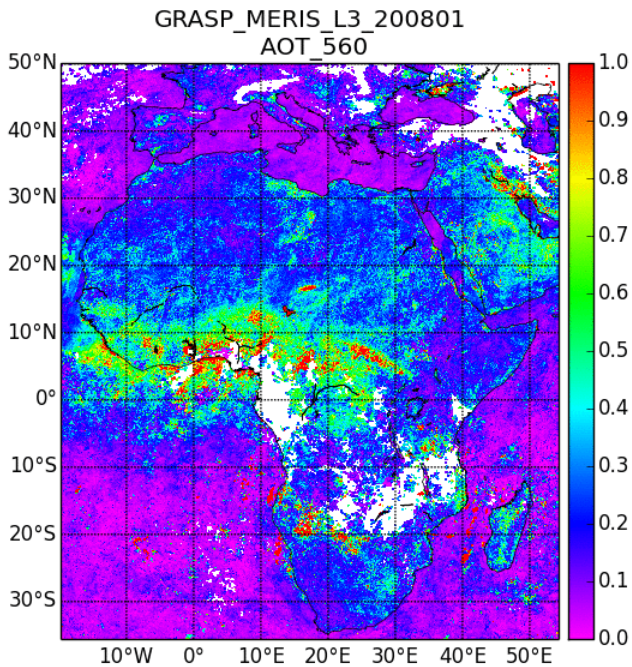
PARASOL



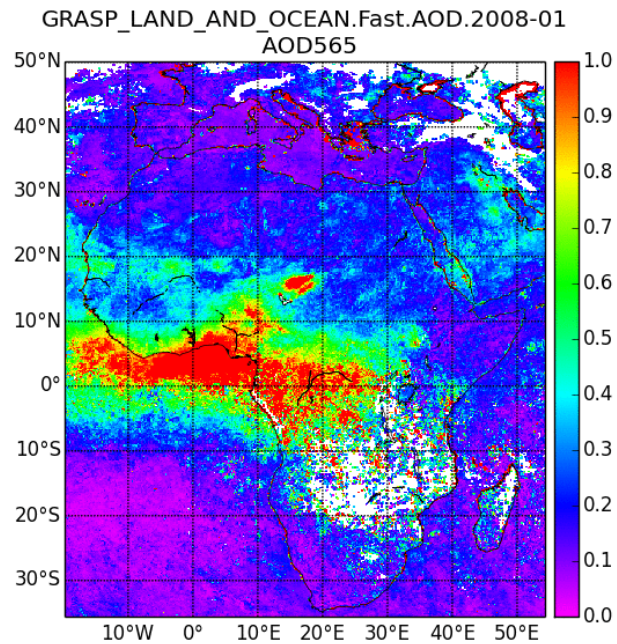
Animation of AOT retrieval from PARASOL over Africa and Mediterranean Region in 2008

Monthly averages

MERIS

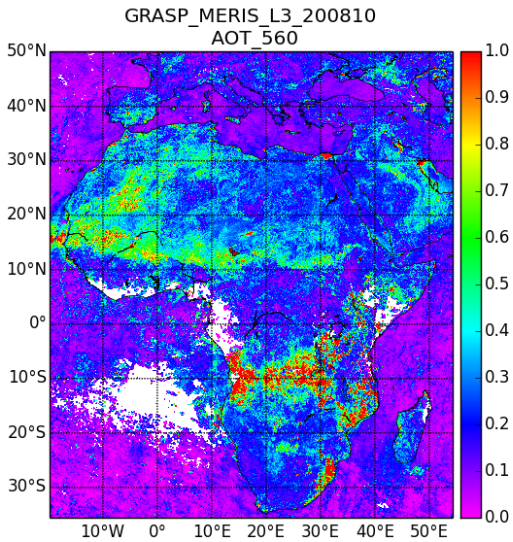


PARASOL

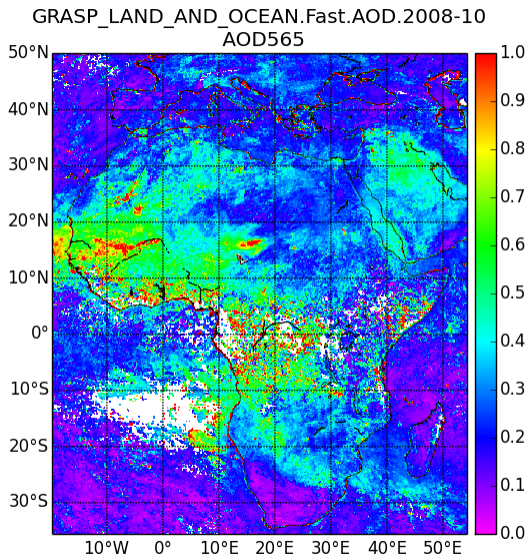


AOT (550 nm) – Africa, October 2008

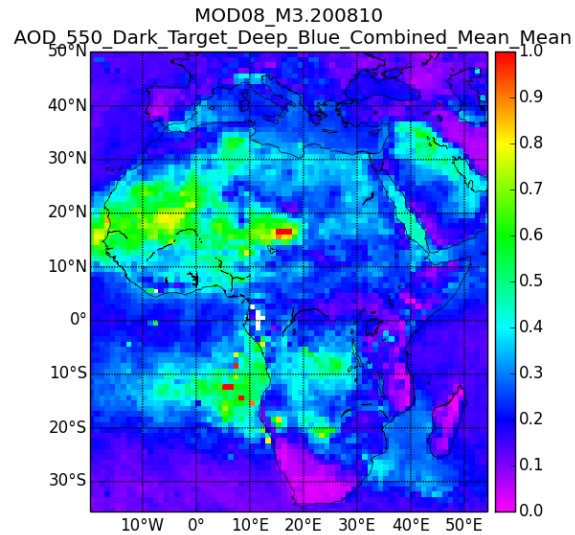
MERIS



PARASOL

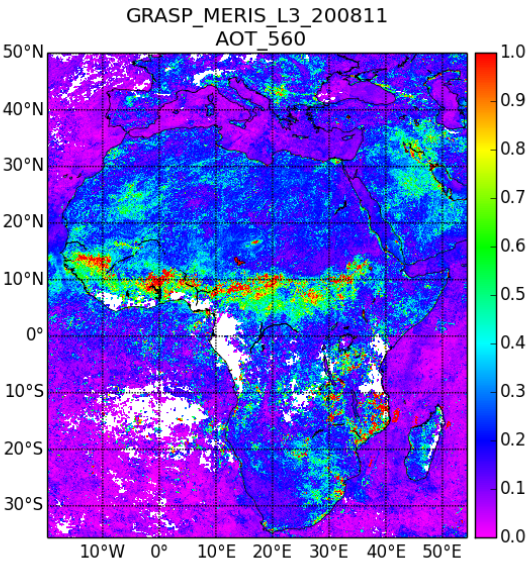


MODIS-TERRA

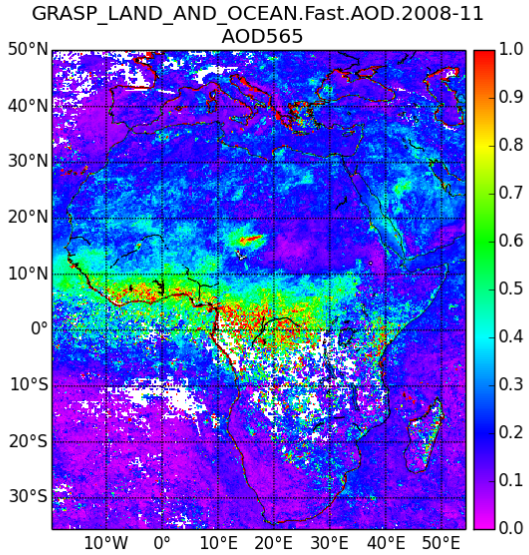


AOT (550 nm) – Africa, November 2008

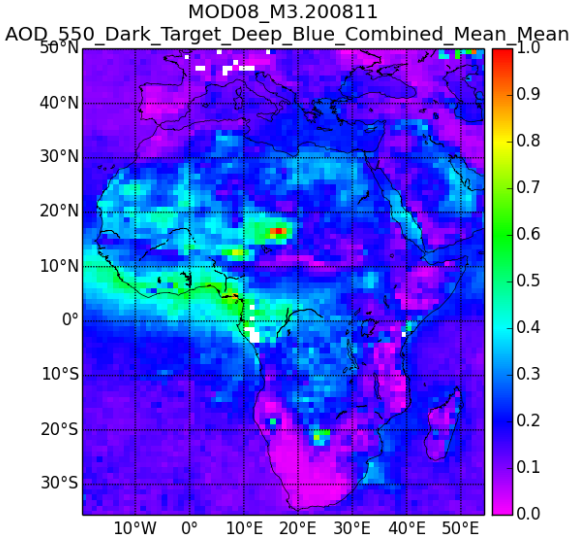
MERIS



PARASOL



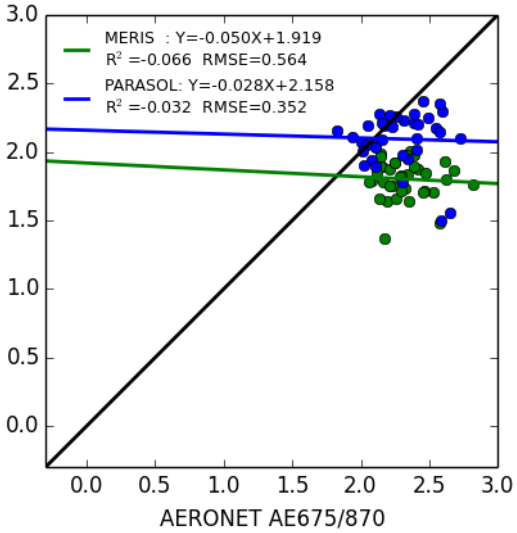
MODIS-TERRA



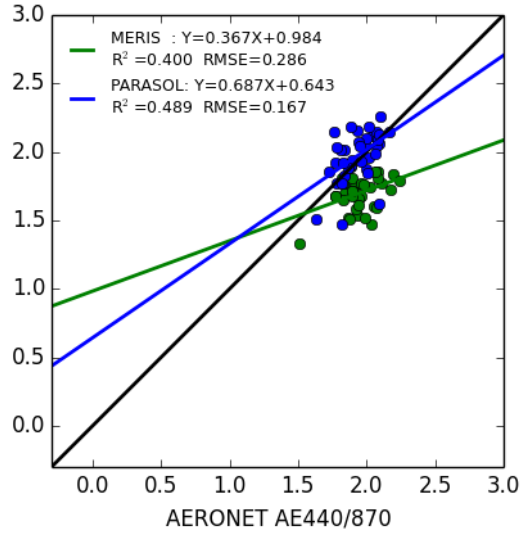
MERIS
PARASOL

Mongu 06/2008 – 08/2008 (1)

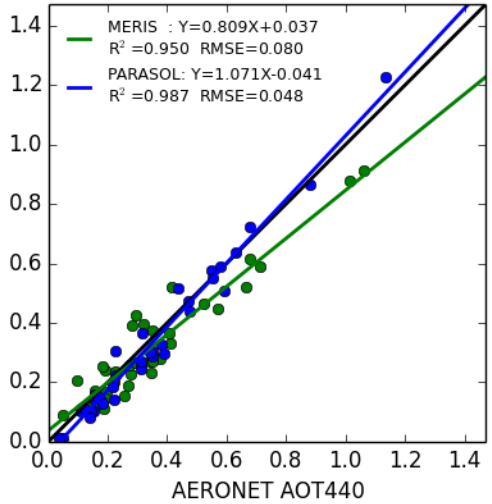
Angstrom (670/870)



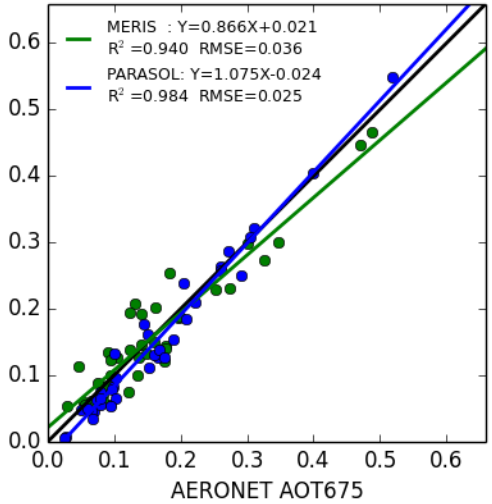
Angstrom (440/870)



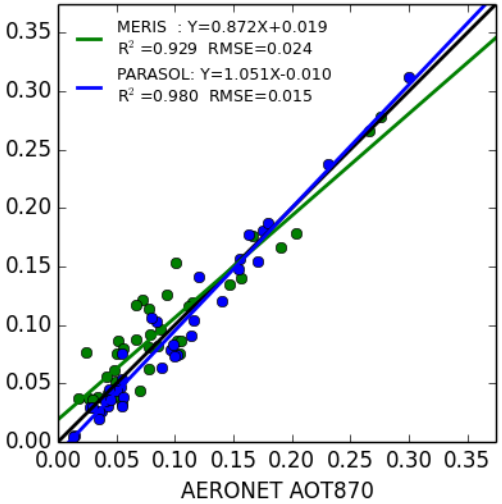
AOD (440)



AOD (670)

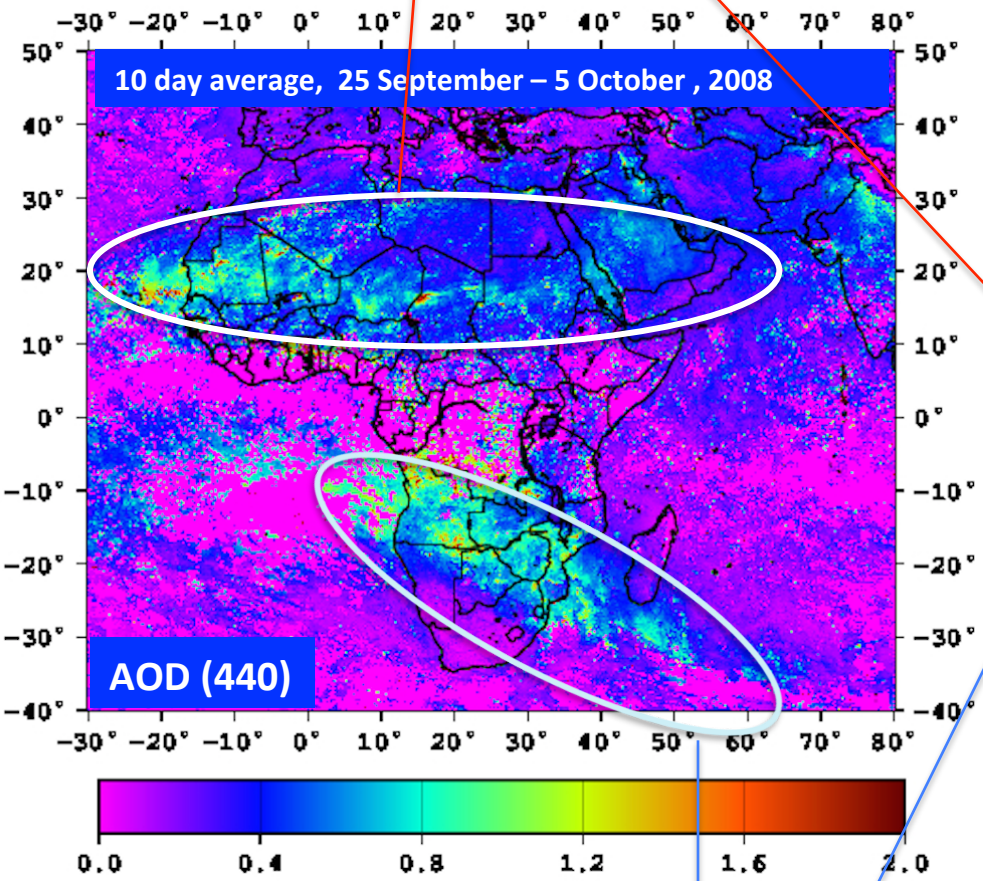


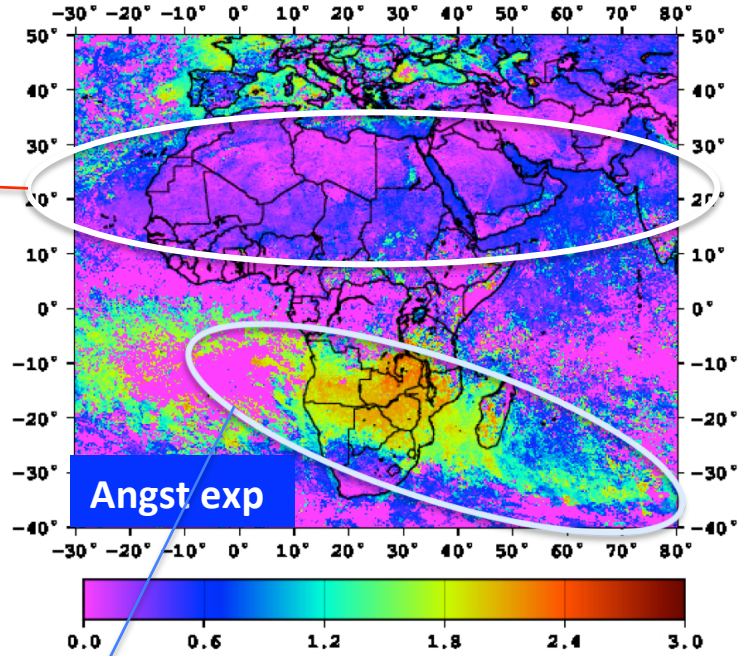
AOD (870)

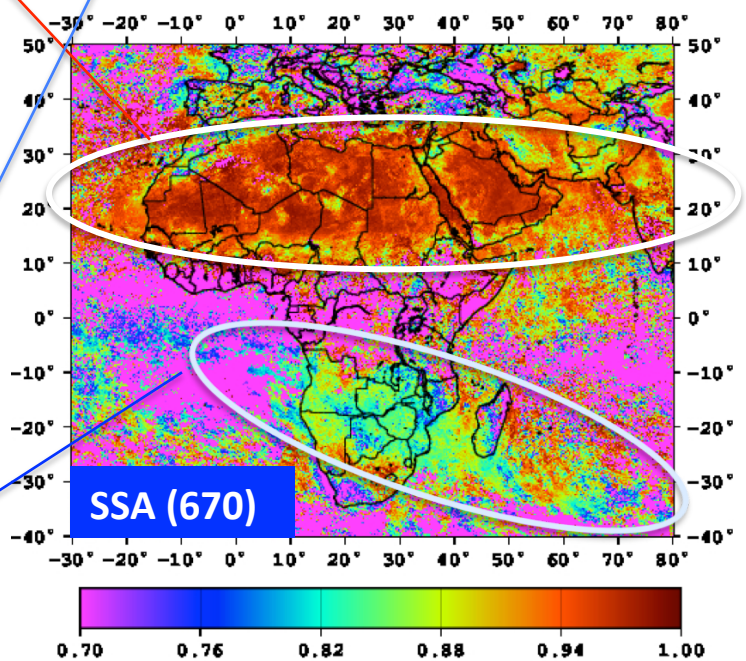


GRASP: towards aerosol classification

Desert Dust

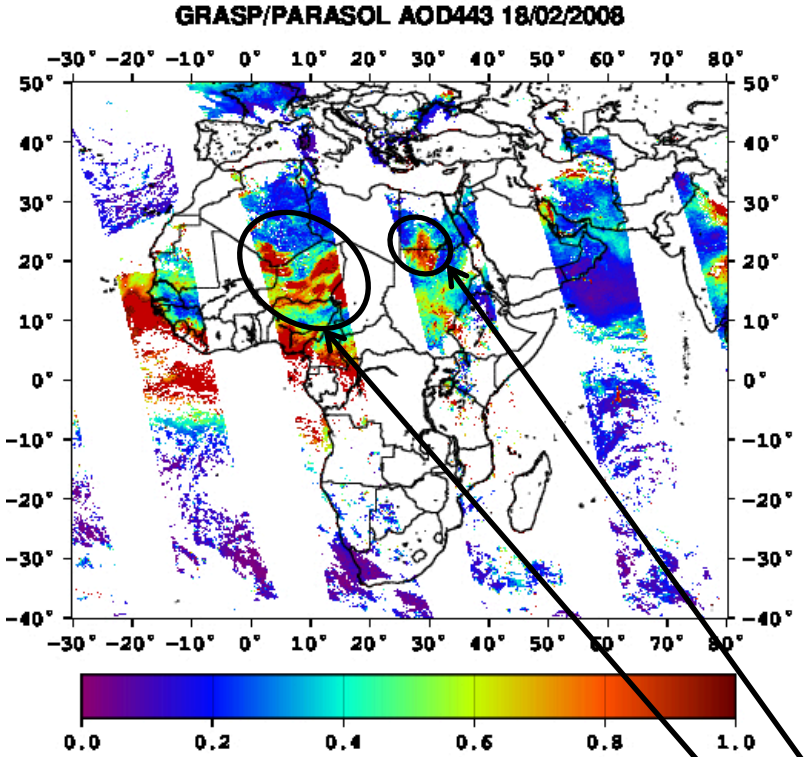


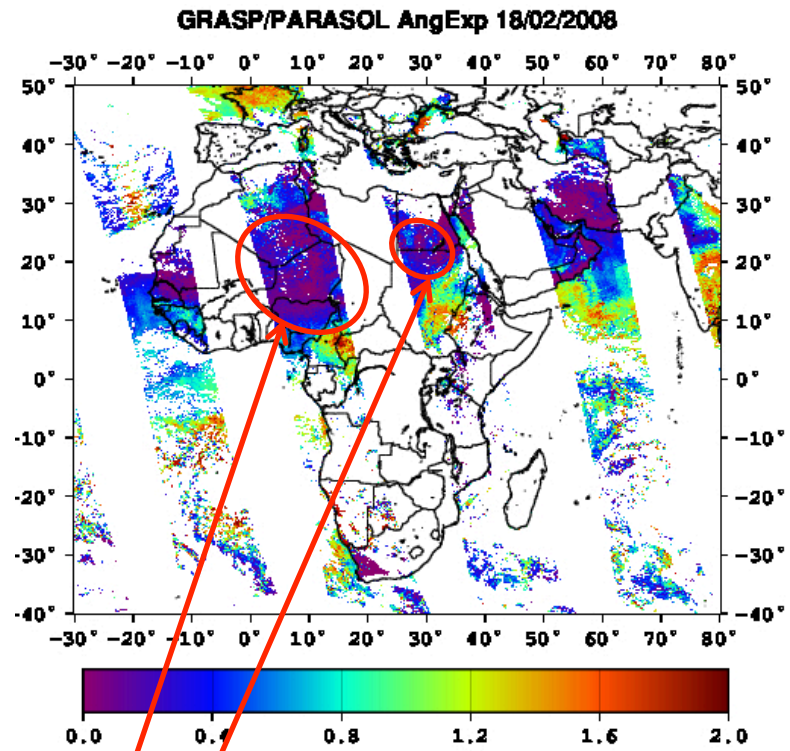


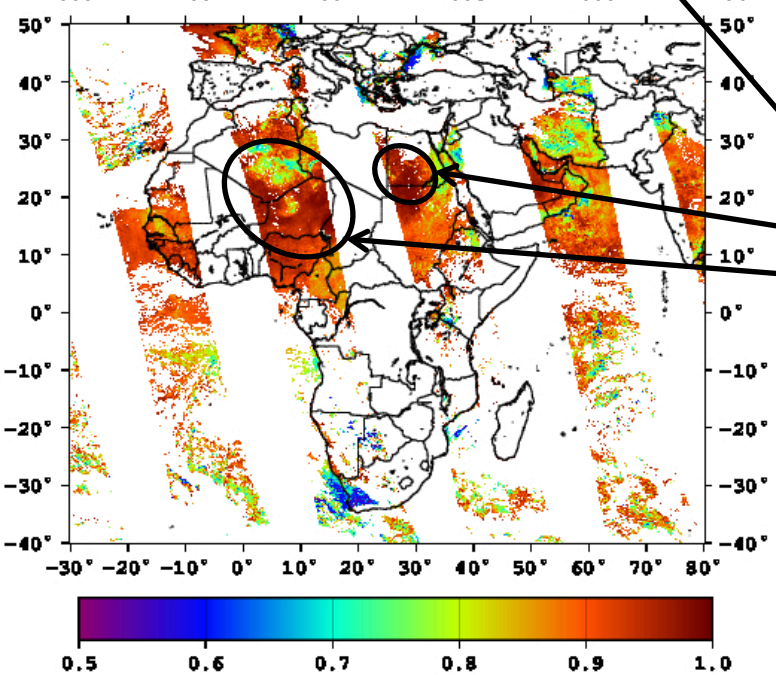


Biomass Burning

Dust detection with GRASP



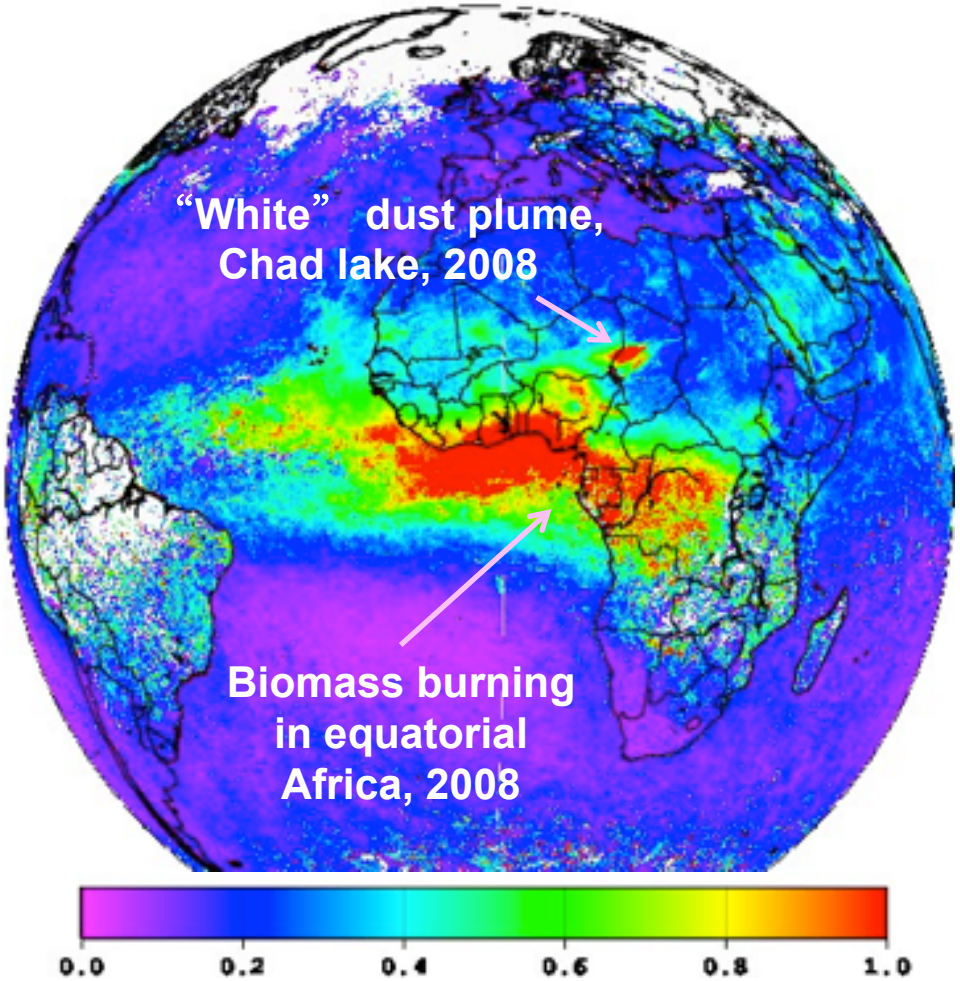


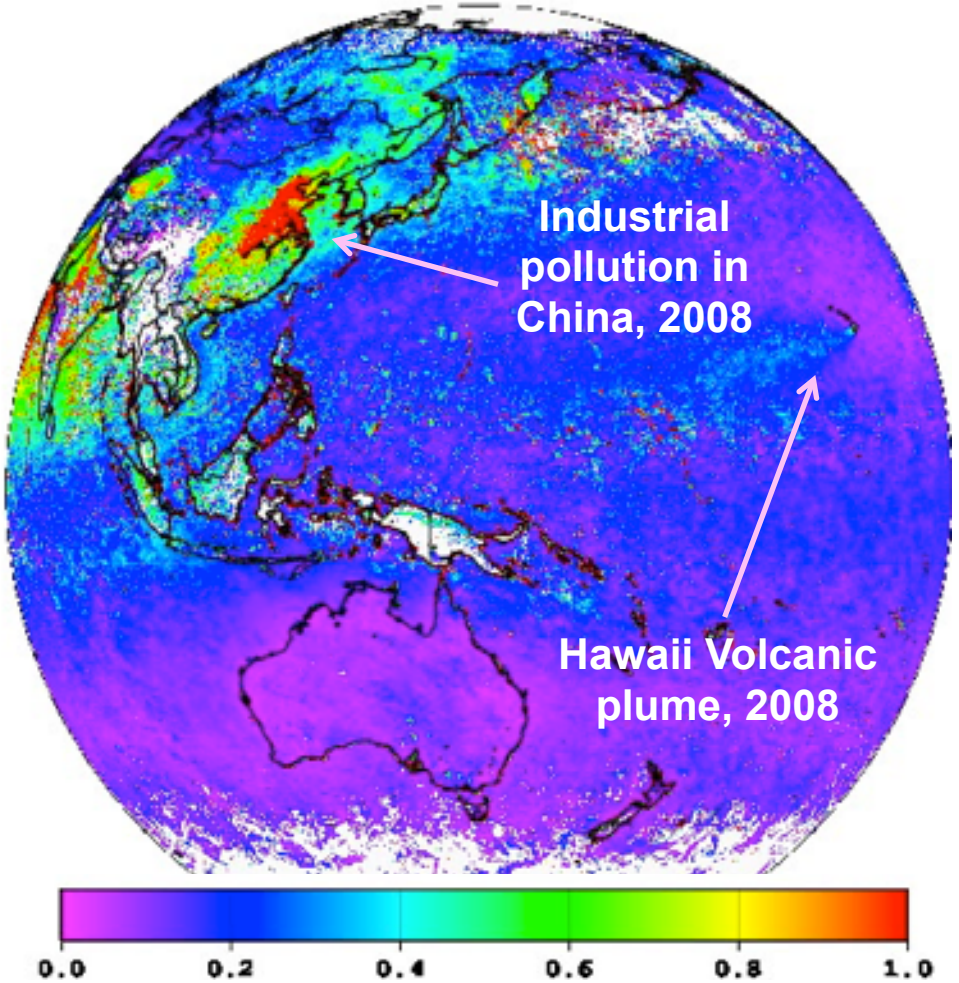


Dust events:

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

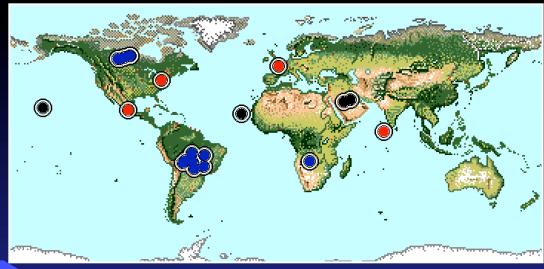
Observation of aerosol events from PARASOL/GRASP retrievals



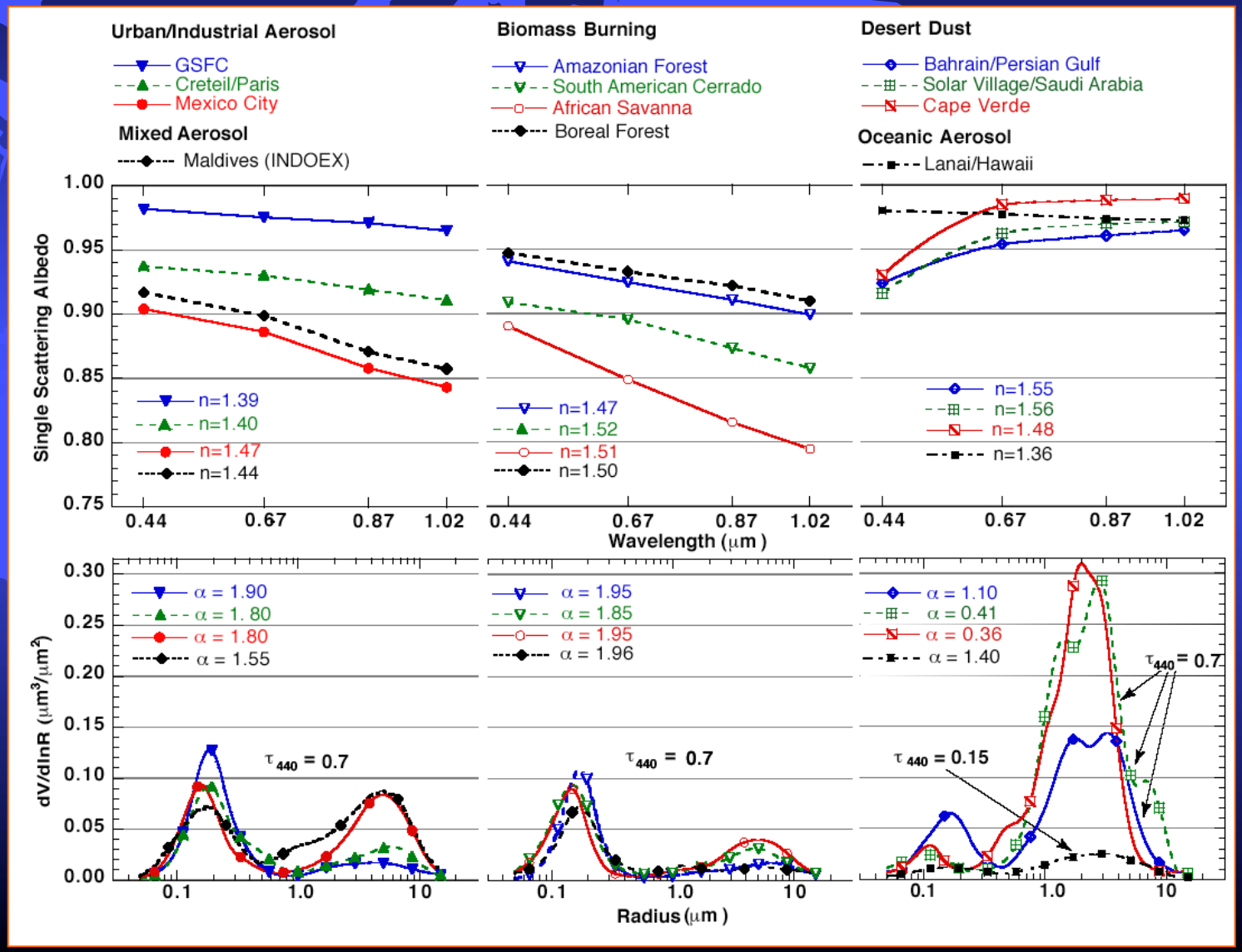


AEROSOL CLASSES ???

(Dubovik et al., 2002, JAS)

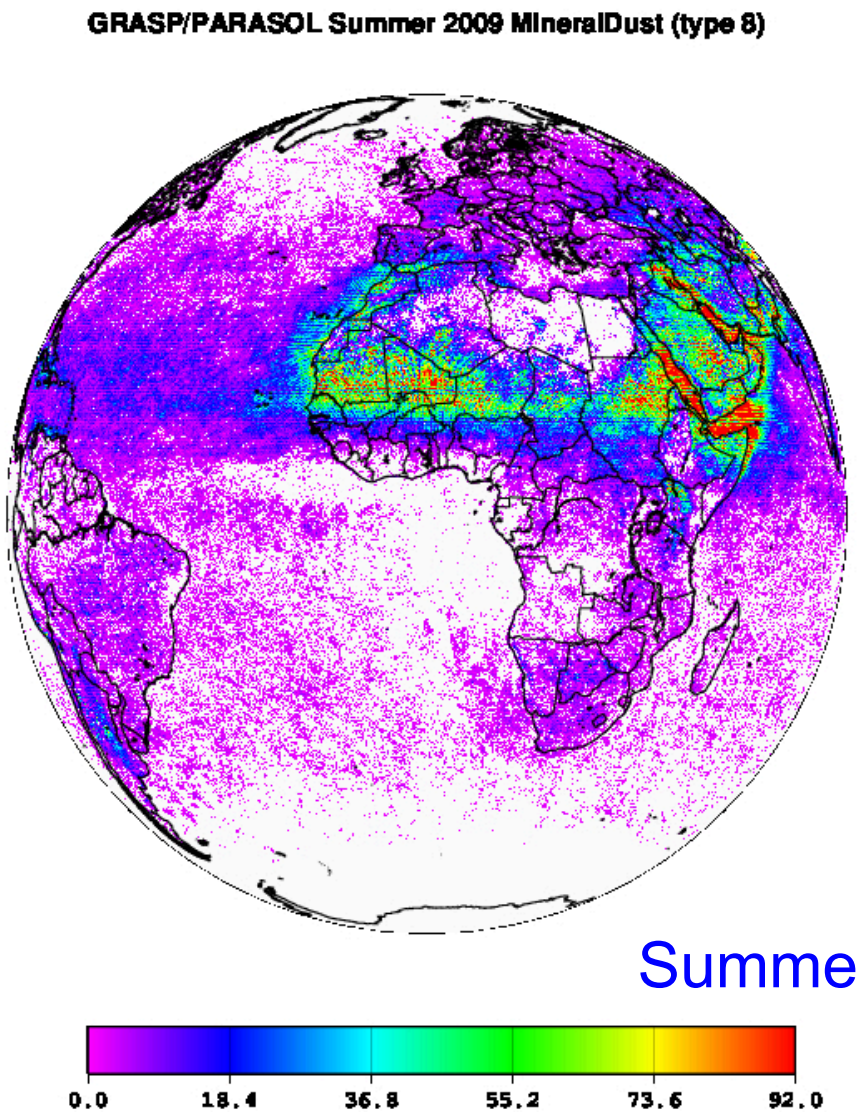


INSPIRATION:

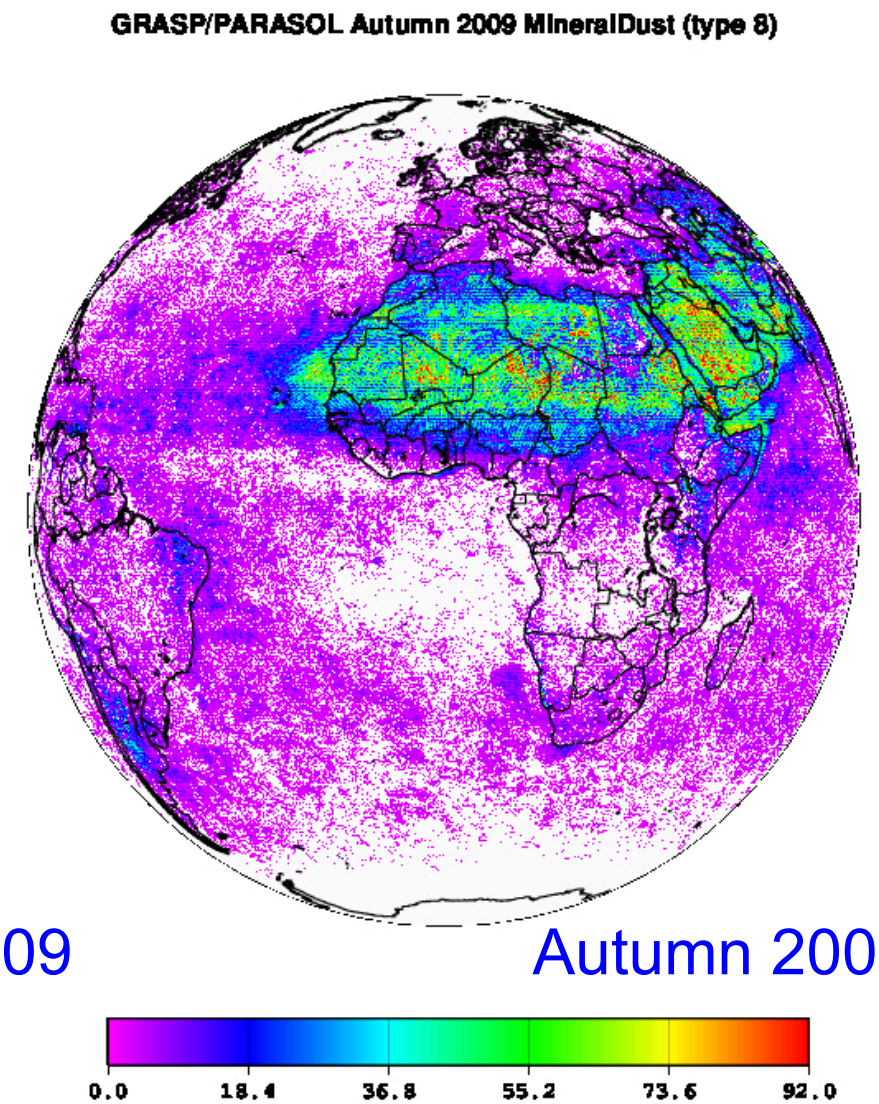


Aerosol type detection with GRASP

Mineral dust frequency of occurrence



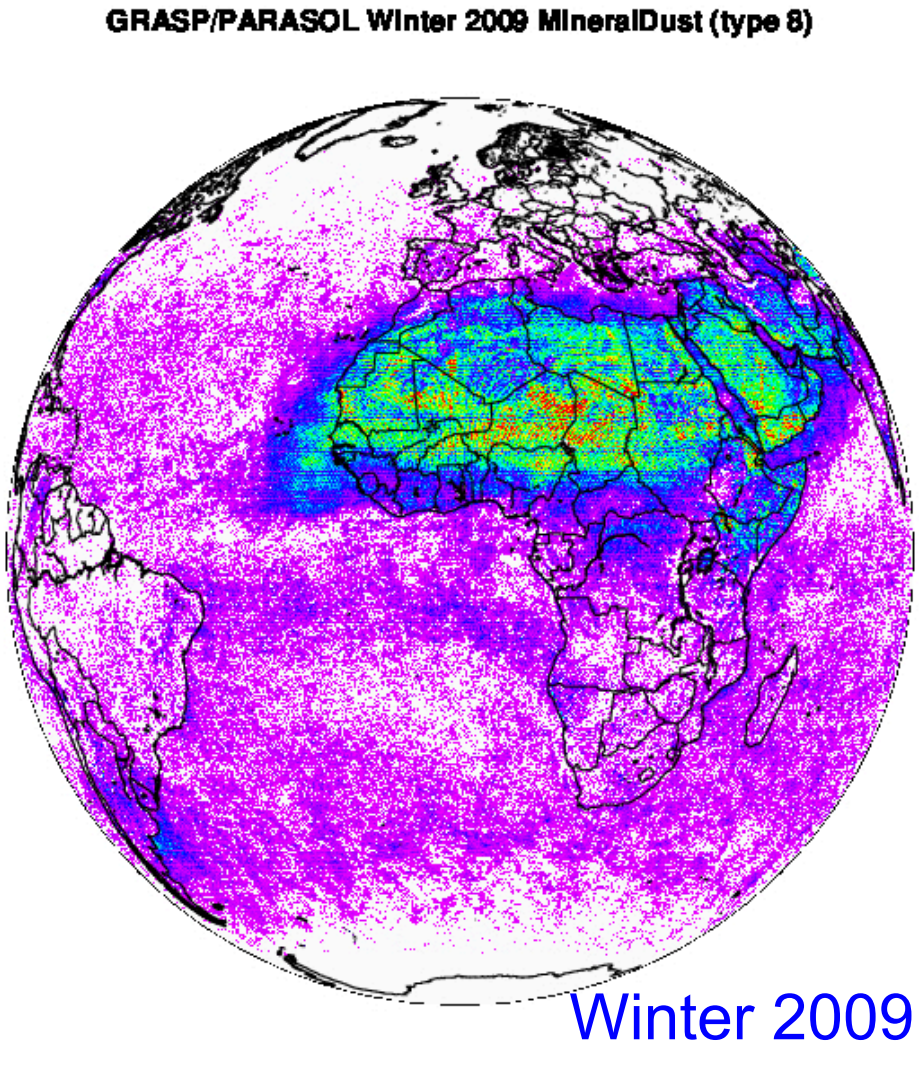
Summer 2009

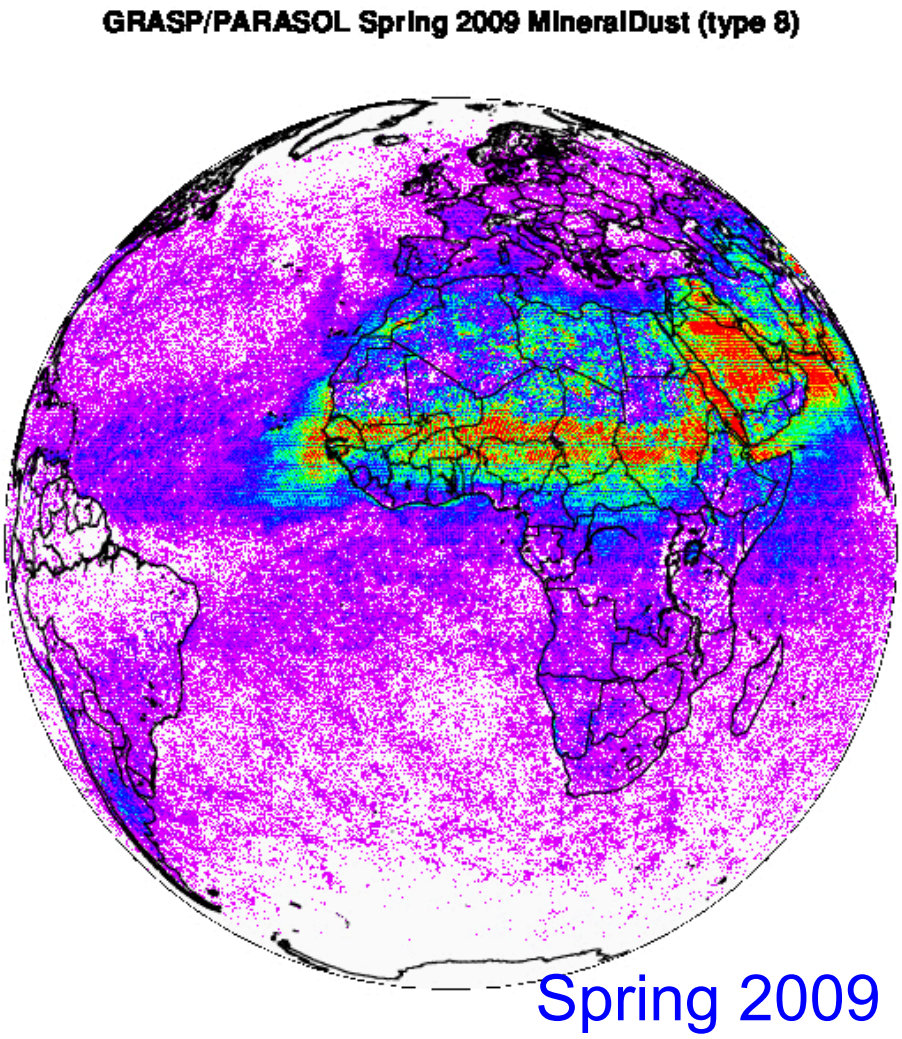


Autumn 2009

Aerosol type detection with GRASP

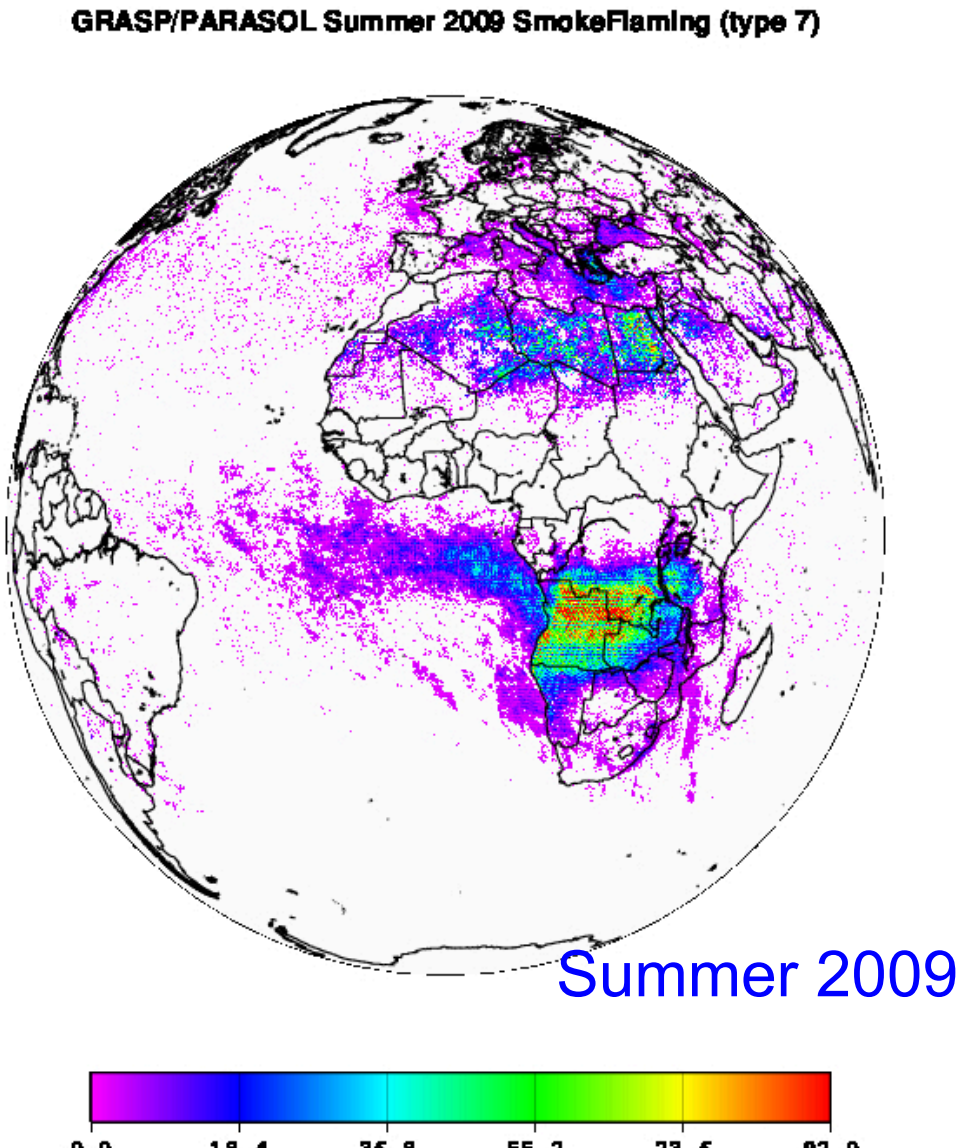
Mineral dust frequency of occurrence

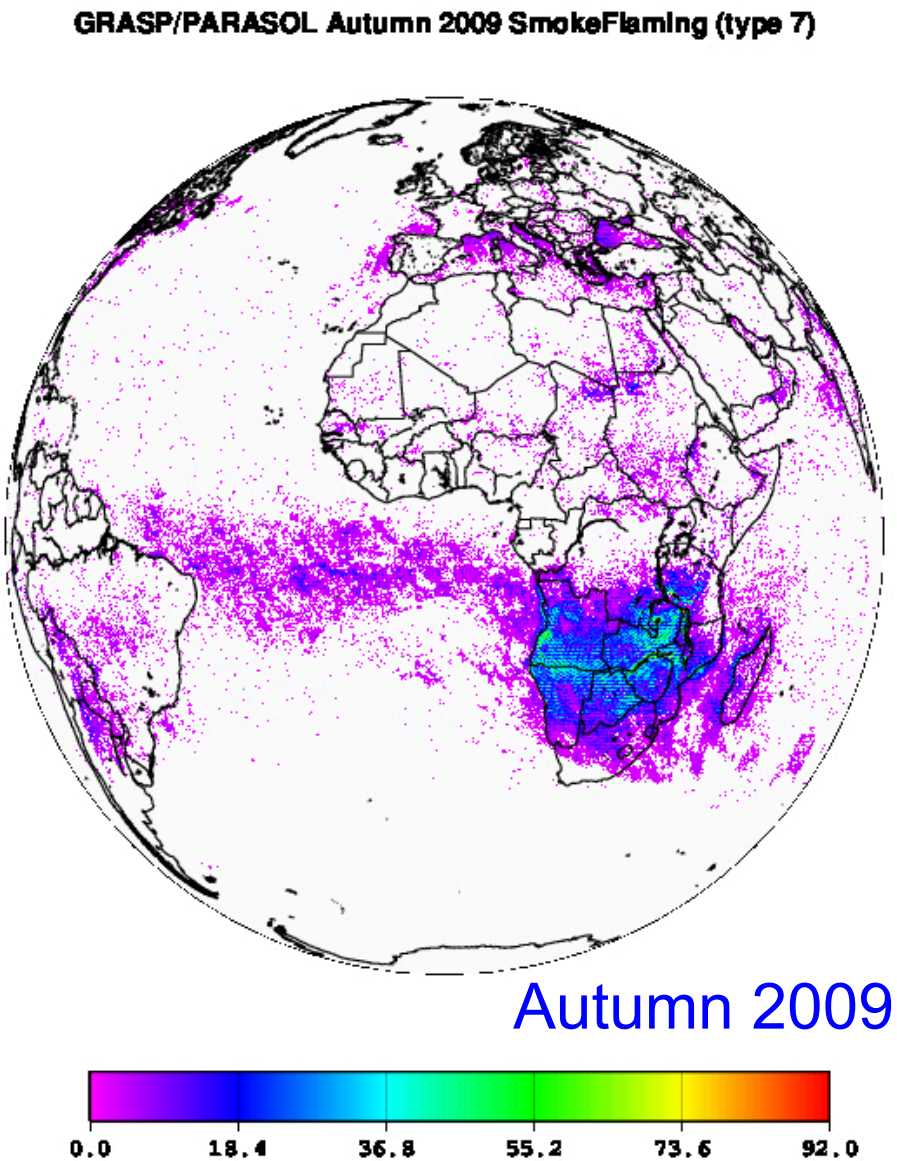




Aerosol type detection with GRASP

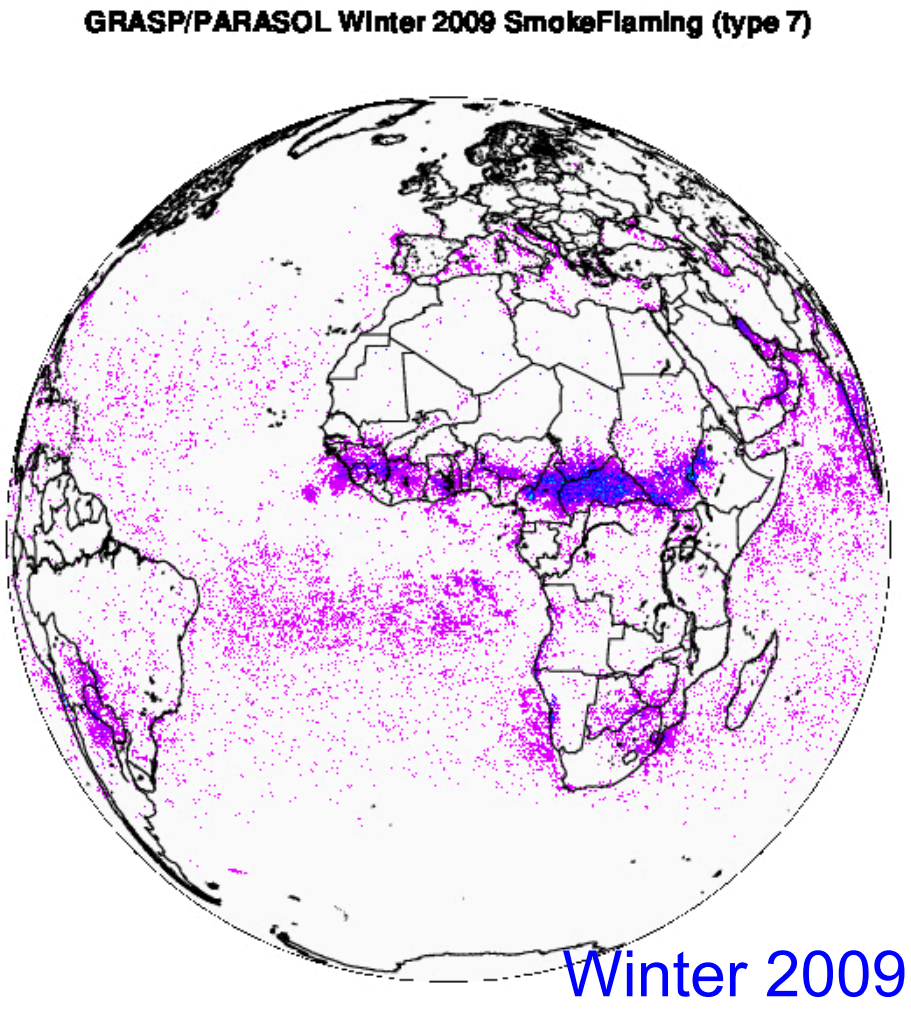
Smoke frequency of occurrence

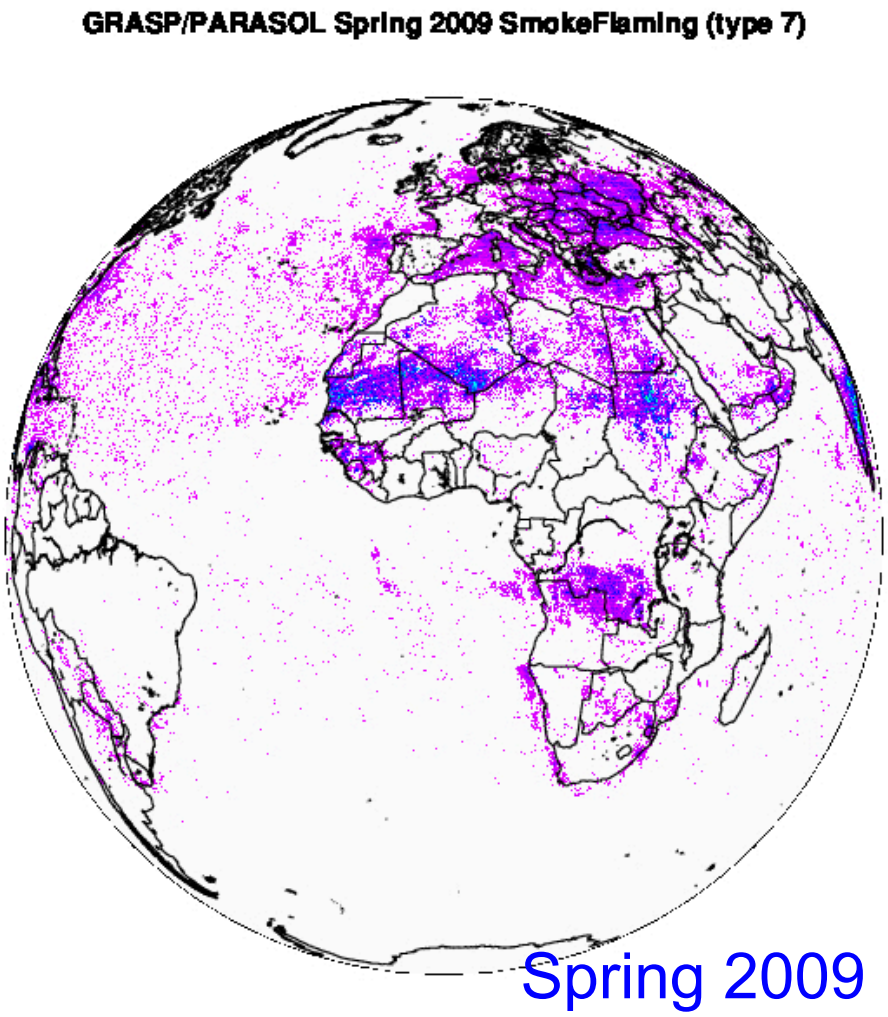




Aerosol type detection with GRASP

Smoke frequency of occurrence

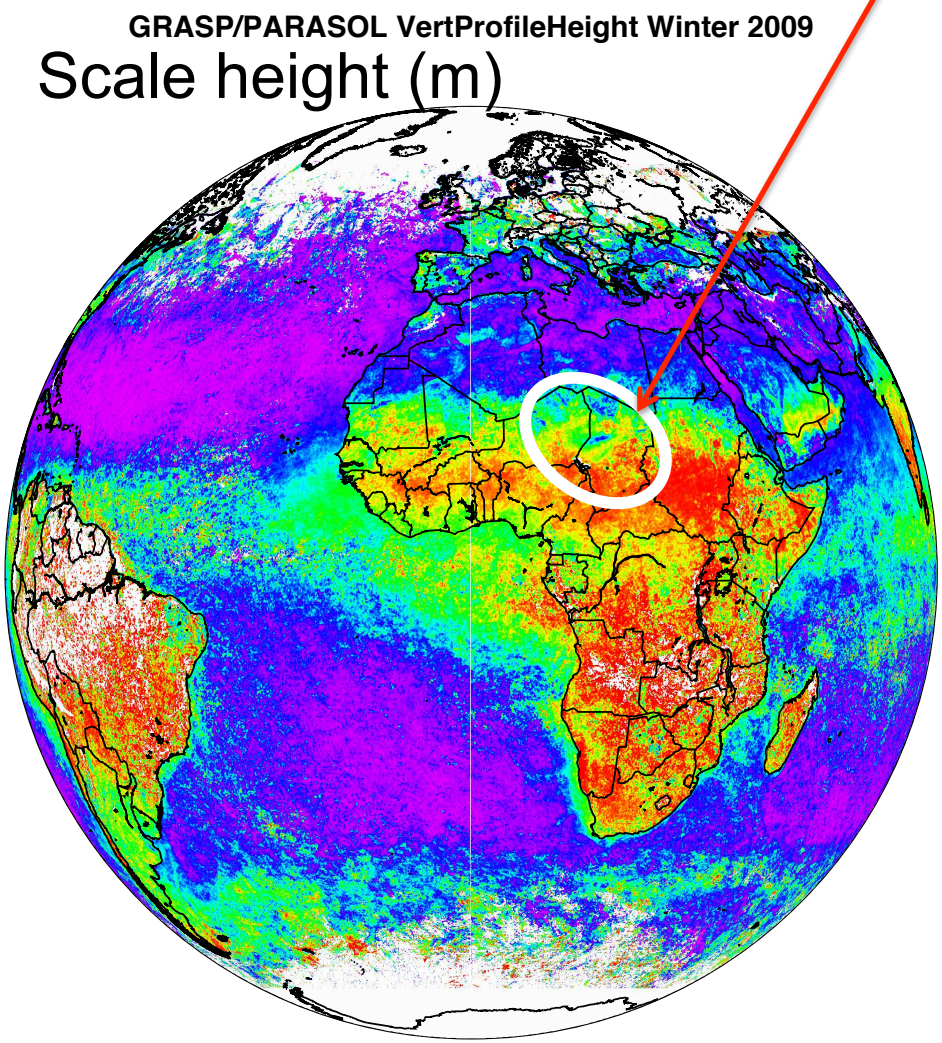


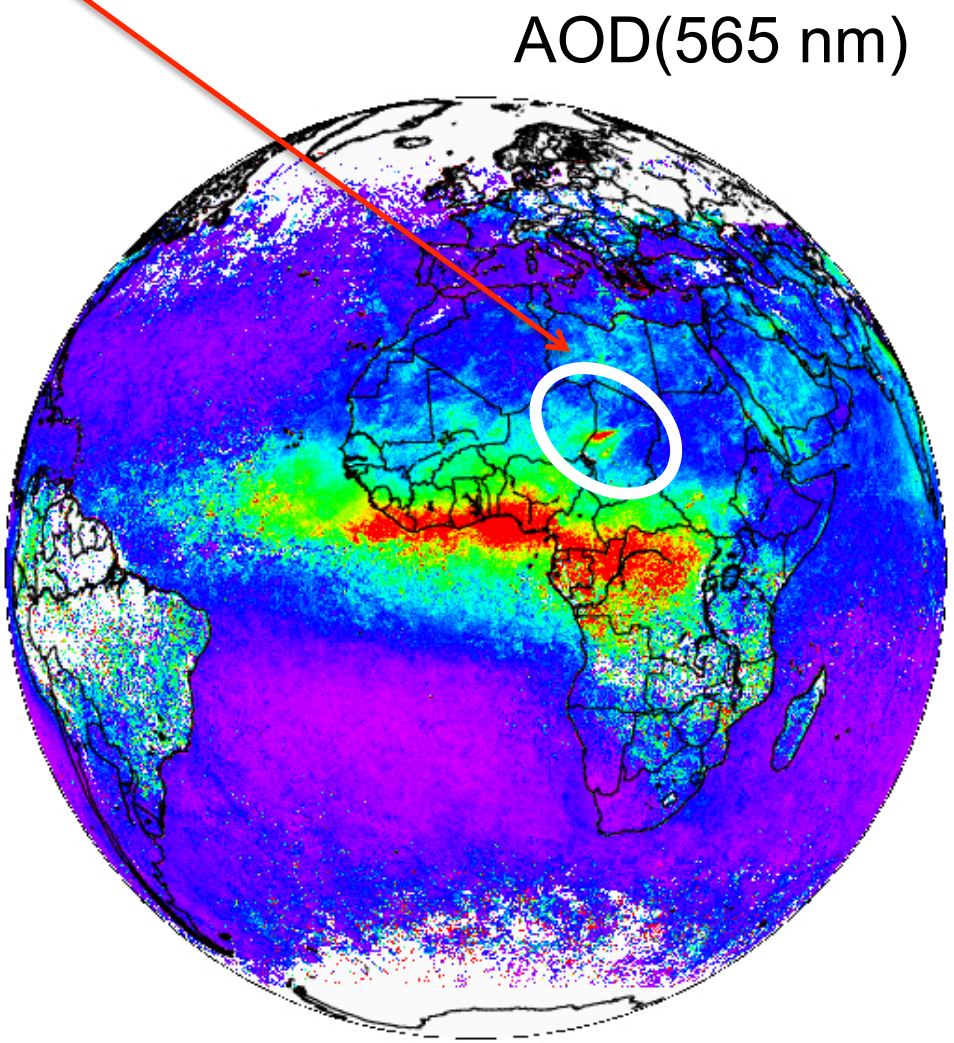


Aerosol Scale Height: winter, 2009

PARASOL/GRASP

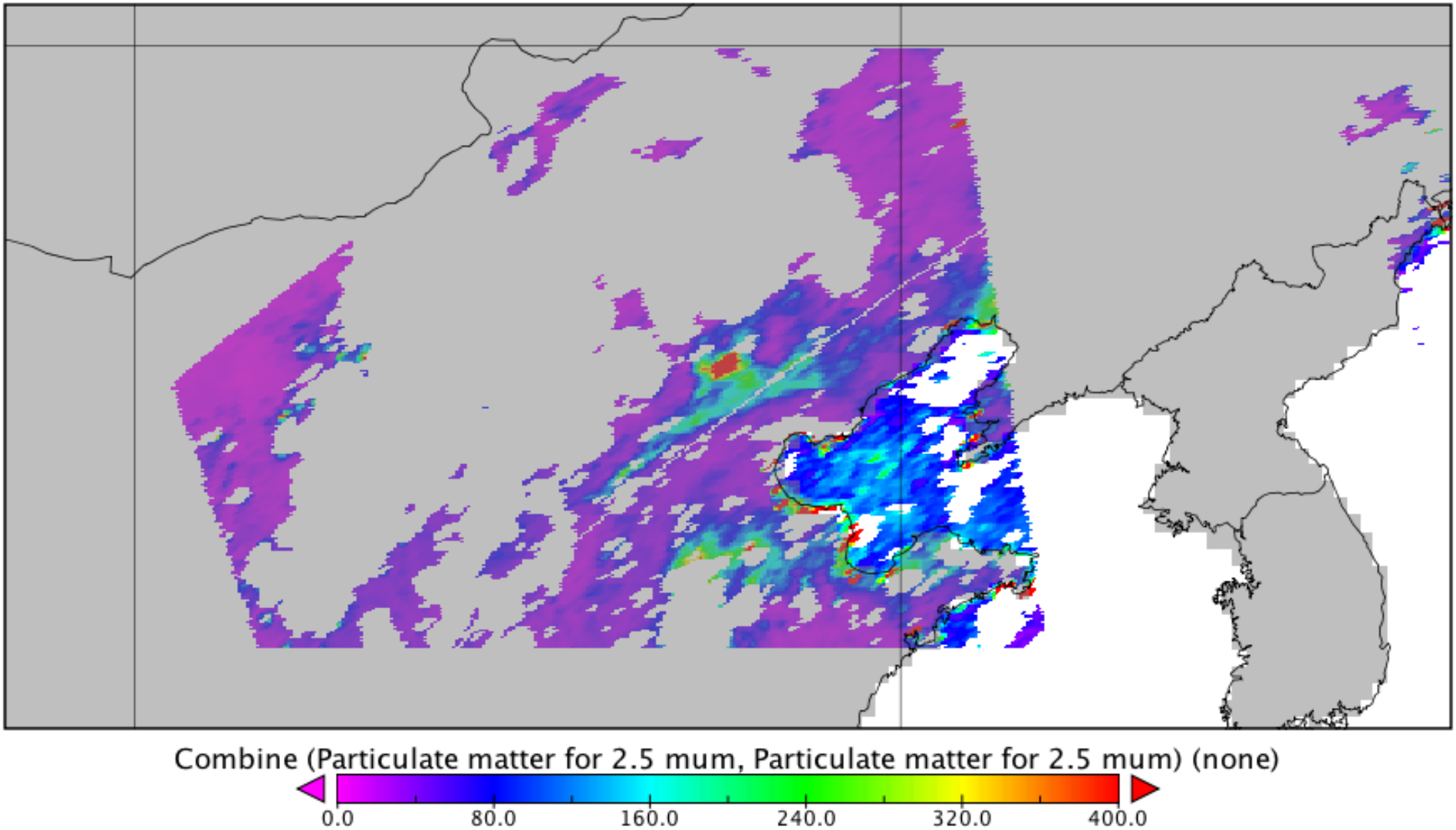
Bodélé Depression

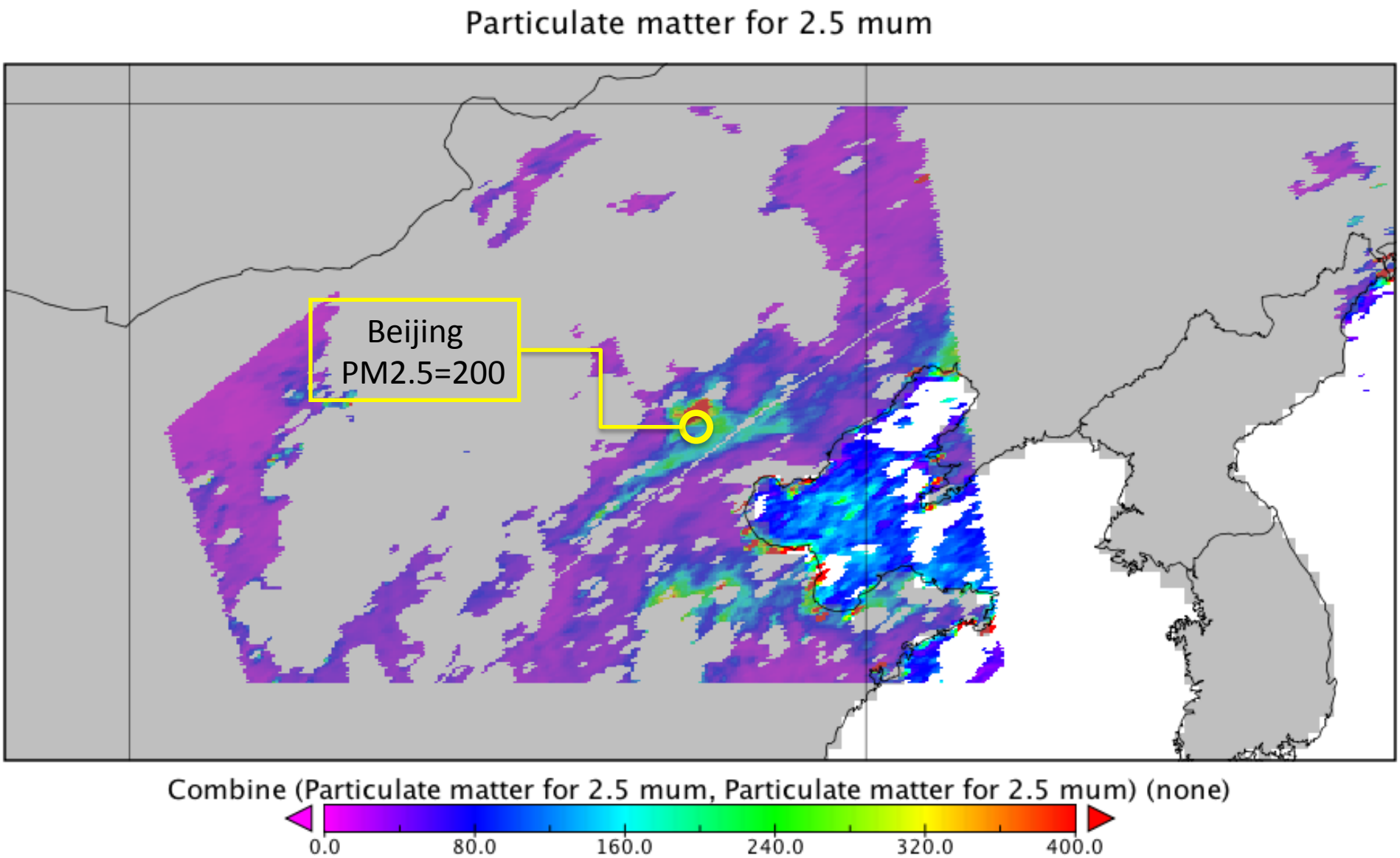




Particulate matter for 2.5 mum

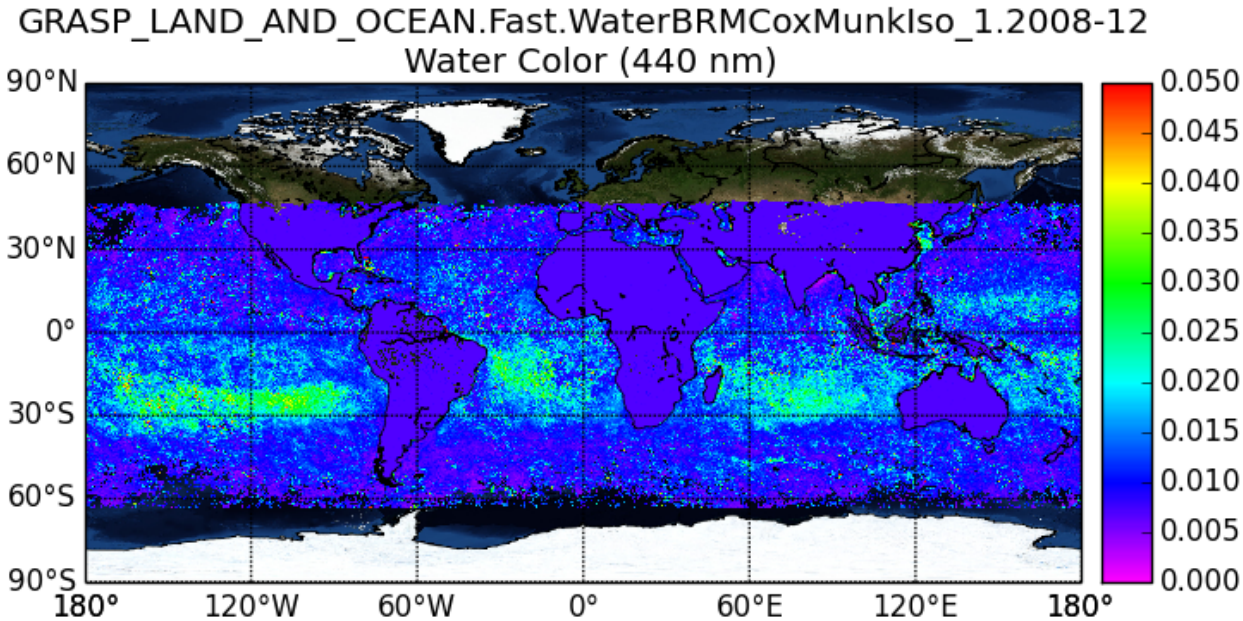
August 15, 2009

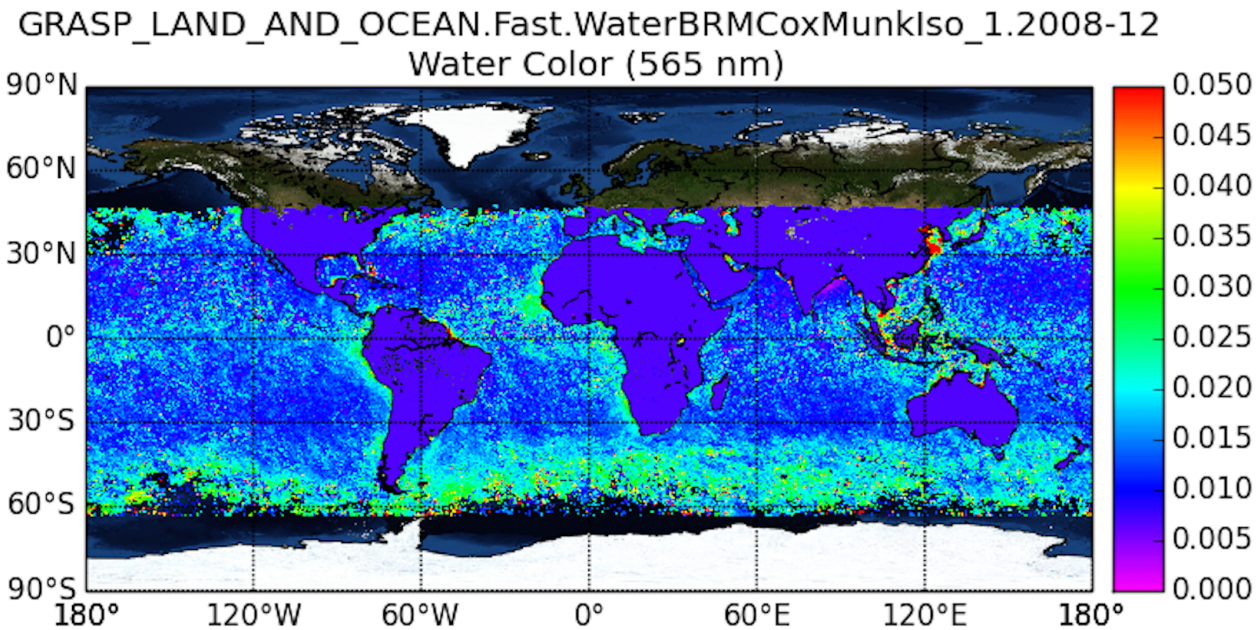



Particulate matter for 2.5 mum
Beijing
PM2.5=200
Combine (Particulate matter for 2.5 mum, Particulate matter for 2.5 mum) (none)
0.0
80.0
160.0
240.0
320.0
400.0

PARASOL

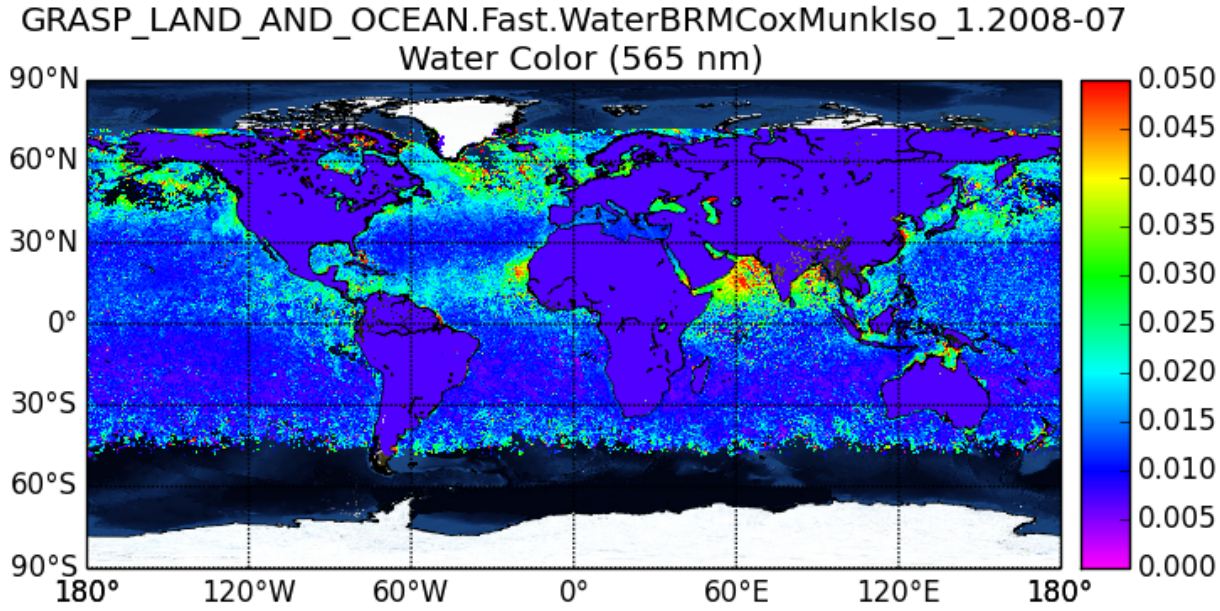
December 2008

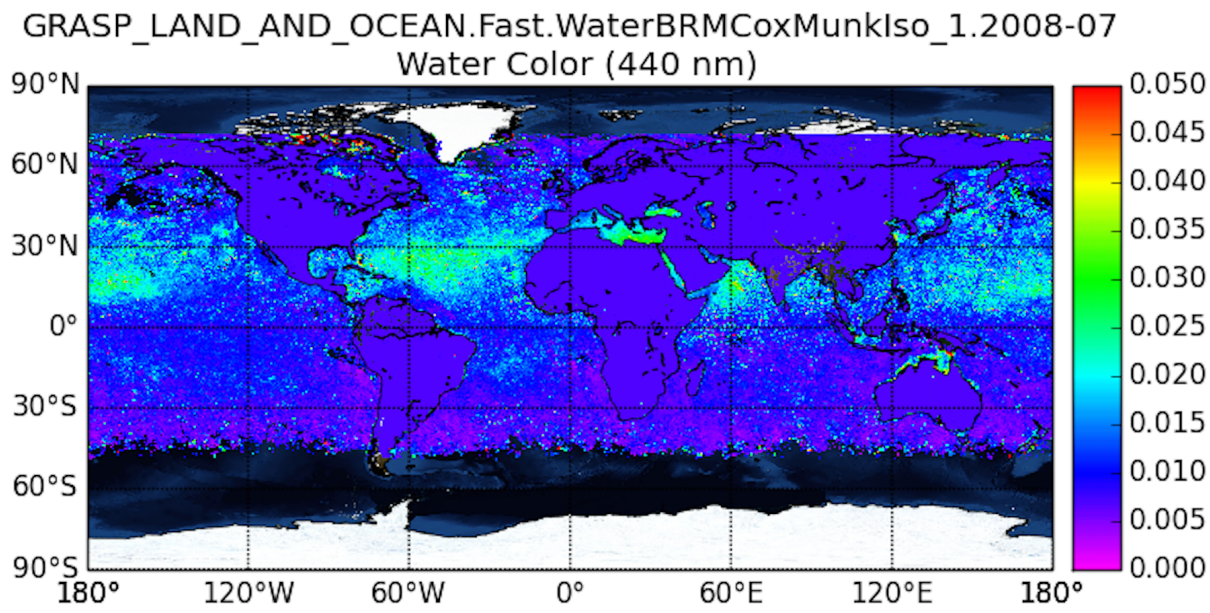




PARASOL

July 2008

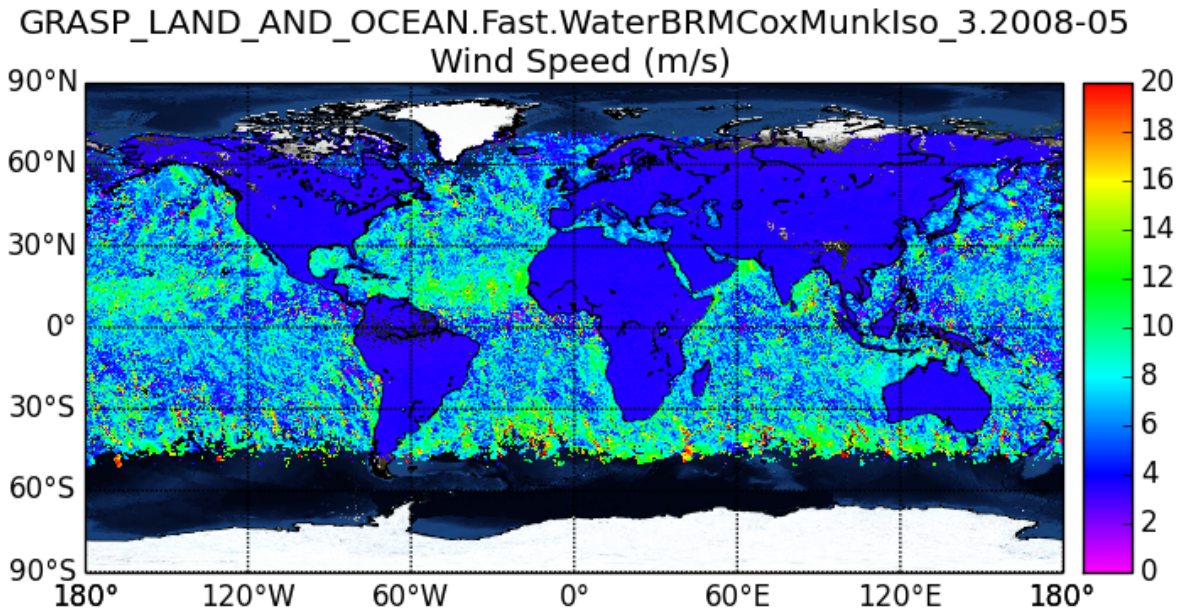




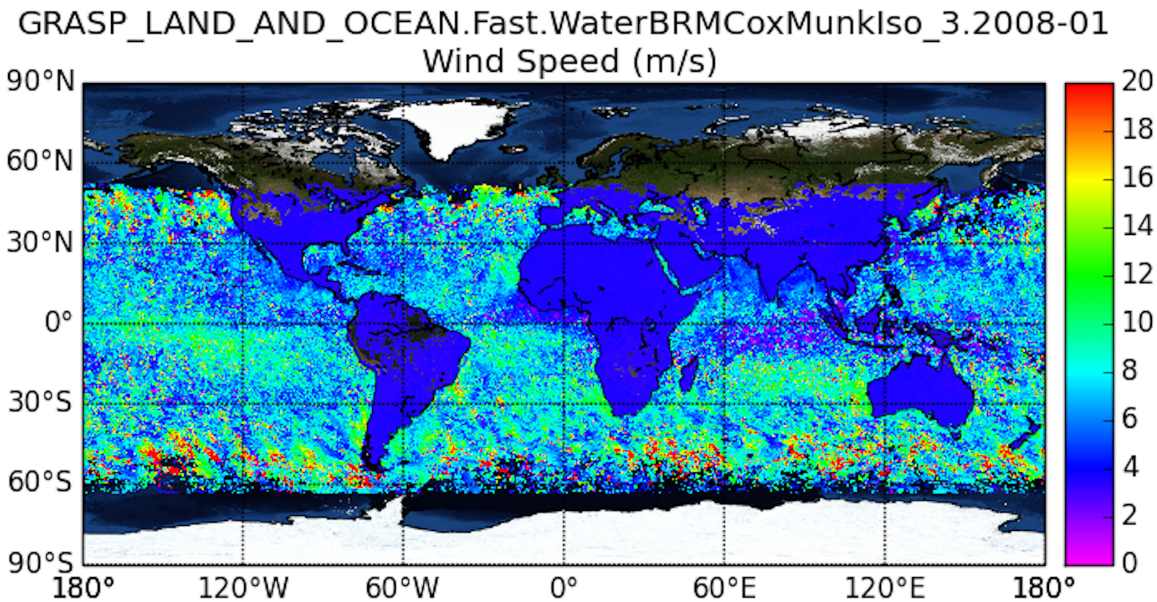
PARASOL

2008

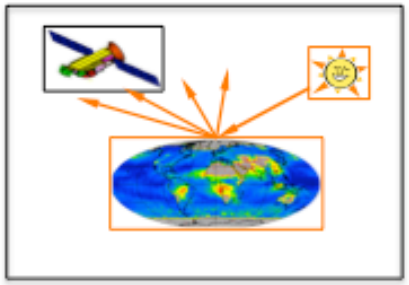
May



January

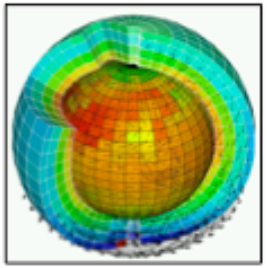


Retrieving aerosol sources from satellite observations by inverting transport model



$$m(t,\mathbf{x}) = \int_{t_0}^{t} T(t',\mathbf{x})(m(t',\mathbf{x}) + s(t',\mathbf{x}))dt'$$

$$T(t,x) = T_q T_{q-1} \ldots T_3 T_2 T_1$$



Satellite data: observations of ambient aerosol

INVERSION: (e.g. via adjoint model)

Transport Model:
- meteorology
- transport
- chemistry
- removal
- emissions?

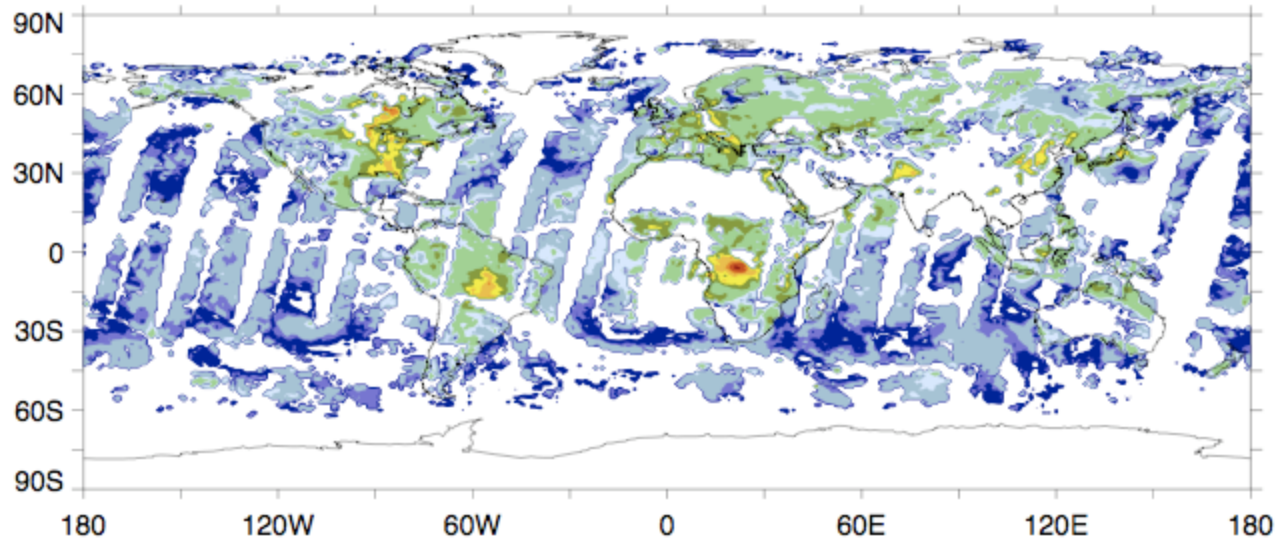
Improved sources (location and strength)
Improved agreement of modeling with observations
Improved aerosol characterization for climate, air quality,etc.

Fine Mode Aerosol:
Black Carbon +
Organic Carbon +
Sulfate + …

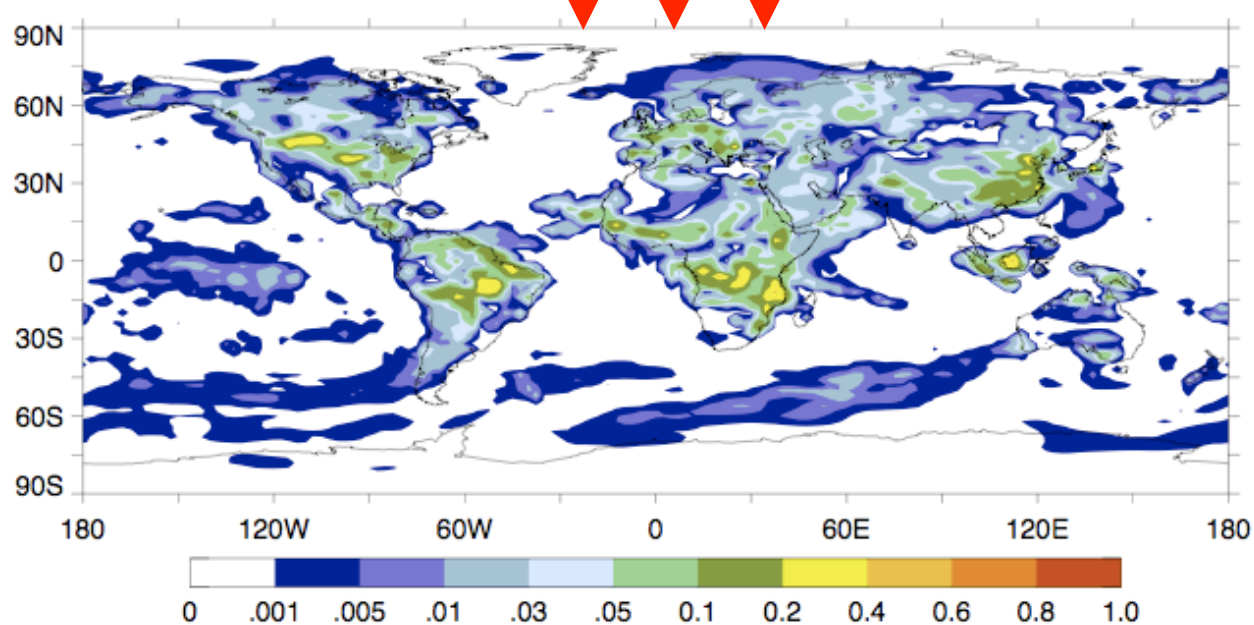
Dubovik et al. 2008

August 20 - 28, 2000

MODIS Observations (opt. thickness)



Retrieved Emission



9 day average, Optical Thickness retrieval is NOT CONSTRAINED to the land

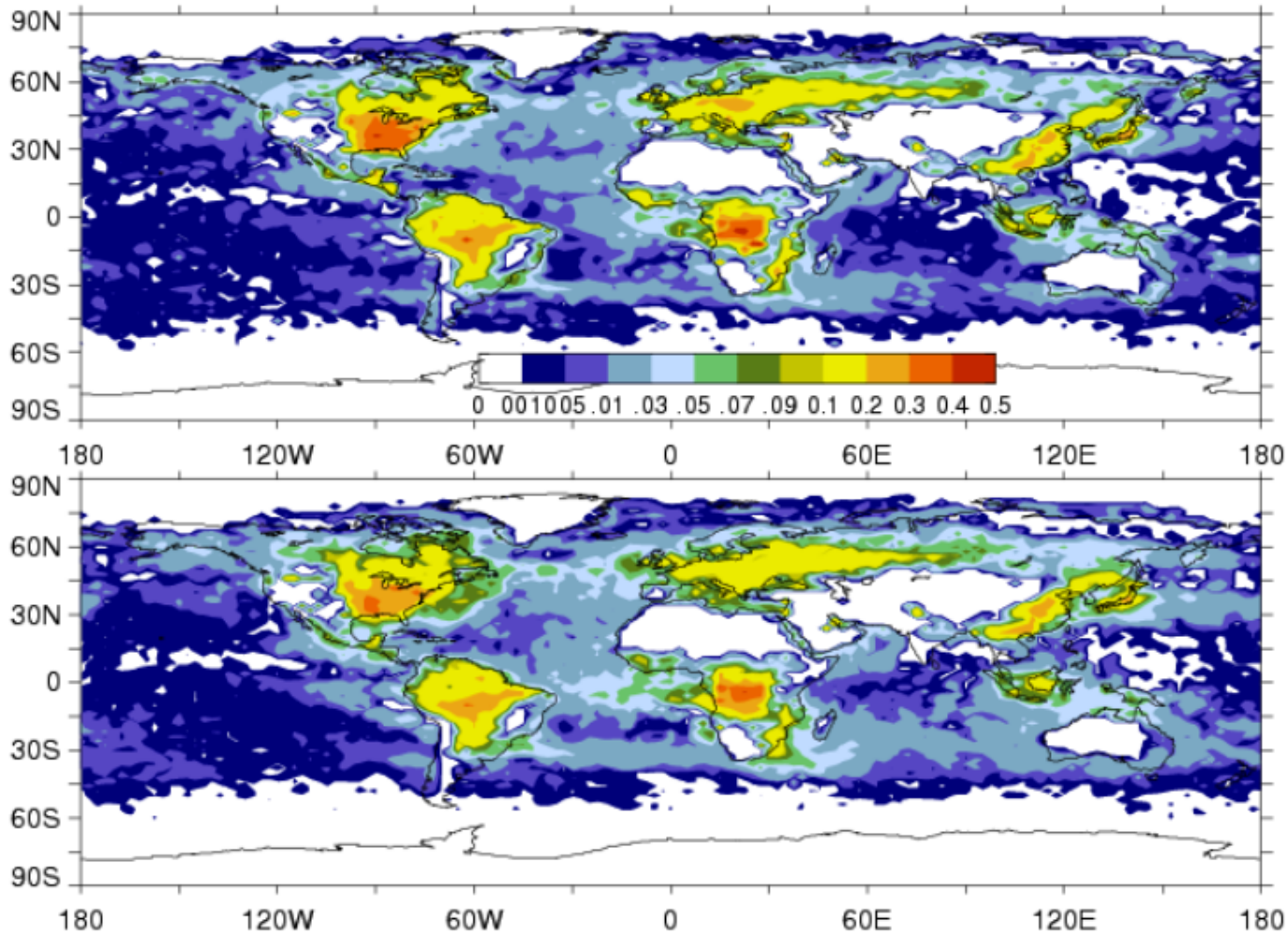
$\sigma_{fit} < \sim 0.04$ (for instantaneous τ values)

$\sigma_{MODIS} = 0.03 + 0.05\,\tau$

Optical Thickness
(August 20-28, 2000)

MODIS+AERONET Observations
(Fine Mode opt. Thickness,
(degraded to $2^0 \times 2.5^0$)

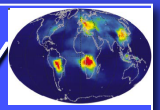
Model output using retrieved emission



Model ≠ Observations

GOCART output

MASS: $M(x;y$



$2^o \times 2.5^o$, ~20 min

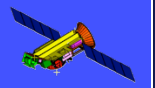
Components:

- BC hydrophilic
- BC hydrophobic
- OC hydrophilic
- OC hydrophobic
- sulfates
- dust (size d.)
- sea salt (fine, coarse)

≠

MODIS products

Aerosol Optical thickness:



$\tau(x;y;t)$

$1^o \times 1^o$,

global coverage in ~2 days

Components:

- $\tau_{fine}(0.55\mu m)$
- $\tau_{coarse}(0.55\mu m)$

Extra - assumptions in the inversion

24 hours constant emissions

Components:

- $M_{fine}(x;y;z;t)$ (BC + OC + sulfates + fine dust + fine sea salt)
- $M_{coarse}(x;y;z;t)$ (coarse dust + coarse sea salt)

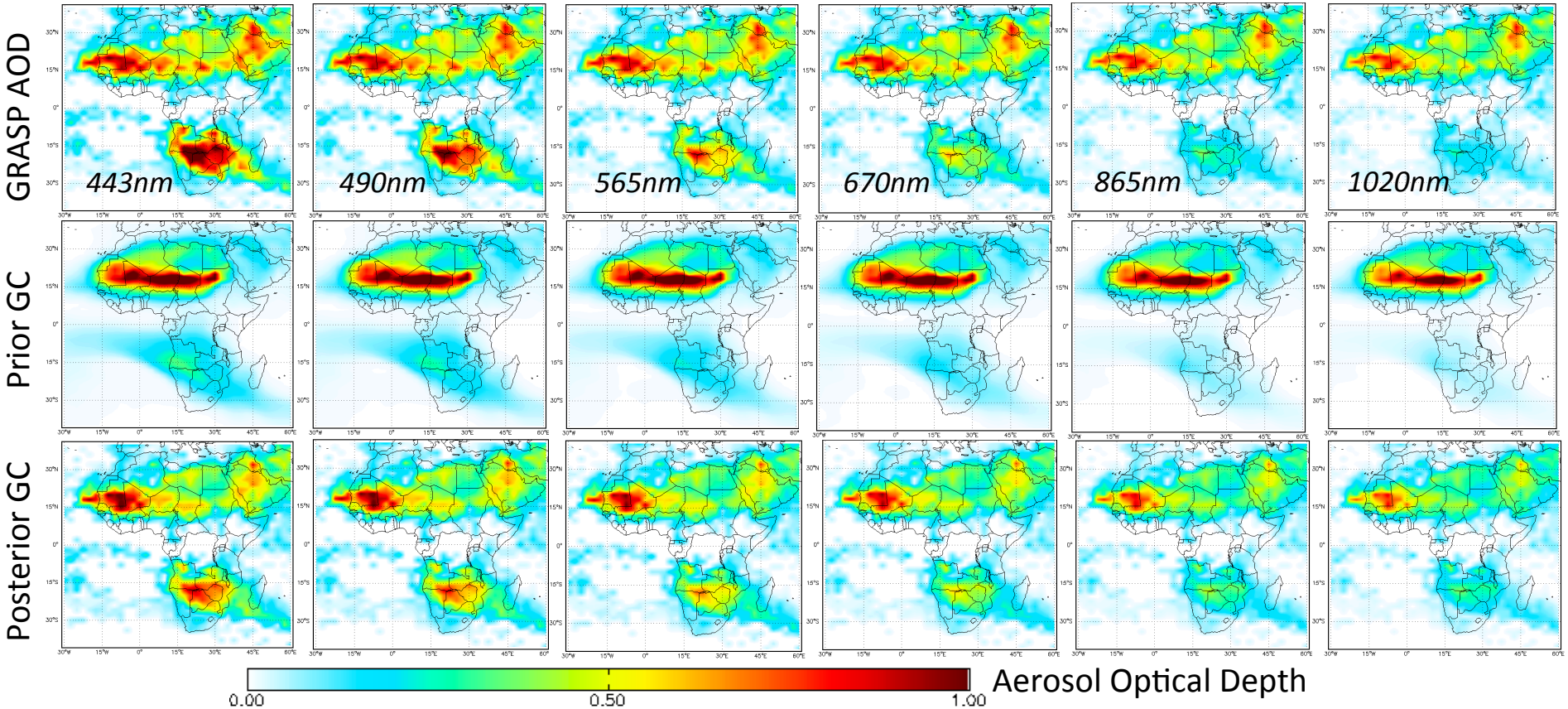
A priori constraints

Using GOCART emissions as a priori estimates

(~ assimilation)

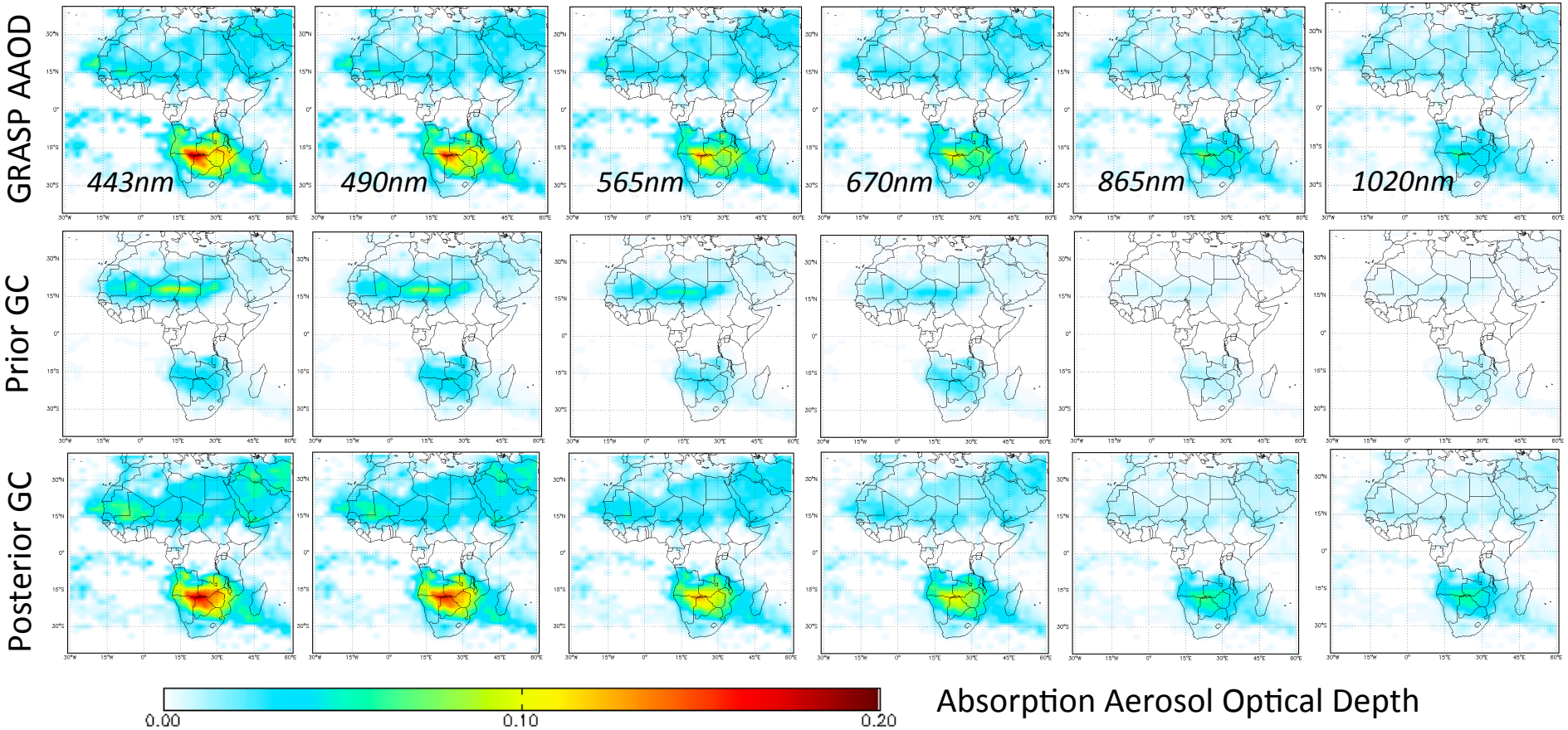
Aerosol Optical Depth Fitting by GEOS-CHEM

Time period: Sept. 25th ~ Oct. 5th 2008



Absorption Aerosol Optical Depth Fitting by GEOS-CHEM

Time period: Sept. 25th ~ Oct. 5th 2008



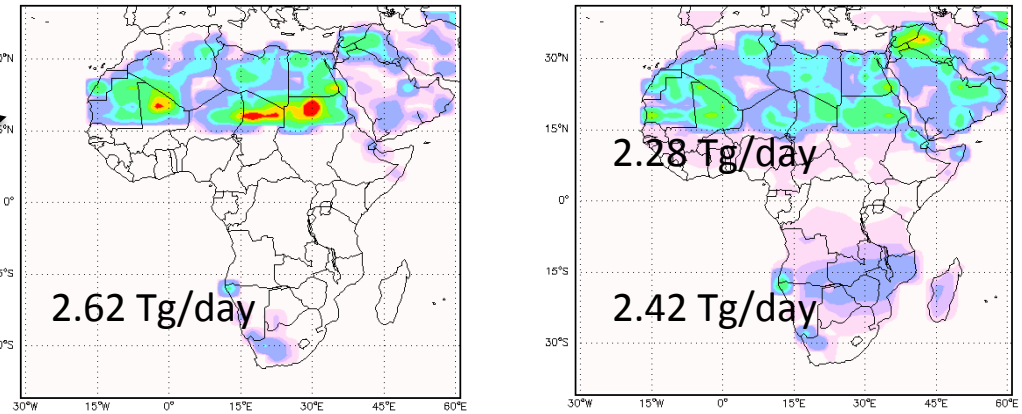
Time period:
Sept. 25th ~
Oct. 5th 2008

GEOS-CHEM

Dust Emission (kg)

Prior GC Model

Posterior GC Model



0.0e+00 1.0e+05 5.0e+05 1.0e+06 5.0e+06 1.0e+07 3.0e+07 5.0e+07 7.0e+07 1.0e+08

Unit: kg/pixel/day

GEOS-CHEM

Retrieved

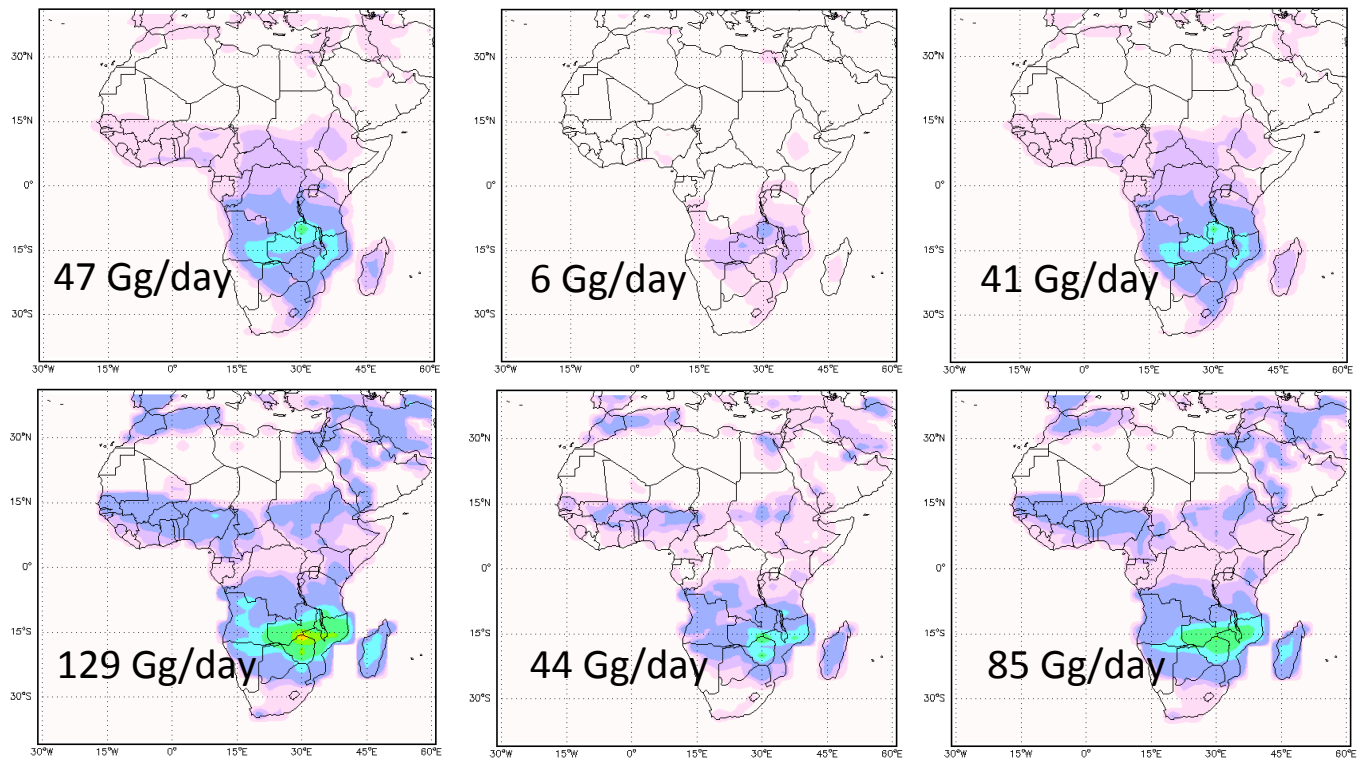
Prior GC

Posterior GC

BC+OC

BC

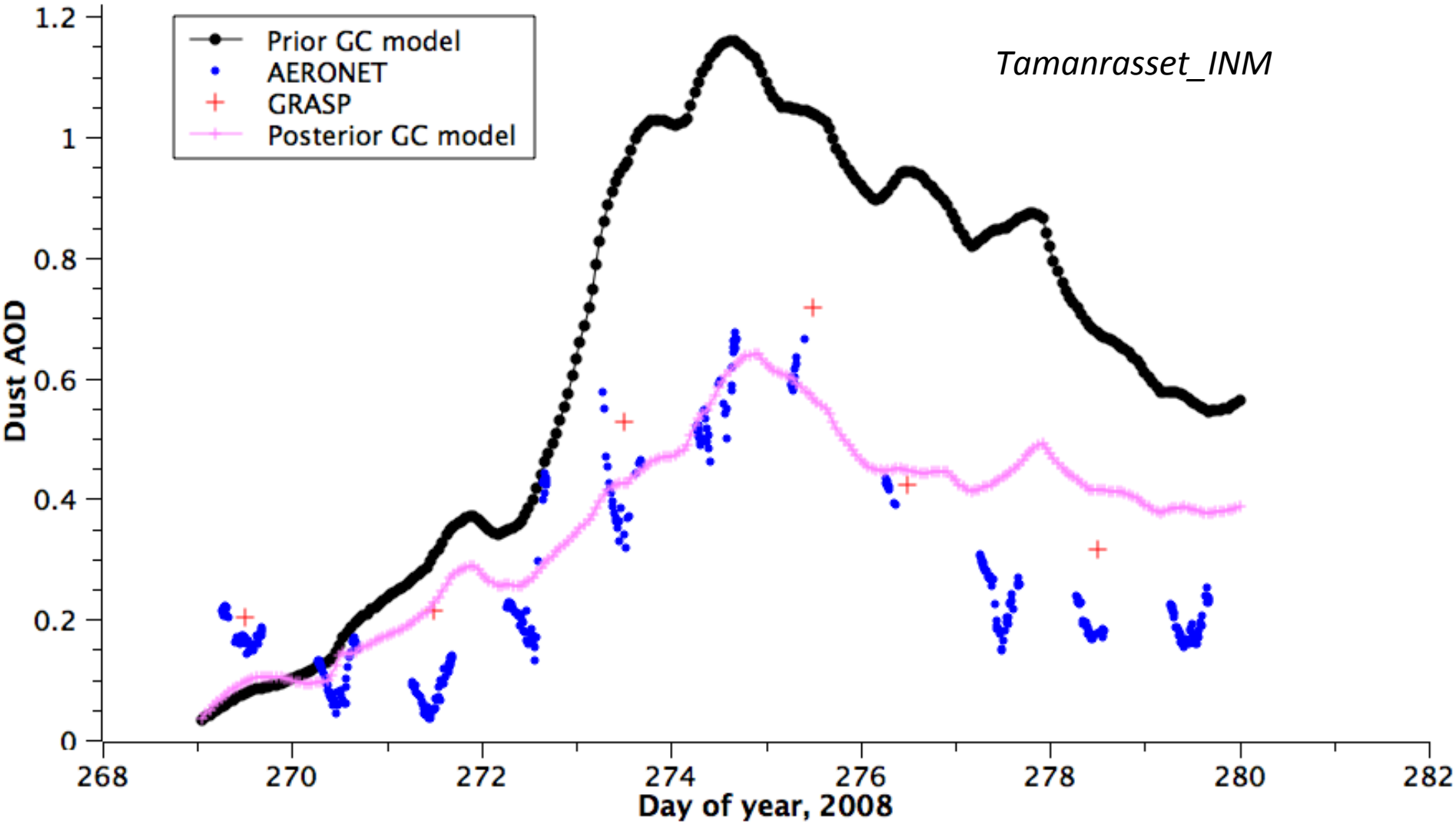
OC



0.0e+00 1.0e+04 5.0e+04 1.0e+05 5.0e+05 1.0e+06 2.0e+06 3.0e+06 4.0e+06 5.0e+06

Unit: kg/pixel/day

Validation with AERONET Site



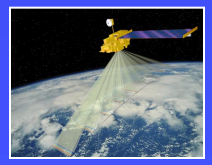
Conclusions:

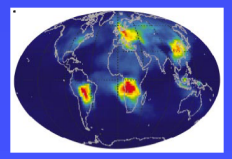
GRASP concept:

- ✓ *Proposes new approach for remote sensing:*
  - retrieving many characteristics simultaneously (aerosol + surface);
  - statistically optimized "multi-pixel" inversion;

- ✓ *First results are promising for different remote sensing observations:*
  - satellite (*PARASOL*, MERIS, 3MI, S-3, S-4 …);
  - ground based (passive + active);
  - various synergies;

- ✓ *Helps to provide new information about atmospheric parameters and Increases constraints for inverse modeling and assimilation*

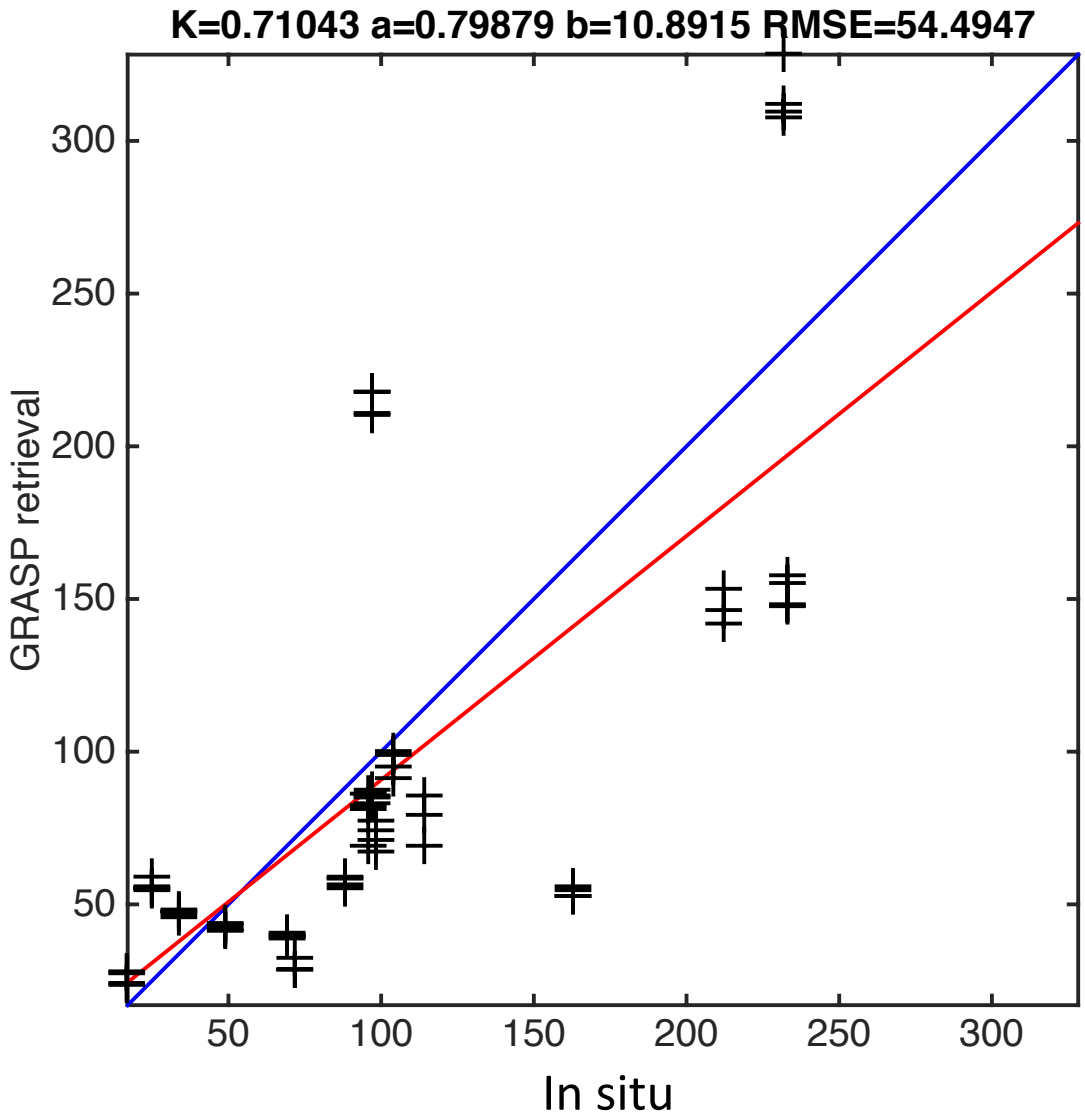





Thank you Yoram !!!

Hope our results wouldn't disappoint you..

PM2.5: Comparison of PARASOL results with in situ



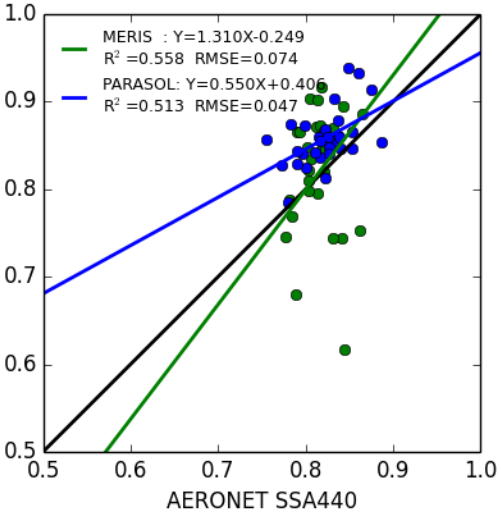
March 1- 31, 2013

US Embassy Beijing

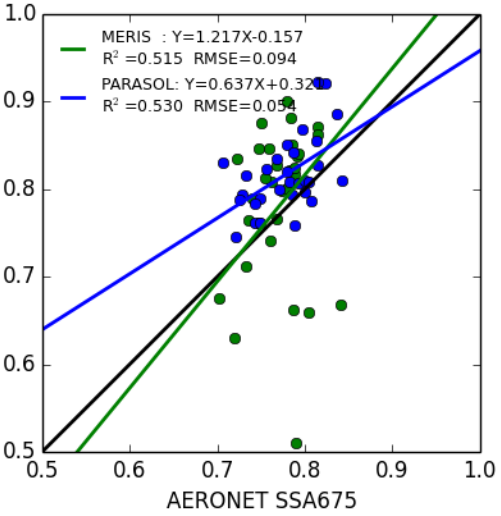
MERIS
PARASOL

Mongu 06/2008 – 08/2008 (2)

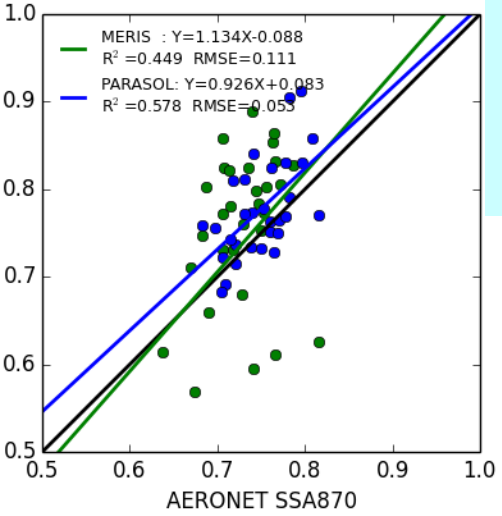
SSA (440)



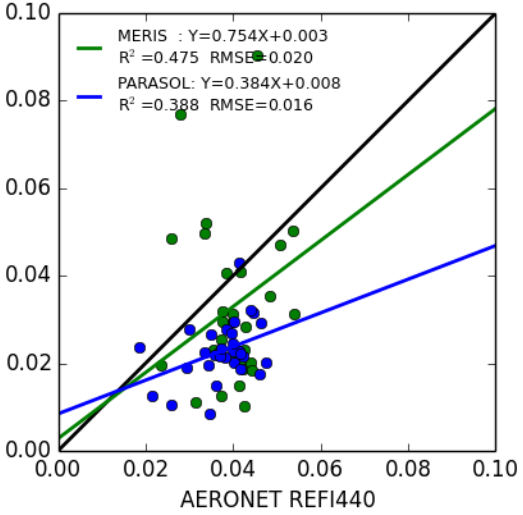
SSA (670)



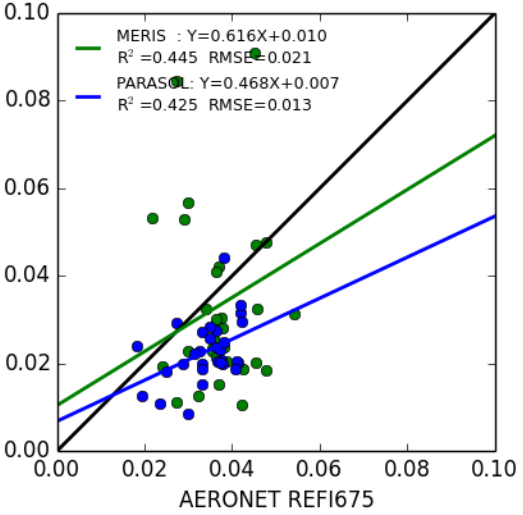
SSA (870)



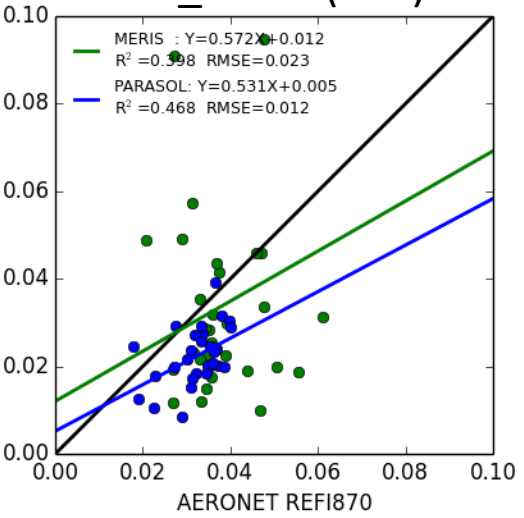
RE_IMAG (440)



RE_IMAG (670)



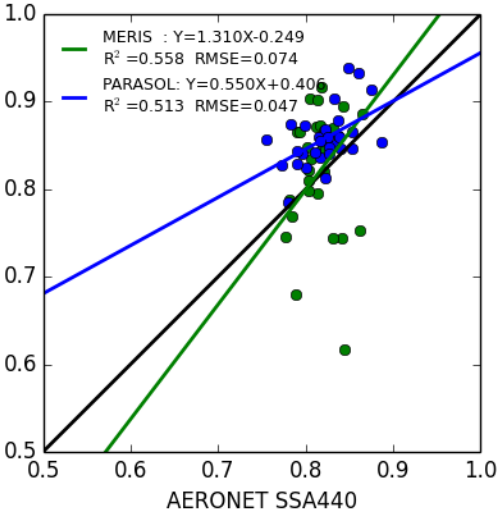
RE_IMAG (870)



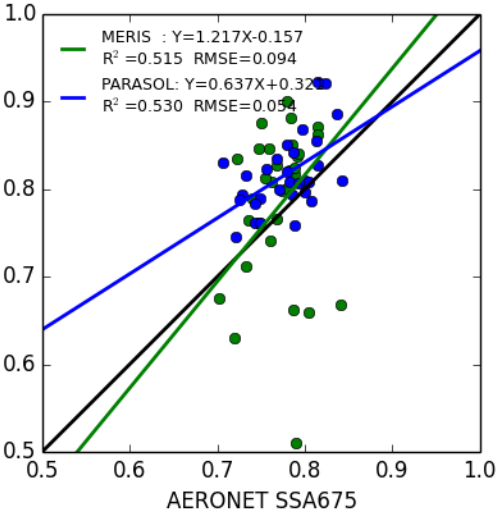
MERIS
PARASOL

Mongu 06/2008 – 08/2008 (2)

SSA (440)



SSA (670)



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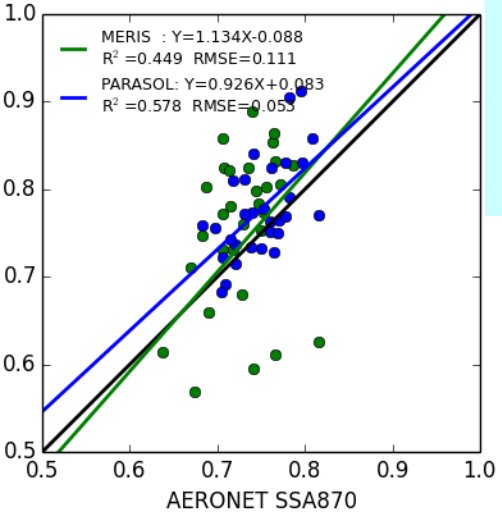
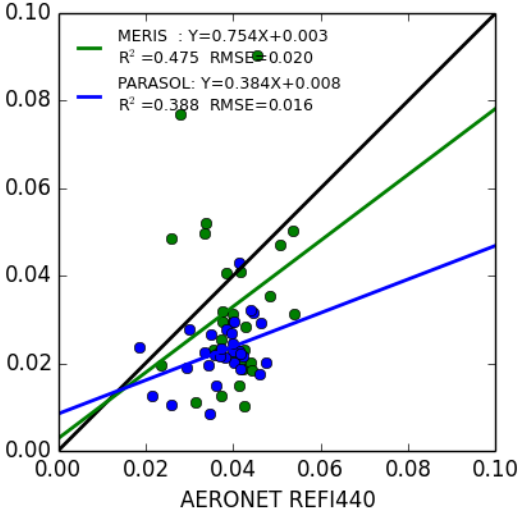
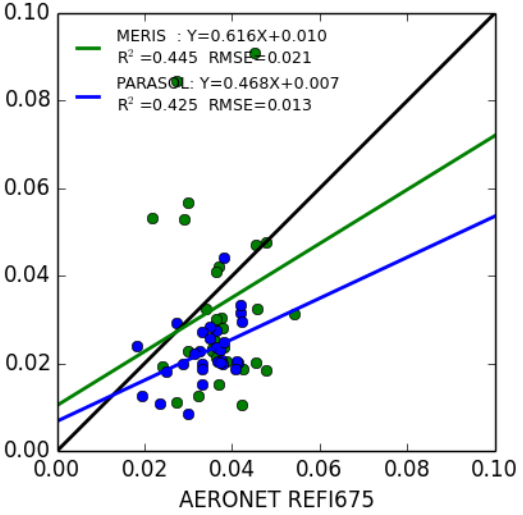


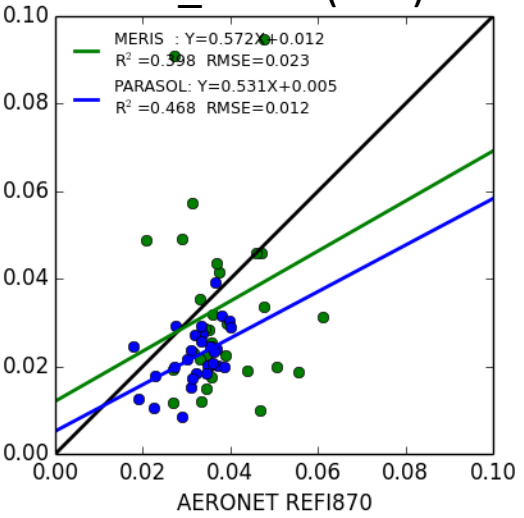
RE_IMAG (440)



RE_IMAG (670)

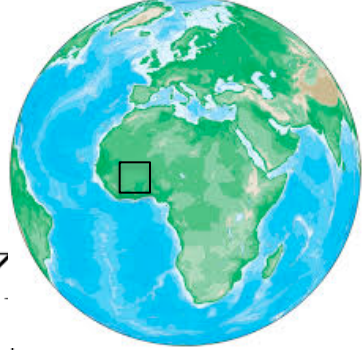


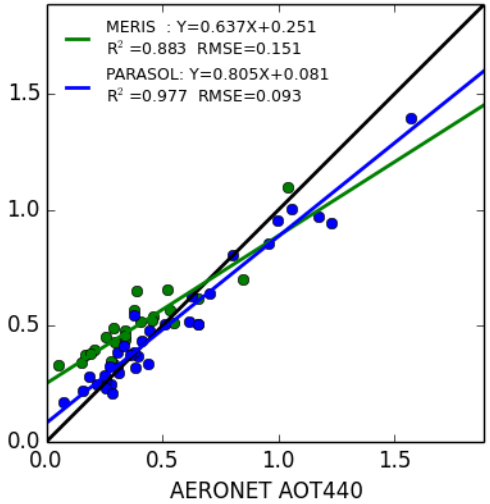
RE_IMAG (870)

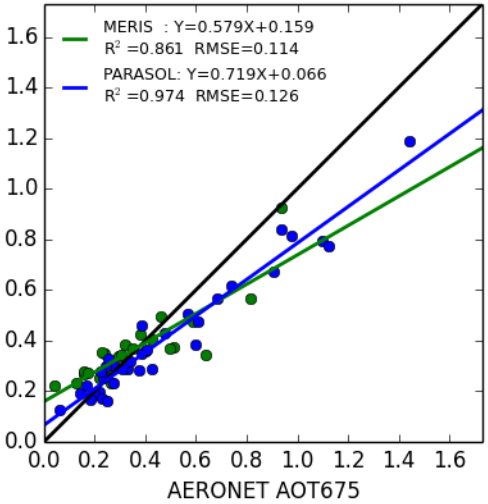


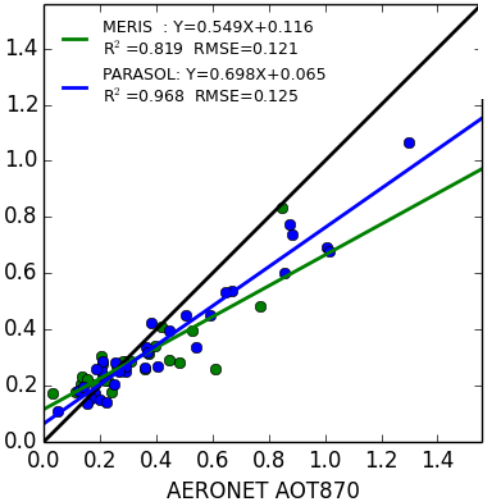
MERIS
PARASOL

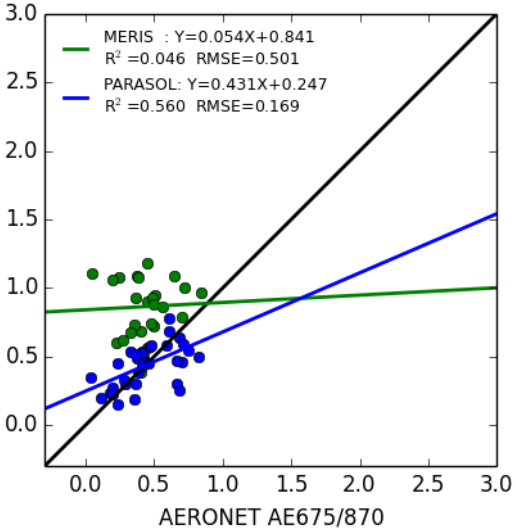
Banizoumbou 01/2008 – 03/2008 (1)

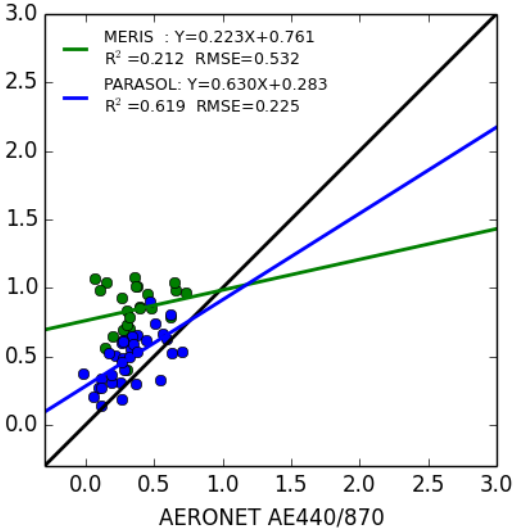






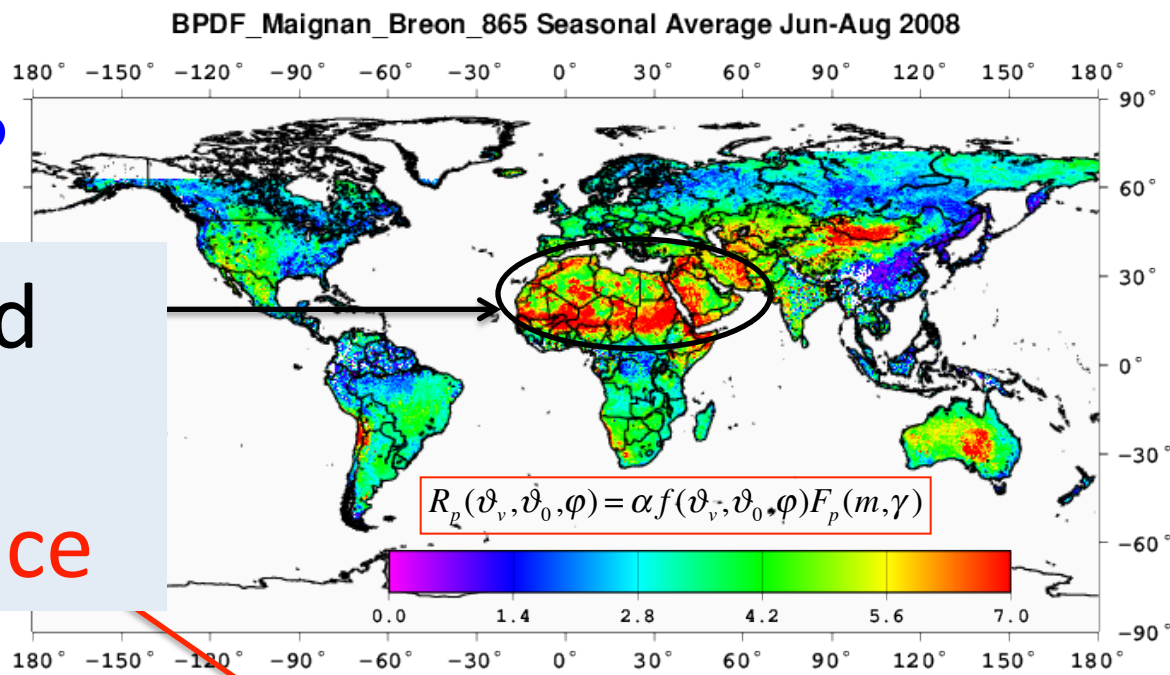


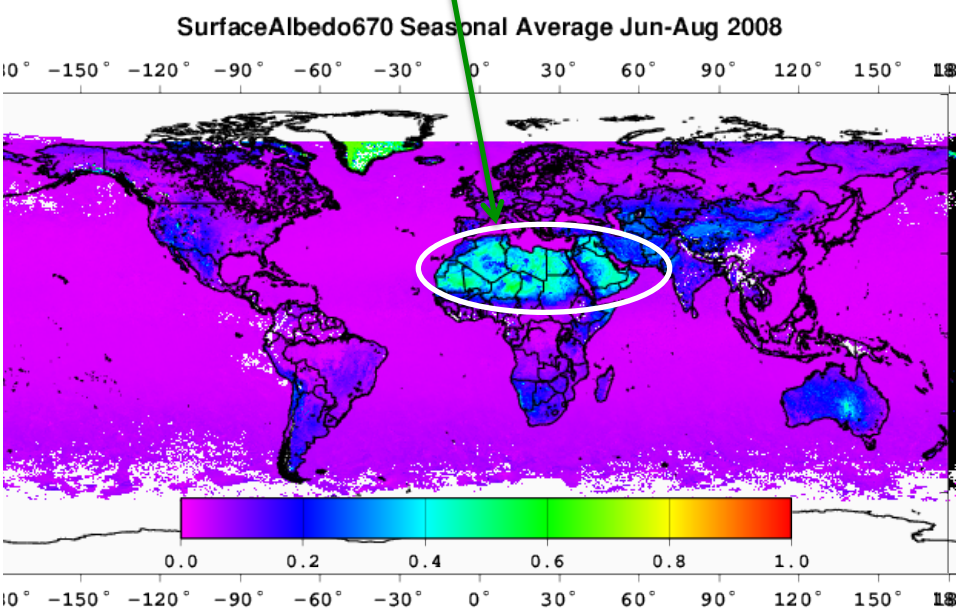


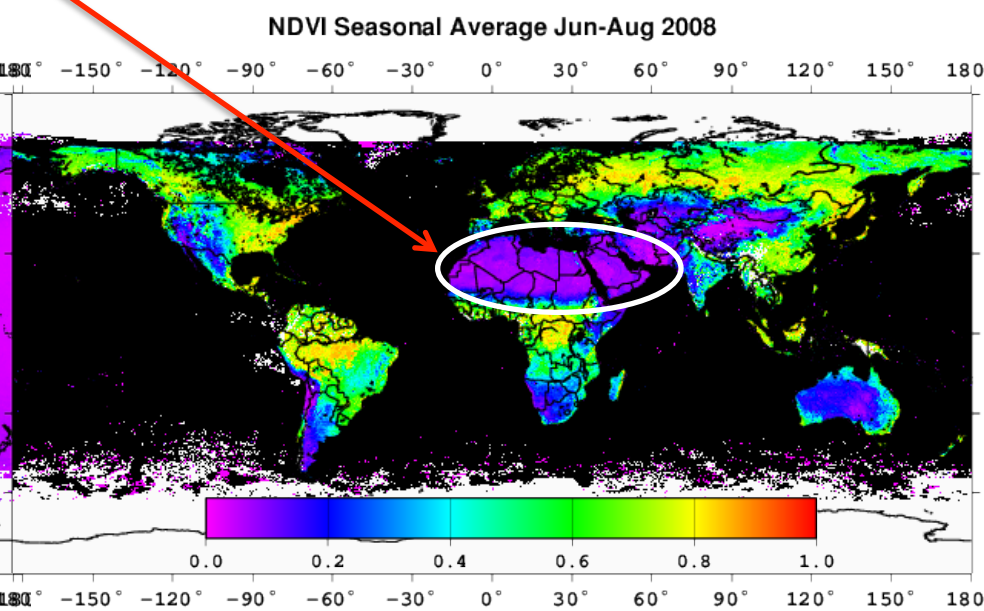


Advanced surface retrieval with GRASP

The same NDVI and DHR but different Polarized reflectance

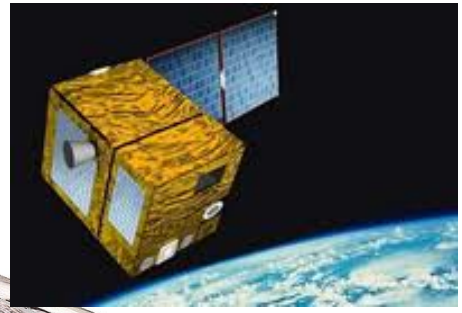




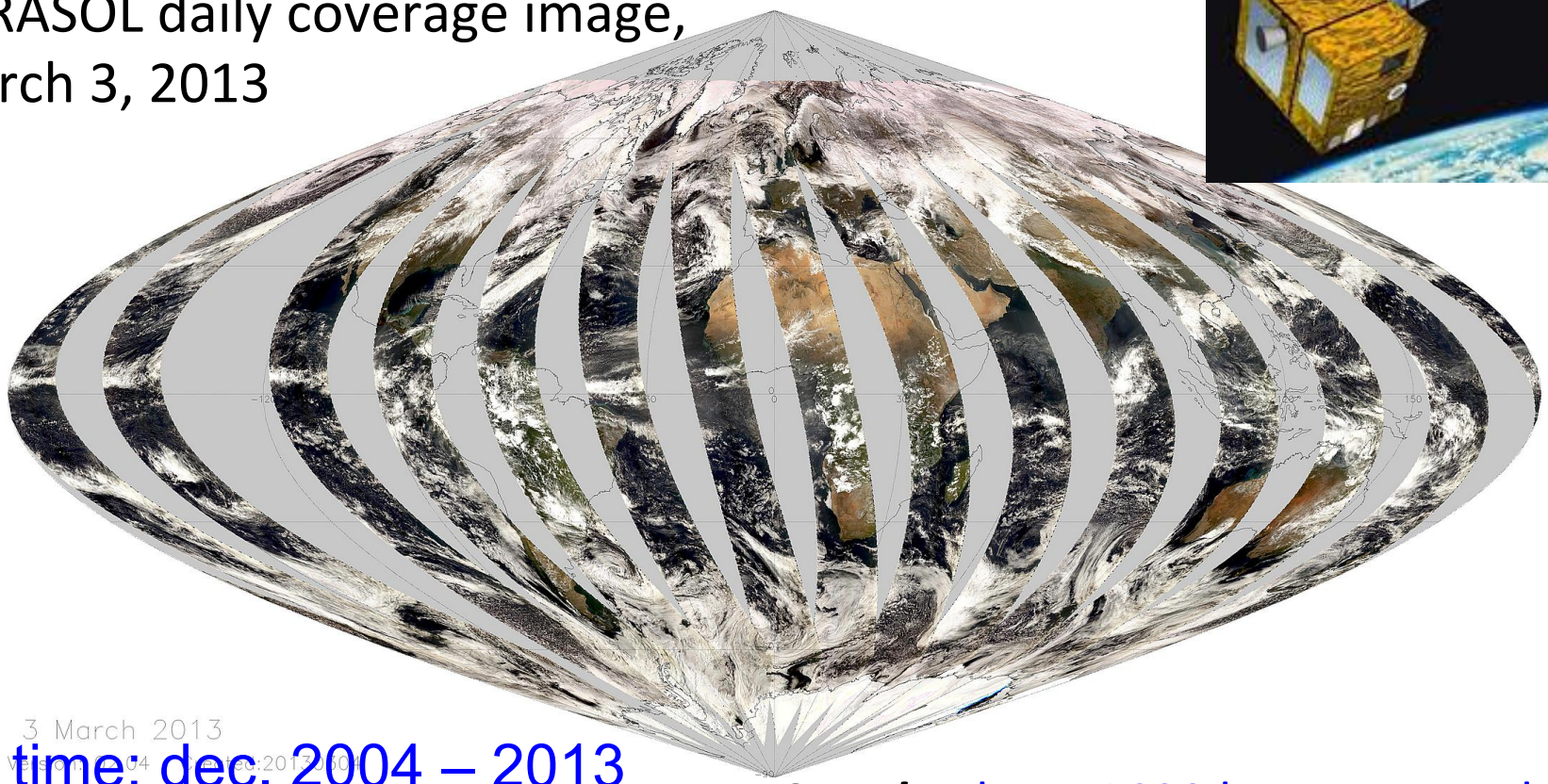


Polarized reflectance provides new information about surface type!

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



PARASOL daily coverage image, March 3, 2013



life time: dec. 2004 – 2013

INTENSITY

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)

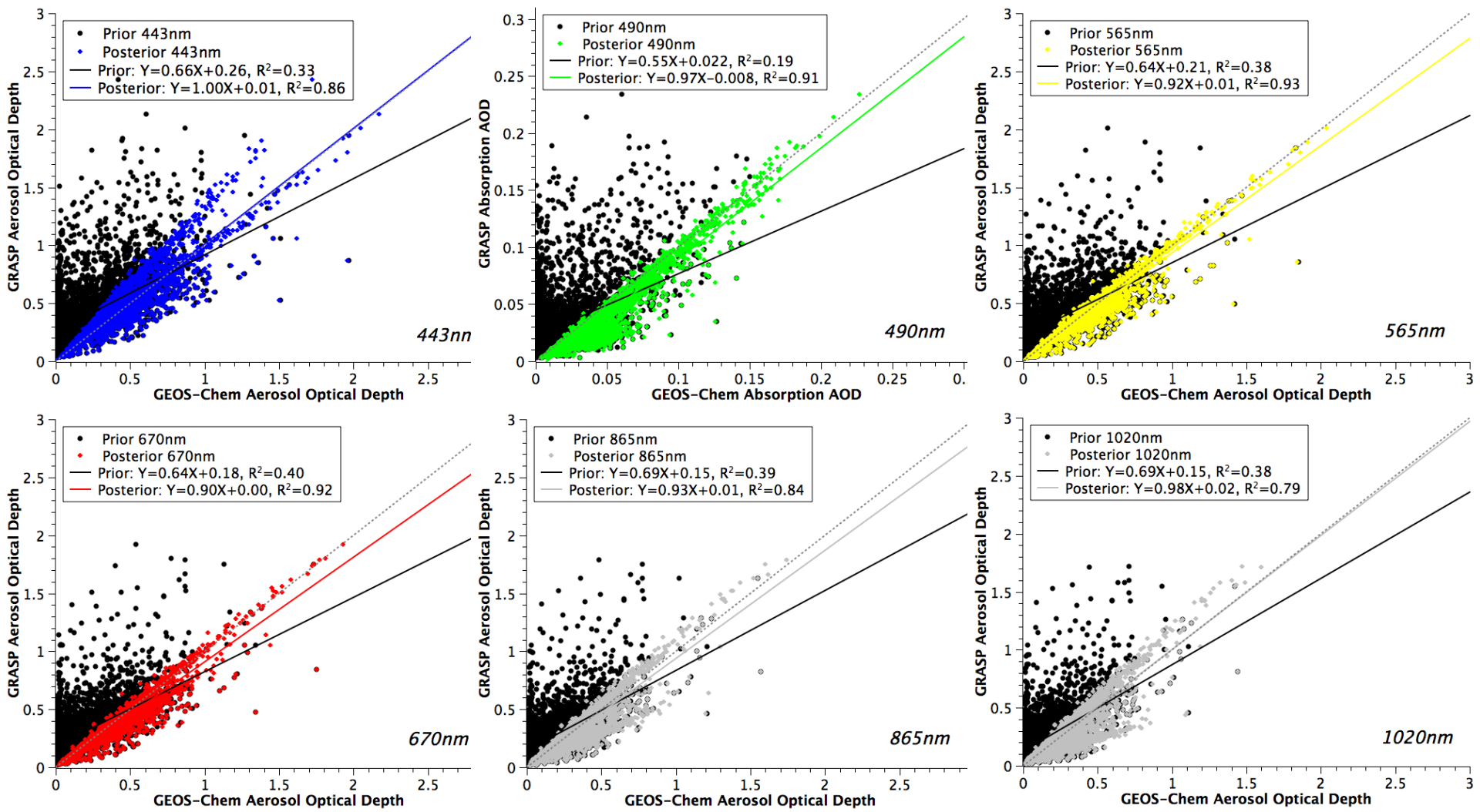
POLARIZATION (Q, U): (0.49, 0.67, 0.865 μm)

Swath: about 1600 km cross-track

Global coverage: every 2 days

1 pixel spatial resolution: 5.3km × 6.2km

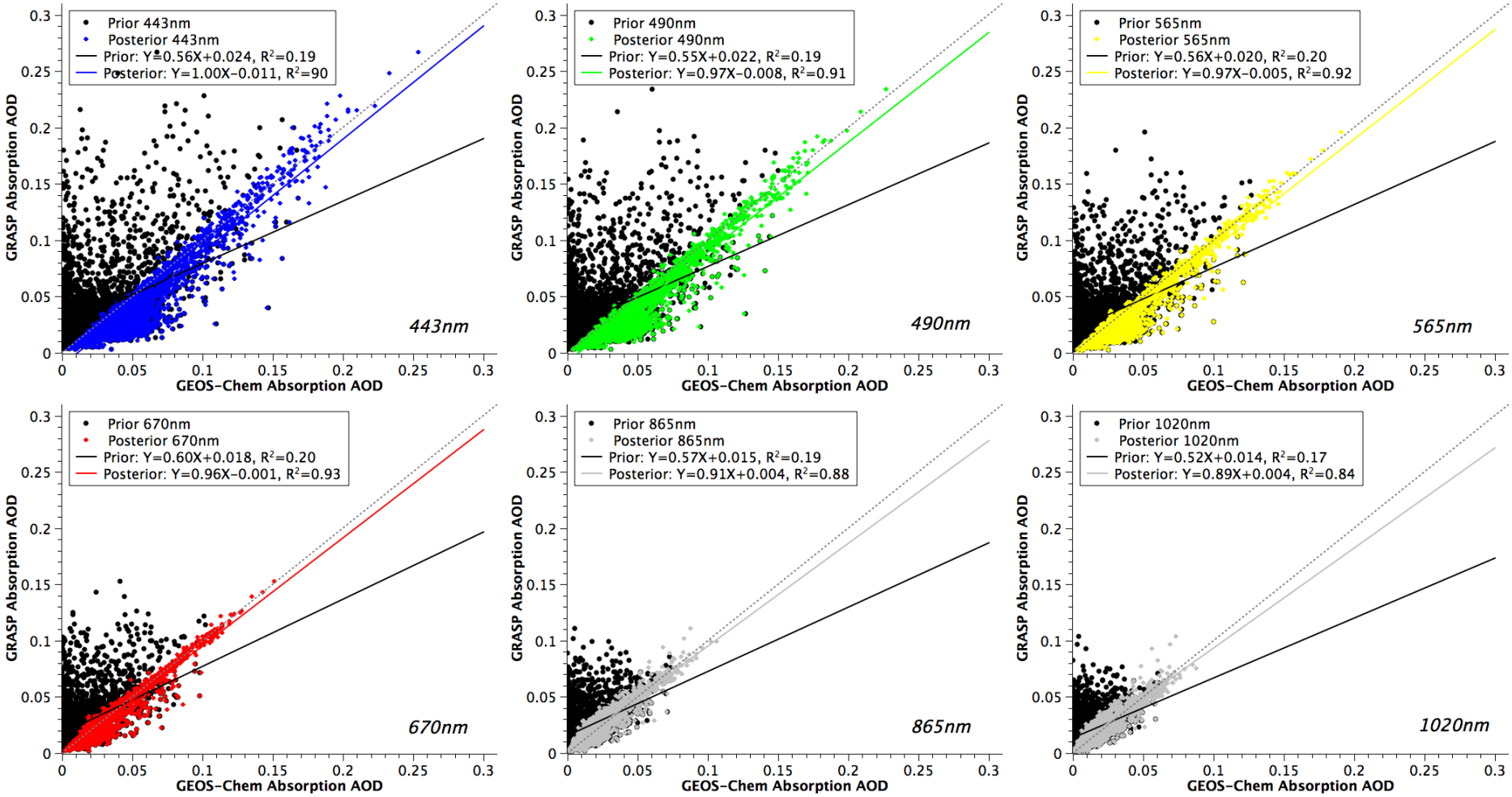
Viewing directions: 16: (80^0 – 180^0)



Fitting of AOD(λ)

Table. Slopes and intercepts from linear regression analysis of spectral GRASP AOD(λ) versus Prior and Posterior GEOS-Chem model AOD(λ).

Wavelength (nm)	Prior			Posterior		
	slope	intercept	R^2	slope	intercept	R^2
443	0.66	0.26	0.33	1.00	0.01	0.86
490	0.64	0.24	0.35	0.95	0.02	0.90
565	0.64	0.21	0.38	0.92	0.01	0.93
670	0.64	0.18	0.40	0.90	0.00	0.92
865	0.69	0.15	0.39	0.93	0.01	0.84
1020	0.74	0.13	0.38	0.98	0.01	0.79



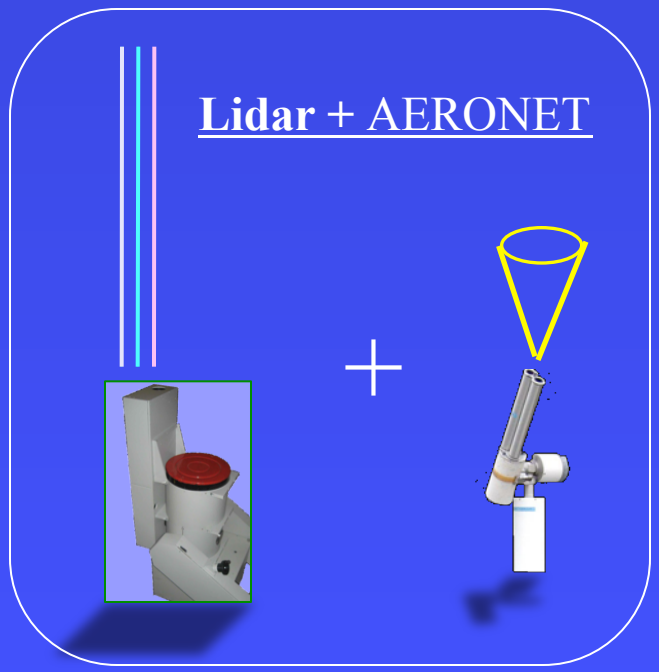
Fitting of AAOD(λ)

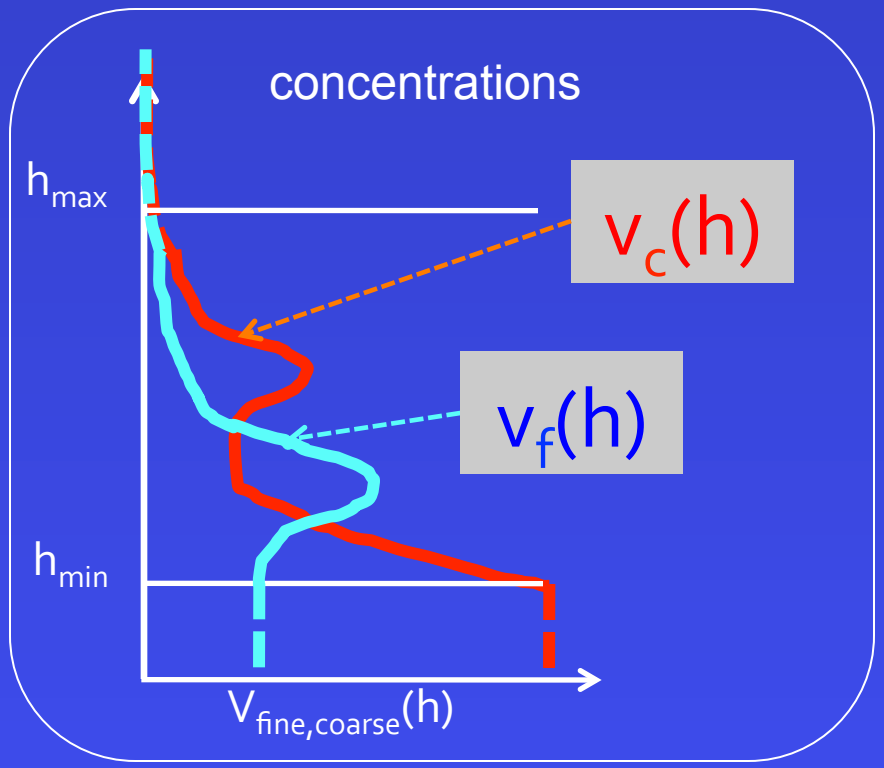
Table. Slopes and intercepts from linear regression analysis of spectral GRASP AAOD(λ) versus Prior and Posterior GEOS-Chem model AAOD(λ).

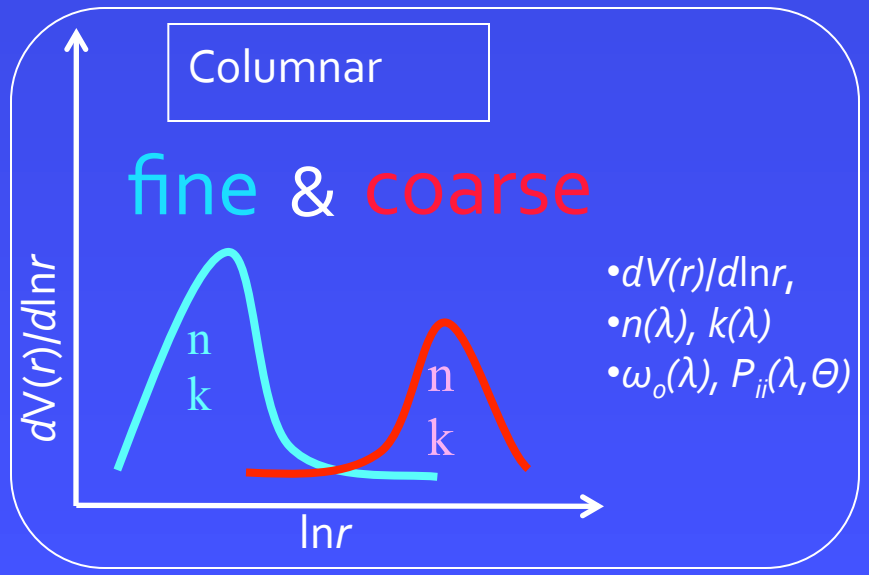
Wavelength (nm)	Prior			Posterior		
	slope	intercept	R^2	slope	intercept	R^2
443	0.56	0.024	0.19	1.00	-0.011	0.90
490	0.55	0.022	0.19	0.97	-0.008	0.91
565	0.56	0.020	0.20	0.97	-0.005	0.92
670	0.60	0.018	0.20	0.96	-0.001	0.93
865	0.57	0.015	0.19	0.91	0.004	0.88
1020	0.53	0.014	0.17	0.89	0.004	0.84

Synergy realized within GRASP for ground-based observations

GARRLiC/GRASP
Generalized Aerosol Retrieval from Radiometer and Lidar Combined data



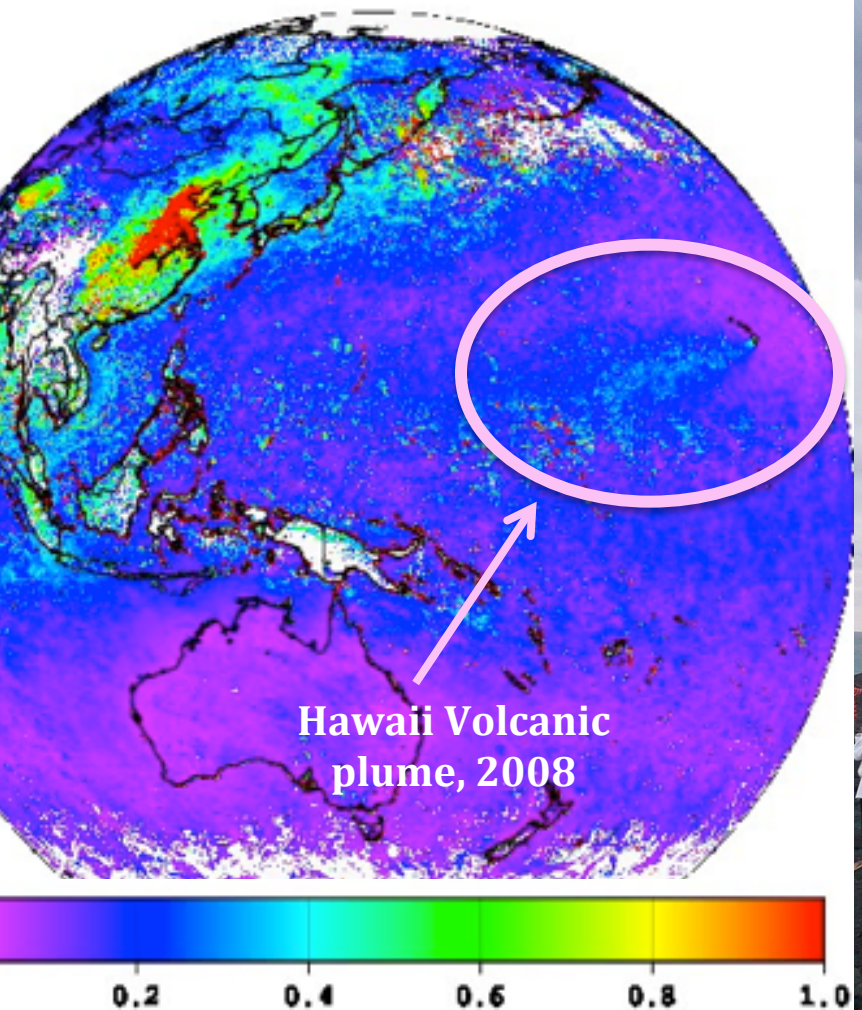




Lopatin et al. 2013

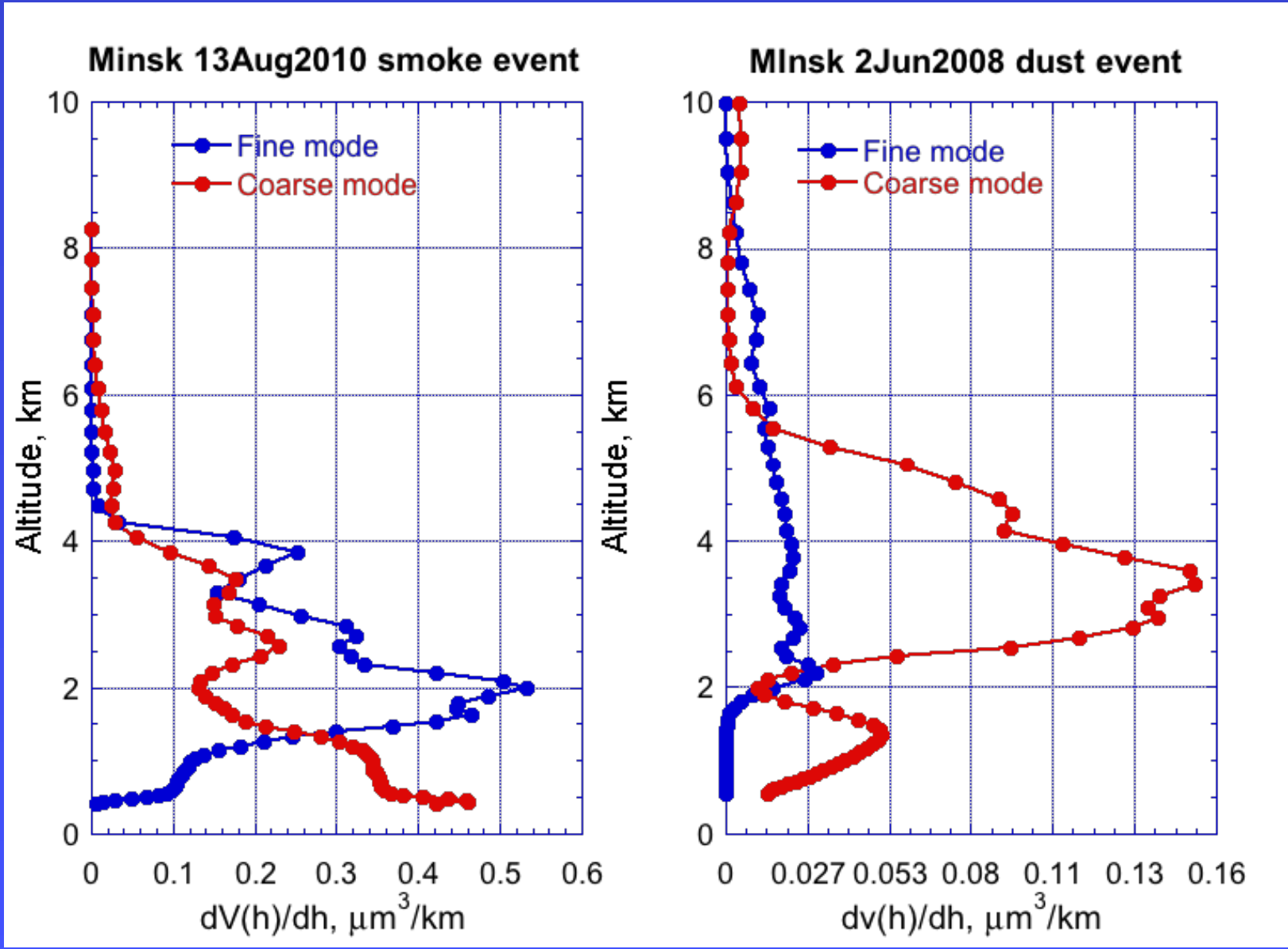
ACTRIS

GRASP retrieval: Kilauea volcano (Hawaii, Halemaumau Crater, June-August, 2008)



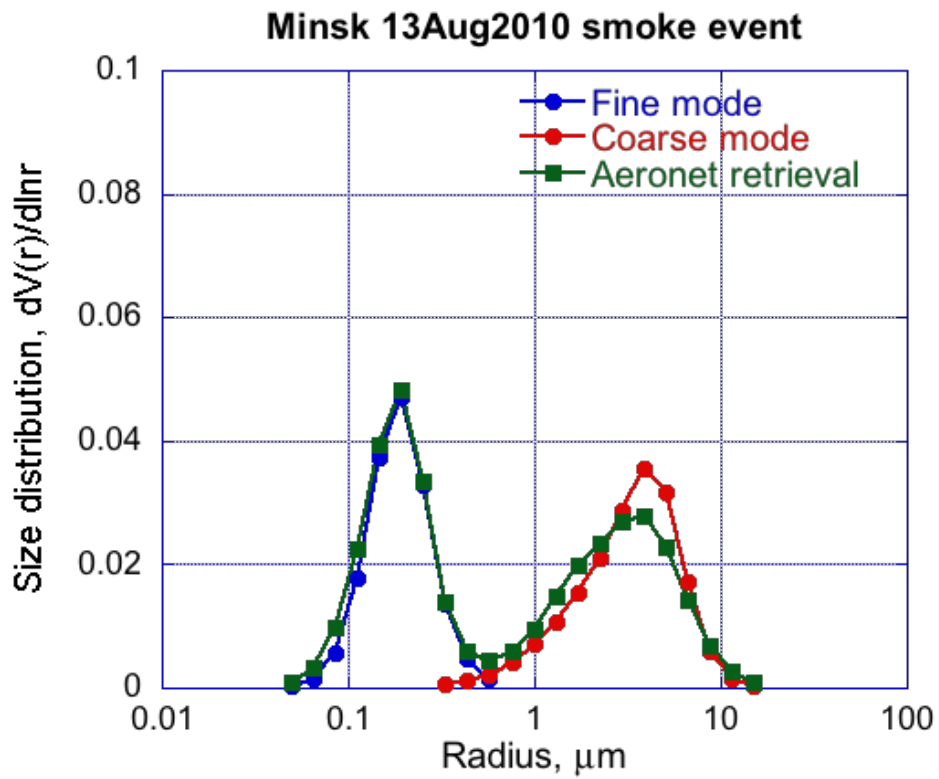
VERTICAL DISTRIBUTIONS

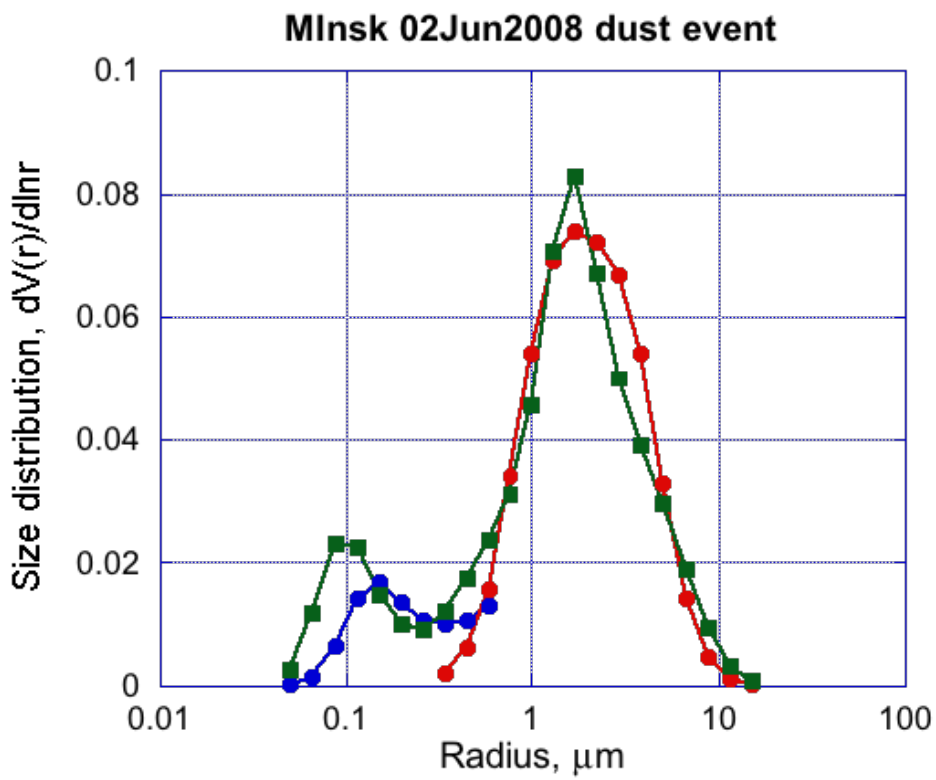
GARRLIC/GRASP



GARRLIC/GRASP

SIZE DISTRIBUTION



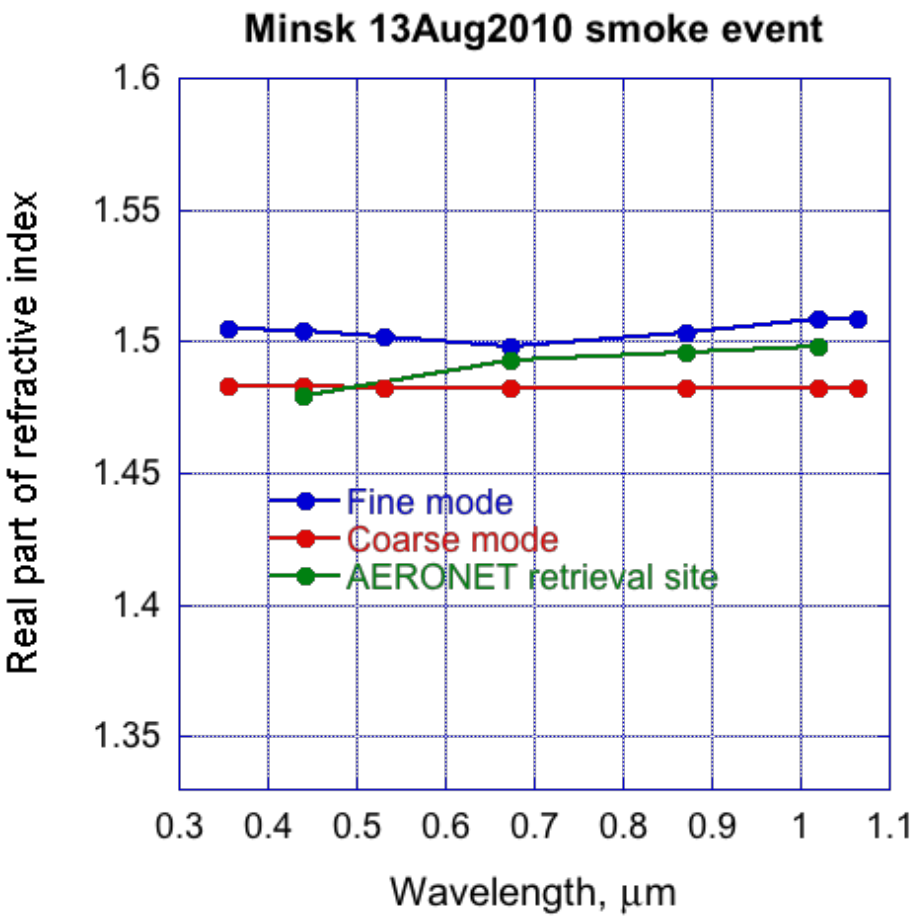


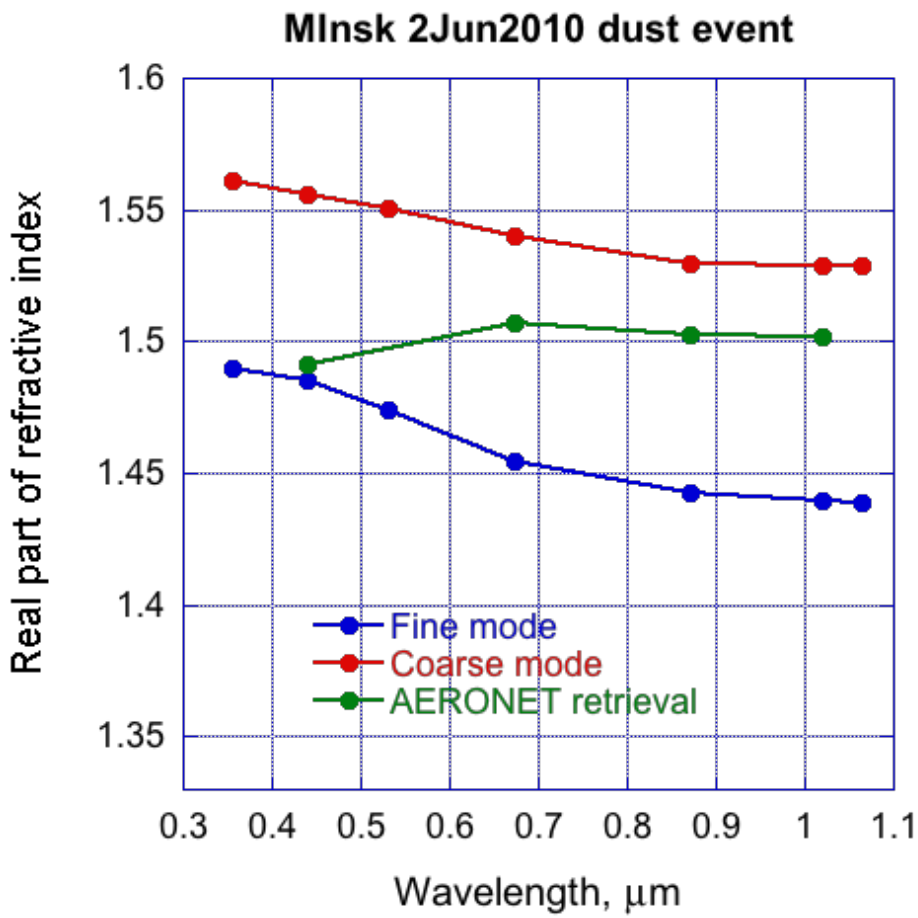
$\tau_{440}=0.46$
$\tau^{f}_{440}=0.42$
$\tau^{c}_{440}=0.04$

$\tau_{440}=0.36$
$\tau^{f}_{440}=0.19$
$\tau^{c}_{440}=0.17$

REAL PART OF REFRACTIVE INDEXES

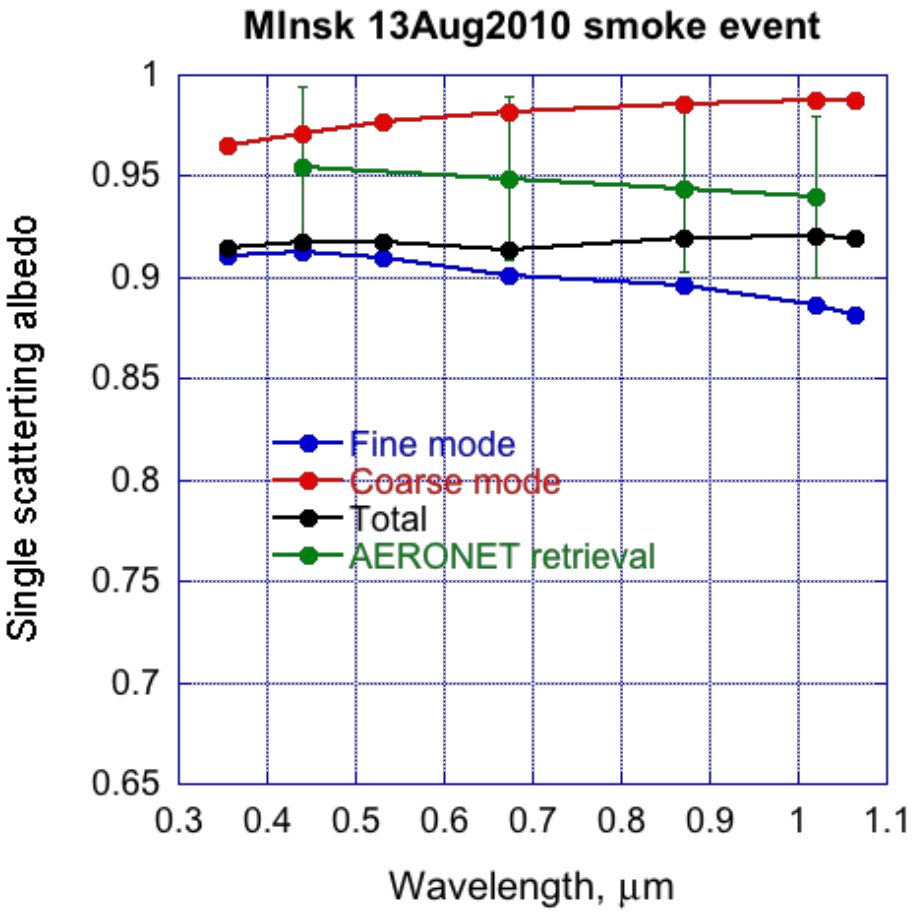
GARRLIC/GRASP

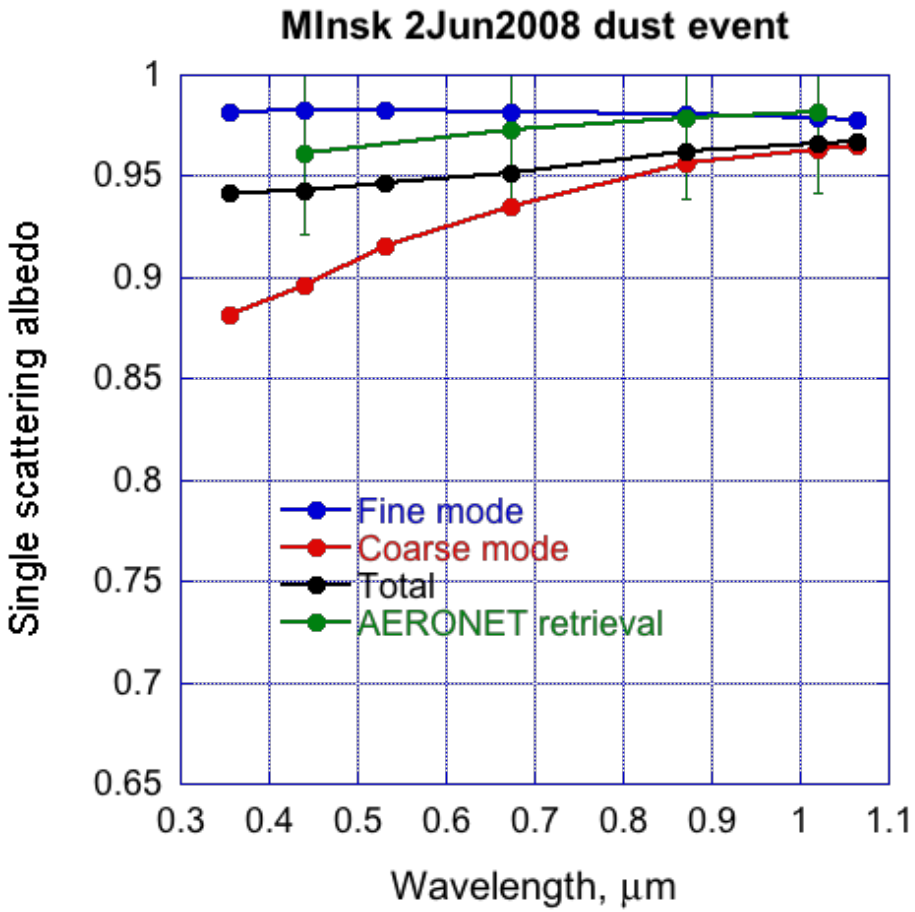




SINGLE SCATTERING ALBEDO

GARRLIC

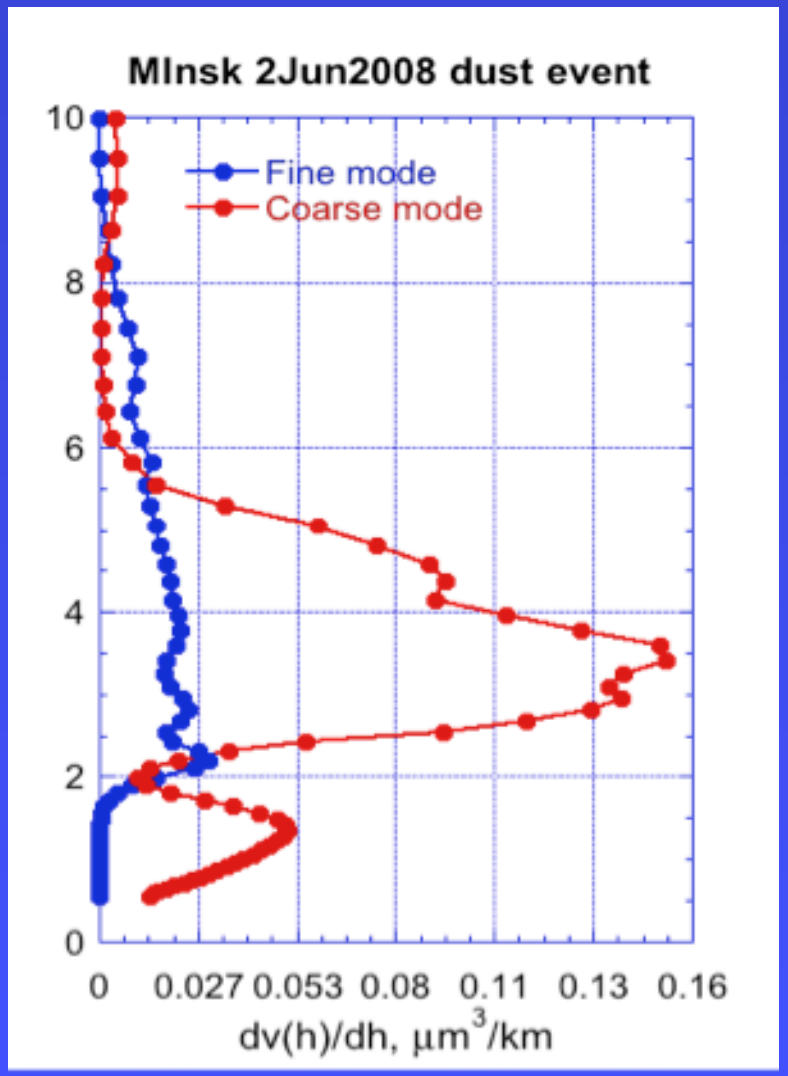




VERTICAL DISTRIBUTIONS

GARRLIC

concentration profiles



SSA profiles