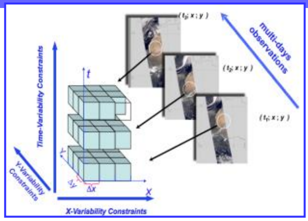
GRASP: applications to enhanced retrievals retrieval of aerosol from PARASOL satellites observations



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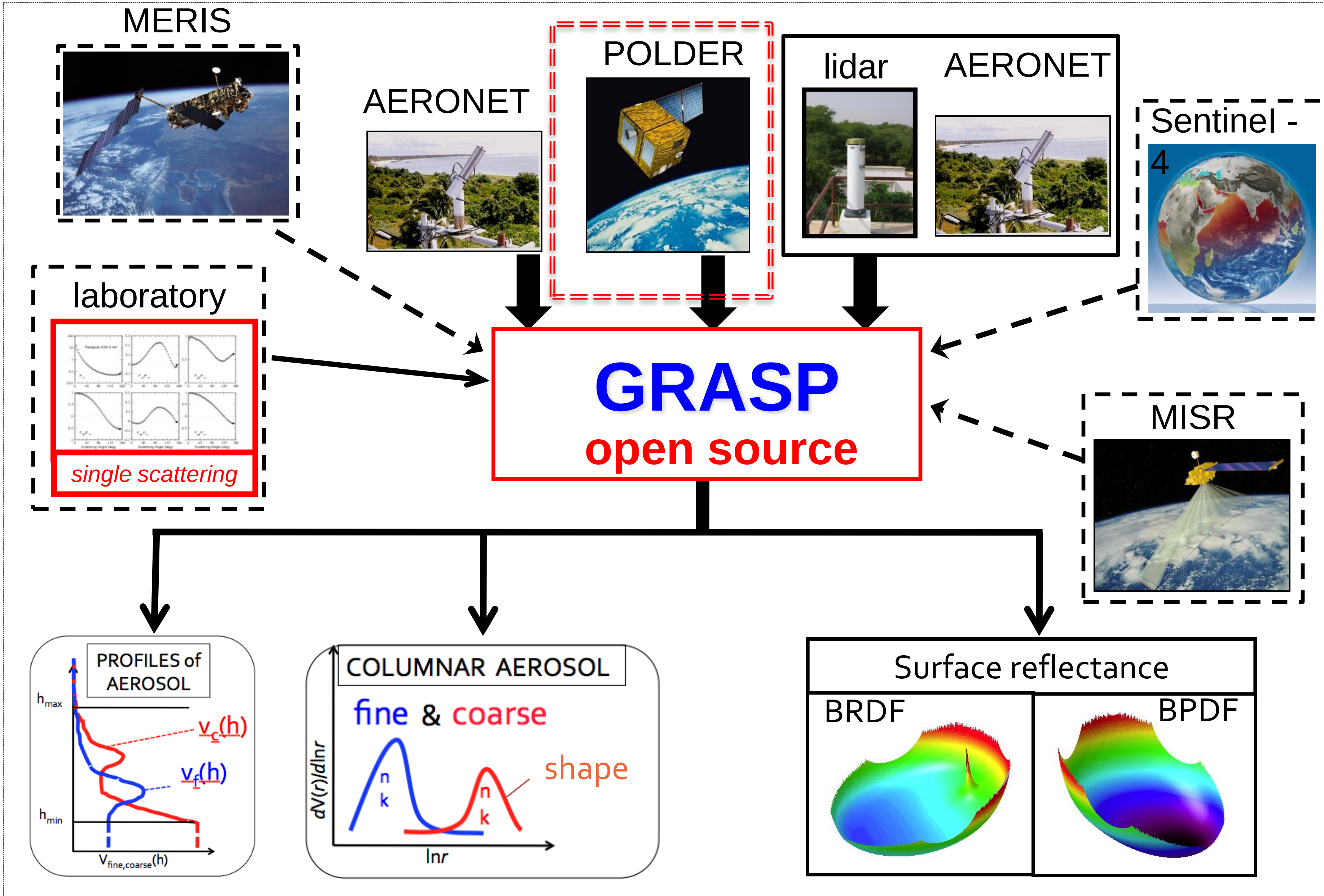
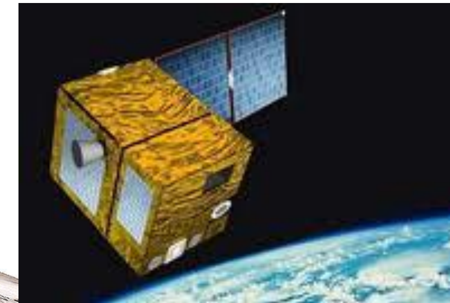
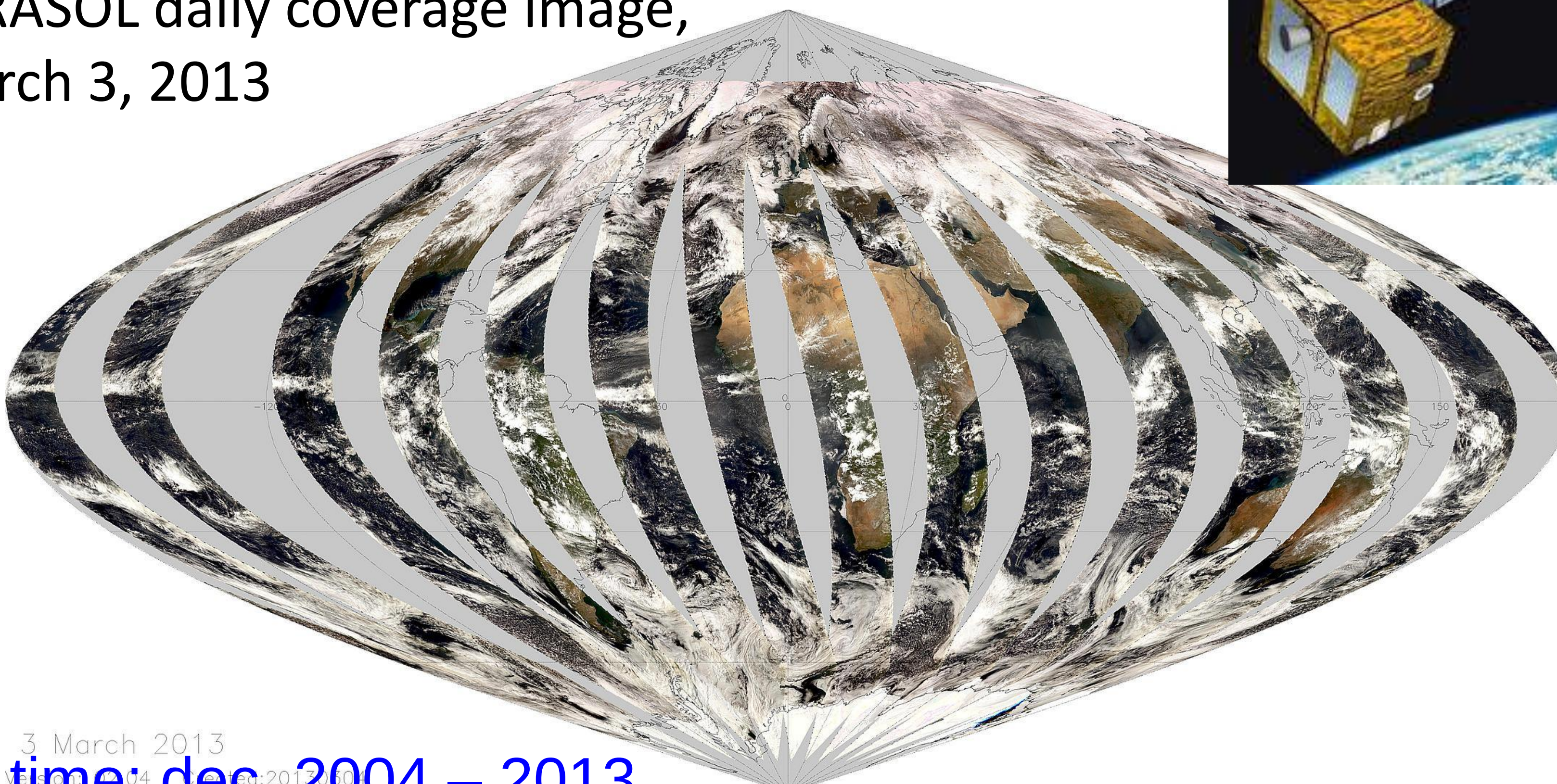
GRASP: Generalized Retrieval of Aerosol and Surface Properties



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)

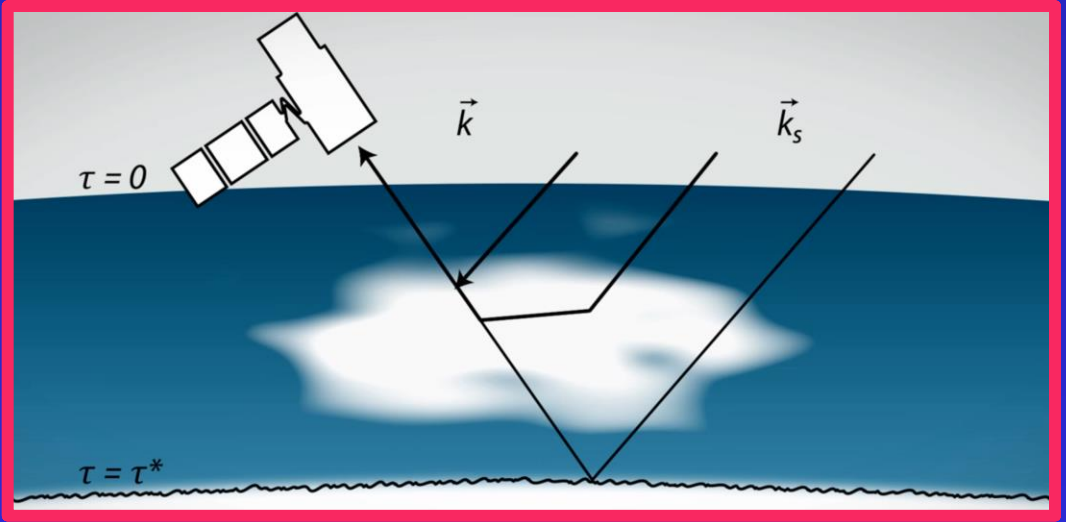
Swath: about 1600 km cross-track

Global coverage: every 2 days

1 pixel spatial resolution: 5.3km × 6.2km

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

GRASP specifics:

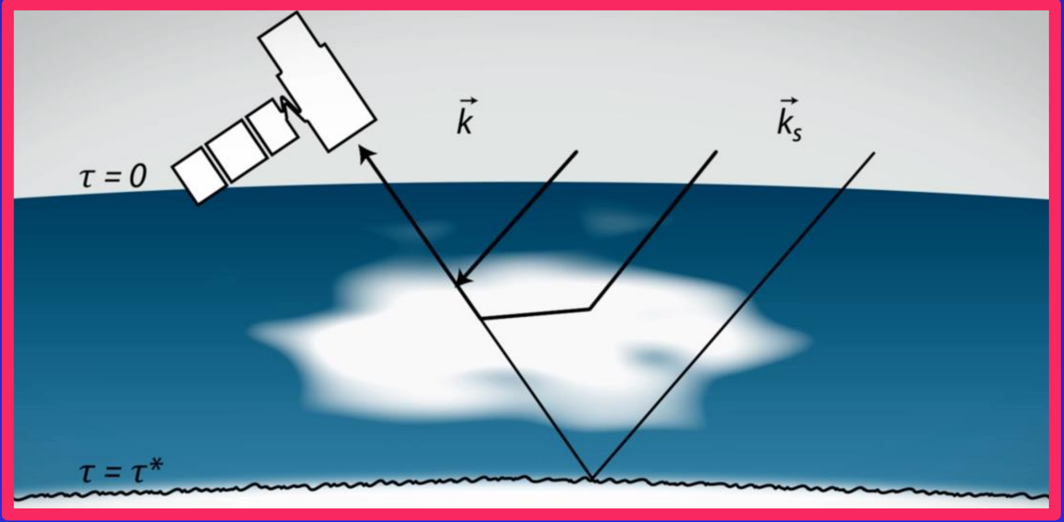


✓ Forward model:

- applicable to diverse remote sensing observations;

- accurate radiance modeling:
  - direct “on-line” computations;
  - it is driven by many parameters (43 for PARASOL, 41 for MERIS);

GRASP specifics:



✓ Forward model:

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- accurate radiance modeling:
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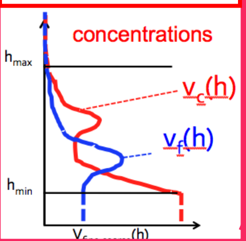
Forward Model

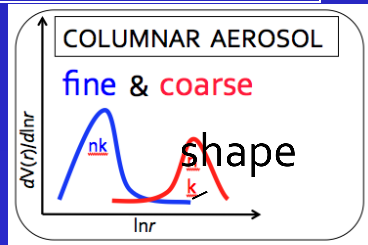
Vector of retrieved parameters :

a^{aer} - aerosol properties

a^{surf} - surface properties

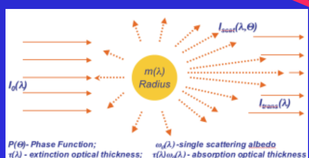
Vertical distribution





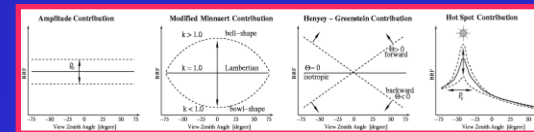
a^{aer}

a^{surf}



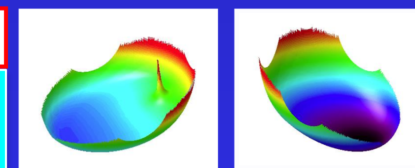
Aerosol single scattering

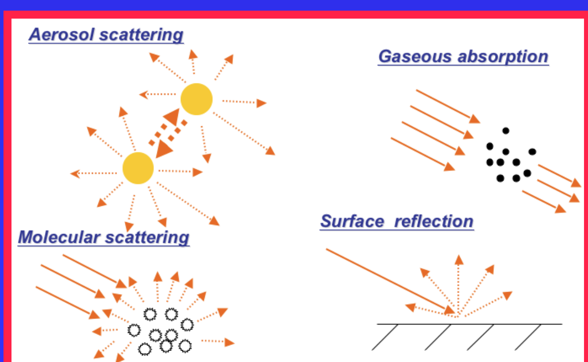
$\tau(\lambda, h)$, $\omega_0(\lambda, h)$, $P(\lambda, \Theta, h)$



Surface reflectance

BRDF | BPDF



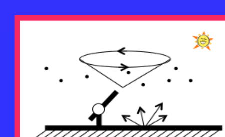


Multiple scattering effects

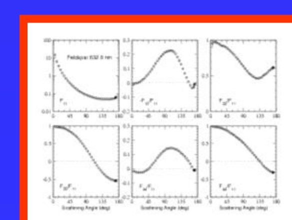
Radiative Transfer:

$F(\lambda, \Theta, \square)$

Simulated observations:



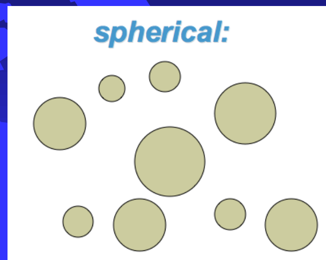
In situ, laboratory



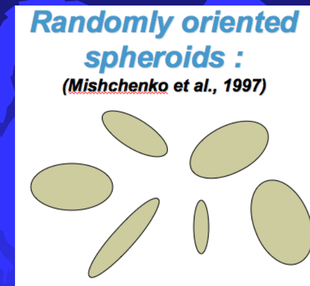
Mixing of particle shapes

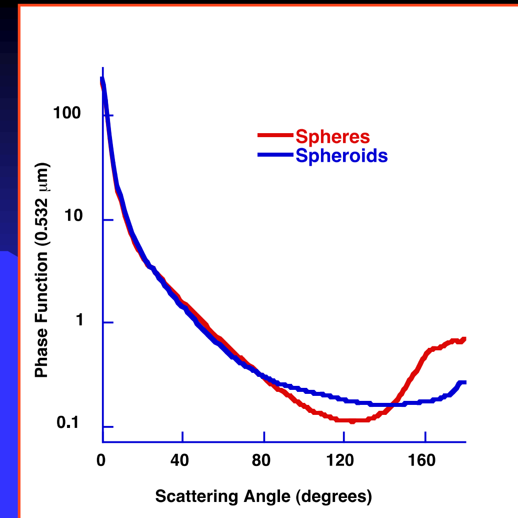
retrieved

C ×



+ (1-C) ×





$$\tau(\lambda) = C \int_{r_{min}}^{r_{max}} K_{\tau}^{spherical}(k;n;r)\,V(r)\,dr + (1-C)\int_{r_{min}}^{r_{max}} \left(\int_{\varepsilon_{min}}^{\varepsilon_{max}} K_{\tau}^{\varepsilon}(k;n;r,\varepsilon)\,N(\varepsilon)\,d\varepsilon \right) V(r)\,dr$$

Aspect ratio distr.

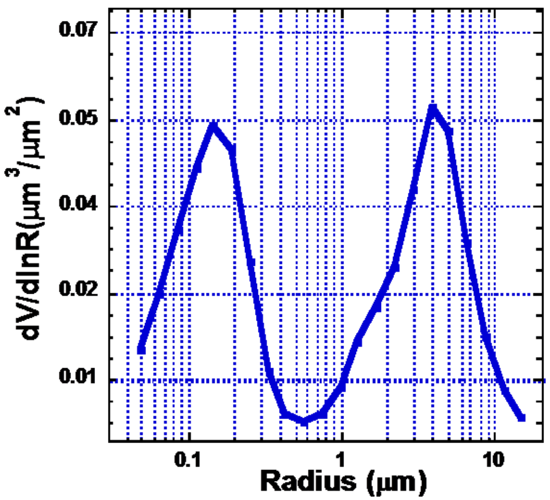
ASSUMPTIONS:

- dV/dlnr - volume size distribution is the same for both components;
- non-spherical - mixture of randomly oriented polydisperse spheroids;
- aspect ratio distribution N(ε) is fixed to the retrieved by Dubovik et al. 2006

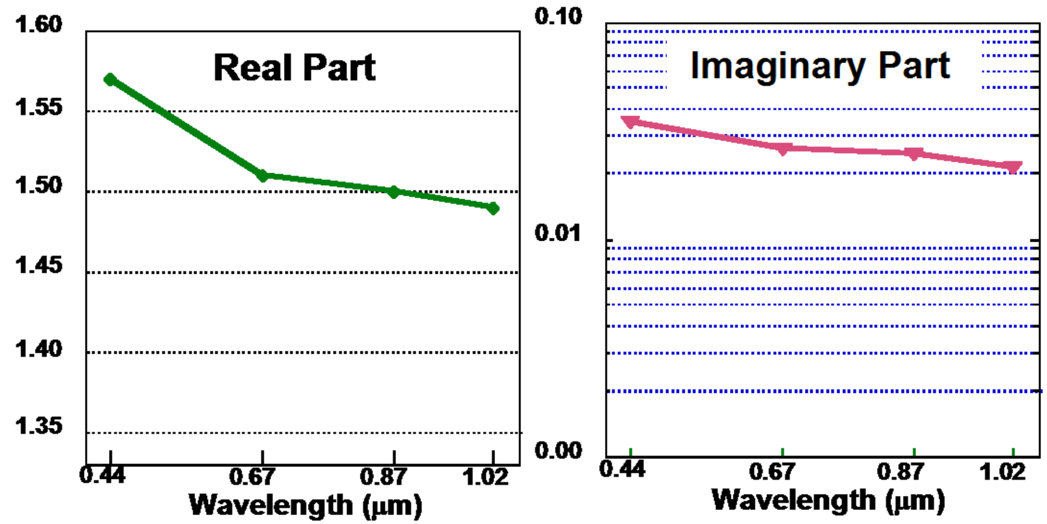
AERONET retrievals are driven by 31 variables :

dV/lnr - size distribution (22 values);
n(λ) and k(λ) - ref. index (4 +4 values)
C_{spher} (%) - spherical fraction (1 value)

Particle Size Distribution: 0.05 μm ≤ R (22 bins) ≤ 15 μm

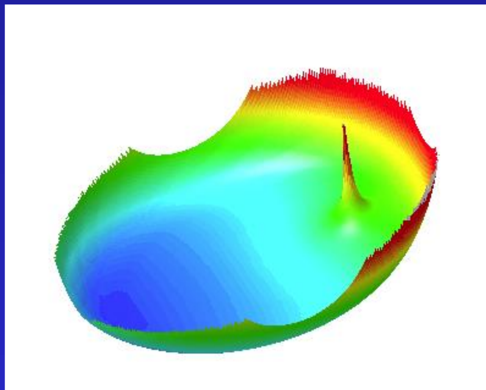


Complex Refractive Index at λ = 0.44; 0.67; 0.87; 1.02 μm



Surface Reflectance

BRDF

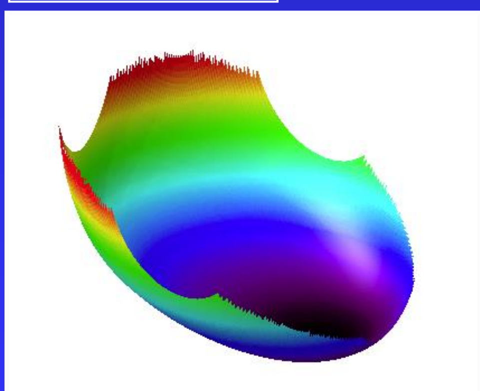


(1) ***Rahman-Pinty-Verstraete*** (RPV) model
(Rahman et al., 1993)

$$\rho_{sfc}(\vartheta_1,\varphi_1;\vartheta_2,\varphi_2) = \rho_0 M_i(k) F_{HG}(\Theta) H(h)$$

(2) ***Li – Ross*** *model* (MODIS, etc)
(Ross, (1981); Li, X., Strahler (1992))

BPDF



(1) ***Maignan et al., (2009)***

$$R_p^{surf}(q_s,q_v,j_r) = \frac{B\exp(-\tan(a_i))\exp(-v)}{4(m_0+m_1)}\mathbf{F}_p(g)$$

(*B* - empirical parameter)

(2) ***Nadal and Bréon, (1999)***

(3) *Fresnel facet model for Gaussian surfaces*
(Litvinov et al., 2011)

BRDF +BPDF

Physically based models

(1) ***Cox-Munk model (ocean surface)***

(2) *Physical models for land surface reflection matrix*
(Litvinov et al., 2012)

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 ;

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

- ✓ 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;

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Multi-Term LSM

(e.g. see Dubovik and King 2000, Dubovik 2004, Dubovik et al. 2011)

sensor 1

sensor 2

Independent !!!

$$\begin{cases} \boldsymbol{f}_1^* = \mathbf{F}_1\, \boldsymbol{a} + \Delta_1 \\ \boldsymbol{f}_2^* = \mathbf{F}_2\, \boldsymbol{a} + \Delta_2 \\ \ldots \end{cases}$$

$$\hat{\boldsymbol{a}} = \left(\mathbf{F}_1^T \mathbf{C}_1^{-1} \mathbf{F}_1 + \mathbf{F}_2^T \mathbf{C}_2^{-1} \mathbf{F}_2 + \ldots\right)^{-1} \left(\mathbf{F}_1^T \mathbf{C}_1^{-1} \boldsymbol{f}_1^* + \mathbf{F}_2^T \mathbf{C}_2^{-1} \boldsymbol{f}_2^* + \ldots\right)$$

---

sensor

a priori

$$\begin{cases} \boldsymbol{f}^* = \mathbf{F}\, \boldsymbol{a} + \Delta_f \\ \boldsymbol{a}^* = \boldsymbol{a} + \Delta_a \end{cases}$$

$$\hat{\boldsymbol{a}} = \left(\mathbf{F}^T \mathbf{C}_f^{-1} \mathbf{F} + \mathbf{C}_a^{-1}\right)^{-1} \left(\mathbf{F}^T \mathbf{C}_f^{-1} \boldsymbol{f}^* + \mathbf{C}_a^{-1} a^*\right)$$

Kalman Filter,
"Optimal Estimation" by Rodgers, etc.

---

sensor

a priori

$$\begin{cases} \boldsymbol{f}_1^\bullet = \boldsymbol{f}^* = \mathbf{F}\, \boldsymbol{a} + \Delta_f \\ \boldsymbol{f}_2^\bullet = \boldsymbol{0}^* = \mathbf{S}\boldsymbol{a} + \Delta(\Delta \boldsymbol{a}) \end{cases}$$

$$\hat{\boldsymbol{a}} = \left(\mathbf{F}^T \mathbf{C}_f^{-1} \mathbf{F} + \mathbf{S}^T \mathbf{S}\right)^{-1} \left(\mathbf{F}^T \mathbf{C}_f^{-1} \boldsymbol{f}^*\right)$$

Phillips – Tikhonov –Twomey
Constrained Inversion

Single - Pixel Retrieval:

RT calculation on fly !!!

f_j^* - ***PARASOL data:***

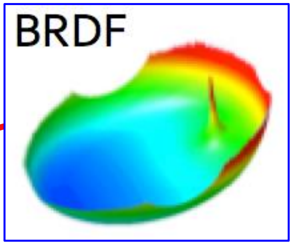
Angular measurements (~15 angles) of

- ***Intensity*** (λ = 0.49; 0.67; 0.87; 1.02 μm)
- ***Polarization*** (λ = 0.49; 0.67; 0.87 μm)

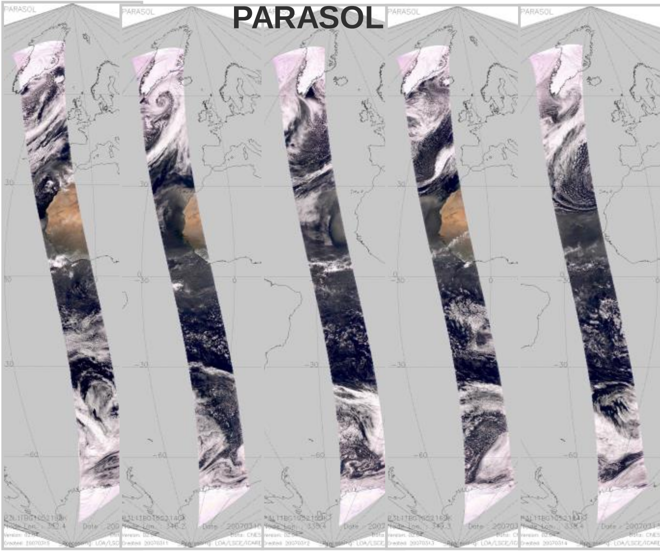
a_j - ***Parameters to be retrieved***:

-***Aerosol*** propetries:
- size distribution; - real refractive index
- imaginary refractive index; - particle shape, - height

-***Surface*** properties (***over land***):
- BRF parameters; - BPRF parameters



$$\begin{cases} f_j^* \\ 0_j^* \end{cases} = \begin{pmatrix} \mathbf{F}_j \\ \mathbf{S}_j \end{pmatrix} \mathbf{a}_j + \begin{pmatrix} \Delta_j^m \\ \Delta_j^a \end{pmatrix}$$



A Priori Constraints limiting derivatives (e.g. *Dubovik 2004*) of

- *for aerosols* (e.g. in AERONET, *Dubovik and King 2000)* **:**
- aerosol size distribution variability over size range;
- spectral variability of complex refractive index;

- *for surface* (e.g. in AERONET/satellite retrievals, *Sinuyk et al. 2007)* **:**
- spectral variability of BRF/ PBRF parameters.

Multi-term LSM statistically optimized ***Solution*** *(Dubovik and King 2000, Dubovik 2004)* **:**

$$\mathbf{a}_j = \left(\mathbf{F}_j^T \mathbf{W}_j^{-1} \mathbf{F}_j + \gamma_j \Omega_j\right)^{-1} \left(\mathbf{F}_j^T \mathbf{W}_j^{-1} \mathbf{f}_j^*\right)$$

,where $\mathbf{W}_j = \mathbf{S}_j^T \mathbf{S}_j; \ \mathbf{W}_i = \frac{1}{\varepsilon_f^2} \mathbf{C}_f; \quad \gamma_j = \frac{\varepsilon_f^2}{\varepsilon_a^2}$

Array matrices:

$$
\begin{cases}
\mathbf{f}_j^{*} \\
0_j^{*}
\end{cases}
=
\begin{pmatrix}
\mathbf{F}_j \\
\mathbf{S}_j
\end{pmatrix}
\mathbf{a}_j +
\begin{matrix}
\Delta_j^{m} \\
\Delta_j^{a}
\end{matrix}
$$

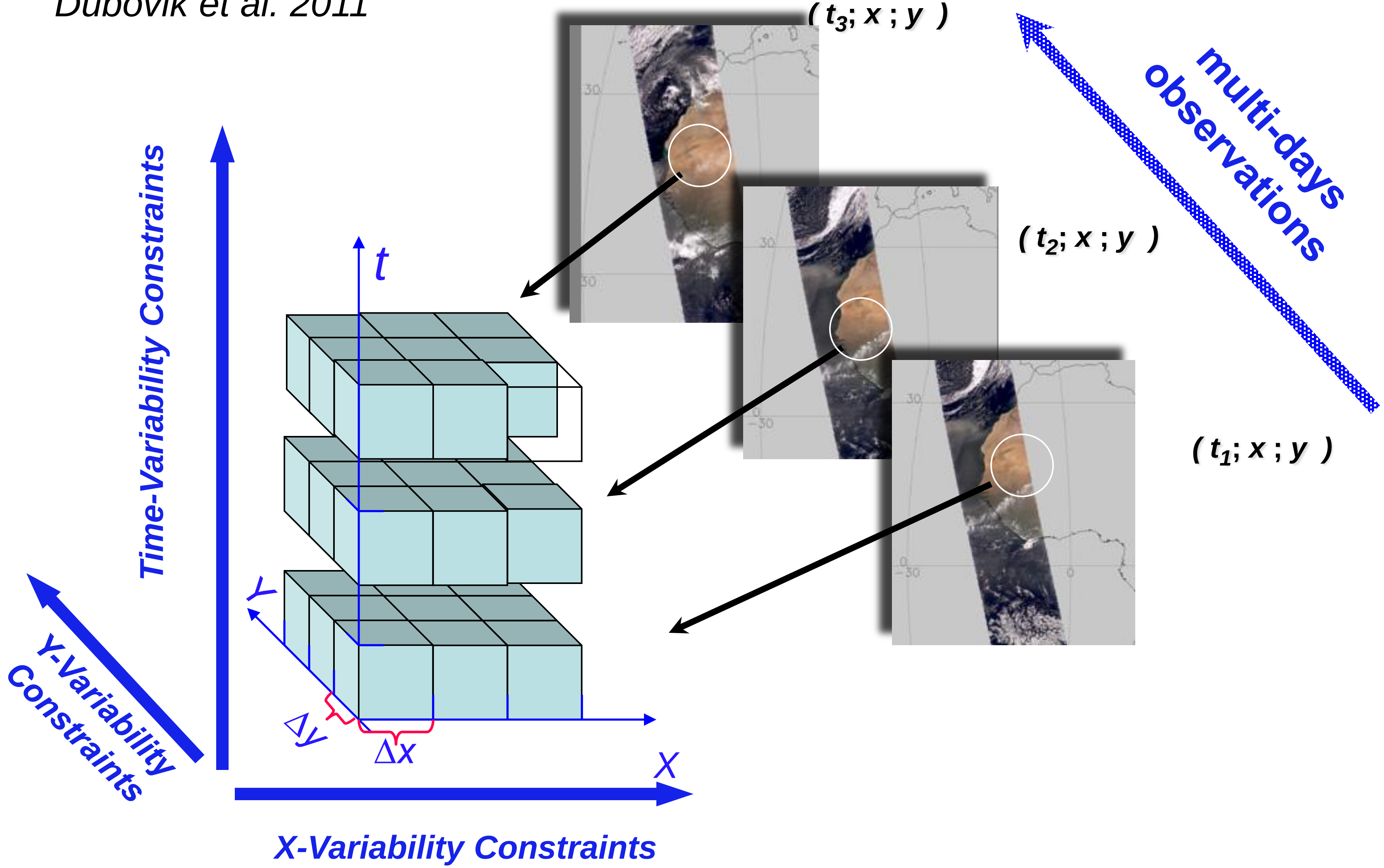
$$
\mathbf{Sa} =
\begin{pmatrix}
\mathbf{S}_v & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\
\mathbf{0} & \mathbf{S}_n & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\
\mathbf{0} & \mathbf{0} & \mathbf{S}_k & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{S}_{brdf,1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\
\mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{S}_{brdf,2} & \mathbf{0} & \mathbf{0} \\
\mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{S}_{brdf,3} & \mathbf{0} \\
\mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{S}_{bpdf}
\end{pmatrix}
\begin{pmatrix}
\mathbf{a}_v \\
\mathbf{a}_n \\
\mathbf{a}_n \\
a_h \\
a_{sph} \\
a_{Vc} \\
\mathbf{a}_{brdf,1} \\
\mathbf{a}_{brdf,2} \\
\mathbf{a}_{brdf,3} \\
\mathbf{a}_{bpdf}
\end{pmatrix}
$$

$$
\mathbf{a}_j = \left(\mathbf{F}_j^T \mathbf{W}_j^{-1} \mathbf{F}_j + \gamma_j \Omega_j\right)^{-1} \left(\mathbf{F}_j^T \mathbf{W}_j^{-1} \mathbf{f}_j^{*}\right)
$$

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

The concept of multi-pixel retrieval

Dubovik et al. 2011



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

Dubovik et al. 2011

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

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

$$\begin{pmatrix} \mathbf{a}_v\\ \mathbf{a}_n\\ \mathbf{a}_n\\ a_h\\ a_{sph}\\ a_{Vc}\\ \mathbf{a}_{brdf,1}\\ \mathbf{a}_{brdf,2}\\ \mathbf{a}_{brdf,3}\\ \mathbf{a}_{bpdf}\end{pmatrix}$$

43 parameters

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

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

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

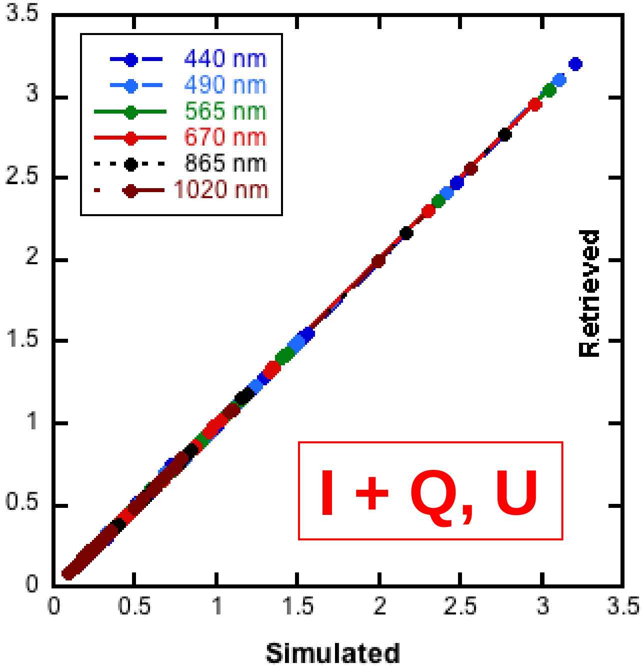
$$\mathbf{S}_t^T\mathbf{S}_t = \begin{pmatrix}
\begin{pmatrix}\lambda_{d_{11}}&0&0\\0&\lambda_{d_{11}}&0\\0&0&\lambda_{d_{11}}\end{pmatrix} & \begin{pmatrix}\lambda_{d_{12}}&0&0\\0&\lambda_{d_{12}}&0\\0&0&\lambda_{d_{12}}\end{pmatrix} & \begin{pmatrix}\lambda_{d_{13}}&0&0\\0&\lambda_{d_{13}}&0\\0&0&\lambda_{d_{13}}\end{pmatrix}\\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

Test with synthetic measurements

Aerosol Optical Thickness

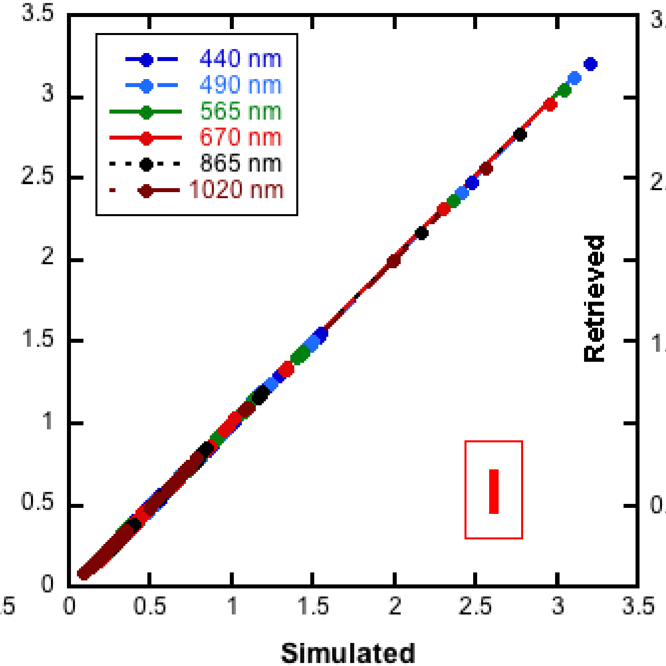
PARASOL over Banizoumbou in January, February 2008

AOD (Retrieved: *I,Q,U*-retrieval. Simulation: *I,Q,U*)



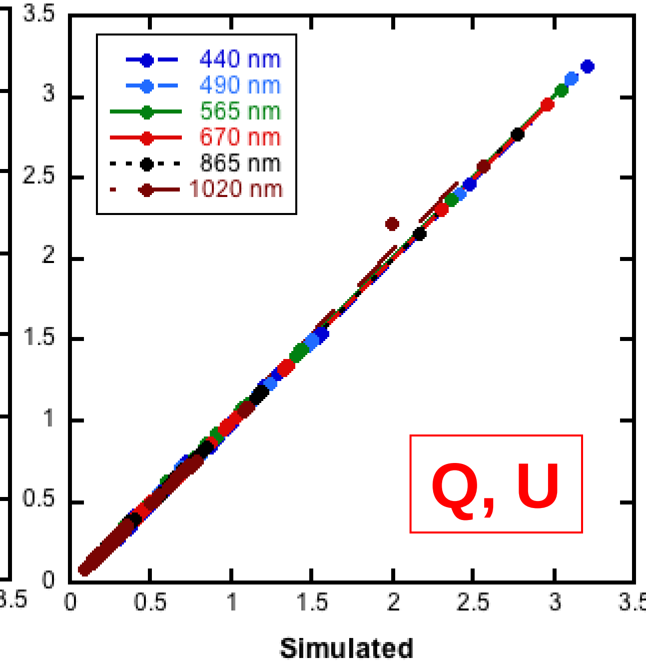
y = -0.0043839 + 1.0023x R= 0.99995
y = -0.0045597 + 1.0029x R= 0.99996
y = -0.0056832 + 1.0029x R= 0.99997
y = -0.0052555 + 1.0031x R= 0.99998
y = -0.0057708 + 1.0041x R= 0.99998
y = -0.0053979 + 1.0049x R= 0.99996

AOD (Retrieved: *I*-retrieval. Simulation: *I,Q,U*)



y = -0.0071561 + 1.008x R= 0.99987
y = -0.007389 + 1.0073x R= 0.99986
y = -0.0088212 + 1.0087x R= 0.99985
y = -0.0092578 + 1.0092x R= 0.99987
y = -0.0072864 + 1.0071x R= 0.99989
y = -0.005577 + 1.0055x R= 0.99989

AOD (Retrieved: *Q,U*-retrieval. Simulation: *I,Q,U*)

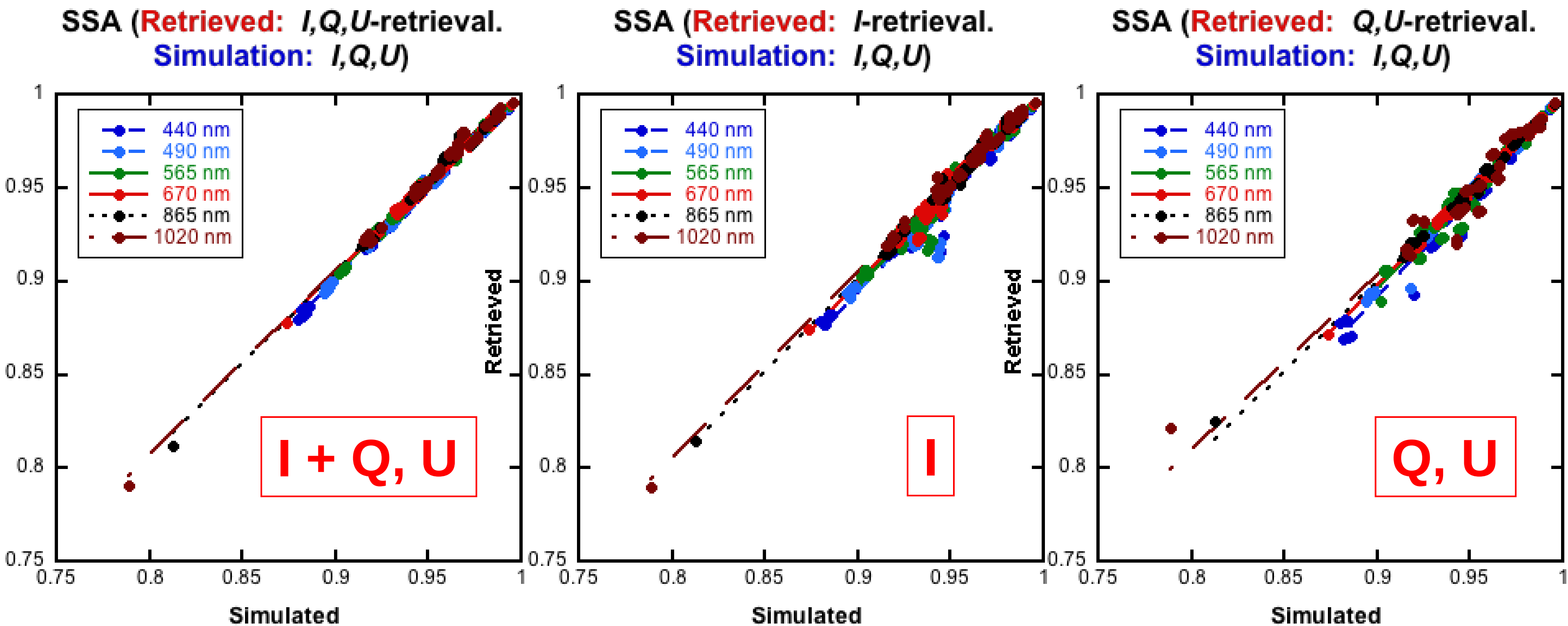


y = -0.0052906 + 1.0007x R= 0.99986
y = 0.0010661 + 1.0003x R= 0.99995
y = 0.00096879 + 1.0044x R= 0.99991
y = 0.0012797 + 0.99963x R= 0.99997
y = 0.0016497 + 0.99921x R= 0.99997
y = -0.011559 + 1.0302x R= 0.99806

Test with synthetic measurements

Single Scattering Albedo

PARASOL over Banizoumbou in January, February 2008



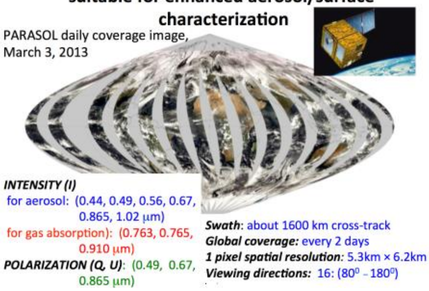
y = -0.0029473 + 1.0043x R= 0.99908	y = -0.060718 + 1.0609x R= 0.98367	y = -0.084303 + 1.0834x R= 0.98944
y = 0.0052418 + 0.99605x R= 0.99862	y = -0.065772 + 1.0666x R= 0.97889	y = -0.035547 + 1.0356x R= 0.99707
y = 0.017893 + 0.9843x R= 0.99775	y = -0.058311 + 1.0604x R= 0.9817	y = -0.040899 + 1.04x R= 0.98086
y = 0.031334 + 0.97052x R= 0.99709	y = -0.036232 + 1.0388x R= 0.98726	y = -0.022387 + 1.0219x R= 0.9984
y = 0.016615 + 0.98672x R= 0.99583	y = -0.00051278 + 1.0029x R= 0.99568	y = 0.023316 + 0.9743x R= 0.99565
y = 0.019672 + 0.9836x R= 0.99633	y = 0.014386 + 0.98835x R= 0.99588	y = 0.067708 + 0.92724x R= 0.95841

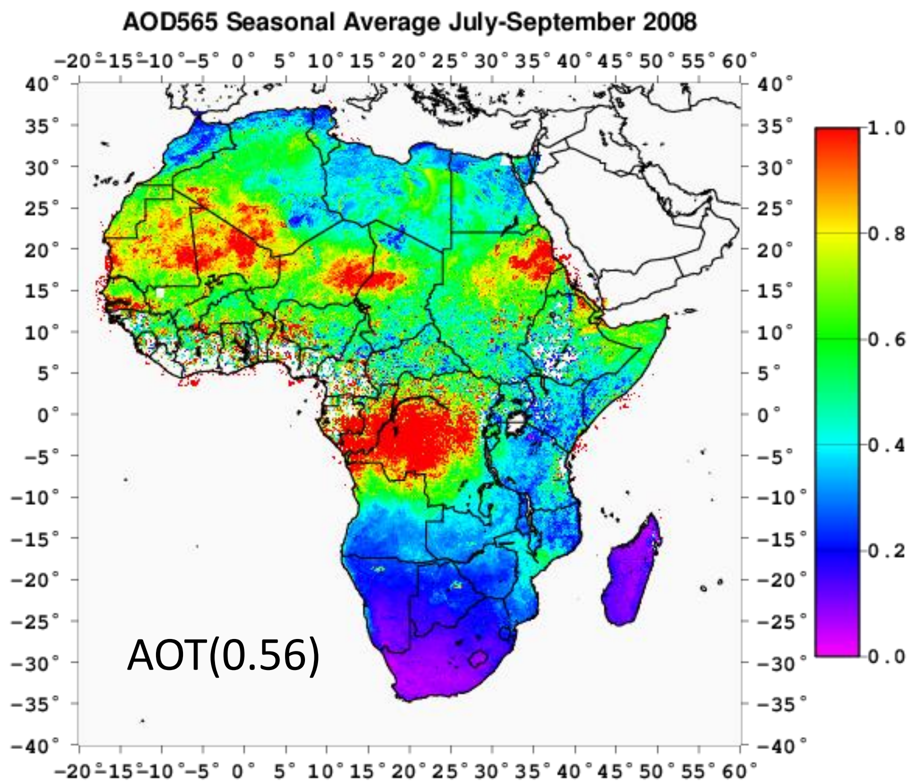
EXAMPLES of PARASOL/GRASP retrievals - 2008

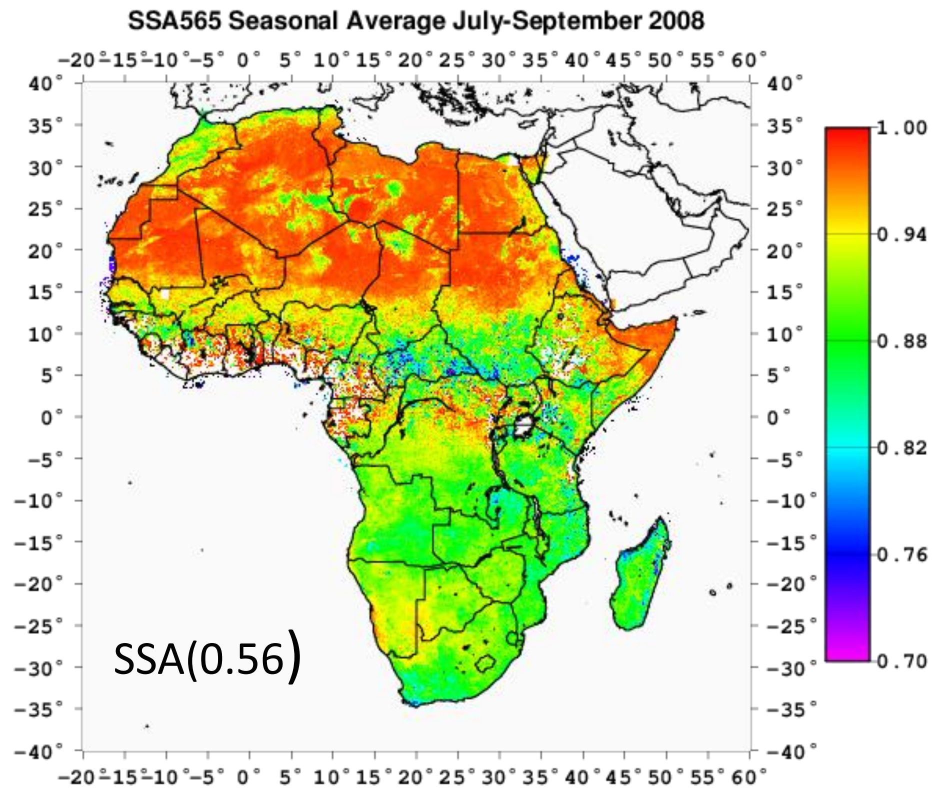
NO location specific ASSUMPTIONS on aerosol and surface

All calculation on the fly

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







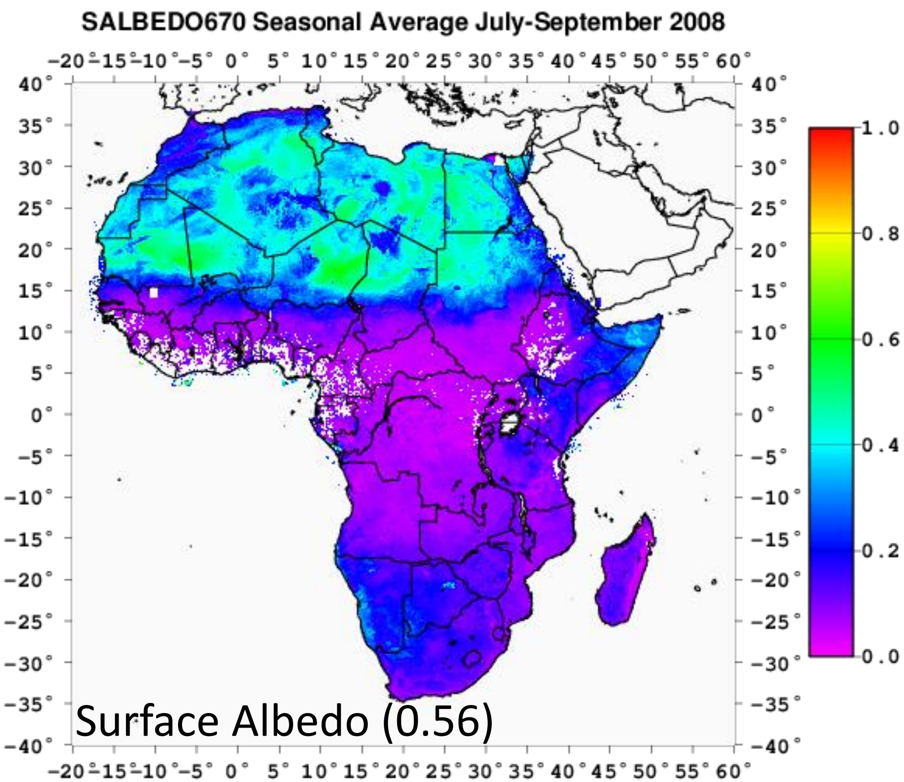
AOT(0.56) - **loading**

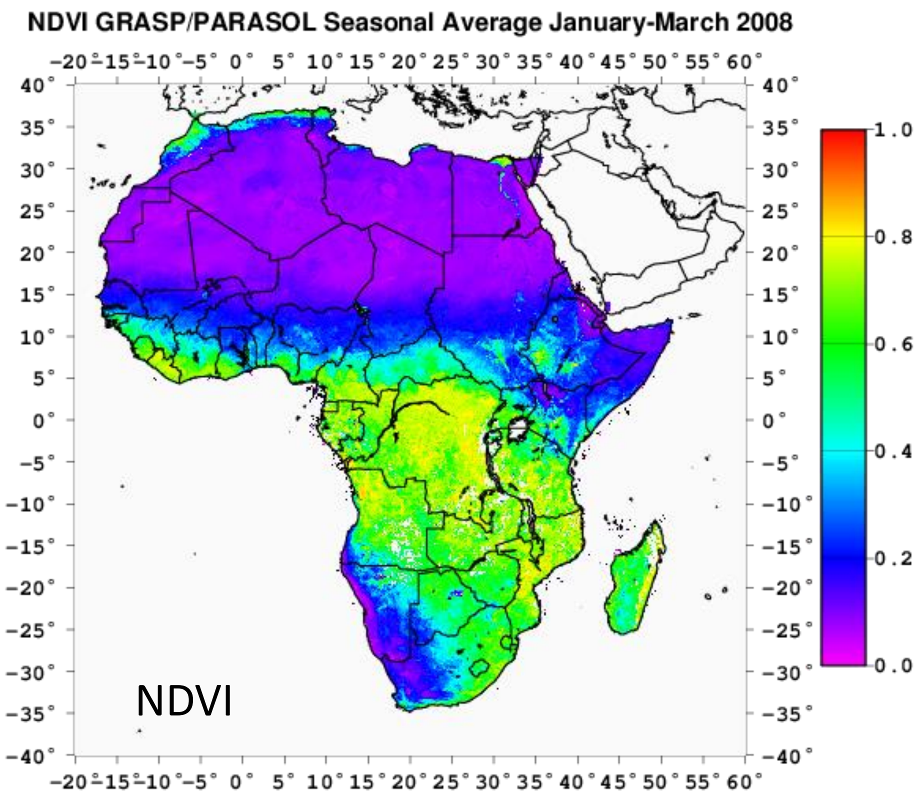
SSA(0.56) - **absorption**

Processed at ICARE

EXAMPLES of PARASOL/GRASP retrievals - 2008

NO location specific ASSUMPTIONS on aerosol and surface
All calculation on the fly





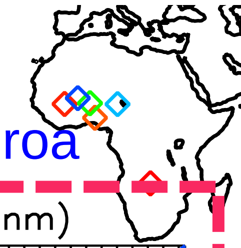
Albego(0.56) - **surface**

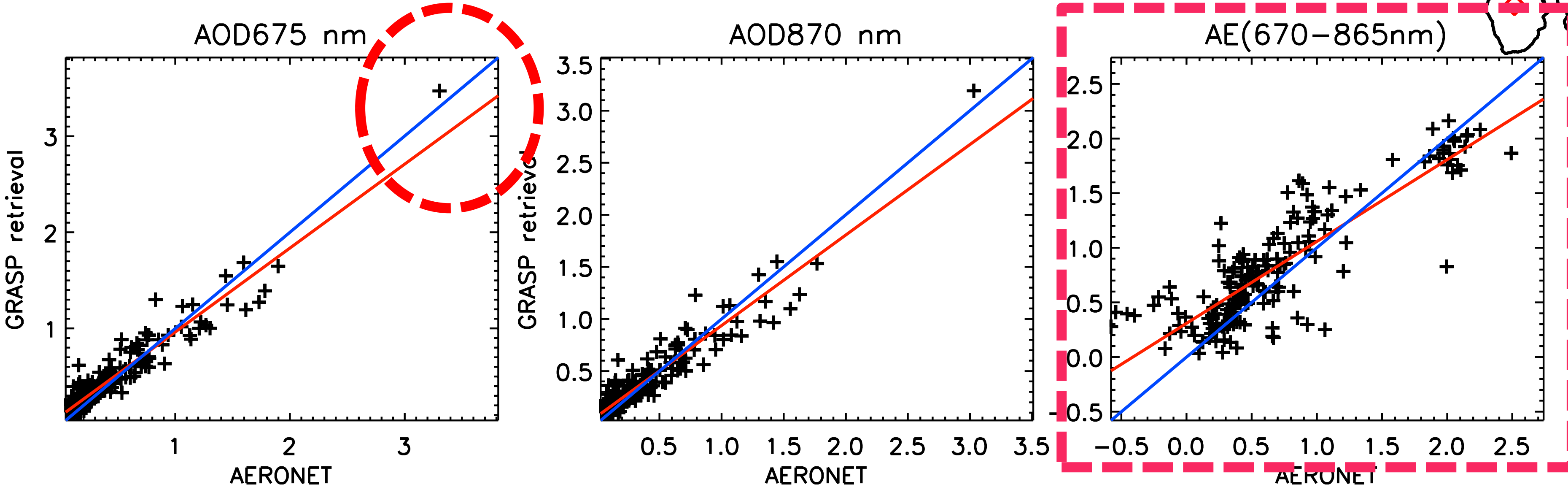
NDVI

Processed at ICARE

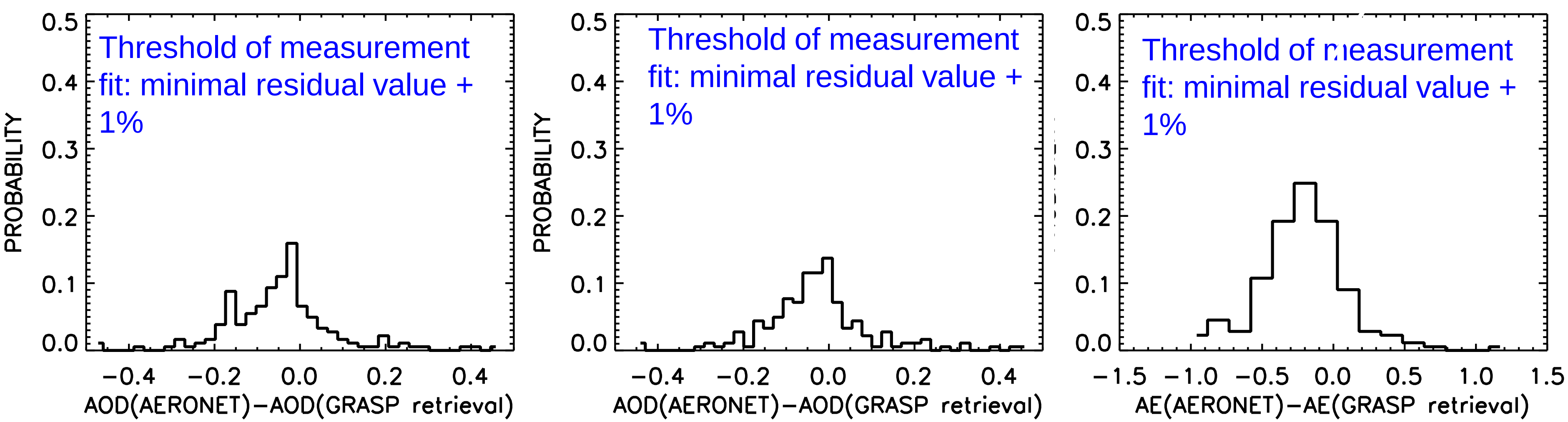
PARASOL/GRASP vs. AERONET (Africa, 2008).

Mongu, Banizoumbou, IER_Cinzana, Agoufou, Ilorin, DMN_Maine_Soroa





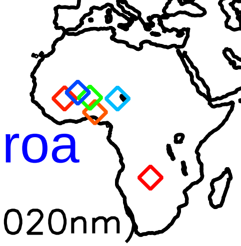
K=0.951 a= 0.87 b= 0.09 RMSE= 0.135 K=0.945 a= 0.87 b= 0.07 RMSE= 0.129 K=0.866 a= 0.75 b= 0.31 RMSE= 0.346

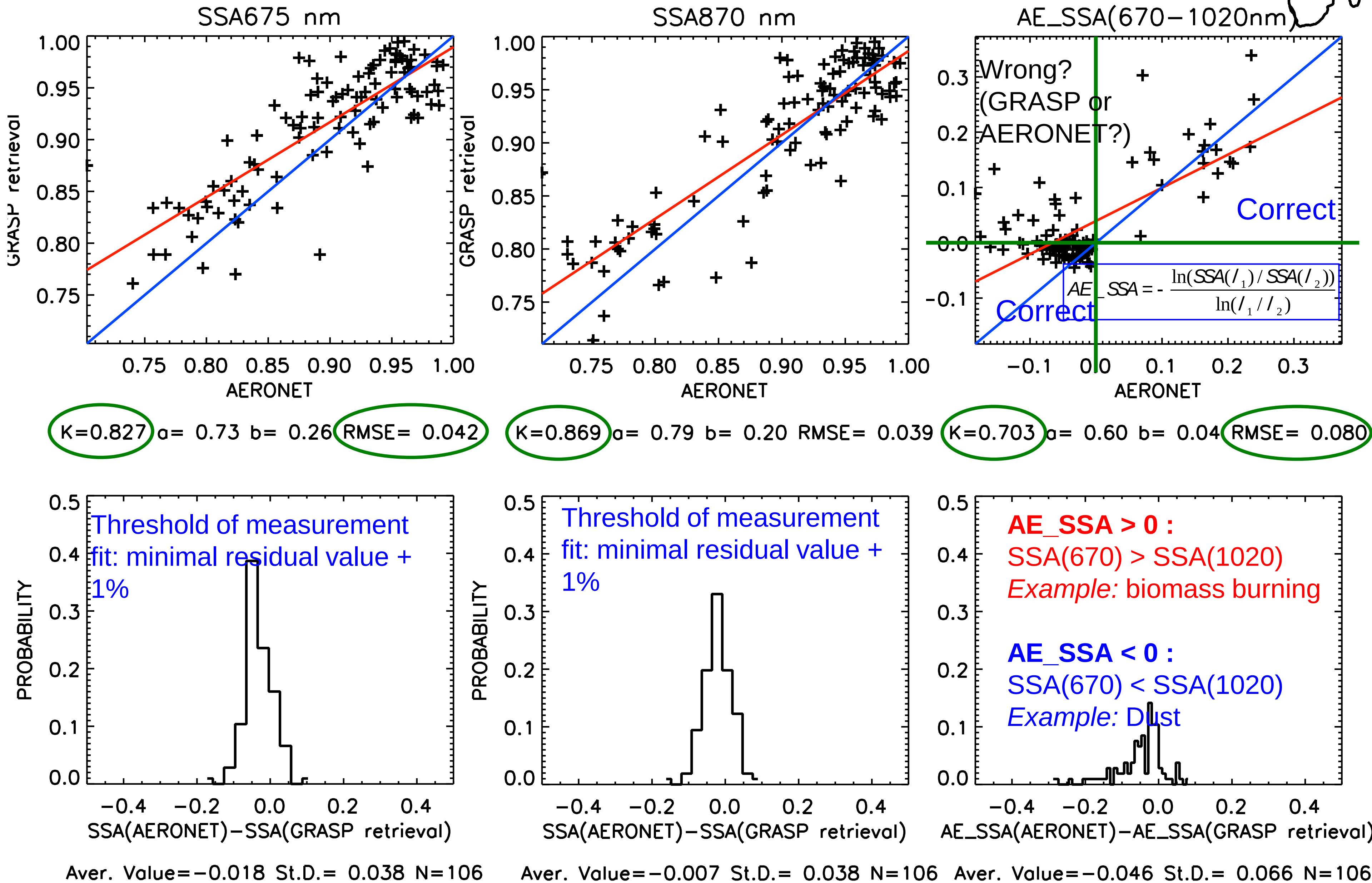


Aver. Value=−0.034 St.D.= 0.130 N=182 Aver. Value=−0.016 St.D.= 0.128 N=182 Aver. Value=−0.141 St.D.= 0.316 N=177

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

Mongu, Banizoumbou, IER_Cinzana, Agoufou, Ilorin, DMN_Maine_Soroa





GRASP specifics:

- more time consuming than LUT

✓ Software implementation:

- advance programing:

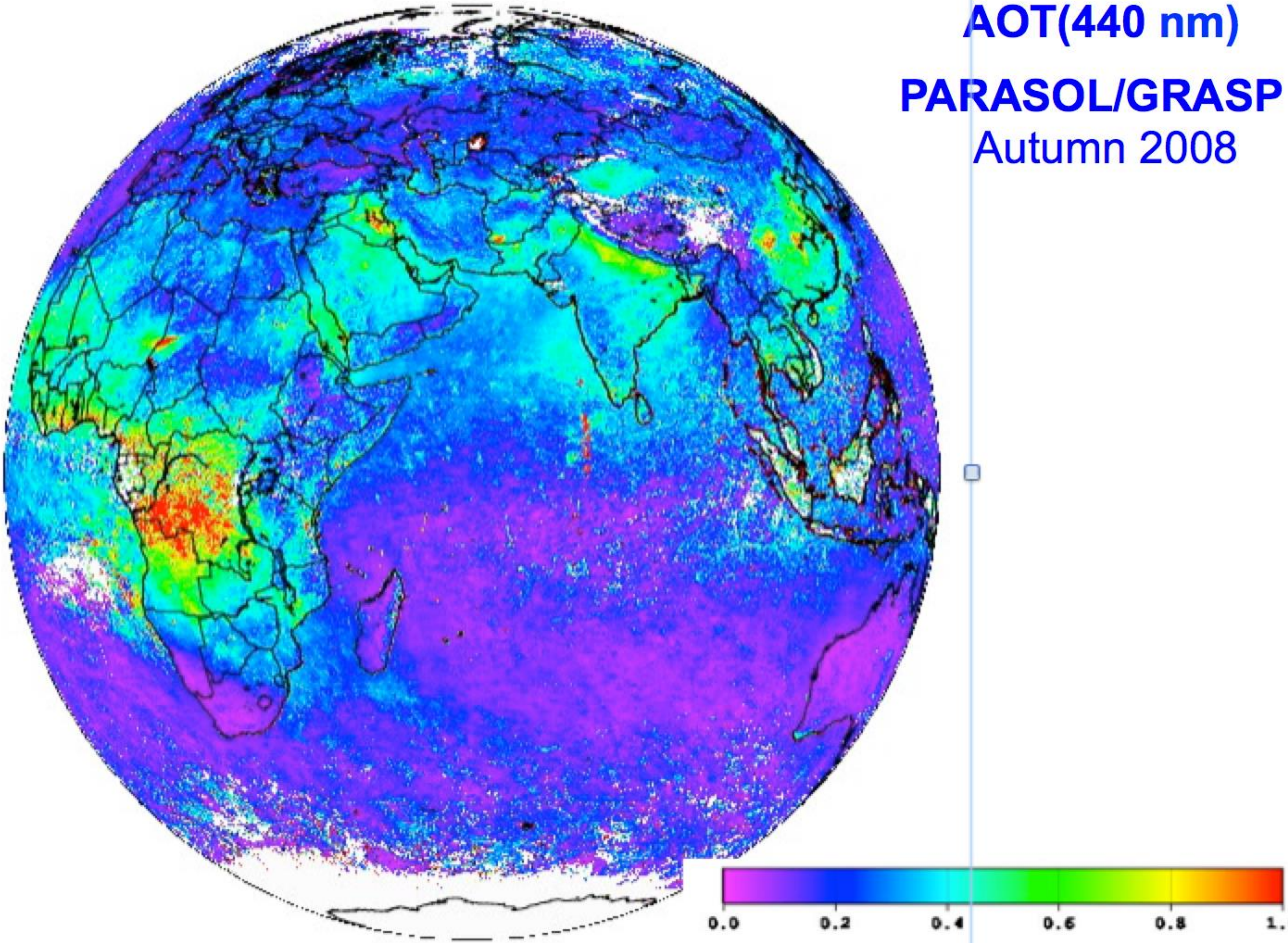
✓ highly parallelized (currently runs at LOA at ~100 CPU)

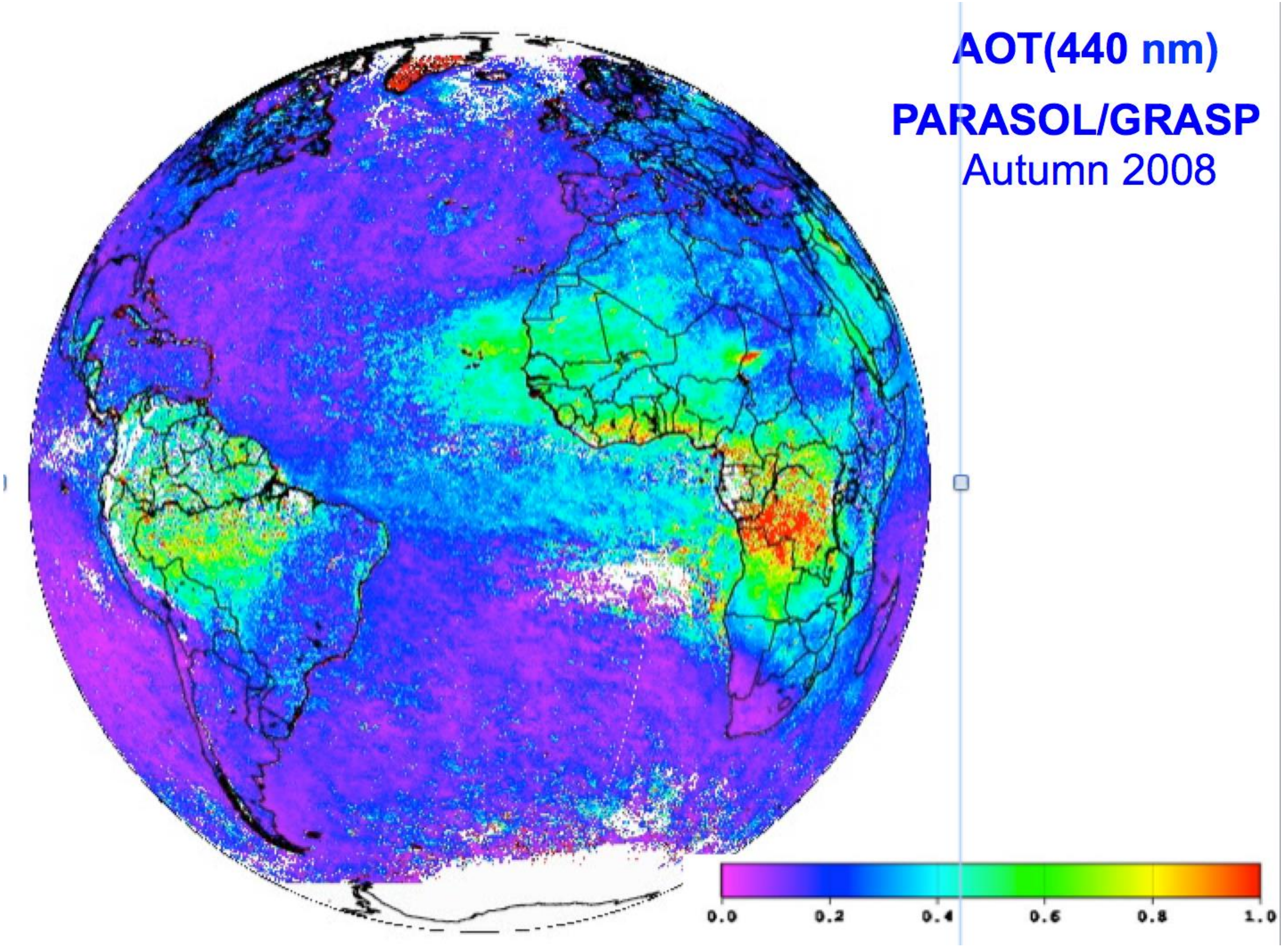
✓ uses CPI / GPU;

✓ Current inversion is 0.1-0.3 sec per sec, optimization continues constantly;

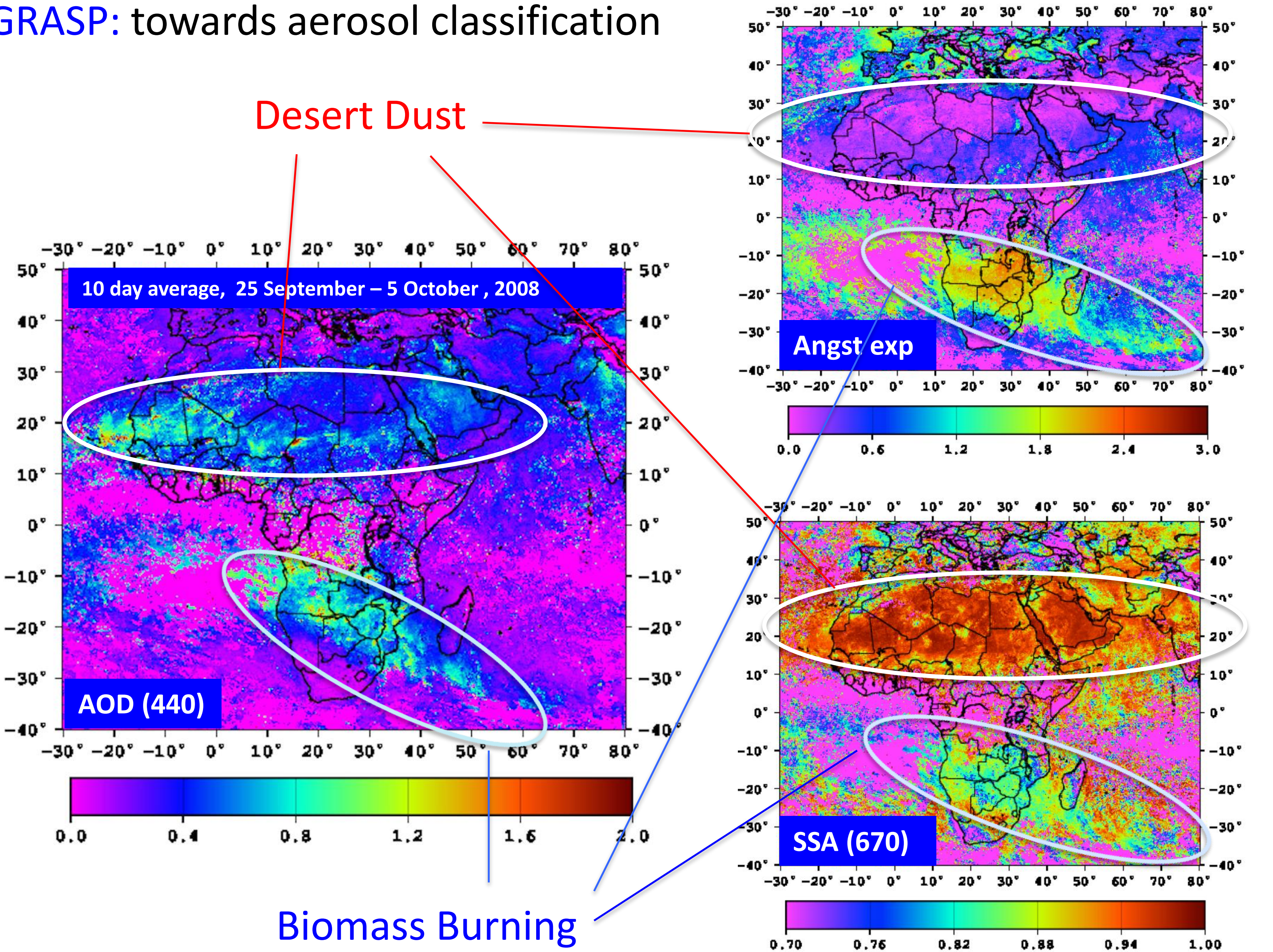
Currently processed > 7 years (2006 – 2012) with “fast” version, soon the whole archive is expected to be processed;

✓ to be available as OPEN SOURCE code;

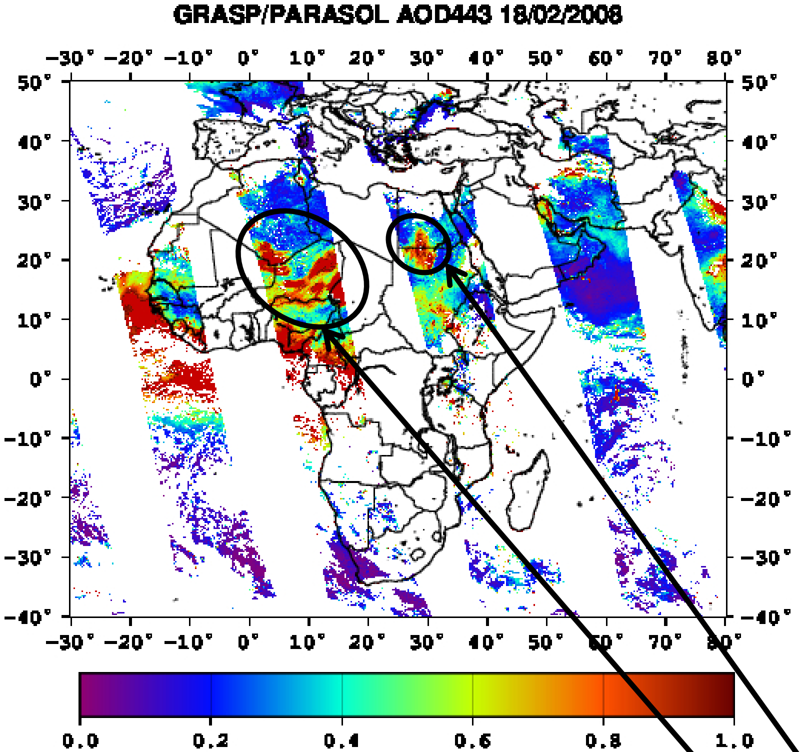

AOT(440 nm)
PARASOL/GRASP
Autumn 2008
0.0
0.2
0.4
0.6
0.8
1.0

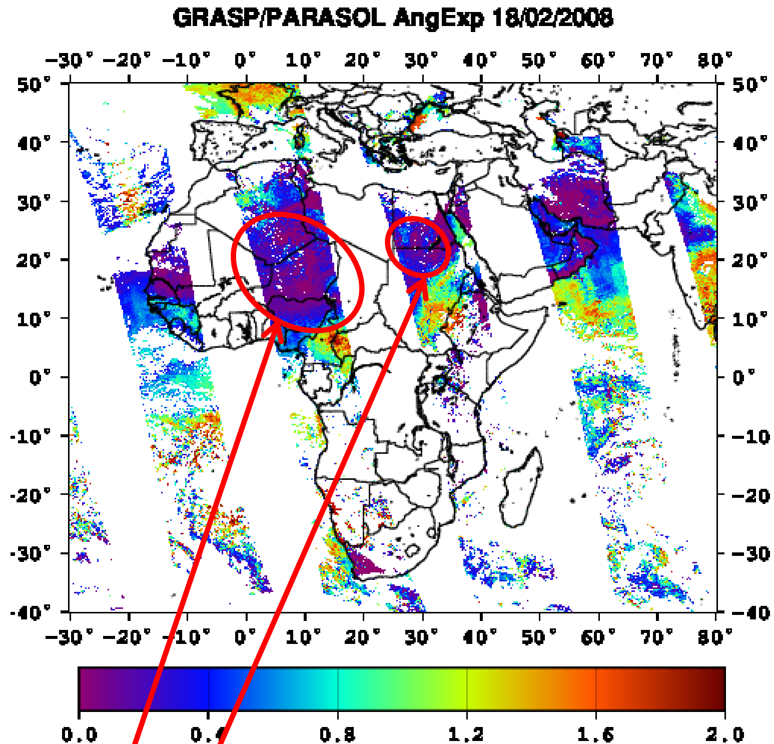

AOT(440 nm)
PARASOL/GRASP
Autumn 2008
0.0
0.2
0.4
0.6
0.8
1.0

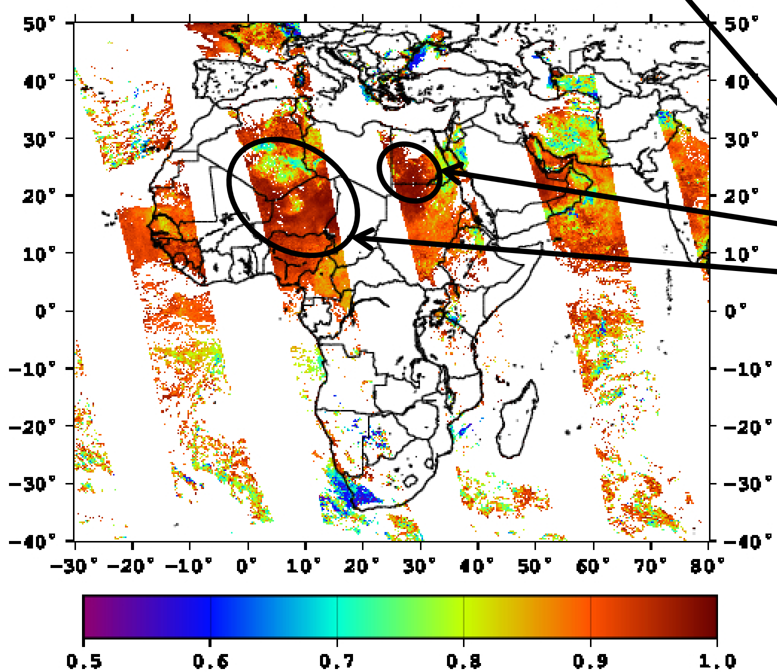
GRASP: towards aerosol classification



Dust detection with GRASP



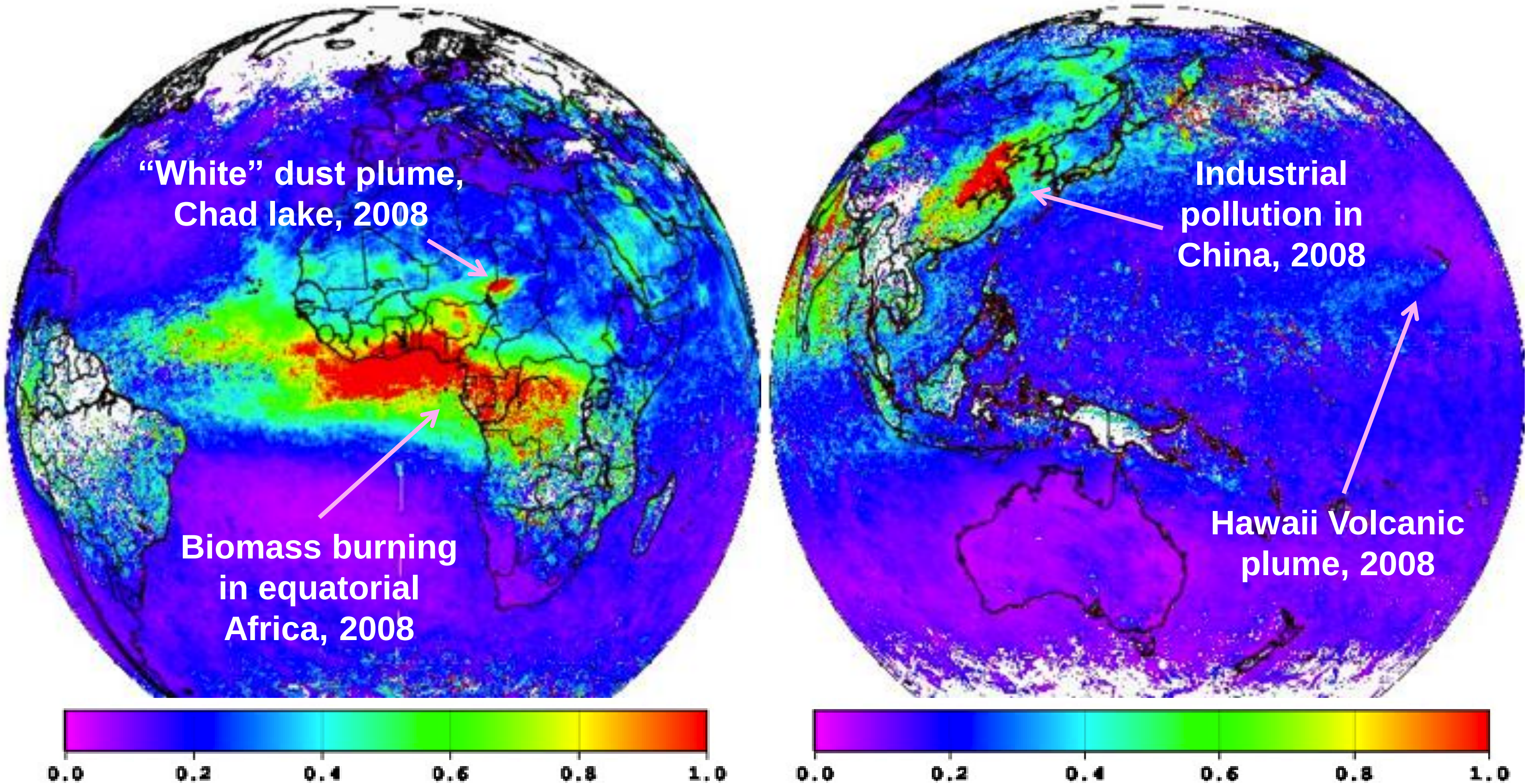




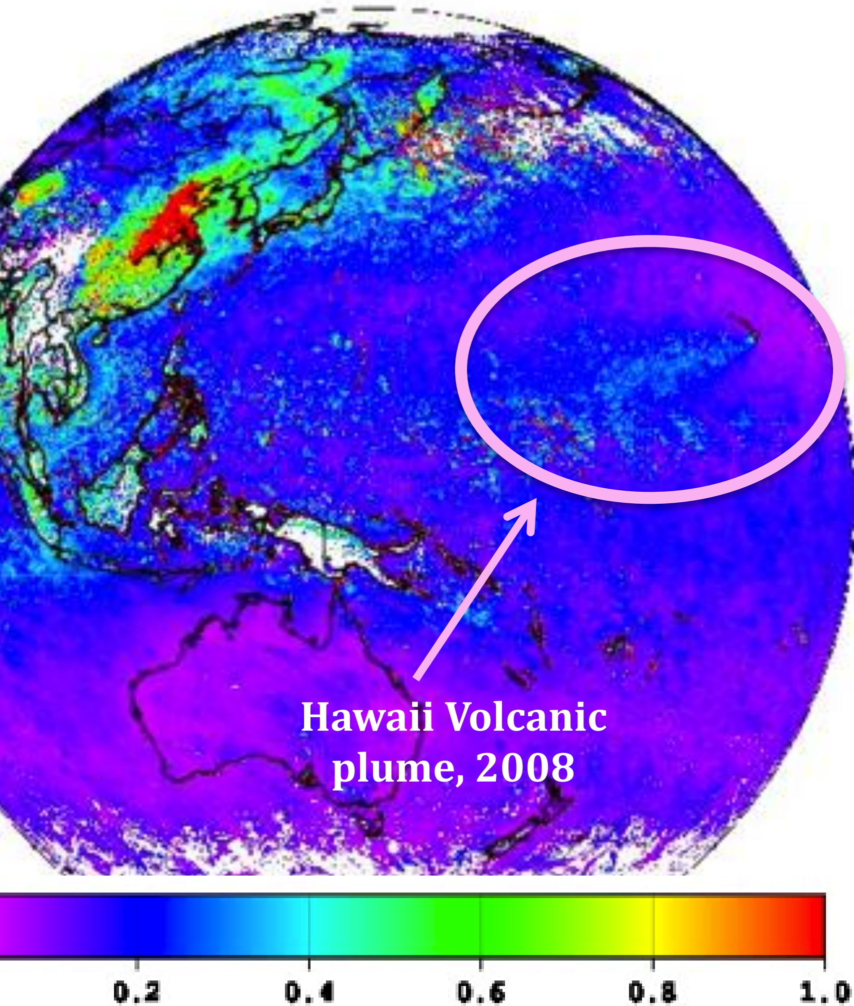
Dust events:

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

Observation of aerosol events from PARASOL/GRASP retrievals

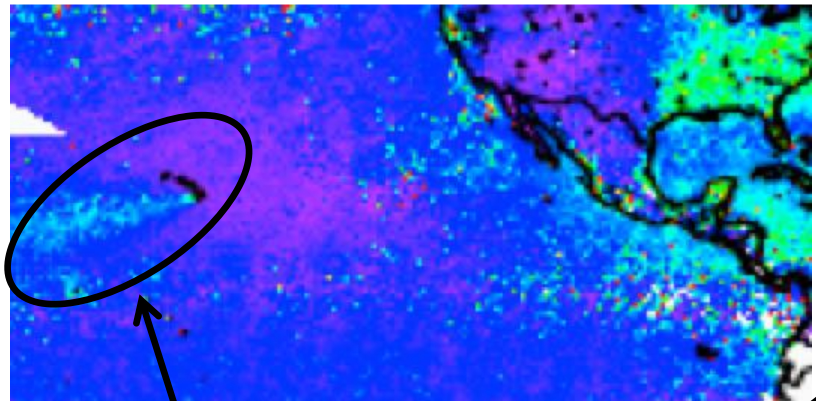


GRASP retrieval: Kilauea volcano (Hawaii, Halemaumau Crater, June-August, 2008)

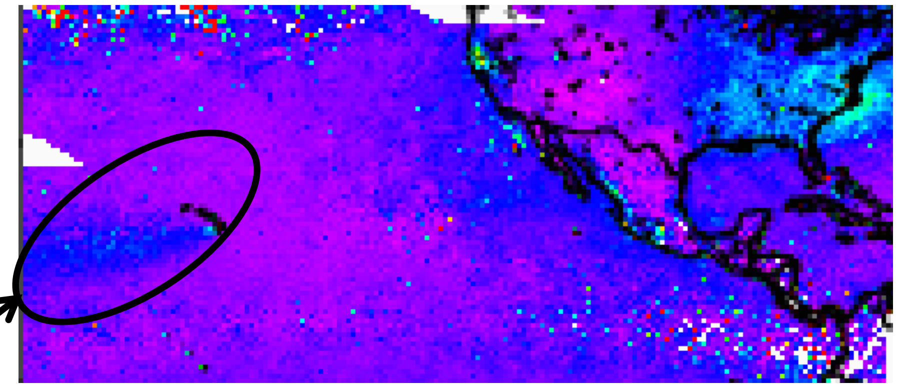


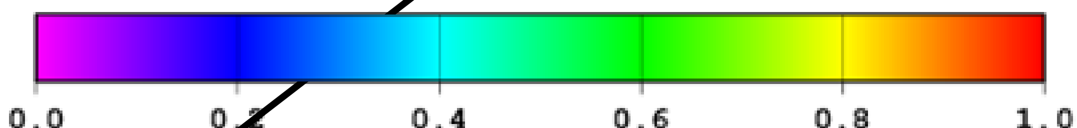
GRASP retrieval: Kilauea volcano (Hawaii, Halemaumau Crater, June-August, 2008)

AOD, 443 nm

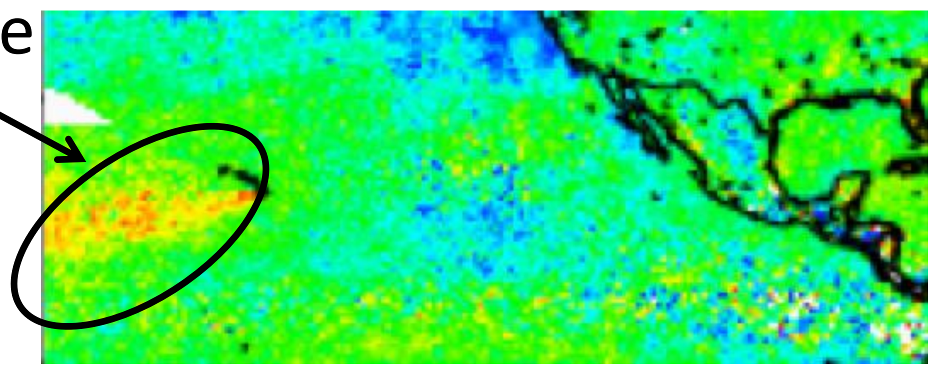


Fine mode AOD, 443 nm

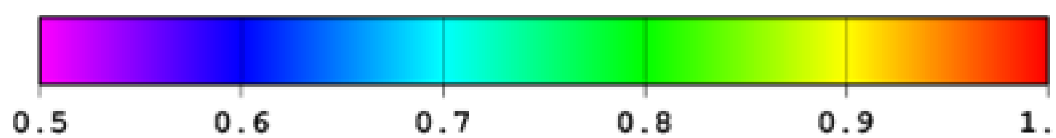




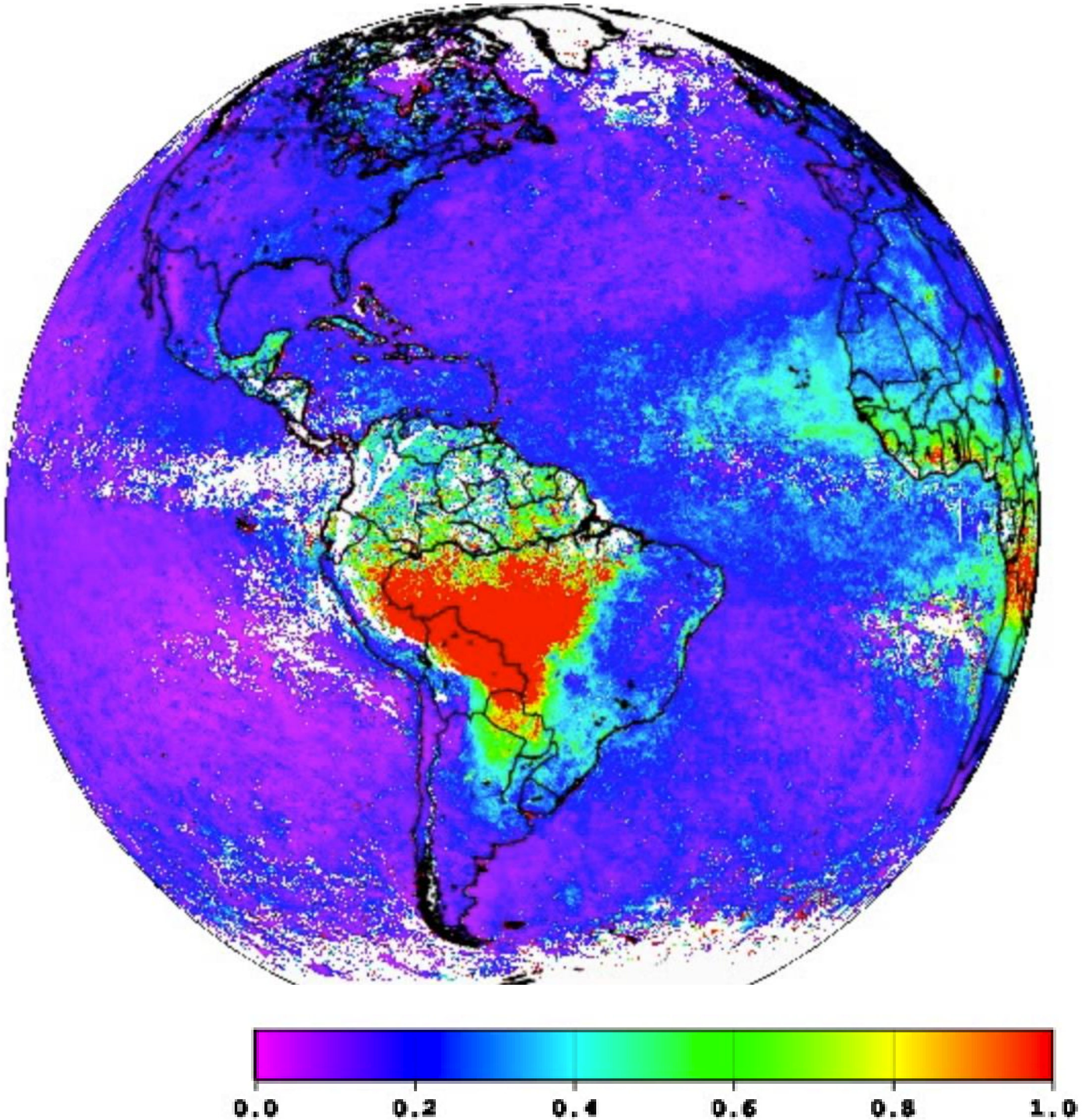
SSA, 443 nm

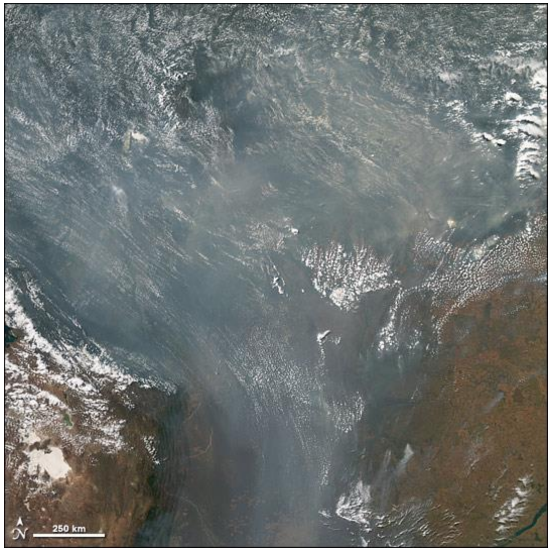


Halemaumau Crater ash plume

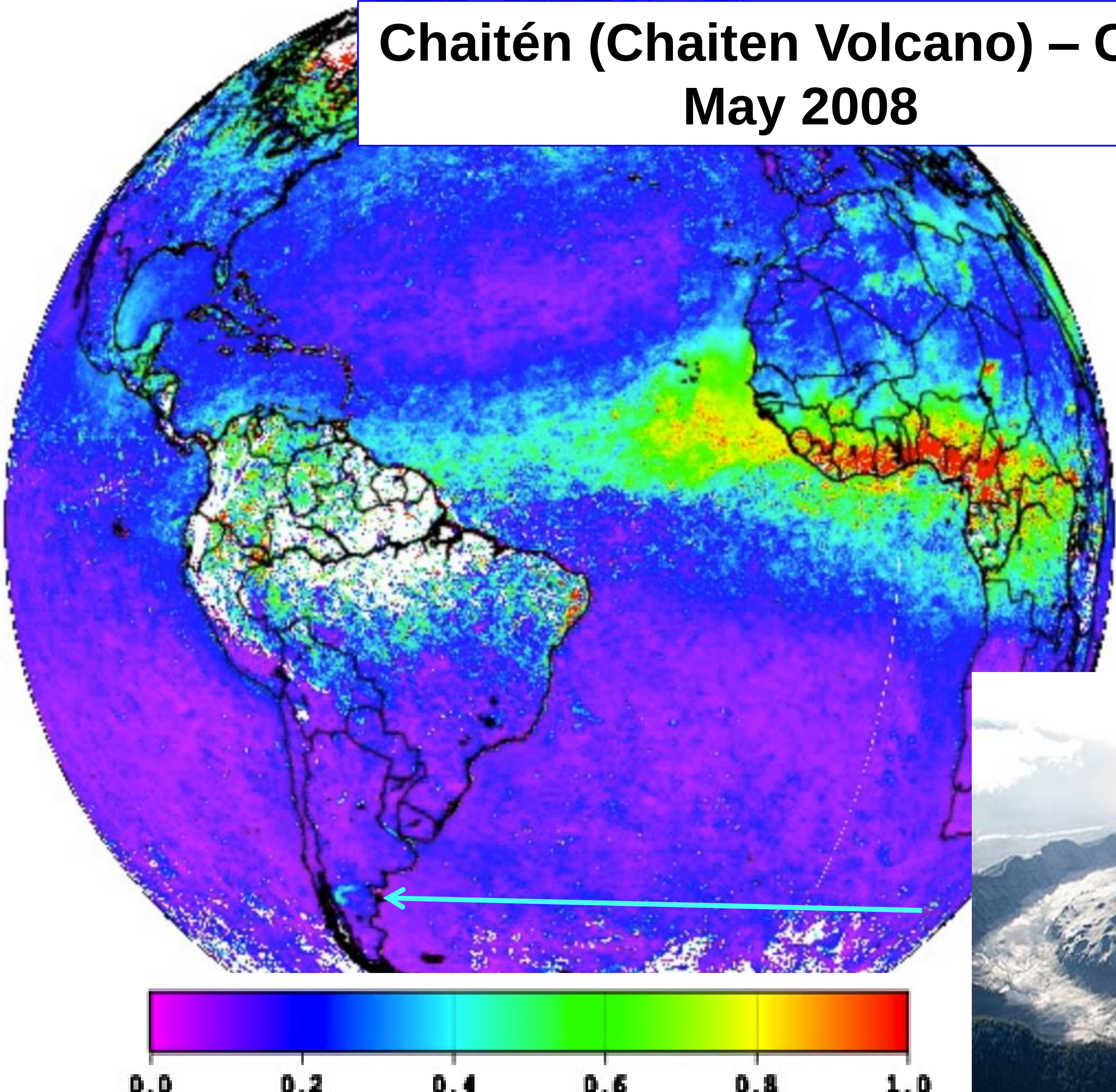


Brazil biomass burning fires
Autumn 2007



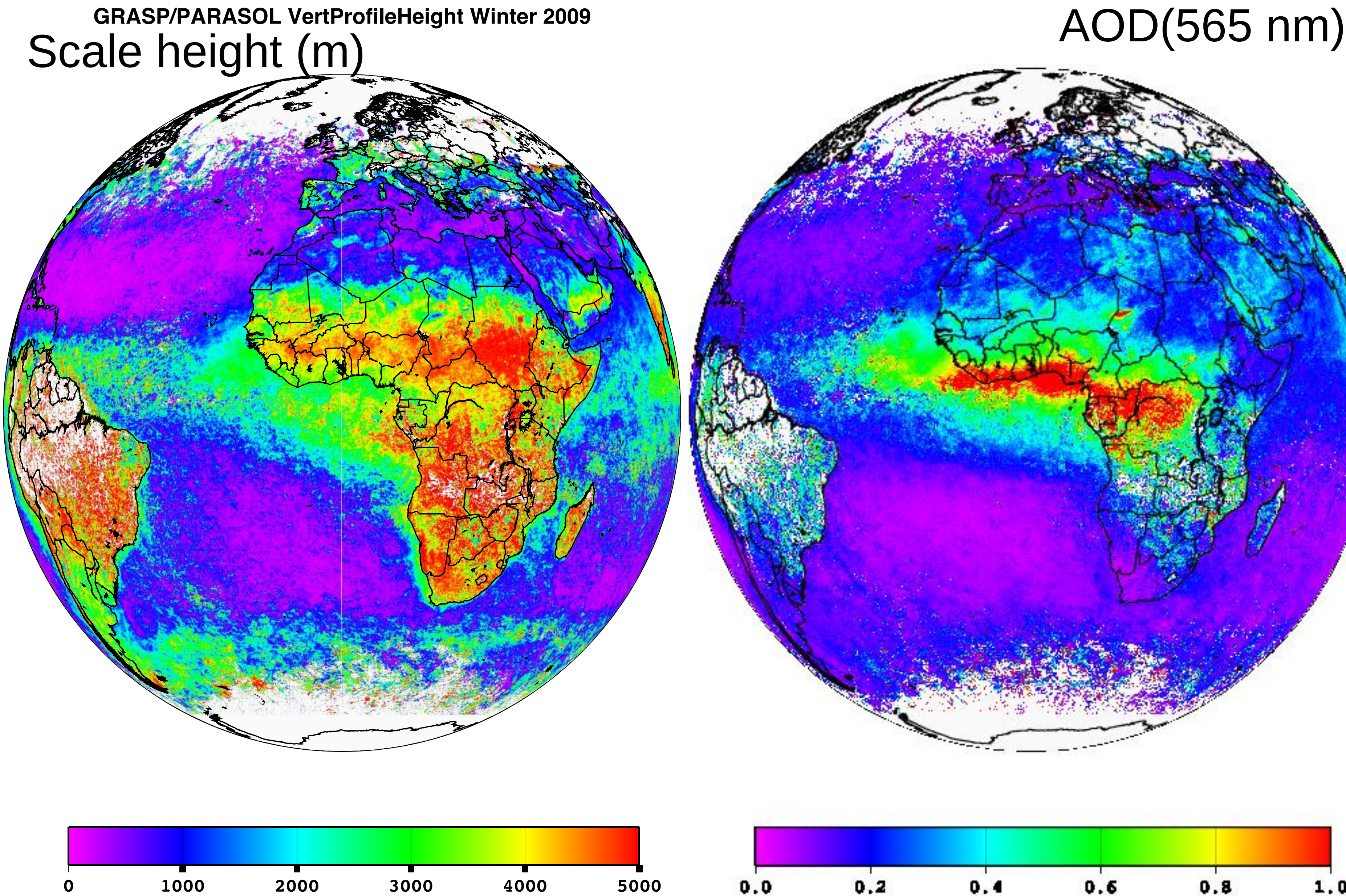


Chaitén (Chaiten Volcano) – Chile May 2008

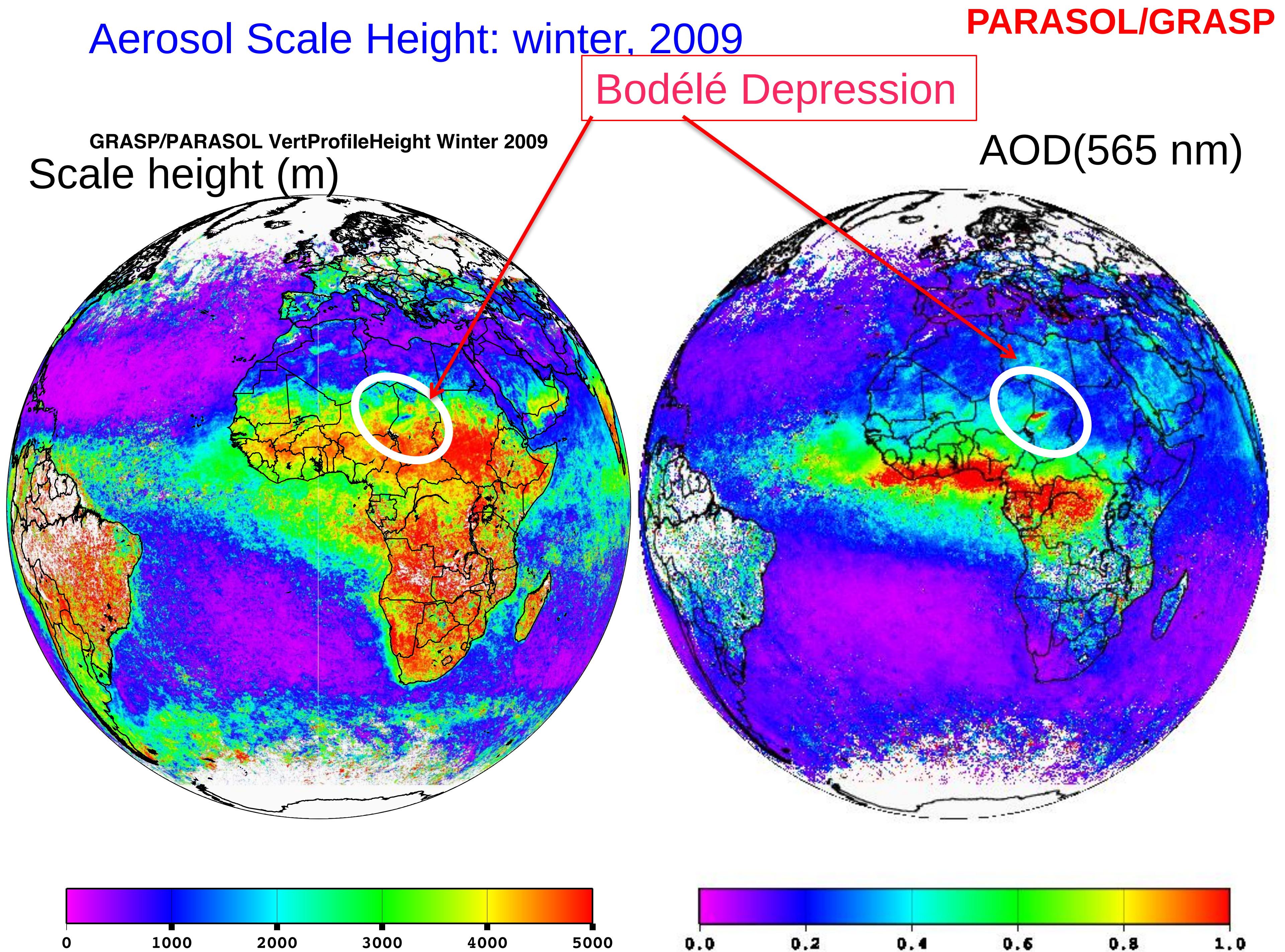


Aerosol Scale Height: winter, 2009

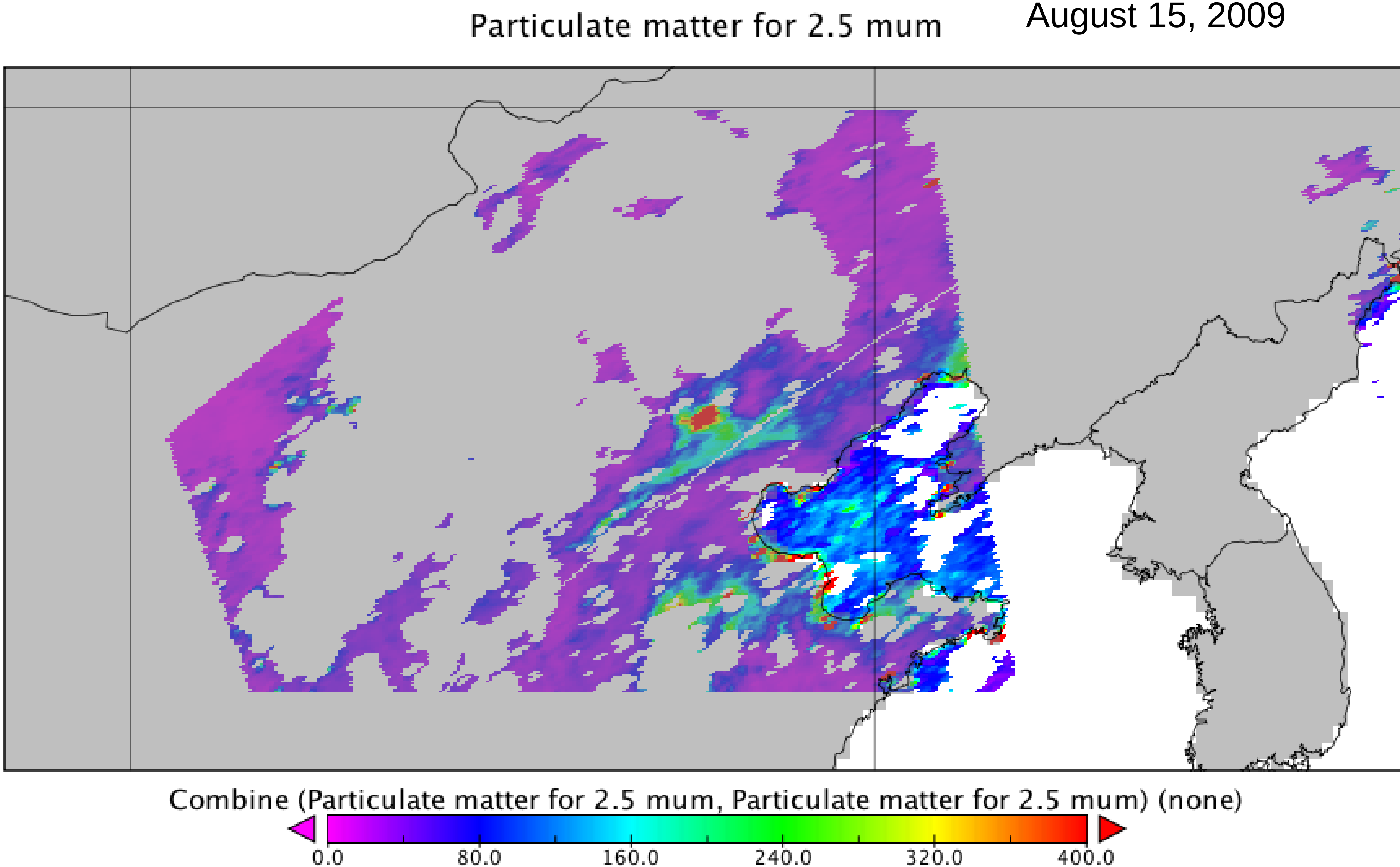
PARASOL/GRASP

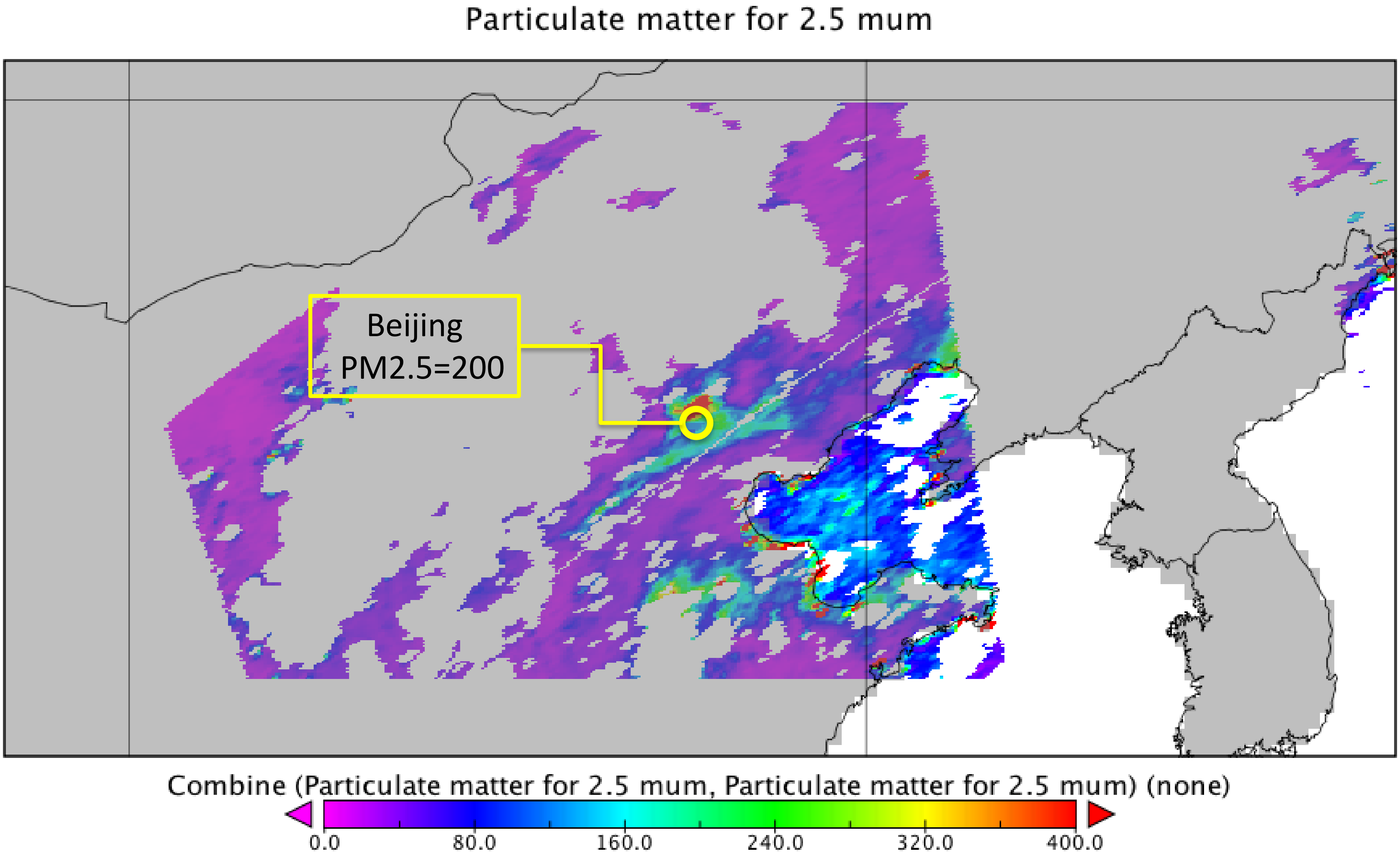


Aerosol Scale Height: winter, 2009

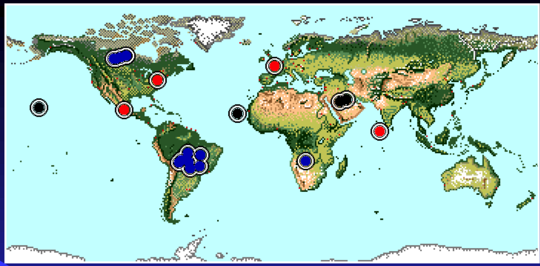


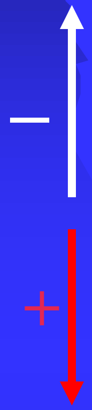
August 15, 2009

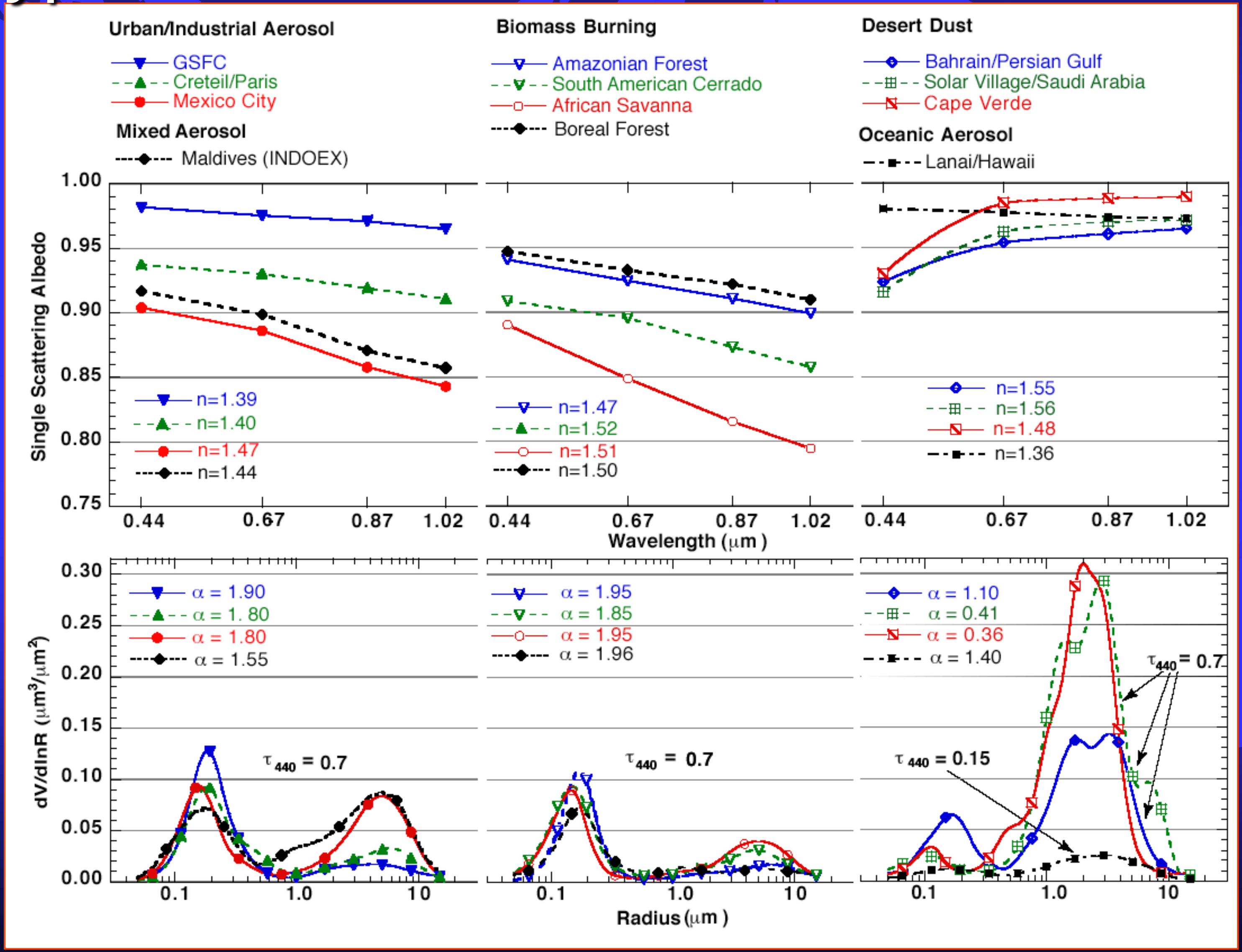



Particulate matter for 2.5 mum
Beijing
PM2.5=200
Combine (Particulate matter for 2.5 mum, Particulate matter for 2.5 mum) (none)
0.0
80.0
160.0
240.0
320.0
400.0

The averaged optical properties of various aerosol types (Dubovik et al., 2002, JAS)

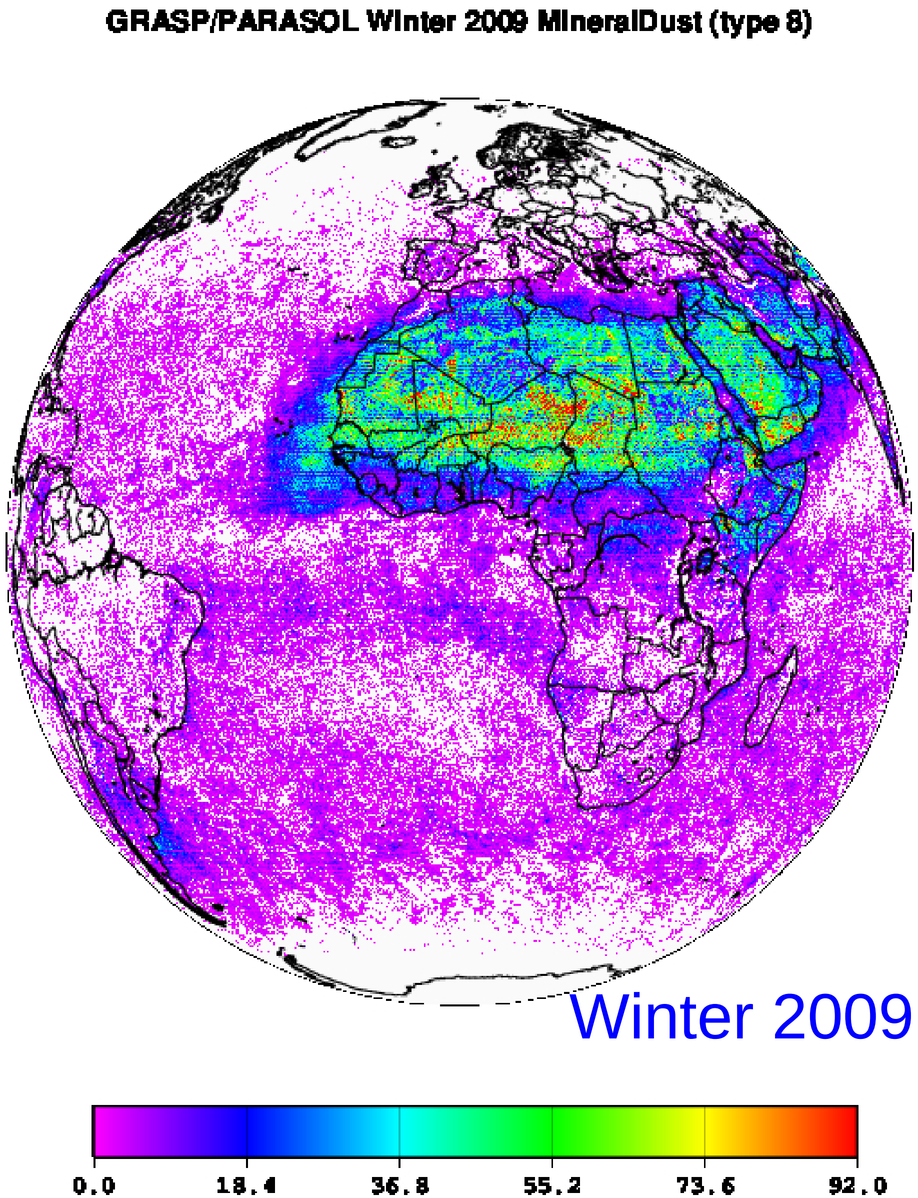


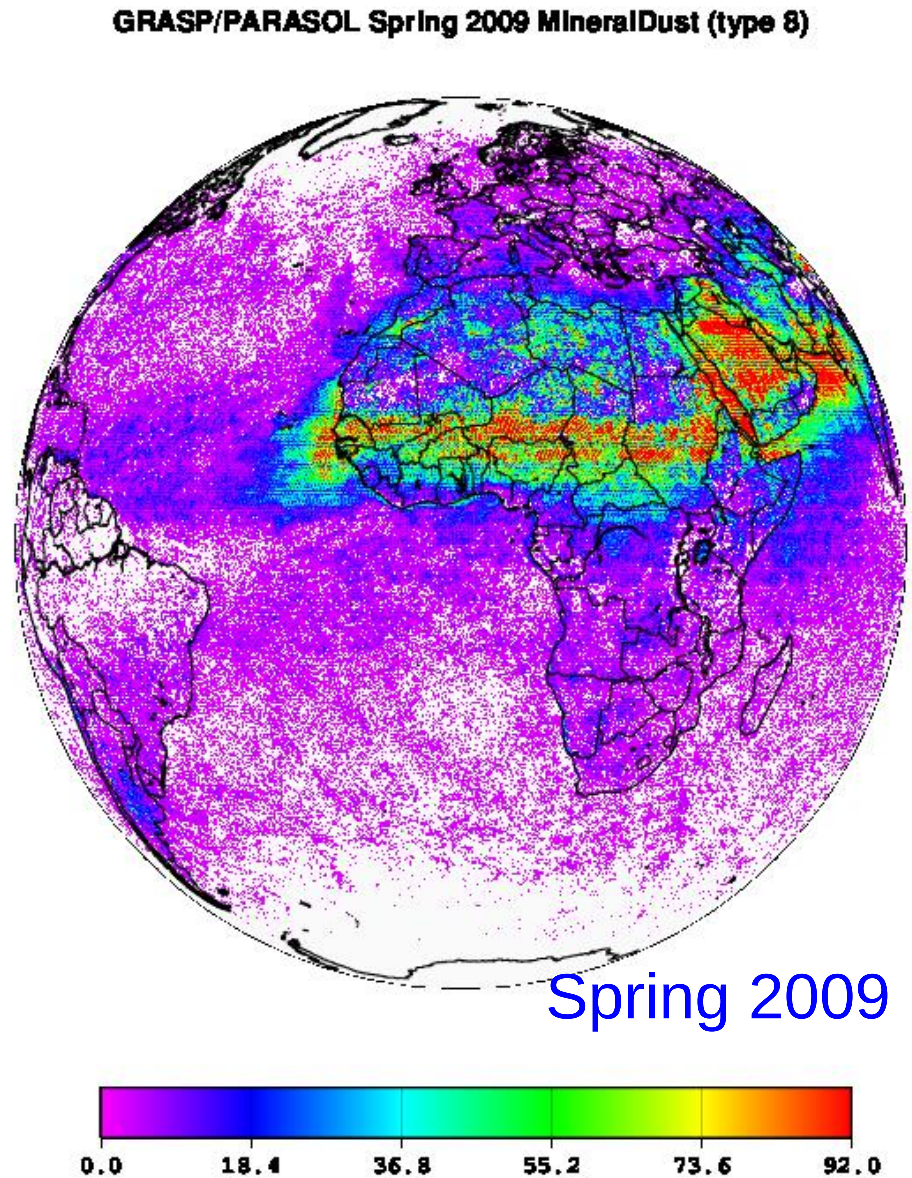




Aerosol type detection with GRASP

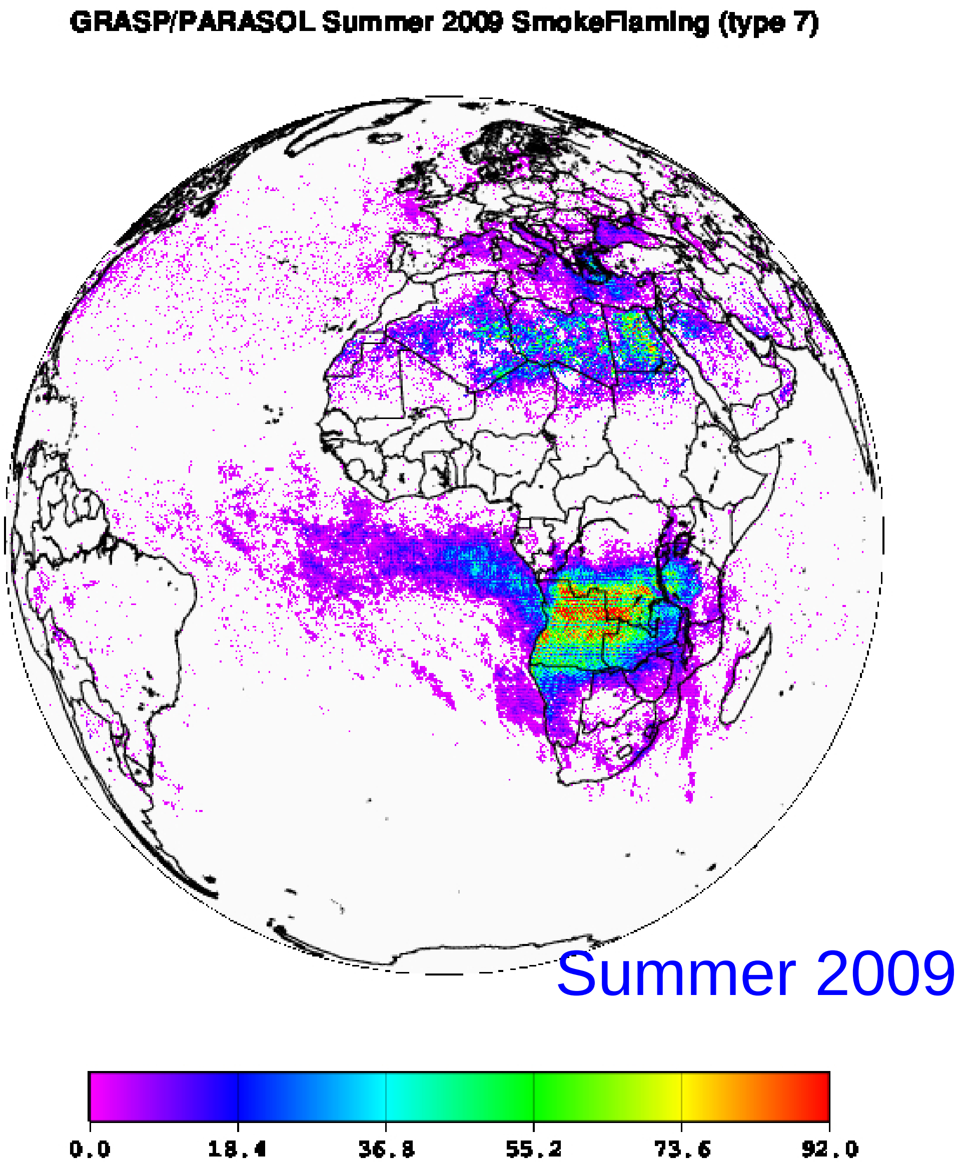
Mineral dust frequency of occurrence

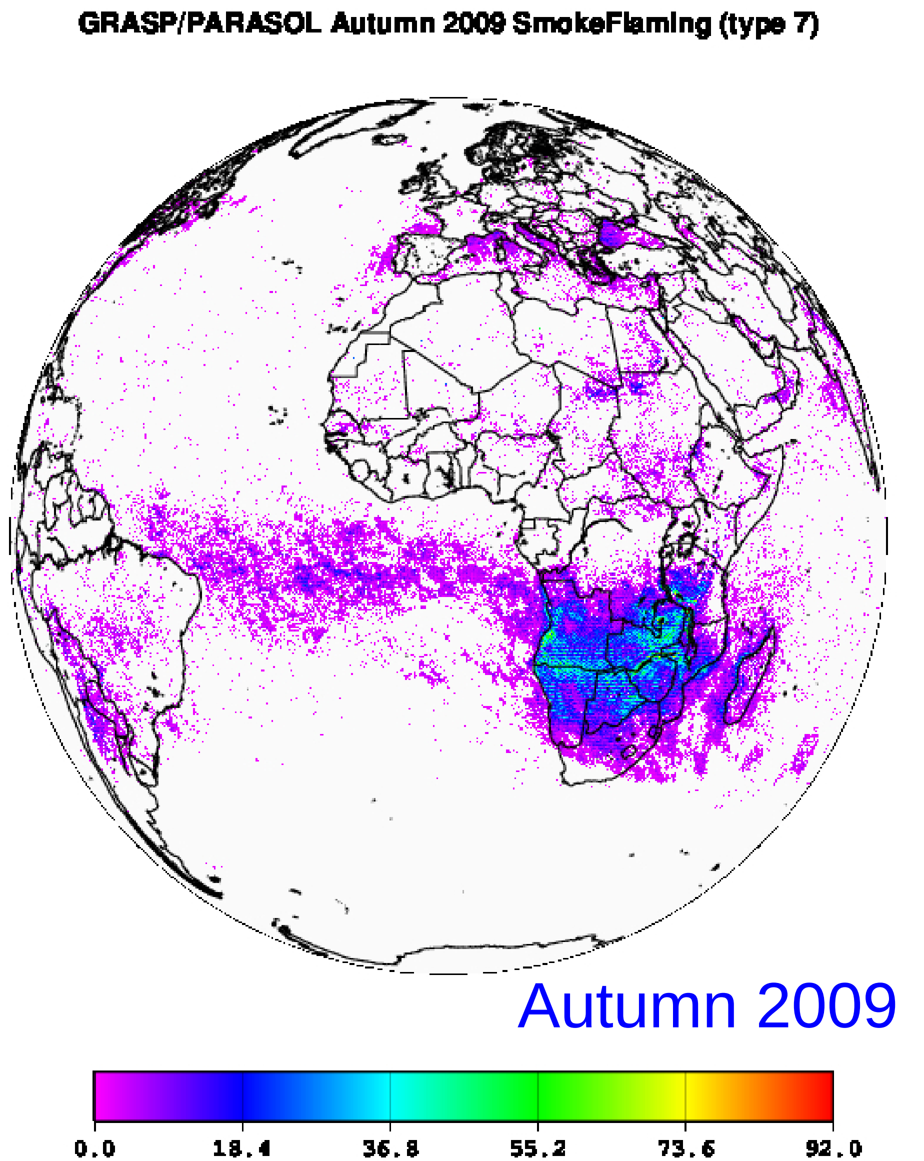




Aerosol type detection with GRASP

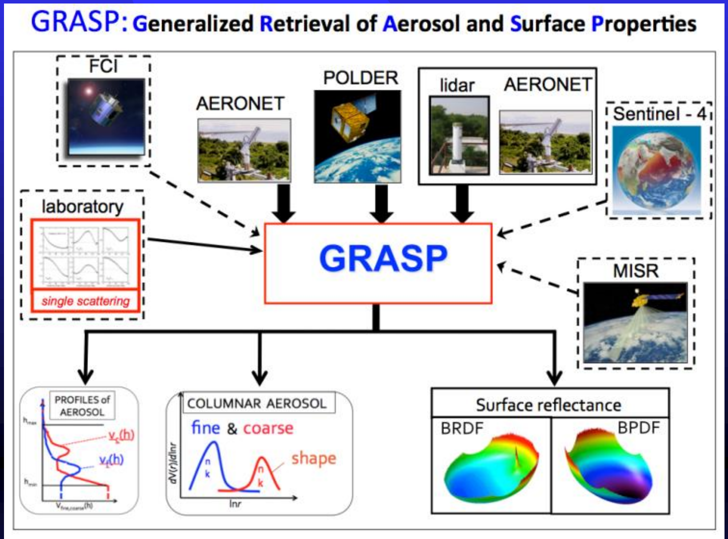
Smoke frequency of occurrence

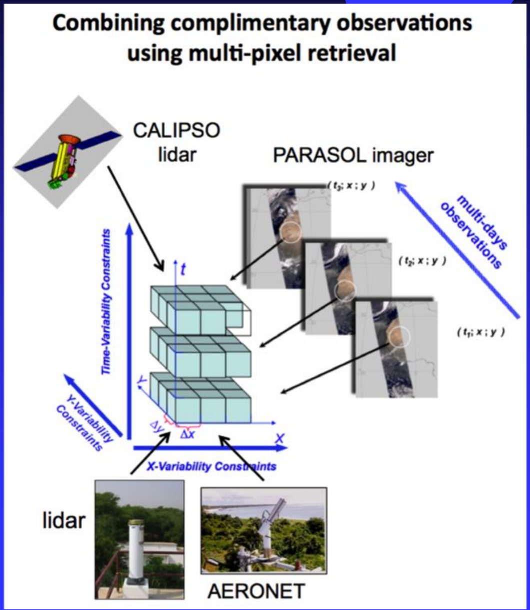




CONCLUSION: GRASP processing provides first global detailed aerosol characterization from PARASOL

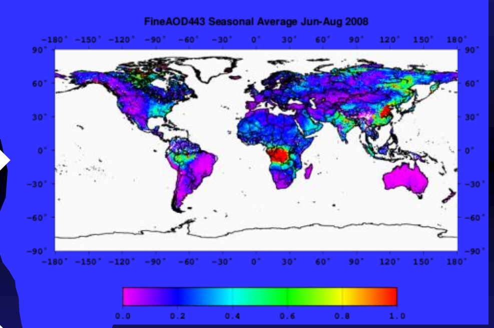
(including global distribution of aerosol types and absorption)

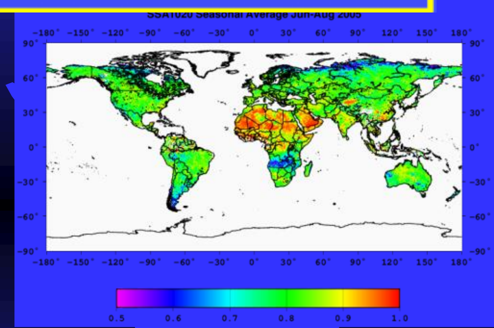


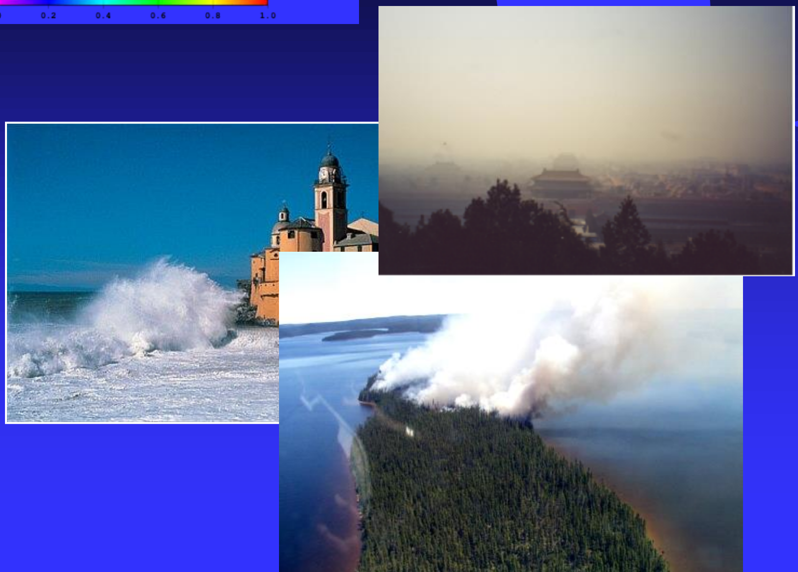


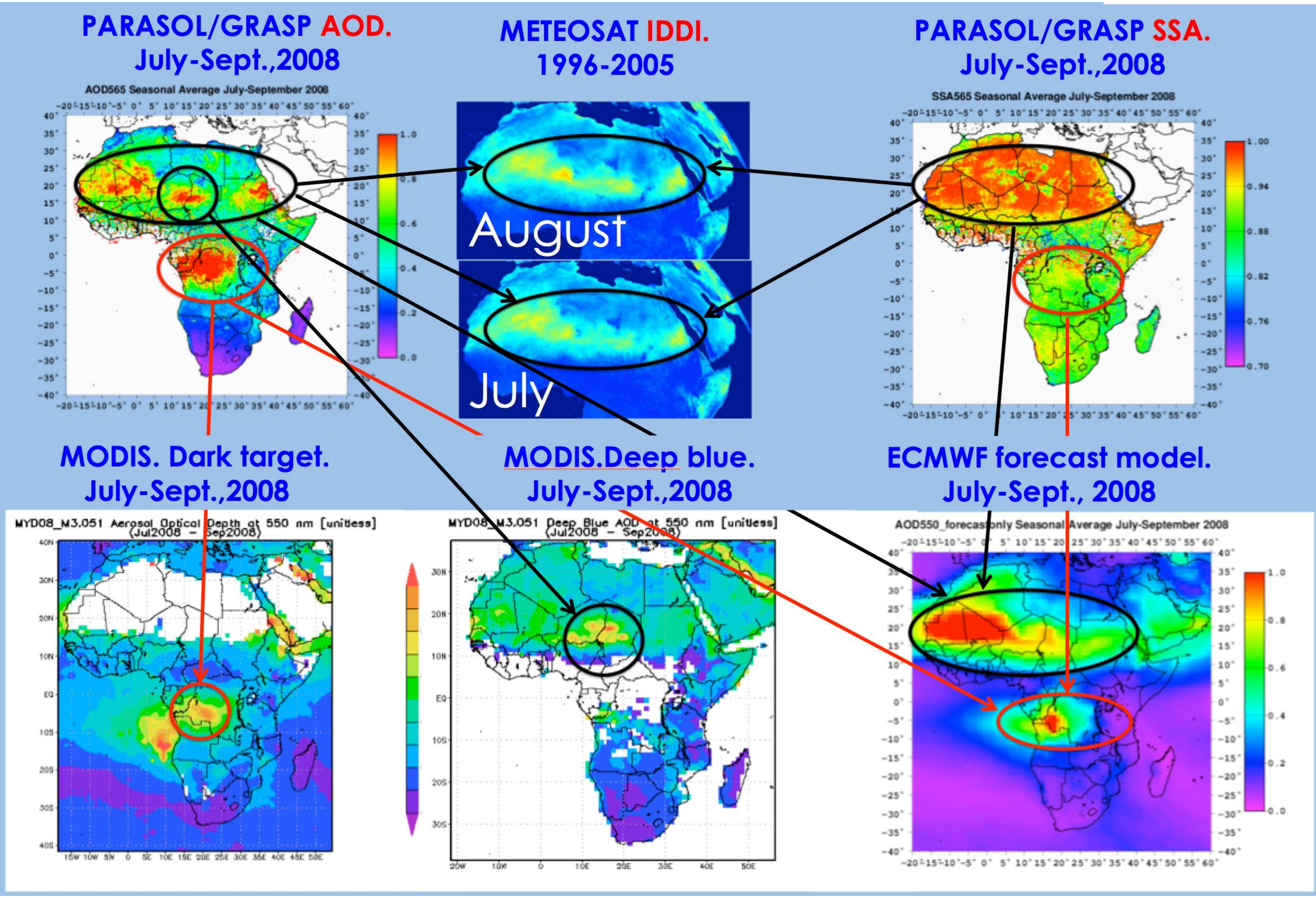
Promising for future missions :

- 3MI / EPS-SG;
- Sentinel-3, (OLCI, SLSTR; OLCI + SLSTR);
- Sentinel- 4 ; FCI/MTG, etc.



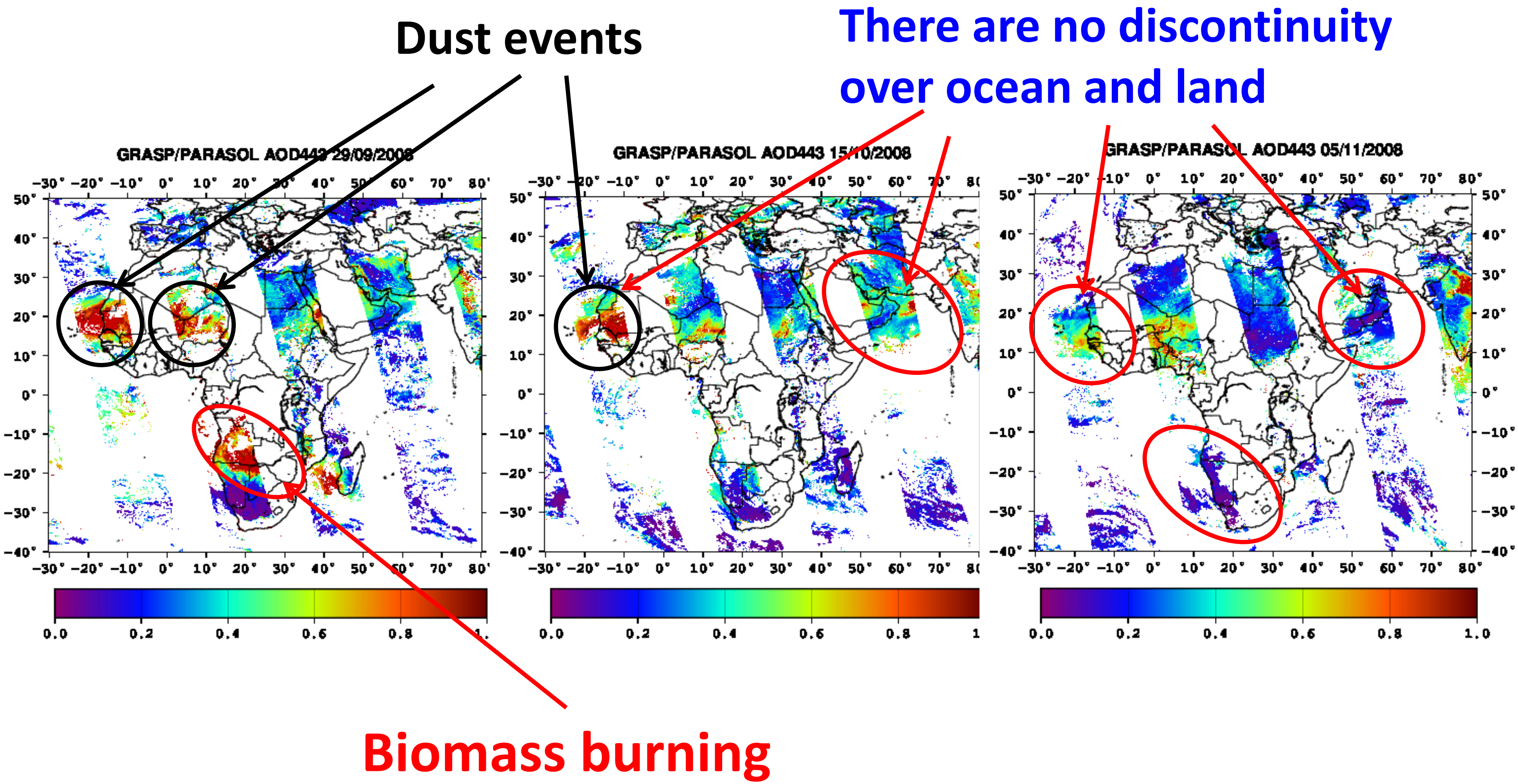




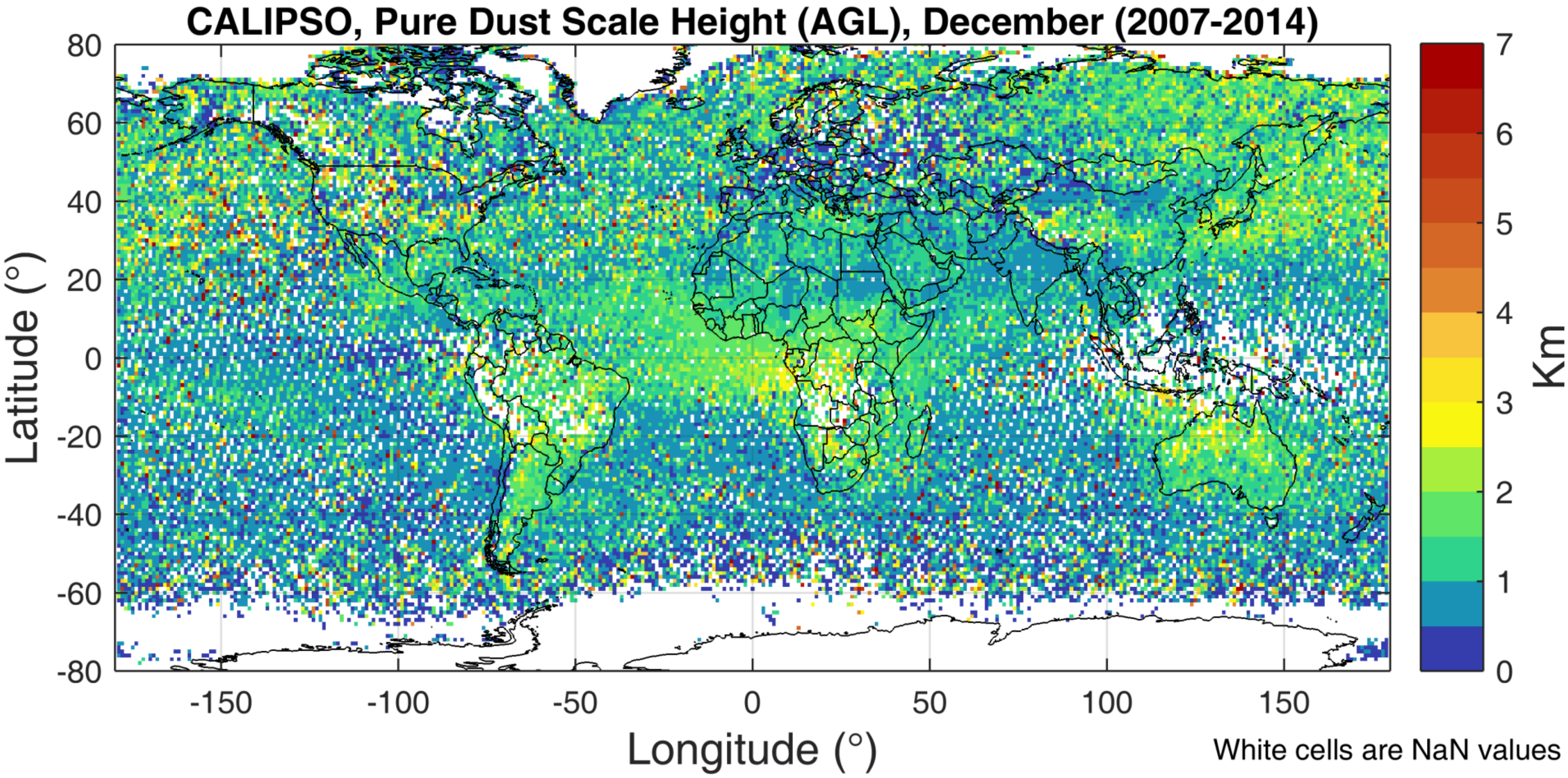


PARASOL/GRASP AOD.
July-Sept.,2008
AOD565 Seasonal Average July-September 2008
METEOSAT IDDI.
1996-2005
August
July
PARASOL/GRASP SSA.
July-Sept.,2008
SSA565 Seasonal Average July-September 2008
MODIS. Dark target.
July-Sept.,2008
MYD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jul2008 – Sep2008)
MODIS.Deep blue.
July-Sept.,2008
MYD08_M3.051 Deep Blue AOD at 550 nm [unitless]
(Jul2008 – Sep2008)
ECMWF forecast model.
July-Sept., 2008
AOD550_forecastonly Seasonal Average July-September 2008

GRASP over land and ocean



Courtesy of V. Amiridis et al.



Multi-sensor data

Multi-Term LSM

(e.g. see Dubovik 2004)

sensor 1

sensor 2

Independent !!!

$$\begin{cases} \mathbf{f}_1^* = \mathbf{F}_1\, \mathbf{a} + \Delta_1 \\ \mathbf{f}_2^* = \mathbf{F}_2\, \mathbf{a} + \Delta_2 \\ \dots \end{cases}$$

$$\hat{\mathbf{a}} = \left(\mathbf{F}_1^T \mathbf{C}_1^{-1} \mathbf{F}_1 + \mathbf{F}_2^T \mathbf{C}_2^{-1} \mathbf{F}_2 + \dots\right)^{-1} \left(\mathbf{F}_1^T \mathbf{C}_1^{-1} \mathbf{f}_1^* + \mathbf{F}_2^T \mathbf{C}_2^{-1} \mathbf{f}_2^* + \dots\right)$$

Single-sensor data

$$\hat{\mathbf{a}} = \left(\mathbf{F}^T \mathbf{C}_f^{-1} \mathbf{F} + \mathbf{C}_a^{-1} + \gamma \mathbf{S}^T \mathbf{S}\right)^{-1} \left(\mathbf{F}^T \mathbf{C}_f^{-1} \mathbf{f}^* + \mathbf{C}_a^{-1} a^*\right)$$

sensor

a priori

$$\begin{cases} \mathbf{f}_1^* = \mathbf{f}^* = \mathbf{F}\, \mathbf{a} + \Delta_f \\ \mathbf{f}_2^* = \mathbf{a}^* = \mathbf{a} + \Delta_a \\ \mathbf{f}_3^* = \mathbf{0}^* = \mathbf{S}\mathbf{a} + \Delta(\Delta \mathbf{a}) \end{cases}$$

Generalization of "Optimum estimation" and Phillips-Tikhonov-Twomey formulas

Dubovik et al., 2006

AERONET model of aerosol