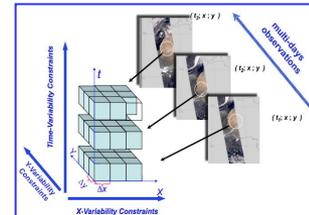




# SEOM's Sentinel-3/OLCI project CAWA:

## advanced **GRASP** aerosol retrieval



Oleg Dubovik<sup>1</sup>, Pavel Litvinov<sup>1</sup>, Xin Huang<sup>1</sup>,  
Michael Aspetsberger<sup>2</sup>, David Fuertes<sup>3</sup>, Carsten Brockmann<sup>4</sup>,  
And Jürgen Fischer<sup>5</sup>.

1- University of Lille-1, CNRS, France;

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

3- GRASP-SAS, Lille, France;

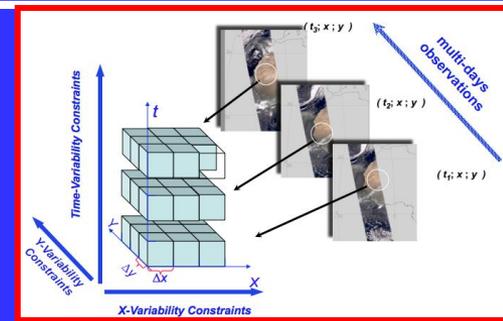
4- Brockmann-Consult GmbH, Geesthacht, Germany;

5- Free University Berlin,, Berlin, Germany;



# MERIS:

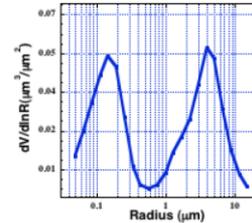
- radiances at seven wavelengths: (413, 443, 490, 510, 560, 665, and 870 nm);
- single view



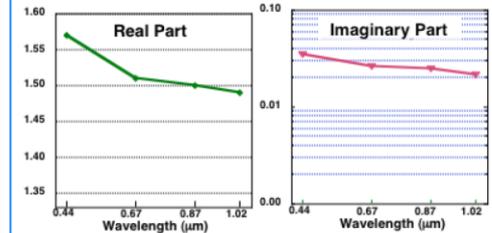
# AEROSOL:

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

Particle Size Distribution:  
 $0.05 \mu\text{m} \leq R \text{ (22 bins)} \leq 15 \mu\text{m}$

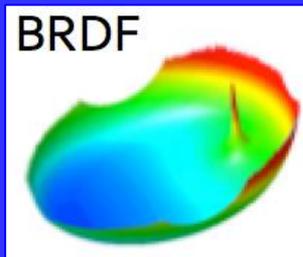


Complex Refractive Index at  
 $\lambda = 0.44; 0.67; 0.87; 1.02 \mu\text{m}$



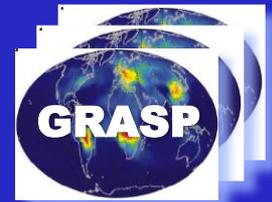
# SRFACE:

- BRDF
- (3 spectrally dependent parameters);



$$41 = (5 \text{ (SD)}) + 14 \text{ (ref. ind.)} + 1 \text{ (nonsp.)} + 21 \text{ (BRDF)}$$

# GRASP specifics:



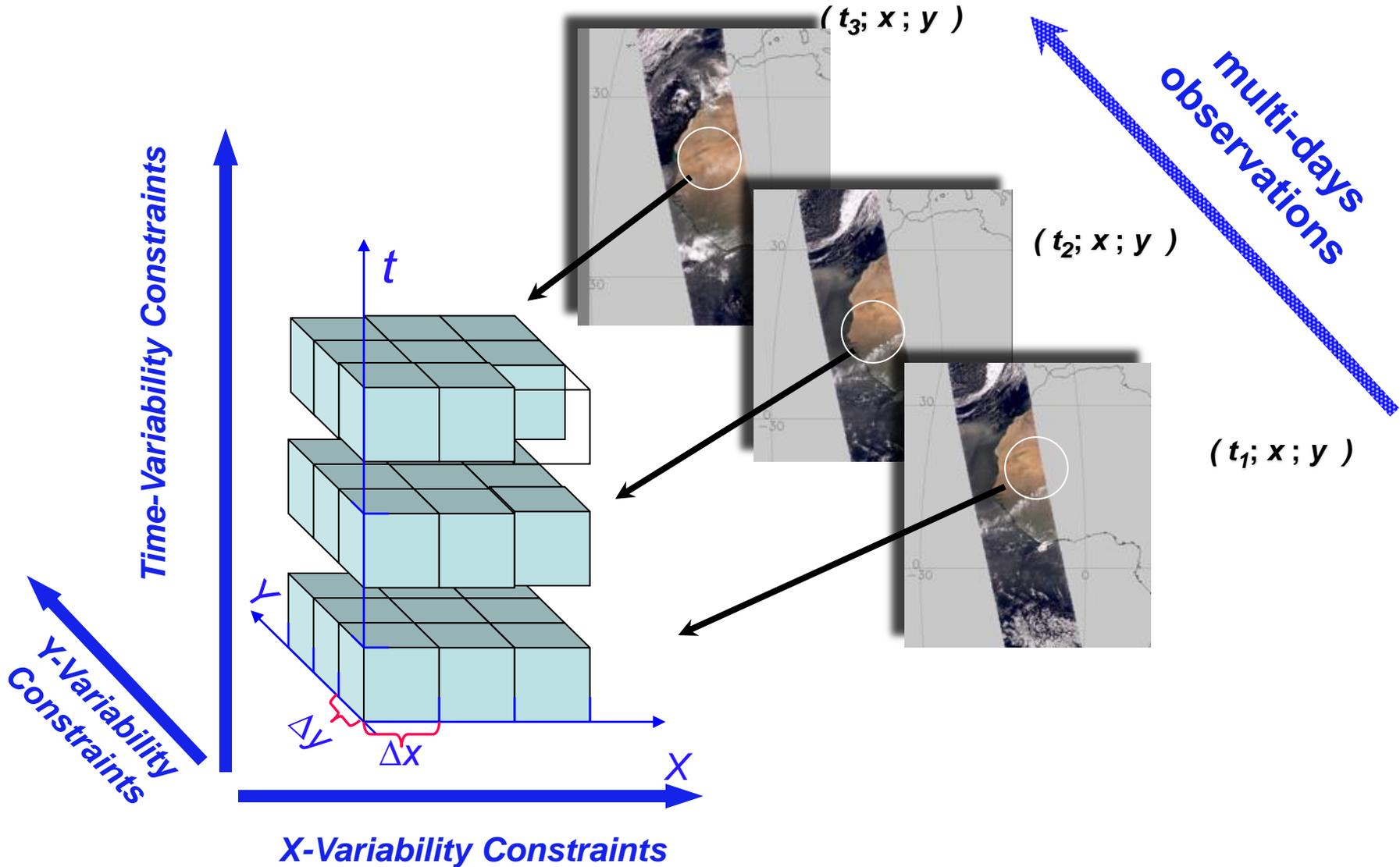
## Inversion scheme:

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

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

- ✓ 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);
- ✓ single initial guess;

# The concept of multi-pixel retrieval



# Multi-term LSM Multi-Pixel Solution:

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

$$\mathbf{W}_x = \mathbf{s}_x^T \mathbf{s}_x; \quad \mathbf{W}_y = \mathbf{s}_y^T \mathbf{s}_y; \quad \mathbf{W}_t = \mathbf{s}_t^T \mathbf{s}_t;$$

- $\mathbf{a}_v$
- $\mathbf{a}_n$
- $\mathbf{a}_n$
- $\mathbf{a}_h$
- $\mathbf{a}_{sph}$
- $\mathbf{a}_{Vc}$
- $\mathbf{a}_{brdf,1}$
- $\mathbf{a}_{brdf,2}$
- $\mathbf{a}_{brdf,3}$
- $\mathbf{a}_{bpdf}$

$$g_D \mathbf{W} = \begin{pmatrix} g_{D,1} W_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & g_{D,2} W_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & g_{D,3} W_3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & g_{D,4} W_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & g_{D,5} W_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & g_{D,6} W_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & g_{D,7} W_7 \end{pmatrix}$$

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

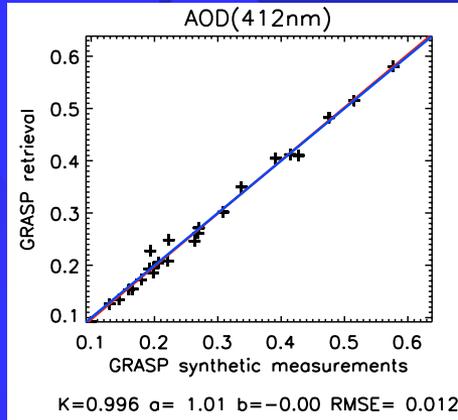
$$\mathbf{s}_y^T \mathbf{s}_y = \begin{pmatrix} I_{d_{11}} & I_{d_{12}} & I_{d_{13}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & I_{d_{21}} & I_{d_{22}} & I_{d_{23}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & I_{d_{31}} & I_{d_{32}} & I_{d_{33}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 &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

$$\mathbf{s}_t^T \mathbf{s}_t = \begin{pmatrix} I_{d_{11}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & I_{d_{11}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & I_{d_{11}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & I_{d_{11}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & I_{d_{11}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & I_{d_{11}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & I_{d_{11}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & I_{d_{11}} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I_{d_{11}} \end{pmatrix}$$

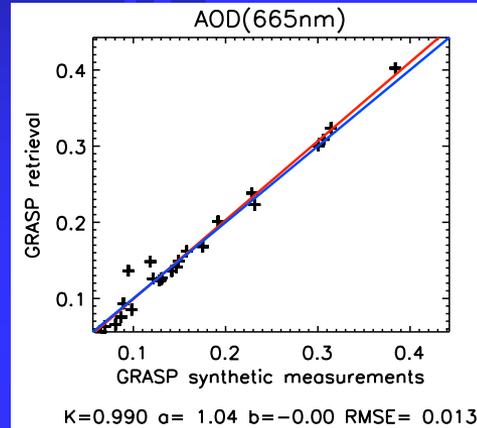
43 parameters

# The concept MERIS/GRASP retrieval works good with synthetic measurements

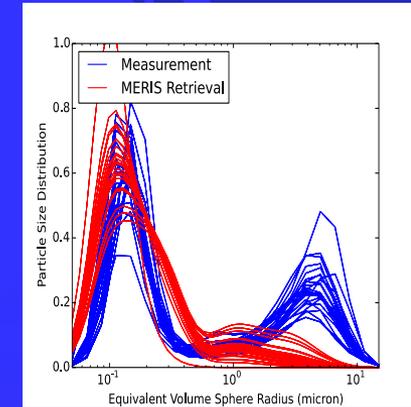
## AOD



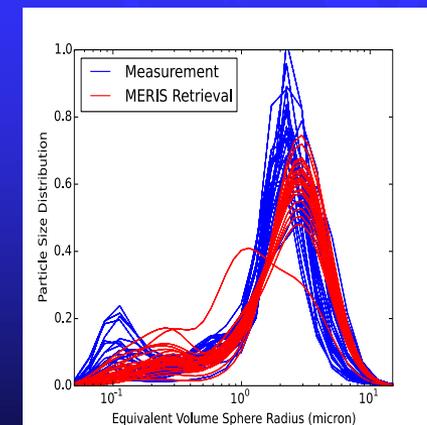
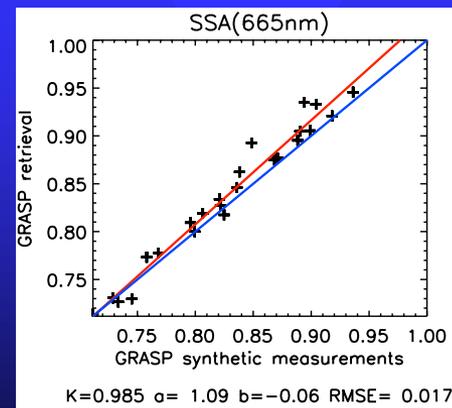
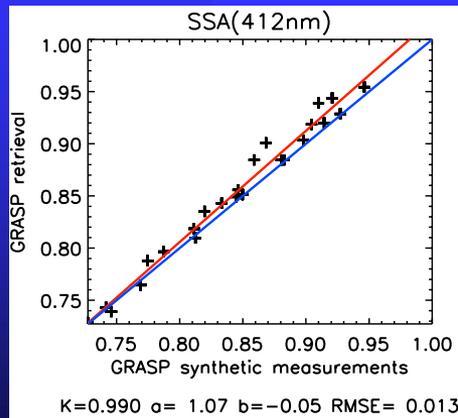
## SSA



## Smoke



## Dust



# GRASP/MERIS: AOD(560 nm), January – March 2008

GRASP is somewhat slow compared to conventional retrievals, but easily mitigated using advanced IT technology such as GPGPU

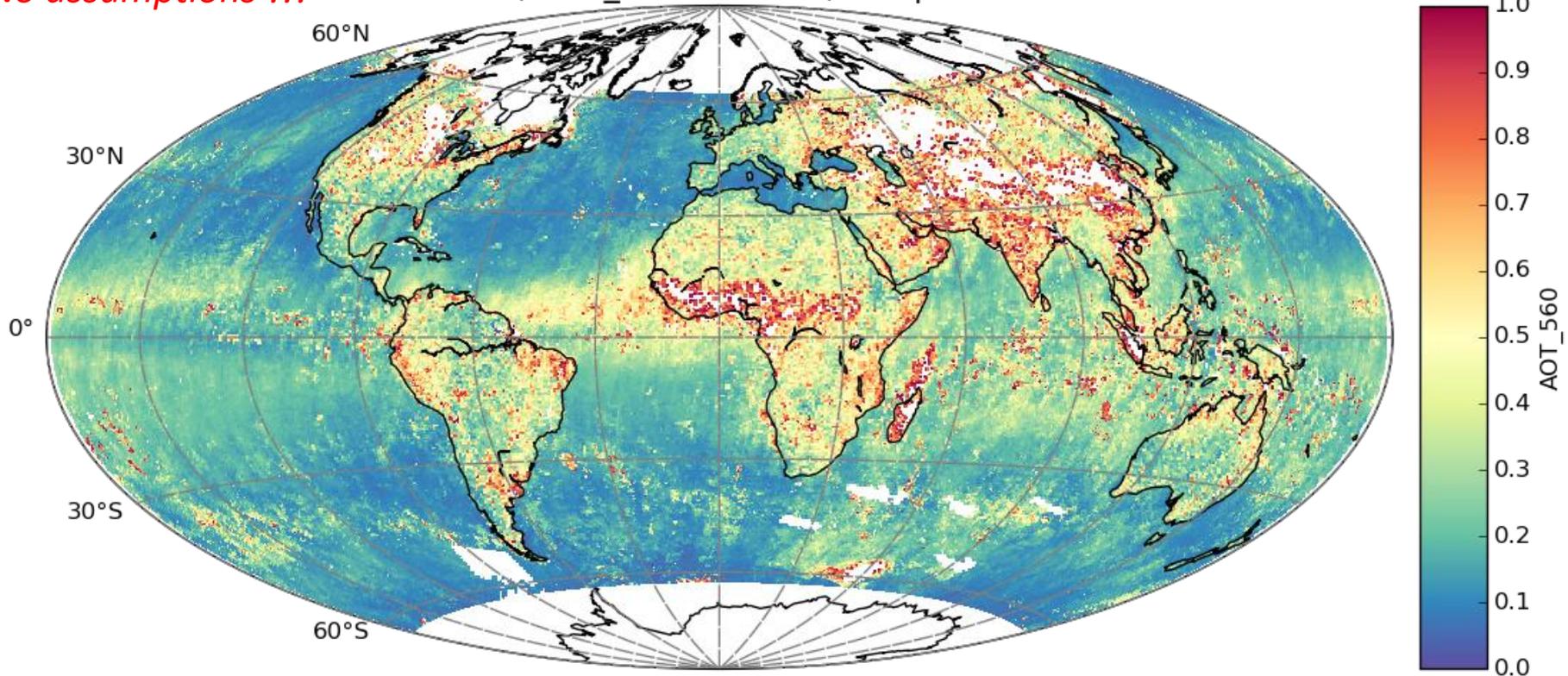
Catalysts

First results: *Aerosol*, 35 km resolution

*No assumptions !!!*

meris, AOT\_560 -- Global, composite

*ESA CAWA project*



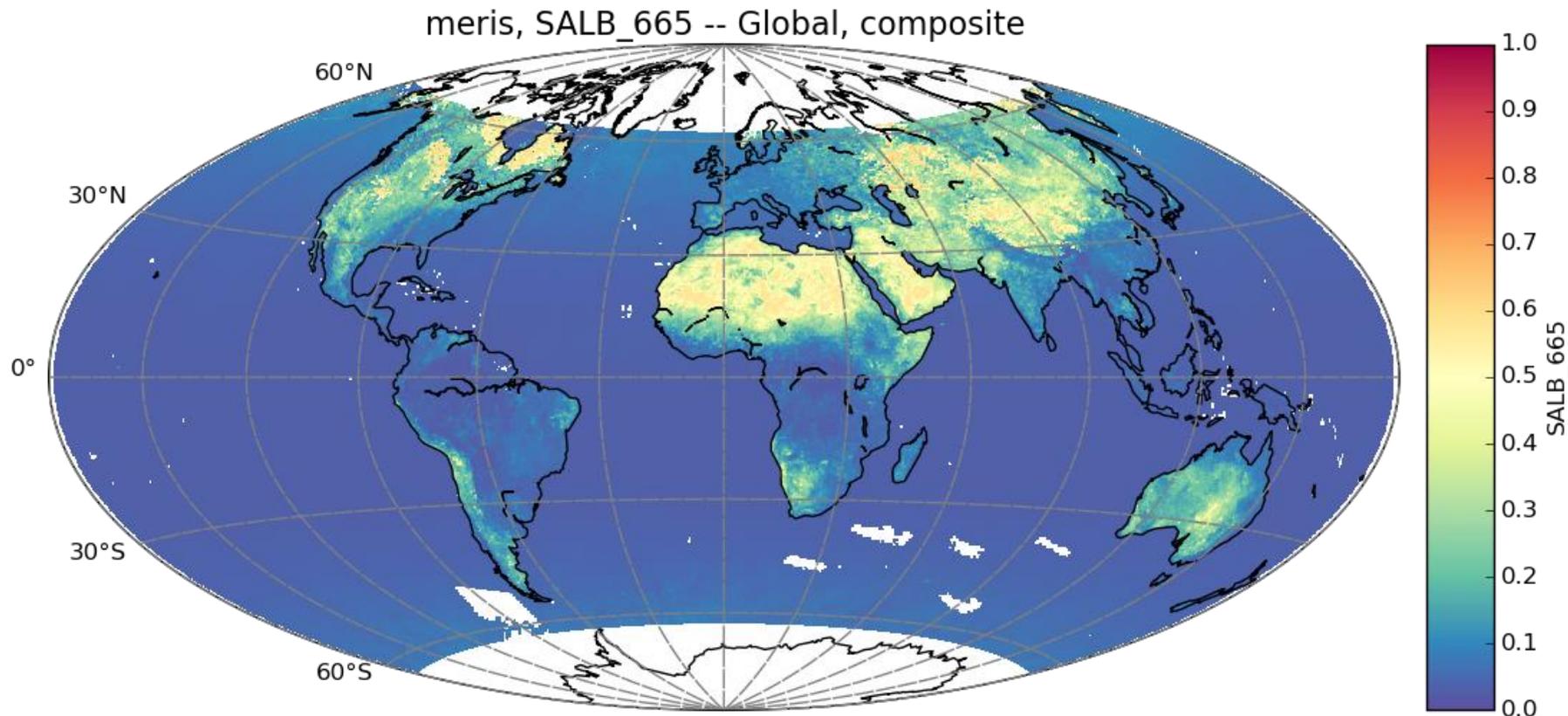
# GRASP/MERIS: AOD(560 nm), January - March 2008

Retrieves both: surface (over land) and detailed aerosol properties

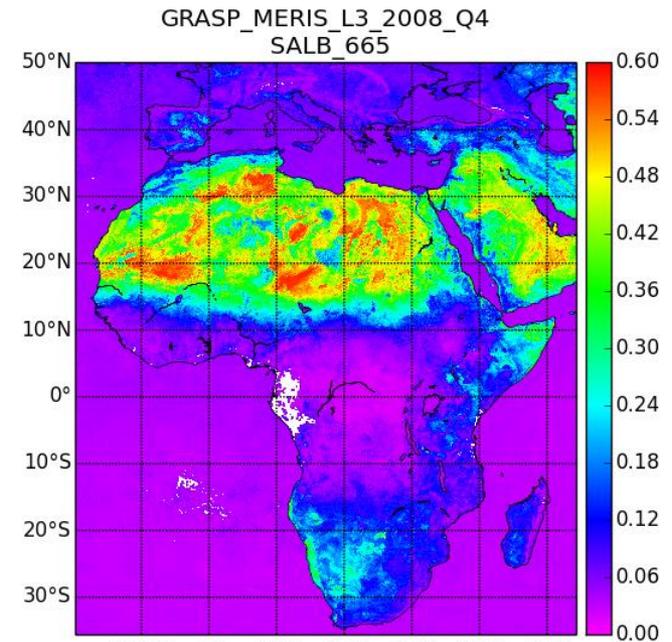
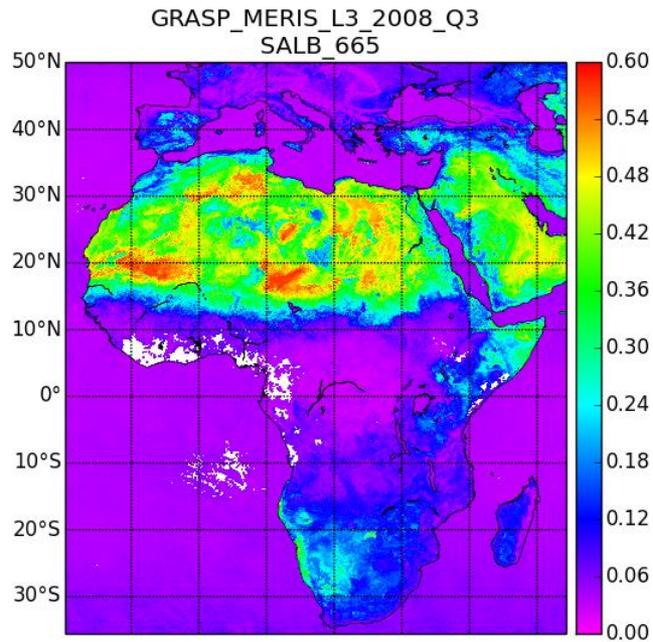
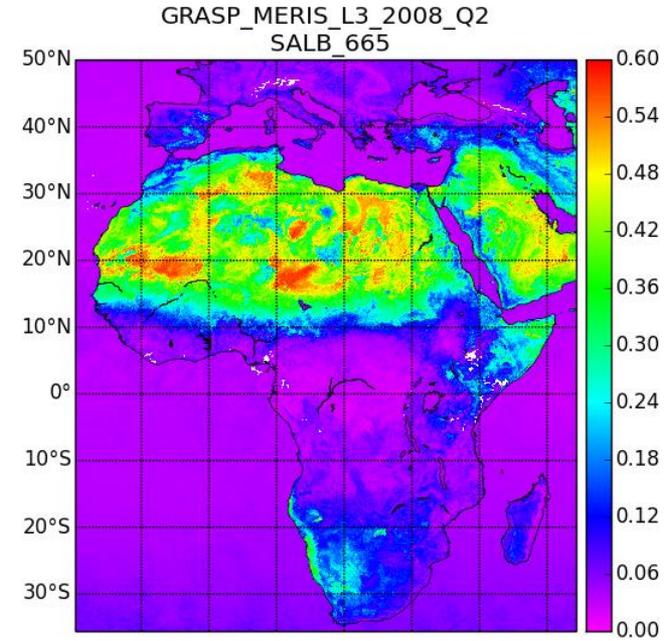
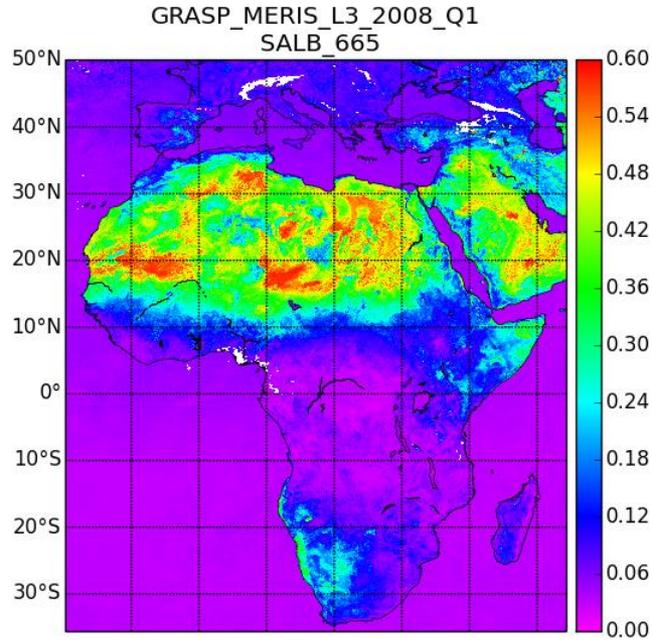
*No assumptions !!!*

*ESA CAWA project*

*First results: Surface reflectance, 35 km resolution*



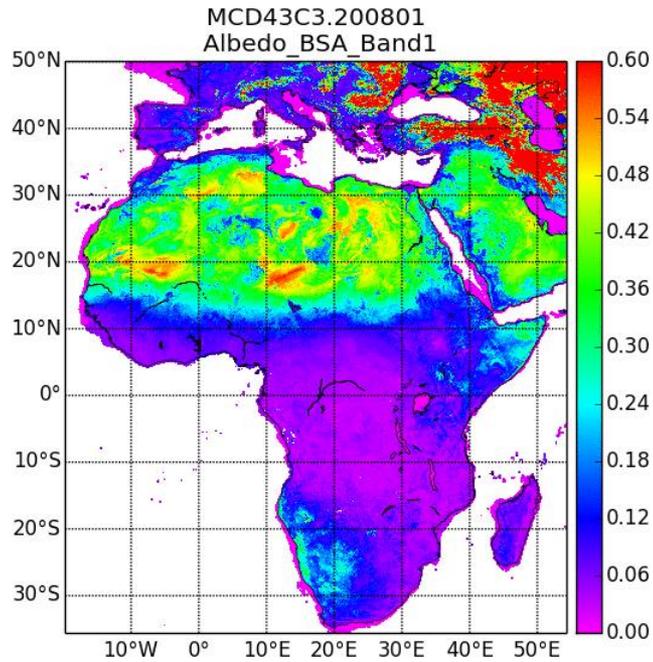
# MERIS Surface Reflectance over Africa and Mediterranean Region in 2008



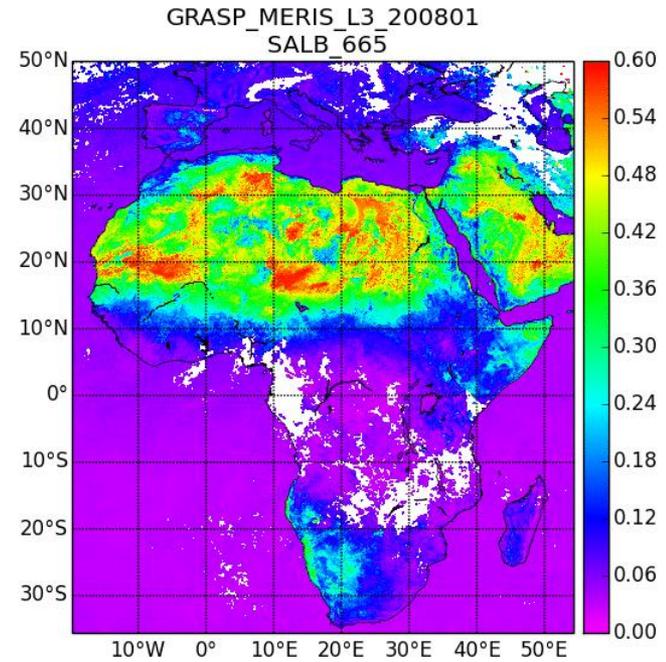
# Animation of SALB retrieval from PARASOL over Africa and Mediterranean Region in 2008

## Monthly averages

### MODIS (AQUA + TERRA)



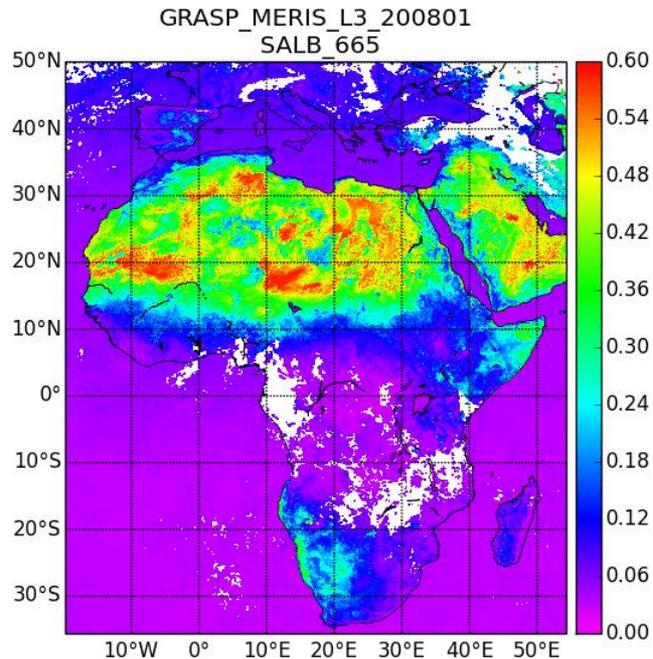
### MERIS



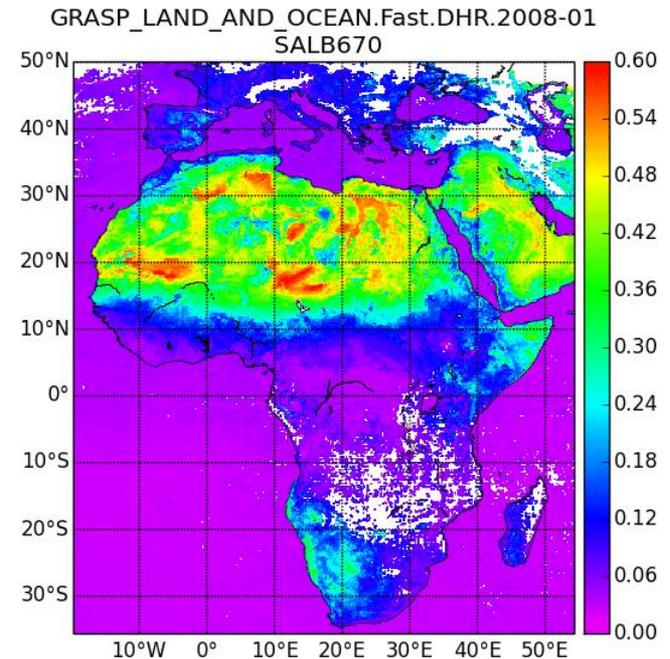
# Animation of AOT retrieval from PARASOL over Africa and Mediterranean Region in 2008

## Monthly averages

### MERIS



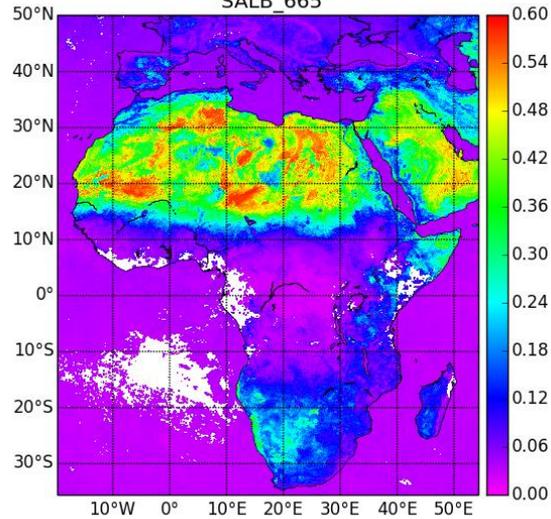
### PARASOL



# Surface Albedo (670 nm) – Africa, October 2008

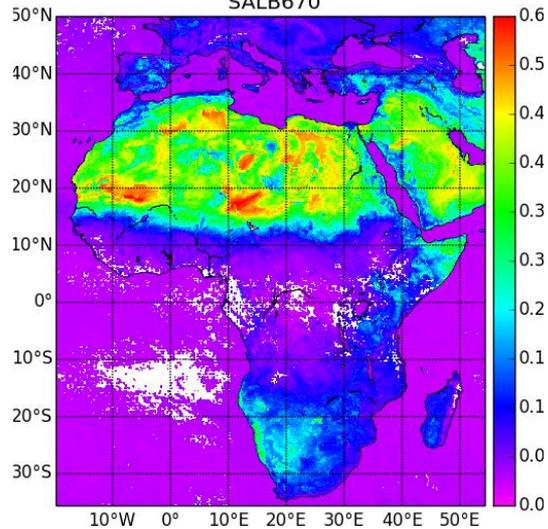
## MERIS

GRASP\_MERIS\_L3\_200810  
SALB\_665



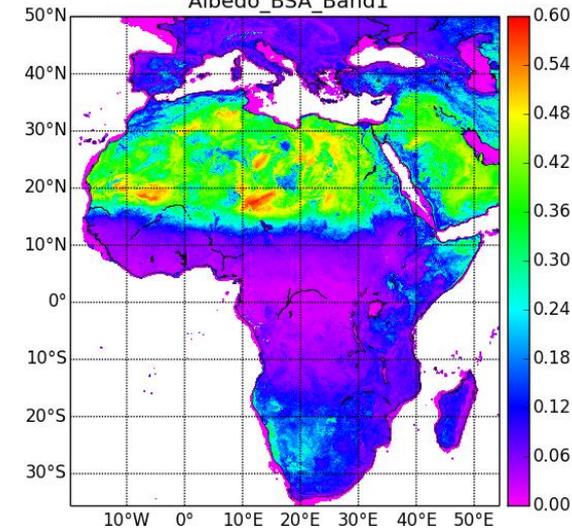
## PARASOL

GRASP\_LAND\_AND\_OCEAN.Fast.DHR.2008-10  
SALB670



## MODIS-TERRA

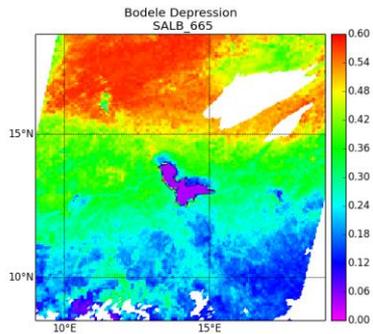
MCD43C3.200810  
Albedo\_BSA\_Band1



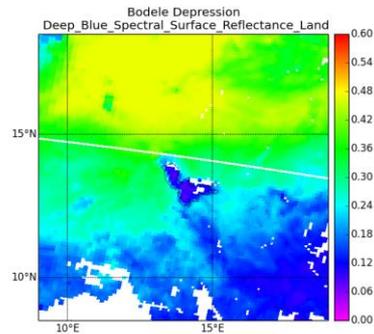
# Surface Reflectance (660 nm) – Bodélé Depression

## 30/03/2008

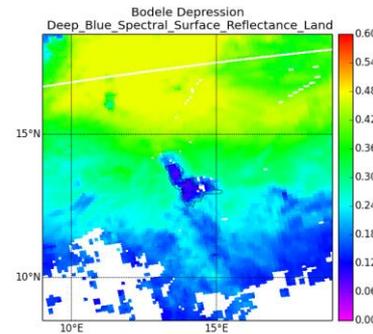
### MERIS



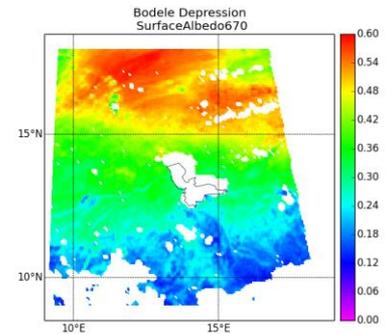
### MODIS/Terra



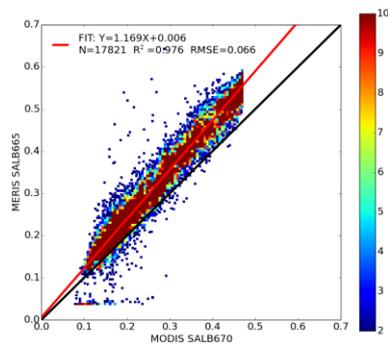
### MODIS/Aqua



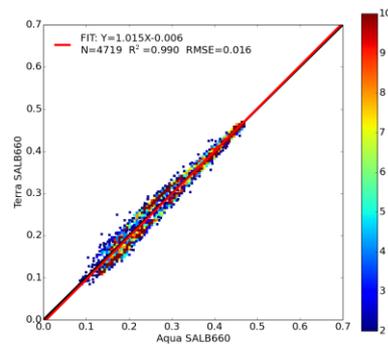
### PARASOL



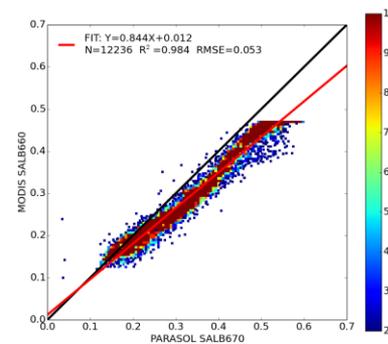
### MERIS vs. Terra



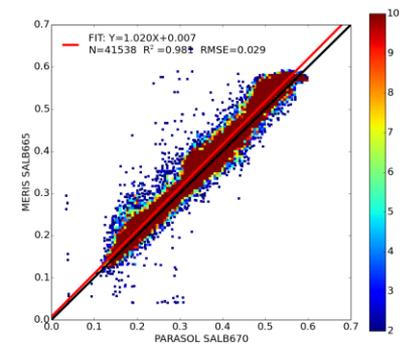
### Terra vs. Aqua



### Aqua vs. PARASOL



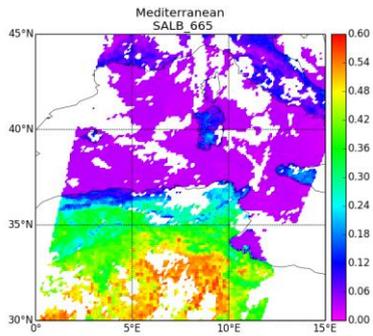
### MERIS vs. PARASOL



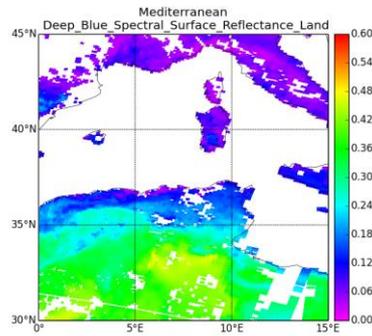
# Surface Reflectance (660 nm) – Mediterranean

## 25/08/2008

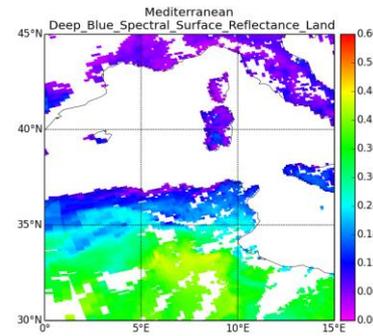
**MERIS**



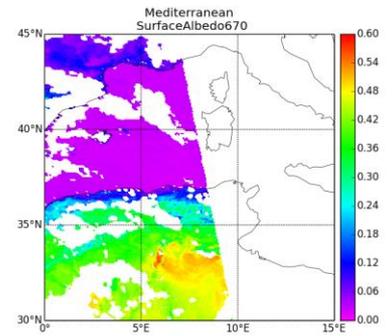
**MODIS/Terra**



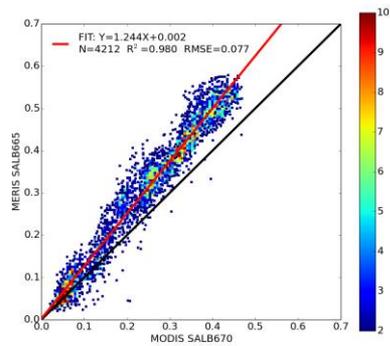
**MODIS/Aqua**



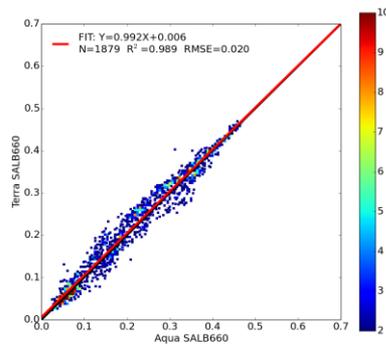
**PARASOL**



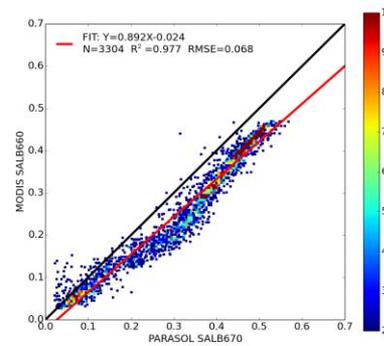
**MERIS vs. Terra**



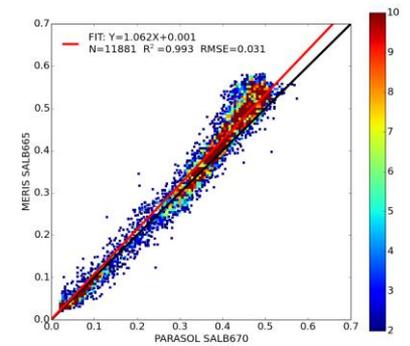
**Terra vs. Aqua**



**Aqua vs. PARASOL**



**MERIS vs. PARASOL**

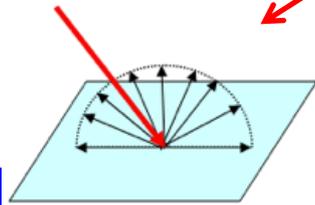


# BRDF model

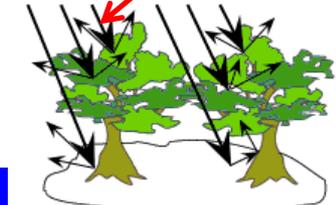
Ross-Li (Ross, (1981); Li, X., Strahler (1992)):

$$BRDF_{Ross-Li} = a_{iso}(\theta) \times (1 + a_{vol} f_{vol} + a_{geom} f_{geom})$$

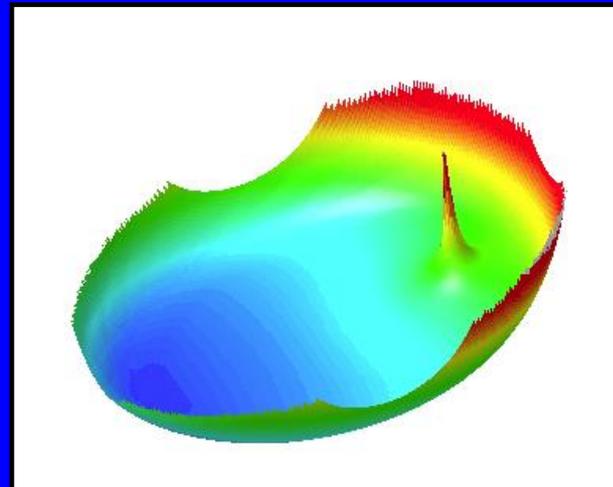
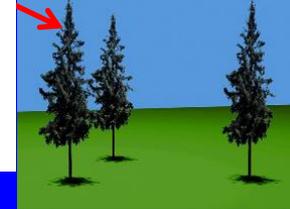
Isotropic  
term:



Volumetric  
term:



Geometric  
term:



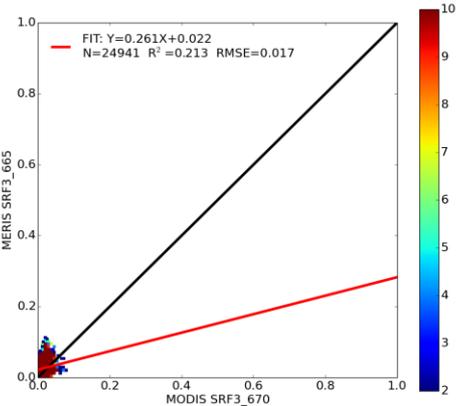
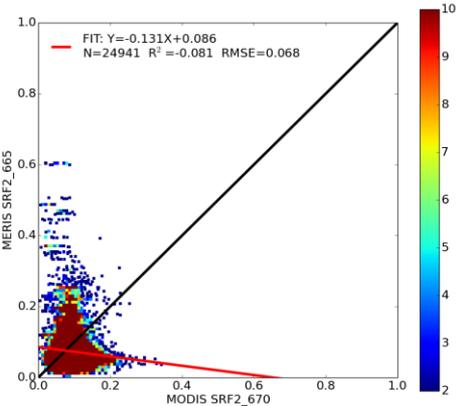
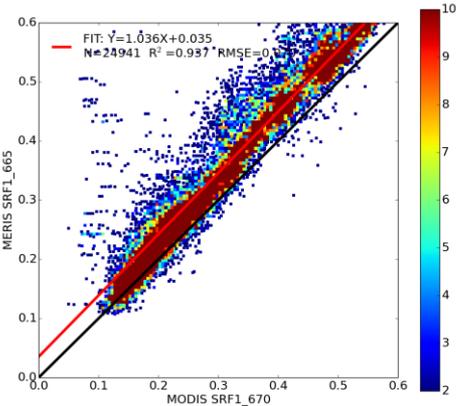
# Surface Parameters – Bodélé Depression 30/03/2008

### Lambertian Component

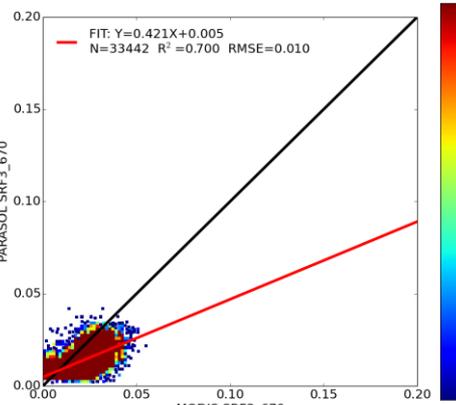
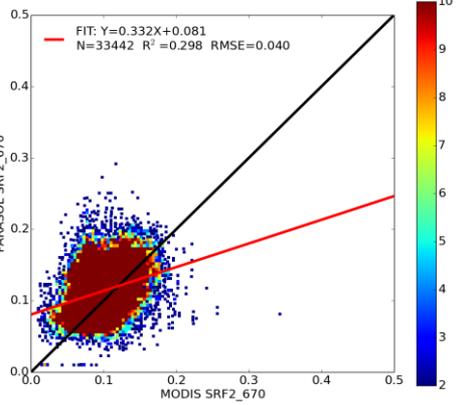
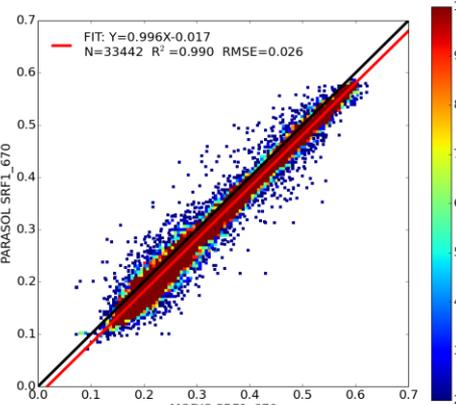
### Volumetric Component

### Geometric Component

MODIS - MERIS



MODIS - PARASOL

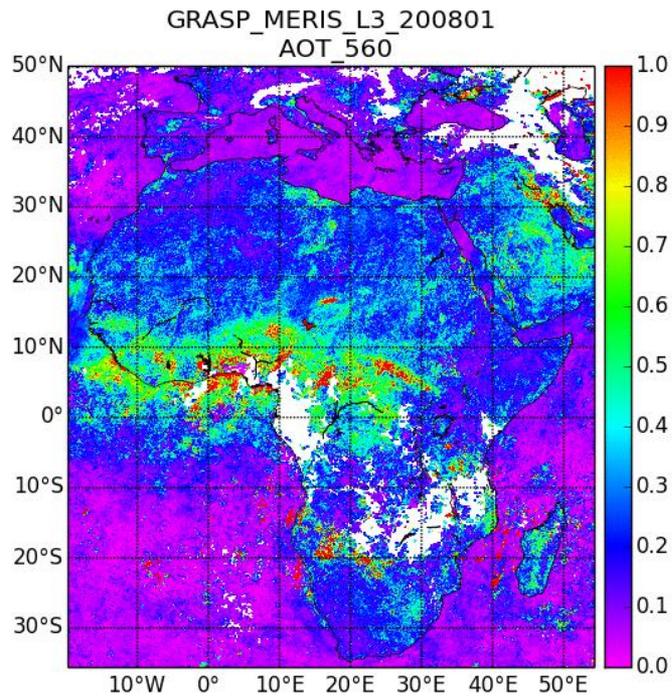


# Animation of AOT retrieval from PARASOL over Africa and Mediterranean Region in 2008

## Monthly averages

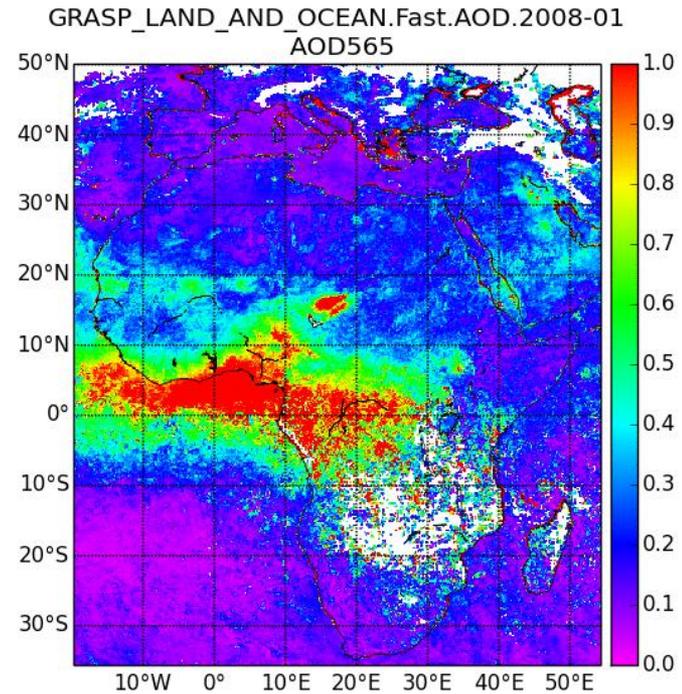
Processed at 10 km

**MERIS**



Processed at 6 km

**PARASOL**



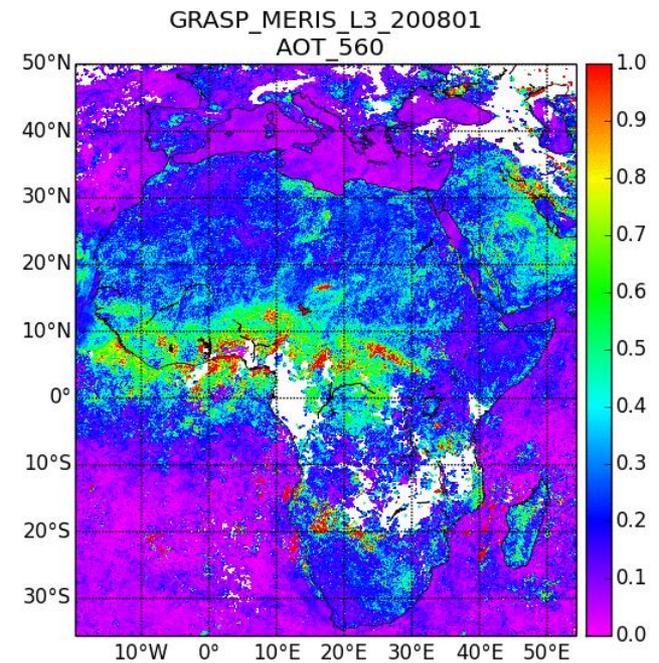
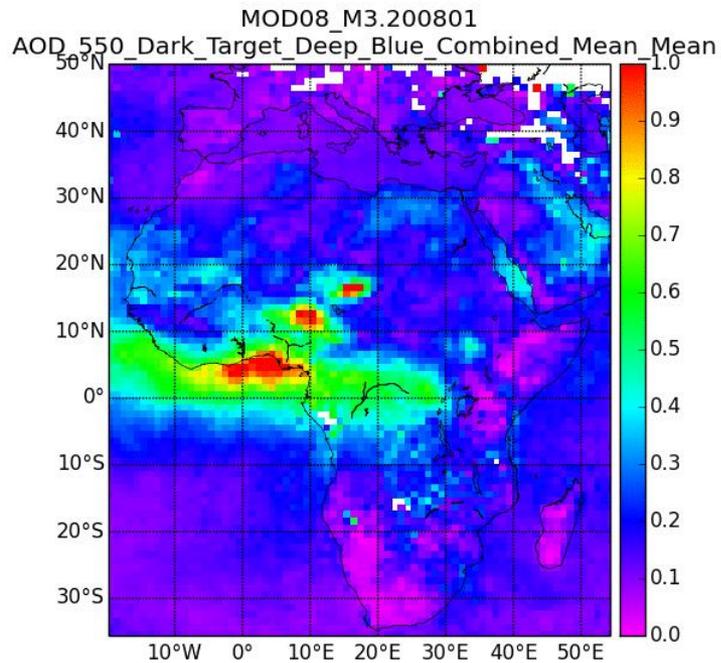
# Animation of AOT retrieval from PARASOL over Africa and Mediterranean Region in 2008

## Monthly averages

**MODIS**

Processed at 10 km

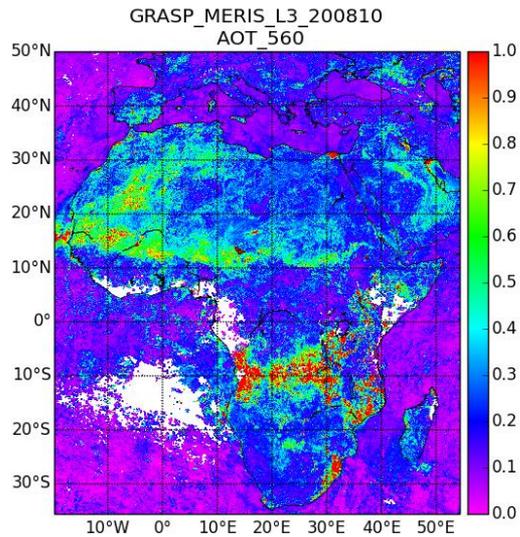
**MERIS**



# AOT (550 nm) – Africa, October 2008

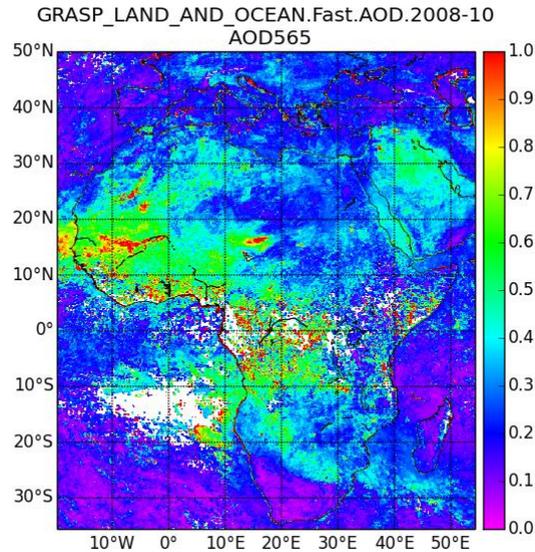
Processed at 10 km

## MERIS

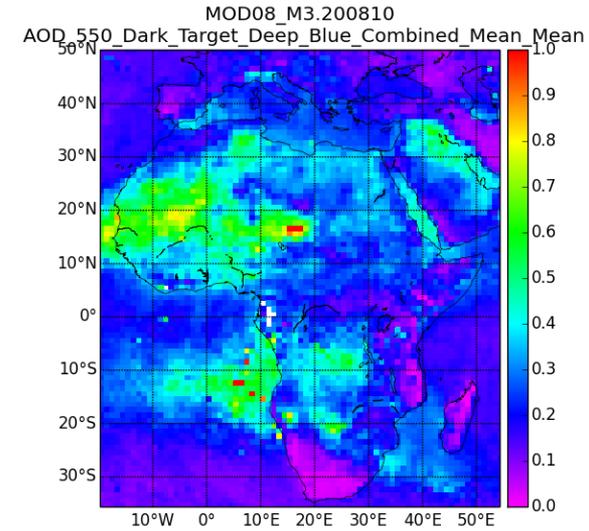


Processed at 6 km

## PARASOL



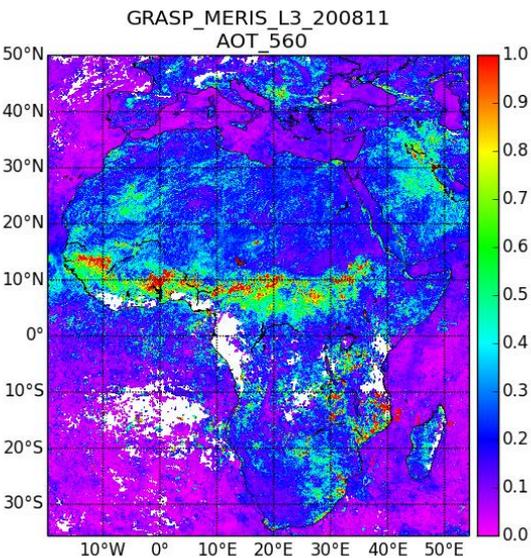
## MODIS-TERRA



# AOT (550 nm) – Africa, November 2008

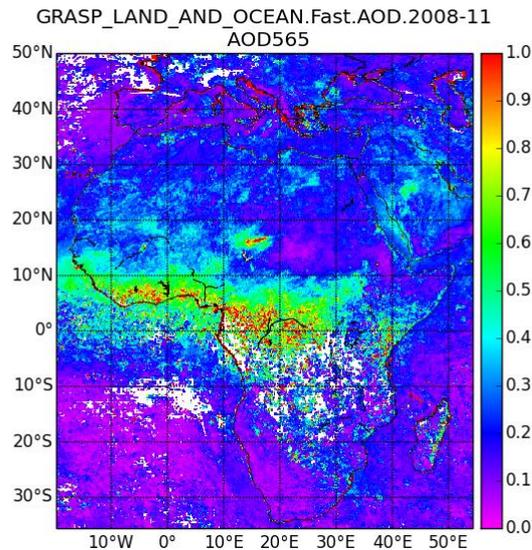
Processed at 10 km

## MERIS

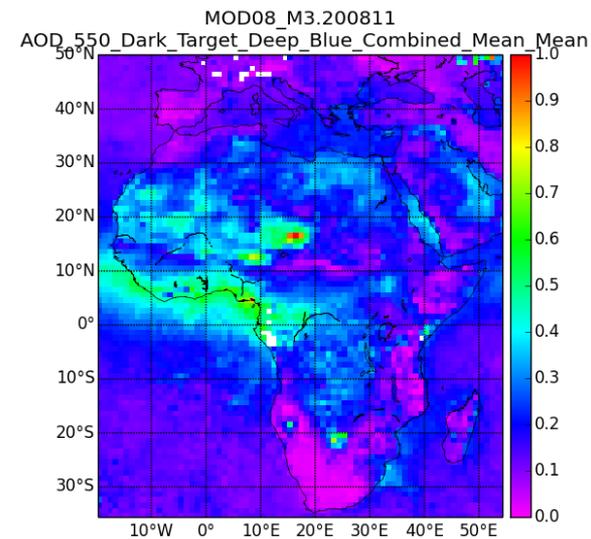


Processed at 6 km

## PARASOL

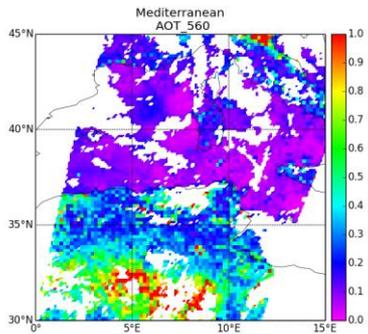


## MODIS-TERRA

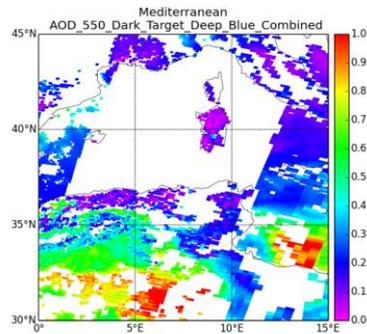


# AOT (550 nm) – Mediterranean 30/03/2008

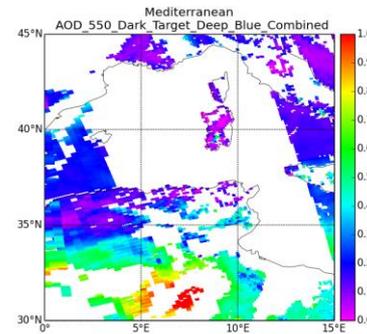
## MERIS



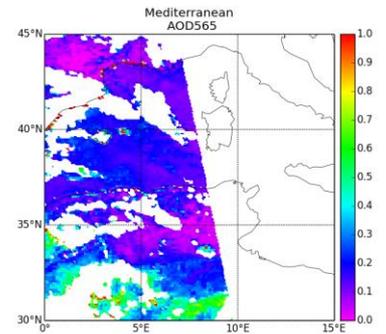
## MODIS/Terra



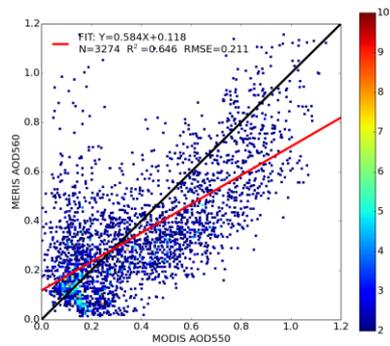
## MODIS/Aqua



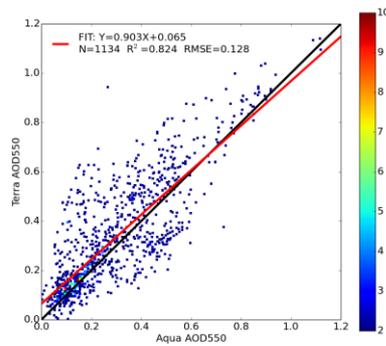
## PARASOL



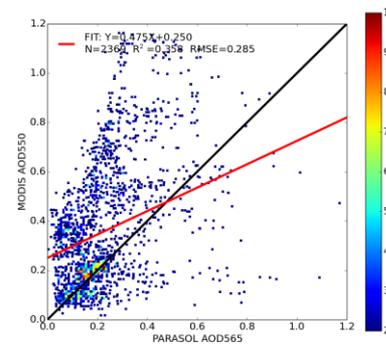
## MERIS vs. Terra



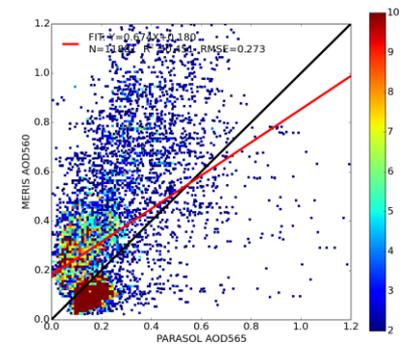
## Terra vs. Aqua



## Aqua vs. PARASOL

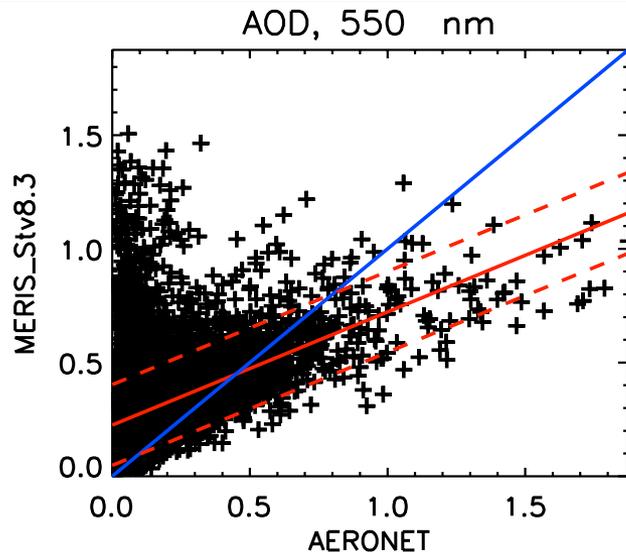


## MERIS vs. PARASOL

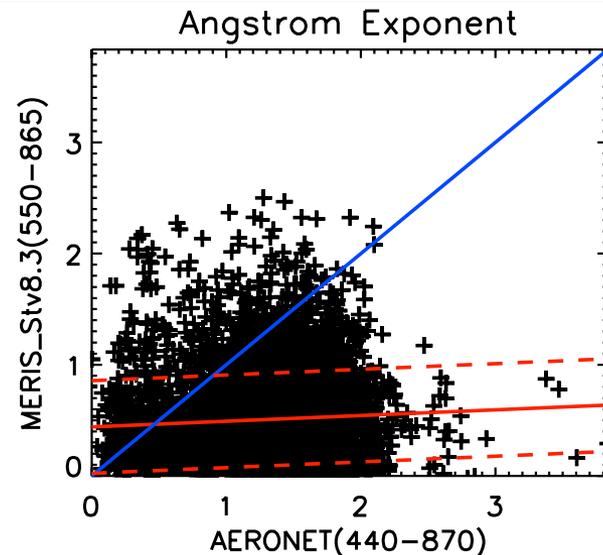


# MERIS validation in ESA aerosol CCI project

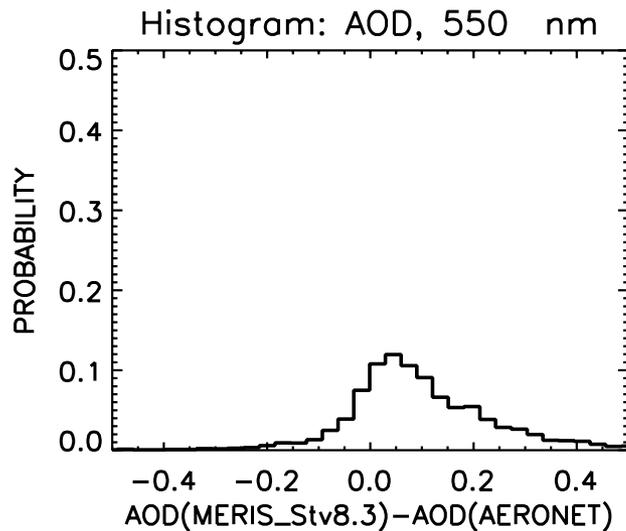
MERIS ESA  
standard  
aerosol  
product over  
land (with  
CCI aerosol  
model).  
2002 – 2012



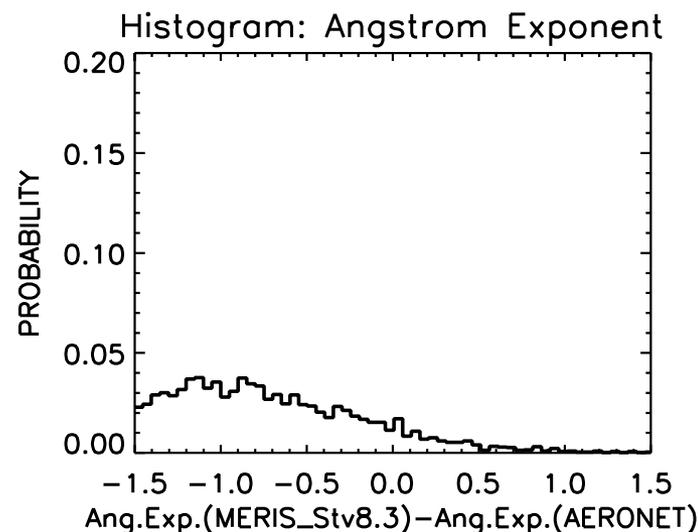
$K=0.465$   $a=0.50$   $b=0.23$   $RMSE=0.241$



$K=0.059$   $a=0.05$   $b=0.44$   $RMSE=0.992$



Aver. Value= 0.133 St.D.= 0.201 N=656:



Aver. Value=-0.774 St.D.= 0.620 N=4516

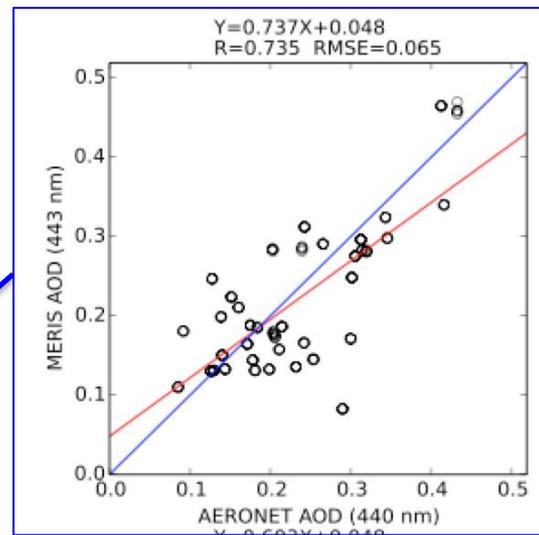
# GRASP/ MERIS

(January - March 2008, 10 km resolution)

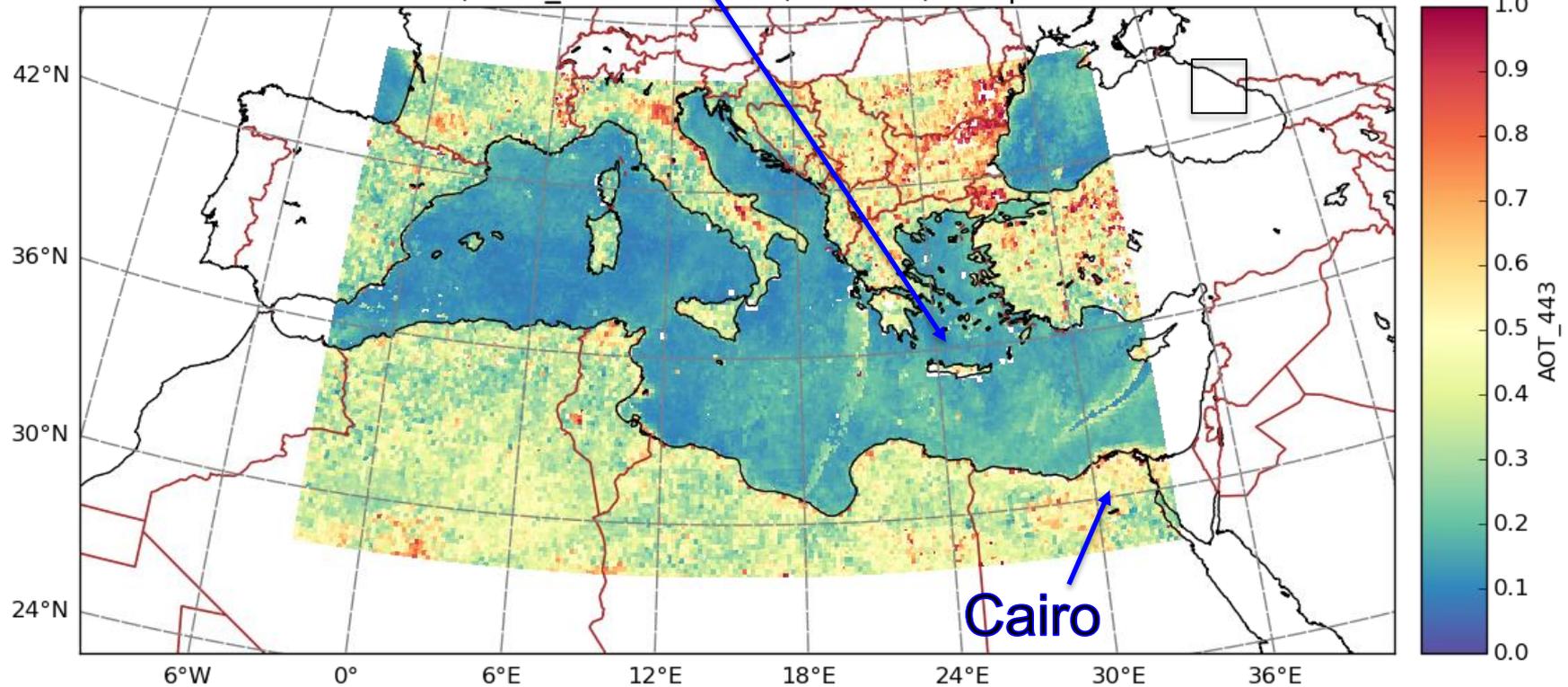
No assumptions !!!

AOT(440)

Crete AERONET  
validation

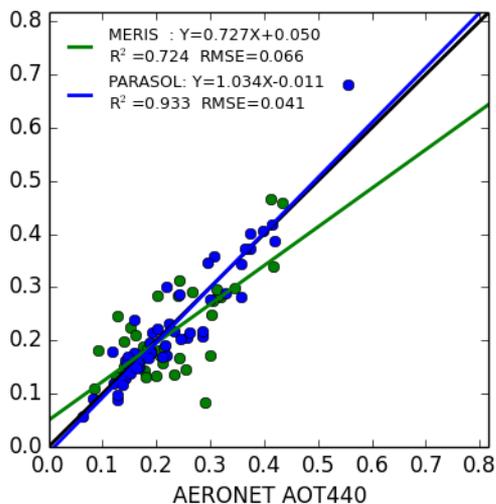


meris, AOT\_443 -- 37.06 N, 15.23 E, composite

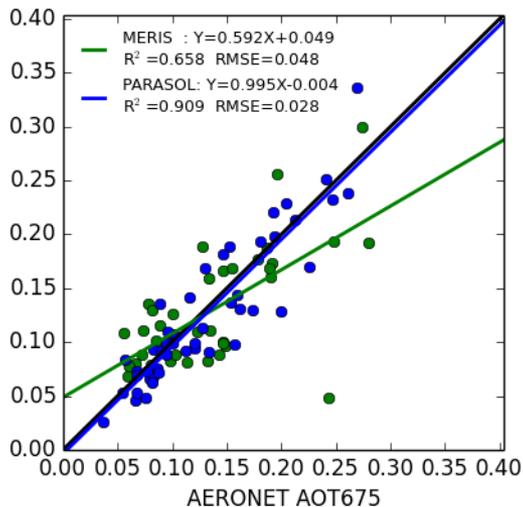


# Crete 06/2008 – 08/2008 (1)

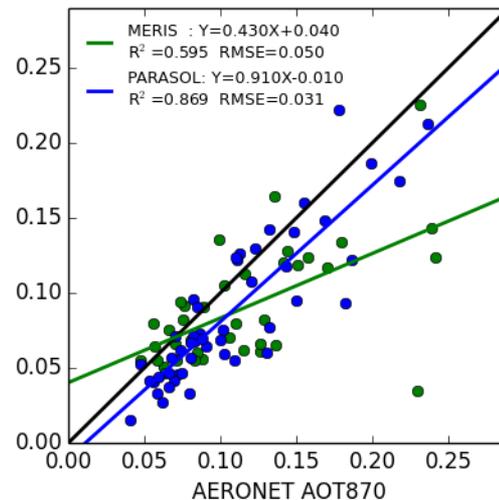
### AOD (440)



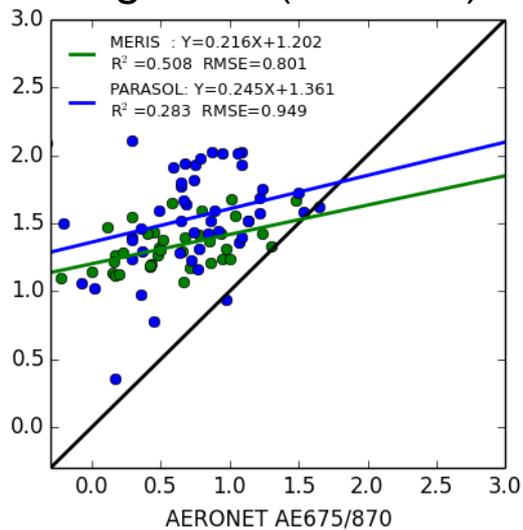
### AOD (670)



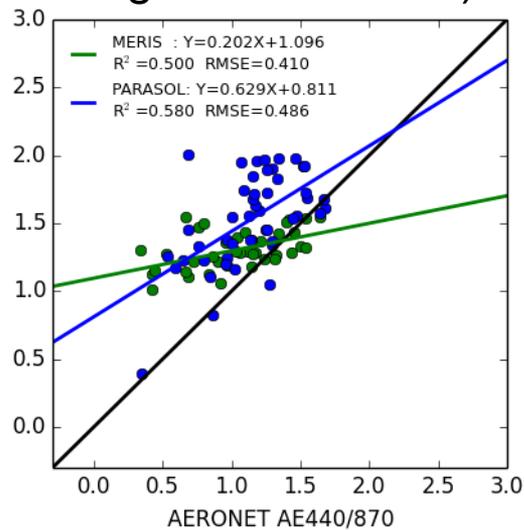
### AOD (870)



### Angstrom (670/870)

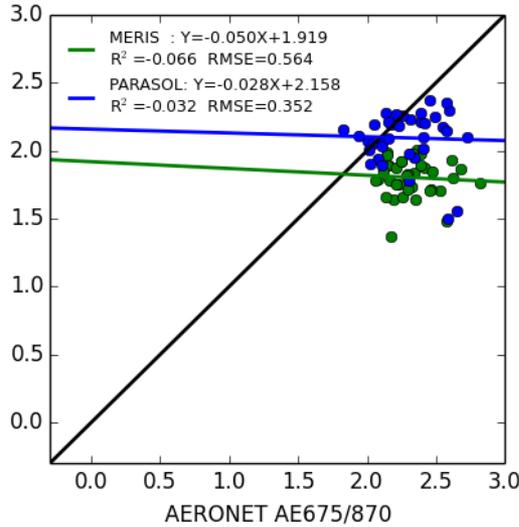


### Angstrom 440/870

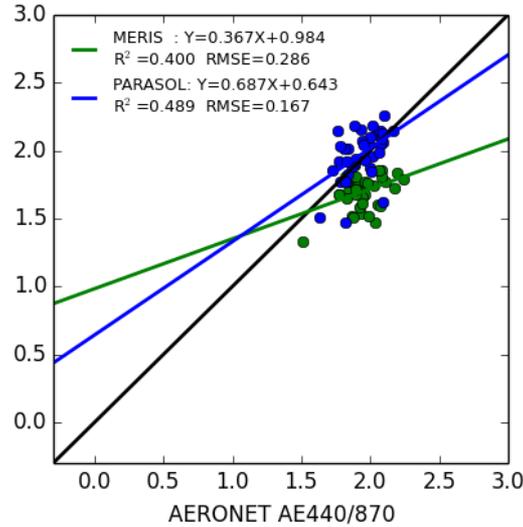


# Mongu 06/2008 – 08/2008 (1)

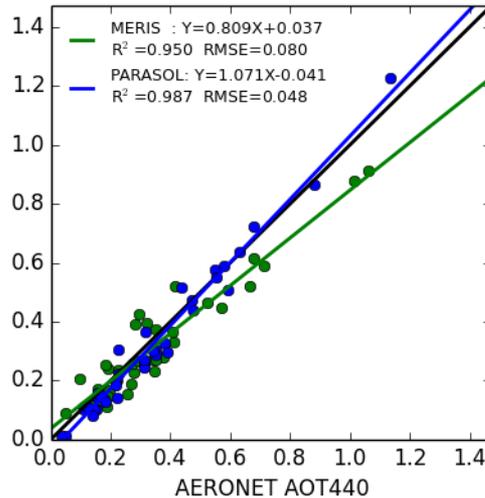
### Angstrom (670/870)



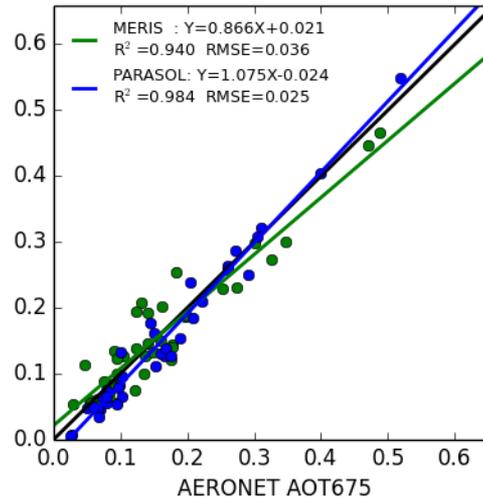
### Angstrom (440/870)



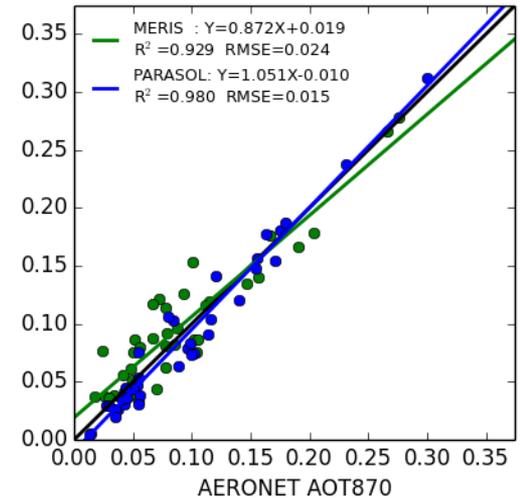
### AOD (440)



### AOD (670)



### AOD (870)

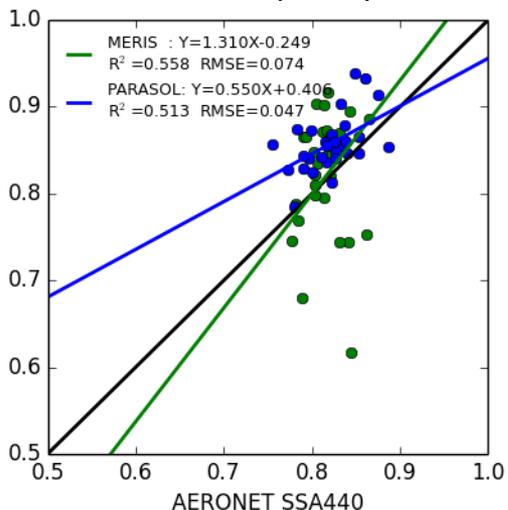


# MERIS PARASOL

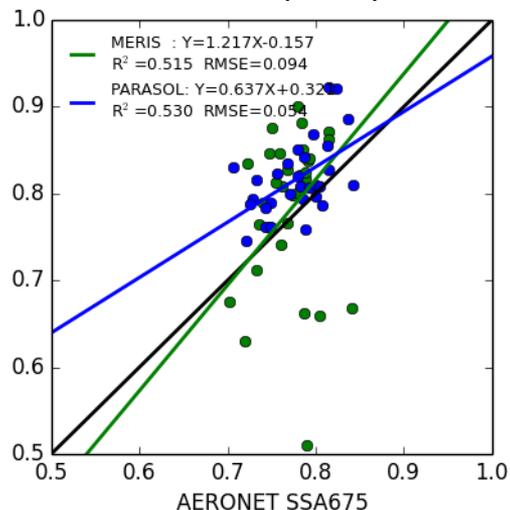
## Mongu 06/2008 – 08/2008 (2)



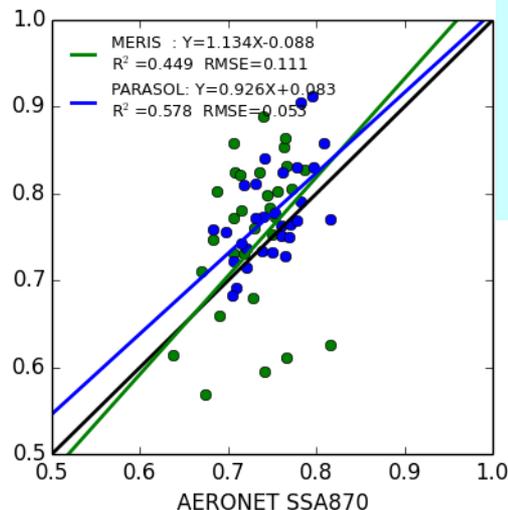
### SSA (440)



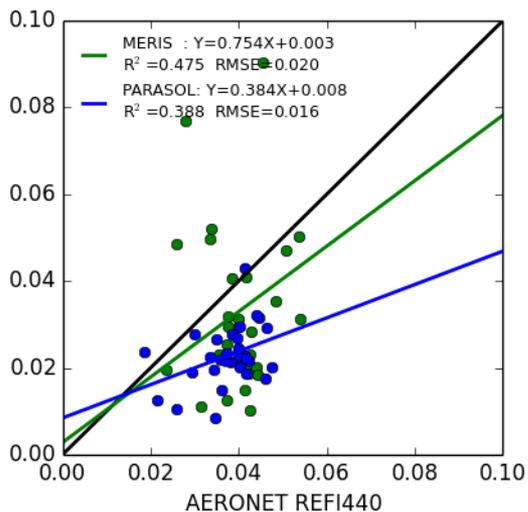
### SSA (670)



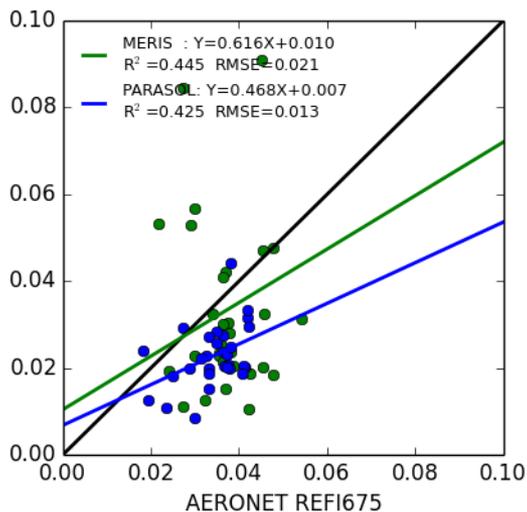
### SSA (870)



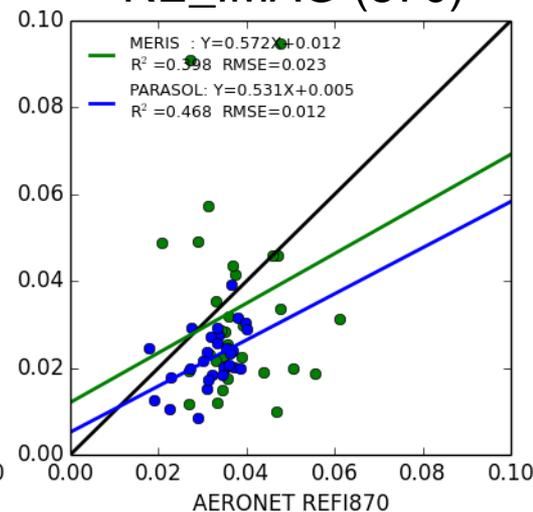
### RE\_IMAG (440)



### RE\_IMAG (670)

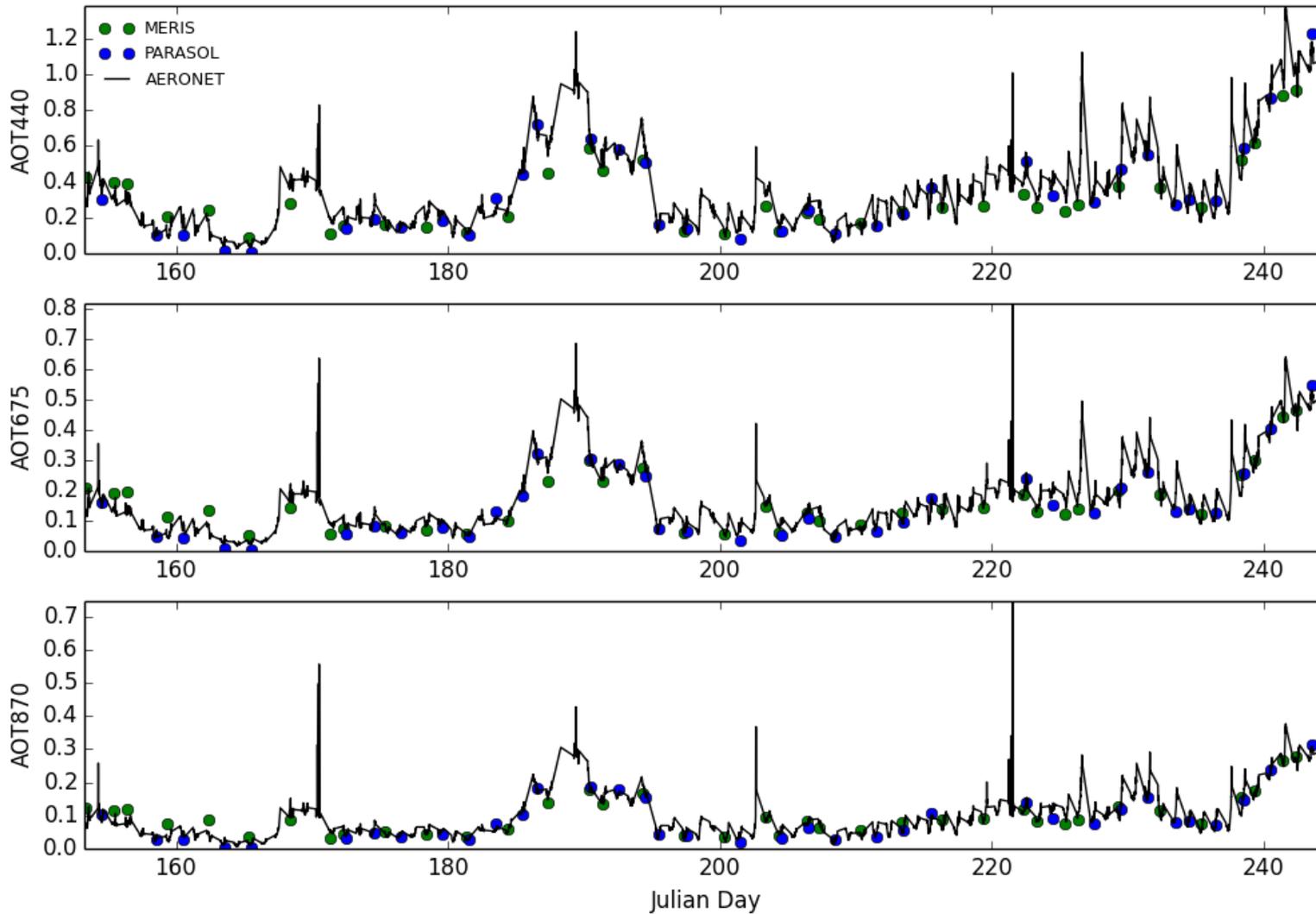


### RE\_IMAG (870)



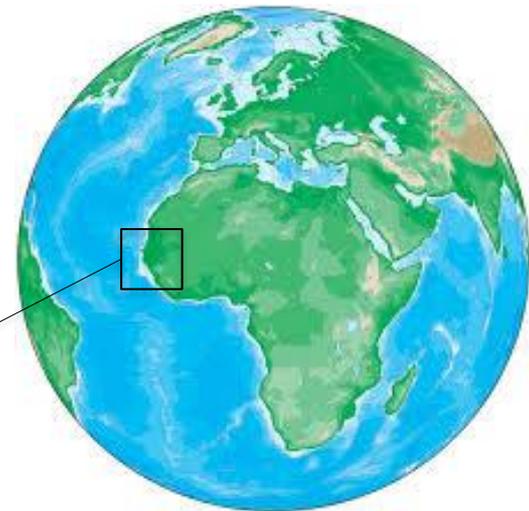
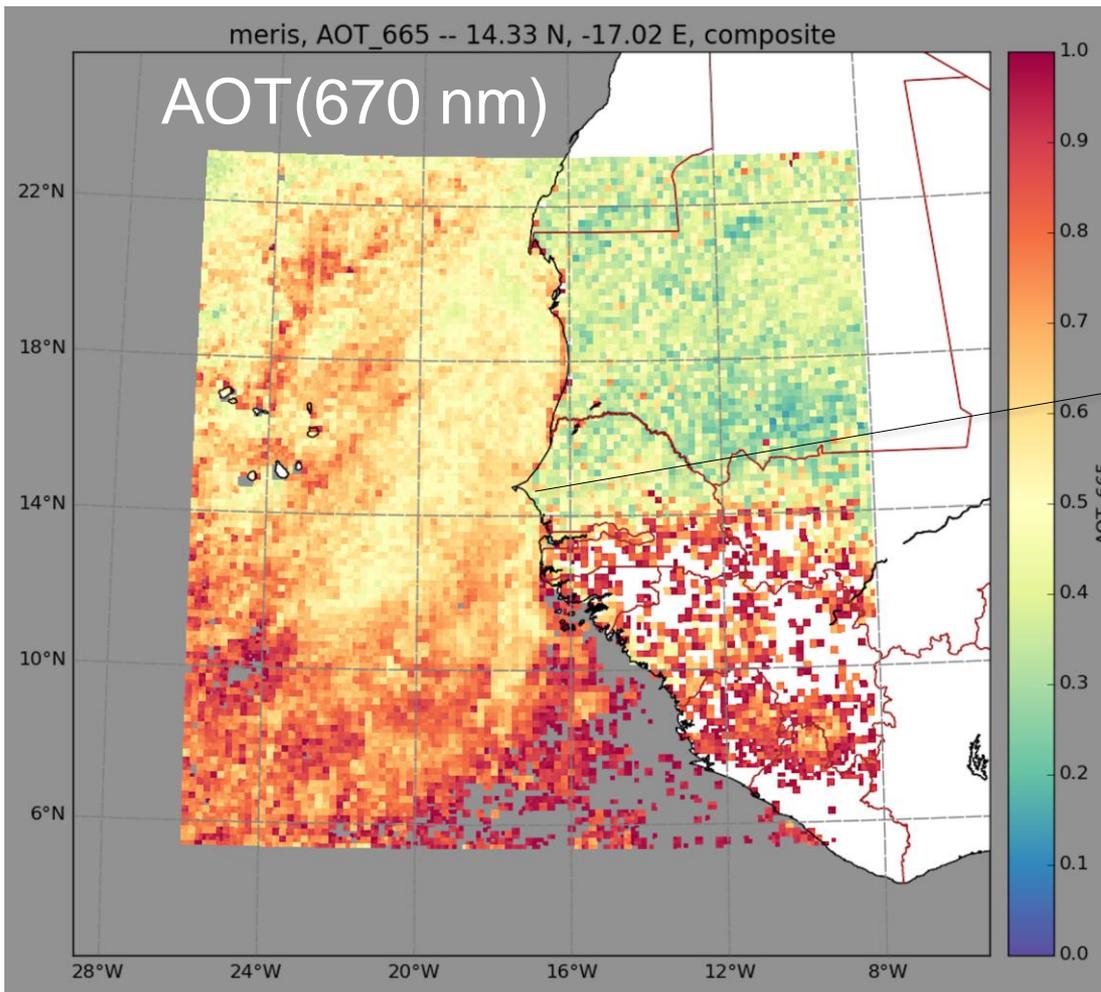
MERIS  
PARASOL

# Mongu 06/2008 – 08/2008 (3)

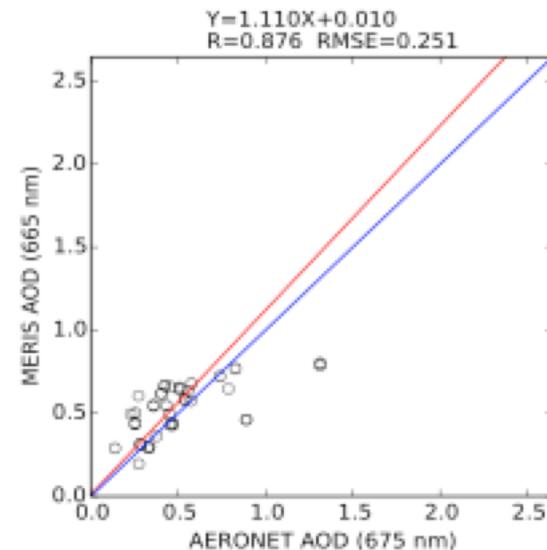


# GRASP/ MERIS – land/water

(January - March 2008, 10 km resolution)



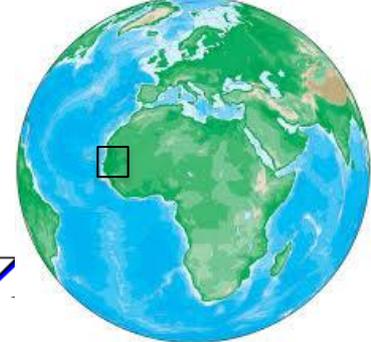
Dakar AERONET  
validation



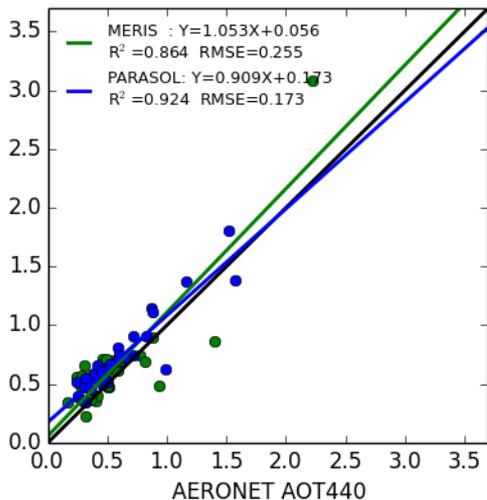
*ESA CAWA project*

# MERIS PARASOL

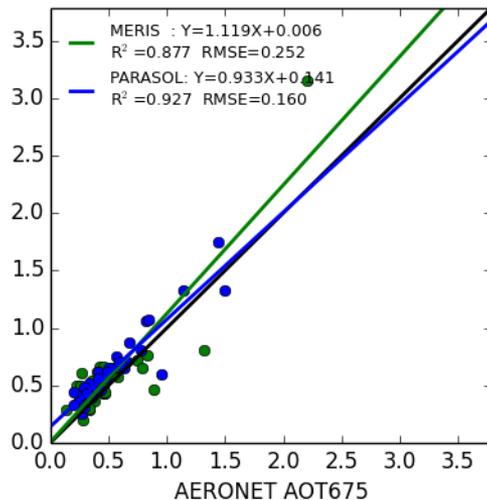
## Dakar 03/2008 – 05/2008 (1)



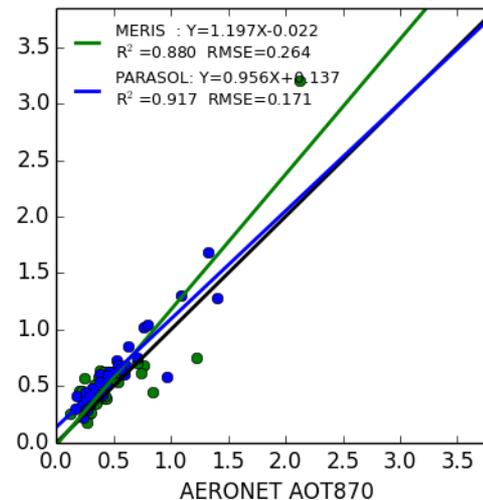
### AOD (440)



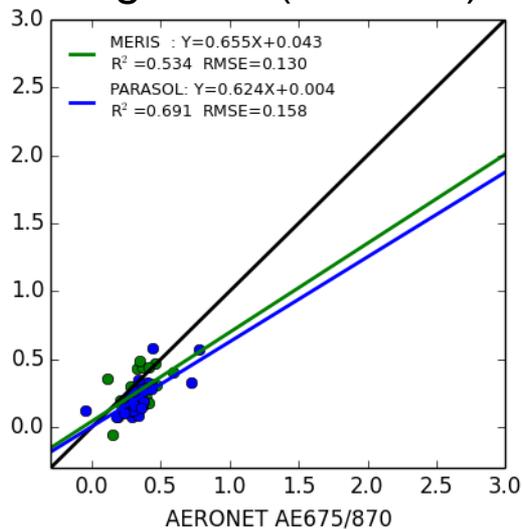
### AOD (670)



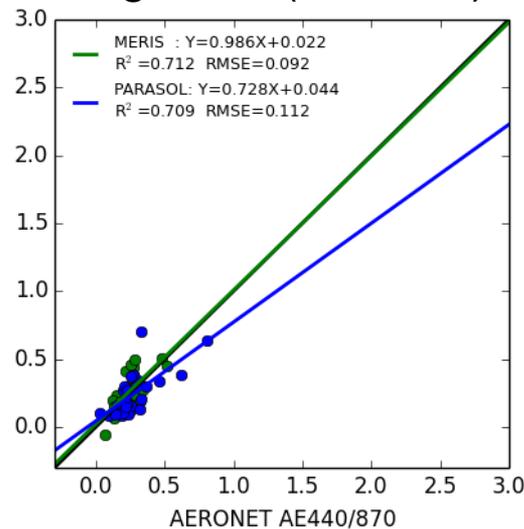
### AOD (870)



### Angstrom (670/870)

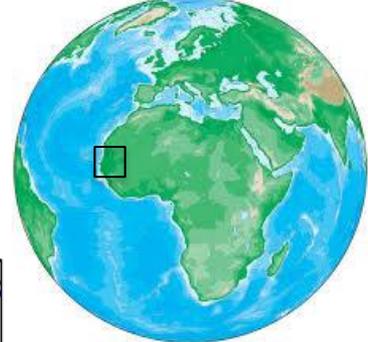


### Angstrom (440/870)

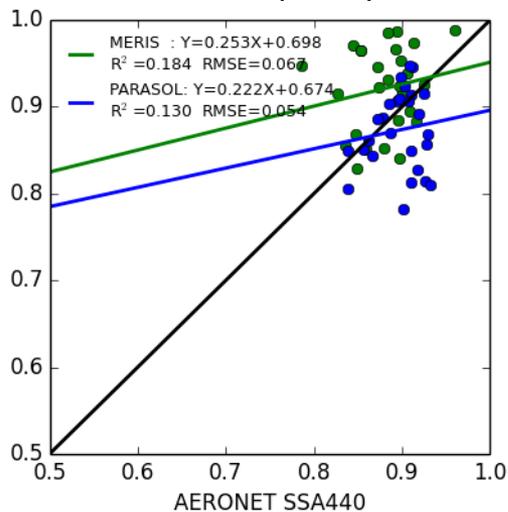


# MERIS PARASOL

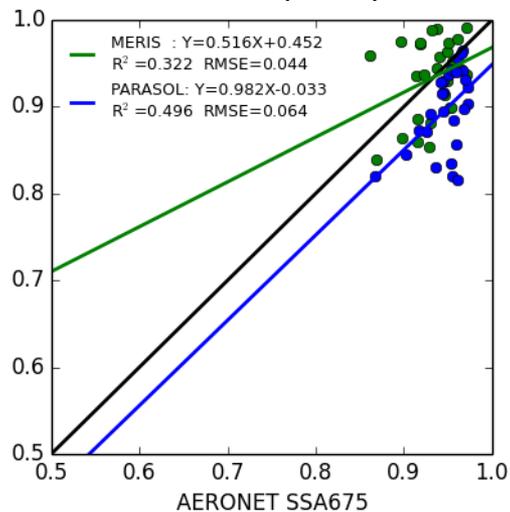
## Dakar 03/2008 – 05/2008 (2)



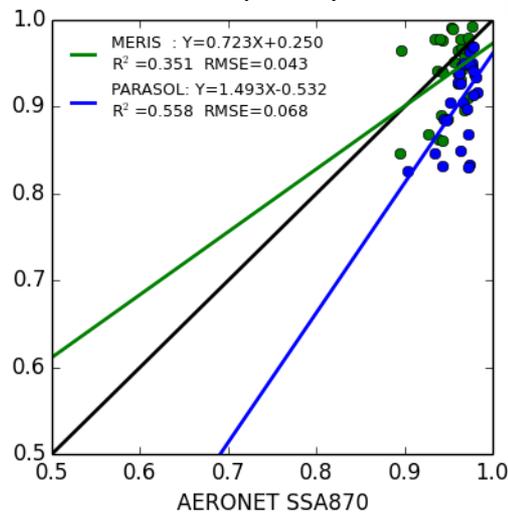
### SSA (440)



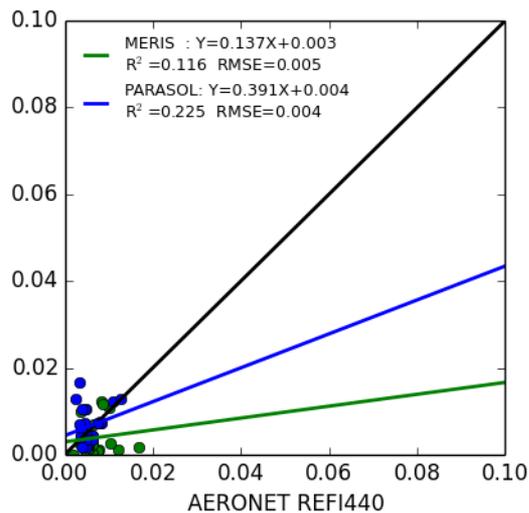
### SSA (670)



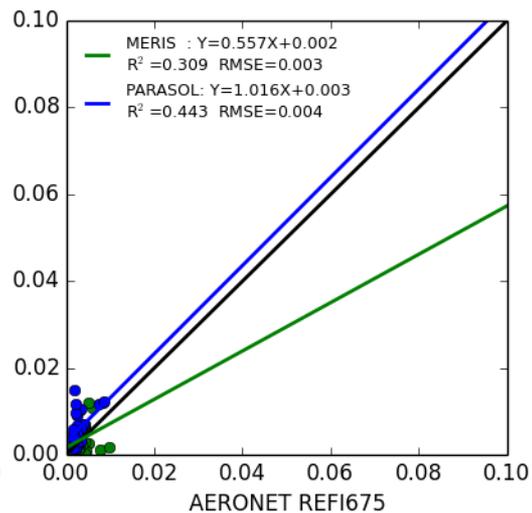
### SSA (870)



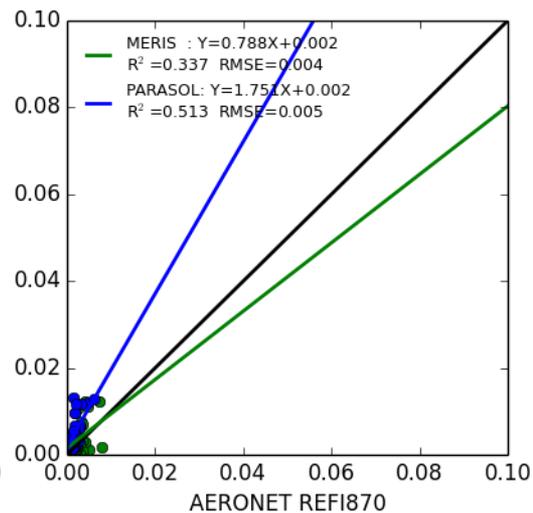
### RE\_IMAG (440)



### RE\_IMAG (670)

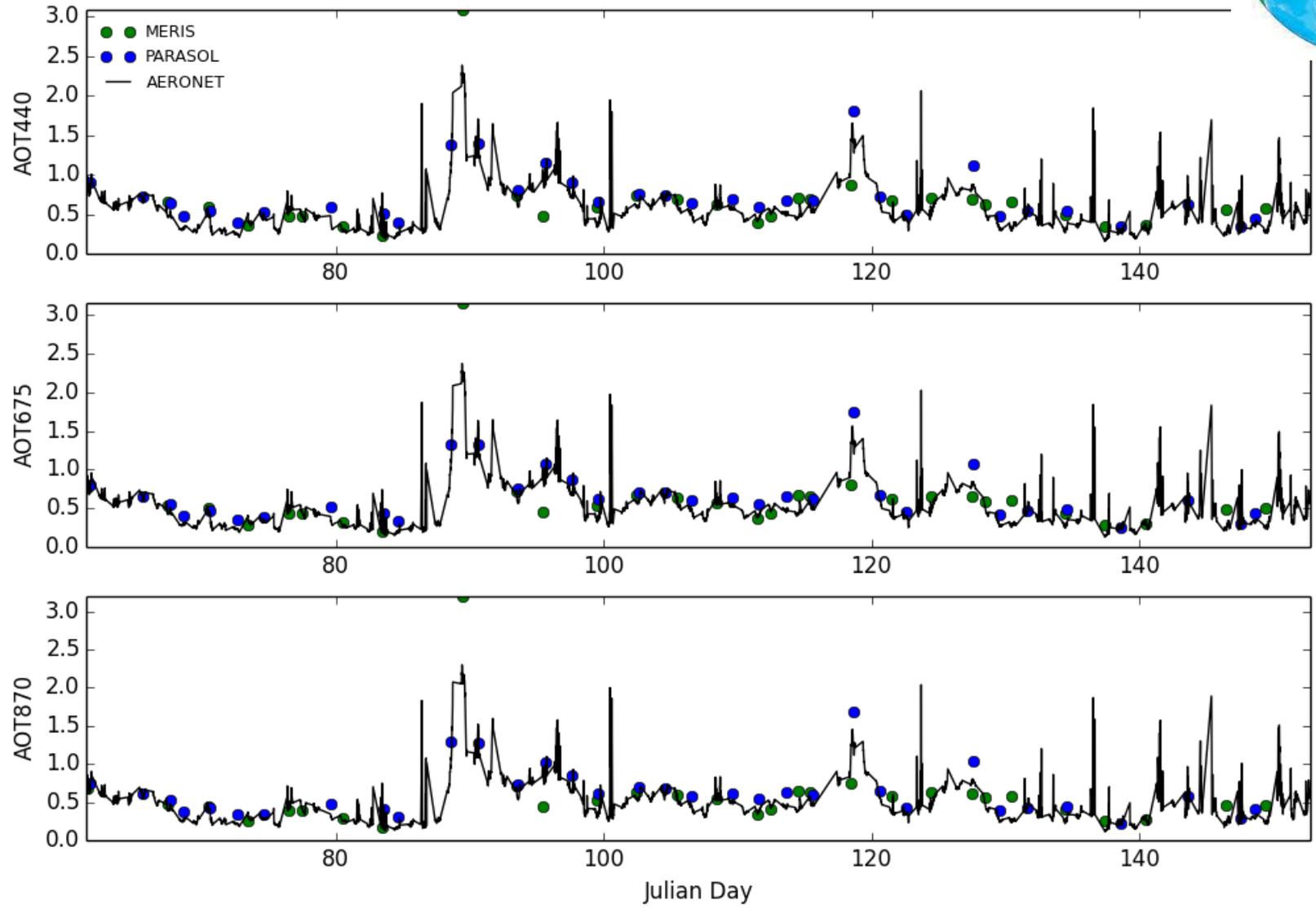
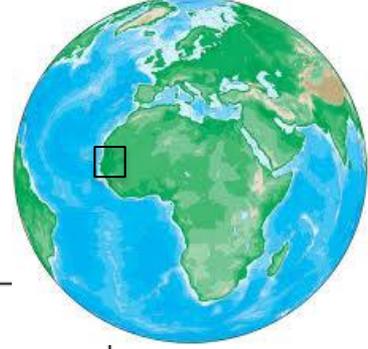


### RE\_IMAG (870)



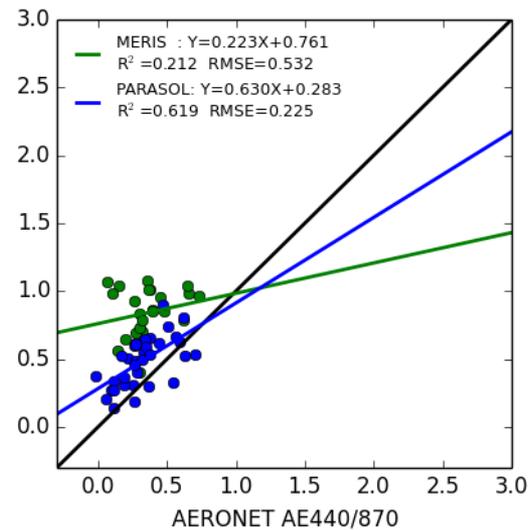
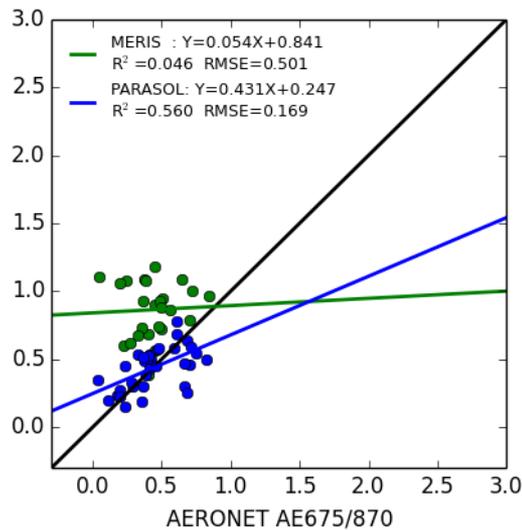
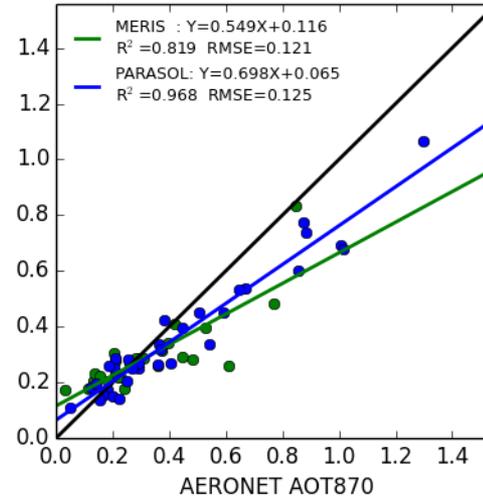
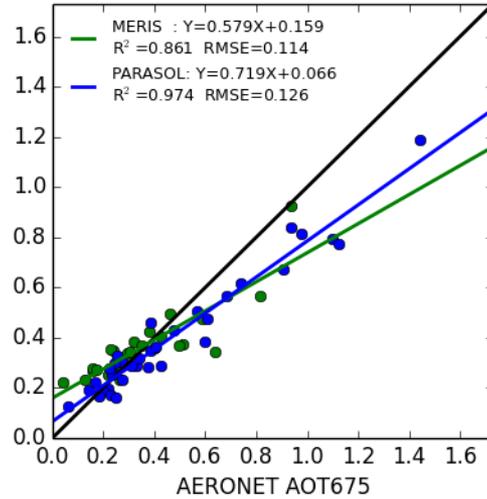
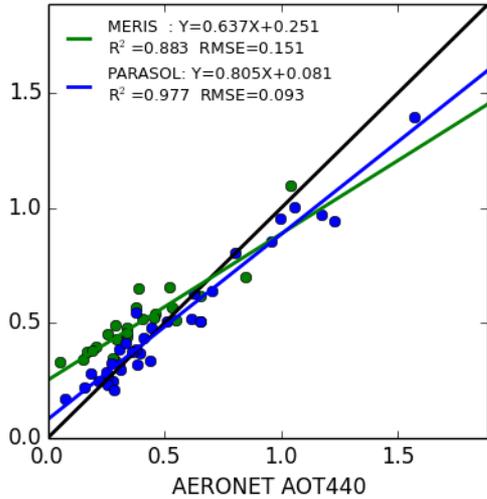
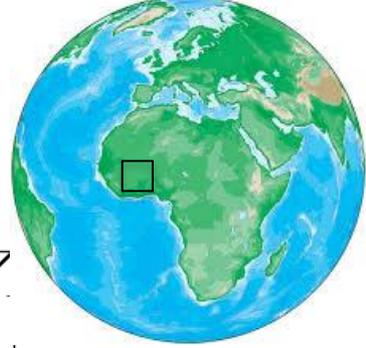
MERIS  
PARASOL

# Dakar 03/2008 – 05/2008 (3)

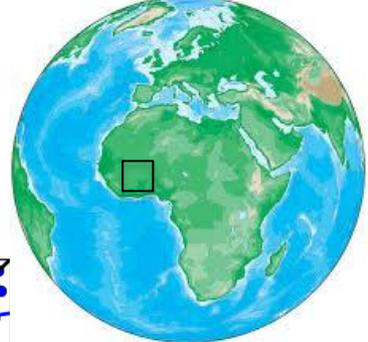


# MERIS PARASOL

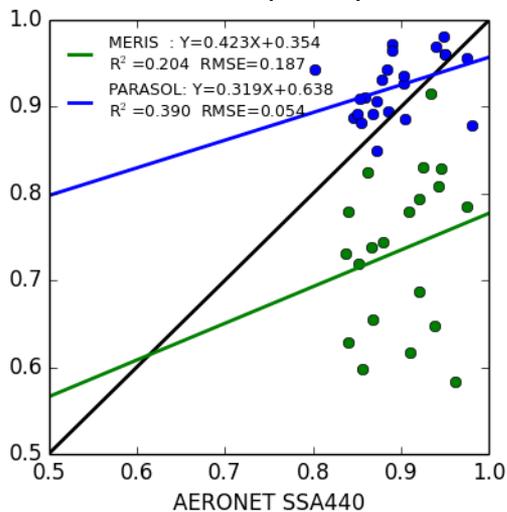
## Banizoumbou 01/2008 – 03/2008 (1)



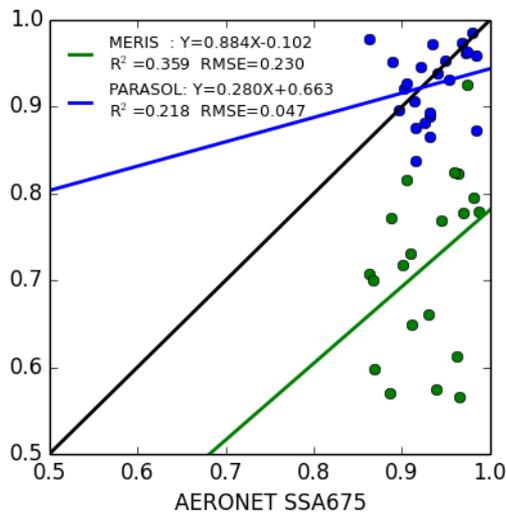
# Banizoumbou 01/2008 – 03/2008 (2)



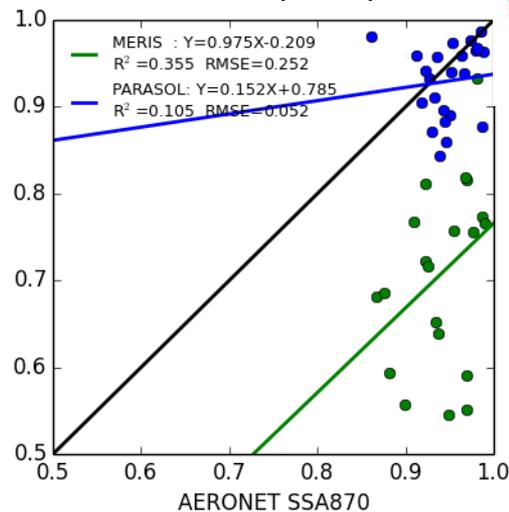
## SSA (440)



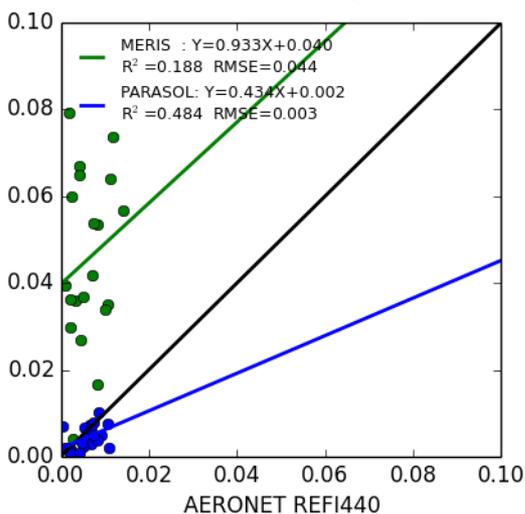
## SSA (670)



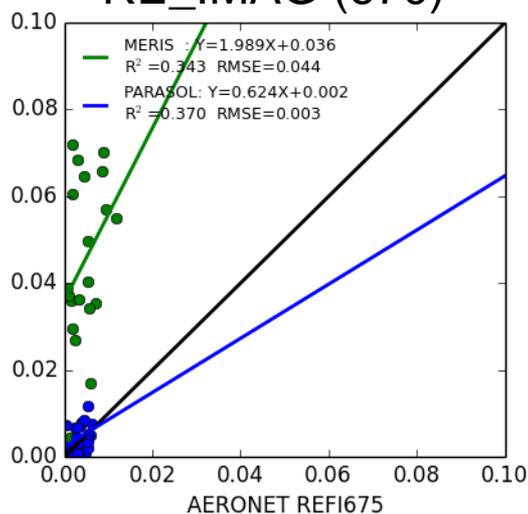
## SSA (870)



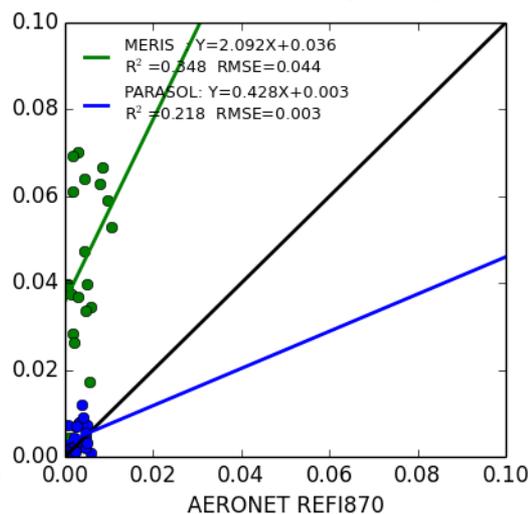
## RE\_IMAG (440)



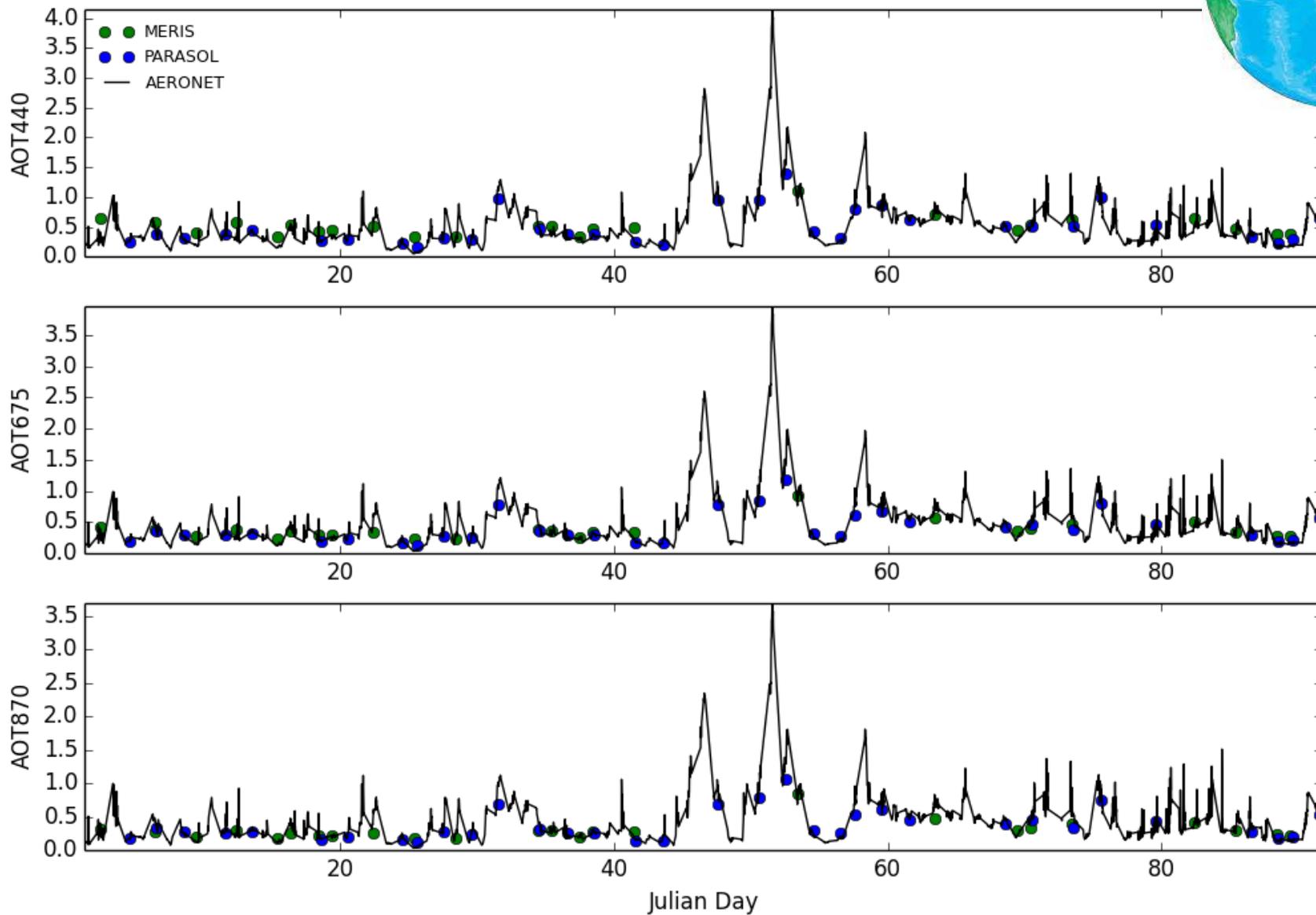
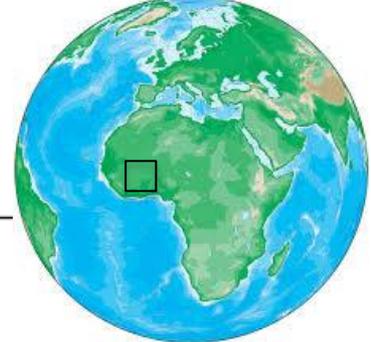
## RE\_IMAG (670)



## RE\_IMAG (870)



# Banizoumbou 01/2008 – 03/2008 (3)



# Conclusions:

## GRASP concept:

- ✓ - retrieving many characteristics simultaneously (aerosol + surface);
- statistically optimized “multi-pixel” inversion;
- etc.

## *First results are promising for MERIS:*

- reliable AOD and Angstrom,
- promising for SSA (dark surfaces, bright-???)
- main issue – cloud mask

- ✓ Promising alternative retrieval approach for **S-3** :
  - OLCI
  - OLCI + SLSTR;
  - OLCI + SLSTR + etc.

