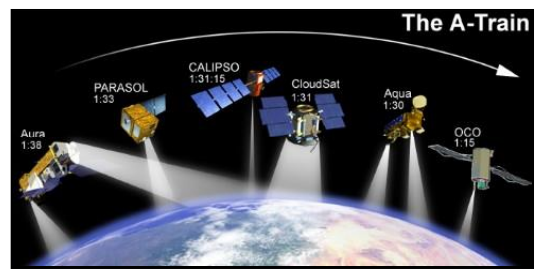


# Enhancement and restrictions of aerosol/surface properties retrieval over land: experience based on new POLDER retrieval algorithm GRASP

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F. Ducos, D. Tanre*

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CNRS, Université Lille-1, FRANCE

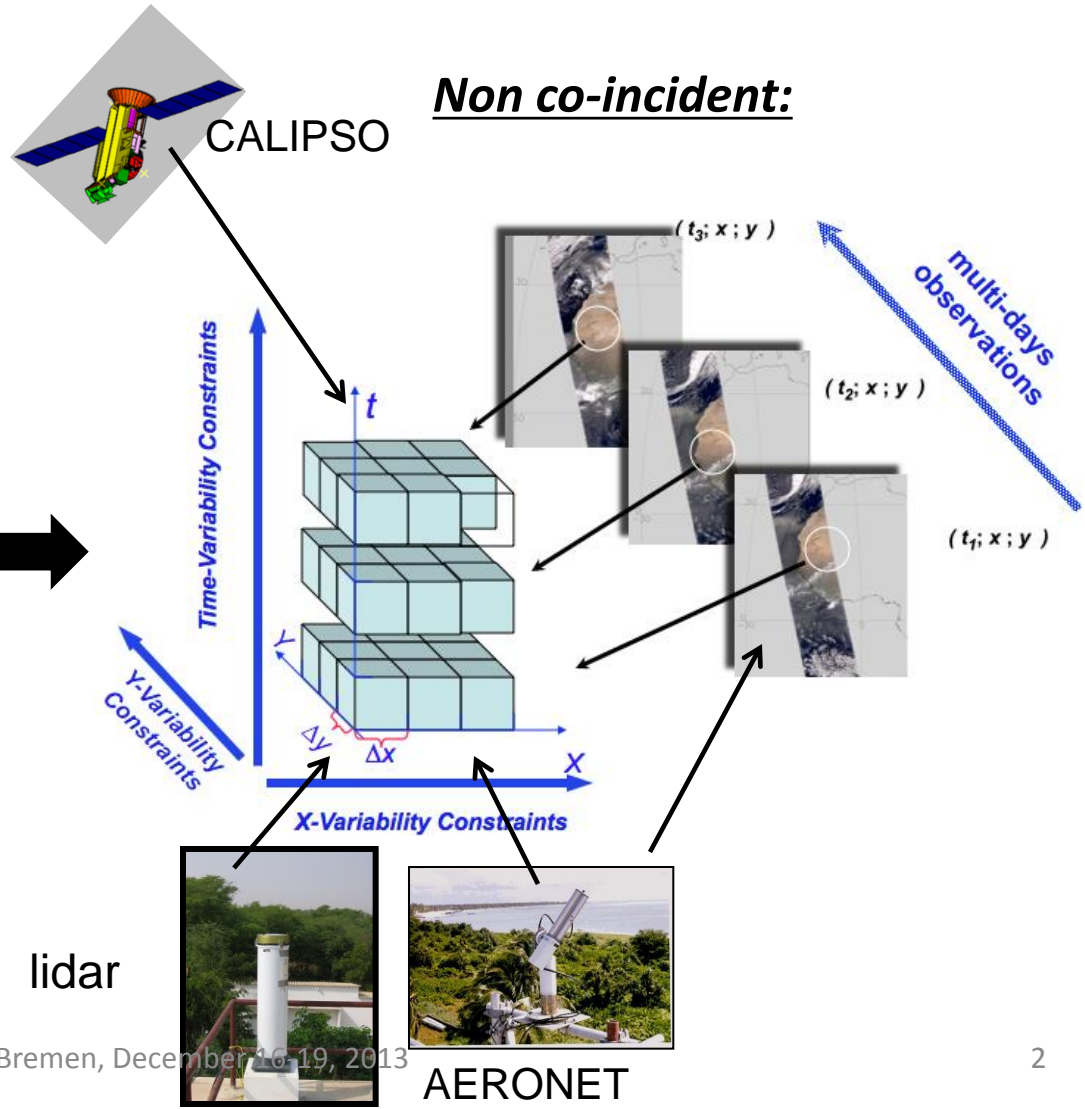
# GRASP: algorithm for multi-instrument remote sensing:



## Co-incident:



## Non co-incident:



# New POLDER/PARASOL algorithm (GRASP) *(Dubovik et al, AMT, 2011)*

- The new algorithm uses complete set of PARASOL angular measurements in all spectral bands including both radiance and linear polarization measurements.
- Continuous space of aerosol and surface properties is used.
- The algorithm is based on statistically optimized fitting.

The core of the new PARASOL algorithm is based on the same concept as AERONET aerosol retrieval (*O. Dubovik and M. King, 2000; O. Dubovik, 2004; O. Dubovik et al, 2006*).

# The concept of the algorithm

Two scenarios of retrieval (*Dubovik et al., AMT, 2011*):

- **Conventional: single-pixel retrieval** (each single pixel is inverted independently)
- **New concept: multiple-pixel retrieval** (group of pixels are inverted simultaneously)

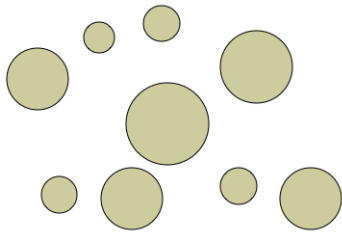
# GRASP aerosol model: the most comprehensive existent aerosol model

Aerosol model is the same as in AERONET retrieval  
*(Mixing of particle shapes (Dubovik et al., 2006))*

retrieved

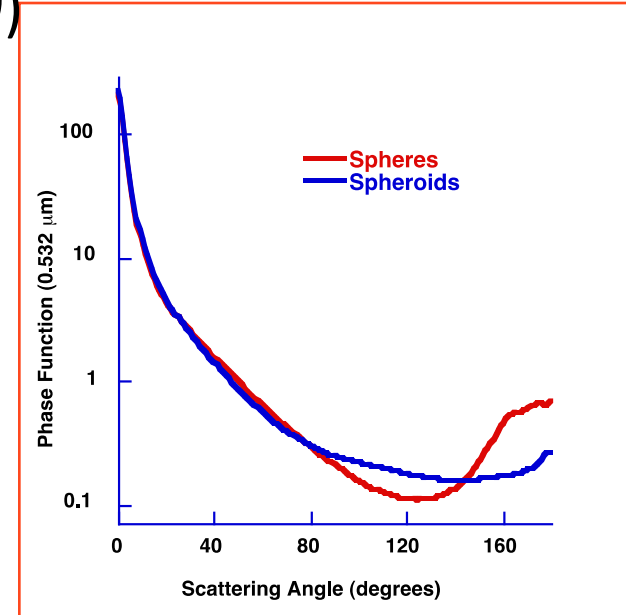
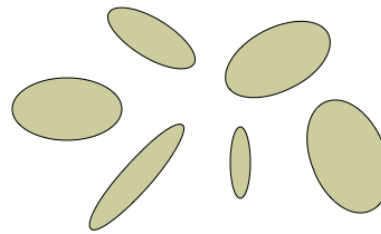
C

spherical:



+ (1-C)

Randomly oriented spheroids:  
*(Mishchenko et al., 1997)*



0.012  $\leq x \leq$  625

1.3  $\leq n \leq$  1.7

$1 \times 10^{-10} \leq k \leq$  0.5

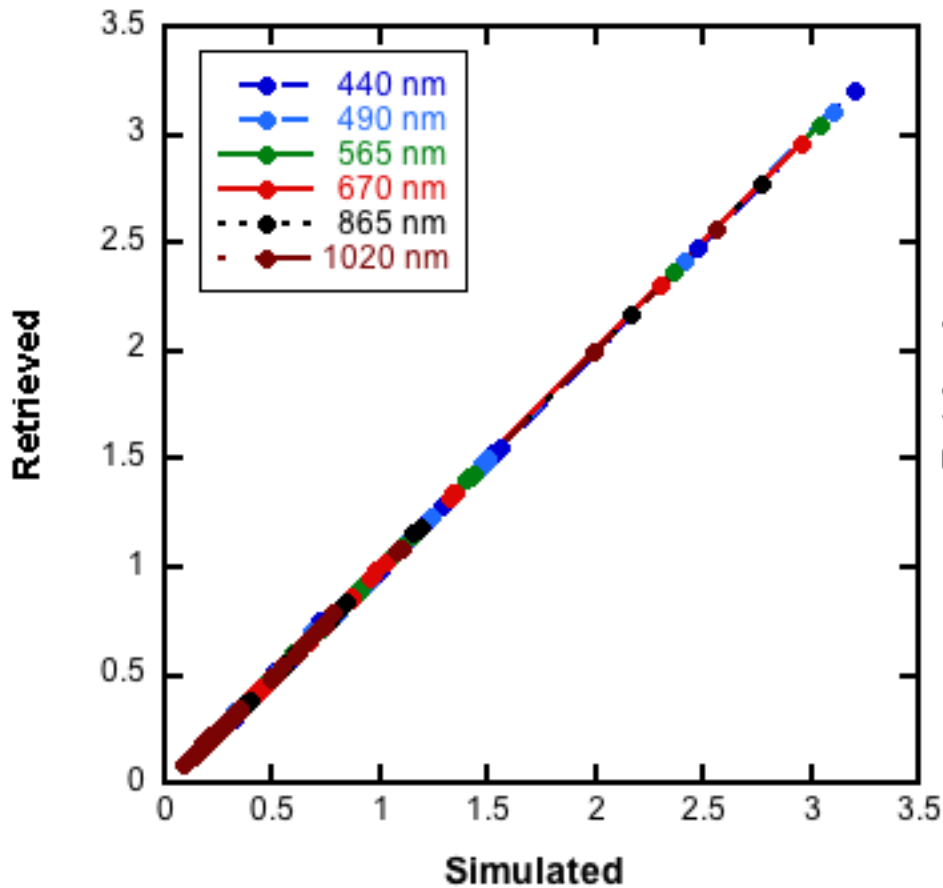
# Surface reflection model

- ***Semi-empirical*** models for **surface total reflectance**  
description:
  - RPV model (*Rahman et al., (1993)*)
  - Ross-Li (*Ross, (1981); Li, X., Strahler (1992)*)
  - Ross-Roujean model (*Roujean et al., (1992)*)
- ***Semi-empirical*** models for **surface polarized reflectance**  
description:
  - Nadal-Breton model (*Nadal and Bréon, (1999)*)
  - Maignan model (*Maignan et al., (2009)*)
  - Fresnel facet model for Gaussian surfaces (*Litvinov et al., 2011*)
- ***Physically based*** models for **reflection matrix** for surfaces:
  - Cox-Munk model (for aerosol retrieval over ocean)
  - Physical models for land surface reflection matrix (*Litvinov et al., 2012*)

# Synthetic measurements retrieval

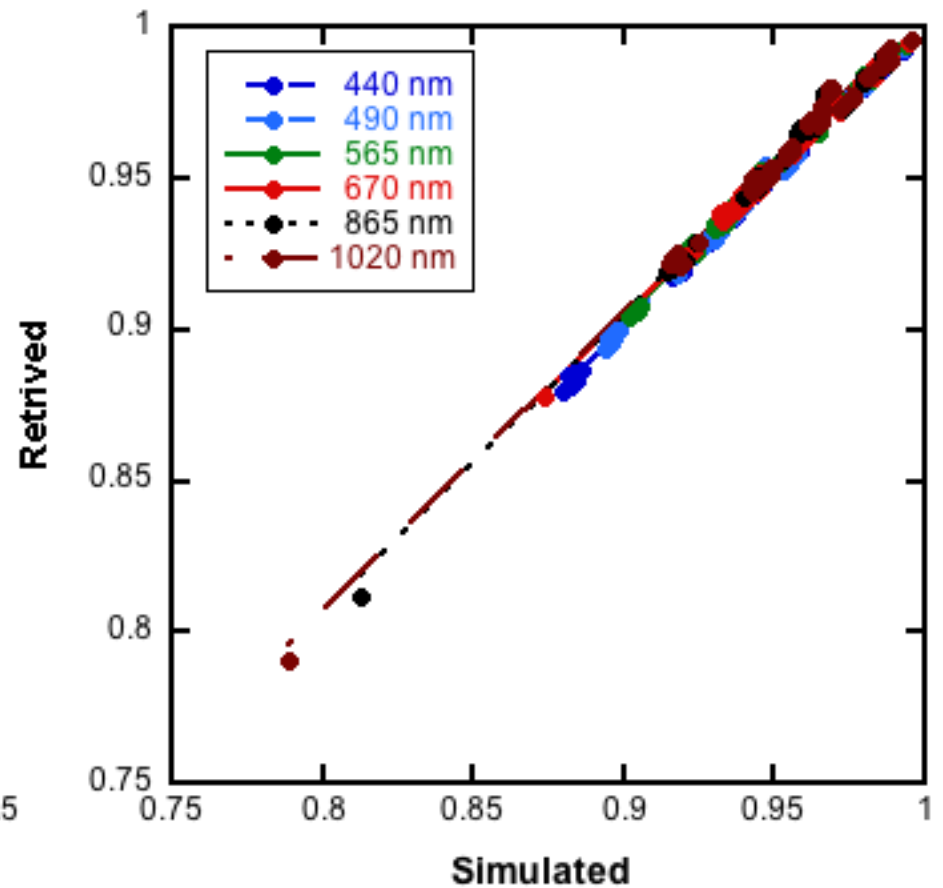
- We simulated **2 months of PARASOL measurements**
- **Aerosol and surface** properties and **aerosol concentration** were taken typical for Banizoumbou in January, February 2008.
- **The geometry** is the same as for PARASOL measurements over Banizoumbou in January, February 2008.
- **Physical models** for land surface reflection matrix (*Litvinov et al., 2012*) was used in the simulation.

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



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

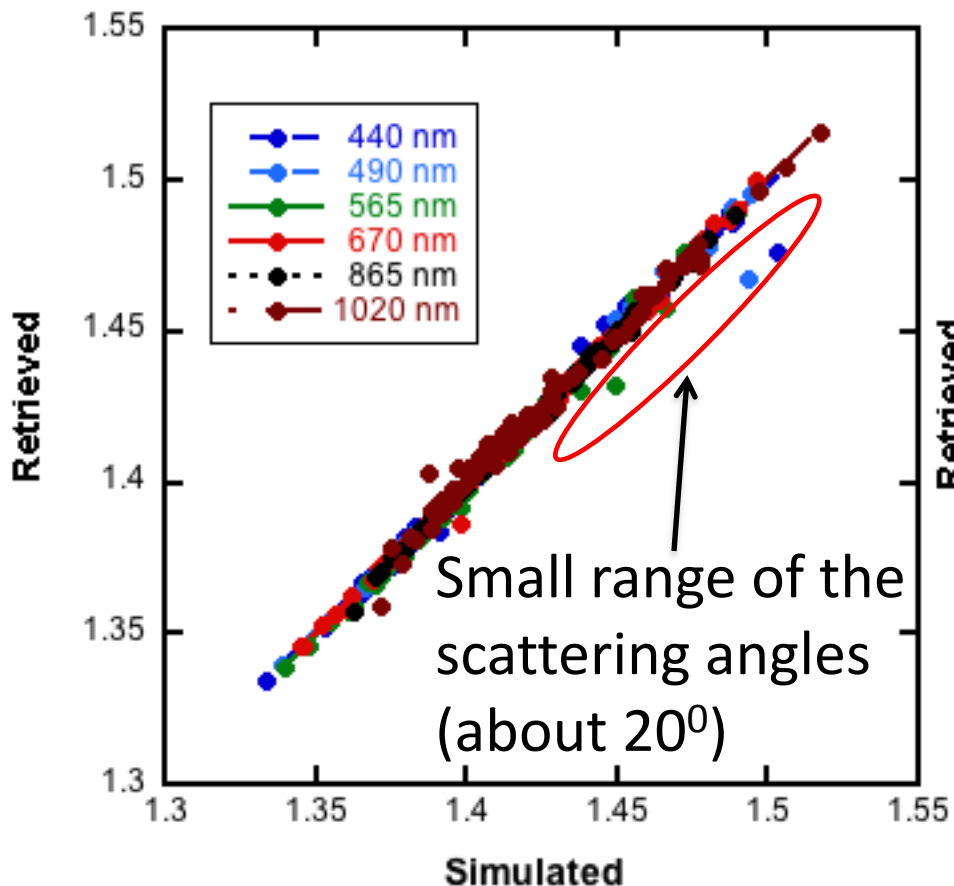
**SSA (Retrieved:  $I, Q, U$ -retrieval.  
Simulation:  $I, Q, U$ )**



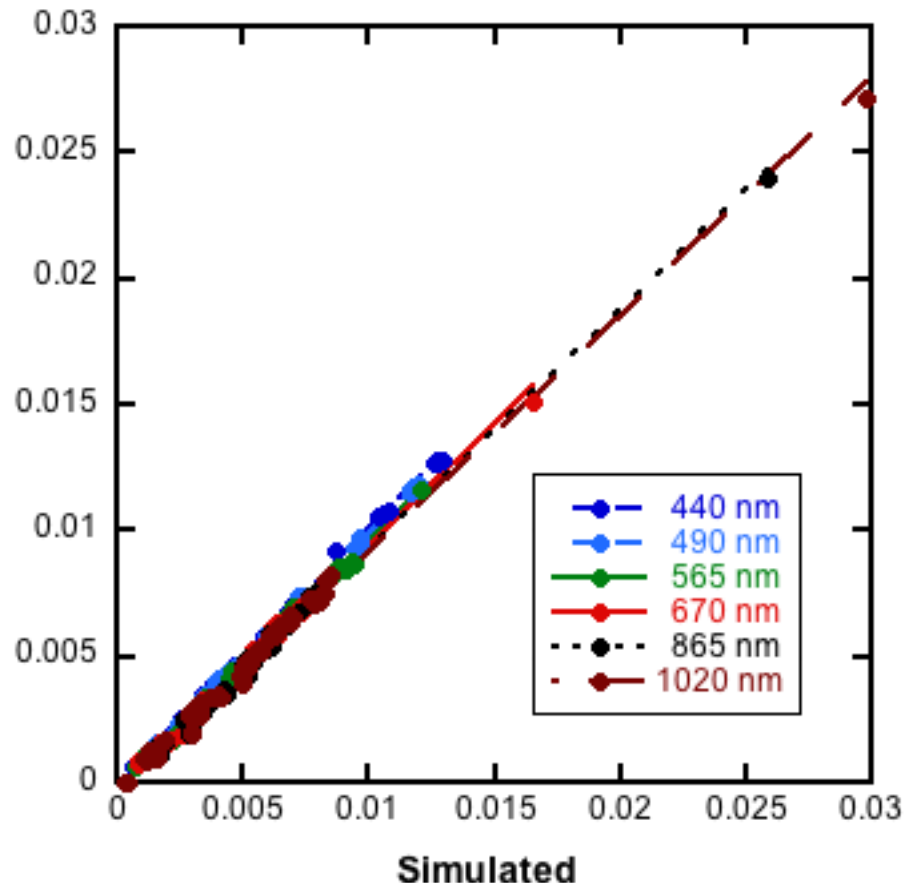
- -  $y = -0.0029473 + 1.0043x$   $R = 0.99908$   
 - -  $y = 0.0052418 + 0.99605x$   $R = 0.99862$   
 —  $y = 0.017893 + 0.9843x$   $R = 0.99775$   
 —  $y = 0.031334 + 0.97052x$   $R = 0.99709$   
 ····  $y = 0.016615 + 0.98672x$   $R = 0.99583$   
 - —  $y = 0.019672 + 0.9836x$   $R = 0.99633$



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



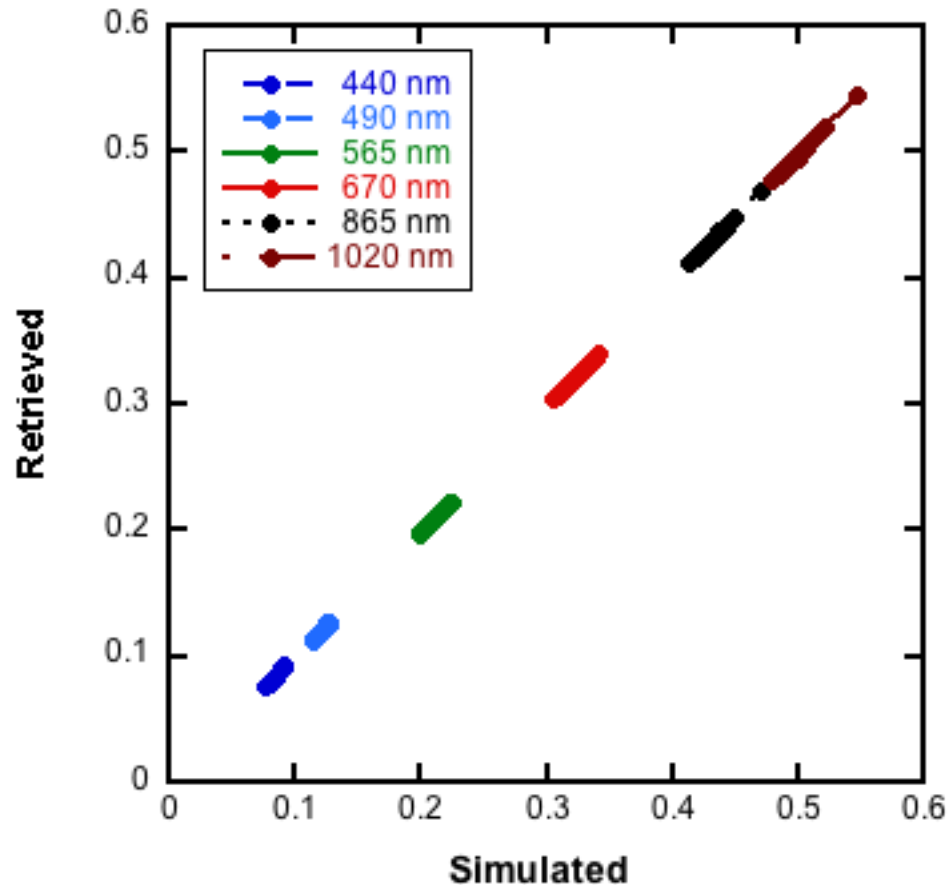
**Im(m) (Retrieved: I,Q,U-retrieval.  
Simulation: I,Q,U)**



- y = 0.02697 + 0.98023x R= 0.99402
- y = 0.014274 + 0.98951x R= 0.99594
- y = -0.010894 + 1.0066x R= 0.99717
- y = -0.010484 + 1.0072x R= 0.99895
- y = -0.0038963 + 1.0023x R= 0.99925
- y = 0.014557 + 0.99005x R= 0.99476

- y = -0.00011281 + 1.0118x R= 0.99928
- y = -0.00010855 + 1.0028x R= 0.99909
- y = -0.00017203 + 0.97747x R= 0.99852
- y = -0.00013111 + 0.96086x R= 0.99782
- y = -0.00021565 + 0.95096x R= 0.99732
- y = -0.0001892 + 0.93962x R= 0.99711

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



---  $y = -0.0017606 + 1.0185x$   $R = 0.99865$

---  $y = -0.0018067 + 1.0115x$   $R = 0.99842$

—  $y = -0.00059013 + 0.99775x$   $R = 0.99934$

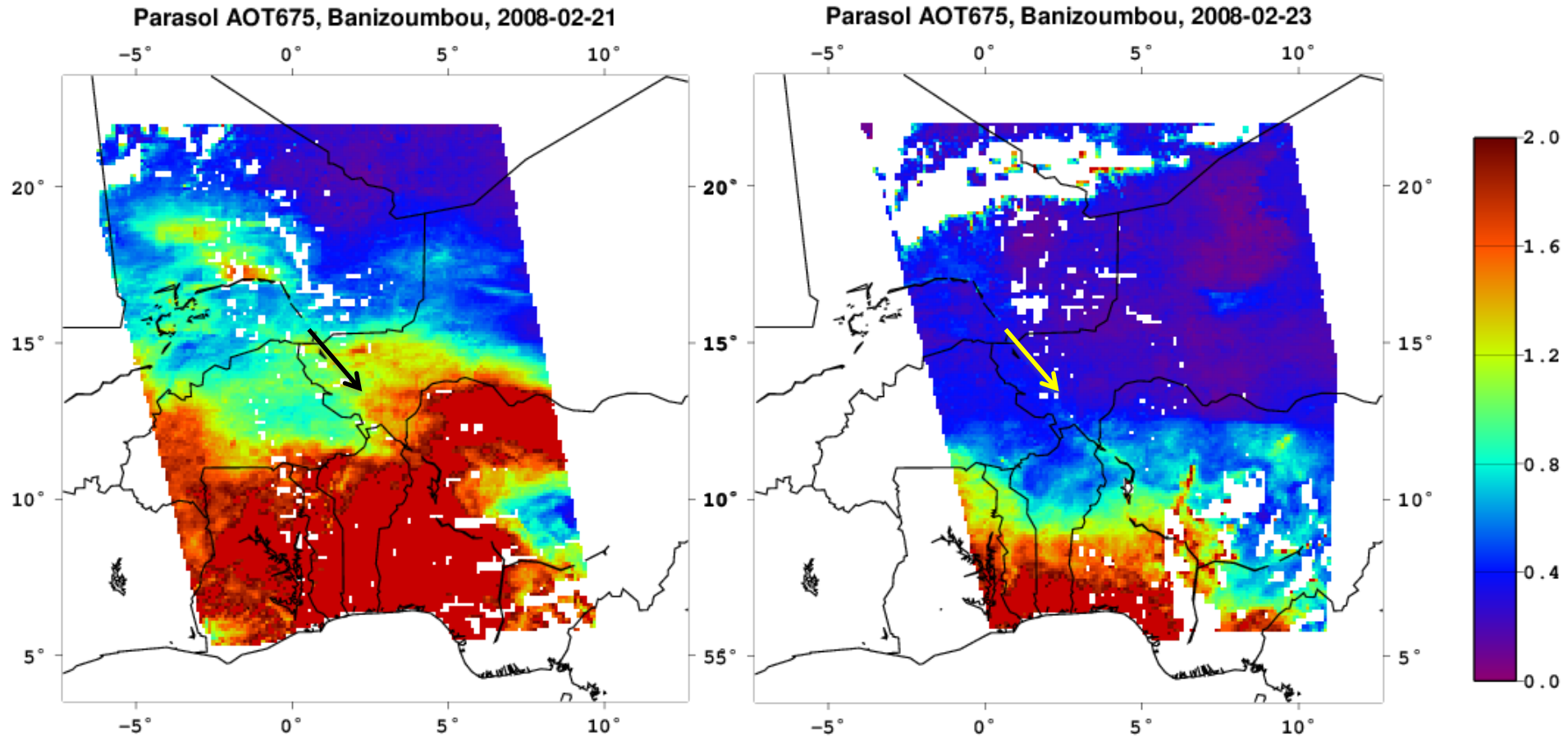
—  $y = 0.00077775 + 0.99273x$   $R = 0.99876$

.....  $y = -0.0056004 + 1.0083x$   $R = 0.99759$

- -  $y = -0.0032522 + 1.0022x$   $R = 0.99713$

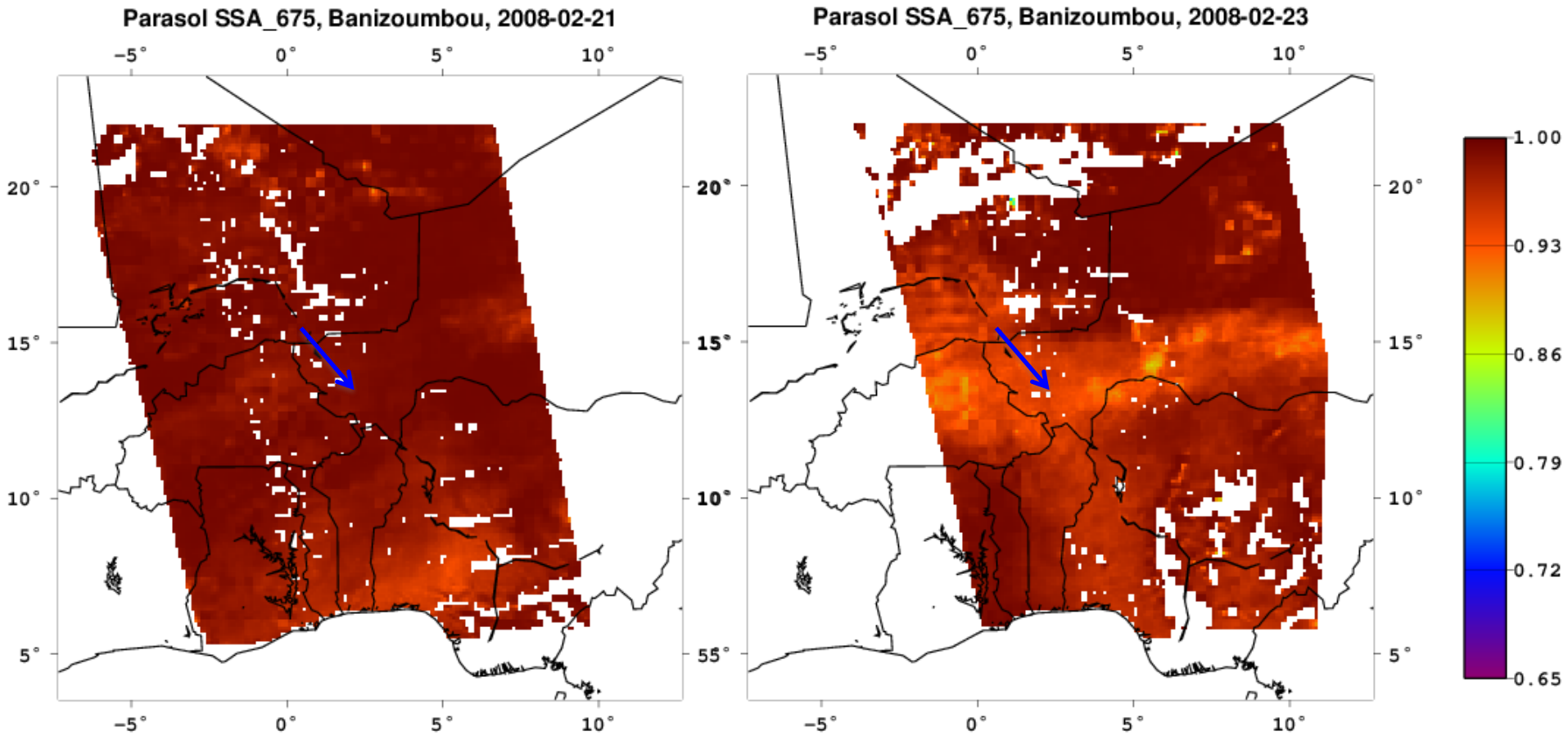
When aerosol and surface models  
are accurate enough, GRASP  
algorithm provides highly accurate  
retrieval of extended aerosol and  
surfaces properties!!!

# Regional maps (1800 x 1800 km). Banizoumbou, AOD 670 nm



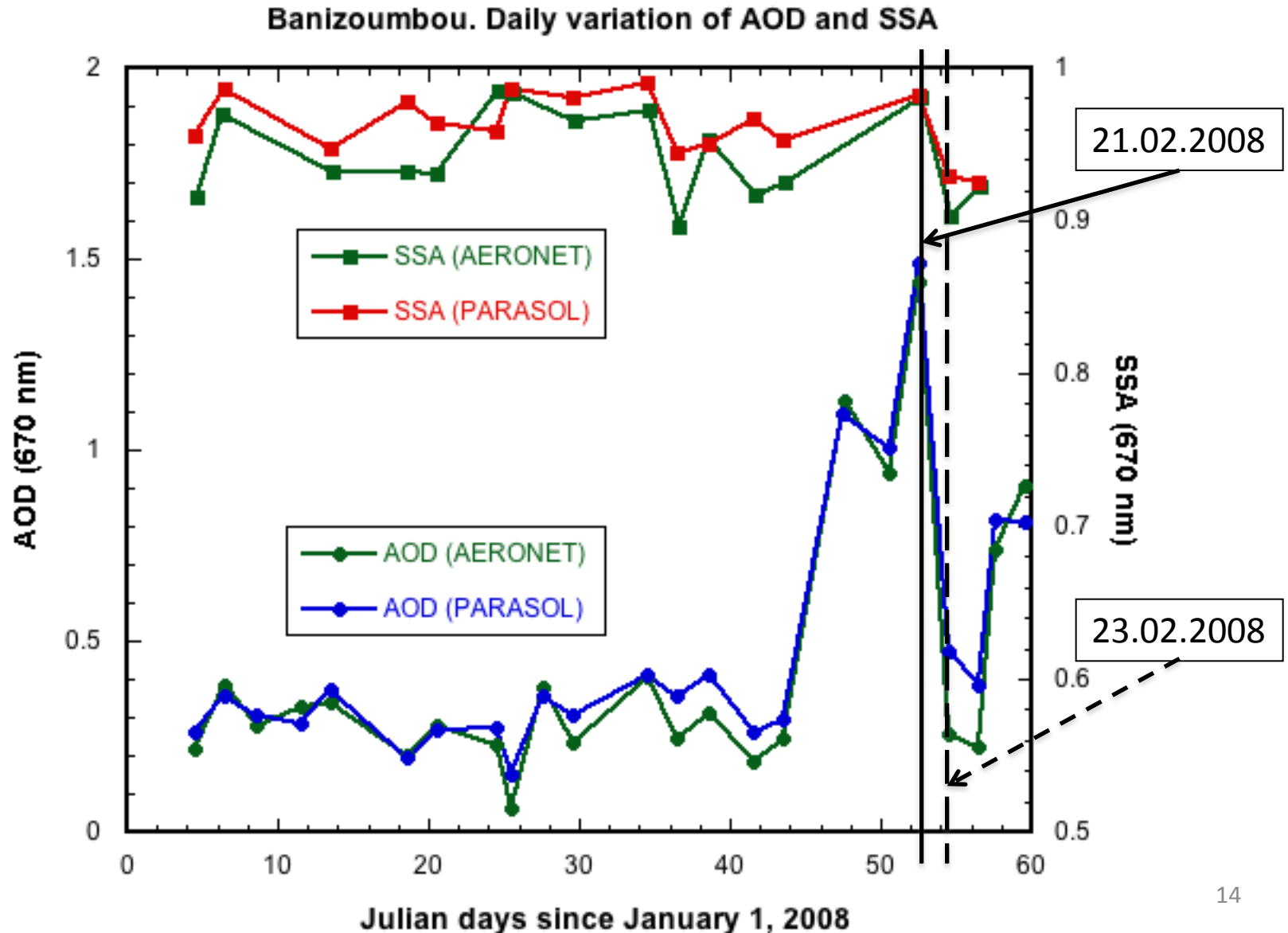
**Strong spatial and temporal variation of AOD**

# Regional maps (1800 x 1800 km). Banizoumbou, SSA 670 nm

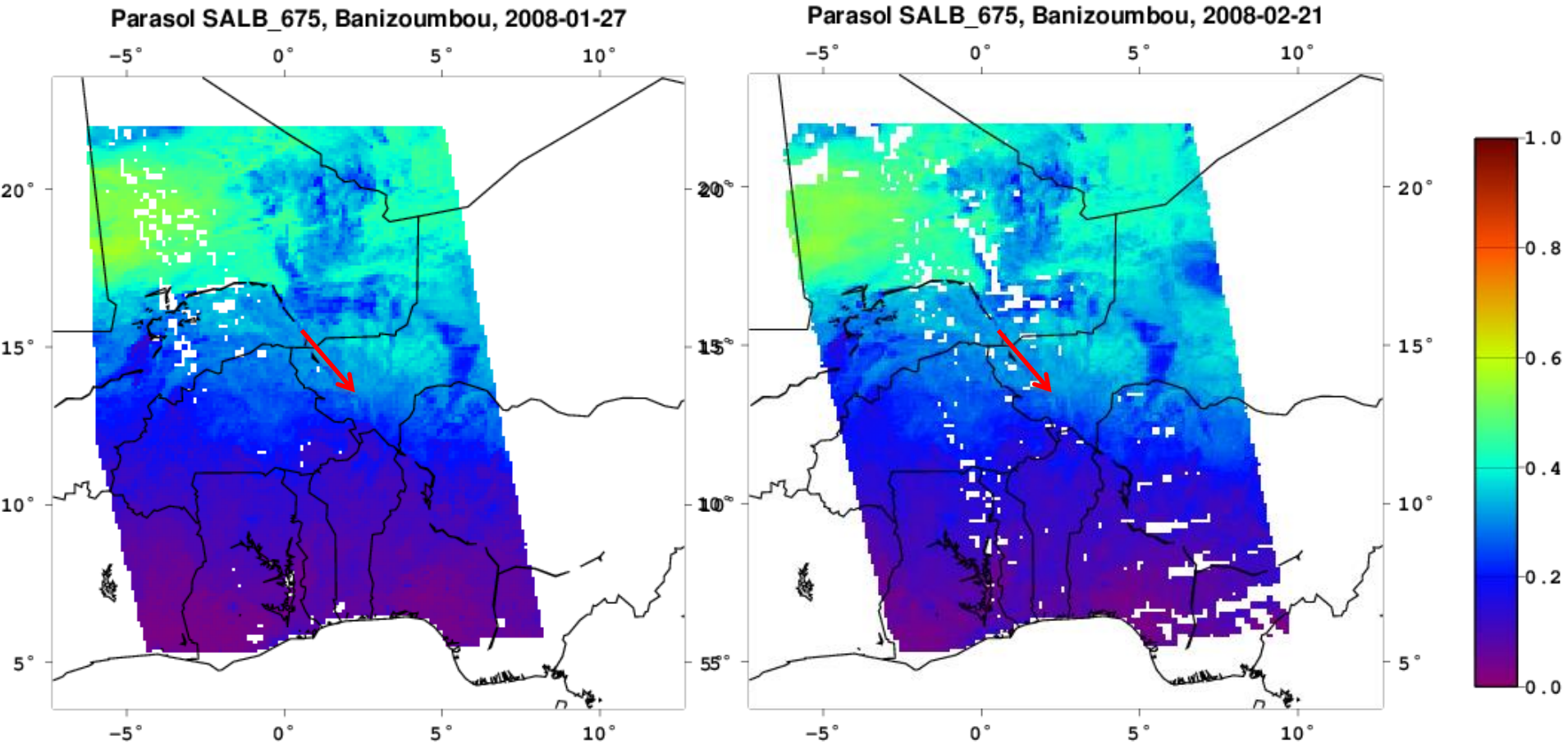


Essential temporal variation of SSA

# Daily variation of AOD and SSA at 670 nm. Banizoumbou (Jan., Febr. 2008).

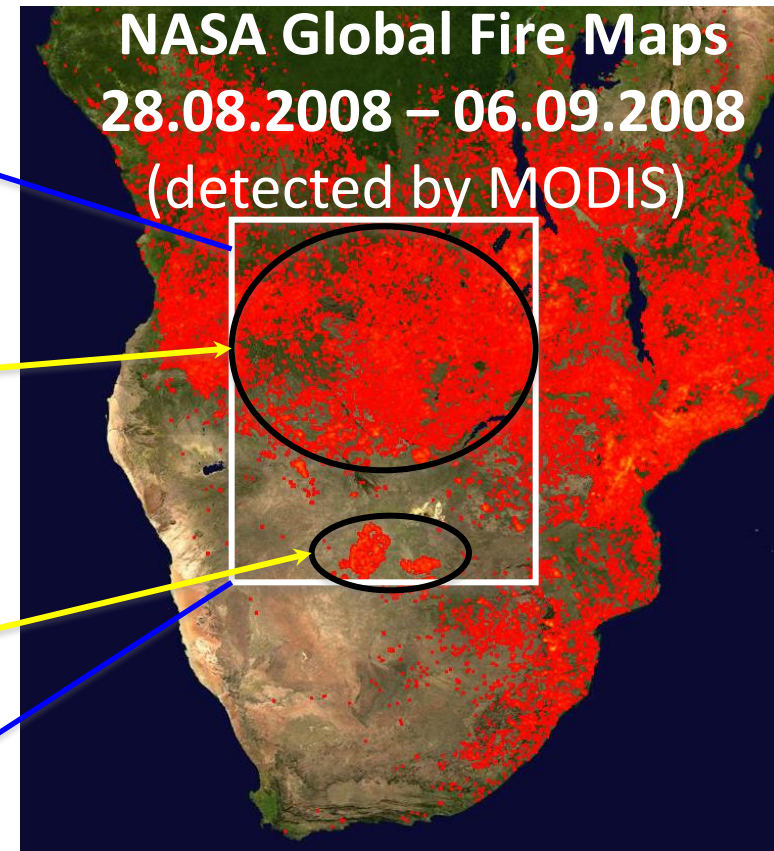
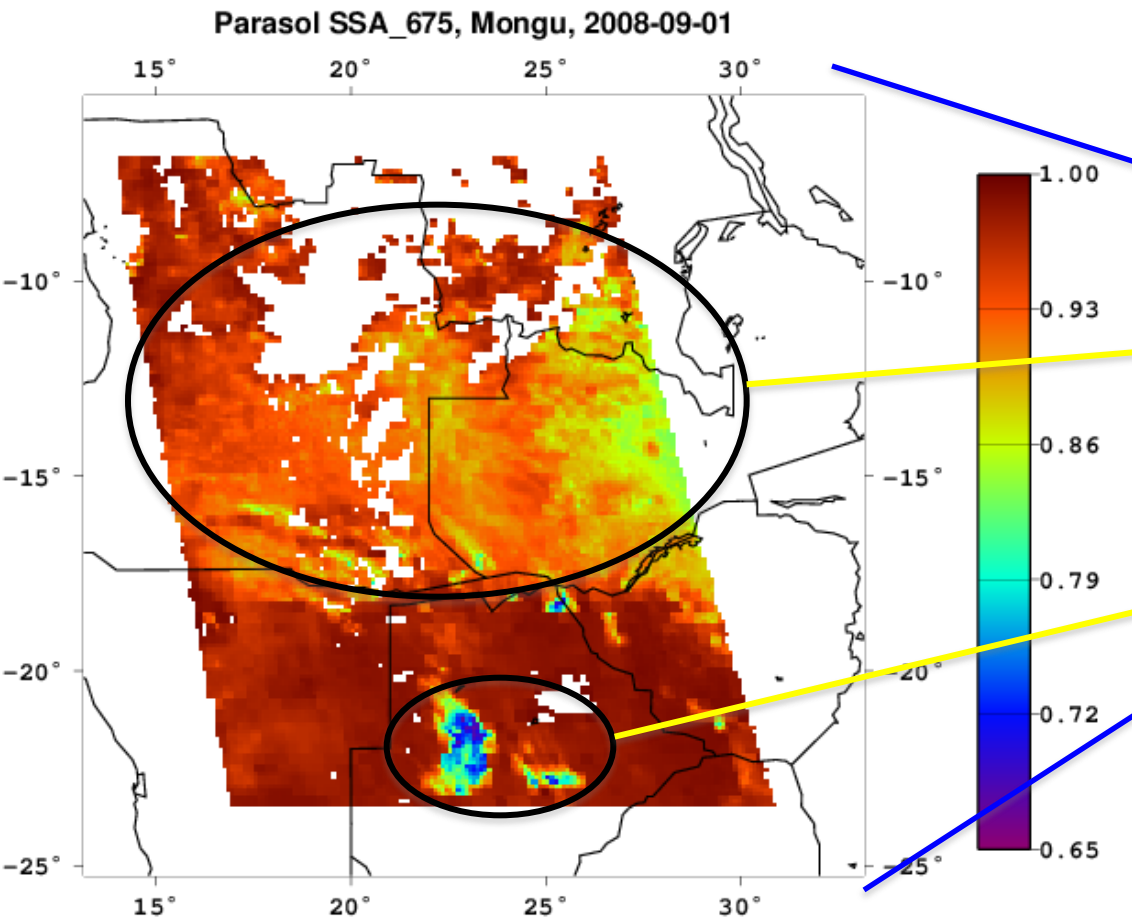


# Regional maps (1800 x 1800 km). Banizoumbou, SALB 670 nm



Surface is very stable for Jan. and Febr.!

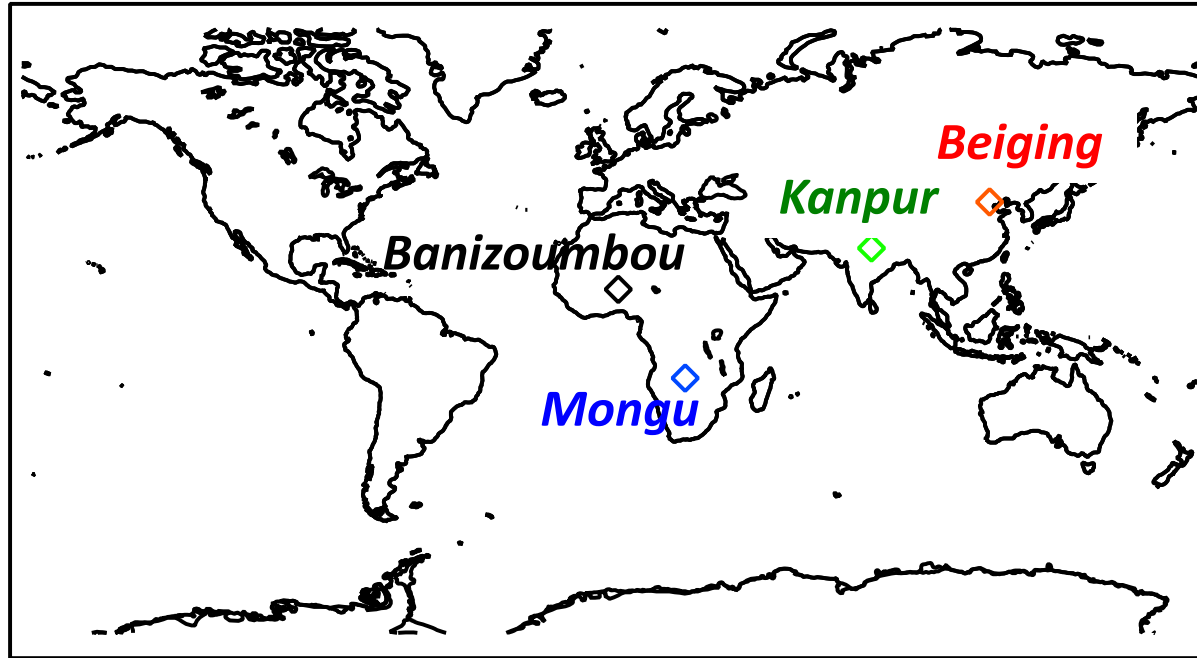
# GRASP retrieval. Regional maps (1800 x 1800 km). *Mongu, SSA 670 nm*



**Small SSA correspond to biomass burning!**



# Comparison with AERONET



**Banizoumbou:** *January, February, 2008*

**Surface:** Grassland.      **Aerosol:** Coarse mode is dominated.

**Mongu:** *August, September, 2008*

**Surface:** Savanna.      **Aerosol:** Fine mode is dominated.

**Beijing:** *April, December, 2008*

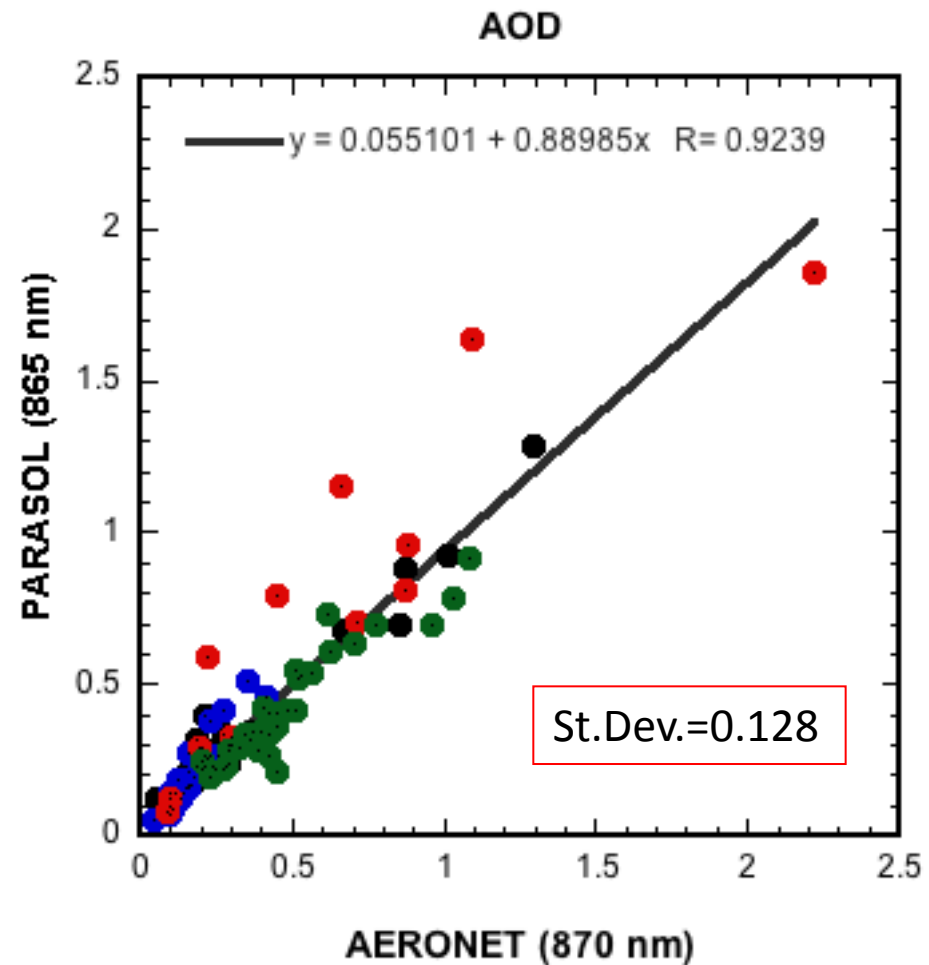
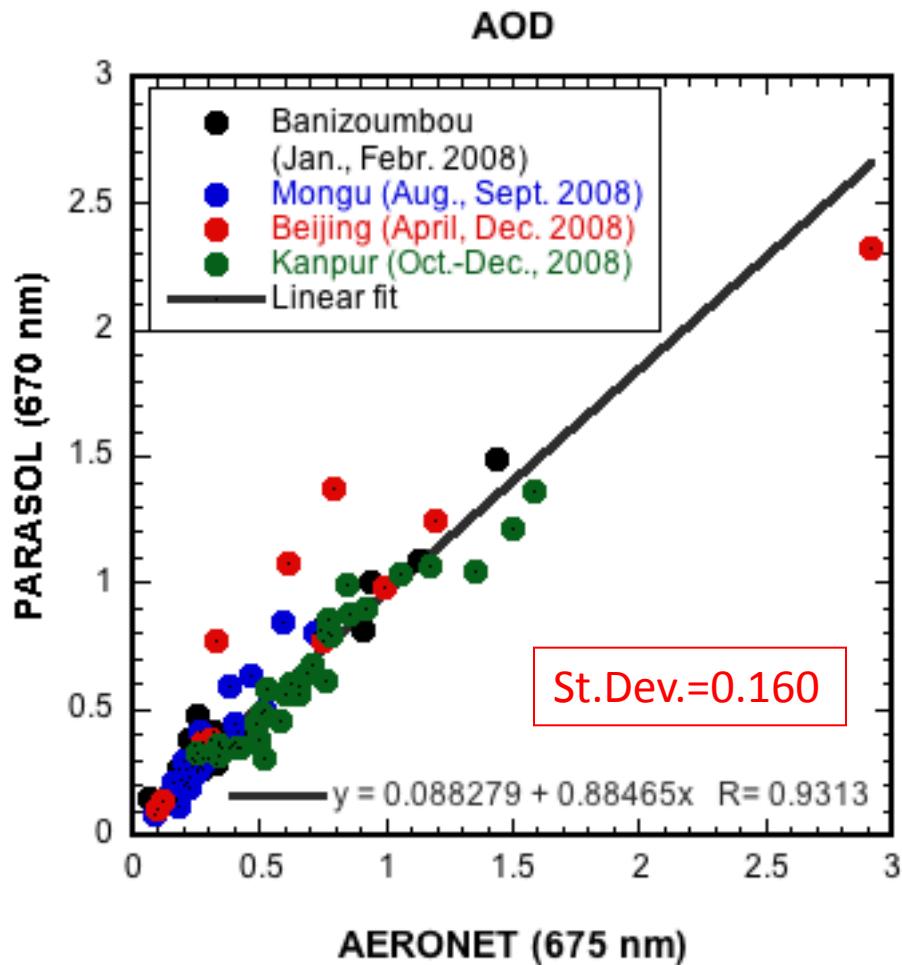
**Surface:** Urban.      **Aerosol:** Fine and Coarse modes.

**Kanpur:** *October-December, 2008*

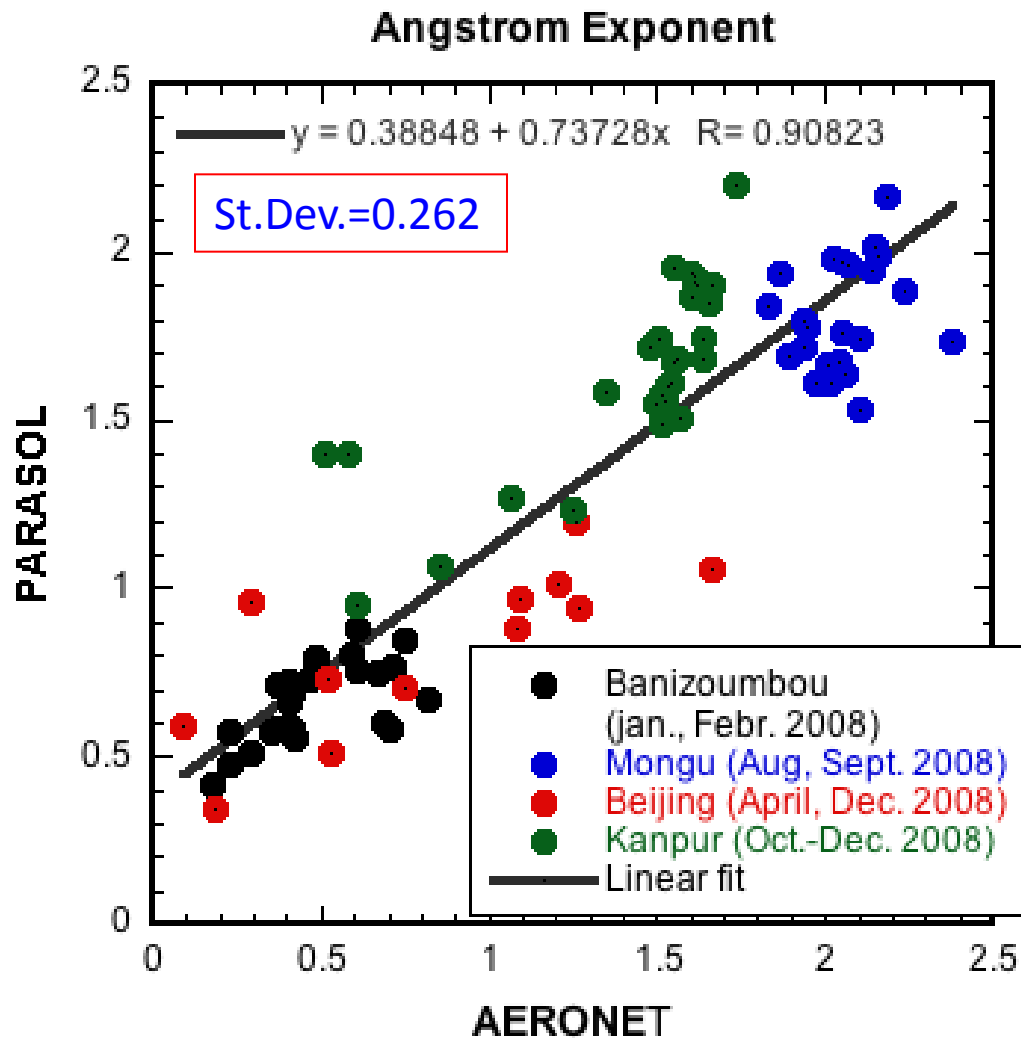
**Surface:** Urban.      **Aerosol:** Fine and Coarse modes.

The IGBP (International Geosphere Biosphere Programme) land type specification was used

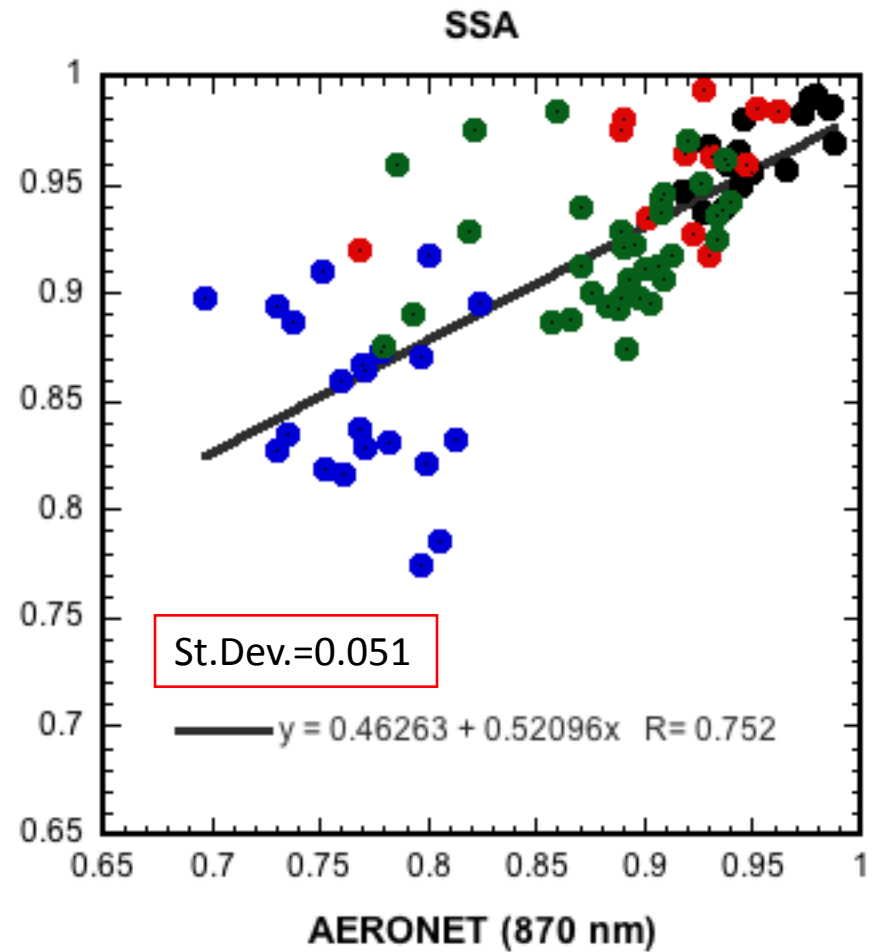
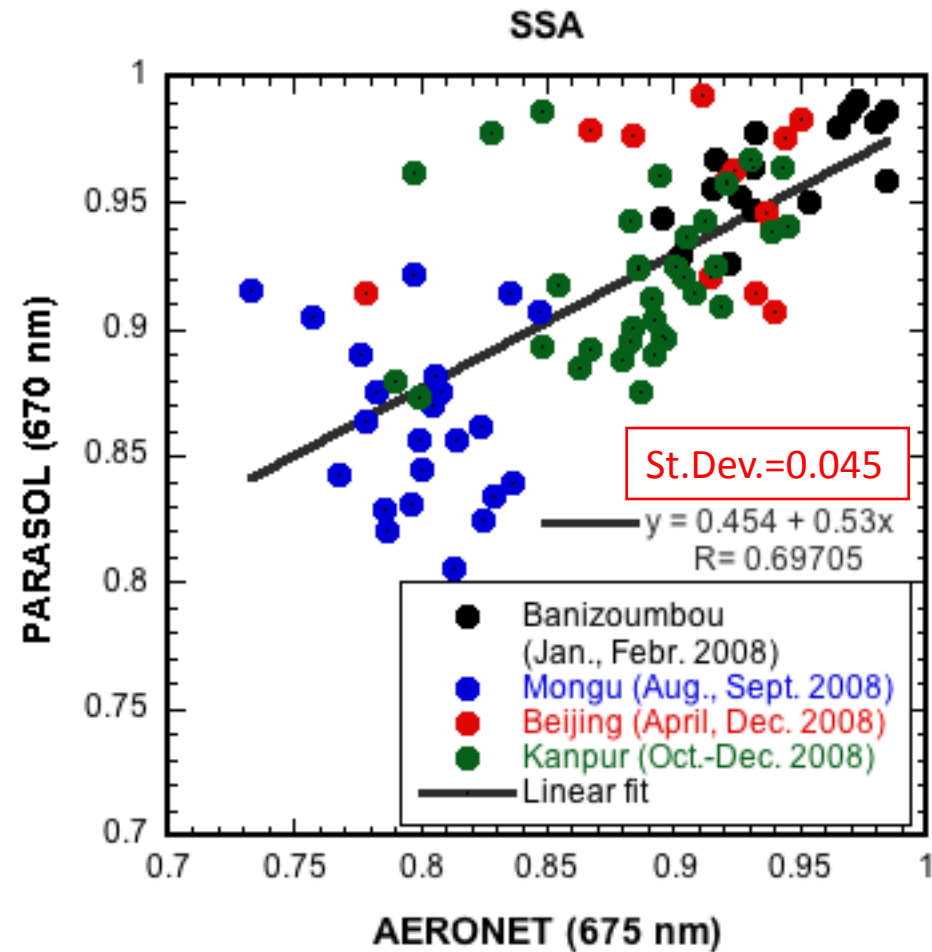
# AOD. POLDER/AERONET



# Angstrom Exponent. POLDER/AERONET



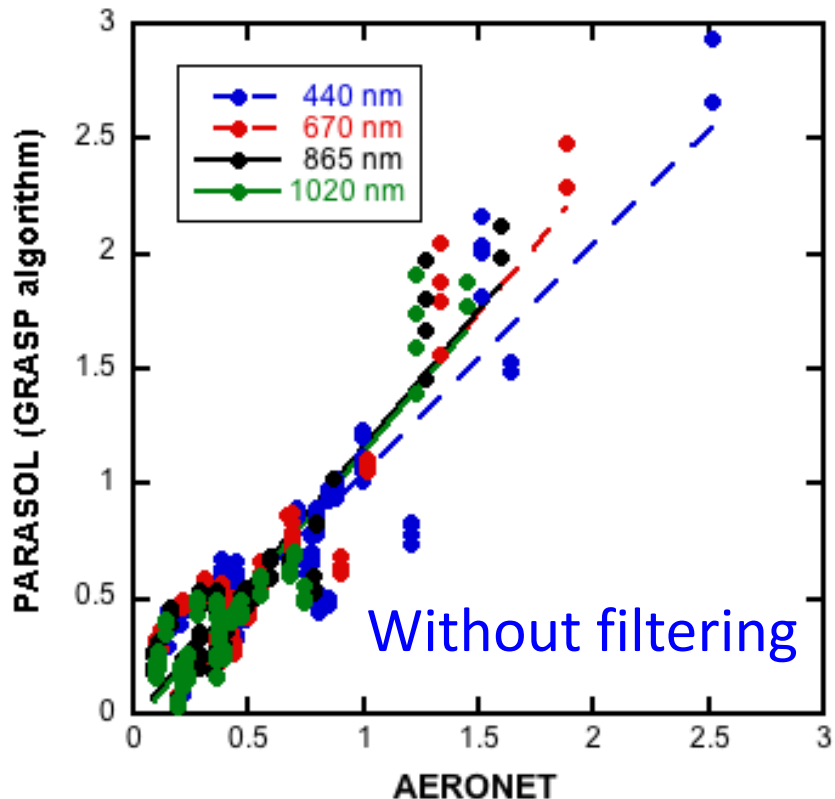
# SSA. POLDER/AERONET



# Selected AERONET station.

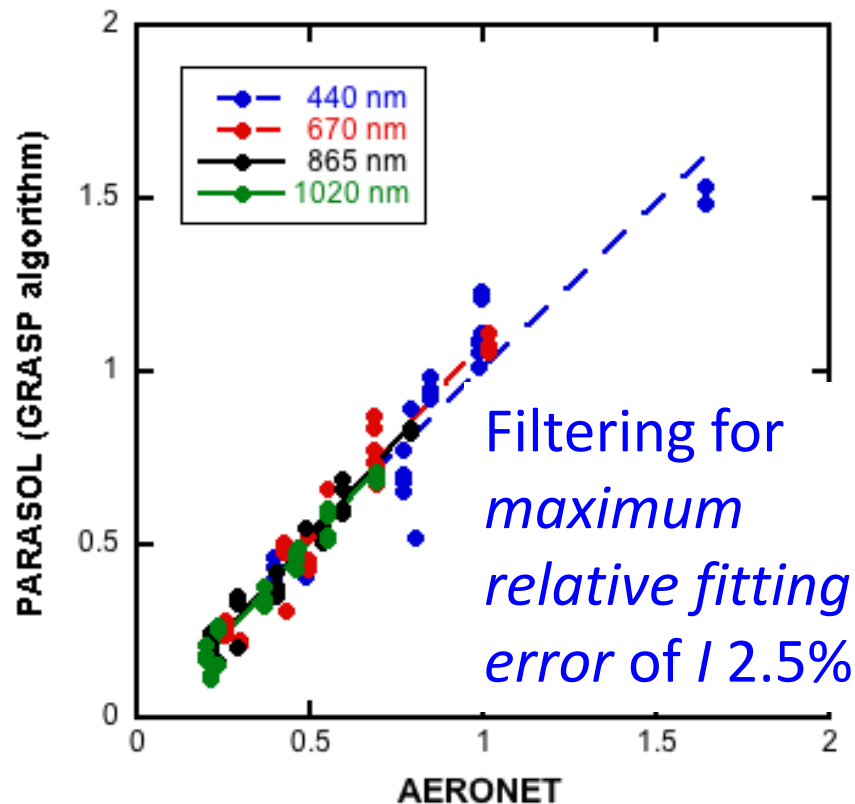
(XiangHe, March – May. 2006).

AOD.  $I, Q, U$  - Retrieval



---  $y = 0.044143 + 0.99634x$   $R = 0.90915$   
---  $y = -0.037195 + 1.1857x$   $R = 0.92858$   
—  $y = -0.045979 + 1.1959x$   $R = 0.9239$   
—  $y = -0.059347 + 1.1865x$   $R = 0.91929$

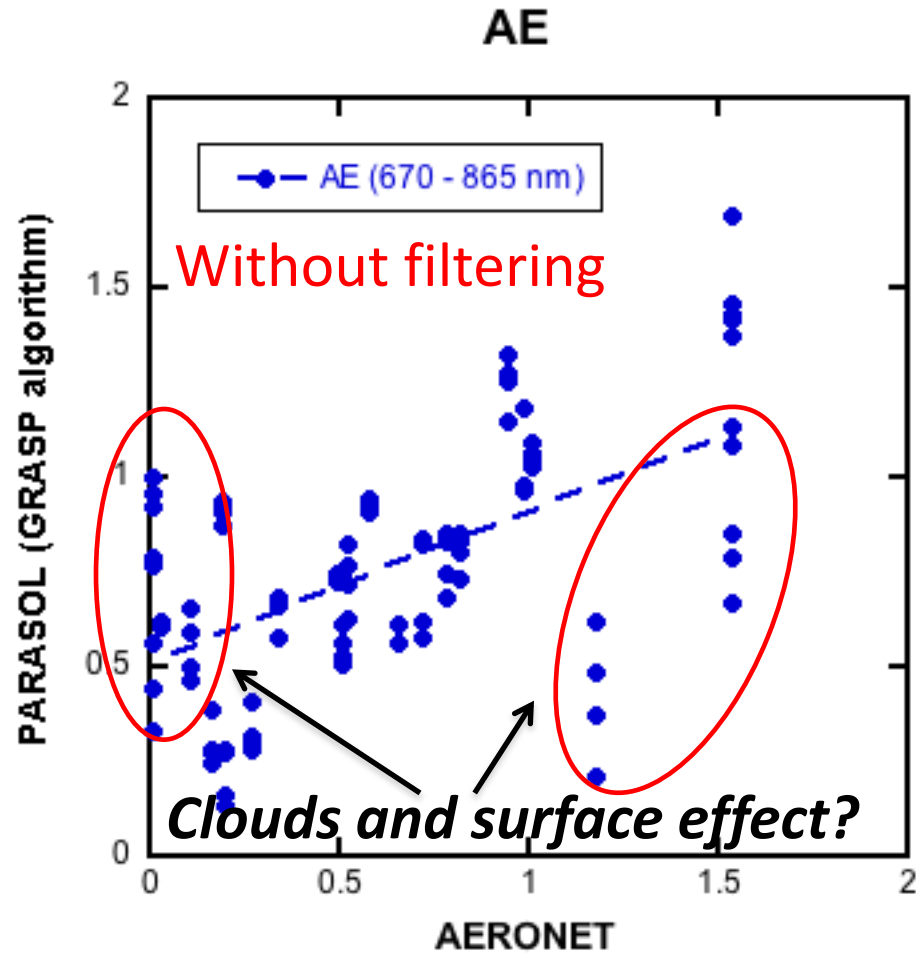
AOD.  $I, Q, U$  - Retrieval



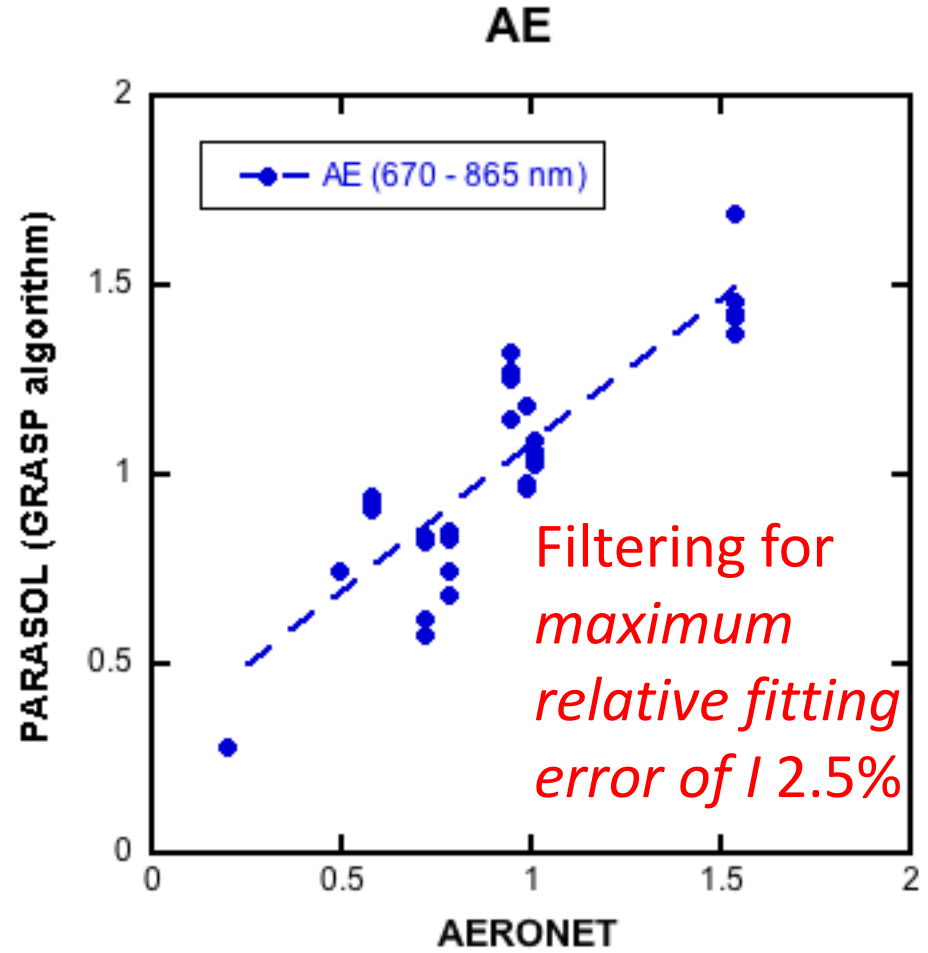
---  $y = 0.047691 + 0.95815x$   $R = 0.95276$   
---  $y = -0.060594 + 1.1536x$   $R = 0.97503$   
—  $y = -0.045632 + 1.1214x$   $R = 0.97943$   
—  $y = -0.049393 + 1.0965x$   $R = 0.98112$

Filtering cuts both large and small AOD (*cloud contamination and surface modeling effect?*)

# Selected AERONET station. (XiangHe, March – May. 2006).



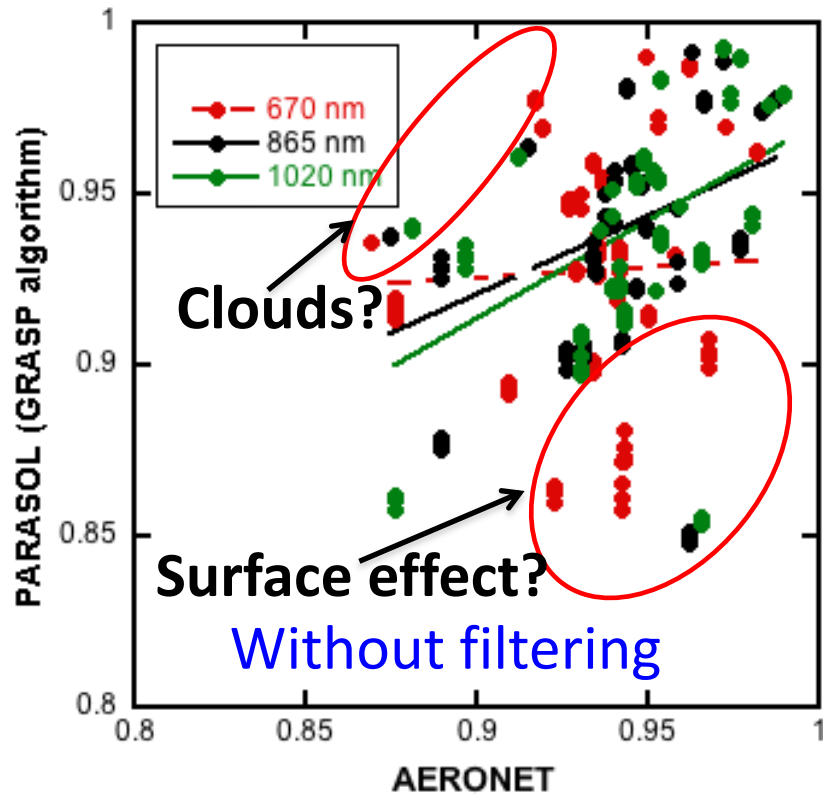
—  $y = 0.51175 + 0.39373x$   $R = 0.58342$



—  $y = 0.30589 + 0.77054x$   $R = 0.8626$

# Selected AERONET station. (XiangHe, March – May. 2006).

SSA. I,Q,U - Retrieval

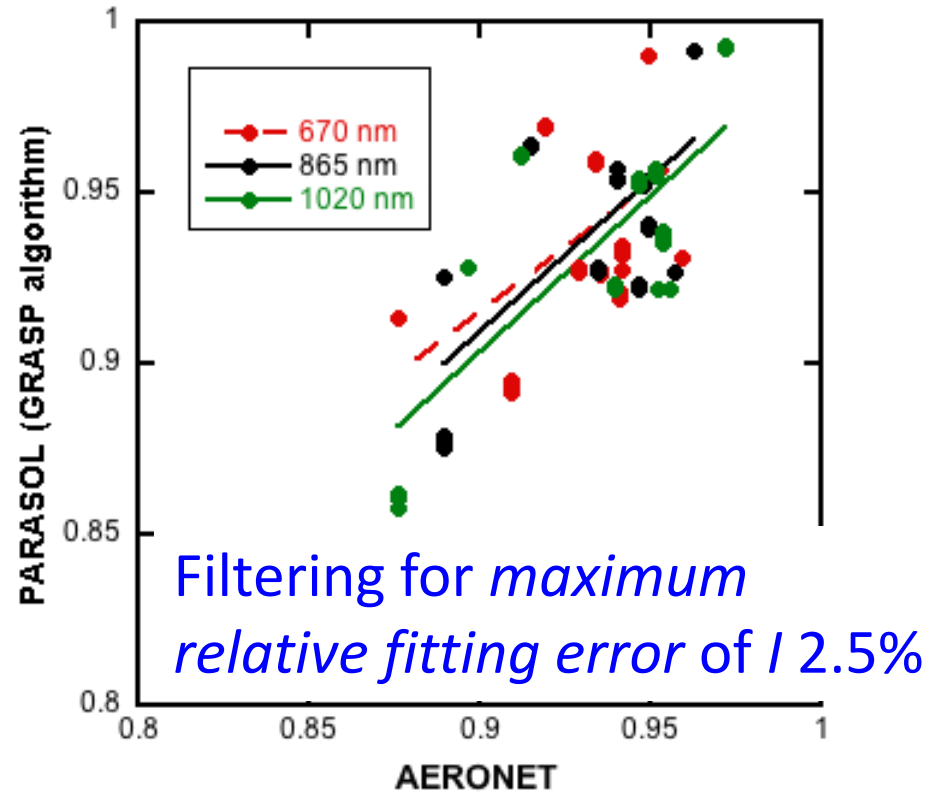


---  $y = 0.86813 + 0.06315x$   $R = 0.035479$

—  $y = 0.5085 + 0.45782x$   $R = 0.37365$

—  $y = 0.39944 + 0.57135x$   $R = 0.47496$

SSA. I,Q,U - Retrieval



---  $y = 0.23483 + 0.75584x$   $R = 0.41847$

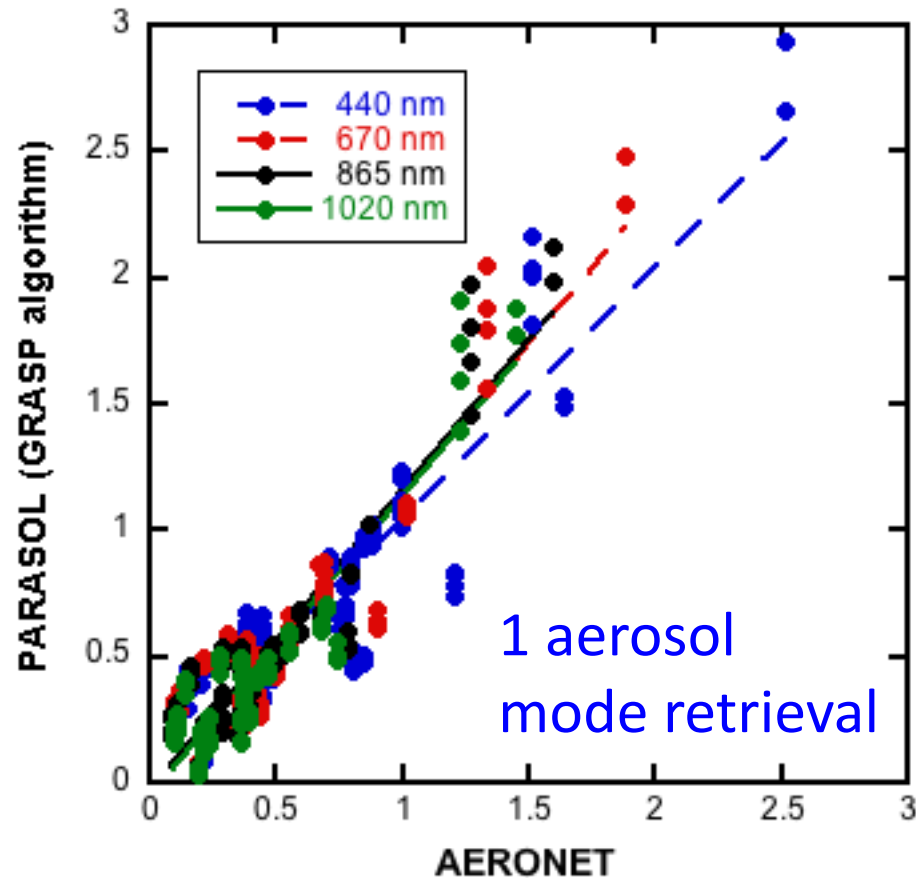
—  $y = 0.10347 + 0.89533x$   $R = 0.6592$

—  $y = 0.090593 + 0.90324x$   $R = 0.72596$

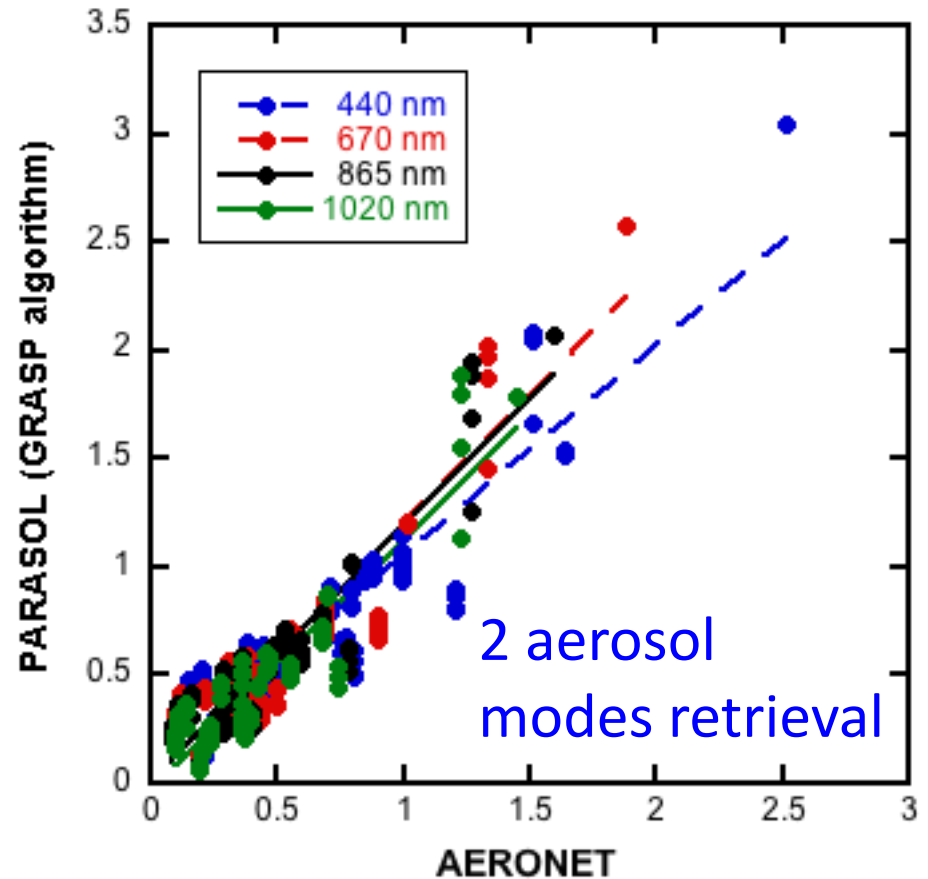
Surface reflection and aerosol/clouds interaction are the main challenges of enhanced aerosol characterization!

# 1 aerosol mode retrieval vs 2 modes (different $m$ , size distribution). XiangHe, China, March-May, 2006

AOD.  $I, Q, U$  - Retrieval



AOD.  $I, Q, U$  - Retrieval



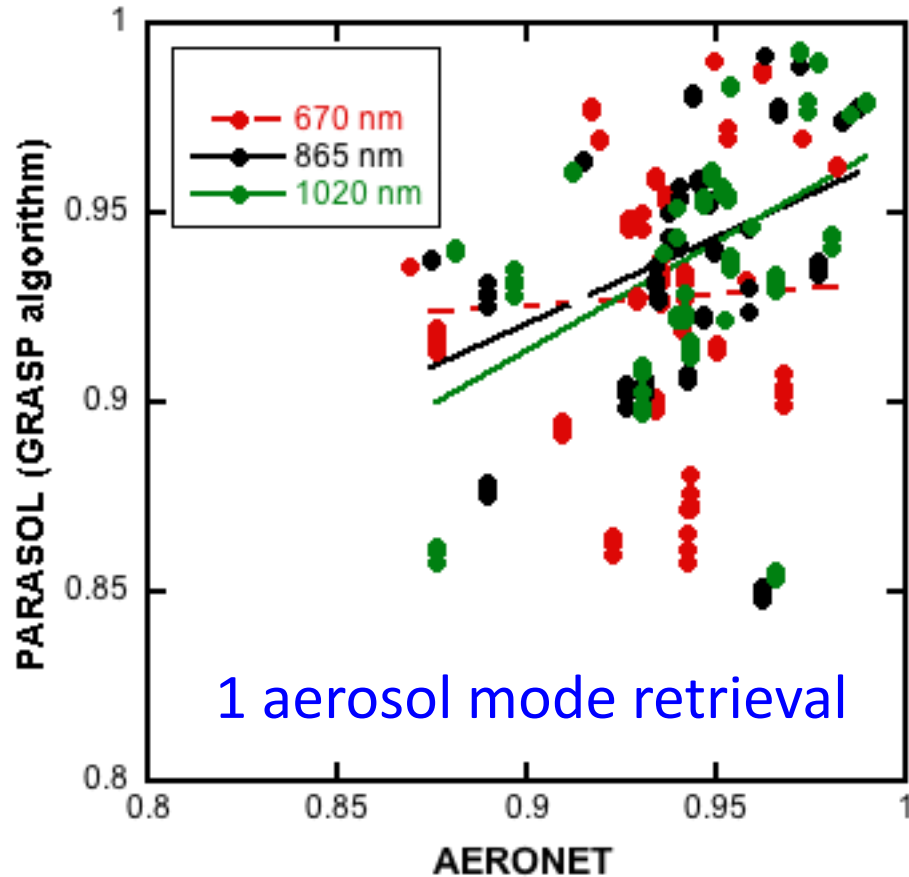
---  $y = 0.044143 + 0.99634x$   $R = 0.90915$   
---  $y = -0.037195 + 1.1857x$   $R = 0.92858$   
—  $y = -0.045979 + 1.1959x$   $R = 0.9239$   
—  $y = -0.059347 + 1.1865x$   $R = 0.91929$

---  $y = 0.080707 + 0.97021x$   $R = 0.9117$   
---  $y = -0.011862 + 1.1998x$   $R = 0.92833$   
—  $y = -0.0071541 + 1.185x$   $R = 0.91604$   
—  $y = -0.020383 + 1.1512x$   $R = 0.90965$



# 1 aerosol mode retrieval vs 2 modes (different $m$ , size distribution). XiangHe, China, March-May, 2006

SSA.  $I, Q, U$  - Retrieval

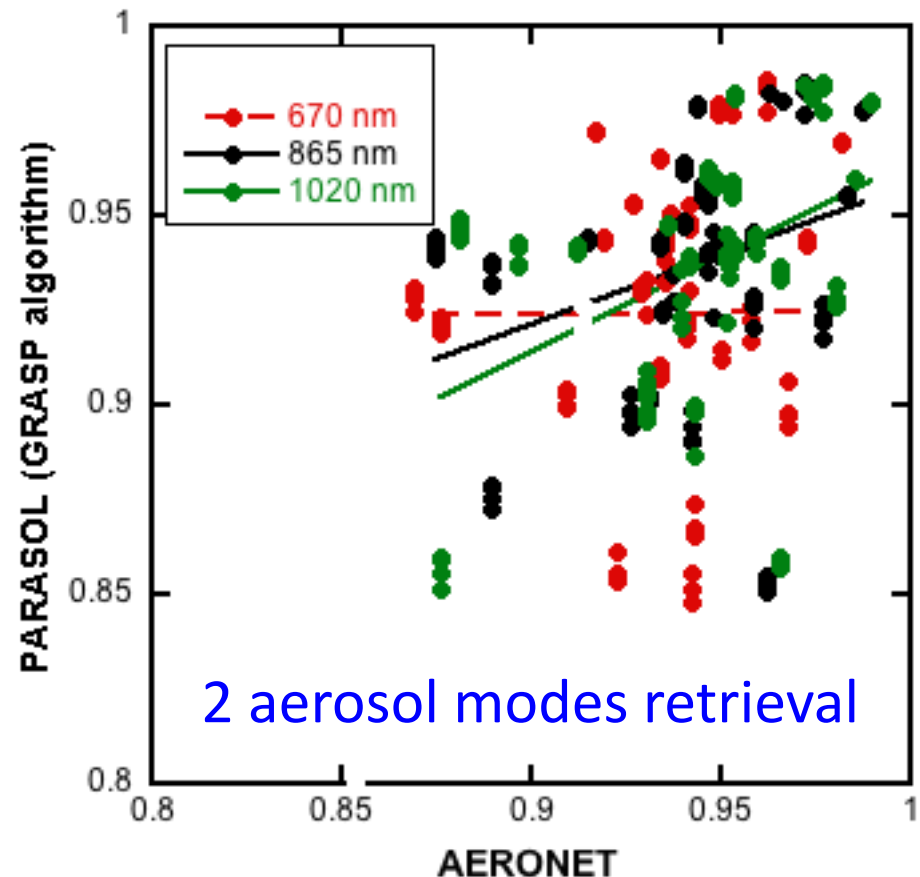


---  $y = 0.86813 + 0.06315x$   $R = 0.035479$

—  $y = 0.5085 + 0.45782x$   $R = 0.37365$

—  $y = 0.39944 + 0.57135x$   $R = 0.47496$

SSA.  $I, Q, U$  - Retrieval



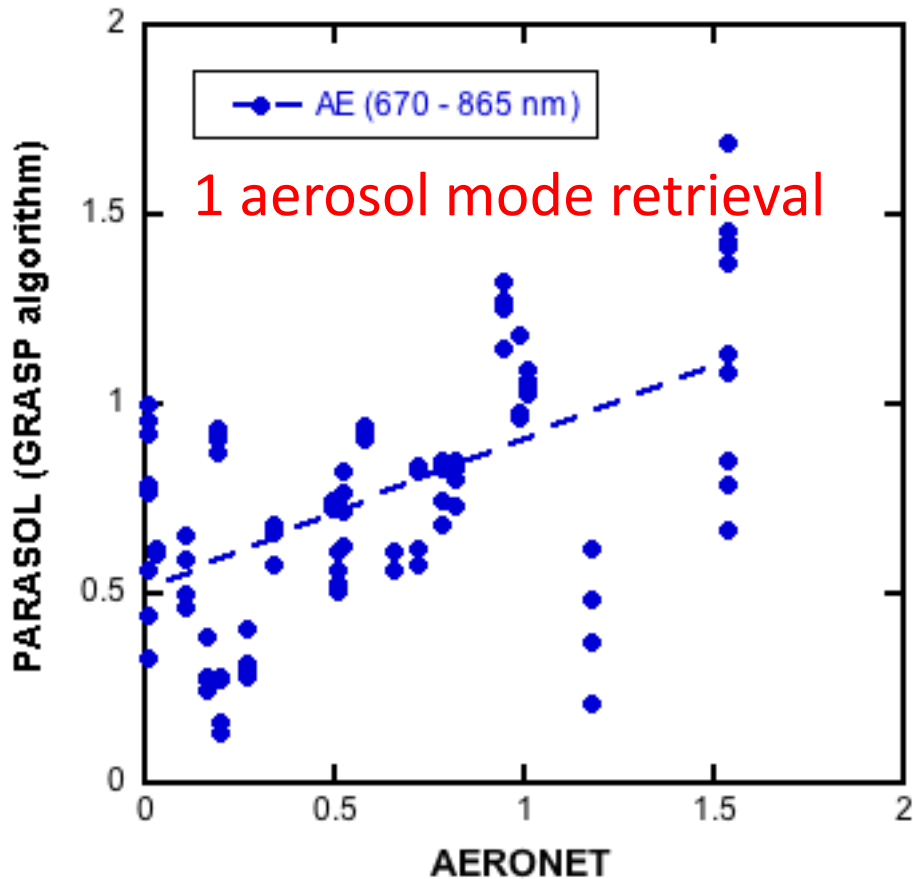
---  $y = 0.92053 + 0.0040002x$   $R = 0.0022678$

—  $y = 0.59111 + 0.36679x$   $R = 0.31157$

—  $y = 0.46166 + 0.50304x$   $R = 0.43325$

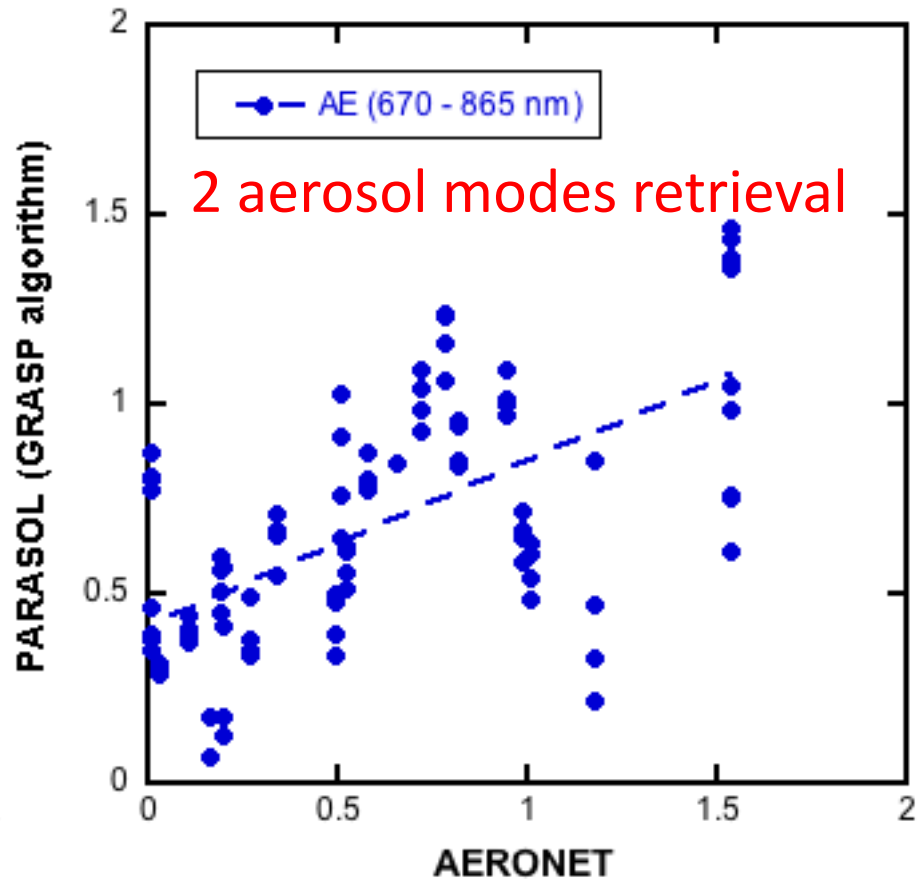
# 1 aerosol mode retrieval vs 2 modes (different $m$ , size distribution). XiangHe, China, March-May, 2006

AE



---  $y = 0.51175 + 0.39373x$   $R = 0.58342$

AE



---  $y = 0.41102 + 0.43216x$   $R = 0.6132$

**Sensitivity to several aerosol modes (with different complex refractive index and size distribution) is small !!!**

# Possible reasons of little sensitivity to different aerosol modes (complex refractive index)

1. **Limited range of scattering angles** from the space-borne instruments.

*The widest ranges for PARASOL (XiangHe, March-May, 2006):*

80<sup>0</sup>-155<sup>0</sup>; 70<sup>0</sup>-140<sup>0</sup>; 90<sup>0</sup>-177<sup>0</sup>.

2. **Averaged single scattering properties** in RTE:

$$\langle \mathbf{P} \rangle = \frac{\hat{a} \langle W_k \rangle \times \langle \mathbf{P}_k \rangle t_k}{\langle W \rangle t_{total}}$$

3. **Multiple scattering washes out the single scattering properties.**

# How can we increase sensitivity to different aerosol modes?

## 1. **Combination with LIDAR measurements**

(increased sensitivity is already demonstrated for combination of ground based sun-photometer and LIDAR measurements (*A.Lopatin et al. AMT, 2013*))

## 2. **Multi-sensor retrieval** (include additional information from different space-borne and ground-based).

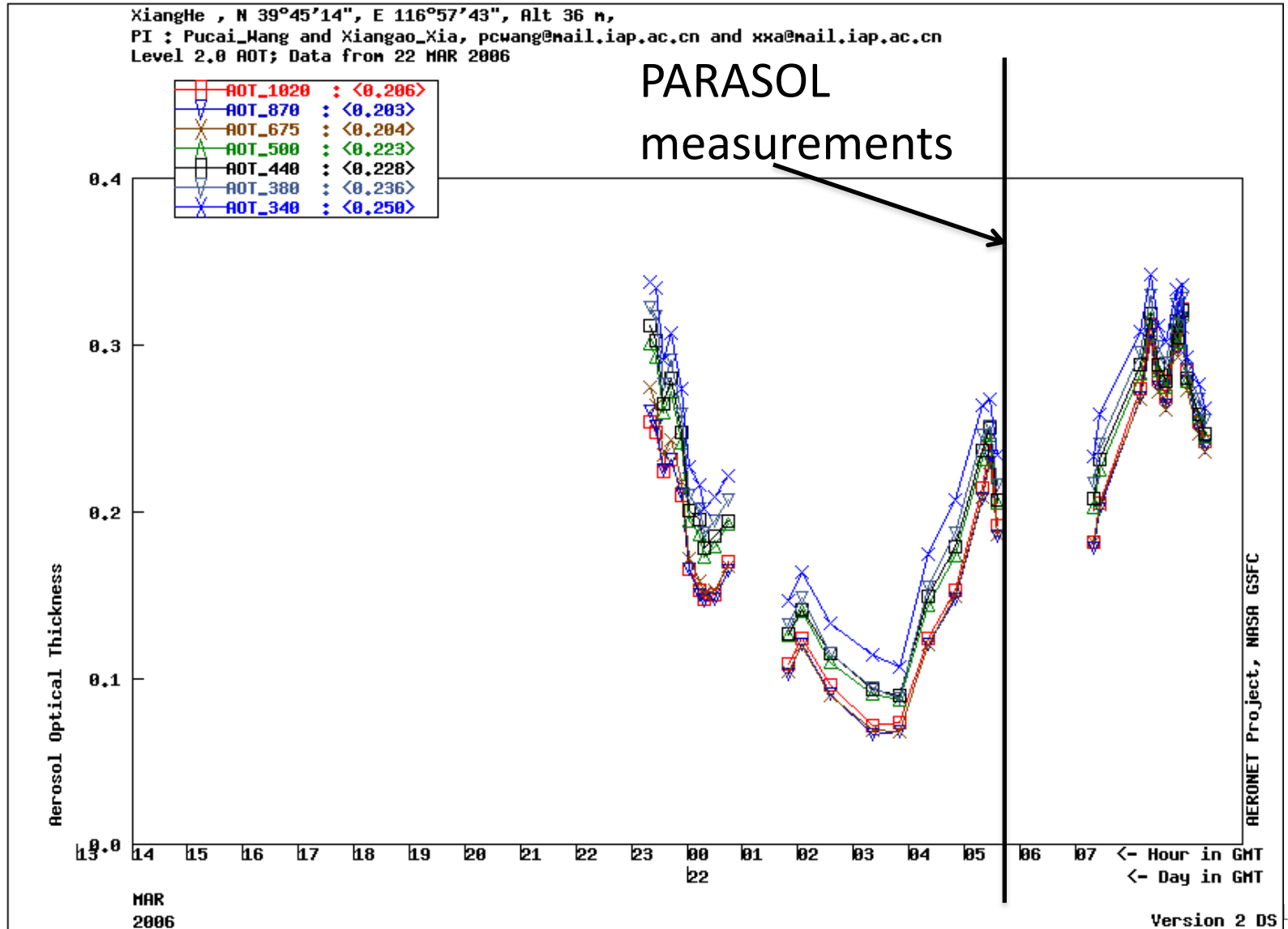
# Resume

- **GRASP algorithm performs well** for different aerosol and surface types.
- **GRASP is able provide accurate retrieval of extended aerosol properties.**
- ***Cloud contamination and surface modeling*** are still the main challenges for enhanced aerosol characterization.
- **Multi-sensor retrieval is necessary to enhance retrieval of extended aerosol properties (separate different aerosol modes).**

# Bonus slides

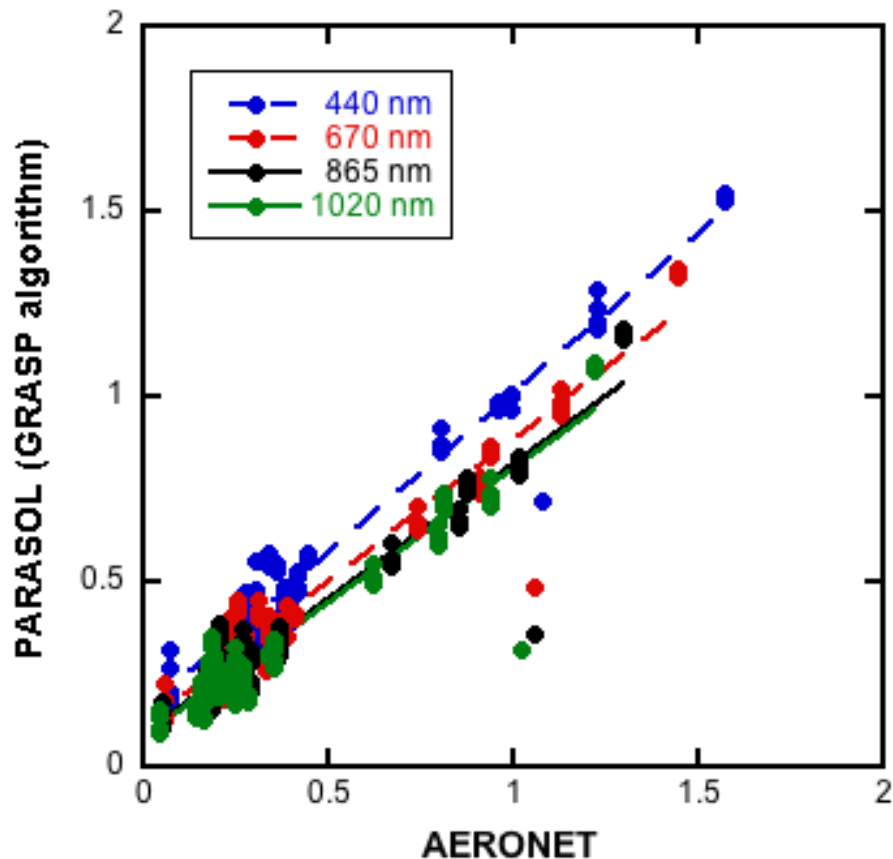
# AERONET and PARASOL measurements.

## XiangHe, 22.03.2006.



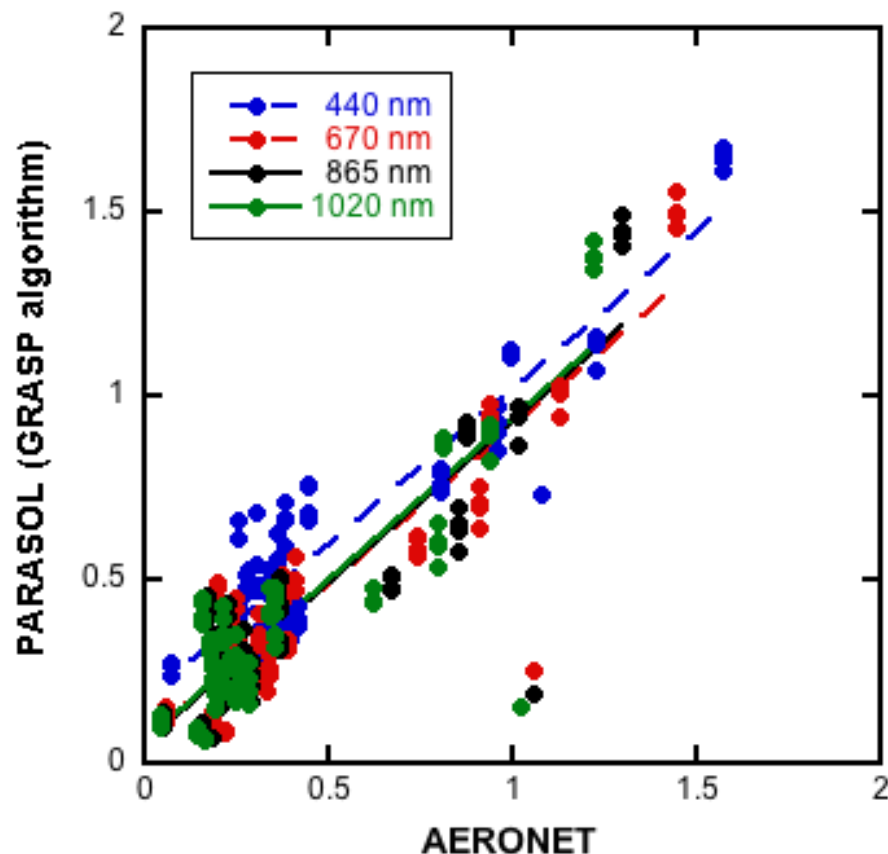
# $I, Q, U$ retrieval vs $I$ -retrieval and $Q, U$ -retrieval: AOD (Banizoumbou)

AOD.  $I, Q, U$  - Retrieval



- -  $y = 0.15245 + 0.85833x$   $R = 0.97574$   
 - -  $y = 0.11197 + 0.77082x$   $R = 0.96402$   
 —  $y = 0.095019 + 0.72412x$   $R = 0.94902$   
 —  $y = 0.07831 + 0.72432x$   $R = 0.94434$

AOD.  $I$  - Retrieval

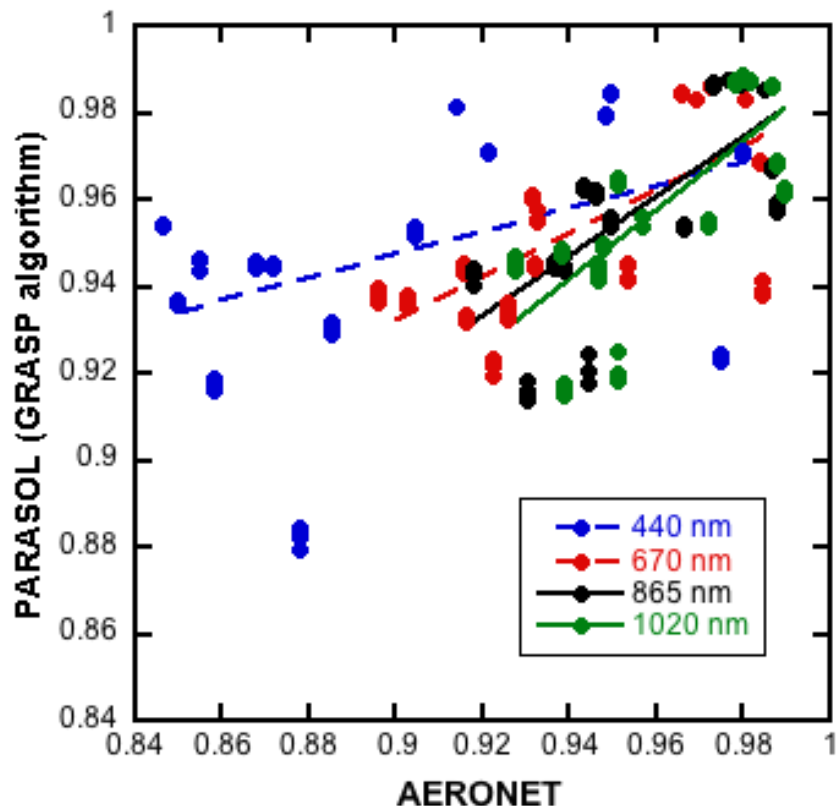


- -  $y = 0.17194 + 0.8511x$   $R = 0.92675$   
 - -  $y = 0.059331 + 0.85975x$   $R = 0.91477$   
 —  $y = 0.05566 + 0.87257x$   $R = 0.89608$   
 —  $y = 0.061256 + 0.87709x$   $R = 0.8854$



# $I, Q, U$ retrieval vs $I$ -retrieval and $Q, U$ -retrieval: SSA (Banizoumbou)

SSA.  $I, Q, U$  - Retrieval



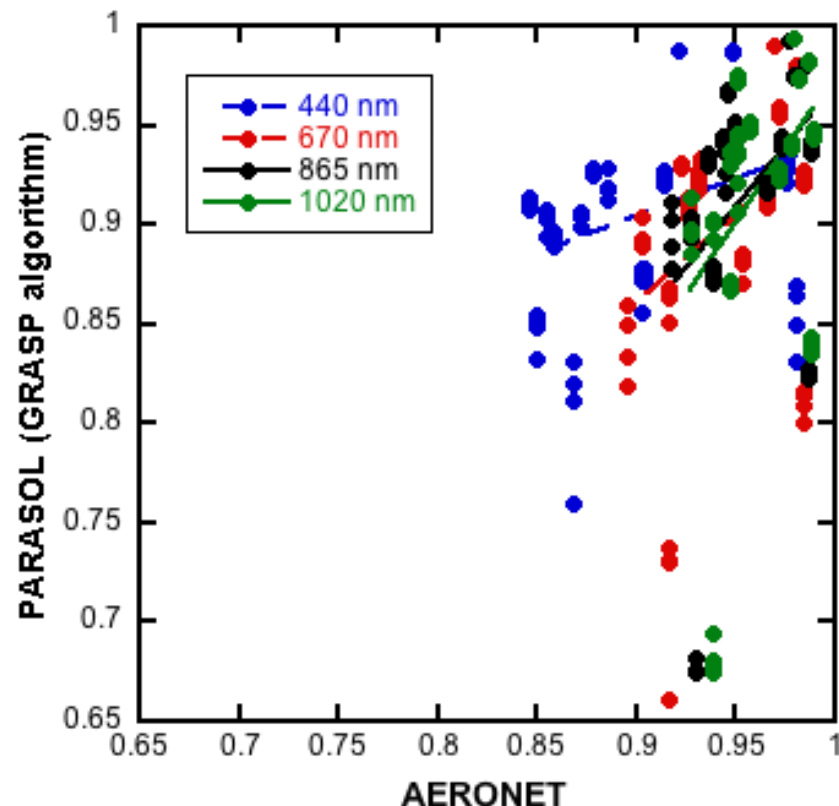
---  $y = 0.70542 + 0.26876x$   $R = 0.43754$

---  $y = 0.48299 + 0.49932x$   $R = 0.69482$

—  $y = 0.29752 + 0.69079x$   $R = 0.73451$

—  $y = 0.19564 + 0.79387x$   $R = 0.73262$

SSA.  $I$  - Retrieval



---  $y = 0.5662 + 0.37595x$   $R = 0.33855$

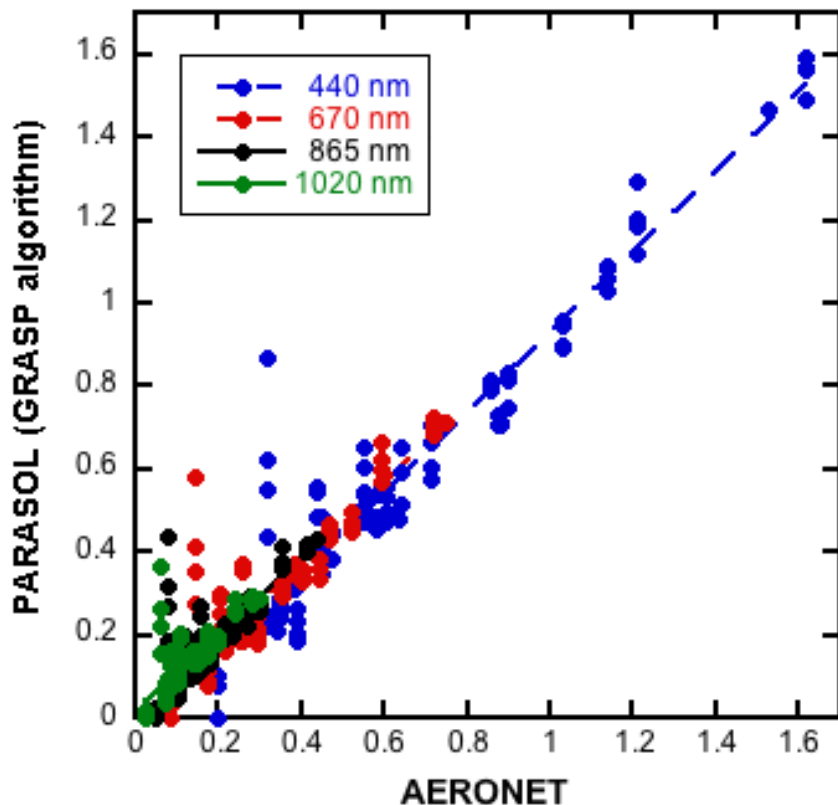
---  $y = 0.066682 + 0.88263x$   $R = 0.38326$

—  $y = -0.27308 + 1.2429x$   $R = 0.3699$

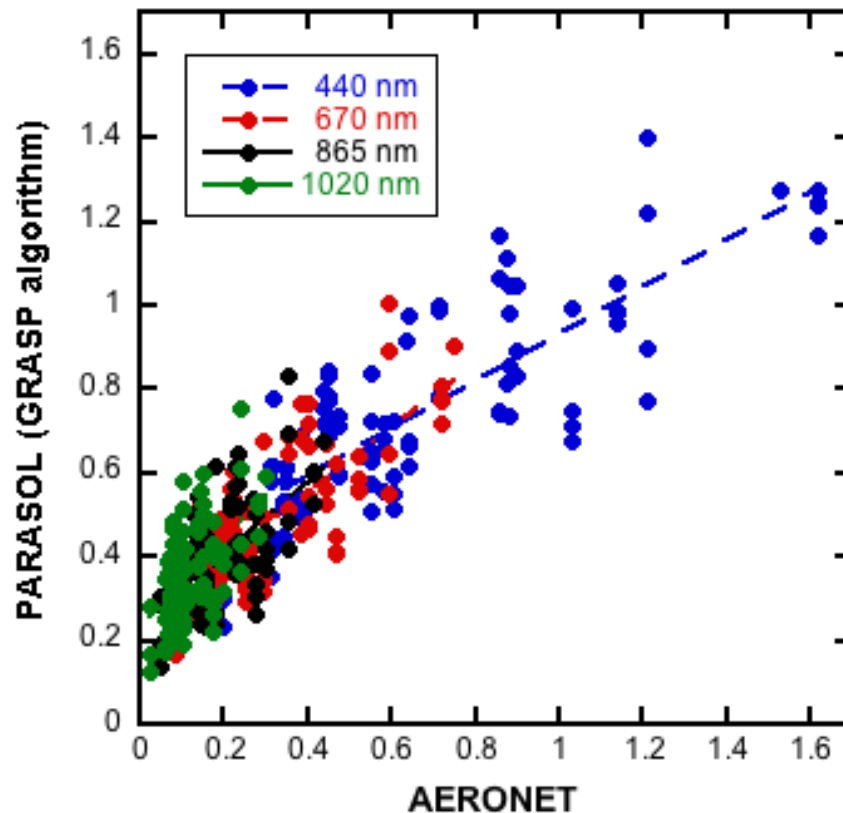
—  $y = -0.50576 + 1.48x$   $R = 0.40026$

# $I, Q, U$ retrieval vs $I$ -retrieval and $Q, U$ -retrieval: AOD (Mongu. August, September 2008)

AOD.  $I, Q, U$  - Retrieval



AOD.  $I$  - Retrieval



---  $y = -0.037907 + 0.96644x$   $R = 0.95542$

---  $y = -0.0045237 + 0.94776x$   $R = 0.89627$

—  $y = 0.014111 + 0.92516x$   $R = 0.82836$

—  $y = 0.021983 + 0.9304x$   $R = 0.78355$

---  $y = 0.36813 + 0.56655x$   $R = 0.82568$

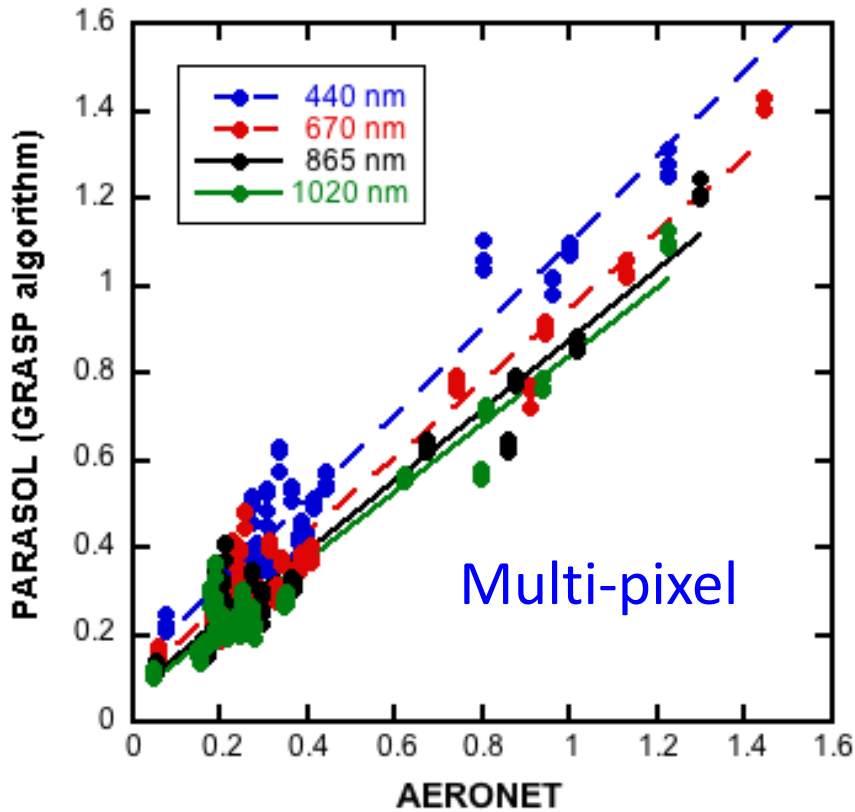
---  $y = 0.24546 + 0.76922x$   $R = 0.7652$

—  $y = 0.24517 + 0.82678x$   $R = 0.6151$

—  $y = 0.2315 + 1.0458x$   $R = 0.55699$

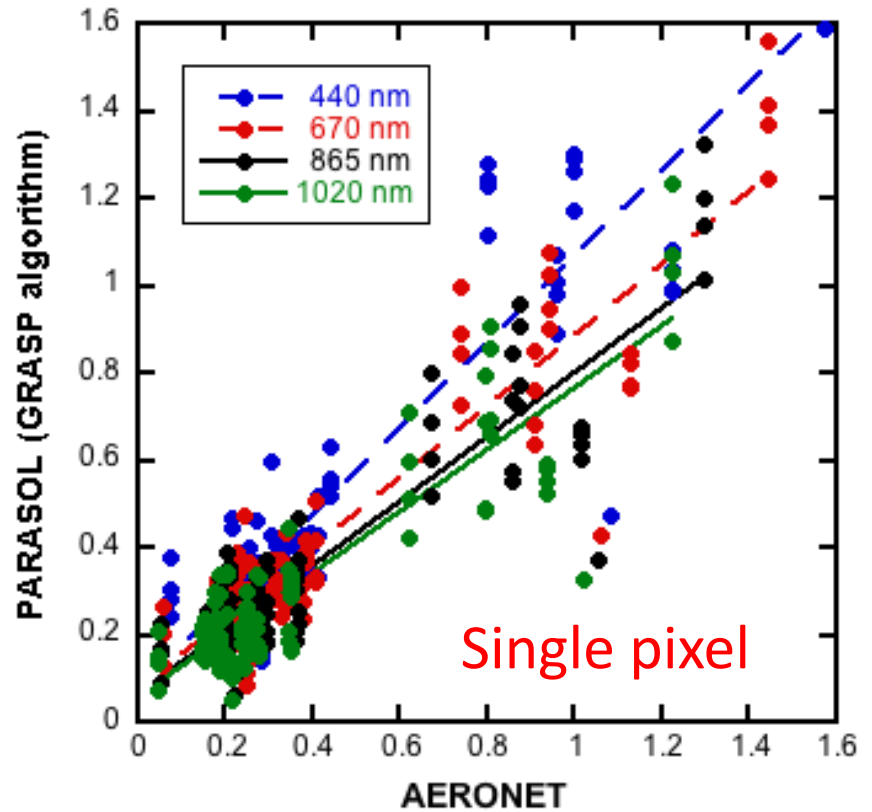
# Multi-pixel vs Single pixel retrieval: AOD (Banizoumbou)

AOD (Ross-Li+Maignan model)



$-\ - y = 0.12192 + 0.97819x \quad R = 0.97994$   
 $-\ - y = 0.087867 + 0.86168x \quad R = 0.97581$   
 $\text{—} y = 0.074249 + 0.8012x \quad R = 0.97066$   
 $\text{—} y = 0.06075 + 0.78051x \quad R = 0.96956$

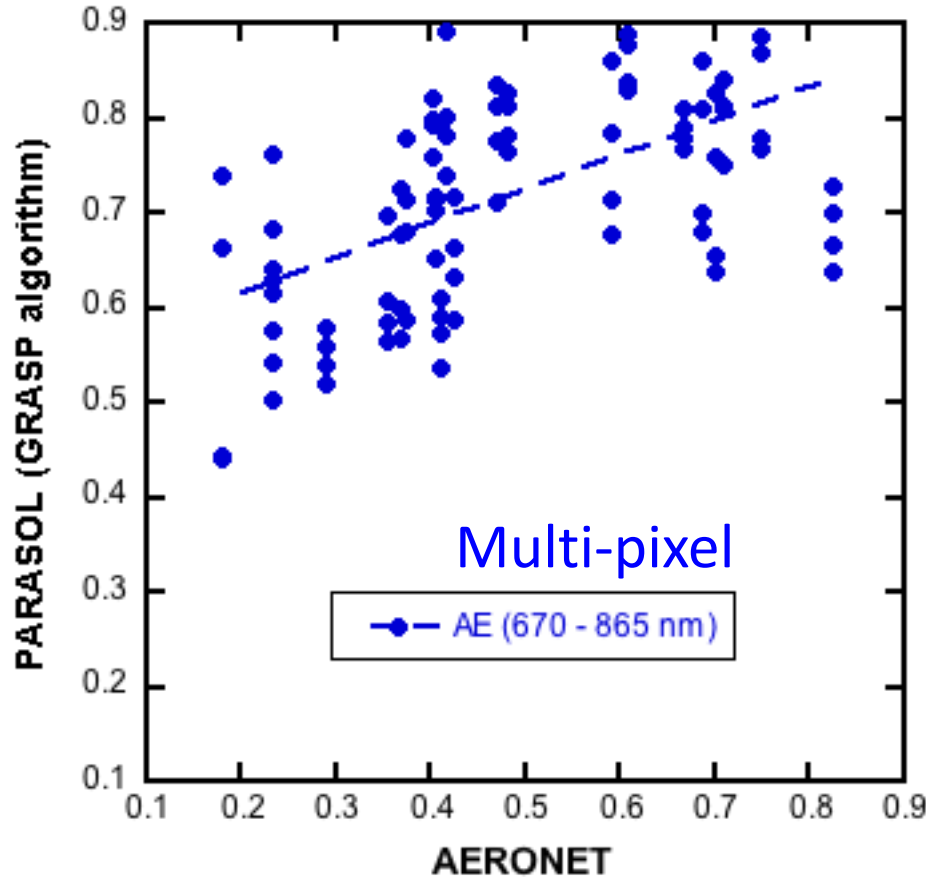
AOD (Ross-Li+Maignan model)



$-\ - y = 0.077448 + 0.98265x \quad R = 0.92246$   
 $-\ - y = 0.06989 + 0.82x \quad R = 0.92278$   
 $\text{—} y = 0.068237 + 0.73534x \quad R = 0.90682$   
 $\text{—} y = 0.058765 + 0.70787x \quad R = 0.89082^{35}$

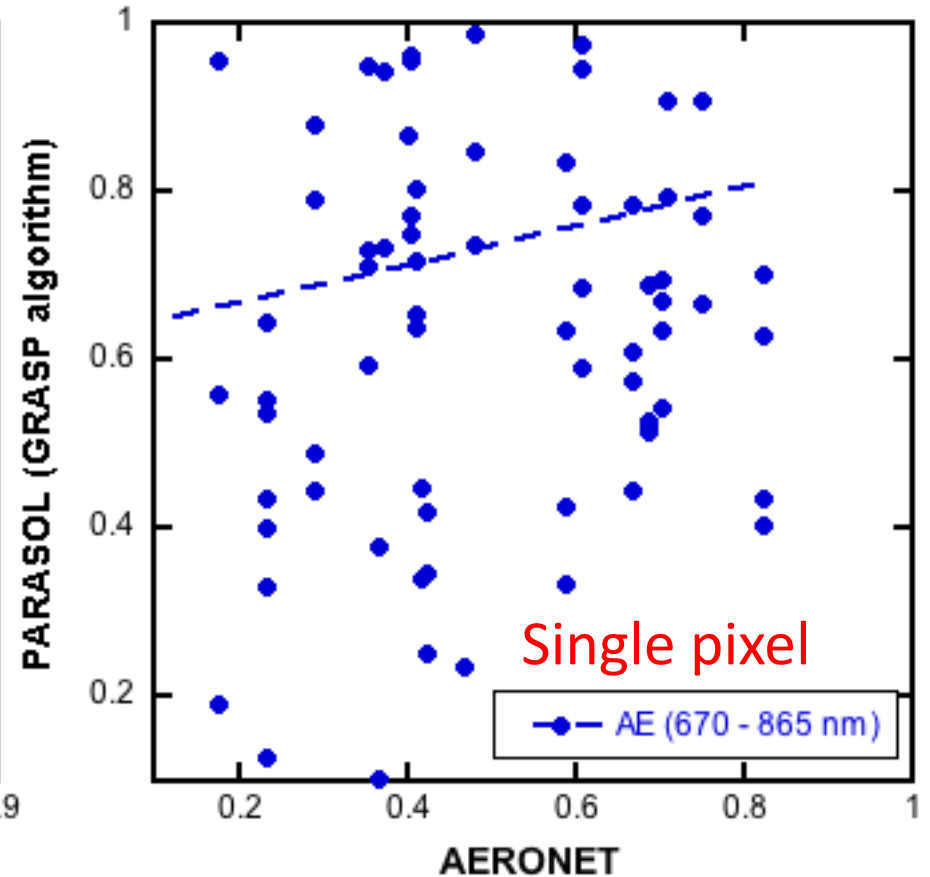
# Multi-pixel vs Single pixel retrieval: AE (Banizoumbou)

AE (Ross-Li+Maignan model)



— —  $y = 0.5438 + 0.36217x$   $R = 0.55666$

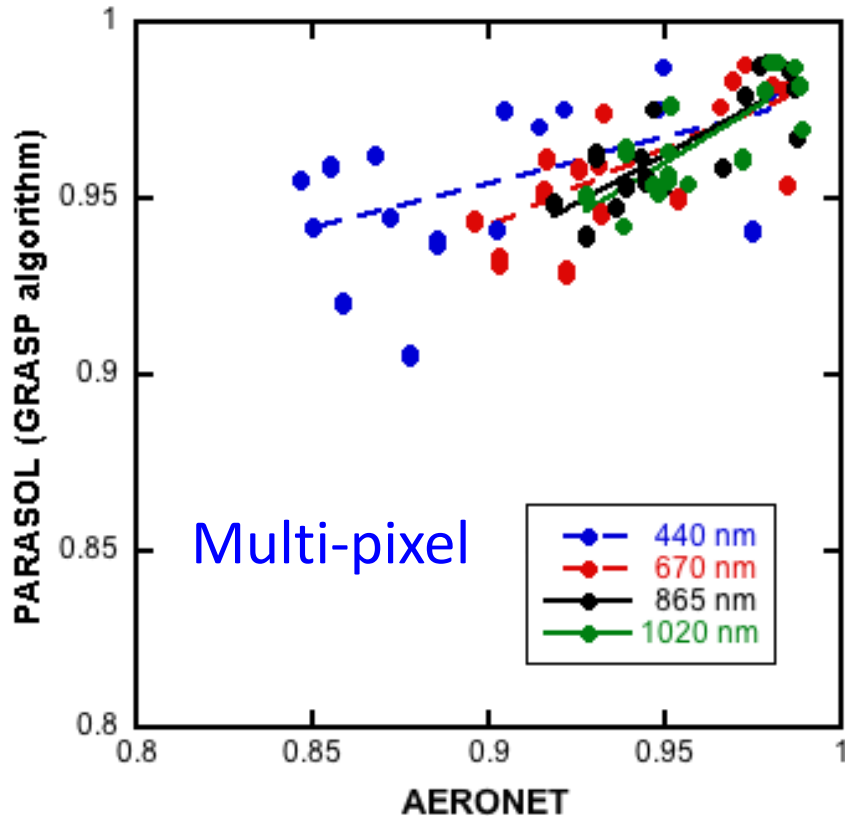
AE (Ross-Li+Maignan model)



— —  $y = 0.62026 + 0.22953x$   $R = 0.13322$

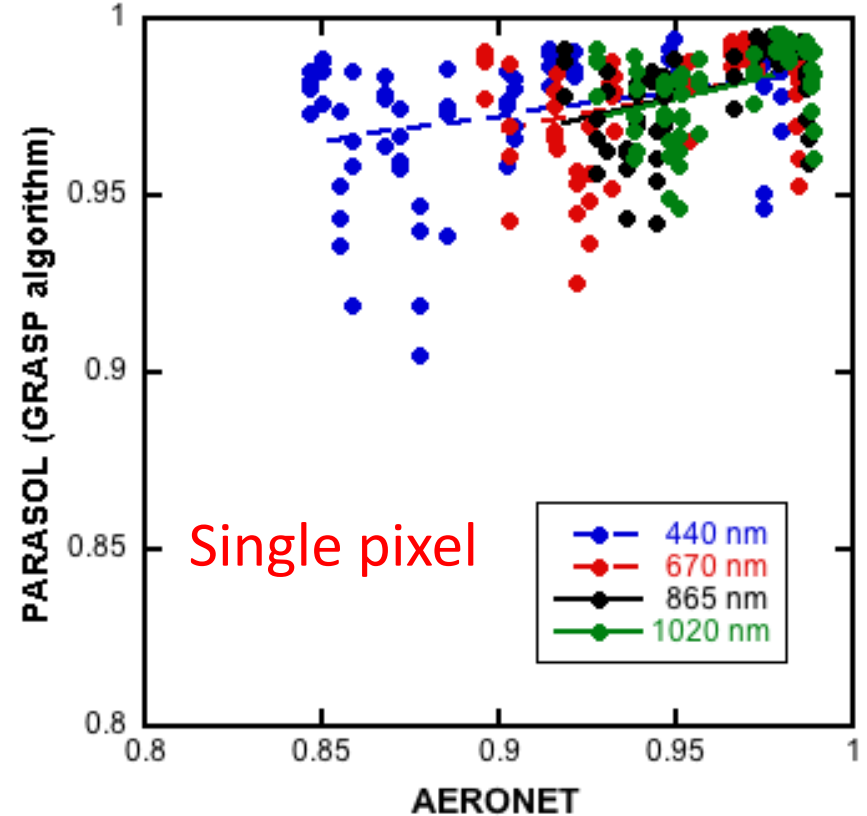
# Multi-pixel vs Single pixel retrieval: SSA (Banizoumbou)

SSA (Ross-Li+Maignan model)



$y = 0.7228 + 0.25749x$   $R = 0.49915$   
 $y = 0.54358 + 0.44259x$   $R = 0.7131$   
 $y = 0.44172 + 0.5481x$   $R = 0.80708$   
 $y = 0.39217 + 0.59789x$   $R = 0.799$

SSA (Ross-Li+Maignan model)



$y = 0.84577 + 0.14078x$   $R = 0.3042$   
 $y = 0.78305 + 0.20531x$   $R = 0.37627$   
 $y = 0.76297 + 0.22631x$   $R = 0.39847$   
 $y = 0.74845 + 0.24105x$   $R = 0.39955$