Comparison of three SeaWiFS Atmospheric Correction Algorithms for Turbid Waters using AERONET-OC Measurements

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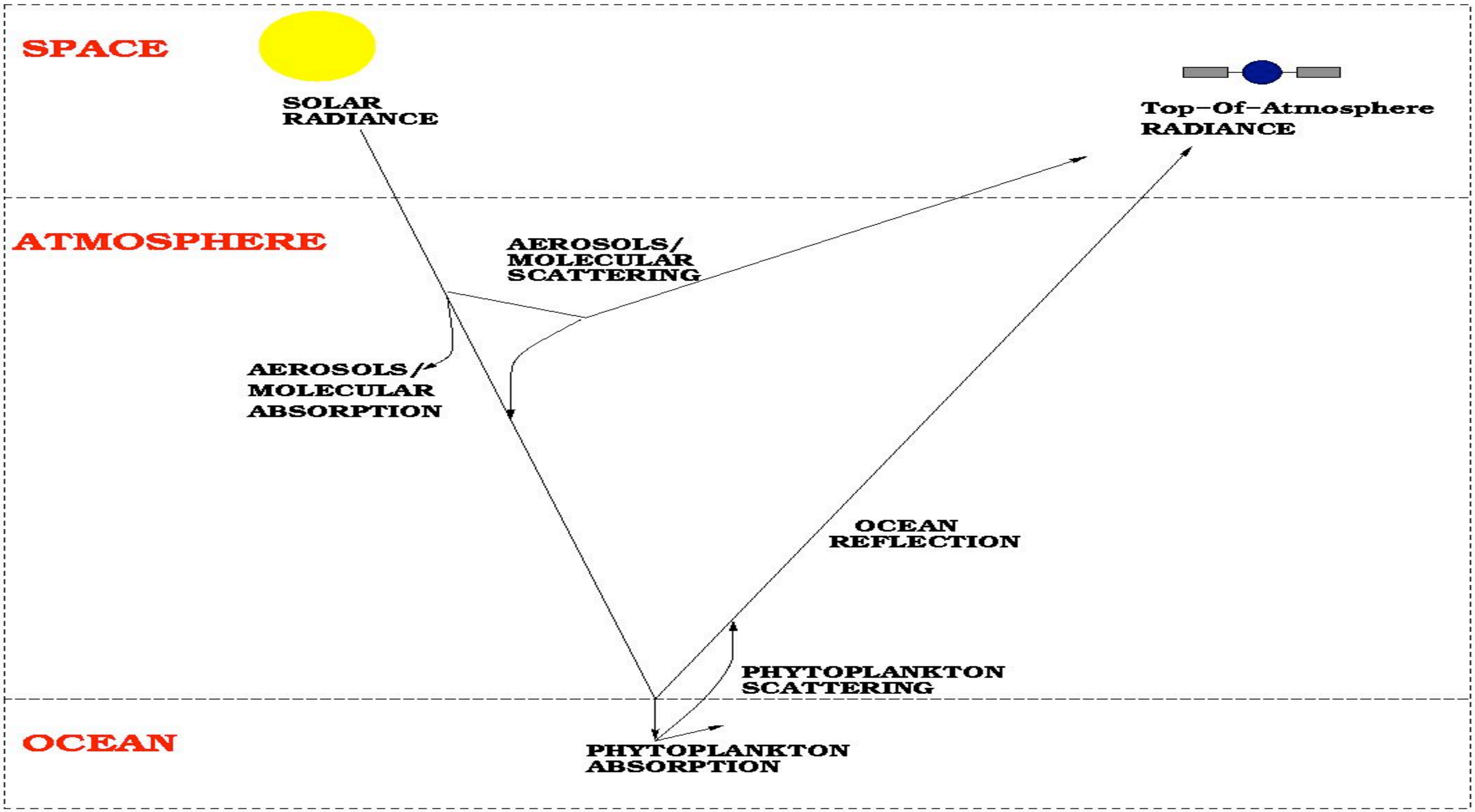
AERONET-OC worskhop
24th, February 2011

Context of the study

- SeaWiFS (R.I.P.): almost « 13 » years of data
  - Unique opportunity to study seasonal and intra-seasonal variability of IOPs in coastal waters
  - Need of very accurate Atmospheric Correction (AC)
- Since 2000: ~ half dozen AC for SeaWiFS
- Complement of the IOCCG report #10: « *Atmospheric Correction for Remotely-Sensed Ocean-Colour Products* » (Wang, 2010)
- **Goal:** understand where differences come from using *in-situ* and theoretical data to develop a new AC

Principle of Atmospheric Correction

- Radiative Transfer Equation: $L_{toa} = L_r + L_A + t * L_w$



Principle of Atmospheric Correction

- Radiative Transfer Equation: $$L_{toa} = L_r + L_A + t * L_w$$

OPEN OCEAN → L_w ~ 0 in NIR bands
→ L_{toa} ~ L_A in NIR bands
→ Determination of the aerosol properties
→ Determination of L_w in visible bands

TURBID WATERS → $L_w \neq 0$ in NIR bands
→ L_A over-estimated
→ Selection of aerosol model affected
→ Negatives L_w in blue bands

Atmospheric Correction Algorithms

- Three NIR ocean contribution removing/AC algorithms
  - Stumpf et al. (2003)/ Bailey et al., (2010) S03:
    - Based on Gordon and Wang atmospheric correction (GW94)
    - SeaWiFS/MODIS standard algorithm
    - Iterative process
    - Bio-optical model used to determine $b_b(670)$
  - Ruddick et al. (2000) R00:
    - Based on Gordon and Wang atmospheric correction (GW94)
    - Spatial homogeneity of the L_w(NIR) and L_A(NIR) ratios over the subscene of interest
    - [illegible]: Ratio of L_w(NIR) cst = 1.72
    - ε: Ratio of L_A(NIR) determined for each subscene
  - Kuchinke et al. (2009) K09:
    - Spectral optimization algorithm
    - Junge aerosol models
    - GSM bio-optical model (Garver, 2002)
    - Atmosphere and ocean coupled

DATA

- **Satellite data:**
  - (M)LAC SeaWiFS 1km at nadir → Processed with SeaDAS 5.4 and 6.1 (Fu et al., 1998)
  - nLw(412→865), [illegible](865), [illegible](510,865)

- ***In situ* data:** *AERONET-OC* network (Zibordi et al., 2006, 2009)

  - **Three sites:**
    - ***AAOT*: 2002-2007**
    - ***COVE*: 2006-2008**
    - ***MVCO*: 2004-2005**

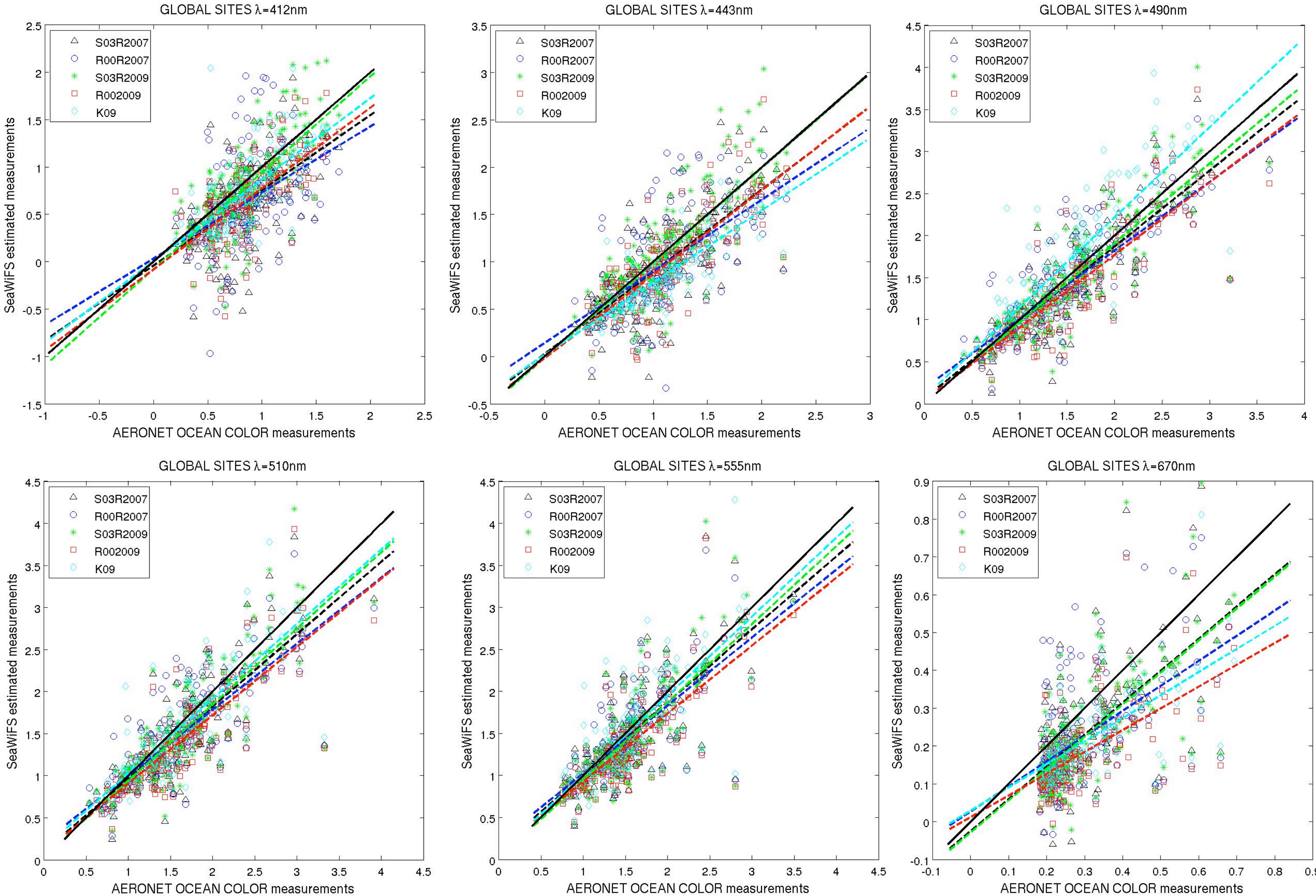
Results

- Only **turbid** waters (Robinson et al., 2003): nLw(670)>0.186

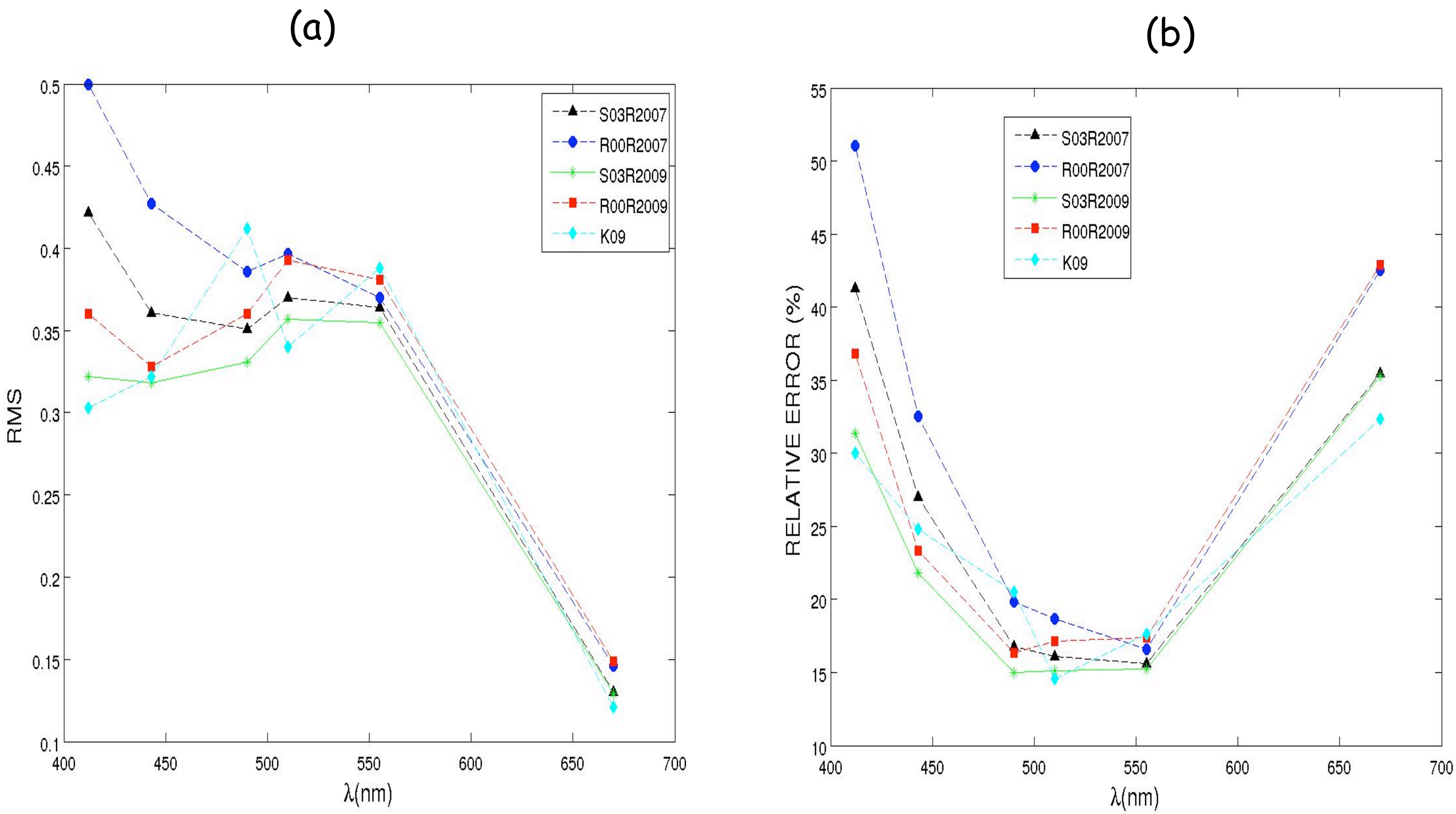
- Comparison of the normalized water-leaving radiances nL_w between 412 and 670 nm and of the aerosol optical properties (the Ångström coefficient α(510,865) and the optical thickness τ(865))

	MVCO	AAOT	COVE	TOTAL	nL_w(412) <0
S03R2009	20	163	18	**201**	7
R00R2009	19	129	17	165	6
Kuchinke	13	134	13	160	**0**

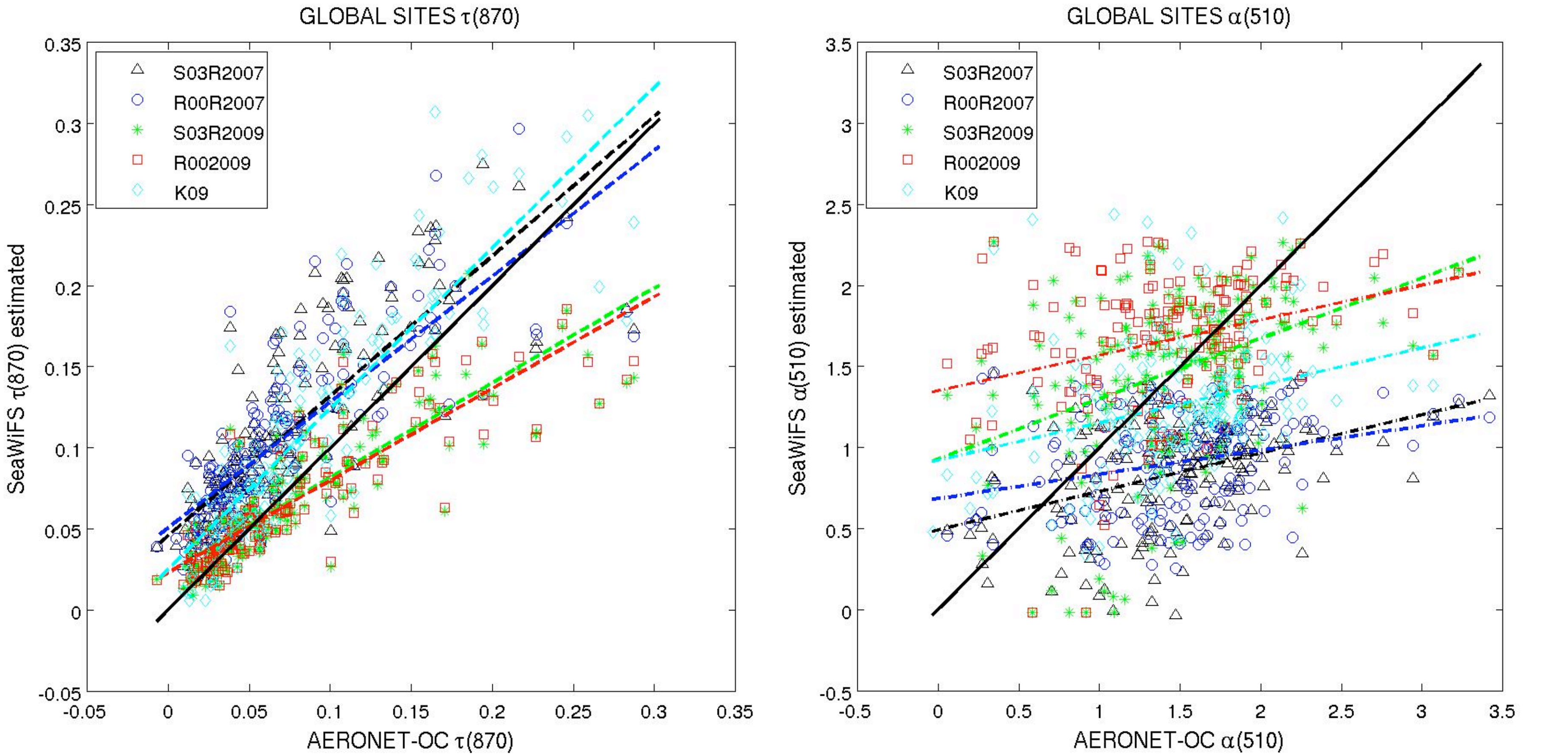
# of matchups for each algorithm and each AERONET-OC site



Scatter plots of the retrieved nL_w() by S03R2007 (△R00R2007 (), S03R2009 (*), R00R2009 () and K09 () vs AERONET-OC measurements at the MVCO and AAOT sites. The continuous line represents the 1:1 line, the line -- represents the linear regression lines.

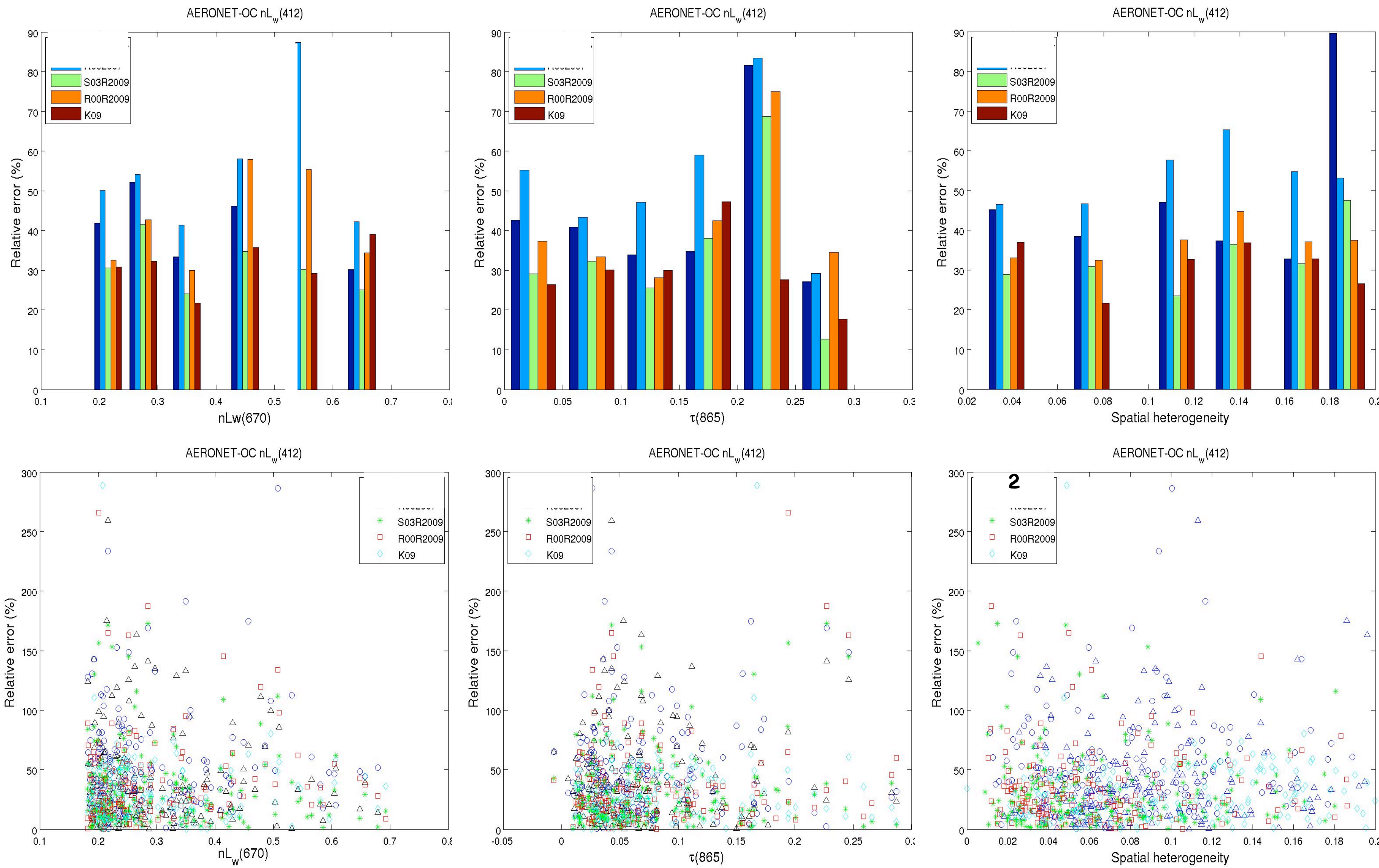


Variation of the RMS (a) and the relative error (b) as a function of the wavelength obtained with S03R2007 ( ), R00R2007 ( ), S03R2009 (*), R00R2009 ( ) and K09 ( ).



Scatter plots of the retrieved τ(865) (left panel) and α(510) (right panel) by S03R2007 (△), R00R2007 (○), S03R2009 (*), R00R2009 (□) and K09 (◇) vs AERONET-OC measurements at the MVCO and AAOT sites. The continuous line represents the 1:1 line, the line -- represents the linear regression for S03 and the line -.- represents the linear regression for R00.

Sensitivity to environmental factors



Variation of the relative error on nLw(412) as a function of the values of (top to bottom):
(i) nLw(670) (e.g., turbidity, (ii) τ(865) and (iii) the spatial homogeneity.

Impact of the aerosol models

- S03 and R00
  - 80 models based on AERONET *in situ* measurements → more realistic
  - Ratio of L_A(NIR) cst over the region of interest → way to calculate □ very sensitive → **Moderate to big impact** of the aerosol parameter □ for **Ruddick for nLw**
  - **"no effect"** on the estimation of nLw with standard algorithm R2009 (Ahmad, 2010)
  - **Improvement of the estimation of the aerosol properties**
    - **Increase of □(510,865)**
    - **Decrease of □(865)**

- K09:
  - Junge power-law distribution
  - Mainly designed for absorbing carbonaceous aerosols →**is it the case over our three sites??**

Impact of the bio-optical model

- S03: **Big impact** of the change of the definition of nLw and $b_b(670)$
  - **Better accuracy**, more noticeable for short wavelengths
  - **Less negative values**
- R00: **Very weak impact**
  - ratio of nLw(NIR) cst over the region of interest
- K09: **Big impact**
  - **Okay for coastal regions where bio-optics are uniform but seasonally varying**
  - **need to tune the bio-optical parameters in GSM model**

Conclusions (1/2)

- Comparison of 3 SeaWiFS Atmospheric Correction algorithms
  - SeaWiFS standard algorithm: **best overall estimates**
  - Ruddick algorithm: **less accurate**
  - Kuchinke: **good estimates for short wavelengths**

Conclusions (2/2)

- **Sensitivity tests** on assumptions of each algorithm
  - *Ruddick: High impact* of a bias of the value of the aerosol ratio ε
  - *Stumpf R2009: Low impact of the new aerosol models for nLw; Moderate to High impact of the new definition of $b_b(670)$*
  - *Kuchinke: High impact of the Junge aerosol models; "high impact" of the bio-optical parameters in GSM → need to tune the bio-optical models*

Perspectives

- Paper in revision in Remote Sensing of Environment journal
- PhD started on this subject on Oct. 2010: C. Goyens
- Adding others SeaWiFS AC: Hu (2000), Shanmugam (2007), Spurr (2007)
- Adding other AERONET-OC sites: Dalen Tower, Helsinki Lighthouse, Lucinda
- Adding very turbid waters sites (French Guyana, Eastern English Channel)
- Complete sensitivity study based on synthetic data → **Comprehension** of the **assumptions** of the AC
- Others OC sensors for all AERONET-OC sites:
  - MODIS- Aqua: SWIR (Wang, 2005), Schroeder (2007), …
  - MERIS: Moore (1999), Doerrfer (2007), Schroeder (2007), Brajard (2010), S03, POLYMER (Steinmetz, 2011), …

→ Ultimate goal: Development of a new algorithm:

→ SWIR seems the most interesting AC but no SWIR bands in the near-future sensors (to my knowledge)

→ Based on iterative process (optimization technique)

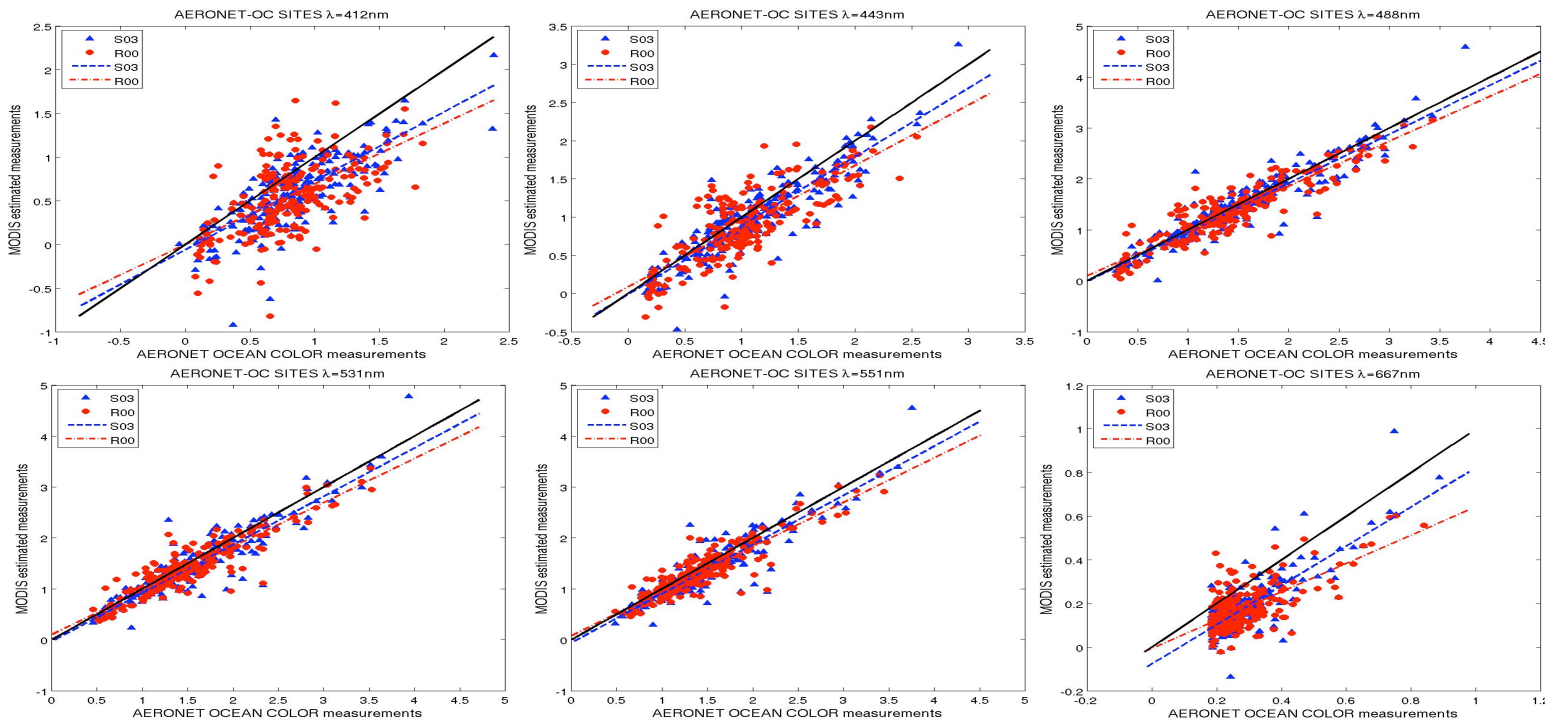
→ Taking account of the spectral shape of nLw

→ Adding constrains as R00 ratios

→ Work on the bio-optical model in coastal waters (based on IOPs)

Same work for MODIS-Aqua

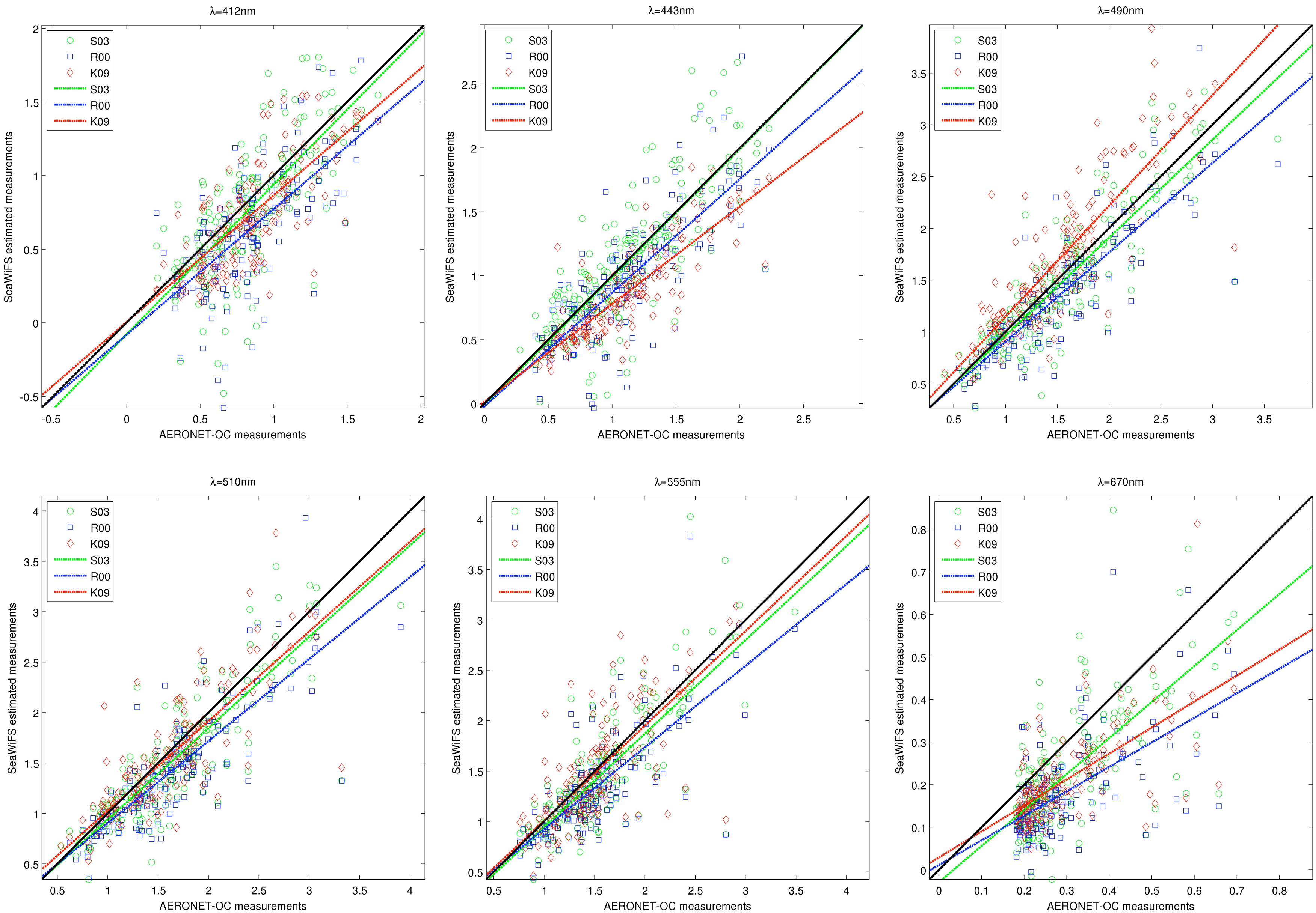
- S03 and R00 for two AERONET-OC sites: AOOT, MVCO for previous reprocessing (R2007)



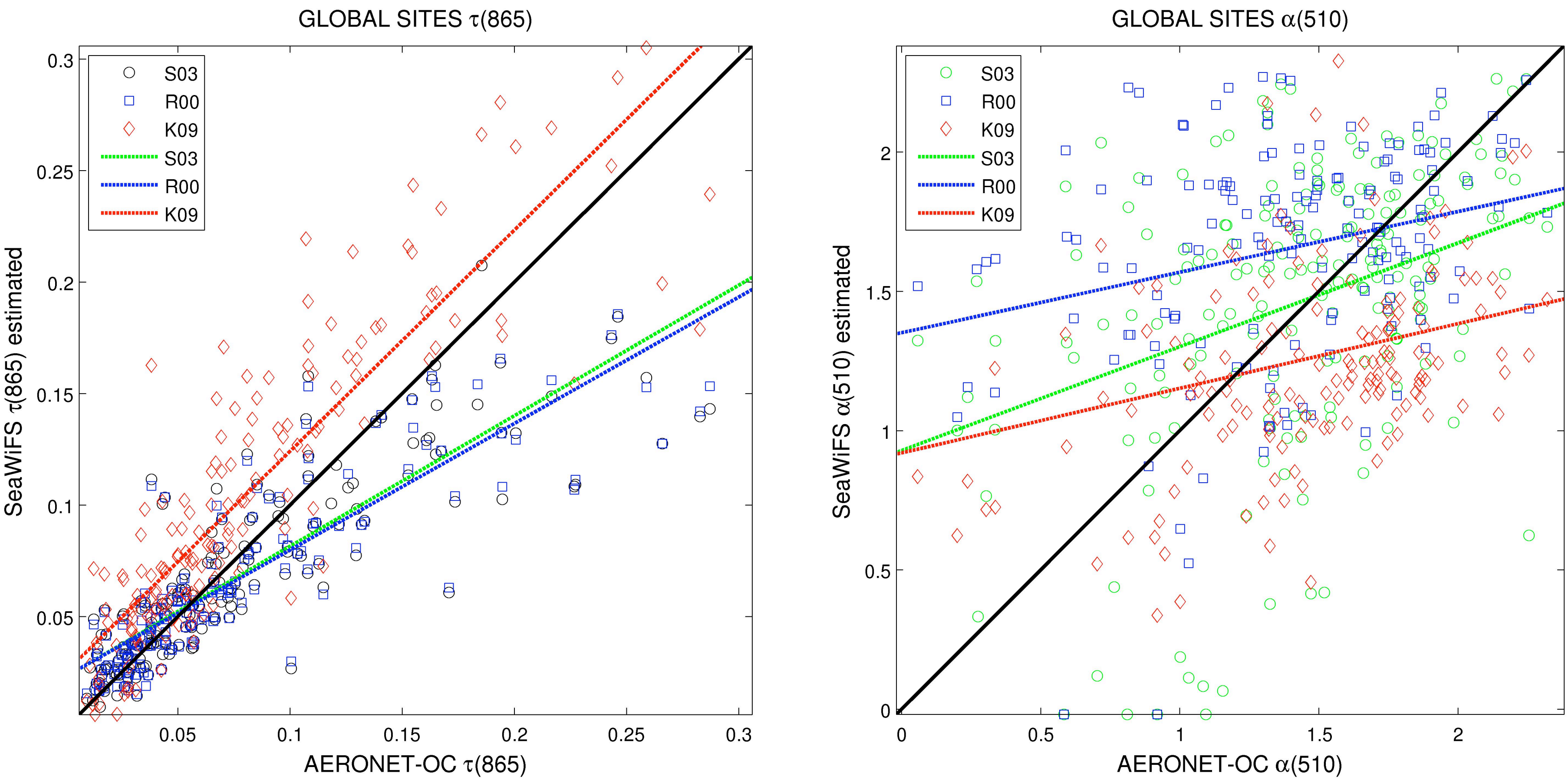
Stumpf	*Lwn(412)*	*Lwn(443)*	*Lwn(488)*	*Lwn(531)*	*Lwn(551)*	*Lwn(667)*
RMSE	**0.353**	**0.256**	**0.243**	0.261	0.254	0.129
Relative error (%)	**41.31**	**22.32**	**13.06**	12.02	12.53	41.06
Ruddick	*Lwn(412)*	*Lwn(443)*	*Lwn(488)*	*Lwn(531)*	*Lwn(551)*	*Lwn(667)*
RMSE	0.425	0.323	0.255	0.248	0.235	0.136
Relative error (%)	55.66	32.18	16.74	13.29	12.66	41.77

Acknowledgments

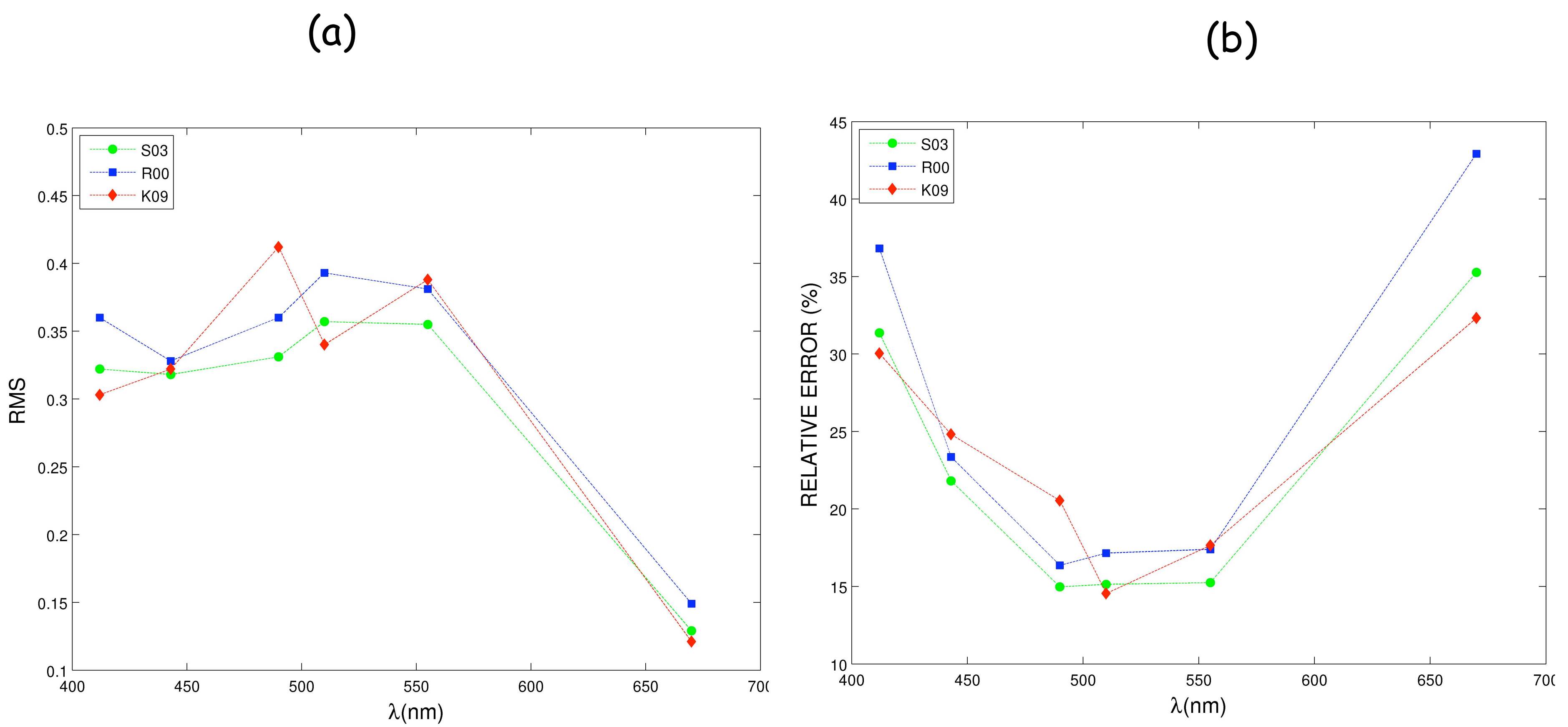
- CNES for funding through the TOSCA program
- Dr. Brent Holben and co-workers for maintaining the COVE SeaPRISM site
- GSFC NASA for providing the SeaWiFS L1 data
- OBPG for advices and discussions for the use of SeaDAS



Scatter plots of the retrieved nL_w( ) by S03 ( ), R00 ( ) and K09 ( ) vs AERONET-OC measurements at the MVCO, COVE and AAOT sites. The continuous line represents the 1:1 line, the colored lines represent the linear regression lines.



Scatter plots of the retrieved $\tau(865)$ (left panel) and $\alpha(510)$ (right panel) by S03 ( ), R00 ( ) and K09 ( ) vs AERONET-OC measurements at the MVCO, COVE and AAOT sites. The continuous line represents the 1:1 line, the colored lines represent the linear regression lines.



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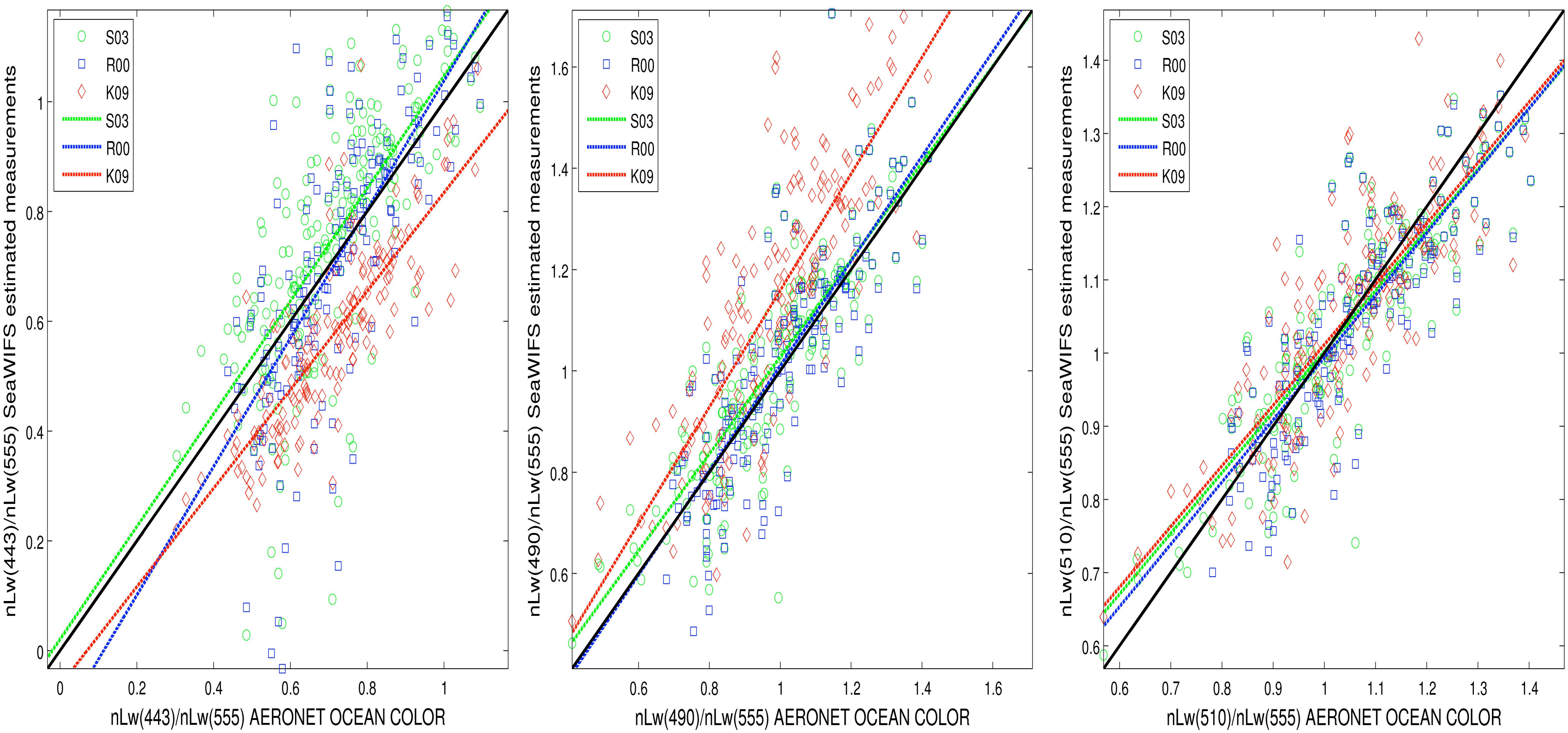


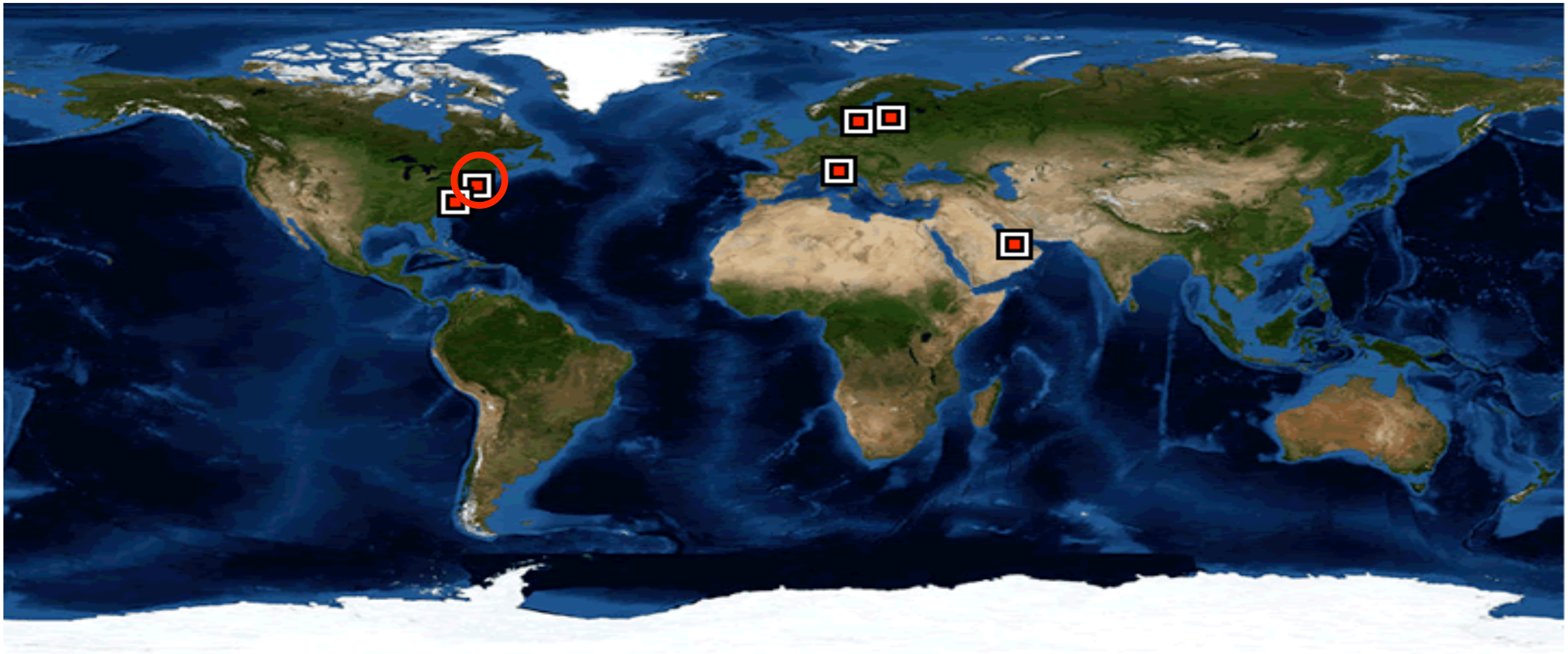
Fig.3. Same as Fig.2 but for the ratios from the left to the right: $nL_w(443)/nL_w(555)$, $nL_w(490)/nL_w(555)$, $nL_w(510)/nL_w(555)$.

Protocols of comparison:match-ups

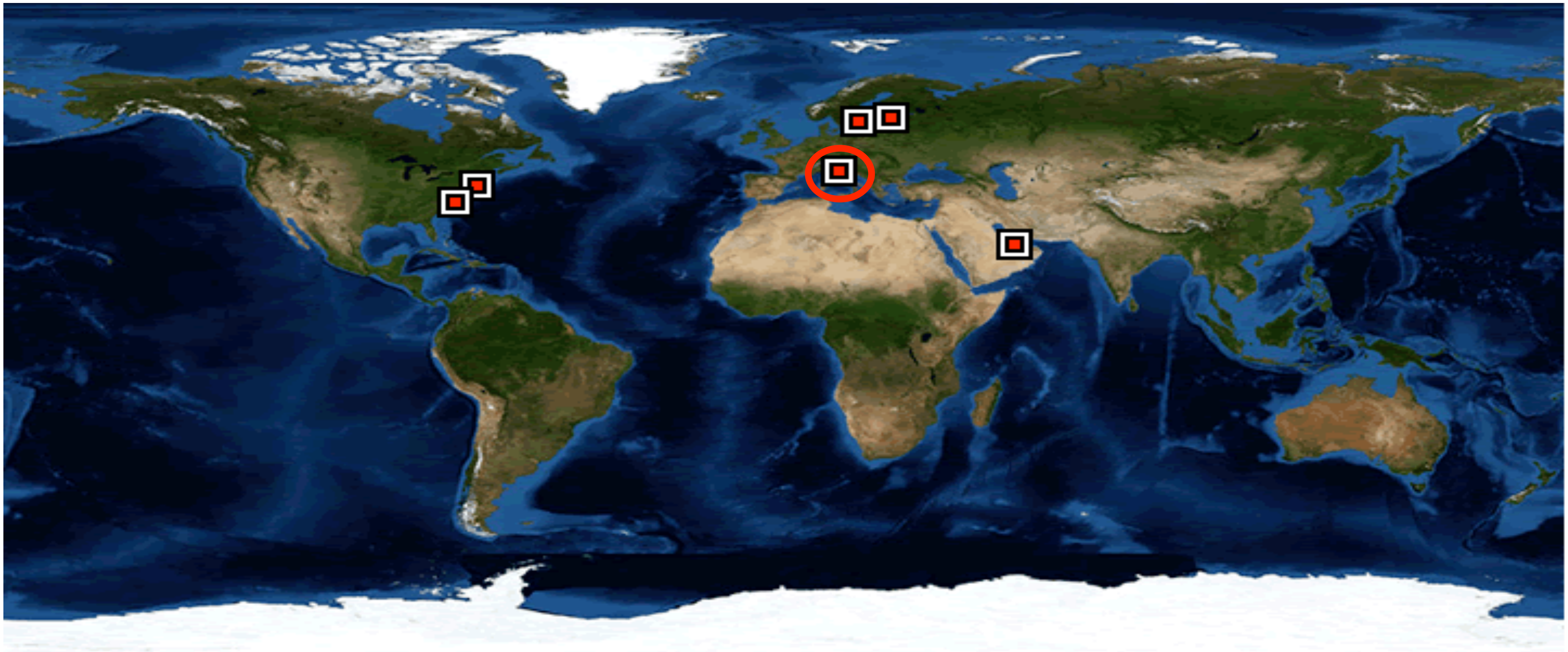
- Similar protocol that Bailey & Wang (2001) and Feng et al. (2008)
- 2-hour time window
- Valid pixel criterion:
  - No exclusion flags (land effect, high sun glint, high solar zenith (higher than 70^o), high satellite viewing zenith (higher than 60^o), cloud or ice, and total radiance saturation)
  - Match-up accepted if all 6 (9 for AAOT) 'valid'.
- Mean on 2x3 pixels box for MVCO (3x3 box for AAOT and COVE)
- Match-up pair accepted if coeff. spatial variation < 0.2 in [illegible](865).

SeaWiFS 2009 reprocessing

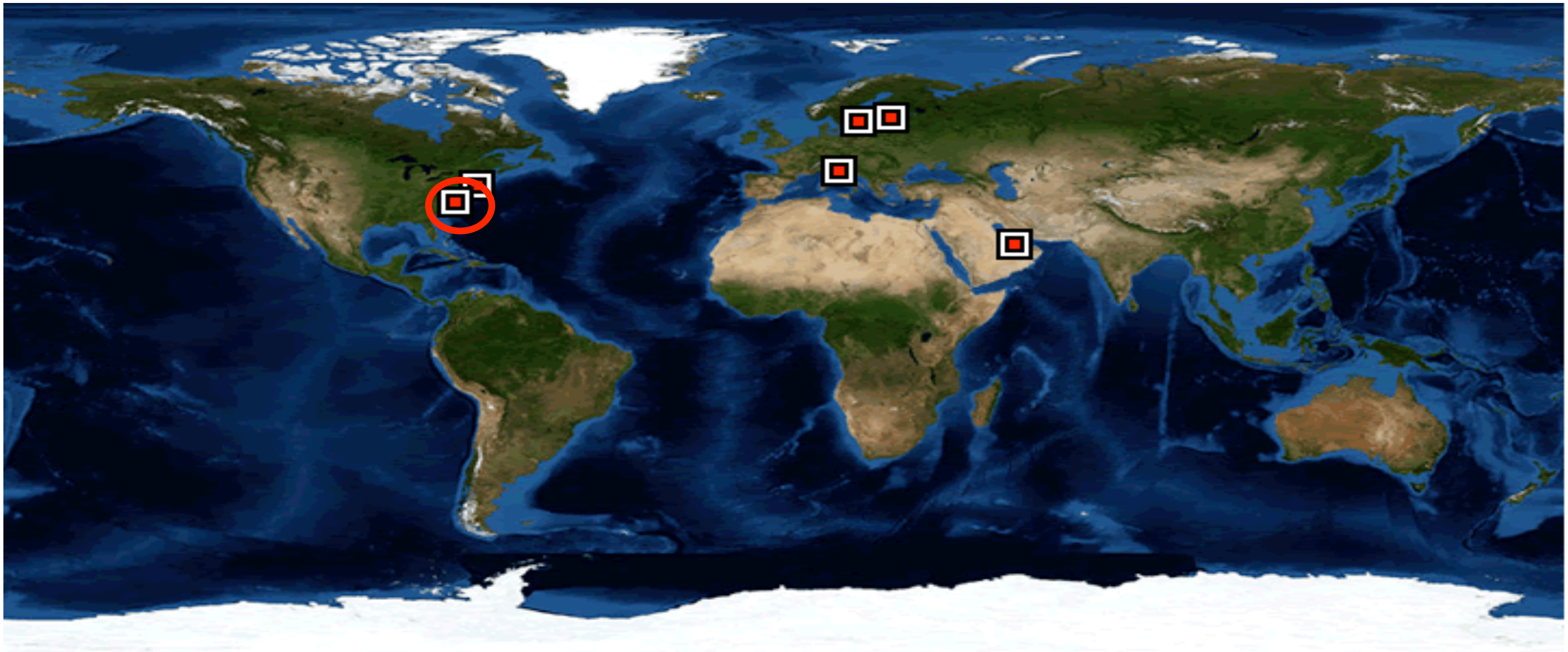
- Two SeaWiFS reprocessings: R2007 and R2009 for S03 and R00
  - **Change in aerosol models**
    - R2007: 12 Gordon and Wang (1994) models
    - R2009: 80 models based on AERONET *in situ* measurements → more realistic
  - **Change in the bio-optical model (Bailey, 2010)**
    - Change of the definition of nLw and $b_b(670)$
      - Alternative spectral backscattering relationship
      - Alternative estimate for absorption in the red wavelength
    - Revised iteration scheme
  - Change in vicarious calibration (Stumpf, 2010)



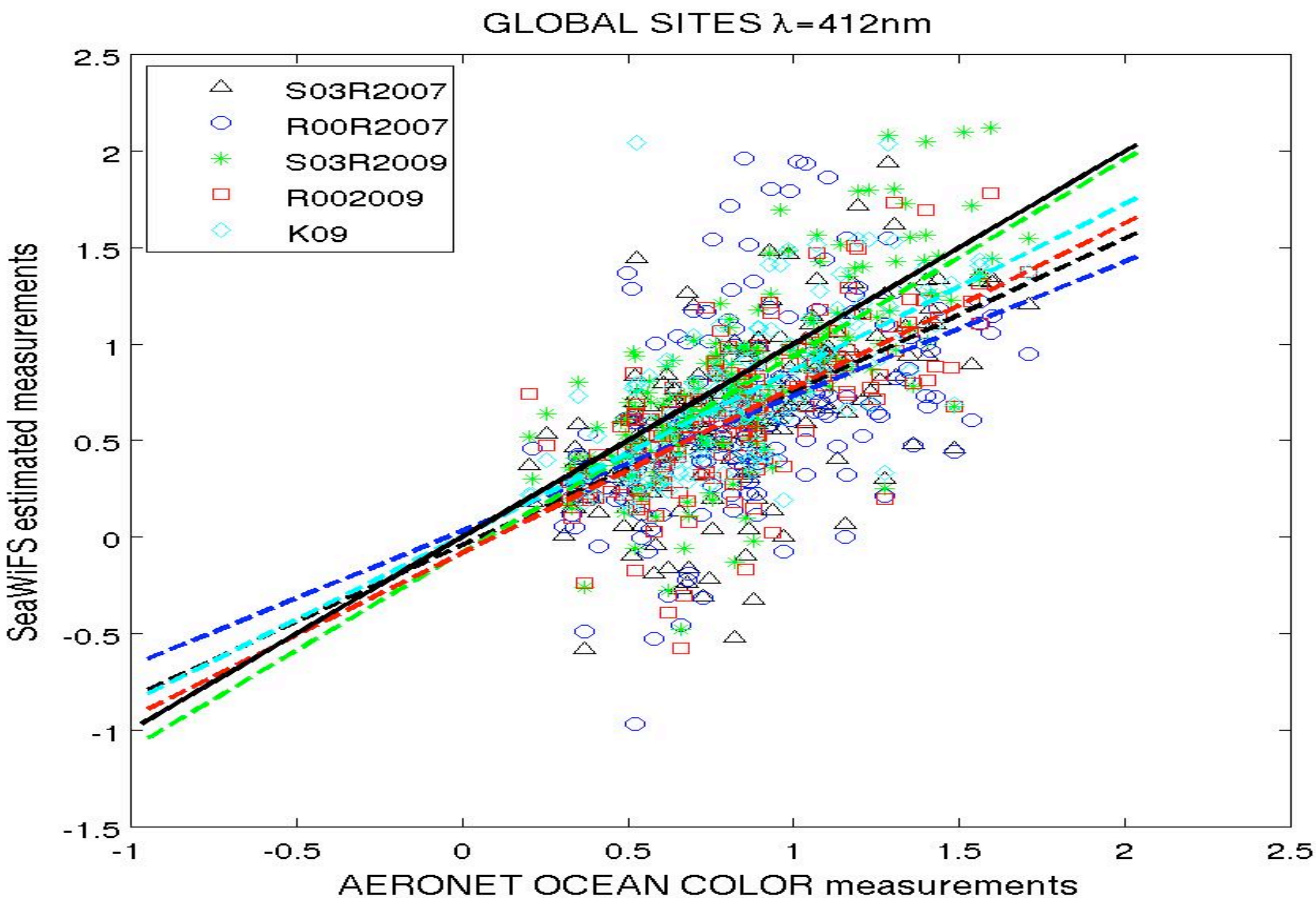
- *MVCO* (Feng et al., 2008) :
  - North Atlantic Bight: 41.33°N and 70.57°W
  - 5 km offshore
  - 14 months: Feb. 2004 →Nov. 2005
  - Moderately dominated by sediments
  - TSM: 1.5 +/-0.9 $mg.L^{-1}$; a_{ys}=0.12+/-0.01 m^{-1}



- *AAOT* (Zibordi et al., 2006) :
  - Northern Adriatic Sea: 45.31°N; 12.50°E
  - 14.8 km off the Venice Lagoon
  - 68 months: Apr. 2002 →Nov. 2007
  - Characterized by case-I (65%) and –II waters (35%)
  - TSM: 1.1 +/-0.7 mg.L^{-1}; a_{ys}=0.20+/-0.10 m^{-1}



- *COVE* (Zibordi et al., 2009) :
  - Chesapeake Bay offshore: 36.90°N; 75.71°E
  - 25 km off Virginia Beach, Virginia
  - 24 months: Apr. 2006 →Dec. 2008
  - Moderately dominated by sediments
  - TSM: a_{ys}=0.17+/-0.06 m^{-1}



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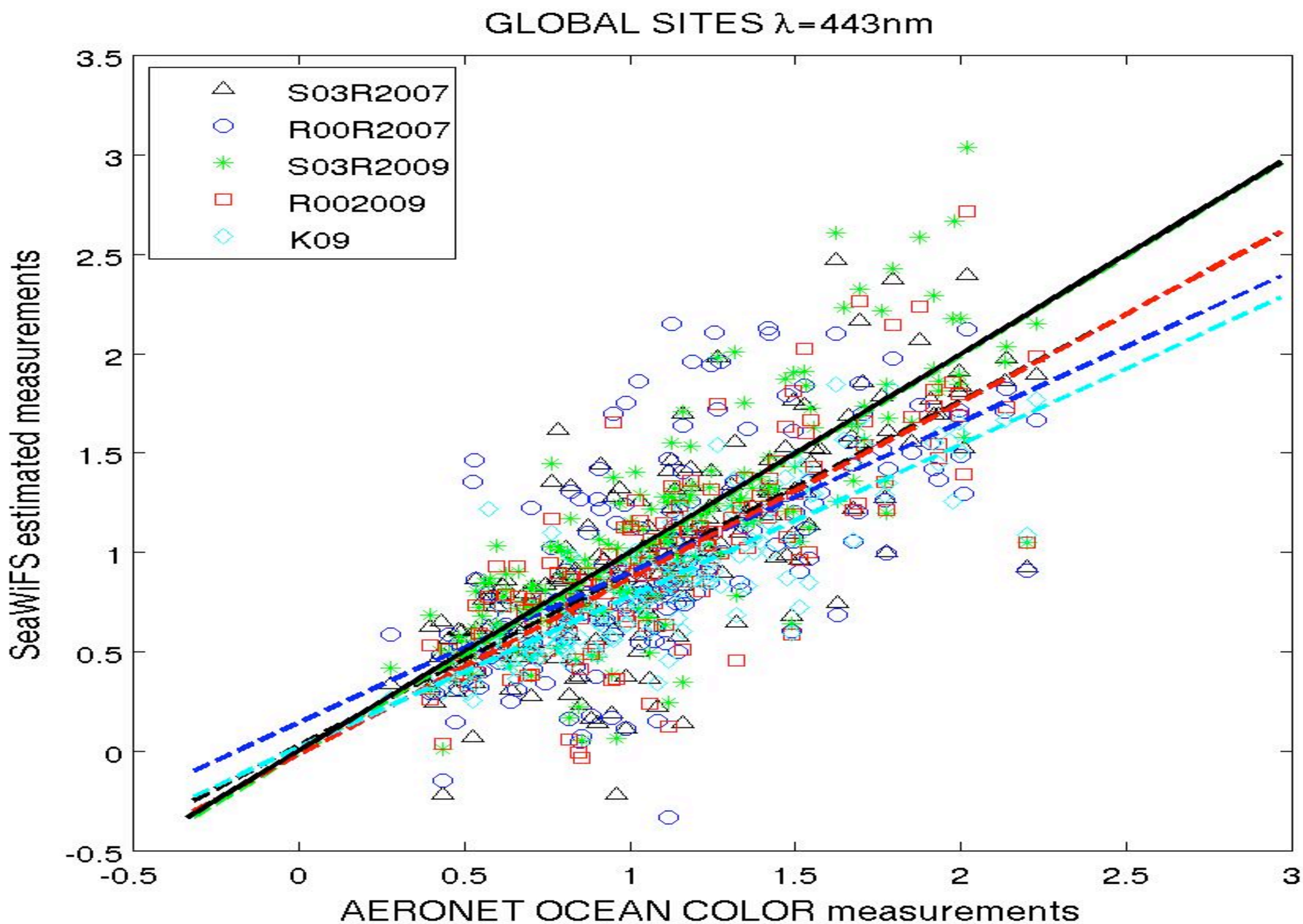

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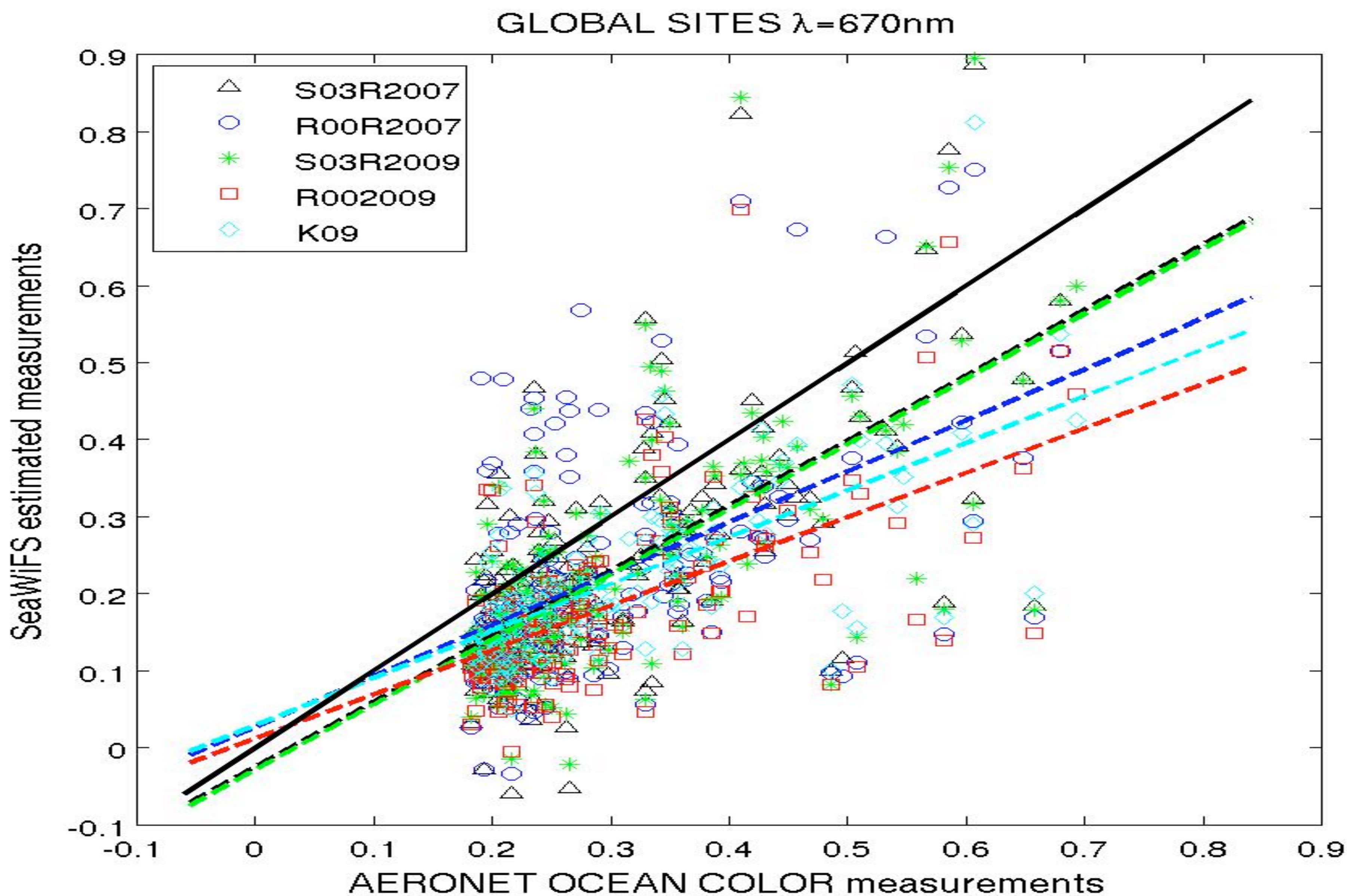

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Conclusions (3/3)

- ***Time processing:***
  - Standard algorithm: **fastest algorithm**
  - Kuchinke: **very time consuming** (as any optimization technique)
  - Ruddick: **twice slower than standard algorithm** (need to process two times the same image)