Uncertainties of Remote Sensing Reflectance

Synthesis of published methods & colocation approach

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Comparison with in situ data (validation)


**MODIS**

![MODIS graph](image)

**MERIS**

![MERIS graph](image)

**AAOT**

![AAOT graph](image)

**MG5S7/8 + GLI**

![MERIS / GLI graph](image)

$\Delta$: RMS difference

Mélin & Franz 2014

Jamet et al. *RSE* 2011

Goyens et al. *RSE* 2013
$R_{RS}$ validation results $f^n$ of Case1/Case2, $ssa$, $\tau_a$, geometry...

Mélin et al. *RSE* 2007

$R_{RS}$ validation results $f^n$ season, geometry....

Zibordi et al. *RSE* 2012

SeaWiFS

MODIS-A

MODIS-T
Validation results $f^n$ of optical water types (classes)

Goyens et al. RSE 2013
MODIS over coastal waters for 3 ACs

Mélin & Franz 2014
MODIS at AAOT

Moore et al. RSE 2009

Moore et al. RSE 2015
SeaBASS
Application to the OC Climate Change Initiative (CCI)

Definition of uncertainty for each optical water type

Moore et al. (2009)

- Compute class membership $w_{k,i}$ for each class $k$ and each match-up $i$

- Compute validation stat for each class $k$:

$$
\Delta_k^2 = \frac{\sum_{i=1}^{N} w_{k,i} (x_{i,s} - x_{i,f})^2}{\sum_{i=1}^{N} w_{k,i}}
$$

RMSD

$$
\delta_k = \frac{\sum_{i=1}^{N} w_{k,i} (x_{i,s} - x_{i,f})}{\sum_{i=1}^{N} w_{k,i}}
$$

BIAS

Difference between satellite and field values
Application to any grid point:

- For pixel $p$, compute class membership $w_{k,p}$ for each class $k$

- Compute uncertainty for pixel $p$:
  \[
  \Delta_p^2 = \frac{\sum_{k=1}^M w_{k,p} \Delta_k^2}{\sum_{p=1}^M w_{k,p}}
  \]
  \[
  \delta_p = \frac{\sum_{k=1}^M w_{k,p} \delta_k}{\sum_{k=1}^M w_{k,p}}
  \]

Dominant optical water type

See poster! Jackson et al. #64
Algorithm-based approach – Hu et al. *RSE* 2013

Based on the comparison of the outputs of 2 Chla algorithms: OC4v4 and OCI (3-band subtraction method)

Hypothesis: If ~identical outputs, then $R_{RS}$ close to ‘true’ value

Uncertainties (relative and absolute): Standard deviation of differences with respect to these ‘true’ data, as $f_n$(Chla)

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**Fig. 7.** Absolute uncertainties (in $R_{rs}$ units, $\Omega$ of Eq. 3) of SeaWiFS and MODISA $R_{rs}$ data for the North Atlantic (NA) and South Pacific (SP). The x-axis is Chl$_{OC4}$. About 68% of the non-flagged (i.e., valid) pixels have $R_{rs}$ errors (gauged against the corresponding $R_{rs,true}$) less than the uncertainties. $R_{rs}$ noise has been removed using a 3 x 3 median filter before uncertainty calculations. Data are listed in Table 3.
Other methods

- Sensitivity analyses, simulated datasets, boot-strapping...
  - Bulgarelli et al., *Ocean.* 2003, IOCCG #10, 2010, Steinmetz et al. *OE* 2011, etc...

This session:

- Bayesian method  
  - Frouin & Pelletier *RSE* 2015
- Uncertainty propagation  
- NN-based method
Uncertainty Estimates by Colocation

SeaWiFS, MODIS-A, MERIS data
Remote Sensing Reflectance $R_{RS}(\lambda)$ expressed on common $\lambda$'s by a band-shifting process

Inter-Comparison per cell (1/3rd deg.) and day

Total number of match-ups
SWF/MOD 2003-2007

Mélin et al., RSE submit
Sensor 1 \((x_i)_{i=1,N}\) and Sensor 2 \((y_i)_{i=1,N}\):

**mean absolute relative difference**  
\[ |\psi| = \frac{1}{N} \sum_{i=1}^{N} \frac{2|y_i - x_i|}{y_i + x_i}; \quad [\%] \]

**mean relative difference (relative bias)**  
\[ \psi = \frac{1}{N} \sum_{i=1}^{N} \frac{2(y_i - x_i)}{y_i + x_i}; \quad [\%] \]

**mean difference (bias)**  
\[ \delta = \frac{1}{N} \sum_{i=1}^{N} (y_i - x_i) \quad [sr^{-1}] \]

**RMS difference**  
\[ \Delta = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (y_i - x_i)^2} \quad [sr^{-1}] \]

**unbiased RMS difference**  
\[ \Delta_u = \sqrt{(\Delta^2 - \delta^2)} \quad [sr^{-1}] \]

Mélin & Franz 2014
random error $\sigma$ [sr$^{-1}$] (part of the uncertainty budget not affected by bias)

$\sigma$ can be estimated by a colocation analysis

\[
\begin{align*}
    x_i &= r_i + \varepsilon_i \\
    y_i &= \alpha + \beta r_i + \zeta_i
\end{align*}
\]

$\alpha$: additive bias  
$\beta$: multiplicative  
$\varepsilon, \zeta$: random error

solved with the assumption:

\[
\lambda = \frac{\sigma_{\zeta}^2}{\sigma_{\varepsilon}^2} = 1
\]

Mélin, *IEEE GRSL*, 2010  
Mélin & Franz 2014  
Mélin et al. *RSE* submit
σ

a) 443

b) 555

comparison SWF/MOD

Mélin et al., RSE submit
- Characteristic U-shape for $|\psi|$ 
- Small spatial variability for $\sigma$
Comparison with validation results and OC-CCI

\[ \sigma \quad \text{VS} \quad \Delta u \]

Mélin et al., RSE submit

Gergely & Zibordi Metrology 2014
Comparison with OC-CCI and Hu et al. *RSE* 2013

\[ \sigma \quad \text{VS} \quad \Delta u \quad \text{VS} \quad \Omega \]
σ between 0.9 $10^{-3}$ sr$^{-1}$ at 412 nm and 0.05-0.1 $10^{-3}$ sr$^{-1}$ at 670 nm in $\lambda^{-n}$ with n~4-5

- Small variability for σ

- $\sigma/\langle R_{RS} \rangle$ ~7% for 412-490 nm for Chla<0.3 mg m$^{-3}$
- ~5% for 412-490 nm for Chla<0.1 mg m$^{-3}$
- ~11% at 555 nm
- ~22% at 670 nm

Coherence between σ and other estimates express requirements in units of $R_{RS}$?
General Conclusions

- Variety of methods for $R_{RS}$ uncertainty estimates (should need to be clear about what they produce)
- General coherence of results, but differences should be understood
- Not many cases of methods ready to be applied on a grid-point basis
- Even less applied in actual processing
References


