Validation of Sentinel-3A OLCI ocean colour products in the Atlantic Ocean.

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Open-ocean oligotrophic waters are under-sampled in the global ocean.

FRMs required in low Chl-a waters to properly test case 1 Ocean Colour algorithms.
Semi-autonomous optical radiometers.

Schematic of PML Radiometer set-up on NERC/BAS ships.

Coincident in water TRIOS courtesy G. Zibordi.
Semi-autonomous IOP system.

IOP along track system:
ac-S calibrated with HPLC Chl-a.

Brewin et al. (2016) RSE, 183: 82-97.

(a.) Cruise track for AMT26, Sept-Nov 16. Relationship between (b.) ac-S \( ap(676) \) & underway HPLC Chl-a; (c.) HPLC & ac-9 inferred Chl-a.

N Chl-a = 40,000

Brewin et al. (2016) RSE, 183: 82-97.
Use of semi-autonomous systems, significantly increases the number of match-ups with Sentinel-3A. On AMT26, from 40 CTD stations sampled ~6 match-ups; using the semi-autonomous systems on a single AMT, >460 match-ups.
Fiducial Reference Measurements (FRM) are distinct from in situ measurements: “The suite of independent ground measurements using accepted satellite protocols, traceable to metrology standards, referenced to inter-comparison exercises, with a full uncertainty budget to provide independent, high quality, satellite validation measurements for the duration of a satellite mission.” ESA S-3 Validation Team.

Characterising uncertainties in Rrs for Fiducial Reference Measurements

Satellite Match-up Criteria:
- Within a +/-1 hour window.
- 3x3 pixel centred on in situ data.
- median coefficient of variation (CV) <0.15
- Std QC satellite flags applied.
Validation of S-3A OLCI Rrs – pb2.23.

Performance of OLCI Rrs pb2.23 (RPD): Blue bands 8 %, Green – 18 %, over-estimate in red 88 %.
Comparison of AC processors.

Which is the most accurate atmospheric correction model?

Relative Percentage Difference of AC processors (443 nm):
OLCI 4 %; VIIRS 3%; MODIS-A 48%.

Conclusion:
The most accurate AC is Std OLCI, which is similar to VIIRS. Systematic bias in MODIS-Aqua.
PB 2.16: 47 %, PB 2.23 >100% under-estimate in OLCI Chl-a in open ocean areas.

OLCI Chl-a PB 2.23; no data <0.05 mg m\(^{-3}\)
Consistent under-estimate in OLCI Chl-a compared to VIIRS and MODIS-A.
Atlantic Gyres: S-3A OC4Me & OCI Chl-a.

Under-estimate in S-3A OC4Me in open ocean waters can be corrected by implementing Ocean Chlorophyll Index algorithm.

North Atlantic Gyre Chl-a 0.01 mgm$^{-3}$
Conclusions.

- AMT4SentinelFRM has supplied FRMs in open-ocean blue waters, which represent 60% of the global ocean.
- **Maximising Sentinel Match-ups:** through deployment of semi-autonomous optical systems, 10 fold increase in S-3A match-ups.
- **OLCI PB 2.23**, the FRMs showed that there was an over-estimate in $R_{rs}$ ranging from 8% in blue, 18% in green & 88% in red bands. However std OLCI $R_{rs}$ is more accurate than other AC models & consistent with VIIRS.
- This produced a large under-estimate in OLCI PB 2.23 Chl-a in open ocean areas & over-estimate at higher Chl-a, relative to MODIS-A & VIIRS.
- **Under-estimate in OLCI Chl-a** can be improved using Colour Index algorithm.
Recommendations.

- The NERC UK Atlantic Meridional Transect is an ideal platform to validate multiple Satellite products across a range of oceanographic conditions and especially in the oligotrophic blue waters, of the Atlantic Ocean.

- Specific funding to facilitate collection of high quality FRMs for continued validation of satellite products.

- For accurate Sentinel-3 remote sensing reflectance \((R_{rs})\) in the Atlantic Ocean, use std OLCI processor or POLYMER.

- Under-estimate in OLCI Chl-a in oligotrophic waters can be improved using Colour Index algorithm.

- Integration of the most accurate Sentinel products into Global Earth Observation Systems (GEOS) for societal benefit for the Atlantic Ocean; for estimating carbon / CO\(_2\) flux budgets, maintaining healthy seas & sustainable food provision.
Thank you
TWO AMT4SentinelFRM Campaigns:

**AMT26**: UK to Falkland Islands, 20 Sept - 5 Nov 16.

Calculation of uncertainty – HyperSAS $R_{rs}$ example

$$R_{rs} = \frac{L_t - \rho L_i}{E_s}$$

Calculation equation for $R_{rs}$

$$\sigma_{R_{rs}}^2 = \left(\frac{\delta R_{rs}}{\delta L_t} \sigma_{L_t}\right)^2 + \left(\frac{\delta R_{rs}}{\delta L_i} \sigma_{L_i}\right)^2 + \left(\frac{\delta R_{rs}}{\delta E_s} \sigma_{E_s}\right)^2 + \left(\frac{\delta R_{rs}}{\delta \rho} \sigma_{\rho}\right)^2$$

Measurement equation and sensitivity coefficients

$$+2 \frac{\delta R_{rs}}{\delta L_t} \frac{\delta R_{rs}}{\delta L_i} \sigma_{L_t} \sigma_{L_i} R(L_t, L_i) + 2 \frac{\delta R_{rs}}{\delta L_t} \frac{\delta R_{rs}}{\delta E_s} \sigma_{L_t} \sigma_{E_s} R(L_t, E_s) + 2 \frac{\delta R_{rs}}{\delta L_i} \frac{\delta R_{rs}}{\delta E_s} \sigma_{L_i} \sigma_{E_s} R(L_i, E_s)$$

Further uncertainty terms to be added

$$+ \sigma_{\text{others}}^2$$

Correlation terms
Calculation of uncertainty – HyperSAS $L_t$ example

$$L_t = \left( C_{L_t} - D_{L_t} \right) S_{L_t}$$

**Calculation equation for $L_t$**

$$\sigma_{L_t}^2 = \left( \frac{\delta L_t}{\delta C_{L_t}} \sigma_{C_{L_t}} \right)^2 + \left( \frac{\delta L_t}{\delta D_{L_t}} \sigma_{D_{L_t}} \right)^2 + \left( \frac{\delta L_t}{\delta S_{L_t}} \sigma_{S_{L_t}} \right)^2 + \sigma_{\text{others}}^2$$

**Measurement equation and sensitivity coefficients**

$$S_{L_t} = \frac{S_{2016} + S_{2017}}{2}$$

**Calculation equation for $L_t$ calibration coefficient (S)**

$$\sigma_{S_{L_t}}^2 = \left( \frac{\delta S_{L_t}}{\delta S_{2016}} \sigma_{S_{2016}} \right)^2 + \left( \frac{\delta S_{L_t}}{\delta S_{2017}} \sigma_{S_{2017}} \right)^2$$

**Measurement equation and sensitivity coefficients**

2% uncertainty in calibration process
Match-up selection:

- Within a +/-1 hour window (though played with this window)
- 3x3 pixel box centred in the coordinates of the in situ observation.
- When multiple in situ data in pixel, the average value used.
- Match-ups were excluded if the median coefficient of variation (CV) of Rrs was higher than 0.15
- Standard deviation of the satellite derived Rrs over the 3x3 pixels extraction used as index of variation.
- QC flag used:
  INVALID, LAND, CLOUD, CLOUD_AMBIGUOUS, CLOUD_MARGIN, SNOW_ICE, SUSPECT, HISOLZEN, SATURATED, HIGHGLINT, WHITECAPS, AC_FAIL, OC4ME_FAIL, ANNOT_TAUo6, RWNEG_O2, RWNEG_O3, RWNEG_O4, RWNEG_O5, RWNEG_O6, RWNEG_O7 and RWNEG_O8.
OLCI Validation: Impact of Uncertainty.

HyperSAS 412 nm ± 1 hour window, CV < 0.15, no unc. QC

N = 115  
\( r = 0.834 \)  
\( \psi = 0.0015 \)  
\( \Delta = 0.0013 \)  
\( \delta = 0.0007 \)  
S = 0.724  
I = 0.003

HyperSAS 412 nm ± 1 hour window, CV < 0.15, unc. < 5%

N = 16  
\( r = 0.774 \)  
\( \psi = 0.0006 \)  
\( \Delta = 0.0006 \)  
\( \delta = 0.00003 \)  
S = 0.647  
I = 0.002