Alternative vicarious gain estimates for Sentinel-3 OLCI: Investigation of atmosphere-typed spectral optical thickness corrections for the processor vicarious calibration, from the open ocean to the shore

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OLCI 250 m resolution image over Logan, 20170821 eclipse day !!
Why changing gain formulation in the future?

- The classic (actual) gain formulation:

\[
G \cdot rho_{gc}(\lambda) = rho_{path}(\lambda) + T_{\theta s}(\lambda) \cdot T_{\theta v}(\lambda) \cdot rho_{w}(\lambda) + \varepsilon
\]

with \(\varepsilon \sim f(\varepsilon_m + \varepsilon_{TOA})\) \(\varepsilon_m = \text{direct model errors}, \varepsilon_{TOA} = \text{TOA errors}\)

- OLCI L2 processor estimates the total optical thickness \(\text{Tau } T = \tau_a + \tau_r\). It is therefore natural to align (i.e. apply gains to) the model using an estimated correction on \(\tau\).

- A new gain formulation for (Plan of the presentation):
  - 1/ Understand the OLCI level 2 errors to enhance in the future the processor.
  - 2/ Correct the estimated Tau with the underlying idea that the non-linear correction on \(Rhow(\lambda)\) will be more generic, and therefore applicable in a more robust way to other areas, than the actual linear correction.
  - 3/ Enhancements of the actual OLCI level 2 products , from open ocean to the shore, with the introduction of conditional gains.
I/ Understand the significant sources of errors for the OLCI L2 processor
I/ Data alignment between OLCI L2 processor and the SVC dataset

\[ \text{Rho}_{gc} = \text{Rho}_{path} + \text{td} \ast \text{Rho}_w \]

- Estimated by the processor
- In-Situ

From what we see, to adjust the model:

- Td is underestimated?
- Rho_path is underestimated?

**SVC dataset** = 3150 climatological measurements + 350 in-situ measurements
I/ Understand the significant sources of errors for the OLCI L2 processor

PCA decomposition of forcing parameters (covariates) at Moby

Modelling (RTM) covariates

Inversion covariates
I/ Understand the **significant** sources of errors of the OLCI processor

**Moby**

Correlation of errors onto Rho_W(λ) with PCA proj coeffs

MOBY 2106 & 2017

- RTM Rayleigh errors
- RTM geometrical dependency errors
- BPAC errors
- Inversion errors

PC0  PC1  PC2  PC3  PC4

- 412
- 443
- 490
- 510
- 560
- 620
- 665
- 681
II/ Gains for OLCI in the visible onto the spectral optical thicknesses: Correct the estimated variable of the L2 processor
II/ Gains for OLCI in the visible onto the spectral optical thicknesses

- Classical formulation

\[ G \cdot \rho_{gc}(\lambda) = \rho_{path}(\lambda) + T_{\theta s}(\lambda) \cdot T_{\theta v}(\lambda) \cdot \rho_w(\lambda) \]

- Proposed formulation:

  \[ T_{\theta s}(\lambda) = e^{-\tau(\lambda)M_s(\lambda)} + e^{-\tau(\lambda)M_s*coeffs(\lambda)} \]

  Is the total downward transmittance

  \[ T_{G\theta s}(\lambda) = e^{-G(\lambda)\tau(\lambda)M_s(\lambda)} + e^{-G(\lambda)\tau(\lambda)M_s*coeffs(\lambda)} \]

  Is the total downward transmittance with gains onto Tau

  \[ \rho_{gc}(\lambda) = \left[ \frac{1 - T_{G\theta s}(\lambda) \cdot T_{G\theta v}(\lambda)}{1 - T_{\theta s}(\lambda) \cdot T_{\theta v}(\lambda)} \right] \cdot \rho_{path}(\lambda) + T_{G\theta s}(\lambda) \cdot T_{G\theta v}(\lambda) \cdot \rho_w(\lambda) \]

Where \( G \) is a vector of gains to be estimated for bands 400,412,443,490,510,560,620,665,670,681 given the inversion results of the OL2 processor and an in-situ dataset.
II/ Gains for OLCI in the visible onto the spectral optical thicknesses

Estimation using a robust minimisation procedure on data from:

1/ Radiometric In-situ dataset

- MOBY
- BOUSSOLE
- AAOT
- CASES
- CoveSEAPRISM
- Gloria
- GustavDalenTower
- HelsinkiLighthouse
- LISCO
- MVC0
- WaveCIS
- MOBY
- Kent Hughes
- David Antoine
- John Icely
- Selima Ben Mustapha
- Greg Schuster
- Giuseppe Zibordi
- Giuseppe Zibordi
- Giuseppe Zibordi
- Giuseppe Zibordi
- Alex Gilerson
- Annelies Hommersom
- Alan Weidemann
- Bill Gibson
- University of Miami
- NOAA
- LOV
- JRC
- University of Algarve
- Fisheries and Oceans Canada
- NASA GSFC
- JRC
- JRC
- JRC
- City college of New York
- IVM
- Naval Research Laboratory, NRLSSC
- Coastal Studies Inst. LSU

2/ Climatologcal radiometric dataset

Daily Satellite time-integrated average from 1997-now from ESA Globcolor & NASA Oceancolor datasets at global scale from 1997 no now
II/ Estimation of the gains for OLCI on Tau for clear waters

❖ Estimation using a robust minimisation procedure

Stations= MP15-SAGOPT-SPGOPT-SIOOPT-NWPOPT-NEPOPT-NAGOPT-HyBOUS-MOBY4O

Gains on Tau= [1.00969002, 1.0181875, 1.01301313, 1.00797925, 1.00522232, 1.00242976, 1.00128386, 1.00128386, 1.0006125]

❖ Slight underestimation of the total optical thicknesses by the OLCI processor
II/ Validation of the gains for OLCI on Tau for clear waters

- Rhow residuals

<table>
<thead>
<tr>
<th>Histogram (rhow errors), 412</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear water gains median 0.085%, std 0.003, rms 0.006</td>
</tr>
<tr>
<td>SVC gains median 0.467%, std 0.003, rms 0.005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Histogram (rhow errors), 443</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear water gains median 0.022%, std 0.002, rms 0.004</td>
</tr>
<tr>
<td>SVC gains median 0.004%, std 0.002, rms 0.004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Histogram (rhow errors), 510</th>
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</thead>
<tbody>
<tr>
<td>Clear water gains median 0.005%, std 0.001, rms 0.002</td>
</tr>
<tr>
<td>SVC gains median -0.850%, std 0.001, rms 0.002</td>
</tr>
</tbody>
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<tr>
<th>Histogram (rhow errors), 490</th>
</tr>
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<tbody>
<tr>
<td>Clear water gains median 0.012%, std 0.001, rms 0.002</td>
</tr>
<tr>
<td>SVC gains median -0.613%, std 0.001, rms 0.002</td>
</tr>
</tbody>
</table>

⇒ Same correction as performed by the S3 OLCI SVC but correction of the OT and AOT products
II/ Validation of the gains for OLCI on Tau for **clear waters**

- **Rhow residuals**

  ![Histogram (rhow errors), 560](image1)
  - Clear water gains median 0.092%, std 0.001, rms 0.001
  - SVC gains median -0.938%, std 0.001, rms 0.001

  ![Histogram (rhow errors), 665](image2)
  - Clear water gains median 0.000%, std 0.000, rms 0.001
  - SVC gains median -0.000%, std 0.000, rms 0.001

  ![Histogram (rhow errors), 881](image3)
  - Clear water gains median 0.000%, std 0.000, rms 0.001
  - SVC gains median 0.000%, std 0.000, rms 0.001

  => Same correction as performed by the S3 OLCI SVC but **correction of the OT and AOT products**
Il Estimation of the gains for OLCI on Tau on coastal areas


Gains on Tau= 1.0077223, 1.01188601, 1.0077223, 1.00616707, 1.00373133, 1.00248754, 1.00114387, 0.99859752, 0.99917006

➢ Slight underestimation of the total optical thicknesses by the OLCI L2 proc.
Il Estimation of the gains for OLCI on Tau on coastal areas

- **Rhow residuals**

![Graph](image)

- Applied gains onto Turb water Cal sites 5*5

- Standard SVC leads to underestimate Rhow at the shore inc. negative reflectances

⇒ Standard SVC leads to underestimate Rhows at the shore inc. negative reflectances
The vicarious calibration issue, from the open ocean to the shore

- Gains estimated on clear atmospheres & waters =>
  Good performance over clear waters BUT underestimation in coastal areas (including negative reflectance)

- Gains estimated on turbid atmospheres & waters =>
  Good performance over coastal waters BUT overestimation for clear waters
III/ Investigations for enhancements of the actual OLCI level 2 products with the introduction of conditional mixture of gains: to be better in every case
III Conditional mixture of gains

- Introduction of conditional gains:

\[ \text{Gains} = \sum_{k} P(i = k) \text{Gains}_k \]

The probability \( P \) being given by a robust TOA indicator to identify coastal and clear TOA observations

![Gains on tau clear](image1)

![Gains on tau turb](image2)
III Conditional mixture of gains

- Seeking for robust TOA indicators to characterise clear and coastal areas

Example of the Spectral Angle Mapper:

\[ \theta = \arccos\left( \frac{\mathbf{Rho}_{GC}(\lambda) \cdot \mathbf{Rho}_{GC_{ref}}(\lambda)}{|\mathbf{Rho}_{GC}(\lambda)||\mathbf{Rho}_{GC_{ref}}(\lambda)|} \right) \]

2 Refs={clear, coastal}

Coastal areas

Open ocean

Prob(i=clear)
III Validation of mixed gains

\[ \text{Gains} = \sum_k P(i = k) \text{Gains}_k \]

Open ocean  \rightarrow  Coastal areas

Rhow residuals

\( \text{Applied gains onto Clear water Cal sites } 5 \times 5 \)

\( \text{Applied gains onto Turb water Cal sites } 5 \times 5 \)

\[ \text{Open ocean} \]

\[ \Rightarrow \text{ Equivalent results as the S3 SVC} \]

\[ \Rightarrow \text{ Better results than the S3 SVC} \]
III Validation of mixed gains on coastal waters
⇒ Improvements compared with the S3 SVC
III Mixed gains for the OLCI L2 processor

- Less negative reflectances: level 2 coverage increase from 2 to 10% for coastal waters
III Mixed gains for the OLCI L2 processor

- Less negative reflectances: level 2 coverage increase for coastal waters

SVC OLCI Chl-a

Mixed Gains Chl-a
III Mixed gains for the OLCI L2 processor

- Less negative reflectances: level 2 coverage increase for coastal waters

SVC OLCI Chl-a  
Mixed Gains Chl-a
Preliminary conclusions

1/ Error analysis using PCA will provide soon ways to quantify and discriminate the modelling errors and the inversion errors => returns towards the RTM designers

2/ Vicarious calibration on Tau, the inversed variables, correct the estimated Tau conversely to the gains onto rho_gc.

=> Soon, provision of the results of the correction onto Tau using the Aeronet in-situ data

3/ Conditional gains provide a simple way to improve the Level 2 in coastal areas while preserving the atmosphere model’s calibration in open ocean. We can increase the coverage from to 2 to 10 % at the shore of the OL2 processor.

=> L2 OLCI processor enhancements

=> Guide for a multi-model inversion scheme for OLCI
Future improvements

Further major improvements of the L2 OLCI processor will be also soon proposed:

- **Correction of the BPAC including spatial regularisation terms.**

- **Optimisation** of the estimation of Tau_865 and the aerosol model selection to avoid meaningless (incl. negative) Rhows.

- **Inversion over block of pixels to minimize the noise** and introduce the existing spatial continuity of the atmospheric variables (ongoing paper for Sentinel 2).

- **Enhancement of the coupling between td_up and Rhow** to take into account the BRDF of the water (**correction of the Lambertian hypothesis of the OL2 processor**).
Annex
Validation of the proposed formulation with the OLCI LUTS:

$$\rho_{gc}(G, \lambda) = \left[\frac{1 - T_{G\theta_s}(\lambda) * T_{G\theta_v}(\lambda)}{1 - T_{\theta_s}(\lambda) * T_{\theta_v}(\lambda)}\right] * \rho_{path}(\lambda) + T_{G\theta_s}(\lambda) * T_{G\theta_v}(\lambda) * \rho_{w}(\lambda)$$

SZA=31, VZA=25, RAA=24, Tau_a=0.1, Aer=3

SZA=31, VZA=35, RAA=44, Tau_a=0.3, Aer=1

OLCI based LUTs % of error of the tau gain based model; dtau 560= +/- 5%

+- 5% dTau => Error performed TOA < 0.1% = < 1% BOA