Vicarious Calibration for MERIS 4th Reprocessing

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FRM4SOC

Options for future European satellite OCR vicarious adjustment infrastructure for the Sentinel-3 OLCI and Sentinel-2 MSI series

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• History: the MERIS 3rd reprocessing (M3RP) vicarious adjustment

• MERIS 4th reprocessing (M4RP) algorithmic evolutions

• Vicarious adjustment for M4RP

• Alternative methodology

• Results and validation
MERIS 3rd reprocessing vicarious adjustment

- ATBD 2.24 M3RP (ACRI-ST 2011): “it is chosen to use the terminology of a **vicarious adjustment, rather than calibration** […] The vicarious adjustment is not just a sensor calibration, but an **adjustment** of the **whole system sensor+processing** chain (in particular atmospheric correction). It should be updated at every change in the Level1 or Level2 ground segment”

- Adjustment on $\rho_{GC}(\lambda) = \rho_{path}(\lambda) + t_d(\lambda) \cdot \rho_w(\lambda)$ (TOA reflectance corrected for gaseous absorption, smile, and glint), not $\rho_{TOA}(\lambda)$

- Uses the historical approach **decoupling VIS/NIR** for the assessment of vicarious gains (Franz et al. 2007, Bailey et al 2008), NASA ATBD modified in the NIR

- **NIR** adjustment over SIO/SPG clear waters
  - single-scattering approach (use aerosol reflectance and model retrieved at L2), different to NASA vicarious adjustment
  - assume two bands perfectly calibrated (709, 779 nm) to calibrate the other one with derived Angström exponent (865 nm)
  - the set of bands to fix/adjust is derived by a sensitivity analysis

- **VIS** vicarious adjustment using colocated in-situ measurements from **BOUSSOLE** and **MOBY** (open oceans, homogeneity of targets)
  - propagate in situ $\rho^I_S$ to TOA using satellite-retrieved atmosphere $\rightarrow \rho^IS_{GC}(\lambda)$
  - gain = $\rho_{GC}(\lambda)/\rho^IS_{GC}(\lambda)$
M3RP final gains computed from:
1) NIR gains: SIO/SPG
2) VIS gains: BOUSSOLE/MOBY
Uncertainties: standard deviations of per-matchup individual gains

**MERIS 3rd final gains**

- **1) NIR adjustment** using observations over SIO/SPG 709/775 fixed
- **2) VIS adjustment** using in-situ collocated data
MERIS 4th reprocessing algorithmic evolutions

- Changes in all steps of the processing: L1 calibration, preprocessing (gaseous transmissions, classification...), cloud, land and water branches including the possibility to process a pixel into different branches if ambiguity in the classification

- Water branch especially:
  - pressure adjustment scheme modified with an initial view on processing over high altitude lakes → see next
  - bright-pixel atmospheric correction (BPAC) evolutions, supposed to handle NIR adjustment → no NIR gains as BPAC performs spectral alignment similar to what is done in M3RP NIR gain computation
  - aerosol models now from Goddard Space Flight Center (GSFC) instead of the so-called Standard Aerosol Models (SAM)

→ no reason to obtain same set of gains as M3RP
MERIS 4RP pressure adjustment change

- Pressure adjustment (both in M3RP and M4RP): adjust the signal, before atmospheric correction (AC), to a reference pressure over which radiative transfer model has provided look-up-tables (LUTs)

- AC: determine $\rho_{path}(\lambda)$, $t_d(\lambda)$ from aerosol models retrieved at 779/865 nm
  $$\rho_{GC}(\lambda) = \rho_{path}(\lambda) + t_d(\lambda).\rho_w(\lambda)$$

- M3RP:
  - $\rho_{GC}(\lambda)$ at local pressure $P_{pix}$: corrected for gas. abs., smile, glint
  - $\rho_{path}(\lambda$) at $NIR$ adjusted at Pref to perform AC (i.e. determine $\rho_{path}(\lambda)$ over all spectrum) at reference pressure (1013 hPa)
  - $\rho_{path}(\lambda)$ retrieved at Pref then deadjusted at $P_{pix}$

- M4RP:
  - $\rho_{GC}(\lambda)$ at local pressure $P_{pix}$: corrected for gas. abs., glint
  - $\rho_{GC}^*(\lambda)$ at reference pressure $P_1$: corrected for smile, Bodhaine (lat. dependency of Rayleigh), and pressure via equivalent Rayleigh optical thickness $\tau_{RAY\_meas}(\lambda)$
  - AC performed on $\rho_{GC}^*(\lambda)$ at reference pressure $P_1$ closest to $P_{pix}$

→ the effect on VIS vicarious adjustment methodology is the necessary adjustment on $\rho_{GC}^*(\lambda)$ in M4RP ($\rho_{GC}(\lambda)$ at reference pressure)
MERIS 4RP: handle AC over high altitude lakes

- Goal: since lakes can be at high altitudes RTM LUTs have been built to model $\rho_{GC}^*(\lambda)$ for reference pressures \{1040, 1013, 970, 900, 800, 700\} hPa.

- Depending on water-body altitude one reference pressure level must used preferably.

- A sensitivity analysis proved necessary to retrieve $\rho_{GC}^*(\lambda)$ at two bracketing reference pressures P1 and P2:
  - $\rho_{GC\_P1}^*(\lambda)$ and $\rho_{GC\_P2}^*(\lambda)$ with P1/P2 being the bracketing pressure levels
  - $\rho_{GC\_P1}^*(\lambda) \rightarrow \rho_{w\_P1}(\lambda)$
  - $\rho_{GC\_P2}^*(\lambda) \rightarrow \rho_{w\_P2}(\lambda)$

- final $\rho_w(\lambda)$ via interpolation using $\tau_{RAY\_meas}(\lambda)$, $\tau_{RAY\_P1}(\lambda)$, $\tau_{RAY\_P2}(\lambda)$
  - $\rho_w(\lambda) = \alpha. \tau_{RAY\_meas}(\lambda) + \beta$
  - $\rho_{w\_P1}(\lambda) = \alpha. \tau_{RAY\_P1}(\lambda) + \beta$
  - $\rho_{w\_P2}(\lambda) = \alpha. \tau_{RAY\_P2}(\lambda) + \beta$

- Vicarious adjustment in the VIS: perform over $\rho_{GC\_P1}^*(\lambda)$ and $\rho_{GC\_P2}^*(\lambda)$
MERIS 4RP vicarious adjustment in the VIS

→ Two propositions from QWG:

• apply two set of gains separately for \( \rho^*_\text{GC}_P(\lambda) \) and \( \rho^*_\text{GC}_P(\lambda) \) then interpolate

• compute one unique gain to apply on both \( \rho^*_\text{GC}_P(\lambda) \) and \( \rho^*_\text{GC}_P(\lambda) \)

• Both solutions lead to same estimations of the gains over oceanic waters (BOUSSOLE / MOBY)

• Solutions may diverge over high altitude targets: gains determined over oceanic targets may not be transferable, but no possibility to assess (no in situ site available over high altitude lakes)

→ second solution kept by coherence with M3RP implementation of the gains through the L2 processor: one set of gains applied

\[
\rho^{\text{vic}}_{\text{GC}_P}(\lambda) = g(\lambda) \cdot \rho^*_\text{GC}_P(\lambda) \text{ and } \rho^{\text{vic}}_{\text{GC}_P}(\lambda) = g(\lambda) \cdot \rho^*_\text{GC}_P(\lambda)
\]
MERIS 4RP vicarious adjustment in the VIS

- latest BOUSSOLE and MOBY reprocessings since M3RP + more data
- latest MERIS processor

- individual gains computed per pixels within 5x5 matchups carefully filtered (no glint, no cloud, low AOT...)

- median gain computed per matchup $\rho_{GC}(\lambda)/\rho_{IS}^W(\lambda)$

- mean gain = weighted-average over all matchups

- uncertainties being:
  - $\sigma = \sqrt{\sigma_{sat}^2 + \sigma_{IS}^2}$,
  - with $\sigma_{sat}$ std over the macropixel
  - $\sigma_{IS} = 5\%$ of $\rho_{IS}^{WME}$
MERIS 4th vicarious adjustment in the VIS

- Time series M3RP vs M4RP (example 490 nm):
M3RP vs M4RP vicarious gains

No reason to obtain same gains in M4RP as in M3RP:
- no gains in the NIR
- many processors changes, not only in the VIS
Alternative methodology

Perform a **zero adjustment** of the measuring system, i.e. offset, and a **span adjustment**, i.e. gain → Vicarious Adjustment (VA)

→ apply gain and offset to $\rho_{gc}^*(\lambda)$ to align $\rho_w$ on $\rho_{w,IS}$
→ proper zero or no bias: resolve a potential residual bias of the processor, corrected at AC input
→ proper representation of **range** for all potential measurements, i.e. quantity values being attributed to the measure, or **coverage** ($\neq$ trueness though correcting systematic errors)
→ gain corrects instrumental errors as processor errors

$$\rho'_{gc}(\lambda) = \alpha(\lambda).\rho_{gc}(\lambda) + \beta(\lambda)$$ where $\alpha$ is the gain and $\beta$ is the offset

**Recommended methodology:**
- atmospheric correction behaves like an « instrument » transfer function
- search for ‘optimal’ gains + offsets by
  - maximizing likelihood on estimated $\hat{\rho}_w$
  - taking matchups’ uncertainties into account

(identification of ranges of "authorized" gains and offsets, with regards to samples’ representativeness and to noise)

= better constrained adjustment but on the same line as M3RP ‘s
Alternative methodology: description

For each $\alpha(\lambda)$ and $\beta(\lambda)$:

- apply gain+offset to $\rho_{gc}(\lambda)$:
  \[ \rho'_{gc}(\lambda) = \alpha(\lambda) \cdot \rho^*_G(\lambda) + \beta(\lambda) \]

- compute $\rho'_w(\lambda)$ such that
  \[ \rho'_{gc}(\lambda) = \rho_{path}(\lambda) + t_d(\lambda) \cdot \rho'_w(\lambda) \]

- compute mean of residuals:
  \[ R = \frac{1}{N} \sum \left( \frac{\rho_{wSM}^I(\lambda) - \rho'_w(\lambda)}{\sigma} \right)^2 \]

\[ \sigma = \sqrt{\sigma_{sat}^2 + \sigma_{IS}^2} \], with $\sigma_{sat}$ std over the macropixel, $\sigma_{IS} = 5\%$ of $\rho_{IS}^{I_{SM}}$

→ Find $\hat{\alpha}, \hat{\beta}$ minimizing $R$, band per band

- as if there was no correlation between $\rho_w$ at different wavelength, though there are because of the atmospheric transfer -
Alternative methodology (uncertainty)

Cramer-Rao bound for variance of an estimator (lower bound on the variance of unbiased estimators of a deterministic parameter: inverse of the Fisher information \( I \))

\[
\text{Var}(\hat{\theta}) \geq \frac{1}{I(\theta)} = \frac{1}{-\mathbb{E} \left[ \frac{\partial^2}{\partial \theta^2} \ln f(X; \theta) \right]}
\]

here we have an estimator of gain and offset \( \hat{\theta} = (\hat{\alpha}, \hat{\beta}) \)
with pdf as product of independent pdfs for each matchup

\[
f = \prod \frac{1}{\sigma \sqrt{2\pi}} e^{-\left( \frac{(\rho_{\mathrm{w}}^{SME}(\lambda) - \rho_{\mathrm{w}}'(\lambda))^2}{2\sigma^2} \right)}
\]

where \( \rho_{\mathrm{w}}'(\lambda) \) depends on \( \alpha(\lambda) \) and \( \beta(\lambda) \)

\( \rightarrow \) constraints on \( \text{Var}(\hat{\alpha}) \) and \( \text{Var}(\hat{\beta}) \) (resp. on \( \sigma_{\hat{\alpha}} \) and \( \sigma_{\hat{\beta}} \))

\( \rightarrow \) defines a domain where \( \alpha \pm \sigma_{\hat{\alpha}} \) and \( \beta \pm \sigma_{\hat{\beta}} \) can be considered as statistically acceptable solutions

\( \rightarrow \) such domain corresponds to acceptable values of the mean residual, upper bound = \( \max R(\alpha \pm \sigma_{\hat{\alpha}} \text{ and } \beta \pm \sigma_{\hat{\beta}}) \)
Alternative methodology (result)

Domain of $R$ with $\text{Var}(\hat{\theta}) < \text{boundary}$ as function of $\alpha(\lambda)$ and $\beta(\lambda)$:

- $\text{Var}(\hat{\theta}) \geq \text{CR bound}$
- e.g.: BOUSSOLE 510 nm

$\text{Var}(\hat{\theta}) < \text{CR bound}$ corresponding to all acceptable solutions

→ gain with offset=0 is among solutions (same at all wavelengths)
→ can be a solution based on a priori knowledge that offset=0
Alternative methodology: comparisons with M4RP

Domain of R with $\text{Var}(\hat{\theta}) < \text{boundary}$ as function of $\alpha(\lambda)$ and $\beta(\lambda)$, valid domain for both BOUSSOLE and MOBY

→ boundary gains where offset=0
→ uncertainties

→ nearly identical gains within CR domain

→ all solutions are acceptable

Objective: decrease uncertainty of the estimator

→ directly linked to IS and SAT uncertainties
Validation

Comparison nogains / M4RP gains: removing bias differences to IS, 412 nm

\[ \rho_{wN}(412) \text{ vs } \text{In Situ } \rho_{wN ISME}(412) \]

\[ \text{mean: } -7.43 \times 10^{-4}, \text{ std: } 4.21 \times 10^{-3} \]

No gains

M4RP gains
Comparison M3RP / M4RP (RPD): 412

Less bias in M4RP
Comparison M3RP / M4RP (RPD): 490

Validation

Less dispersion in M4RP
Comparison M3RP / M4RP (RPD): 560

- Less dispersion in M4RP

Validation

\[ \approx 55\% \quad \approx 40\% \]
Conclusions

• ATBD 2.24 M3RP: “vicarious adjustment [...] should be updated at every change in the Level1 or Level2 ground segment”
→ that is what is done for M4RP

• M4RP evolutions

→ adaptation and update of the vicarious adjustment, leading to very different vicarious gains profiles between M3RP and M4RP

→ M4RP: less bias and dispersion in comparison with MERMAID data

• many algorithmic changes in M4RP reprocessing chain are already transferred to S3 OLCI operational processing

→ some aspects of the vicarious adjustment can be transferred to OLCI
Expectations from FRM4SOC

• provide total uncertainty budget to better constrain the gains computation

• systematically provide ancillary parameters (e.g. wind, cloudiness, wave height...) + AOT / Angström in the NIR to better constrain the retrieval and the analysis

• in situ data deliveries: common naming conventions and quantities would be nice
THANK YOU!