# Vicarious Calibration for MERIS 4$^{th}$ 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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## Adressed points

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

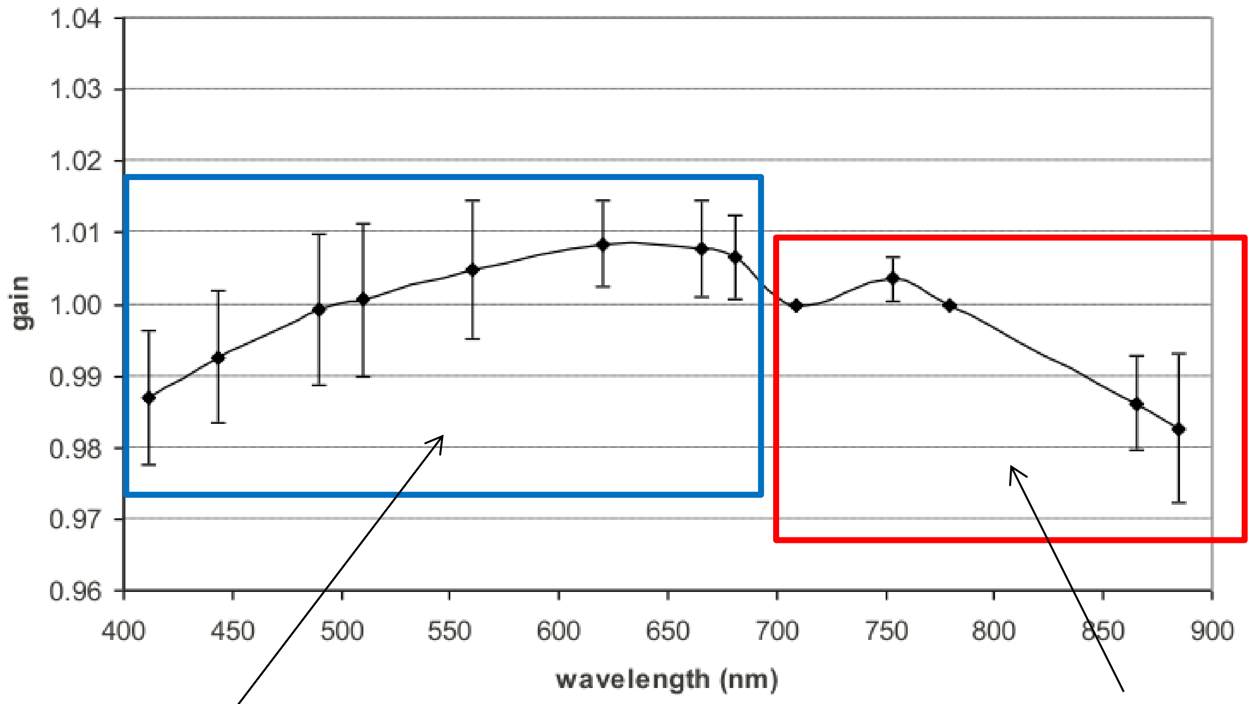
- Uses the historical approach **decoupling VIS/NIR** for the assessment of vicarious gains (Franz et al. 2007, Bailey et al 2008), NASA ATBD modified in the NIR

- **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 $\rho_w^{IS}$ to TOA using satellite-retrieved atmosphere → $\rho_{GC}^{IS}(\lambda)$
  - gain = $\rho_{GC}(\lambda)/\rho_{GC}^{IS}(\lambda)$

# MERIS 3rd final gains

M3RP final gains computed from:
1) NIR gains: SIO/SPG
2) VIS gains: BOUSSOLE/MOBY
Uncertainties: standard deviations of per-matchup individual gains




2) VIS adjustment using in-situ colocated data

1) NIR adjustment using observations over SIO/SPG 709/775 fixed

# 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** Ppix: corrected for **gas. abs., smile, glint**
  - $\rho_{path}(\lambda\ NIR)$ **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 Ppix**

- M4RP:
  - $\rho_{GC}(\lambda)$ at **local pressure** Ppix: corrected for **gas. abs., glint**
  - $\rho^*_{GC}(\lambda)$ at **reference pressure** P1: corrected for smile, Bodhaine (lat. dependency of Rayleigh), and pressure via equivalent Rayleigh optical thickness $\boldsymbol{\tau_{RAY\_meas}(\lambda)}$
  - AC performed on $\rho^*_{GC}(\lambda)$ at **reference pressure** P1 closest to Ppix

→ 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 $\rho^{*}_{GC\_P1}(\lambda)$ and $\rho^{*}_{GC\_P2}(\lambda)$ then interpolate
- compute one unique gain to apply on both $\rho^{*}_{GC\_P1}(\lambda)$ and $\rho^{*}_{GC\_P2}(\lambda)$

- 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

$$\rho^{vic}_{GC\_P1}(\lambda) = g(\lambda).\rho^{*}_{GC\_P1}(\lambda) \text{ and } \rho^{vic}_{GC\_P2}(\lambda) = g(\lambda).\rho^{*}_{GC\_P2}(\lambda)$$

## MERIS 4RP vicarious adjustment in the VIS

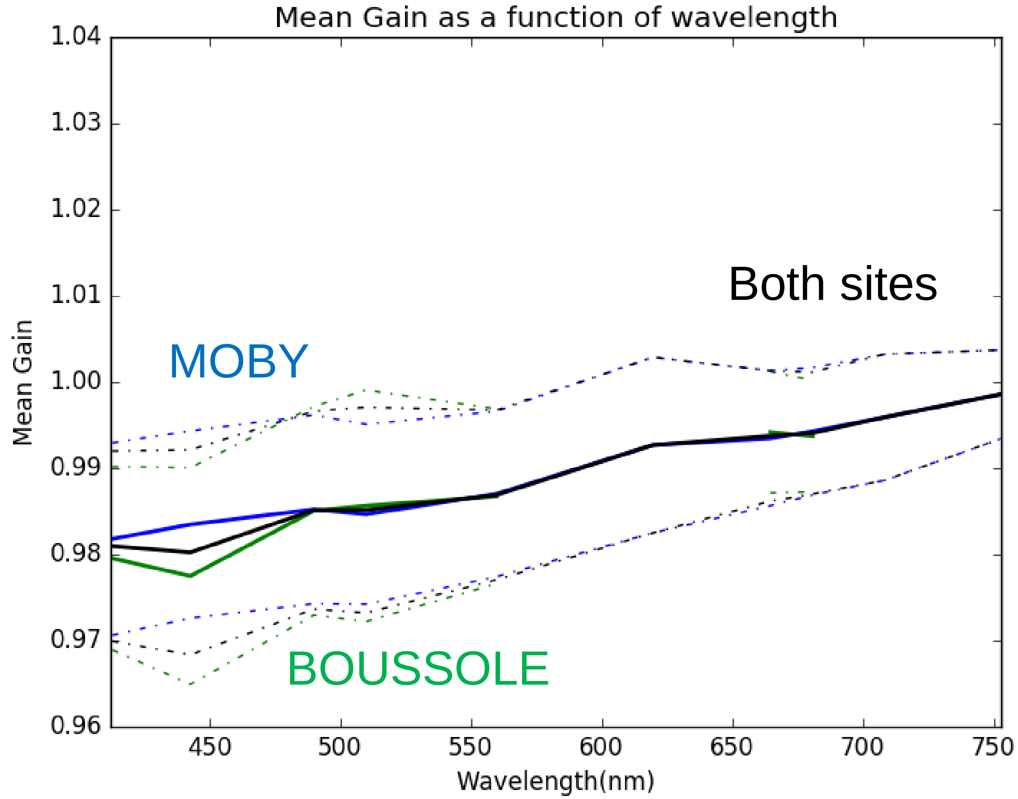
- latest BOUSSOLE and MOBY reprocessings since M3RP + more data
- latest MERIS processor

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

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

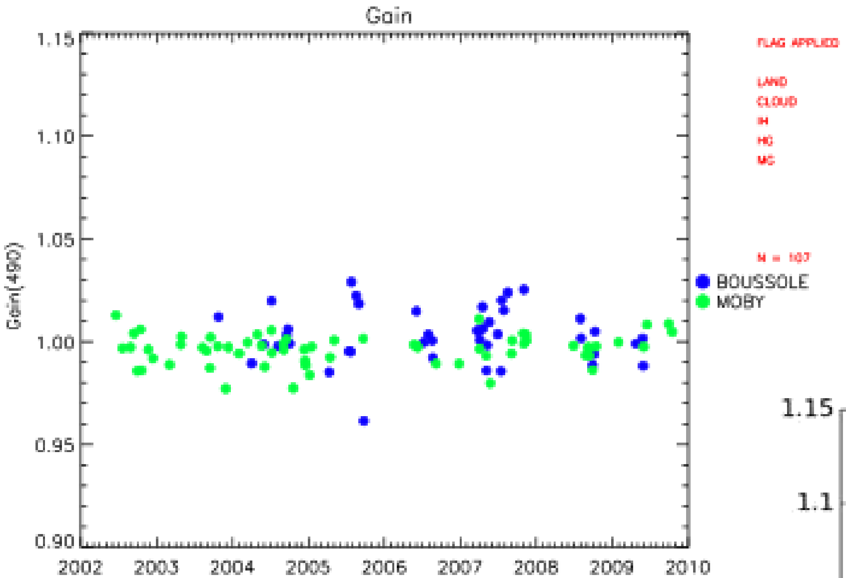
- mean gain = weighted-average over all matchups

- uncertainties being:
  - $\sigma = \sqrt{{\sigma^{sat}}^2 + {\sigma^{IS}}^2}$,
  - with $\sigma_{sat}$ std over the macropixel
  - $\sigma_{IS} = 5\%$ of $\rho_w^{ISME}$



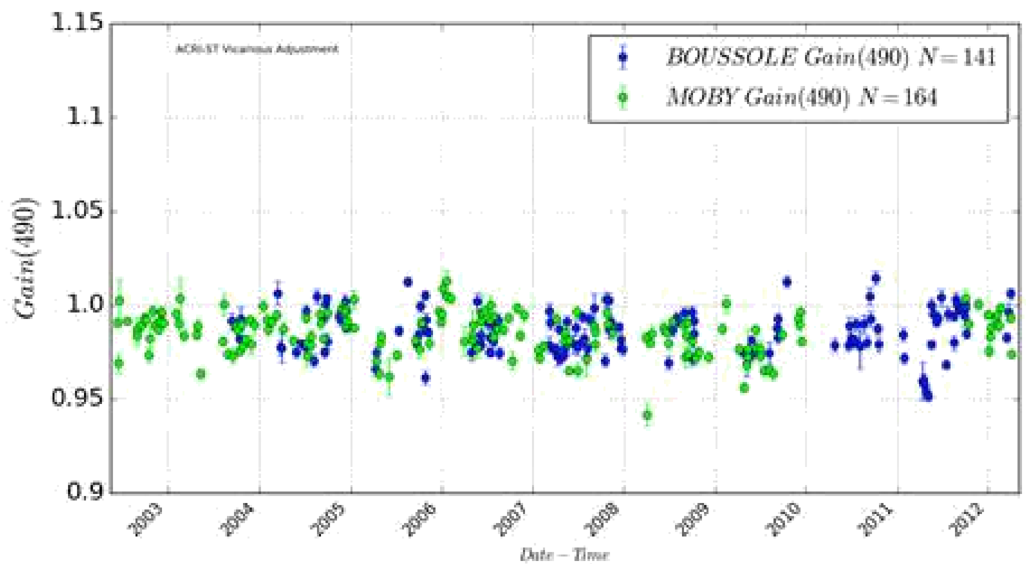
# MERIS 4th vicarious adjustment in the VIS

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

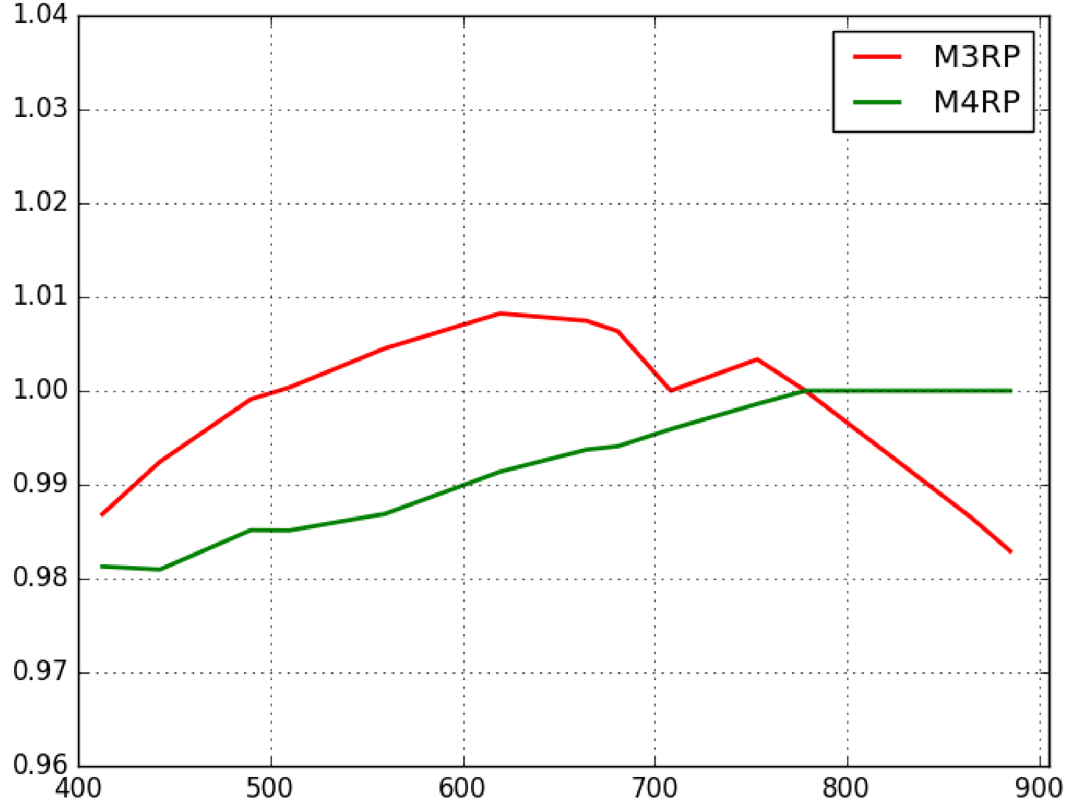



M3RP

M4RP



# 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 <u>no bias</u>: 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 <u>coverage</u> **(**≠ trueness though correcting systematic errors)
- → gain corrects instrumental errors as processor errors

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

**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 α($\lambda$) and β($\lambda$) :

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

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

- compute mean of residuals:
$$R = \frac{1}{N}\sum\left(\frac{\rho_w^{ISME}(\lambda) - \rho'_w(\lambda)}{\sigma}\right)^2$$

- $\sigma = \sqrt{{\sigma^{sat}}^2 + {\sigma^{IS}}^2}$, with $\sigma_{sat}$ std over the macropixel, $\sigma_{IS} = 5\%$ of $\rho_w^{ISME}$

→ 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*)

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

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

$$f = \prod \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\rho_w^{ISME}(\lambda) - \rho_w'(\lambda))^2}{2\sigma^2}}$$

where $\rho_w'(\lambda)$ depends on $\alpha(\lambda)$ and $\beta(\lambda)$

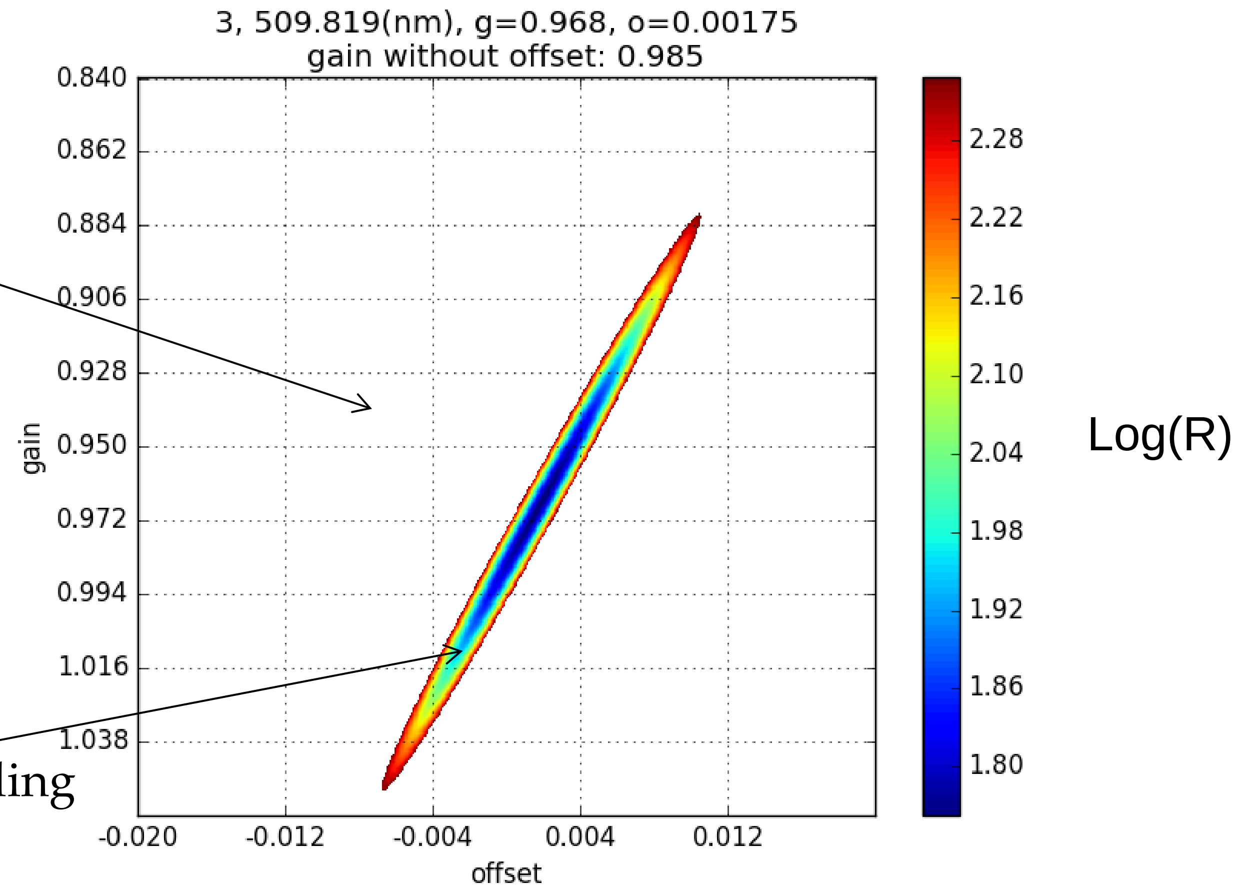
→ constraints on $\mathrm{Var}(\hat{\alpha})$ and $\mathrm{Var}(\hat{\beta})$ (resp. on $\sigma_{\hat{\alpha}}$ and $\sigma_{\hat{\beta}}$)

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

→ such domain corresponds to acceptable values of the mean residual, upper bound = max R($\alpha \pm \sigma_{\hat{\alpha}}$ and $\beta \pm \sigma_{\hat{\beta}}$)

# *Alternative methodology (result)*

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




$Var(\hat{\theta}) \geq$ CR bound

e.g.: BOUSSOLE 510 nm

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

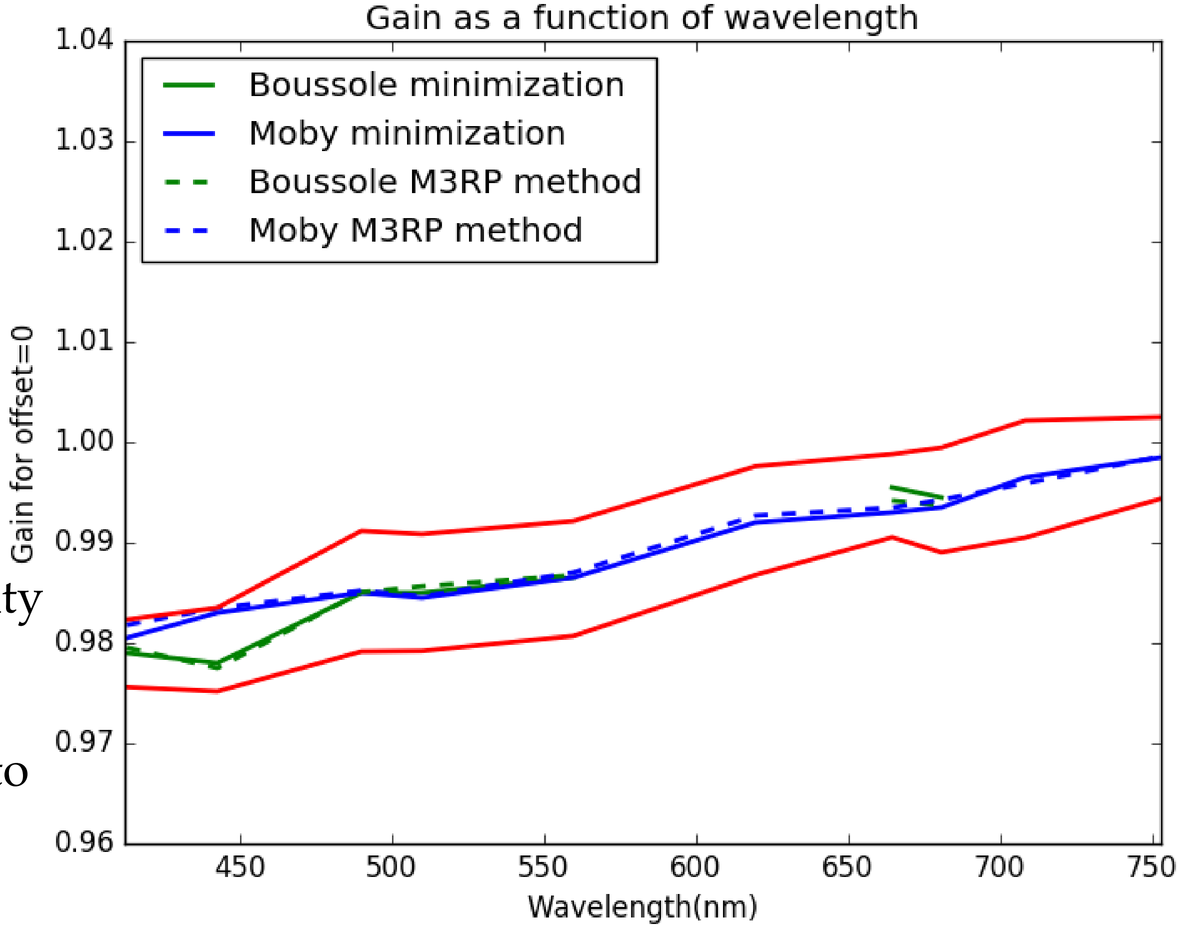
→ boundary gains where offset=0
→ uncertainties

→ nearly identical gains within CR domain

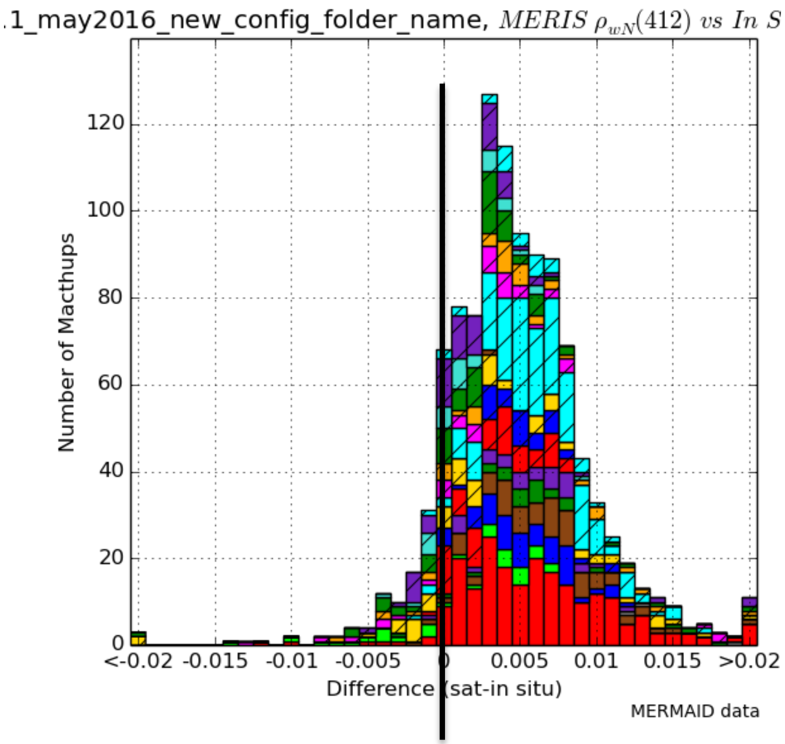
→ all solutions are acceptable

Objective:
decrease uncertainty of the estimator

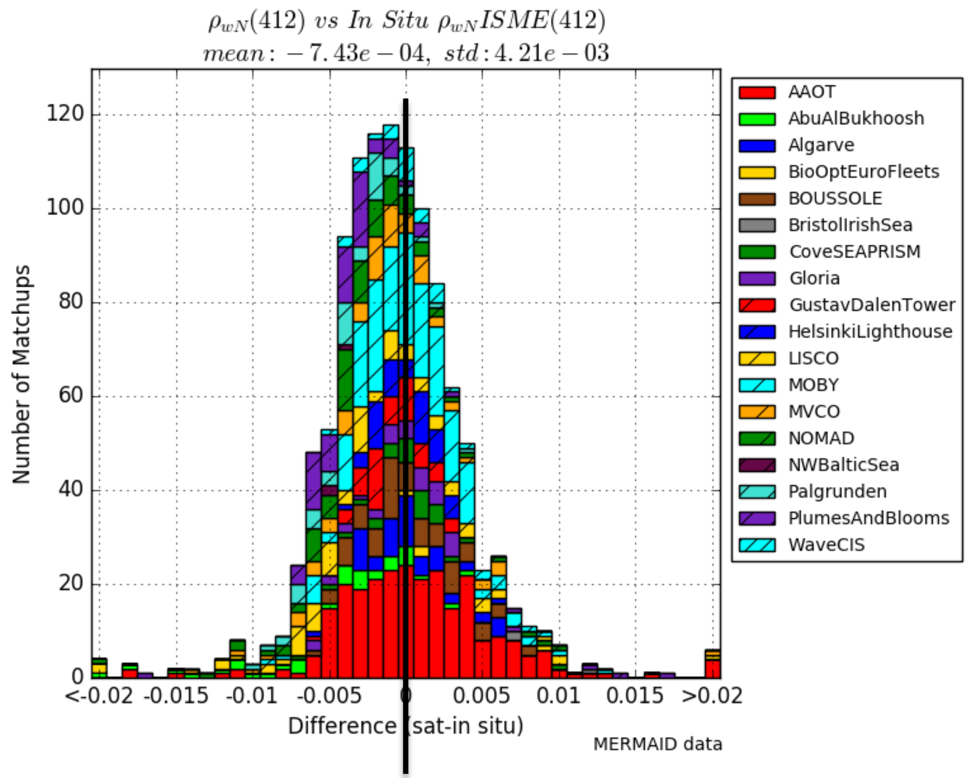
→ directly linked to IS and SAT uncertainties



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



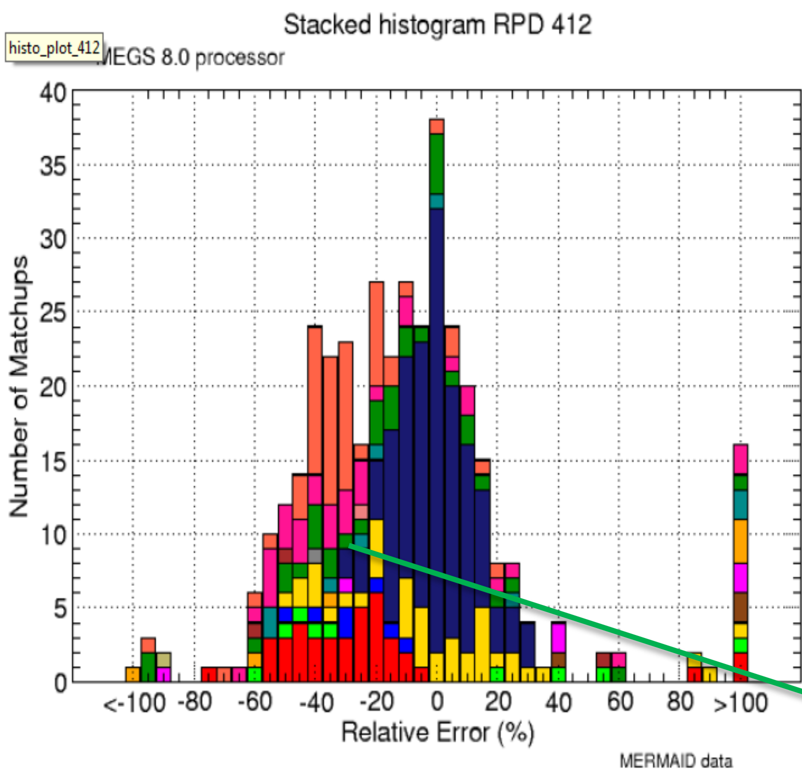

No gains




M4RP gains

## Validation

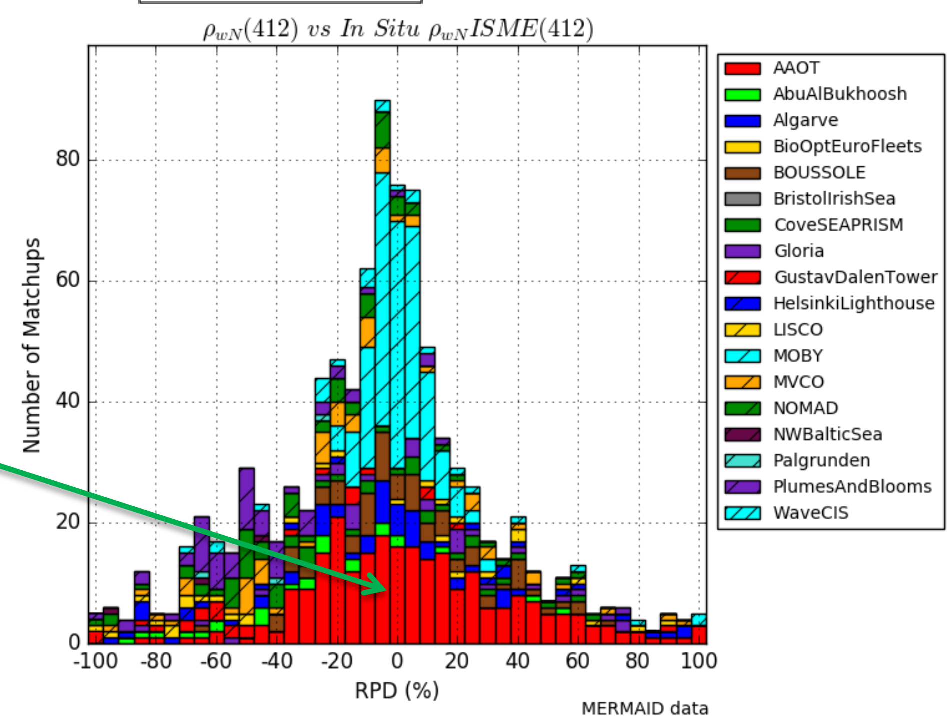
# Comparison M3RP / M4RP (RPD): 412





M3RP

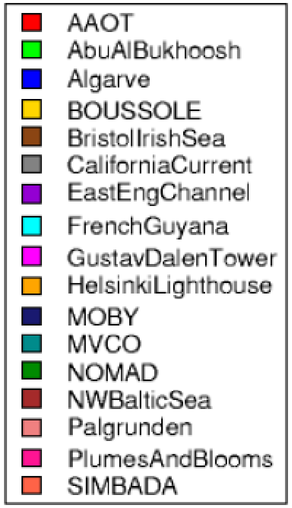
M4RP

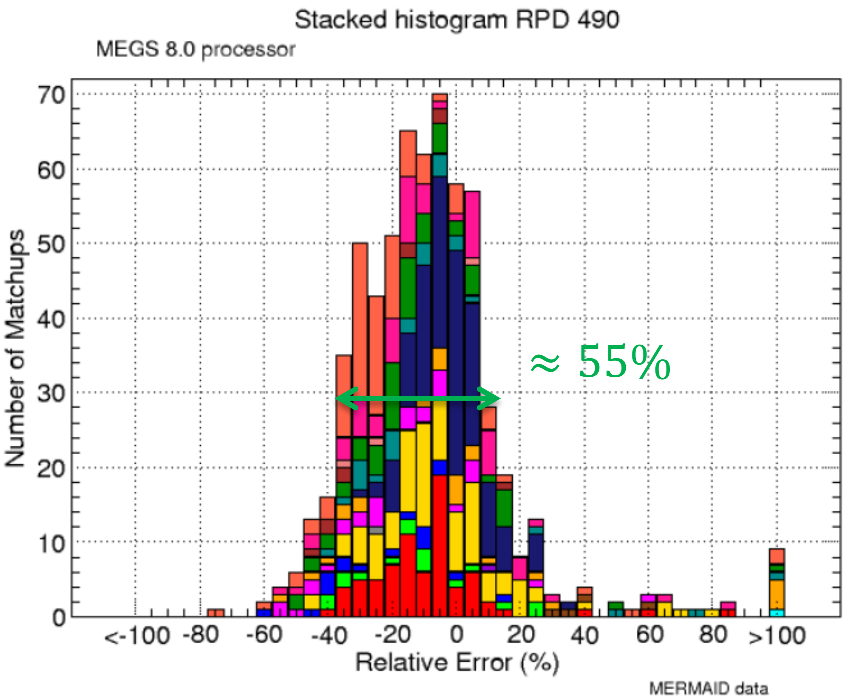



Less bias in M4RP

# Validation

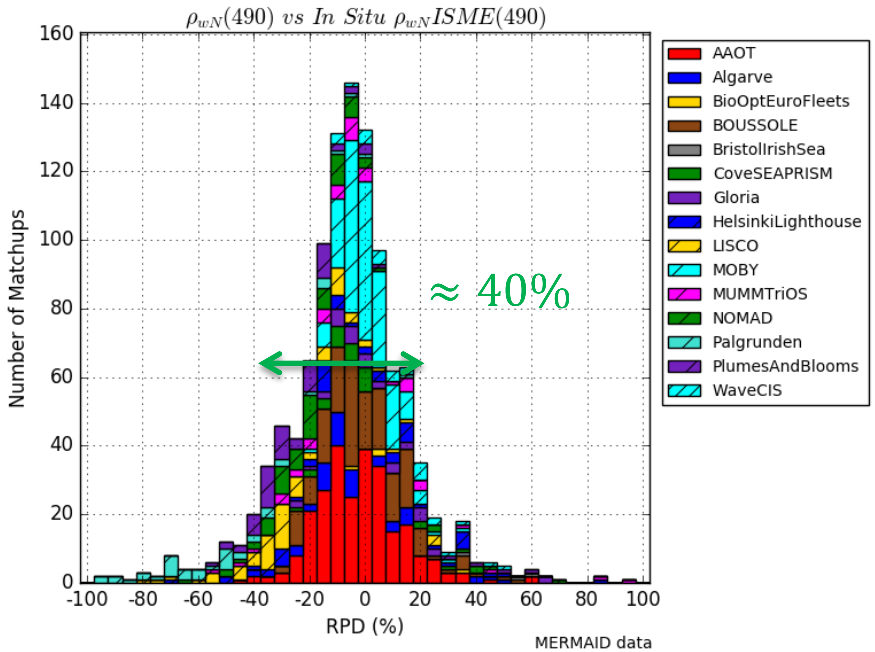
Comparison M3RP / M4RP (RPD): 490




M3RP

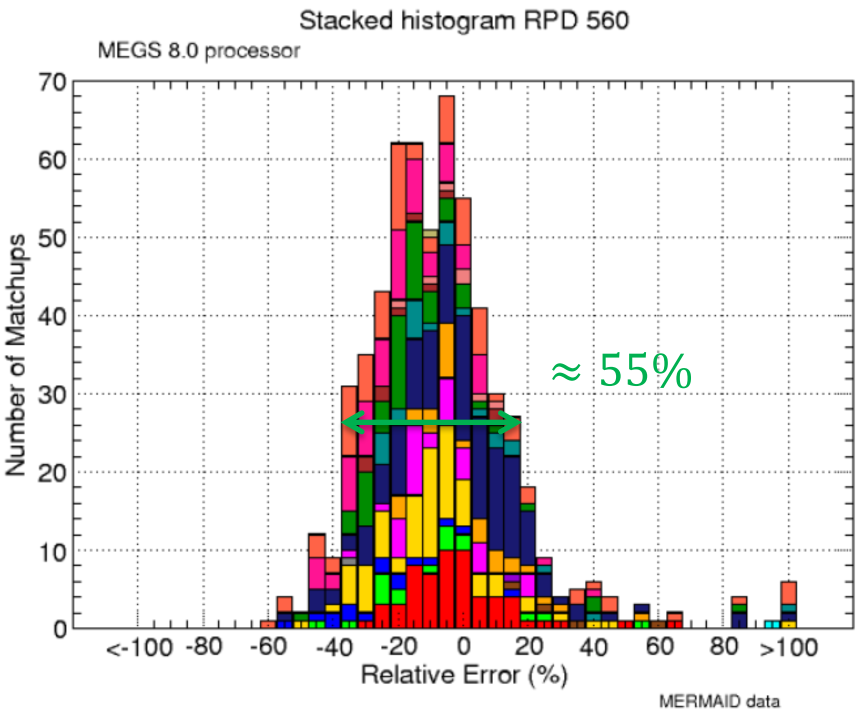
M4RP




Less dispersion in M4RP

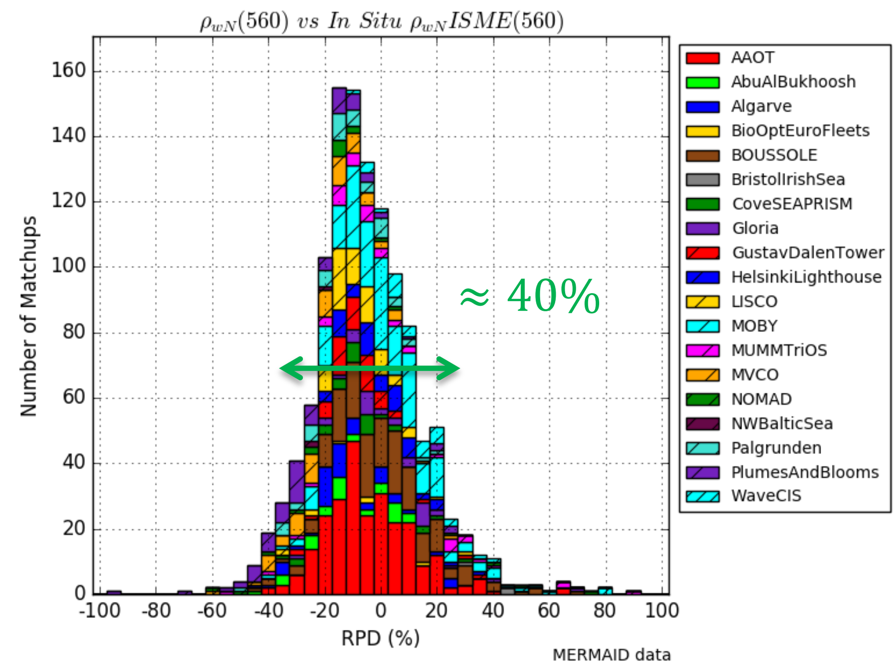
# Validation

## Comparison M3RP / M4RP (RPD): 560


M3RP

M4RP




Less dispersion in M4RP

## 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 !