IDEAS-QA4EO

ADVANCED RETRIEVAL METHODS AND UNCERTAINTIES ASSESSMENT FOR OCEAN COLOR PRODUCTS

Constant Mazeran (WP 2120)
solvo
France

Francis Zagolski (WP 2155)
Par Bleu technologies
Quebec, Canada

IDEAS-QA4EO Cal/Val workshop #4
Potsdam (Germany) - 28 Feb. – 02 Mar. 2023

WORK PACKAGES OVERVIEW

CONTEXT OF WP 2120 & 2155

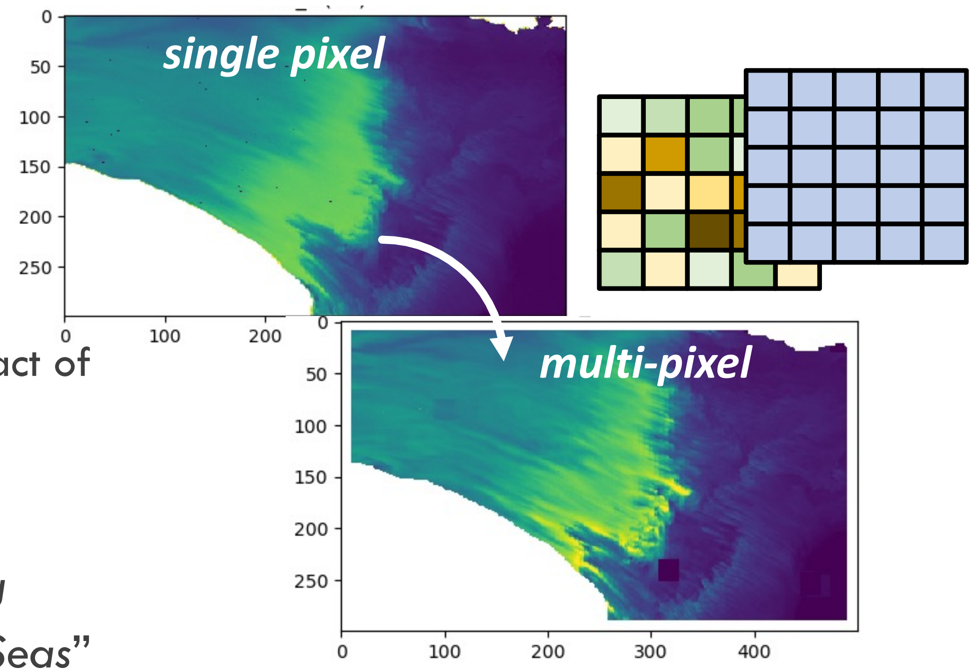
- **R&D activity focusing on Ocean Color Radiometry** (OCR, i.e. water-leaving radiance from blue to NIR)
  - Primary satellite measurement used by oceanographers & modelers to derive bio-geophysical products
  - TOA signal corrected for atmospheric effects (absorption & scattering) and other potential contaminations (sky-dome, residual sun-glint, white-caps, adjacency effects in vicinity of land, …)

- **Limitations of standard algorithms for MERIS & OLCI, developed for ideal conditions:**
  - Spectral range: Detection of aerosols in 2 NIR spectral bands + extrapolation to VIS bands
  - Spatial range: Processing performed sequentially on a pixel-basis, without accounting for information from surrounding pixels and potential spatial constraints
  - Purely optical: No synergy with other sensors in Space (due to operational constraints) or external data (except for meteorology)

OC inverse problem very challenging in actual conditions (complex waters, sun-glint, absorbing aerosols…) ⇒ Need to investigate more innovative approaches in term of signal processing than what is done in current operational processor

Par Bleu technologies solvo

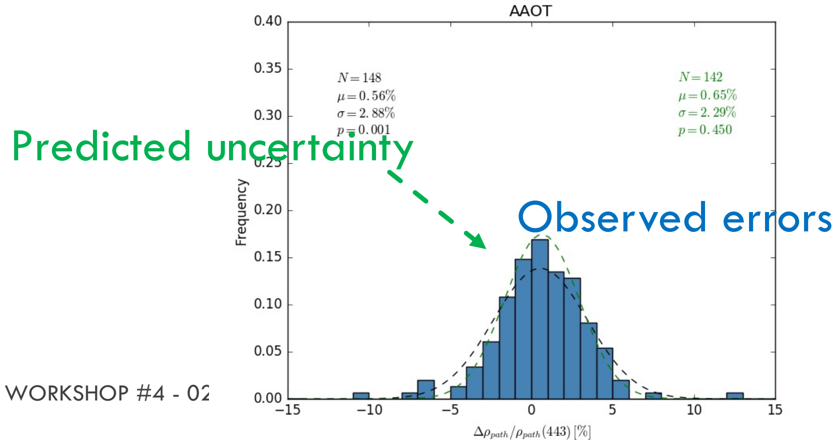
WP DELIVERABLES AND WORKLOAD



- Deliverables of IDEAS-QA4EO Phase-1 now all closed:
  - WP 2120 (SOLVO): ATBD with multi-pixel inversion completed
  - WP 2155 (PARBLEU): Radiative transfer DB + Technical report on impact of aerosol vertical profile (conclusions of WS#3 now inputs to WS#4)
- Publication submitted to IJRS: "*Uncertainty of atmospheric scattering functions relevant for satellite ocean colour radiometry in European Seas*"

$$\left(\frac{u(\rho_w)}{\rho_w}\right)^2 \approx \left(\frac{u(\rho_{gc})}{\rho_{gc}}\right)^2 \cdot \left(\frac{\rho_{gc}}{t.\rho_w}\right)^2 + \left(\frac{u(\rho_{path})}{\rho_{path}}\right)^2 \cdot \left(\frac{\rho_{path}}{t.\rho_w}\right)^2 + \left(\frac{u(t)}{t}\right)^2$$

$$-2.\frac{u(\rho_{path}.t)}{t.\rho_{path}} \cdot \frac{\rho_{path}}{t.\rho_w} + 2.\frac{u(\rho_{gc}.\rho_{path})}{\rho_{gc}.\rho_{path}} \cdot \frac{\rho_{gc}}{t.\rho} \cdot \frac{\rho_{path}}{t. \ldots} - 2.\frac{u(\rho_{gc}.t)}{t. \ldots} \cdot \frac{\rho_{gc}}{t. \ldots}$$



- Phase 2 schedule:
  - Need to focus the workload on less than 2.5 years to be more efficient (FTE = 20% over 1.5 year)
  - Phase-2 really started in 2023
  - Deliverables: OCR processor + uncertainties + ATBD + RTM DB (for OLCI) & technical note

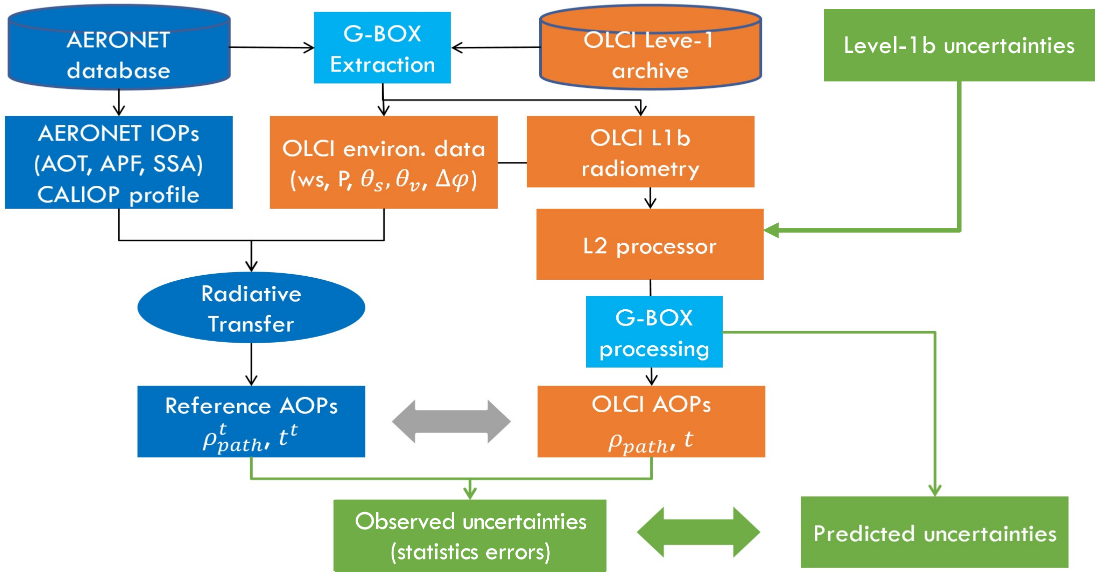
PLAN FOR IDEAS-QA4EO PHASE 2 (WP 2120, 2155)

I. OCR processor consolidation

- i. Implement CALIOP climatology in standard AC, assess performance ← **Q1 2023, today presentation**
- ii. Improve formulation of aerosol transmittance (impact of BRDF, analytical approach) ← **Started**
- iii. Further investigate the multi-pixel approach (full Atmospheric Correction chain, until the VIS) ← **Q3 2023**

II. Validation of OLCI AC and AC uncertainties: prototype tool using the IDEAS-QA4EO Cal/Val platform

- Start from OLCI Level-1b uncertainties characterization (← ESA)



← **Q4 2023 (Oct. 2023-Oct. 2024)**

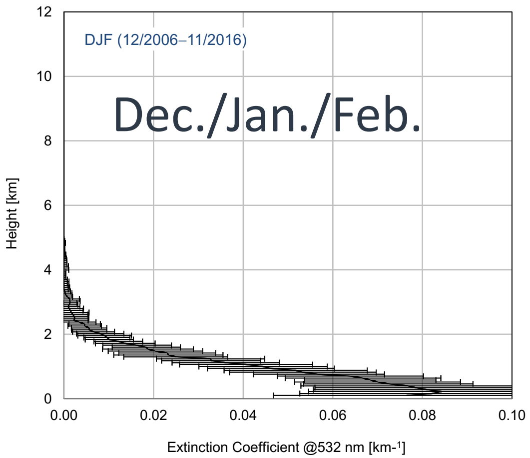
IDEAS-QA4EO collaboration with NPL, using CoMet toolkit?

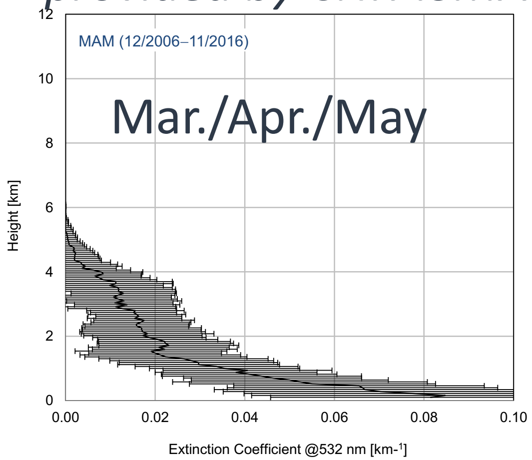
IMPACT OF AEROSOL VERTICAL PROFILE ON OCEAN COLOUR PRODUCTS

MOTIVATION AND METHOD

- **Aerosol vertical distribution impacts the coupling with Rayleigh**
  - Standard modelling in OC processor: fixed vertical profile in boundary layer (0-2 km) and troposphere (2-12 km)
  - Seasonal variation of vertical distribution of extinction coefficient @ 532nm measured by CALIOP from Dec.-2006 to Nov.- 2016 over Lampedusa

provided by CNR-ISMAR





- **Case study:** Lampedusa site with 9 years MERIS time-series; impact on vicarious gains and marine reflectance
  cf. Liberti et al. (2020), European Radiometry Buoy and Infrastructure (EURYBIA): A Contribution to the Design of the European Copernicus Infrastructure for Ocean Colour System Vicarious Calibration. Remote Sens., 12, 1178
- **AERONET data (inversion):** $AOT(\lambda) + SSA(\lambda) + P_{aer}(\Theta, \lambda)$ at $\lambda = \{440, 675, 870\}\ nm$
- **CALIOP data:** Vertical profiles of extinction coefficient derived from total backscatter measurements at 532 & 1064 nm from a near-nadir-viewing geometry during both day and night phases of CALIPSO orbit
- **Radiative transfer simulation:** Successive Orders of Scattering Code

Par Bleu technologies solvo

FROM ERRORS TO UNCERTAINTIES: EXAMPLE WITH VICARIOUS CALIBRATION GAINS

estimate of the measurand

error

truth

$$\Delta x = x - \hat{x}$$

theoretical target: $\rho_{gc}^{t}(\lambda) = \rho_{atm}^{t}(\lambda) + t_{atm}^{t}(\lambda)\rho_{w}^{t}(\lambda)$

Vicarious gains: $x = g(\lambda) = \dfrac{\rho_{gc}^{t}(\lambda)}{\rho_{gc}(\lambda)}$ ← observation (no error in this study)

error of ρ_{w}^{t} — error of t_{atm}^{t} — error of ρ_{atm}^{t}

<u>Exact</u> error of gain:

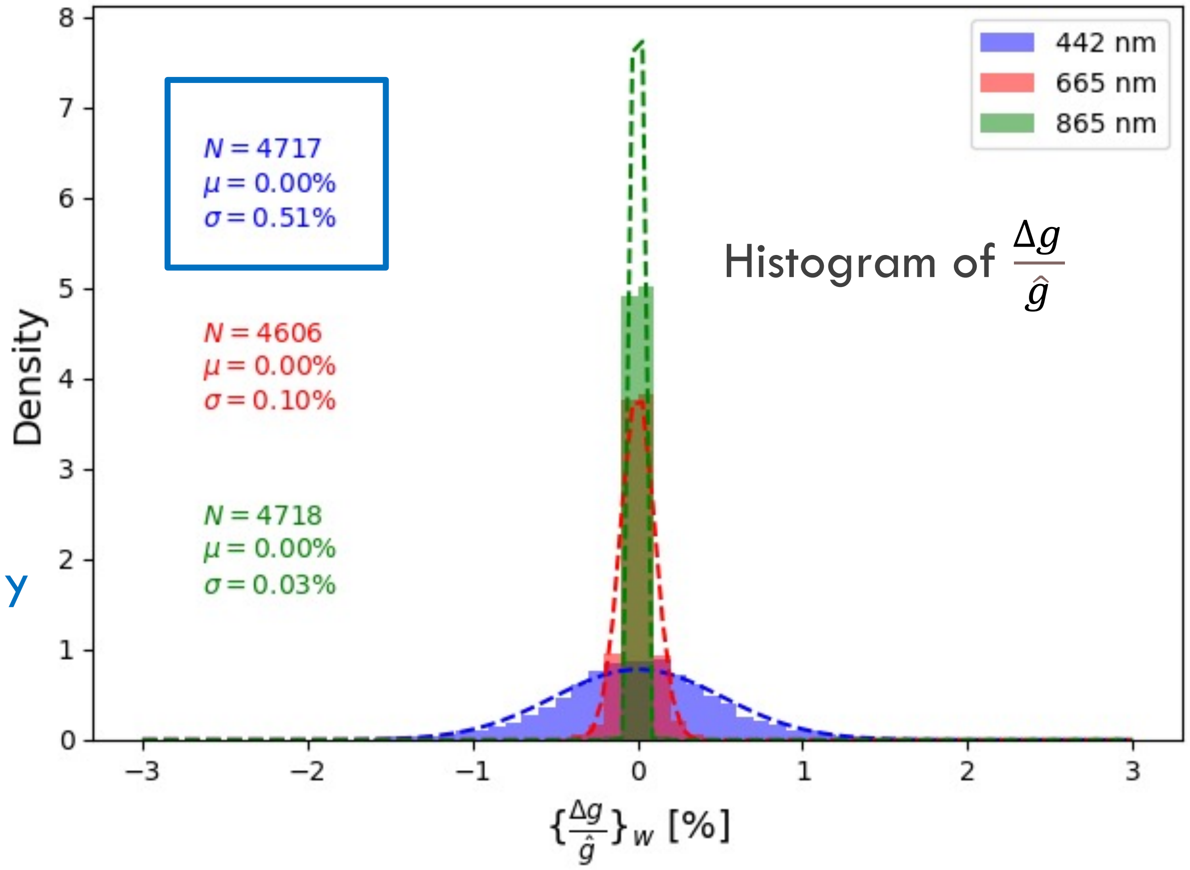
$$\frac{\Delta g}{\hat{g}} = \hat{c}_{w}^{t}\left(1 + \frac{\Delta t_{atm}^{t}}{\hat{t}_{atm}^{t}}\right)\frac{\Delta \rho_{w}^{t}}{\hat{\rho}_{w}^{t}} + \hat{c}_{w}^{t}\frac{\Delta t_{atm}^{t}}{\hat{t}_{atm}^{t}} + \hat{c}_{atm}^{t}\frac{\Delta \rho_{atm}^{t}}{\hat{\rho}_{atm}^{t}}$$

marine contribution ~10% in the blue

atm. contribution ~90% in the blue

FROM ERRORS TO UNCERTAINTIES: EXAMPLE WITH VICARIOUS CALIBRATION GAINS

- Let assume $\frac{\Delta\rho_w^t}{\widehat{\rho_w^t}} \sim \mathcal{N}(0; 5\%)$ and no error on the atmospheric terms
- Then $\frac{\Delta g}{\hat{g}} = \hat{c}_w^t \frac{\Delta\rho_w^t}{\widehat{\rho_w^t}}$



Histogram of $\frac{\Delta g}{\hat{g}}$

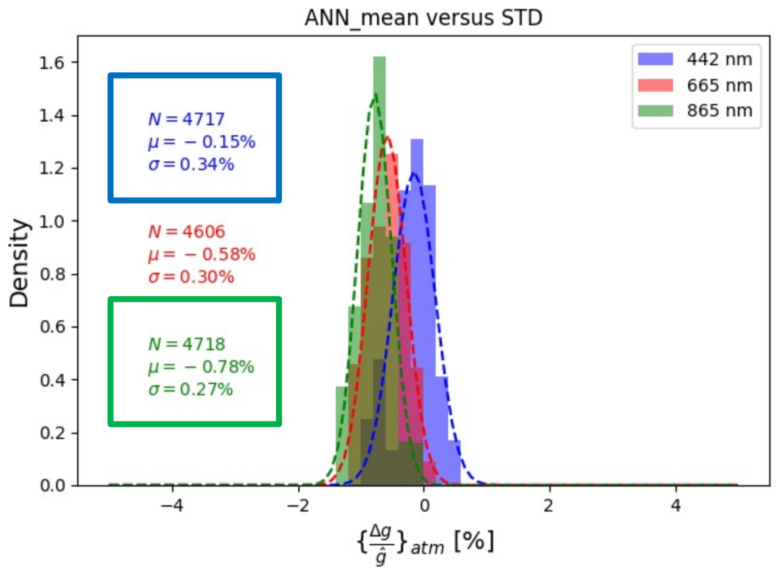
$$\frac{\Delta g}{\hat{g}}(442) \sim \mathcal{N}(0; 0.5\%)$$

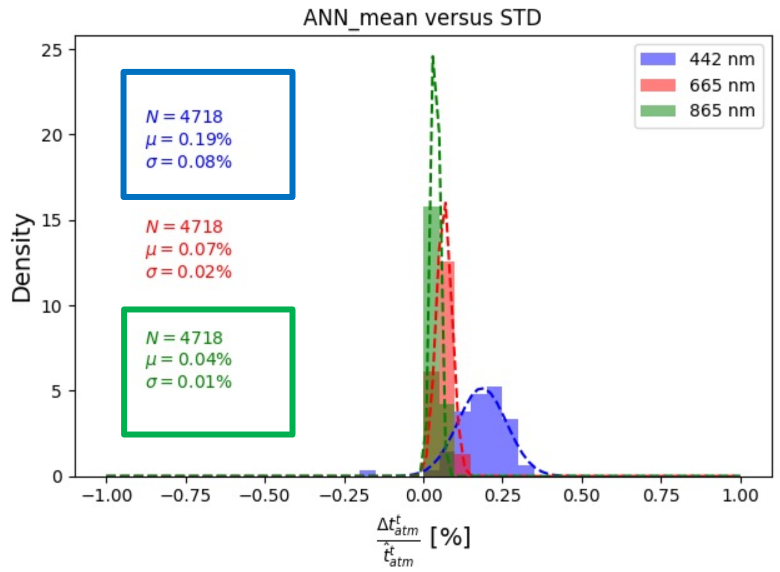
→ $\frac{u(g)}{g}(442)$ ~ 0.5% for the marine contribution only

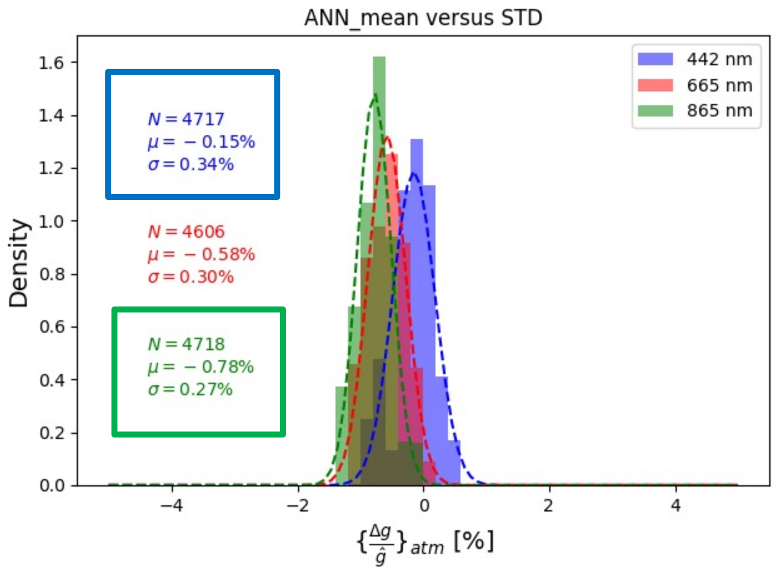
FROM ERRORS TO UNCERTAINTIES: EXAMPLE WITH VICARIOUS CALIBRATION GAINS

- Now, let assume $\Delta\rho_w^t$ =0 and that errors on atmospheric quantities are due to erroneous vertical profile
- First case: **MEASURAND = STD** profile, **TRUTH=CALIOP MEAN ANNUAL** profile

Histogram of $\frac{\Delta\rho_{atm}^t}{\widehat{\rho}_{atm}^t}$ + Histogram of $\frac{\Delta t_{atm}^t}{\hat{t}_{atm}^t}$ → Histogram of $\frac{\Delta g}{\hat{g}}$





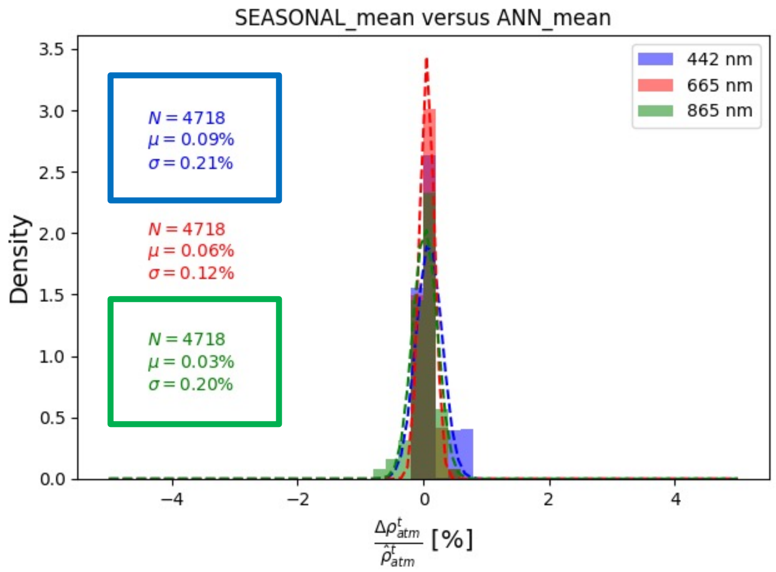


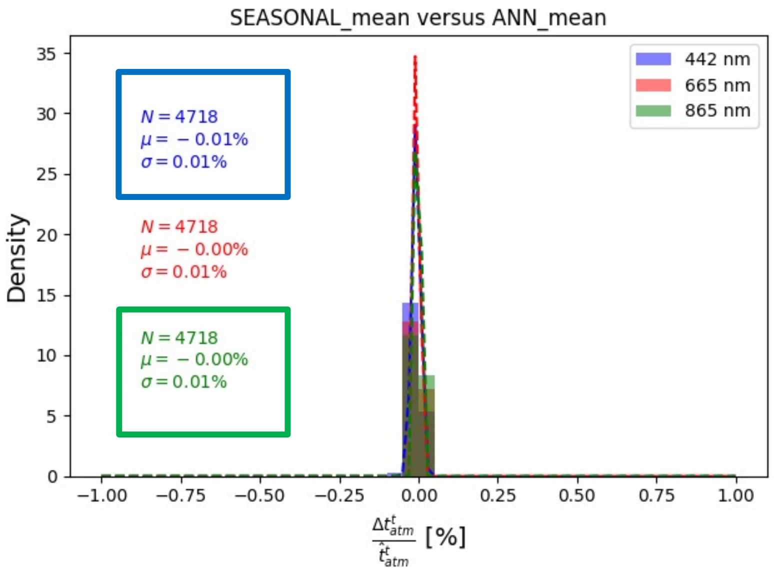
- Negative bias in all bands. Error in the red larger than error due to ρ_w^t

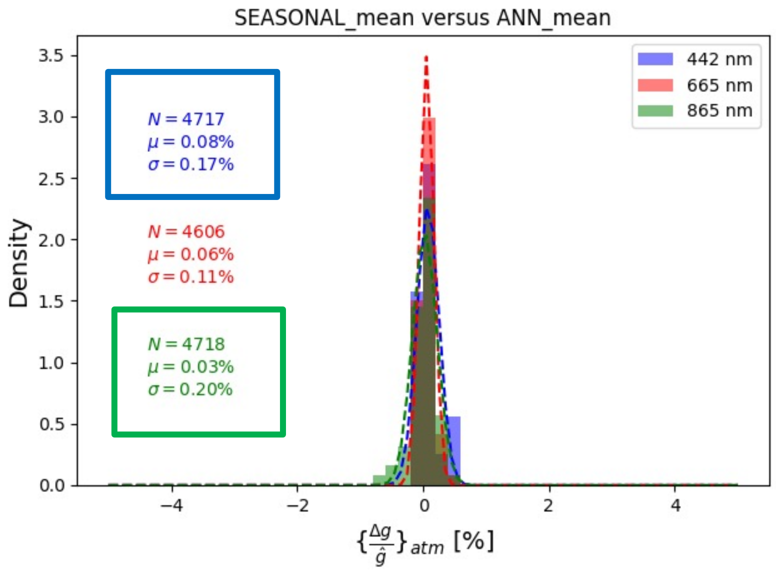
FROM ERRORS TO UNCERTAINTIES: EXAMPLE WITH VICARIOUS CALIBRATION GAINS

- Now, let assume $\Delta\rho_w^t$ =0 and that errors on atmospheric quantities are due to erroneous vertical profile
- Second case: **MEASURAND = MEAN ANNUAL** profile, **TRUTH = MEAN SEASONAL** → seasonal effect

Histogram of $\frac{\Delta\rho_{atm}^t}{\hat{\rho}_{atm}^t}$ + Histogram of $\frac{\Delta t_{atm}^t}{\hat{t}_{atm}^t}$ → Histogram of $\frac{\Delta g}{\hat{g}}$







- $\mu \approx 0$ but $\sigma(442)$ about half of previous error; same order in the NIR: not negligible in a full unc. budget

TRANSFERRING THEORETICAL ERRORS TO UNCERTAINTY ASSESSMENT

- *Exact error* on vicarious gains:

error of ρ_w^t — error of t_{atm}^t — error of ρ_{atm}^t

$$\frac{\Delta g}{\hat{g}} = \hat{c}_w^t \left(1 + \frac{\Delta t_{atm}^t}{\hat{t}_{atm}^t}\right) \frac{\Delta \rho_w^t}{\hat{\rho}_w^t} + \hat{c}_w^t \frac{\Delta t_{atm}^t}{\hat{t}_{atm}^t} + \hat{c}_{atm}^t \frac{\Delta \rho_{atm}^t}{\hat{\rho}_{atm}^t}$$

- Application of GUM to "measurement" equation of vicarious gains: *approximate uncertainty*

Better suited for unc. budget in operational processor than Monte-Carlo - if correct!

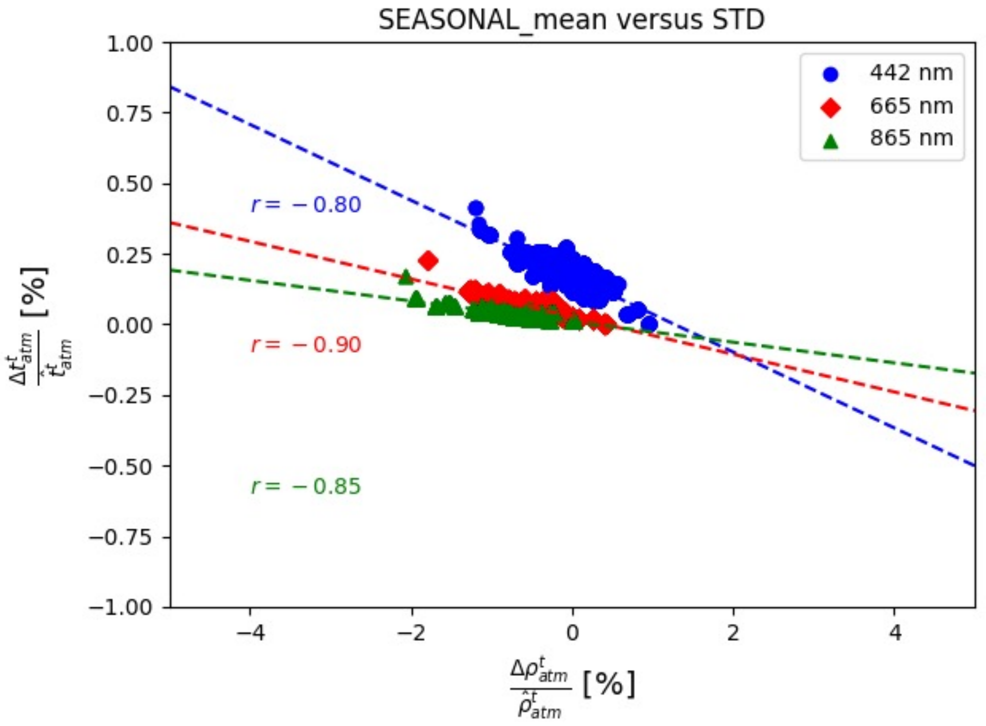
unc. of ρ_w^t — unc. of t_{atm}^t — unc. of ρ_{atm}^t — covariance

$$\left(\frac{u(g)}{g}\right)^2 \approx {c_w^t}^2 \left(\frac{u(\rho_w^t)}{\rho_w^t}\right)^2 + {c_w^t}^2 \left(\frac{u(t_{atm}^t)}{t_{atm}^t}\right)^2 + {c_{atm}^t}^2 \left(\frac{u(\rho_{atm}^t)}{\rho_{atm}^t}\right)^2 + 2 c_w^t c_{atm}^t \frac{u(t_{atm}^t, \rho_{atm}^t)}{t_{atm}^t \rho_{atm}^t}$$

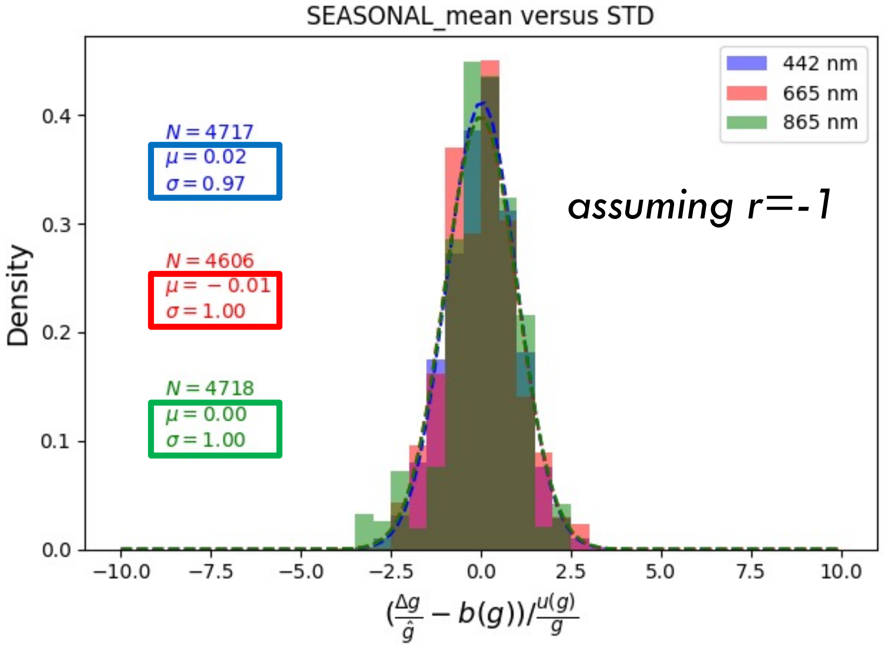
Systematic bias: $\frac{b(g)}{g} \approx c_w^t \frac{b(\rho_w^t)}{\rho_w^t} + c_w^t \frac{b(t_{atm}^t)}{t_{atm}^t} + c_{atm}^t \frac{b(\rho_{atm}^t)}{\rho_{atm}^t}$

TRANSFERRING THEORETICAL ERRORS TO UNCERTAINTY ASSESSMENT

- Strong correlation between $\frac{\Delta t_{atm}^t}{\hat{t}_{atm}^t}$ & $\frac{\Delta \rho_{atm}^t}{\hat{\rho}_{atm}^t}$



- Full example: include $\frac{\Delta \rho_w^t}{\widehat{\rho_w^t}} \sim \mathcal{N}(0, 5\%)$, **MEASURAND = STD** profile, **TRUTH=CALIOP MEAN SEASONAL**
- Uncertainty estimate check: histogram of $\left(\frac{\Delta g}{\hat{g}} - b\right) / \left(\frac{u(g)}{g}\right)$ should match normal standard law



CONCLUSIONS

- **The QA4EO uncertainty framework** can be applied to assess the impact of aerosol vertical profile in ocean colour: description of the uncertainty structure (distribution and its parameters)
- **Current stage: impact on vicarious gains**
  - Findings relevant for Level-1 vicarious calibration activities such as DIMITRI and RadCalNet-OC
  - Uncertainty due to aerosol profile is of same order as that due to marine reflectance in the blue, growing in the red, and with negative bias → it has to be considered in the uncertainty budget
- **On-going work**:
  - Similar analysis on marine reflectance, i.e. uncertainty of atmospheric correction:

$$\frac{\Delta\rho_w}{\hat{\rho}_w} = \frac{1}{1+\frac{\Delta t_{atm}}{\hat{t}_{atm}}}\left(\frac{\Delta g}{\hat{c}_w} - \frac{\Delta t_{atm}}{\hat{t}_{atm}} - \frac{\hat{c}_{atm}}{\hat{c}_w}\frac{\Delta\rho_{atm}}{\hat{\rho}_{atm}}\right)$$

  - Uncertainty compensation in a full System Vicarious Calibration approach (calibration + atmospheric correction)
  - Ideally duplicate the analysis done with MERIS for OLCI
  - IDEAS-QA4EO technical reports under preparation

THANK YOU