Uncertainty propagation

Current status in OLCI processor and MERIS 4th reprocessing

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Overview

- Uncertainties in a more general context
- Restricting to propagation of TOA radiometric uncertainties down to geophysical parameters
  - Further restricting to the core step toward OC products: the AC
  - Validation methodology & results
  - Examples and correlation with aerosol retrieval and existing QIs
- Conclusion and recommendations

Uncertainties: definitions and assumptions

- **Model linking a geophysical parameter to a remote sensing measurement**

Ideally: $y = f(x, v)$

In practice: $\hat{y} = f(\hat{x}, \hat{v}) + r \quad (with\ \hat{z} = z + z')$

Geophysical parameter

Remote sensing measurement

Model parameters (ADF)

Model error

- **Example:**
  - y : water leaving reflectance
  - x : L1 TOA radiances
  - v : inversion parameters, e.g. geometry, meteo conditions…
  - f : transfer function of the atmosphere correction

Uncertainties: model

❖ Assumptions for application:

- normal distribution (no bias)
- Small uncertainties (linearization is possible)
- Statistical independence of uncertainty sources (x,v)

❖ Under these assumptions uncertainty on y follows:

$$E(y' \times {}^t y') = \partial_x f E(x' \times {}^t x')^t \partial_x f + \partial_v f E(v' \times {}^t v')^t \partial_v f + E(R \times {}^t R)$$

Parameter uncertainty covariance

Propagation of measurement error

Propagation of parameter uncertainties

Model error covariance

Uncertainties: breakdown

- **1. Remote Sensing Measurement (L1) Uncertainty**
  - Intrinsic (shot) noise
  - Instrument measurement error residuals (after correction/calibration)
- **2. External parameters uncertainties**
  - e.g. uncertainty on meteo/environment conditions (not straightforward!)
- **3. geophysical transfer function « model error »**
  - Estimate impact of approximations made in the L2 model
  - Examples: RT LUTs, natural variability…
- **4. Propagate uncertainties**
  - Compute partial derivatives of the transfer function with respect to all terms

Uncertainties: status

- 1. Remote Sensing Measurement (L1) Uncertainty
  - Intrinsic (shot) noise
  - Instrument measurem

Empirical workaround at L2 (mostly shot noise + inter-band correlation matrix)

- 2. External parameters uncertainties
  - e.g. uncertainty on meteo/environment conditions)

Ignored

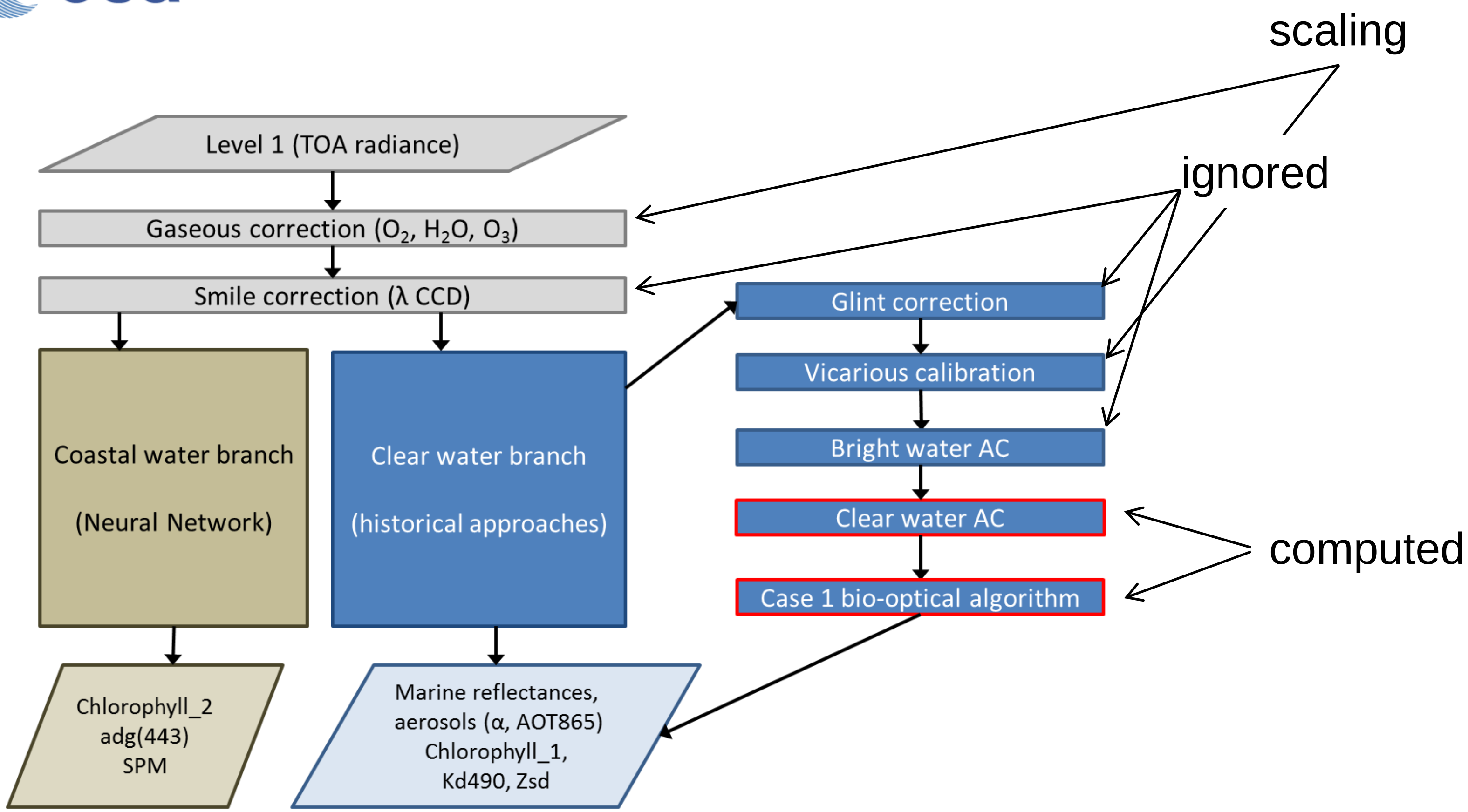
- 3. geophysical transfer function « model error »
  - Estimate impact of approximations made in the L2 r
  - Examples: RT LUTs, natural variability…

Ignored

- 4. Propagate uncertainties
  - Compute partial derivatives of the transfer function with respect to all terms

MERIS/OLCI status: propagation of TOA measurement errors (shot noise assumption) to BOA reflectance errors (other terms ignored)

Application: where in the Level 2 chain



- Inputs of this work are $\rho_{path}(779)$, $\rho_{path}(865)$ and $\rho_{gc}(\lambda_{VIS})$
- Goal of error propagation: from TOA σ_{779}, σ_{865} and $\sigma_{\lambda_{VIS}}$, deduce $\sigma_{\rho_w(\lambda_{VIS})}$ and σ_{Chl}, σ_{Kd} etc.
- TOA uncertainty refers here to radiometric noise

Application to the CWAC problem

- **Consider function** $\rho_{w,\lambda}(x,y,z)=\frac{x-\zeta_\lambda(y,z)*\rho_R(\lambda)}{t_\lambda(y,z)}$

  with $x=\rho_{gc}(\lambda)$**,** $y=\rho_{path}(779)$ **and** $z=\rho_{path}(865)$
- **Variance-covariance matrix is**

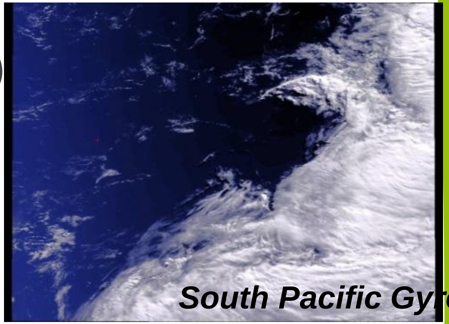
$$C=\begin{pmatrix}\sigma_\lambda^2 & \sigma_{\lambda,779} & \sigma_{\lambda,865}\\ \sigma_{\lambda,779} & \sigma_{779}^2 & \sigma_{779,865}\\ \sigma_{\lambda,865} & \sigma_{779,865} & \sigma_{865}^2\end{pmatrix}$$

to be determined from sensor/Level 1 characterisation

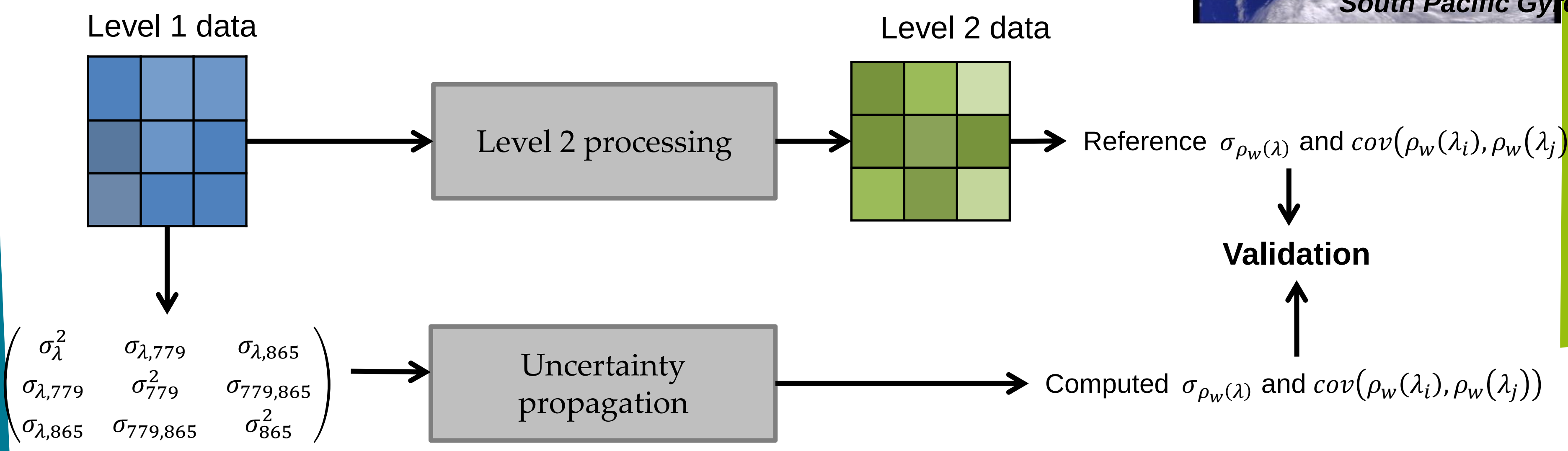
In the Antoine & Morel atmosphere correction (1999), it is possible to derive analytically all terms $\frac{\partial\rho_w}{\partial x}$, $\frac{\partial\rho_w}{\partial z}$, $\frac{\partial\rho_w}{\partial z}$ and compute $var(f)$ → Pixel by pixel uncertainty propagation

Validating uncertainty propagation (1/3)

- **Data**
  - **Very homogenous targets: radiometric uncertainty can be assessed by spatial standard deviation around each pixel (small scale wrt errors due to modelling)**
  - **South Pacific Gyre and South Indian Ocean (NIR vicarious calibration sites, no bias)**

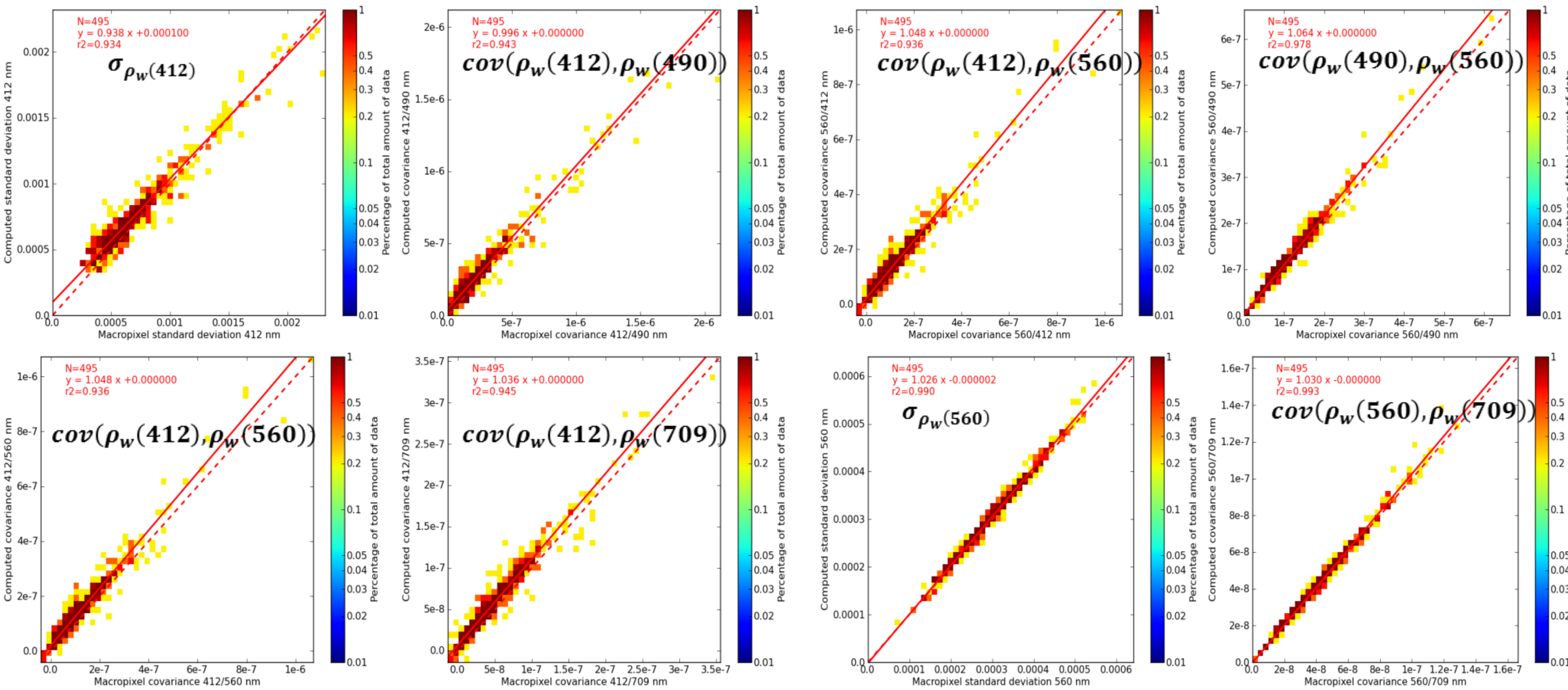


- **Method**



Validating uncertainty propagation (2/3)

- **Comparison between reference (x-axis) and computed uncertainty (y-axis)**
- **Variances and spectral covariances are very well retrieved, on the full range of errors (495 scenes)**

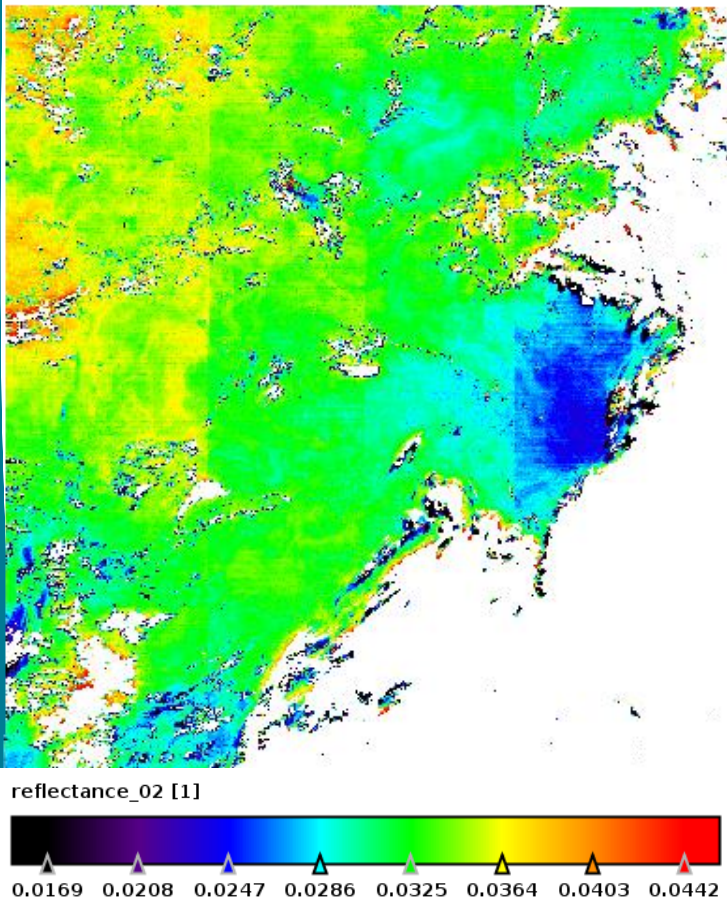


- **Note: inputs uncertainties are derived from TOA *macropixels statistics*, not *modelled*!**

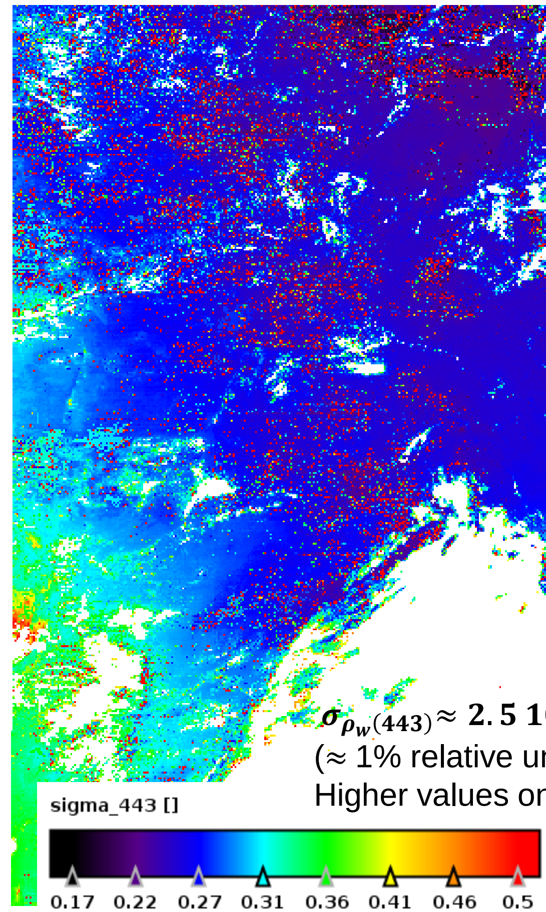
MERIS RR uncertainty maps

(this time L1 uncertainty from shot noise model + covariance matrix)

$\rho_w(443)$

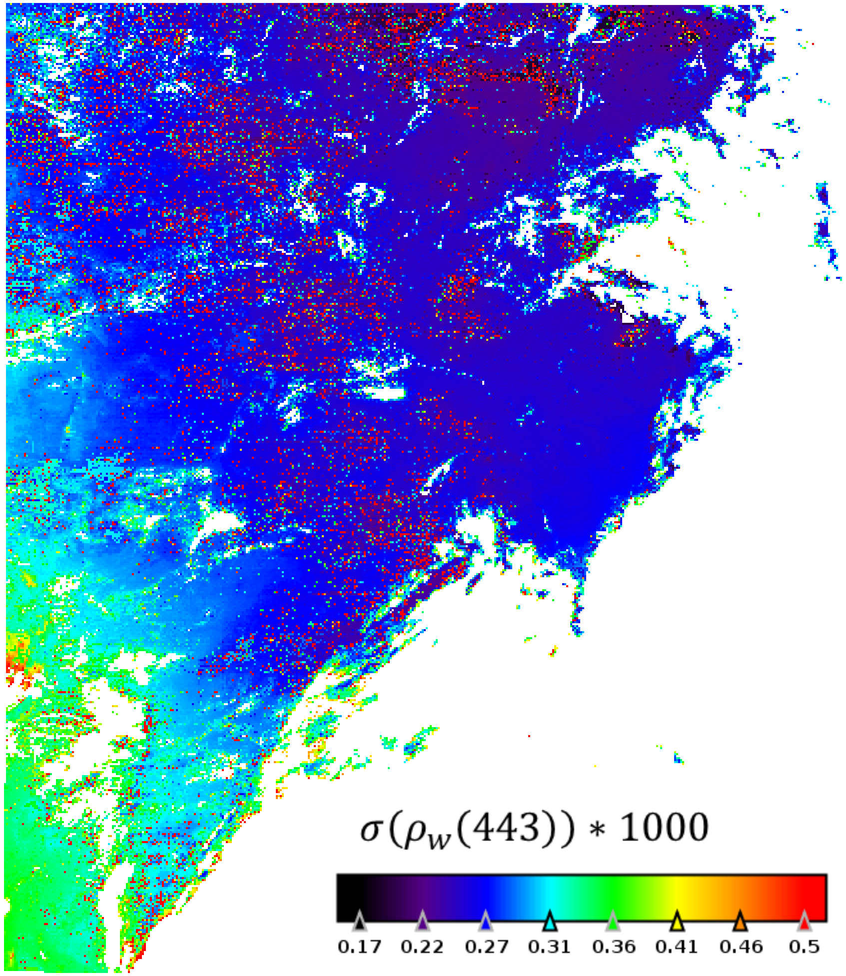


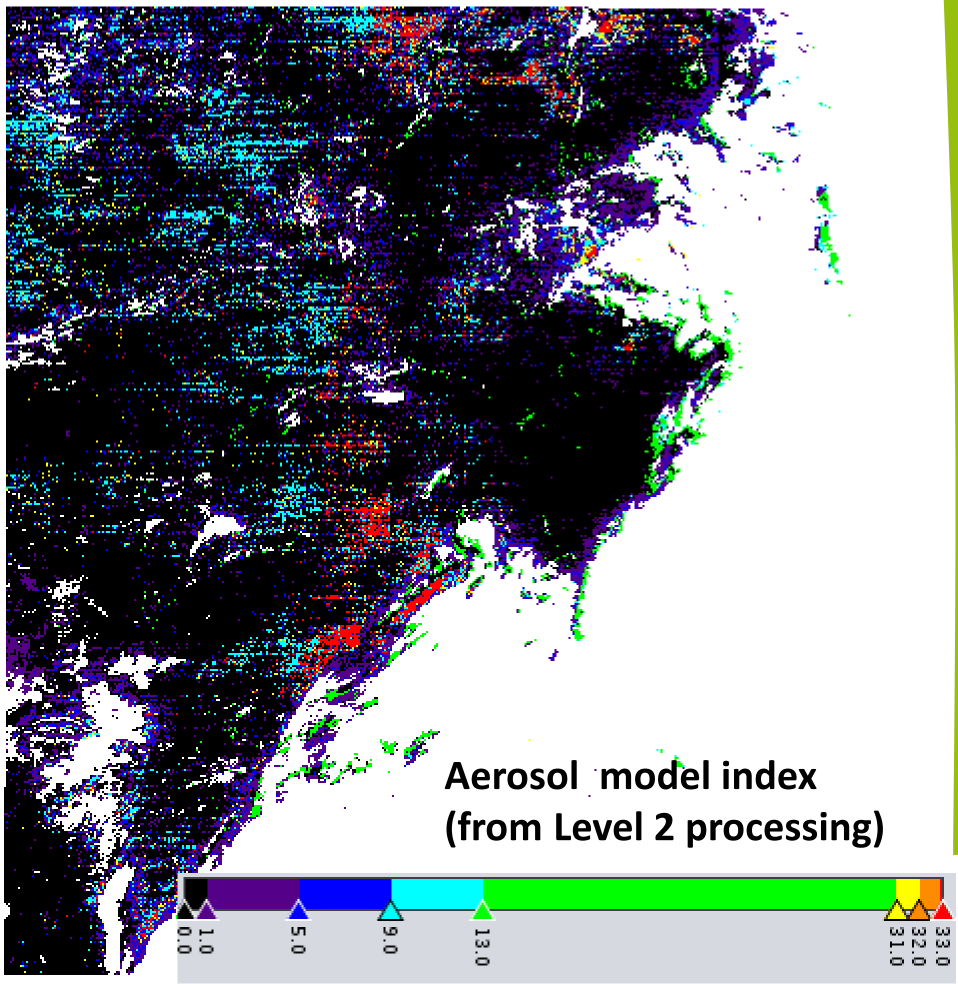
$\sigma_{\rho_w(443)}$*1000



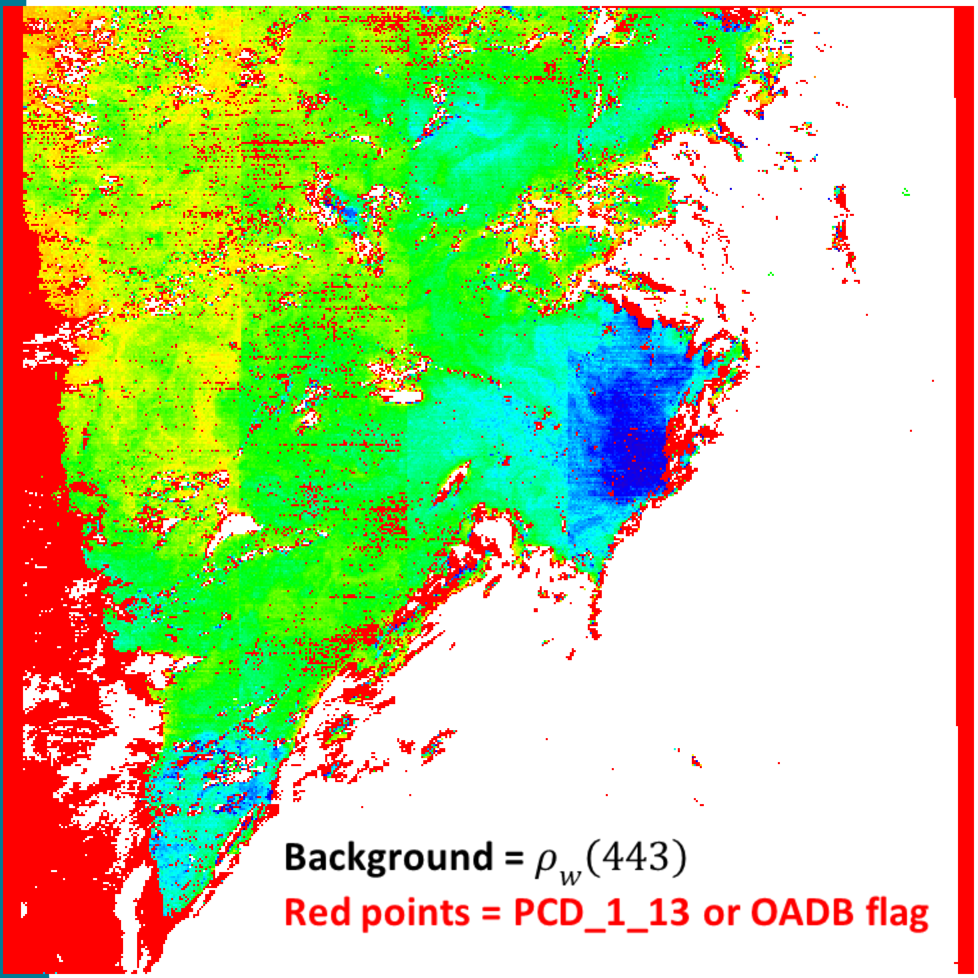
$\sigma_{\rho_w(443)} \approx \mathbf{2.5\ 10^{-4}}$ for most of the scene
($\approx$ 1% relative uncertainty)
Higher values on specifics pixels and regions

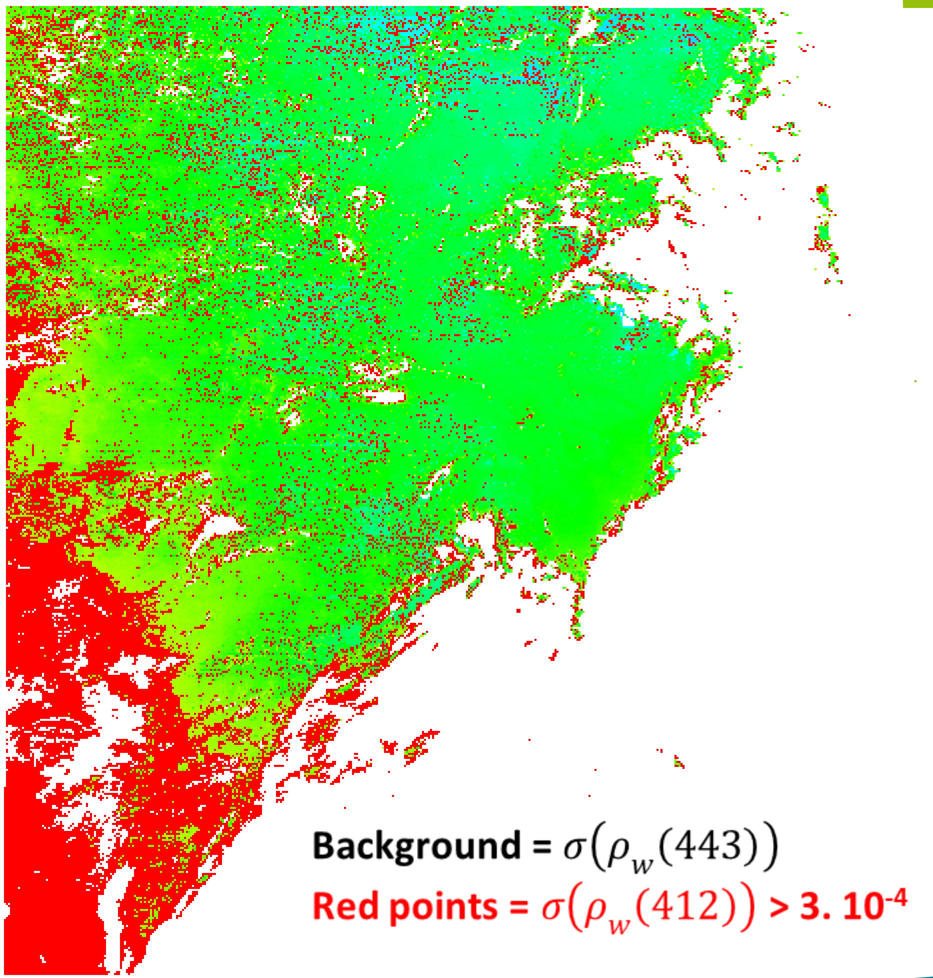
Uncertainty versus aerosol models





Uncertainty versus Level2 flags





Conclusions and recommendations

- **Following ESA's QA4EO guidelines for OLCI products uncertainty estimates**
  - **it is possible to analytically propagate radiometric uncertainty through Level 2 inversions such as atmosphere correction and ocean color.**
  - **the method is documented in S3 Optical product ATBD and DPM**
  - **the method is implemented in the OLCI Level 2 ground segment and will be for MERIS 4th reprocessing**
- **Experience leads to following recommendations:**
  - **The full characterization of Level 1 radiometric uncertainty is absolutely required (in particular spectral variance-covariance matrix)**
  - **Uncertainties from upstream steps need to be accounted for (smile correction, bright pixel atmospheric correction, glint correction…)**
  - **Contributions from external parameters (meteo) need to be computed**
  - **With current OC sensors radiometric performance, uncertainties from physics (e.g. bio-optical model, RT) are important contributors: need to be assessed as well.**