Requirements for Copernicus Ocean Colour Vicarious Calibration Infrastructure

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Approach & preliminary requirements

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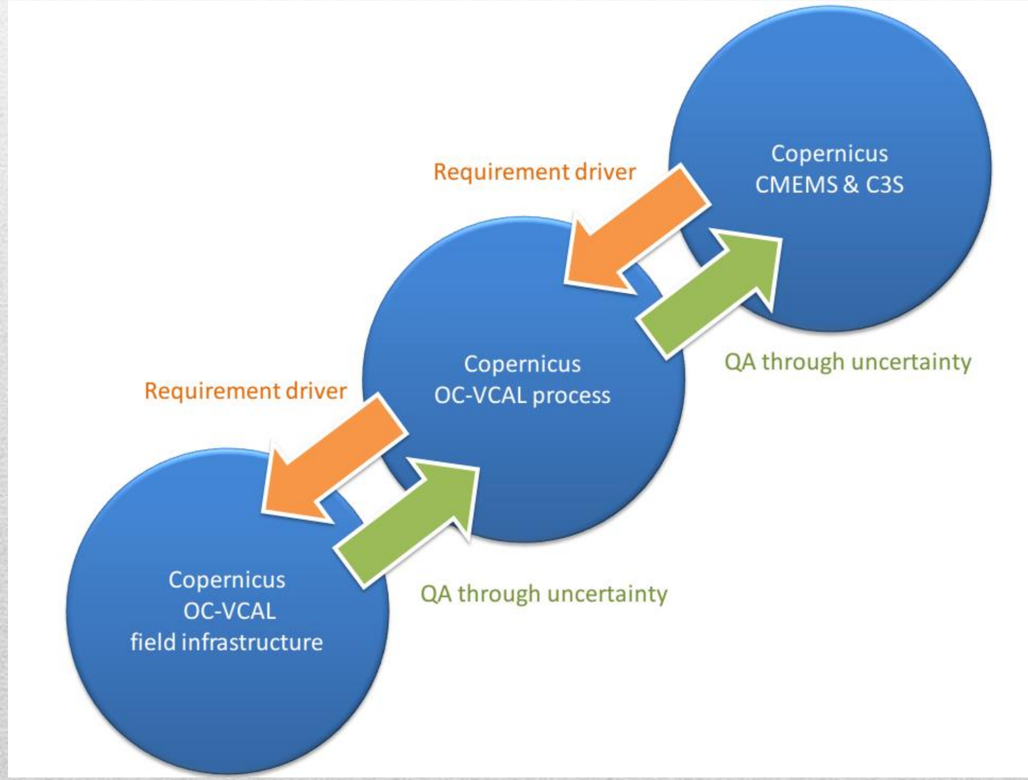
Outline

- Goal & logic of the study: uncertainty driven
- Physics of SVC
- SI-traceability
- Overall uncertainty budget
- Overview of preliminary requirements
  - Requirements on the SVC process
  - Requirements on the field infrastructure
  - Requirements on the data processing
  - Requirements on the operation & maintenance
- Status on the document

Goal & logic of the study

- Write a **requirements document** that can be used as a traceable reference for the development and operation of an OC-VCAL infrastructure, in the Copernicus Programme

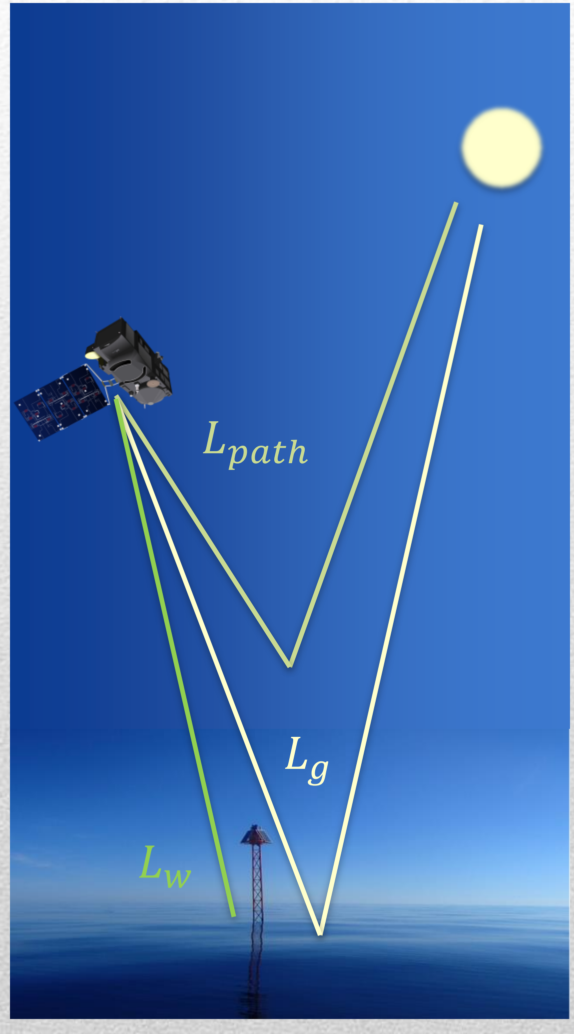


- Requirements on vicarious gains are driven by requirements on OC products
- Requirements on OC-VCAL infrastructure are driven by the **uncertainty budget** of the vicarious gains – not by the applications
- Existing infrastructures provide **guidances**

Plan of the report

1. Introduction	Required quality in OCR, physics of SVC, international background
2. Traceability chain & uncertainty approach	SI-traceability & uncertainty budget
3. Requirements on the SVC process	Link with Space sensor calibration, methodology, required quantities
4. Requirements on field infrastructure	Radiometer, platform, measurements, environmental conditions…
5. Requirements on the data processing	QC, post-processing, match-ups…
6. Requirements on the operation & service	Field operation & maintenance, ground segment, access, human aspects …
7. Conclusion	The way towards an European programme

Physics of SVC



- Focus on **standard atmospheric correction** (AC) (Gordon and Wang 1994, Antoine and Morel 1999): still operationally used by Space agencies

$$L_t(\lambda_i) = t_g(\lambda_i) \cdot \left(L_{path}(\lambda_i) + T(\lambda_i)L_g + t(\lambda_i)L_w(\lambda_i)\right)$$

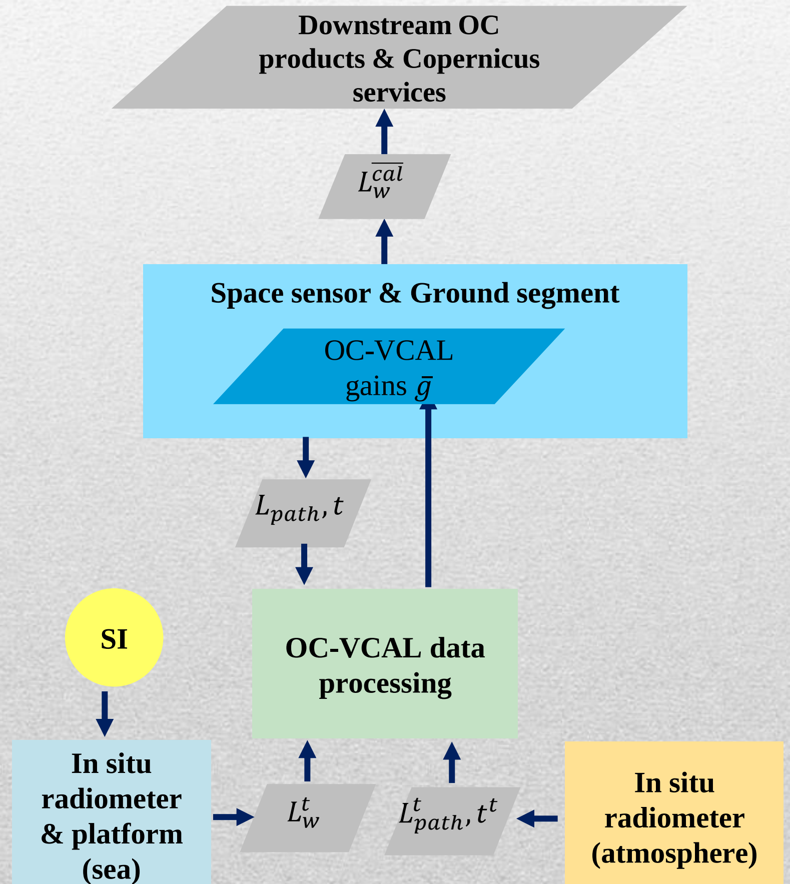
$$\frac{\Delta L_w}{L_w}(\lambda_i) = \frac{\Delta L_t}{L_t}(\lambda_i) \Big/ \frac{t_g t L_w(\lambda_i)}{L_t(\lambda_i)}$$

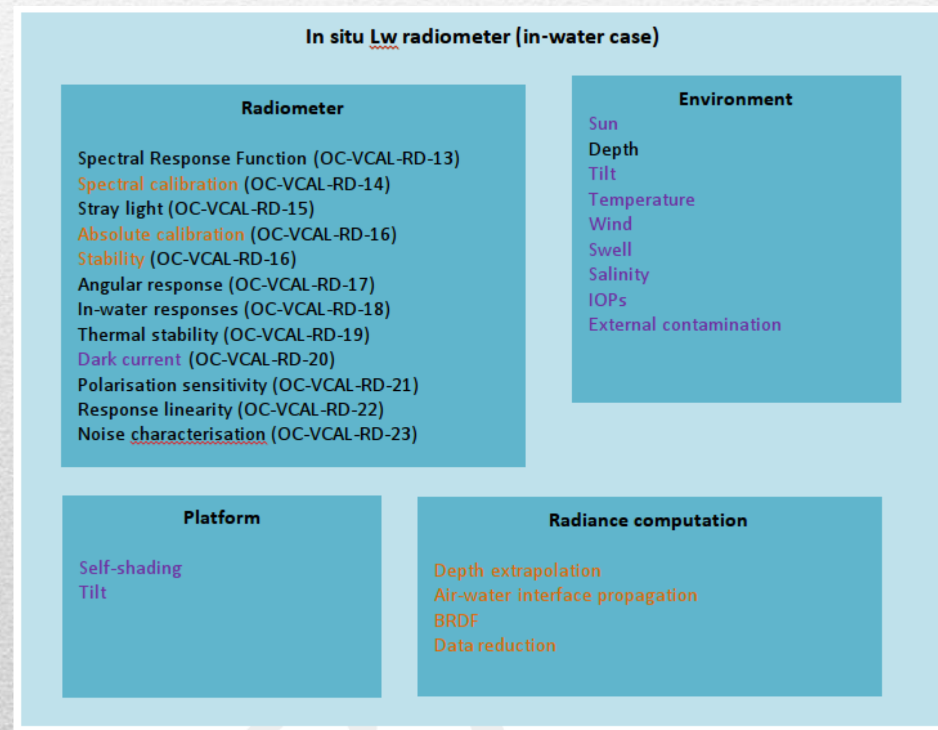
⚠ Not true for spectral matching AC

- Focus on **System Vicarious Calibration (SVC):** most achievable approach to be implemented in a near-future: $L_t^t(\lambda_i) = t_g(\lambda_i) \cdot \left(L_{path}(\lambda_i) + t(\lambda_i)C_Q(\lambda_i)L_w^t(\lambda_i)\right)$
- Compute individual gains $g(\lambda_i) = \frac{L_t^t(\lambda_i)}{L_t(\lambda_i)}$ + averaging
- After SVC: $\overline{L_w^{cal}}(\lambda_i) = \left(\bar{g}(\lambda_i)\frac{L_t(\lambda_i)}{t_g(\lambda_i)} - L_{path}(\lambda_i)\right)/t(\lambda_i)$

Traceability chain

- Traceability of $\overline{L_w^{cal}}$ to SI unit is ensured by traceability of the in situ L_w^t
- All steps are rigorously described by mathematical equations and protocols





- Temporally stable
- Temporally changing with low frequency
- Changing concurrently with the measurement itself

Overall uncertainty budget

Uncertainty on OCR due to SVC: $\frac{\sigma_{\overline{L_w^{cal}}(\lambda_i)}}{\overline{L_w^{cal}}(\lambda_i)} = \sigma_{\bar{g}(\lambda_i)} / \left(\frac{t_g(\lambda_i) t(\lambda_i) \overline{L_w^{cal}}(\lambda_i)}{L_t(\lambda_i)} \right)$

→ The goal of 5% (blue bands) at Level 2 with tL_w/L_t=10% requires $\sigma_{\bar{g}}$=0.5%

Uncertainty on average gains: if uncertainty is <u>random</u> and <u>identical</u> for all match-ups $\sigma_{\bar{g}(\lambda_i)} = \frac{\sigma_{g(\lambda_i)}}{\sqrt{N}}$ → σ_g has to be < than 3.5% with N=50

Uncertainty on individual gains:

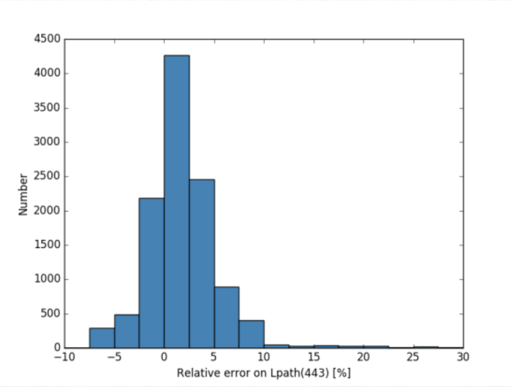
$$\sigma_g = \sqrt{\left(\frac{\sigma_{L_w^t}}{L_w^t}\right)^2 + \left(\frac{\sigma_{C_Q}}{C_Q}\right)^2 + \left(\frac{\sigma_t}{t}\right)^2 + \left(\frac{\sigma_{L_{path}}}{L_{path}}\right)^2 \left(\frac{L_t}{t_g t C_Q L_w^t} - 1\right)^2} \; \frac{t_g t C_Q L_w^t}{L_t}$$

Contribute to the uncertainty, even if not seen at the SVC site

Doing the **complete** uncertainty budget (including realistic number of match-ups) is required for selecting any SVC instrumentation and site

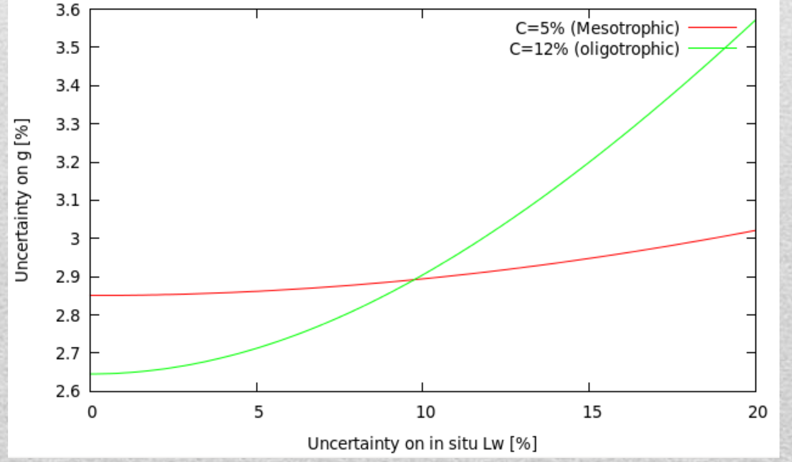
Example of overall uncertainty

- Uncertainty of L_{path}, t using AERONET measurements and inversion
  - Example at Forth Crete (Med. Sea; PI : Andrew Clives Bank)
  - MERIS data from 3rd reprocessing extracted by Calvalus (Brockmann Consult) & processed by ODESA (ESA/ACRI)
  - RTM using the Successive Order code



$$\sigma_g = \sqrt{\underbrace{\left(\frac{\sigma_{L_w^t}}{L_w^t}\right)^2}_{} + \overbrace{\left(\frac{\sigma_{C_Q}}{C_Q}\right)^2}^{1\%} + \overbrace{\left(\frac{\sigma_t}{t}\right)^2}^{1\%} + \overbrace{\left(\frac{\sigma_{L_{path}}}{L_{path}}\right)^2\left(\frac{L_t}{t_g t C_Q L_w^t} - 1\right)^2}^{3\%}}\ \frac{t_g t C_Q L_w^t}{L_t}$$

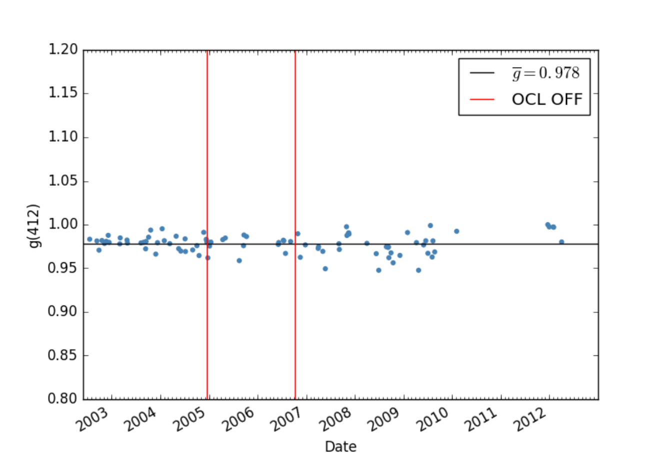
- Atmospheric terms are important contributors (~ 2.8%)
- How much can be $\sigma_{L_w^t}/L_w^t$? Depends on the contribution tL_w/L_t
- Mesotrophic waters minimise uncertainty propagation at TOA but may add other sources of errors (BRDF, etc.)

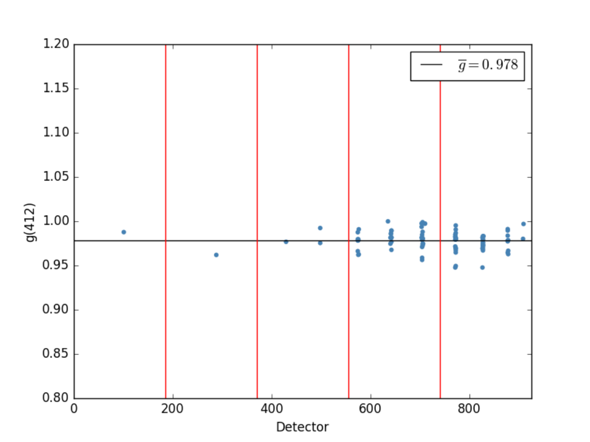


Requirements on the SVC process (1/2)

- Examples of requirement related to the Space sensor:

OC-VCAL-RD-1. The justification for one unique average gain across track (i.e. for all pixels of all cameras) shall be to rely on a Level-1 relative calibration, such as the on-board diffuser on MERIS and OLCI.



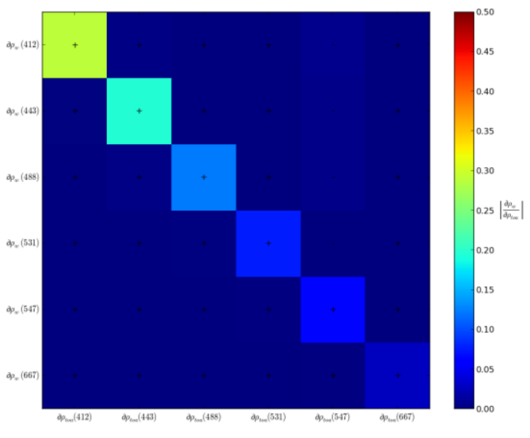


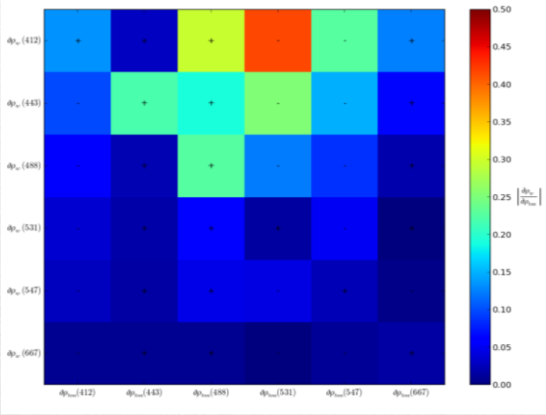
MERIS SVC gains at MOBY (MERIS 4th reprocessing; MERIS QWG data)

Requirements on the SVC process (2/2)

- Example of requirement related to the Level-2 ground segment:

OC-VCAL-RD-4. The Level-2 chain shall be characterised through computation of the Jacobian matrix to conclude on bands to calibrate and effects of TOA gains on the marine reflectance.





Jacobian matrix over a clear water pixel acquired by MODIS for SeaDAS processor (left) and POLYMER (right). Colours give the amplitude of $\frac{\partial L_w(\lambda_i)}{\partial L_t(\lambda_j)}$ and the sign is printed in the cell.

Requirements on the field infrastructure (1/4)

- Example of non-quantified requirement: Stray light

OC-VCAL-RD-15. Uncertainty associated with stray light shall be estimated for each measurement after any stray light correction

OC-VCAL-RU-15. Stray light shall be characterized for individual instruments through the stray light distribution function (SDF). Characterisation at series level may be sufficient as far as this supplementary source of error is included in the uncertainty budget. Measurements shall be corrected systematically for stray light with quality-controlled algorithms taking into account the spectral composition of both calibration light source and in situ measurement. Residual uncertainty of the correction shall be documented.

OC-VCAL-RV-15. Laboratory tests should be reported, following best existing practices as documented by Feinholz et al. 2009, providing the SDF for each instrument or each instrument class together with an estimate of the inter-instrument variability of SDF. Residual uncertainty of the correction shall be verified, e.g. by taking a variety of L_w spectra typical of the measurement location, convoluting with the instrument SDF (and its variability) and applying the straylight correction scheme to estimate the original L_w spectra. Test measurements should be done during routine recalibrations to verify stability of the SDF.

Requirements on the field infrastructure (2/4)

- Example of quantified requirement: radiometric calibration

OC-VCAL-RD-16. Radiometric calibration of the instrument must be held to 1-2% accuracy and tied to a National Metrological Institute. This calibration must be maintained to within 1% during each deployment. Stability of the radiometric calibration during deployments must be monitored.

OC-VCAL-RU-16. The residual uncertainties in the laboratory radiometric calibration and the radiometric stability of instruments during deployments must be understood and quantified.

OC-VCAL-RV-16. A full radiometric calibration history shall be supplied for each OC VCAL instrument including both laboratory calibrations and field calibrations. The impact of uncertainties in the radiometric calibration both during the laboratory calibrations and because of temporal variability during deployments shall be propagated to give uncertainties in the L_w^t measurement.

Requirements on the field infrastructure (3/4)

- Example of quantified uncertainty requirement: depth extrapolation

$$L_u(\lambda,0^-) = L_u(\lambda,z)e^{K_L(\lambda,0,z)z} \qquad K_L(\lambda,z_1,z_2) = -\frac{\ln\left(\frac{Lu(\lambda,z_2)}{Lu(\lambda,z_1)}\right)}{z_2-z_1}$$

$$\left(\frac{\sigma_{L_u(0^-)}}{L_u(0^-)}\right)^2 = \left(\frac{\sigma_{L_u(z)}}{L_u(z)}\right)^2 + \left(z * \sigma_{K_L}\right)^2$$

1.5% uncertainty on Lu at z=4m propagates to 4% at 0^- with $\sigma_{K_L} = 0.01\ m^{-1}$ (red bands)

OC-VCAL-RD-26. Depths of measurement shall be optimised to limit the uncertainty due to surface effect and depth extrapolation. The exponential extrapolation shall be systematically corrected for inelastic scattering at wavelengths above 550 nm, based on radiative transfer simulation.

OC-VCAL-RU-26. The uncertainty due to depth extrapolation shall be rigorously derived following Eq. (26). For a one meter depth extrapolation, the uncertainty on K_L shall be of the order of 0.01 m^{-1}.

OC-VCAL-RV-26. Verification of the depth extrapolation, its correction and uncertainty shall be assessed at the SVC site using profile measurements (see e.g. Voss et al. 2017).

Requirements on the field infrastructure (4/4)

- Example of realistic uncertainty budget of the field infrastructure (Excel annex of the report):

OC-VCAL ID	Uncertainty source	rel_unc(400)	rel_unc(412)
	Marine in situ component		
OC-VCAL-RU-13	Spectral resolution	1.00%	1.00%
OC-VCAL-RU-14	Spectral calibration	0.10%	0.10%
OC-VCAL-RU-15	Stray-light	0.75%	0.75%
OC-VCAL-RU-16	Radiometric calibration & stability	2.00%	2.00%
OC-VCAL-RU-17	Angular response		
OC-VCAL-RU-18	Immersion factor		
OC-VCAL-RU-19	Thermal stability	0.30%	0.30%
OC-VCAL-RU-20	Dark current		
OC-VCAL-RU-21	Polarisation sensivity	0.20%	0.20%
OC-VCAL-RU-22	Non-linearity response	0.10%	0.10%
OC-VCAL-RU-23	Noise characterisation		
OC-VCAL-RU-24	Shading	0.50%	0.50%
OC-VCAL-RU-26	Depth-extrapolation	1.00%	1.00%
OC-VCAL-RU-27	Surface propagation	0.25%	0.25%
	Data reduction		
	Total uncertainty on in situ Lw	2.65%	2.65%

Other examples of requirements

- Related to the SVC data processing:

OC-VCAL-RD-32. The required number of match-ups shall be determined by taking into account the real uncertainty in the vicarious gains at match-up level and the averaging process. For instance, with a constant uncertainty of 3.5% on individual gains, 50 match-ups are necessary to reach a 0.5% uncertainty on the mission average gain. The required number of satellite observations to produce these high quality match-up depends strongly on the SVC site(s) (cloud coverage, glint perturbation, spatial homogeneity, etc.) and shall be assessed by climatological study on past archive (see Zibordi and Mélin 2017). A target is to derive the mission average gain in the first year of operation.

OC-VCAL-RU-32. Statistical tests (like chi2 test) shall be implemented to demonstrate the relevance of the averaging. Stabilisation of the mission average gain shall be within 0.1%

- Related to the operation:

OC-VCAL-RD-33. In-water system shall limit bio-fouling by the use of antifouling paint and copper around the instrument. The system shall also be cleaned by divers at least on a monthly basis.

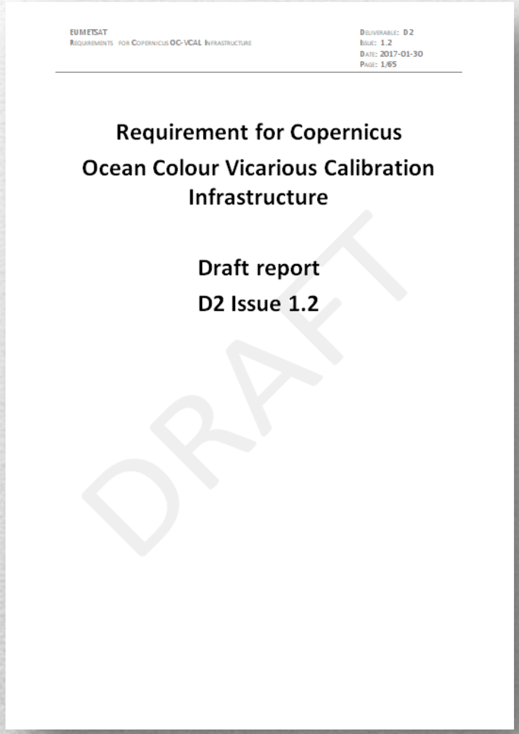
OC-VCAL-RU-33. Uncertainty due to bio-fouling shall be assessed by comparing data before and after each cleaning operations.

Conclusion

- Status of the document:
  - Overall uncertainty budget ready
  - Nearly 40 requirements so far
  - *Data processing* & *operation* to be completed
  - Excel annex to be consolidated

- Example of issue: requirements of OCR are a pre-requisite not always well defined or justified (Red bands? Coastal waters?...).

- On-going review process to ensure international harmonisation:
  - Review meeting on 23rd & 24th February
  - Breakout Workshop during IOCS 2017 (17th May)
    - Participant must register before 31st March!



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Ocean Colour Vicarious Calibration
Infrastructure

Draft report
D2 Issue 1.2

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Thank you