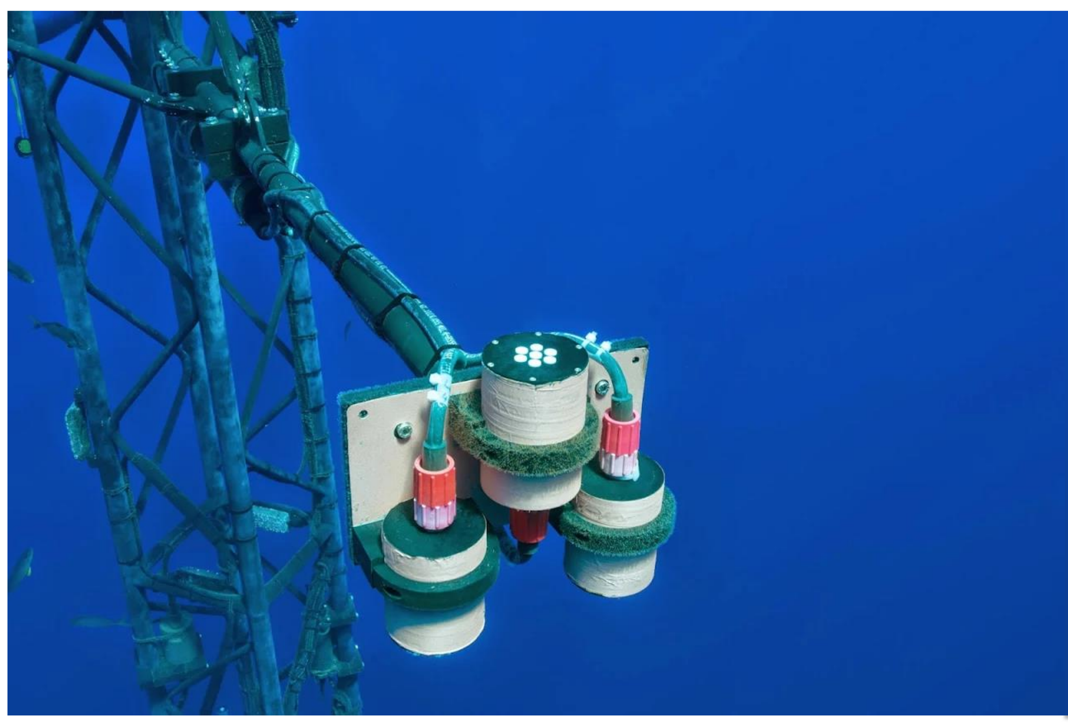

An uncertainty budget for the BOUSSOLE radiometry,
as derived using a Monte Carlo Method

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Abstract

The BOUSSOLE buoy [1,2,3] provides a long-term time series of radiometric quantities optical properties in support of calibration and validation activities of satellite ocean colour missions and bio-optics research in oceanic waters. The buoy is in continuous operation since 2003 and provided system vicarious calibration (SVC) data for the European MERIS instrument on-board ENVISAT, and will continue doing so for the new Copernicus Sentinel 3 satellites series. Remote Sensing Reflectance is the main product used for SVC therefore in real need for robust uncertainty budget assessment.

Methodology

The Monte Carlo Method (MCM) for uncertainty evaluation[2] is based on a model (a measurement equation as Eq 1.) that uses inputs (Eq 1. right hand side) with associated probability distribution functions (PDFs) that hold information about their uncertainties. Then the model is run a large number of times repeating the same calculation each time by randomly drawing input values from theirs PDFs. The result of the MCM is a PDF of the outcome value (R_{rs} in our case) that is crated from those repeated calculations. The best estimate and uncertainty of the output value is then evaluated from this distribution.

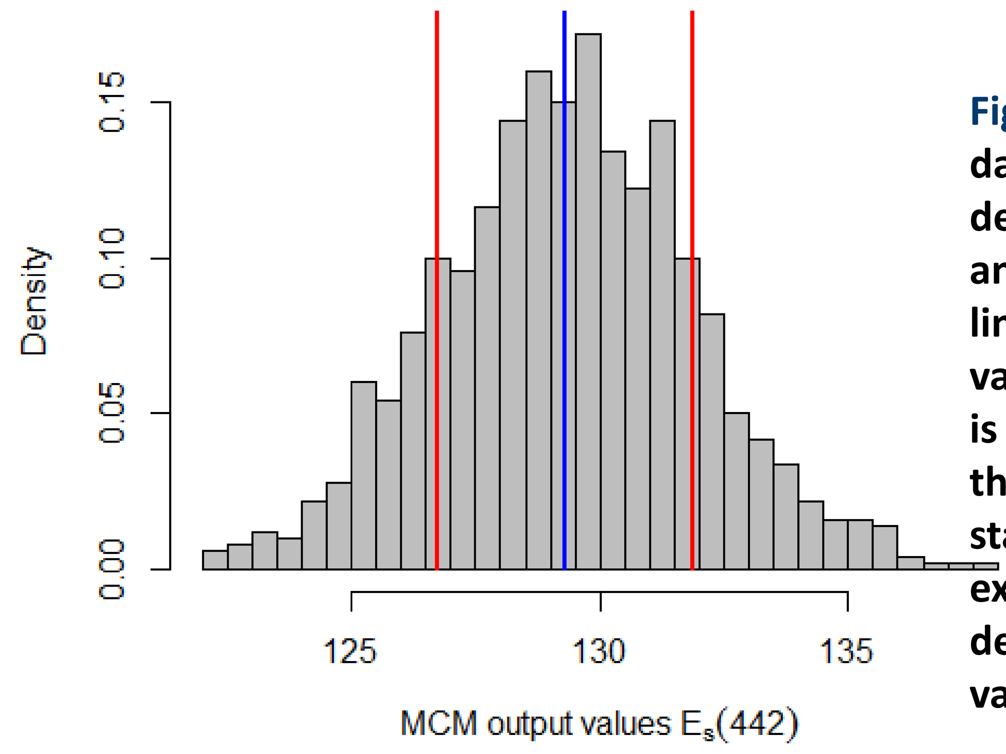


Fig 1. $E_s(442)$ for a single data point i.e. full denominator in Eq. 1. SZA=24 and buoy tilt < 4°. The blue line represents the calculated value, the histogram behind is the output form MCM and the red lines indicate standard uncertainty expressed as a standard deviation of the output values.

$$R_{rs} = \frac{\overline{L_{u4}} f_{cal} f_s exp\left[z_4\left(\frac{-\ln\left(\overline{L_{u9}} f_{cal} f_s / \overline{L_{u4}} f_{cal} f_s\right)}{z_9 - z_4}\right)\right] f_H f_{\rho n}}{\overline{E_s} f_{cal} f_{cos} f_{tilt} f_{dir} + (1 - f_{dir})\overline{E_s} f_{cal}} \quad \text{Eq. 1.}$$

$\overline{L_{u4}}$,$\overline{L_{u9}}$, $\overline{E_s}$ are median values of 1 minute measurements of two OCR radiometers (upwelling radiance at 4 m, L_{u4}, and 9 m, L_{u9}) Satlantic 200 series and one OCI (surface irradiance, E_s) with 7 VIS spectral bands. The f_i terms represent correction factors for:

- absolute radiometric calibration (f_{cal}), diffuser cosine response (f_{cos}),
- shading (f_s), buoy tilt (f_{tilt}), z_4 and z_9 are the actual instruments depths corrected for buoy tilt,
- extrapolation to surface using *Hydrolight* simulation (f_H), the constant for water-air interface and fraction of the direct to total solar irradiance (f_{dir}).

Equation Components and Uncertainty Assessment

Raw Readings

Median and standard deviation of Quality Controlled (QC) readings for SVC.

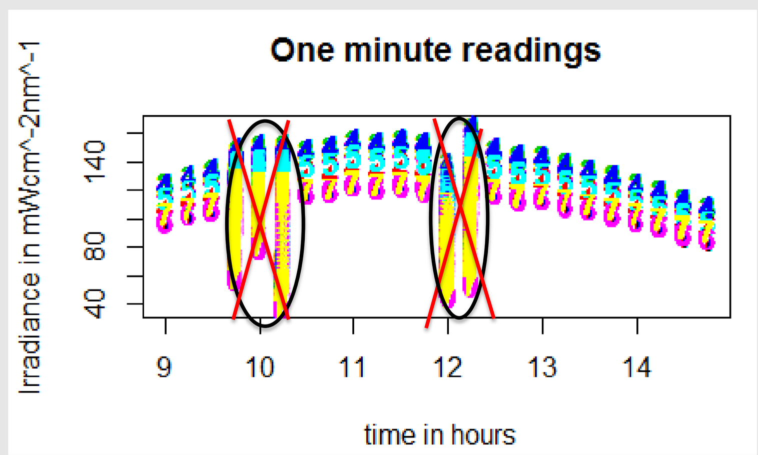


Fig 2. Example of one minute E_s data readings. Numbers correspond to spectral channels. σ>2% in one reading rejects the data from the SVC set (circled and crossed out series).

Instrument Related

Derived from laboratory tests with uncertainties defined in the traditional way. Gaussian PDFs with standard uncertainty equal standard deviation.

Fig 3. Radiometer in the calibration lab.

Environmental

Come from ancillary buoy data e.g. the buoy tilt, actual depth and MC Shading modelling [3]. Uncertainties have rectangular PDFs.

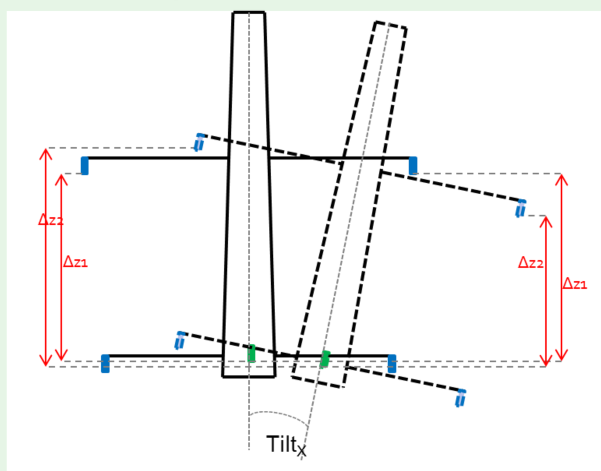


Fig 4. Buoy schematic change in the actual depths due to tilt.

Modelling

Defined by theory derived from available models, uncertainty estimated from literature, or sensitivity study on the model.

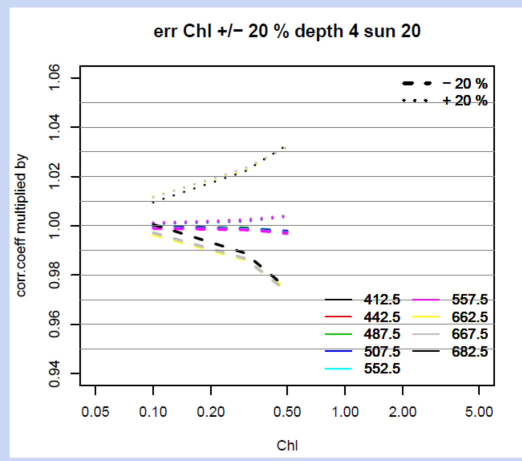


Fig 5. Simulated change in *Hydrolight* correction due to error in Chlorophyll concentration.

Results

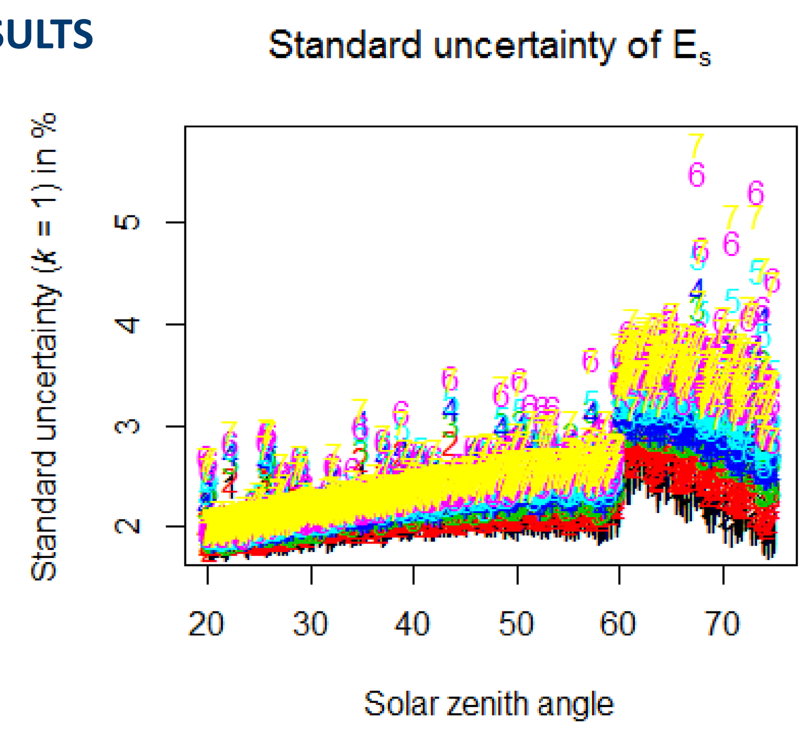


Fig 6. E_s standard uncertainties. Series numbers correspond to spectral channels. Each point corresponds to the evaluation of the denominator of Eq.1 with f_{cal} , f_{cos}, f_{tilt} and f_{dir} randomly selected through the MC process.is a result from MC simulation. The visible step at SZA 60° is due to the average factory uncertainty of cosine diffuser response. Further decrease in values at higher SZA is due to the decrease of the direct light fraction.

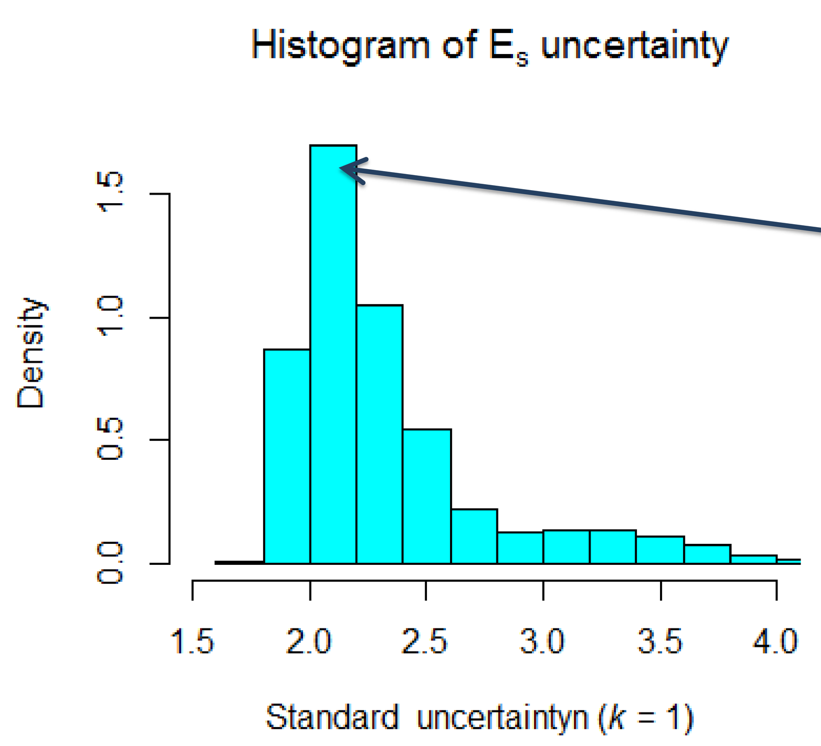
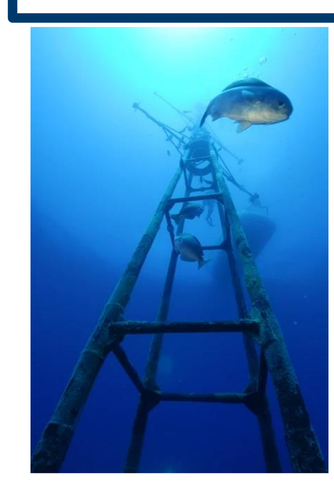


Fig 7. Summary of all simulations on SVC data set for all channels, SZAs and qualified environmental conditions. The uncertainty value used as representative of the whole set is 2.1 % which corresponds to the highest density. Uncertainty values for each variable and wavelength are derived in a similar manner.

u in % / λ in nm	E_s	L_{u4}	L_W	R_{rs}	$u_{abs}(R_{rs})$ $[\mathrm{mWcm^{-2}sr^{-1}nm^{-1}}]$
412	2.1	2.6	3.1	3.7	0.000215
443	2.0	2.6	3.1	3.7	0.000225
490	2.0	2.6	3.0	3.7	0.000175
510	2.0	2.6	3.0	3.7	0.000155
560	2.0	2.6	3.1	3.7	0.0000725
665	2.1	3.9	5.9	6.3	0.00000410
681	2.1	4.0	5.9	6.3	0.00000195

Table 1. Preliminary uncertainty budget.



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Acknowledgements

esa, NPL, Metrology for Earth Observation and Climate, LOV, UPMC Sorbonne Universités, EMRP, CNRS INSU, cnes