BOUSSOLE UNCERTAINTY

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D. Antoine and N. Fox
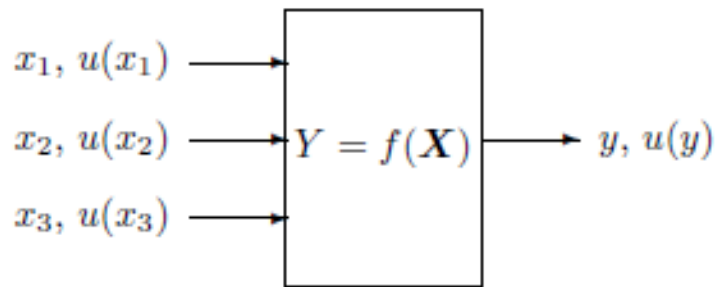
> Uncertainty evaluation method

> Field data Quality Control
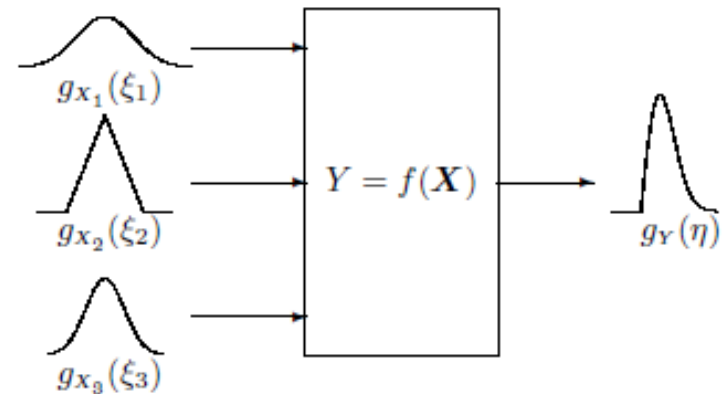
> Uncertainty evaluation

> Conclusion

UNCERTAINTY EVALUATION

> GUM – Law of propagation of uncertainty
> GUM supplement 1 – Monte Carlo Methods

GUM

MCM

## GUM ASSUMPTIONS AND RESTRICTIONS

> Output value has Normal distribution
> First order approximation applies to linear models
> Symmetric distribution of inputs

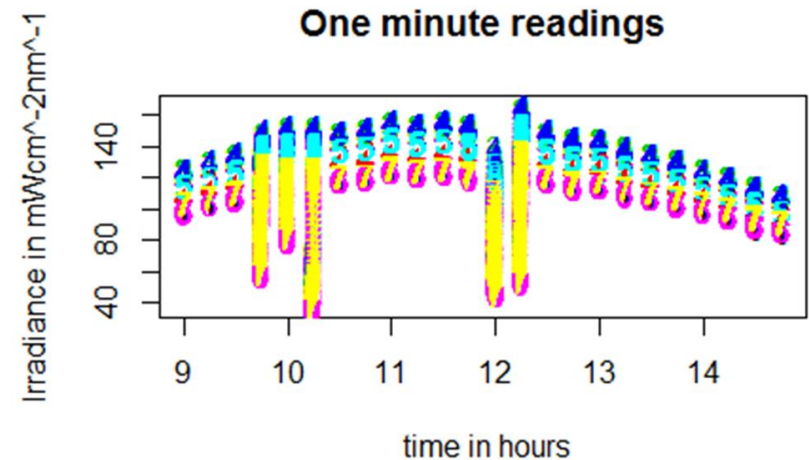# GUM AND MCM COMMONALITIES

> Traceability Chain ✓
> Calculation Equation ✓
> Sources of Uncertainty ✓
> Measurements Equation ✓
> Sensitivity Coefficients ✗
> Assigning Uncertainties ⟶ PDF's
> Combining Uncertainties ⟶ Running the model

Method	$\widehat{\delta m}$ /mg	$u(\widehat{\delta m})$ /mg	Shortest 95 % coverage interval /mg	d_{low} /mg	d_{high} /mg	GUF validate ($\delta = 0.005$)?
GUF$_1$	1.234 0	0.053 9	[1.128 5, 1.339 5]	0.045 1	0.043 0	No
MCM	1.234 1	0.075 4	[1.083 4, 1.382 5]			
GUF$_2$	1.234 0	0.075 0	[1.087 0, 1.381 0]	0.003 6	0.001 5	Yes

JCGM 101:2008 p 41
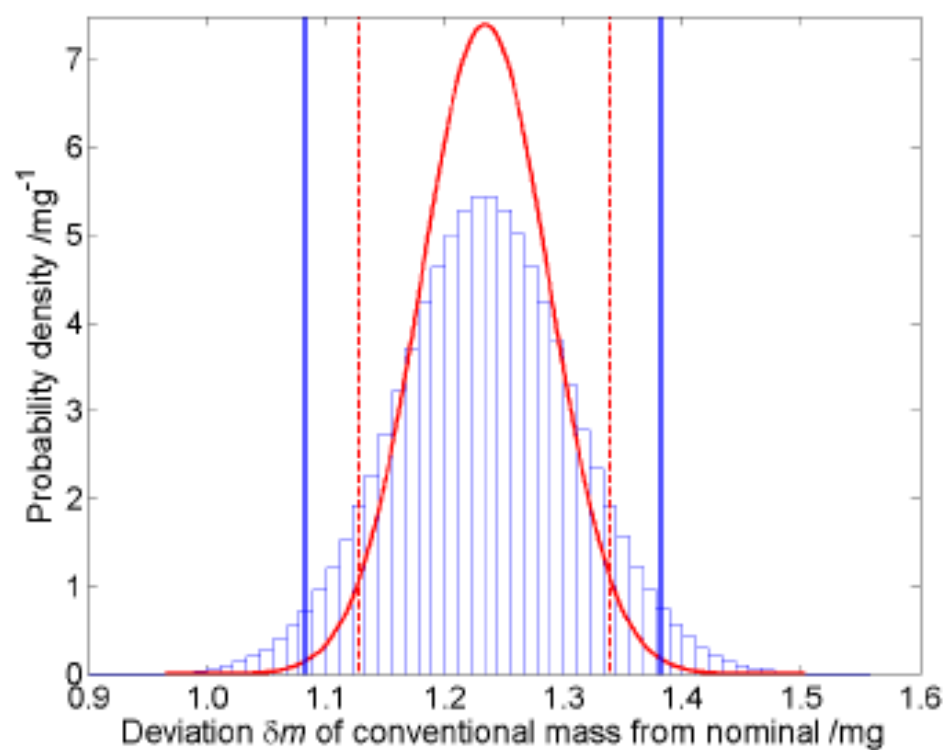
SELECTION CRITERIA	THRESHOLD
σ.Es(443) One minute readings stability	< 2 %
i.es(443) Clear sky test	0.9 < & > 1.1
Tilt	< 10 °
SZA	< 70 °
Depth	< 11 m
Shading	< 5 %
Bio fouling	N
DCI – Screening for inter calibration issue	N

One minute readings

| SIGNAL	$\overline{L_{u4}}$, $\overline{L_{u9}}$, $\overline{E_s}$ are median values of 1 minute measurements of two OCR (upwelling radiance at 4 m, L_{u4}, and 9 m, L_{u9}) and one OCI (surface irradiance, E_s) Satlantic 200 series radiometers with 7 VIS spectral bands.
INSTRUMENT RELATED	absolute radiometric calibration (f_{cal}) diffuser cosine response (f_{cos})
ENVIRONMENTAL	shading (f_s) buoy tilt (f_{tilt}) z_4 and z_9 are the actual instruments depths corrected for buoy tilt
MODELLING	extrapolation to surface correction using *Hydrolight* simulation (f_H) the constant for water-air interface fraction of the direct to total solar irradiance (f_{dir})
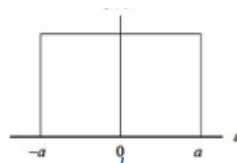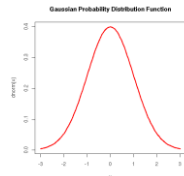
$$R_{rs} = \frac{\overline{L_{u4}} f_{cal} f_{s4} \exp\left[z_4 \left(\frac{-\ln\left(\overline{L_{u9}} f_{cal} f_{s9} / \overline{L_{u4}} f_{cal} f_{s4}\right)}{z_9 - z_4}\right)\right] f_H f_{\rho n}}{\overline{E_s} f_{cal} f_{cos} f_{tilt} f_{dir} + (1 - f_{dir}) \overline{E_s} f_{cal}}$$

SIMULTANEOUS 1 MINUTE READINGS (~360 MEASUREMENTS)
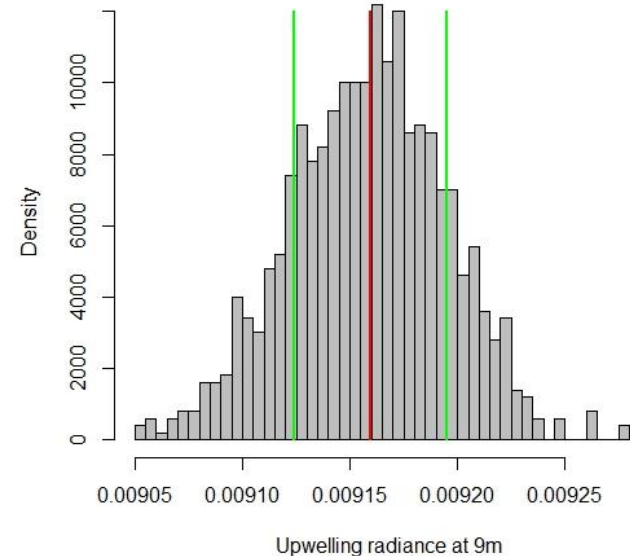
$$\overline{L_{u4}}, \overline{L_{u9}}, \overline{E_s}$$

One minute readings

Density — Upwelling radiance at 9m
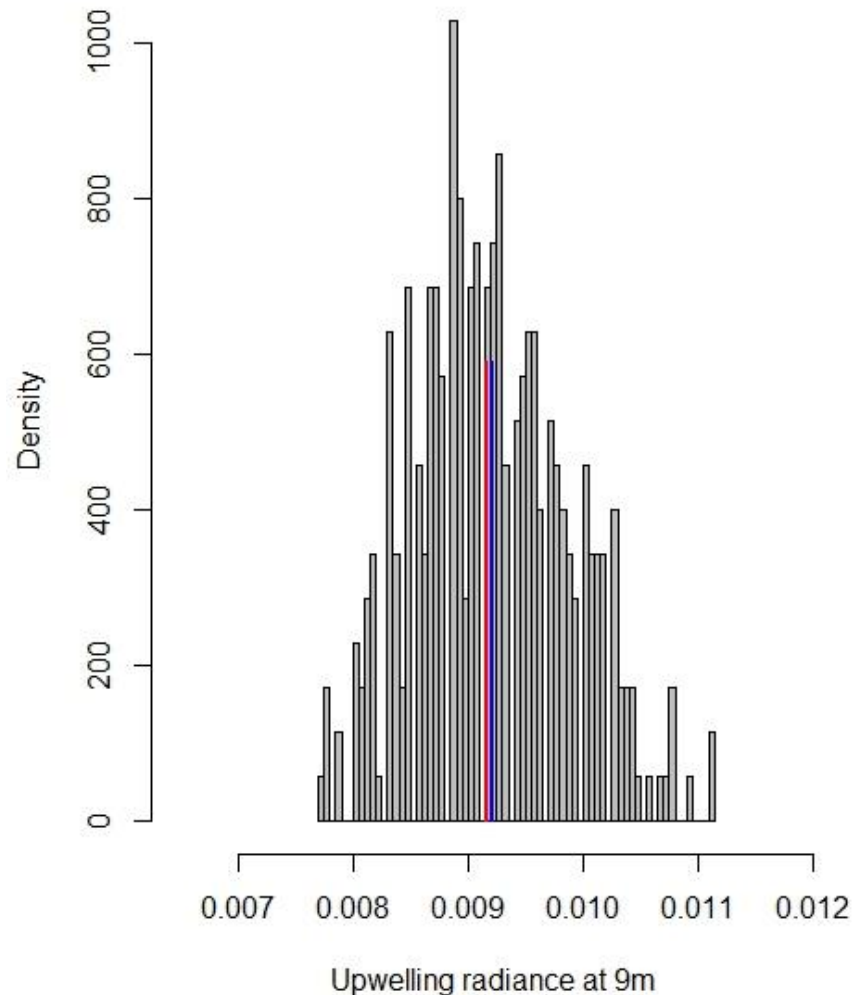
PDF

> Median value of one minute readings is used as a best estimate
> Standard deviation of the mean is the expectation of the standard uncertainty
> PDF is Gaussian

**PDF for one minure readings**

Density — Upwelling radiance at 9m

INSTRUMENTAL

> Derived from laboratory tests with uncertainties defined in the traditional way.

> Gaussian PDFs with standard uncertainty equal standard deviation.

Source of uncertainty	B1 411.96 nm	B1 442.03 nm	B3 488.86 nm	B4 508.93 nm	B5 559.12 nm	B6 669.4 nm	B7 682.74 nm
Light Short-term effect;	0.042%	0.029%	0.017%	0.014%	0.010%	0.006%	0.006%
Dark Short-term effect;	0.045%	0.033%	0.018%	0.016%	0.010%	0.006%	0.006%
Stability;	0.06%	0.06%	0.06%	0.06%	0.06%	0.06%	0.06%
Signal related	0.083%	0.073%	0.064%	0.063%	0.061%	0.061%	0.061%
FEL calibration;	0.54%	0.48%	0.40%	0.39%	0.38%	0.36%	0.36%
Calibration distance;	0.052%	0.052%	0.052%	0.052%	0.052%	0.052%	0.052%
Realignment;	0.157%	0.157%	0.157%	0.157%	0.157%	0.157%	0.157%
Current;	0.030%	0.029%	0.026%	0.025%	0.022%	0.019%	0.018%
Aging;	0.289%	0.289%	0.289%	0.289%	0.289%	0.289%	0.289%
Off-centre error	0.546%	0.059%	0.127%	0.516%	0.211%	0.177%	0.000%
Multi-centre Irradiance related	0.635%	0.585%	0.521%	0.513%	0.506%	0.491%	0.491%
Single-centre Irradiance related	0.837%	0.588%	0.536%	0.728%	0.548%	0.522%	0.491%
Multi-centre Combined standard uncertainty ($k=1$)	0.64%	0.59%	0.52%	0.52%	0.51%	0.49%	0.49%
Multi-centre Expanded uncertainty ($k=2$)	1.28%	1.18%	1.05%	1.03%	1.02%	0.99%	0.99%
Single-centre Combined standard uncertainty ($k=1$)	0.84%	0.59%	0.54%	0.73%	0.55%	0.53%	0.49%
Single-centre Expanded uncertainty ($k=2$)	1.68%	1.18%	1.08%	1.46%	1.10%	1.05%	0.99%
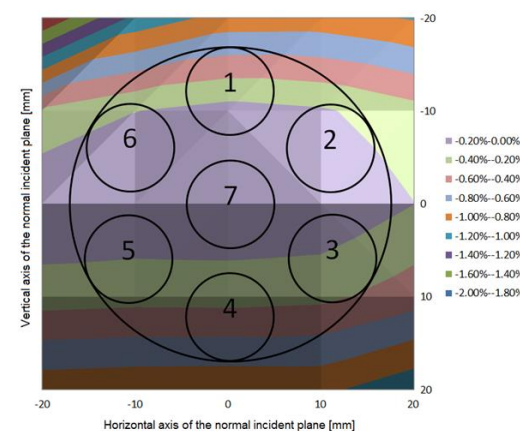
INSTRUMENTAL	UNCERTAINTY ($\kappa = 1$)	SOURCE
Absolute radiometric calibration (Irradiance)	1.6% - 1.1% (1.5%)	NPL calibration and comparison to Satlantic coefficients
Cosine diffuser (Irradiance)	3% below 60°, 10% above	Satlantic specifications
Absolute radiometric calibration (Radiance)	2.5% - 2.0% (2.2%)	NPL calibrations and comparison to Satlantic coefficients
Radiometric stability	1% (Not included)	From repeated calibrations, if no instruments issues
Immersion coefficient	Bias of 0.4 % with 0.19 % uncertainty, currently not included	Literature, Zibordi 2006
Temperature dependence	Negligible	NPL test in 2013 (for the observed at the site range)
Detector linearity	Negligible	NPL test in 2013

ENVIRONMENTAL

> Evaluated from ancillary buoy data e.g. the buoy tilt, actual depth and MC shading modelling

> Uncertainties have rectangular PDFs or actual derived form MCM
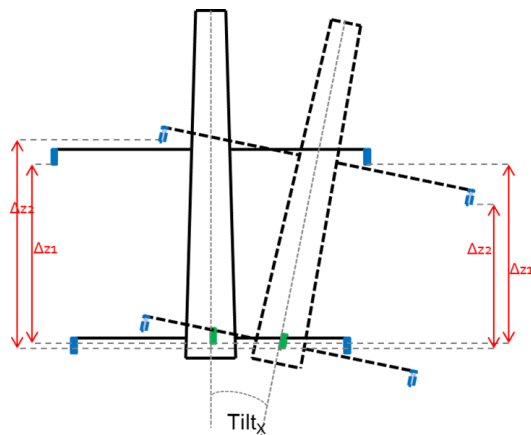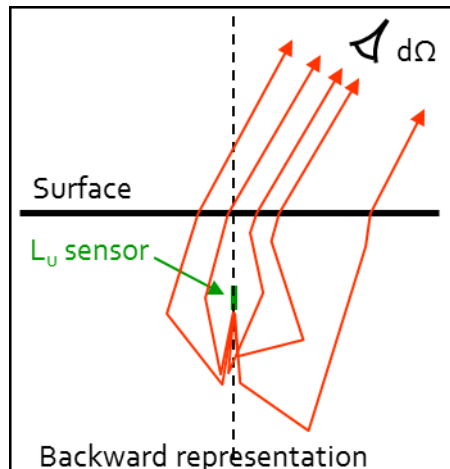

Shading coefficient matrix $L_u(443, 4m)$ Chl = 0.1 µg/l
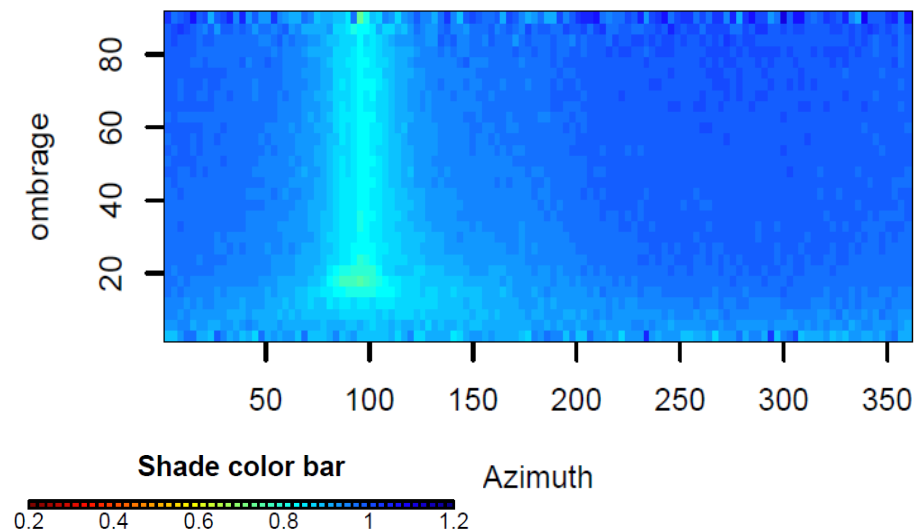
| ENVIRONMENTAL	UNCERTAINTY ($\kappa = 1$) converted to normal distribution	SOURCE
Depth	1%	To be refined by a mini MCM model
Tilt (E_s)	2%	To be refined by a mini MCM model
Shading	1.2%	Comparison of LOV MC photon tracking model with others corrections
BRDF (effect of the tilt under water)		Currently being estimated

MODELLING

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

> PDF's rectangular or Gaussian.
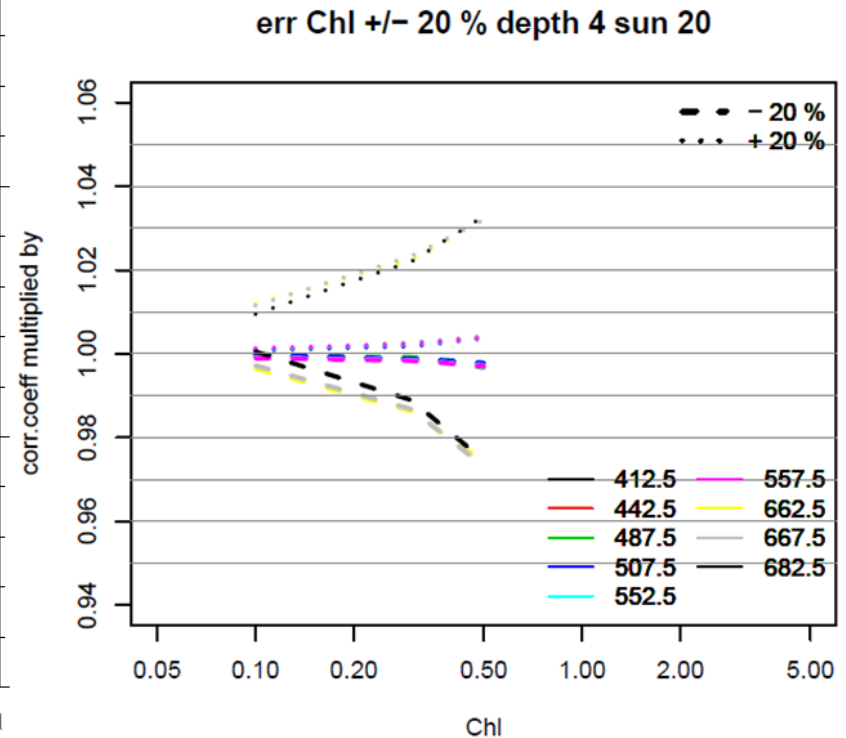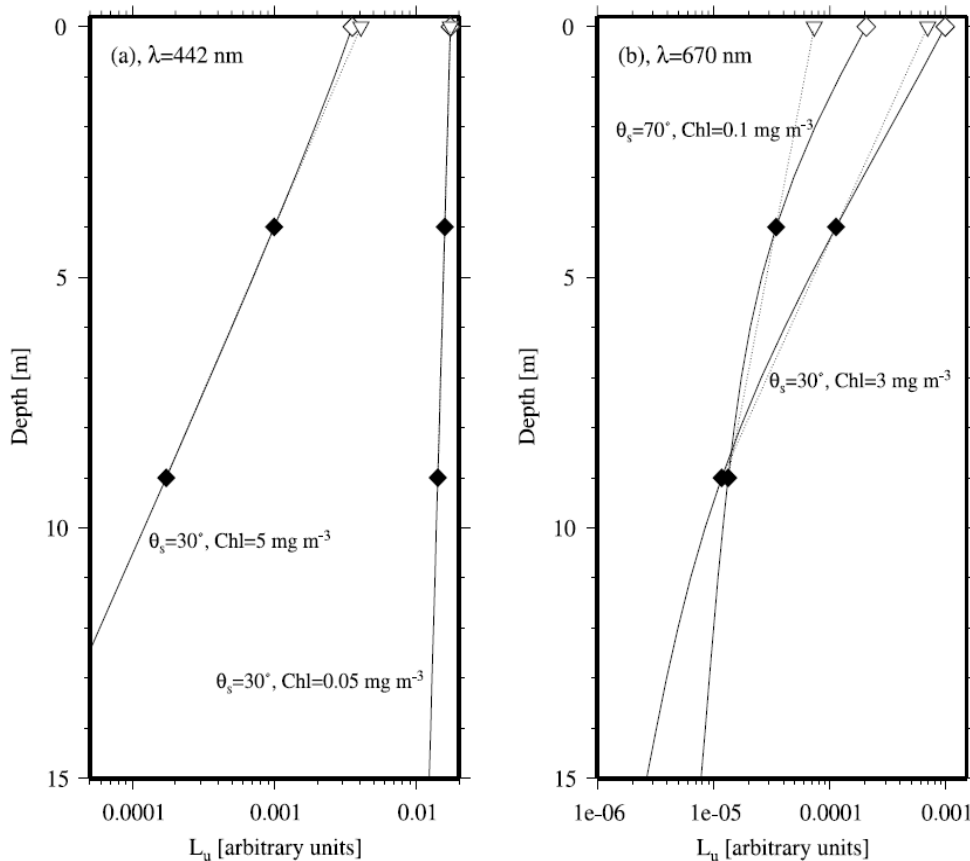
MODELLING	UNCERTAINTY ($\kappa = 1$) converted to Normal distribution	SOURCE
Hydrolight correction	0.5% below 600 nm 2% - 3% above 600nm (Chla dependent) (1.5%)	Sensitivity study by modelling
Water – air constant	0.5%	Literature Austin 1976, Austin and Halikas 1976, Wei et al. 2015 plus modelling
Direct to total fraction	3.5%	Literature

MCM output values $E_s(442)$

Histogram of E_s uncertainty

Standard uncertainty of E_s
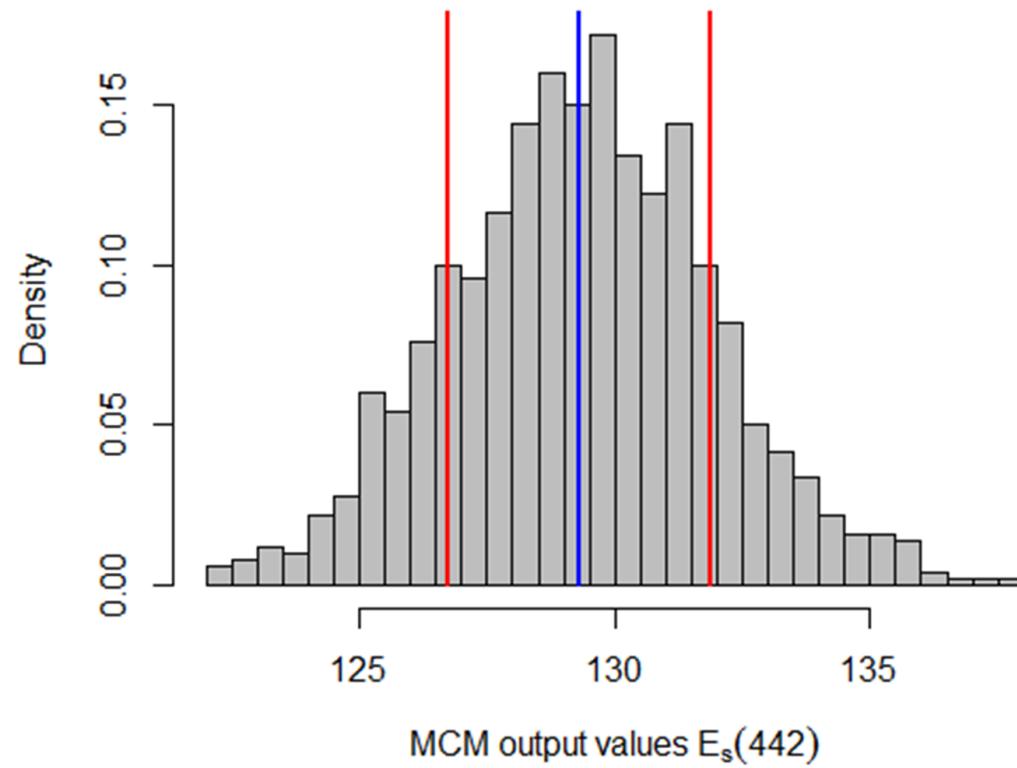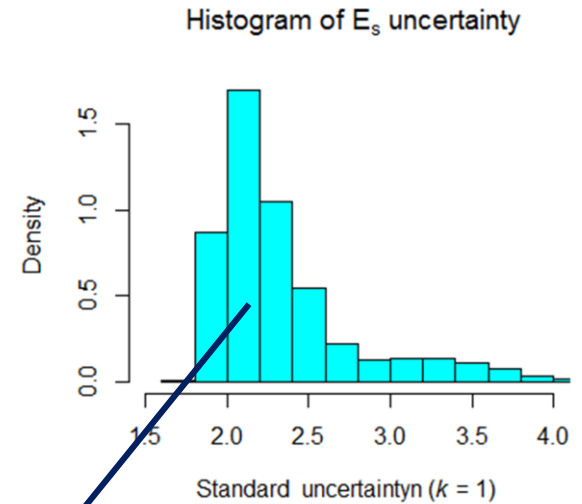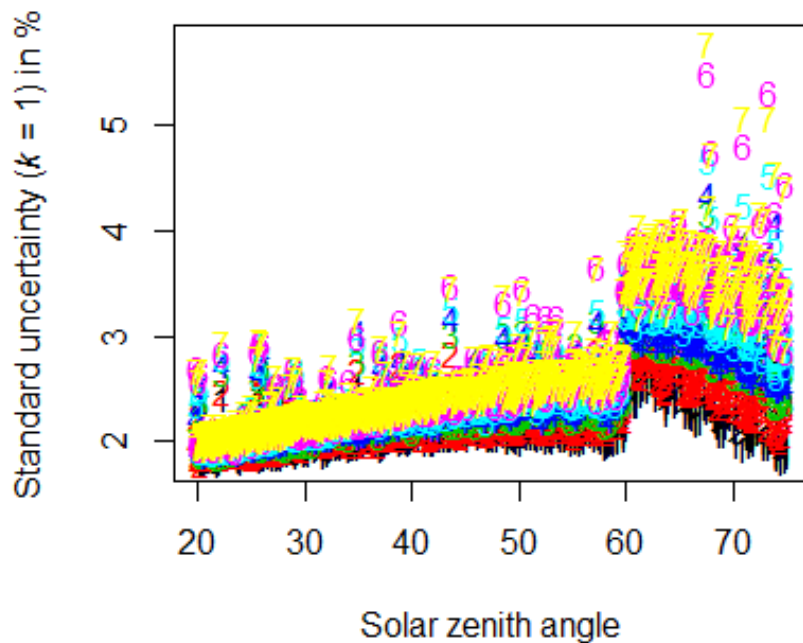
u in % / λ in nm	E_s	L_{u4}	L_W	R_{rs}	$u_{abs}(R_{rs})$
412	2.1	2.6	3.1	3.7	0.000215
443	2.0	2.6	3.1	3.7	0.000225
490	2.0	2.6	3.0	3.7	0.000175
510	2.0	2.6	3.0	3.7	0.000155
560	2.0	2.6	3.1	3.7	0.0000725
665	2.1	3.9	5.9	6.3	0.00000410
681	2.1	4.0	5.9	6.3	0.00000195

CONCLUSIONS

> "Dynamic" uncertainty value per observation, thus per match-up point rather then one generic value
> Generic available as well as the most probable uncertainty value from all data uncertainties
> MCM deals with nonlinear functions and not normal probability distributions
> The set up framework can be easily used to model and estimate the effect of additional efforts to reduce individual uncertainty components on the overall budget

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B. Gentili – Code development
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Bricaud – CDOM
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