https://frm4soc2.eumetsat.int

The second FRM4SOC-2 WORKSHOP

on Calibration and Characterisation of Ocean Color Field Radiometers

20 – 22 May 2025

@ Tartu Observatory, University of Tartu, Estonia

Measurement uncertainties in processing field data with HyperCP.

Agnieszka Bialek, NPL

PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

IMPLEMENTED BY EUMETSAT

UNIVERSITY OF TARTU Tartu Observatory

Brockmann Consult GmbH

EOScience

Consiglio Nazionale delle Ricerche

NPL National Physical Laboratory

OUTLINE

- HyperCP a brief introduction
- Uncertainty evaluation what is different from the lab calibration
- Uncertainties in HyperCP

HyperCP Project Team

GODDARD EARTH SCIENCES

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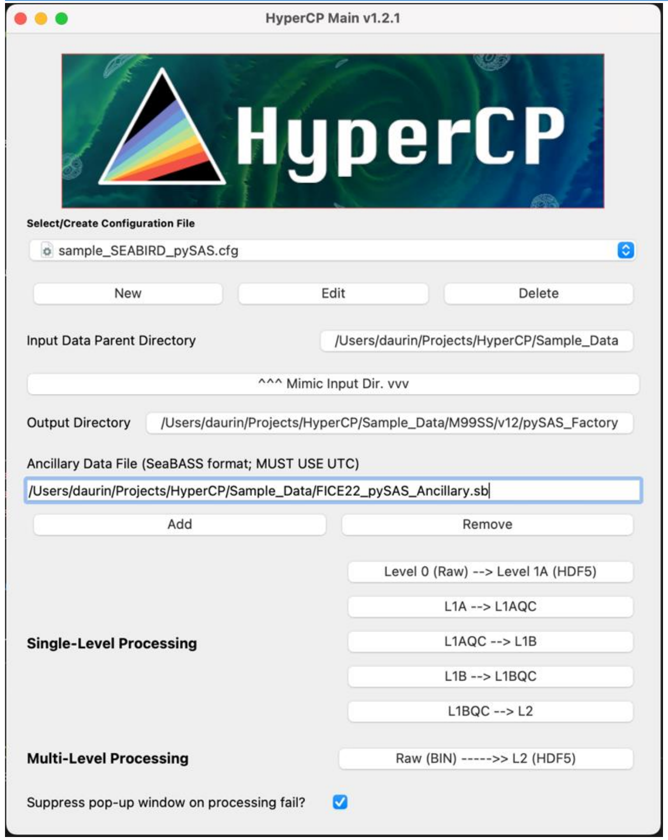
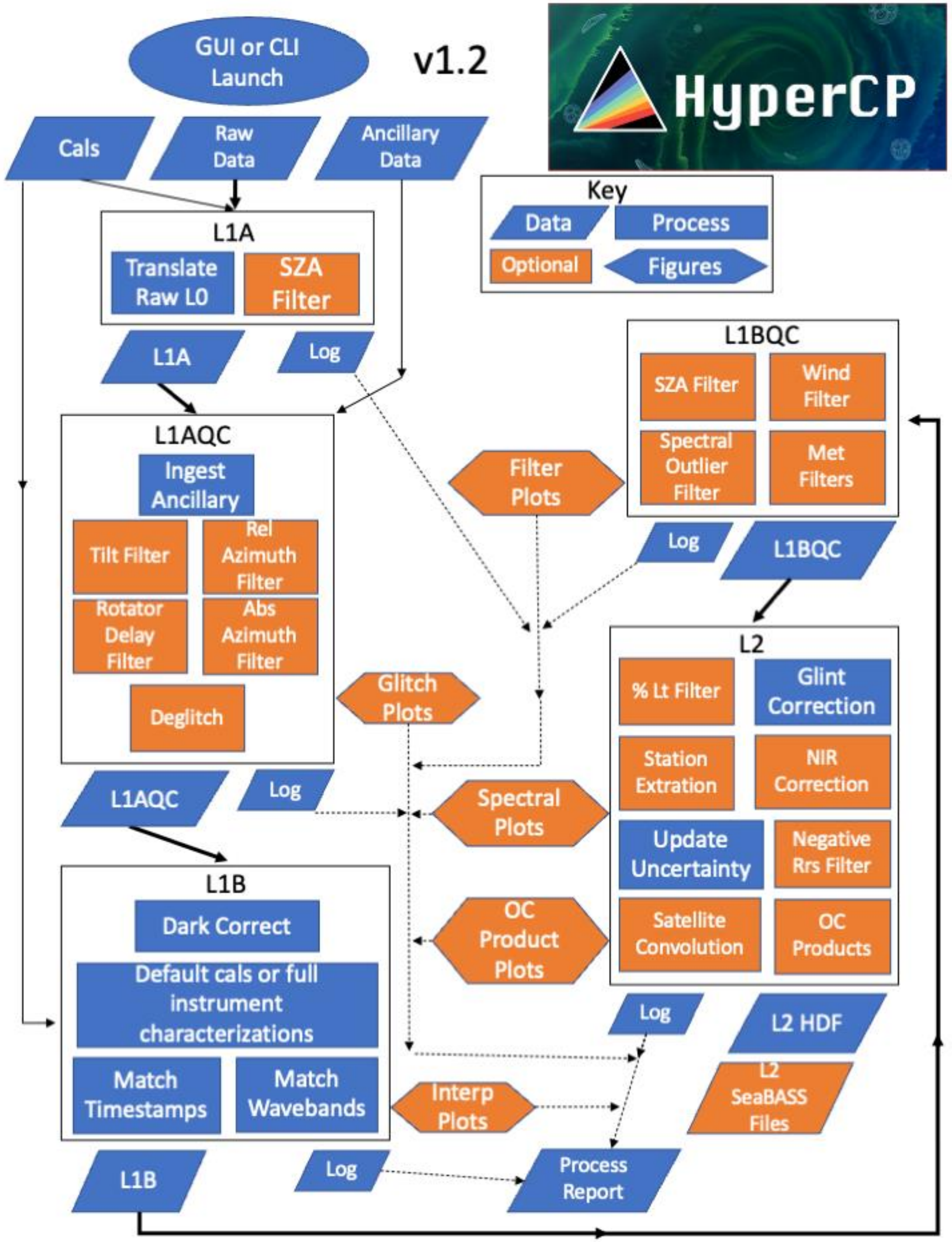


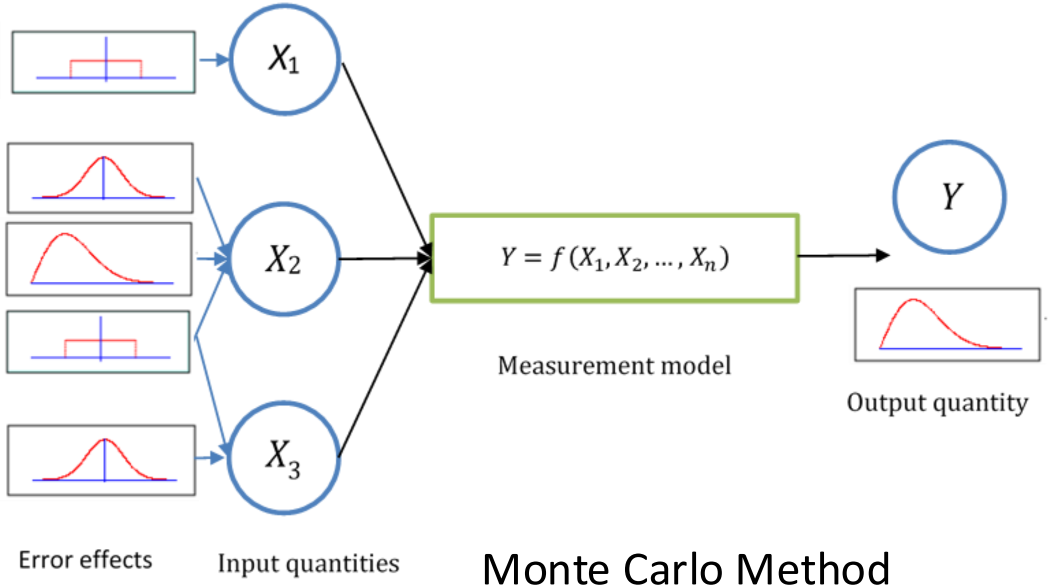
https://github.com/nasa/HyperCP

- See README for instruction/description
- See Discussion for support
- See Issues for reporting



Methodology and resources

- the Guide to the expression of Uncertainty in Measurement (GUM) and its supplements



Monte Carlo Method

$$u^2(y) = \sum_{i=1}^{N} c_i^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=i}^{N} c_i c_j u(x_i, x_j)\,,$$

The Law of Propagation of Uncertainties

HyperCP

http://www.bipm.org/en/publications/guides/

Bureau International des Poids et Mesures – the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.

CoMet

About Tools Examples News People

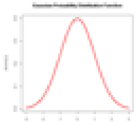
CoMet Toolkit

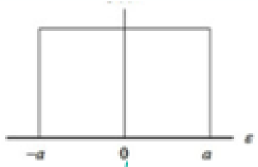
The **CoMet Toolkit** (Community Metrology Toolkit) is an open-source software project to develop Python tools for the handling of error-covariance information in the analysis of measurement data.

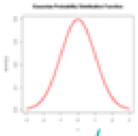
```
import xarray as xr
import obsarray
from punpy import MeasurementFunction, MCPropagation

# read digital effects table
ds = xr.open_dataset("digital_effects_table_gaslaw_example.nc")

# Define your measurement function inside a subclass of MeasurementFunction
class IdealGasLaw(MeasurementFunction):
    def meas_function(self, pres, temp, n):
        return (n *temp * 8.134)/pres

# Create Monte Carlo Propagation object, and create MeasurementFunction class
# object with required parameters such as names of input quantites in ds
prop = MCPropagation(10000)
gl = IdealGasLaw(prop, xvariables=["pressure", "temperature", "n_moles"],
                 yvariable="volume", yunit="m^3")

# propagate the uncertainties on the input quantites in ds to the measurand
# uncertainties in ds_y (propagate_ds returns random, systematic and structured)
ds_y = gl.propagate_ds(ds, store_unc_percent=True)
```

https://www.comet-toolkit.org/

GUM Methodology applied in CoMET tool







$$R_{rs} = (L_t c_{cal0222} - (\rho * L_i c_{cal0223})/E_s c_{cal0258}$$

random

systematic

$$u_c^2(y) = \sum_{i=1}^{N} c_i^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=1+1}^{N} c_i c_j u(x_i) u(x_j) r(x_i, x_j)\,,$$

$$\begin{array}{ccccccc}
L_t & c_{c2} & \rho & L_i & c_{c3} & E_s & c_{c8} \\
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 1 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 1
\end{array}$$

JCGM100:2008. Evaluation of measurement data - *Guide to the expression of uncertainty in measurement*
JCGM101:2008. Evaluation of measurement data - *Supplement 1 to the Guide to the expression of uncertainty in measurement - Propagation of distributions using a Monte Carlo method.*

Calibration

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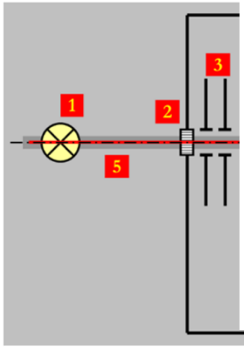
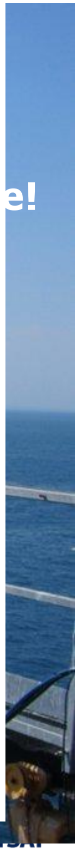
"operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication."





http://jcgm.bipm.org/vim/en/index.html

Radiance, L_i, L_t

$$S_{rad} = DN_{\mathrm{Light}} - DN_{\mathrm{Dark}}$$

$$c_{stab} = f(c_{cal}, c_{cal,t}) + 0$$

$$S_{corr} = S_{rad}\, c_{lin}\, c_{stray}$$

$$L_{cal} = S_{corr}\, c_{\mathrm{cal}}\, c_{stab}\, c_{\mathrm{T}}\, c_{\mathrm{pol}} + 0$$

Sea-surface reflectivity constant, ρ

$$\rho_{sun} = f(\lambda, \theta, w_s, AOD, L_{sun}, L_{sky}) + 0$$

$$\rho_{sky} = f(\lambda, \theta, w_s, AOD, L_{sky}) + 0$$

$$\rho(\lambda) = \rho_{sky}(\lambda) + \rho_{sun}(\lambda) + 0$$

CoMet

CoMet is a python toolkit, developed at NPL, which is used to propagate uncertainty using Monte Carlo Propagation.

Sea surface reflectance (ρ) – the uncertainty of ρ comes from model error and uncertainty from the ancillary data it relies upon.

$$L_{\mathrm{w}}(\theta, \Delta\phi, \theta_s) = L_t\,(\theta, \Delta\phi, \theta_s) - \rho\,(\theta, \Delta\phi, \theta_0, w_s)\, L_i(\theta', \Delta\phi, \theta_s)$$

Instrument characterization - the uncertainty contribution of non-linearity, temperature, polarisation, stray-light, & cosine response

$$R_{rs}(\theta, \Delta\phi, \theta_s) = \frac{L_{\mathrm{w}}(\theta, \Delta\phi, \theta_s, \theta_0, W)}{E_{\mathrm{d}}(\theta_s)} + 0$$

Model error – Other sources of uncertainty can be included as a model error for the processor.

Irradiance, E_d

$$c_{stab} = f(c_{cal}, c_{cal,t}) + 0$$

$$S = DN_{\mathrm{Light}} - DN_{\mathrm{Dark}}$$

$$S_{corr} = S\, c_{lin}\, c_{stray}$$

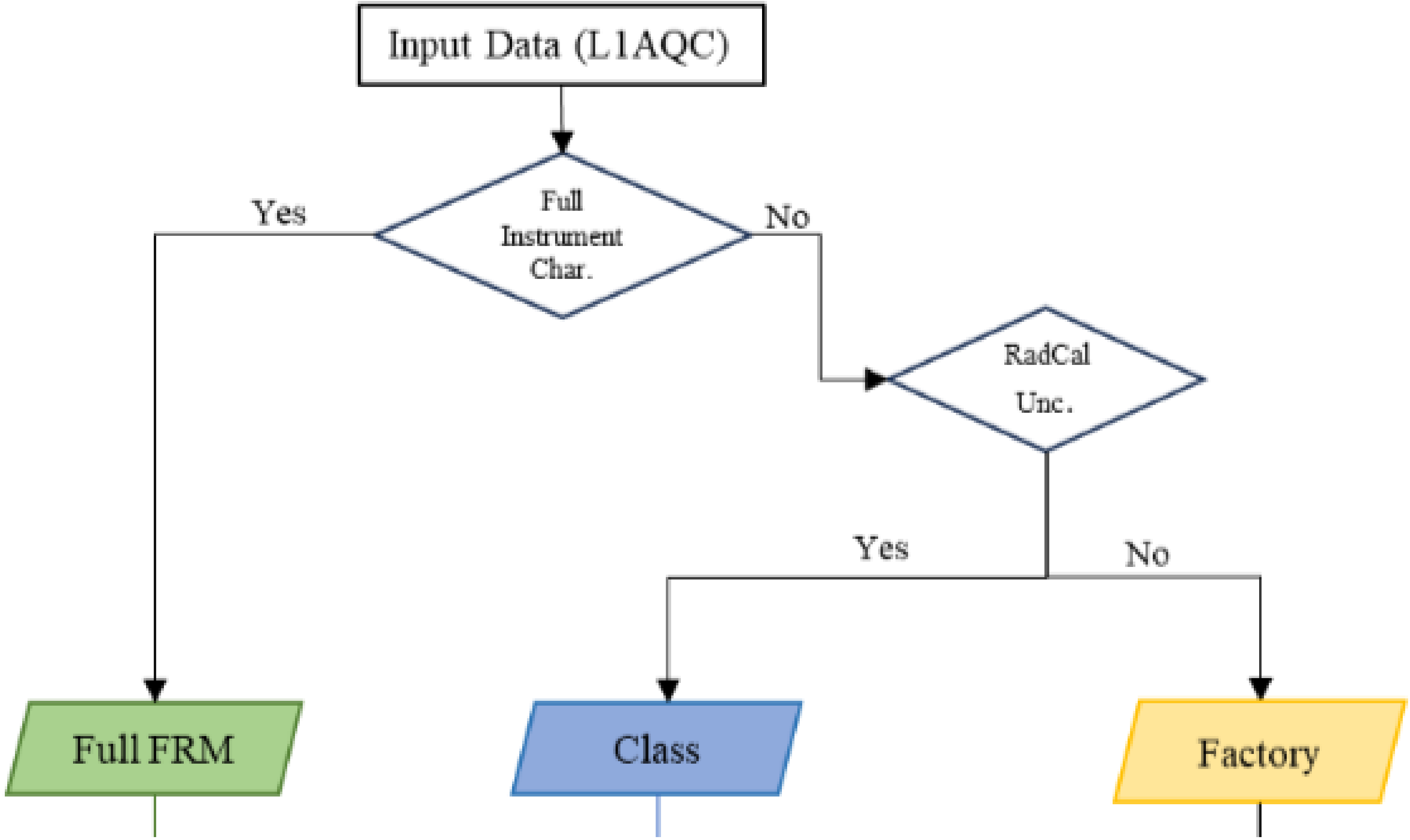
$$E_{cal} = S_{corr}\, c_{\mathrm{cal}}\, c_{stab}\, c_{\mathrm{T}} + 0$$

$$E_d(\theta_s) = f_{dirr}\, E_{cal}(\theta_s)\, f_{cos} + (1 - f_{dirr})\, E_{cal}(\theta_s)\, f_{hcos} + 0$$

$$f_{cos} = f(\theta, \lambda) + 0$$

$$f_{dirr} = f(AOD, Aerosol\ model) + 0$$

$$f_{hcos} = \int_0^{\pi/2} f_{cos}(\theta)\, \sin(2\theta)\, d\theta + 0$$


Input Data (L1AQC)
Yes
Full Instrument Char.
No
RadCal Unc.
Yes
No
Full FRM
Class
Factory

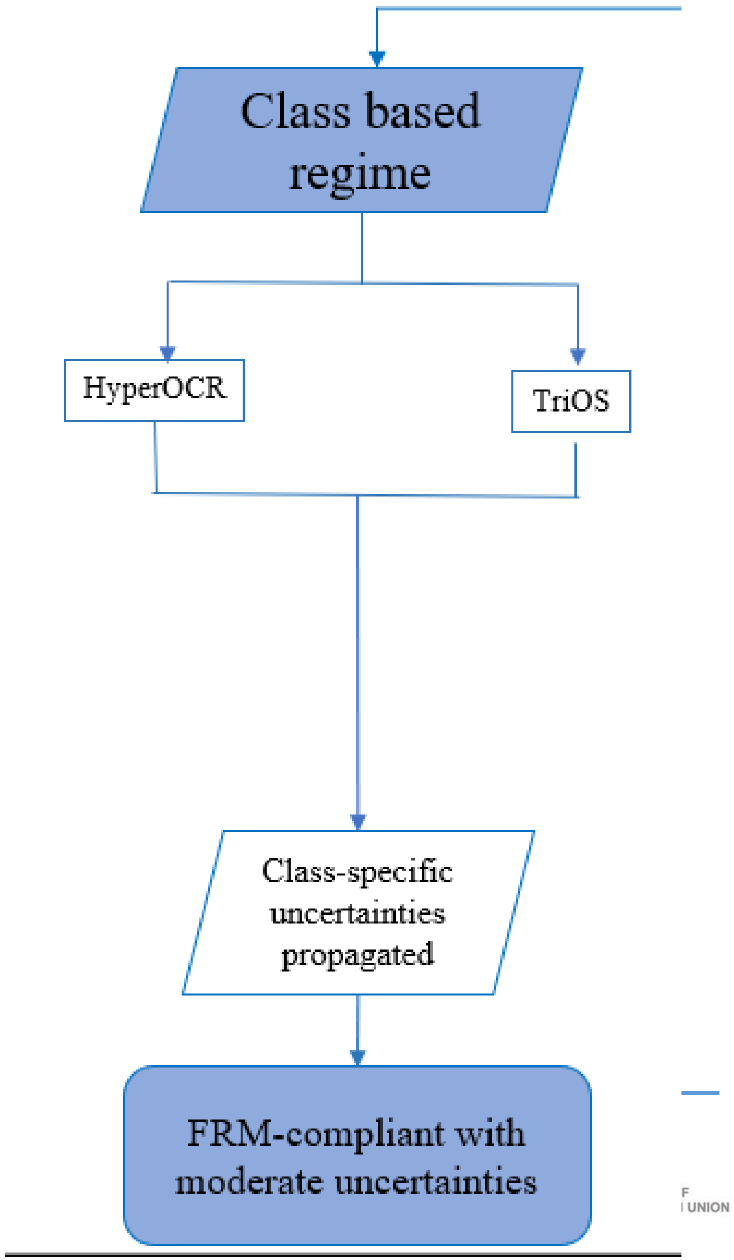
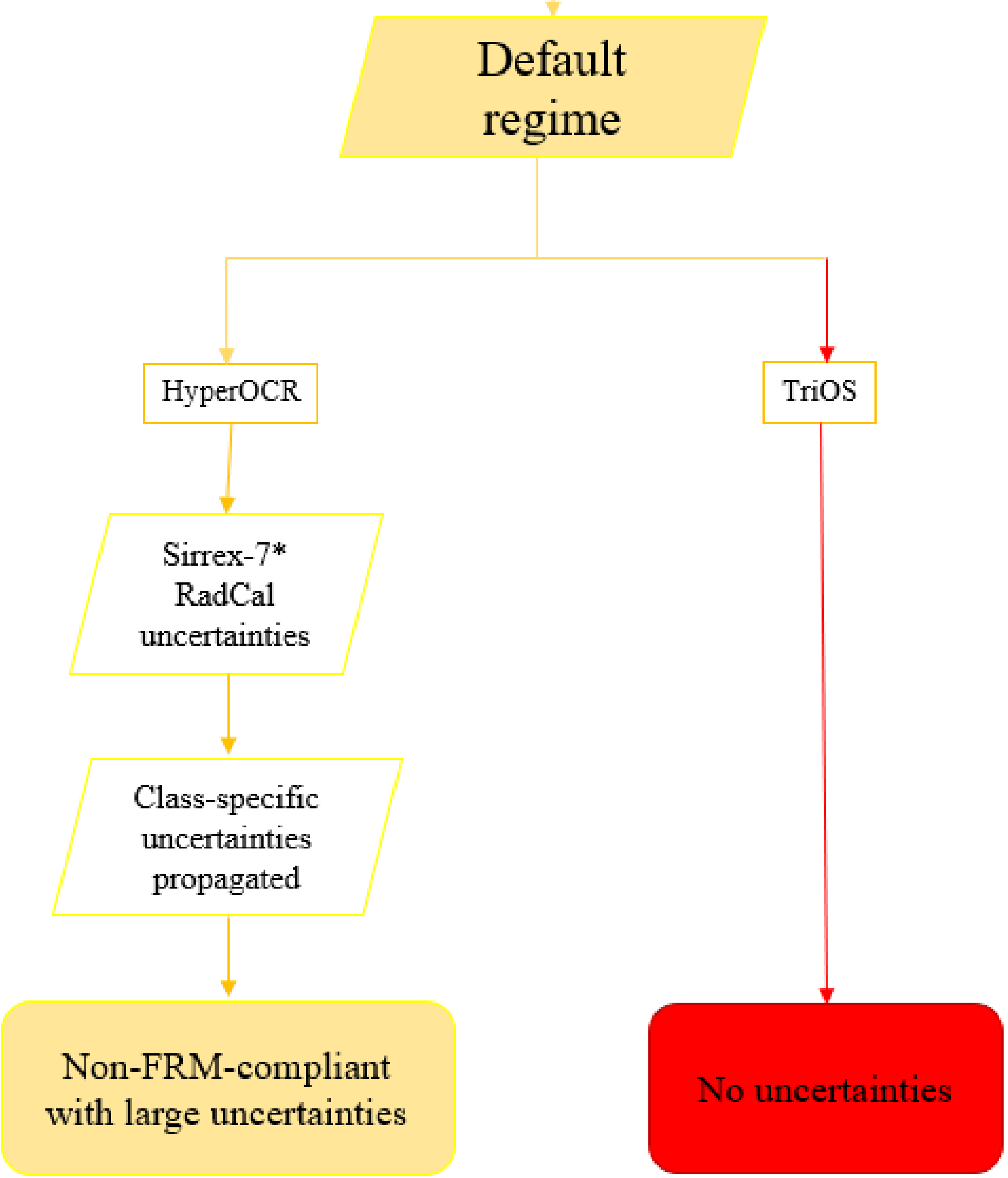
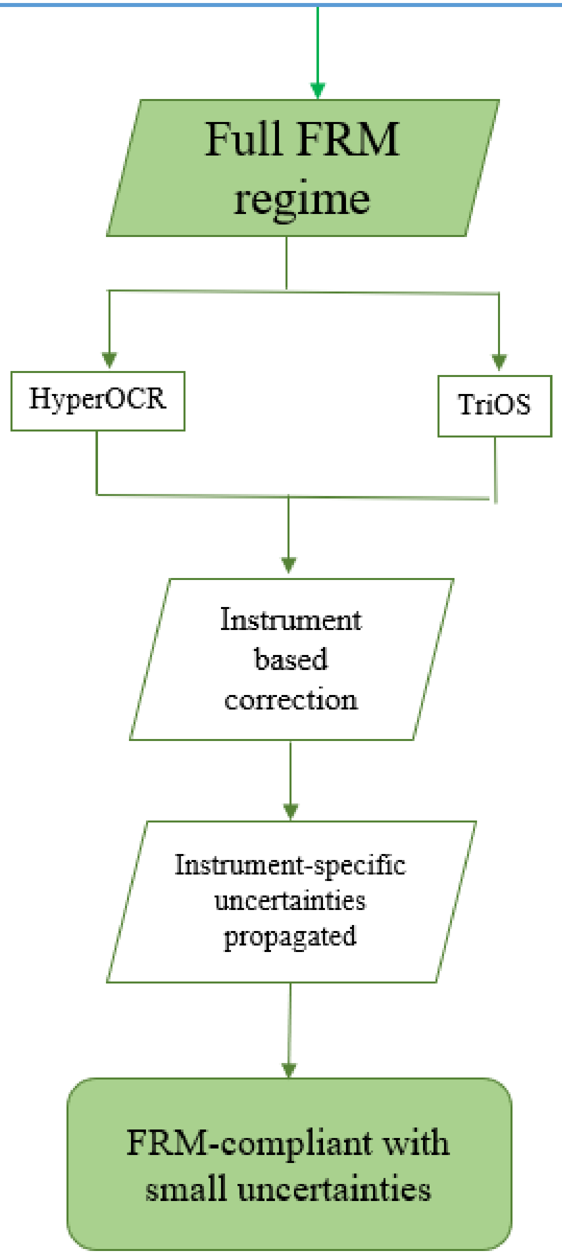


Table 3. Summary information about each uncertainty component values for class-based approach (blue branch, Fig. 5)

Variable symbol	Variable name/description	Exemplary uncertainty magnitude for class-based characterisation		PDF shape	Correlation 'corr_x'	Correlation between 'corr_between'
		TRIOS	HyperOCR			
$(DN_{\mathrm{light},Lx} - DN_{dark,Lx})$ $(DN_{\mathrm{light},Es} - DN_{dark,Es})$	Mean value of DNs measured by a single instrument at a "station"	Standard deviation calculated per measurement from data statistics		Normal	Random	N/A
c_{cal}	Absolute radiometric calibration	Uncertainty values from calibration certificate divided by 2 to convert them back into standard uncertainty, k=1		Normal	Systematic	Between all three instruments
c_{stab}	Absolute calibration stability	1%		Rectangular	Systematic	N/A
c_{lin}	Detector non-linearity	2%		Normal	Systematic	Between all three instruments
c_{stray}	Spectral stray light	Vary spectrally and per instrument due to difference in spectral shape of the signal, should come from the class-based stray light file		Normal	Systematic	Between all three instruments
c_T	Temperature sensitivity	Vary spectrally come from the class-based temperature sensitivity file		Normal	Systematic	Between all three instruments
c_{pol}	Polarisation sensitivity (Radiance only)	Vary spectrally and per instrument to use published data from (Talone and Zibordi, 2016)	Vary spectrally and per instrument triple values for TRIOS, as shown in [AD-1]	Normal	Systematic	Between two radiance instruments
c_{cos}	Cosine response (Irradiance only)	Directional 3.5%	Directional 2%	Normal	Systematic	N/A

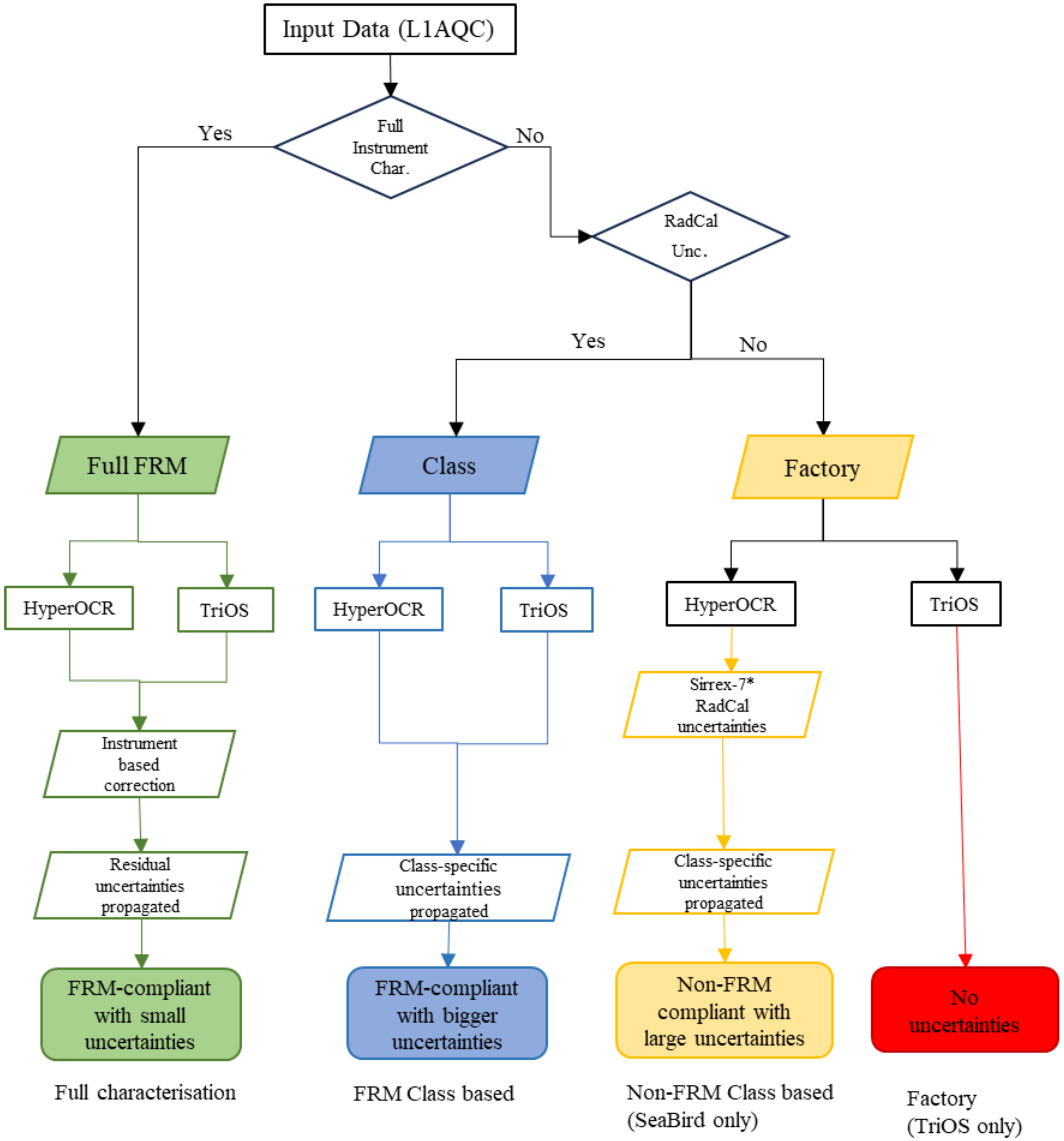


* The Seventh SeaWiFS Intercalibration Round-Robin Experiment (SIRREX-7), March 1999.



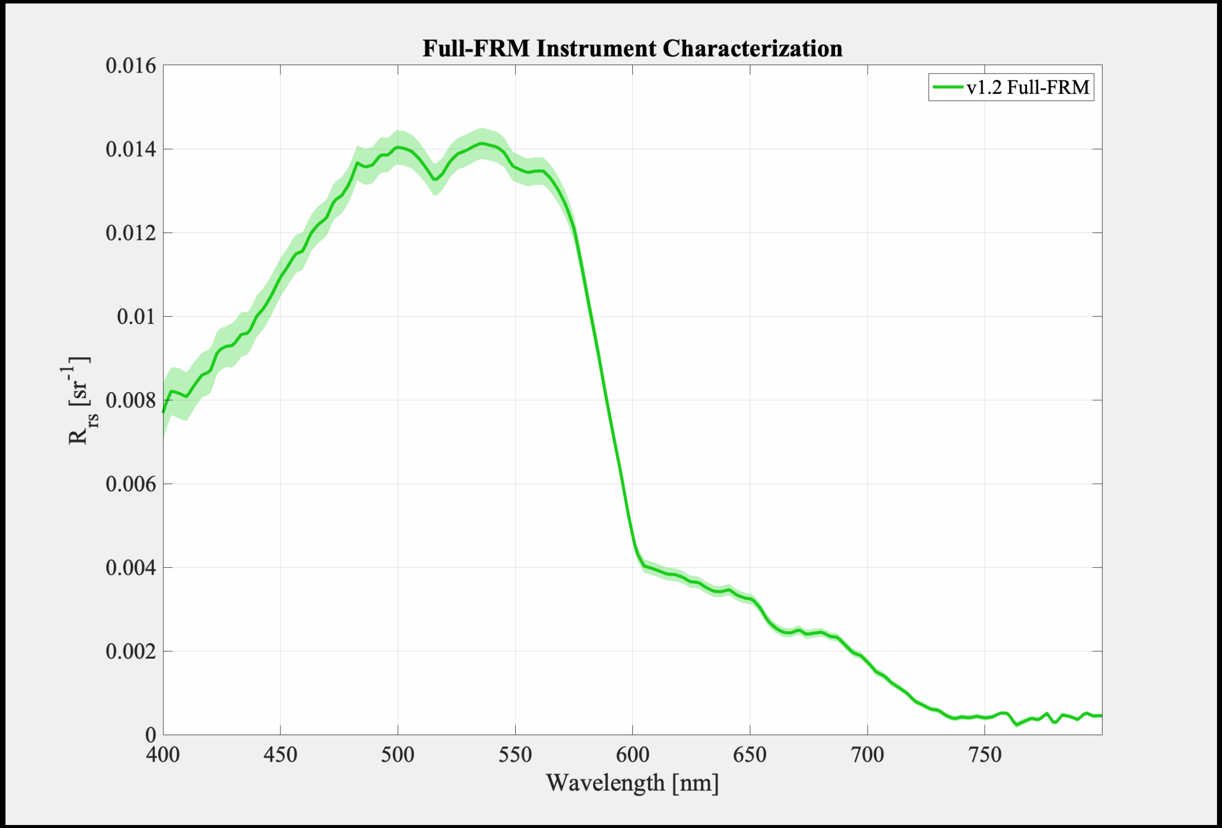
Characterisation file for each instument

angular	04/04/2023 17:05	File folder
linearity	04/04/2023 17:05	File folder
pol	04/04/2023 17:05	File folder
radcal	04/04/2023 17:05	File folder
stability	04/04/2023 17:05	File folder
straylight	04/04/2023 17:05	File folder
thermal	04/04/2023 17:05	File folder



* The Seventh SeaWiFS Intercalibration Round-Robin Experiment (SIRREX-7), March 1999.

Improved Precision and Uncertainty Estimation



v1.1:

- ✓ No instrument-specific characterizations, corrections, or uncertainty
- ✓ Only environmental variability and uncertainty course estimate for the glint correction (Mobley 1999).

v1.2 Class-based:

- ✓ Class-based (Sea-Bird, TriOS) characterizations and uncertainties (no corrections) in addition to environmental variability.
- ✓ Monte Carlo estimates of uncertainty for glint correction.

v1.2 Full-FRM:

- ✓ Instrument-specific characterizations, corrections, and uncertainties applied in addition to environmental variability.
- ✓ Monte Carlo estimates of uncertainty for glint correction.

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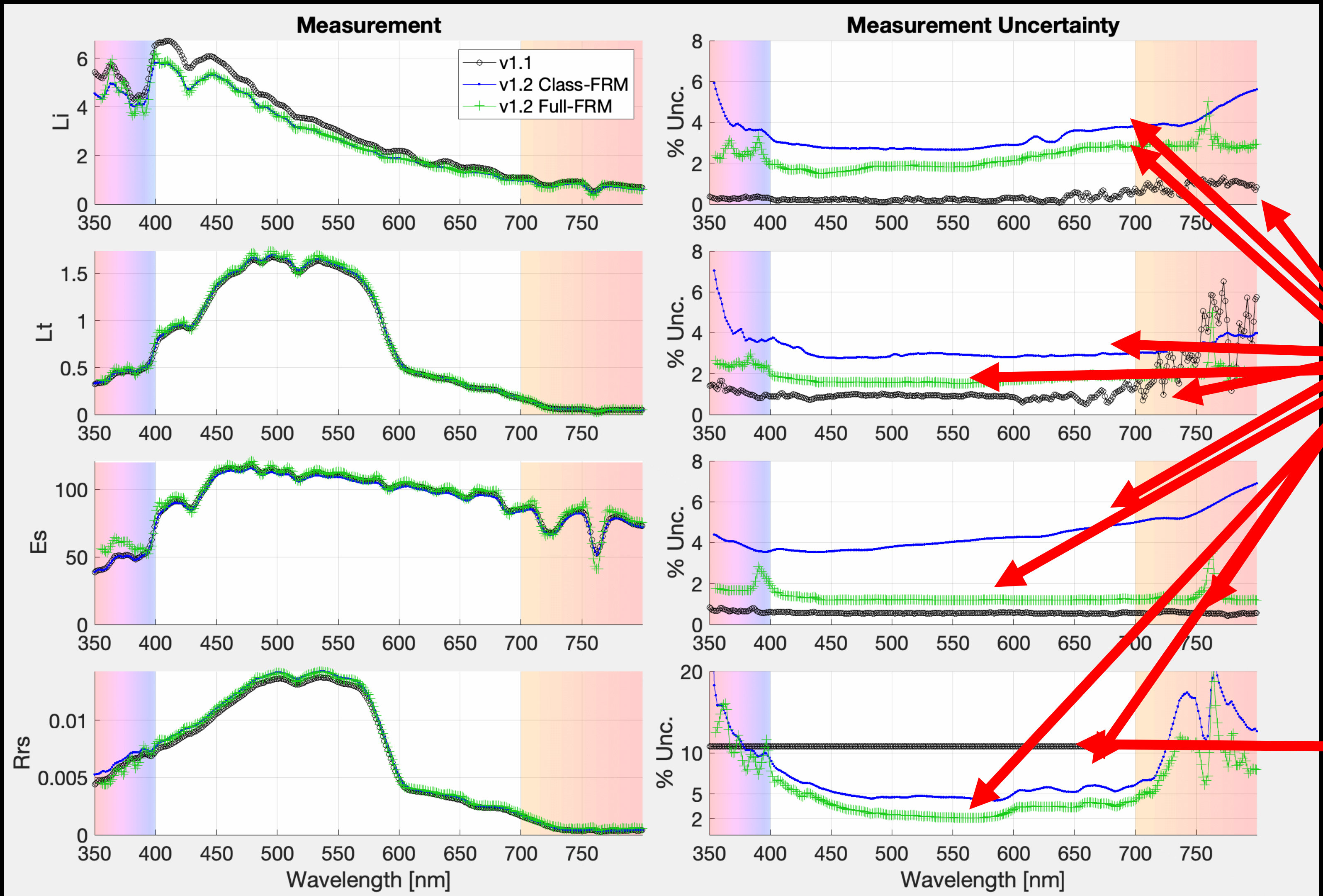
Improved Precision and Uncertainty Estimation



v1.1 underestimates; lack instrument characterization

Full-FRM with instrument characterization and correction; most accurate (and precise)

v1.1 overestimates; glint uncertainty poorly parameterized

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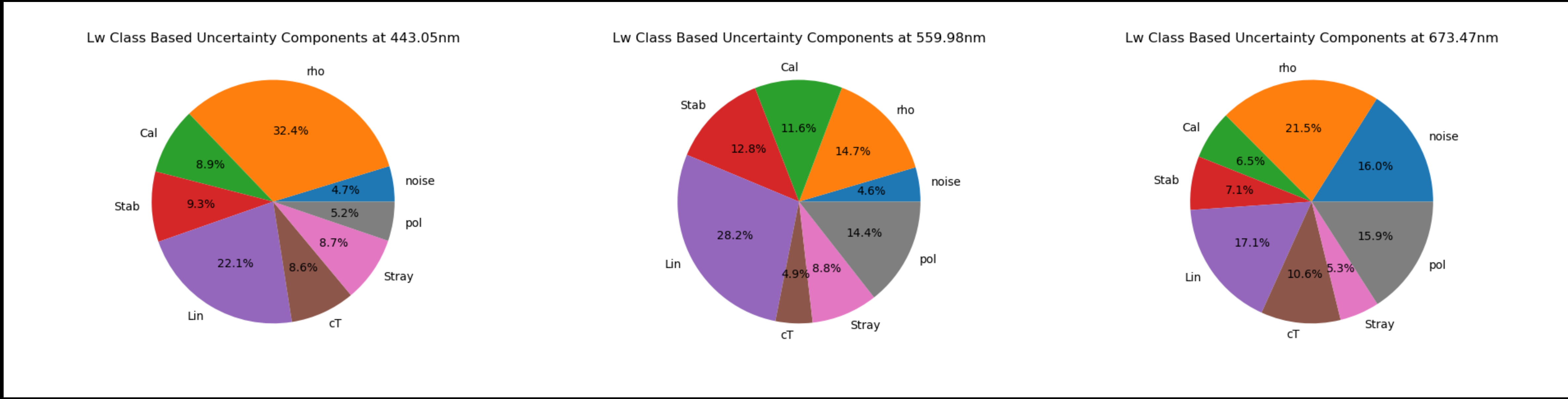
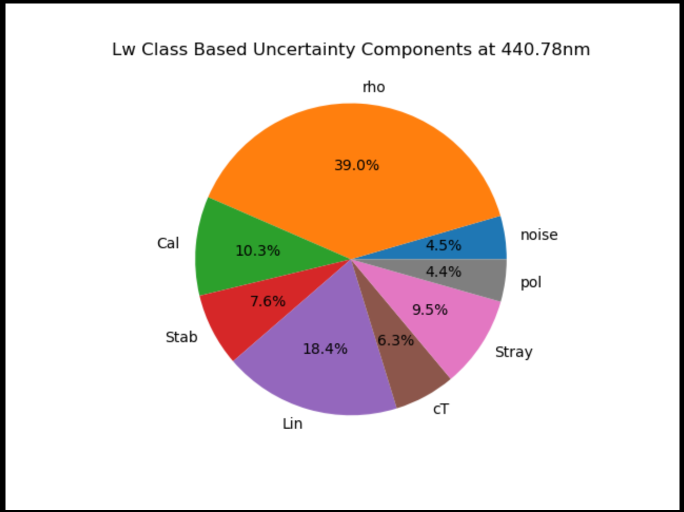
Uncertainty Breakdowns for Class-based





Key message to remember

- No absolute radiometric calibration uncertainty –
  no uncertainty in is situ data

- For TRIOS and SeaBird radiometric calibration files with two dark – corrected DN values recorded at two integration time allow us to apply non-linearity correction