Copernicus FICE 2025

Training on
In situ Ocean Colour Above-Water Radiometry towards Satellite Validation

Uncertainty analysis in HyperCP

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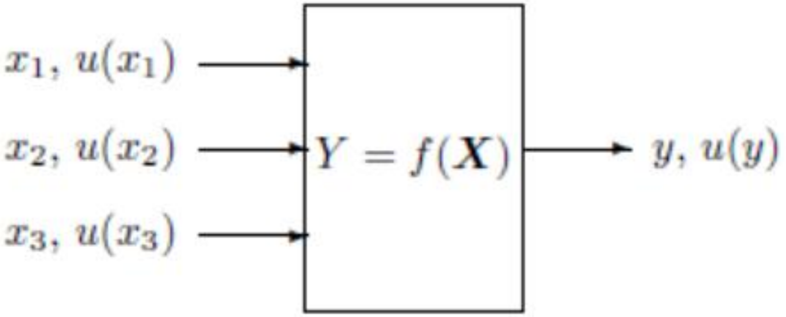
Uncertainty Evaluation

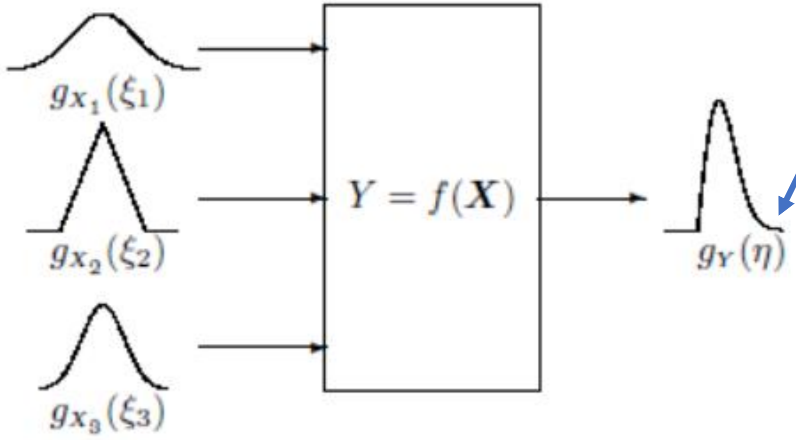
- GUM – Law of propagation of uncertainty
- GUM supplement 1 – Monte Carlo Methods

HyperCP

GUM



MCM



GUM Assumptions and Restrictions

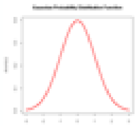
- Output value has Normal distribution
- First order approximation applies to linear models
- Symmetric distribution of inputs

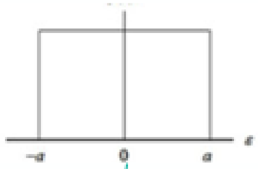
http://www.bipm.org/en/publications/guides/

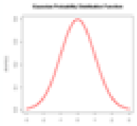
Bureau International des Poids et Mesures – the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.

GUM Methodology applied in CoMET tool

CoMet







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

random

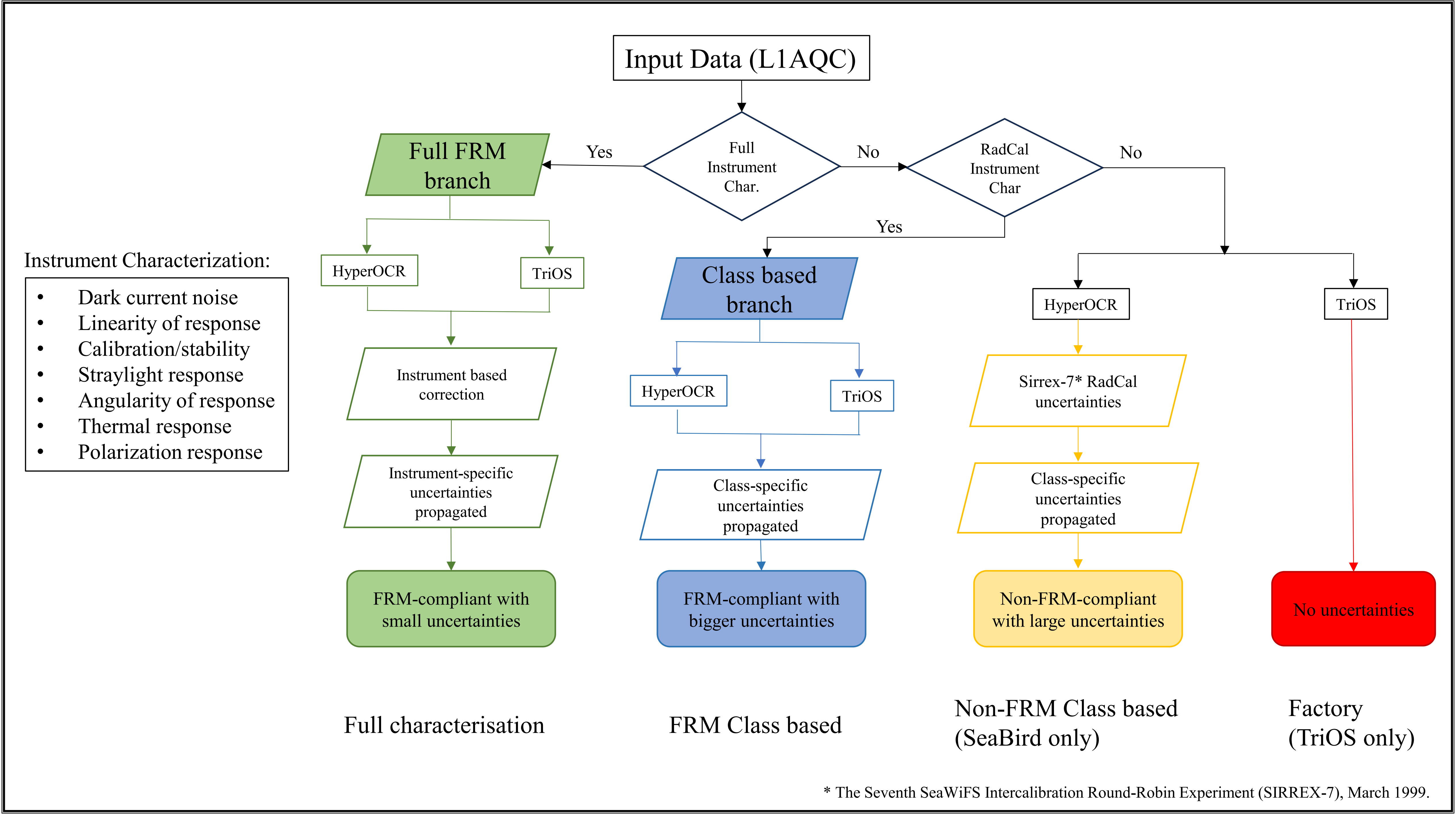
systematic

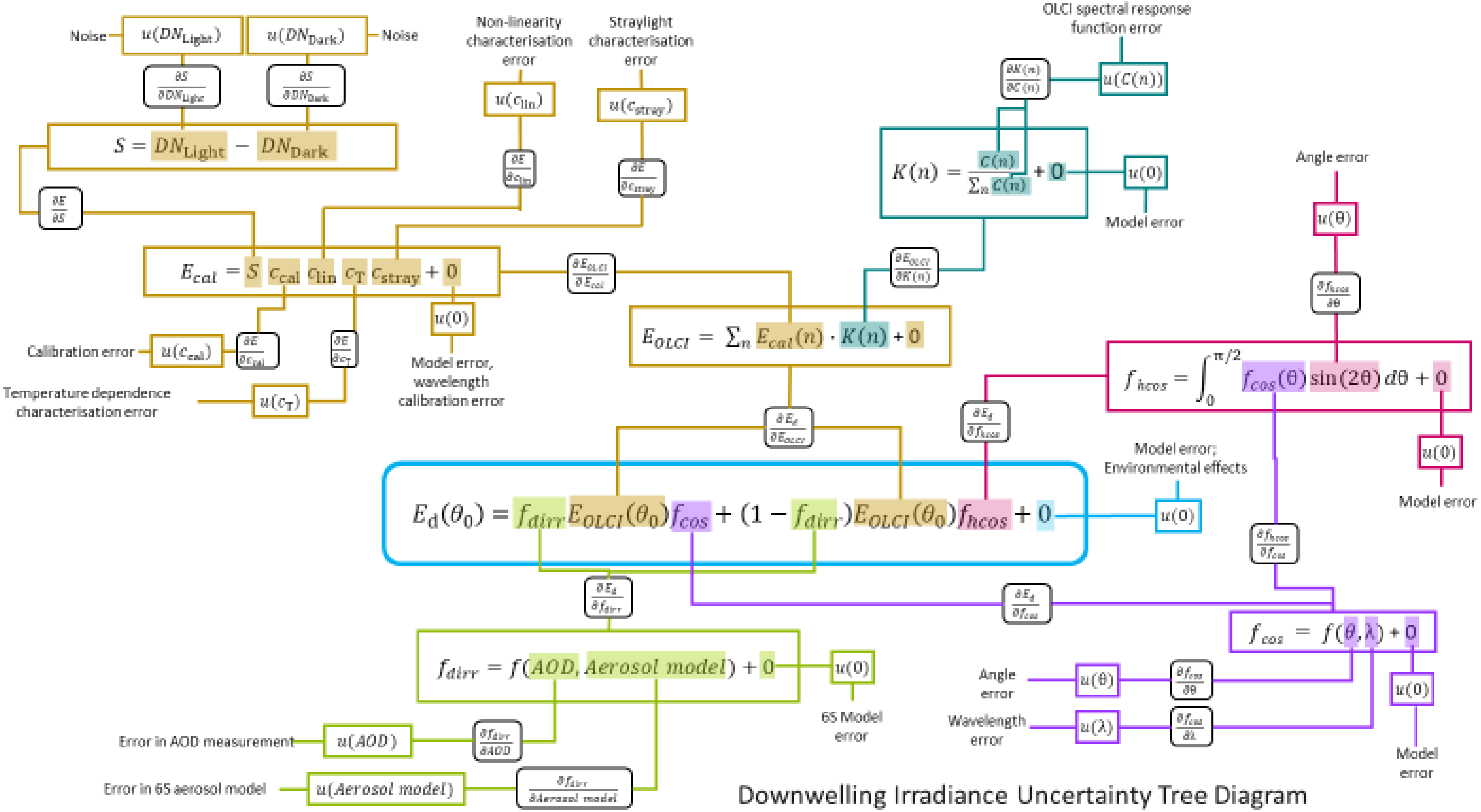
$$u_c^2(y) = \sum_{i=1}^{N} c_i^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=1+1}^{N} c_i c_j u(x_i) u(x_j) r(x_i, x_j),$$

L_t	c_{c2}	ρ	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

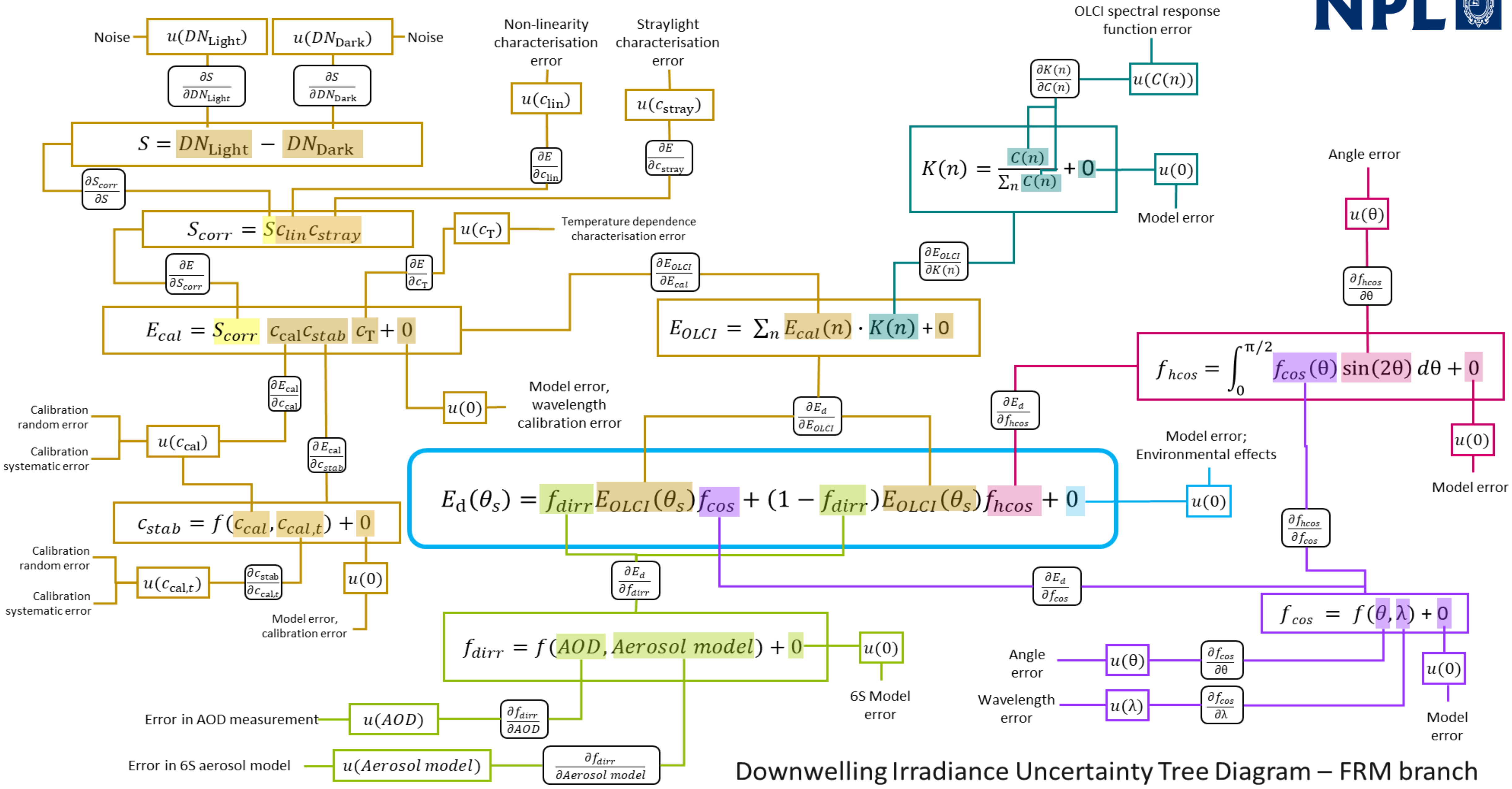
JCGM100:2008. Evaluation of measurement data - *Guide to the expression of uncertainty in measurement*

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.*


Input Data (L1AQC)
Full Instrument Char.
Yes
No
RadCal Instrument Char
No
Yes
Full FRM branch
Instrument Characterization:
Dark current noise
Linearity of response
Calibration/stability
Straylight response
Angularity of response
Thermal response
Polarization response
HyperOCR
TriOS
Instrument based correction
Instrument-specific uncertainties propagated
FRM-compliant with small uncertainties
Class based branch
HyperOCR
TriOS
Class-specific uncertainties propagated
FRM-compliant with bigger uncertainties
HyperOCR
TriOS
Sirrex-7* RadCal uncertainties
Class-specific uncertainties propagated
Non-FRM-compliant with large uncertainties
No uncertainties
Full characterisation
FRM Class based
Non-FRM Class based (SeaBird only)
Factory (TriOS only)
* The Seventh SeaWiFS Intercalibration Round-Robin Experiment (SIRREX-7), March 1999.



Downwelling Irradiance Uncertainty Tree Diagram



NPL

Downwelling Irradiance Uncertainty Tree Diagram – FRM branch

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 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

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

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

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

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

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

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

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

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

Co

Default branch measurements equations

- Irradiance

$$E_d(\lambda) = \overline{E_d(\lambda)} \cdot c_{cal}(\lambda)c_{stab}(\lambda)c_{lin}(\lambda)c_{stray}(\lambda)c_T(\lambda)f_{cos}$$

- Radiance

$$L_t(\lambda) = \overline{L_t(\lambda)} \cdot c_{cal}(\lambda)c_{stab}(\lambda)c_{lin}(\lambda)c_{stray}(\lambda)c_T(\lambda)c_{pol}(\lambda)$$

Approach

NPL

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			
$(DN_{\text{light},L_X} - DN_{dark,L_X})$ $(DN_{\text{light},E_S} - DN_{dark,E_S})$	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

Approach

Table 3 . Summary information about each uncertainty component for sea surface reflectance factor (ρ) estimation using Mobley method to estimate the sea-surface reflectance factor (ρ).

Variable symbol	**Variable name/description**	**Exemplary uncertainty magnitude**	**PDF shape**	**Correlation** ‘corr_x’	**Correlation between** 'corr_between'
ρ	Sea surface reflectance	Calculated for each cast depends on all input components, especially wind speed	Normal	Random	N/A
w_s	Wind speed	2 ms^{-1}	Normal	Random	N/A
$\Delta\phi$	Relative azimuth	3°	Normal	Random[1]	N/A
θ_s	Solar zenith angle	0.5°	Normal	Random	N/A
+0	Model error	Difference between Mobley and Zhang method	Rectangular	Systematic	N/A

Default Branch CP Implementation Example

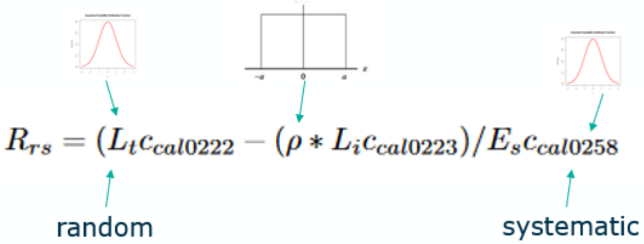
Source of Uncertainty	Input Uncertainty
DN_{light}	Std (*k*=1)
DN_{dark}	Std (*k*=1)
c_{cal}	Tartu file
c_{stab}	1%
c_{lin}	2%
c_{stray}	FRM4SOC-1
c_{temp}	Tartu file
c_{cos}	2%

```python
@staticmethod
def Es(DNLight, DNDark, Ccal, Cstab, Clin, Cstray, Ct, Ccos):
    """(DNLIGHT-DNDARK).Ccal.Cstab.Clin.Cstray.Ct.Ccos"""
    return (DNLight - DNDark) * Ccal * Cstab * Clin * Cstray * Ct * Ccos
```

- Occurs at L1B during dark correction, c_{cal} is taken from Tartu file.
- Time average DN_{light} & DN_{dark}.
- Remaining coefficients are set to 1.
- Measurement function is defined in python.
- Punpy generates samples from inputs and uncertainties.
- Runs M=10000 Monte Carlo uncertainty propagation according to the GUM.
- Output is divided by signal to generate relative uncertainty.
- Saved in the uncertainty budget group.

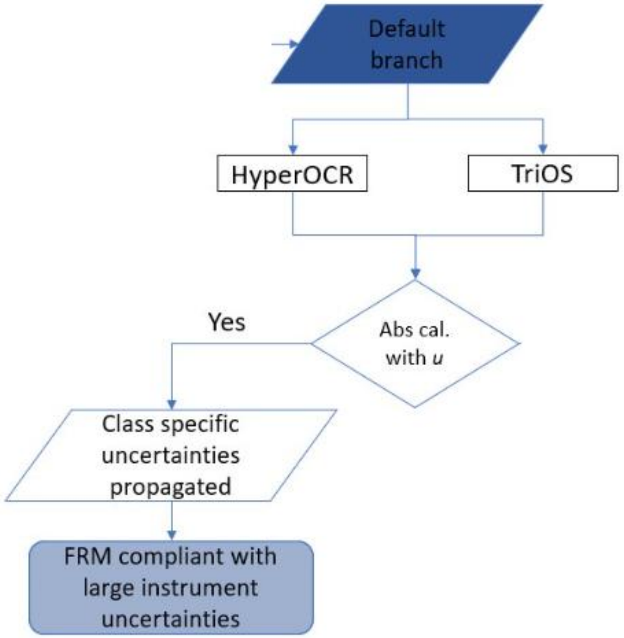
Using Monte Carlo

GUM Methodology applied in CoMET tool



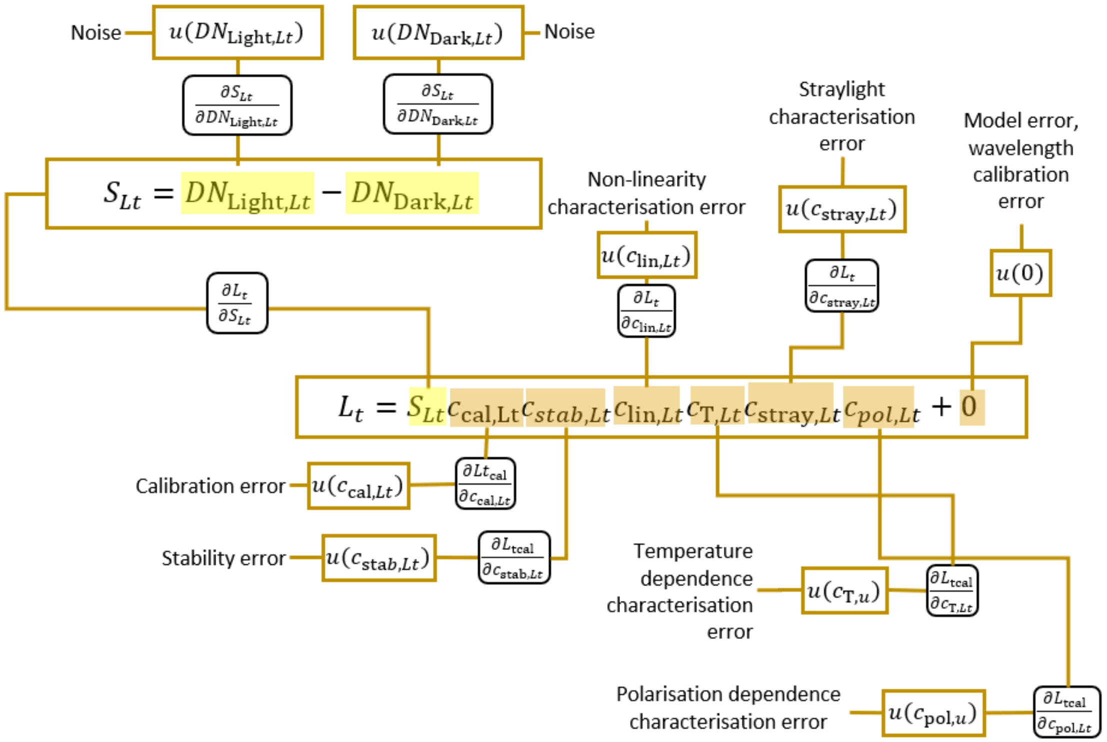
	L_t	c_{c2}	ρ	L_i	c_{c3}	E_s	c_{c8}
L_t	1	0	0	0	0	0	0
c_{c2}	0	1	0	0	1	0	1
ρ	0	0	1	0	0	0	0
L_i	0	0	0	1	0	0	0
c_{c3}	0	1	0	0	1	0	1
E_s	0	0	0	0	0	1	0
c_{c8}	0	1	0	0	1	0	1

- First, we need to identify our measurement function, f
- We need our inputs to the measurement function with their associated uncertainties
- Then we build samples of M draws, based on known input correlation
- We run those samples through f
- $u_c(y)$ can be found from the statistics o the output

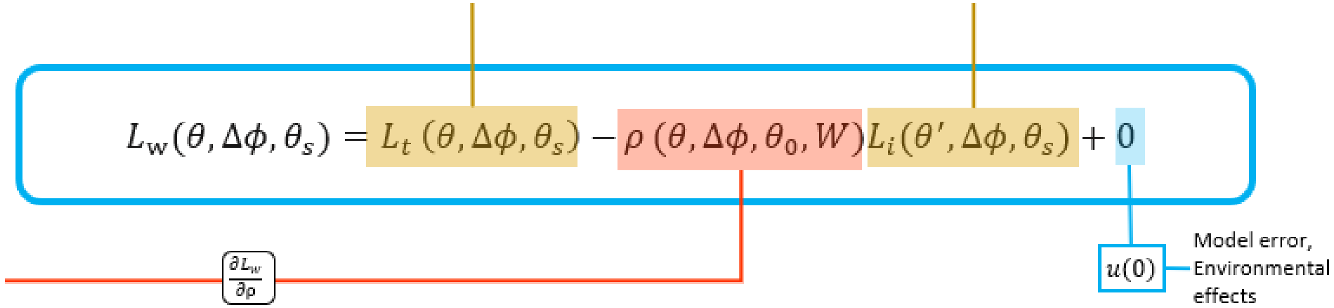


How FRM Uncertainties are Propagated

- We combine and process samples directly
- We calculate uncertainty (in theory) alongside the processor
- Correlations are engendered within the samples
- L2 uncertainties (R_{rs}, Lw, NLw), are calculated using distributions of Es, Li, Lt, & Rho which contain information of uncertainty and correlation



FRM Uncertainties – an example




```python
        sample_Lw = Propagate_L2_FRM.run_samples(Propagate.Lw_FRM, MC_x: [ltSample, rhoSample, liSample])
        sample_Rrs = Propagate_L2_FRM.run_samples(Propagate.Rrs_FRM, MC_x: [ltSample, rhoSample, liSample, esSample])
```

```python
    3 usages  ARamsay17
    @staticmethod
    def Lw_FRM(lt, rho, li):
        """ Lw FRM branch measurment function """
        return lt - (rho * li)

```

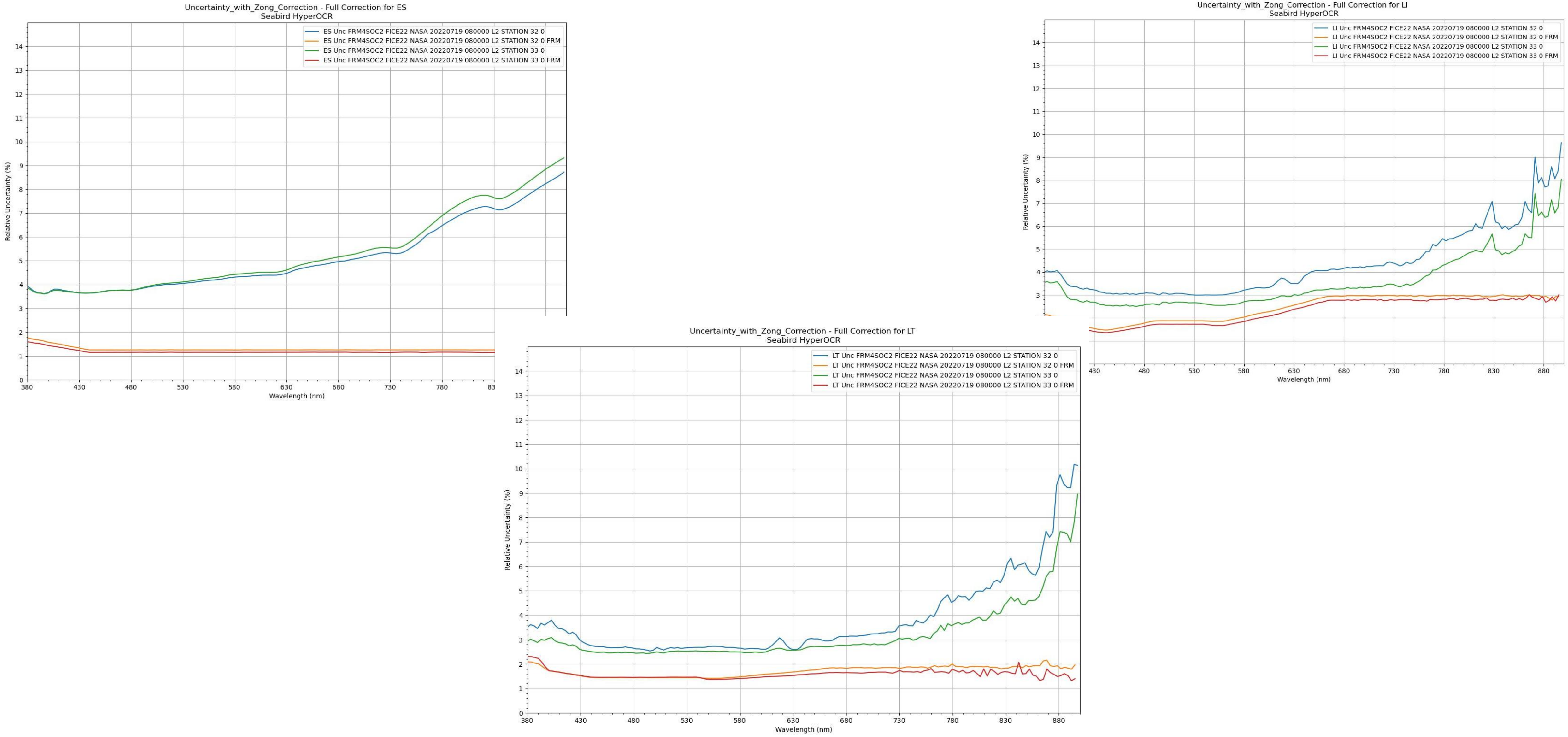
```python
    @staticmethod
    def Rrs_FRM(lt, rho, li, es):
        """ Rrs FRM branch measurment function """
        return (lt - (rho * li)) / es

```

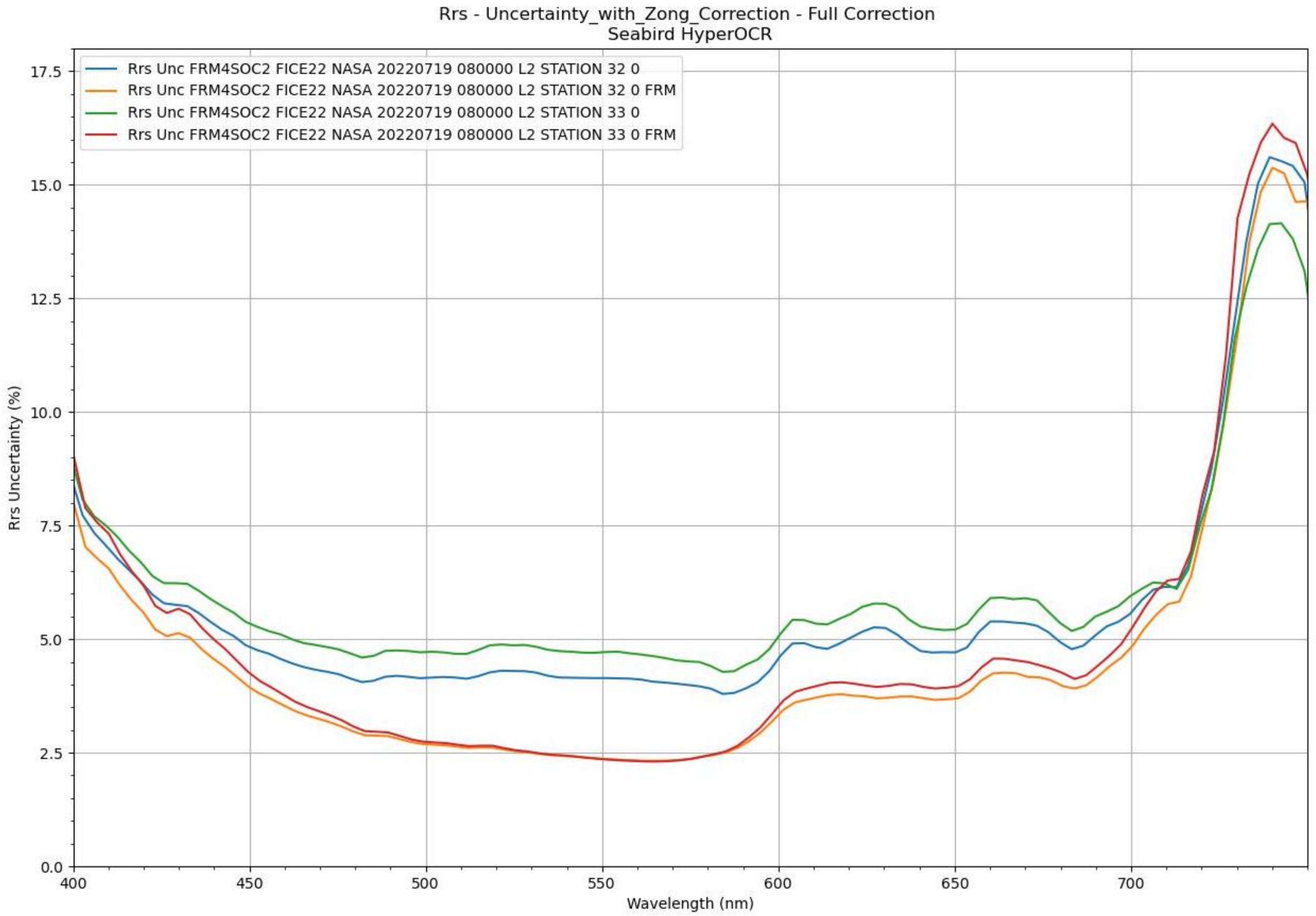
HyperCP

Variable Symbol	Variable Name	Uncertainty Source	Class Based	FRM
			Correction Applied	
$\left(DN_{\text{light},L_X} - DN_{dark,L_X}\right)$ $\left(DN_{\text{light},E_S} - DN_{dark,E_S}\right)$	Mean value of DNs measured by a single instrument at a "station"	Standard deviation calculated from statistics of filtered measurements	NA	NA
c_{cal}	Absolute Radiometric Calibration	Instrument specific characterisation	NA	NA
c_{stab}	Absolute Calibration Stability	Instrument specific characterisation	NA	NA
c_{lin}	Detector Non-Linearity	Instrument specific characterisation	No	Yes
c_{stray}	Spectral Stray Light	Zong stray light correction method	No	Yes
c_T	Temperature Sensitivity	Instrument specific characterisation	No	Yes
c_{pol}	Polarisation Sensitivity (Radiance)	Class specific characterisation	No	No
c_{cos}	Cosine Response (Irradiance)	Instrument specific characterisation	No	Yes

Uncertainty Results – PySAS sample data



Uncertainty Results – PySAS sample data



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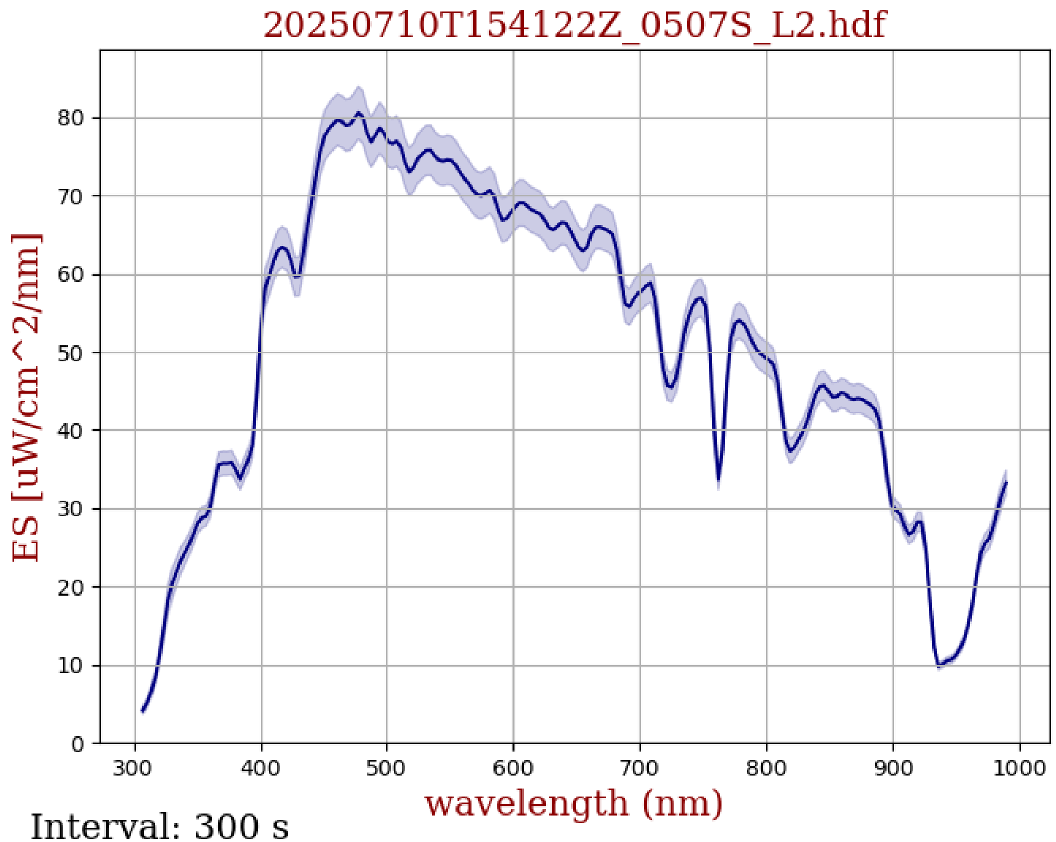
/wind_speed=4.29
SZA =59.5



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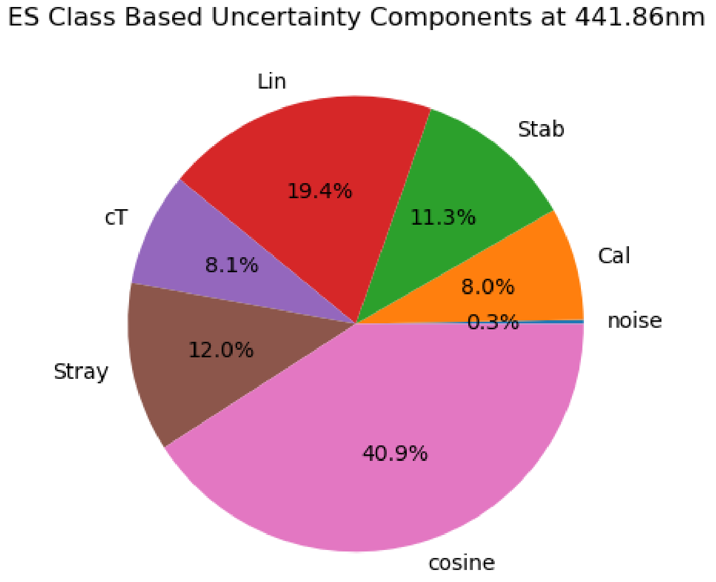
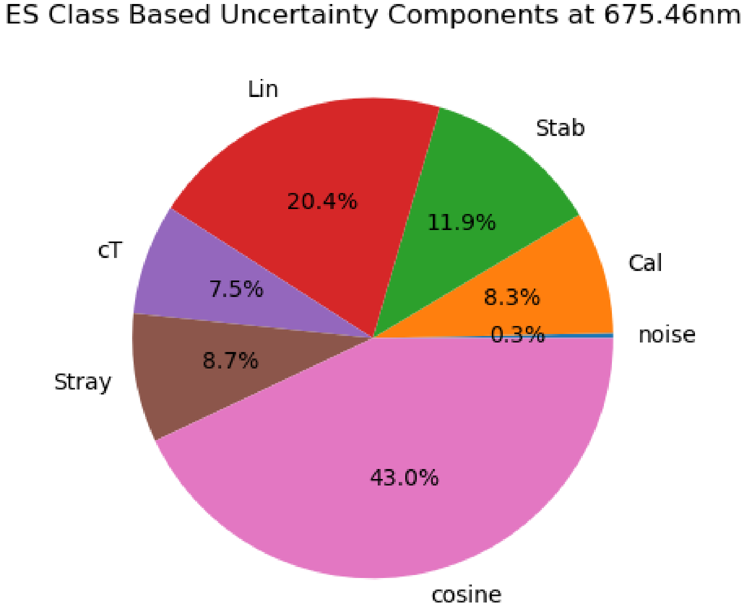
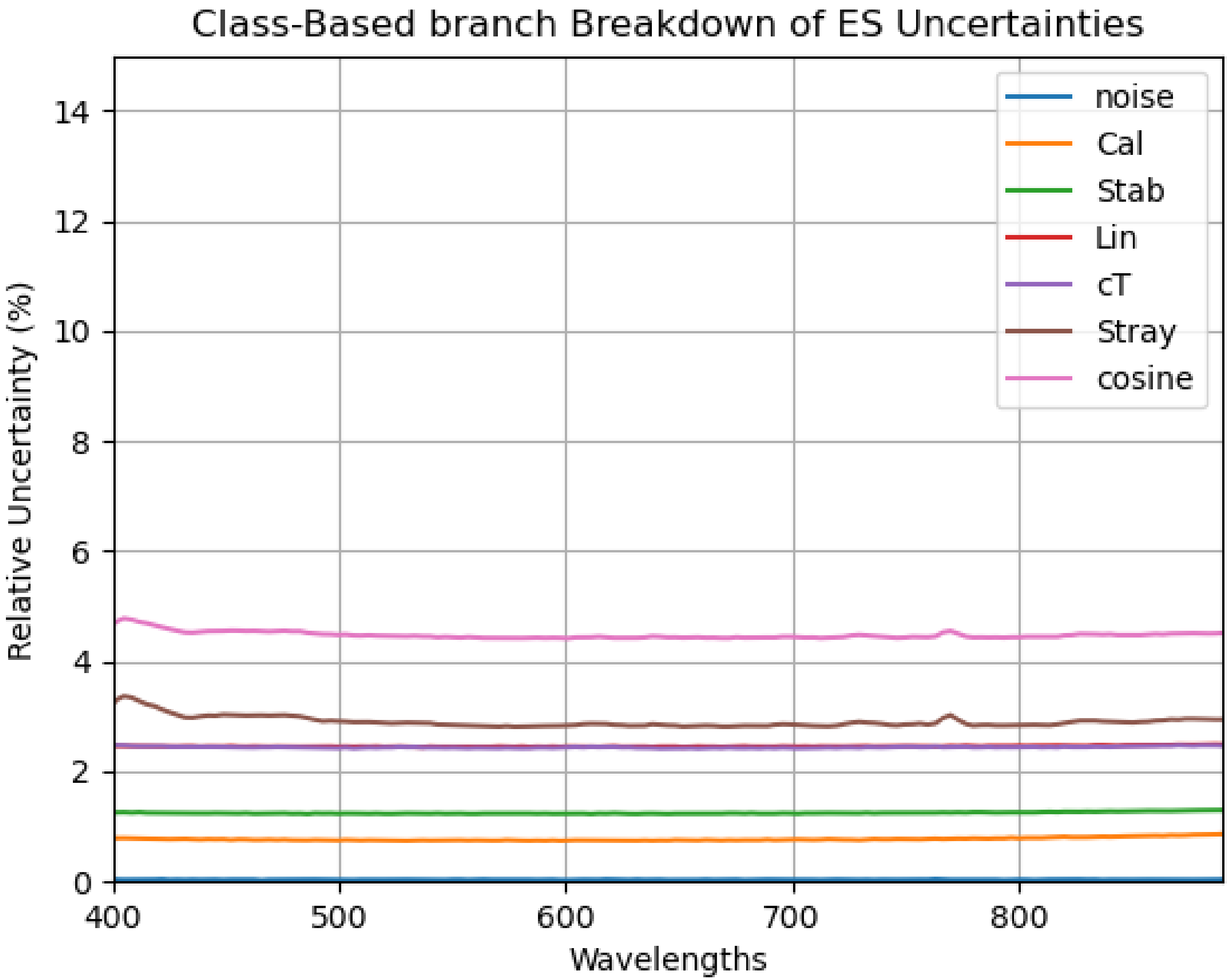




Cumulative Uncertainty breakdown



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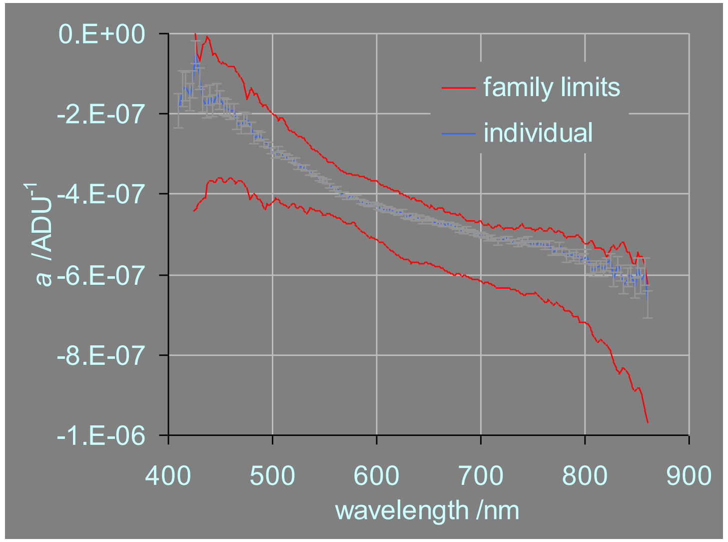
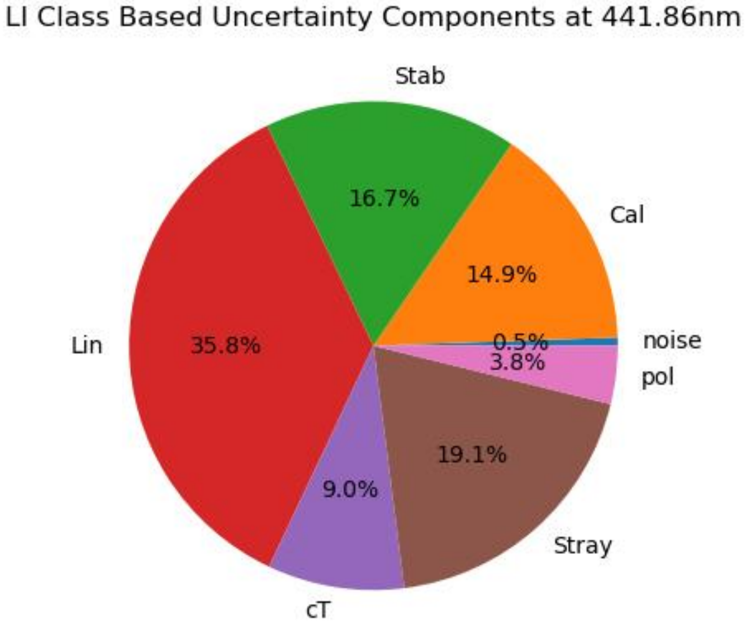
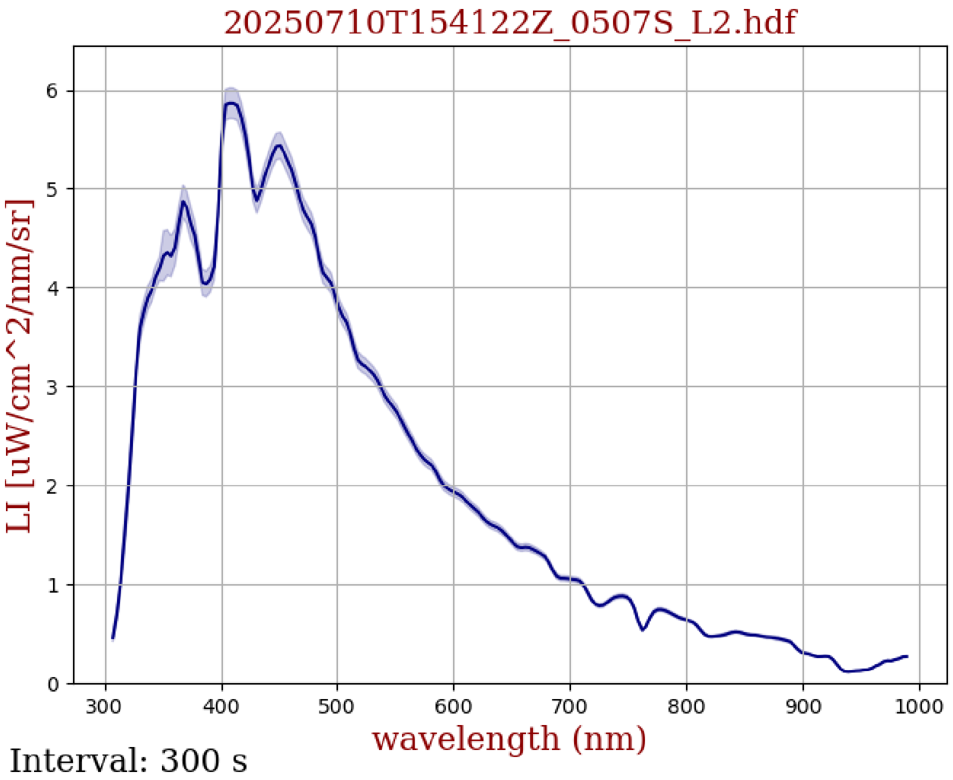


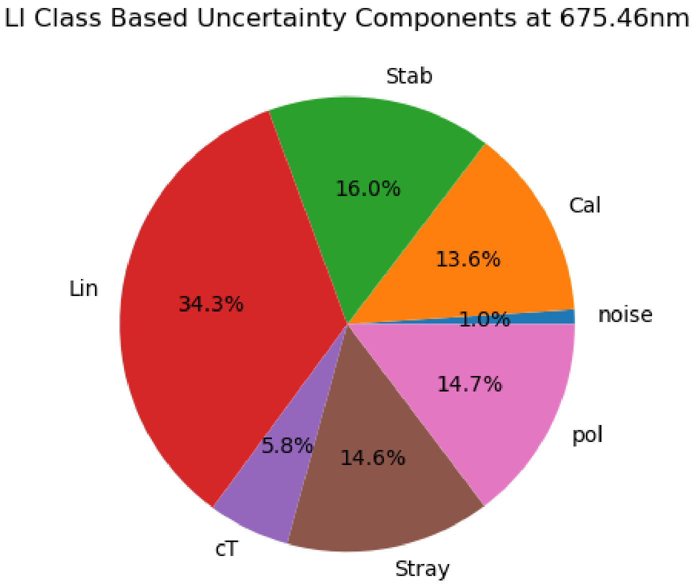
0.E+00
-2.E-07
-4.E-07
-6.E-07
-8.E-07
-1.E-06
a /ADU-1
400
500
600
700
800
900
wavelength /nm
family limits
individual



LI Class Based Uncertainty Components at 441.86nm
Stab
16.7%
Cal
14.9%
noise
0.5%
pol
3.8%
Stray
19.1%
cT
9.0%
Lin
35.8%

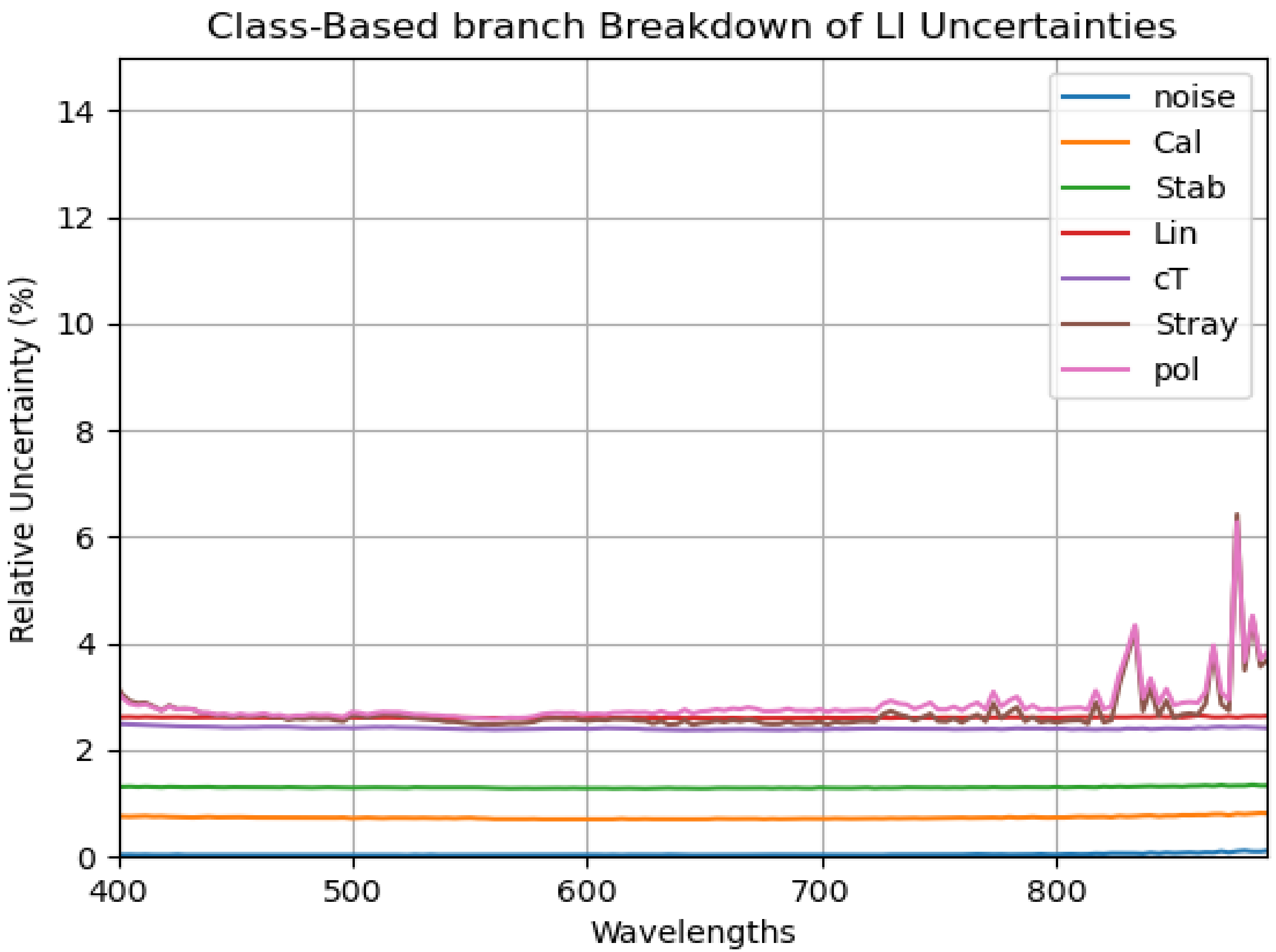


20250710T154122Z_0507S_L2.hdf
LI [uW/cm^2/nm/sr]
wavelength (nm)
Interval: 300 s



LI Class Based Uncertainty Components at 675.46nm
Stab
16.0%
Cal
13.6%
noise
1.0%
pol
14.7%
Stray
14.6%
cT
5.8%
Lin
34.3%

Cumulative Uncertainty breakdown



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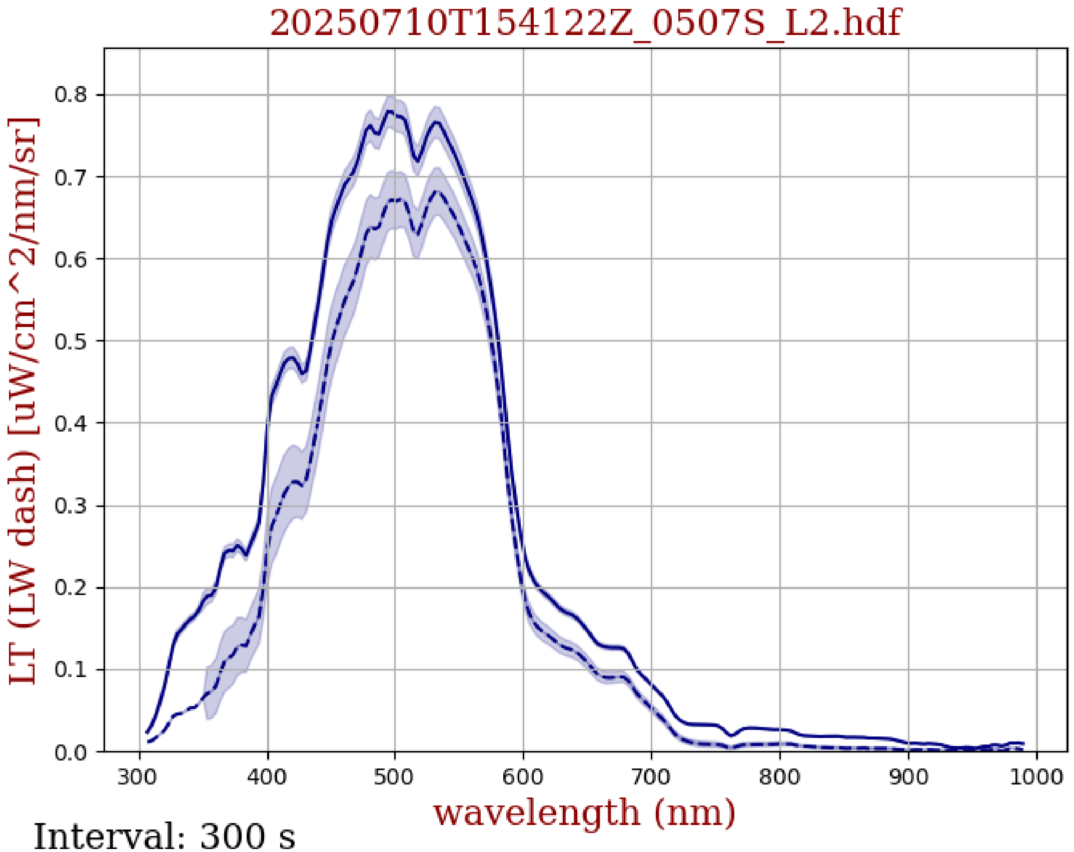
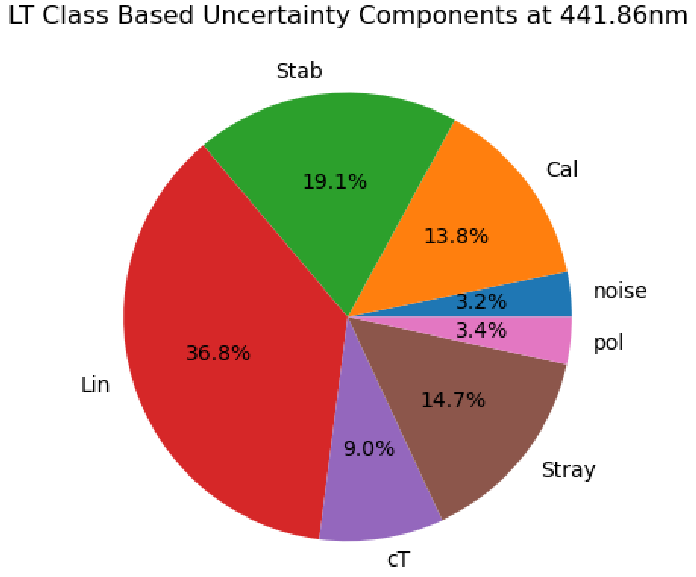
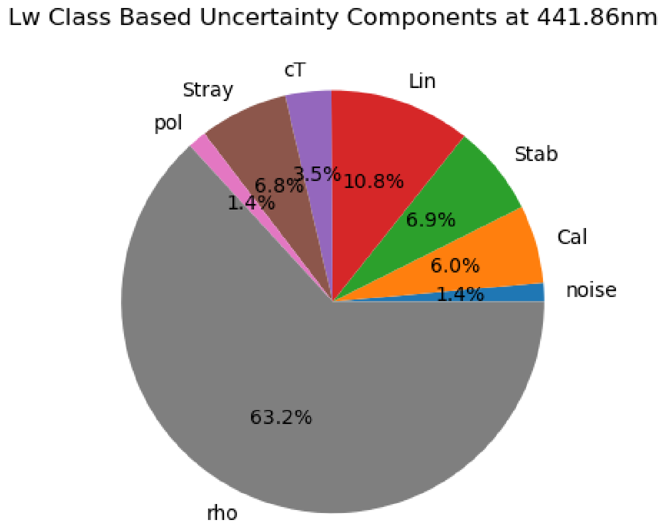
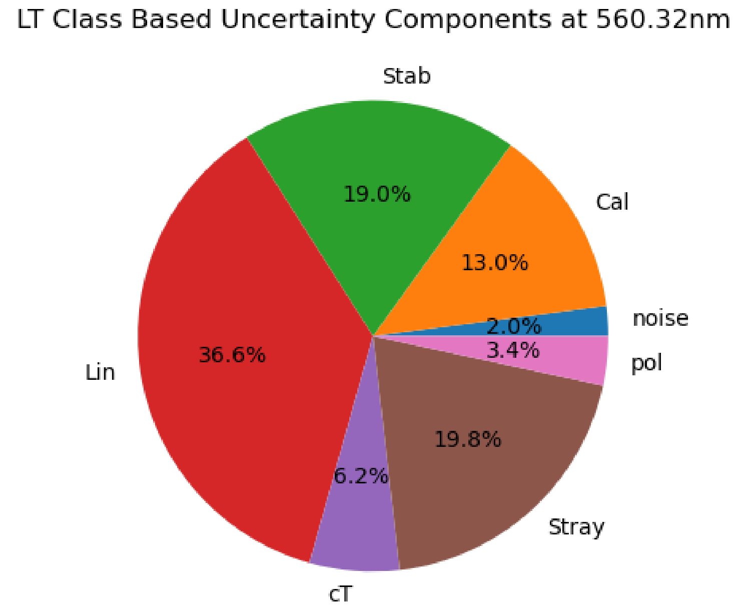
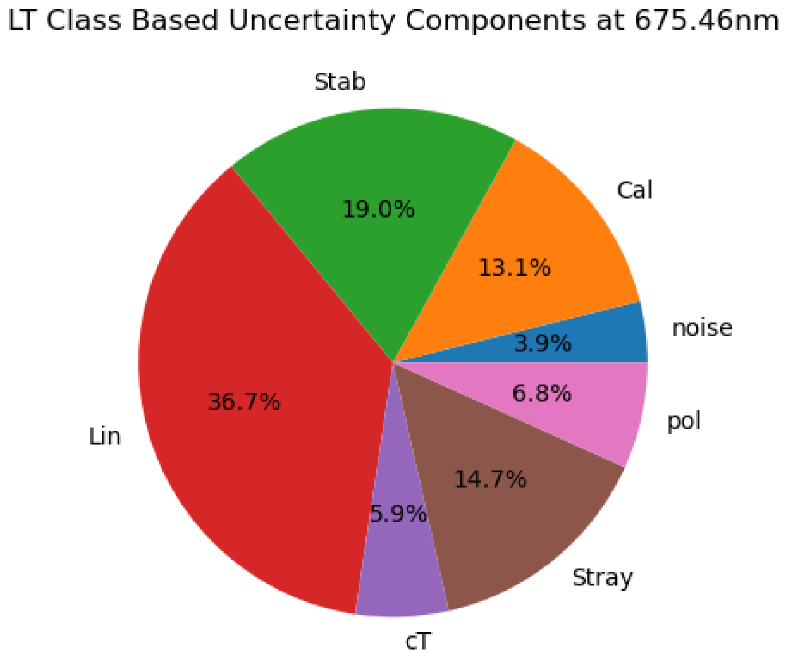


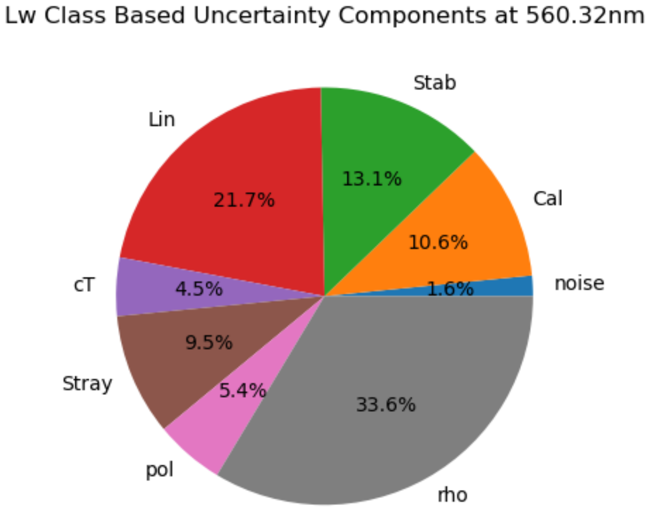
Interval: 300 s

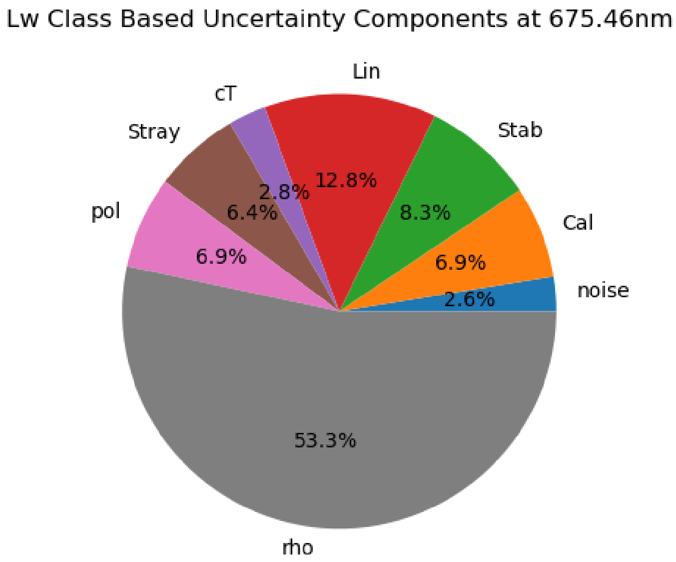




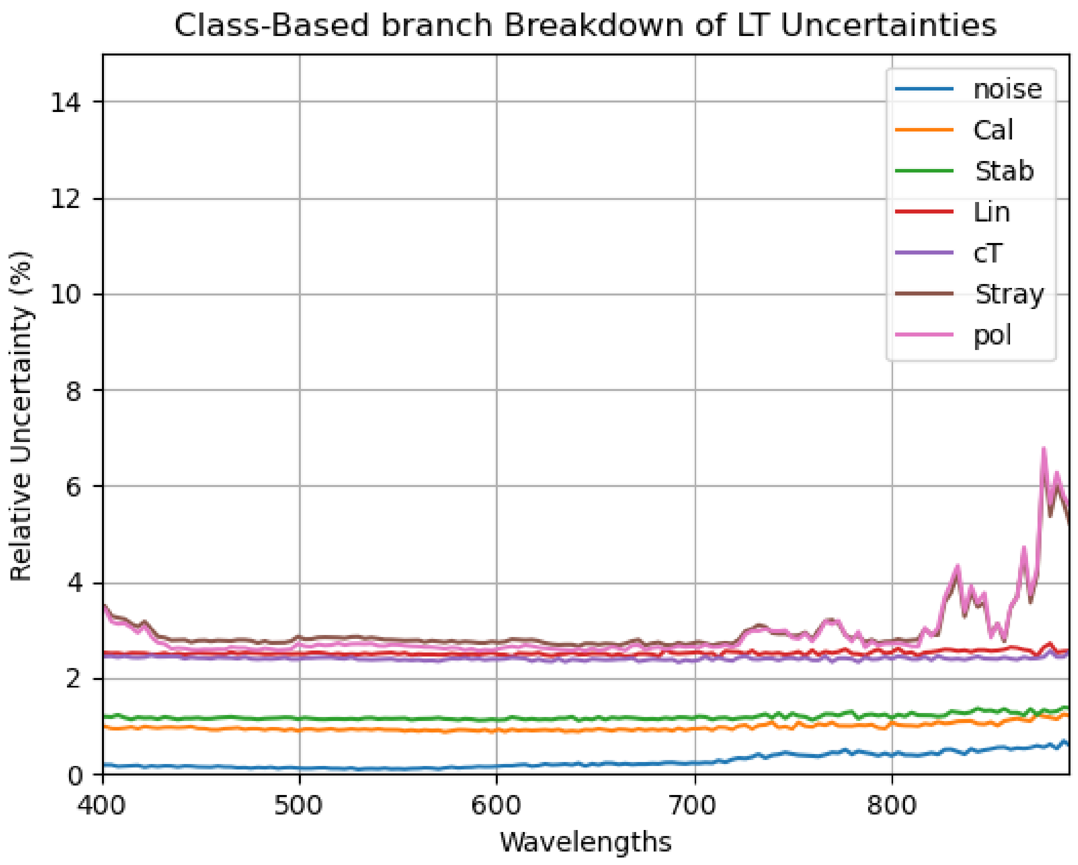

LT Class Based Uncertainty Components at 560.32nm
Stab
19.0%
Cal
13.0%
noise
2.0%
pol
3.4%
Lin
36.6%
19.8%
6.2%
Stray
cT

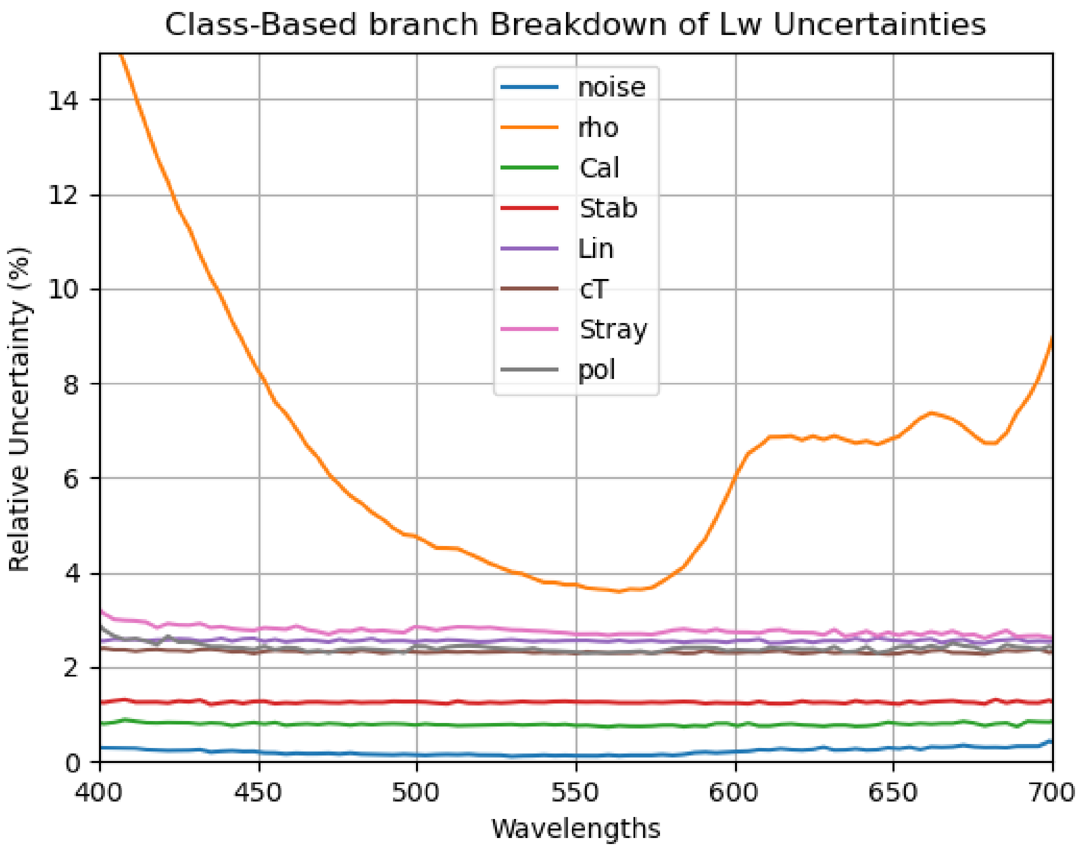

LT Class Based Uncertainty Components at 675.46nm
Stab
19.0%
Cal
13.1%
noise
3.9%
Lin
36.7%
6.8%
pol
14.7%
5.9%
Stray
cT


Lw Class Based Uncertainty Components at 560.32nm
Stab
Lin
13.1%
21.7%
Cal
10.6%
noise
1.6%
cT
4.5%
9.5%
Stray
5.4%
33.6%
pol
rho


Lw Class Based Uncertainty Components at 675.46nm
Lin
cT
Stab
Stray
2.8%
12.8%
pol
6.4%
8.3%
Cal
6.9%
6.9%
noise
2.6%
53.3%
rho

Cumulative Uncertainty breakdown





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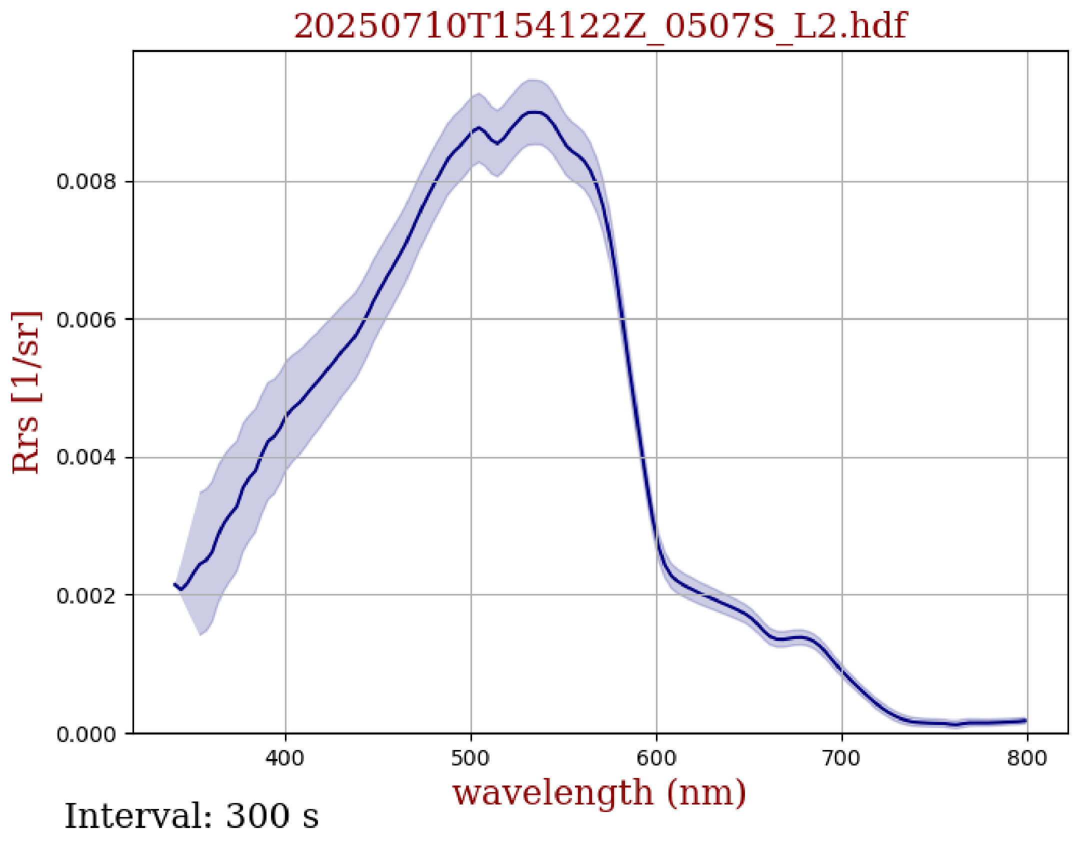
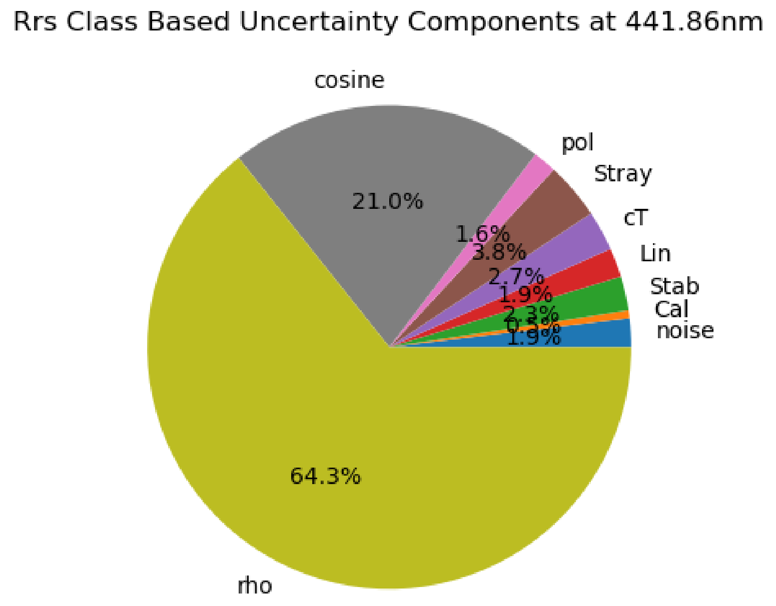
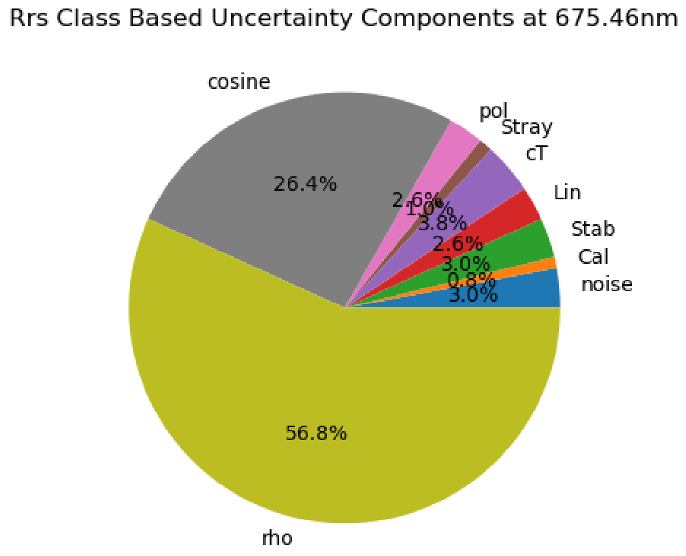


20250710T154122Z_0507S_L2.hdf
Rrs [1/sr]
0.000
0.002
0.004
0.006
0.008
400
500
600
700
800
wavelength (nm)
Interval: 300 s



Rrs Class Based Uncertainty Components at 441.86nm
cosine
pol
Stray
cT
Lin
Stab
Cal
noise
rho
21.0%
1.6%
3.8%
2.7%
1.9%
2.3%
1.9%
64.3%



Rrs Class Based Uncertainty Components at 675.46nm
cosine
pol
Stray
cT
Lin
Stab
Cal
noise
rho
26.4%
2.6%
1.0%
3.8%
2.6%
3.0%
0.8%
3.0%
56.8%

NPL

Congratulation!

I finished and you survived ;-)