Copernicus FICE 2024

Training on

In situ Ocean Colour Above-Water Radiometry towards Satellite Validation

HyperCP Introduction

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PROGRAMME OF THE EUROPEAN UNION
Copernicus Europe's eyes on Earth
IMPLEMENTED BY EUMETSAT
FRM4SOC Phase-2
fiducial reference measurements for satellite ocean colour
CNR ISMAR ISTITUTO DI SCIENZE MARINE

6-17 May 2024
Venice, Italy

NASA

HyperCP Introduction

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NASA Goddard Space Flight Center
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Instructors

HyperCP

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Funding is provided by the NASA PACE Mission and the Copernicus Programme

HyperCP Project Team

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Ryan Vandermeulen [10]

Funding from NASA PACE Mission and Copernicus FRM4SOC Initiative

Welcome, Philipp and Ryan!

[1] NASA Goddard Space Flight Center

[2] Morgan State University

[5] University of Victoria

[7] National Physical Laboratory (UK)

[10] NOAA NMFS

[3] EUMETSAT

[4] Copernicus Programme of European Commission

[6] ACRI-ST

[8] University of Maine

[9] Gybe Inc.

Background

Mission instruments are meticulously characterized prior to launch: stray light, thermal response, SNR, etc. to quantify and correct for anomalies.

On orbit, they require validation and system vicarious calibration to account for radiometric drift and atmospheric correction error.

SVC is traditionally at fixed, dedicated platforms in blue waters, but validation can come from portable platforms in all optical water types.

Rigorous validation requires high-quality, hyperspectral in situ radiometry from many locations and water types.

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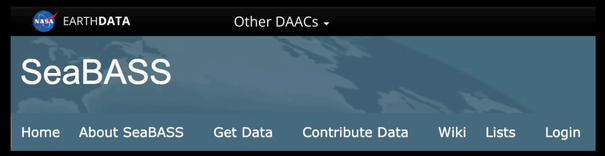
What is HyperCP?

Open-source processor for Above Water Radiometry (AWR) that facilitates **protocol-driven** data correction and reduction yielding high-quality surface reflectance measurements with end-to-end **uncertainty propagation** for submission to NASA's SeaBASS and Copernicus' OCDB archives for use in satellite validation and ocean color algorithm development



HyperCP

What's in a name?

A shameless compound acronym:

HyperCP = HyperInSPACE Community Processor

HyperInSPACE = Hyperspectral In situ Support for PACE

PACE = Plankton, Aerosol, Cloud, ocean Ecosystem [mission]

Hyperspectral In situ Support for Plankton, Aerosol, Cloud, ocean Ecosystem Community Processor

Sure to tax any title or abstract word limit.
We also sometimes call it **HCP**, for short.

HyperCP

HyperCP History

AWR protocols were updated by IOCCG and the community ~2017 - 2019 for the first time since the SeaWiFS era.

HyperInSPACE began at Goddard Space Flight Center toward the end of this period to process NASA's own radiometry and help the community process AWR following these protocols.

NASA/TM-2003-21621/Rev-Vol III

James L. Mueller, Giulietta S. Fargion and Charles R. McClain, Editors

remote sensing

MDPI

Review

A Rev
Meas
Valid
over

Kevin G.
Alexandre
B. Carol J
and Riho

remote sensing

MDPI

Review

A Review of Protocols for Fiducial Reference
Meas
Valid
over W

Kevin G. R
Alex Giler
Michael O

CCG

IOCCG Protocol Series

Ocean Optics & Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation

Volume 3: Protocols for Satellite Ocean Colour Data Validation: In Situ Optical Radiometry (v3.0)

Authors
Giuseppe Zibordi, Kenneth J. Voss, B. Carol Johnson and James L. Mueller

Fiducial Reference Measurements for Satellite Ocean Colour Phase-2

Measurement Procedure Document (MPROCD)

FRM

Fiducial Reference Measurements for Satellite Ocean Colour Phase-2

Title	
Docun	
Projec	Protocols for uncertainty budget calculation of
Contra	FRMOCnet OCR and practical guide for OCR
Delive	measuren
Versio	(FRM4SC
Date is	

Fiducial Reference Measurements for Satellite Ocean Colour Phase-2

Title	
Document ref	
Project	
Contract	Reflectance Measurement Requirements Document (RMRD)
Deliverable	
Version	
Date issued	FRM4SOC2-RMRD

Title	Specifications of minimum requirements for qualification of individual OCRs and their measurements as FRM and process for inclusion of any new instrument models and measurements in the FRMOCnet (RMRD)
Document reference	FRM4SOC2-RMRD
Project	EUMETSAT – FRM4SOC Phase-2
Contract	EUMETSAT Contract No. EUM/CO/21/460002539/JIG
Deliverable	D-2 Reflectance Measurement Requirements Document (RMRD)
Version	v1.2
Date issued	02.11.2022

HyperCP History

2017

PySciDon

Vandenberg Masters Thesis w/ M. Costa U. Victoria

1

2018

2

Initiated at NASA Goddard to incorporate IOCCG draft protocols and other advancements in AWR

2019

3

α release

Internal alpha version shared at NASA

2020

OSM2020

4

β release

Transition from internal NASA testing to invited external release

2021

NASA/FRM4SOC Meeting

6

Discussed collaboration on HyperInSPACE to form a community processor compliant with FRM framework

5

NASA GitHub

Official NASA public release v1.0.x

https://github.com/nasa/HyperInSPACE

2022

HyperCP for FICE-2022

Identified for use in Field Intercomparison Experiment at AAOT

8

7

v1.1.x release

Structural overhaul to accommodate incoming updates from FRM4SOC:

To add TriOS
To add full instrument characterization and uncertainties

2023

9

HyperCP Project Team Formed

Official collaboration guidelines adopted

v1.2.x release

FRM4SOC2 Updates incorporated:

TriOS
Full instrument characterization and uncertainties

10

2024

FICE-2024

Training event for ocean colour above-water radiometry at AAOT

4

HyperCP

Why HyperCP?

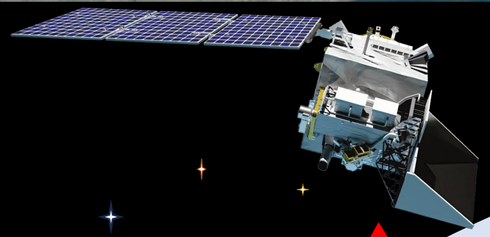
Informed by scientific consensus (protocol driven)
Open Source (transparent)
Open Science (accessible)
Collaborative
Adaptive
Community resource

By the community for the community

Above Water Radiometry (AWR)

Principles and Theory

In Situ Above Water Radiometry (AWR)



Validation

Zenith

L_{cloud}

L_{sky} = Rayleigh + Aerosols

Surface Irradiance (E_s)

Total Radiance (L_t)

θ'_v

L_{glint}

L_{water}

Sea Surface

Zenith

θ_s

North

φ_s

φ_v

Carbon exchange

Algorithm Development

Carbon sinking to the deep ocean

L_{water} contains water quality information:

Inherent Optical Properties
Phytoplankton Pigments and Abundance
Suspended Sediments
Dissolved and Particulate Carbon

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(Cytometry images from Karlusich et al., Front. Mar. Sci., 2002)

HyperCP Ecosystem

Supported Sensors:

- Sea-Bird Scientific HyperOCR
- TriOS RAMSES

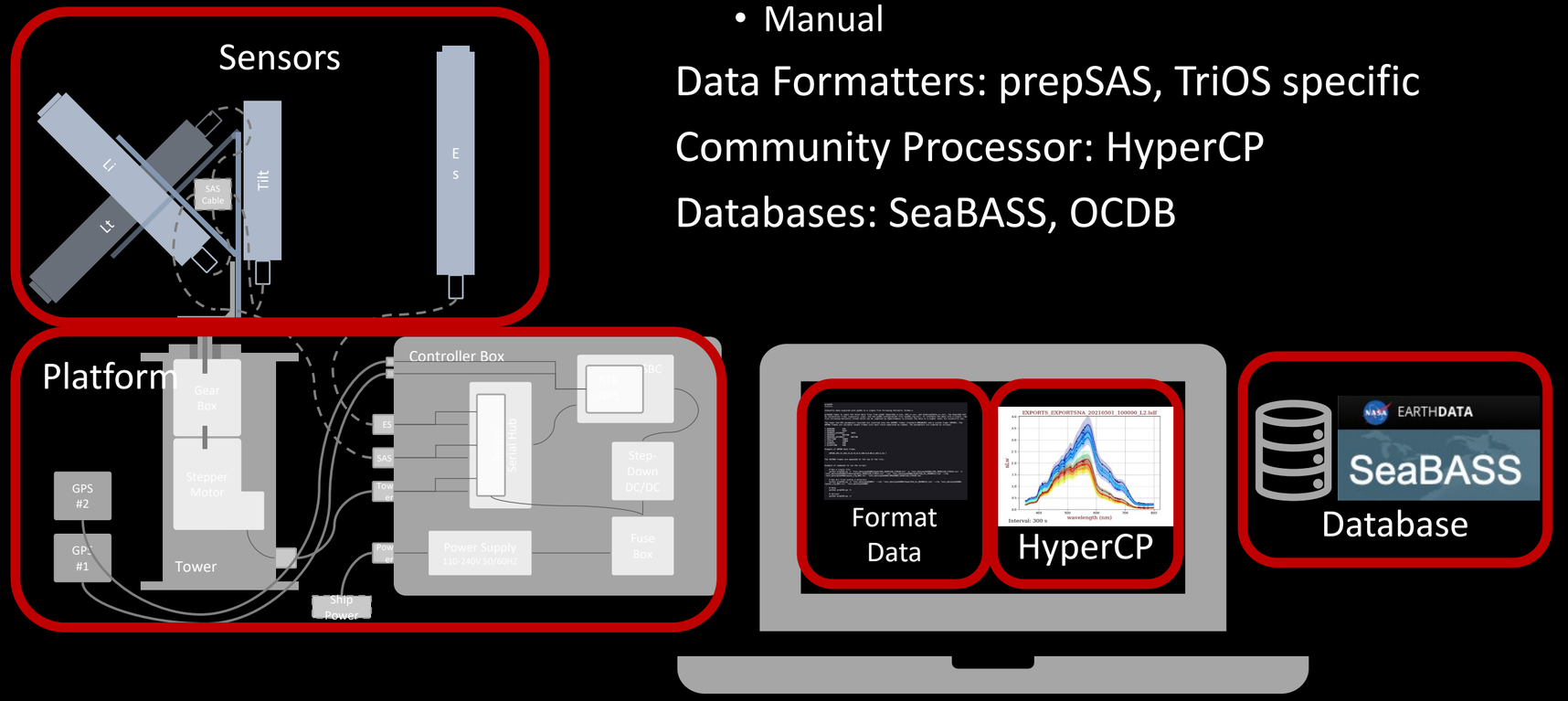
Platforms:

- Robotic: pySAS, Sea-Bird SolarTracker, Panthyr, So-Rad, …
- Manual

Data Formatters: prepSAS, TriOS specific

Community Processor: HyperCP

Databases: SeaBASS, OCDB



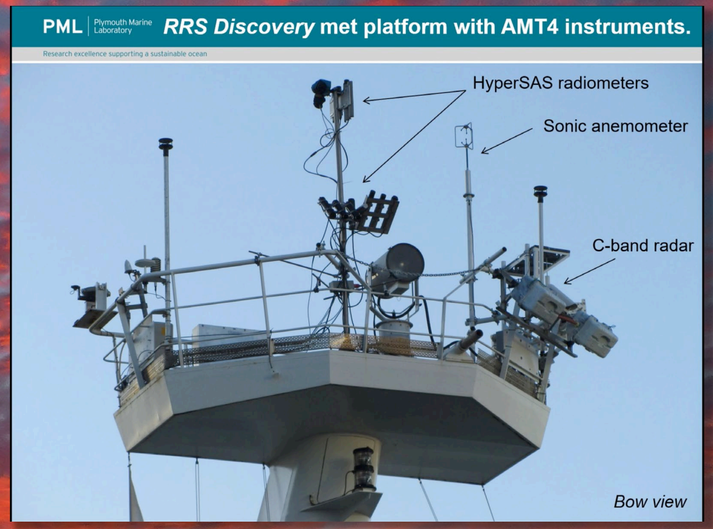
Manual Systems

pySAS

PANTHYR*

SoRad*

Manual Systems



pySAS

SolarTracker

*not currently adapted within HyperCP

SolarTracker

Water Leaving Radiance

Sea surface reflectance factor Skylight radiance

$$L_w(\theta_v, \varphi_v, \lambda) = L_t(\theta_v, \varphi_v, \lambda) - \rho(\theta_s, \varphi_s, \theta_v, \varphi_v, \lambda, \mathrm{W}, \tau, \mathrm{T}, \mathrm{S}) * L_i(\theta_v, \varphi_v, \lambda)$$

Total upwelling radiance

$$= L_t(\theta_v, \varphi_v, \lambda) - L_r(\theta_s, \varphi_s, \theta_v, \varphi_v, \lambda, \mathrm{W}, \tau, \mathrm{T}, \mathrm{S})$$

Remote Sensing Reflectance

$$R_{rs} = \frac{L_w(\theta_v, \varphi_v, \lambda)}{E_s(\lambda)}$$

Sea surface irradiance

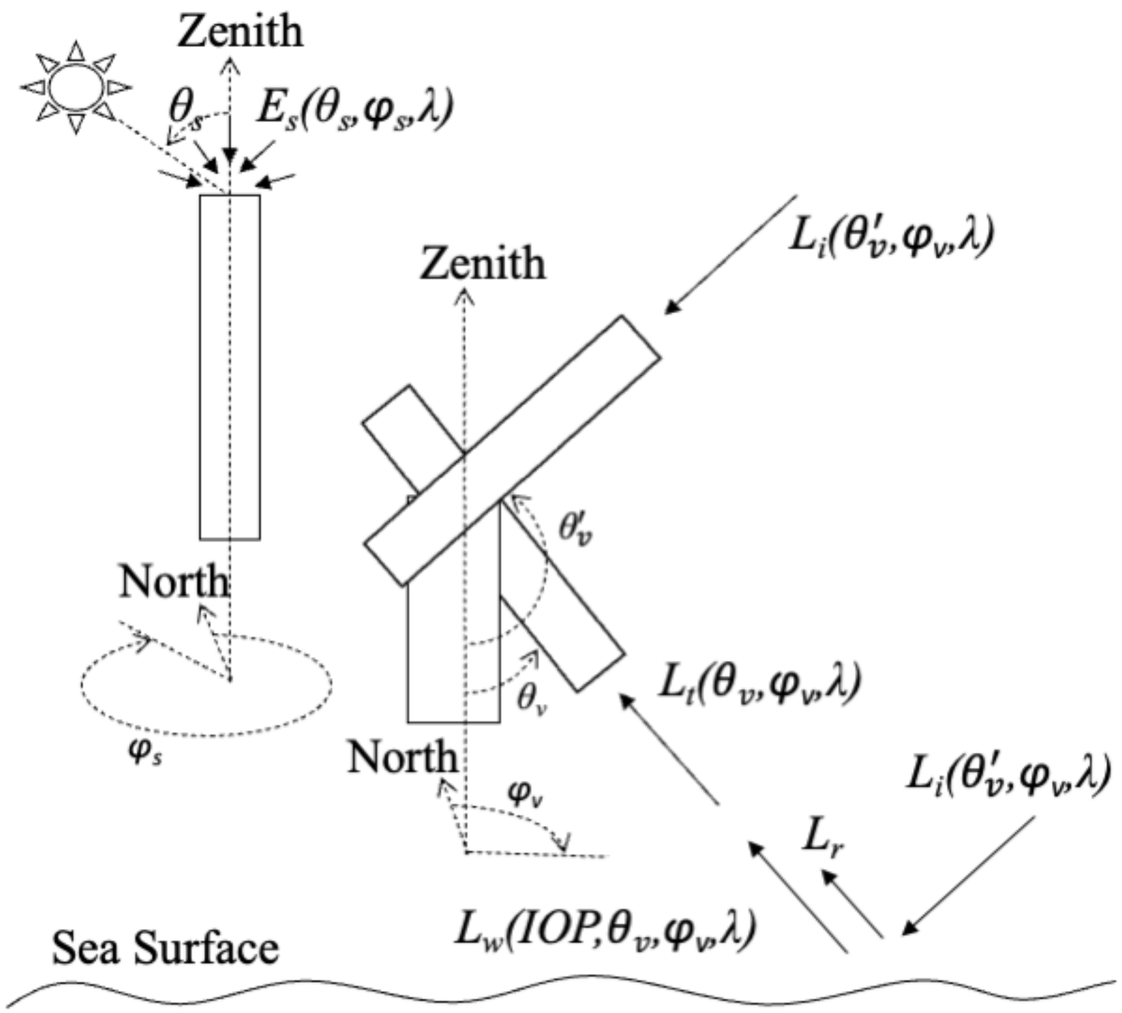
Normalized Water Leaving Radiance

$$nL_w = R_{rs} * F0,$$

TOA irradiance

Exact Normalized Water Leaving Radiance

Corrected for BRDF nL_w^{ex}.
(adjusted to $\boldsymbol{\theta}_s = 0$, $\boldsymbol{\theta}_v = 0$)



Primary Challenges

Sea surface glint, platform perturbations, solar/sensor geometries, the environment, metrology, and traceability

Sun/Sky Glint Subtraction

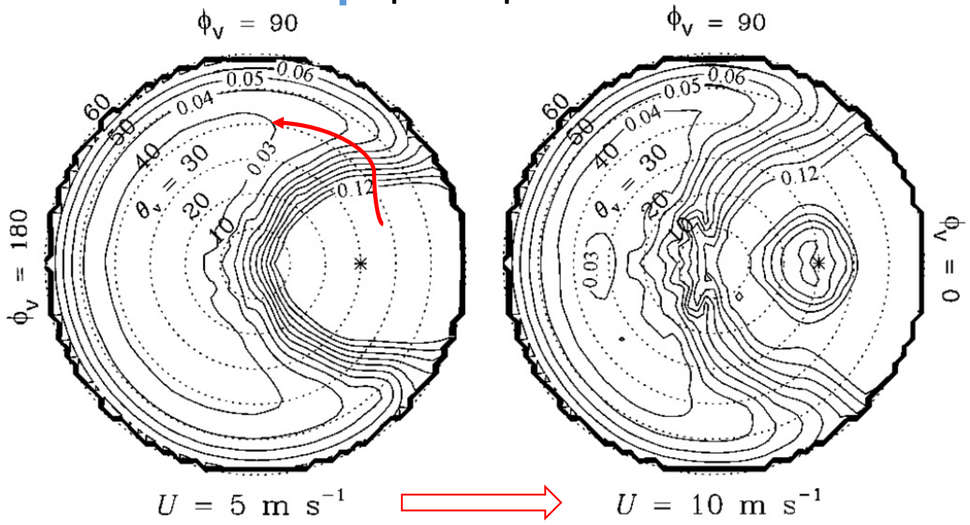
$$L_w(\theta_v, \varphi_v, \lambda) = L_t(\theta_v, \varphi_v, \lambda) - \rho(\theta_s, \varphi_s, \theta_v, \varphi_v, \lambda, \mathrm{W}, \tau, \mathrm{T}, \mathrm{S}) * L_i(\theta_v, \varphi_v, \lambda)$$

ρ: Sea surface reflectance factor

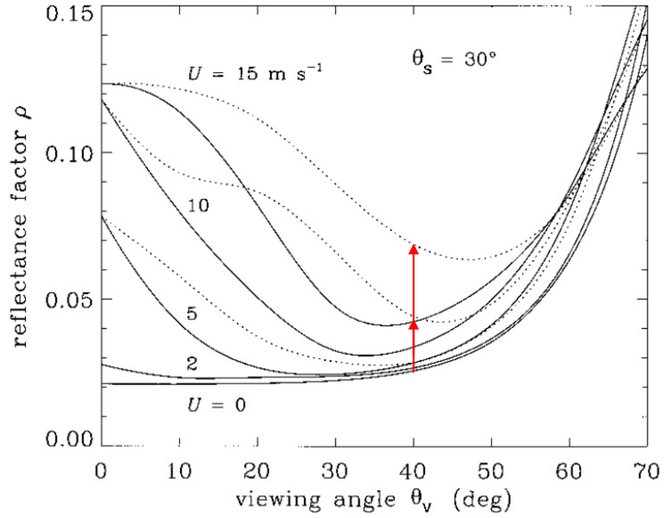
- $\boldsymbol{\theta_s}$: Solar Zenith Angle
- $\boldsymbol{\varphi_s}$: Relative Azimuth Angle
- **W**: Wind speed (Cox & Munk 1954)
- τ: Aerosol optical thickness
- **T**: Temperature
- **S**: Salinity

ρ is also slightly dependent on skylight polarization.
ρ is most dominated by $\boldsymbol{\varphi_s}$, peaking at the specular point of the sun.
ρ is optimal (low) at $\boldsymbol{\varphi_s}$ in 90° – 135°.
However at $\boldsymbol{\varphi_s}$ = 135° superstructure perturbation is typically increased.

ρ: polar plots



High values of **ρ** affecting more viewing geometries as surface becomes rougher



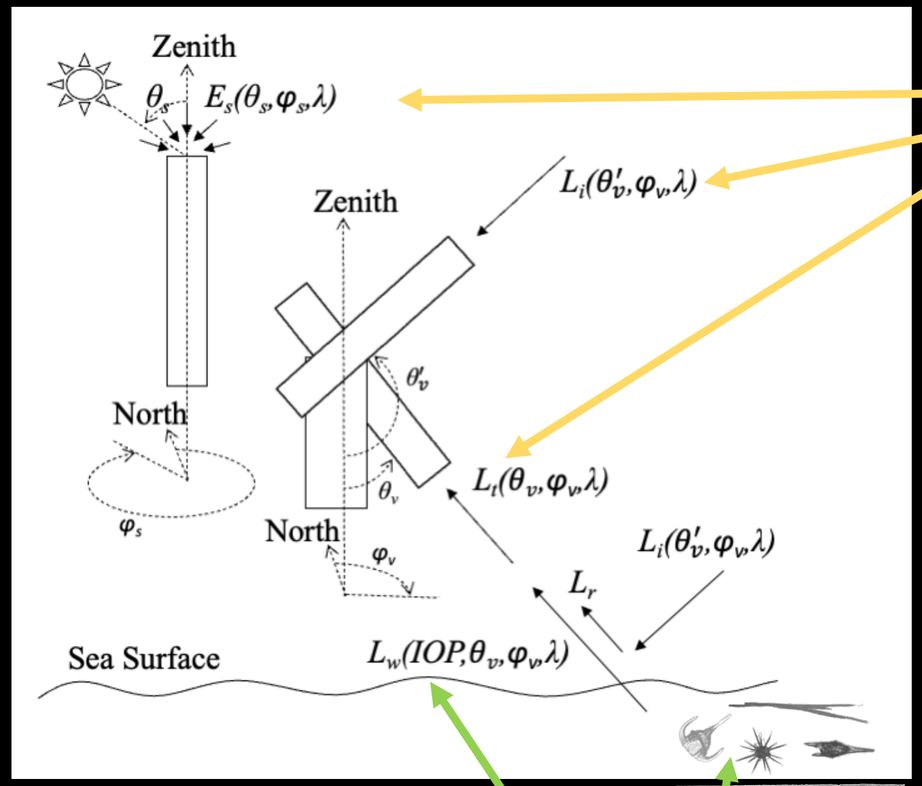
Solid lines are $\boldsymbol{\varphi_s}$ for 135°, dashed for 90°.

Figures adapted from Mobley 1999, Applied Optics

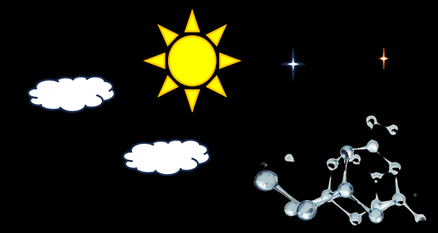
ρ: revisited by Mobley on 2015
Zibordi et al. 2016: Old (1999) values are still preferable

Azimuth and zenith/tilt must be carefully tracked in the field for **ρ**, but also because cosine collectors for downwelling irradiance are very sensitive to tilt.

Above Water Radiometry (AWR)



What we measure



Validation quality AWR requires good conditions (wind, sky, sea-surface, *tilt*, etc., refer to IOCCG Protocols)

Correcting AWR for surface reflectance of sun/sky (glint) is a challenge even in the best conditions. HyperCP can adjust the glint correction for solar/sensor geometries and optical water types. It has multiple options for glint, glitter and NIR residual corrections, and a long list of QC filters.

Sea surface reflectance factor

Skylight radiance

$$L_w(\theta_v,\varphi_v,\lambda) = L_t(\theta_v,\varphi_v,\lambda) - \rho(\theta_s,\varphi_s,\theta_v,\varphi_v,\lambda,\mathrm{W},\tau,\mathrm{T},\mathrm{S}) * L_i(\theta_v,\varphi_v,\lambda)$$

Total upwelling radiance

What we're after

$$R_{rs} = \frac{L_w(\theta_v,\varphi_v,\lambda)}{E_s(\lambda)}$$

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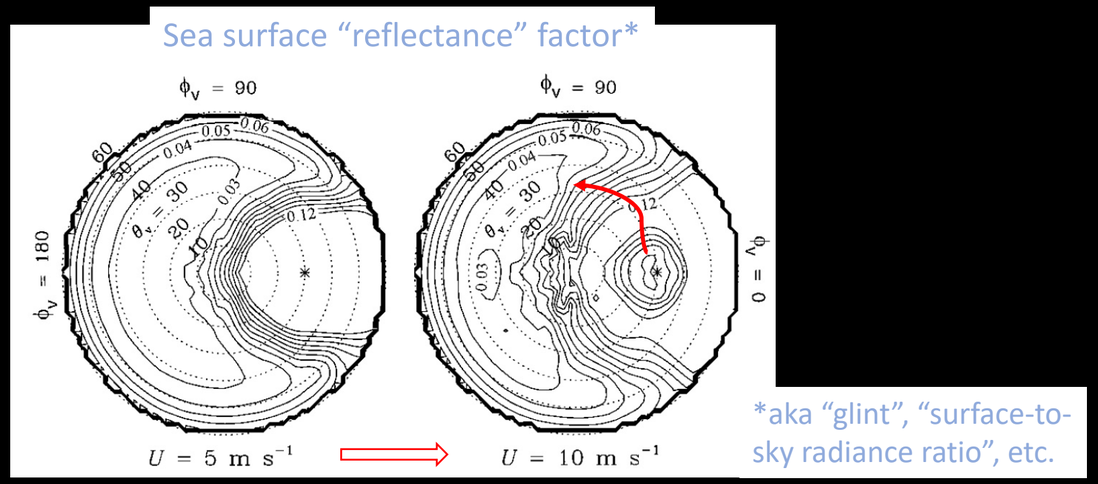
Above Water Radiometry (AWR)



High values of ρ (contours above) affecting more viewing geometries as surface becomes rougher

Validation quality AWR requires good conditions (wind, sky, sea-surface, *tilt*, etc., refer to IOCCG Protocols)

Correcting AWR for surface reflectance of sun/sky (glint) is a challenge even in the best conditions. HyperCP can adjust the glint correction for solar/sensor geometries and optical water types. It has multiple options for glint, glitter and NIR residual corrections, and a long list of QC filters.

HyperCP

L2 Sky/Sunglint Correction (ρ)

- (•) Mobley (1999) ρ
- ( ) Zhang et al. (2017) ρ
- ( ) Groetsch et al. (2017)
- ( ) Your Glint (2023) ρ

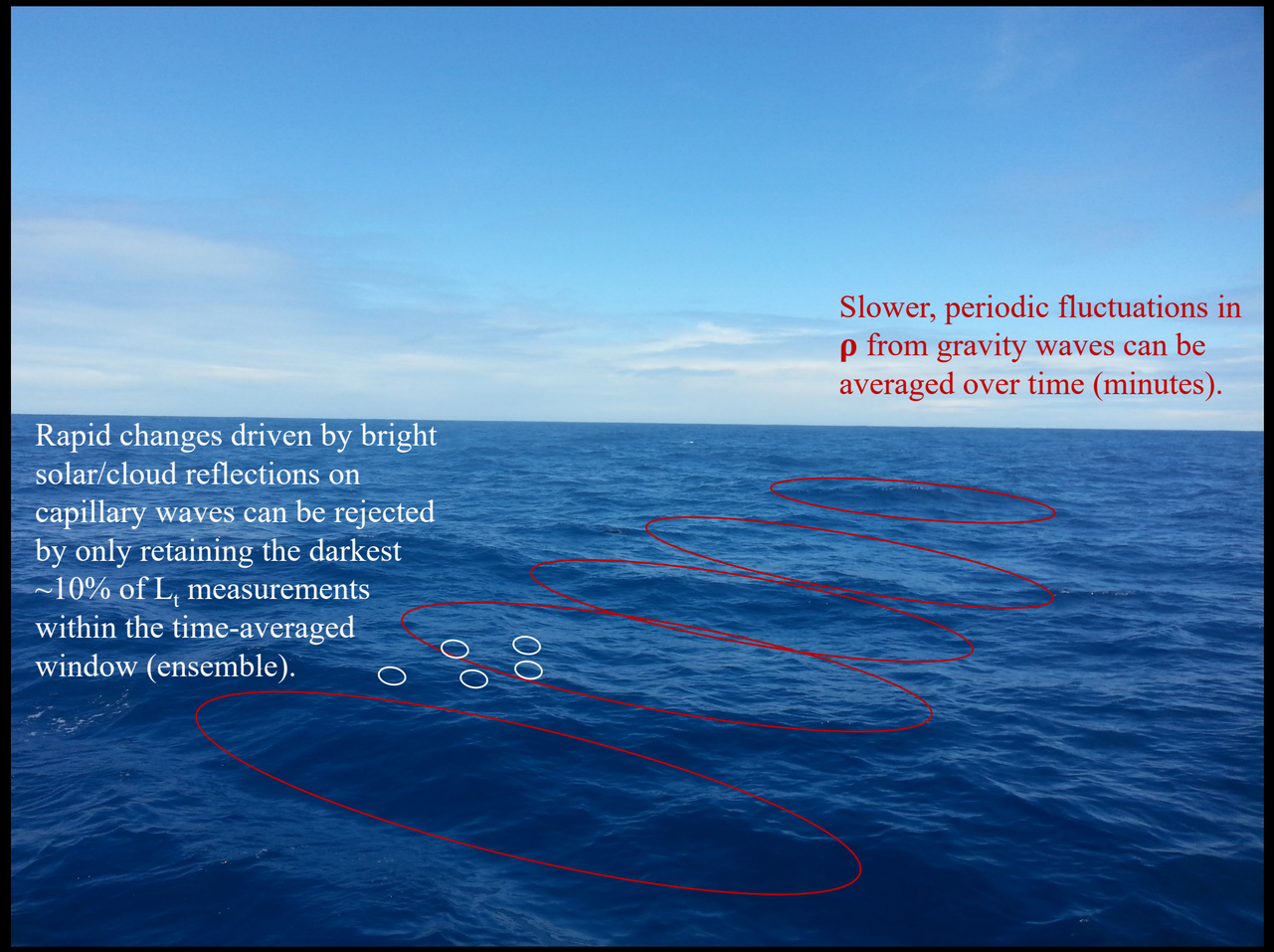
NIR Residual Correction [✓]

- ( ) Mueller and Austin (1995) (blue water)
- (•) SimSpec. Ruddick et al. (2006) (turbid)
- ( ) Your NIR Residual (2023) (universal)

Remove Negative Spectra [✓]

Tilt!

The Challenge of Surface Reflection (Glint)



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Platform Perturbations

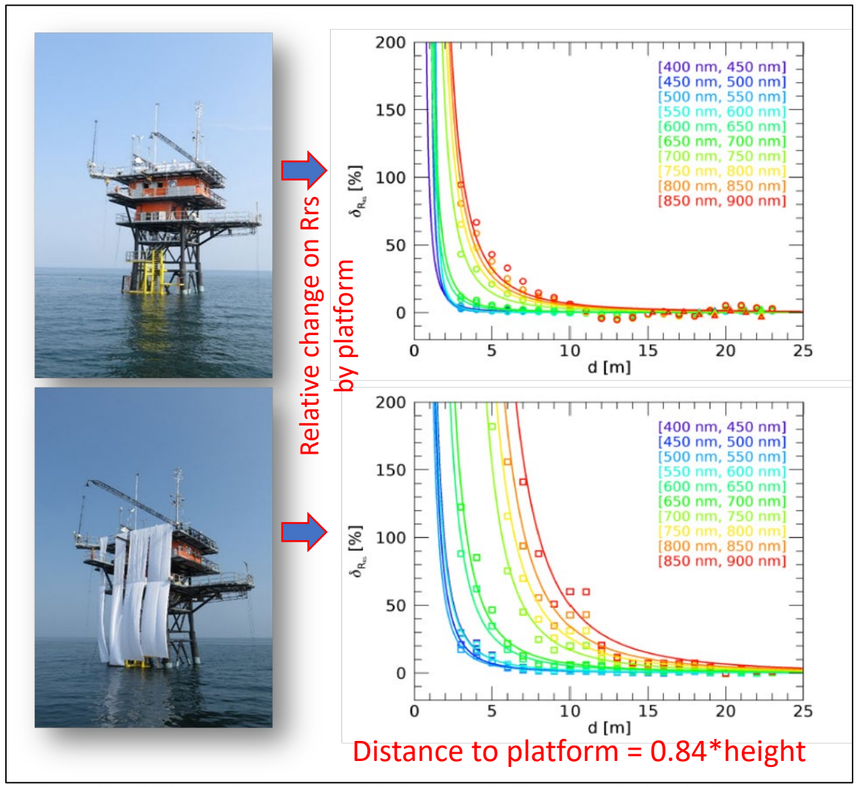
Shadows and platform reflectance

- ρ is minimum at φ_s =180° away from Sun.
- However, φ_s =180° is generally affected by platform shadow
- φ_s=135° is generally outside of the platform shadow.
- However, φ_s =135° still typically affected by platform reflectance (especially if highly reflective)

∴ The compromise φ_s should be between 90° and 135°.

<u>If appropriate φ_s are not maintained and recorded, AWR is effectively useless due to the lack of an accurate glint correction.</u>

ρ: Sea surface reflectance factor
φ_s: Sun-sensor (Li, Lt) relative azimuth



Talone, Zibordi, "Spectral assessment of deployment platform perturbations in above-water radiometry," Opt. Express 27, A878-A889 (2019)

Calibration/Characterization Uncertainty

Overview

Calibration

Additional factors impacting quality and uncertainty of in situ AWR

Absolute calibration

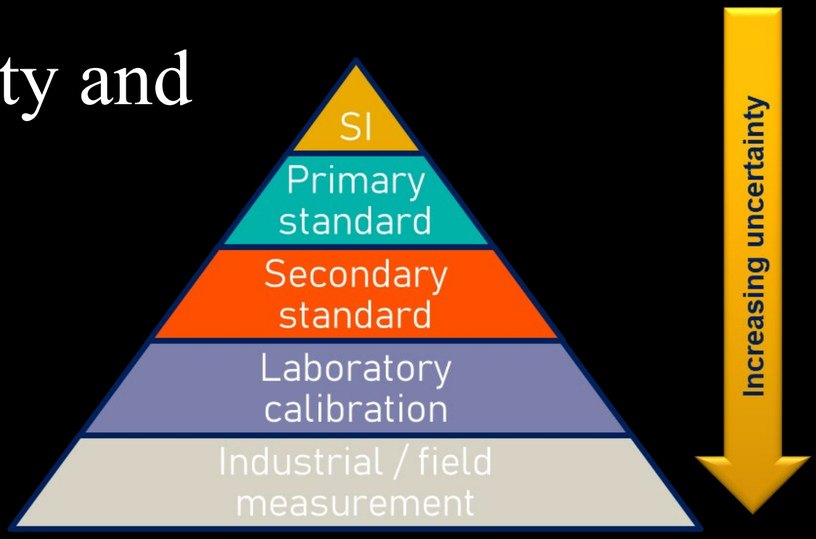
Calibration coefficient

$$\Im(\lambda) = C_{\Im}(\lambda)\,\aleph(\lambda)\,DN(\Im(\lambda))$$

Digital numbers

(Ir)radiance in physical units

Deviations from instrument's expected ideal performance



Calibration of irradiance

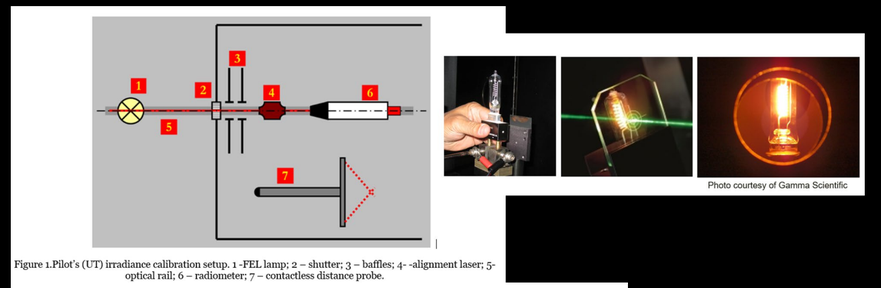


Figure 1.Pilot's (UT) irradiance calibration setup. 1 -FEL lamp; 2 – shutter; 3 – baffles; 4- -alignment laser; 5- optical rail; 6 – radiometer; 7 – contactless distance probe.

Calibration of radiance

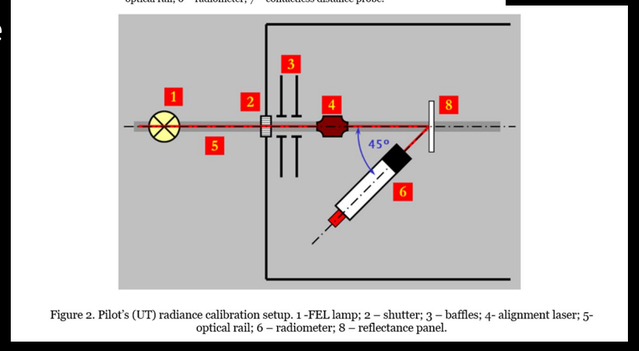


Figure 2. Pilot's (UT) radiance calibration setup. 1 -FEL lamp; 2 – shutter; 3 – baffles; 4- alignment laser; 5- optical rail; 6 – radiometer; 8 – reflectance panel.

Calibration Uncertainty

Additional factors impacting quality and uncertainty of in situ AWR

Absolute calibration

Calibration coefficient

$$\Im(\lambda) = C_{\Im}(\lambda)\,\aleph(\lambda)\,DN(\Im(\lambda))$$

Digital numbers

(Ir)radiance in physical units

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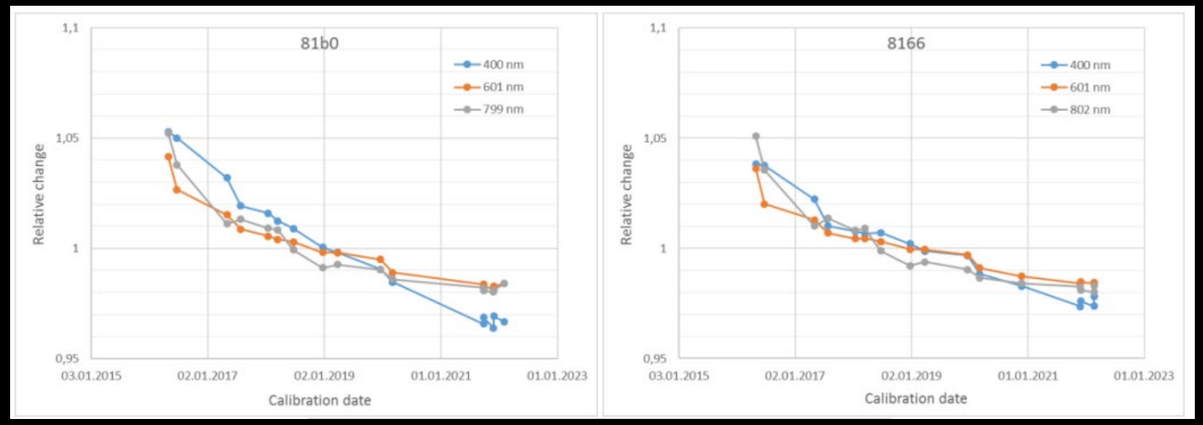

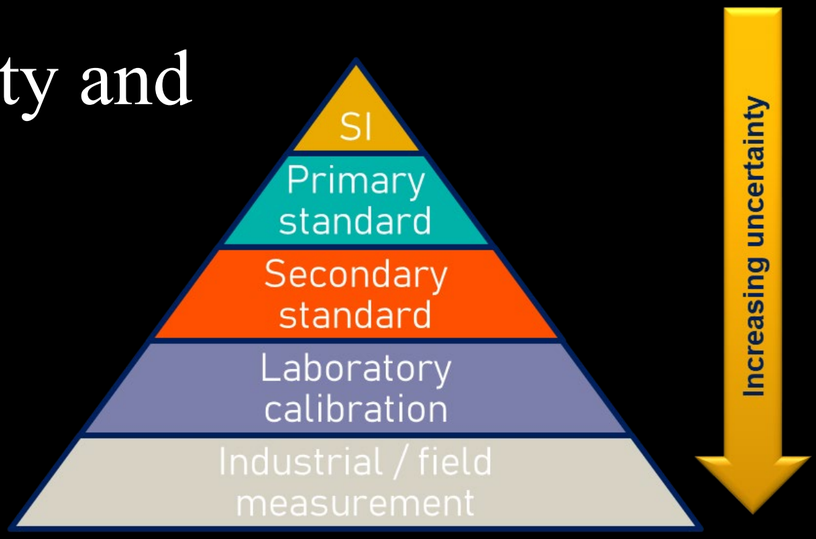

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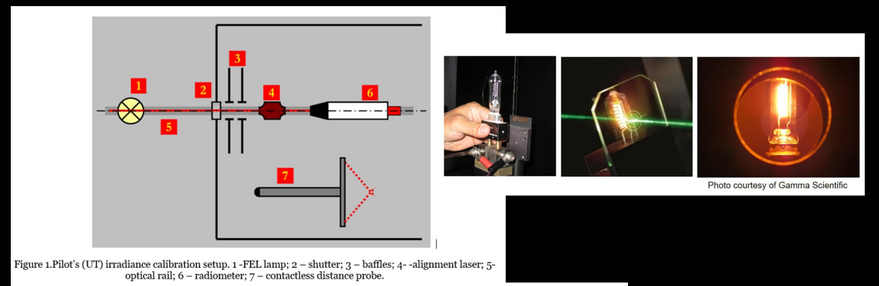

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Calibration of radiance

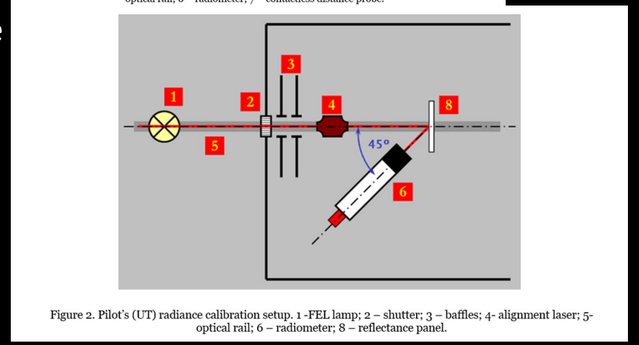


Figure 2. Pilot's (UT) radiance calibration setup. 1 -FEL lamp; 2 – shutter; 3 – baffles; 4- alignment laser; 5- optical rail; 6 – radiometer; 8 – reflectance panel.

Characterization and Uncertainty

Absolute calibration

(Ir)radiance in physical units

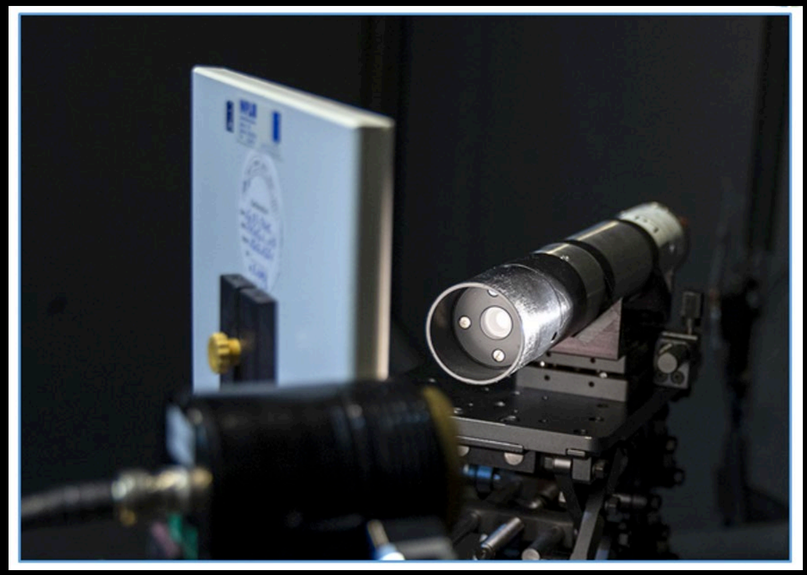
Calibration coefficient

$$\Im(\lambda) = C_{\Im}(\lambda)\,\aleph(\lambda)\,DN(\Im(\lambda))$$

Digital numbers

deviations from instrument's expected ideal performance

- Dark current noise
- Linearity of response
- Calibration/stability
- Straylight response
- Angularity of response
- Thermal response
- Polarization response



Characterization, complementary to absolute radiometric calibration, is the determination of the distinctive features of an instrument allowing us to account for these deviations....

Calibration/Characterization Uncertainty

Regimes Applied in HyperCP v1.2+

Instrument Characterization

Some factors impacting quality and uncertainty of the AWR collected in situ

Cloud cover (record it, at least on station)
Instrument fouling/obstruction (avoid it)
Instrument response/characterization

*

- Dark current noise
- Linearity of response
- Calibration/stability
- Straylight response
- Angularity of response
- Thermal response
- Polarization response

Dark frame subtraction/ correction
Deglitching (L1AQC)

Linearity correction
Calibration correction
Straylight correction
Cosine correction (Es)
Thermal correction

Uncertainty associated with these characterizations can be modeled using Monte Carlo simulations, and added to the reported products

Laboratory measurements can characterize these for **specific instruments** and **classes of instruments**.

Corrections further reduce uncertainty

* Requirements of the Ocean Optics & Biogeochemical Protocols for Satellite Ocean Colour Sensor Validation (IOCCG, 2019)

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Instrument Characterization in v1.2

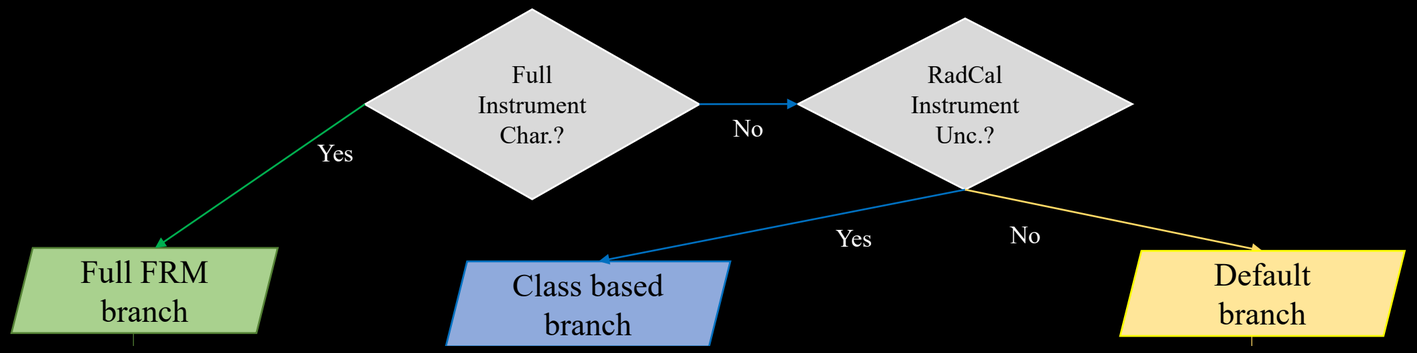
Instrument Characterization:

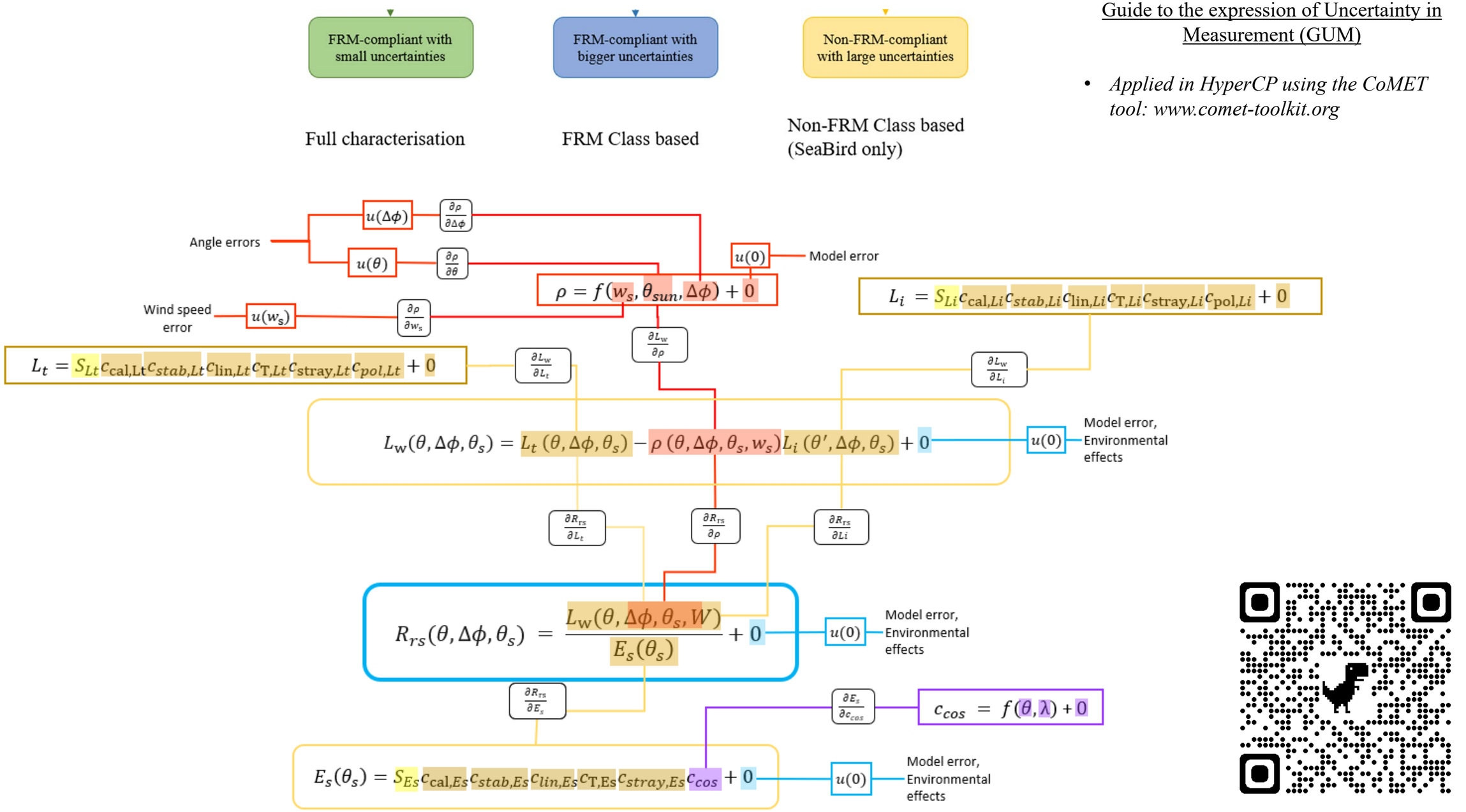
- Dark current noise
- Linearity of response
- Calibration/stability
- Straylight response
- Angularity of response
- Thermal response
- Polarization response

Instrument Classes:

Classes = Instruments:

- Sea-Bird HyperOCR
- TriOS RAMSES (added in v1.2)
- IMO DALEC (planned)



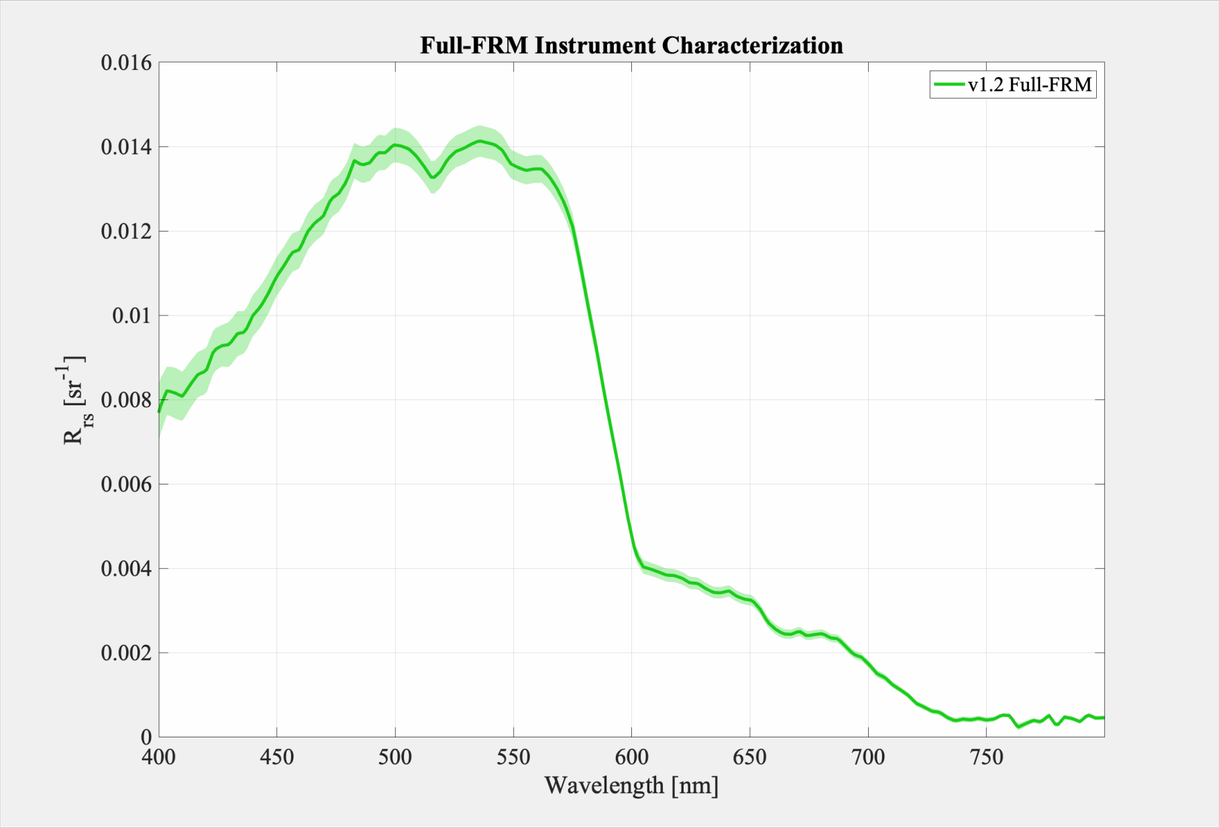


Guide to the expression of Uncertainty in Measurement (GUM)

- *Applied in HyperCP using the CoMET tool: www.comet-toolkit.org*

Aga Bialek, National Physical Laboratory, UK, et al.
Remote Sens. 2020, 12, 780; doi:10.3390/rs12050780

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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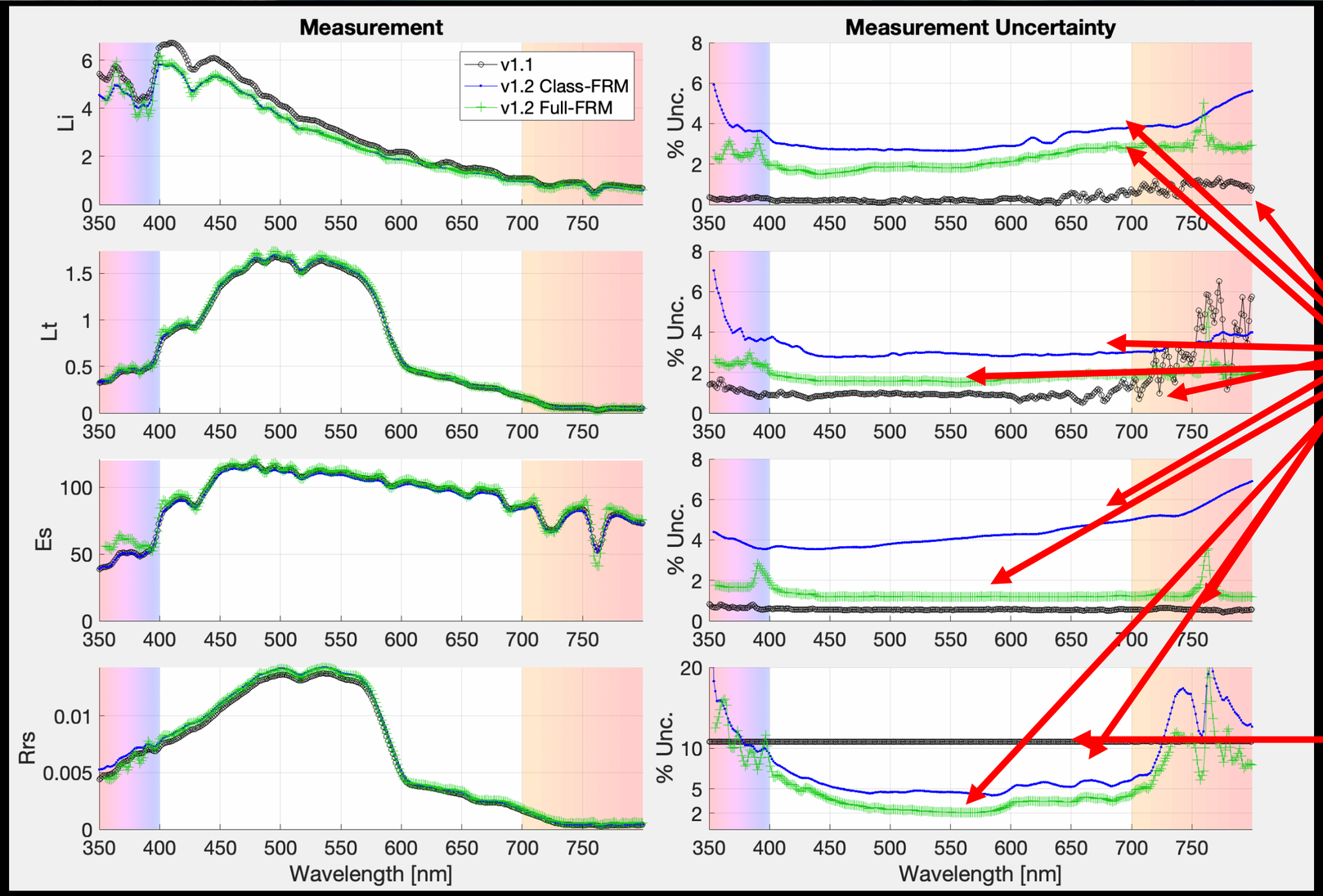
Improved Precision and Uncertainty Estimation



v1.2 Full-FRM: highest uncertainties; lack characterization; most accurate (and precise)

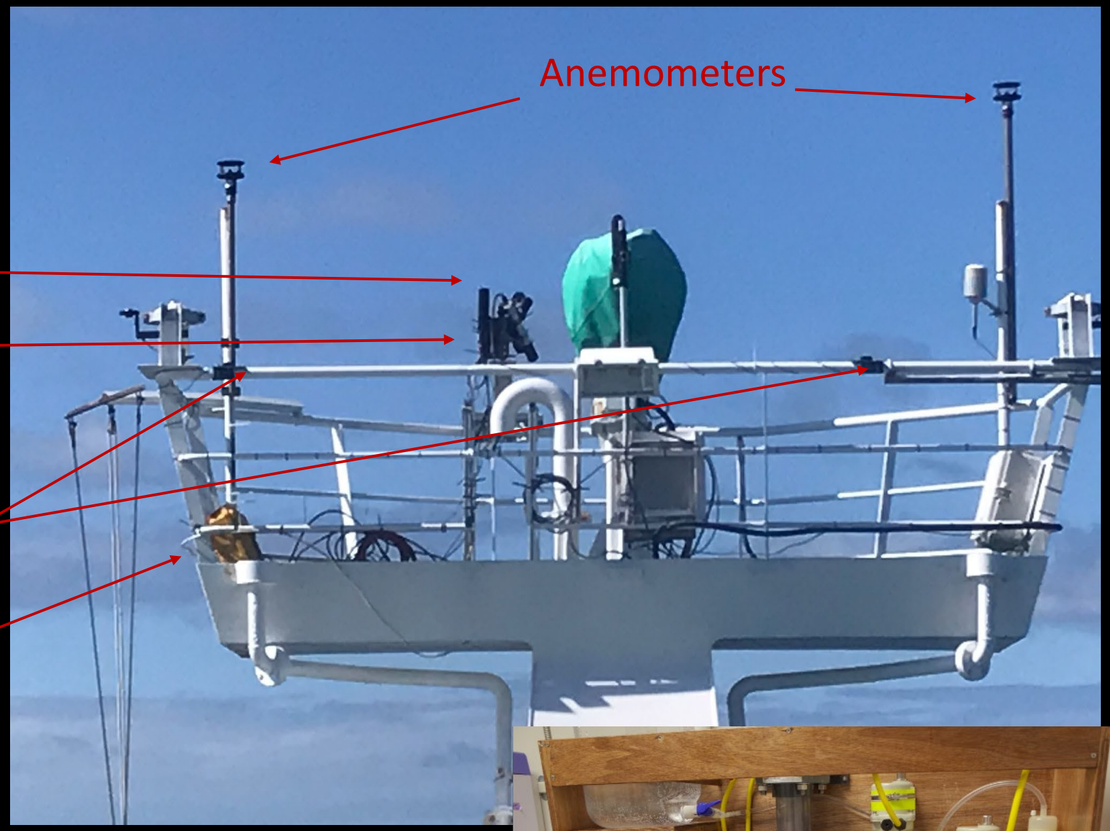
v1.2 Class-FRM: overestimates; lack characterization

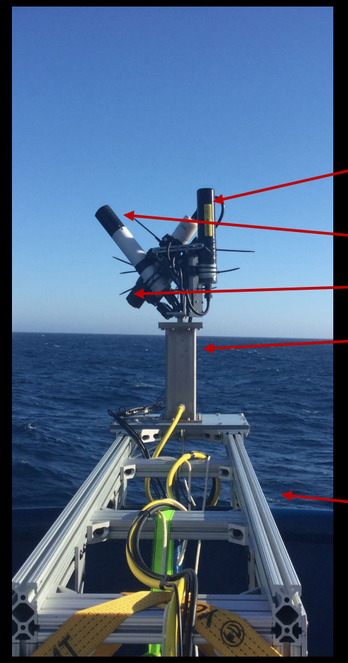
v1.1 overestimates; glint uncertainty poorly parameterized

AWR In the Field

Critical ancillary datasets

On a Ship





Flow-through system (SST, Salinity, chl_fl, IOPs, etc.)

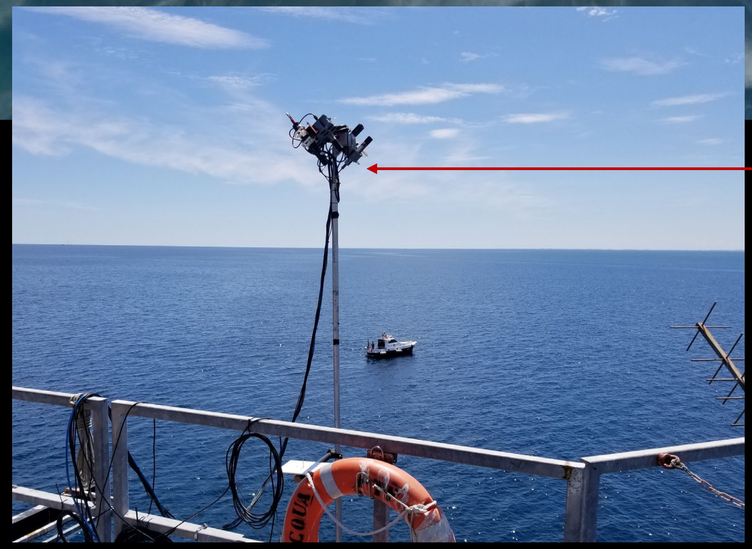
GODDARD EARTH SCIENCES

AAOT

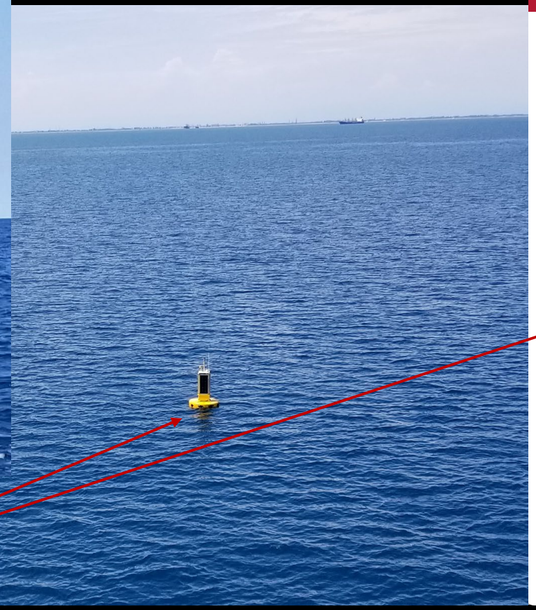
Anemometers

Es

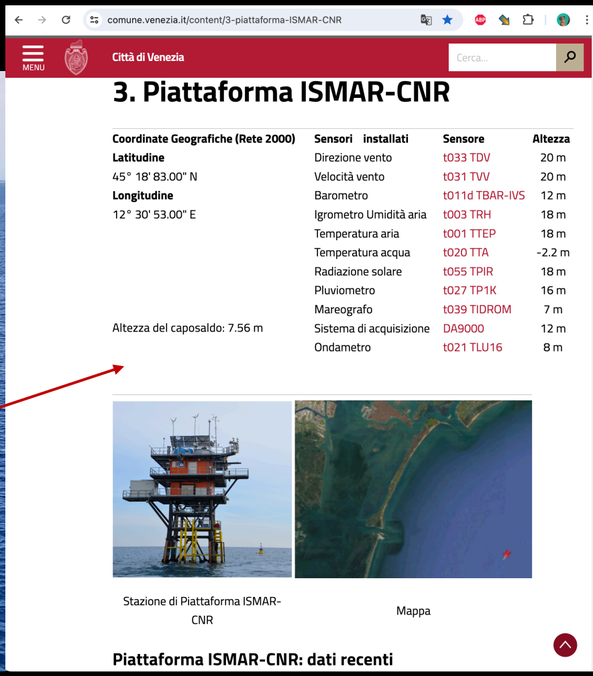
pySAS



Manually operated radiometers



Buoy data



https://www.comune.venezia.it/content/3-piattaforma-ISMAR-CNR

What is required from PIs?

(See the complete requirements at SeaBASS at QR Code above (https://seabass.gsfc.nasa.gov/wiki/data_submission_special_requirements) and refer to IOCCG Protocols)

Primary Requirements:

1. Sensor geometries (and how maintained)
   a. Sensor azimuth and/or relative azimuth (to sun)
   b. Sensor zenith angles
   c. Tilt (particularly for E_s)
2. Wind speed
3. Sky conditions (%cloud, fog, rain)

$$L_w(\theta_v, \varphi_v, \lambda) = L_t(\theta_v, \varphi_v, \lambda) - \rho(\theta_s, \varphi_s, \theta_v, \varphi_v, \lambda, \mathrm{W}, \tau, \mathrm{T}, \mathrm{S}) * L_i(\theta_v, \varphi_v, \lambda)$$

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What is required from PIs?

Secondary Requirements:

1. Aerosol Optical Depth
2. SST
3. Salinity

$$L_w(\theta_v, \varphi_v, \lambda) = L_t(\theta_v, \varphi_v, \lambda) - \rho(\theta_s, \varphi_s, \theta_v, \varphi_v, \lambda, \mathrm{W}, \tau, \mathrm{T}, \mathrm{S}) * L_i(\theta_v, \varphi_v, \lambda)$$

Wind, AOD, SST, and Sal fall back on models in HyperCP (MERRA-2, ECMWF)

What else helps identify validation-quality data?

Recommended Metadata:

1. Bottom depth
2. Ship speed (through the water)
3. Station ID (get your whole cruise team to agree if you can)
4. Wave height
5. Field note comments (e.g., heavy spray - lenses wiped @0800, bloom slick, crossing turbidity front @1210, etc.)

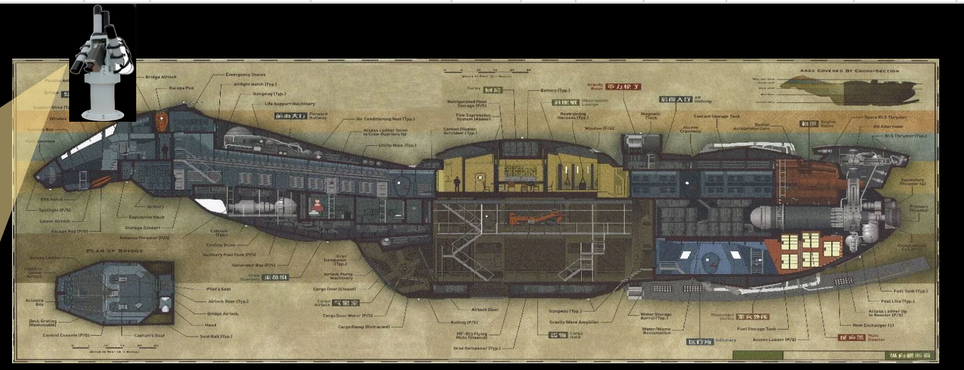
Field Log

AutoSave OFF — IOCCG_IOCS2023_pySAS_Radiometry_Field_Log — No Label

Home Insert Draw Page Layout Formulas Data Review View Automate Tell me — Comments Share

Experiment: FIREFLY02, Cruise: SEASON1, Platform: SERENITY, Operator: Hoban Waskburne. Home angle: 0, Min/Max Az: -20/+140, Height: 7m, Ship hull color: Silver.

station	raw filename	station start date/tim	station end date/tim	lat	lon	ship heading	ship speed	relative azimuth (ship-sensor)	relative azimuth (solar-sensor)	wind speed	wind dir	waves	salinity	sea surface temperature	cloud	bottom depth	comments
(name agreed across sampling platforms)	(not for pySAS when working properly, or if station number is in the name)	(UTC. Confirm all systms set to UTC)	(UTC)	(deg; 3-4 decimals)	(deg)	(deg)	(kts)	(above-water; only if set manually)	(above-water; only if set manually)	(m/s)	(deg)	(m)	(psu)	(deg C)	(% or x/8)	(m)	(haze, fog, rain, optically shallow/bottom reflection, other issues)
checkout	pySAS/prepSAS defaults hourly files	2023-11-12-T-1400	2023-11-12-T-1410	27.764	-82.636	N/A	0	N/A	N/A	5	45	0.5	32	25	25	8	System checked out without incident
1	"	2023-11-12-T-1430	2023-11-12-T-1500	27.764	-82.636		0	"	"	5	50	0.5	33	24	50	35	IOP cast and Hyperpro multicast
2		2023-11-12-T-1600	2023-11-12-T-1645	27.764	-82.636		0			7	55	0.8	32	25	50	10	Clean lenses, IOP and AOP casts



Submission of Field Log in supporting documents is *strongly* encouraged.
Download a template from HyperCP repository
https://github.com/nasa/HyperCP:

GODDARD EARTH SCIENCES

HyperCP

Intermission

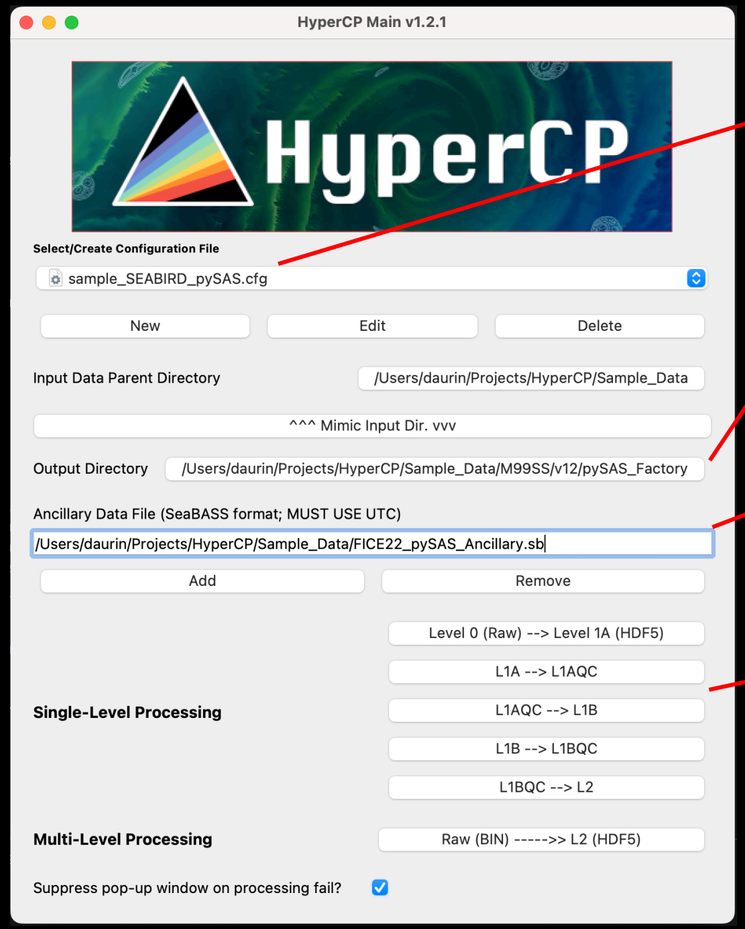
Caffè

HyperCP

Overview

Overview

GUI, or with configuration file on command line. Batch-able either way.

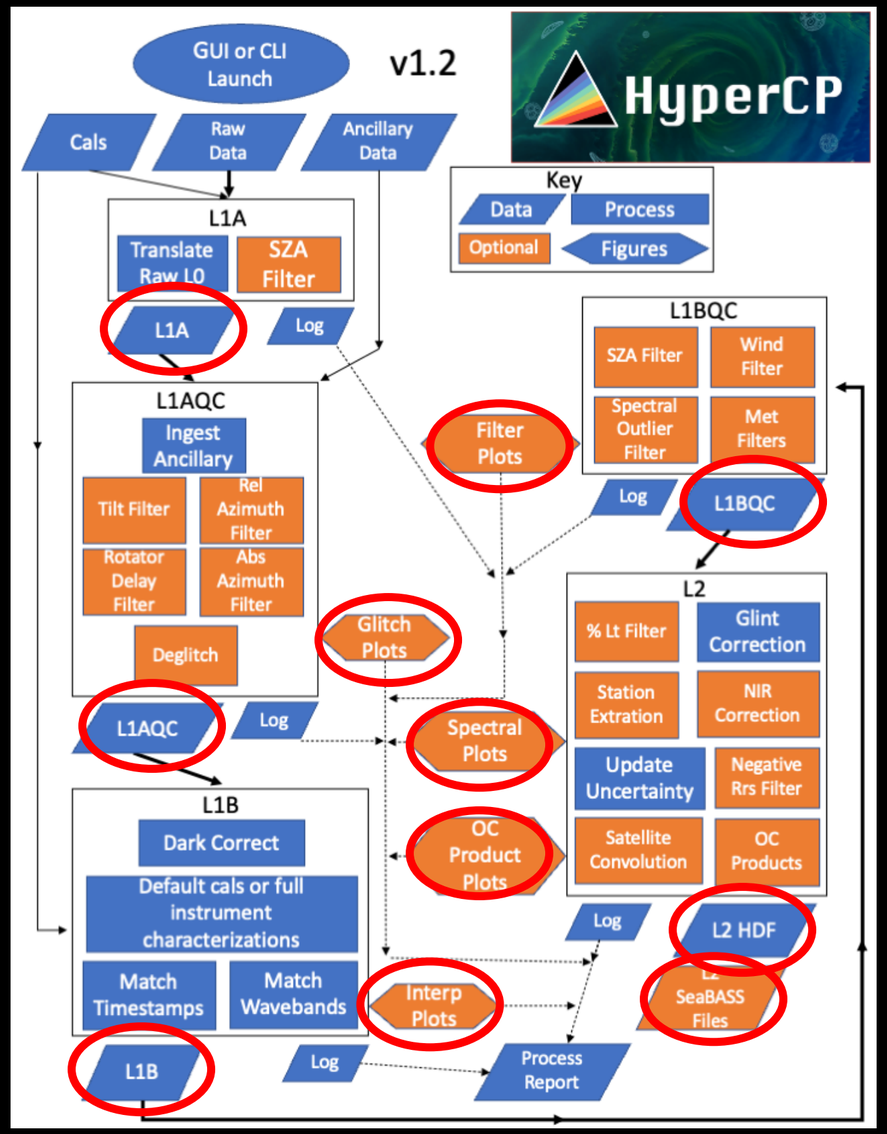


Each instrument deployment or cruise gets a unique configuration

Output directories are automatically created for each level of processing, as well as for Plots, Reports, and SeaBASS files

The Ancillary file for the entire deployment/cruise is provided here

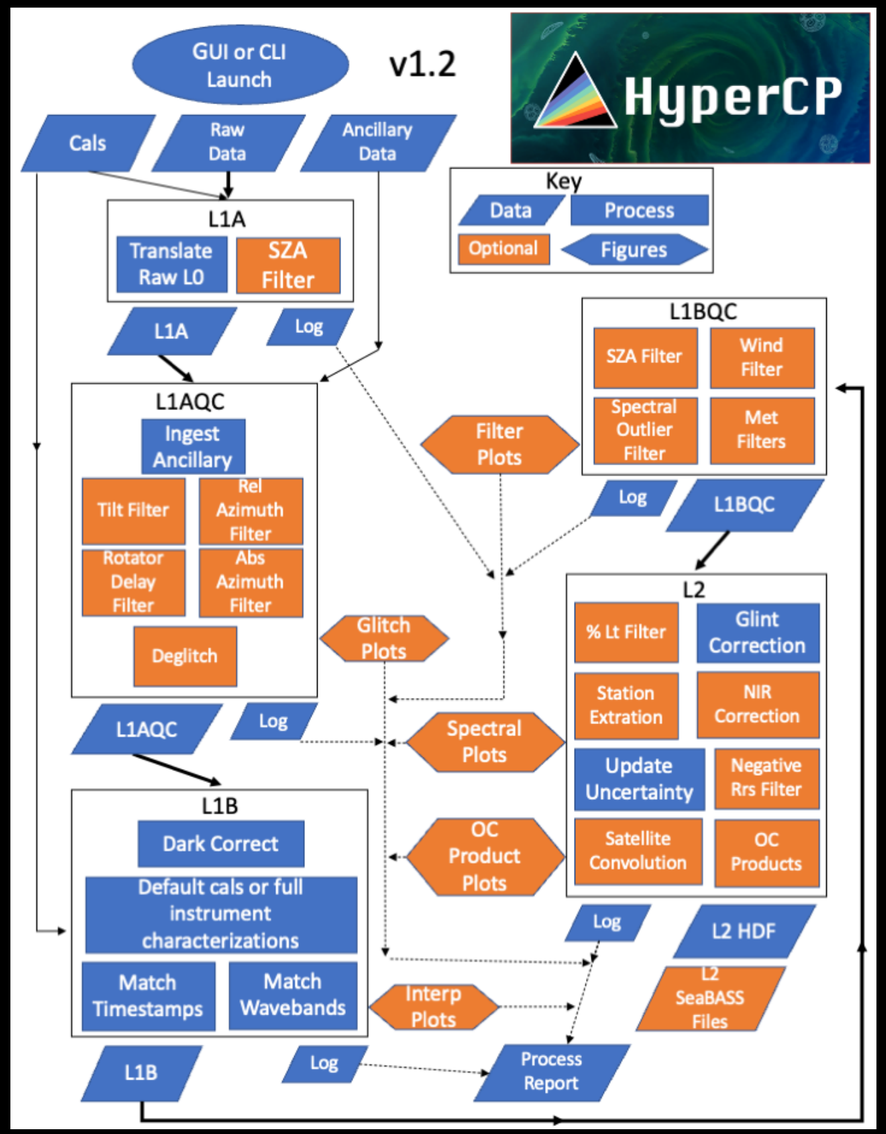
Processing can be run on one file or many files together, and can be run on one level or all levels together

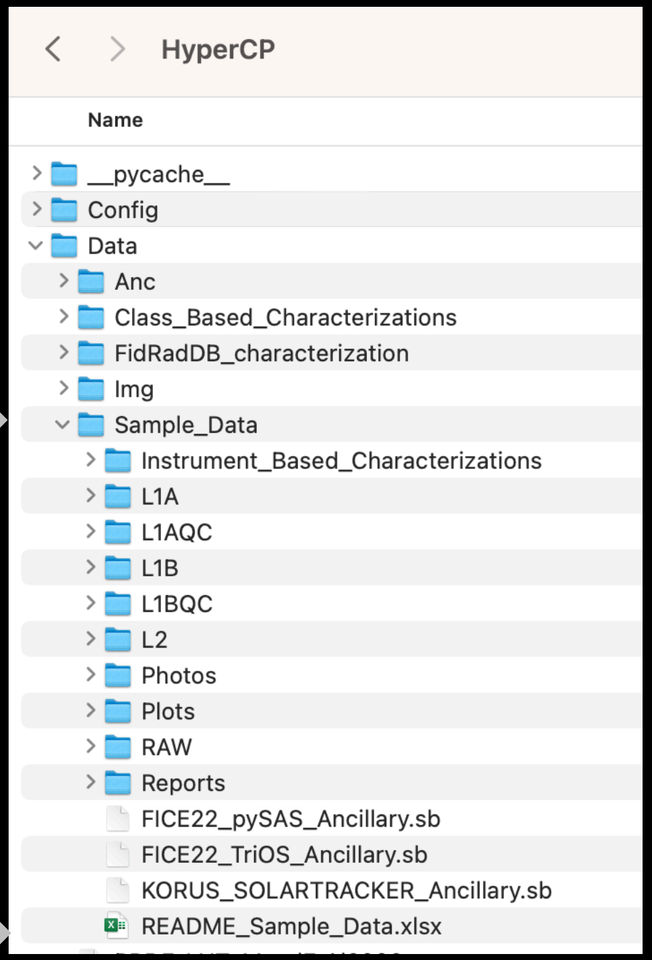


https://github.com/nasa/HyperCP

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

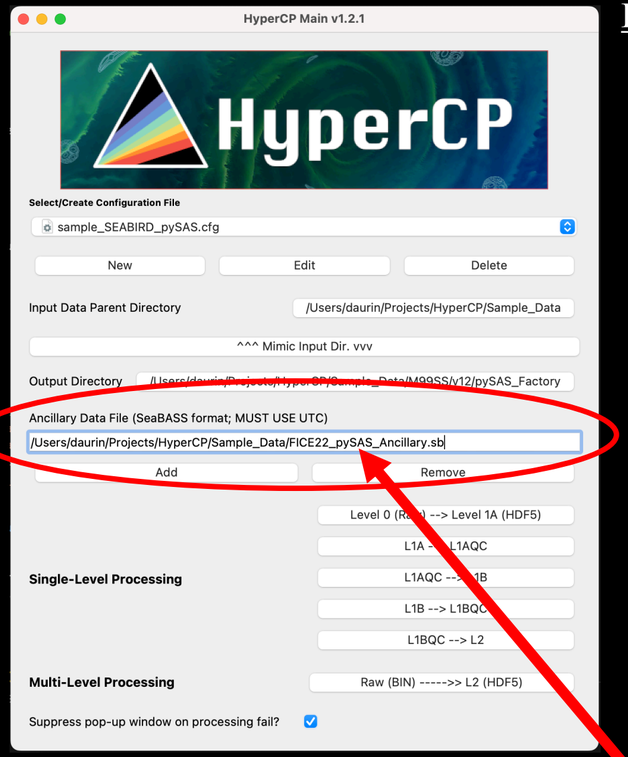
Directory Structure





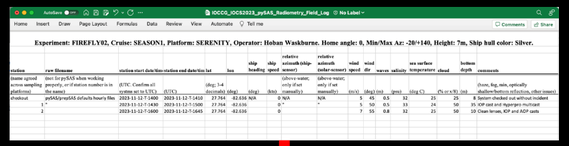
Guide to Sample Data:

Ancillary Data Inclusion/Submission

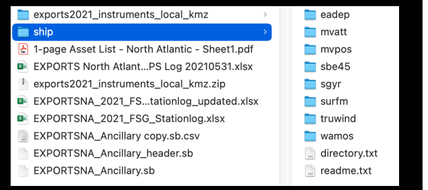


PIs are responsible for tracking and assimilating ancillary datasets.

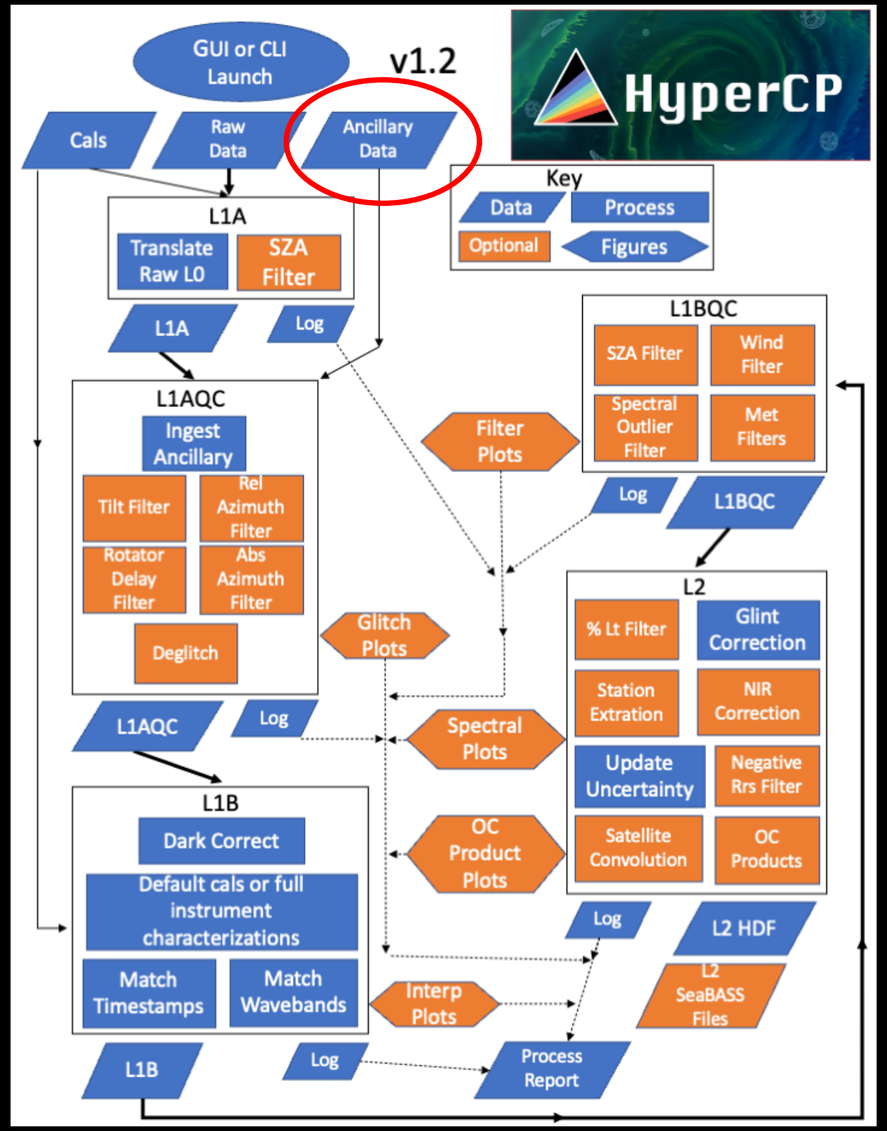
Field notes:



Ship data (meteorological, flow-through):



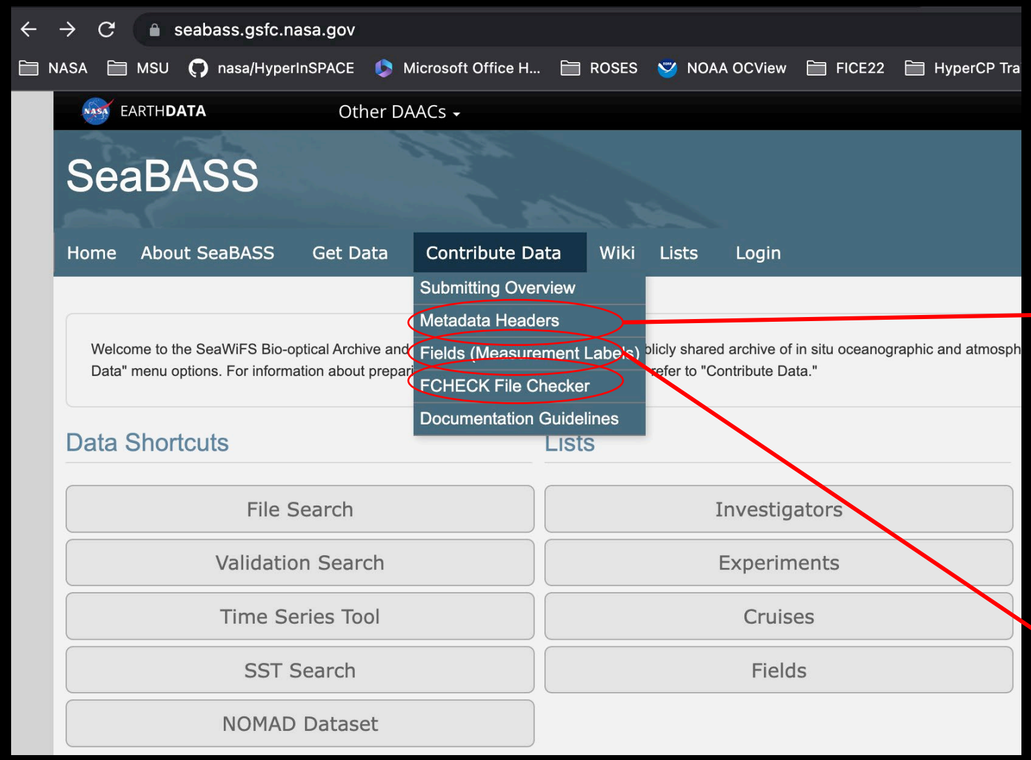
I recommend preparing these early and submitting them to SeaBASS supporting docs. *When you reach out to the team for support on running HyperCP, we will ask for it.*



SeaBASS Format (Ancillary Data)

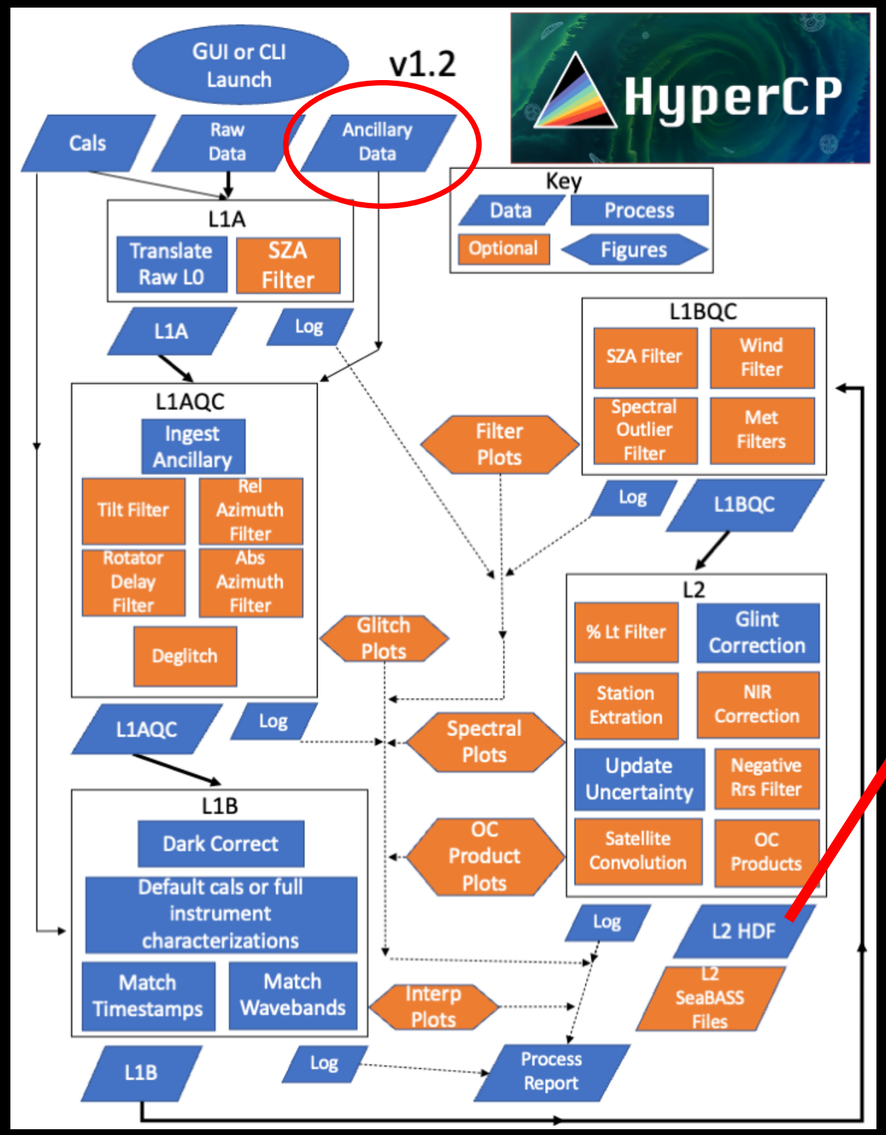
(More information about SeaBASS will be provided on Day 7.)

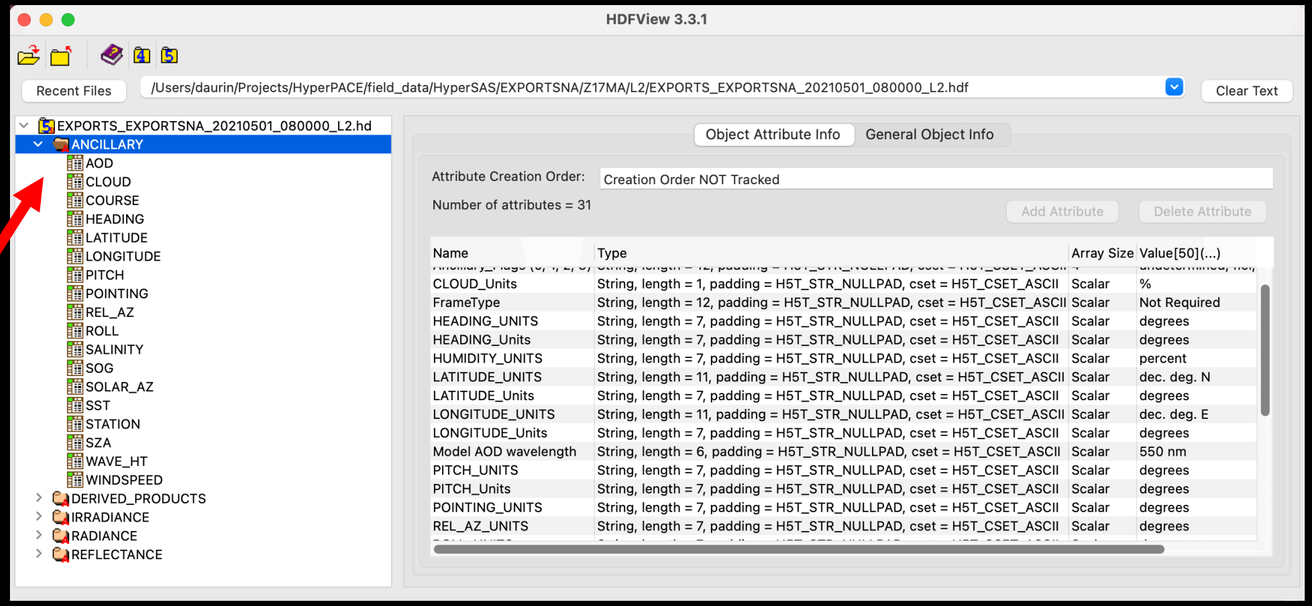
seabass.gsfc.nasa.gov



The SeaBASS FCHECK utility is accessible via email, sftp, or with a downloadable script

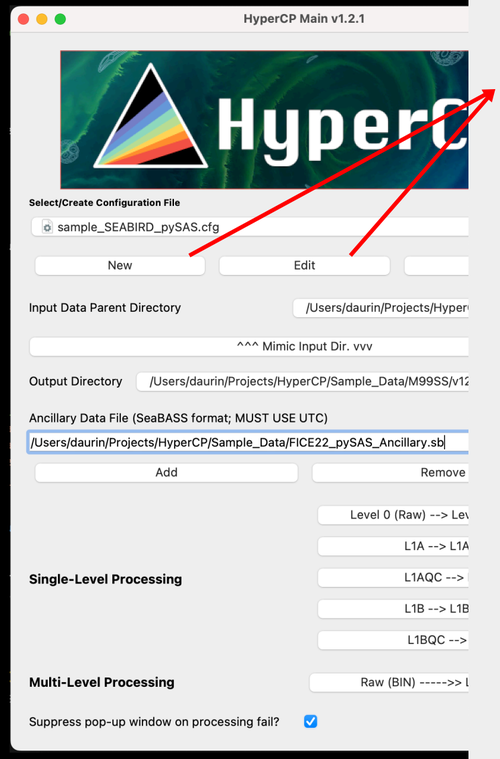
Ancillary Data at L2

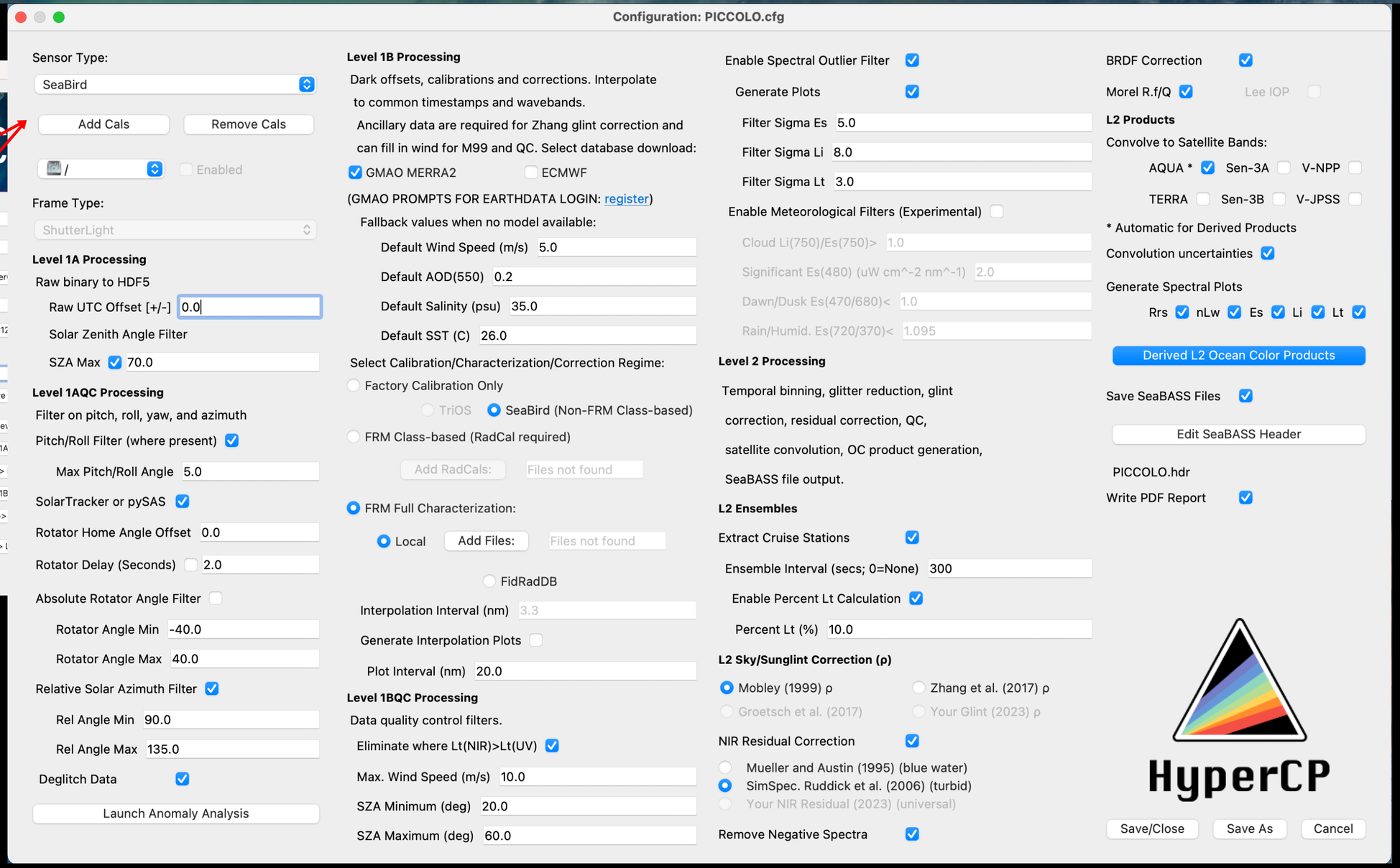




- Some of these are used for processing the data in HyperCP and some are used later in selecting data for mission validation.
- Much of this (not all) is captured automatically in the SeaBASS file metadata.
- We ask that you submit your L2 HDF files (and raw files) with your SeaBASS files.

The Configuration Window





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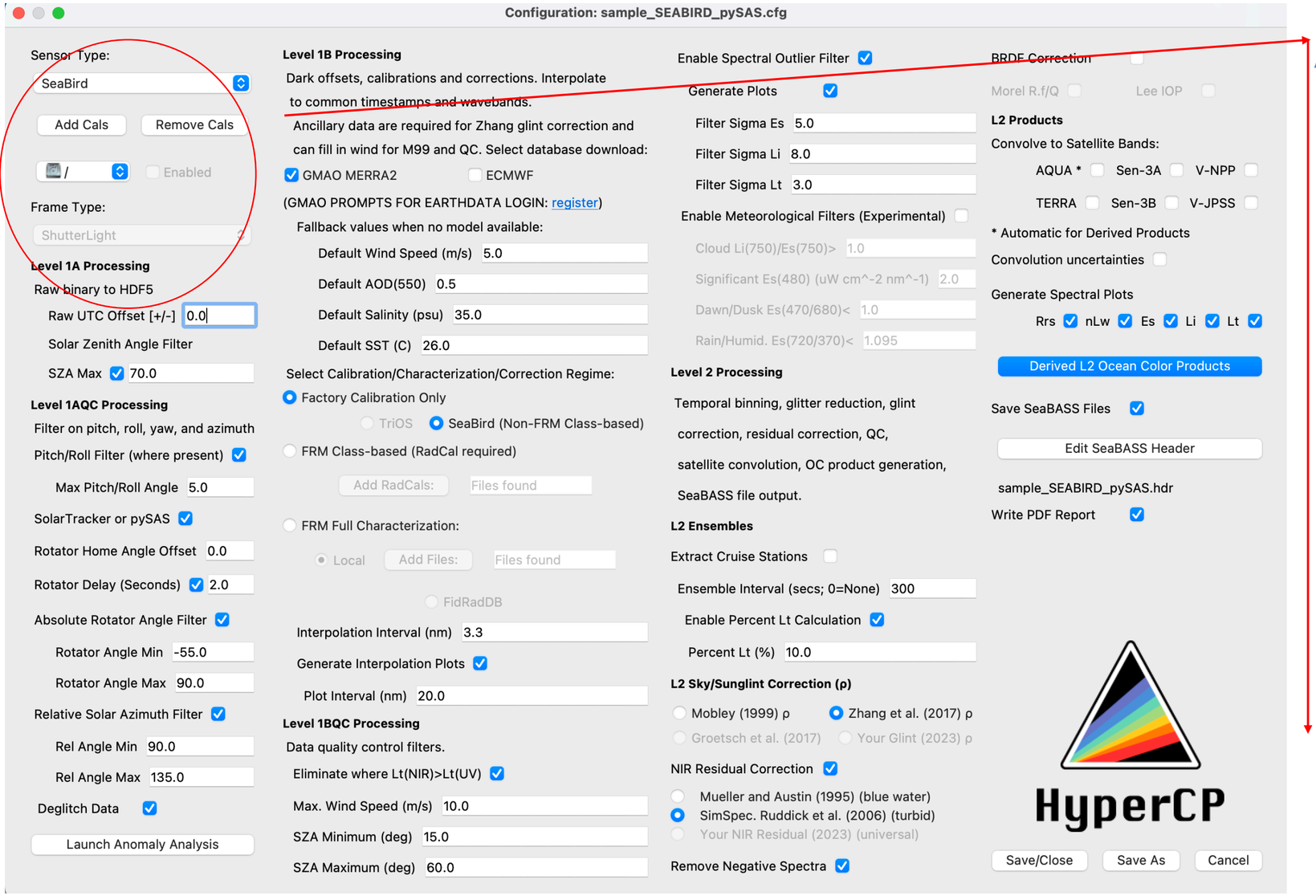
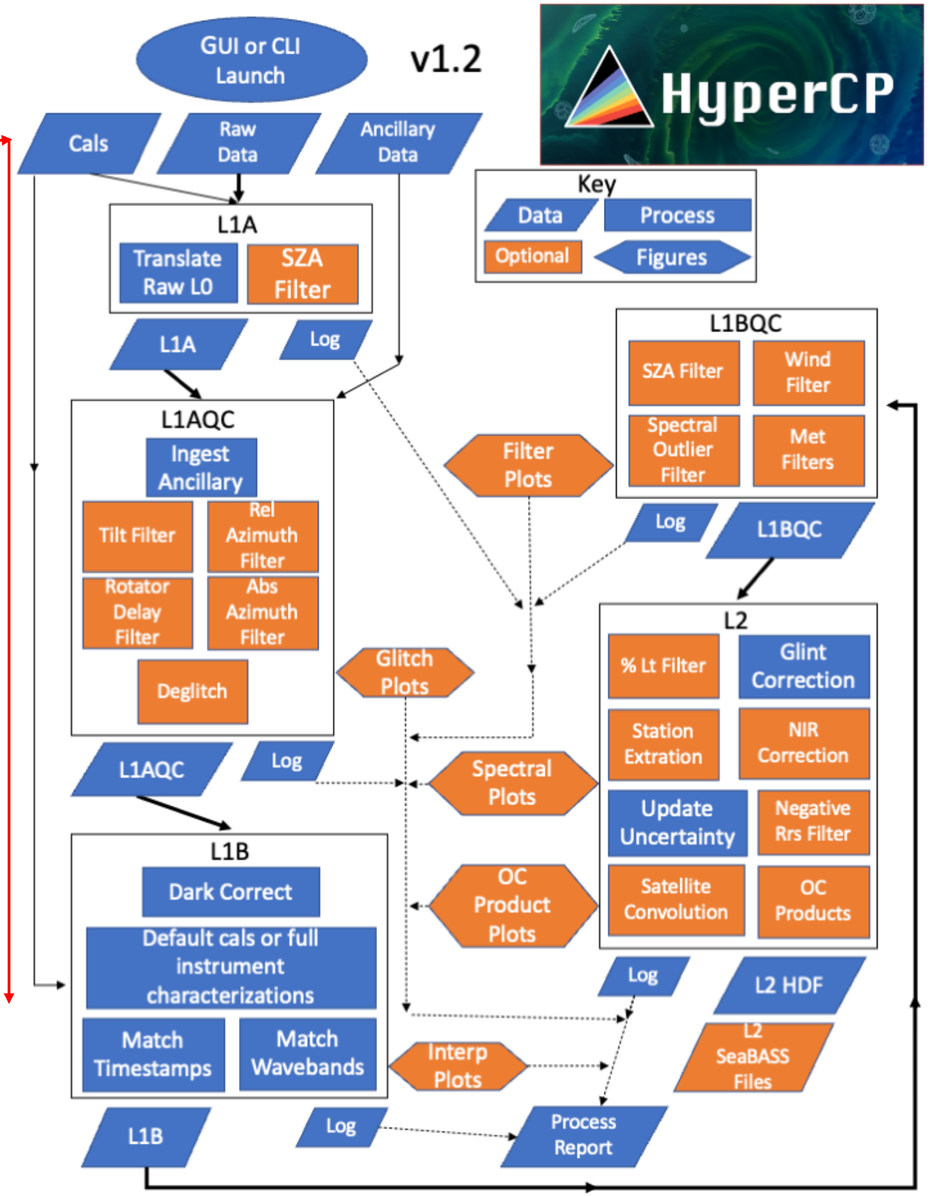
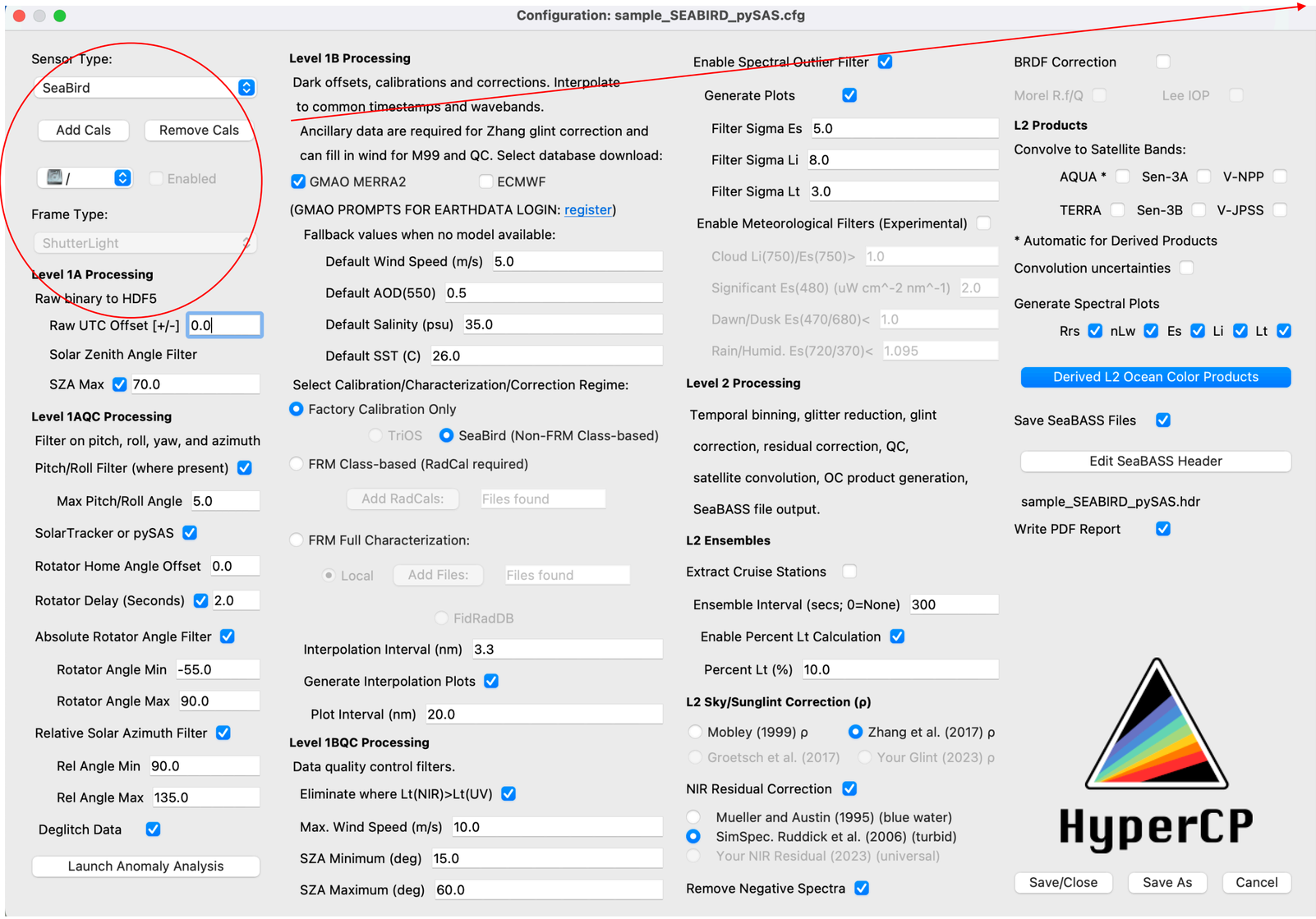
HyperCP: Loading Instrument Calibration

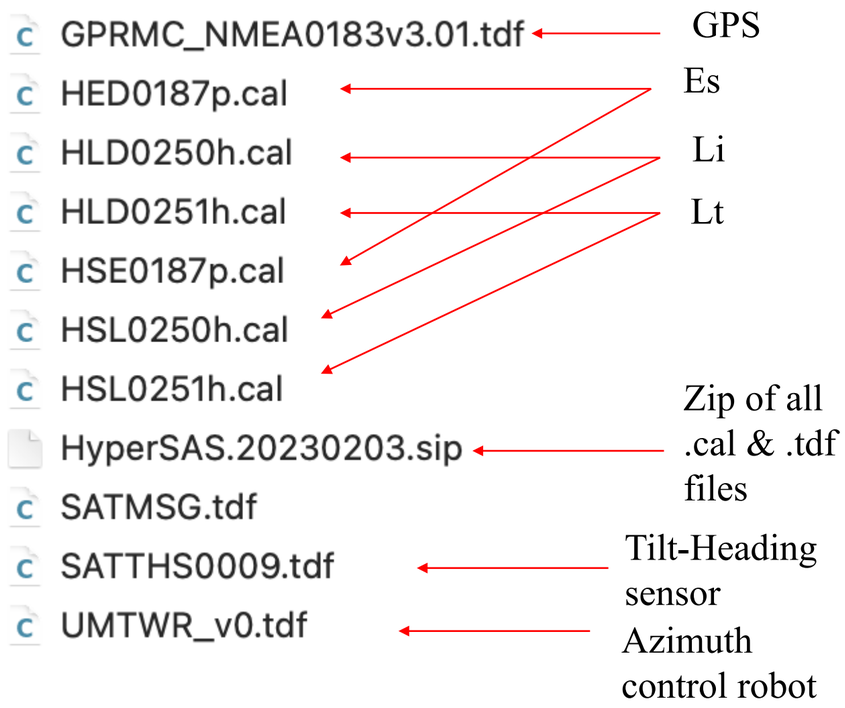




HyperCP: Loading Instrument Calibration



Sea-Bird HyperOCRs, pySAS



HED and HLD are **Dark** cals
HSE and HSL are **Light** cals

[*HyperCP now automatically recognizes .cal files as Light/Dark and enables them by default on import.*]

HyperCP

Demo:
Loading in Calibration and Telemetry Files

(Demo will be provided during Day 3-6 breakouts)

HyperCP Level 1A: Read Data

Configuration: sample_SEABIRD_pySAS.cfg

Sensor Type: SeaBird

Add Cals | Remove Cals

/ Enabled

Frame Type: ShutterLight

Level 1A Processing

Raw binary to HDF5

Raw UTC Offset [+/-] 0.0

Solar Zenith Angle Filter

SZA Max 70.0

Level 1AQC Processing

Filter on pitch, roll, yaw, and azimuth

Pitch/Roll Filter (where present)

Max Pitch/Roll Angle 5.0

SolarTracker or pySAS

Rotator Home Angle Offset 0.0

Rotator Delay (Seconds) 2.0

Absolute Rotator Angle Filter

Rotator Angle Min -55.0

Rotator Angle Max 90.0

Relative Solar Azimuth Filter

Rel Angle Min 90.0

Rel Angle Max 135.0

Deglitch Data

Launch Anomaly Analysis

Level 1B Processing

Dark offsets, calibrations and corrections. Interpolate to common timestamps and wavebands.

Ancillary data are required for Zhang glint correction and can fill in wind for M99 and QC. Select database download:

GMAO MERRA2 ECMWF

(GMAO PROMPTS FOR EARTHDATA LOGIN: register)

Fallback values when no model available:

Default Wind Speed (m/s) 5.0

Default AOD(550) 0.5

Default Salinity (psu) 35.0

Default SST (C) 26.0

Select Calibration/Characterization/Correction Regime:

Factory Calibration Only

TriOS SeaBird (Non-FRM Class-based)

FRM Class-based (RadCal required)

Add RadCals: Files found

FRM Full Characterization:

Local Add Files: Files found

FidRadDB

Interpolation Interval (nm) 3.3

Generate Interpolation Plots

Plot Interval (nm) 20.0

Level 1BQC Processing

Data quality control filters.

Eliminate where Lt(NIR)>Lt(UV)

Max. Wind Speed (m/s) 10.0

SZA Minimum (deg) 15.0

SZA Maximum (deg) 60.0

Enable Spectral Outlier Filter

Generate Plots

Filter Sigma Es 5.0

Filter Sigma Li 8.0

Filter Sigma Lt 3.0

Enable Meteorological Filters (Experimental)

Cloud Li(750)/Es(750)> 1.0

Significant Es(480) (uW cm^-2 nm^-1) 2.0

Dawn/Dusk Es(470/680)< 1.0

Rain/Humid. Es(720/370)< 1.095

Level 2 Processing

Temporal binning, glitter reduction, glint correction, residual correction, QC, satellite convolution, OC product generation, SeaBASS file output.

L2 Ensembles

Extract Cruise Stations

Ensemble Interval (secs; 0=None) 300

Enable Percent Lt Calculation

Percent Lt (%) 10.0

L2 Sky/Sunglint Correction (ρ)

Mobley (1999) ρ Zhang et al. (2017) ρ

Groetsch et al. (2017) Your Glint (2023) ρ

NIR Residual Correction

Mueller and Austin (1995) (blue water)

SimSpec. Ruddick et al. (2006) (turbid)

Your NIR Residual (2023) (universal)

Remove Negative Spectra

BRDF Correction

Morel R.f/Q Lee IOP

L2 Products

Convolve to Satellite Bands:

AQUA * Sen-3A V-NPP

TERRA Sen-3B V-JPSS

* Automatic for Derived Products

Convolution uncertainties

Generate Spectral Plots

Rrs nLw Es Li Lt

Derived L2 Ocean Color Products

Save SeaBASS Files

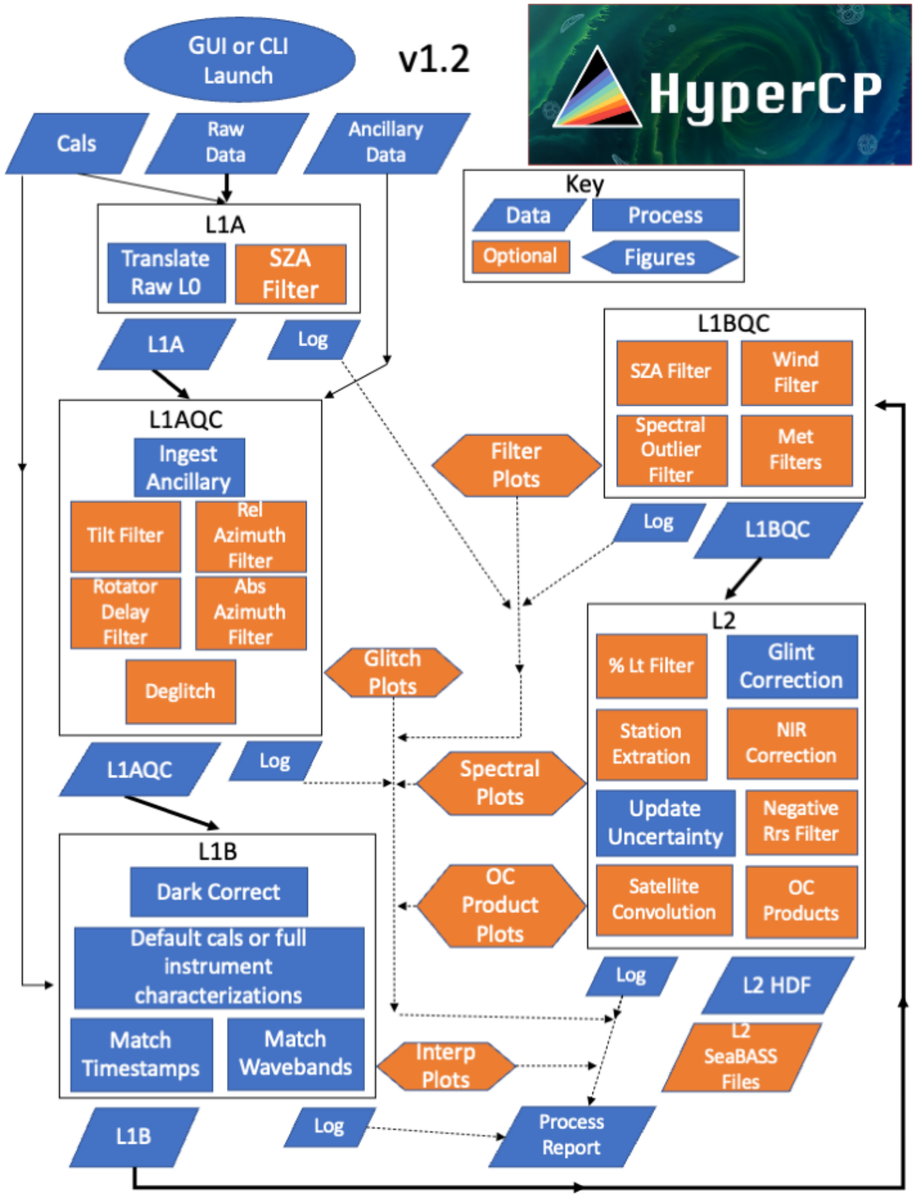
Edit SeaBASS Header

sample_SEABIRD_pySAS.hdr

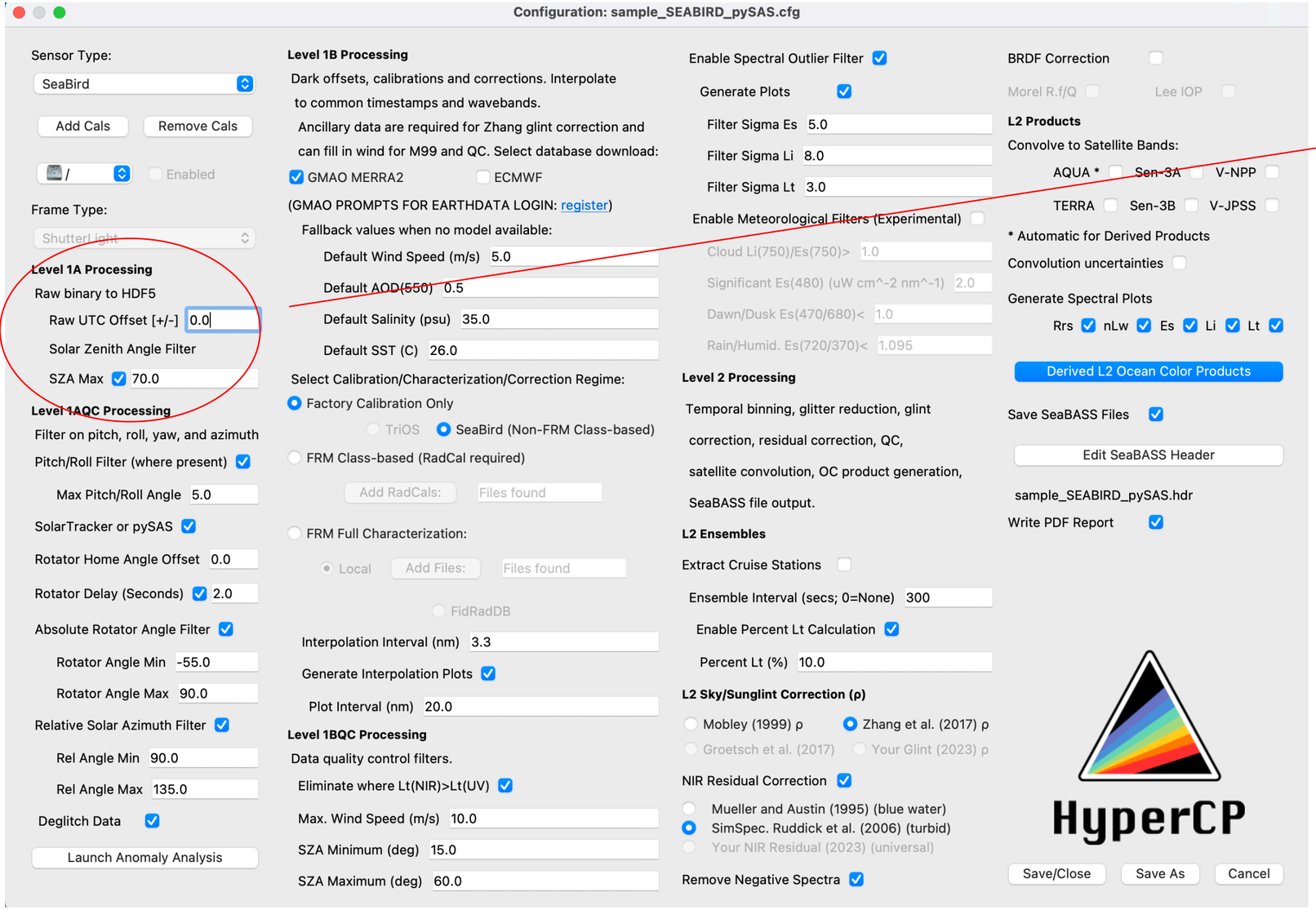
Write PDF Report

HyperCP

Save/Close Save As Cancel



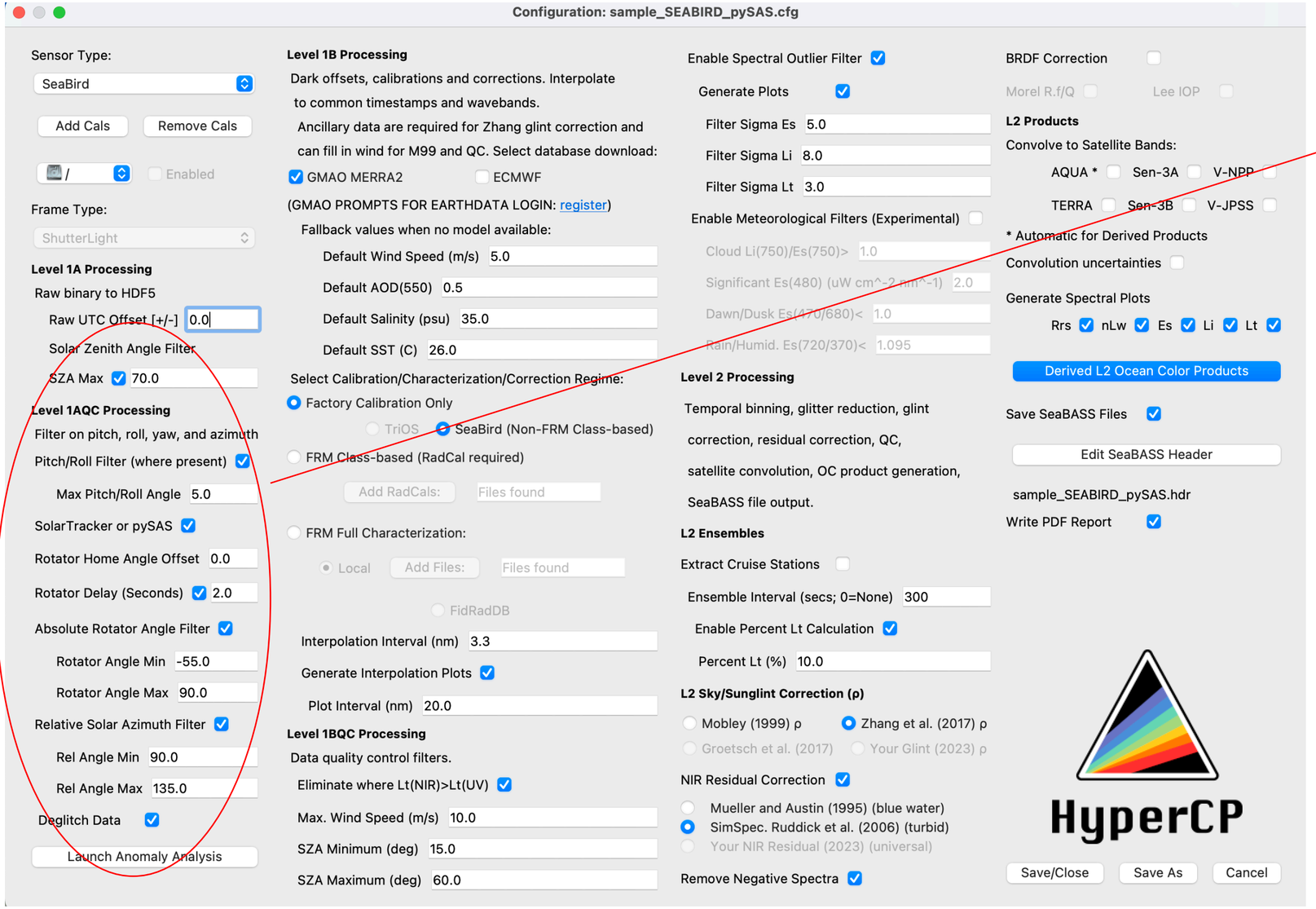
HyperCP Level 1A: Read Data



One should almost always set all computers, instruments, cameras, etc. to UTC when collecting data in the field. (Ancillary file must be UTC, currently. Data and photos can be accommodated for local, but not recommended.)

SZA used here for data reduction of autonomous collections running into the morning/evening. SZA fine tuned in L1BQC.

HyperCP Level 1AQC: Quality Control Data



Tilt of Es should not exceed 5 degrees. (See README for explanation/sources of all default and recommended values throughout configuration.)

Identify whether an azimuth robot (e.g., SolarTracker or pySAS) was used. If not, the Ancillary file must include Sensor Azimuth or Relative Azimuth. If GPS is also missing in the instrumentation above, Latitude and Longitude must be included in the Ancillary file.

Use field logs/notes to identify min/max sensor azimuth (rotator angle to avoid obstruction) and home offset (latest values can also be recovered from pySAS file pysas_cfg.ini)

HyperCP Level 1AQC: Supervised Deglitching

Sea-Bird Only

HyperCP Level 1AQC: Supervised Deglitching

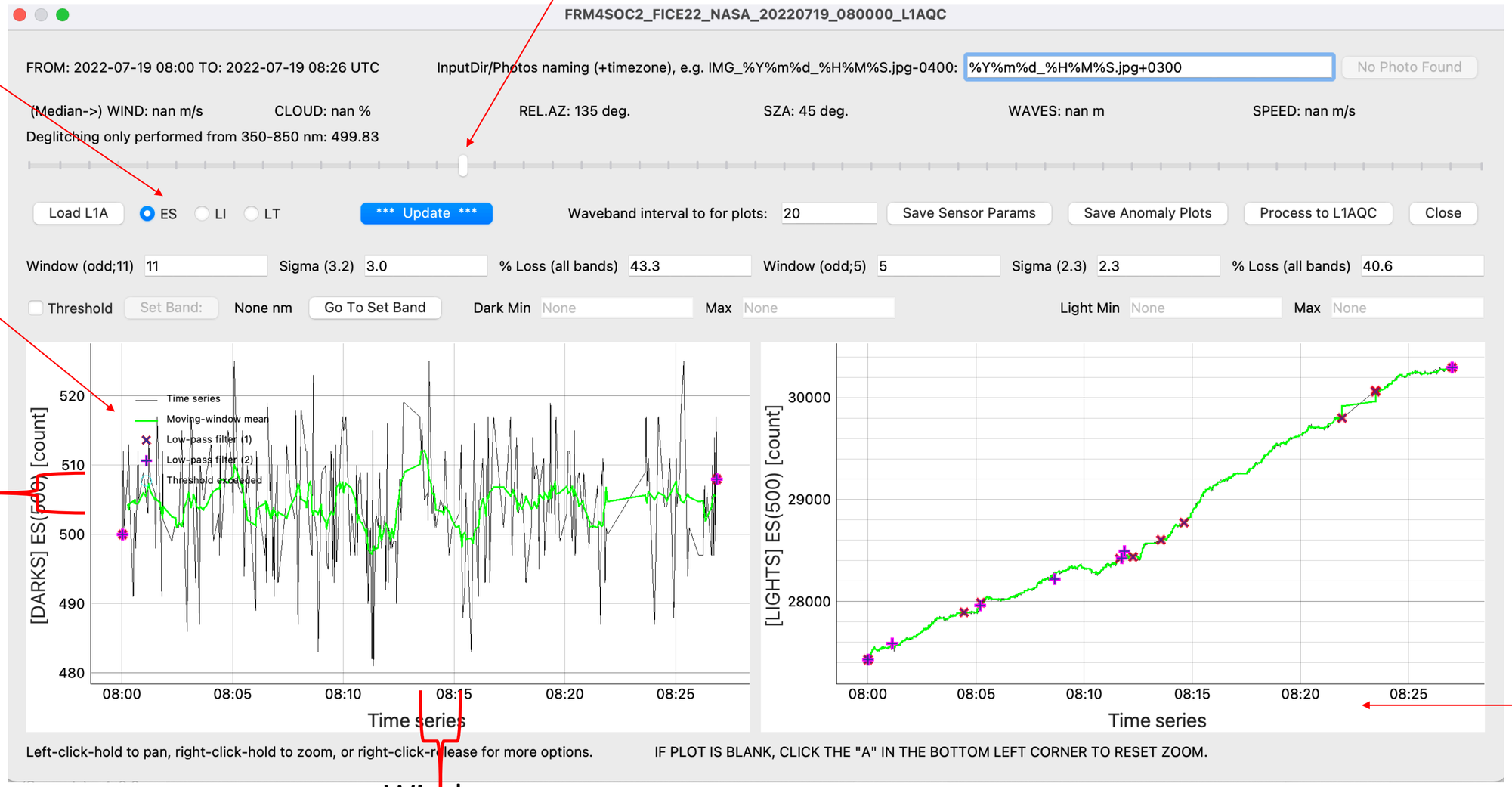
Supervised Deglitching.

Waveband Slider

Sensor

Uncalibrated raw counts

Sigma

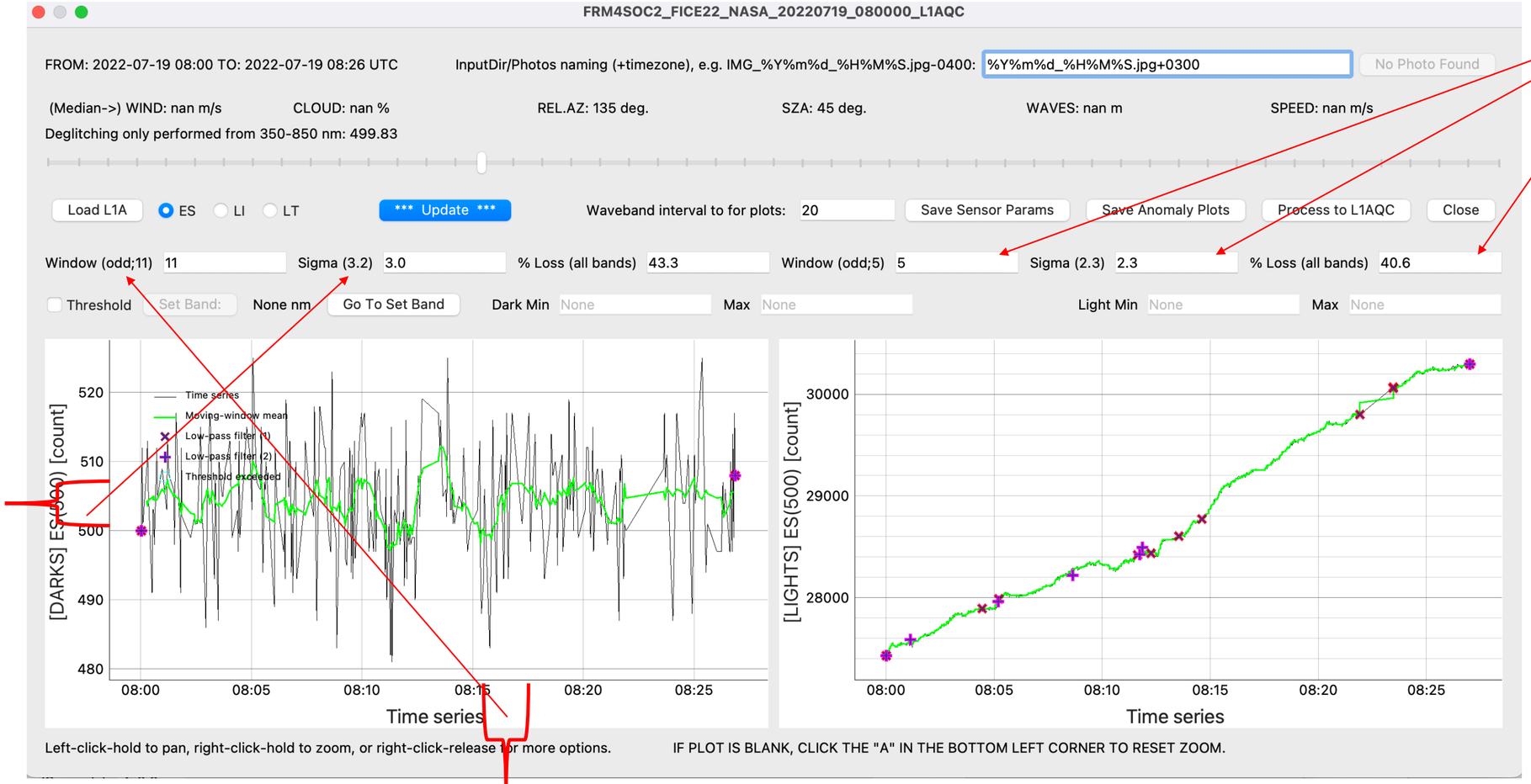


Time

Window

HyperCP Level 1AQC: Supervised Deglitching

Supervised Deglitching.



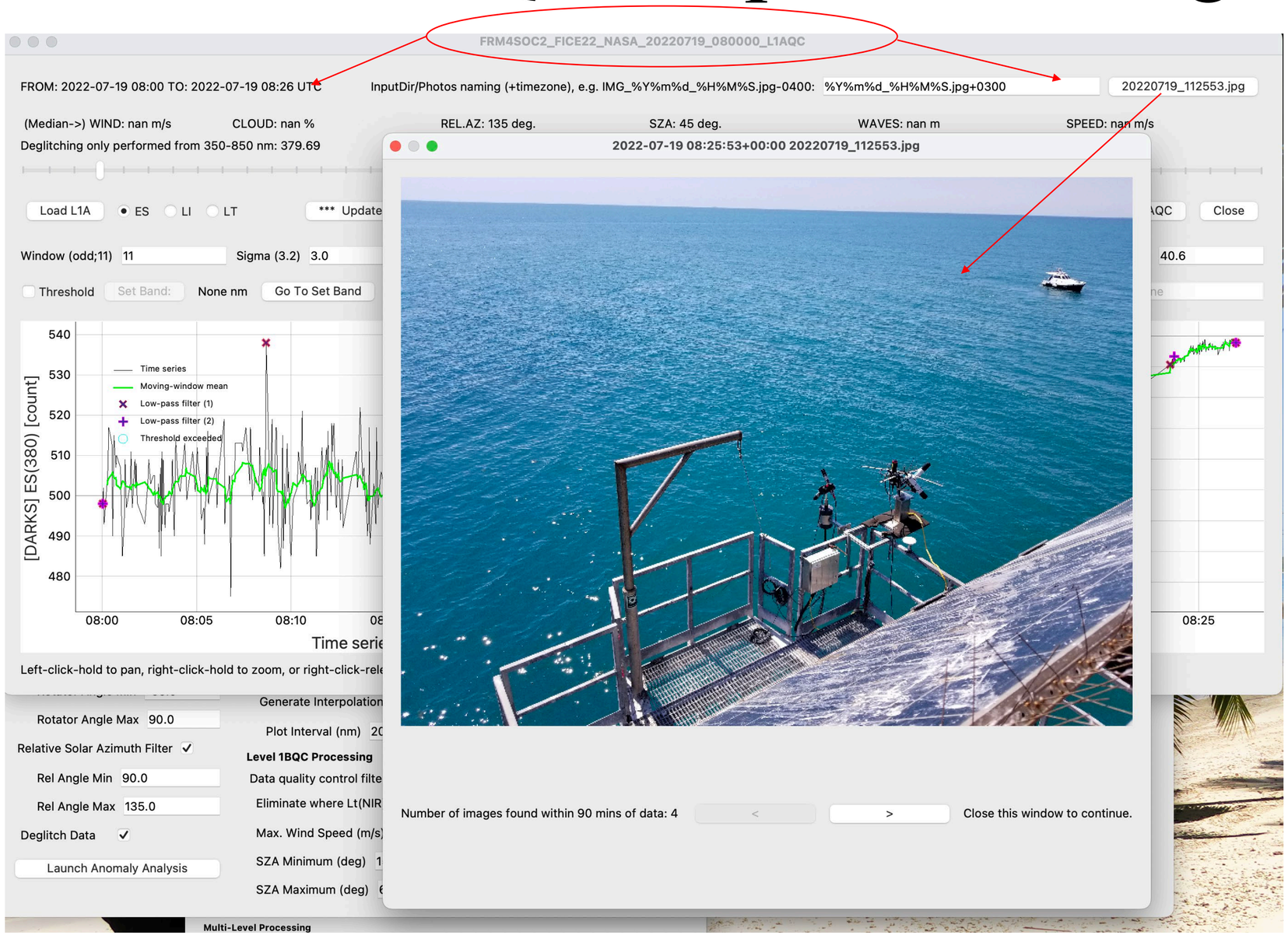
Sigma

Window

Balance these while visually evaluating signal variability throughout the file. More aggressive deglitching yields lower uncertainty traded off against less data.

(Note: This file could be 5 mins or 5 hours, but default pySAS collections are 1 hr autonomous.)

HyperCP Level 1AQC: Supervised Deglitching

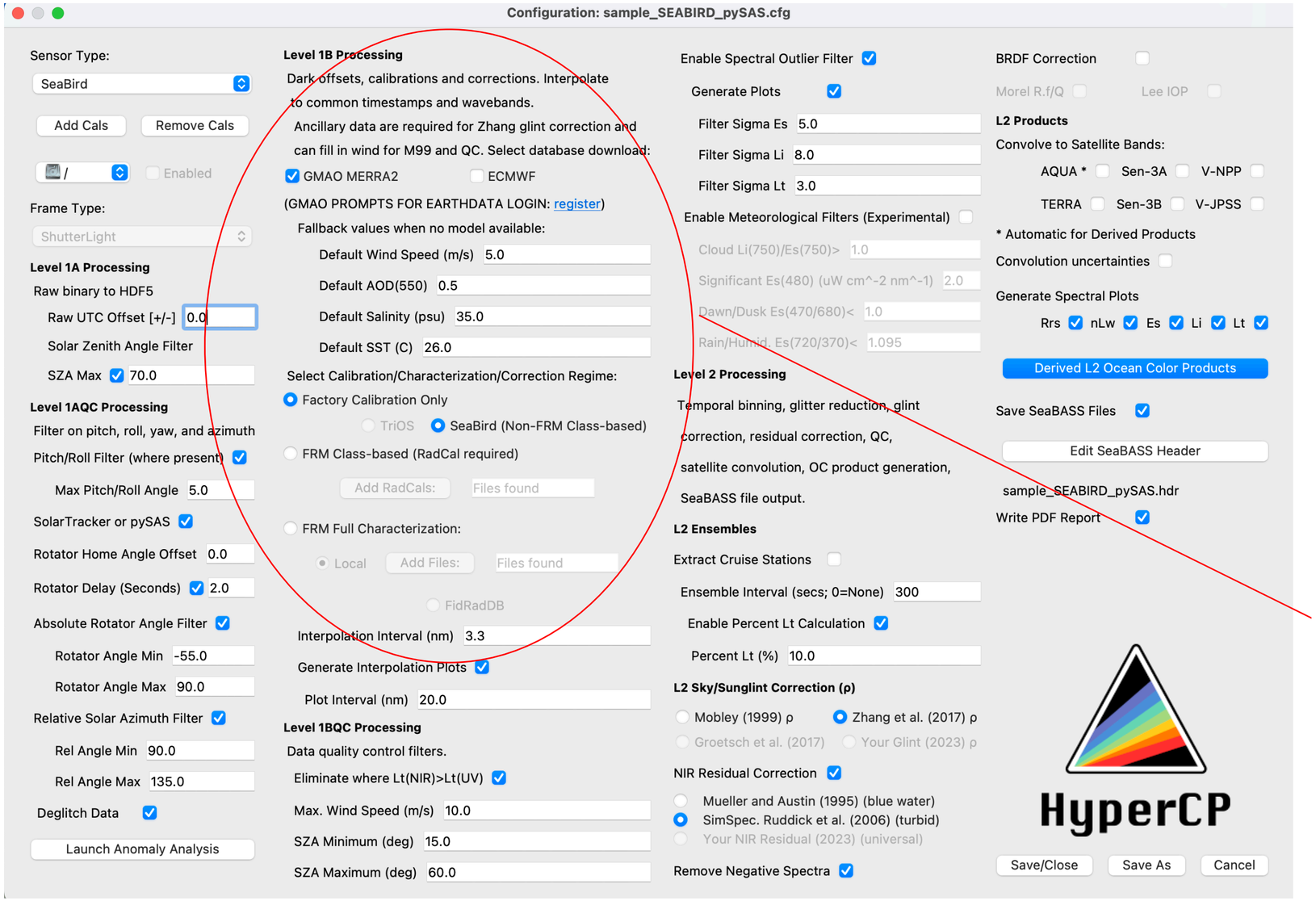


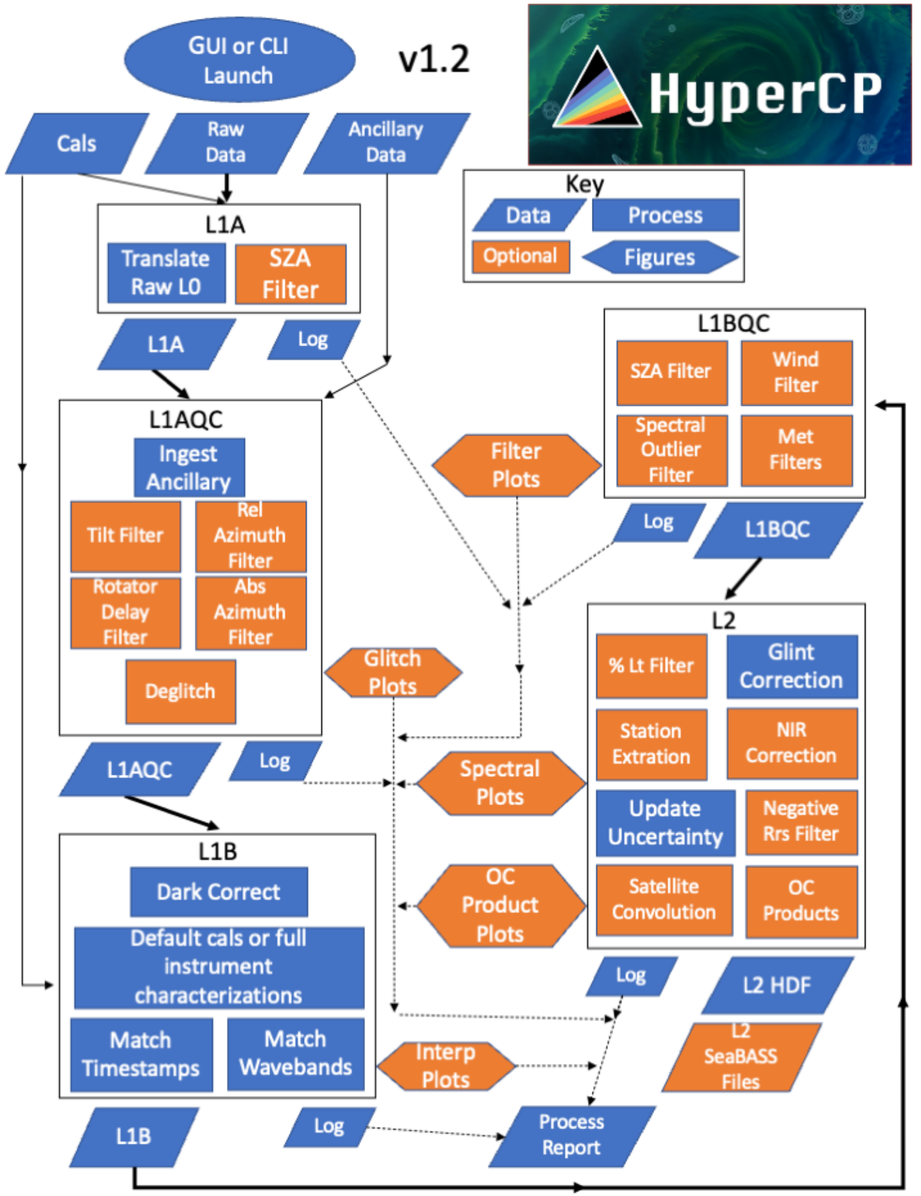
HyperCP

Demo:
Supervised Deglitching

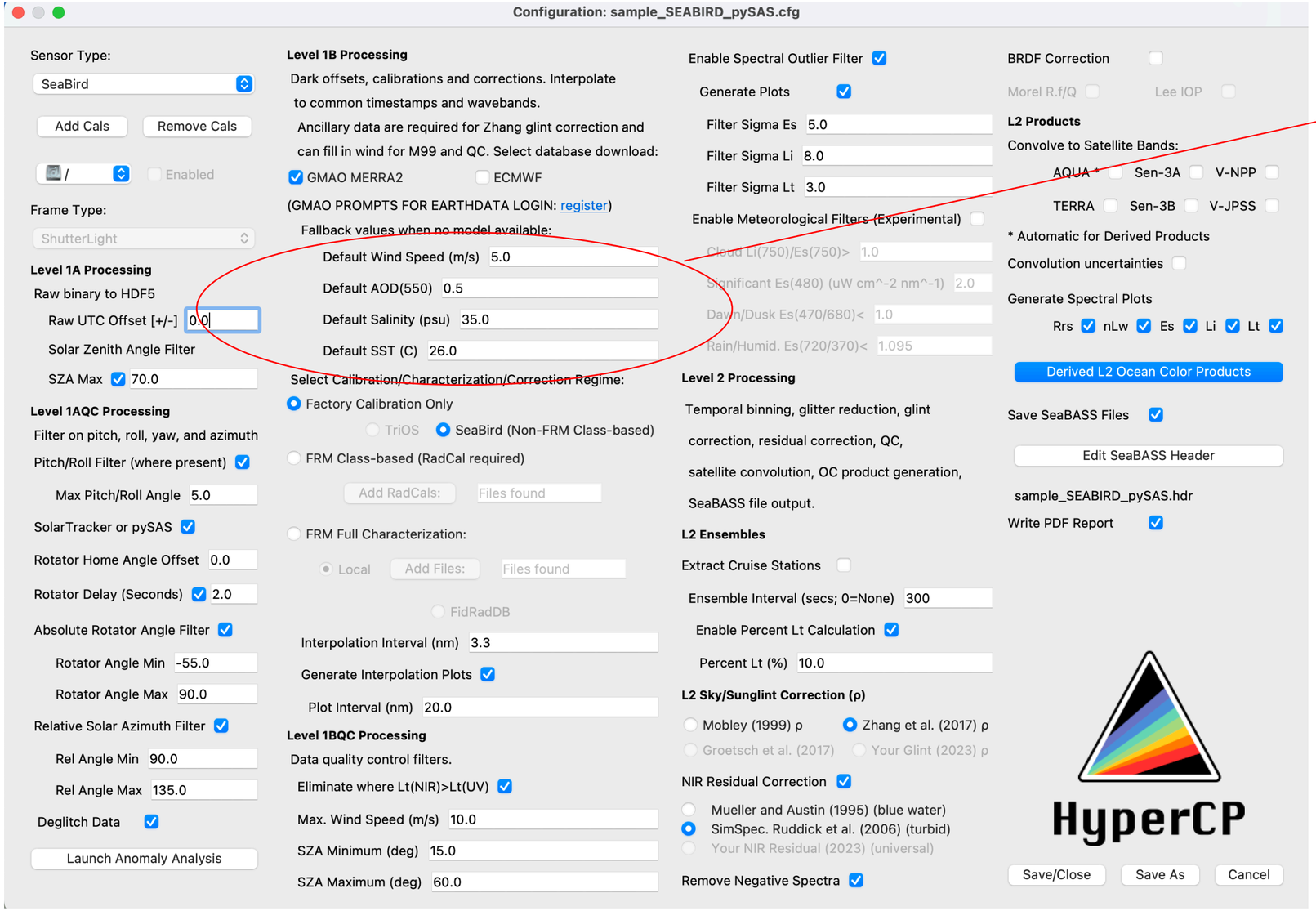
(Demo will be provided during Day 3-6 breakouts)

HyperCP Level 1B: Overview





HyperCP Level 1B: Load Ancillaries



Wind speed is a requirement of L2 glint correction and AOT is a requirement of cosine correction, uncertainty budgets, and the Zhang et al. 2017 glint correction. Any gaps in the Ancillary file provided can be filled using model data -- either NASA GMAO or European ECMWF. GMAO requires a NASA EarthData account (free & easy).

The Default values below the models are last-resort fallback values if neither Ancillary nor model data are found. (*Fallback is not recommended for final process, but often needed for use in preliminary processing and data checks before model data are available, e.g., in the field*)

HyperCP Level 1B: Factory/Class/Full

Configuration: sample_SEABIRD_pySAS.cfg

Sensor Type: SeaBird

Add Cals | Remove Cals

/ Enabled

Frame Type: ShutterLight

Level 1A Processing

Raw binary to HDF5

Raw UTC Offset [+/-] 0.0

Solar Zenith Angle Filter

SZA Max 70.0

Level 1AQC Processing

Filter on pitch, roll, yaw, and azimuth

Pitch/Roll Filter (where present)

Max Pitch/Roll Angle 5.0

SolarTracker or pySAS

Rotator Home Angle Offset 0.0

Rotator Delay (Seconds) 2.0

Absolute Rotator Angle Filter

Rotator Angle Min -55.0

Rotator Angle Max 90.0

Relative Solar Azimuth Filter

Rel Angle Min 90.0

Rel Angle Max 135.0

Deglitch Data

Launch Anomaly Analysis

Level 1B Processing

Dark offsets, calibrations and corrections. Interpolate to common timestamps and wavebands.

Ancillary data are required for Zhang glint correction and can fill in wind for M99 and QC. Select database download:

GMAO MERRA2 ECMWF

(GMAO PROMPTS FOR EARTHDATA LOGIN: register)

Fallback values when no model available:

Default Wind Speed (m/s) 5.0

Default AOD(550) 0.5

Default Salinity (psu) 35.0

Default SST (C) 26.0

Select Calibration/Characterization/Correction Regime:

Factory Calibration Only

TriOS SeaBird (Non-FRM Class-based)

FRM Class-based (RadCal required)

Add RadCals: Files found

FRM Full Characterization:

Local Add Files: Files found

FidRadDB

Interpolation Interval (nm) 3.3

Generate Interpolation Plots

Plot Interval (nm) 20.0

Level 1BQC Processing

Data quality control filters.

Eliminate where Lt(NIR)>Lt(UV)

Max. Wind Speed (m/s) 10.0

SZA Minimum (deg) 15.0

SZA Maximum (deg) 60.0

Enable Spectral Outlier Filter

Generate Plots

Filter Sigma Es 5.0

Filter Sigma Li 8.0

Filter Sigma Lt 3.0

Enable Meteorological Filters (Experimental)

Cloud Li(750)/Es(750)> 1.0

Significant Es(480) (uW cm^-2 nm^-1) 2.0

Dawn/Dusk Es(470/680)< 1.0

Rain/Humid. Es(720/370)< 1.095

Level 2 Processing

Temporal binning, glitter reduction, glint correction, residual correction, QC, satellite convolution, OC product generation, SeaBASS file output.

L2 Ensembles

Extract Cruise Stations

Ensemble Interval (secs; 0=None) 300

Enable Percent Lt Calculation

Percent Lt (%) 10.0

L2 Sky/Sunglint Correction (ρ)

Mobley (1999) ρ Zhang et al. (2017) ρ

Groetsch et al. (2017) Your Glint (2023) ρ

NIR Residual Correction

Mueller and Austin (1995) (blue water)

SimSpec. Ruddick et al. (2006) (turbid)

Your NIR Residual (2023) (universal)

Remove Negative Spectra

BRDF Correction

Morel R.f/Q Lee IOP

L2 Products

Convolve to Satellite Bands:

AQUA * Sen-3A V-NPP

TERRA Sen-3B V-JPSS

* Automatic for Derived Products

Convolution uncertainties

Generate Spectral Plots

Rrs nLw Es Li Lt

Derived L2 Ocean Color Products

Save SeaBASS Files

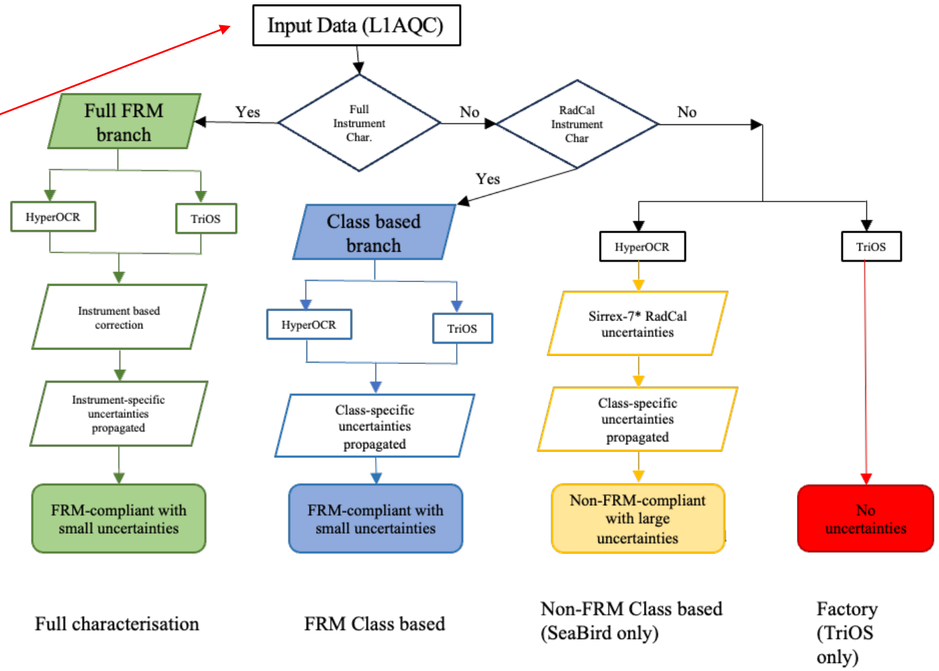
Edit SeaBASS Header

sample_SEABIRD_pySAS.hdr

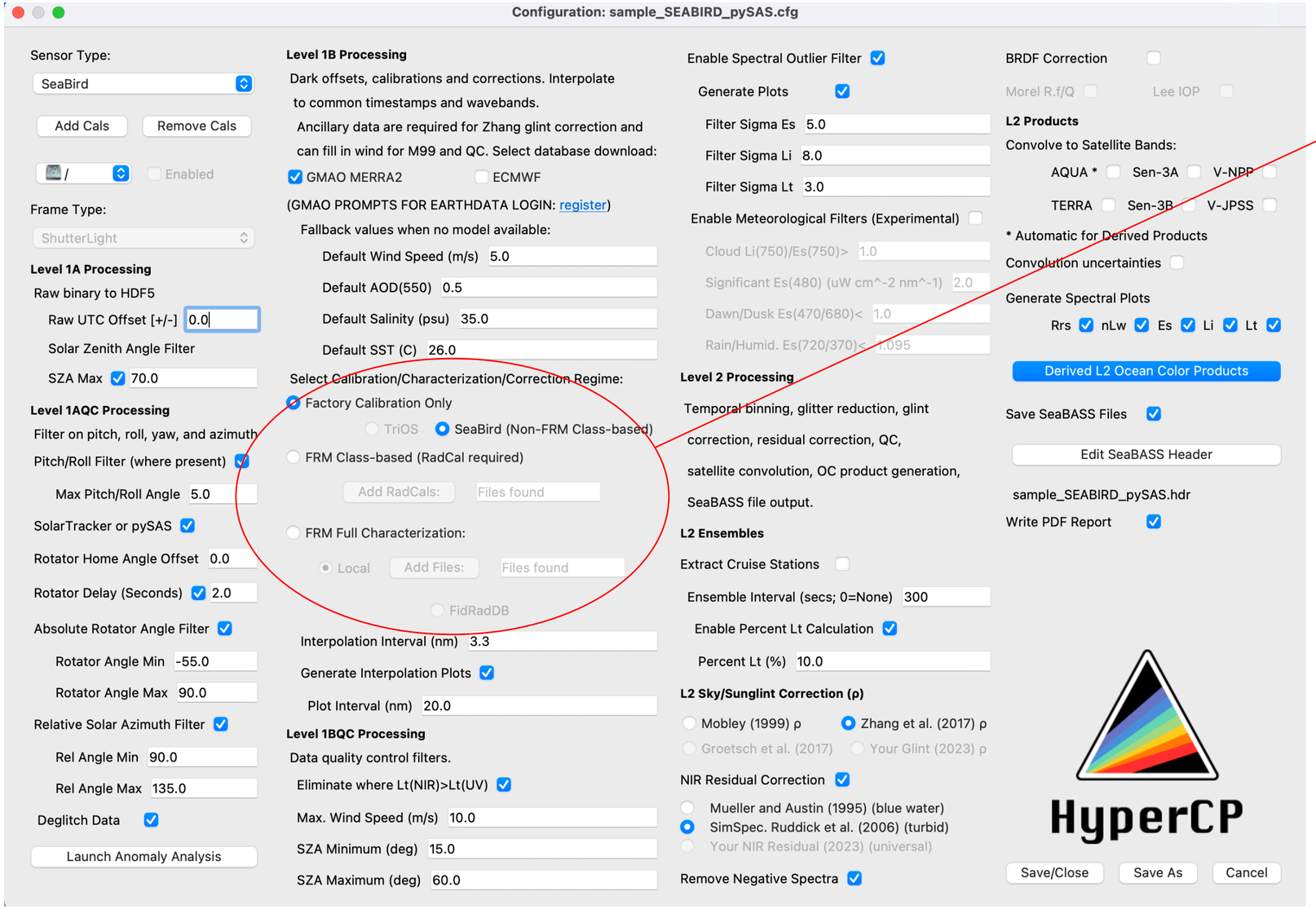
Write PDF Report

HyperCP

Save/Close Save As Cancel



HyperCP Level 1B: Load Full Characterization



Class-based (e.g., Sea-Bird or TriOS) and Instrument-specific (Full, FRM-compliant) characterizations can accurately estimate uncertainties associated with instrument response:

- Linearity of response
- Calibration/stability
- Straylight response
- Angularity of response
- Polarization response
- Thermal response

Using these pathways will also trigger use of Monte Carlo models estimating the uncertainties introduced by processing steps (e.g., glint correction) and environmental variability.

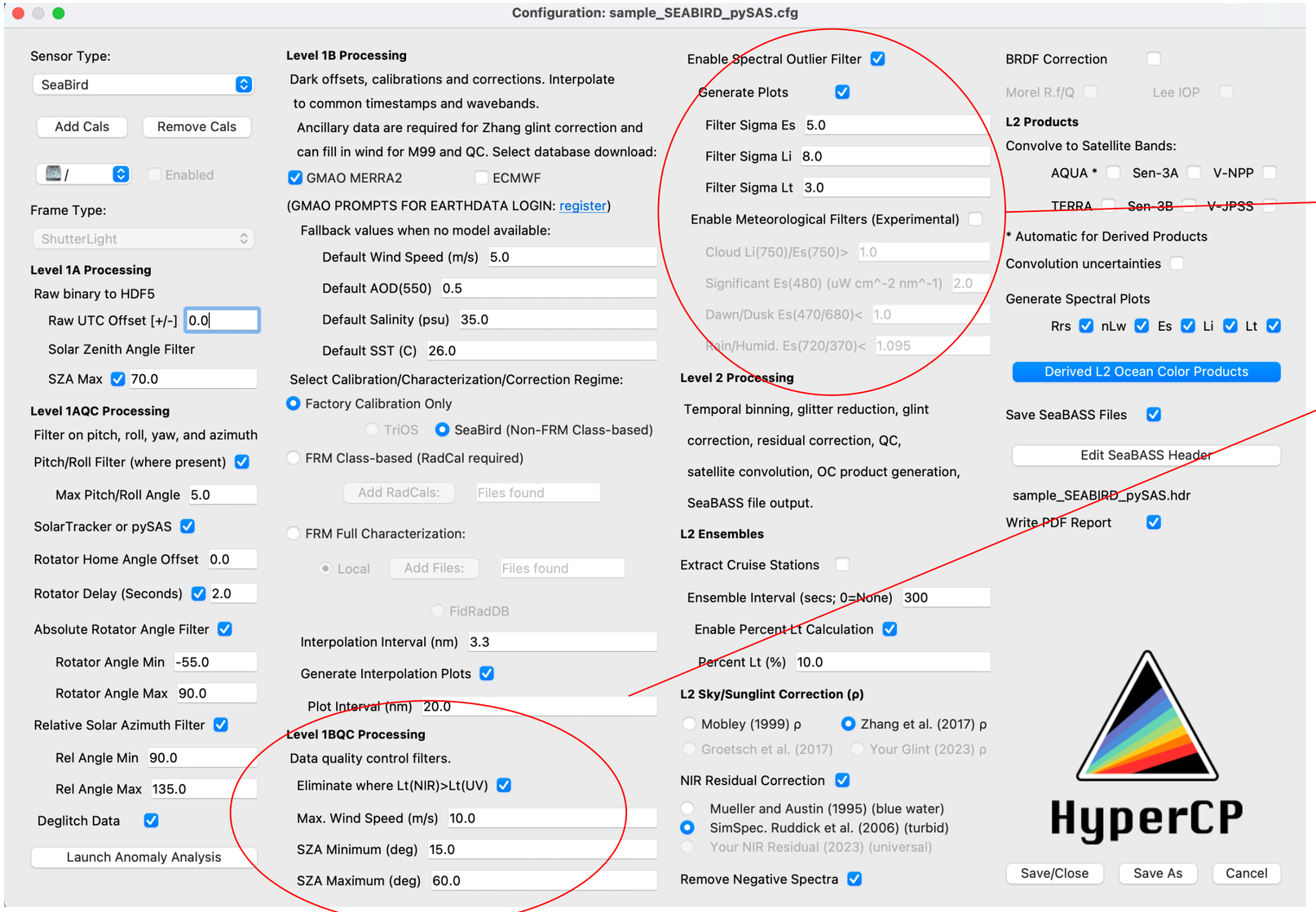
Białek, A., et al.. Example of Monte Carlo Method Uncertainty Evaluation for Above-Water Ocean Colour Radiometry. *Remote Sens.* **2020**, *12*, 780. https://doi.org/10.3390/rs12050780

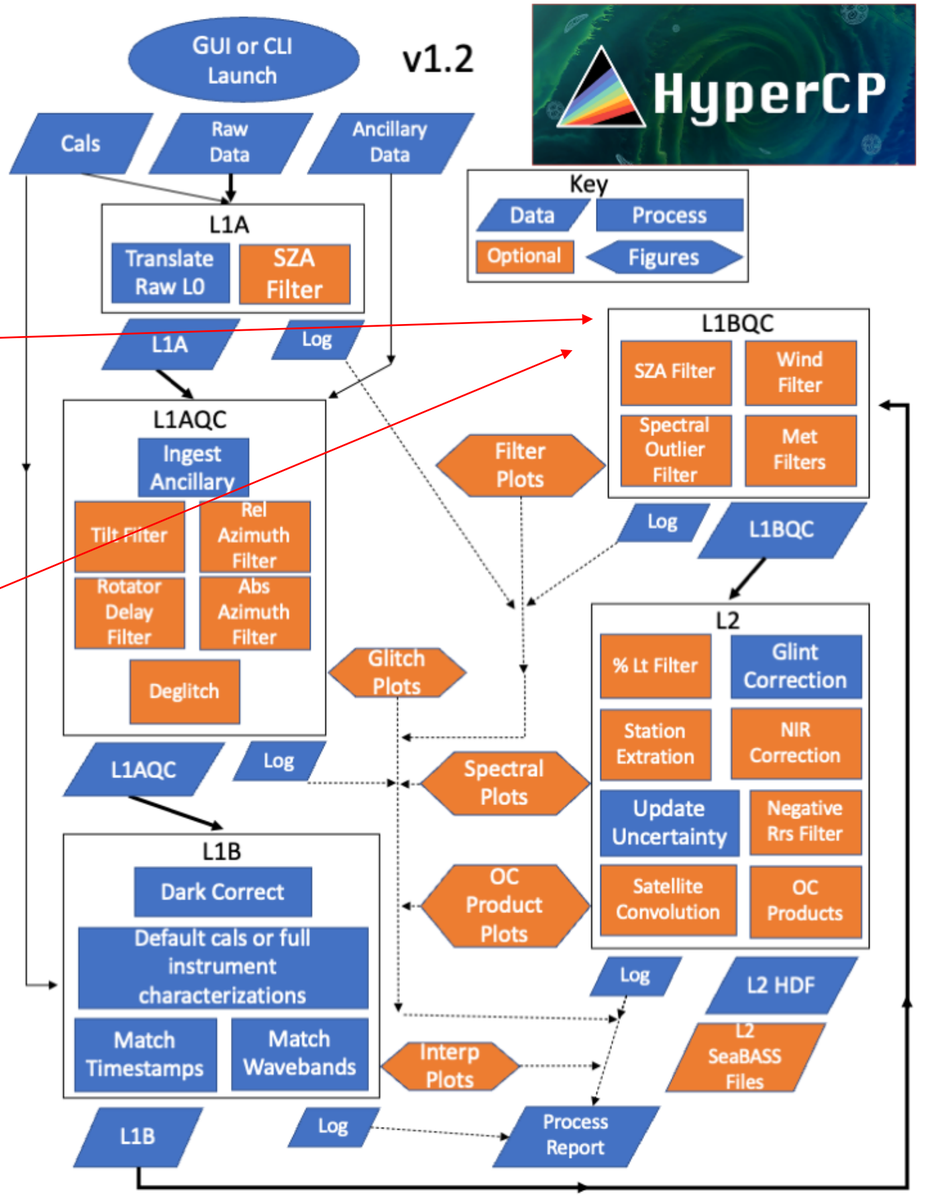
HyperCP

Demo:
Loading RadCal or Full Characterization Files

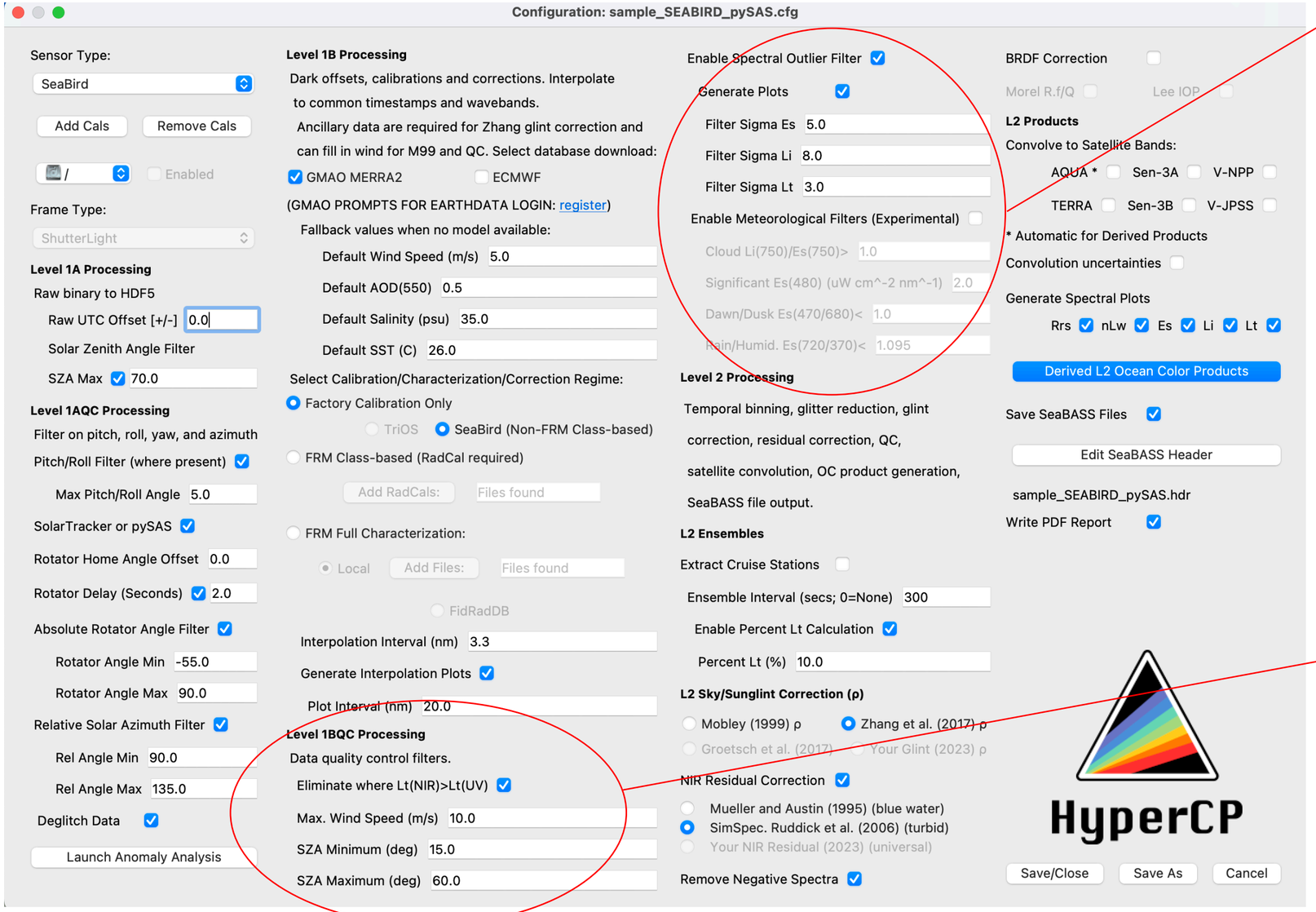
(Demo will be provided during Day 3-6 breakouts)

HyperCP Level 1BQC: Quality Control with Ancillaries





HyperCP Level 1BQC: Quality Control with Ancillaries



Reducing spectral filter sigma factors discards more of the spectra as outliers (see plots in later slides). For HyperSAS/pySAS platforms, one hour of raw data may contain as many as many as ~3,000 spectra, depending on light conditions and integration time.

Met filters are optional and considered experimental.

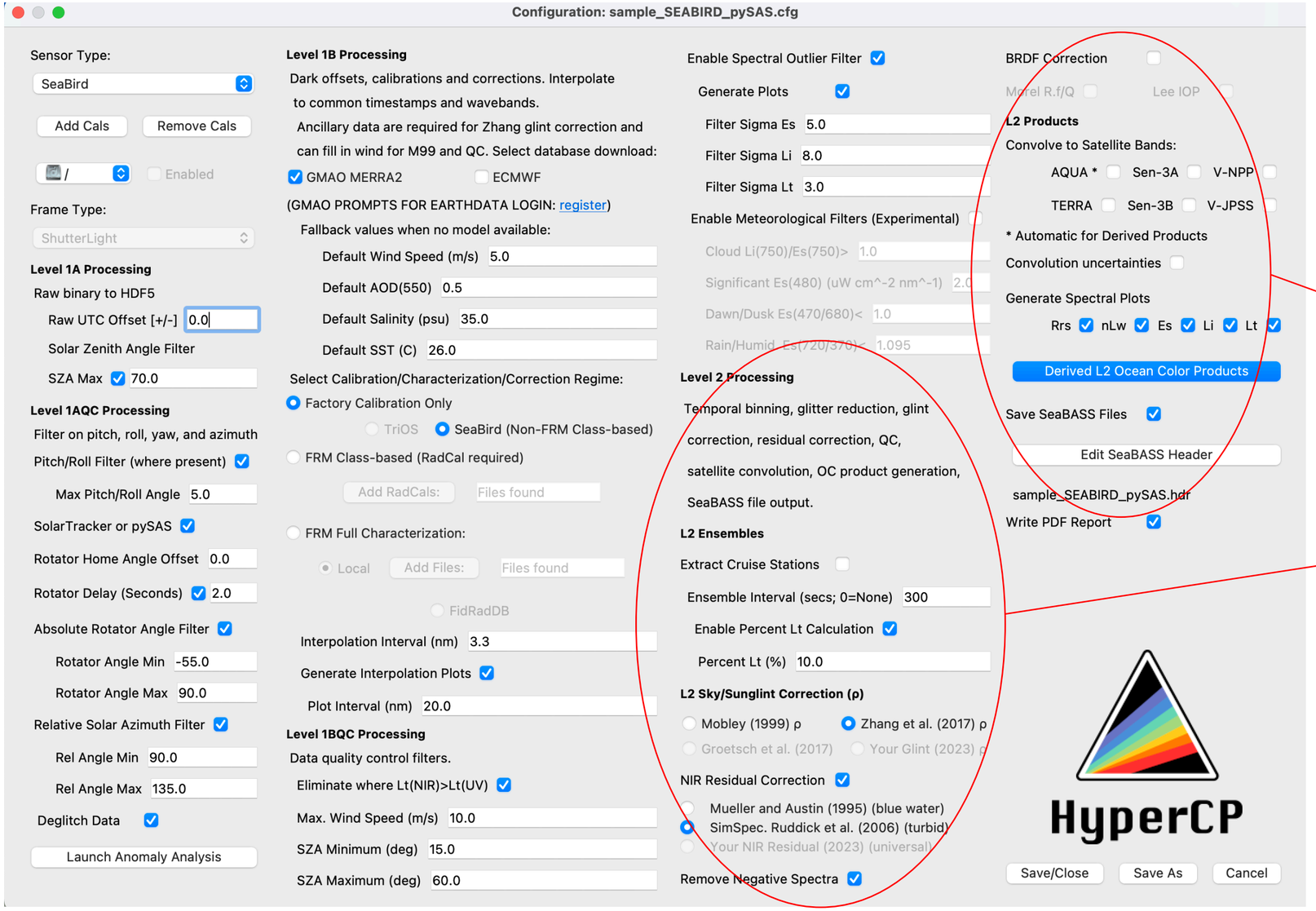
Basic quality controls for spectral shape and environmental conditions.

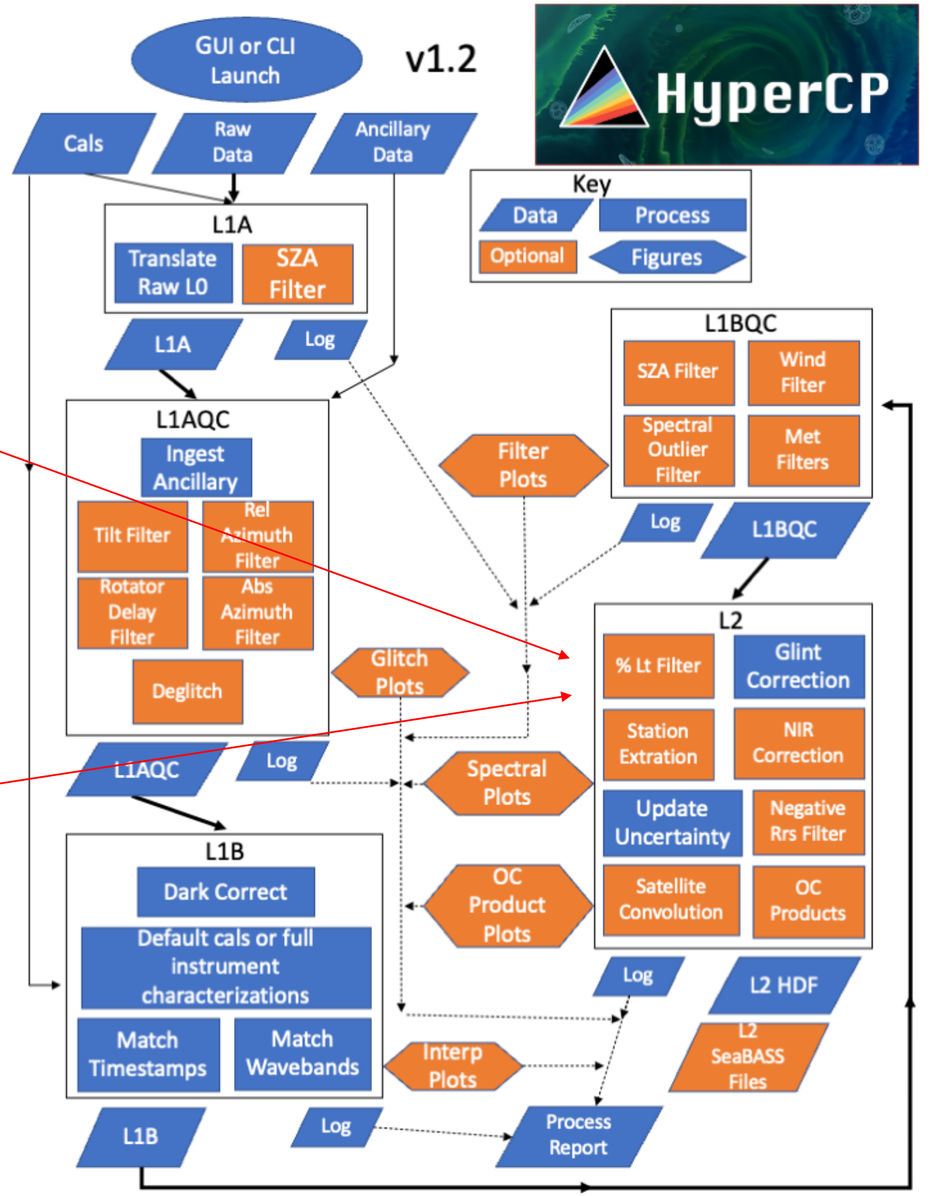
HyperCP

Demo:
Screening Spectral Filters

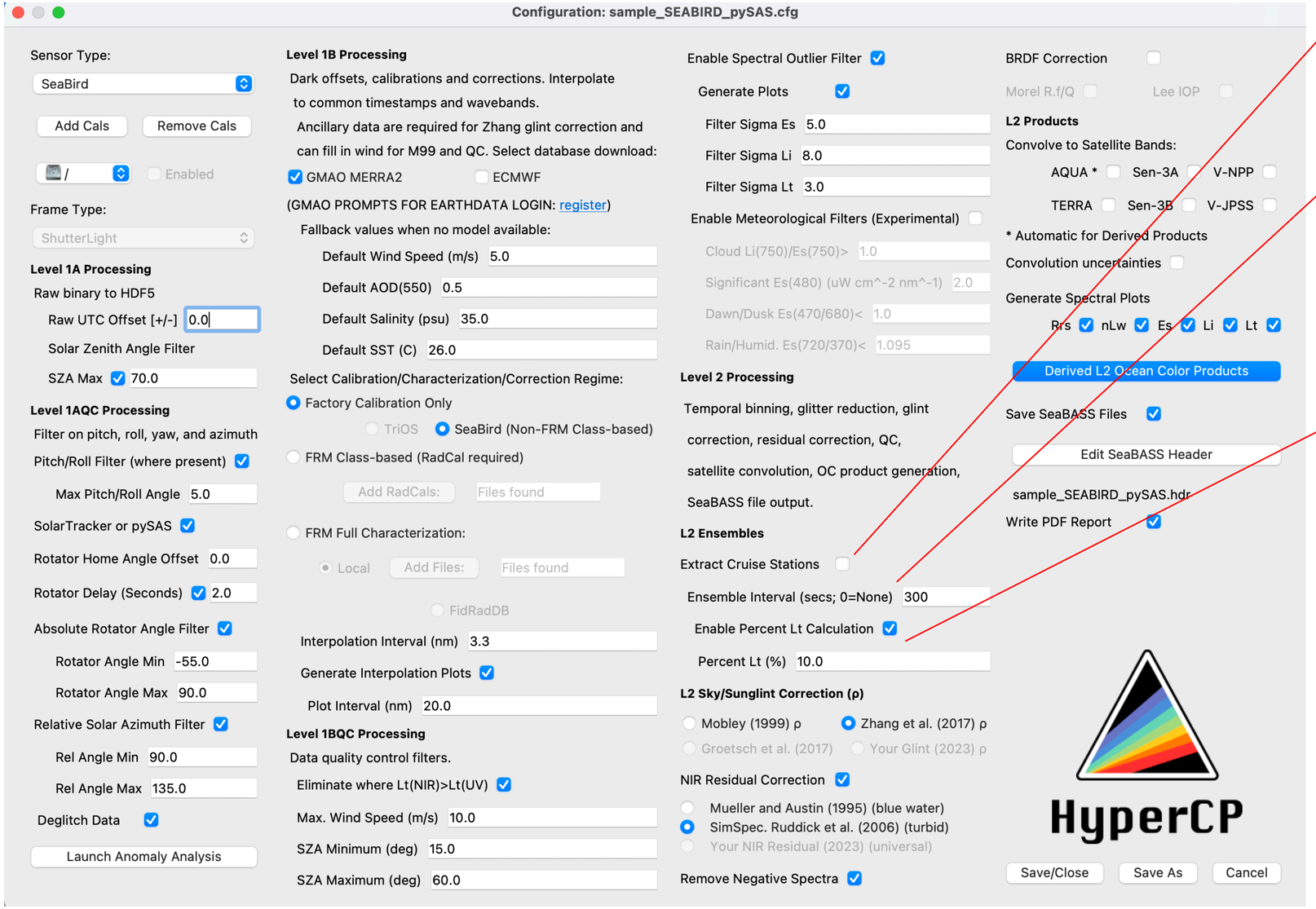
(Demo will be provided during Day 3-6 breakouts)

HyperCP Level 2: Overview





HyperCP Level 2: Binning

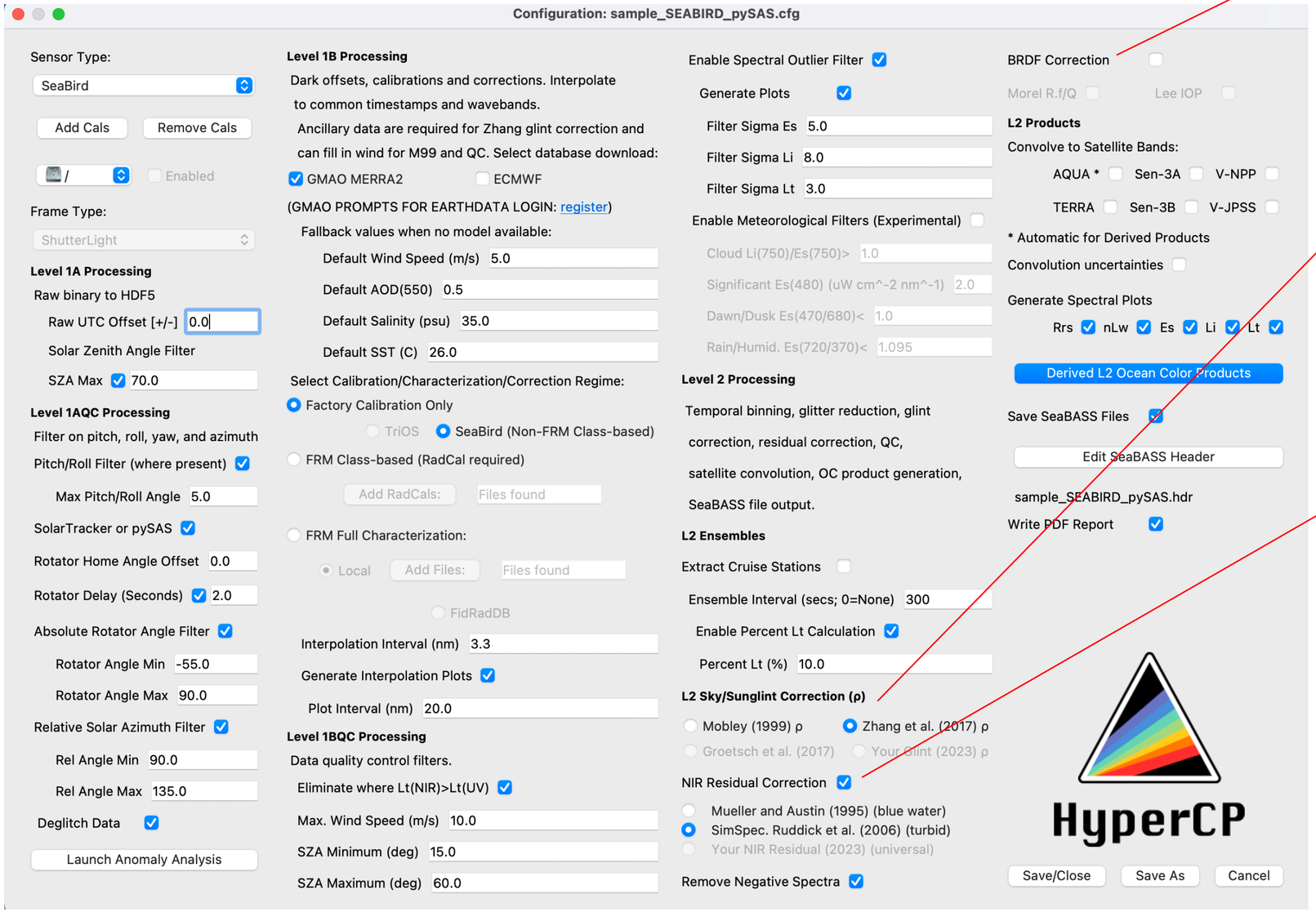


Stations from Ancillary file

Time bin average for smoothing gravity wave effects, to capture variability statistics for uncertainty, and for data reduction

Removes brightest 90% of upwelling radiance to reduce capillary wave reflection

HyperCP Level 2: Corrections…



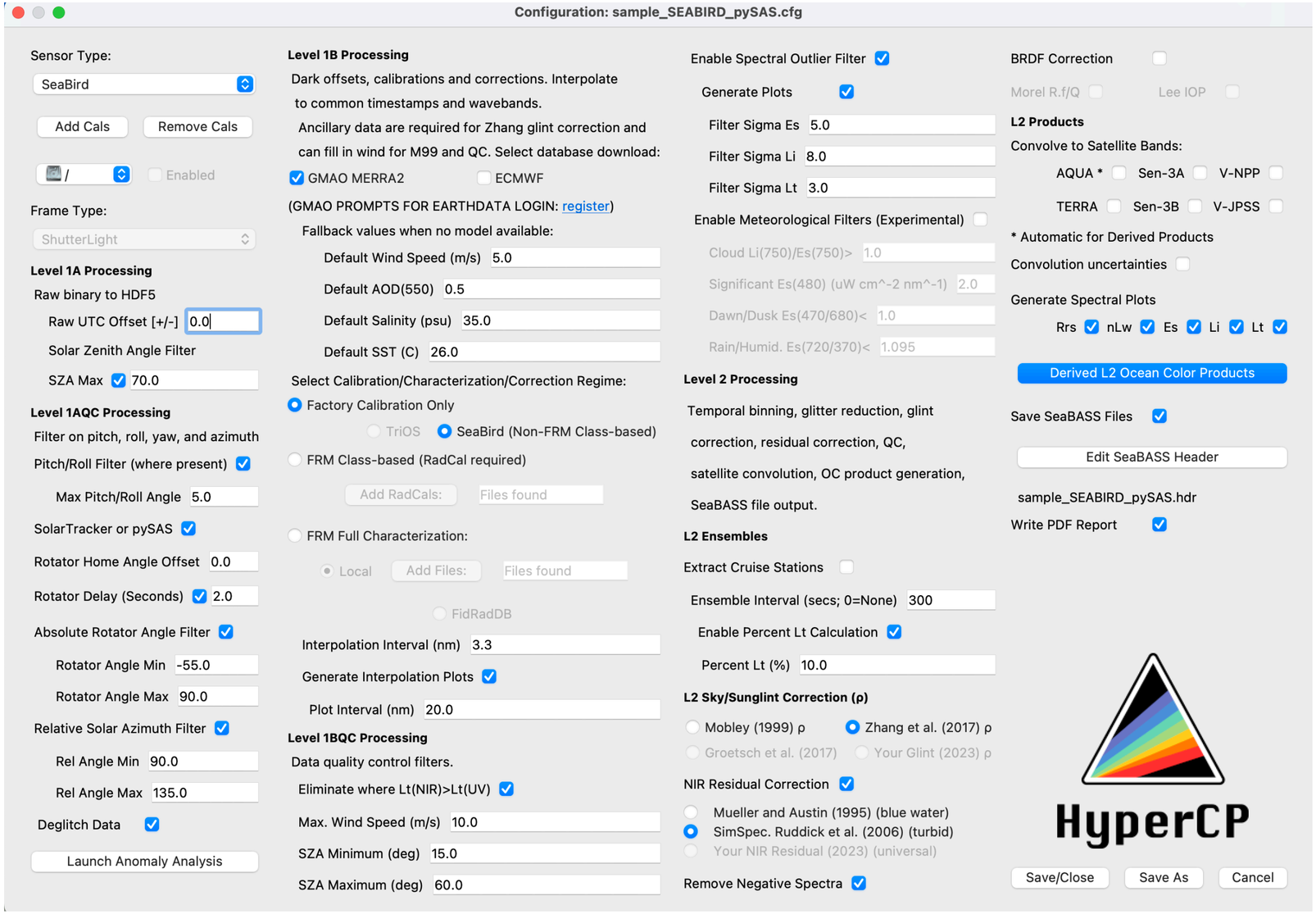
BRDF Correction [optional]
Apply BRDF correction to adjust reflectance for zenith sensor and sun in a non-absorbing atmosphere (e.g., for satellite comparison/validation)

Glint Correction
Most critically, correct total upwelling radiance for the Fresnel reflection of sun and sky (glint) yielding Lw from which reflectance is calculated.

NIR Residual Correction
Remove residual glint identified from reflectances in the NIR, followed by removing any ensemble reflectances that have negative values (VIS).

HyperCP is always under development to stay abreast of emerging science!

HyperCP Level 2: Corrections…



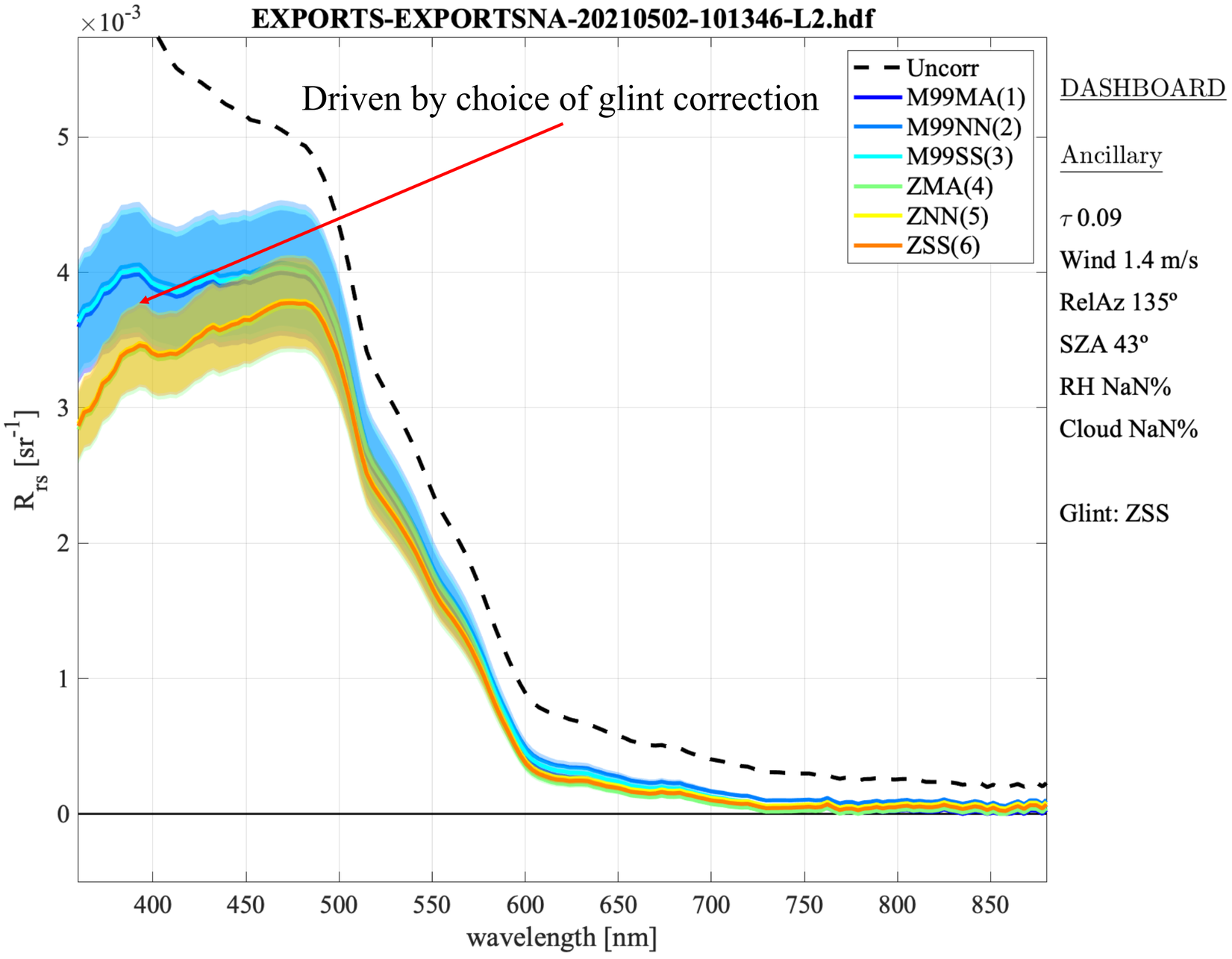
Broadly speaking, the best practices are:

In clear offshore waters

- **ρ** glint factor: Mobley 1999
- NIR residual correction: Mueller and Austin 1995
- f/Q BRDF correction: Morel 2002

More turbid, optically complex waters

- **ρ** glint factor: Zhang et al. 2017 (hyperspectral with polarization)
- NIR residual correction: the Similarity Spectrum approach of Ruddick et al. 2006
- BRDF correction: Lee et al. 2010 IOP-based BRDF correction (pending)



HyperCP

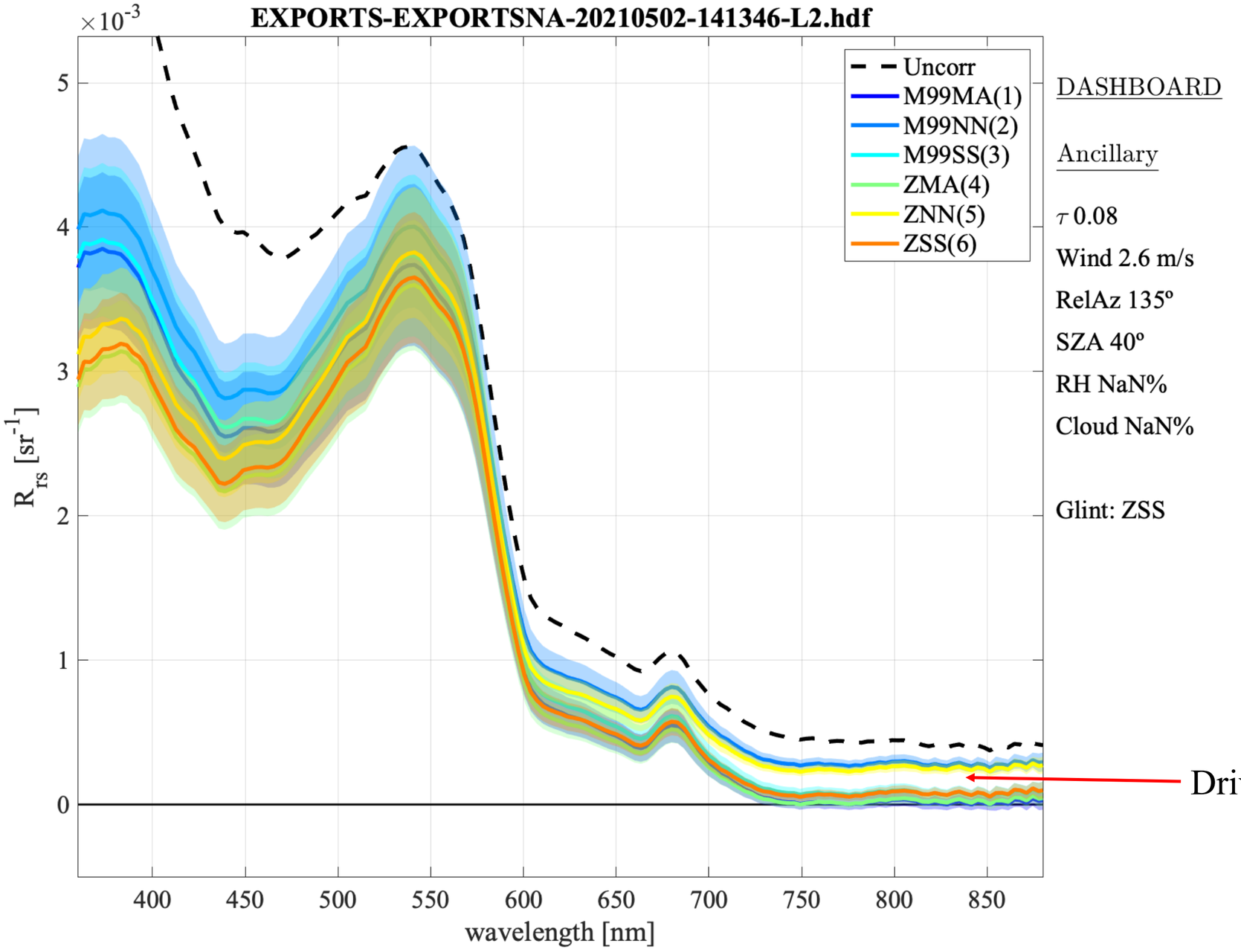
Comparison between various glint and NIR residual corrections of the same L2 ensemble reflectance spectrum where

Glint Correction:

- **M99**: Mobley 1999
- **Z**: Zhang et al. 2017

NIR Residual Glint Correction:

- **NN**: No NIR correction
- **MA**: Mueller and Austin 1995
- **SS**: SimSpec (Ruddick et al. 2006)



DASHBOARD

Ancillary

τ 0.08

Wind 2.6 m/s

RelAz 135°

SZA 40°

RH NaN%

Cloud NaN%

Glint: ZSS

HyperCP

Comparison between various glint and NIR residual corrections of the same L2 ensemble reflectance spectrum where

Glint Correction:

- **M99**: Mobley 1999
- **Z**: Zhang et al. 2017

NIR Residual Glint Correction:

- **NN**: No NIR correction
- **MA**: Mueller and Austin 1995
- **SS**: SimSpec (Ruddick et al. 2006)

Driven by choice of NIR correction

HyperCP Level 2: Spectral Response Weighting for Satellite Band Convolution

Configuration: sample_SEABIRD_pySAS.cfg

Sensor Type: SeaBird

Add Cals | Remove Cals

/ Enabled

Frame Type: ShutterLight

Level 1A Processing

Raw binary to HDF5

Raw UTC Offset [+/-] 0.0

Solar Zenith Angle Filter

SZA Max 70.0

Level 1AQC Processing

Filter on pitch, roll, yaw, and azimuth

Pitch/Roll Filter (where present)

Max Pitch/Roll Angle 5.0

SolarTracker or pySAS

Rotator Home Angle Offset 0.0

Rotator Delay (Seconds) 2.0

Absolute Rotator Angle Filter

Rotator Angle Min -55.0

Rotator Angle Max 90.0

Relative Solar Azimuth Filter

Rel Angle Min 90.0

Rel Angle Max 135.0

Deglitch Data

Launch Anomaly Analysis

Level 1B Processing

Dark offsets, calibrations and corrections. Interpolate to common timestamps and wavebands.

Ancillary data are required for Zhang glint correction and can fill in wind for M99 and QC. Select database download:

GMAO MERRA2 ECMWF

(GMAO PROMPTS FOR EARTHDATA LOGIN: register)

Fallback values when no model available:

Default Wind Speed (m/s) 5.0

Default AOD(550) 0.5

Default Salinity (psu) 35.0

Default SST (C) 26.0

Select Calibration/Characterization/Correction Regime:

Factory Calibration Only

TriOS SeaBird (Non-FRM Class-based)

FRM Class-based (RadCal required)

Add RadCals: Files found

FRM Full Characterization:

Local Add Files: Files found

FidRadDB

Interpolation Interval (nm) 3.3

Generate Interpolation Plots

Plot Interval (nm) 20.0

Level 1BQC Processing

Data quality control filters.

Eliminate where Lt(NIR)>Lt(UV)

Max. Wind Speed (m/s) 10.0

SZA Minimum (deg) 15.0

SZA Maximum (deg) 60.0

Enable Spectral Outlier Filter

Generate Plots

Filter Sigma Es 5.0

Filter Sigma Li 8.0

Filter Sigma Lt 3.0

Enable Meteorological Filters (Experimental)

Cloud Li(750)/Es(750)> 1.0

Significant Es(480) (uW cm^-2 nm^-1) 2.0

Dawn/Dusk Es(470/680)< 1.0

Rain/Humid. Es(720/370)< 1.095

Level 2 Processing

Temporal binning, glitter reduction, glint correction, residual correction, QC, satellite convolution, OC product generation, SeaBASS file output.

L2 Ensembles

Extract Cruise Stations

Ensemble Interval (secs; 0=None) 300

BRDF Correction

Morel R.f/Q Lee IOP

L2 Products

Convolve to Satellite Bands:

AQUA * Sen-3A V-NPP

TERRA Sen-3B V-JPSS

* Automatic for Derived Products

Convolution uncertainties

Generate Spectral Plots

Rrs nLw Es Li Lt

Derived L2 Ocean Color Products

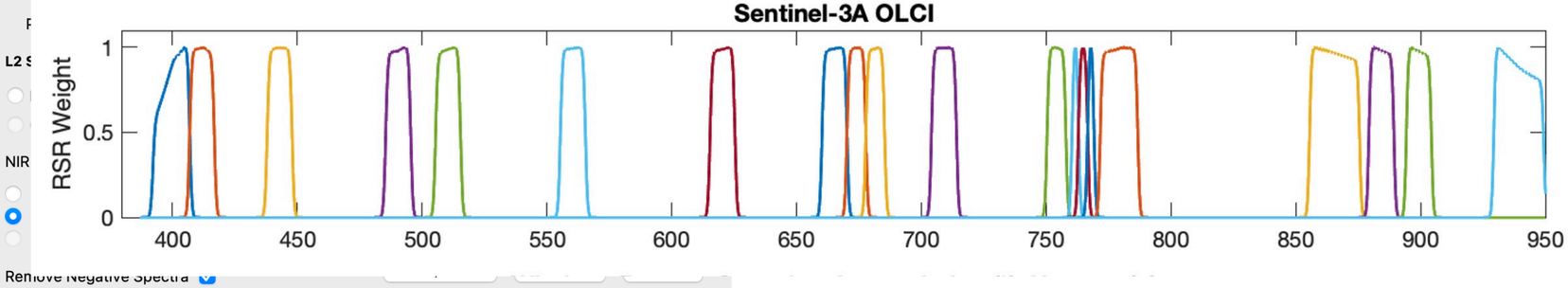
Save SeaBASS Files

Edit SeaBASS Header

sample_SEABIRD_pySAS.hdr

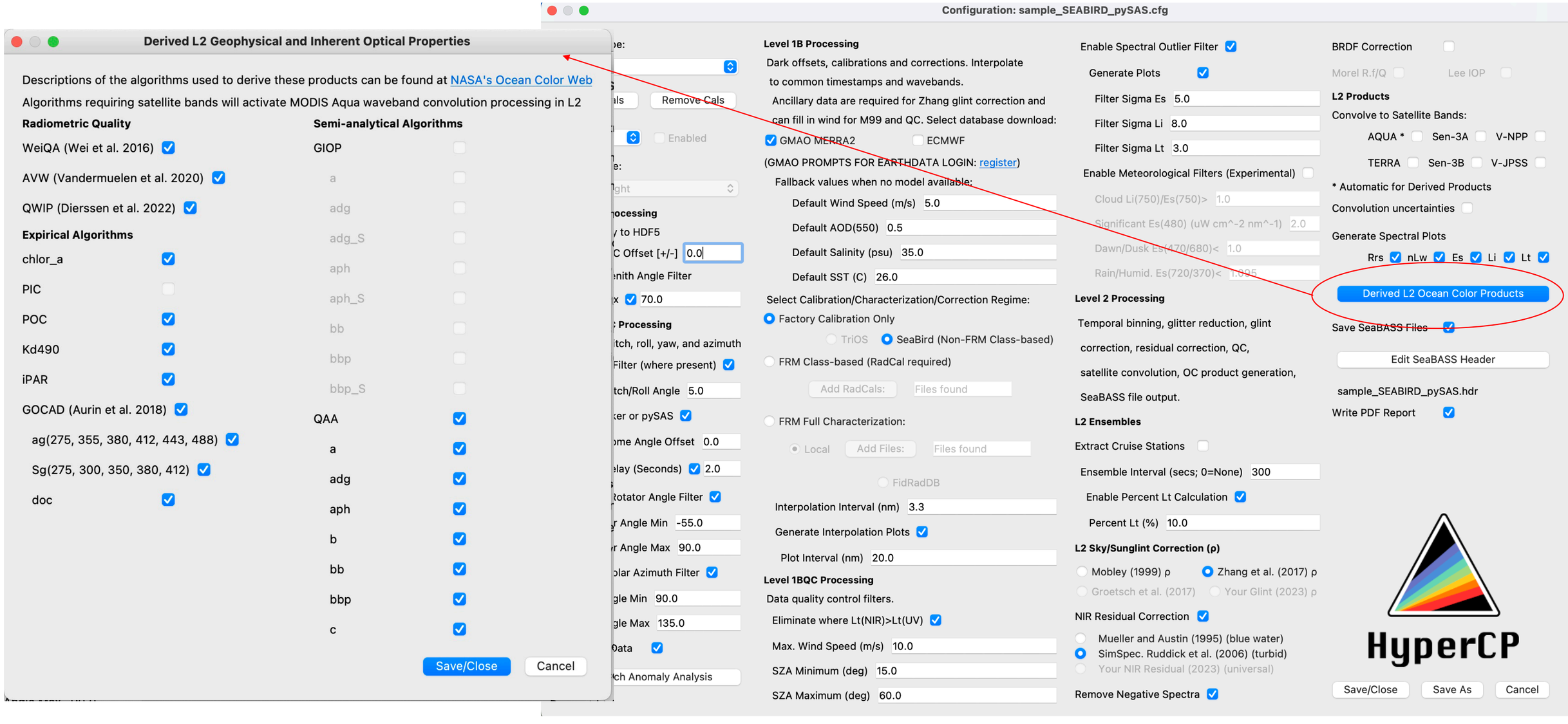
Write PDF Report

Relative Spectral Response (RSR) weighting functions for various multi-spectral satellite sensors are included in order to accurately convolve the hyperspectral L2 (ir)radiances to satellite bands for comparison/validation. (Ir)radiances are convolved prior to reflectance calculations.



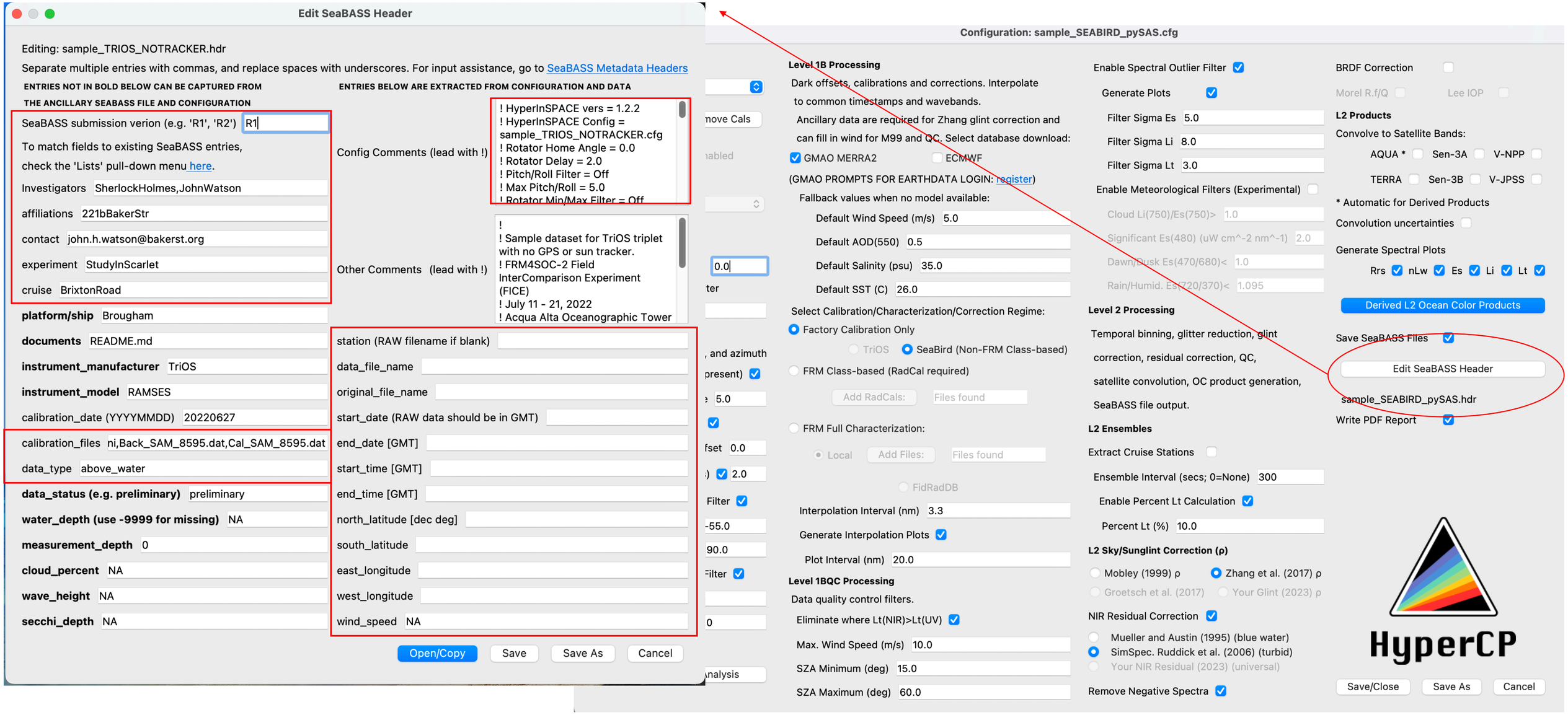
HyperCP Level 2: Derived Products

Several ocean color algorithms for deriving geophysical and inherent optical properties are provided (see README for sources). More are anticipated. Uses spectra convolved to MODIS Aqua bands.



HyperCP Output: SeaBASS & HDF5

Red boxed can be autofilled. Fill in the rest as appropriate.

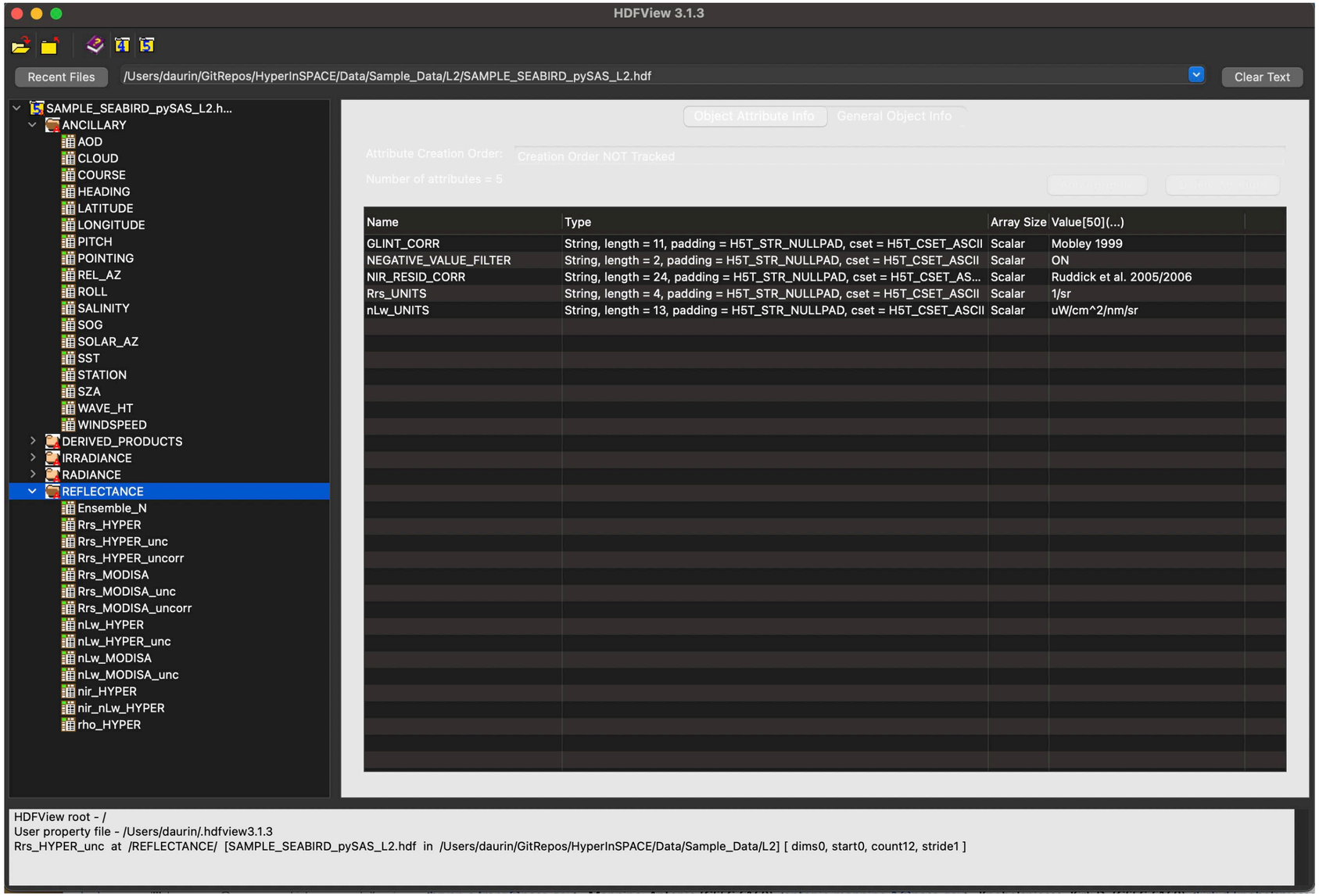


L2 Output

Data and Reports

HyperCP HDF5 Files

HyperCP



HyperCP L2 SeaBASS Files

HyperCP

BogieAndBacall_TheBigSleep_WarnerBros_HyperSAS_201605

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! Rotator Max = 45.0
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! Deglitch Filter = On
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! ES Light Window = 5
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BogieAndBacall_TheBigSleep_WarnerBros_HyperSAS_20160520_0

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! ES Dark Sigma = 3.2
! ES Light Sigma = 3.5
! LI Dark Window = 11
! LI Light Window = 5
! LI Dark Sigma = 3.4
! LI Light Sigma = 3.0
! LT Dark Window = 11
! LT Light Window = 5
! LT Dark Sigma = 3.5
! LT Light Sigma = 3.2
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! Default AOD = 0.5
! Default Salt = 35.0
! Default SST = 26.0
! Max Wind = 10.0
! Min SZA = 20.0
! Max SZA = 60.0
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! Es Flag = 2.0
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! Rain/Humidity Flag = 1.095
! Ensemble Interval = 300
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! Percent Light = 10.0
! Glint_Correction = Mobley 1999
! NIR Correction = Mueller and Austin 1995
! Remove Negatives = On
! DateTime Processed = Fri Jun  2 11:28:12 2023
!
! HyperSAS with Sea-Bird SolarTracker
! Collected around Korean peninsula on RV Onnuri in association with KORUS-OC campaig
KR_2016
/
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BogieAndBacall_TheBigSleep_WarnerBros_HyperSAS_20160520_070223_L2_Rrs_R0.sb

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```

HyperCP Processing Report (PDF)

Processing Reports

File: SAMPLE_SEABIRD_pySAS Col

L1BQC : Process L1B to L1BQC

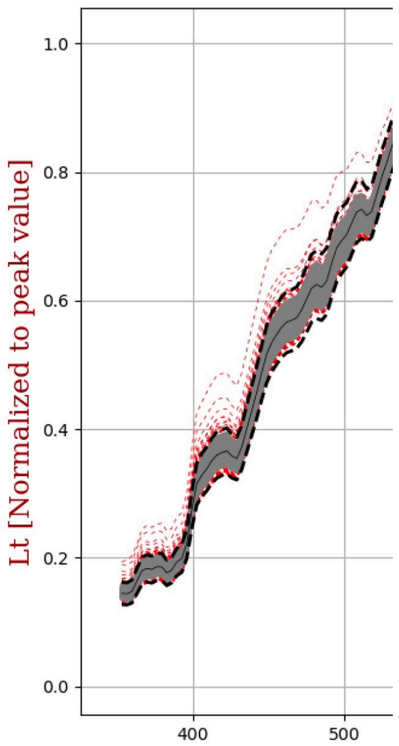
Apply more quality control filters.

Processing Parameters:
Max Wind: 10.0
Min SZA: 15.0
Max SZA: 60.0
Filter Sigma Es: 5.0
Filter Sigma Li: 8.0
Filter Sigma Lt: 3.0

Process log:

Process Single Level
Applying Lt(NIR)>Lt(UV) quality filtering to elin
0.0% of spectra flagged
Percentage of data out of Wind limits: 0 %
Percentage of data out of SZA limits: 0 %
Applying spectral filtering to eliminate noisy spec
0.4% of Es data flagged
0.0% of Li data flagged
4.6% of Lt data flagged
Remove IRRADIANCE Data
Length of dataset prior to removal 1076 long
Length of dataset after removal 1022 long: 5% removed
Remove RADIANCE Data
Length of dataset prior to removal 1076 long
Length of dataset after removal 1022 long: 5% removed
Remove ANCILLARY Data
Length of dataset prior to removal 1076 long
Length of dataset after removal 1022 long: 5% removed

L1BQC Spectral Filter

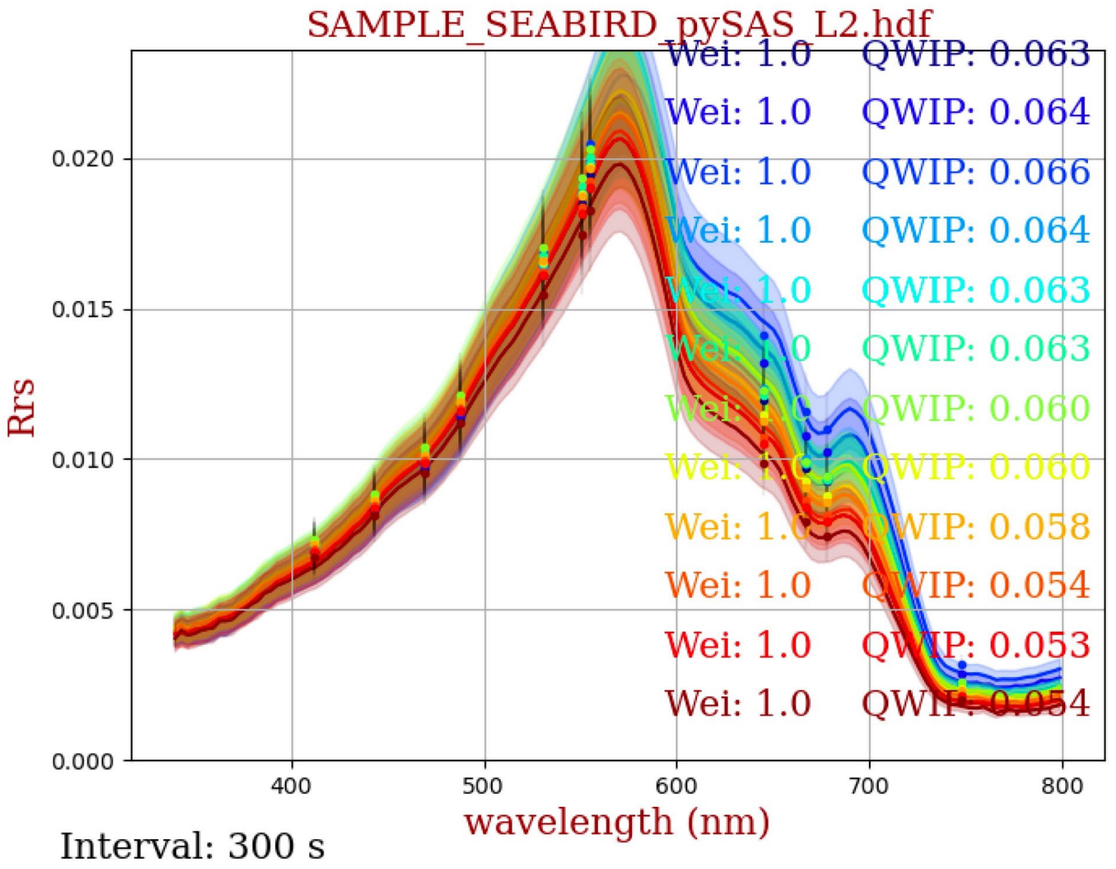


GUI or CLI

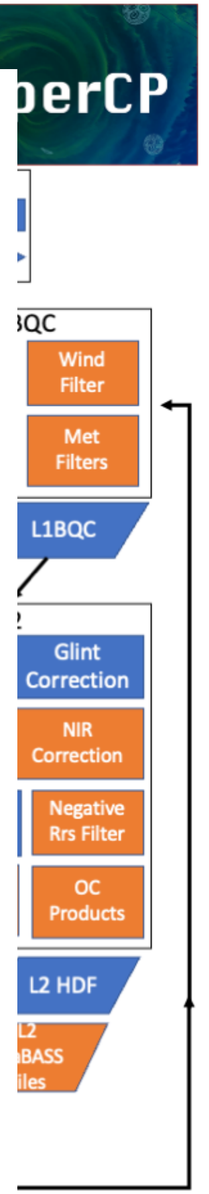
v1.2

File: SAMPLE_SEABIRD_pySAS Collected: Sat May 01 05:54:30 2021

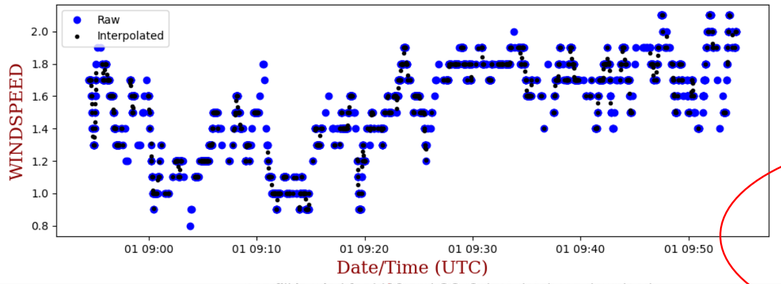
L2 Ensembles Rrs with uncert., convolutions, scores…

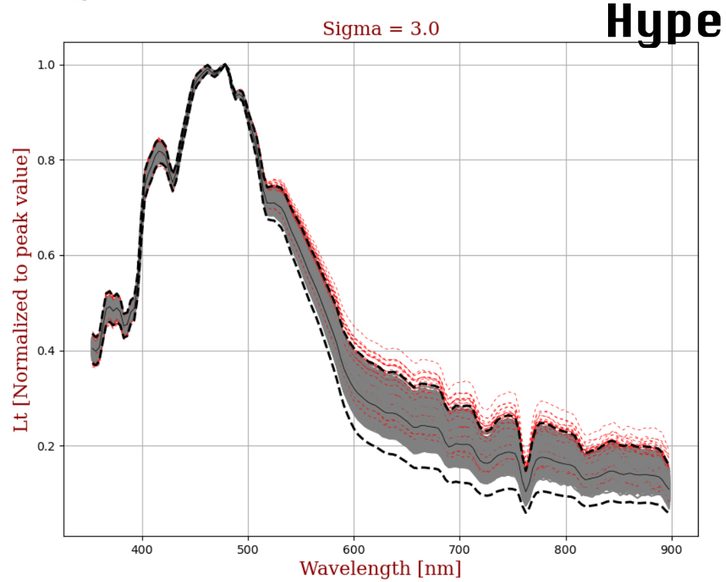


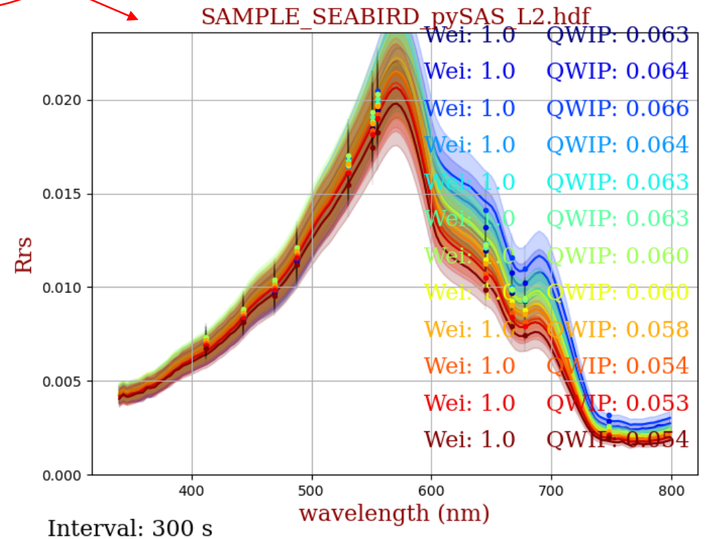
Interval: 300 s



HyperCP Plots for Diagnostics and QC



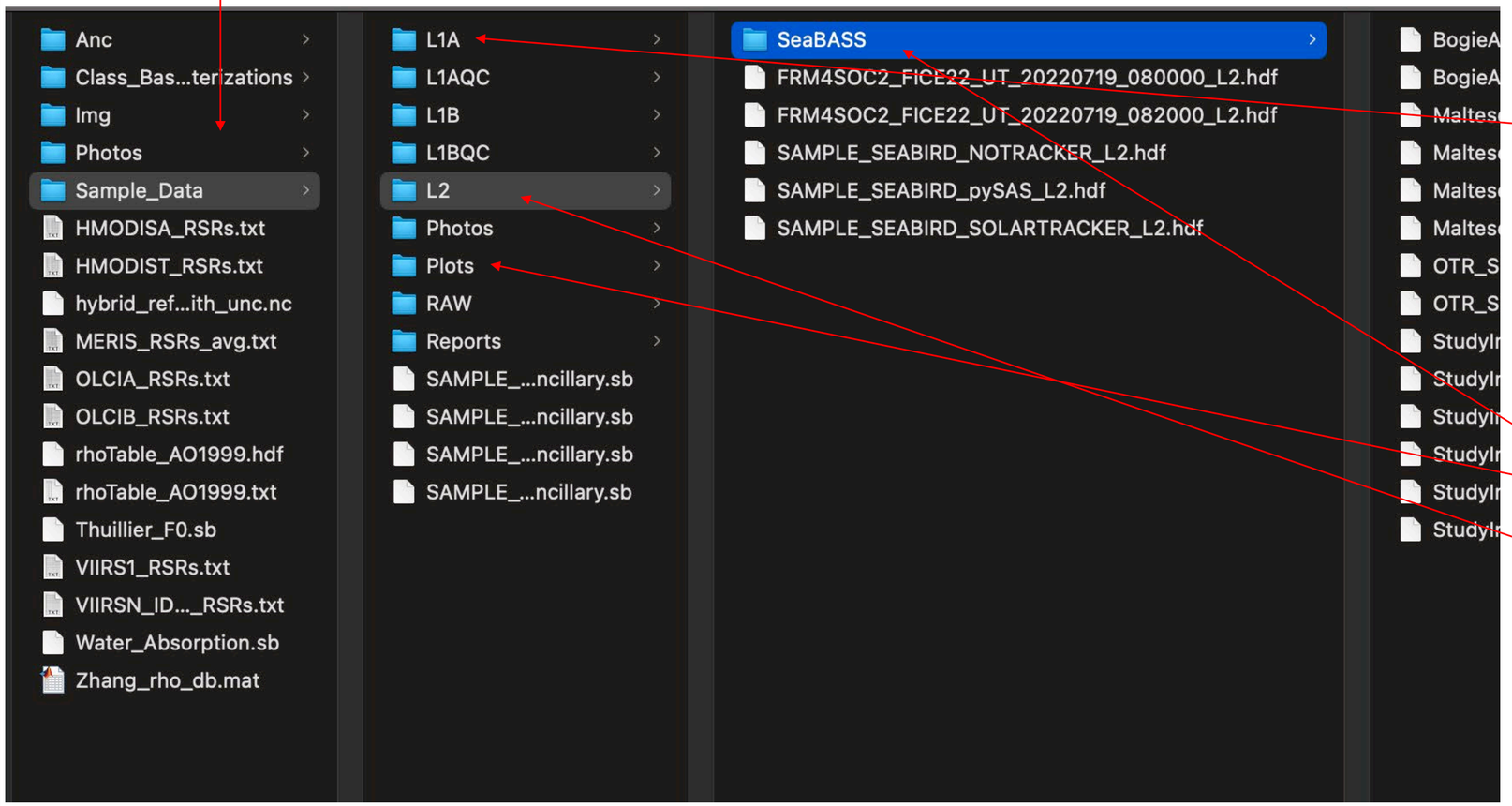


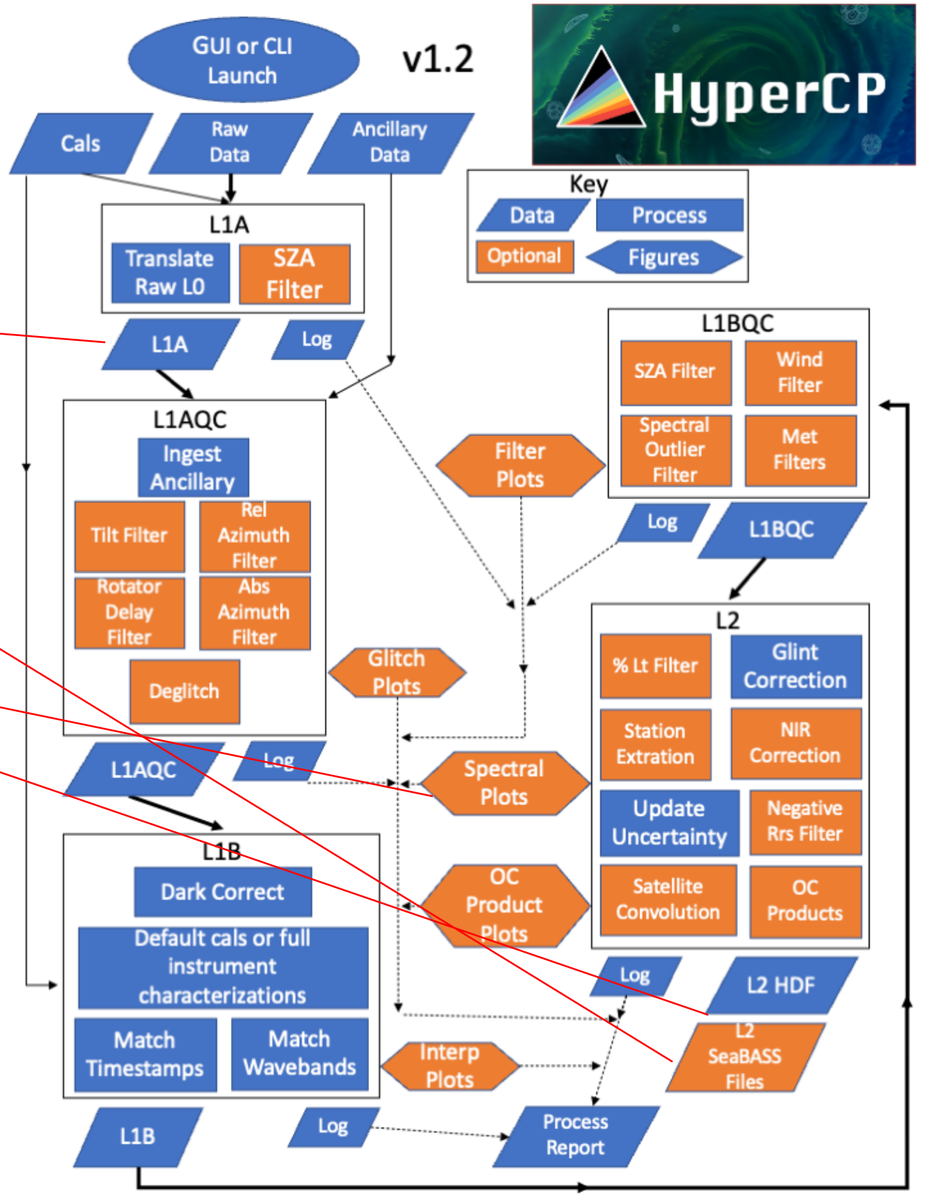


Interval: 300 s

HyperCP Data Directory Overview

Chosen Data Output Folder (Main Window)





Conclusion

Above all, don’t be discouraged if it doesn’t run seamlessly the first time.

Stay up-to-date with latest version before you process

```
› git pull
```

Don’t forget to activate the environment before you run:

```
› conda activate hypercp
› python Main.py
```

A recent major overhaul to v1.2 may have some bugs still, so feel free to report Issues or start Discussions on GitHub!

GODDARD EARTH SCIENCES

HyperCP