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@NPL
#EOMetrology

Uncertainties in ~~sea level and sea ice thickness~~ ocean variables measured from satellites

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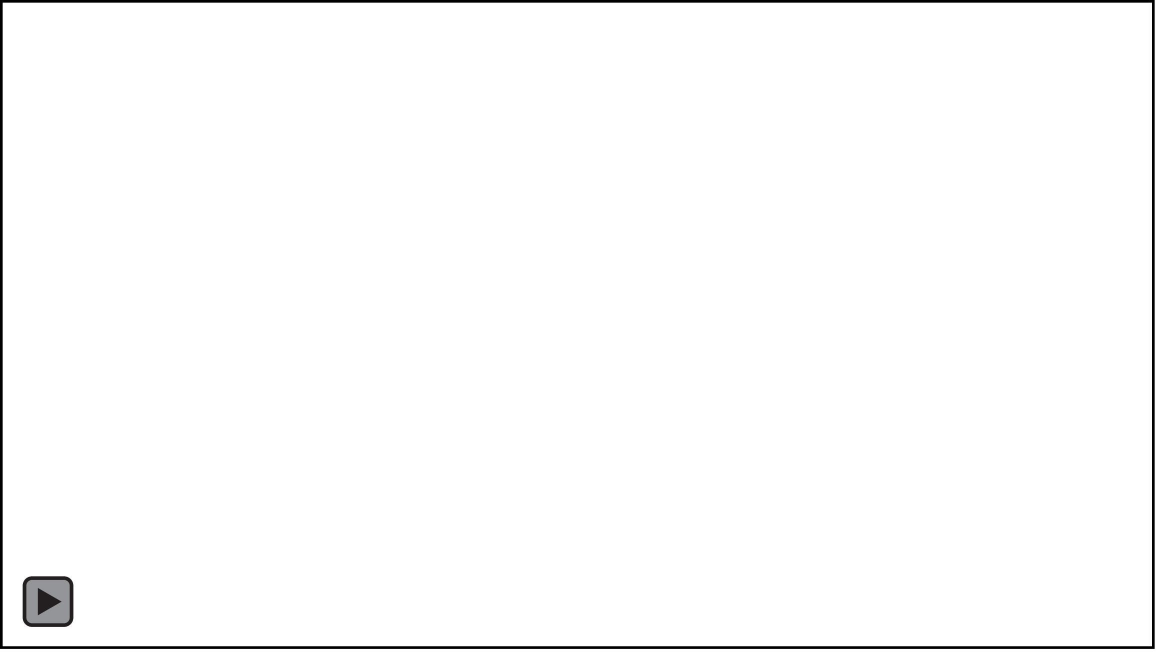
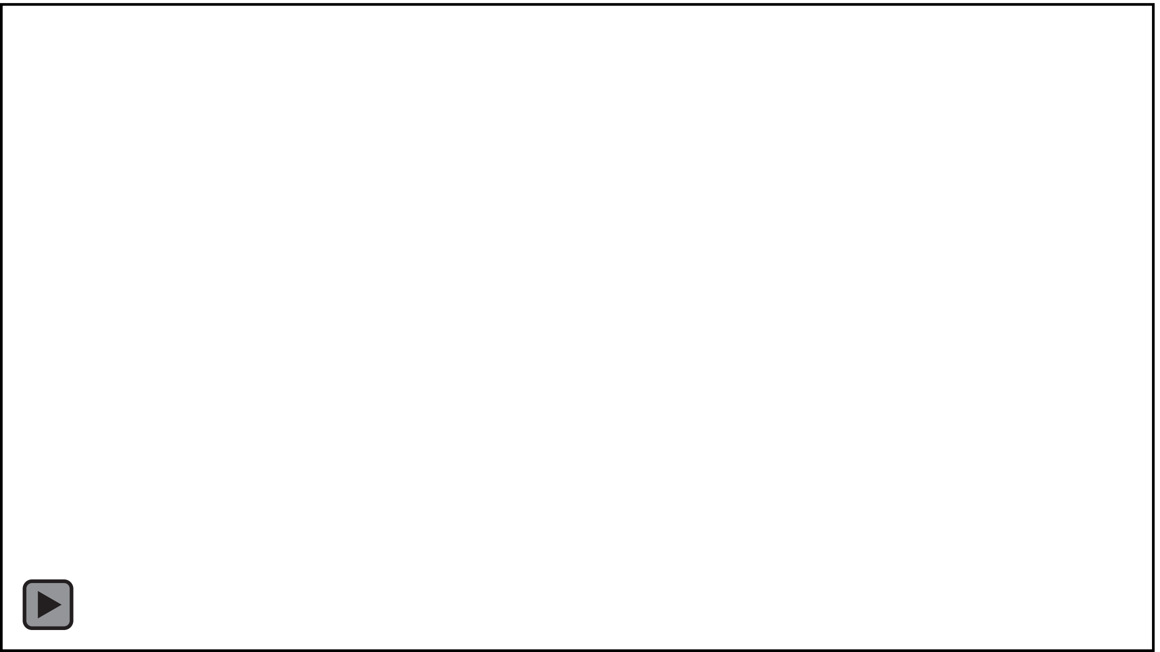
Chair of the European Metrology Network for Climate and Ocean Observation



©ESA (Data source: (below: SST) CLS/OSTIA, 2020, (above: SLA) CMEMS 2019)



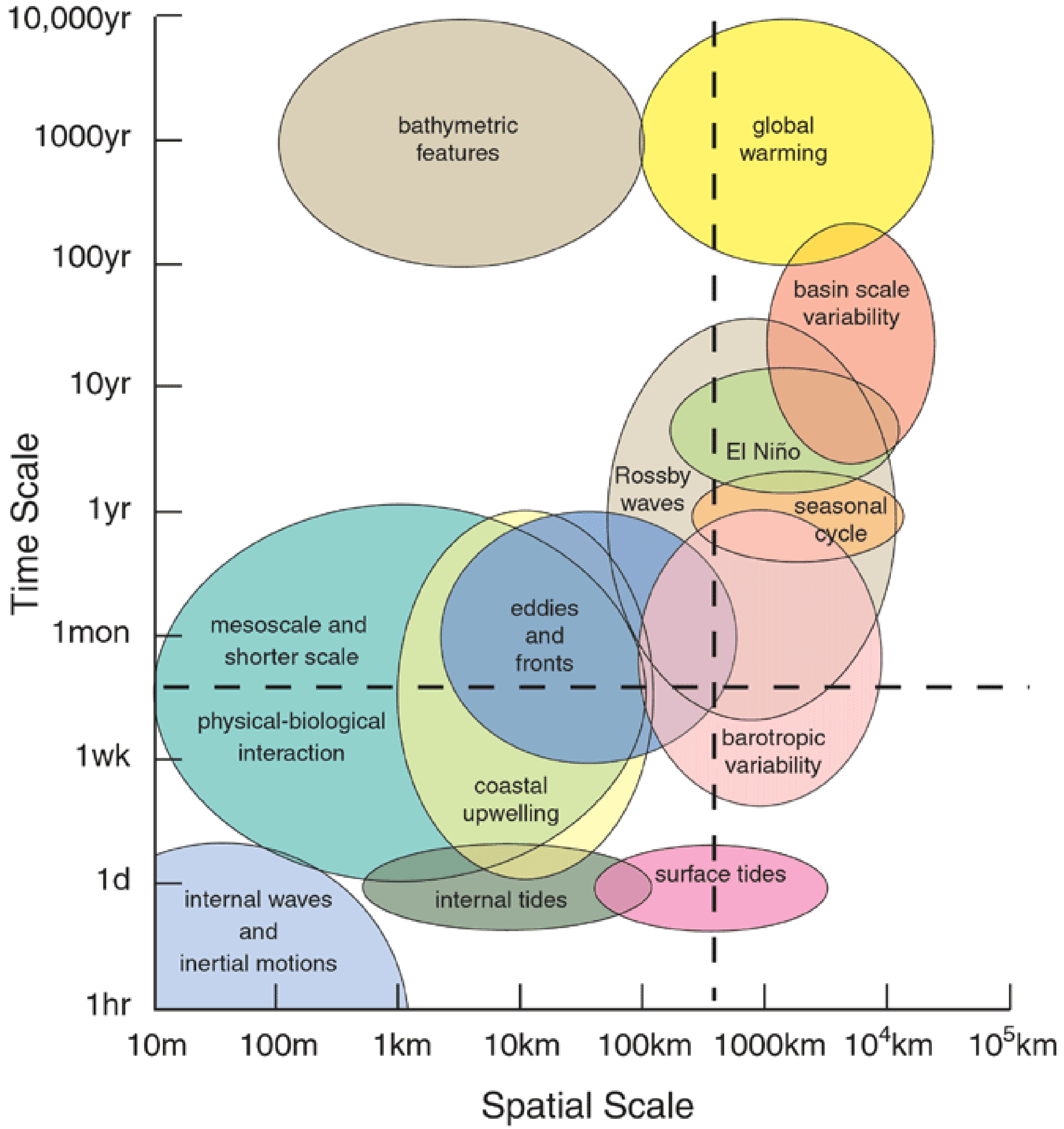
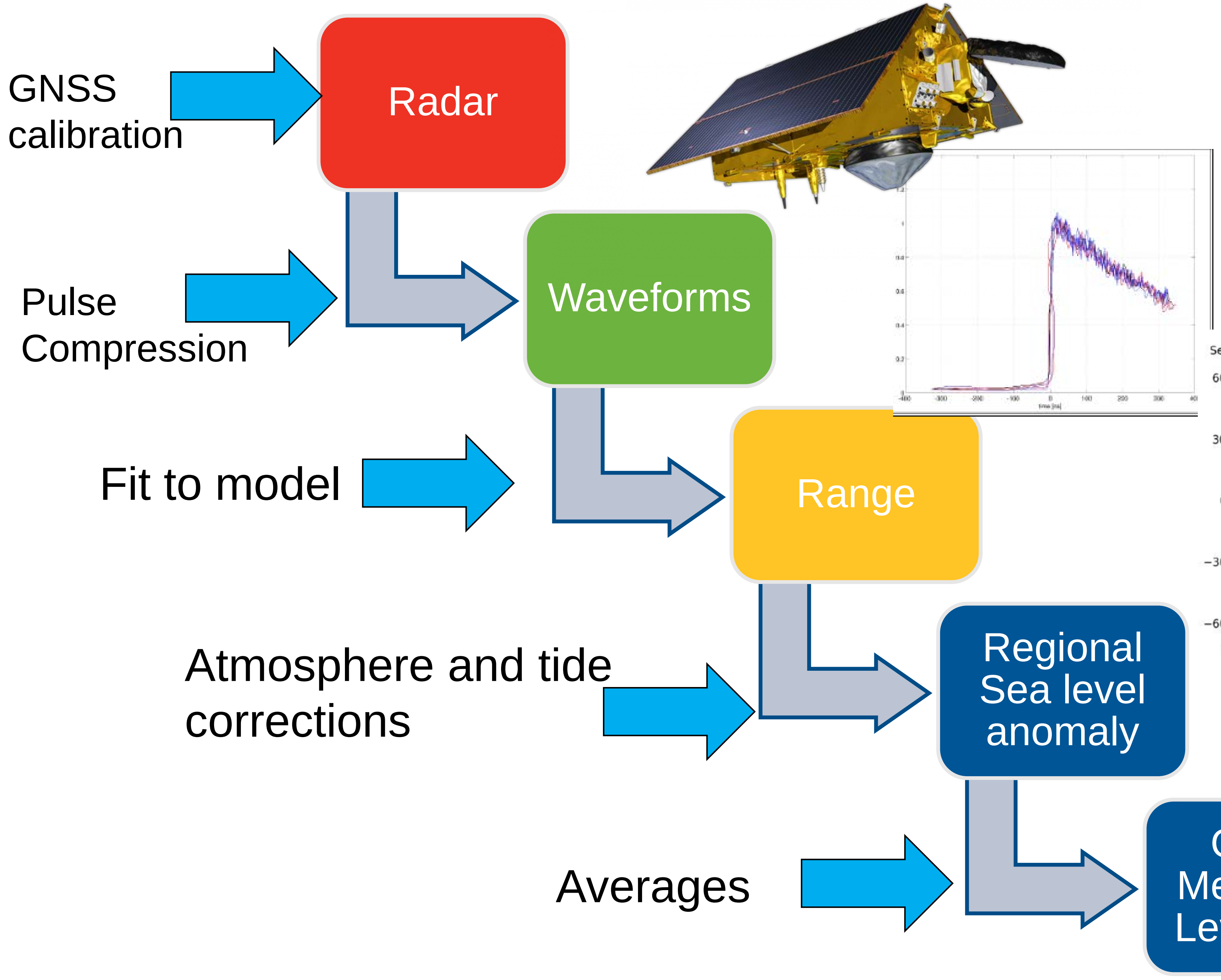
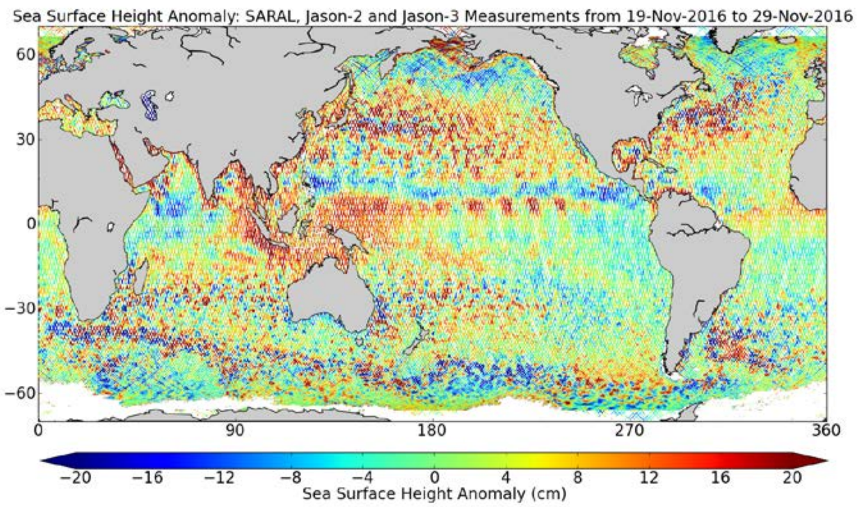
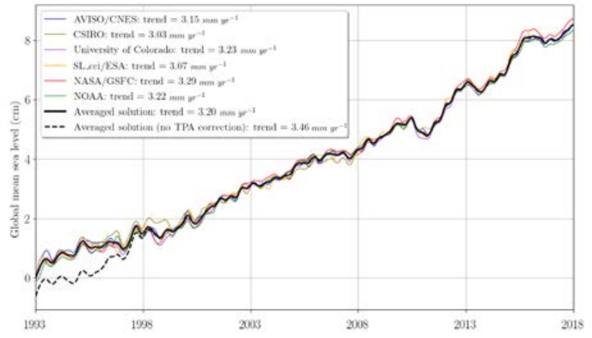


Image: High-Resolution Ocean Topography Science Working Group
https://ceoas.oregonstate.edu/hotswg



How do you pass enough uncertainty information down the chain?



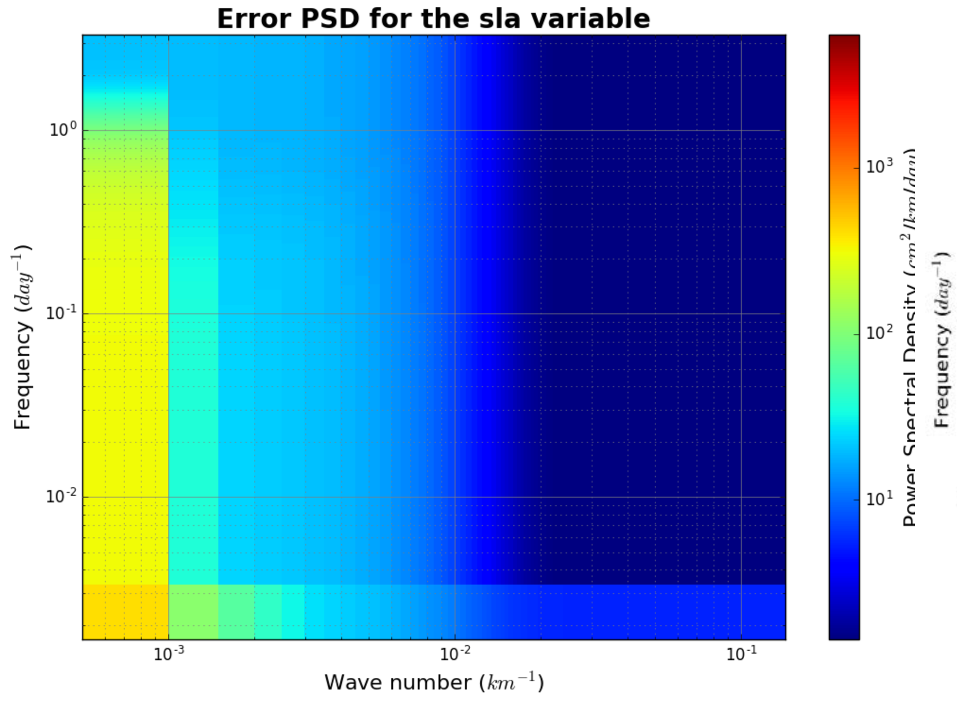


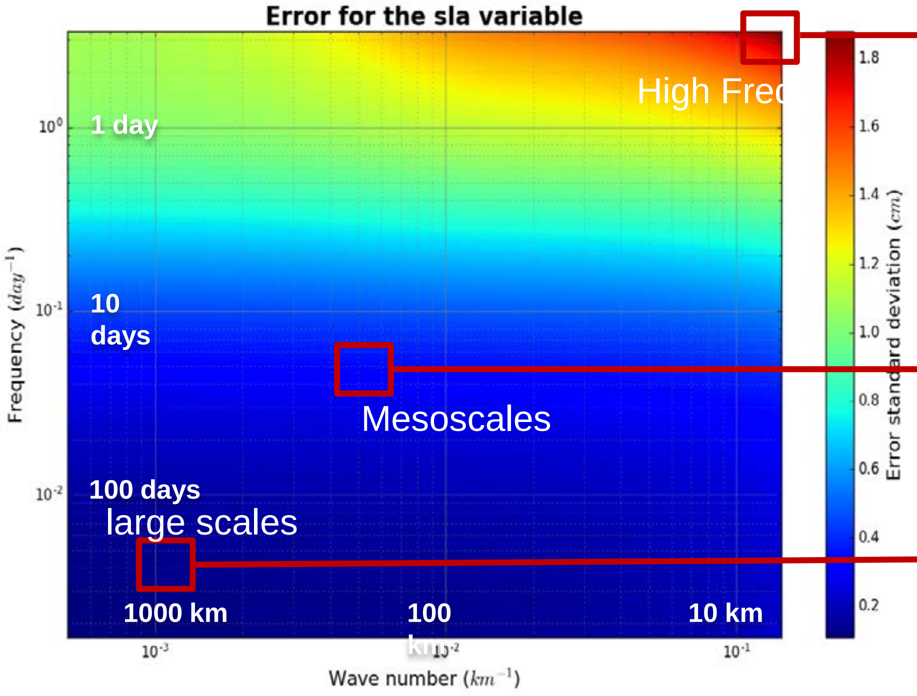
Sentinel-3 Altimeter Performances over ocean

Slide by Pierre Thibault, CLS
Presented at OSTST Oct 2019

SAR Ku, Closed Burst
B=320 MHz
Rad 2 chanels (23/36)
Aux. Band = C band

Error Source	STD (cm)	Spatial correlation length	Temporal correlation length	References
Altimeter Random error	1,2	0 km	0 day	S3 performance doc (CLS)
SSB Noise	0,3	300 km	Inf.	S3 performance doc (CLS)
SSB correlated	0,1	100 km	1 day	Tran & al, 2019
Ionosphere	0,15	600 km	0 day	S3 performance doc (CLS)
Wet Troposphere	1	50 km	1 hour	Brown & al, 2015; Stum & al, 2011
Dry Troposphere	0,2	600 km	2 days	S3 performance doc (CLS)
Mean Sea Surface	0,5	1 km	Inf.	Pujol & al, 2018
Ocean Tides	1	1000 km	< 1 day	Lyard & al, 2018
Orbit solution	1,5	> 10 000 km	< 1 day	Ollivier & al, 2018; Couhert & al, 2015





: 1.86 cm @ very short scales

= 0.34 cm @ meso scales

= 0.11 cm @ large scales

Framework for Uncertainty Analysis for Earth Observation Products (and more)

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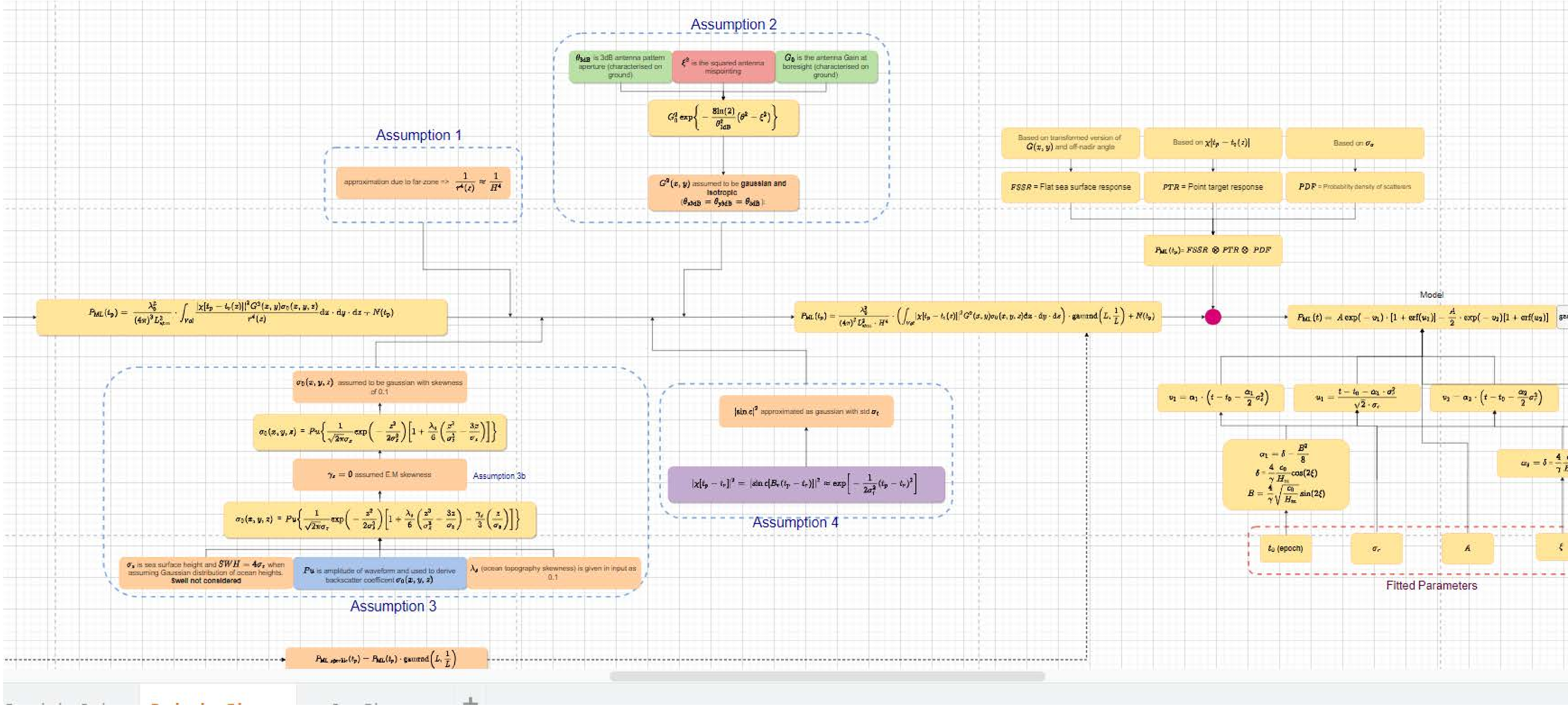
- Understand the observation itself, the processing, traceability and sources of uncertainty with diagrams
- Document, for all sources of uncertainty, the information necessary to propagate that uncertainty including error correlation information in a systematic manner
- Perform your analysis
- Record your analysis (and the maturity of your analysis) for long-term data preservation purposes
- Provide the uncertainty and error correlation information to those who will use the data – giving them the detail they need, but in a simplified way

Example projects

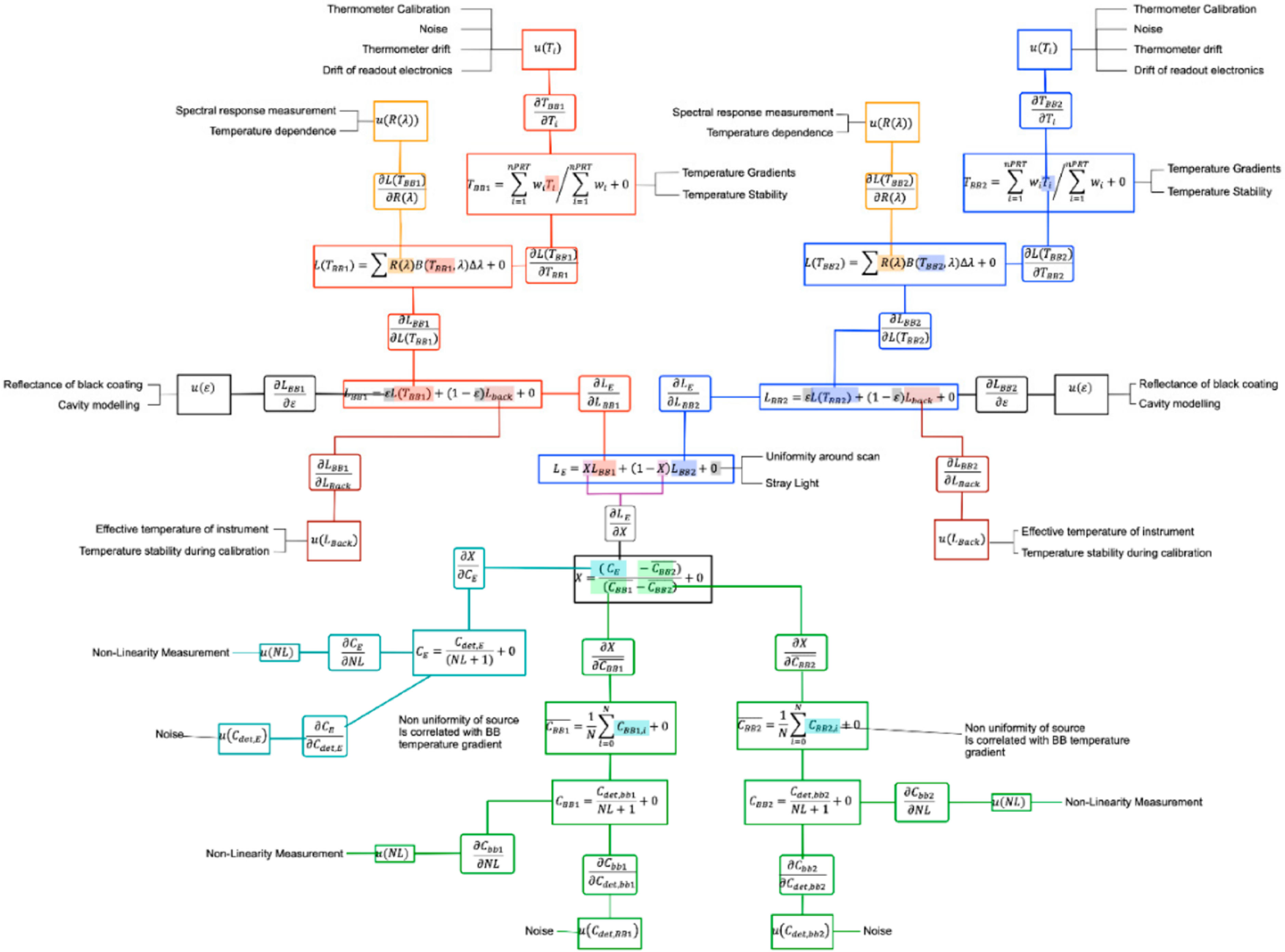
National Physical Laboratory

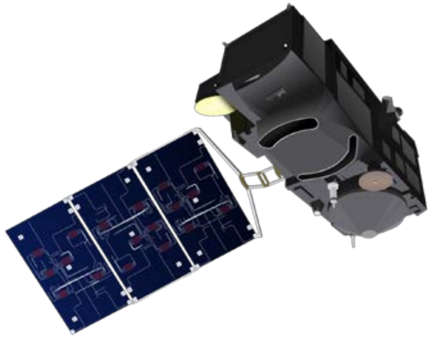
- Sea Surface Temperature from thermal infrared radiometers going back to the 1980s (FIDUCEO project)
- Sea level rise from radar altimeters (historical and modern, and designing next generation) (ASELSU and FDR4ALT)
- Sea ice thickness, land ice thickness and inland water height from satellite altimeters and the in situ measurements to validate them (FDR4ALT and St3TART)
- Ocean Colour (used to determine phytoplankton) from satellites and in situ instruments (FRM4SOC, ROSACE, MetEOC)
- Surface reflectance from satellites and in situ products over deserts, oceans and vegetated sites (trees and crops) (MetEOC, FRM4Veg)
- Atmospheric composition from atmospheric sensors (FDR4ATMO)
- Measurements of the Moon as a reference for reflectance calibration (LIME)

Understand the observation itself, the processing, traceability and sources of uncertainty with diagrams

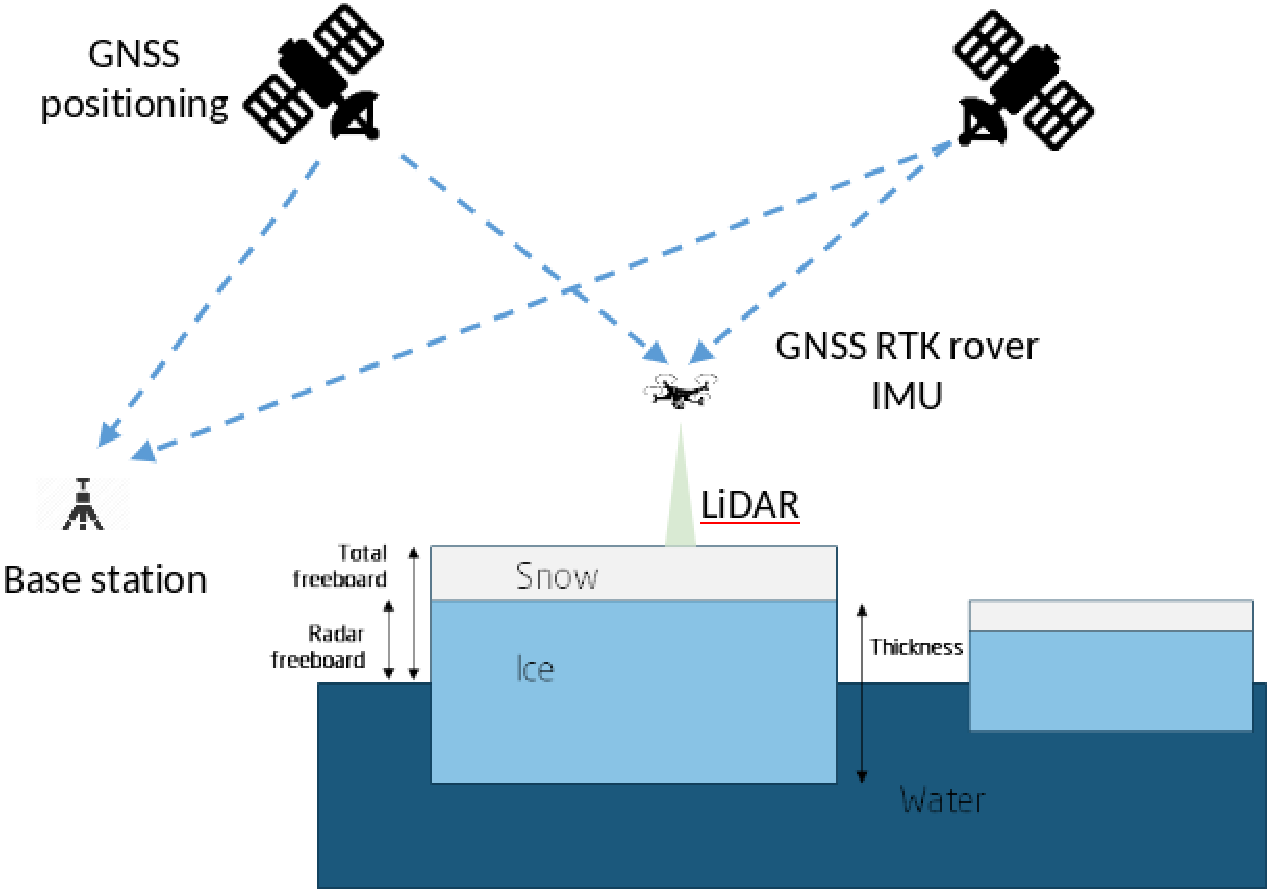


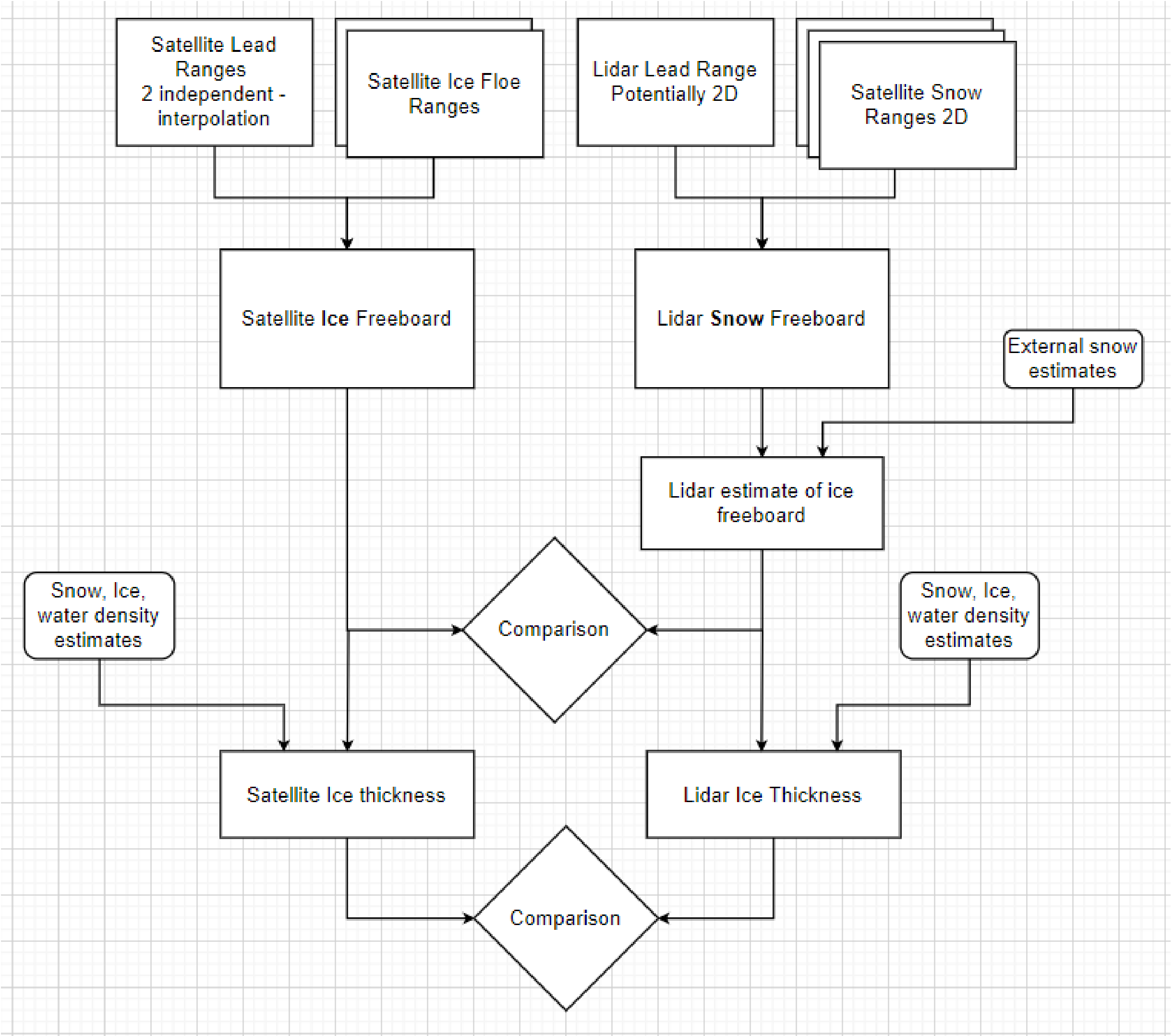
Sentinel 3 SLSTR – uncertainty tree diagram





Sea Ice Thickness





What do we need to know about different sources of uncertainty?

Cause of uncertainty

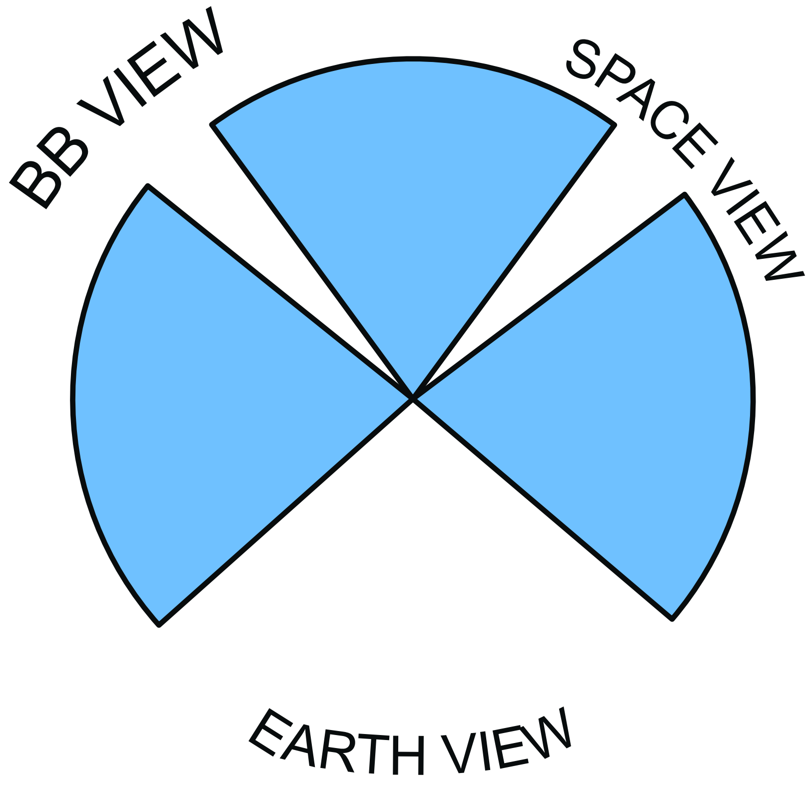
Magnitude of uncertainty and sensitivity coefficient (or how it propagates to measurand)

Error correlation form, and scale

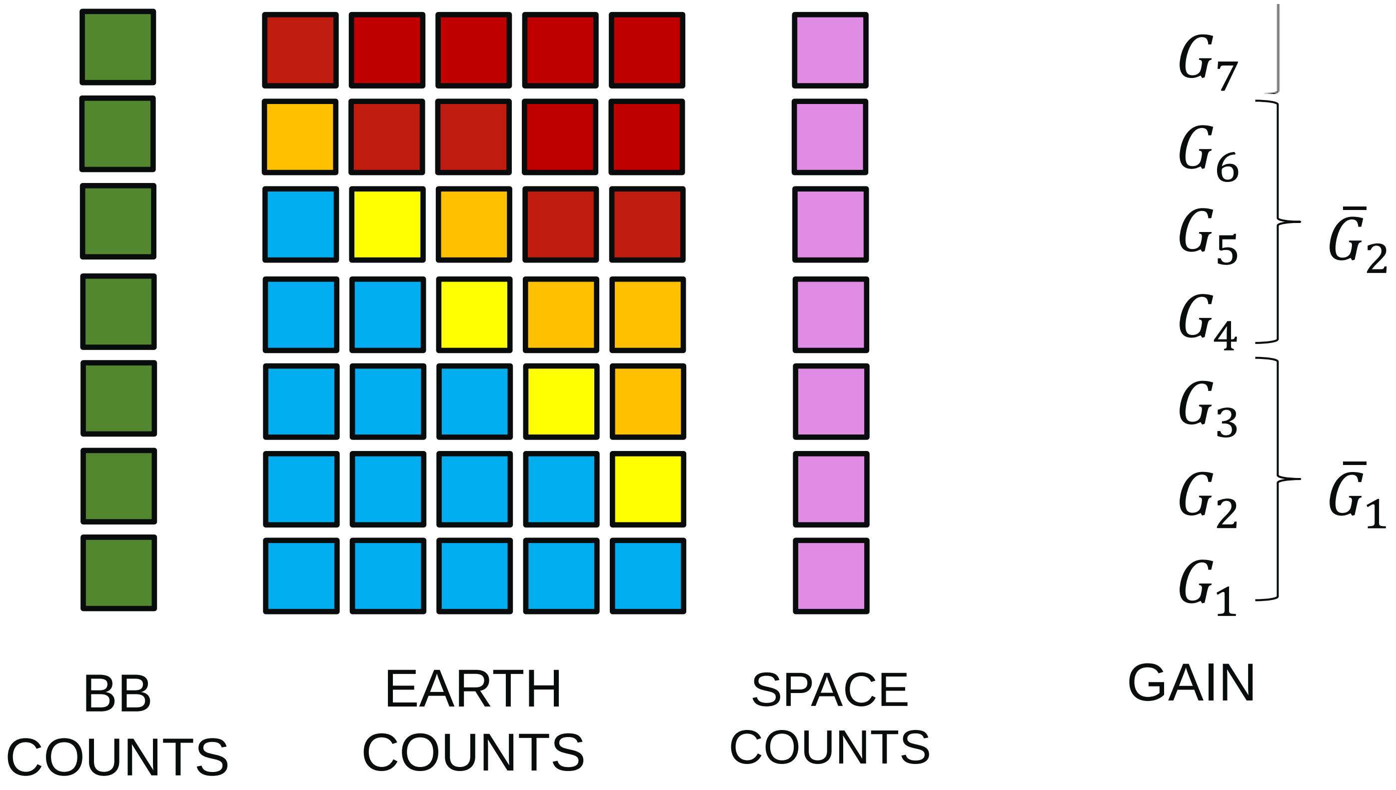
How mature our estimate of these things is

Example of a Sea Surface Temperature Radiometer

National Physical Laboratory



Sea surface temperature – TIR Radiometer – Example



Uncertainties in SST radiometer: Error correlation scales in different dimensions

National Physical Laboratory

Source of uncertainty	Error correlation across track	Error correlation along track	Error correlation from spectral band to spectral band
Emissivity of the blackbody target (measured before launch)	Fully correlated	Fully correlated	Fully correlated
Temperature of the BB target (measured every 50 scan lines)	Fully correlated	Partially correlated – dropping in triangular fashion over 50 scanlines	Fully correlated
Signal (counts) when looking at the BB	Fully correlated	Partially correlated – dropping in triangular fashion over 50 scanlines	Uncorrelated
Signal (counts) when looking at the Earth	Uncorrelated	Uncorrelated	Uncorrelated

Standardised Error-Covariance Metadata: Digital Effects Tables (with NPL CoMET software)

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		Comments
Name of effect		A unique name
Affected term in measurement function		Name and standard symbol
Instruments in the series affected		List names
Correlation type and form	Pixel-to-pixel [pixels]	From a set of defined correlation forms
	from scanline to scanline [scanlines]	
	between images [images]	
	Between orbits [orbit]	
	Over time [time]	
Correlation scale	Pixel-to-pixel [pixels]	As needed to define type
	from scanline to scanline [scanlines]	
	between images [images]	
	Between orbits [orbit]	
	Over time [time]	
Channels/bands	List of channels / bands affected	Channel names
	Error correlation coefficient matrix	A matrix
Uncertainty	PDF shape	Functional form
	units	Units
	magnitude	
Sensitivity coefficient		Value, equation or parameterisation of sensitivity of measurand to term

```
double u_str_temperature(x=2, y=2, time=3);
  :_FillValue = 9.969209968386869E36; // double
  :err_corr_1_dim = "x";
  :err_corr_1_form = "custom";
  :err_corr_1_units = ; // double
  :err_corr_1_params = "err_corr_str_temperature_x";
  :err_corr_2_dim = "y";
  :err_corr_2_form = "systematic";
  :err_corr_2_units = ; // double
  :err_corr_2_params = ; // double
  :err_corr_3_dim = "time";
  :err_corr_3_form = "systematic";
  :err_corr_3_units = ; // double
  :err_corr_3_params = ; // double
  :pdf_shape = "gaussian";
```

Print out of uncertainty variable attributes for netCDF file

FIDUCEO Effects Table

Digital Effects Table

Propagating uncertainty

$$\boldsymbol{CURU}^{\mathsf{T}}\boldsymbol{C}^{\mathsf{T}}$$

$$\tilde{L}_{\mathrm{ICWT,A}} = \frac{\varepsilon_{\mathrm{A}} C_{1,L}}{\lambda_{\mathrm{A}}^{5}\left(\mathbf{exp}\left[c_2/\lambda_{\mathrm{A}} T\right]-1\right)}$$

$$\tilde{L}_{\mathrm{ICWT,B}} = \frac{\varepsilon_{\mathrm{B}} C_{1,L}}{\lambda_{\mathrm{B}}^{5}\left(\mathbf{exp}\left[c_2/\lambda_{\mathrm{B}} T\right]-1\right)}$$

$$\boldsymbol{V}_{L\mathrm{E}} = \sum_{\mathrm{Effects},\, i} \boldsymbol{C}_i \boldsymbol{U}_i \boldsymbol{R}_i \boldsymbol{U}_i^{\mathrm{T}} \boldsymbol{C}_i^{\mathrm{T}}$$

Covariance Matrix for BB temperature uncertainty

$$V_{L\mathrm{E},T} = \begin{pmatrix} c_{L\mathrm{A},T} & 0 & 0 \\ 0 & c_{L\mathrm{B},T} & 0 \\ 0 & 0 & c_{L\mathrm{C},T} \end{pmatrix} \begin{pmatrix} u_T & 0 & 0 \\ 0 & u_T & 0 \\ 0 & 0 & u_T \end{pmatrix} \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} u_T & 0 & 0 \\ 0 & u_T & 0 \\ 0 & 0 & u_T \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} c_{L\mathrm{A},T} & 0 & 0 \\ 0 & c_{L\mathrm{B},T} & 0 \\ 0 & 0 & c_{L\mathrm{C},T} \end{pmatrix}^{\mathrm{T}}$$

Covariance Matrix for Earth Counts uncertainty

$$\boldsymbol{V}_{L\mathrm{E},C\mathrm{E}} = \begin{pmatrix} c_{L\mathrm{A},C\mathrm{E}} & 0 & 0 \\ 0 & c_{L\mathrm{A},C\mathrm{E}} & 0 \\ 0 & 0 & c_{L\mathrm{A},C\mathrm{E}} \end{pmatrix} \begin{pmatrix} u_{CA} & 0 & 0 \\ 0 & u_{CB} & 0 \\ 0 & 0 & u_{CC} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} u_{CA} & 0 & 0 \\ 0 & u_{CB} & 0 \\ 0 & 0 & u_{CC} \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} c_{L\mathrm{A},C\mathrm{E}} & 0 & 0 \\ 0 & c_{L\mathrm{A},C\mathrm{E}} & 0 \\ 0 & 0 & c_{L\mathrm{A},C\mathrm{E}} \end{pmatrix}^{\mathrm{T}}$$

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Support and papers

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- Training course on NPL e-learning platform www.npl.co.uk/e-learning
  Climate Data Records from Satellites (under “specialist”)
- Consolidated material being prepared for CEOS CalVal Portal (due end April)
- NPL CoMET Python tools – being prepared for release very soon (available on request)

Some example papers:

- Mittaz, Merchant, Woolliams:. **Applying principles of metrology to historical Earth observations from satellites.** *Metrologia 2019:* https://doi.org/10.1088/1681-7575/ab1705
- Ma et al. **Uncertainty Analysis for RadCalNet Instrumented Test Sites Using the Baotou Sites BTCN and BSCN as Examples.** *Remote Sens.* **2020**, *12*(11), 1696; **https://doi.org/10.3390/rs12111696**
- Smith, Hunt et al. **Traceability of the Sentinel-3 SLSTR Level-1 Infrared Radiometric Processing.** *Remote Sens.* **2021**, *13*(3), 374; **https://doi.org/10.3390/rs13030374**
- Bialek et al. **Example of Monte Carlo Method Uncertainty Evaluation for Above-Water Ocean Colour Radiometry.** *Remote Sens.* 2020, 12(5), 780; https://doi.org/10.3390/rs12050780