A metrological approach to FRMs:

Uncertainty and Traceability in the QA4EO framework

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QA4EO A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

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Endorsed by CEOS in 2010, adopted by GSICS

QA4EO Principle: It is critical that data and derived products are easily accessible in an open manner and have an associated indicator of quality traceable to reference standards (preferably SI) so users can assess suitability for their applications; i.e., 'fitness for purpose'.'

www.qa4eo.org

Core principles of metrology

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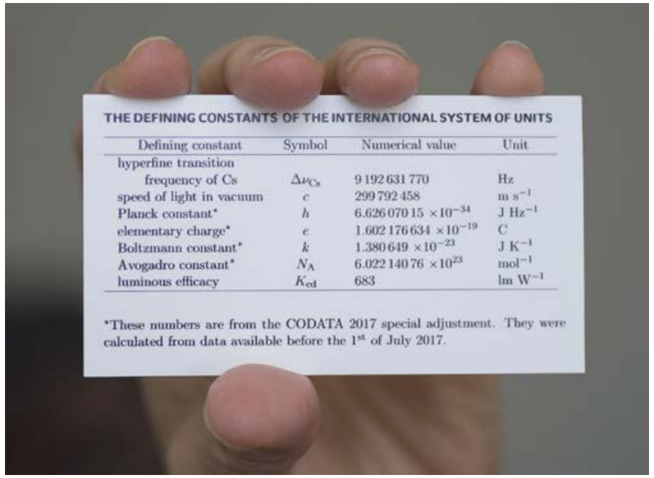
STABILITY
Century scale

INTEROPERABILITY
equivalence world wide

COHERENCE
Combining different measurements

20 May 1875



THE DEFINING CONSTANTS OF THE INTERNATIONAL SYSTEM OF UNITS

Defining constant	Symbol	Numerical value	Unit
hyperfine transition frequency of Cs	$\Delta\nu_{Cs}$	9 192 631 770	Hz
speed of light in vacuum	c	299 792 458	$m\ s^{-1}$
Planck constant*	h	$6.626\,070\,15 \times 10^{-34}$	$J\ Hz^{-1}$
elementary charge*	e	$1.602\,176\,634 \times 10^{-19}$	C
Boltzmann constant*	k	$1.380\,649 \times 10^{-23}$	$J\ K^{-1}$
Avogadro constant*	N_A	$6.022\,140\,76 \times 10^{23}$	mol^{-1}
luminous efficacy	K_{cd}	683	$lm\ W^{-1}$

*These numbers are from the CODATA 2017 special adjustment. They were calculated from data available before the 1st of July 2017.

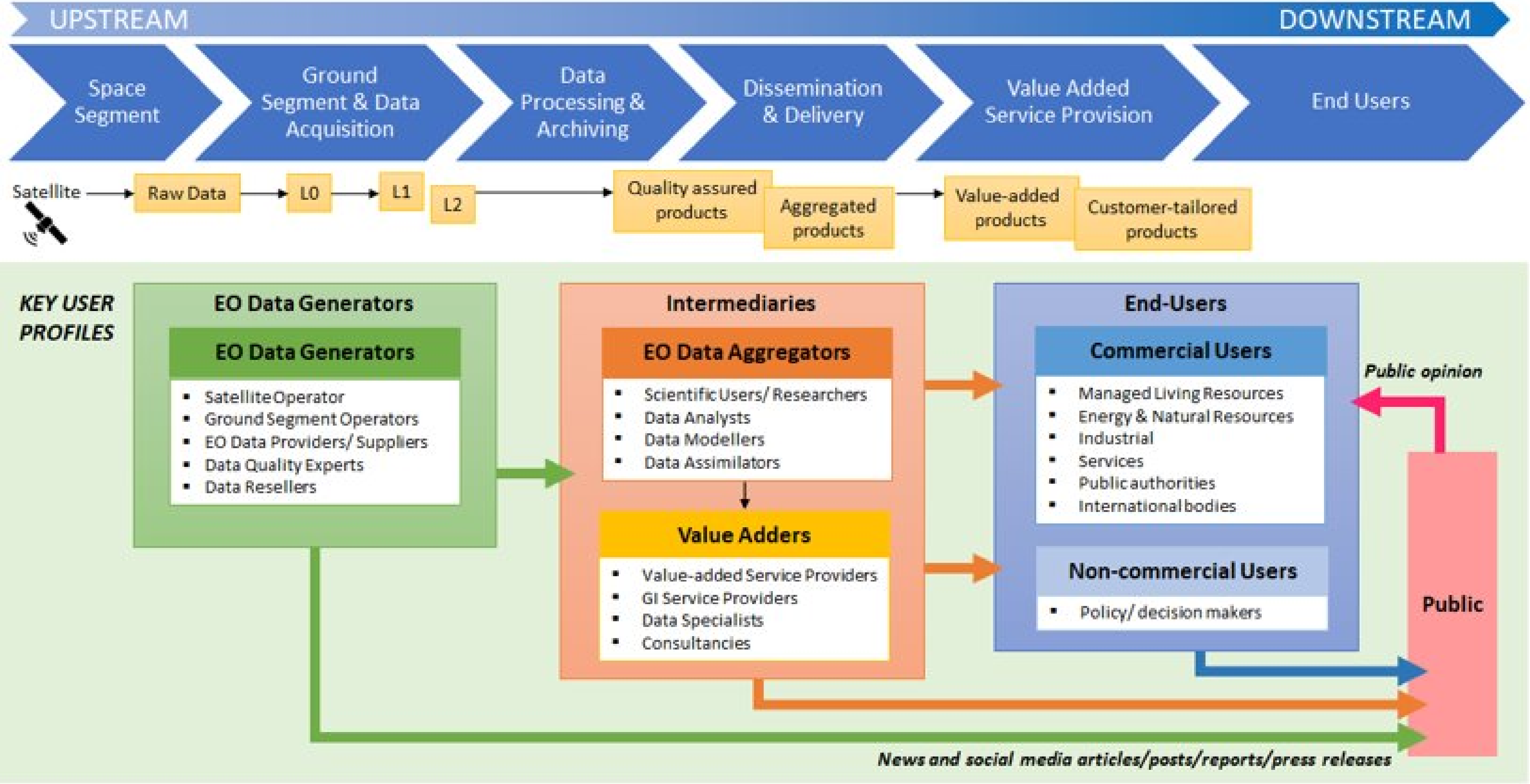
20 May 2019

TRACEABILITY

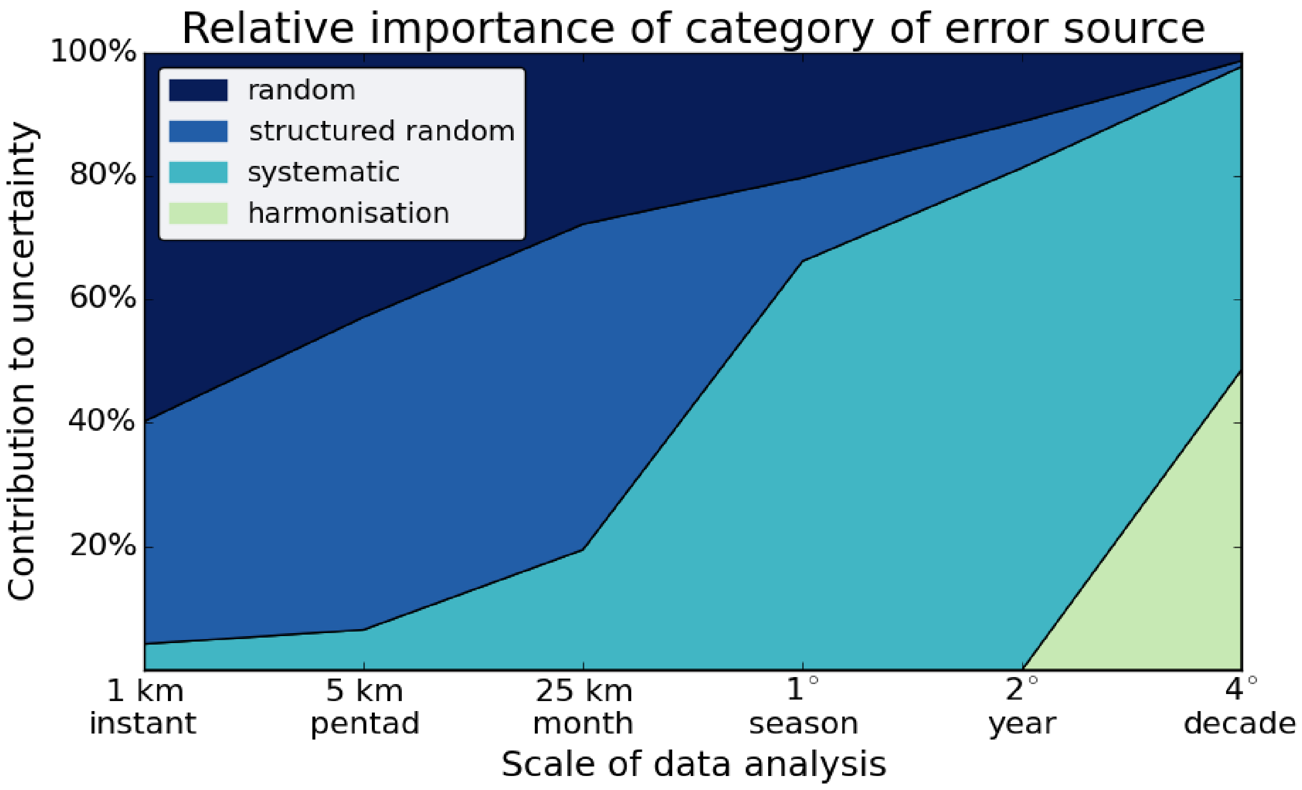
UNCERTAINTY

COMPARISON

Environmental data have long value chains



Science happens on different scales



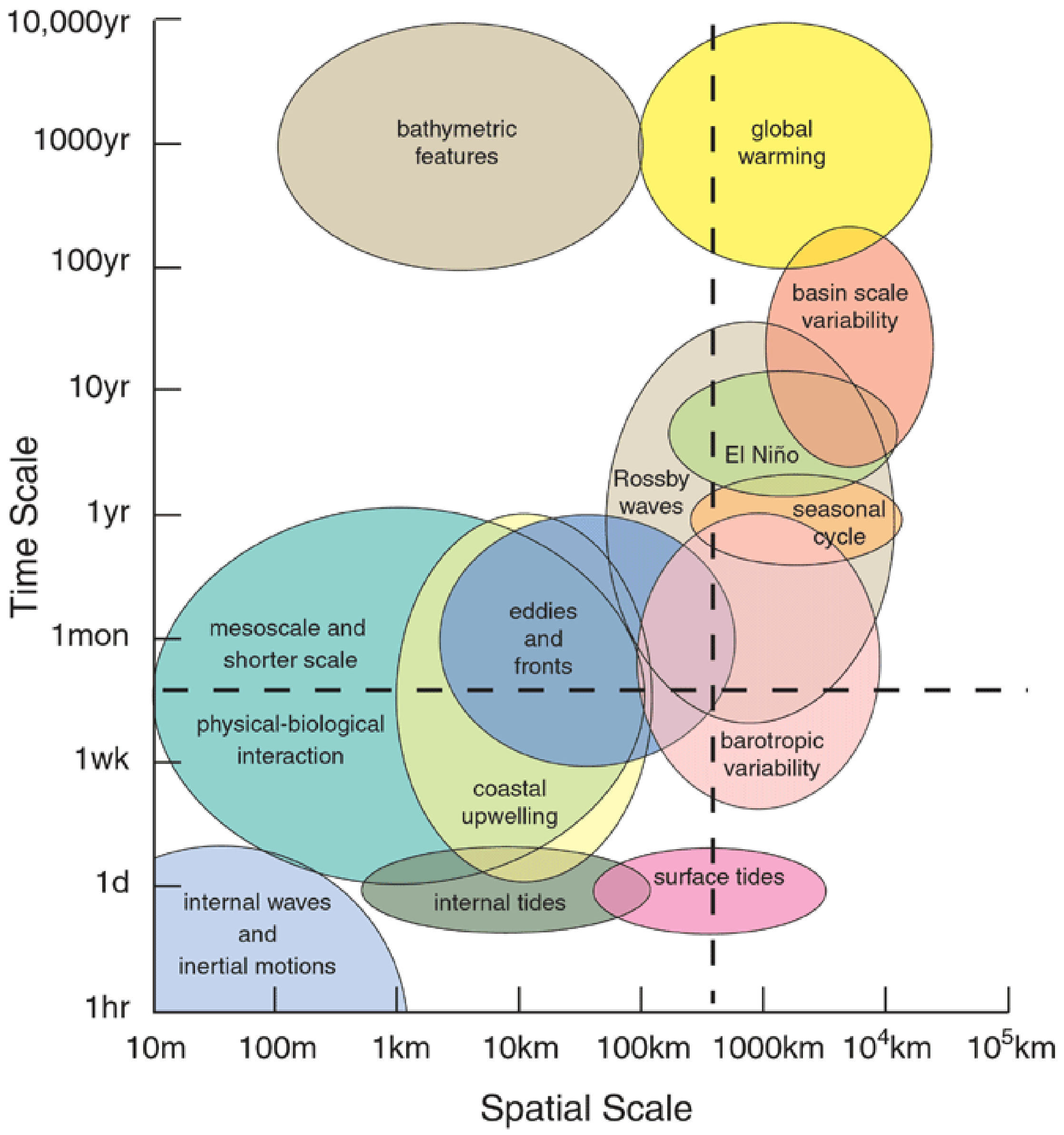
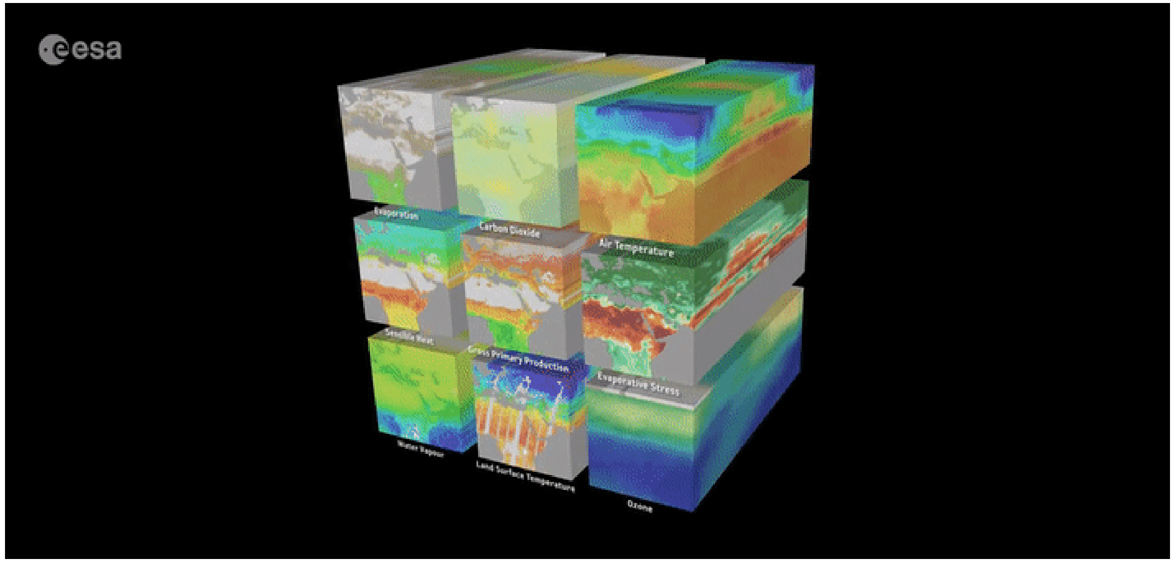


Image: Chris Merchant, Reading University
http://dx.doi.org/10.6084/m9.figshare.1483409

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

Data sets are large and have complicated covariance structures



Data cubes as illustrated by eo4society.esa.int and Earth System Data Lab

- Spatial
- Temporal
- For optical sensors:
  - Spectral
  - Angular
- For sensor networks
  - Instrument type
  - Conditions
  - Calibration approach

FDRs, TDPs, FRMs

(Proposed [not endorsed] definitions)

A fundamental data record (FDR) is a record, of sufficient duration for its application, of uncertainty-quantified sensor observations calibrated to physical units and located in time and space, together with all ancillary and lower-level instrument data used to calibrate and locate the observations and to estimate uncertainty.

A thematic data product (TDP) is a record, of sufficient duration for its application, of uncertainty-quantified retrieved values of a geophysical variable, along with all ancillary data used in retrieval and uncertainty estimation.

Fiducial reference measurements (FRMs) are a suite of independent, fully characterised, and traceable sub-orbital measurements that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO) and have value for space-based observations

Earth Observation metrology toolkit

- The practical application of metrological methods and best practices, analysis must encompass the full data processing chains.
- Established over a decade in collaboration with a wide range of project teams
  - Field measurements (atmosphere, land, water)
  - Passive and active satellite sensors
- Summarised in training, guidance, tools
  - On www.qa4eo.org
- Next steps:
  - International discussion, development, standardization
  - Broader use and applicability

Steps to an FDR / TDP or FRM Uncertainty budget

MEASURAND 01

Define the measurand and measurement function

TRACEABILITY 02

Establish the traceability with a diagram

UNCERTAINTY 03

Evaluate each source of uncertainty and fill out an effects table

CALCULATE 04

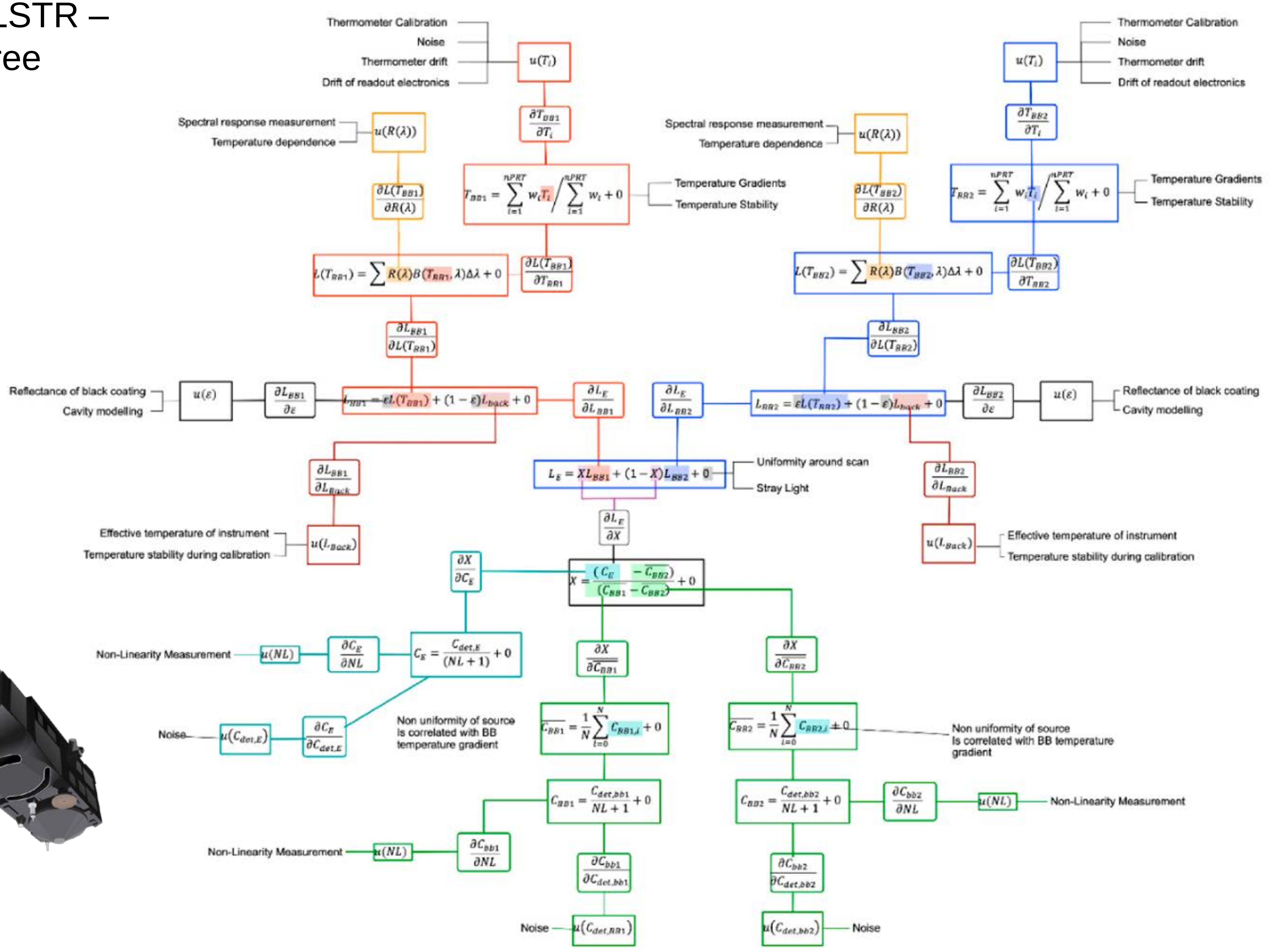
Calculate the product and its uncertainty

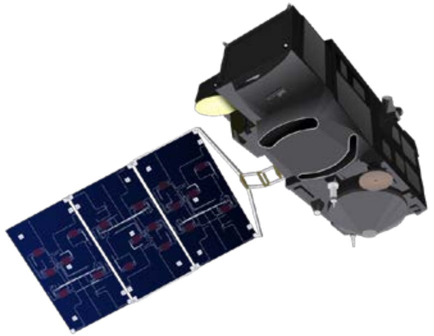
STORE 05

Store relevant information for future users

Guidance documentation and training materials available at www.qa4eo.org

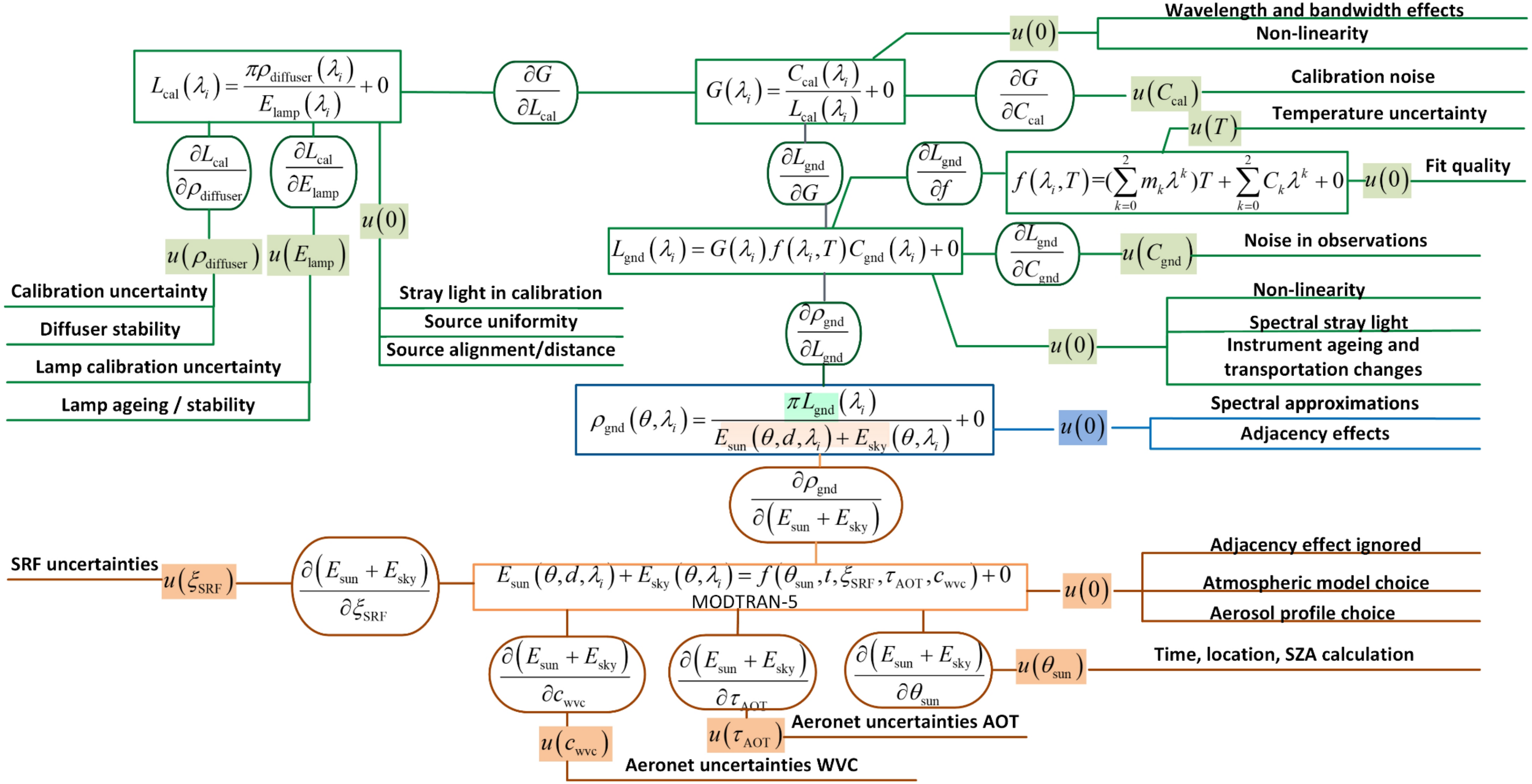
Sentinel 3 SLSTR – uncertainty tree diagram





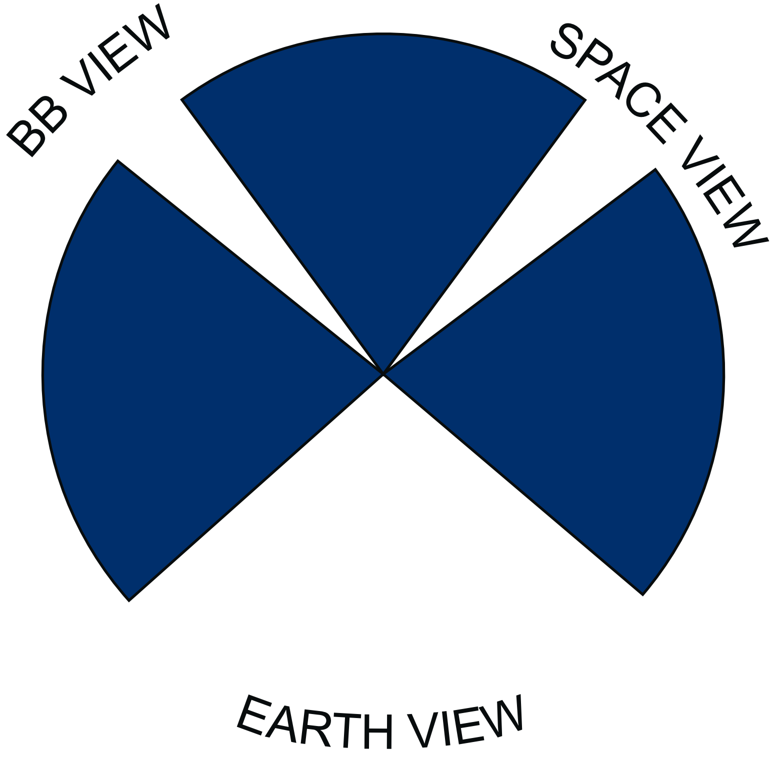
Uncertainty analysis for ground-based FRM (here RadCalNet Baotou sites)

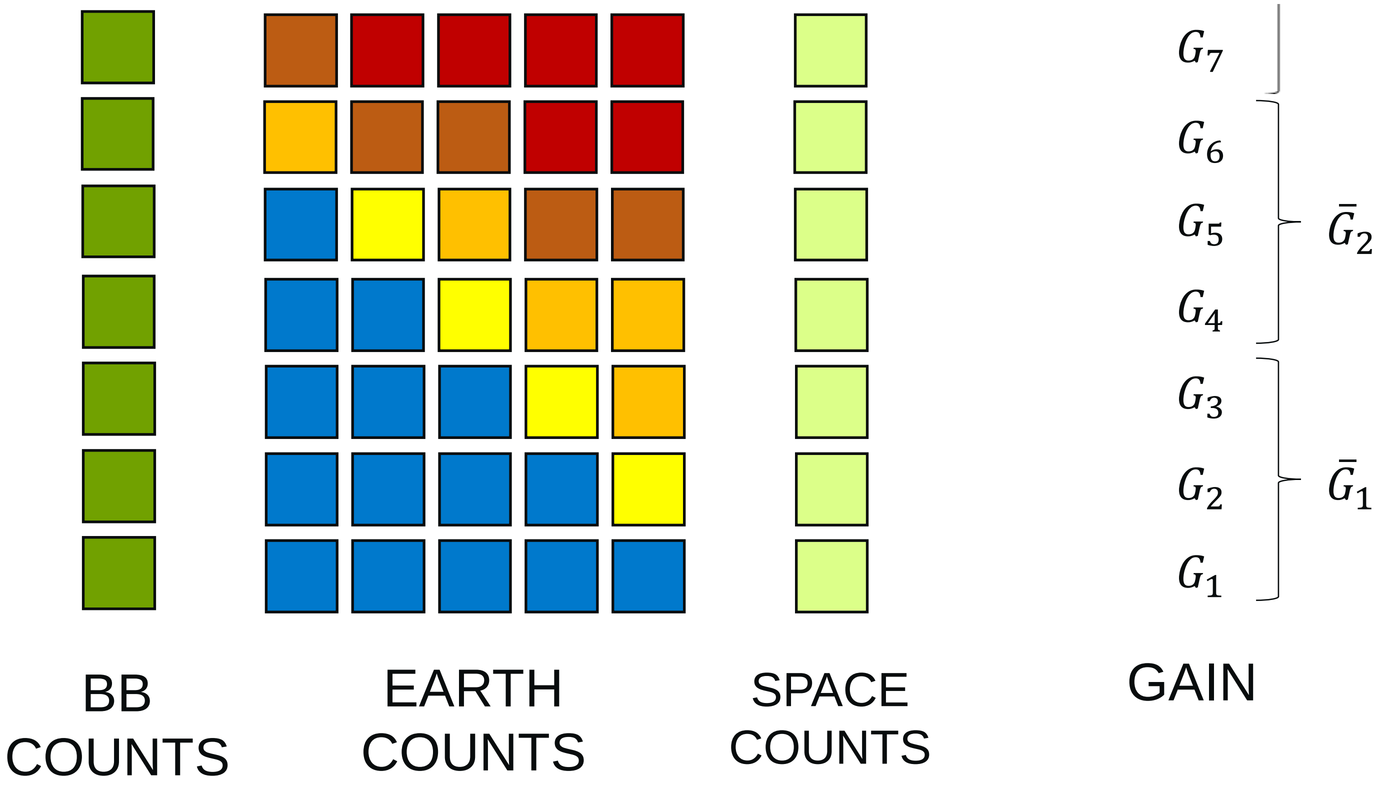
Remote Sens. **2020**, *12*(11), 1696; **https://doi.org/10.3390/rs12111696**



Example of a Sea Surface Temperature Radiometer

Sea surface temperature – TIR Radiometer – Example





Uncertainties in SST radiometer: Error correlation scales in different dimensions

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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)

		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

FIduceo Effects Table

```
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

Digital Effects Table

CoMet Toolkit

- The CoMet Toolkit (“Community Metrology Toolkit”) has been developed to enable easy handling and processing of dataset error-covariance information
- The information in QA4EO effects tables can be stored in digital effects tables
- These uncertainties can be propagated through measurement functions defined in python (allowing for flexibility within that measurement function, as well as flexibility in the provided error-correlations)
- These tools allow the user to rely on quality-assured code, rather than having to reinvent the wheel, and lower the barrier to entry for users new to handling uncertainties.

Tools overview

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Initial open-source release of the **CoMet toolkit** consists of:

- **obsarray**: Tool for storing and handling uncertainty and covariance in NetCDF files
- **punpy**: Propagation UNcertainties in Python
- **comet_maths**: Comet mathematical algorithms and interpolation tools

CoMet

www.comet-toolkit.org
github.com/comet-toolkit

Training material at:
www.comet-toolkit.org/examples

Where you can find information

- www.qa4eo.org
  - Training material
  - Straightforward overview guides
  - Links to CoMet tools

- https://www.npl.co.uk/national-challenges/environment
- https://www.euramet.org/climate-ocean

METROLOGY FOR CLIMATE ACTION

26–30 SEPTEMBER 2022

Bureau International des Poids et Mesures

WORLD METEOROLOGICAL ORGANIZATION

What?

- Online workshop of plenary sessions, papers, posters, and working groups to develop BIPM/WMO recommendations for key technical challenge areas for metrology over the next decade

Who for?

- Experts and stakeholders active in climate science, observations, modelling, GHG mitigation and measurement, and measurement science

Why attend?

- Opportunity to present your latest research findings
- Opportunity to influence BIPM/WMO recommendations for the direction of future metrology activities

How?

- Participation at: www.bipmwmo22.org . Final registration 14 September.