Principles of Metrology, FRM and their applicability to Earth Observation

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- How do we make sure a wing built in one country fits a fuselage built in another?
- How do we make sure measurements are stable and consistent over centuries?
- How do we improve accuracy over time without losing interoperability and stability?

Organisation of World Metrology

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BIPM
ΜΕΤΡΩ ΧΡΩ

Bureau
International des
Poids et
Mesures

- The Convention of the Metre (*Convention du Mètre*) 1875
- International System of Units (SI) (*Système International d'Unités)* 1960
- Mutual Recognition Arrangement (CIPM-MRA) 1999
- Redefinition of SI so that all units defined in terms of constants of nature 2019

Metrology and SI

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The importance of Metrology:

- Worldwide trade/manufacturing
- Public health and safety
- Scientific Research

Provides data that is:

Stable over time

→ so that 'scales' and references aren't changing

Insensitive to the method of measurement

→ so the result doesn't depend on how you make the measurement

Uniform worldwide

→ so you can build the wings in France and the fuselage in Spain

Based on references that can improve

→ methods will improve over time as new technologies are available

Same criteria needed for Climate Data and FCDRs/FDRs

Magna Carta - 1215

"There is to be one measure of wine and ale and corn within the realm, namely the London quarter, and one breadth of cloth, and it is to be the same with weights."

'measurements' of the Earth if they are to be trusted, meaningful and interoperable should be treated in the

…ceable to international agr…

…me… …ncert…

…vide…

For EO and Climate ECVs needs some translation & adaptation of standards and methods.

One of the oldest documents formalising measurement in the UK

QA4EO

A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

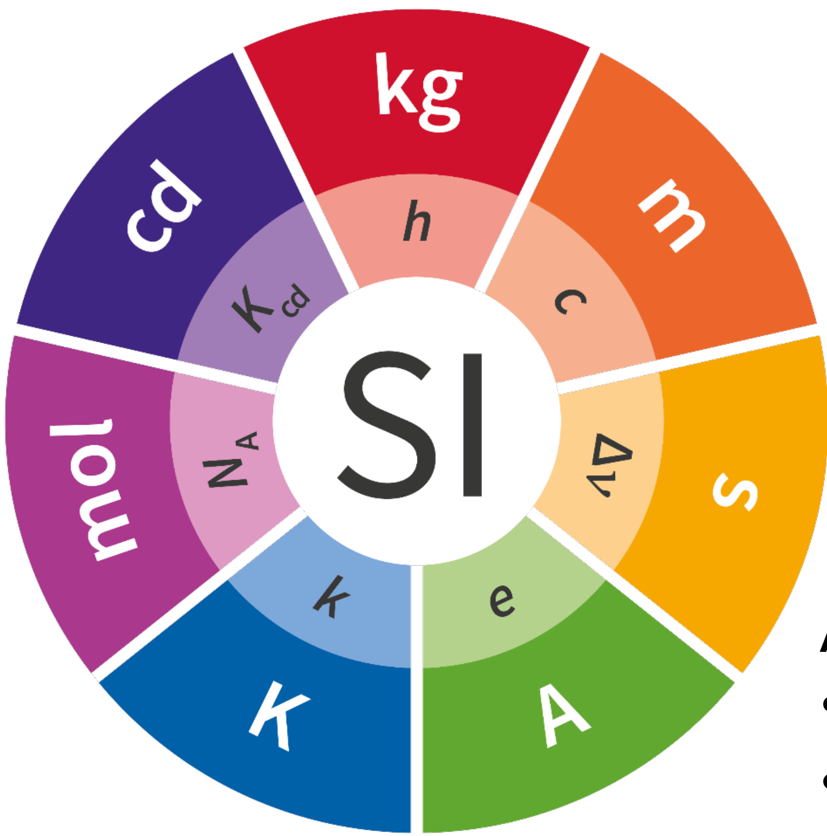
- The CEOS endorsed Quality Assurance framework for Earth Observation (QA4EO)
- Looks to make the GUM accessible to the EO community

Community-specific guidelines Click to close

Identifier	Description
QA4 CLP	
QA4 CLP	
QA4 CLP	
QA4 CLP	
QA4 CLP-005	applications
QA4EO-WGCV-IVO-CLP-006	Methodologies that should be applied to determine immersion factors for both radiance and irradiance underwater sensors
QA4EO-WGCV-IVO-CLP-007	Absolute Calibration using Rayleigh Scattering
QA4EO-WGCV-IVO-CLP-008	Protocol for the CEOS WGCV pilot Comparison of techniques/instruments used for vicarious calibration of land surface imaging through a ground reference standard test site

(2010) QA4EO Principle:
'All data and derived products shall have associated with them a fully traceable indicator of their quality', documented and quantitatively tied to an international standard ideally SI

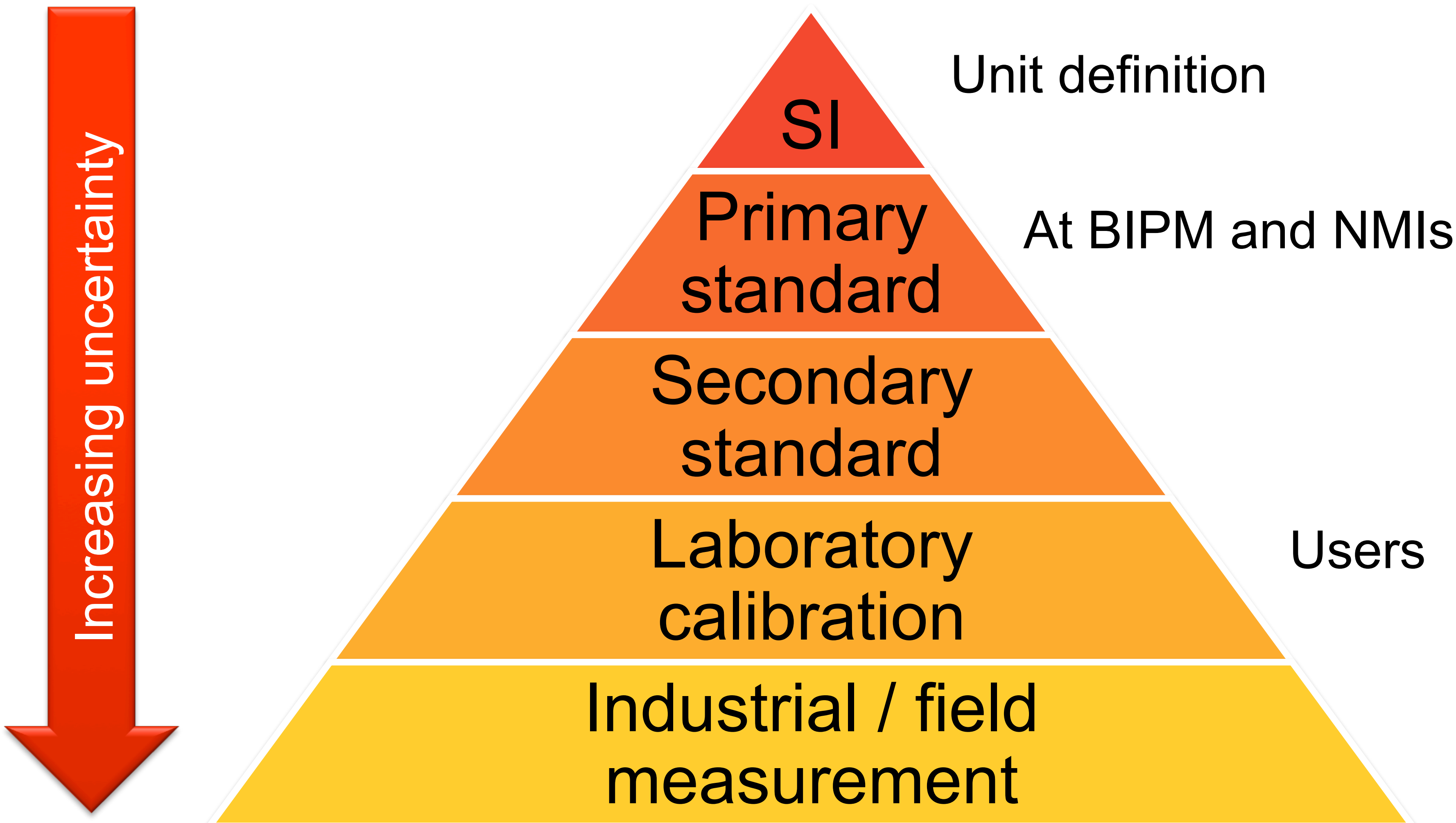
Confidence in information
- Trust in data/measurement



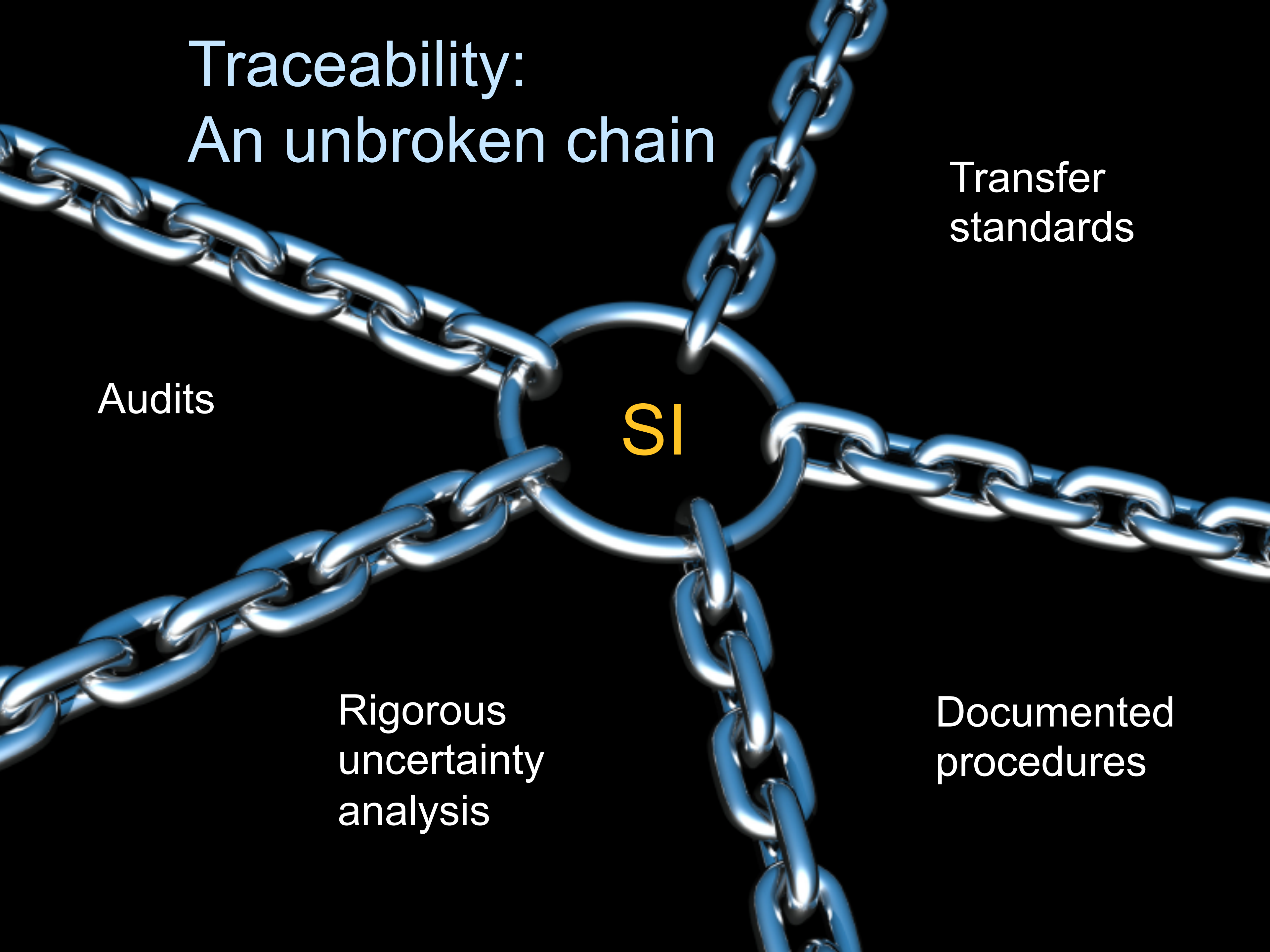
- Identical worldwide
- Century-long stability
- Absolute accuracy

Achieved through 3 principles:
- Traceability
- Uncertainty Analysis
- Comparison

Traceability



Traceability: An unbroken chain



Rigorous Uncertainty Analysis


BIPM

JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

First edition September 2008

© JCGM 2008

METPΩ XPΩ

The Guide to the expression of Uncertainty in Measurement (GUM)

- The foremost authority and guide to the expression and calculation of uncertainty in measurement science
- Written by the BIPM, ISO, etc.
- Covers a wide number of applications
- Also a set of supplements

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

Evidencing traceability: e.g. AVHRR

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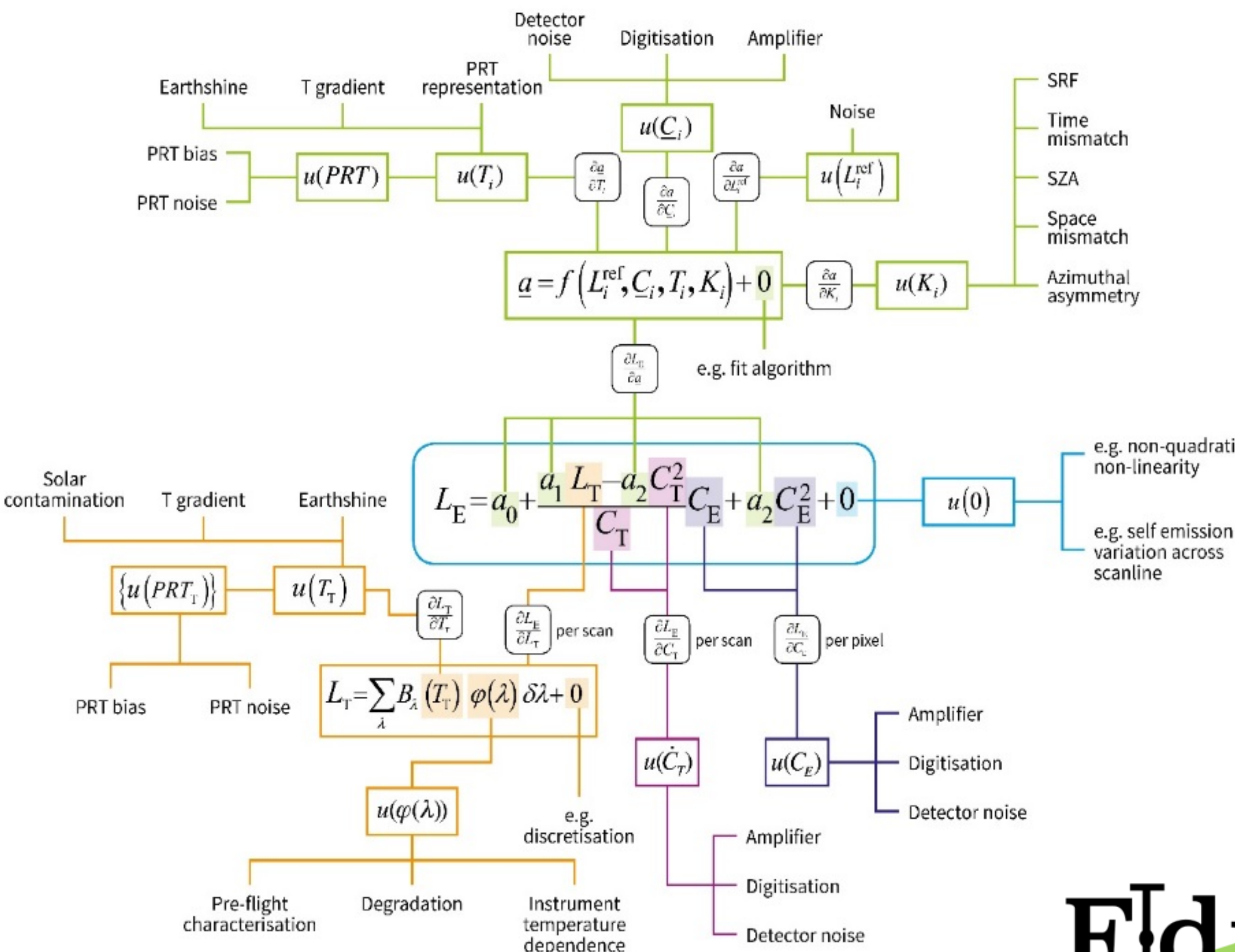
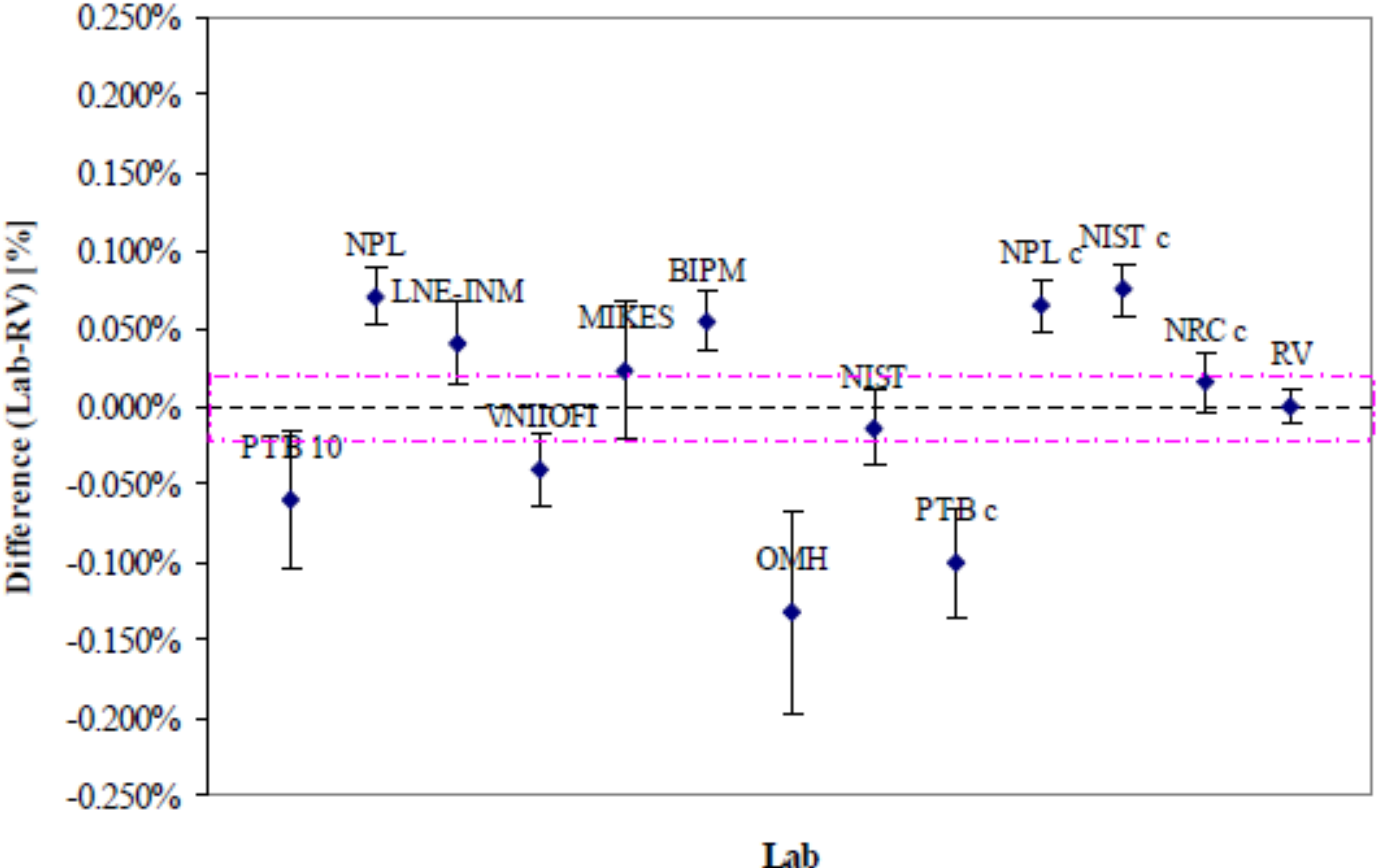


FIduceo

Table descriptor		Comments	Example
Name of effect		A unique name	Internal calibration target count noise
Affected term in measurement function		Name and standard symbol	$\mathcal{C}_{\mathrm{ICT}}$
Instruments in the series affected		Identifier	All instruments all satellites
Correlation type and form	Pixel-to-pixel [pixels]	One of the types	Rectangular absolute
	from scanline to scanline [scanlines]		Triangular relative
	between images [images]		N/A for orbiting satellite
	Between orbits [orbit]		Random
	Over time [time]		Random
Correlation scale	Pixel-to-pixel [pixels]	As needed to define type	[-∞,∞] (fully correlated across scan)
	from scanline to scanline [scanlines]		n = 51 (51 scanlines averaged in rolling average)
	between images [images]		N/A for orbiting satellite
	Between orbits [orbit]		0
	Over time [time]		0
Channels/bands	List of channels / bands affected	Channel names	All channels
	Error correlation coefficient matrix	A matrix	Identity matrix (diagonal).
Uncertainty	PDF shape	Functional form	Gaussian
	units	Units	Counts
	magnitude		Given once per orbit file
Sensitivity coefficient		Value, equation or parameterisation of sensitivity of measurand to term	$\frac{\partial L_{\mathrm{E}}}{\partial \mathcal{C}_{\mathrm{ICT}}}$

Lab-to-lab
(results of a scientific comparison)



The traceability chain is broken

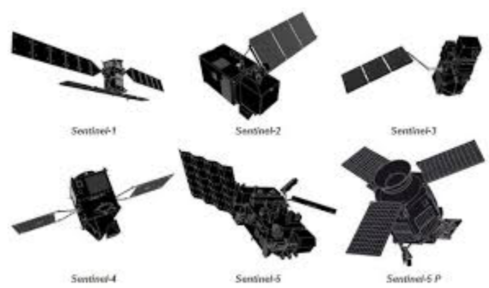
No reference in space …

No reference in space … yet

www.npl.co.uk/truths

Climate most demanding requirement

Flow of uncertainty from FCDR to final product



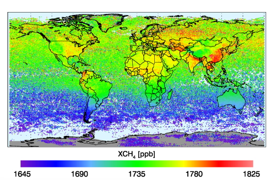
Metrological rigour for climate data ***requires metrological processes*** for FCDRs

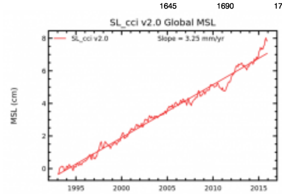
(Similar for FDRs used for other applications)

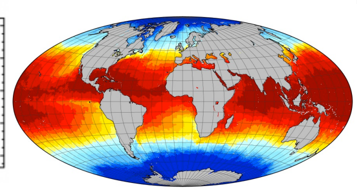
- Raw satellite data (L0)
- Calibrated radiances (L1)
- Climate data record (L2)
- Gridded CDR (L3)
- Analysed / processed (L4+)
- Climate index / information
  - Decision
  - Insurance
  - Liability

Uncertainties due to each processing step

Traceable uncertainties allow trust in data

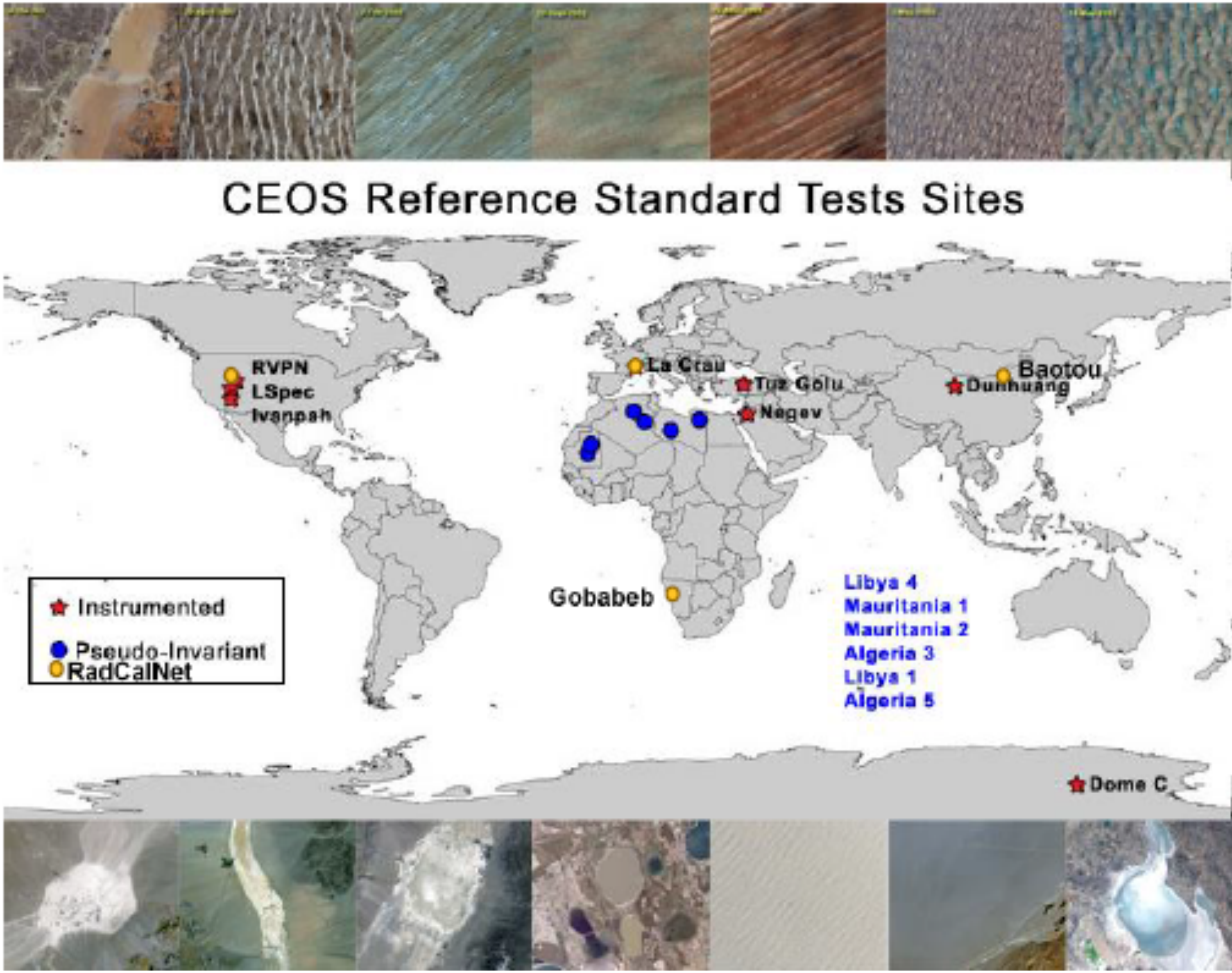


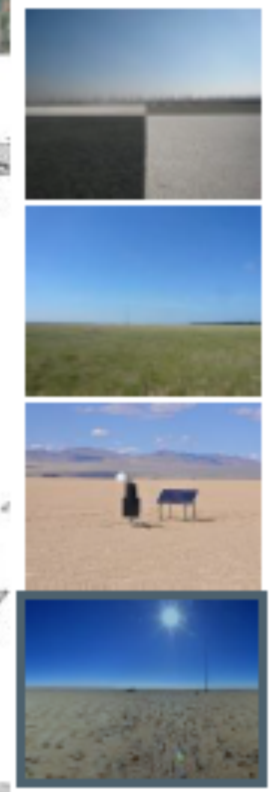




Traceable Uncertainties

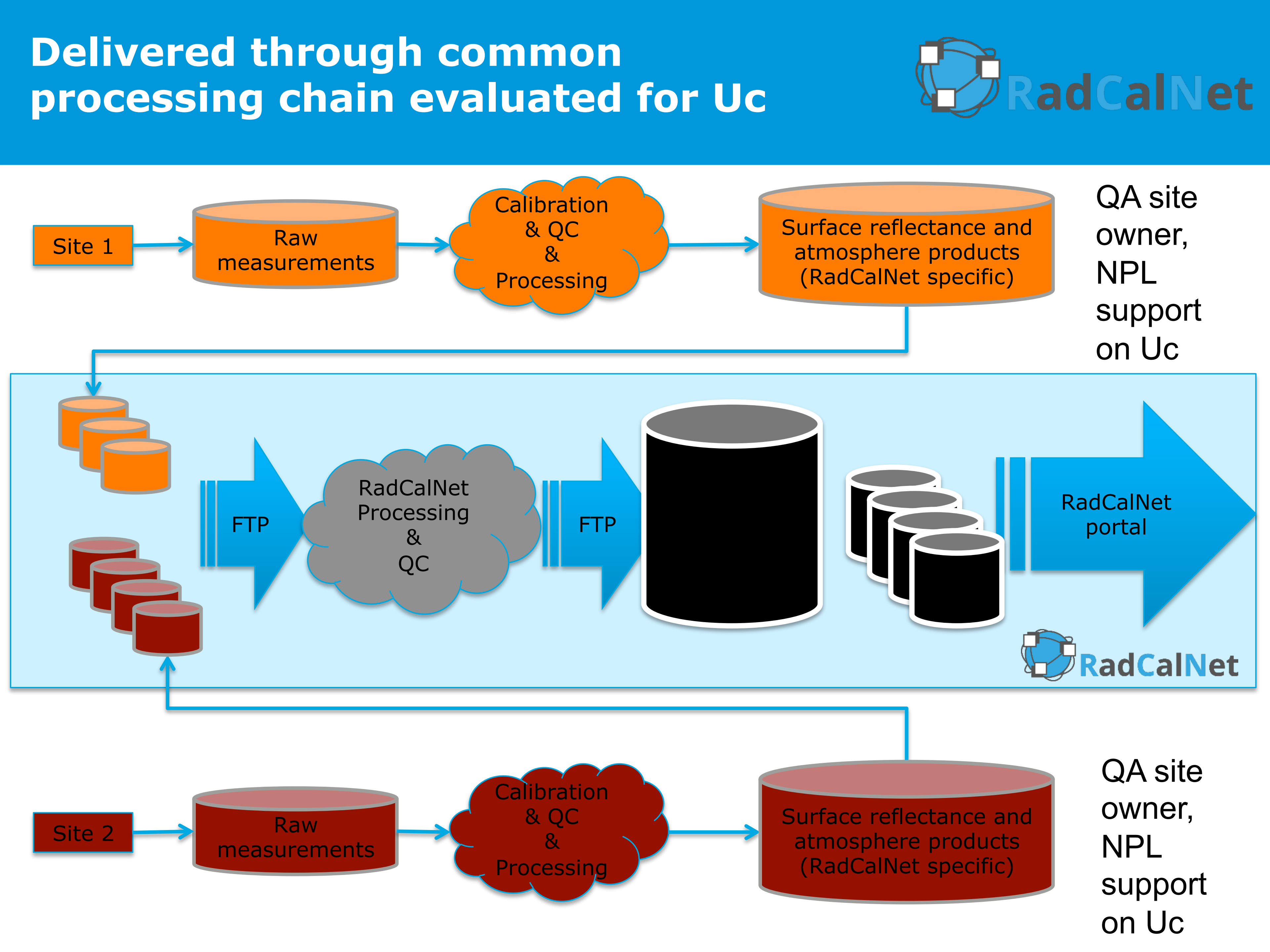
Start with Level 1



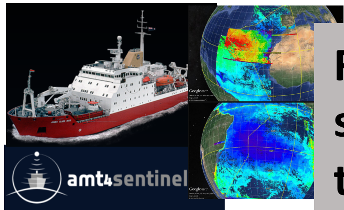


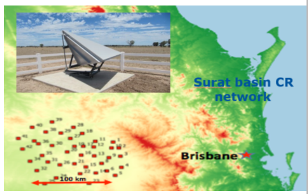
RadCalNet

Delivered through common processing chain evaluated for Uc

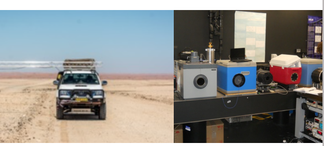


SI traceable validation (FRM4…) mitigate against data gaps & test/anchor FDRs

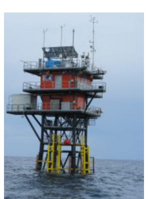




FRM4SAR



fiducial reference temperature measurements



fiducial reference measurements for satellite ocean colour

Fiducial Reference Measurements (FRM) are a sub-set of 'in-situ' measurements of satellite measured parameters (L1/L2) that can be <u>compared</u> to those independently derived from a satellite to:

- Validate sensor performance and any processing chain
- Provide a means to bridge any potential data-gaps
- Facilitate interoperability between sensors and anchor/establish FDRs
  - Providing they are of sufficient accuracy!

(Noting that the comparison process has its own uncertainty)

FRMs <u>MUST</u>:

- Have documented evidence of metrological traceability to SI (or appropriate international community standard) including full uncertainty budget (instrumentation and useage), which must be at a level commensurate with the application.
- be independent of any satellite geophysical retrieval process.
- Be carried out following community agreed protocols

Fiducial Reference Measurements for Greenhouse Gases

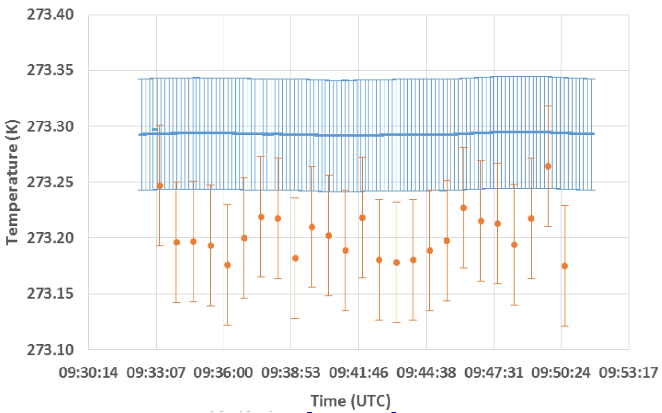
fiducial reference measurements for vegetation

FRM4DOAS

pandonia
Fiducial Reference Measurements for Atmospheric Composition

Fiducial Reference Measurements for Altimetry
FRM4ALT

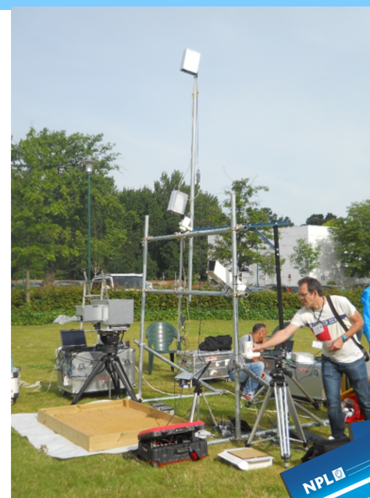
FRM comparisons

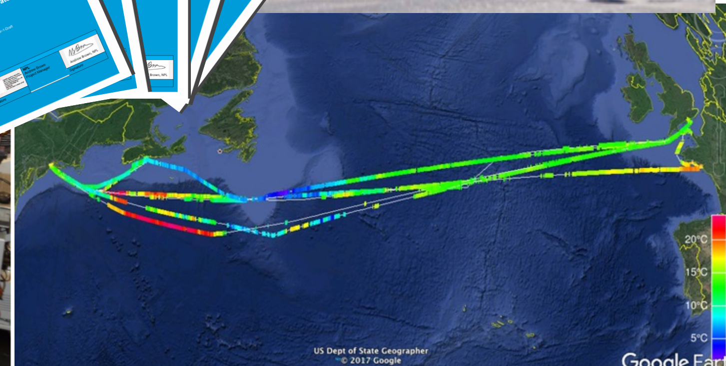


Uc for Validation measurements MUST also be evaluated and compared to assess consistency with that derived by sensor

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement	U_{Repeat}		U_{Repeat}
Reproducibility of measurement	U_{Repro}		U_{Repro}
Blackbody emissivity		U_{emis}	U_{emis}
BB Thermometer Calibration		U_{therm}	U_{therm}
BB cavity temperature non-uniformity		U_{Unif}	U_{Unif}
BB temperature stability		U_{stab}	U_{stab}
Reflected ambient radiation		U_{Refl}	U_{Refl}
Radiant heat/loss gain		$U_{Radiant}$	$U_{Radiant}$
Convective heat/loss gain		$U_{Convect}$	$U_{Convect}$
Primary Source		U_{Prim}	U_{Prim}
RMS total	$((u_{Repeat})^2+(u_{Repro})^2)^{½}$		





Future ?   Extension adaptation of EDAP like processes

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Colour coded information for easy assimilation by users
Multi-layered ‘maturity matrix’

Product Details	Product Generation	Ancillary Information	Uncertainty Characterisation	Validation
Product Information	Sensor Calibration & Characterisation Pre-Flight	Product Flags	Uncertainty Characterisation Method	Reference Data Representativeness
Availability & Accessibility	Sensor Calibration & Characterisation Post-Launch	Ancillary Data	Uncertainty Sources Included	Reference Data Quality
Product Format	Retrieval Algorithm Method		Uncertainty Values Provided	Validation Method
User Documentation	Retrieval Algorithm Tuning		Geolocation Uncertainty	Validation Results
Metrological Traceability Documentation	Internal Processes			

Key
Not Assessed
Not Assessable
Basic
Intermediate
Good
Excellent

EDAP

Conclusion

- SI-Traceability including robust Uncertainty assessment and its evidence is recognised as critical for climate and risk/cost sensitive applications
  - End to end
  - Start with Level 1 – level 2+
  - Documentation and comparison evidence critical

- Post-launch Cal/Val must methods must also be SI-traceable and Uncertainty associated with comparison methods included

- The concept of FRM4… initiatives provides a mechanism and template for consistent Satellite Validation
  - Potentially enhanced with EDAP like maturity matrix reporting

- Networks of FRM quality sites (underpinned by comparisons) provide QA framework for sustainable product interoperability and user confidence