National Physical Laboratory

Level 1 EO QA and Uncertainties

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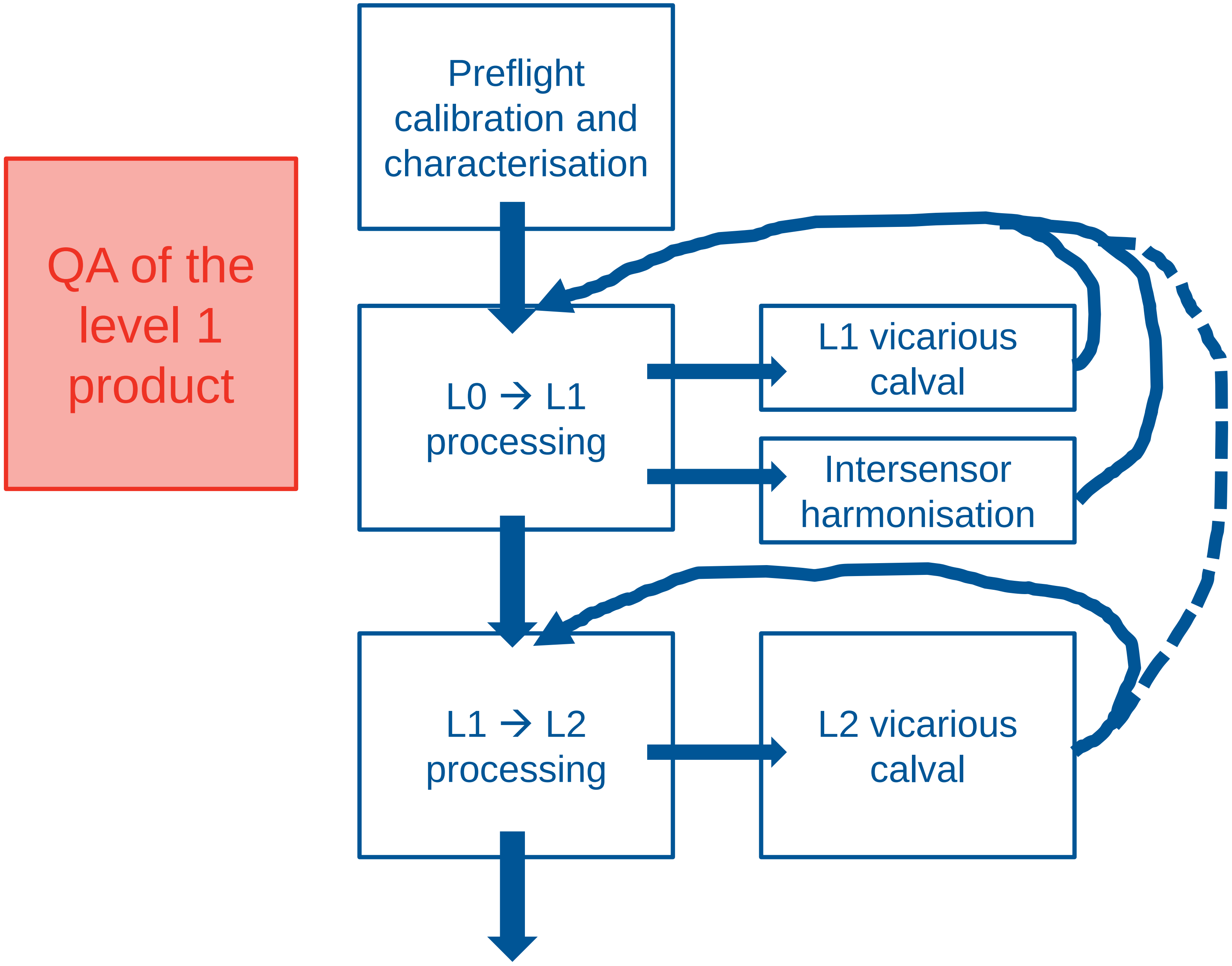
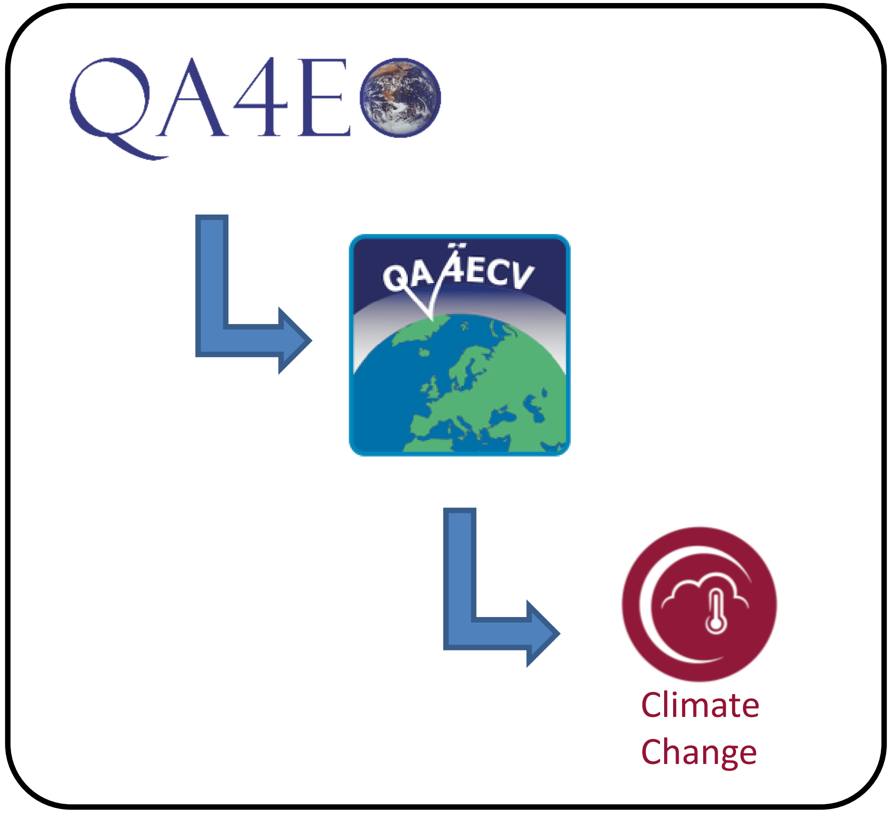
QA4EO Principle

"It is critical data and derived products are easily accessible in an open manner and have associated with them an indicator of their quality traceable to reference standards (preferably SI) to enable users to assess its suitability for their application i.e. its fitness for purpose."


QA of the level 1 product
Preflight calibration and characterisation
L0 → L1 processing
L1 vicarious calval
Intersensor harmonisation
L1 → L2 processing
L2 vicarious calval

Framework Heritage



Experience from previous projects provides basis for EDAP framework

Climate Change

Quality Assurance Evaluation

Details	Generation	Quality flags	Uncertainty Characterisation	Validation	Inter-comparison
Product Information	Input data and uncertainties	Quality Flags	Uncertainty Characterisation Method	Reference data representativeness	Scale of inter-comparison activities
Product Description	Sensor Calibration		Uncertainty sources included	Reference data uncertainty inclusion	Inter-comparison method
Coverage and Resolution	Algorithm method		Uncertainty values provided	Validation method	Product uncertainties inclusion
Data gaps	Algorithm tuning to reference data		Temporal stability	Validation results	Discrepancy between products identified and, if possible, resolved
Data set limitations and target applications	Sensitivity analysis		Geolocation uncertainty		
Documentation	Internal Processes				
	Traceability Chain				

Key
Basic
Intermediate
Good
Excellent

-> To understand whether the product producer provides **sufficient information** to allow a user to fully understand the status of the data product and to determine if **best practices** are being followed in generating the product

Evolved from QA4ECV

opernicus Europe's eyes on Earth

European Commission

EDAP Framework Principles

- Should describe high-level principles and activities common for assessment of all EO missions.
- Starting point is to describe the “ideal” case for a given category – aspiration which may not often be met.
- Grading based on mission fitness for purpose based on stated performance and application area.
- Assessment itself is the “ideal” case. Some aspects of assessment may be out of scope within EDAP.

Quality Assessment Matrix

Product Details	Product Generation	Product Flags	Uncertainty Characterisation	Validation
Product Information	Sensor Calibration & Characterisation Pre-Flight	Product Flags	Uncertainty Characterisation Method	Reference Data Representativeness
Product Availability & Accessibility	Sensor Calibration & Characterisation Post-Launch		Uncertainty Sources Included	Reference Data Quality
Product Format	Retrieval Algorithm Method	If target mission data product is Level 2	Uncertainty Values Provided	Validation Method
Product Documentation	Retrieval Algorithm Tuning		Geolocation Uncertainty	Validation Results
Product Metrological Traceability - Documentation	Internal Processes			

Key
Not Assessed
Not Assessable
Basic
Intermediate
Good
Excellent

Quality Assessment Guidelines document then provides criteria for how to grade each category

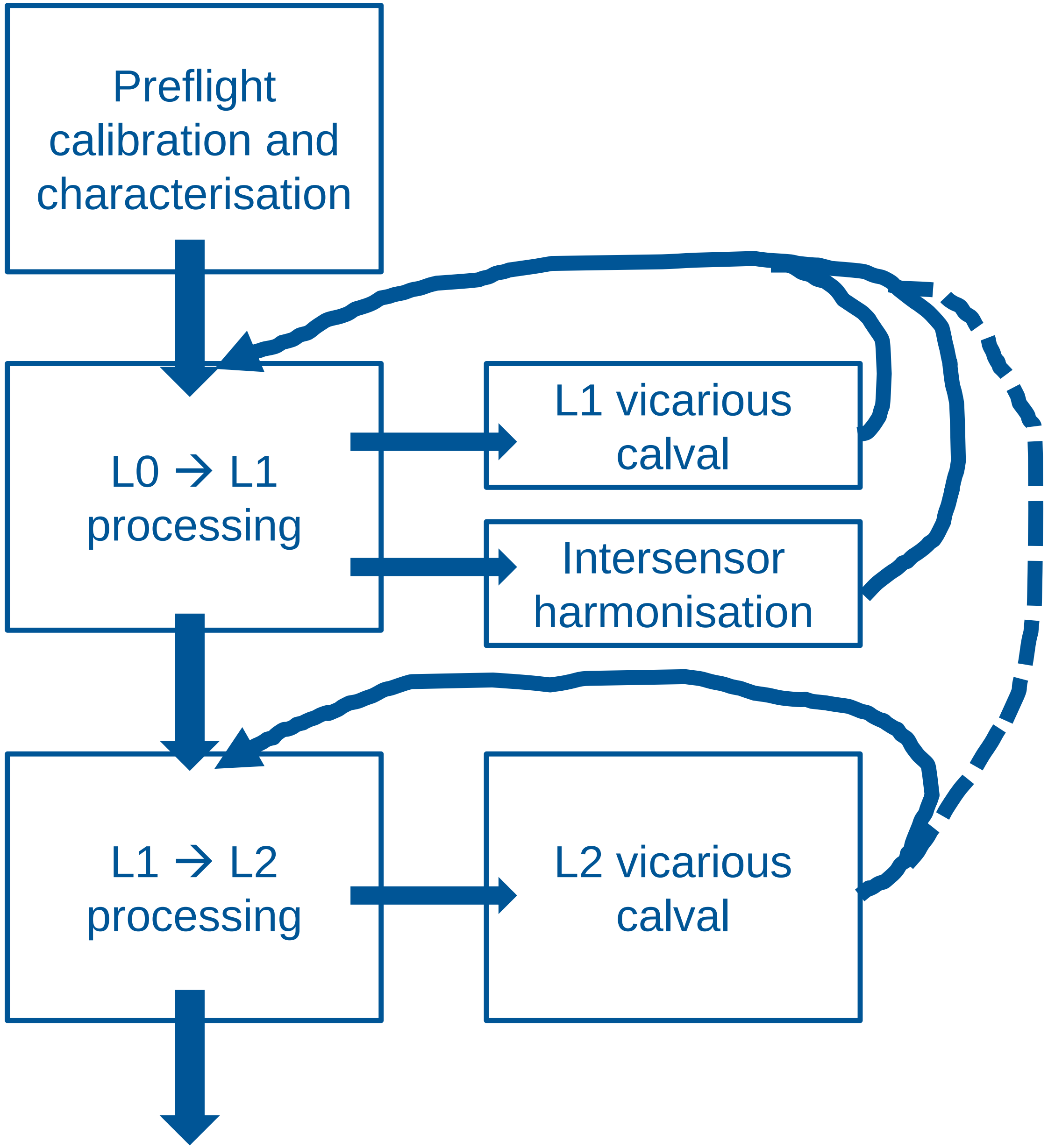
Grading Criteria
Example: Sensor Calibration Pre-flight

Grade	Criteria
Not Assessed	Assessment outside of the scope of study.
Not Assessable	Pre-flight calibration & characterisation not documented or information not available.
Basic	Pre-flight calibration & characterisation misses some important aspects of instrument behaviour and/or is not entirely of a level of quality to be judged fit for purpose.
Intermediate	Pre-flight calibration & characterisation covers most important aspects of instrument behaviour at a level of quality to be judged fit for purpose.
Good	Pre-flight calibration & characterisation covers all reasonable aspects of instrument behaviour to a quality that is “fit for purpose” in terms of the mission’s stated performance. Calibration traceable to SI or community reference, characterisation meets good practice.
Excellent	As *Good*, additionally calibration and characterisation includes the measurements needed to assess uncertainties at component level and their impact on the final product.

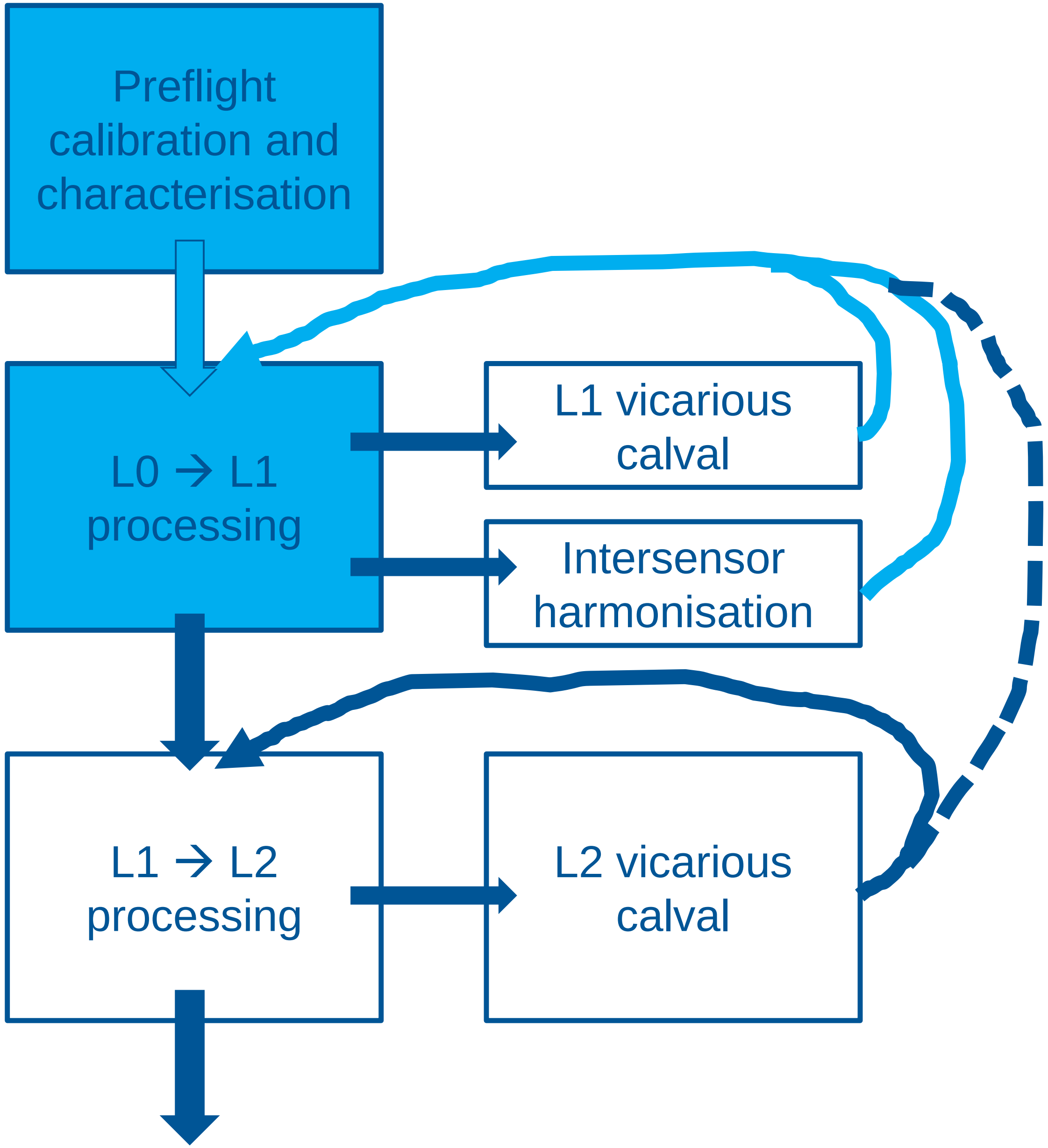
Grading Criteria
Example: Uncertainty Characterisation Method

Grade	Criteria
Not Assessed	Assessment outside the scope of study.
Not Assessable	Uncertainty characterisation not performed or method not documented.
Basic	Uncertainty established by limited comparison to measurements by other sensor/s Not by independent assessment and then comparison.
Intermediate	Limited use of GUM approach, and/or, an expanded comparison to measurements by other sensors.
Good	GUM approach to estimate measurement uncertainty with full breakdown of components and separated as Type A or B classification.
Excellent	GUM approach to estimate measurement uncertainty, including a treatment of error-covariance.

QA of the level 1 product



QA of the level 1 product



The Measurement Function

- The measurement function converts the observed quantities into the measurand

$$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$$

(AVHRR like example)

- Note that in FIDUCEO we try and ensure that we understand the uncertainties associated with each term but also have a physically based understanding of all components of the equation

The Measurement Function

Calibration Parameters

Calibration Target Counts

Earth Counts

$$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$$

Radiance of calibration target

The Measurement Function

$$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$$

Instrument Gain term. For the AVHRR especially Impacted by errors in L_T

Assumptions and approximations in measurement function

Bias term. May be related to difference is the view of the instrument between Earth view and Space View for example. May be a function of time/instrument temperature

Non-linear term. Assumes a quadratic.

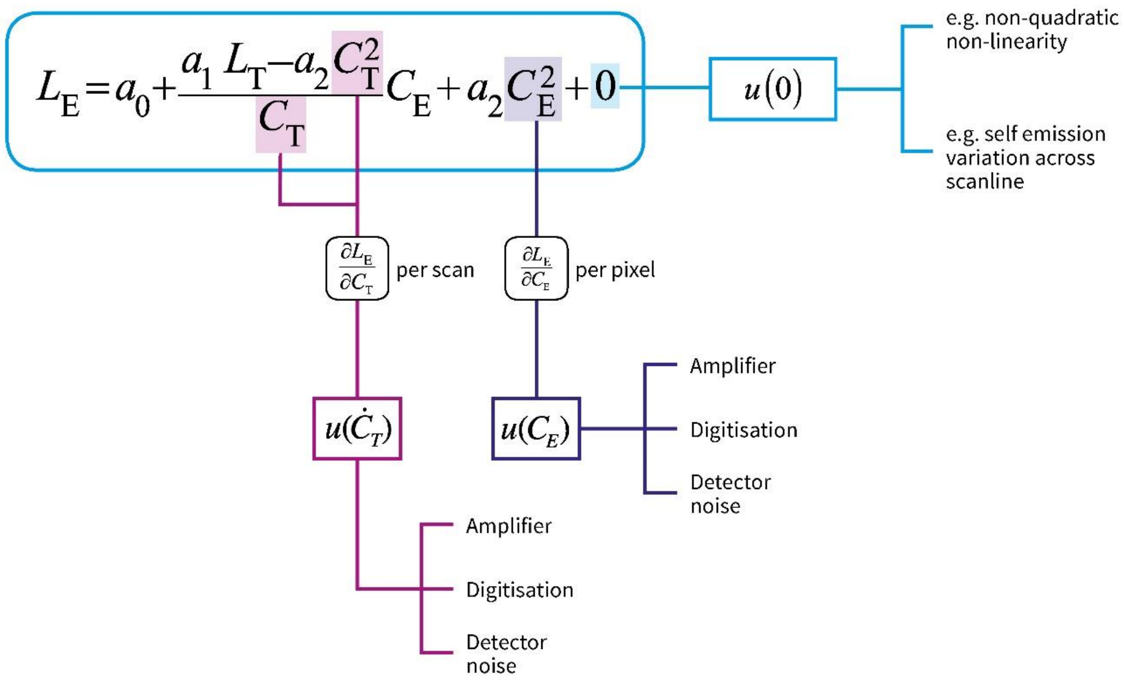
$$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$$

$$L_{\mathrm{E}} = a_0 + \frac{a_1 L_{\mathrm{T}} - a_2 C_{\mathrm{T}}^2}{C_{\mathrm{T}}} C_{\mathrm{E}} + a_2 C_{\mathrm{E}}^2 + 0$$

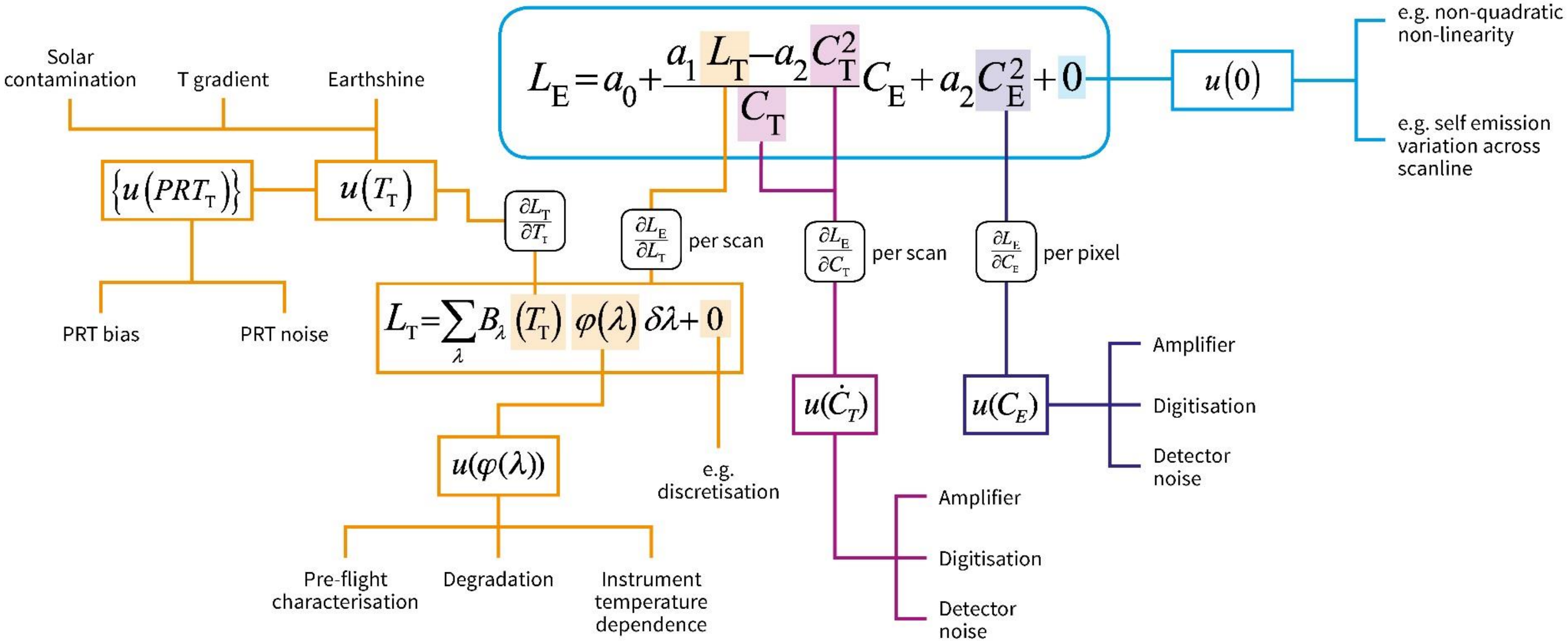
$u(0)$

e.g. non-quadratic non-linearity

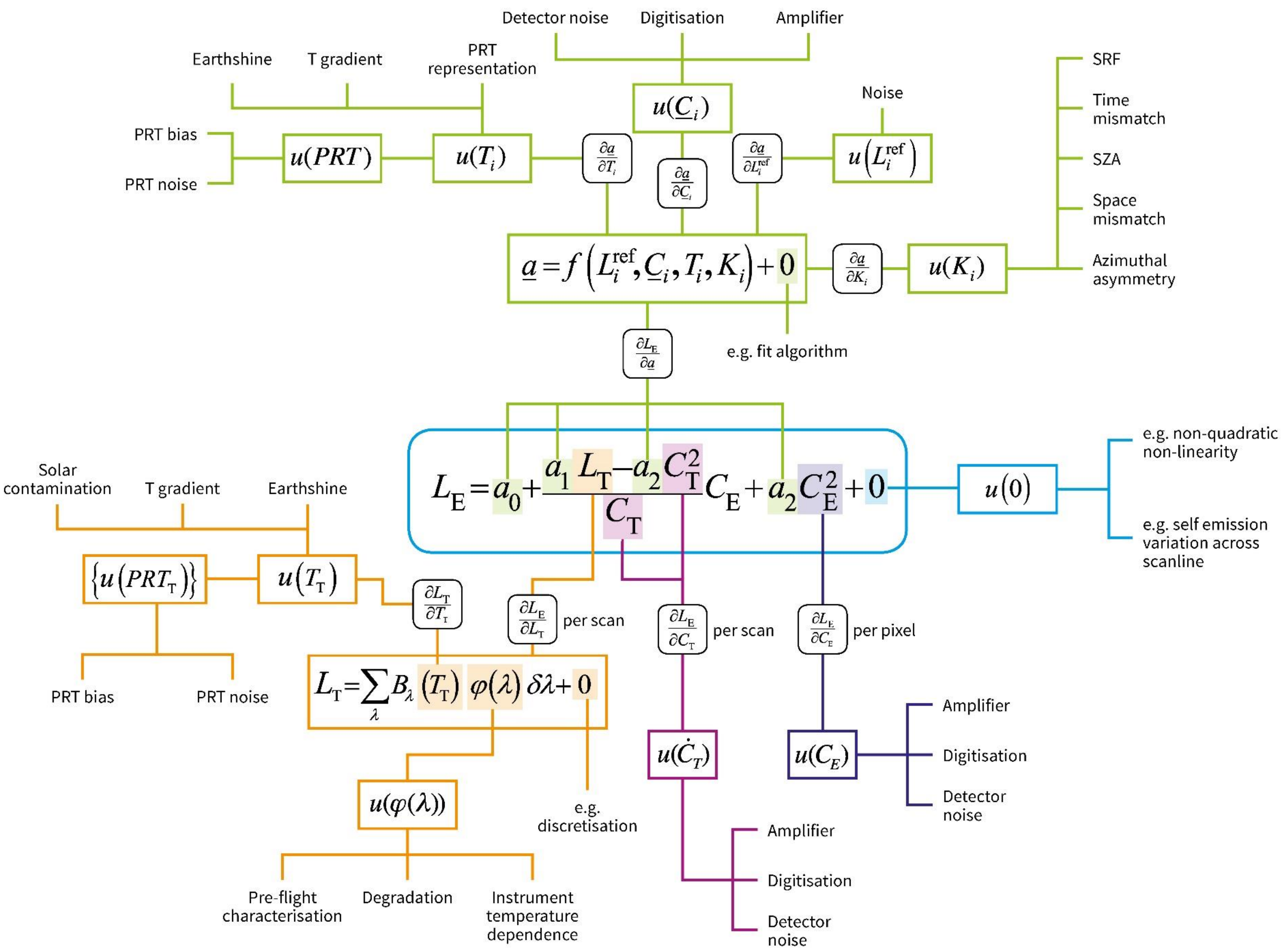
e.g. self emission variation across scanline



$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$
$u(0)$
e.g. non-quadratic non-linearity
e.g. self emission variation across scanline
$\frac{\partial L_E}{\partial C_T}$
per scan
$\frac{\partial L_E}{\partial C_E}$
per pixel
$u(\dot{C}_T)$
$u(C_E)$
Amplifier
Digitisation
Detector noise
Amplifier
Digitisation
Detector noise



$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$
$u(0)$
e.g. non-quadratic non-linearity
e.g. self emission variation across scanline
Solar contamination
T gradient
Earthshine
$\{u(PRT_T)\}$
$u(T_T)$
PRT bias
PRT noise
$\frac{\partial L_T}{\partial T_T}$
$\frac{\partial L_E}{\partial L_T}$ per scan
$\frac{\partial L_E}{\partial C_T}$ per scan
$\frac{\partial L_E}{\partial C_E}$ per pixel
$L_T = \sum_\lambda B_\lambda (T_T)\, \varphi(\lambda)\, \delta\lambda + 0$
$u(\varphi(\lambda))$
e.g. discretisation
Pre-flight characterisation
Degradation
Instrument temperature dependence
$u(\dot{C}_T)$
Amplifier
Digitisation
Detector noise
$u(C_E)$
Amplifier
Digitisation
Detector noise


Detector noise
Digitisation
Amplifier
Earthshine
T gradient
PRT representation
$u(\underline{C}_i)$
Noise
SRF
Time mismatch
SZA
Space mismatch
Azimuthal asymmetry
PRT bias
PRT noise
$u(PRT)$
$u(T_i)$
$\frac{\partial \underline{a}}{\partial T_i}$
$\frac{\partial \underline{a}}{\partial \underline{C}_i}$
$\frac{\partial \underline{a}}{\partial L_i^{\text{ref}}}$
$u\left(L_i^{\text{ref}}\right)$
$\underline{a} = f\left(L_i^{\text{ref}}, \underline{C}_i, T_i, K_i\right) + 0$
$\frac{\partial \underline{a}}{\partial K_i}$
$u(K_i)$
$\frac{\partial L_E}{\partial \underline{a}}$
e.g. fit algorithm
$L_E = a_0 + \frac{a_1 L_T - a_2 C_T^2}{C_T} C_E + a_2 C_E^2 + 0$
$u(0)$
e.g. non-quadratic non-linearity
e.g. self emission variation across scanline
Solar contamination
T gradient
Earthshine
$\{u(PRT_T)\}$
$u(T_T)$
$\frac{\partial L_T}{\partial T_T}$
$\frac{\partial L_E}{\partial L_T}$
per scan
$\frac{\partial L_E}{\partial C_T}$
per scan
$\frac{\partial L_E}{\partial C_E}$
per pixel
PRT bias
PRT noise
$L_T = \sum_{\lambda} B_\lambda (T_T)\, \varphi(\lambda)\, \delta\lambda + 0$
$u(\dot{C}_T)$
$u(C_E)$
Amplifier
Digitisation
Detector noise
$u(\varphi(\lambda))$
e.g. discretisation
Amplifier
Digitisation
Detector noise
Pre-flight characterisation
Degradation
Instrument temperature dependence

Capture in an effects table

Table descriptor		Value / Expression	How this is provided	Notes
Name of effect				
Affected term in measurement function				
Correlation type and form	within scanline [pixels]			
	from scanline to scanline [scanlines]			
	between orbits [orbits]			
	Across time [e.g. days, months, years]			
Correlation scale	within scanline [pixels]			
	from scanline to scanline [scanlines]			
	between orbits [orbits]			
	Across time			
Channels / bands	List channels and bands affected			
	Correlation matrix			
Uncertainty	PDF shape			
	Uncertainty units			
	Uncertainty magnitude			
Sensitivity Coefficient				

Correlation forms:

- Random
- Systematic / Rectangular absolute
- Triangular (simple average)
- Bell shaped (weighted average and other effects)
- Repeating rectangular/bell shaped (orbital effects)

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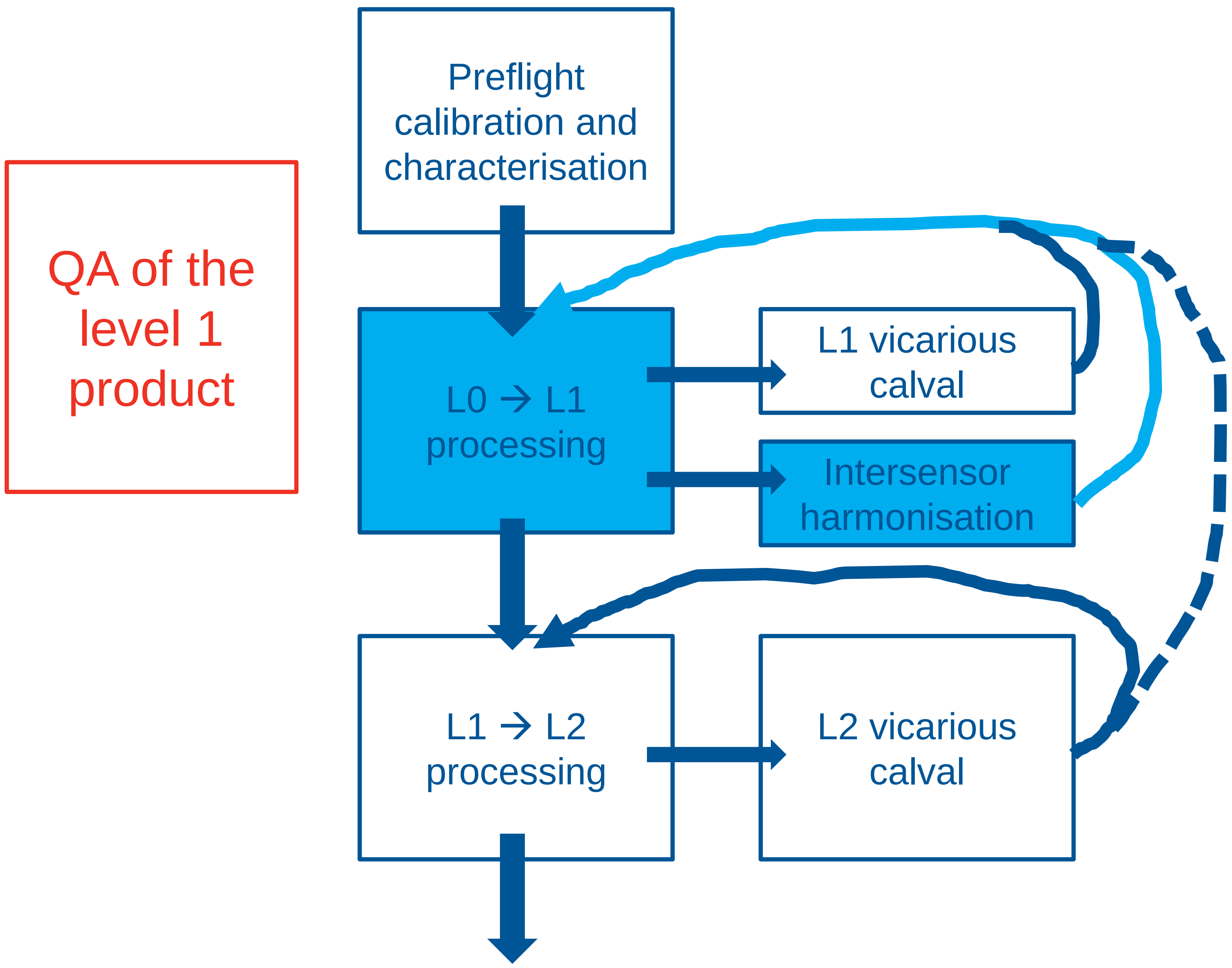
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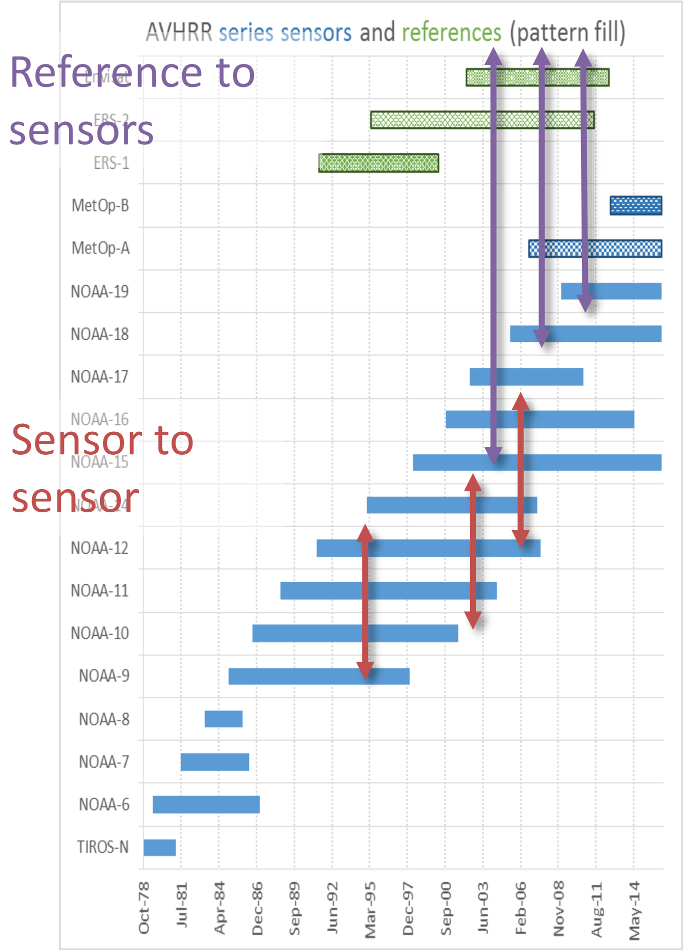
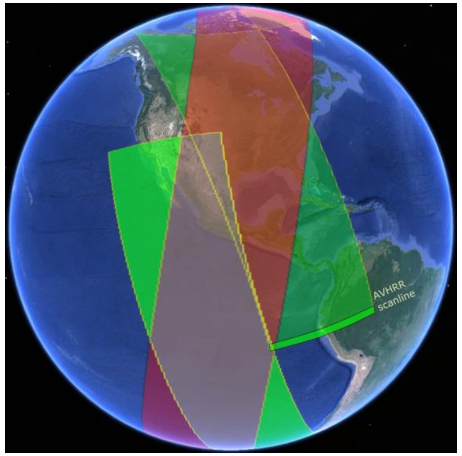
Match-ups



- Reference radiance, or sensor-to-sensor
- Many (150 million +)
- Correlated



Harmonisation

For all dual-sensor matchups in the full sensor series minimise

$$K_{i,j} - \left(L_i(\vec{X}_i, \vec{a}_i) - L_j(\vec{X}_j, \vec{a}_j)\right)$$

where for the reference sensor

$$L_i(\vec{X}_i, \vec{a}_i) \equiv L_i$$

Calibration models

Calibration coefficients

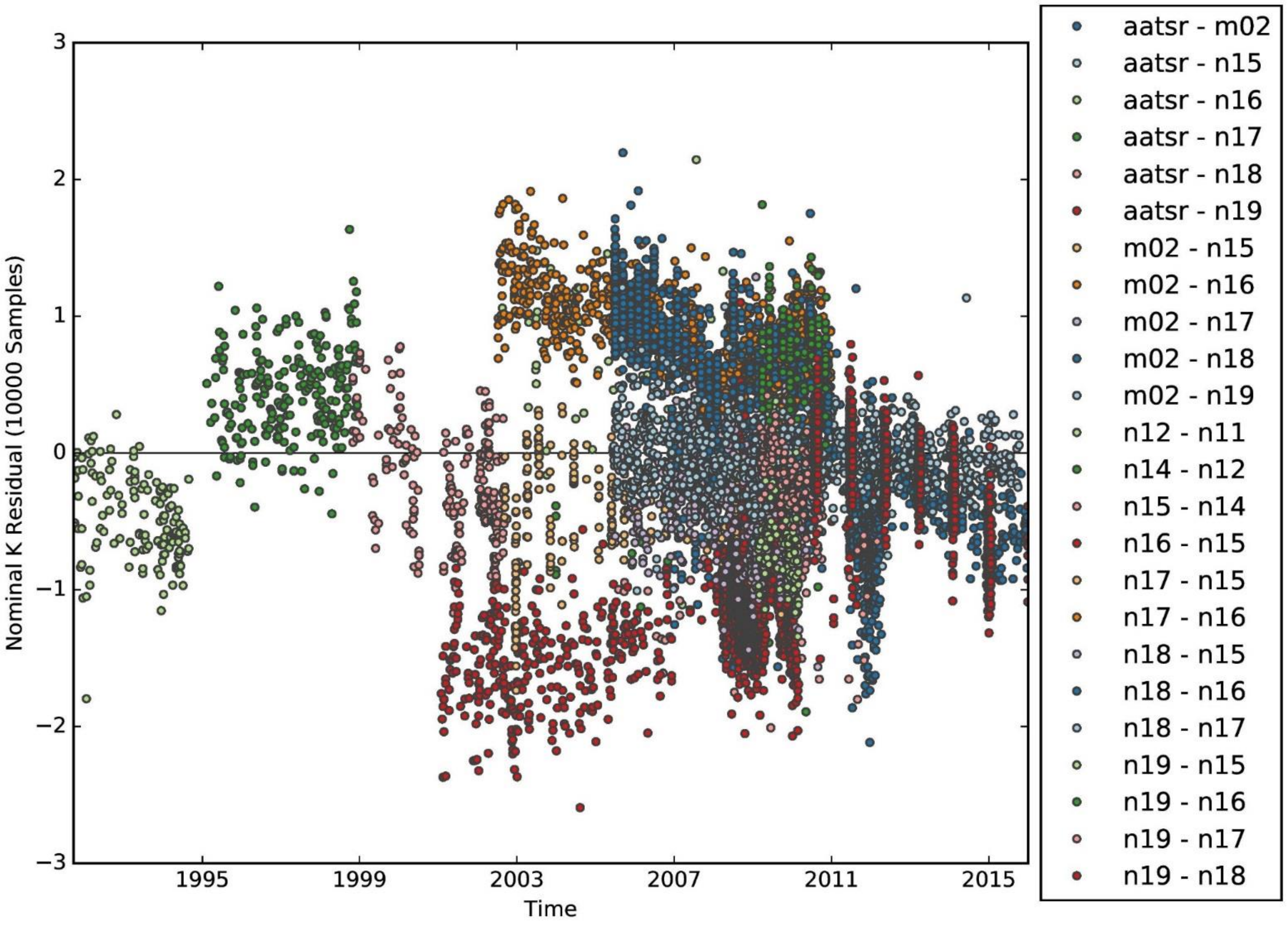
Sensor state variables (i.e. Level-0 data)

Radiance measured by the reference sensor (i.e. Level-1 data)

Radiance difference expected due to differing spectral response

FIDUCEO develops a palette of optimisation methods

		ODR	EIV	m-ODR	m-EIV
Optimise	calibration parameters	*yes*	*yes*	*yes*	*yes*
	sensor state variables	*yes*	*yes*	-	-
Account	independent random errors	*yes*	*yes*	*yes*	*yes*
	common random errors	*yes*	*yes*	*yes*	*yes*
	structured random errors	-	*yes*	-	*yes*



3
2
1
0
−1
−2
−3
1995
1999
2003
2007
2011
2015
Time
Nominal K Residual (10000 Samples)
aatsr - m02
aatsr - n15
aatsr - n16
aatsr - n17
aatsr - n18
aatsr - n19
m02 - n15
m02 - n16
m02 - n17
m02 - n18
m02 - n19
n12 - n11
n14 - n12
n15 - n14
n16 - n15
n17 - n15
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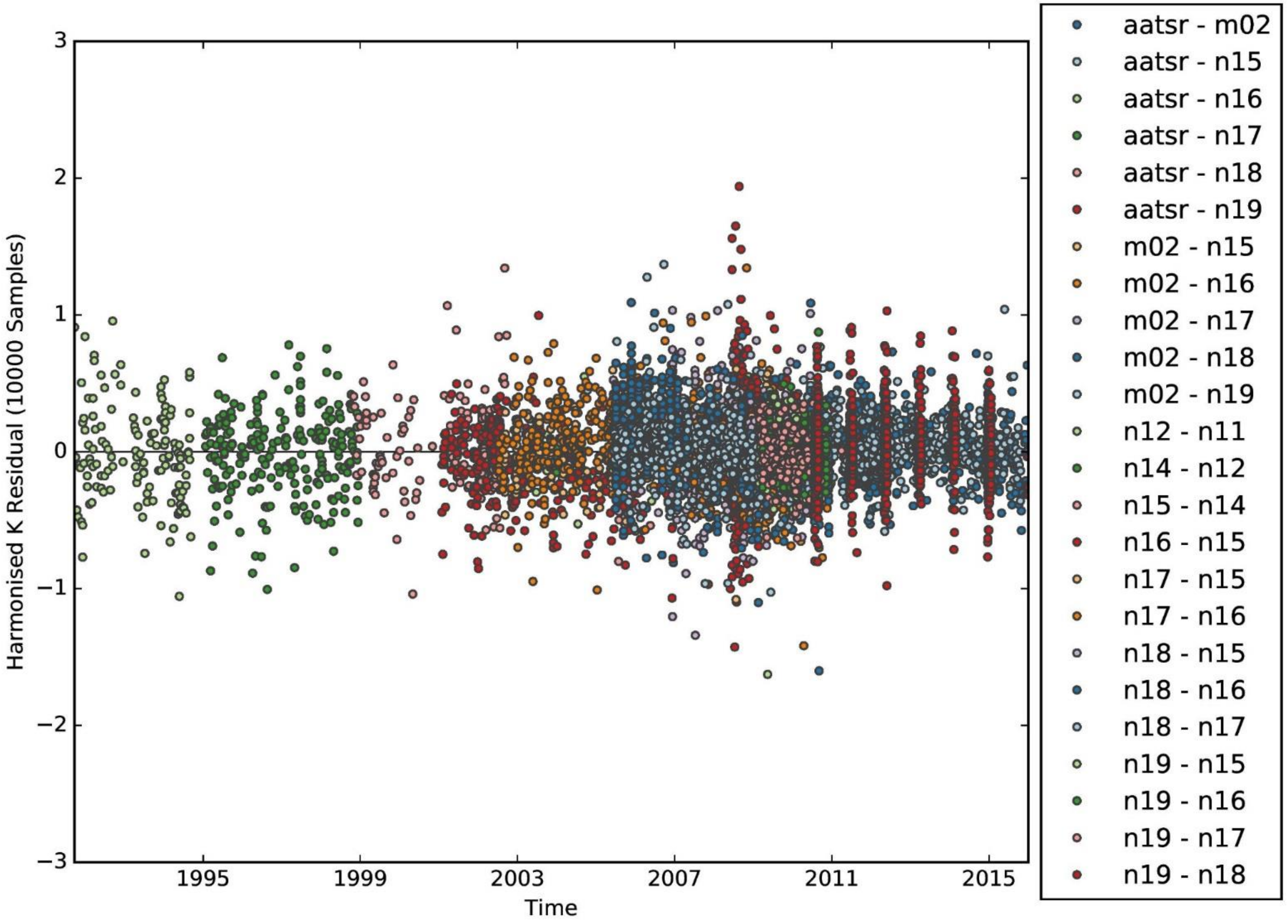
n18 - n16
n18 - n17
n19 - n15
n19 - n16
n19 - n17
n19 - n18



Harmonised K Residual (10000 Samples)
Time
3
2
1
0
−1
−2
−3
1995
1999
2003
2007
2011
2015
aatsr - m02
aatsr - n15
aatsr - n16
aatsr - n17
aatsr - n18
aatsr - n19
m02 - n15
m02 - n16
m02 - n17
m02 - n18
m02 - n19
n12 - n11
n14 - n12
n15 - n14
n16 - n15
n17 - n15
n17 - n16
n18 - n15
n18 - n16
n18 - n17
n19 - n15
n19 - n16
n19 - n17
n19 - n18

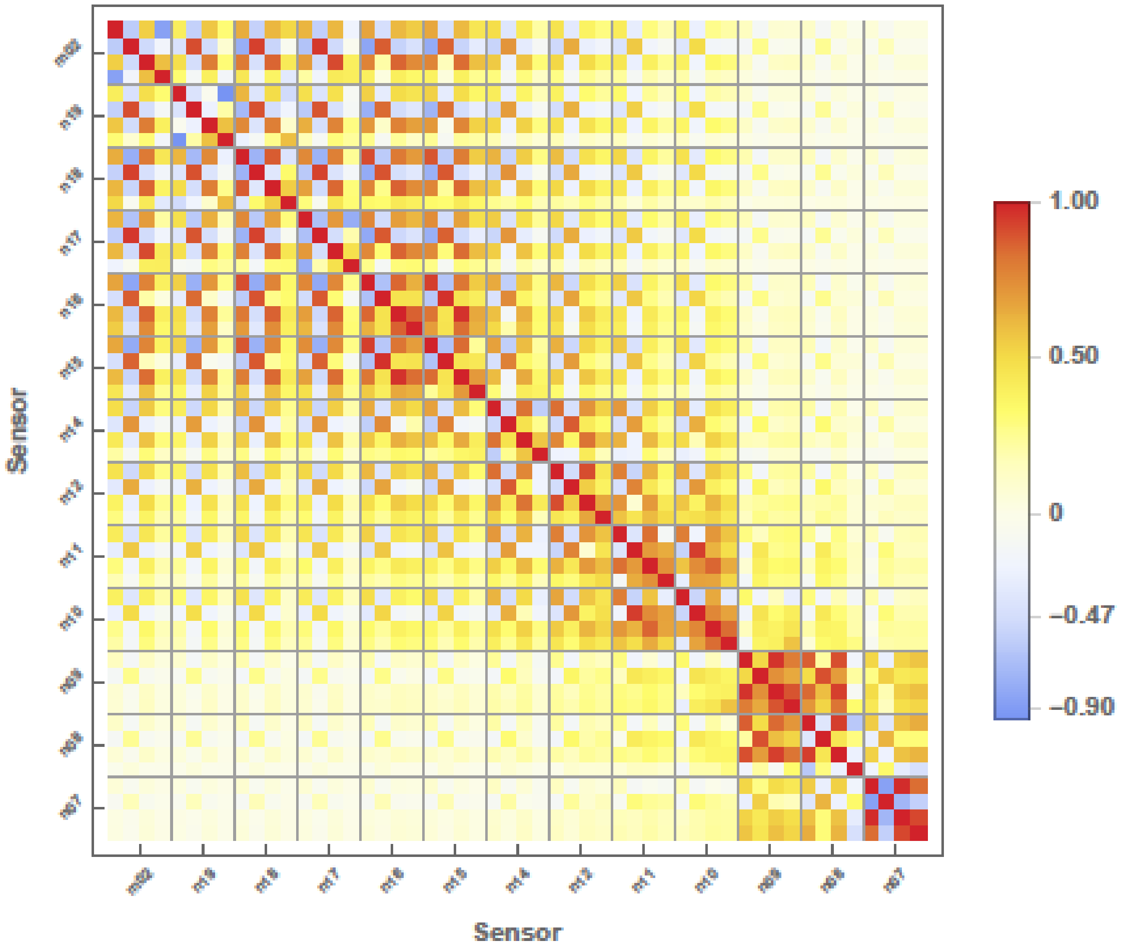
Contents of harmonisation datasets

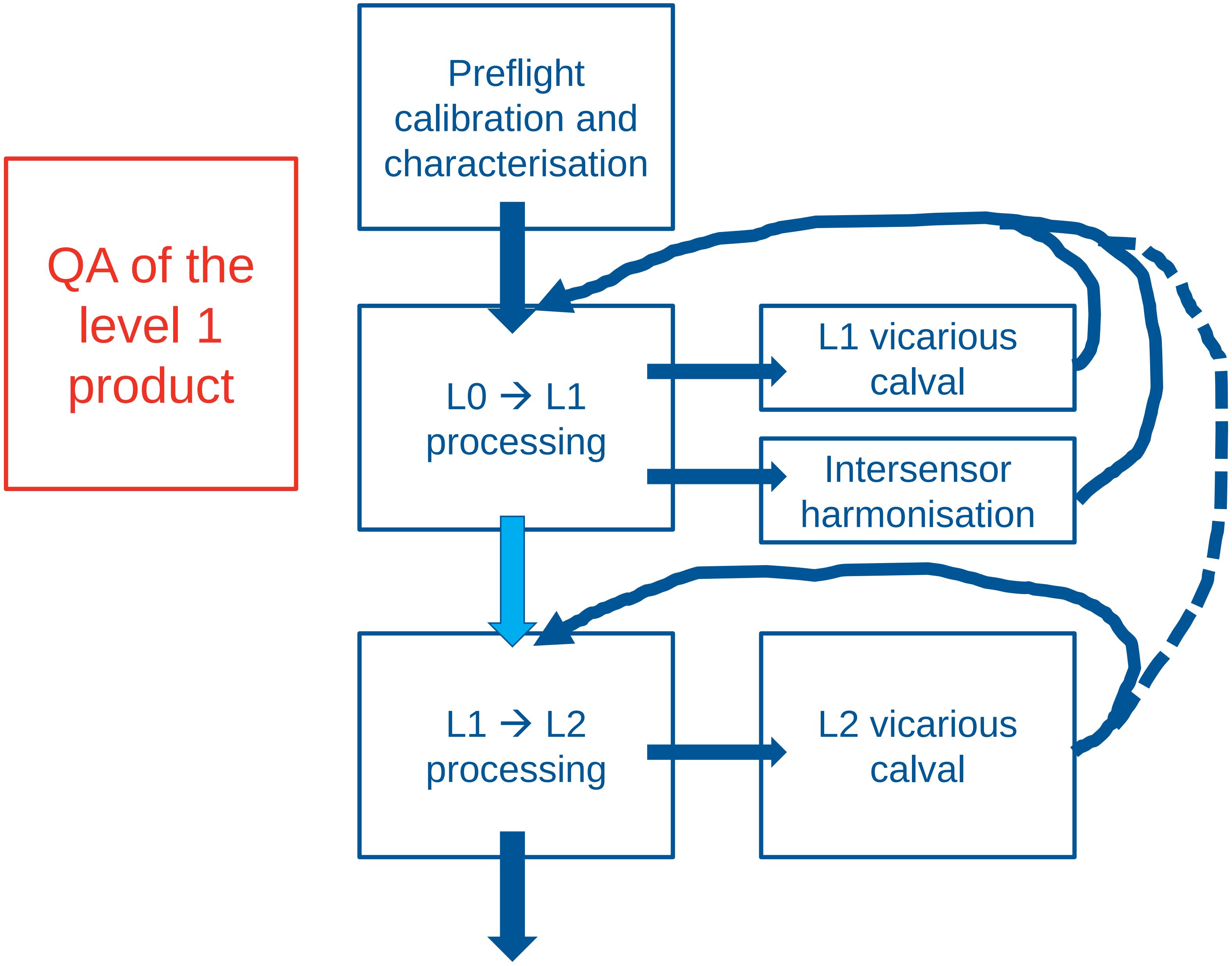
Besides calibration parameters the harmonisation output includes state-of-the-art information on uncertainty.

The uncertainty of calibration coefficients is characterised by an error variance-covariance matrix.

The error variance-covariance matrix is the key to transform the uncertainty of the calibration into an uncertainty of the calibrated radiance!

From the error variance-covariance matrix we can derive the error correlation matrix (see figure) which is more intuitive for explaining the concept.





L1→L2 processing often involves combining data from different spectral channels and sometimes involves combining data from different image pixels

Introducing $\boldsymbol{CURU}^{\mathrm{T}}\boldsymbol{C}^{\mathrm{T}}$

What is the covariance between the Earth radiance values in different spectral channels due to the uncertainty associated with the common effect in the internal calibration target temperature?

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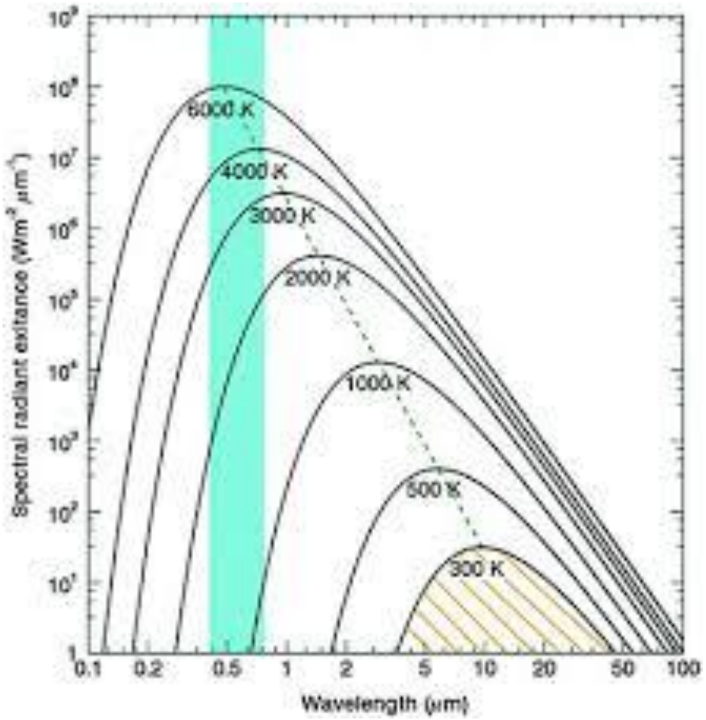
Introducing $\boldsymbol{CURU}^{\mathsf{T}}\boldsymbol{C}^{\mathsf{T}}$

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

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



An error in the temperature of the internal calibration target will affect all channels. But not equally

Introducing $\boldsymbol{CURU}^{\mathrm{T}}\boldsymbol{C}^{\mathrm{T}}$

$$V_{\mathrm{LE},T} = \begin{pmatrix} c_{\mathrm{LA},T} & 0 & 0 \\ 0 & c_{\mathrm{LB},T} & 0 \\ 0 & 0 & c_{\mathrm{LC},T} \end{pmatrix} \begin{pmatrix} u_T & 0 & 0 \\ 0 & u_T & 0 \\ 0 & 0 & u_T \end{pmatrix} \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} u_T & 0 & 0 \\ 0 & u_T & 0 \\ 0 & 0 & u_T \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} c_{\mathrm{LA},T} & 0 & 0 \\ 0 & c_{\mathrm{LB},T} & 0 \\ 0 & 0 & c_{\mathrm{LC},T} \end{pmatrix}^{\mathrm{T}}$$

Covariance matrix for Earth Radiances in different channels due to common temperature error

$u(T)$

Temperature uncertainty in K
The same throughout by definition

Full correlation

$$c_{\mathrm{LA},T} = \frac{\partial L_{\mathrm{E,A}}}{\partial L_{\mathrm{ICT,A}}} \frac{\partial L_{\mathrm{ICT,A}}}{\partial T}$$

Sensitivity coefficient to convert from temperature to Earth radiance uncertainty

More $\boldsymbol{CURU}^{\mathrm{T}}\boldsymbol{C}^{\mathrm{T}}$

Covariance matrix for Earth Radiances in different channels due to errors in Earth Counts

$$\boldsymbol{V}_{\mathrm{LE},CE} = \begin{pmatrix} c_{LA,CE} & 0 & 0 \\ 0 & c_{LA,CE} & 0 \\ 0 & 0 & c_{LA,CE} \end{pmatrix} \begin{pmatrix} u_{CA} & 0 & 0 \\ 0 & u_{CB} & 0 \\ 0 & 0 & u_{CC} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} u_{CA} & 0 & 0 \\ 0 & u_{CB} & 0 \\ 0 & 0 & u_{CC} \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} c_{LA,CE} & 0 & 0 \\ 0 & c_{LA,CE} & 0 \\ 0 & 0 & c_{LA,CE} \end{pmatrix}^{\mathrm{T}}$$

$u(C_{\mathrm{EA}})$

Earth Count uncertainty Likely to change from channel to channel

No correlation

$$c_{LA,T} = \frac{\partial L_{\mathrm{E,A}}}{\partial C_{\mathrm{E,A}}}$$

Sensitivity coefficient to convert from Earth counts to Earth radiance uncertainty

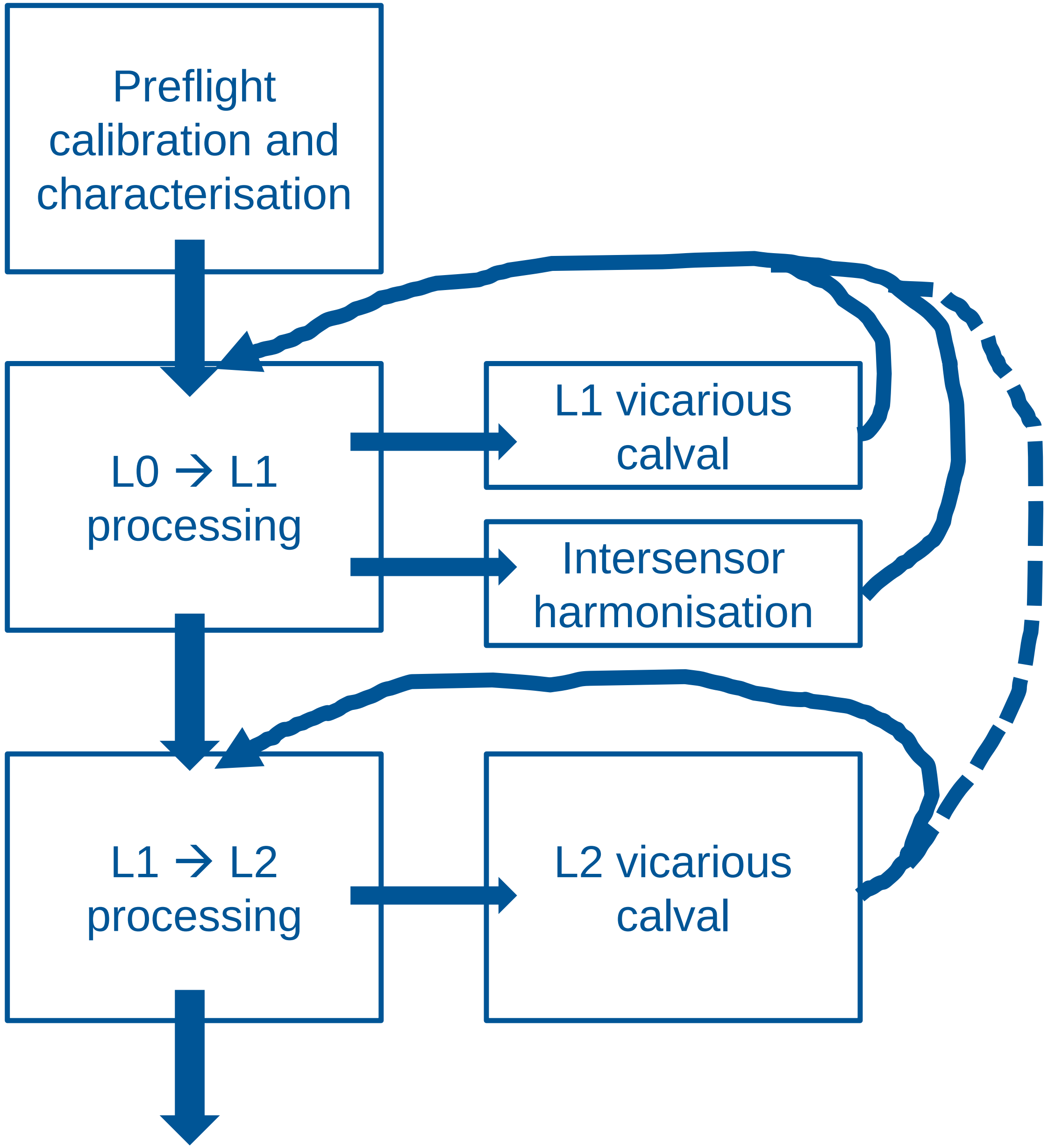
Bringing $\boldsymbol{C}\boldsymbol{U}\boldsymbol{R}\boldsymbol{U}^{\mathrm{T}}\boldsymbol{C}^{\mathrm{T}}$ together

What is the covariance between the Earth radiance values in different spectral channels due to the uncertainty associated with the common effect in the internal calibration target temperature and the uncertainty associated with the independent effect Earth Counts?

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

$$\boldsymbol{V}_{L\mathrm{E}} = \boldsymbol{C}_{C_\mathrm{E}} \boldsymbol{U}_{C_\mathrm{E}} \boldsymbol{R}_{C_\mathrm{E}} \boldsymbol{U}_{C_\mathrm{E}}^{\mathrm{T}} \boldsymbol{C}_{C_\mathrm{E}}^{\mathrm{T}} + \boldsymbol{C}_T \boldsymbol{U}_T \boldsymbol{R}_T \boldsymbol{U}_T^{\mathrm{T}} \boldsymbol{C}_T^{\mathrm{T}}$$

QA of the level 1 product



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Fiduceo

- Uncertainty “Tree Diagrams”
- Effects tables
- Harmonisation

EDAP

- L1 Data QA
- Grading Criteria

Acknowledgements and notices

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- www.fiduceo.eu
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