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GRUAN ICM-11
Uncertainty Discussion

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Contents

- Uncertainty definitions and terminology
- Dealing with correlated uncertainties

What is uncertainty?

Definition in the International Vocabulary of Basic and General Terms in Metrology (VIM) — Third edition (2006)

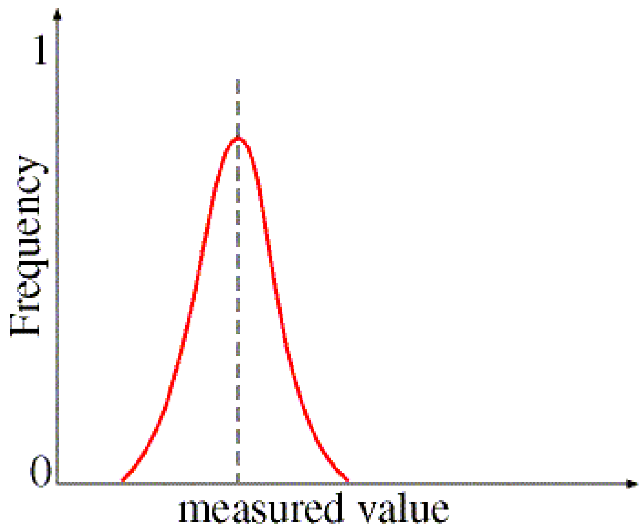
‘Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand’

From which we can conclude:

- Uncertainty is a topic which seems to attract the most obscure and convoluted definitions;
- Uncertainty is a **property of a result;**
- Indicates the likely range within which we think the ‘true’ value of a measured quantity lies, **given all the information we have;**
- Measurement uncertainty is a single value, expressed in terms of the measurand, either as a percentage or in units or the measurement.

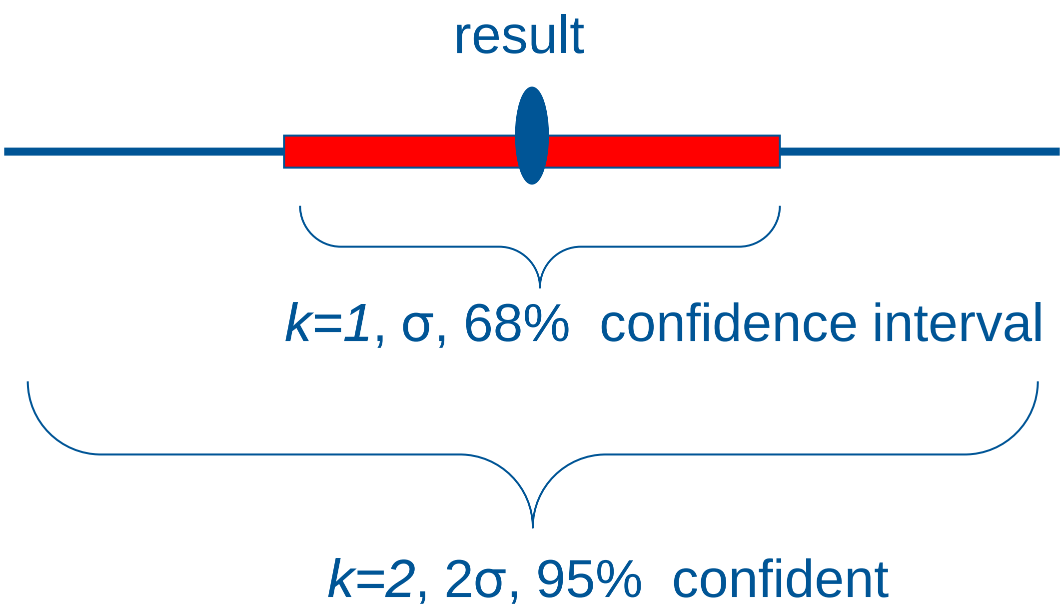
$x \pm U$

(with a given confidence interval defined by a coverage factor, k)



Level of confidence

- Our aim is to quantify the uncertainty to allow the measurement result to be interpreted.
- To do this we must calculate uncertainty in a defined way with a known level of confidence (i.e. the uncertainty of our uncertainty).
- Normally this is ~95% (*k=2*).



More confident, but within a wider interval

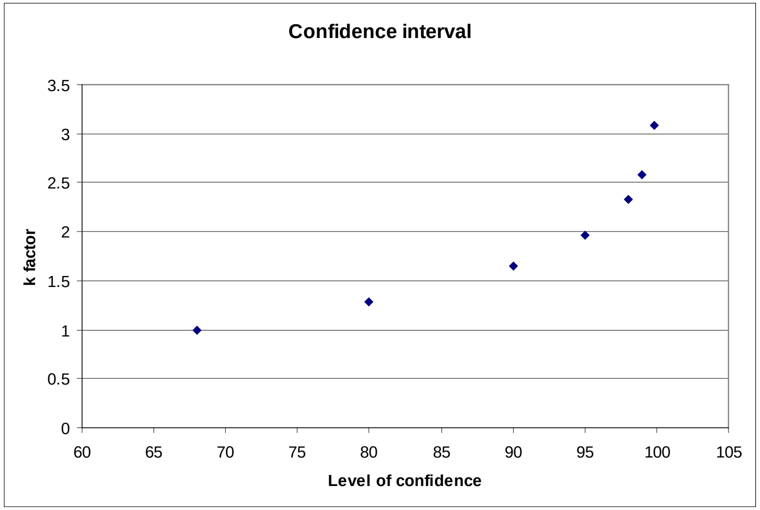


Illustration of the concept of uncertainty

Repeated measurements
(of the same thing)

Average

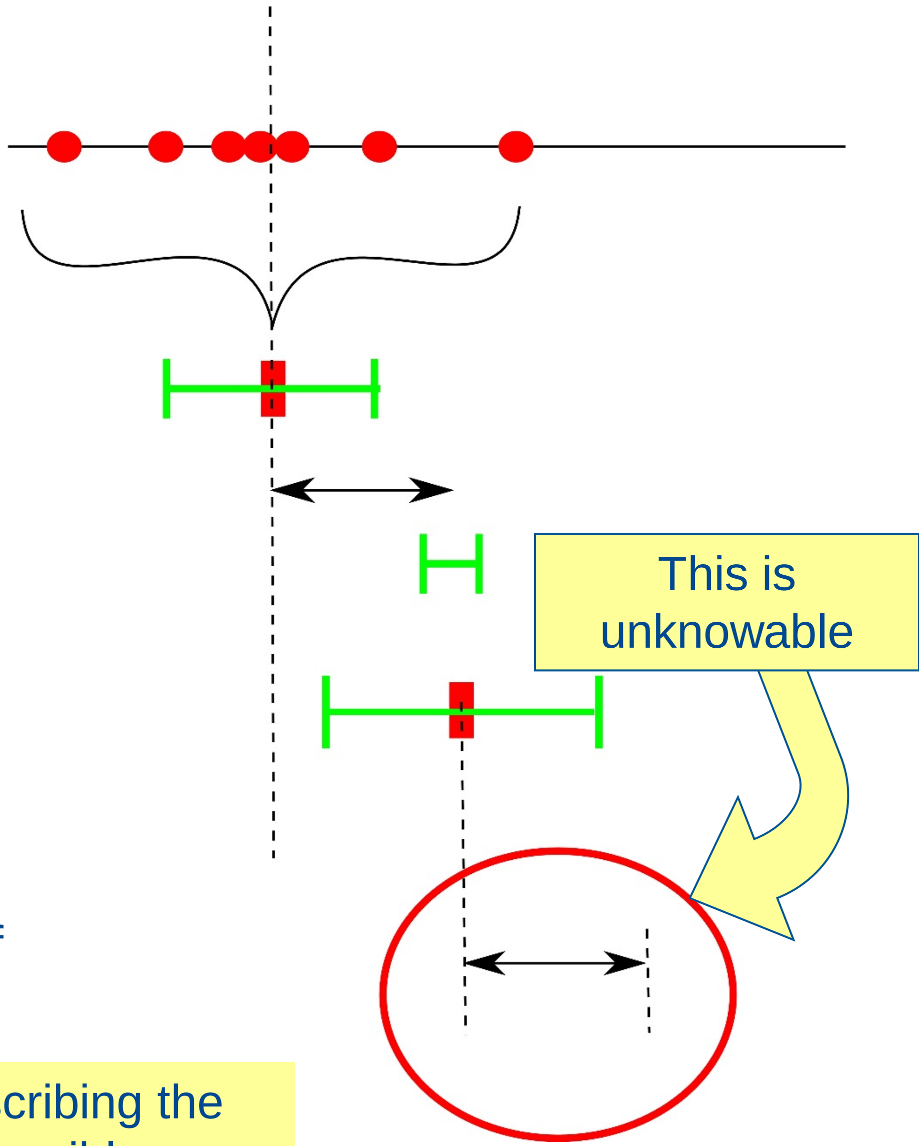
Uncertainty due to repeatability

Correction for external conditions

Uncertainty due to correction

Measurement result and
estimate of uncertainty

However, ‘true’ result may be
outside the uncertainty because of
unknown effects



We minimise this by describing the
method as fully as possible

What isn’t it

- Mistakes
  - Uncertainty doesn’t (can’t) cover mistakes and errors.
- The error in the result
  - An error is the difference between a result and the true answer – we don’t know what the ‘true’ answer is.
  - Better to think of measurement uncertainty as a figure of merit, an indication of what values the true answer might have.
- An absolute fact
  - It is an estimate, at best we are saying that 95 times out of a 100 the true result is (probably) within our uncertainty bounds.
  - Of course, this also means that 5 times out of a 100 a result will be outside these bounds.

Uncertainty terminology (definitions based on VIM, 2008)

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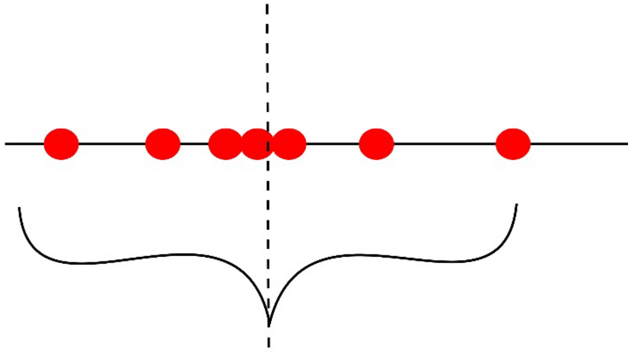
- **Measurement accuracy:** Every measurement has imperfections that cause it to differ from the true value. The measurement accuracy describes the closeness of the agreement between the result of a measurement and the true value of the measurand.
- **Measurement Precision:** closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same measurand under specified conditions. The ‘specified conditions’ can be, for example, repeatability conditions of measurement or reproducibility conditions of measurement.
- **Repeatability:** measurement precision under conditions of measurement that involves the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same measurand over a short period of time.
- **Reproducibility:** measurement precision under conditions of measurement of the same measurand that includes different locations, times, operators, measurement procedures and measuring systems. A specification should give the conditions changed and unchanged, to the extent practical.

Repeatability in atmospheric measurements

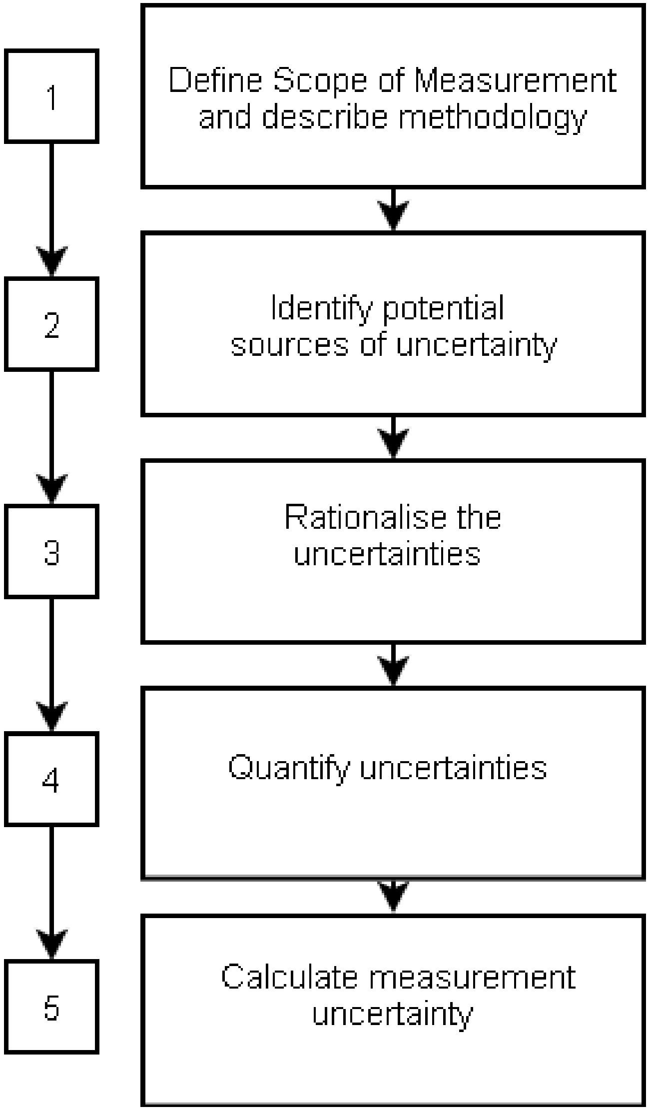


- One key issue in atmospheric measurements is that in general we can’t make repeated measurements of the measurand.
- For example, if what we are measuring is an annual mean, then we can’t just take the scatter of results as a measure of the random uncertainty in the measurement.
- One option is to characterise the repeatability from validation measurements – usually by repeated measurements of a calibration artefact or validation source.

Don’t confuse variability of the measurand with uncertainty of the measurement

Guide to Uncertainty in Measurement (GUM)

- The GUM has been adopted as an overarching methodology
- Approach can be summarised as:
  - Describe measurement steps.
  - Identify uncertainties associated with these and all inputs.
  - Combine them.
  - Assign known level of confidence to this uncertainty.



Random vs Systematic Terms

- Always define the scope of the measurement result that you are determining the uncertainty of.
- What may appear as a systematic term (bias) in one context/time period may be a random term (noise) in another.
- For example over a year the use of different calibrations will randomise some uncertainties.
- If you can randomise a systematic (bias) term then it can be reduced (e.g. use multiple independent calibration artefacts) through multiple measurements.
- Understanding the temporal correlation in the uncertainty is crucial.

Effect of uncertainty correlation in trend detection

The time to detect a trend at the 95% confidence level with probability 0.9 can be approximated by :

$$n^* = \left[\frac{3.3\sigma_N}{|\omega_0|} \sqrt{\frac{1+\varphi_N}{1-\varphi_N}} \right]^{2/3}$$

Where:

n^* is the number of years to detect a trend,

ω_0 is the trend magnitude (% year^{-1}),

σ_N is the std of the total noise in the time series (% of mean value), and

Φ_N is the autocorrelation of the **measurement** noise.

Assumes autoregressive behaviour (order 1) in the data. Weatherhead et al. JGR, 1998.

Uncertainty correlation issues

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- Need to agree common method(s) to determine and report GRUAN uncertainties with particular reference to their temporal correlation.
- How to determine measurement uncertainty correlation that is independent of atmospheric variability?
- Can’t use repeatability statistics, so have to system model with individual uncertainty components.
- First step is to identify correlation behaviour of the individual components making up overall uncertainty.
- Need to combine these and determine temporal behaviour of overall uncertainty.
- This then should be reported in a way that is understandable and useable by different user-groups.

Traceability and uncertainty assessment

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- Traceability and uncertainty assessments were carried out in GAIA-CLIM project for a range of ECV measurements, a number of which are relevant to GRUAN.
- All steps in the process of generating the measurement product are considered in terms of:
  - The uncertainty related to that step.
  - The temporal and spatial correlation of the uncertainty.
  - The influence of the step on the final result.
  - Any correlations with other steps in the process.
  - The traceability and validation relevant to that step.
- Provides current best estimate of uncertainty contributions and their correlations, and identify gaps in current knowledge of uncertainties.
- Doesn’t resolve how to report correlation in overall uncertainty.

Correlation descriptors for uncertainty components (in profile measurements)

- Random
  - uncorrelated uncertainty (noise) on individual measurements.
- Structured Random
  - vertical correlation within a profile but random from one profile to the next.
- Quasi-systematic
  - some correlation from one profile to the next but only for a limited period of time.
- Systematic
  - long-term correlated uncertainties (bias).

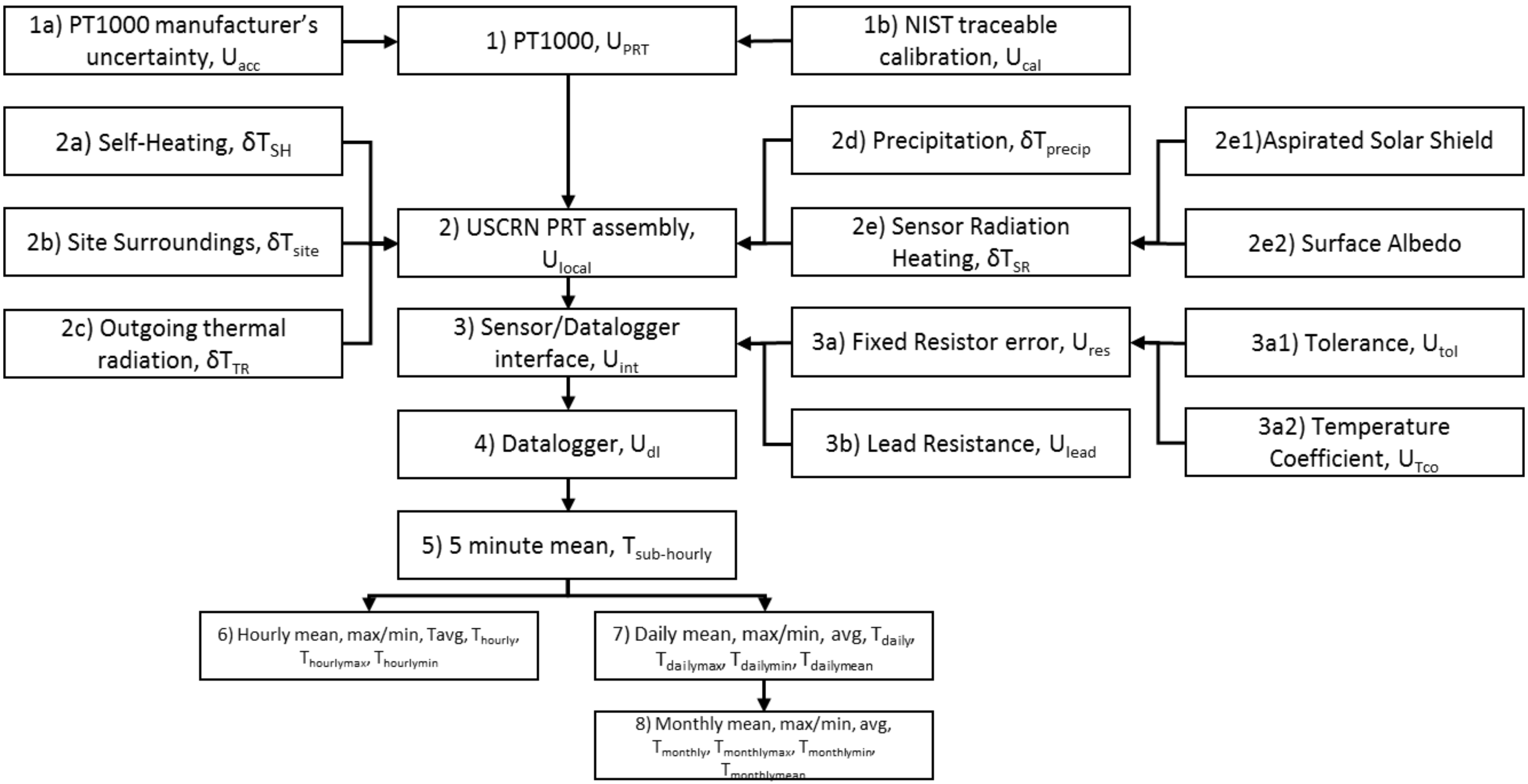
Combined uncertainty – correlation reporting options

- Report total uncertainty for results over different timescales
- Co-variance matrices
  - Matrix representation of uncertainties with random (diagonal) and correlated (off-diagonal) components.
  - Already used for optimal estimation analysis in a number of techniques.
  - Experience for 1-D variation, usually spatial, but harder to implement for 2-D variation – spatial & temporal.
- Uncertainty PDF's and ensembles
  - Use Monte Carlo sampling of individual uncertainty components to generate ensemble of potential outcomes, and also giving combined probability density function.
  - Relatively easy to implement and deal with non-normal uncertainty distributions.
  - Potential issues of data volume and applicability to users.

Uncertainties for different ‘results’

- Follow the VIM uncertainty reporting definition, but provide total uncertainty values for different ‘results’, e.g. provide separate uncertainties values for:
  - Single measurement within profile;
  - Combined profile (total column);
  - Short- (daily), medium- (weekly, monthly) and long-term (annual, decadal) averages.
- Users could select most appropriate timescale for their application and relatively easy to report/use.
- Loses some detail of the correlations, and this detail is still needed to calculate for different periods.
- Case study completed for USCRN near-surface temperature measurements.
- Jordis has developed similar concept for RS/RO comparison.

USCRN Traceability chain



Sources of uncertainty and their classification for the different USCRN data products

Uncertainty source	Sub hourly	Hourly	Daily	Monthly	Long term
Datalogger	Systematic	Systematic	Systematic	Systematic	Quasi-Systematic
PRT noise	Random	Random	Random	Random	Random
Calibration	Systematic	Systematic	Systematic	Systematic	Random
Solar rad.	Systematic	Systematic	Quasi-Systematic	Quasi-Systematic	Random
Rain	Systematic	Quasi-Systematic	Random	Random	Random
Lead	Systematic	Systematic	Systematic	Systematic	Quasi-Systematic
Fixed resistor Tol.	Systematic	Systematic	Systematic	Systematic	Quasi-Systematic
Fixed resistor TD	Systematic	Systematic	Quasi-Systematic	Quasi-Systematic	Quasi-Systematic
Snow	Systematic	Systematic	Quasi-Systematic	Quasi-Systematic	Random

Total Uncertainty Estimate

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- Total uncertainty takes the form:

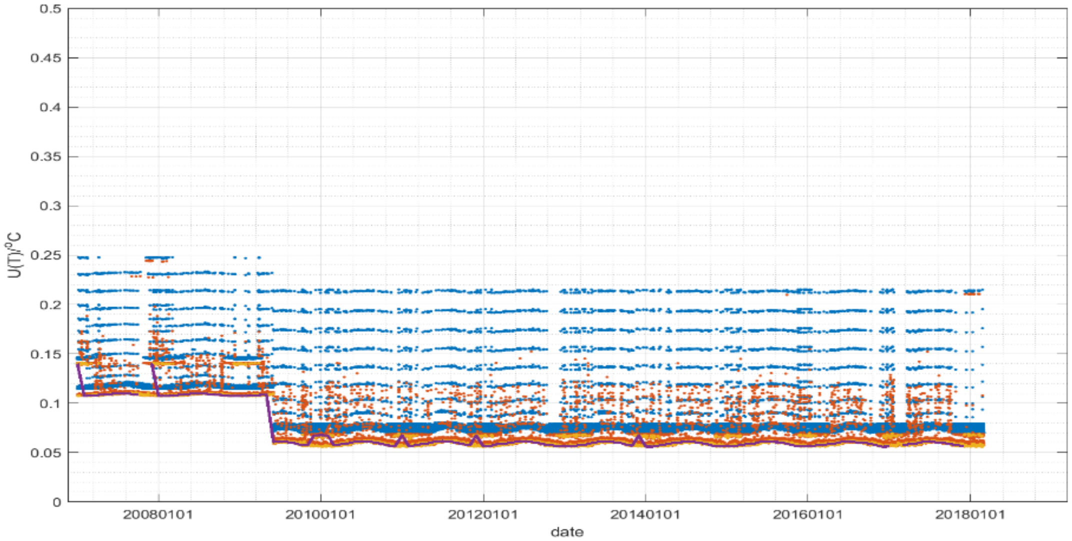
$$\mathrm{U}(T) = \sqrt{\left(\frac{u_{acc}}{\sqrt{N}}\right)^2 + (0.68\, U_{cal}(T))^2 + \overline{U_{local}(T)}^2 + \left(0.68\, U_{int}(T)\right)^2 + U_{dl}(T)^2}$$

- With variation between the different timescale products as a result of:
  - Calculating based on a different number of points, N
  - Different contribution from local effects, u_{local}(T) over different timescales.

- Most of the effects also have a dependence on temperature, in general uncertainty increases with increasing temperature, with the exception of step-changes at certain boundaries.

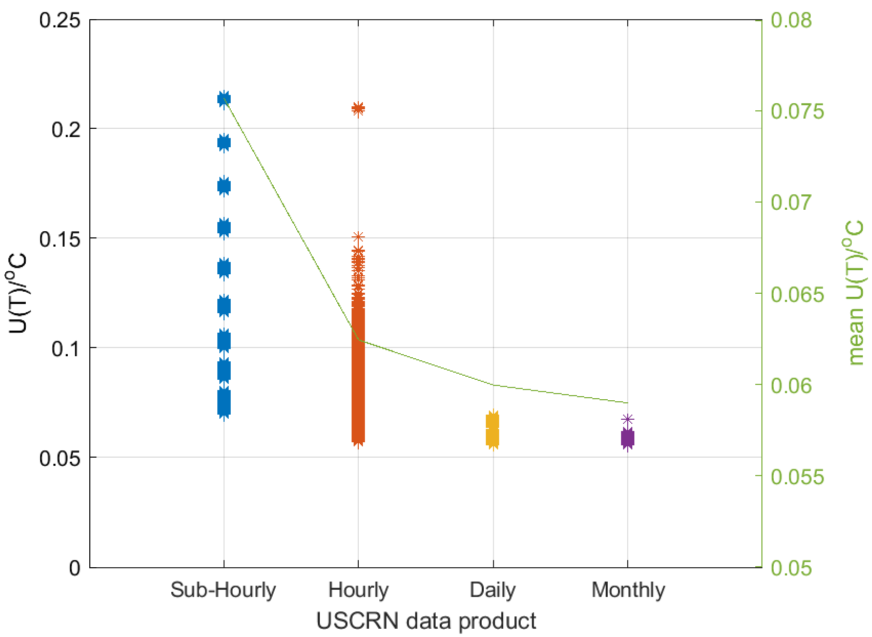
- The uncertainty of the USCRN NST product is > 0.1 K and usually < 0.3 K.

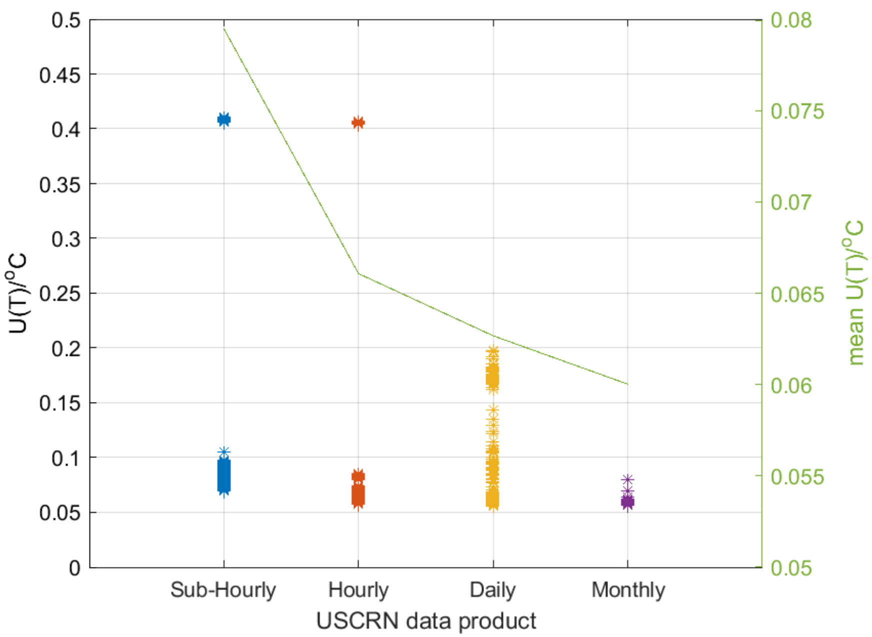
Positive and negative T uncertainties for USCRN site OK Goodwell 2 SE



Blue: sub-hourly
Red: hourly
Yellow: daily
Purple:monthly

Uncertainty values and mean uncertainty for different timescales (USCRN OK-Goodwell 2 SE site)

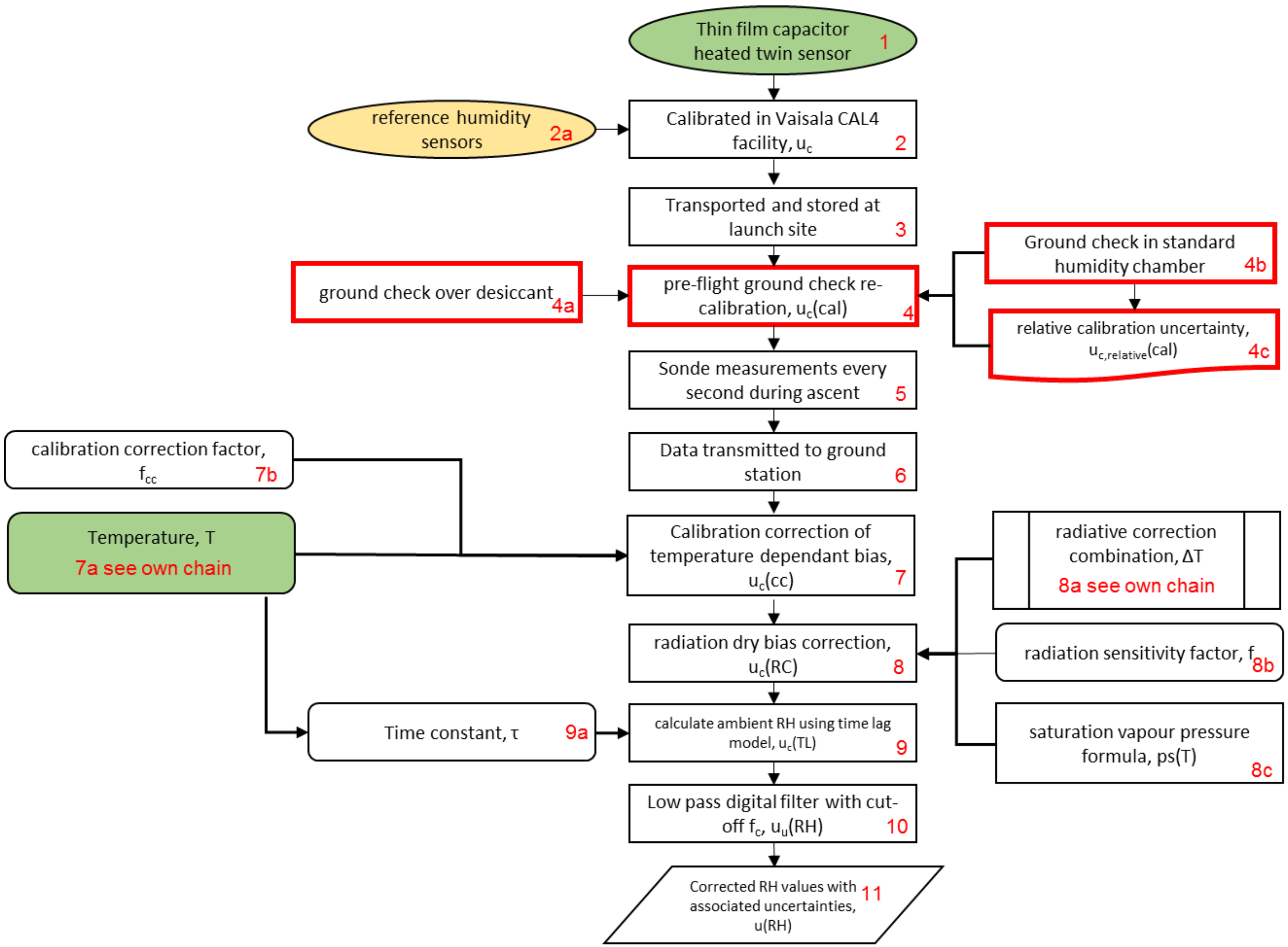




GRUAN RS92 correlated uncertainties

- Base traceability and uncertainty schemes (for T & RH) developed under GAIA-CLIM.
- Currently working on updated version as part of C3S activities.
- Aims to include correlated uncertainty information, and total uncertainties over different timescales.
- Majority of required information already in place in existing GRUAN data product, but some further details required on profile by profile basis.

GRUAN RS92 RH Uncertainties



Next steps

- Complete GRUAN RS92 correlated uncertainty assessment.
- Liaise with Lead Centre on potential use in future sonde products, and relevant Task Teams on other products.
- Prepare GRUAN uncertainty position paper (co-authors?) for internal consideration then publication.
- Potential ongoing Science Coordinator role in reviewing GRUAN outputs to help give metrological consistency.

ANY QUESTIONS / COMMENTS ?