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GRUAN ICM-12
Uncertainty Discussion

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What is uncertainty?

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

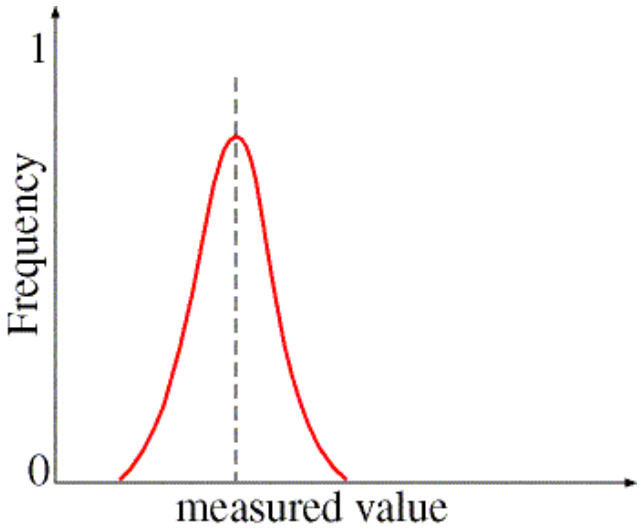
‘Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand’

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.

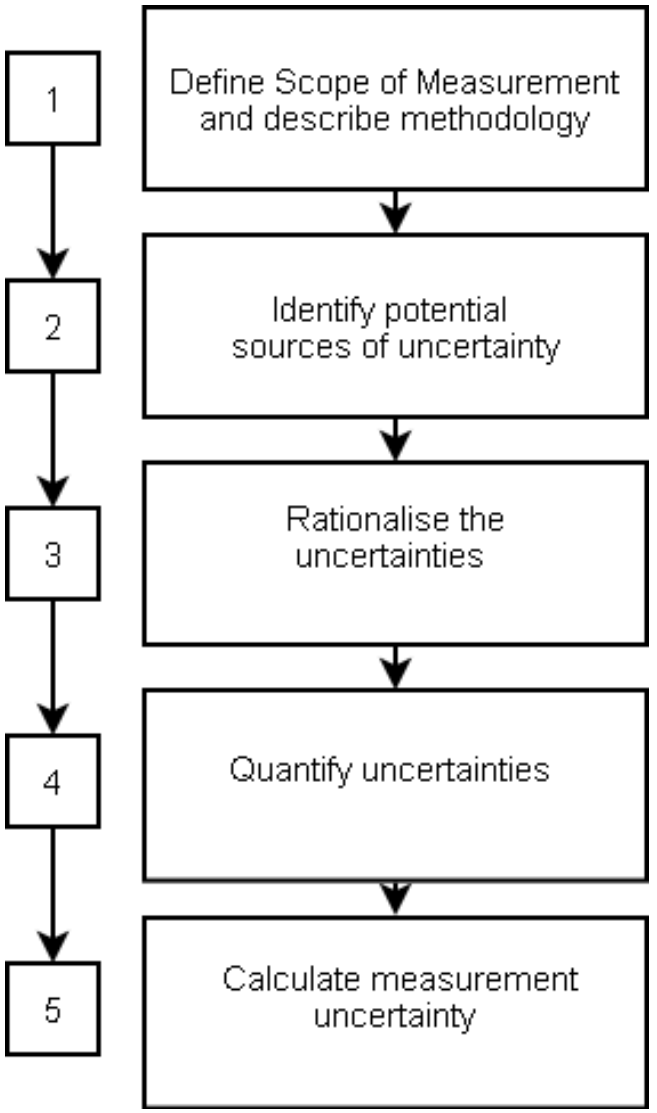
$x \pm U$

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



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

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- 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.

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 from atmospheric measurements, so have to model system with individual uncertainty components.
- First step is to identify correlation behaviour of the individual components making up overall uncertainty.
- Combine these and determine temporal behaviour of overall uncertainty.
- Report in a way that is understandable and useable by different user-groups.

Traceability and uncertainty assessment

- 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.
- G-C work didn't resolve how to report correlation in overall uncertainty.

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’

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- 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 part or complete 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 under C3S activity.
- Working on GRAUN RS-92 data product.

GRUAN RS-92 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 RS-92 Temperature Traceability and Uncertainty Chain

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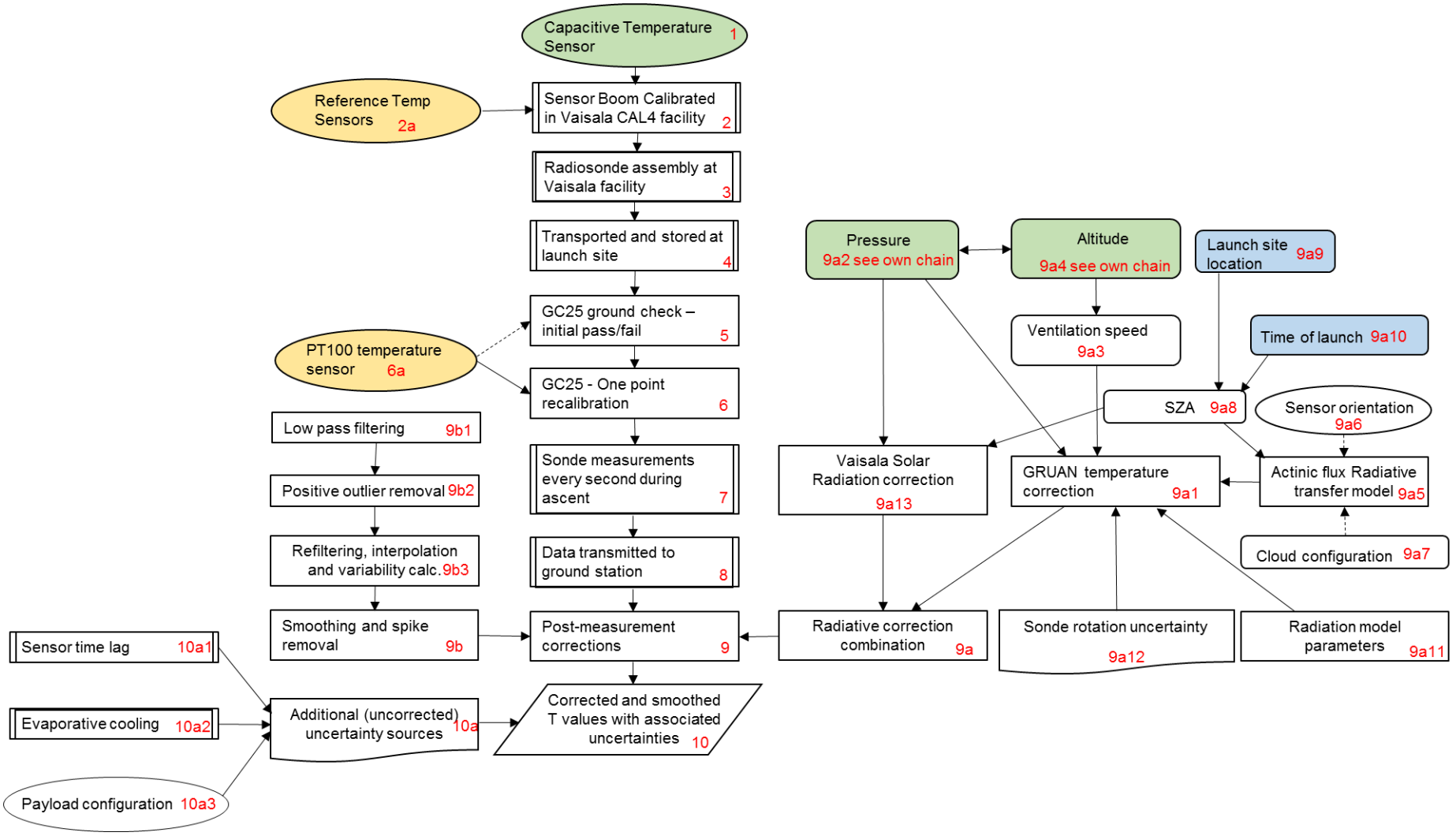
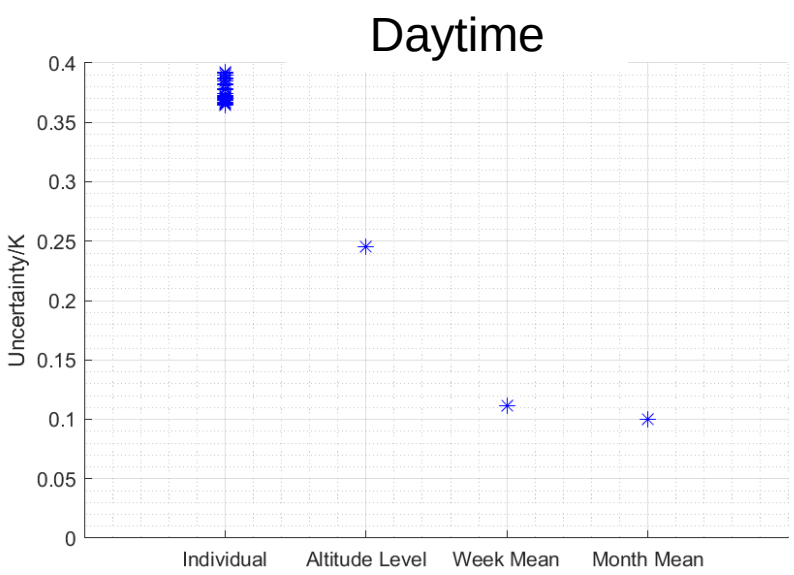
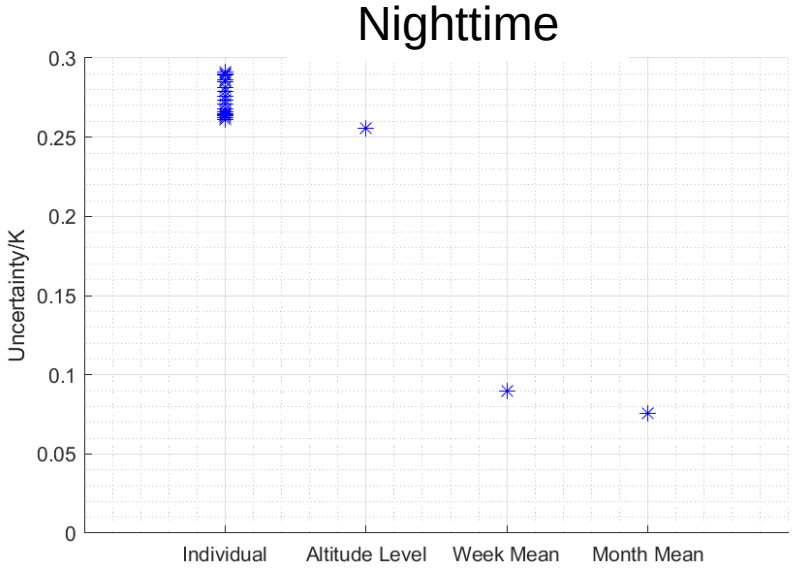


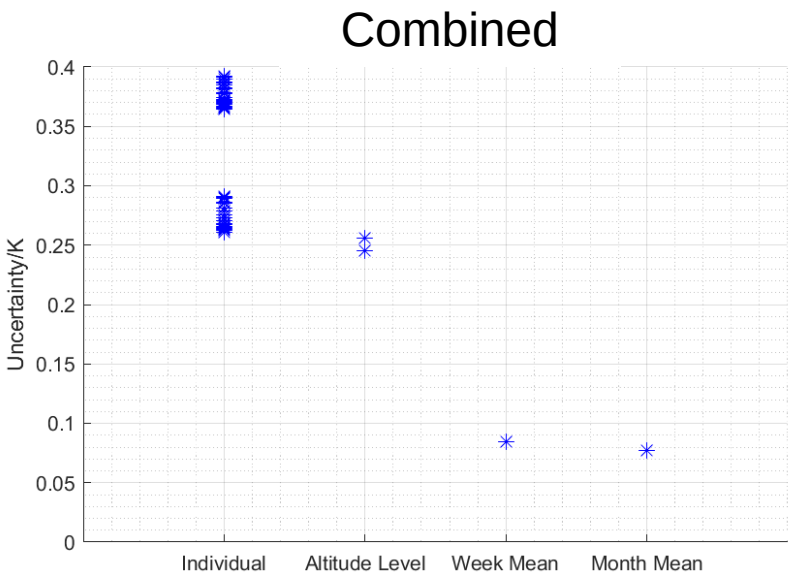
Temporal behaviour of key uncertainty components

Contribution	Sub-contribution	Within profile	Profile-to-Profile Short term	Profile-to-Profile Long term (> 6 Months)
Calibration uncertainty, $u_{c,cal}(T)$	Cal 4 calibration, $u_{cal4}(T)$	Systematic	Random	Random
	Cal 4 reference sensor, $u_{cal4ref}(T)$	Systematic	Systematic	Random
	GC25 Ground check, $u_{GC25}(T)$	Systematic	Random	Random
	GC25 reference sensor, $u_{GC25ref}(T)$	Systematic	Systematic	Random
Statistical uncertainty, $u_u(T)$	none	Structured random, 10s	Random	Random
Radiation correction, $u(\Delta T)$	Rotating sonde, $u_{u,rot}(\Delta T)$	Structured random, >6 s	Random	Random
	Ventilation speed, $u_{u,vent}(\Delta T)$	Random	Random	Random
	Radiation model parameters, $u_{c,RC}(\Delta T)$	Systematic	Systematic	Systematic
	Actinic flux, $u_{c,Ia}(\Delta T)$	Systematic	Random	Random
	Vaisala radiation correction, $u_{vaisala}(\Delta T)$	Systematic	Systematic	Systematic

RS92 Example – Total Uncertainty at 15km







NB. Example based on Lindenberg data from Sept/Oct 2013

RS92 Example – 15 km Combined Uncertainty Components

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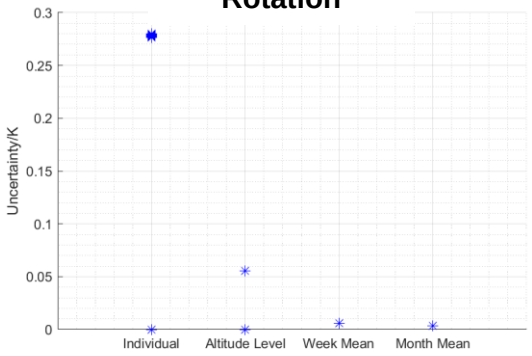
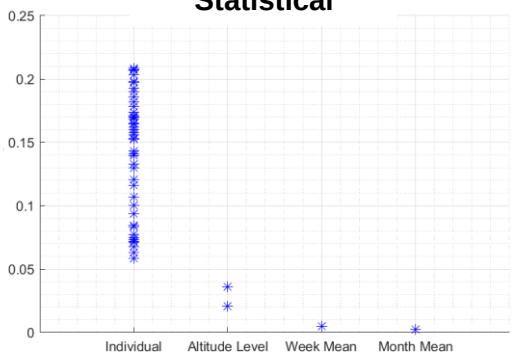
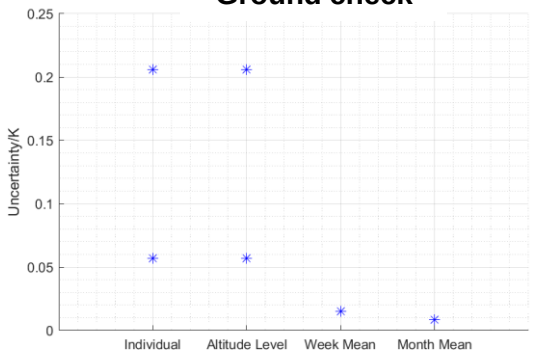
Rotation



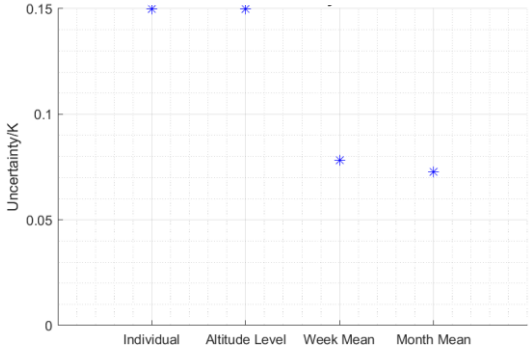
Statistical



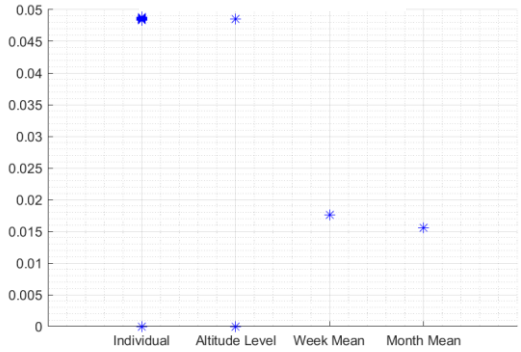
Ground check



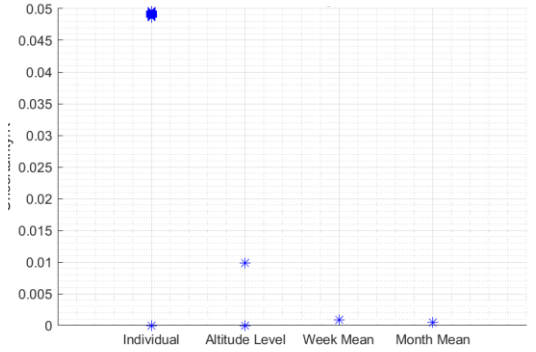
Calibration



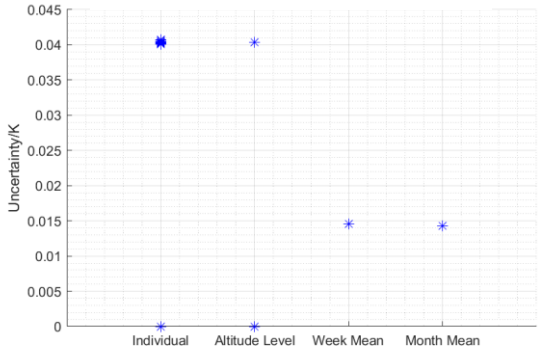
Actinic Flux



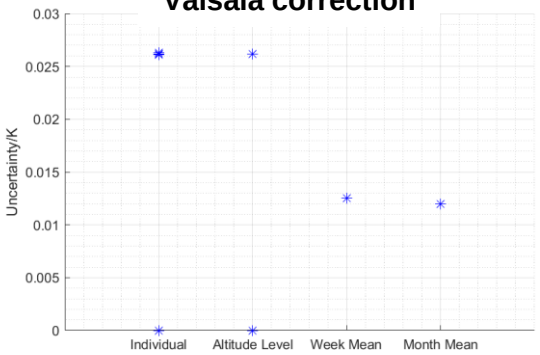
Ventilation



Radiation model params

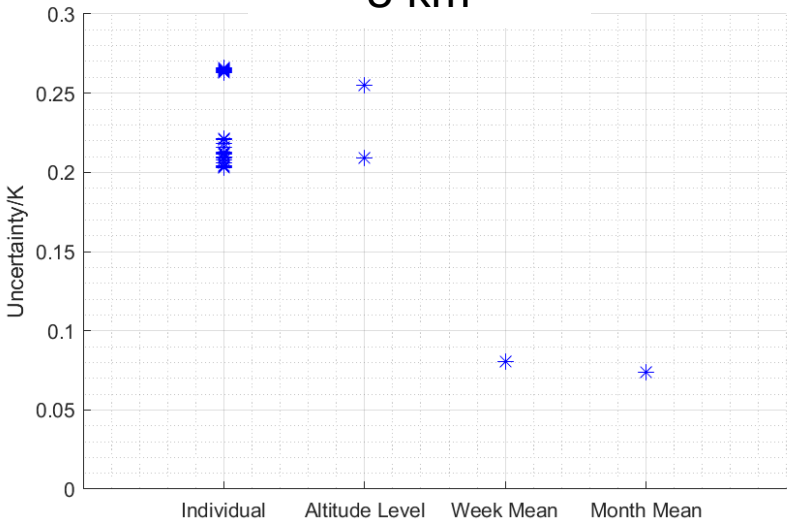


Vaisala correction

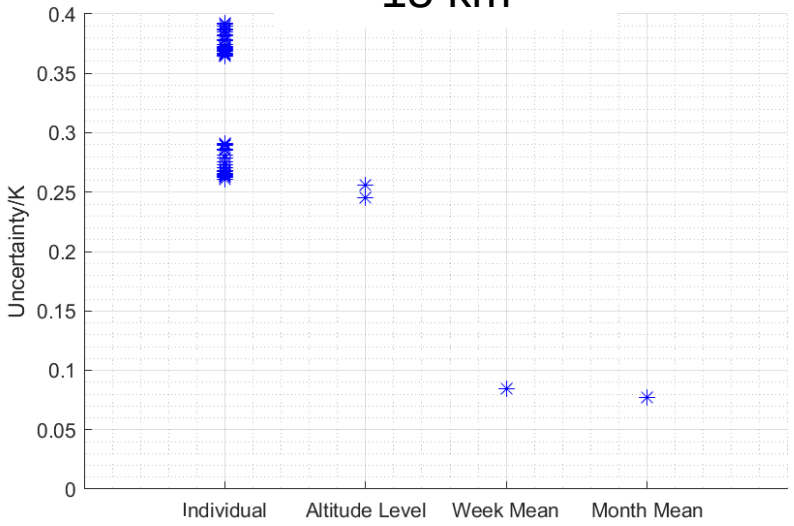


RS92 Example – Combined Uncertainties at Different Altitudes

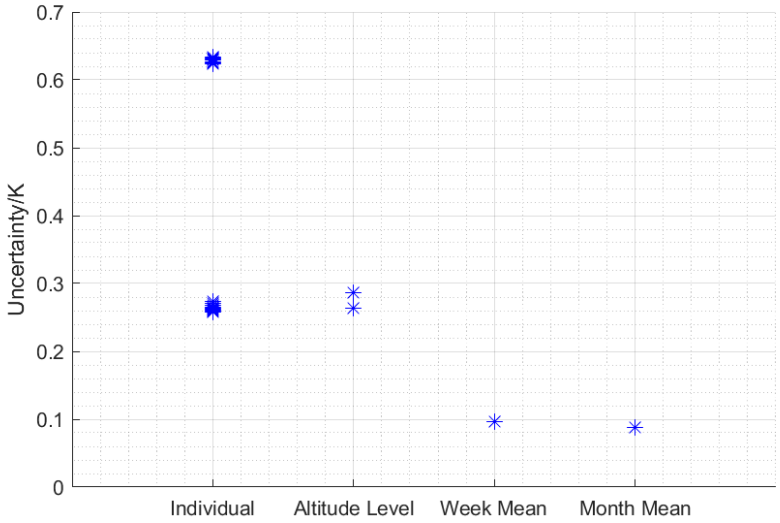
5 km



15 km



25 km



Summary and next steps

- Traceability and uncertainty assessment provides a summary of all the potential uncertainty contributions (and the gaps in this knowledge).
- Provides information for different options for uncertainty reporting, driven by user needs.
- Reporting on different timescale provides a simple way for different users to identify relevant uncertainty for their application.
- Planning to implement for the complete GRUAN RS92 dataset under C3S.
- Discuss potential extension to other GDPs.