GRUAN ICM-14
Measurement Scheduling and Combination Task Team Summary & Uncertainty Reporting

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Background

The long-term objective for the Task Team is to develop tools to characterise the atmospheric column above each site through the combination of measurements from multiple instruments, taking into account relevant collocation effects, with a view to:

- providing the best available estimate of the vertically resolved atmospheric column above the site;
- ensuring continuous measurements of an atmospheric parameter without temporal gaps;
- understanding and better quantifying the total uncertainty budget;
- optimising the operational costs.

In terms of scientific outputs from the task team, since the activity of the team remains a voluntary one without specific funding, the outputs mainly relate to relevant work within other projects.

Recent Activities – Workshops/Conferences/Papers

National Physical Laboratory

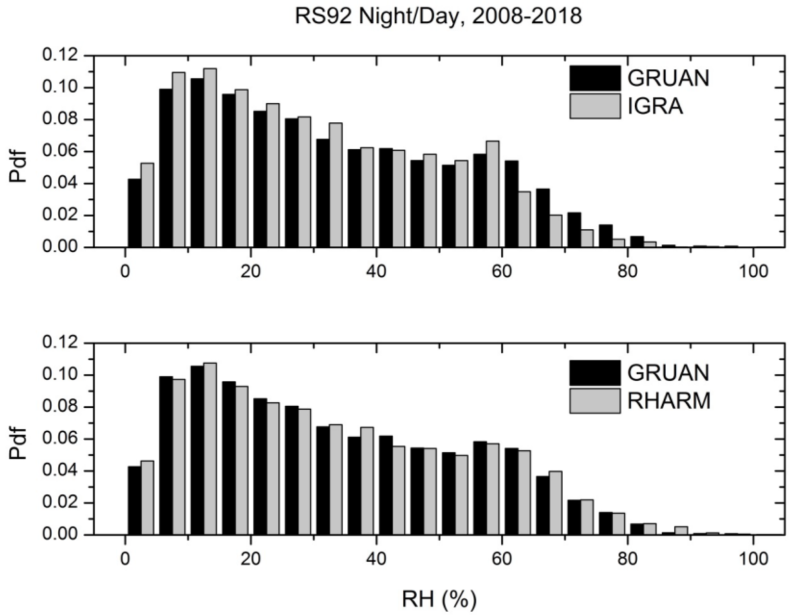
- BIPM-WMO Workshop on Metrology for Climate Action
  - presentations/posters on ‘Estimation of uncertainties in upper air data’ and ‘Determining and Reporting Uncertainty in Atmospheric Reference Networks’.
  - involvement in the preparation of the recommendations for future metrological activities that will be the main output from this event.
- 2nd GCOS conference
  - presentations/posters on ‘Using reference observations to improve homogenized upper-air data records and climate indices’ and ‘Analysis of completeness, coherency and plausibility of ground-based ozone datasets within the Copernicus Climate Change Service’.
- Submission of a paper on ‘Uncertainties on climate extreme indices estimated from U.S. Climate Reference Network (USCRN) near-surface temperatures’
  - aims to demonstrate the impact of undertaking a full measurement uncertainty assessment on atmospheric temperature measurements in order to increase confidence in the evaluation of climate indices and support the validation of reanalysis data.

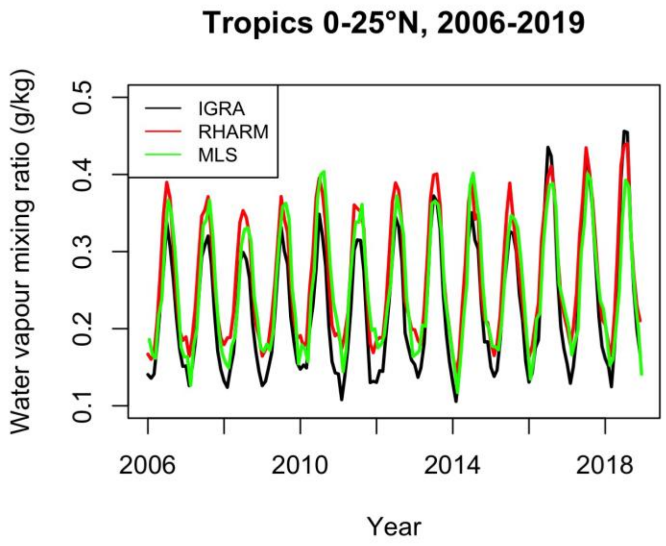
Benefits for wider observing networks

- Fabio has led the development of a new Radiosonde Harmonization (RHARM) approach in the frame of the Copernicus Climate Change Service (C3S) [Madonna et al., 2022, JGR].
- RHARM:
  - Provides homogenized temperature, humidity and wind sub-daily profiles from 1-1-1978 for 697 radiosounding stations globally taken from the Integrated Global Radiosonde Archive (IGRA).
  - Uses reference (GRUAN) and international intercomparison datasets to adjust nonclimatic effects of documented radiosonde types (since 2004).
  - Uses statistical techniques to constrain historical data on the most recent data and to quantify uncertainties in historical data using a data model tested on the reference data.
  - Provides, for the first time in an homogenized data set, an estimation of measurement uncertainties for all pressure levels.

RHARM results

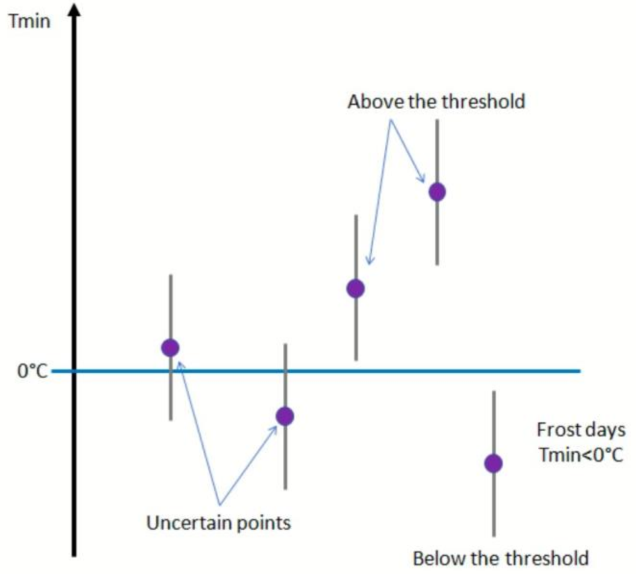
- Radiosounding data from global networks can be post-processed using RHARM, which mimics the GRUAN data processing, improving the quality of upper-air data and reducing the gap with GRUAN products
- For example, the comparison between GRUAN and IGRA RH measurements at 300 hPa for RS92 profiles at GRUAN stations (2008-2018) improves significantly after harmonization.
- As does the agreement with MLS water vapour data in a comparison of monthly timeseries of the water vapour mixing ratio zonal average in the northern tropics.

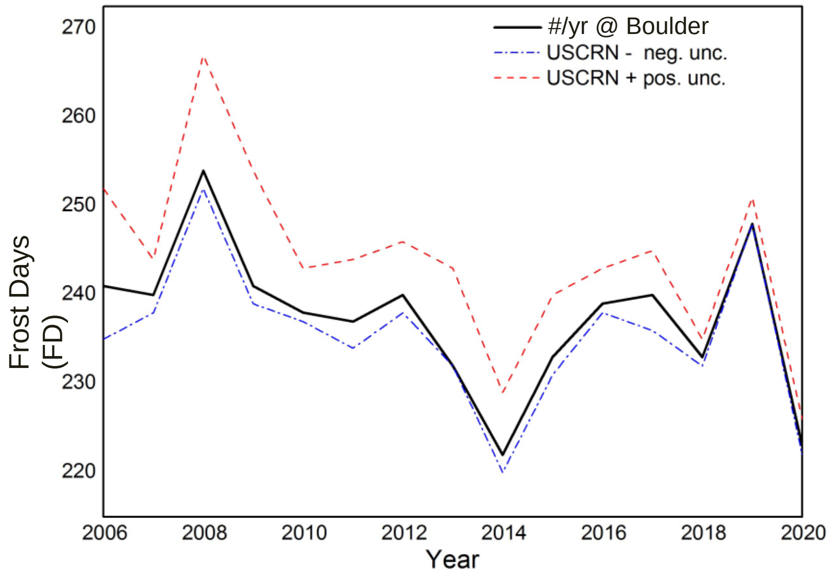




Benefits of uncertainty assessment – USCRN example

- Fabio also led a study utilising C3S work on near-surface temperature measurements from the US Climate Reference Network (USCRN)
- Traceable measurement uncertainties for each USCRN measurement have been estimated (by NPL) exploiting the extensive metadata.
- Enables an assessment of the confidence in meeting extreme event criteria (e.g. Frost Days).
- Provides an example of climate extreme indices estimated with their uncertainties, which are traceable and not inferred from simulations or statistical methods.
- Increases the confidence in the estimation of indices and in decisions for adaptation.
- Paper has been submitted.





Recent Activities – Metrology Development

- An NPL guidance document is in preparation to provide a ‘White Paper on the Effect and Management of Error Covariance Structures in Climate Data Records’.
- Brings together input from Atmospheric, Earth Observation and Data Science metrological research activities on the assessment, representation and impact of correlated uncertainties within long-term climate data.

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Recent Activities – Uncertainty Reporting

- Drafting paper on ‘Uncertainty reporting in reference upper atmospheric measurements’
  - aims to address the challenge of providing information on the measurement uncertainty in a way that is accessible and usable to the wide range of potential applications and interested user groups, with an example uncertainty reporting assessment of the Vaisala RS-92 radiosonde temperature GDP.
- Major issue is the wide range of timescales for GRUAN data uses from single point measurements through to long-term trends, and how to estimate and report uncertainty over this range.
- Understanding and evaluating the uncertainty correlations is key.

Combined uncertainty – correlation reporting options

- 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 dealing with spatial correlations, but harder to implement for combined spatial & temporal effects.
- 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.

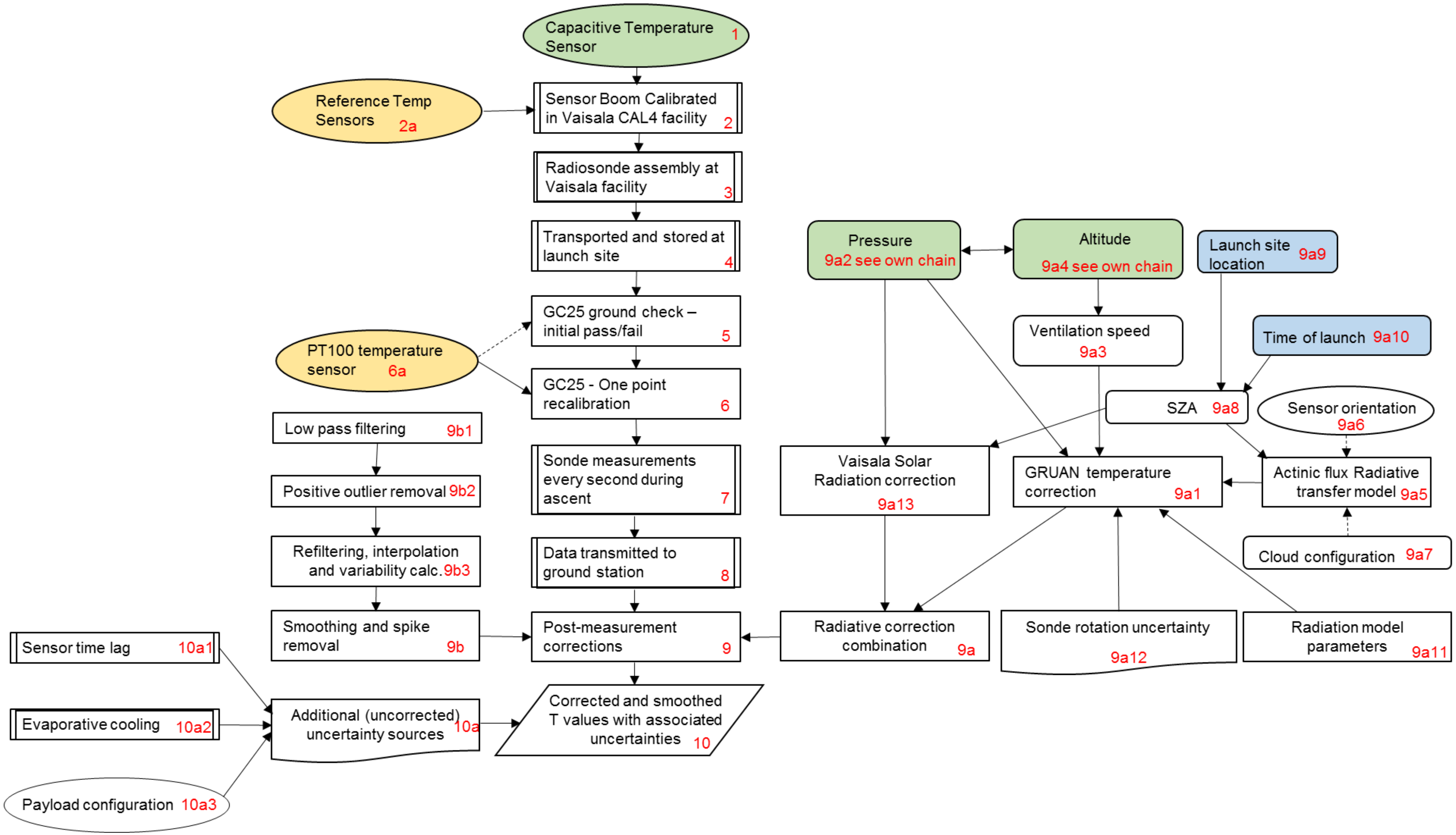
Uncertainties for different ‘results’

- Alternative option is to provide total uncertainty values for different ‘results’, i.e. provide separate uncertainties values for different averaging periods.
- Users can select most appropriate timescale for their application and uncertainties are relatively easy to report/use.
- Looses some detail of the correlations, but this detail is still needed to calculate for different periods and is available for ‘expert’ users.

Product Traceability and Uncertainty

- Following principles developed during GAIA-CLIM and C3S projects (and linked to similar EO activities), the method of estimating the uncertainty is detailed in a Product Traceability and Uncertainty document.
- This involves identifying all individual sources of uncertainty, and assessing:
  - 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.
- A traceability chain can then be created where the individual elements combine through the chain to the end product.
- This traceability chain is used to determine how the different uncertainty elements will combine into the final overall uncertainty.
- There are some cases where missing information means a specific uncertainty contribution can not be measured completely accurately, in these cases tend to assume the worst case scenario.

GRAUN RS-92 Temperature Traceability and Uncertainty Chain



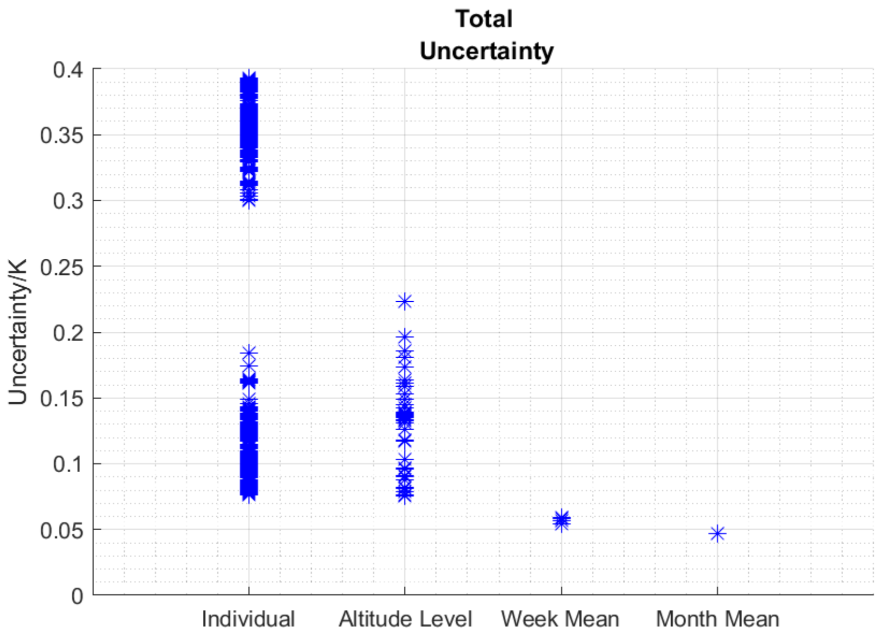
Uncertainty Breakdown Method

- Different uncertainty contributions were identified and classified – Random, Systematic, Structured Random, Quasi-systematic – according to how the uncertainty was expected to change between measurements.
  - Note linkage to RS41 uncertainty reporting: ‘uncorrelated’ (‘ucor’), ‘spatially correlated’ (‘scor’), and ‘correlated in time’ (‘tcor’).
- The method for the single-profile uncertainty breakdown was developed using Dirksen et al 2014, and discussions with the lead centre team.
- To estimate the uncertainties of means of measurements, the uncertainty components of the contributing measurements were combined and reduced according to the number of independent elements used in the estimation of the total uncertainty.

Contribution	Sub-contribution	Within profile	Profile-to-Profile Short term	Profile-to-Profile Long term
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	Quasi-Systematic	Quasi-Systematic

Uncertainty Reduction – Total Uncertainty

- Two distinct uncertainty grouping linked to radiative heating of sensor during day-time and night-time launches.
- Large amount of the variability in total uncertainty is from the statistical uncertainty, so it reduces quickly.
- Further reduction going from the altitude level mean to the weekly and monthly means as many of the uncertainty contributions change from systematic within a profile to random between profiles.



Uncertainties of measurements within 50 m of 25 km altitude for sondes launched between 1/4/2015 and 30/4/2015 at 00 and 12 UTC along with altitude band mean uncertainty, weekly mean uncertainty and monthly mean uncertainty.

Conclusions and Next Steps

- Need to find ways to report uncertainties to different user groups with an appropriate level of detail.
- Methodology developed for assessing traceability and uncertainty in atmospheric reference networks provides a summary of all potential uncertainty contributions (and gaps in this knowledge).
- Once this is complete various reporting options could be implemented.
- Reporting uncertainties on different timescale provides a simple way for different users to identify relevant uncertainty for their application.
- However, full assessment only completed for RS-92 Temperature GDP and extensive work now done on other GDP uncertainties – particularly the RS-41.
- Should this be included?
  - Would provide a route for publication of the complete RS-41 uncertainty assessment.
  - But, would take more time and require significant input from relevant TTs.