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Estimation of uncertainties in historical upper-air data

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Rationale

- Long and homogeneously observed time series of the climate variables are an essential source to diagnose climate change.
- Homogenization and uncertainty characterization of climate data records is a challenging but indispensabile task to improve consistency in the observations collected over the decades.
- Upper-air data have been and are still considered a unique source of information for the study of climate variability and an anchor information for the atmospheric reanalysis (Hersbach et al., 2020).
- More recently, an increasing number of networks is caring of providing measurement uncertainties; few satellite retrievals comes with the uncertainty quantification; atmospheric renalysis is provided with an uncertainty (systematic model errors not taken into account, uncertainties assumed uncorrelated).
- For the upper-air data, a similar effort is still missing and in the most popular homogenized datasets, used by the scientific community, an estimation of measurement uncertainties was never provided.

Upper-air data uncertainties

The quality of the global radiosounding observations depends on:

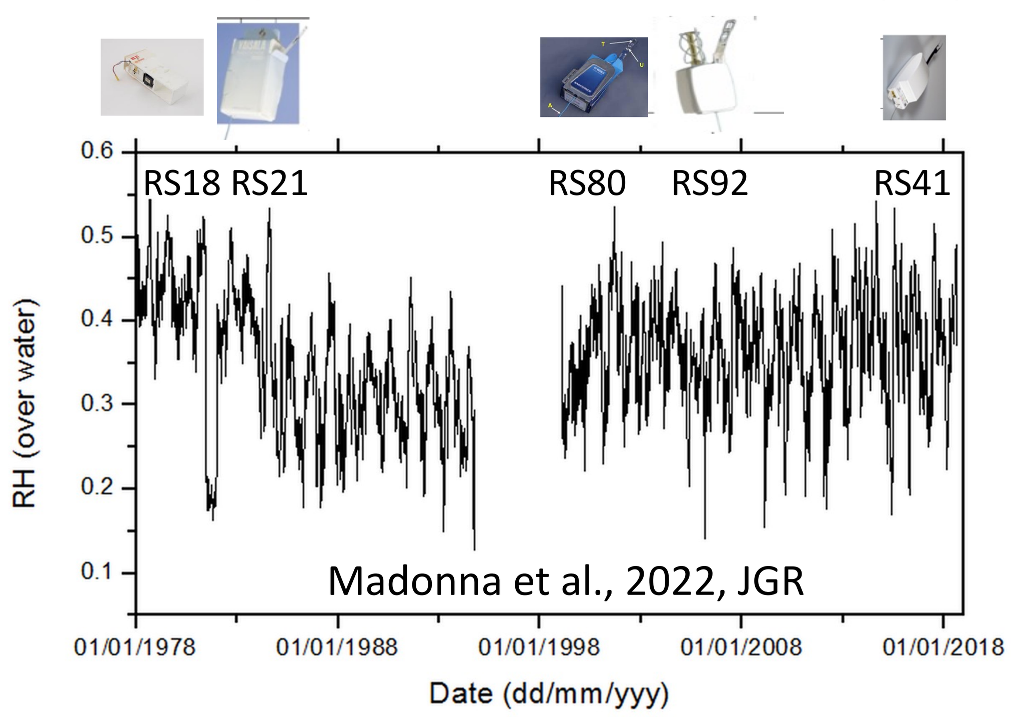
- **Sensor changes,**
- **Changes in the data processing,**
- **Calibration bias and drifts,**
- **Ventilation,**
- **Radiation correction and modelling algorithm,**
- **Sensor orientation,**
- **Sensor time-lag constant.**

Historical time series are also affected by:

- **Station relocations,**
- **Mistakes in the data digitization,**
- **Poor or missing metadata,**
- **Missing information on observation time,**

Sensor changes

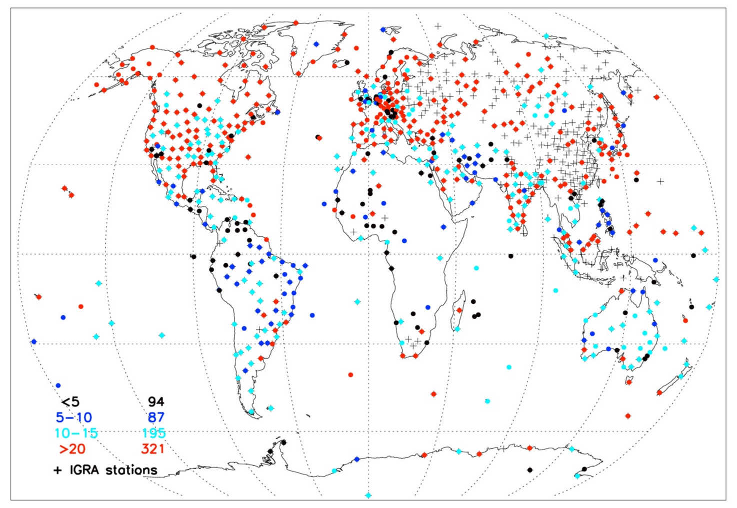
Sodankyla, FI, WMO ID 2836, 300 hPa 00:00 UTC (dark)



Radiosounding HARMonization (RHARM)

- RHARM uses **reference and international intercomparison datasets** to adjust non-climatic effects for ~~of~~ documented radiosonde types (since 2004).
- Use of statistical techniques to **constraint historical data** on the most recent data.
- Use of statistical techniques to quantify **uncertainties** in historical data using data model tested on the reference data.

RHARM is the first homogenized dataset providing an estimation of measurement uncertainties for all pressure levels.



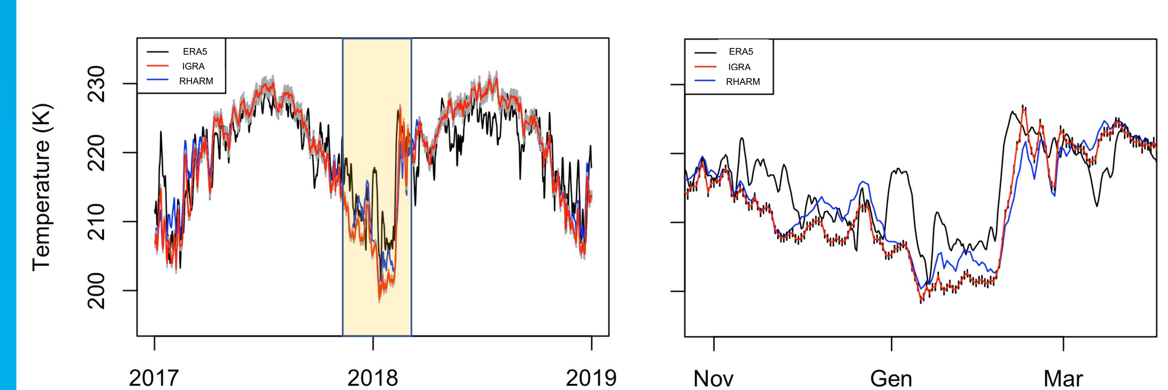
Global distribution and quantity of RHARM homogenized profiles in millions of ascents from 1978 to present. The + symbol indicates IGRA stations (1156) reporting data since 1978 to present (last access to IGRA 31-12-2020).

RHARM estimates combined observational uncertainties using residuals of a time series with respect to predictor model obtained using a LOESS smoother (Madonna et al., 2022).

$$\varepsilon_X = x_i - q_i \quad i = 1, 2, \ldots, T$$

where x_i is the measurement for the variable x at the instant i, q_i is the LOESS modelled value and T is time length of the time series.

- The statistical model is optimized, for each individual station, to match the residuals of the corresponding recent measurements processed using a GRUAN-like algorithm.
- The obtained smoothing parameter is then assumed to be "optimal" for the entire time series.
- The final value of the uncertainty is obtained by averaging the residuals on a monthly time scale.
- RHARM uncertainties have been validated following the approach by Merchant et al., 2017, but using O-B data (RHARM-minus-Background) in the NH and in the tropics at 300 hPa for T and RH.



Comparison during of IGRA (raw upper-air), RHARM (homogenized upper-air) and ERA5 reanalysis during the 2018 Sudden Stratospheric Warmings (SSWs).

Climate applications

The uncertainties in climate observations pose a set of methodological and practical challenges for both the analysis of long-term **trends** and the **comparison** between data and model simulations.

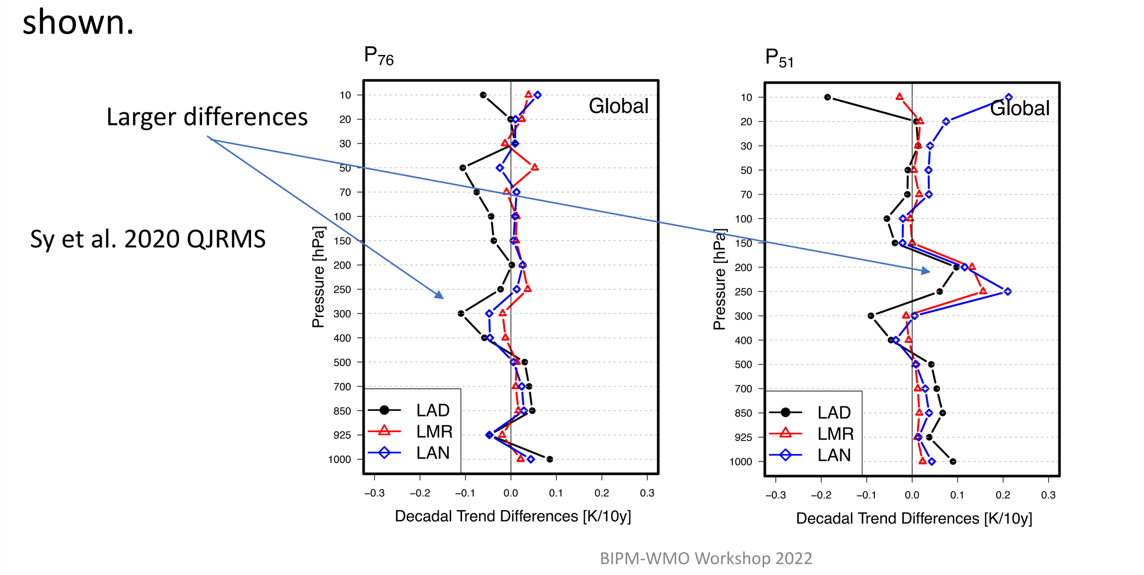
This requires the estimation of further sources of uncertainty, including at minimum:

1. Sampling and structural uncertainties
2. Interpolation uncertainty
3. Representativeness (collocation) uncertainty
4. Residual inhomogeneities

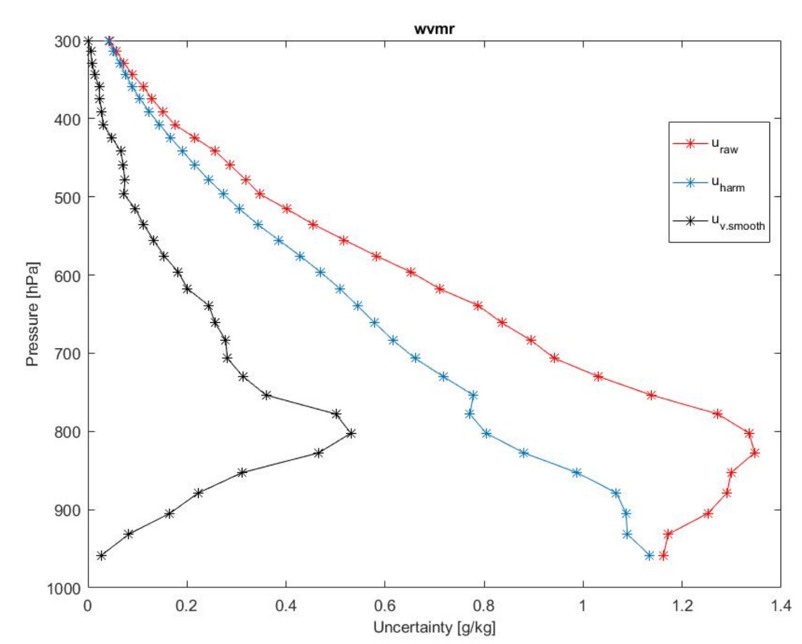
Sampling and structural uncertainties

Differences in the temperature decadal trends estimated from IGRA radiosouding repository, using different data samples (random stations selection, per climate region). P76 and P51 are two dataset selected subsampling the set of IGRA stations (taking 76% and 51% of IGRA stations).

Trend differences due to three robust regression methods are also shown.



Representativeness/collocation uncertainty



Example of quantification of collocation-mismatch uncertainty (in the plot in blue, Immler et al. 2010):

$$\left| m_1 - m_2 \right| \leq k\sqrt{u_1^2 + u_2^2 + \sigma^2}$$

The comparison is based on a likelihood-based approach which exploits the measurement uncertainties in a natural way (Finazzi et al, 2019).

Discussion

- Measurement uncertainties must be always quantified also in upper-air homogenized dataset. RHARM dataset is the first providing measurement uncertainties.
- Uncertainties in historical time series must be properly estimated/evaluated and validated to the possible extent to avoid our conclusions may be mistaken. Metrologists approach oftern differs from the climatologists, for example in the quantificaton of systematic uncertainteis vs bias adjustments.
- The uncertainties in climate observations must include other uncertainty contributions (e.g. sampling, structural interpolation, representativeness, sampling,…).
- More examples showing the impact of using uncertainties in climate applications are recommended.

References

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