Comparison of GRUAN profiles with radio occultation bending angles propagated into temperature space

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Overview

Why am I here?

- I am here to represent the GRUAN community
- 3G workshop in Geneva GRUAN[1]-GSICS[2]-GNSS-RO [WMO, 2014], goals:
  - better connect GRUAN with satellite community
  - compare methods for uncertainty estimation
  - discuss how to better serve climate/meteorological application
- Greg Bodeker, current co-chair of GRUAN, values this cooperation

[1]GCOS Reference Upper-Air Network

[2]Global Space-based InterCalibration System

GRUAN - Global Climate Observing System (GCOS) Reference Upper-Air Network
(www.gruan.org)

- International ground-based reference observing network, currently 28 stations
- Data products with SI-traceable uncertainty estimates
- Currently only radiosonde data product[3], others under development
- GRUAN was established to fill the need for long-term measurements suitable to detect changes in the climate system

[3] `https://www.gruan.org/data/data-products/gdp/rs92-gdp-2/`

Map of GRUAN sites

GCOS Reference Upper-Air Network

Recently published method

A New Method to Correct Radiosonde Temperature Biases Using Radio Occultation Data

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- double differencing approach
- tangent linear RO retrieval
- RO null space
- structural uncertainty

Method to compare GRUAN radiosondes (RS) and RO

- Double differencing using Met Office NWP system as transfer medium

$$\overline{O_{RO} - O_{RS}} \simeq \overline{O_{RO} - B_{RO}} - \overline{O_{RS} - B_{RS}} \tag{1}$$

where O is the observation and B is the background

- Model bias constant over separation distance
$\rightarrow$ distinctively smaller standard deviations than using direct differences between observations
- RO bending angles minus background departures are propagated into dry temperature space with a tangent linear retrieval [Tradowsky et al., 2017]
- Bending angle departures above 35km impact height are set to zero (upper cut-off) [Burrows and Healy, 2016] $\rightarrow$ no upper level initialization

Uncertainty estimation in the RO retrieval

- Sampling uncertainty (see [Tradowsky, 2015])
- Structural uncertainty in a tangent linear RO retrieval (see [Tradowsky et al., 2017])
  - Calculated from the spread of the departures for different cut-off impact heights in the RO retrieval
  - Individual for every upper-air site
- Comparison of global structural uncertainty is similar to the structural uncertainty in conventional RO retrievals (see [Ho et al., 2012, Steiner et al., 2013])

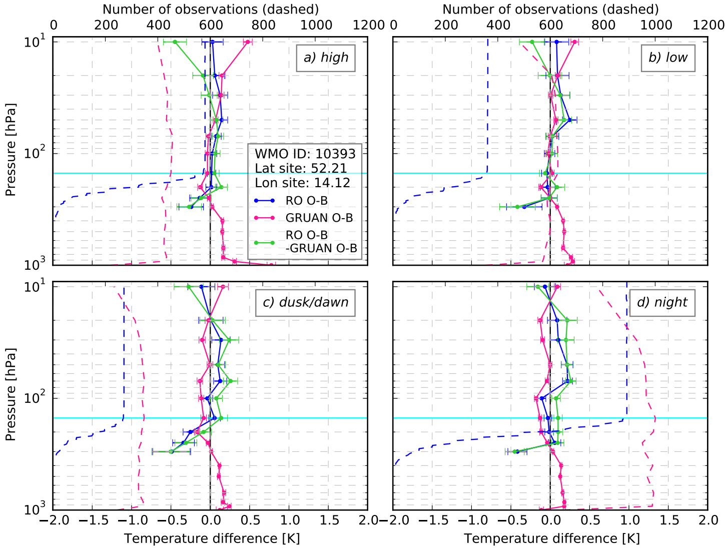
GRUAN - RO comparison

- Calculated GRUAN RS92 and RO departure statistics using data from 2014 and 2015
- Statistics calculated using all GRUAN sondes at one site and all COSMIC profiles within a 500 km circle
- GRUAN uncertainties propagated into the departure uncertainties
- RO combined sampling/structural uncertainties
- Consistency ($k = 2$) or agreement ($k = 1$) is tested based on [Immler et al., 2010]

$$|m_1 - m_2| < k\sqrt{u_1^2 + u_2^2} \qquad (2)$$

m: measurement, k: coverage factor, u: uncertainty

GRUAN - RO comparison Lindenberg



GRUAN - RO uncertainties Lindenberg

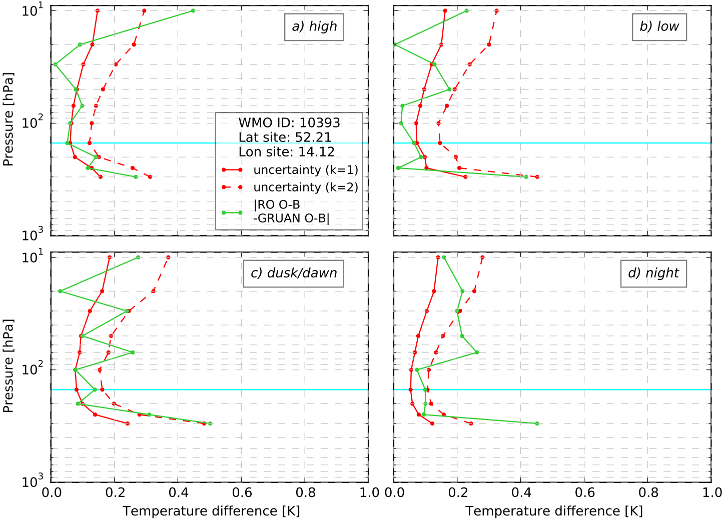
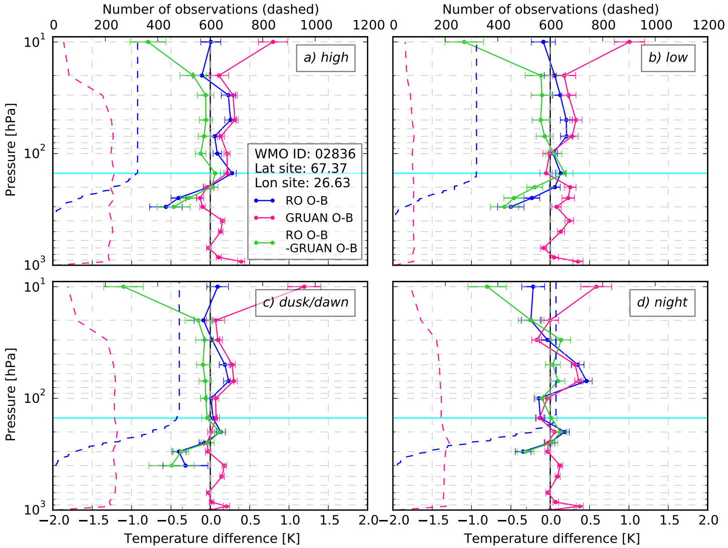


Figure 2: Uncertainty estimates for the difference between the RO minus GRUAN departures for $k = 1$

GRUAN - RO comparison Sodankylä



GRUAN - RO uncertainties Sodankylä

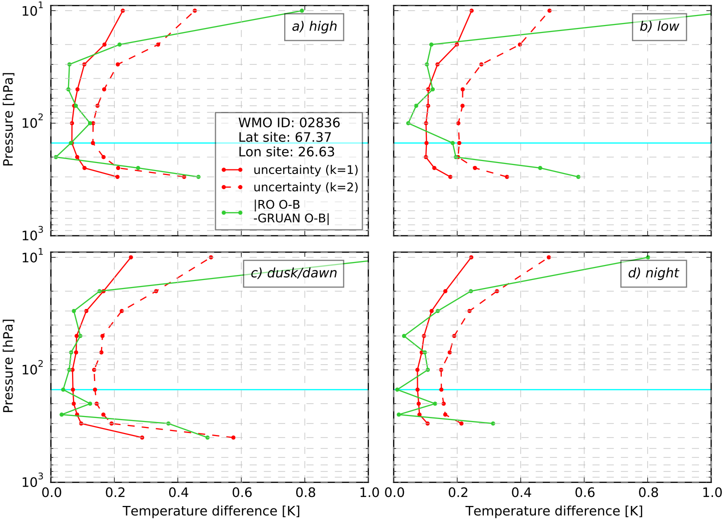


Figure 4: As Fig 2, but for Sodankylä.

Summary

- Comparison between entirely independent measurement techniques can reveal biases in the measurements and problems in the retrieval
- GRUAN and RO consistence or agreement at many levels
- Possibly a warm bias in the GRUAN RS92 version 2 data product
- The ongoing cooperation between GRUAN and RO communities is valuable (Axel, Ben, Bomin, Florian, Greg and others)
- I will aim to join the next IROWG meeting (this depends on funding and we are currently fighting to get money for Greg's co-chair role)

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Thank you for your attention!

GRUAN Measurement Uncertainty Terminology

The uncertainty terminology used by GRUAN is expected to be consistent with that detailed in the *Evaluation of measurement data — Guide to the expression of uncertainty in measurement* (BIPM, 2008).

Measurand:	The quantity to be measured. As its true value is unknown, it is characterized by a probability density function (PDF) that describes the likelihood of any particular value occurring when an infinite number of measurements are made under identical conditions (see upper panel of Figure 1). In the case of measurements in the atmosphere, this is seldom possible.
Uncertainty (U):	An expression of the degree of 'doubt' in a measurement resulting from contributions by systematic errors and random errors. Where possible the uncertainty should be evaluated from experiments but can also be estimated based on other information.
Systematic error:	The difference between the mean of a large number of measurements of the measurand and the true value of the measurand. This is the bias arising from systematic effects. Because the true value of the measurand is not known, the systematic error can only be estimated eg. Through intercomparisons. Systematic errors lead to a bias in the mean of a large set of measurements such that, unlike random errors, averaging does not reduce the systematic error in the mean.
Accuracy:	Closeness of agreement between the mean of a large number of measurements of a measurand and the true value of the measurand. The preference is to refer to this as the systematic error. In some situations the median of the large number of measurements may be a better estimate of the most representative value than the mean.
Standard uncertainty (u):	The 1σ width (standard deviation) of the PDF of a large number of measurements of the measurand once all systematic errors have been accounted for and all covariance in errors have been removed (this cannot usually be achieved in practice).
Random error:	The result of stochastic variation in quantities that influence the measurement that can never be completely avoided. Averaging over a large set of measurements reduces the random error in the mean.

Once corrections have been made for systematic errors and correlated measurement errors, it is assumed that the PDF of the measurements becomes Gaussian in shape and the mean value of that Gaussian is assumed to be the true value of the measurand (lower panel of Figure 1). This is not always the case e.g. ocean surface winds retrieved from scatterometer data have a PDF which is inherently non-Guassian. If, after systematic and correlated measurement errors have been accounted for, the PDF becomes Gaussian in shape, the PDF then provides a valid description of the measurement uncertainty i.e. the uncertainty on the measurement can be expressed as the standard uncertainty (u) which is calculated as the standard deviation of U. Provided that corrections have been made for all systematic errors, the expected value of the uncertainty (U) is zero.

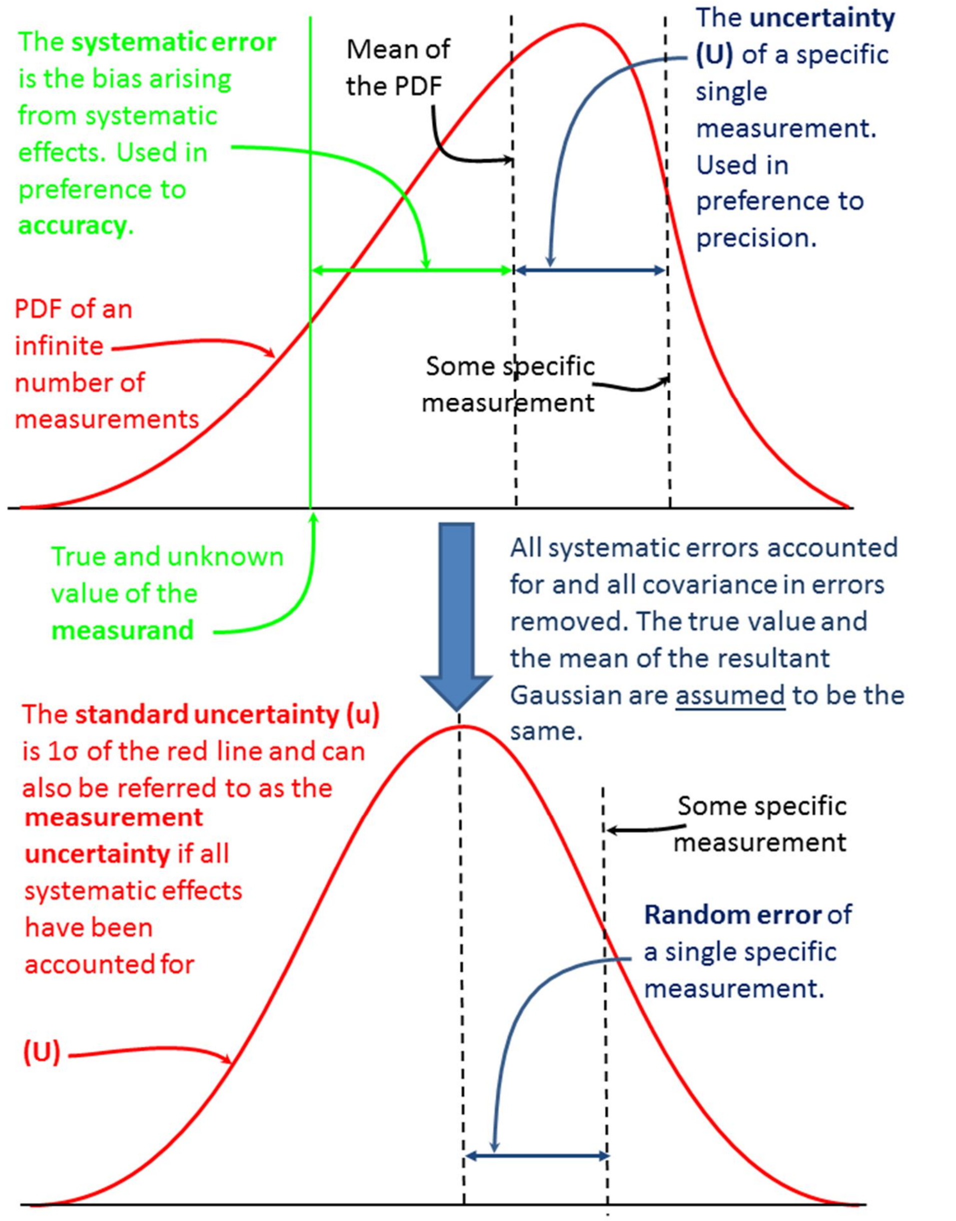

Figure 1: A graphical representation of the GRUAN uncertainty lexicon. The word 'error' is reserved for those quantities pertaining directly to the (unknown) value of the measurand, while the word 'uncertainty' is reserved for those quantities that are directly observable or derivable. The large vertical arrow in the centre represents an ideal situation. In practice it is usually not possible to account for and remove all systematic errors and all covariance in errors.

Type A evaluation of uncertainty:	Evaluation of a component of the measurement uncertainty via a statistical analysis of measurements of the measurand obtained **under defined measurement conditions**.
Type B evaluation of uncertainty:	Evaluation of a component of the measurement uncertainty **determined by means other than a Type A evaluation**.

Since it is seldom possible to make multiple measurements of the measurand in the atmosphere at the same location and time, Type B evaluation plays a major role for determining the uncertainty of upper-air measurements made within GRUAN. In a Type B evaluation, the variance, or the standard uncertainty (u), are evaluated using scientific judgment based on all of the available information on what the structure of the PDF of multiple simultaneous measurements would look like.

GRUAN provides **estimates of standard uncertainty and measurement uncertainty** (U) after correction for known systematic biases, together with uncertainties resulting from signal smoothing and instrumental time-lags.

Bias:	The contribution to the uncertainty arising from systematic effects.
Coverage probability:	The probability that the true value of a measurand is contained within a specified coverage interval.
Metrological traceability:	A property of a measurement result whereby the result can be **related to a reference through a documented unbroken chain of calibrations**, each contributing to the measurement uncertainty.
Representativeness error:	Random and systematic contributions to this source of error result from sampling and collocation mismatches, horizontally, vertically and temporally. Representativeness error can only be defined relative to some "true" scale e.g. it is necessary to decide whether the true value is a point value or a spatial mean.
Traceability:	A property of the result of a measurement, or the value of a standard, whereby it can be **related to stated references, usually national or international standards**, through an unbroken chain of comparisons all having stated uncertainties.
Variability:	The standard deviation of a set of measurements of a variable in a given temporal or spatial range. Not to be confused with the measurement uncertainty.