Copernicus Climate Change Service

Product User Guide and Specification for GRUAN Temperature, Relative Humidity and Wind profiles

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Access to observations from baseline and reference networks

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Acronyms

CDM	Common Data Model
CDR	Climate Data Records
CDS	Climate Data Store
ECV	Essential Climate Variable
GDP	GRUAN Data Processing
GRUAN	GCOS Reference Upper-Air Network
GUAN	GCOS Upper-Air Network
IGRA	Integrated Global Radiosonde Archive
PTU	??
RAOB	Universal Rawinsonde OBservation program
SI	Système international
WIS	WMO Information System

1. Summary

This document provides a short description of the radiosounding profiles observations of temperature, relative humidity and wind provided by the GCOS Reference Upper-Air Network (GRUAN). Concept of Reference observations is outlined in Thorne et al., 2017 [1] where it is also described the System Maturity Matrix (SMM) approach, developed in the frame of GAIA-CLIM H2020 research project (www.gaia-clim.eu). For convenience, the GRUAN maturity matrix is included in Appendix A.

GRUAN measurements are providing long-term, high-quality climate data records from the surface, through the troposphere, and into the stratosphere.

The purpose of GRUAN is to:

1. Provide long-term high quality climate records;
2. Constrain and calibrate data from more spatially-comprehensive global observing systems (including satellites and current radiosonde networks);
3. Fully characterize the properties of the atmospheric column.

To achieve these goals, sites within the network provide vertical profiles of reference measurements of temperature, pressure and water vapour (and additional Essential Climate Variables) suitable for reliably detecting changes in global and regional climate, on multi-decadal time scales, for major climatically distinct regions of the globe. The uniformity and coherence of standard operating procedures at GRUAN sites and the resultant homogeneity of GRUAN climate data records not only provides a global reference standard for operational upper-air network sites, but improves the detection of changes in the climate of the troposphere and stratosphere.

GRUAN is envisaged as a global network of eventually 30-40 sites that, to the extent possible, builds on existing observational networks and capabilities [2]. Nowadays, GRUAN is mainly providing long-term, high-quality climate radiosounding data records at several sites around the world with characterized uncertainties, ensuring the traceability to SI units or accepted standards, providing extensive metadata and full description documentation of measurements and algorithms.

The CDS provides access to the GRUAN data version 2 (V2). Currently, only two GRUAN data products (GDP) [3], from Vaisala RS92 and Meisei RS-11G sondes, are available. In due time GRUAN data products for the new Vaisala RS41 sondes [4] will become available. Specific GRUAN data products for other sonde types are under development. The dataset can also be reached via the GRUAN website (www.gruan.org).

In achieving its goals, GRUAN will address some of the current deficiencies of the global baseline radiosouding networks/initiatives, such as GUAN or RAOB. However, GUAN sites seldom include additional systems to validate data stability, and rely on the assumption of stability in the radiosonde quality with time. GUAN sites are also more likely to use instrument manufacturer proprietary software which does not permit a robust traceability of all sources of measurement uncertainty. If GRUAN can identify the changes that occur in production consumables, this will benefit those using

GUAN measurements and all users of WIGOS (WMO Integrated Global Observing System) and GAW (Global Atmospheric Watch) upper-air measurements.

2. Data and metadata sources

Data collection of GRUAN reference observing capabilities to the CDS is based on the IGRA data portal:

- GRUAN data portal (ftp://ftp.ncdc.noaa.gov/pub/data/gruan/).

The GRUAN data V2 is used. In Figure 1, the map of GRUAN sites as at May 2019 is shown: GRUAN currently comprises of 26 sites, 12 of which have been GRUAN certified (Bodeker et al., 2016). In addition, in Figure 2, the time coverage of the measurements available at each GRUAN staion is shown. Table 1 reports the details of the current and historical inactive GRUAN stations: in the last column of Table 1, the availability in the CDS of the GRUAN data products for each station is detailed: for a few stations, measurements could be available in the GRUAN data archive but products might not be available yet, because measurements are performed using a radiosonde type (e.g. RS41) which is not yet processed by GRUAN. Vertical profiles measured using many of these radiosondes will be processed in the near future by GRUAN.

GRUAN datasets are the result of the quality assurance algorithms applied to improve their reliability (e.g. correction of specific earlier errors such as an erroneous unit conversion, spikes in the temperature data, etc.) as well as the users' capability to fully exploit the available datasets. GRUAN also provides a full and extensive ensemble of metadata which should enable to fully reprocess the raw data or to properly adjust unknown effect in the data at present.

Metadata information for all GRUAN measurements have been described and documented in great detail in the literature. For example, in the case of a radiosonde launch, a complete description of the set-up is required that includes the description of the balloon, the gas, filling weight, unwider type and length and so forth. Such a detailed description is generally not available from the existing observational networks. A complete and extensive version of metadata will be available for the GRUAN dataset in the CDS only in the NetCDF files (under development), and not in the CSV (comma-separated-value) files. These latter only contain small subset of metadata.

The GRUAN data and metadata fields available in the CDS files are described in the summary table available in the Appendix B.

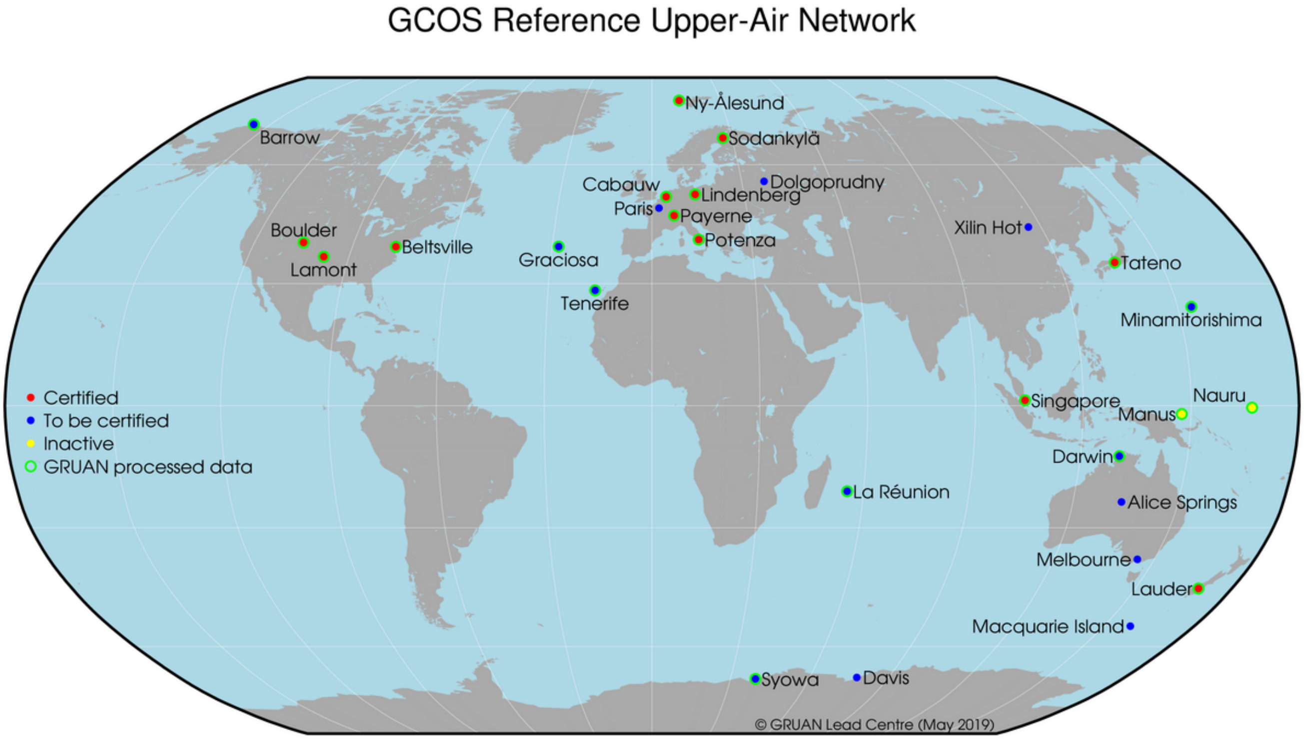

Figure 1: Distribution of GRUAN sites as of May 2019. Sites with certified measurement programs are shown in red, while sites in the process of being certified, or awaiting certification, are shown in blue. Previous GRUAN sites that are now inactive are shown in yellow. Sites for which GRUAN processed data are available are circled in green.

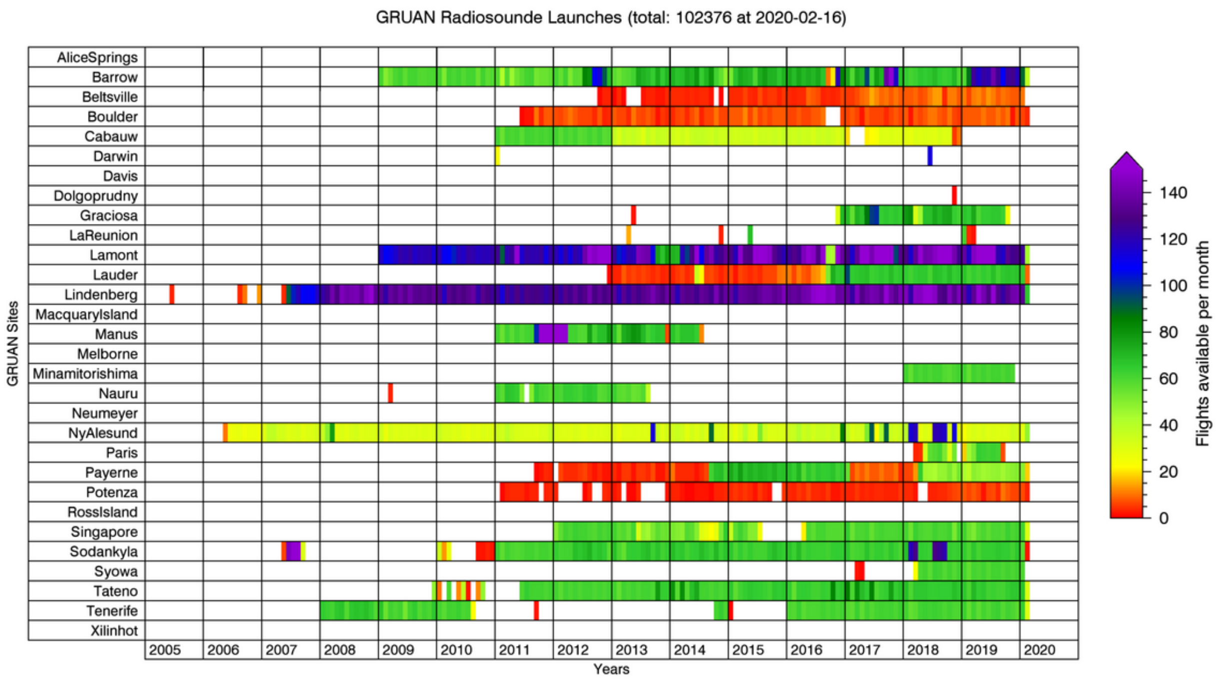

Figure 2: Diagrame of the measurements coverage at the GRUAN station. A comprehensive volume of measurement data has been collected by GRUAN since 2008. The archive includes raw data and related meta-data. For the Vaisala RS92 and the Meisei RS-11G radiosonde, GRUAN Data Products (GDP) have been fully implemented and certified (www.gruan.org).

Code	Name	Latitude	Longitude	Altitude	WMO No.	Status	Data available in CDS (yes/no)
ALC	Alice Springs, Australia	-23.79°	133.89°	546 m	94326	to be certified	no
BAR	Barrow, AK, USA	71.32°	-156.61°	8 m	70027	to be certified	yes
BEL	Beltsville, MD, USA	39.05°	-76.88°	53 m		certified	yes
BOU	Boulder, CO, USA	39.95°	-105.20°	1743 m	72471	certified	yes
CAB	Cabauw, Netherlands	51.97°	4.92°	1 m	6260	certified	yes
DAR	Darwin, Australia	-12.43°	130.89°	30 m	94120	to be certified	no
DVS	Davis, Antarctica (AU)	-68.57°	77.97°	18 m	89571	to be certified	no
DLG	Dolgoprudny, Russia	55.56°	37.52°	185 m	27612	to be certified	no
GRA	Graciosa, Portugal	39.09°	-28.03°	30 m	507	to be certified	yes
GVN	Neumayer, Antarctica (DE)	-70.65°	-8.25°	43 m	89002	to be certified	no
LAU	Lauder, New Zealand	-45.05°	169.68°	370 m	93817	certified	yes
LIN	Lindenberg, Germany	52.21°	14.12°	98 m	10393	certified	yes
MAQ	Macquarie Island, Australia	-54.50°	158.94°	6 m	94998	to be certified	no
MAN	Manus, Papua New Guinea	-2.06°	147.42°	6 m		*inactive*	*yes*
MEL	Melbourne, Australia	-37.67°	144.83°	113 m	94866	to be certified	no
MTS	Minamitorishima, Japan	24.29°	153.98°	9 m		to be certified	no
NAU	Nauru, Nauru	-0.52°	166.92°	7 m		*inactive*	*yes*
NYA	Ny-Ålesund, Svalbard (DE, FR)	78.92°	11.93°	5 m	1004	certified	yes
PAY	Payerne, Switzerland	46.81°	6.95°	491 m	6610	certified	yes
POT	Potenza, Italy	40.60°	15.72°	720 m		certified	yes
REU	La Réunion, France	-21.08°	55.383°	2200 m		to be certified	yes
ROS	Ross Island, Antarctica (NZ, US)	-77.85°	166.65°	10 to 200 m	89664 / 89665	to be certified	no
SGP	Lamont, OK, USA	36.60°	-97.49°	320 m	74646	certified	yes
SIR	Paris, France	48.7°	2.2°	156 m	7151	to be certified	no
SNG	Singapore, Singapore	1.30°	103.80°	21 m	48698	certified	no
SOD	Sodankylä, Finland	67.37°	26.63°	179 m	2836	certified	yes
SYO	Syowa, Antarctica (JP)	-69.00°	39.58°	18 m		to be certified	no
TAT	Tateno, Japan	36.06°	140.13°	27 m	47646	certified	yes
TEN	Tenerife, Spain	28.32°	-16.38°	115 m	60018	to be certified	yes
XIL	Xilin Hot, China	43.95°	116.12°	1013 m	54102	to be certified	no

Table 1: List of GRUAN station with the geographical coordinates, the WMO index and the status of the certification within GRUAN.

3. GRUAN data processing

Currently, the GRUAN observarions originate from two types of radiosoundings: RS92 Vaisala and Meisei RS-11G.
GRUAN processing for the RS92 Vaisala radiosoudings are described in great detail in technical documents on traceability of GRUAN measurements for tempreature, humidity and geopotential height (version 2.0). These are available from the CDS documentation webpage and in the Technical document describing the GRUAN data processing for RS-92 GRUAN data product. Similar documents (though, due to it's recent availablility less detailed) are available for the Meisei RS-11G radiosondes.

These documents provide an extensive description of the adjustments and uncertainties estimated for the GRUAN products, as applied in the GRUAN Data Processing (GDP). The most relevant are:

- The solar radiation effect. During daytime, the radiosonde sensor boom is heated by solar radiation, which introduces biases in temperature and humidity. The net heating of the temperature sensor and the dry-bias affecting the relative humidity sensors depends on the amount of absorbed radiation and, therefore, by the solar elevation angle, as well as on the cooling by thermal emission and ventilation by air flowing around the sensor.
- Sensor time-lag error. This is caused by slow sensor response at temperatures below about -40°C, which "smooths" and distorts features in the RH profile in the UT/LS;
- Mean calibration bias. This is due to the inaccuracy of factory calibration (apart from sensor-to-sensor "random production variability"); the mean calibration bias is inherently a function of RH and T, and it can change with time due to drift in the factory calibration references, periodic re-calibration of the references, or tweaks in the calibration function or manufacturing process.

Other sources of error include temperature spikes due to patches of warm air coming off the sensor housing and the balloon and evaporative cooling of the wetted sensor after exiting a cloud.

All the steps of GRUAN approach are summarized in Figure 3.

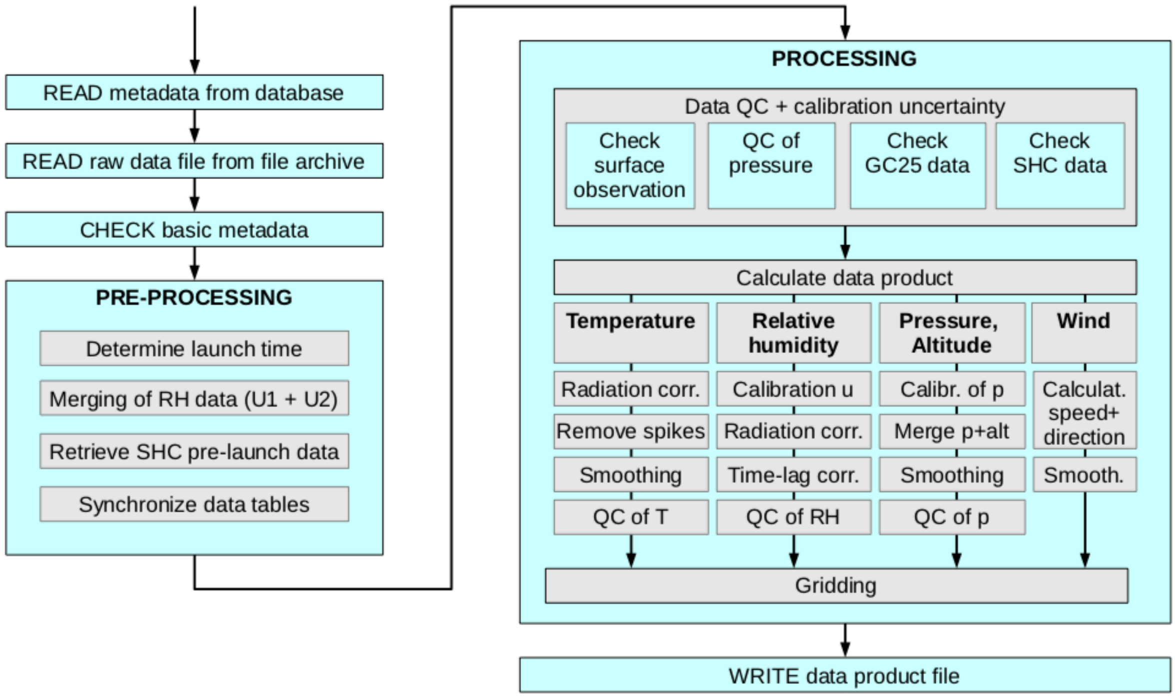

Figure 3: Schematic representation of the data-flow, processing steps, quality control (QC) and correction algo-
steps, quality control (QC), and correction algorithms applied in the GRUAN data processing. From Dirksen et al. 2014.

4. Product Quality and routine comparisons

The initial quality control verifies that the readings of the PTU sensors during the ground check are within pre-defined limits before GRUAN corrections are applied [3]. This includes checking the difference between the two humidity sensors which the radiosonde is equipped with. For the data to be processed, the corrections determined in the GC25 must be less than 1K for temperature, 1.5hPa for pressure, and less than 2% relative humidity. A standard humidity chamber (SHC) is used as a traceable standard to test the radiosonde performance: readings should be within 5 % RH of the ambient humidity. During ground check in the GC25 and the SHC, the difference between U1 and U2 should be less than 1.5 % RH.

After the GRUAN corrections have been applied, a second quality control step checks that more than 95% of data in a profile are within valid ranges and ensures that the GRUAN uncertainty estimates are within the Vaisala-provided uncertainties.

In addition, monthly comparisons among different radiosonde types and between radiosondes and the Cryogenic Frostpoint Hygrometer (CFH), which is considered as a reference instrument for stratospheric water vapour measurements, are carried out at the GRUAN Lead center in Lindenberg to monitor potential changes in the radiosonde sensors and in the data processing operated by the manufacturers (documented or not). The outcome of the comparisons can be found along with additional comparisons carried out by the various GRUAN stations on the GRUAN website (https://www.gruan.org/data/measurements/comparisons).

5. Examples

This section shows two examples from Dirksen et al. (2014) [3]. In Figure 4, the GRUAN data product is compared to the Vaisala product (FLEDT, DigiCora software version 3.64, however without the corrections for radiative heating that were introduced in 2011) for daytime and night-time radiosoundings performed in Lindenberg in 2012. The GRUAN profiles used in this comparison have passed the GRUAN quality control. A good agreement for night-time soundings is found. During daytime, the temperature difference between GRUAN and Vaisala is less than 0.05 K up to 25 km but increases above this altitude with the GRUAN temperature to more than 0.05K colder than Vaisala at 30 km.
The bottom panels of Figure 4 show that the average GRUAN humidity profile is moister than that of Vaisala. For night-time measurements, the difference increases from 0 % at the surface to approximately 7 % near the tropopause at 10 km. The sudden decrease of the GRUAN–Vaisala difference at the tropopause (around 12 km) is due to the time-lag correction. The comparison of the daytime humidity profiles show that the difference between GRUAN and Vaisala steadily increases between the surface and upper troposphere, which is clearly a result of the daytime dry bias correction.

Figure 5 shows an overview of the various sources that contributes to the uncertainty budget of the humidity profile. A detailed description can be found in Dirksen et al. (2014) [3].

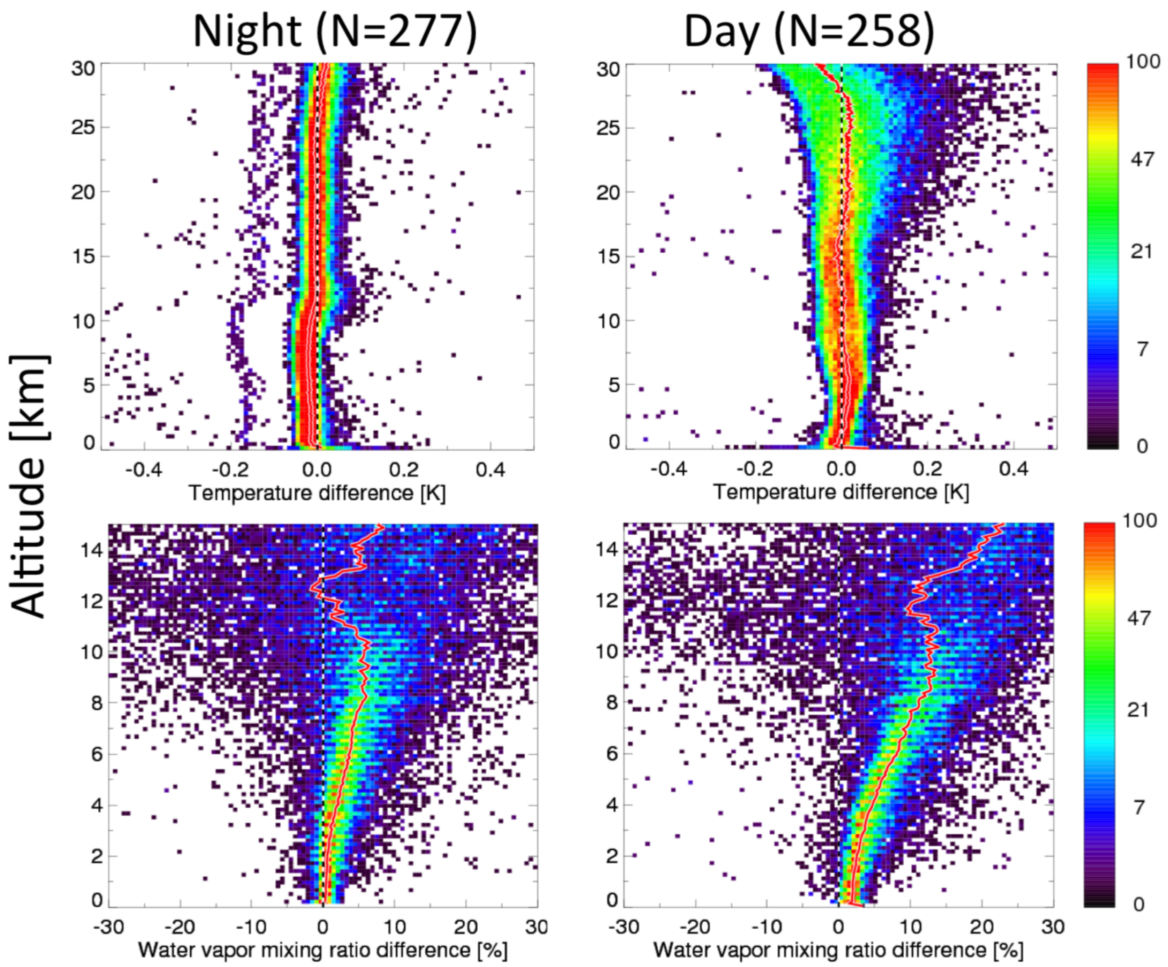

Figure 4: Comparison of GRUAN data processing (GDP) and Vaisala (FLEDT) for RS92 radiosoundings performed in Lindenberg in 2012. The graphs show scatter density plots of 100 % × (GDP − FLEDT)/GDP for temperature (top row) and humidity (bottom row). Data were taken from radiosoundings performed at local midnight (00:00 UTC, left column, N = 277) and local noon (12:00 UTC), right column, comparison of GRUAN data processing (GDP) and Vaisala (FLEDT) for RS92 radiosoundings per- N = 258). The GRUAN and Vaisala profile data are gridded in 100 m wide altitude bins prior to comparison. The logarithmic colour scale represents the number of data points in each bin, and the solid red line represents the average. From Dirksen et al. 2014.

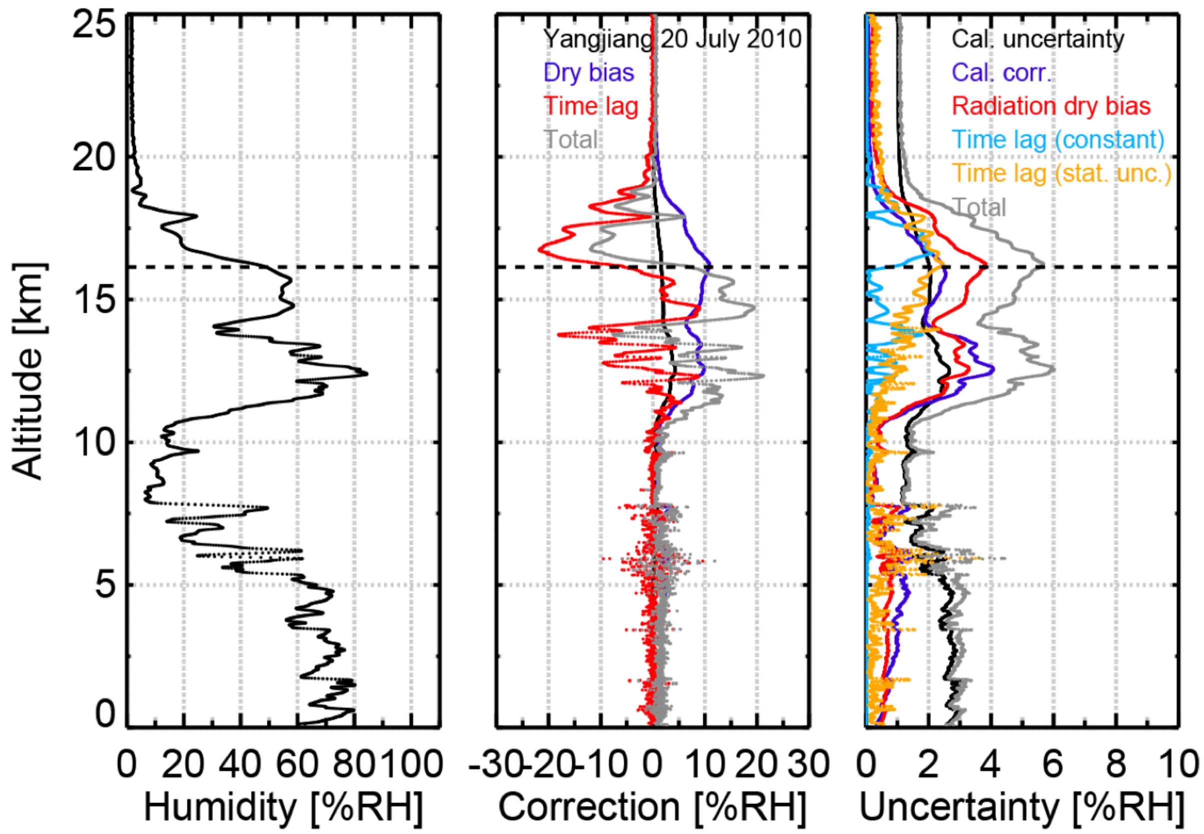

Figure 5: Corrections and their estimated uncertainties to the relative humidity. Left panel: Relative Humidity; Middle panel: profiles of the corrections for the temperature-dependent calibration correction (black), radiation dry bias (blue), and time-lag (red). The grey trace represents the total correction; Right panel: estimates of the total uncertainty (grey) and the various contributions due to the correction for calibration uncertainty (black), the correction for the temperature-dependent calibration correction (blue), radiation dry bias (red), time-lag constant u(τ) (light blue), and the statistical uncertainty of the time-lag correction (orange). The horizontal dashed line at 16.1 km represents the tropopause. From Dirksen et al. 2014.

6. Algorithm Change Record

GRUAN data provided to the CDS refer to the RS92 GRUAN Data Product Version 2 (RS92-GDP.2), released in 2012.

7. Data Format

The CDS web interface provides data in two CSV formats:

- Level-wise rows;
- Observation-wise rows.

The option to download the data NetCDF4 format will become soon available.

All CDS in-situ observations share a common data model (CDM). This format is described in the CDS documentation.

8. Product Availability and data license

The GRUAN data policy can be found in the "License" section of the related "Overview" page in the CDS.

9. Acknowledgements

We are gratefull to The GRUAN Lead Center for sharing most of content and plots reported in this user guide.

10. References

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[4] Jensen, M. P., Holdridge, D. J., Survo, P., Lehtinen, R., Baxter, S., Toto, T., and Johnson, K. L.: Comparison of Vaisala radiosondes RS41 and RS92 at the ARM Southern Great Plains site, Atmos. Meas. Tech., 9, 3115-3129, https://doi.org/10.5194/amt-9-3115-2016, 2016.

11. Appendix A: GRUAN maturity matrix

GRUAN

Metadata	Documentation	Uncertainty characterization	Public access, feedback and update	Usage	Sustainability	Software (optional)
Standards	Formal Description of Measurement Methodology	Traceability	Access	Research	Siting environment	Coding standards
Collection level	Formal Validation Report	Comparability	User feedback mechanism	Public and commercial exploitation	Scientific and expert support	Software documentation
File level	Formal Measurement Series User Guidance	Uncertainty Quantification	Updates to record		Programmatic support	Portability and numerical reproducibility
		Routine Quality Management	Version control			Security
			Long term data preservation			

Legend

1	2	3	4	5	6	Not applicable

The maturity assessment carried out above was performed under the auspices of GAIA-CLIM, http://www.gaia-clim.eu/page/maturity-matrix-assessment, in September 2016. It assesses certain quantifiable aspects of typical measurement system maturity across the network for those ECVs and associated measurement systems that are relevant to GAIA-CLIM ,www.gaia-clim.eu.
Users should be aware that this is a first effort to systematically quantify measurement system performance. Redundant assessments suggest a minimum uncertainty arising from assessor-to-assessor variations in any category of at least 1 score. Although the assessment may be useful to certain applications; at this time and until it is more broadly tested it should not constitute a primary or unique decision-making tool.

12. Appendix B: GRUAN data table for CSV files

standard name	description	Units
station_altitude	Altitude	m
altitude	Geometric altitude above sea level calculated from air pressure and GPS altitude	m
gruan_station_code	station identifier according to the list of GRUAN sites available at the following link: www.gruan.org/network/sites/	
report_id	Identifier in the GRUAN meta-database	
ascent_speed	Ascent speed of the radiosonde calculated from altitude	m s-1
air_relative_humidity_bias_correction	Bias corrections applied to relative_humidity by the GRUAN correction scheme	1
air_temperature_bias_correction	Bias corrections applied to air_temperature by the GRUAN correction scheme estimated from calibration and radiation correction uncertainty	K
frostpoint	Frost point temperature calculated from relative_humidity using vapor pressure formula HylandWexler based on the water vapor pressure fomula of HylandWexler, corrected by GRUAN correction scheme	K
geopotential_height	Geopotential altitude from corrected pressure product	m
latitude	Observation latitude	degree_north
longitude	Observation longitude	degree_east
air_pressure	Barometric air pressure using silicon sensor up to 18.6 km, derived from GPS-altitude above	hPa
air_relative_humidity_effective_vertical_resolution	Resolution (defined by 1 / cut_off frequency) of the relative_humidity in terms of time	s

air_relative_humidity	Relative humidity collated from U1 and U2 based on the water vapor pressure formula of HylandWexler, corrected by GRUAN correction scheme	1
shortwave_radiation	Short wave radiation field (actinic flux) derived from model for given sun elevation (mean between a cloudy and cloudfree case)	W m-2
shortwave_radiation_total_uncertainty	Standard uncertainty (k=1) of short_wave_radiation	W m-2
air_temperature	Air temperature, uncertainty estimated with GRUAN correction scheme	K
time	Time after launch	s
zonal_wind	Wind towards the east	m s-1
altitude_uncertainty	Standard uncertainty (k=1) of altitude dominated by correlated uncertainty	m
air_relative_humidity_systematic_uncertainty	Correlated uncertainty of relative_humidity estimated from systematic uncertaintiy sources estimated from calibration, calibration correction, radiation correction, time-lag	1
air_temperature_systematic_uncertainty	Correlated uncertainty of air_temperature estimated from systematic uncertainty sources estimated from calibration and radiation correction uncertainty	K
air_pressure_total_uncertainty	Standard uncertainty (k=1) of air_pressure dominated by correlated uncertainty	hPa
air_relative_humidity_total_uncertainty	Standard uncertainty (k=1) of relative_humidity calculated by the geometric sum of the correlated and random uncertainties	1
air_relative_humidity_random_uncertainty	Statistical standard deviation (k=1) of relative_humidity	1
air_temperature_random_uncertainty	Statistical standard deviation (k=1) of air_temperature	K
air_temperature_total_uncertainty	Standard uncertainty (k=1) of air_temperature	K

wind_direction_total_uncertainty	Standard uncertainty (k=1) of wind_from_direction derived from statistics only	degree
wind_speed_total_uncertainty	Standard uncertainty (k=1) of wind_speed derived from statistics only	m s-1
meridional_wind	Wind towards the north	m s-1
wind_direction	Wind direction with 0°:north, 90°:east, 180°:south, 270°:west	degree
wind_speed	Wind Speed	m s-1
water_vapour_volume_mixing_ratio	Volume mixing ratio (mol/mol) of water vapor calculated from relative_humidity using vapor pressure formula HylandWexler based on the water vapor pressure fomula of HylandWexler, corrected by GRUAN correction scheme	1

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