

RS41 GRUAN Data Product Version 1 (RS41-GDP.1)



**Michael Sommer, Christoph von Rohden,
Tzvetan Simeonov, Ruud Dirksen**


GRUAN Lead Centre, DWD

14th GRUAN Implementation and Coordination Meeting (ICM-14)

La Réunion, Session 2, 28 November 2022

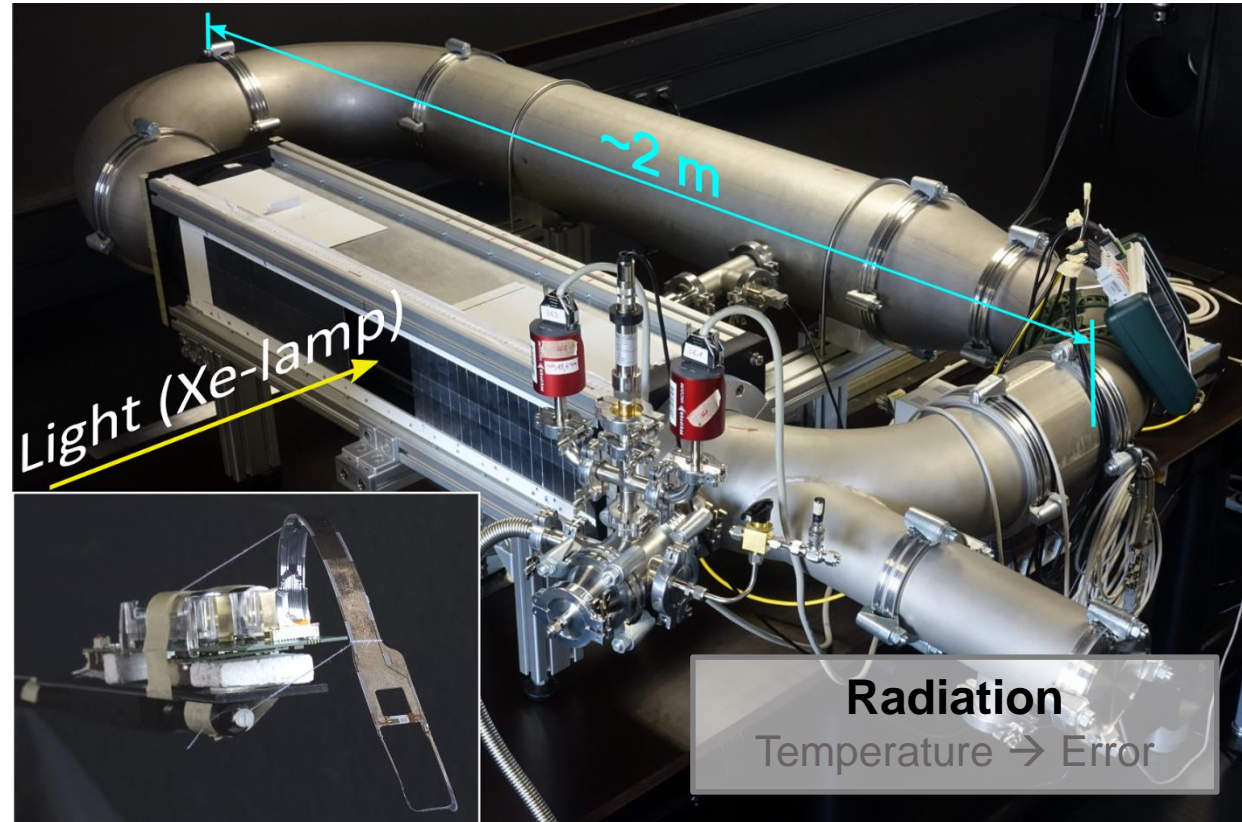
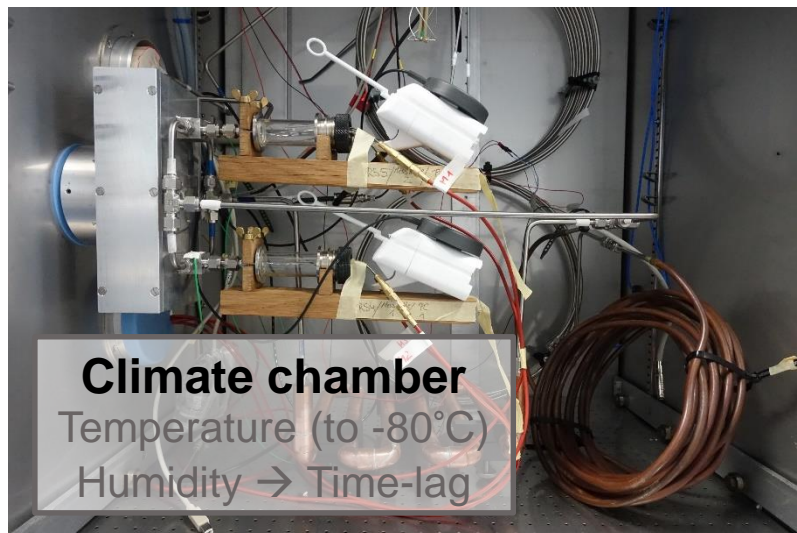
- Long journey
- Characterisation
- Data processing & GDP
- Documentation
- Invitation

Long journey to final GDP

- 
- 2014-07 → first **calibration check** of RS41 in lab (SHC)
 - 2014-12 → first **launches** with RS41 at Lindenberg
 - 2015-03 → first **time-lag experiments** in climate chamber
 - 2016-03 → start of development of **radiation wind tunnel** (SISTER)
 - 2016-06 → start restructuring of **GDPS** and optimising of modules
 - 2017-07 → first **radiation experiments** inside SISTER
 - 2019-02 → first official **alpha version** of GDP (ALPHA.1)
 - 2020-03 → start writing **technical document** (TD)
 - 2020-05 → start writing **radiation paper**
 - 2020-06 → first official **beta version** of GDP (BETA.1)
 - 2021-06 → **last beta** version of GDP (BETA.3) as RC
 - 2021-06 → radiation **paper submitted** (amt-2021-187)
 - 2021-11 → **final version** 1 of GDP (provisional certification)

ICM-13

- 2021-12 → start writing comparison paper (RS92 vs. RS41)
- 2022-01 → radiation **paper published** (amt-15-383-2022)
- 2022-04 → technical document (TD) submitted to **review**
- 2022-11 → **user guide published** as technical note (TN)



Development of and experiments with
new radiation wind tunnel

Simulator for Investigation of Solar Temperature
Error of Radiosondes (SISTER)

Atmos. Meas. Tech., 15, 383–405, 2022
<https://doi.org/10.5194/amt-15-383-2022>
© Author(s) 2022. This work is distributed under
Creative Commons Attribution 4.0 License.

Atmospheric
Measurement
Techniques
Open Access
EGU

<https://doi.org/10.5194/amt-15-383-2022>

Published
2022-01-27

Laboratory characterisation of the radiation temperature error of radiosondes and its application to the GRUAN data processing for the Vaisala RS41

Christoph von Rohden¹, Michael Sommer¹, Tatjana Naebert¹, Vasyi Motuz², and Ruud J. Dirksen¹

¹GRUAN Lead Centre, Meteorologisches Observatorium Lindenberg, Deutscher Wetterdienst, Am Observatorium 12, 15848 Tauche, Germany

²Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology, Cottbus-Senftenberg, Siemens-Halske-Ring 15a, 03046 Cottbus, Germany

Correspondence: Christoph von Rohden (christoph.rohden-von@dwd.de)

Received: 25 June 2021 – Discussion started: 20 July 2021

Revised: 13 December 2021 – Accepted: 20 December 2021 – Published: 27 January 2022

Abstract. The paper presents the Simulator for Investigation of Solar Temperature Error of Radiosondes (SISTER), a setup that was developed to quantify the solar heating of the temperature sensor of radiosondes under laboratory conditions by recreating as closely as possible the atmospheric and illumination conditions that are encountered during a daytime radiosounding ascent. SISTER controls the pressure (3

tion with model calculations of the actual radiation field during the sounding to estimate the correction profile. In the second part of this paper it is described how this procedure was applied in the development of the GRUAN data product for the Vaisala RS41 radiosonde (version 1, RS41-GDP1). The magnitude of the averaged correction profile increases gradually from 0.1 K at the surface to approximately 0.8 K at 35 km

GDPS – Processing of RS41-GDP.1

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



General &
ground check

Pressure &
altitude

Wind &
ventilation

Temperature

Humidity

Make time axis
steady

Calculate position
(XYZ → LLA)

Pendulum
analyse

Position of sun

Time-lag
correction

Combine & grid
data sources

Pressure
calibration

Calculate
ventilation

Estimate radiation
(RTM simulations)

Smoothing
(time-lag related)

Quality control
of all input vars.

Recalculate alt.
MSL, GPH

Calculate wind
speed & direction

Radiation
correction

Recalculation
(internal T to air T)

Detected launch
points

Calculate pressure
using alt. (GNSS)

Smoothing
(pendulum effects)

Smoothing
(pendulum effects)

Estimate
uncertainties

Detected launch
points

Estimate
uncertainties

Estimate
uncertainties

Estimate
uncertainties

Calculate further
humidity variables

Quality control
of pressure & alt.

Quality control
of wind

Quality control
of temperature

Quality control
of humidity

Completely
new developed



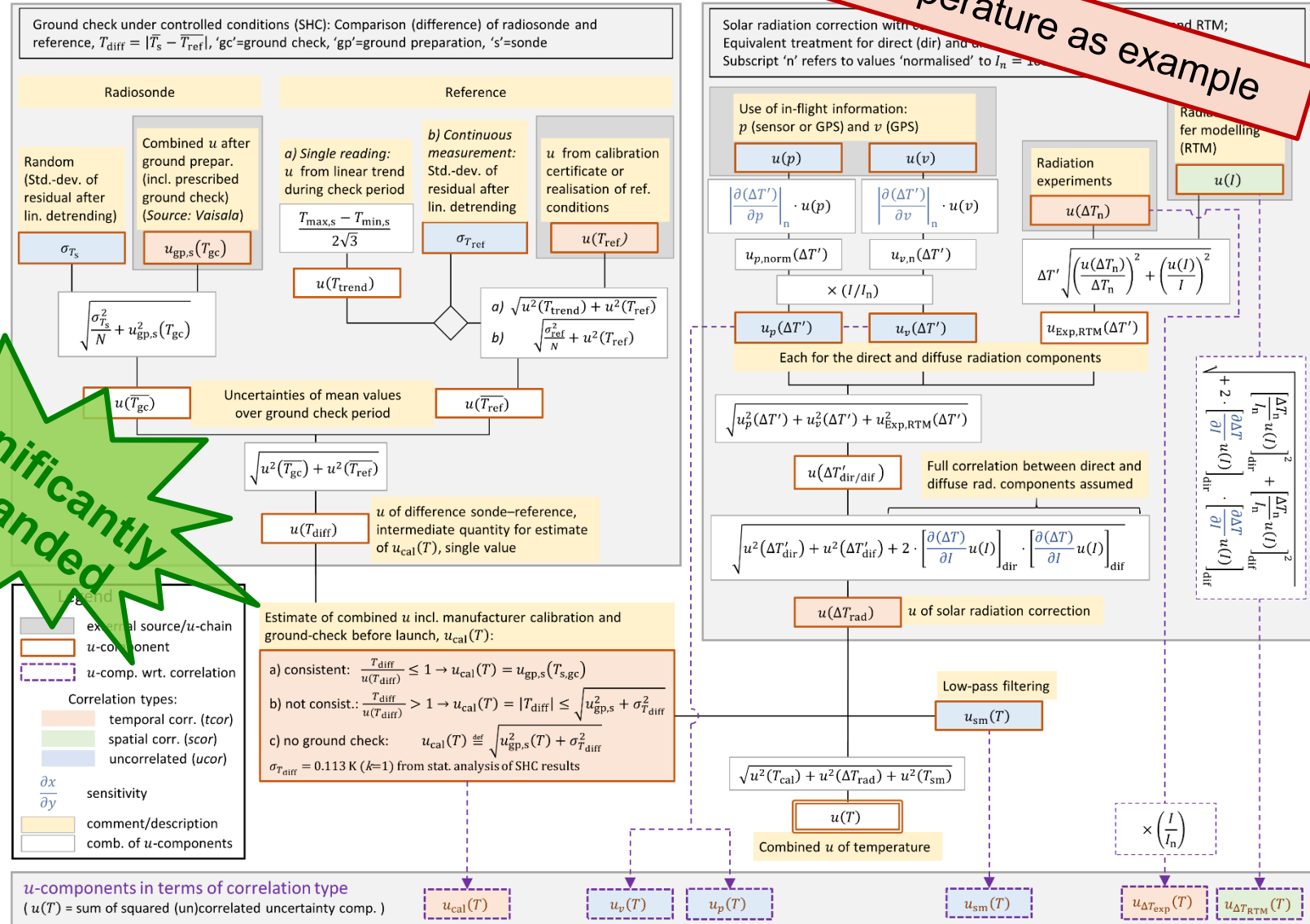
Estimation of uncertainty

Temperature
Relative humidity
Pressure (sensor)
Pressure (gnss)
Altitude (gph)
Altitude (amsl)
Altitude (wgs84)
Latitude
Longitude

Wind direction
Wind speed
Zonal wind component
Meridional wind component
Dew point temperature
WV mass
WV volume
WV partial pressure
WV saturation pressure
Ventilation
Ascent speed

Significantly expanded

Combination of uncertainty components for temperature in GDP for Vaisala RS41 radi



➤ Meta-data

significantly expanded

- Product, file, site, measurement system, measurement setup, surface obs., measurement (times, equipment, day/night, position, pwc, tropopause, burst point), main/telemetry sonde, ground system, ground checks (ri41, shc, shelter), ...

➤ Variables

significantly expanded

- Position (lat, lon), altitude (gph, wgs84, amsl), pressure (sensor, gnss), temperature, humidity (rh, dp, mr, ...), wind variables (wdir, speed, wzon, wmeri), supplementary variables (sun angles, radiation, ventilation, pendulum, ...)

➤ Corrections

significantly expanded

- Final data, total correction, correction components, raw data (+ flags)

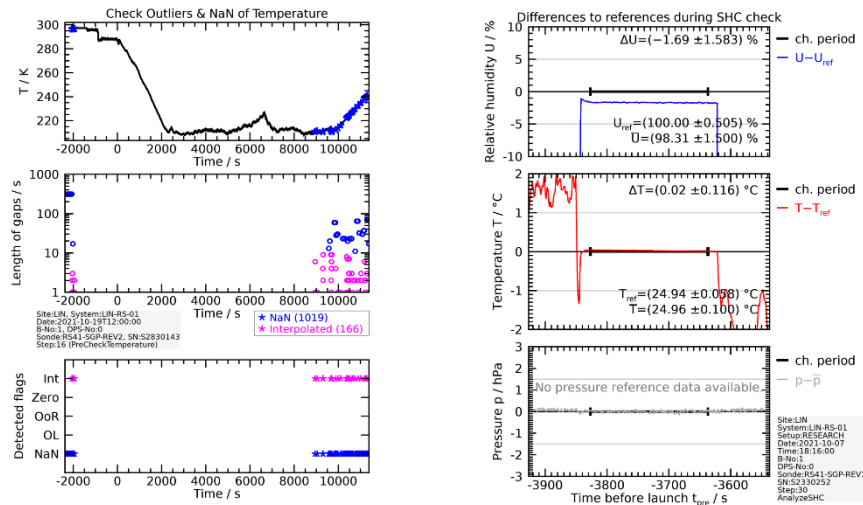
➤ Uncertainties

significantly expanded

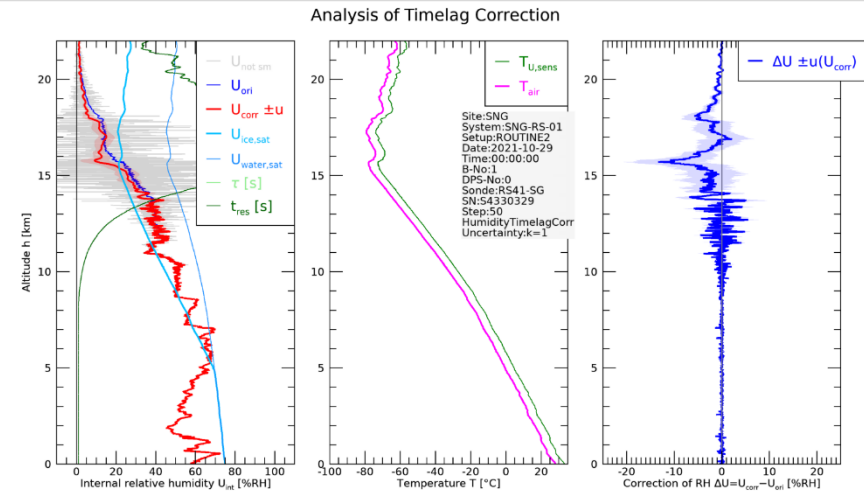
- Combined, correlation parts, source components

Compared to RS92-GDP.2

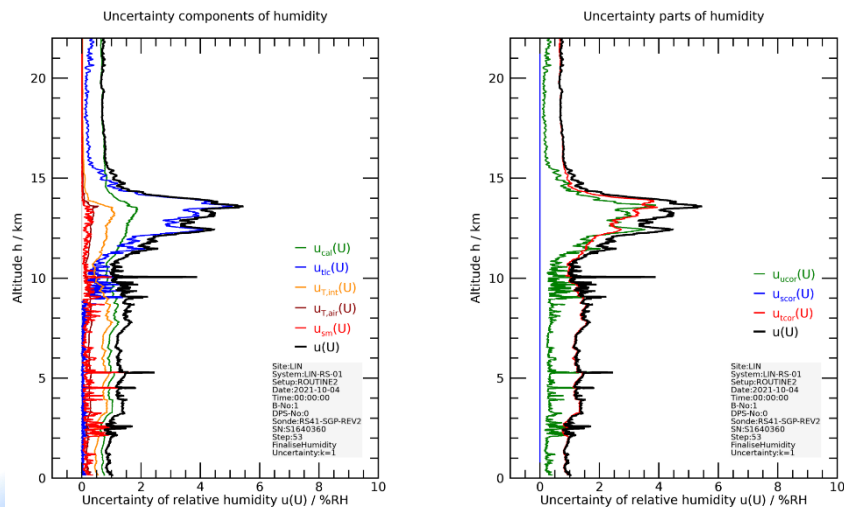
Raw data analysis & ground check plots



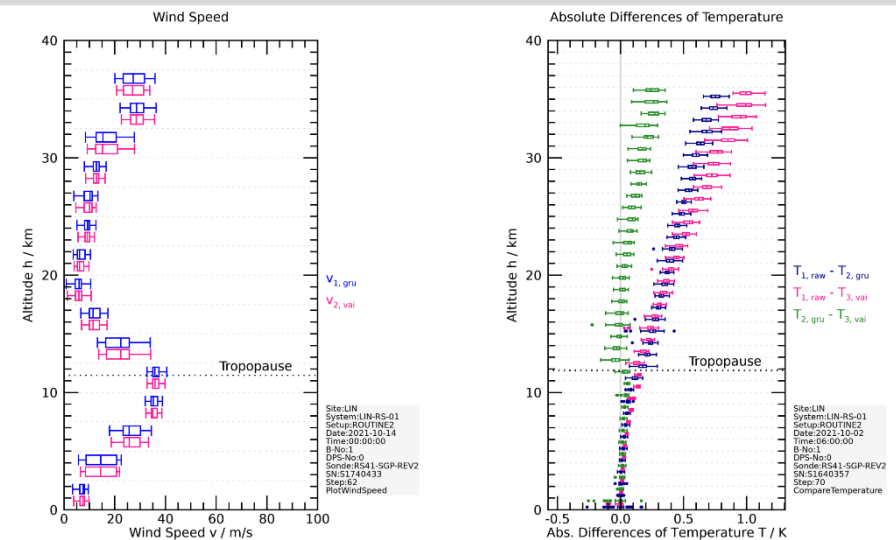
Internal analysis plots



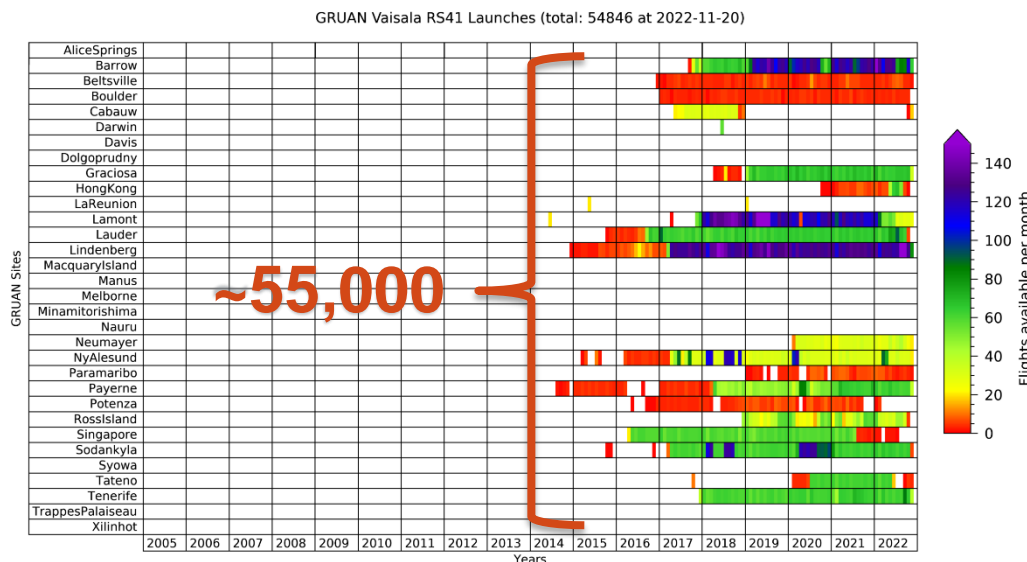
Plots of uncertainty components & parts



Comparison plots (GDP vs. Vaisala)



- Full characterisation → extensive & intensive experiments
- Comprehensive processing → correction & estimation of uncertainties
- GDP provided as very detailed NetCDF 4 files
- Analysis plots → Should they be available at website?
- Operational processing of RS41-GDP.1 (since 2021-11-09)



Title: “GRUAN characterisation and data processing of the Vaisala RS41 radiosonde”

Authors: Michael Sommer, Christoph von Rohden, Tzvetan Simeonov, Peter Oelsner, Tatjana Naebert, Hannu Jauhiainen, Petteri Survo, Ruud Dirksen

Aim: Full description of RS41 in GRUAN incl. instrumentation, measurement practice, characterisation, data processing, data flow

Status: on 2022-11-09, 198 pages, 100% complete → in review

Table of contents

| | |
|--|-----------|
| 1 Introduction | 9 |
| 1.1 Motivation | 9 |
| 1.2 Instrument heritage | 10 |
| 1.3 The role of the RS41 radiosonde in GRUAN | 10 |
| 1.4 Terminology | 12 |
| 2 Instrumentation | 14 |
| 2.1 RS41 radiosonde | 14 |
| 2.1.1 Sonde construction | 14 |
| 2.1.2 Additional sensor support (Xdata) | 17 |
| 2.1.3 Sensor technology | 18 |
| 2.1.4 Manufacturer calibration and uncertainty specifications | 23 |
| 2.2 Sounding system | 24 |
| 2.2.1 Ground preparation | 25 |
| 2.2.2 Autosonde sounding station | 26 |
| 3 Measurement practice | 28 |
| 3.1 Process of a GRUAN RS41 sounding | 28 |
| 3.1.1 Manual soundings | 28 |
| 3.1.2 Autosonde sounding station | 32 |
| 3.2 Calibration and pre-launch procedures | 36 |
| 3.2.1 Calibration at manufacturer | 36 |
| 3.2.2 Ground check prescribed by manufacturer | 38 |
| 3.2.3 GRUAN ground check in the Standard Humidity Chamber (SHC) | 40 |
| 3.3 Measurement scheduling | 42 |
| 4 Sensor characterisation and evaluation of GDP variables | 47 |
| 4.1 Effect of solar radiation on RS41 temperature measurements | 47 |
| 4.1.1 Solar heating of radiosonde temperature sensors | 47 |
| 4.1.2 Experimental approach | 48 |
| 4.1.3 Data evaluation | 53 |
| 4.1.4 Simulation of solar shortwave radiation using RTM S | 58 |
| 4.1.5 Radiation correction and uncertainties | 69 |
| 4.2 Time-lag for Humidity Measurements | 68 |
| 4.2.1 Effect of time-lag | 68 |
| 4.2.2 Experiment for time-lag measurements | 69 |
| 4.2.3 Data evaluation and time-lag correction | 70 |
| 4.3 Pressure measurements with sensor (RS41-SGP) | 74 |

| | |
|--|------------|
| 4.4 Evaluation of GPS and GPS-derived variables | 79 |
| 4.4.1 Uncertainty in GPS measurements | 84 |
| 4.4.2 GPS-based pressure | 88 |
| 4.4.3 Wind speed and wind direction | 92 |
| 4.4.4 Ventilation | 95 |
| 4.5 Humidity-related variables | 95 |
| 4.5.1 Conversion of relative humidity | 96 |
| 4.5.2 Water vapour partial pressure | 96 |
| 4.5.3 Integrated Water Vapour (IWV) | 100 |
| 4.5.4 Water vapour mixing ratio | 100 |
| 4.5.5 Dew point and frost point temperature | 102 |
| 5 Traceability | 102 |
| 5.1 Temperature | 102 |
| 5.2 Relative humidity | 103 |
| 5.3 Pressure sensor | 104 |
| 5.4 GPS receiver | 105 |
| 6 Combination of uncertainties | 107 |
| 6.1 Correlations of uncertainties | 107 |
| 6.2 Uncertainty combination | 108 |
| 6.2.1 Temperature | 108 |
| 6.2.2 Relative humidity | 110 |
| 6.2.3 Pressure | 112 |
| 7 GRUAN Data Product (GDP) | 115 |
| 7.1 General overview of the processing system | 115 |
| 7.2 Input data | 116 |
| 7.2.1 Original MW41 sounding archive file (MWX) | 117 |
| 7.2.2 Converted as NetCDF file (GNC-RAW) | 118 |
| 7.2.3 Metadata from GMDb (MD) | 118 |
| 7.2.4 Data from external sensors of ground checks | 119 |
| 7.2.5 Gridding and merging of input data | 120 |
| 7.2.6 Additional resources directly accessed by the processing modules | 120 |
| 7.3 Data processing | 120 |
| 7.3.1 Data normalisation and preparation | 120 |
| 7.3.2 Data check and ground checks | 121 |
| 7.3.3 Data normalisation, altitude and wind | 124 |
| 7.3.4 Data normalisation, temperature | 127 |
| 7.3.5 Data normalisation, humidity | 129 |
| 7.3.6 Humidity | 131 |
| 7.3.7 Comparisons and evaluation plots | 134 |
| 7.3.8 Further variables and retrievals | 137 |
| 7.4 Quality assessment | 138 |
| 7.5 GDP composition | 140 |
| 7.5.1 File content of GDP | 140 |
| 7.5.2 Log file | 140 |

| | |
|--|-----|
| 7.5.3 Data analysis plots | 140 |
| 7.6 Data management in GRUAN | 141 |
| 7.6.1 Data collection | 142 |
| 7.6.2 Converting of MWX to NetCDF | 142 |
| 7.6.3 The Processing Centre (PC) | 143 |
| 7.6.4 Processing and reprocessing | 143 |
| 7.6.5 Archiving of raw data and data product files | 144 |
| 7.6.6 Distribution of data product | 144 |
| 7.6.7 Monitoring and feedback | 144 |

Appendix

| | |
|---|------------|
| A Collection of relevant formulas and algorithms | 149 |
| A.1 Manufacturer calibration uncertainties | 149 |
| A.1.1 Temperature | 149 |
| A.1.2 Humidity | 149 |
| A.1.3 Pressure | 150 |
| A.2 Saturation vapour pressure for water | 150 |
| A.3 Smoothing algorithm | 151 |
| A.4 Conversion of GPS-position data | 155 |
| A.5 Gravitational acceleration | 156 |
| B Additional information about processing system | 157 |
| B.1 Details of workflow of the processing system | 157 |
| C Documentation of processing steps and related processing modules | 160 |
| C.1 Processing steps | 160 |
| C.2 Main steps related to specific variables | 165 |
| D Additional discussion on GPS positioning within the RS41 system | 171 |
| D.1 Pseudorange observations of GPS satellites | 171 |
| D.2 Dilution of Precision (DOP) measurements | 172 |
| D.3 Derivation of uncertainty of pressure from GPS altitudes | 174 |
| E File Content | 177 |
| E.1 Possible content structure of MD files | 177 |
| E.2 Available tables in Zipped MW41 sounding archive file (MWX) files | 178 |
| E.3 Details of relevant tables in Zipped MW41 sounding archive file (MWX) files | 180 |
| Acronyms | 192 |
| Bibliography | 194 |

Submitted on
2022-04-12

Title: “User Guide of the RS41
GRUAN Data Product Version 1
(RS41-GDP.1)”

Authors: Michael Sommer, Christoph von
Rohden, Tzvetan Simeonov

Aim: Describe content of GDP files of
RS41 and help users to handle
these files correctly

Status: on 2022-11-21, 60 pages,
100% complete, GRUAN-TN-13



Table of contents

| | | |
|-----------------|--|-----------|
| 1 | Introduction | 6 |
| 2 | GRUAN processing of RS41 data | 7 |
| 2.1 | Processing concept and inclusion of uncertainties | 7 |
| 2.2 | Pre-checks of raw data | 8 |
| 2.3 | Ground checks | 9 |
| 2.4 | Position, altitude, and geopotential height | 10 |
| 2.5 | Pressure | 10 |
| 2.6 | Temperature | 11 |
| 2.7 | Humidity | 12 |
| 2.8 | Wind | 13 |
| 2.9 | Supplementary variables | 14 |
| 3 | Basic structure and use of NetCDF files | 16 |
| 3.1 | Global attributes | 16 |
| 3.2 | Variables | 17 |
| 3.2.1 | Uncertainty components | 17 |
| 3.2.2 | Corrections and their components | 18 |
| 3.3 | Attributes assigned to variables | 18 |
| 3.4 | Usage of files | 18 |
| 3.4.1 | Use of uncertainties in spatial and temporal gridding | 18 |
| 3.4.2 | Optimising GDP files | 21 |
| 3.4.3 | Reading GDP files | 22 |
| 4 | Distribution and naming of files | 23 |
| 4.1 | Distribution | 23 |
| 4.2 | File naming | 23 |
| 5 | Known issues | 25 |
| 5.1 | Occasionally undefined temporal uncertainty “tcor” for altitude parameters | 25 |
| Appendix | | |
| A | Details of GDP file contents | 27 |
| A.1 | Global attributes (metadata) | 27 |
| A.2 | Variables (data) | 46 |
| A.3 | Attributes of variables (metadata) | 57 |
| Acronyms | | 59 |

Title: “RS41/RS92 Radiosondes GRUAN Data Products comparison for more than 1000 flights: Characterization of radiosonde Temperature and Relative Humidity profiles”

Authors: Tzvetan Simeonov, Michael Sommer, Christoph von Rohden, Tatjana Naebert, Ruud Dirksen, Peter Oelsner

Aim: Compare GRUAN processing and data product (GDP) of both RS92 and RS41

Status: on 2022-11-21, 19 pages, active in progress

Table of contents

Abstract

1 Introduction

2 Description of radiosonde sensors, data handling and corrections

2.1 Temperature

2.2 Humidity

3 RS41 GDP data uncertainties

3.1 Temperature

3.2 Humidity

4 Comparison methodology

5 RS92/RS41 comparison

4.2 Temperature

4.3 Humidity

6 Summary and conclusions

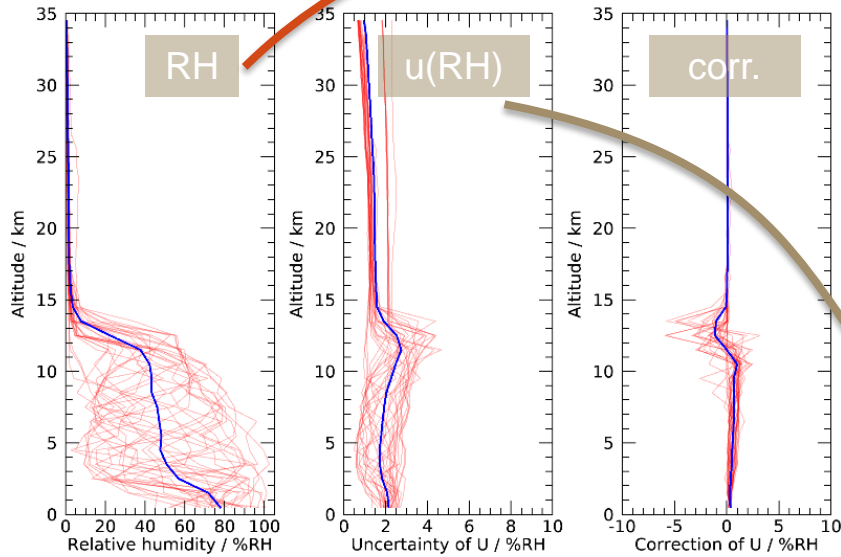
Invitation – please use the GDP, e.g. make long-term statistics ...

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

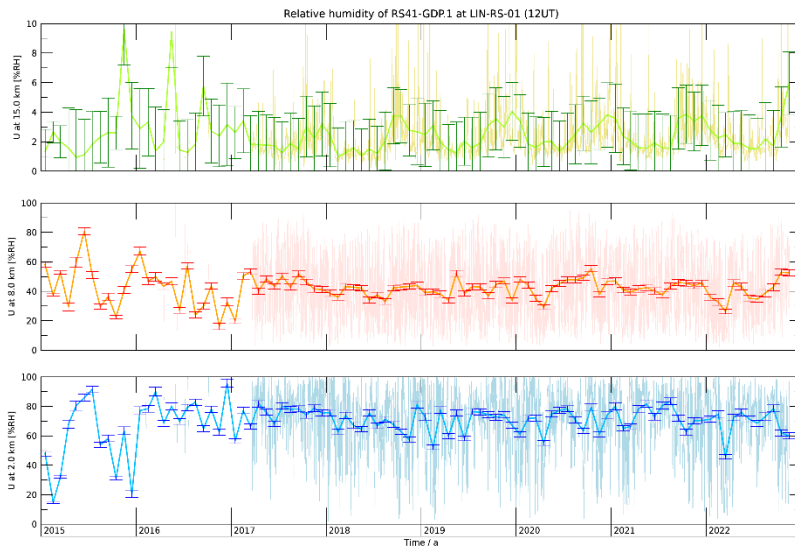


1km bins & monthly mean

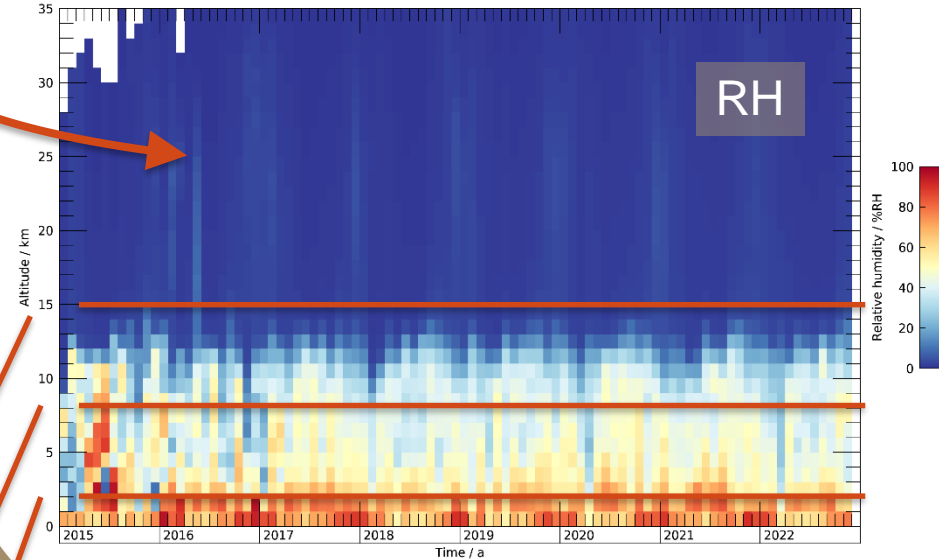
Relative humidity of RS41-GDP.1 at LIN-RS-01 (2021-09 12UT)



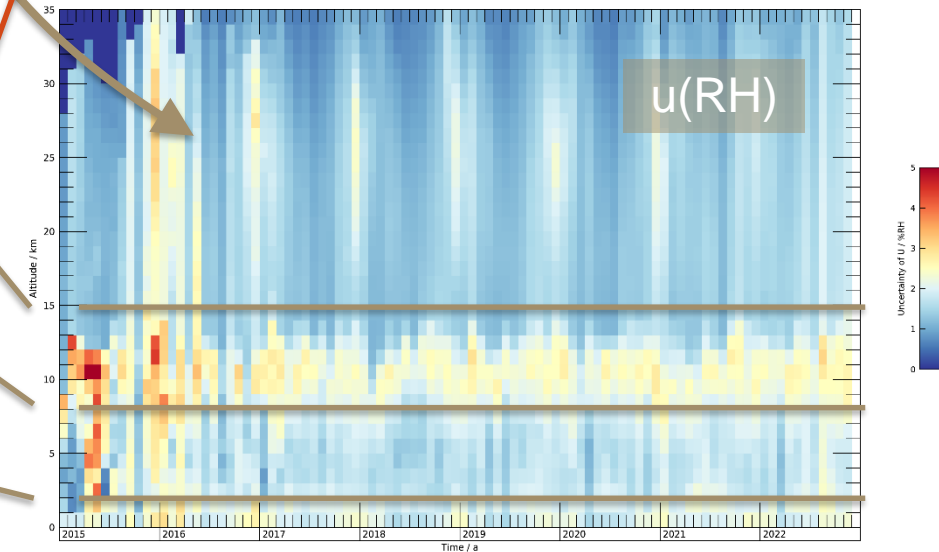
Time series at alt. levs



Relative humidity of RS41-GDP.1 at LIN-RS-01 (12UT)



u(RH)



Usage of GRUAN data products as working standard in WMO Upper-Air Instrument Intercomparison 2022 (UAI2022)

Acknowledgement

T. Naebert, S. Körner,
M. Fiedler-Krüger, R. Tietz,
H. Friedrich, P. Oelsner

UAI 2022, Lindenberg/DE

| | | |
|---|----------------------------------|----------------------|
| $\phi=52.48425^\circ\text{N}$ | $\lambda=14.85853^\circ\text{E}$ | $h=29956.8\text{ m}$ |
| $p=12.55\text{ hPa}$ | $T=-40.19^\circ\text{C}$ | $U=0.50\text{ \%RH}$ |
| $ws=7.84\text{ m/s}$ | $wd=275.51^\circ$ | $as=3.92\text{ m/s}$ |
| 01:42:51 | | |
| F68 (2022-09-09T09:22:29.298Z) launched at 2022-09-09 07:37:27 | | |

Thank you for your attention.