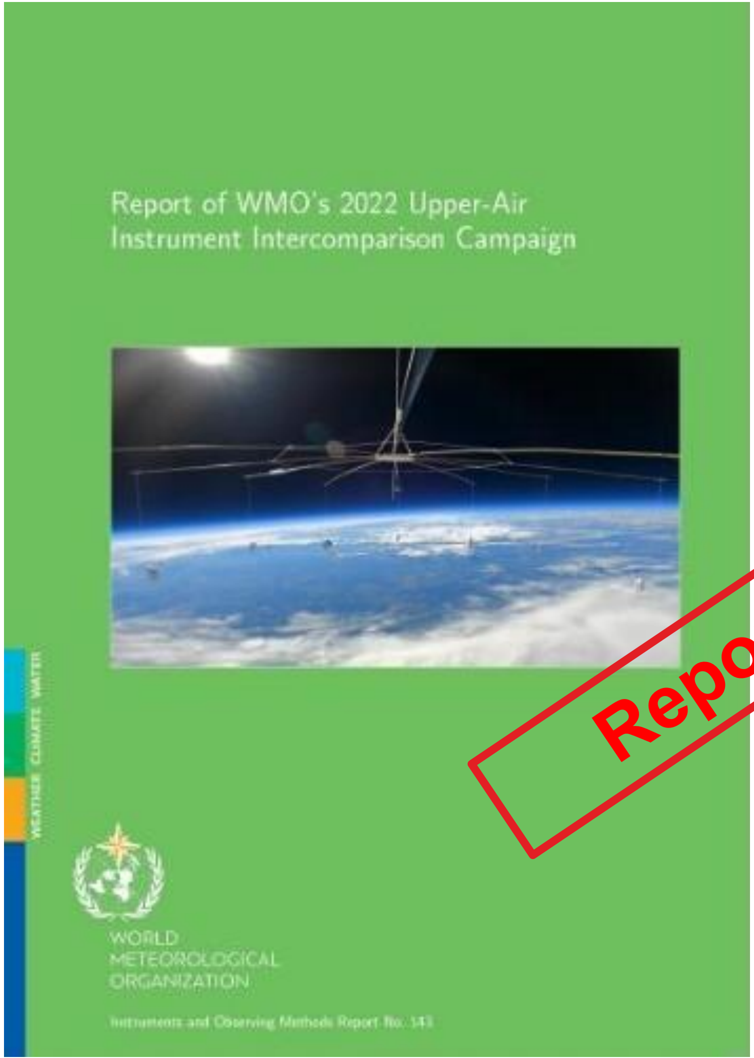
Lessons learned from the WMO Upper-Air Instrument Intercomparison - UAII2022

Ruud Dirksen & Frédéric Vogt



Report published

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Report of WMO's 2022 Upper-Air Instrument Intercomparison Campaign

Collection(s)	Technical
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Summary	This report presents the outcomes of WMO's Upper-Air Instrument Intercomparison performed in 2022. The intercomparison included a laboratory and a field phase for the 10 participating radiosonding systems, and a field phase for the surface-based remote-sensing systems. The intercomparison was performed with the help of independent radiosonde operators. GRUAN data products, which are well characterized working measurement standards, were used as reference for the data analysis. The evaluation of the various participating systems was performed against the uncertainty requirements defined in WMO's OSCAR database for various application areas.
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Number of pages	400 p.

UAII 2022 in short

What: UAII = Upper-Air Instrument Intercomparison

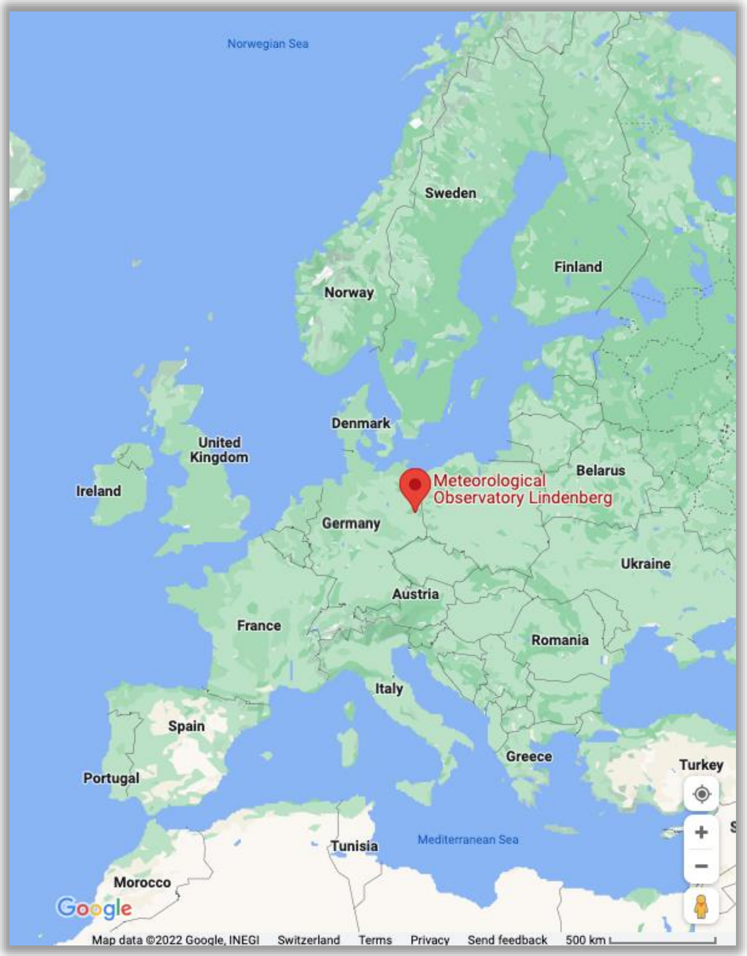
Assess **operational** radiosonde systems at the same location and time.
As many major manufacturers from all regions of the World as possible.

When:

2019: Start of preparations
2021: postponement due to Covid-19
02.2022 - 01.2023: lab campaign
08.2022 - 09.2022: field campaign

Where: Lindenberg, Germany

Who: DWD and MeteoSwiss,
under the auspices of the WMO



UAII 2022 in numbers

- **12 radiosondes selected**
  - China (3), Finland, France, Germany, India (2), Japan, Russia, South Africa, South Korea
  - Selection criteria: product maturity, market share, BUFR* capacity
- **10 radiosondes participated**
  - China (2), Finland, France, Germany, India (2), Japan, South Africa, South Korea
- **Lab campaign**
  - 2 weeks for each manufacturer (6 measurement days + preparation + contingency)
  - 3 test setups (Standard Humidity Chambers, Climate Chamber, Radiation Test)
- **Field campaign**
  - 16 night & 18 day flights for each sonde, 3(4) twin flights for each category
  - Manufacturers only see their own data, proper operation [= blind campaign]
  - Remote sensing: radiometers, wind profiler, wind lidar, GNSS IWV

* BUFR: Binary Universal Form for the Representation of meteorological data

UAII 2022 novelties

1. Use of GCOS Reference Upper Air Network (GRUAN) Data Products as working measurement standards.
   https://www.gruan.org/data/data-products

   New references !

2. Assess radiosonde performances w.r.t. OSCAR requirements.
   https://space.oscar.wmo.int/

   New evaluation methodology !

3. Investigate errors and uncertainties of radiosonde sensors under laboratory conditions.
   [+ background info for analysis field campaign, GRUAN practices]

   New methods !

4. Independent operators for neutral assessment.
   [+ capacity building, user-friendliness]

5. Demonstrate the added-value of remote-sensing.

   New benefits !

UAII 2022 participants

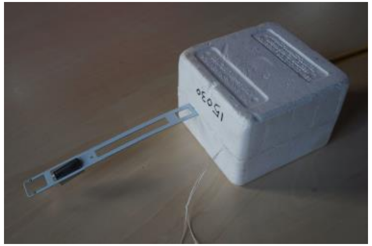
Weathex
WxR-301D

Aerospace Newsky
CF-06AH

InterMet
iMet-54-AA

Vaisala
RS41-SG

Meisei
iMS100



Vikram
PS01B3M

Azista
ATMS-3710

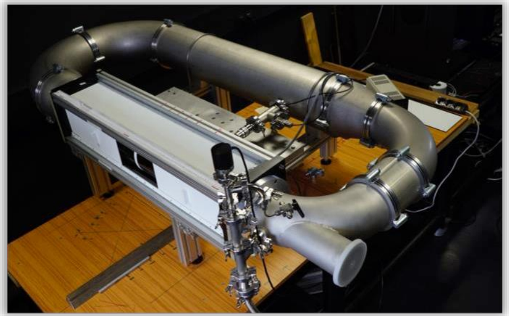
Modem
M20

Graw
DFM-17

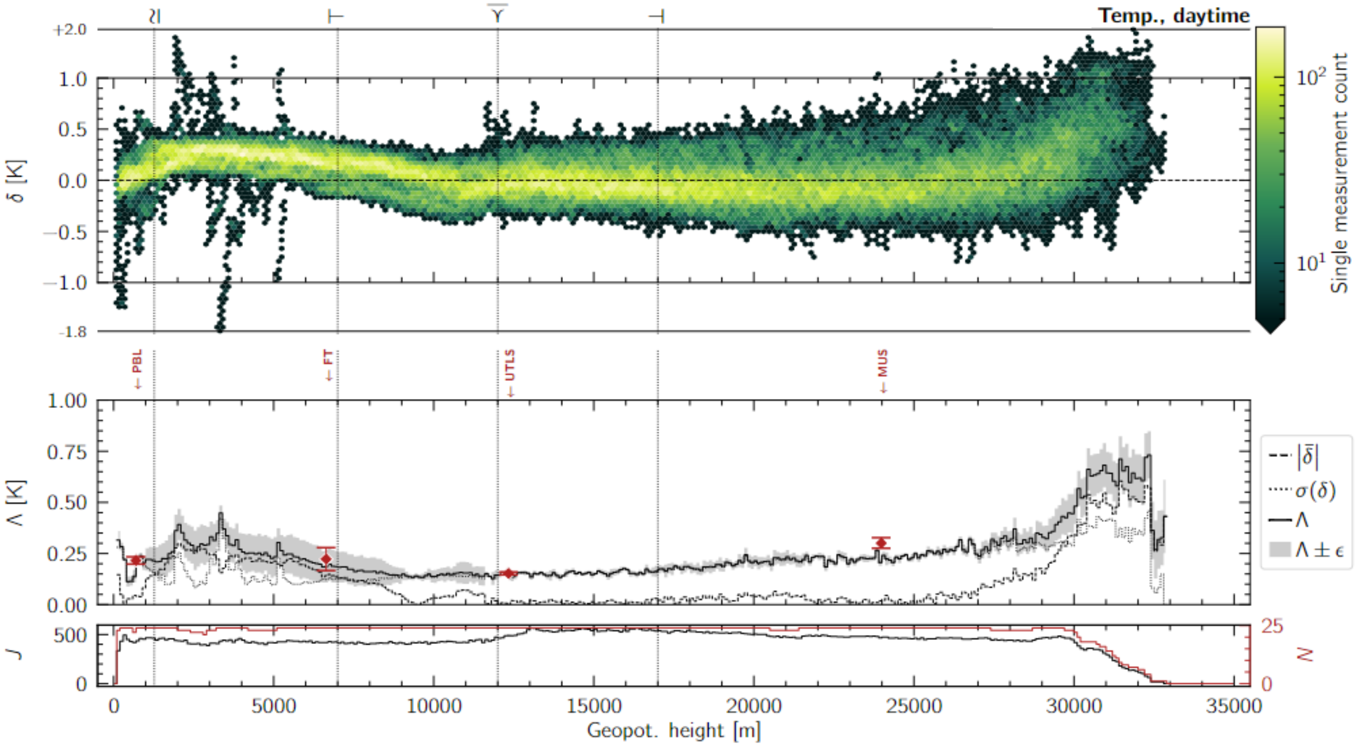
Huayuntianyi
HT-GTS(U)2-1

Selected conclusions from lab-campaign

- Considerable range in uncertainty of RH sensor calibration [<1 , 10]%RH
  - Improvement of the calibration of the humidity sensors
- Considerable range in time constant among radiosonde models [factor 100 at -70°C]
- Temperature calibration should cover the full operational temperature range



Results (example): daytime temperature



OSCAR requirements

4 Application areas

Aeronautical Meteorology
Nowcasting
NWP
Climate Monitoring

3 Variables

Temperature
Relative humidity
Wind vector

Geophysical variable x	Atmospheric layer $\mathcal{L}$	Unit	$\Theta^T_{x,\mathcal{L}}$	$\Theta^B_{x,\mathcal{L}}$	$\Theta^G_{x,\mathcal{L}}$	OSCAR Id
2.8 - Aeronautical Meteorology						
Atmospheric temperature	PBL FT UTLS	K	5.0	3.0	2.0	15
Relative humidity	PBL	%RH[1]	10.0	7.0	5.0	21
Wind (horizontal) vector	PBL UTLS	m s^{-1}	5.0	3.0	2.0	23
Wind (horizontal) vector	FT	m s^{-1}	5.0	2.7	2.0	22
2.3 - Nowcasting / Very Short-Range Forecasting						
Atmospheric temperature	PBL	K	3.0	1.0	0.5	427
Atmospheric temperature	FT	K	2.0	1.0	0.5	428
Relative humidity	PBL	%RH[1]	10.0	5.0	2.0	704
Relative humidity	FT	%RH[1]	20.0	8.0	5.0	448
Wind (horizontal) vector	PBL UTLS	m s^{-1}	5.0	2.0	1.0	452, 453
Wind (horizontal) vector	FT	m s^{-1}	8.0	2.0	1.0	451
2.1 - Global Numerical Weather Prediction and Real-time Monitoring 2.2 - High-Resolution Numerical Weather Prediction						
Atmospheric temperature	PBL FT UTLS	K	3.0	1.0	0.5	255-257, 339-341
Atmospheric temperature	MUS	K	5.0[2]	3.0[2]	0.5[2]	254
Relative humidity	PBL FT	%RH[1]	10.0	5.0	2.0	302, 303, 378, 379
Wind (horizontal) vector	PBL UTLS	m s^{-1}	5.0	3.0[3]	1.0	312, 313, 384, 385
Wind (horizontal) vector	FT	m s^{-1}	8.0	3.0	1.0	311, 383
Wind (horizontal) vector	MUS	m s^{-1}	10.0[2]	5.0[2]	1.0[2]	310
2.5 - Atmospheric Climate Forecasting and Monitoring						
Atmospheric temperature	PBL FT UTLS MUS	K	0.5[4]	0.25[4]	0.05[4]	778, 779, 780, 1016
Relative humidity	PBL FT	%RH	0.5[4]	0.25[4]	0.05[4]	789, 997
Relative humidity	UTLS	%RH	1.0[4]	0.5[4]	0.25[4]	790
Wind (horizontal) vector	PBL FT UTLS	m s^{-1}	2.5[4]	1.5[4]	0.5[4,5]	781, 988, 989
Wind (horizontal) vector	MUS	m s^{-1}	5.0[4]	2.5[4]	0.5[4]	1017

[1] Converted from % g kg^{-1} to %RH (see Appendix J)
[2] High-Resolution Numerical Weather Prediction: n.a.
[3] High-Resolution Numerical Weather Prediction, for the PBL: 2.0
[4] Converted from 2σ to 1σ level (see Sec. 9.3.1.2).
[5] For the PBL: 0.25

3 Levels

Threshold
Breakthrough
Goal

4 Atmospheric layers

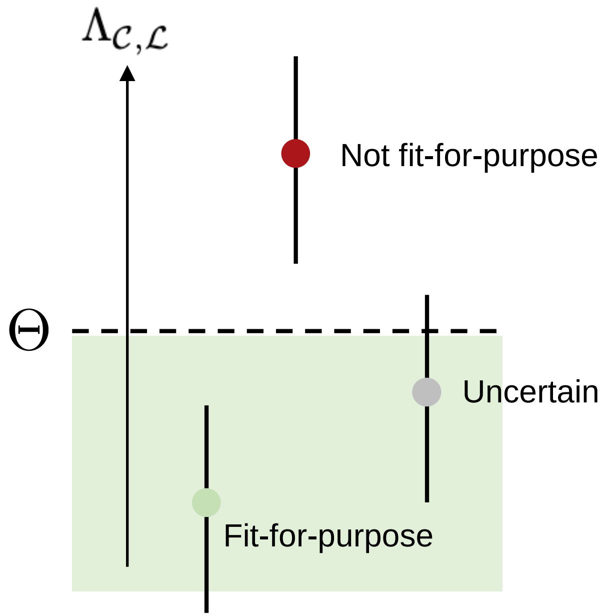
PBL – FT – UTLS – MUS

Example (ORUC):

$$\Theta^{B}_{\mathrm{temp,UTLS}}(\mathrm{NWP}) = 1.0\,[\mathrm{K}]$$

OSCAR => Fitness-for-purpose

$$\Lambda_{\mathcal{C},\mathcal{L}} = \sqrt{\frac{1}{J}\sum_{\substack{x_{e,i}\in\mathcal{L}\\ e\in\mathcal{C}}} (\overbrace{x_{e,i}}^{\text{Sonde}} - \overbrace{\Omega_{e,i}}^{\text{Reference (CWS)}})^2},$$



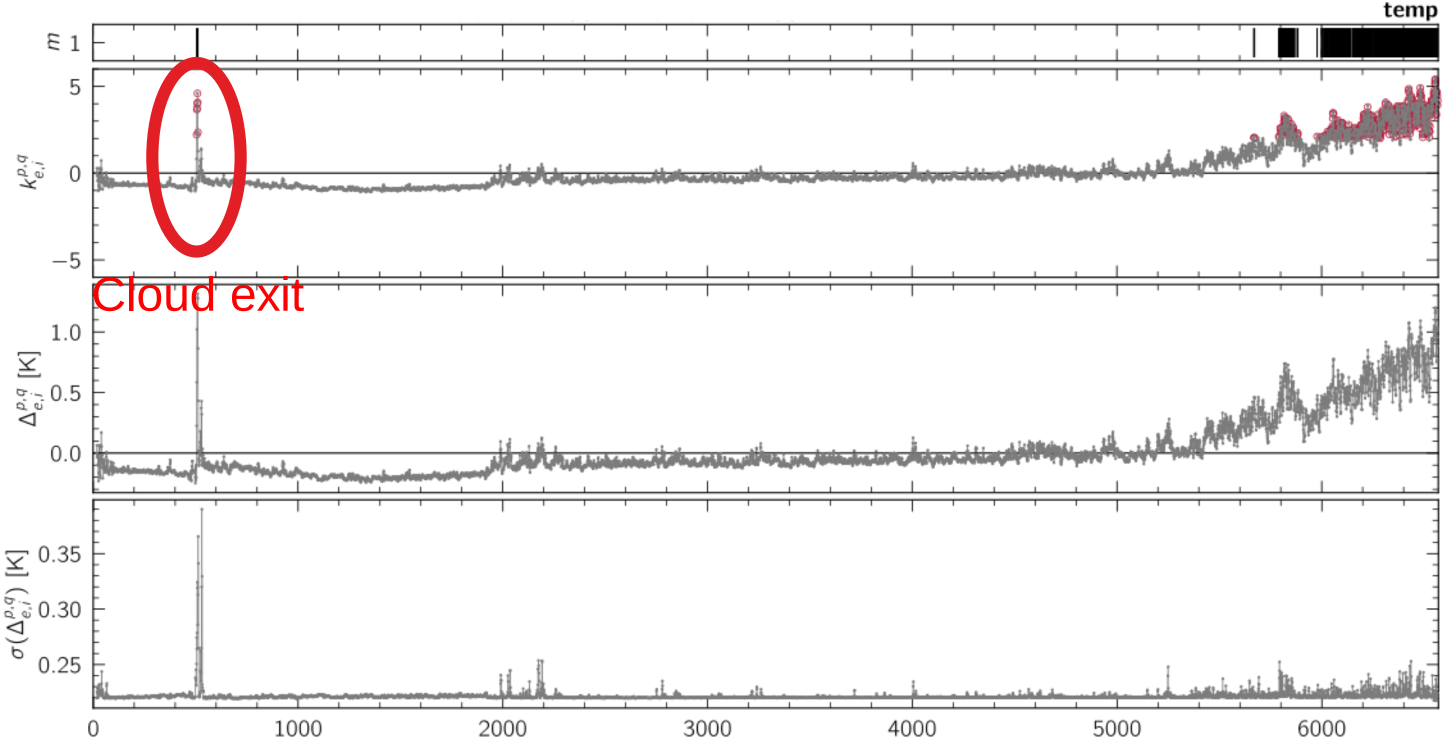
- *create CWS from GDPs (where consistent)*
- *compare profile with CWS, include CWS uncertainty*
- *statistical analysis of entire dataset.*
- *ORUC: OSCAR requirement uncertainty criterion*

Campaign conclusions

- Successful campaign; the chosen approach worked-out well
  (independent operators, GDPs, OSCAR, lab/field campaign, dvas, open-source approach)
- Most of the systems are fit for routine operation in terms of system maturity, user friendliness and data quality.
- All but one sonde meet the breakthrough <u>temperature</u> requirements for NWP in all atmospheric layers. Consistent with the laboratory results.
- <u>Humidity</u>: two systems meet breakthrough requirements for NWP, consistent with limitations observed during laboratory tests.
- Complete conclusions in report

GRUAN-related: consistency of GDPs

I.3 ASSESSING THE STATISTICAL COMPATIBILITY OF GDPs



$$k = \frac{\Delta}{\sigma(\Delta)}$$

$$\Delta$$

$$\sigma(\Delta)$$

GDP-issues

Badness scale

Format/data inconsistency

- 😕 • RS41: k=2 vs iMS-100: k=1
- 😖 • iMS-100: lacks “`g.Measurement.InternalKey`”
- 😵 • RS41: time as float(= `float64`) vs iMS-100: time as long (= `int64`)
- 😭 • RS41: gph jumps of –(25-30)m

Violation of GRUAN principles

- 😨 • RS41: GPS time offsets **[up to ~5 sec]**
- 😱 • RS41: valid gph with no uncertainty **[up to 250/profile; see RS41 GDP user guide, Sec 5.1]**
- 😱 • iMS-100: valid wdir/wspeed with no uncertainty **[up to 10/profile]**
- 😱 • iMS-100: invalid rh with valid uncertainty **[up to 2500/profile]**
- 🤯 • RS41 vs iMS-100: T mismatch at high altitude at night
- 🤯 • RS41 and iMS-100: mis-estimation/mis-assignment of uncertainties

Lessons learned

- CWS based on GDPs worked well, however more GDPs from different manufacturers needed
- Shorter interval between UAIIs
  - 14 years exceeds lifecycle of radiosonde model
- Small-scale UAIIs with limited number of systems + CWS-GDPs
  - Link to UAII2022 and adopt the applied methods
  - @GRUAN sites?

Benefits for GRUAN

- Acceptance of GRUAN methods by manufacturers
- Helwan site (Egypt) joining GRUAN
- Intensive use of OSCAR requirements and GDPs
  - (mis-)estimation of GDP uncertainties
  - incomplete documentation
- Experience with radiosondes outside the GRUAN-universe
  - Calibration uncertainty
  - Operational (T-)range of RH sensors
  - Forcing of RH data in stratosphere

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