Impact of Greenhouse Gases: Measuring temperature change

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Water vapor trends in the troposphere?

e.g.: Lindenberg 8km (0:00 UT)
Water vapor trends in the troposphere?

e.g.: Lindenberg 8km (0:00 UT)

Year


0 10 20 30 40 50 60 70 80 90 100

RH over liquid

Freiberg RKS-2 RKS-5 MARZ RS80 RS92
GRUAN’s relationship to existing observational networks

- Comprehensive Observing Network
  All stations, observing systems, reanalyses, etc.
  161 stations

- GCOS Upper Air Network (GUAN)

- GCOS Reference Upper Air Network (GRUAN)
  30-40 stations

Seidel et al., 2009

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GRUAN goals

- Maintain consistent observations over decades
- Validate satellite systems
- Understand atmospheric processes
- Numerical weather prediction
- Deliberate measurement redundancy
- Standardization and traceability
- Quality management and managed change

Priority 1: Water vapor, temperature, (pressure and wind)

Priority 2: Ozone, …
A GRUAN reference observation:

- Is traceable to an SI unit or an accepted standard
- Provides a comprehensive uncertainty analysis
- Maintains all raw data
- Includes complete meta data description
- Is documented in accessible literature
- Is validated (e.g. by intercomparison or redundant observations)
Establishing reference quality

- Traceable sensor calibration
- Transparent processing algorithm

GRUAN Measurement

- Best estimate
- + Uncertainty

- Disregarded systematic effects
- Black box software
- Proprietary methods

Uncertainty of input data
Example GRUAN product – RS92

- The RS92 sonde model is the production sonde used by many sites around the world
- Vaisala provides raw (unprocessed) measurement data
- GRUAN Lead Centre and colleagues have undertaken an end-to-end processing understanding and quantifying uncertainty in each step. Following slides just a subset for illustration.
- Data and metadata are captured in consistent manner
- See Dirksen et al. AMT, 2014
Radiation error: Laboratory experiments

Shadow RS92 records background temperature & ambient pressure.

Simultaneous testing of 3 radiosondes

p=[3 hPa , ambient]

Difference illuminated – background radiosonde

Temperature difference [K]

Shutter open

Shutter closed

Time [s]

100 hPa (5 m/s)

RS92
Sources of measurement uncertainty:
- Sensor orientation
- Ventilation
- Unknown radiation field (albedo)
- Lab measurements of the radiative heating
- Ground check
- Calibration
Humidity

Undo RH recalibration

Errors

• T-dependent calibration
• Dry bias
• Time lag
Ground check in SHC

- Traceability
- 4% change over ~8 years
- SHC readings enter uncertainty budget
- Future: use SHC to scale profile

Lindenberg

RS92 groundcheck SHC (100%RH) Lindenberg

A (2005)  
B (2006)  
C (2007)  
D (2008)  
E (2009)  
F (2010)  
G (2011)  
H (2012)  
J (2013)  
K (2014)  
L (2015)  

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RH: time-lag

Relevant below $-40^\circ$ C, $	au = 20s$ ($\tau > 100s$ @ $-80^\circ$ C)
Flattens features in humidity profile

Correction:
numeric inversion of low-pass filter. Enhances structures & noise (a-posteriori filtering)

Uncertainties: time constant, statistical noise
Dominant uncertainties:
• Calibration
• Cal. correction
• Dry bias
Consistency for perfectly co-located measures

- Two well defined and understood measurements should be consistent:

\[ |m_1 - m_2| < k \sqrt{u_1^2 + u_2^2} \]

- No meaningful consistency analysis possible without uncertainties
- If \( m_2 \) has no uncertainties use \( u_2 = 0 \) or some design specification

| \(|m_1 - m_2| < k \sqrt{u_1^2 + u_2^2}\) | TRUE | FALSE | significance level |
|---------------------------------|------|-------|-------------------|
| \( k=1 \)                       | consistent | suspicious | 32%               |
| \( k=2 \)                       | in agreement | significantly different | 4.5%              |
| \( k=3 \)                       | - | inconsistent | 0.27%             |
Co-location / co-incidence matters and inflates the expected difference

- Determine the variability ($\sigma$) of a variable ($m$) in time and space from measurements or models
- Two observations on different platforms are consistent if

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

✓ This test is only meaningful, i.e. observations are co-located or co-incident if:

$$\sigma < \sqrt{u_1^2 + u_2^2}$$
Management of Change

- Change management is mandatory
- A new system, software, or procedure must be evaluated prior to implementation
- Systematic and random errors must be quantified for the new system
- Redundant observations verify the new system (overlap)
- Use transfer functions on old data where required
GRUAN achievements

• GRUAN data product for Vaisala RS92 radiosonde
• Other radiosonde products are being developed (Modem M10, Meisei RS11-G, Meteolabor SRS34, Frost point hygrometer)
• Other products & data streams being developed:
  • GNSS total water vapor column
  • Lidar (T, U)
  • μ-wave radiometer (T, U)
  • FTS (various trace gases)
• Archive with ~30,000 GRUAN-processed radiosounding profiles
• > 20 GRUAN-related publications

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GRUAN and metrology community

- GRUAN has at its heart metrological best practices
- To be sustainable requires a sustained engagement between climate, operational and metrological communities
- There are plenty of opportunities to get involved
- There are many potential projects if funding can be secured
- Please contact the Lead Centre - gruan.lc@dwd.de with any ideas / suggestions
Questions