VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD
Centre for Metrology MIKES

MIKES METROLOGY

Towards SI traceable humidity measurements with radiosondes

GRUAN ICM-9, MeteoMet Training Course
FMI, Helsinki, 15th June 2017

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METEOMET
Metrology for Meteorology

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Outline

- Introduction
- SI traceability in humidity measurements
- Challenges of establishing traceability in radiosonde-based humidity measurements
- Development of a reference humidity calibration system for radiosondes at VTT MIKES
- Future
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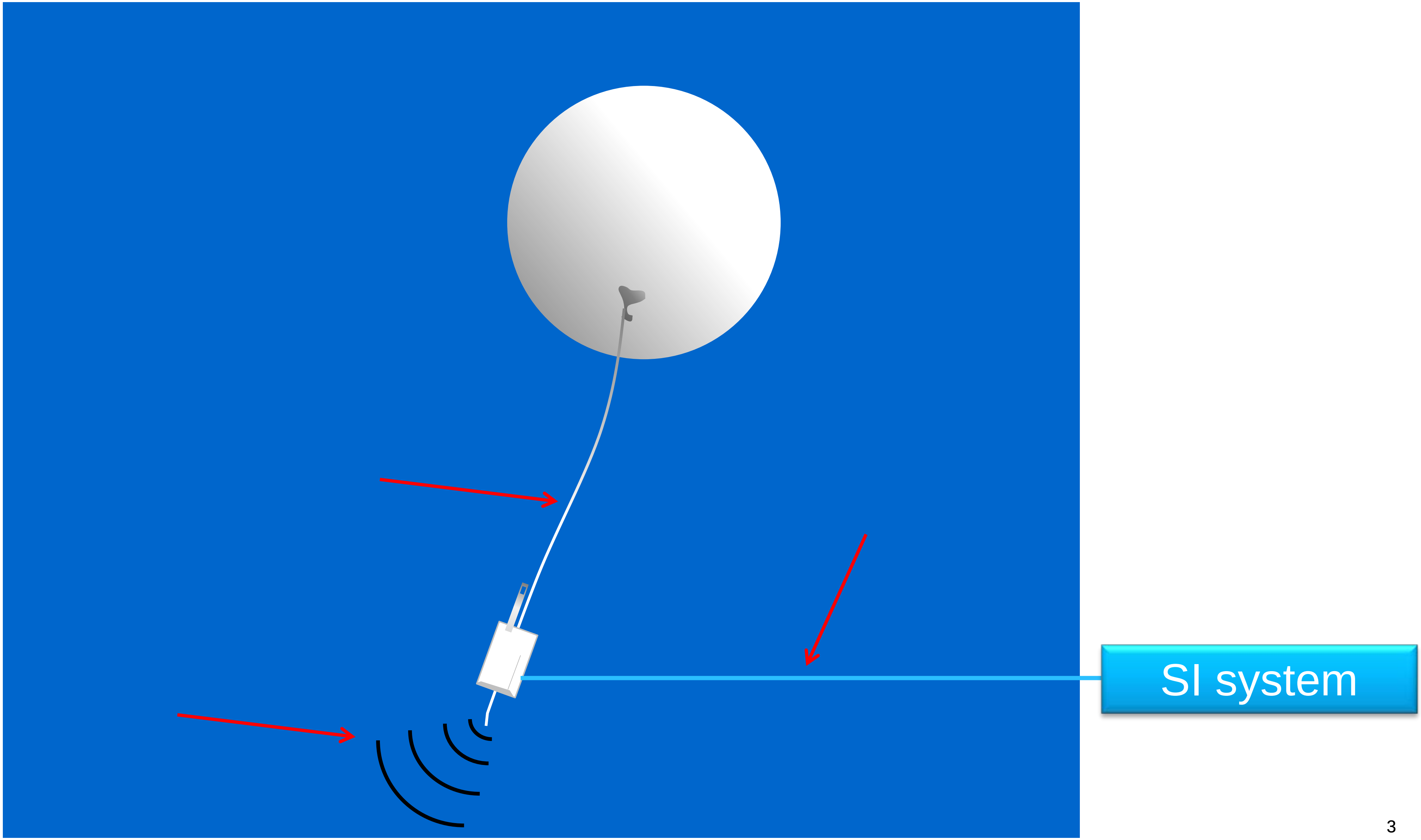
Introduction



SI traceability in humidity measurements

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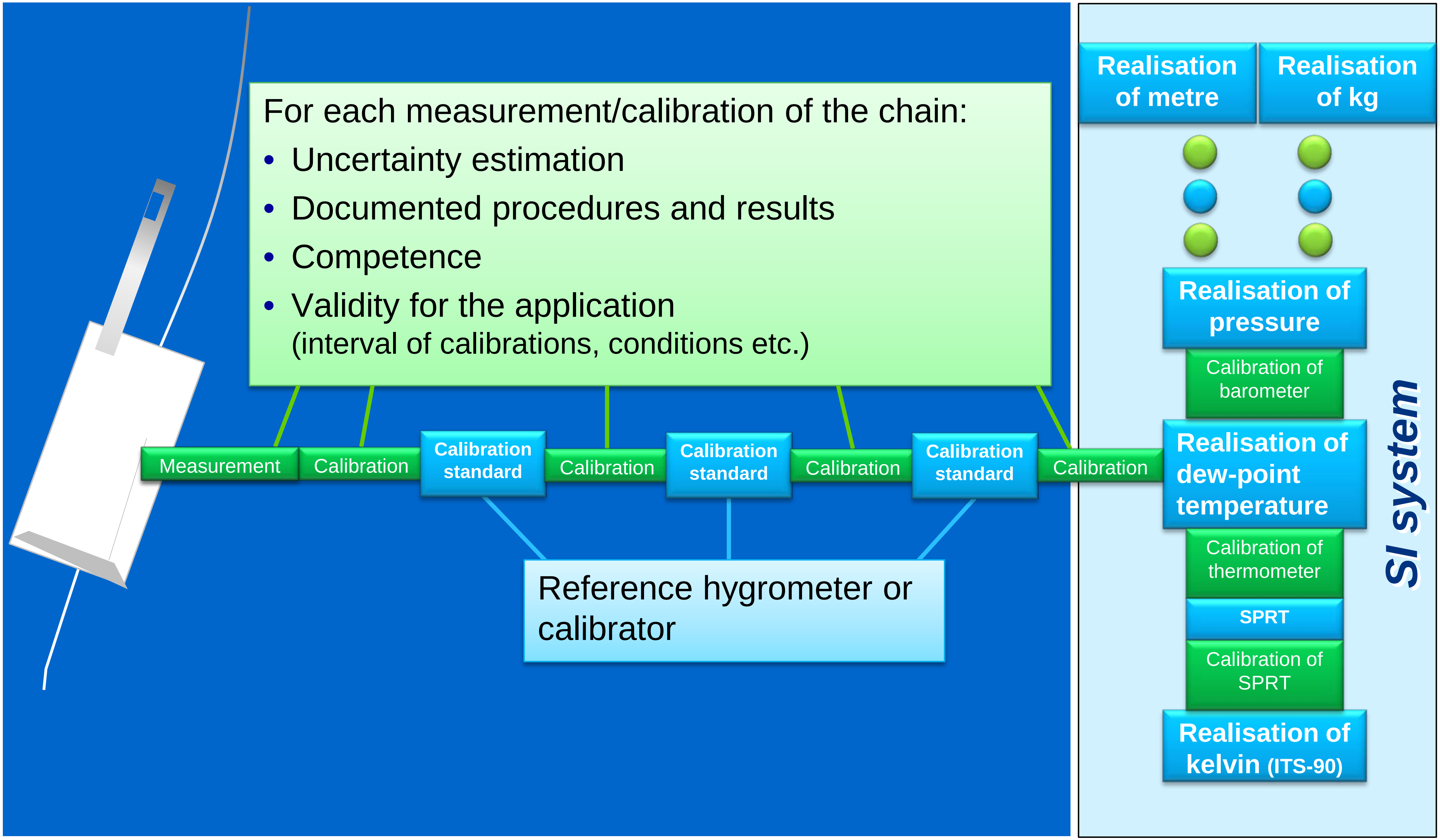
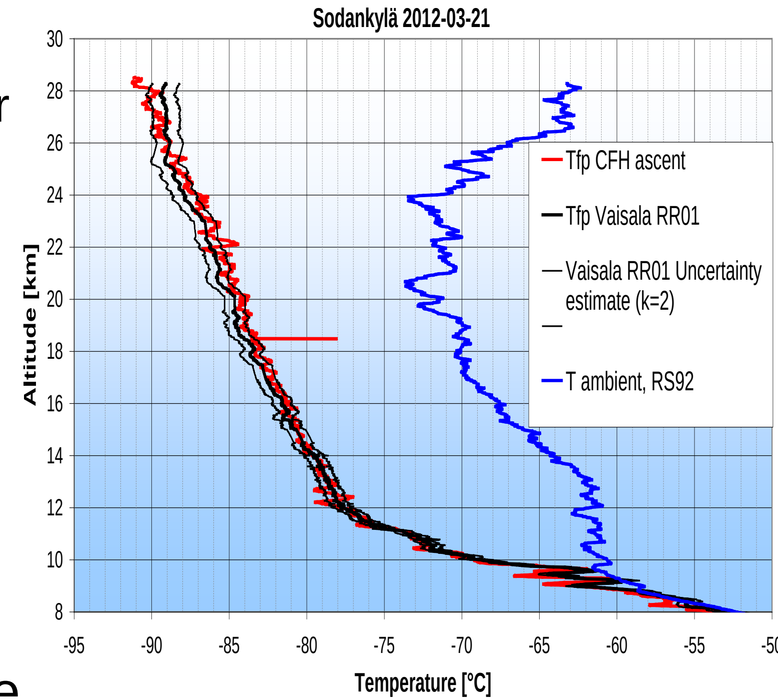


Challenges of establishing traceability in radiosonde-based humidity measurements

- Uncertainties due to measurement conditions
- Calibration of a radiosonde
  - It's not feasible to calibrate each device by user
  - Disposable => re-calibration is not possible
  - Representativity of the calibration:
    - Large operating dew-point temperature, air temperature and pressure ranges
  - Measurements down to trace humidity region => stabilisation time for any calibration setup is long



[H. Turtiainen, MeteoMet Workshop, Helsinki 10.9.2013]

Manufacturers have a key role in establishing the traceability link to radiosondes

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Development of a reference humidity calibration system for radiosondes at VTT MIKES (1/2)

- Motivation:
  - To enable **manufacturers** to demonstrate their humidity calibration capability of radiosondes in a full operation range
  - To enable **users** of radiosondes to perform comparative humidity measurements in well-controlled conditions
  - To support the development of radiosondes to fulfil the GRUAN requirements

EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

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Development of a reference humidity calibration system for radiosondes at VTT MIKES (2/2)

- Major challenges:
  - To meet GRUAN accuracy requirements
  - To enable smooth and fast calibration
- Development in EMRP MeteoMet projects:
  - MeteoMet1 (2011 – 2014): calibrations at surface pressures
  - MeteoMet2 (2014 – 2017): extension to low pressures (down to 7 hPa, absolute pressure) and improved operation at low frost-point temperatures
  - Tests with RR01 prototype reference radiosondes of Vaisala

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Progress

- Concept of a new calibration apparatus for reference radiosondes [1]
- New measurement chamber for radiosonde calibrations [2]
- Characterization of the apparatus at 1000 hPa absolute pressure [3,4]
- The development of the apparatus continues by extending the operation range down to 10 hPa (abs.) [5,6]

1) Sairanen H., Heinonen M., Högström R., Lakka A., Kajastie H. (2014). A calibration system for reference radiosondes that meets GRUAN uncertainty requirements. *NCSLI Measure*, *9*(3), 56-60.
2) Lakka, A., Sairanen, H., Heinonen, M., & Högström, R. (2015). Comsol Simulations as a tool in Validating a Measurement Chamber. *Int. J. Thermophysics*, 36(12), 3474-3486.
3) Sairanen, H., Heinonen, M., & Högström, R. (2015). Validation of a calibration set-up for radiosondes to fulfil GRUAN requirements. *Meas. Sci. Technol.*, *26*(10), 105901.
4) Sairanen, H. (2015). Advances in Humidity Measurement Applications in Metrology. Doc.Thesis, Aalto University.
5) Salminen J., Sairanen H., Grahn P., Högström R., Lakka A., Heinonen M., Characterization of the humidity calibration chamber by numerical simulations, *Int. J. Thermophys*. (2017) 38:84-97
6) Sairanen H., Heinonen M., Högström R., Lakka A., Kajastie H., Low pressure and temperature dew/frost-point generator, submitted to *Int. J. Thermophys*.

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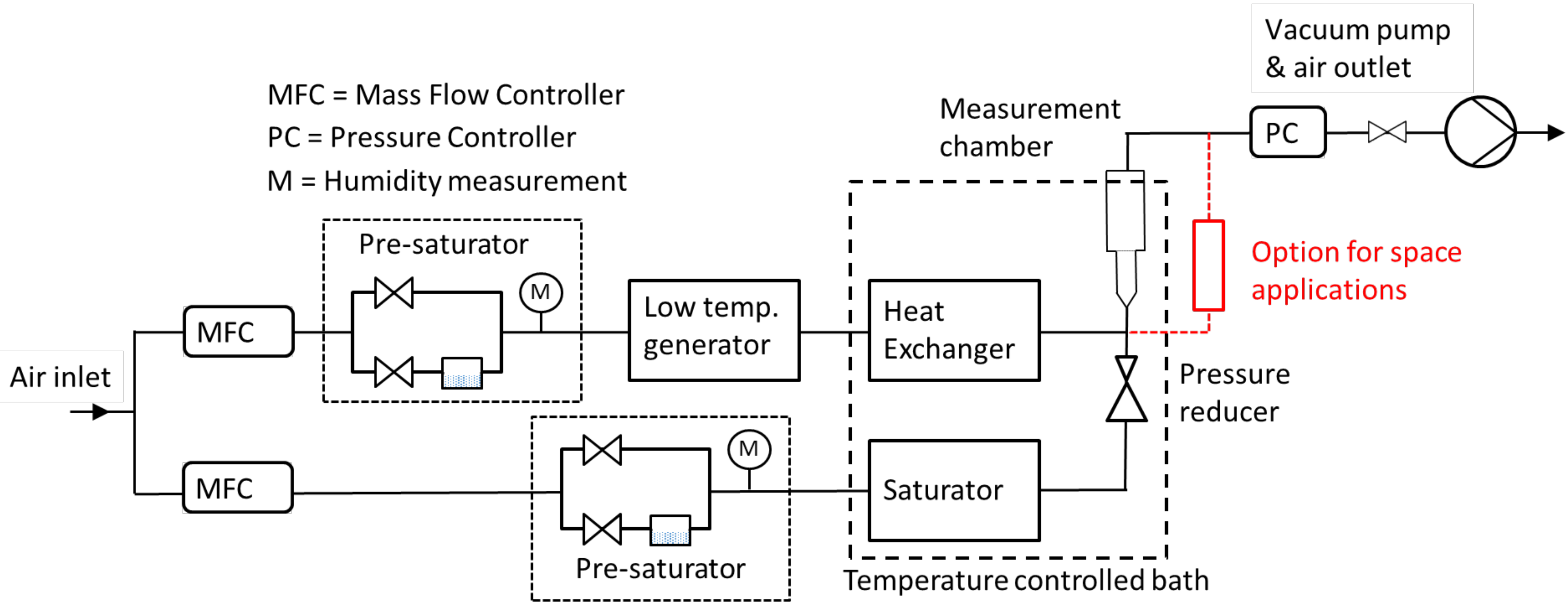
GRUAN specifications

- GRUAN (GCOS Reference Upper-Air Network) requires accuracy of 2 % in terms of mixing ratio in humidity measurements
- The GRUAN requirements should be achieved
  - in humidity range down to 0.1 ppm(v), corresponding to frost-point of about -90 °C
  - in temperature range down to 170 K
- Vertically the measurement range is up to 50 km (except humidity up to 30 km)

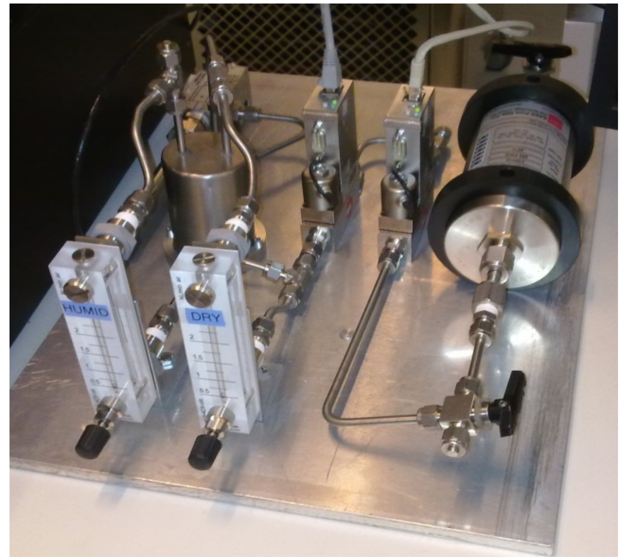
  → About 10 hPa (abs.) is the minimum pressure

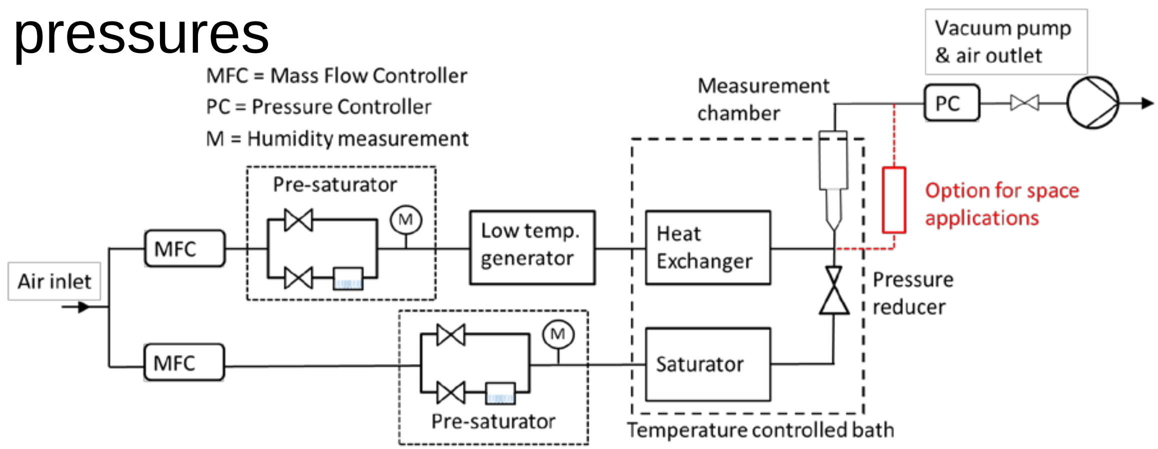
Calibration apparatus (1/5)



Calibration apparatus (2/5)

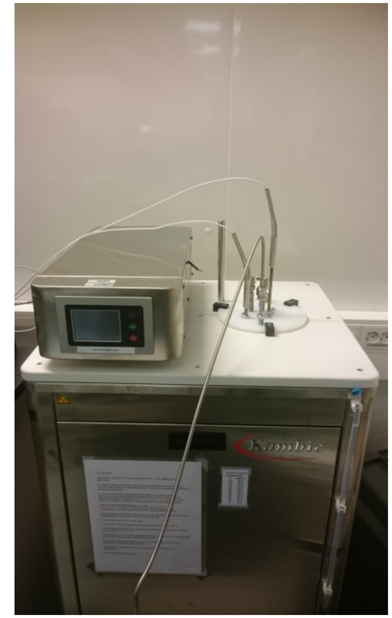
- Flow control unit includes
  - Mass flow controllers (Bronkhorst)
  - Pre-saturator
  - Dew-point temperature measurement (Vaisala DMP248)
- MFCs were characterized and calibrated for varying outlet pressures

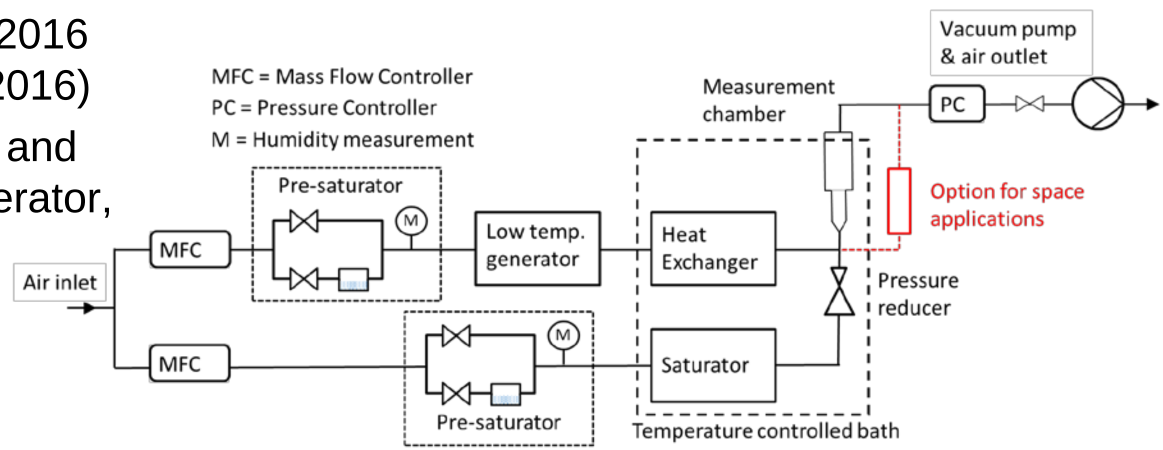




Calibration apparatus (3/5)

- Low temperature generator includes
  - Ethanol bath (Kambic ULT-22)
  - Pressure measurement
  - Temperature probes (Fluke 5609-20)
- Further details in
  - H. Sairanen et al., TEMPMEKO 2016 (Zakopane, Poland, 26.6. – 1.7.2016)
  - H. Sairanen et al., Low pressure and temperature dew/frost-point generator, submitted to *Int. J. Thermophys.*

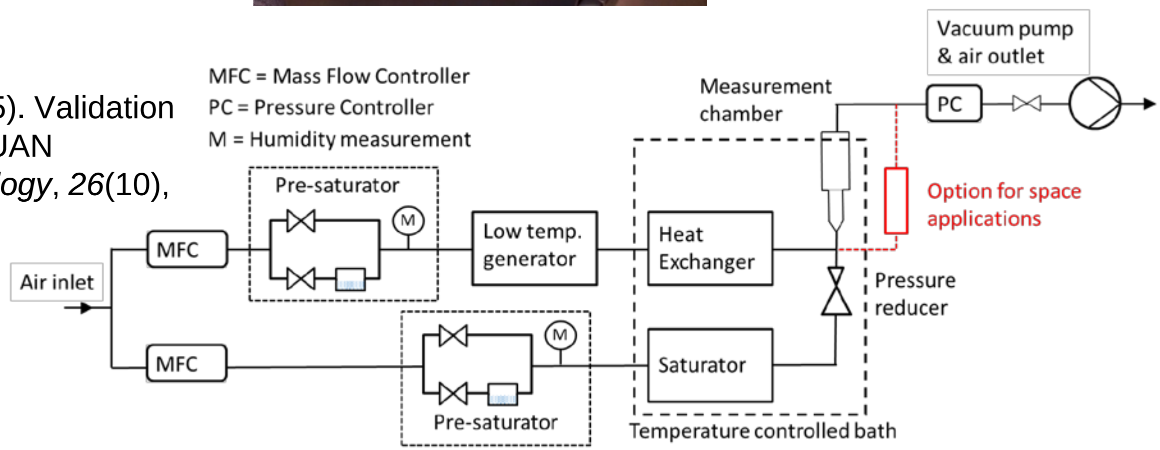




Calibration apparatus (4/5)

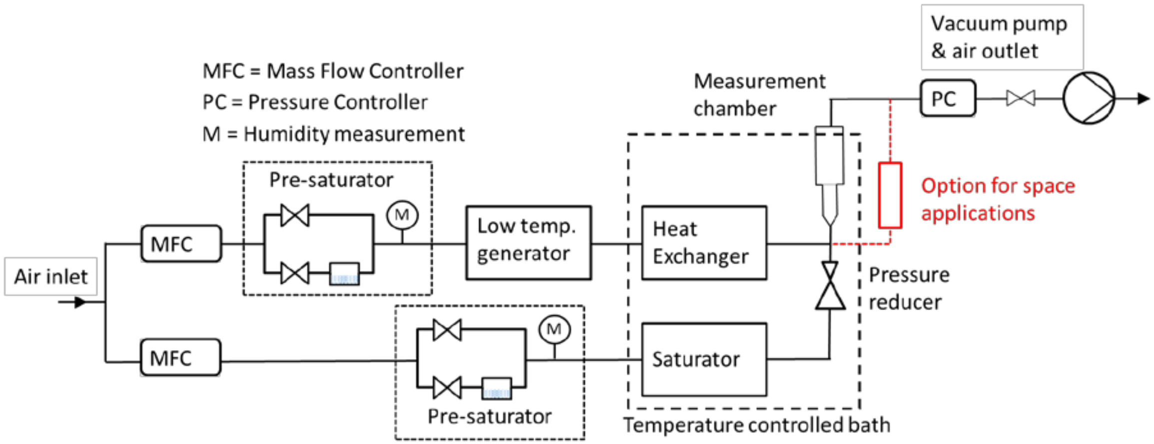
- Immersed in the bath
  - Saturator
  - Pressure reducer
  - Heat exchanger
  - Measurement chamber
- This part of the apparatus was characterized in

  Sairanen, H., Heinonen, M., & Högström, R. (2015). Validation of a calibration set-up for radiosondes to fulfil GRUAN requirements. *Measurement Science and Technology*, *26*(10), 105901.



Calibration apparatus (5/5)

- Pressure control includes
  - Pressure controller (Bronkhorst)
  - Vacuum pump (Edwards nXDS 15i)



Characterization of the apparatus

- The apparatus was first characterized at 1000 hPa (abs.)
- Improvements for 10 hPa (abs.) were completed and the apparatus was characterized to the complete pressure range
  - Performance of the apparatus was tested for both descending and ascending pressures
  - Different flow rates were also tested
  - Characterization was carried out in two steps:

    1) independently for key parts

    2) for the complete apparatus
  - Outcomes of the characterization measurements indicated no pressure dependancy in the performance of heat exchangers and saturators

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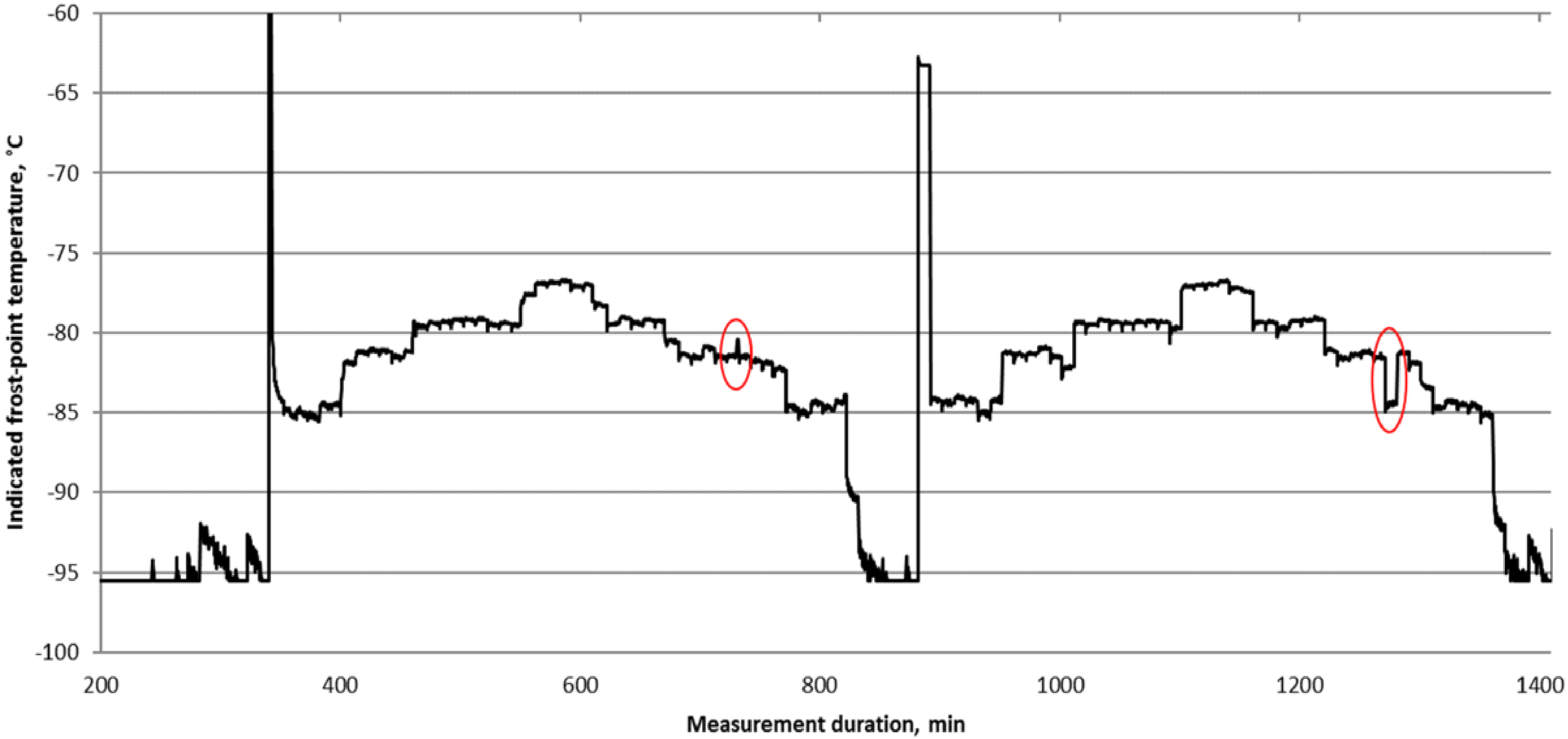
Performance



An example of a test measurement run with a RR01. Red ellipses indicate data that were recorded during tests for the effect of changing flow rate through the test chamber.

Uncertainty analysis

- Uncertainty of the apparatus was analysed according to GUM [1]
- Combined uncertainty of the apparatus depends on flow rates, temperatures and pressures
  - Most dominant uncertainty source depends on operating conditions
  - Largest contributors are low temperature generator, saturator, MFCs and adsorption/desorption effects
- When operating at about 1000 hPa (abs.) relative expanded uncertainty (k = 2) is less than 1.7 % (GRUAN requires 2 %)
- Experiments carried out show no pressure dependancy for the uncertainty.

[1)] JCGM 2008 *Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement*

Example of an uncertainty estimation for the VTT MIKES humidity calibration system at water vapour mixing ratio of 1.9 × 10^{-7} (0.2 ppm)

Source	Estimate	Uncertainty of the input quantity	Contribution to the combined standard uncertainty
Low temp. generator			
Dew-point temperature	183.15 K	0.043 K	2.22 × 10^{-10}
Air flow rate	1.09 × 10^{-2} g s^{-1}	1.09 × 10^{-4} g s^{-1}	6.78 × 10^{-10}
Water vapour pressure	9.67 × 10^{-3} Pa	2.90 × 10^{-5} Pa	8.77 × 10^{-11}
Pressure	103800 Pa	20 Pa	5.63 × 10^{-12}
Enhancement factor	1.0085	1.01 × 10^{-3}	2.92 × 10^{-11}
Dew-point generator 2			
Dew-point temperature	193.15 K	0.015 K	3.92 × 10^{-10}
Air flow rate	1.09 × 10^{-2} g s^{-1}	1.09 × 10^{-4} g s^{-1}	6.78 × 10^{-10}
Water vapour pressure	5.47 × 10^{-2} Pa	1.64 × 10^{-4} Pa	4.95 × 10^{-10}
Pressure	104000 Pa	20 Pa	3.17 × 10^{-11}
Enhancement factor	1.0076	1.01 × 10^{-3}	1.65 × 10^{-10}
Molar masses			
Air	28.96 g mol^{-1}	2.55 × 10^{-5} g mol^{-1}	1.71 × 10^{-13}
Water	18.02 g mol^{-1}	2.54 × 10^{-5} g mol^{-1}	2.74 × 10^{-13}
Adsorption / desorption	0	5.82 × 10^{-10}	5.82 × 10^{-10}
Combined standard uncertainty of mixing ratio			1.32 × 10^{-9} **0.68 %**
Expanded uncertainty (*k* = 2)			**1.36 %**

Discussion

- The reference humidity calibration system for radiosondes developed at VTT MIKES
  - Can be used for demonstrating calibrations at the uncertainty level specified by GRUAN in the complete operation range
- This is the first primary humidity standard for low pressures and thus it is extremely important to demonstrate its performance by an interlaboratory comparison
  - VTT MIKES will carry out a comparison with INRiM (Italy) in summer 2017
- The measurement chamber was optimised for RR01; modifications and/or further development is needed to enable measurements with other types of sensors

Future

- Services for customers
- Development of more versatile measurement chamber
  - Enabling calibrations for different kinds of radiosondes
- Extension to space applications
  - System has already been used in testing sensors developed for monitoring atmosphere on Mars
  - Non-air atmosphere

Conclusion

- Metrological traceability is a key feature of results with known quality
- Manufacturers have an important role in establishing the traceability link between individual radiosondes and SI
  - Also, uncertainties related to actual measurement are important for the traceability of measurement results
- MeteoMet developed tools for
  - demonstrating calibration capability of radiosonde manufacturers
  - performing comparative humidity measurements in well-controlled conditions

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