



## Session 3: Reference measurement specifications

### A guideline for upper-air reference measurements

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# Outline

- Introduction
- Terminology
  - Errors and uncertainty
  - Traceability
  - Reference
  - Redundancy and consistency
- Establishing operational upper-air reference observations
- Case study: Reference measurements for temperature based on Vaisala RS-92 radiosonde data.

# •Introduction

- Important background literature:  
→ **The GUM**

JCGM/WG\_1, **2008**, Evaluation of measurement data – Guide to the expression of uncertainty in measurement , available at:

**[http://www.bipm.org/utils/common/documents/jcgm/JCGM\\_100\\_2008\\_E.pdf](http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)**

## → **CIMO guide for observation**

WMO, 2006.: Guide to Meteorological Instruments and Methods of Observation, World Meteorological Organization, 7th edn.,

**[http://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/CIMO Guide-7th Edition-2006.html](http://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/CIMO%20Guide-7th%20Edition-2006.html)**

# Uncertainty

- The GUM 1980: new concept introduced
  - The "true value" of a physical quantity is no longer used as an important concept.
  - error is replaced by uncertainty
  - result of a measurement = a range of values generally expressed by  $m \pm u$ 
    - **m is corrected for systematic effects**
    - **u is (random) uncertainty.**
  - Type A evaluation: statistical analysis
  - Type B evaluation:
    - **previous measurement data**
    - **experience with or general knowledge of the behaviour and properties of relevant instruments**
    - **manufacturer's specifications**
    - **data provided in calibration and other certificates**
    - **uncertainties assigned to reference data taken from handbooks**

# Uncertainty of multiple measurements

Some formula:

uncertainty of mean

$$u_m = \sqrt{\frac{1}{N(N-1)} \sum_{i=1}^N (x_i - \bar{x})^2}$$

averaging or smoothing of data:

derived uncertainty for uncorrelated input quantities

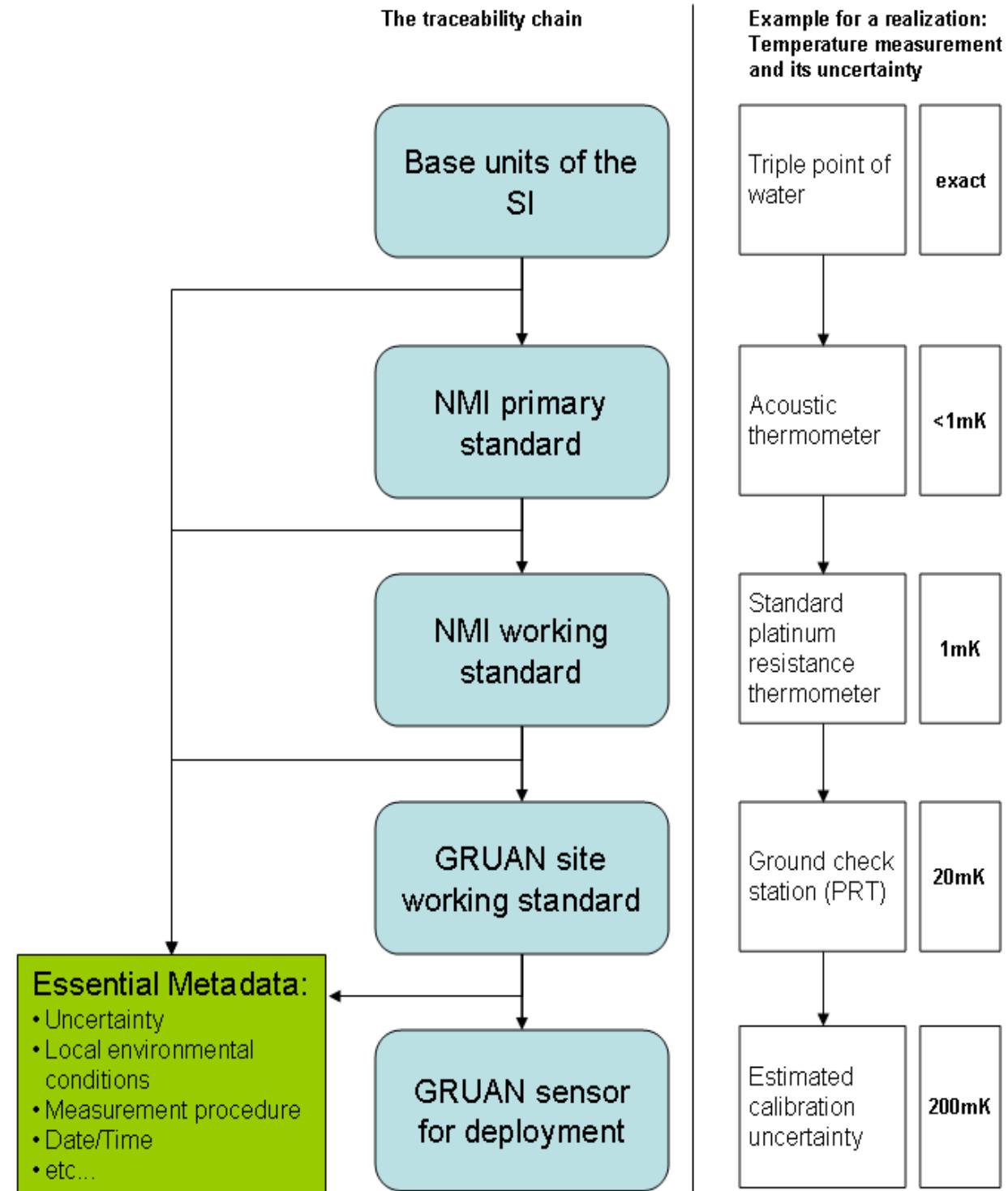
$$u_m = \frac{1}{N} \sqrt{\sum_{i=1}^N u_i^2}$$

derived uncertainties for correlated input quantities

$$u_m = \frac{1}{N} \sum_{i=1}^N u_i$$

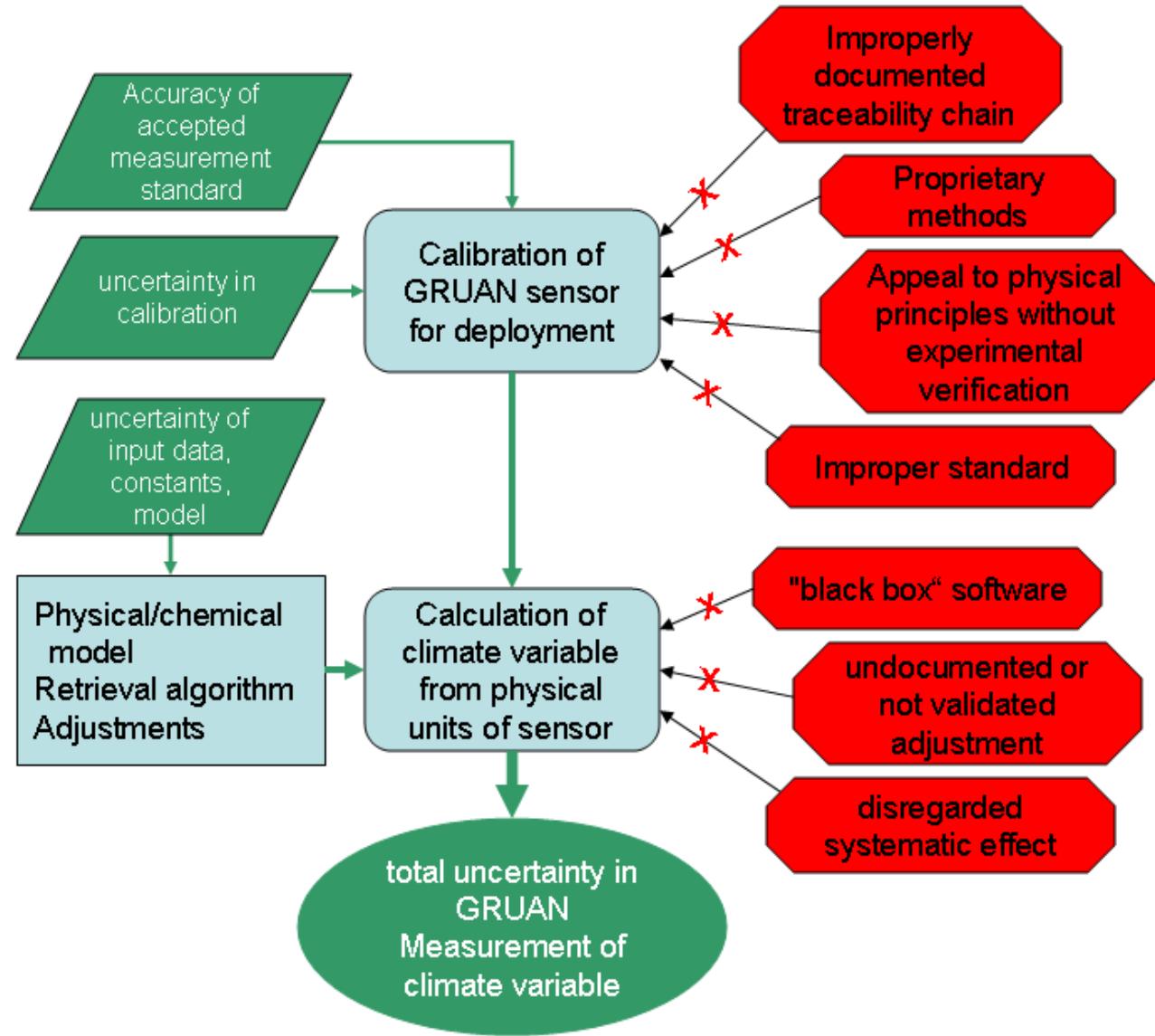
# Metrological Traceability

- The result of a measurement can be related to the definition of a unit by an unbroken document chain of calibrations, each of which contributes to the measurement uncertainty





# Establishing reference quality



# Redundancy and Consistency

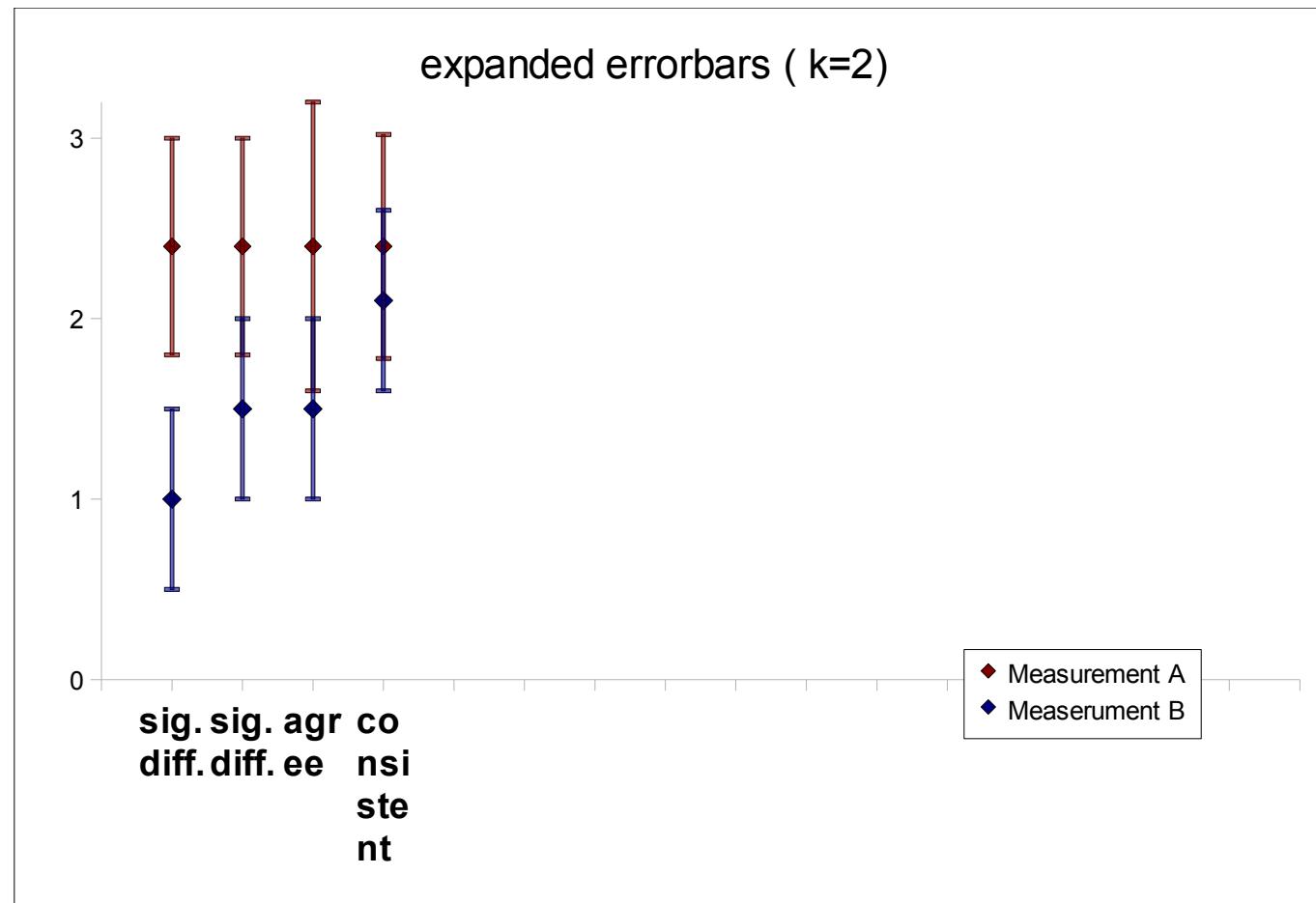
- Ideally GRUAN stations provide redundant measurements of the same variable ( → collocation issue)
- Redundant measurements should be in agreement.
  - an essential part of operational quality assurance
- Consistency:  $|m_1 - m_2| < k \sqrt{u_1^2 + u_2^2}$ 
  - No meaningful consistency analysis possible without uncertainties
  - if  $m_2$  has no uncertainties use  $u_2 = 0$  "agreement within errorbars"

$ 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%



# consistency analysis

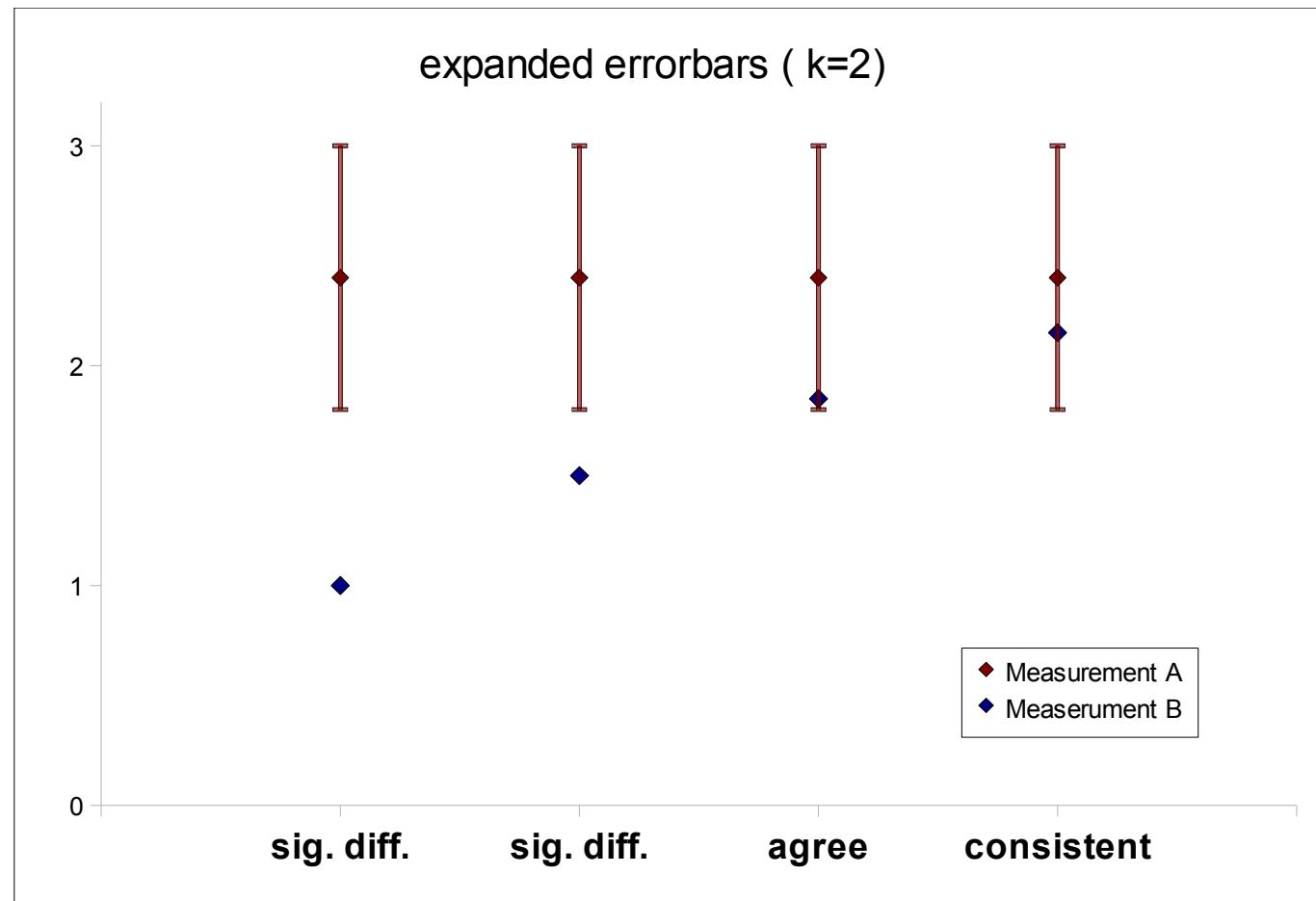
$$|m_1 - m_2| < k \sqrt{u_1^2 + u_2^2}$$





# consistency analysis

$|m_1 - m_2| < k u_1$



# consistency in a finite atmospheric region

- The co-location co-incidence issue
  - the variability  $\sigma$  in the temporal and spatial region that enclose both measurements need to be determined (from measurement or model)

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

- $\sigma$  needs to be in the same order or smaller to make this a meaningful consistency test
- the two measurements are co-located if

$$\sigma \leq \sqrt{u_1^2 + u_2^2}$$

$$\sigma = \sqrt{\frac{1}{(N-1)} \sum_{i=1}^N (x_i - \bar{x})^2}$$

# Reference measurement

- Relating to the definition of a unit or a transfer standard (Metrological traceability)
- Specified uncertainty
- Traceable (meta-data, documentation)

# Establishing operational upper-air reference observations



## 1. Defining requirements

- GCOS-112
- GATNDOR

## 2. Reviewing existing instruments and choosing candidate

- tradeoff between the desirable and the feasible

## 3. Identifying and quantifying sources of uncertainty

## 4. Defining in-field recalibration and validation (QA/QC) procedures

- comparison to model prediction and redundant measurements

## 5. Data archiving and processing issues

- raw data, meta data
- more details in Michael Sommer's talk (session 8)



# GRUAN Temperature soundings

- Defining requirements:  
→ GCOS-112:

Variable	Temperature
Priority (1-4)	1
Measurement Range	170 – 350 K
Vertical Range	0 – 50 km
Vertical Resolution	0.1 km (0 to ~30 km) 0.5 km (above ~30 km)
Precision	0.2 K
Accuracy	0.1 K (troposphere) 0.2 K (stratosphere)
Long-Term Stability	0.05 K *



# RS-92 calibration



## TEMPERATURE SENSOR

Measurement range

Response time (63.2%, 6 m/s flow)

1000 hPa

100 hPa

10 hPa

Resolution

Accuracy

Total uncertainty in sounding\*

Repeatability in calibration\*\*

Reproducibility in sounding\*\*\*

1080 - 100 hPa

100 - 20 hPa

20 - 3 hPa

TYPE: CAPACITIVE WIRE

+60 °C to -90 °C

<0.4 s

<1 s

<2.5 s

0.1 °C

0.5 °C

0.15 °C

0.2 °C

0.3 °C

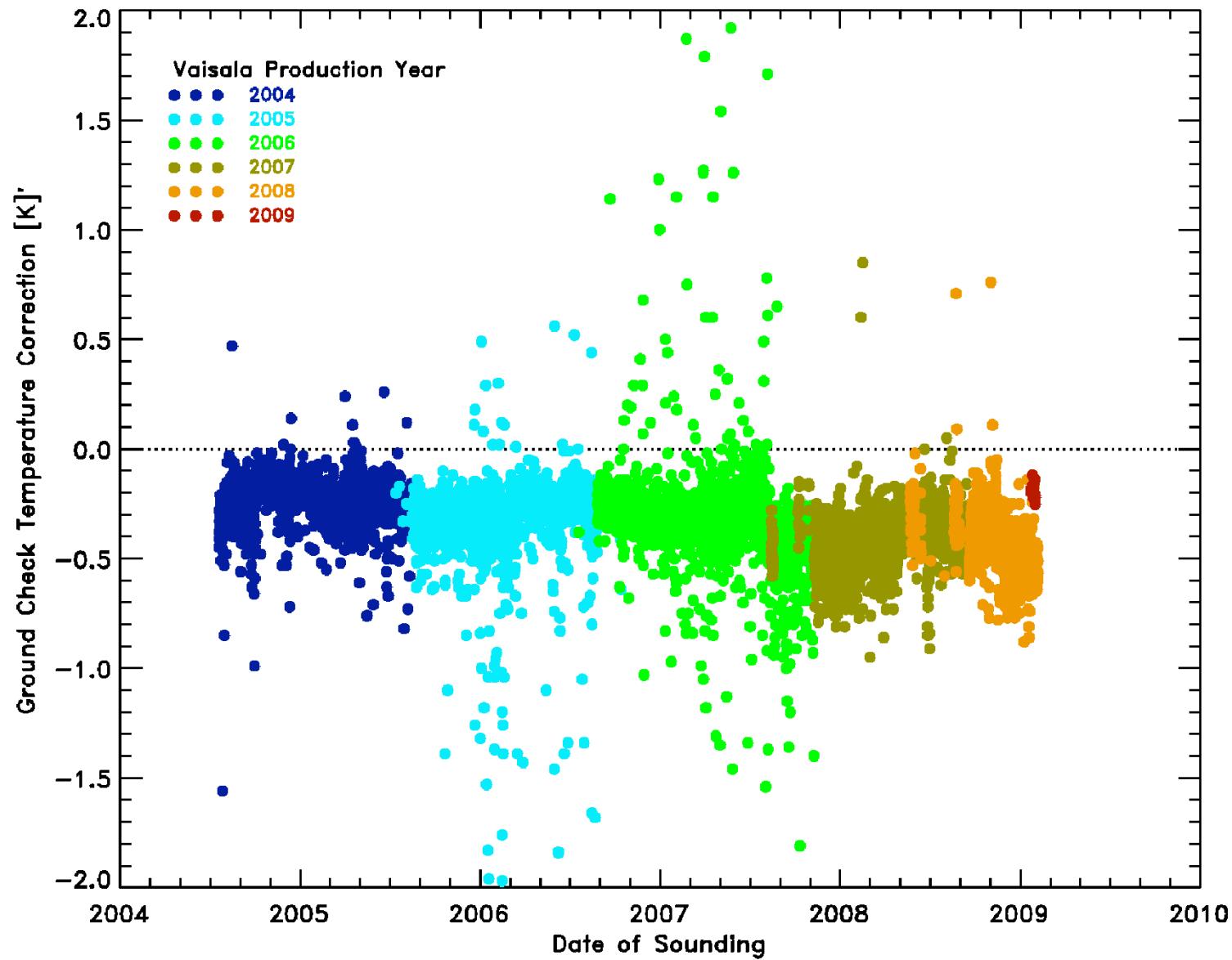
0.5 °C

# RS-92 uncertainty analysis

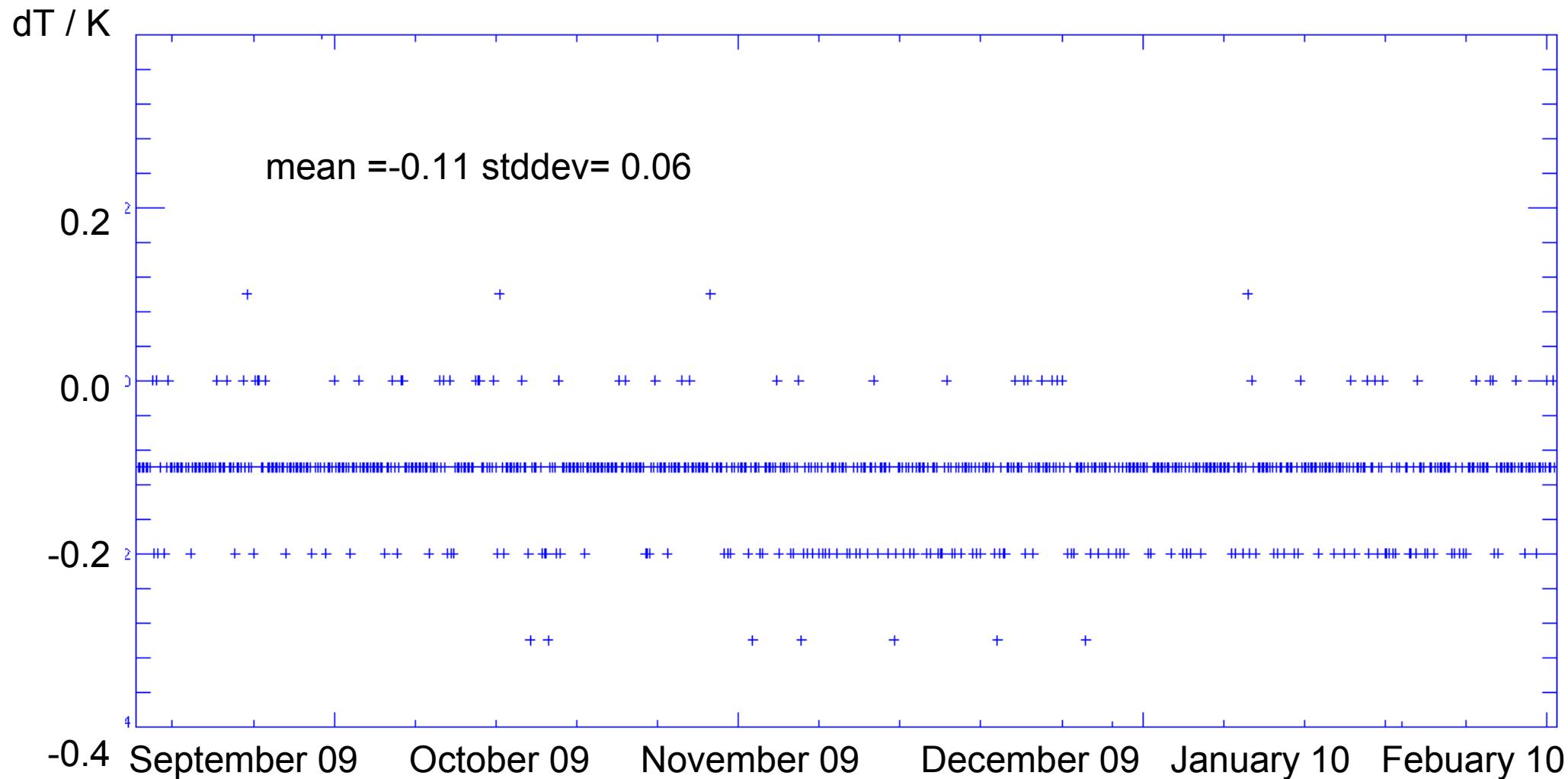
- Calibration
  - CAL4 Calibration presumably very accurate << 0.1 K
  - Ground\_check
- corrections
  - Radiation effect



# Ground check correction

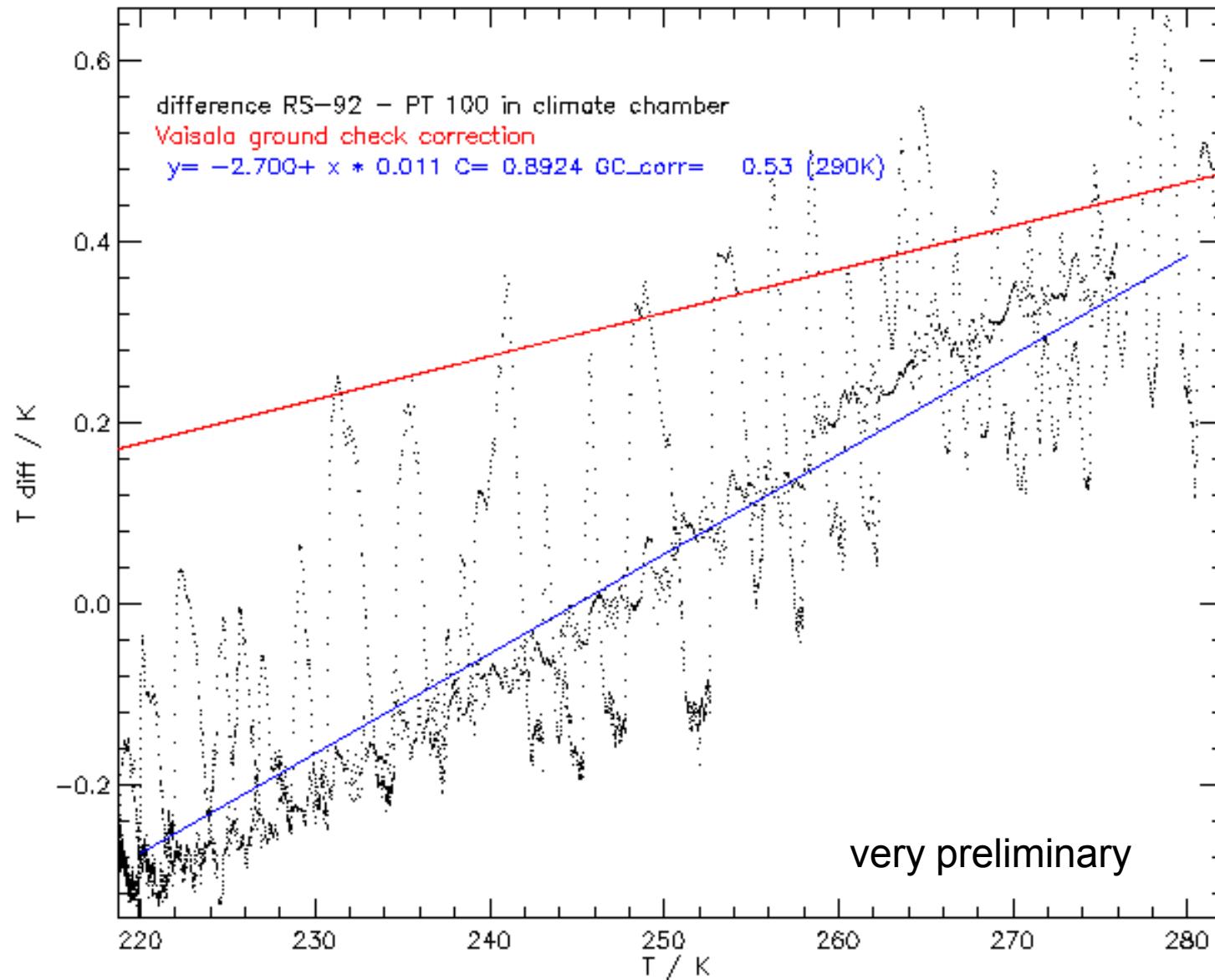


# Lindenberg additional groundcheck to certif. PT 100 Thermometer



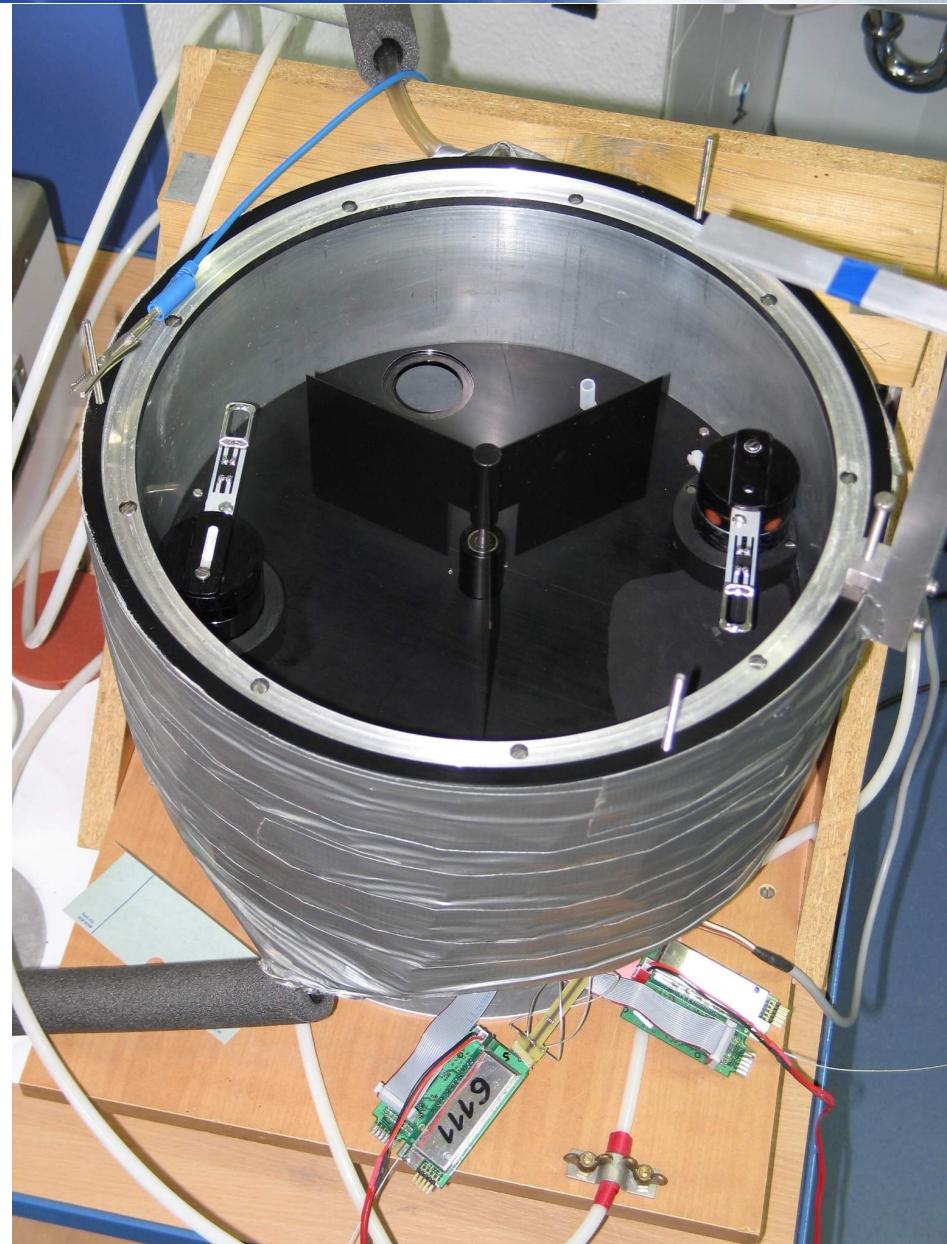


# Climate chamber calibration check



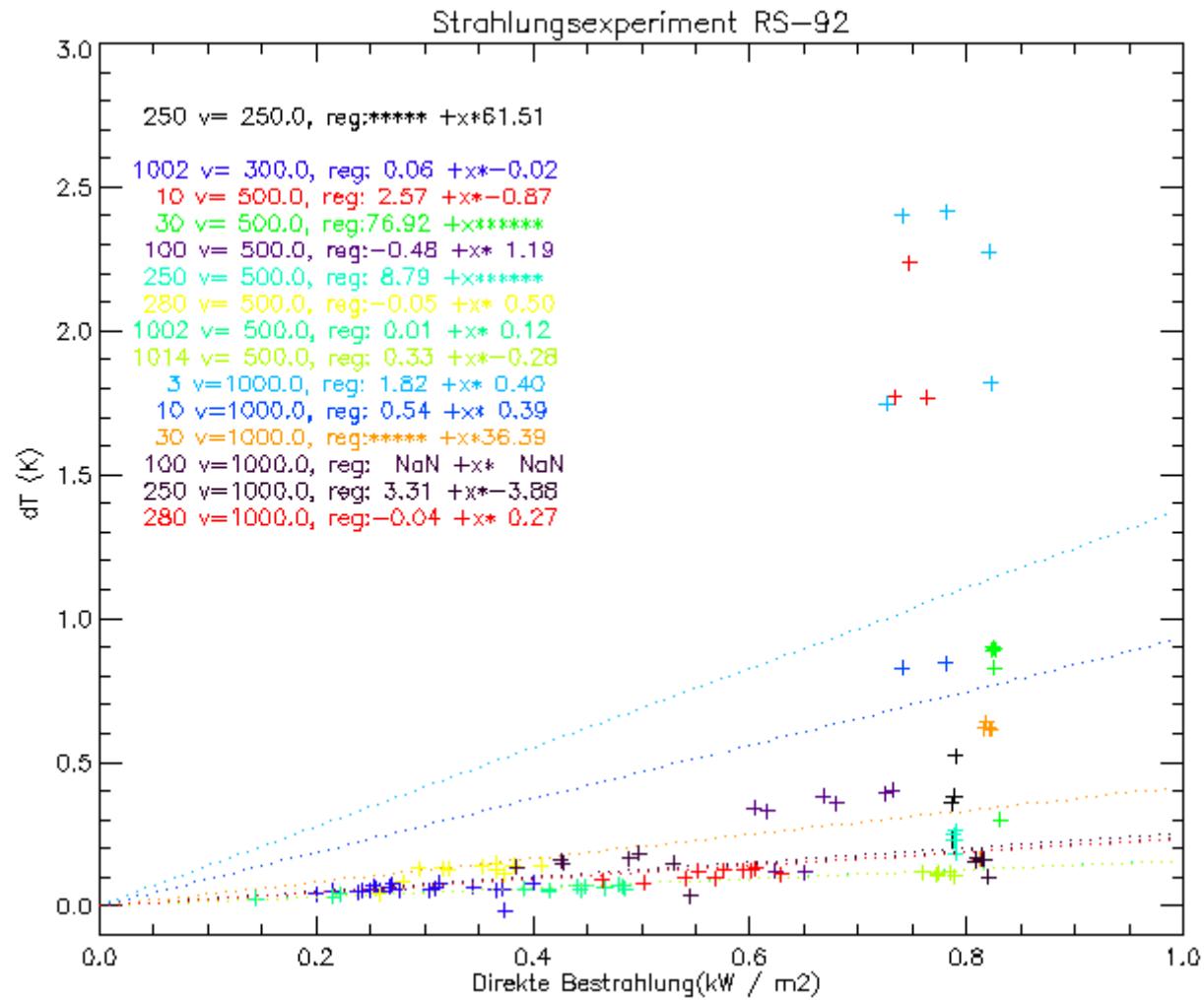
# Determination of the radiation effect

- Vacuum chamber used for measuring the radiation effect using direct sunlight.
- Radiation data of BSRN station was used.
- RS-92, DFM-06 and Imet1 sensors tested.
- Ventilation measured and varied during measurement.





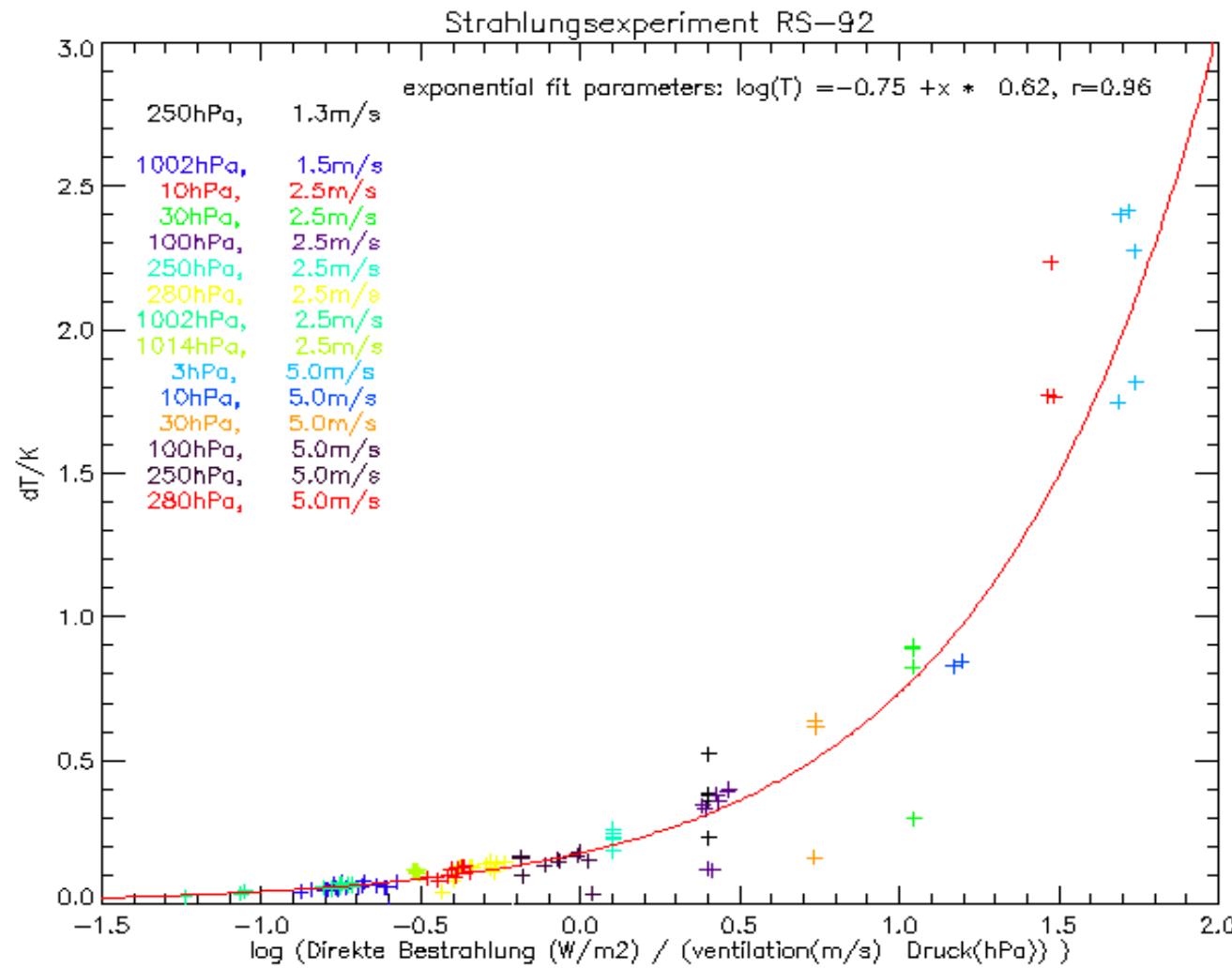
# Radiation effect on RS-92



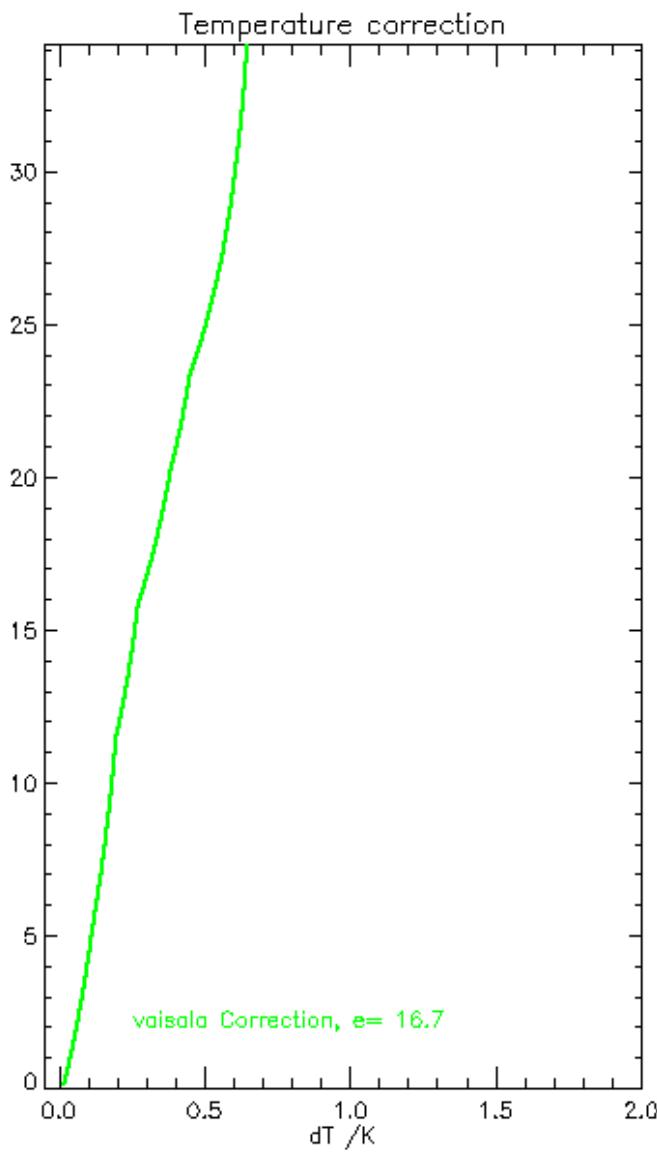
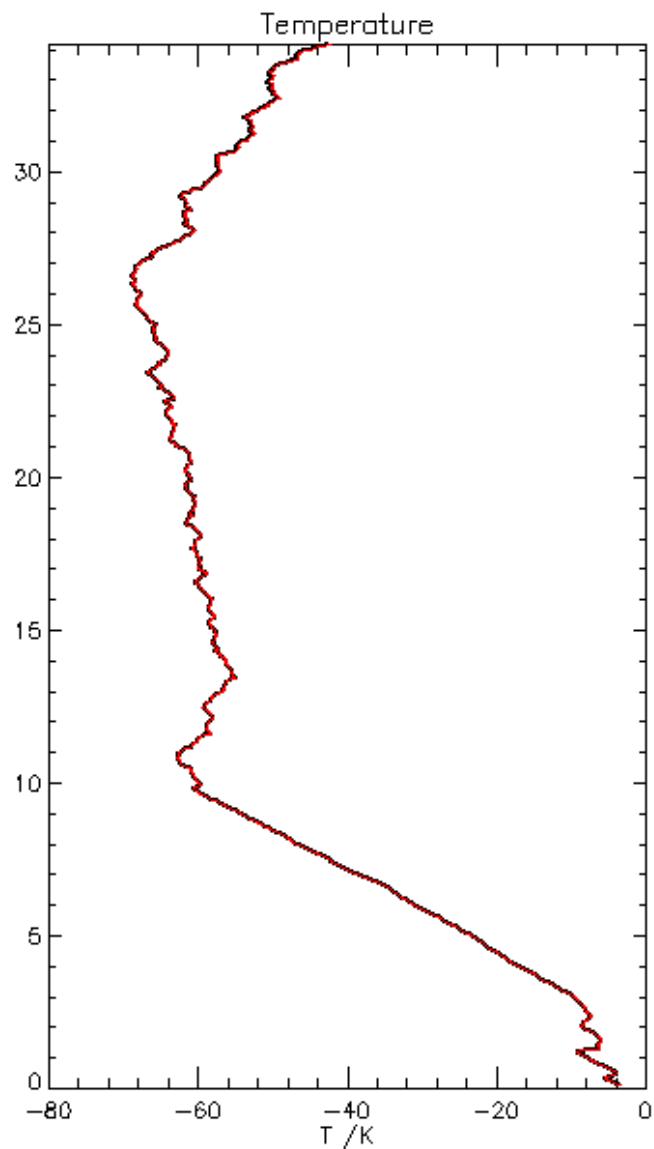


# Radiation effect on RS-92

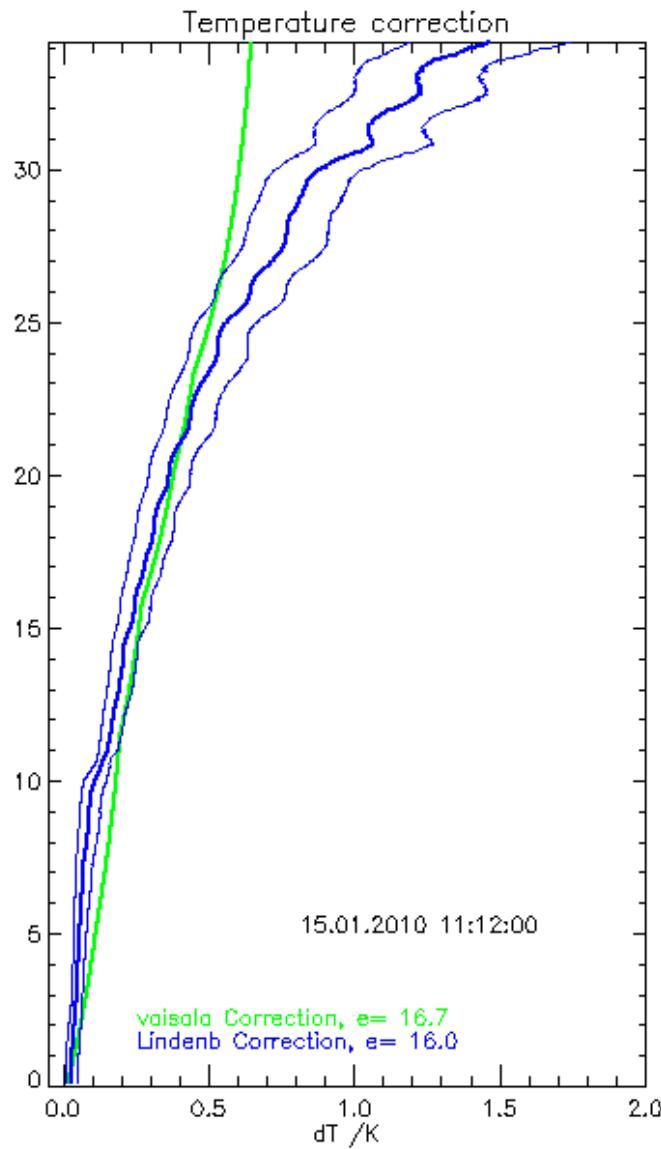
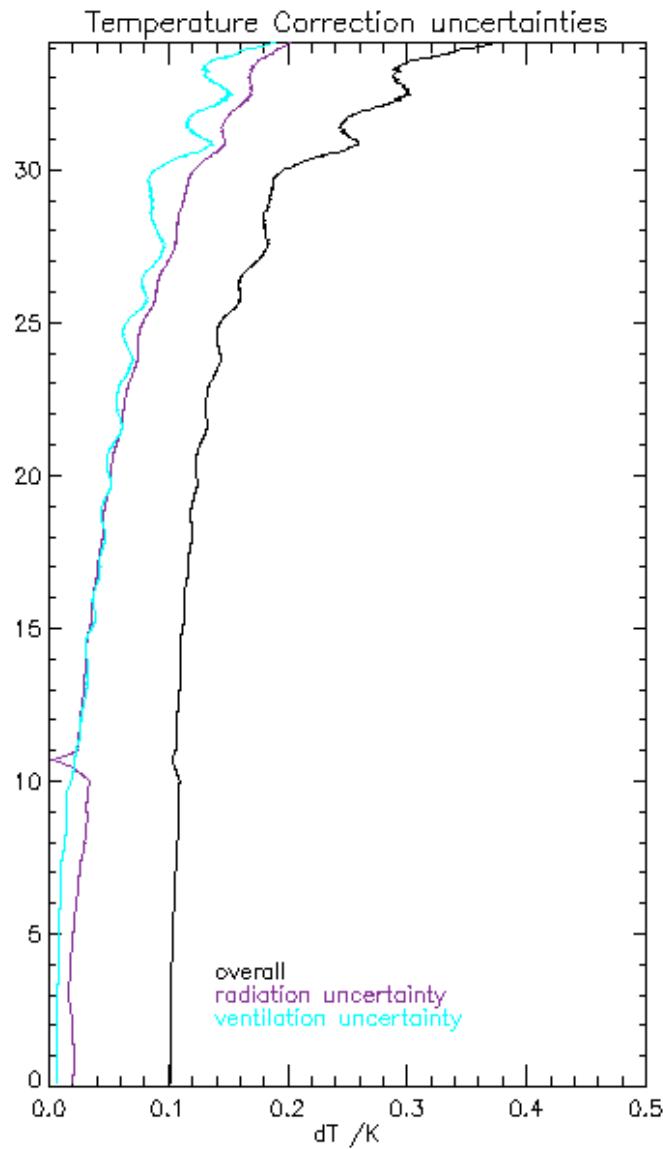
- Radiation effect is a exponential function of radiation and ventilation



# Vaisala RS-92 radiation correction

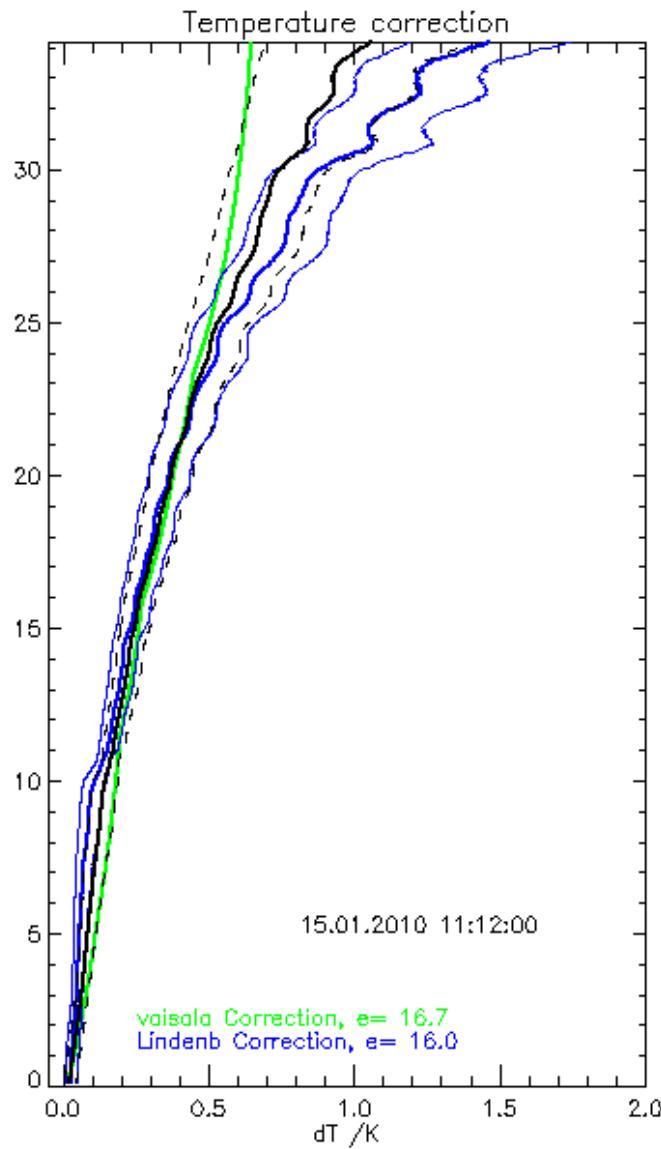
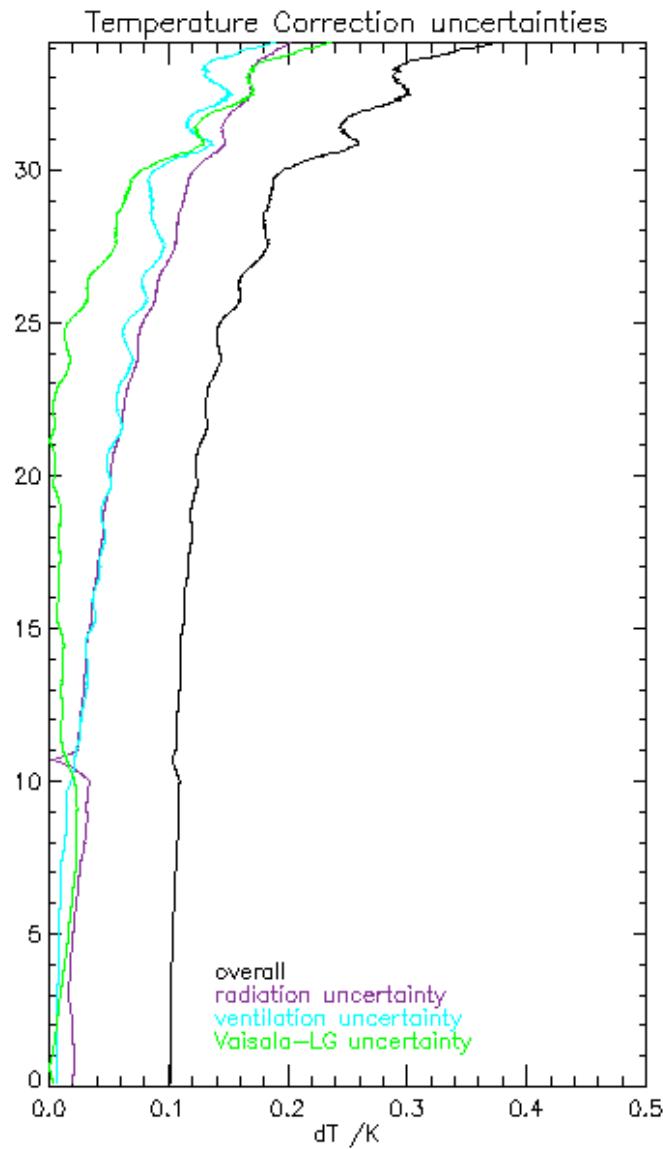


# Vaisala RS-92 radiation correction



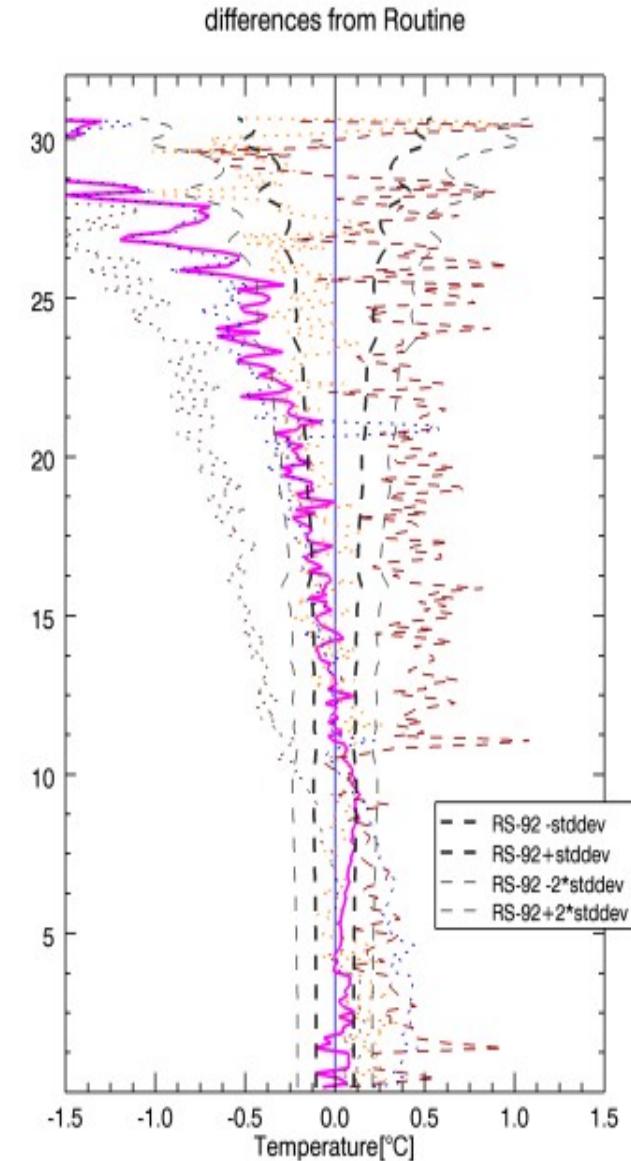
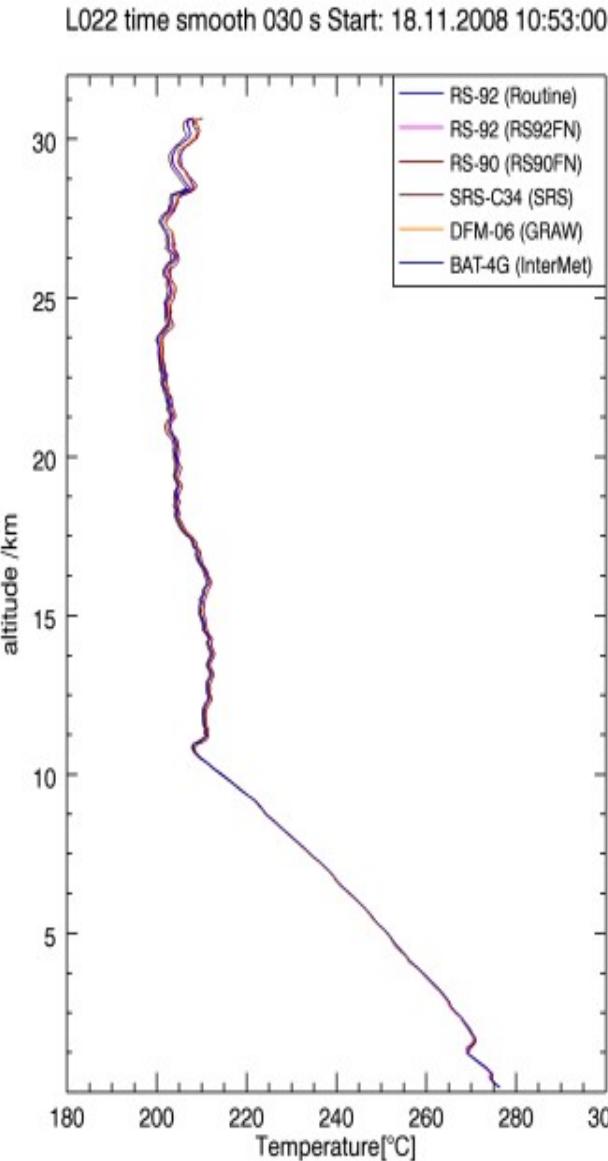


# Vaisala RS-92 radiation correction

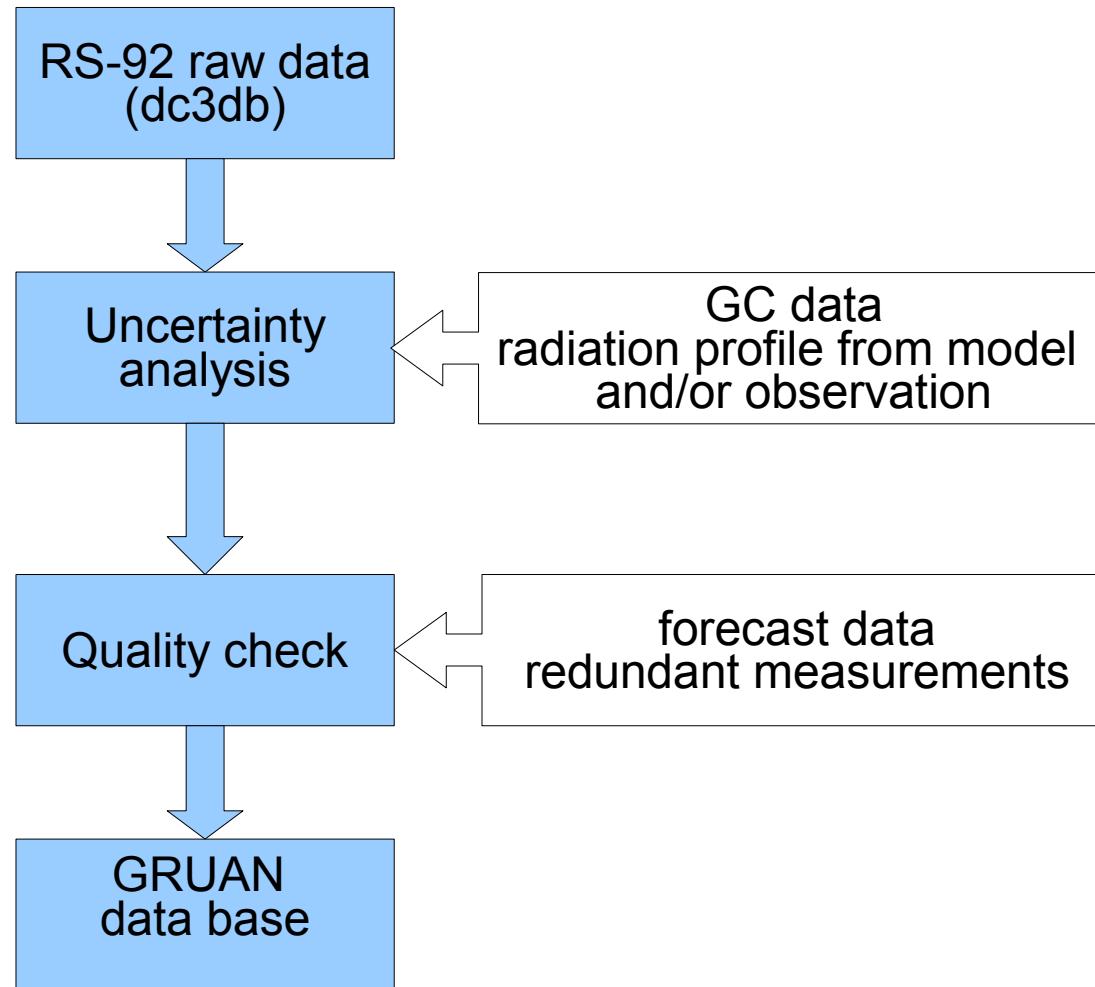




# LUAMI radiosonde intercomparison



# RS-92 Temperature data flow



# Conclusion

- Careful ground recalibration may provide accuracy of 0.1 K at room temperature
  - calibration uncertainty at lower temperatures need some more investigations still
- Radiation uncertainty small in the troposphere but significant above 25 km
  - ventilation should be considered
  - discrepancy between Vaisala and Lindeberg correction needs solving
- Uncertainty analysis for humidity data will follow soon.

# Discussion

- Reference specifications
  - SI traceability
  - Specified uncertainty
  - documentation
- Measurement Specifications for climate
  - requirements for detecting climate trends
    - accuracy
    - frequency
-

# Terminology

- metrology: the science of measurement
- measurand: quantity subject to measurement