SI TRACEABILITY OF VAISALA RADIOSONDE RS41 SOUNDING DATA – CALIBRATION AND UNCERTAINTY ANALYSIS

Petteri Survo*, Raisa Lehtinen and Jari Kauranen
Vaisala Oyj, P.O. Box 26, FI-00421 Helsinki, Finland
*e-mail: petteri.survo@vaisala.com

ABSTRACT

The need for more accurate atmospheric observations sets strong demands on the traceability of measurement results to international standards. Furthermore, a comprehensive uncertainty analysis of the measurements is imperative, for example, in order to interpret small changes in long-term data series. These challenges concern, to a great extent, in-situ upper air measurements for sounding data, which serve as reference information for satellites and other remote sensing technologies, in addition to their primary use in meteorology and climatology. Recognizing the needs described above, the aspects of traceability of calibration and uncertainty analysis of measurements have been incorporated in the design of Vaisala Radiosonde RS41.

The calibration of RS41 temperature and humidity measurements are conducted using references that are traceable to the National Institute of Standards and Technologies (NIST). Likewise, determination of temperature and humidity sensor models relies on NIST traceable references. The traceability chains were structured and the calibration and sensor model uncertainties analyzed according to recommendations of JCGM 100:2008, Evaluation of Measurement Data [1]. Moreover, the uncertainty analysis was expanded to include uncertainties due to storage and uncertainty terms arising in sounding conditions. This comprehensive uncertainty analysis of RS41sounding data is valid over a wide range of atmospheric conditions. For temperature, the considered range covers +60°C to -100°C, and for relative humidity, 0 % to saturation.

By implementing traceability of calibration references and comprehensive uncertainty analysis of sounding data, Vaisala Radiosonde RS41 supports credibility of in-situ upper air observations in general.

AIM AND METHODS OF THE WORK

According to WMO Guide to Meteorological Instruments and methods of Observation [2], traceability is based on unbroken chain of comparisons which refer back to national or international standards and have stated uncertainties. In the development of Vaisala Radiosonde RS41 traceability of temperature and humidity measurements was set as one of the main goals. Supporting this, an important task was to identify all significant sources of uncertainty in the process of producing upper air measurement data. For the uncertainty analysis the calibration phase is an evident starting point, as it links the measurements to international standards, but uncertainties were studied also in storage, sounding preparation and in actual sounding conditions.

The work resulted in an uncertainty calculation model which incorporates all identified uncertainty components from the calibration to a sounding. The model takes into account prevailing sounding conditions and calculates the effect of each individual uncertainty component to the combined uncertainty at those conditions. This approach, presented in JCGM 100:2008, gives case dependent estimates of the actual uncertainty of the measurement, making the model a valuable tool for data analysis and for development of the instrument’s performance.

The uncertainty estimates presented in this paper were obtained using algorithms of Vaisala DigiCORA® Sounding System MW41 software version 2.1. All uncertainty estimates are expressed using coverage factor k=2, encompassing approximately 95 % of the dispersion of the results.

RESULTS

Traceability and uncertainties in calibration

Traceability

Both temperature and humidity calibrations of RS41 are traceable to SI-units. For temperature calibration the reference platinum resistance thermo-meters (PRT) and the involved resistance measurements are traceable to National Institute of Standards and Technologies (NIST, USA), as illustrated in Figure 1. Likewise, for the humidity calibration the prevailing dewpoint is SI-traceable to NIST, and for the temperature information needed in relative humidity calculation the chain of traceability is similar to RS41 temperature calibration, Figure 1.

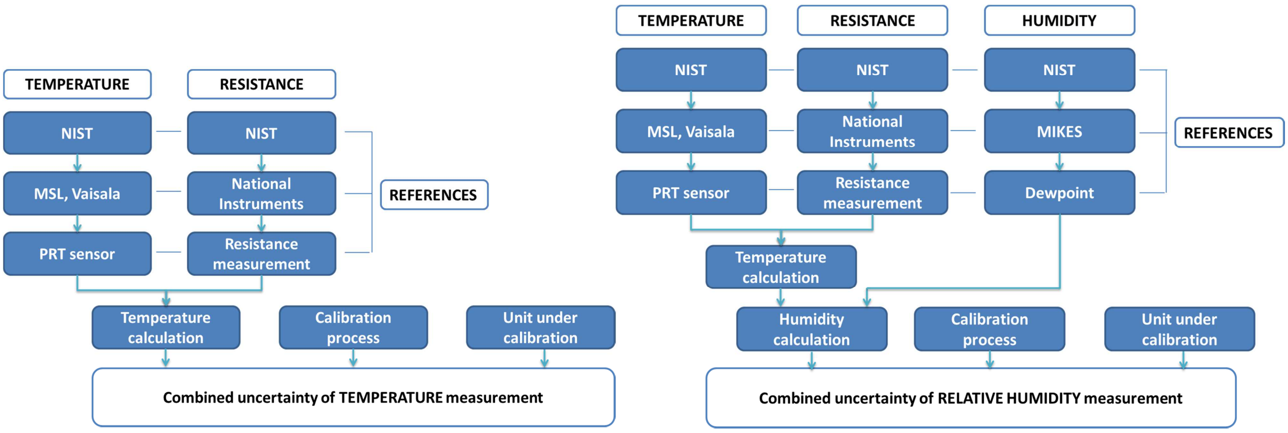

Figure 1. Chain of traceability and uncertainty components in RS41 temperature (left) and humidity (right) calibration.

Calibration uncertainties

Calibration uncertainties have been studied as part of the comprehensive uncertainty analysis of RS41 temperature and humidity measurements. As shown in Figure 1, sources of calibration uncertainties are divided into three main terms: Reference measurements, Calibration process and Radiosonde unit. For the uncertainty analysis these are further divided into sub-terms, of which some essential ones are listed below.

Reference measurements:

- Calibration uncertainty
- Linearity
- Long-term stability
- Short-term stability

Calibration process:

- Chamber homogeneity
- Long-term stability
- Short-term stability

Radiosonde units:

- Short-term stability

The combining the listed uncertainties result in temperature and humidity calibration uncertanties presented in Figure 2.

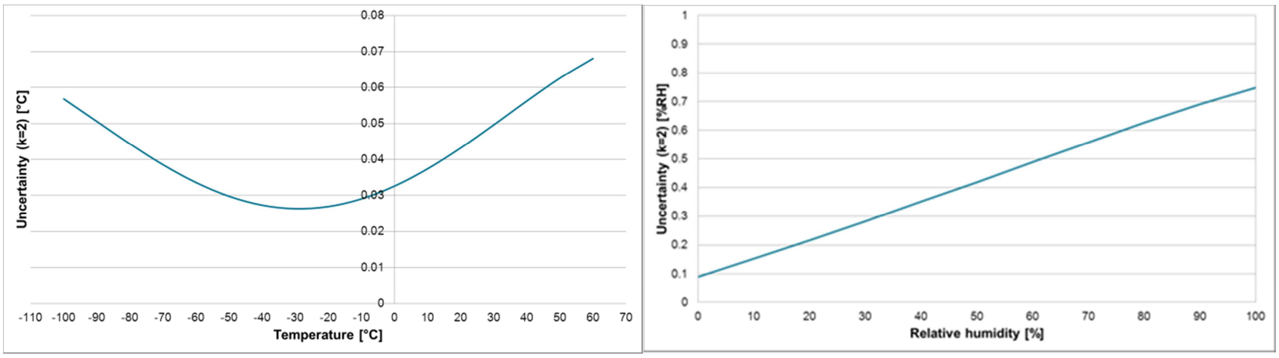

Figure 2. The calibration uncertainty (k=2) of RS41 temperature measurement (left) and humidity measurement (right).

For defining the uncertainty of the relative humidity measurement of a calibrated radiosonde unit, uncertainties of air and humidity sensor temperature readings, used in relative humidity calculations, need to be included. In a calibration situation these readings come from the temperature reference measurements, whereas for an independent radiosonde unit from its own temperature measurements. As well as the previously mentioned uncertainties, components arising from sensor model formulas also need to be taken into account in the uncertainty budget of humidity measurement. Regarding RS41, the uncertainty analysis resulted in combined uncertainties presented in Figure 3.

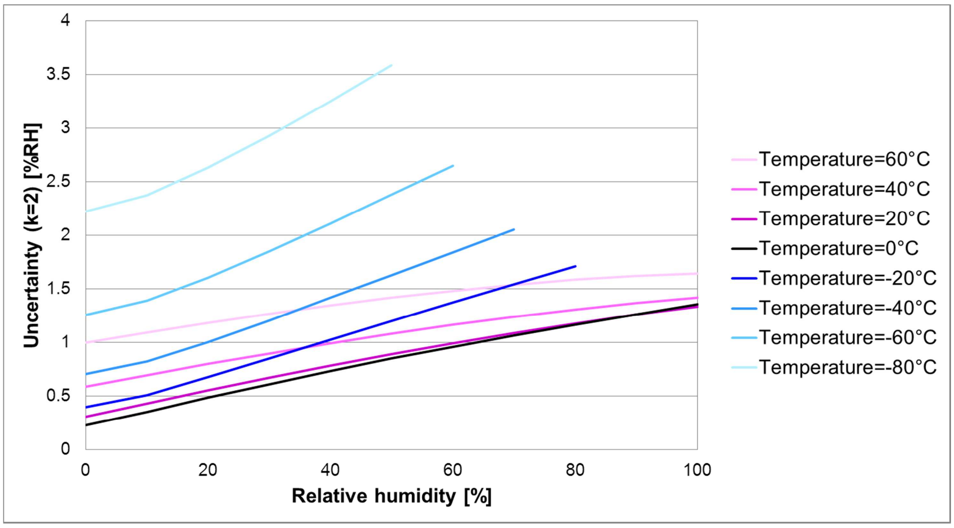

Figure 3. The combined calibration uncertainty (k=2) of RS41 humidity measurement including uncertainty components of temperature measurements and sensor model.

Uncertainty after ground preparation

The analysis of temperature and humidity measurement uncertainty after ground preparation includes all relevant uncertainty components present prior to launch. Thus, in addition to calibration uncertainties, also uncertainty terms from sensor models, storage drifts and operations in ground preparation are taken into account.

Temperature

The sensor model, in practice linearity, of the RS41 temperature measurement was investigated in a laboratory test chamber. The uncertainty of the reference temperature measurement was 0.04°C (k=2) and the studied range covered temperatures from -98°C to +39°C. According to the test results, the uncertainty related to nonlinearity of the RS41 temperature measurement is 0.05°C (k=2), and there is no systematic bias in sensor calibration. An example of the test results is presented in Figure 4.

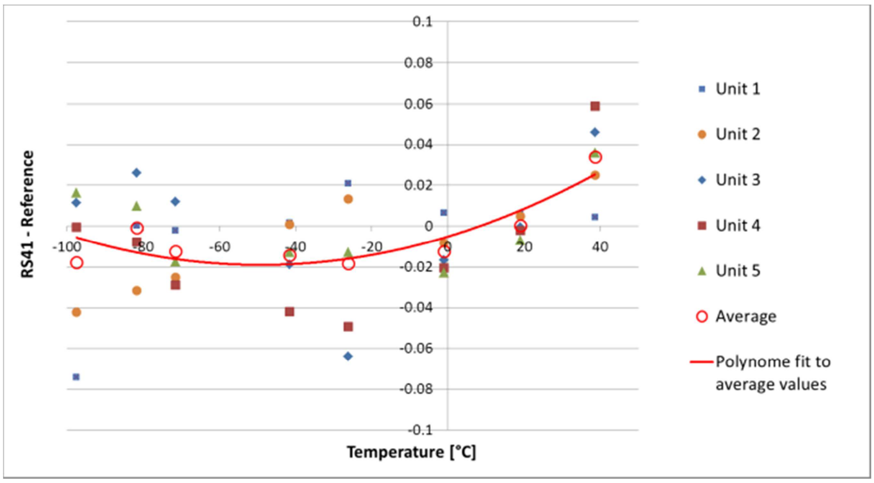

Figure 4. Typical linearity of the Vaisala Radiosonde RS41 temperatture measurement studied in a temperature test chamber.

The stability of the RS41 temperature measurement has been studied in storage tests. In the test presented here, three types of storage conditions were applied: room temperature (23°C), +40°C/90% RH, and +65°C/dry. The radiosondes were kept in their standard packages and after storage periods of two, five, and ten weeks, a set of yet untested units were unpacked and measured at a temperature of 20°C. The test results in **Figure 5** show that no systematic drift is observed during storage. Based on storage tests the estimated uncertainty related to measurement drifts is 0.06°C (k=2).

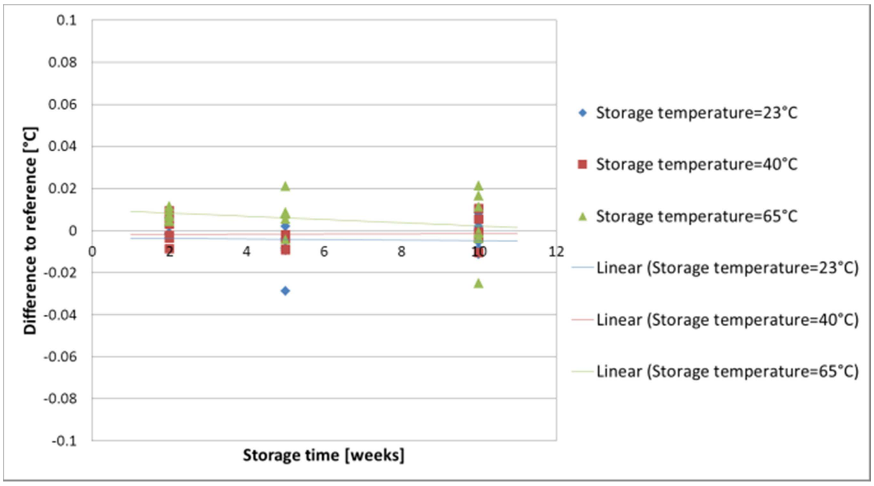

Figure 5. Stability of the RS41 temperature sensor after storage at room temperature and in accelerated storage test conditions.

Platinum resistor temperature sensors are known to be extremely stable, as demonstrated in the RS41 stability tests. Therefore a check against an external reference sensor in conjunction with sounding preparation is not necessary. For quality control purposes an inbuilt functional test, including comparison with humidity sensor temperature, is carried out during preflight preparations with a Vaisala Ground Check Device RI41. As no corrections are applied there is no need for additional uncertainty term related to ground preparation.

To assess the combined uncertainty in the Vaisala Radiosonde RS41 temperature measurement after ground preparation, the uncertainty components of the sensor model and calibration, together with uncertainties relating to storage, are taken into consideration. Uncertainty factors related to solar radiation and dynamic sounding conditions are excluded. The results of the uncertainty analysis model are shown in Figure 6.

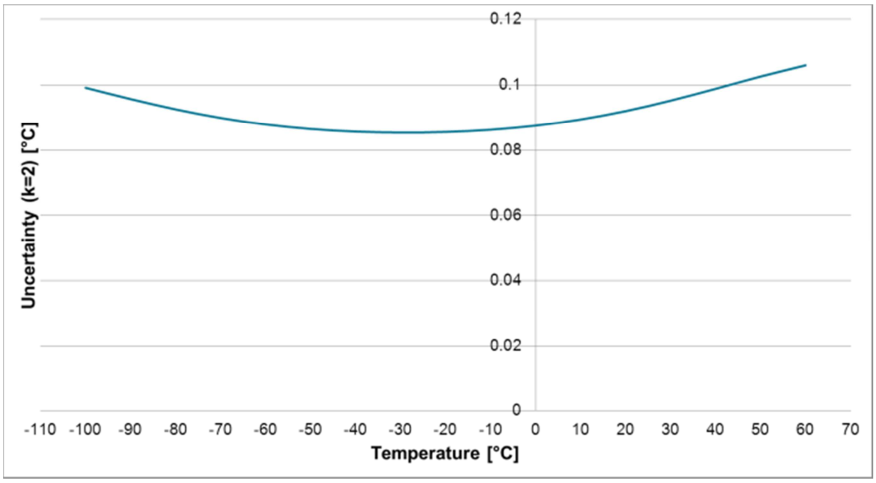

Figure 6. The combined uncertainty of the Vaisala Radiosonde RS41 temperature measurements after ground preparation (k=2).

Humidity

The stability of the RS41 humidity measurement has been studied in storage tests. In the test presented here, three types of storage conditions were applied: room temperature (23°C), +40°C/90% RH, and +65°C/dry. The radiosondes were kept in their standard packages and after storage periods of two, five, and ten weeks, a set of new units were unpacked and measured in conditions of 45% RH at a temperature of 20°C. The test results in Figure 7 show that no systematic drift is observed during storage.

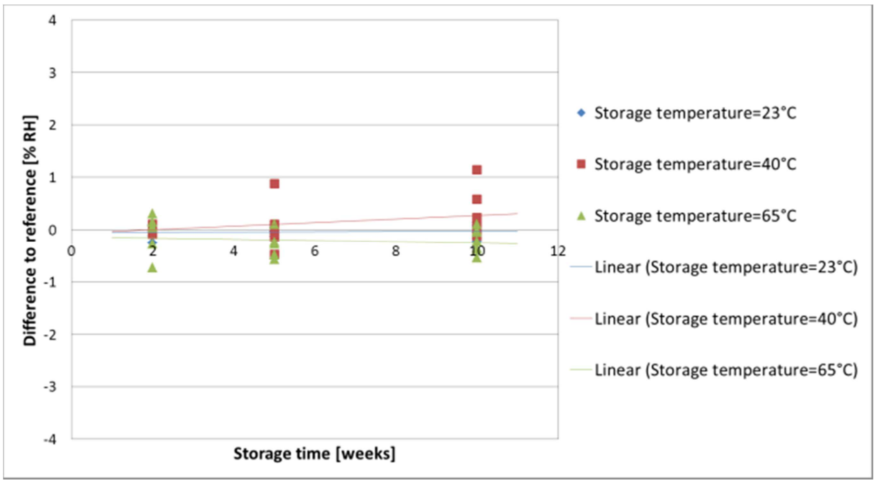

Figure 7. Stability of the RS41 humidity sensor after storage at room temperature and in accelerated storage test conditions.

During sounding preparation, reconditioning of the humidity sensor begins soon after the radiosonde is turned on. This heating phase removes possible contaminants that may affect the measurement result. When a Vaisala Ground Check Device RI41 is used in sounding preparation, an inbuilt zero humidity check is also conducted in conjunction with the reconditioning. This check detects and corrects possible offset type errors in humidity measurement. During the check a dry reference condition is generated by heating the humidity sensor. Compared to earlier radiosonde models the reliability of the correction is improved as its accuracy is no longer dependent on a measurement chamber with desiccants of limited drying capability. As a result of the two quality assurance procedures – the reconditioning and the desiccant free zero humidity check – the factory calibration of the RS41 humidity sensor is restored with good consistency. To assess the combined uncertainty in the humidity measurement of the RS41 after ground preparation, the following sources of uncertainty are taken into consideration:

- Sensor model and calibration
- Storage
- Humidity sensor temperature measurement
- Ambient temperature measurement

Uncertainty factors related to dynamic sounding conditions are excluded. The results of the uncertainty analysis model are shown in Figure 8.

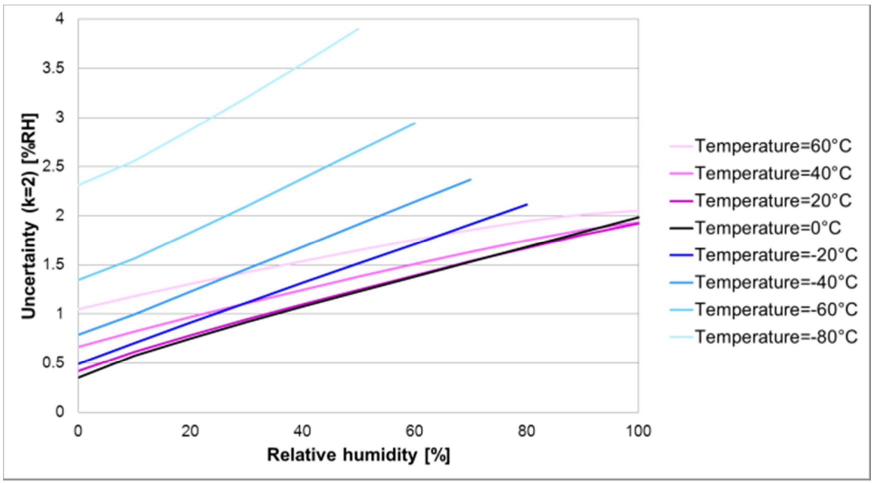

Figure 8. The combined uncertainty of the humidity measurement of the Vaisala Radiosonde RS41 after ground preparation. The humidity range is restricted by water vapor saturation at the coldest temperatures.

Uncertainty in sounding

Temperature

The impact of various uncertainty factors on temperature measurement accuracy was modeled with the specific analysis software that uses given atmospheric model and sounding specific parameters. The following parameters were chosen when assessing the performance of the Vaisala Radiosonde RS41:

- Temperature profile: U.S. Standard Atmosphere 1976
- Ascent rate: 6 m/s
- Solar angle: 60° relative to the horizon

These conditions, combining all the uncertainty components from calibration, storage, and sounding, resulted in the uncertainties presented in Figure 9. This analysis shows that uncertainty in the RS41 temperature measurement is nearly constant in the troposphere. In the stratosphere uncertainty gradually increases due to the emerging dominance of uncertainty in radiation correction.

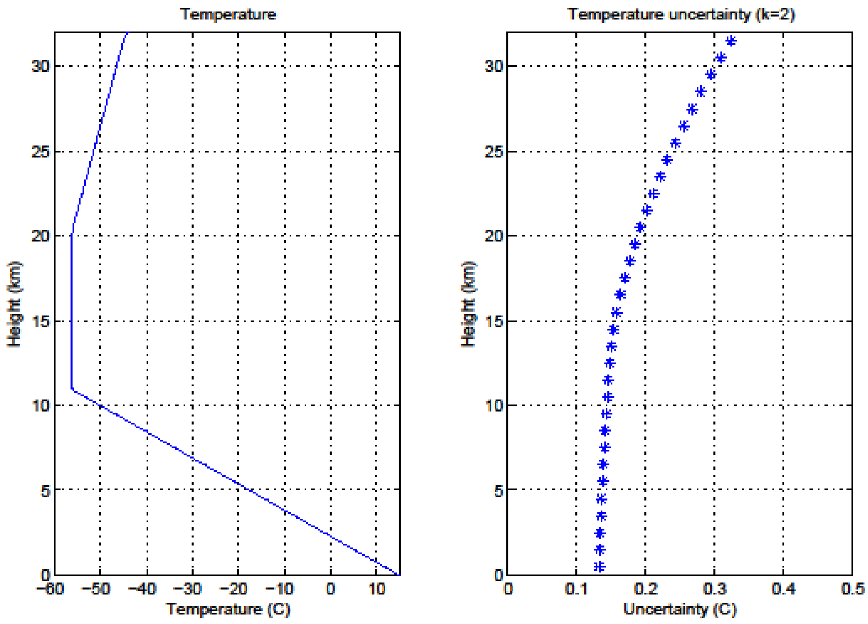

Figure 9. The combined measurement uncertainty of Vaisala Radiosonde RS41 temperature measurement (k=2). The U.S. Standard Atmosphere 1976 temperature profile used in the uncertainty analysis (left) and the resulting temperature measurement uncertainty (right).

Humidity

Also humidity measurement accuracy was modeled with the analysis software. To assess the performance of the Vaisala Radiosonde RS41 humidity measurement, the U.S. Standard Atmosphere 1976 temperature profile was chosen. For humidity, a set of five profiles was used for the troposphere: saturated humidity and an 80, 60, 40, and 20% portion of the vapor pressure of the saturated humidity. These conditions, combining all the uncertainty components from sensor model and calibration, storage, and sounding, resulted in the uncertainties presented in Figure 10. Because the equation for saturated water vapor (ITS-90 compatible form of Wexler's formula by Hardy [3]) used in relative humidity calculation involves temperature, the analysis also includes the combined uncertainty of temperature measurement discussed above.

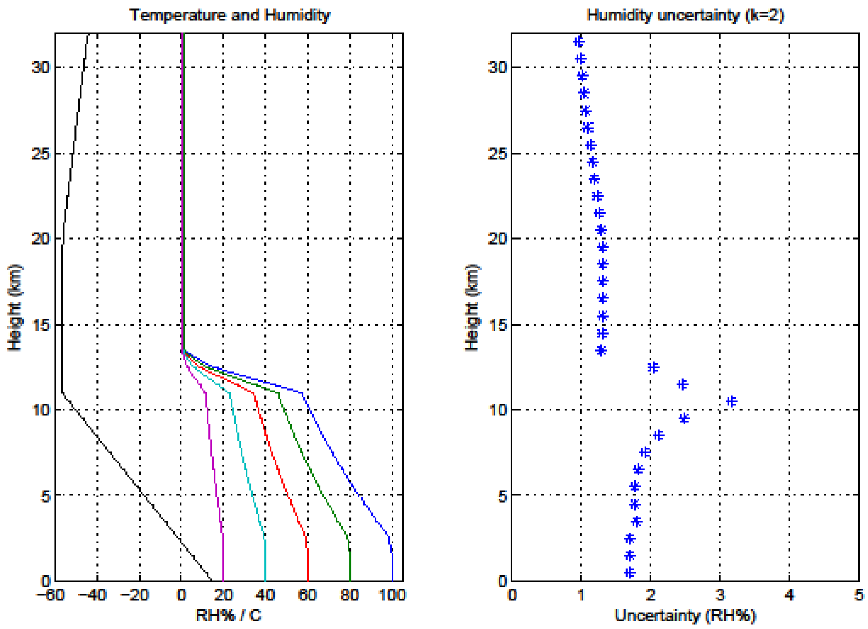

Figure 10. The combined measurement uncertainty of Vaisala Radiosonde RS41 humidity measurement (k=2). The uncertainty analysis model applied U.S. Standard Atmosphere 1976 temperature profile and a set of humidity profiles (left), and the resulting humidity measurement uncertainty (right).

CONCLUSIONS

SI traceability of an upper air observation is a sum of two elements, SI traceability of the calibration and a profound uncertainty analysis of the measurement. Regarding Vaisala Radiosonde RS41, the temperature and humidity calibrations are traceable to NIST. The comprehensive uncertainty analysis of RS41 measurements covers all phases affecting the end result: the calibration, storage, ground preparations and the actual sounding. The results of the uncertainty analysis give valuable information for several user groups of the sounding data and establish the credibility of upper air observations.

REFERENCES

[1] WG_1, 2008, Evaluation of measurement data – Guide to the expression of uncertainty in measuremen

[2] WMO Guide to meteorological instruments and methods of observation, WMO-No. 8 (2008 edition, Updated in 2010)

[3] Hardy B., ITS-90 Formulations for Vapor Pressure, Frostpoint Temperature, Dewpoint Temperature, and Enhancement Factors in the Range –100 to +100 °C, The Proceedings of the Third International Symposium on Humidity & Moisture, London, England, 1998