

6.2 THE IMPLICATIONS OF VAISALA'S NEW RADIOSONDE RS41 ON IMPROVED IN-SITU OBSERVATIONS FOR METEOROLOGICAL APPLICATIONS

Hannu Jauhiainen*, Johanna Lentonen, Petteri Survo, Raisa Lehtinen and Tomi Pietari

Vaisala, Helsinki, Finland

1. INTRODUCTION

With radiosondes temperature, humidity, pressure, wind, vertical and horizontal location can be measured in-situ up to 35 kilometers. Accurate in-situ observations provide value for many meteorological applications. Vaisala Radiosonde RS41 and Vaisala DigiCORA® Sounding System MW41, that is, the 4th generation sounding products, support these needs and requirements, and bring new possibilities for all categories of users (for example, data providers, forecasters, researchers).

Vaisala Radiosonde RS41 introduces an improved level of in-situ observation accuracy and quality. RS41 sensor technologies and state-of-the-art design and manufacturing methodologies, combined with extreme ease of use, ensure reliable and highly accurate atmospheric observations. For instance, a new humidity measurement concept allows for improvements in humidity data. In addition, a new temperature sensor delivers improved consistency and measurement accuracy throughout the measured temperature profile.

Atmospheric pressure in Vaisala Radiosonde RS41-SG is calculated with a measurement principle based on Global Positioning System (GPS). The GPS-based pressure measurement provides a high-quality end a model available with pressure sensor. A pressure sensor measurement can bring added value, for example, in research applications and climatological data series.

Corresponding author address:

Hannu Jauhiainen
Vanha Nurmijärventie 21
FI-01670 Vantaa, Finland
E-mail: hannu.jauhiainen@vaisala.com

The RS41 calibration references are traceable to International System of Units (SI units). This unbroken meteorological traceability chain to internationally recognized measurement standards, together with defined measurement accuracy over the measurement range, forms the basis for a good performance. In terms of measurement accuracy and quality, anchoring the measurement results to a known reference provides an increased level of confidence for the end users. The RS41 radiosonde performance has been well-characterized and thoroughly tested in both laboratory and environmental settings.

Good sounding observations are dependent on a high-quality, optimized sounding process. As ease of use can reduce the potential for human error, it is a key factor in the sounding process and enables consistent, high-quality observations. As a result, user-centric design methodologies have been extensively used during the development of the 4th generation products.

The RS41 measurement accuracy was evaluated using a comprehensive uncertainty analysis. A wide range of laboratory tests and several comparative test soundings were conducted. These results served as input data for estimating measurement uncertainties in a wide range of atmospheric conditions.

RS41 Radiosondes have been tested in campaigns in several locations representing different climatological conditions. Comparison test results between Vaisala RS41 and RS92 radiosondes models are presented.

In summary, this paper discusses the 4th generation sounding system, Vaisala Radiosonde RS41 and DigiCORA® Sounding System MW41, with an emphasis on the data retrieval process, improvements in data quality, and implications on observations and data continuity.

2. DEVELOPMENT BACKGROUND

Vaisala Radiosonde RS41 is a major new platform in the long continuum of the history of Vaisala radiosonde development. The first generation of Vaisala radiosondes was largely based on the innovations of Professor Vilho Väisälä, the founder of the Vaisala company. Later, the introduction of RS80 radiosonde shaped the outlook of the modern radiosonde by introducing an integrated sensor boom with small-size temperature sensor and polymer humidity sensor (Humicap®) and sensor selection with purely electrical means. The latter feature enabled radiosonde construction without any mechanical moving parts. Vaisala RS92 radiosondes introduced the thin-wire capacitive temperature sensor, silicon pressure sensor, and the heated twin sensor humidity measurement concept, capable of preventing sensor icing in freezing sounding conditions.



Figure 1: Vaisala Radiosonde RS41 is a major new platform in Vaisala radiosonde development continuum

User-centric design methodologies have been in use throughout the whole development process of the new Vaisala Radiosonde RS41 and Vaisala DigiCORA® Sounding System MW41. This has covered co-operation with several user groups in four application areas, five countries, and 17 customer groups, altogether involving more than 50 people.

The study has included discussions with the users, gathering of user requirements, field observations, usability testing, and feedback.



Figure 2: User-centric design methodologies were used in the new generation sounding system development

New technological capabilities have been utilized for the radiosonde electronics and sensor technology development. Vaisala Radiosonde RS41 introduces a new humidity measurement concept, as well as a new resistive platinum temperature sensor.

In addition to extensive laboratory testing, over 1000 test soundings were performed during the RS41 development phase.

3. VAISALA RADIOSONDE RS41

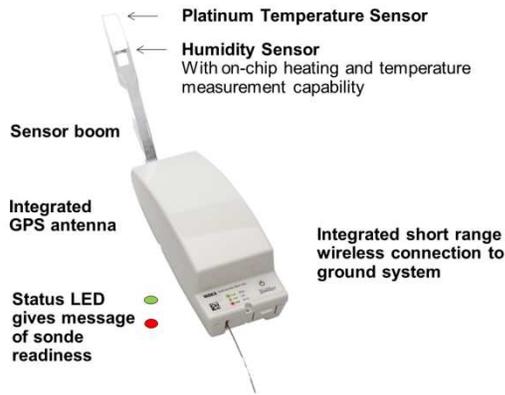


Figure 3: Vaisala Radiosonde RS41-SG

Figure 3 presents the construction of RS41-SG Radiosonde. On the top, the sensor boom serves as a support structure for the new type of platinum technology temperature sensor and a humidity sensor with integrated features. The sensor assembly is designed for the undisturbed ventilation of the sensors. For improved ruggedness, the GPS antenna is integrated to the radiosonde electronics board, residing in the radiosonde body. The radiosonde is powered with integrated batteries, contributing to automated sounding preparations.

During the preparation phase, RS41-SG gives a message of the radiosonde's readiness by green and red LED lights.

Radiosonde communication with the sounding system is implemented with a dedicated short-range wireless link. The solution increases reliability when compared with the galvanic contact currently in use in the radiosonde ground preparation phase with RS92 Radiosonde.

4. TEMPERATURE MEASUREMENT

4.1 Platinum Technology Temperature sensor

Vaisala Radiosonde RS41-SG temperature measurement relies on resistive platinum temperature sensor technology, commonly used in temperature reference measurement applications. Platinum resistor temperature sensors are characterized by linearity and excellent calibration stability. As a result,

there is no need to perform any additional calibration during the radiosonde ground preparation phase. The sensor is specifically designed for the atmospheric temperature measurement in the radiosonde application. Figure 4 presents the temperature sensor assembly. The sensor is integrated to the sensor support structure so that the measurement noise in the higher part of the atmosphere is significantly reduced compared with radiosonde RS92 design. RS41 temperature sensor also incorporates effective protection from evaporating cooling, the phenomenon encountered occasionally when a radiosonde emerges from a cloud top.

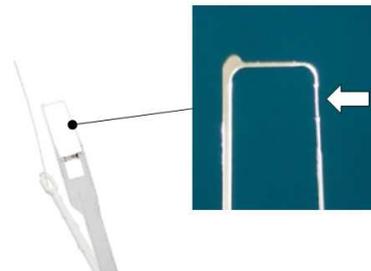


Figure 4: Vaisala Radiosonde RS41-SG temperature sensor

4.2 Temperature calibration and measurement uncertainty

In calibration of RS41 temperature measurement 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 5.

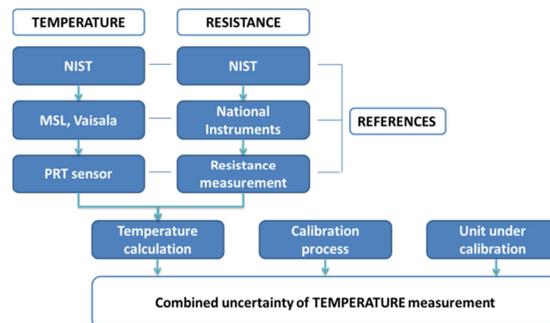


Figure 5: Chain of traceability and uncertainty components in RS41 temperature calibration.

The uncertainty analysis of RS41 Radiosonde is implemented following the recommendations of JCGM 100:2008 and it takes into account all the uncertainty terms identified in calibration, storage, ground preparation, and in dynamic sounding conditions [1],[2]. The resulting combined uncertainties of temperature measurement are presented in **Figure 6** and summarized in **Table 1**. All uncertainty estimates are expressed using coverage factor $k=2$, encompassing approximately 95 % of the dispersion of the results.

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.

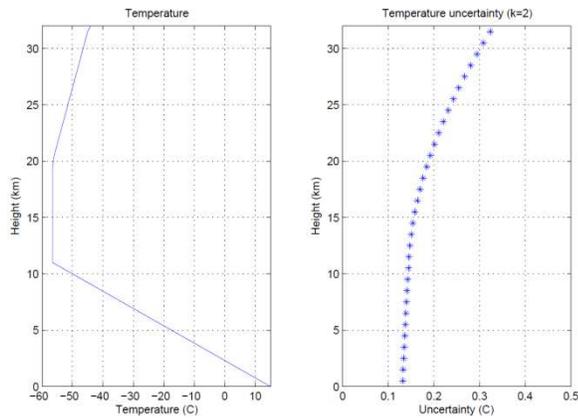


Figure 6: The combined measurement uncertainty of RS41 temperature measurement ($k=2$). The U.S. Standard Atmosphere 1976 temperature profile used in the uncertainty analysis (left) and the resulting temperature measurement uncertainty (right).

Temperature		RS41-SG	RS92-SGPD
Combined uncertainty in sounding	< 16 km	0.3 °C	0.5 °C
	> 16 km	0.4 °C	0.5 °C

Table 1: RS41 and RS92 specifications. Temperature combined uncertainty in sounding

5. HUMIDITY MEASUREMENT

5.1 RS41 Humidity sensor

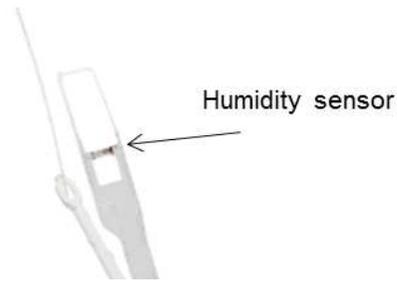


Figure 7: RS41-SG Radiosonde humidity sensor

The humidity measurement of RS41 Radiosonde is based on the capacitive Vaisala Humicap® polymer sensor technology, with optimized features for atmospheric humidity profile measurement. The sensor chip incorporates integrated heating and temperature measurement features. Firstly, the sensor heating function enables active and effective de-icing method as a radiosonde is flying through layers with freezing conditions. Secondly, by measuring the on-chip temperature the accuracy of the humidity measurement can be considerably improved. The new function can be utilized especially in the humidity measurement of upper troposphere at day time conditions. In former designs the intense solar radiation, combined with reduced ventilation at low pressures have caused additional humidity sensor heating, leading to humidity dry bias. For the RS92 Radiosonde the effect is corrected by specific solar radiation calculation SW in the ground system. While the correction gives good result, there still remains case dependent uncertainty. In RS41 the temperature of the humidity sensor is measured directly. By utilizing the temperature data of the chip as integral part of the humidity calculation the effect of solar radiation is eliminated and no radiation corrections are needed.

The heating and temperature measurement capability of humidity sensor are also utilized during radiosonde ground preparation phase for humidity sensor reconditioning and ground checking.

5.2 Humidity calibration and measurement uncertainty

In calibration of RS41 humidity measurement the reference platinum resistance thermo-meters (PRT) and the involved resistance measurements as well as the prevailing dewpoint are traceable to National Institute of Standards and Technologies (NIST, USA), as illustrated in **Figure 8**.

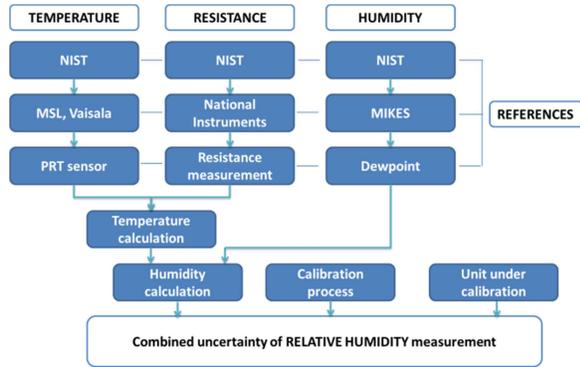


Figure 8: Chain of traceability and uncertainty components in RS41 humidity calibration.

Uncertainties of RS41 humidity measurement have been carefully analyzed taking into account all the uncertainty terms identified in calibration, storage, ground preparation, and in dynamic sounding conditions. The resulting combined uncertainties of humidity measurement are presented in **Figure 9**. and summarized in **Table 2**.

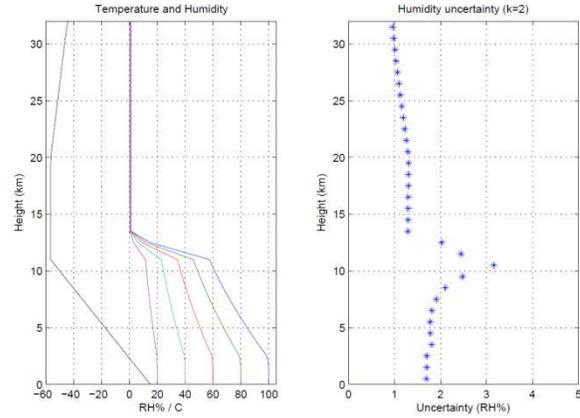


Figure 9: The combined measurement uncertainty of RS41 humidity measurement ($k=2$). The uncertainty analysis model applied U.S. Standard Atmosphere 1976 temperature profile and a set of humidity profiles (left), and the resulting humidity measurement uncertainty (right).

Humidity	RS41-SG	RS92-SGPD
Combined uncertainty in sounding	4 %RH	5 %RH

Table 2: RS41 and RS92 specifications. Humidity combined uncertainty in sounding

6. DigiCORA® SOUNDING SYSTEM MW41



Figure 10: DigiCORA® Sounding System MW41

Vaisala Radiosonde RS41 is used with DigiCORA® Sounding System MW41. The sounding system consists of Sounding Processing Subsystem SPS311, a workstation running the DigiCORA® Sounding System software, and Ground Check Device RI41. The installation also includes antennas for the radiosonde signal and local GPS receiving. Sounding System MW41 can be connected to Vaisala Automatic Weather Stations (AWS), which provide surface weather information automatically, simplifying sounding operations and reducing human error.

The key characteristics of the system are such as easy-to-use user interface, comprehensive diagnostics, real-time remote access, and versatile reporting options.

The MW41 user interface is based on a web browser. The interface is designed to be intuitive and easy to navigate. This can be exploited for reducing human error, as well as reducing operator training time. **Figures 11** and **12** present examples of the user interface with a visually-guided station setup and radiosonde preparation window.

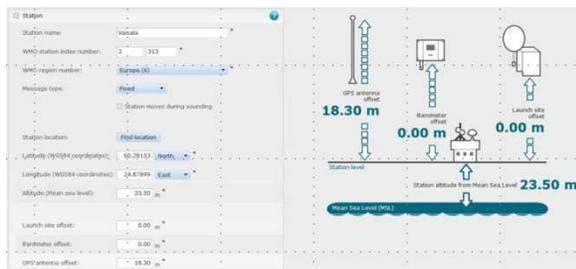


Figure 11: MW41 user interface - visually-guided station setup

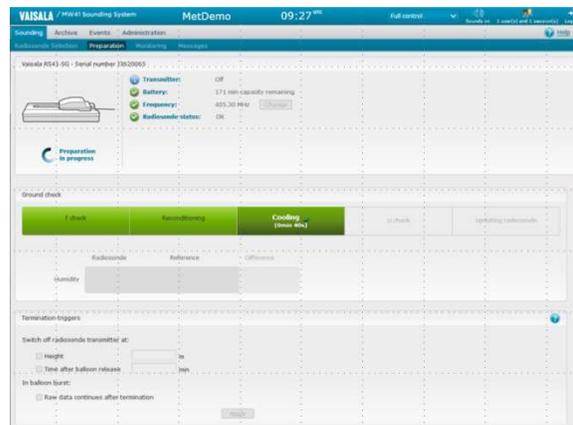


Figure 12: MW41 user interface - Radiosonde RS41 preparation window

The generation of meteorological messages in MW41 follows the latest WMO regulations, including TEMP, PILOT and BUFR coding. For specific purposes the data is also available in XML format. In addition, easy to use report templates can be used for creating customer-specific data outputs. Furthermore, Python scripting capability offers an option for even more intense sounding data utilization.

One of the key advantages of the DigiCORA® Sounding System MW41 is the capability to transfer the control of the system to a specified location. Such a configuration is presented in **Figure 13**. For example, configuring of the systems can be made remotely. As another example, a radiosonde can be released at a launch site, but the control of the rest of the sounding and reporting can be changed to the central observatory. In addition to above MW41 gives ability to monitor and retrieve real-time sounding data in graphical and numerical format from a remote location, either through a local area network, or internet.

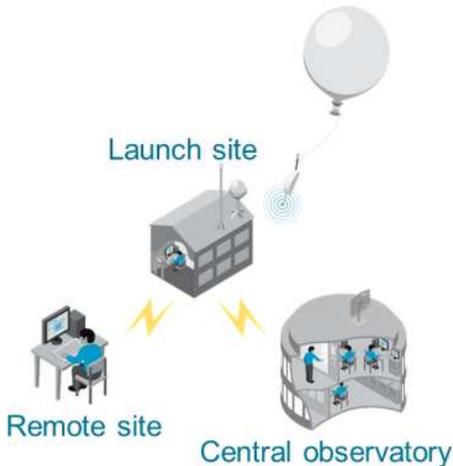


Figure 13: Remote access to DigiCORA® Sounding System MW41

7. RS41 RADIOSONDE PREPARATION WITH GROUND CHECK DEVICE RI41

New Ground Check Device RI41 is used in RS41 Radiosonde ground preparations. The procedure has been simplified with wireless communication and low-maintenance design with no drying desiccant material, nor temperature reference sensor. **Figure 14** presents Ground Check Device RI41 with Radiosonde RS41.

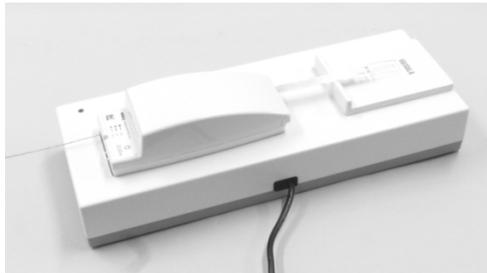


Figure 14: Ground Check Device RI41 with Radiosonde RS41

When sounding preparations are started, the MW41 user interface instructs the operator to place the radiosonde on RI41. The radiosonde starts to communicate with MW41 software through the short range wireless connection interface enabled by RI41. All preparation phases from now on are performed automatically. In the first phase, the radiosonde humidity sensor is heated to elevated temperature.

This is to remove any residual chemical contamination that might have occurred during transportation, thus purifying the sensor for accurate humidity measurement. In the next phase, the sensor is heated for the zero humidity reference measurement and corresponding calibration fine-tuning. The method enables an accurate and maintenance-free dry reference, and is a clear improvement compared with the previous method with RS92, which relied on drying desiccant beads as the low-humidity reference. The desiccant tends to moisten over time and needs to be replaced regularly. If the operation conditions are very humid and the interval of changing the desiccant is long, this may lead to errors in %RH humidity measurement. With the heated physical zero method, the residual humidity corrections are typically in the order of some tenths of %RH.

In addition to several electrical checks the temperature element of the humidity sensor is used to accomplish check against RS41 temperature sensor giving additional confidence and redundancy for functional check during in-built functional temperature check. No temperature calibration fine-tuning is performed during the ground check.

During radiosonde ground preparations, the radiosonde transmitter frequency is set to the predefined value automatically. If needed, the frequency can be changed during the preparation phase. Furthermore, it is possible to program the radiosonde to stop signal transmission at a predefined altitude, pressure, or time.

8. TEST FLIGHT CAMPAIGNS

Radiosonde RS41 has been tested in sounding test campaigns in several locations representing different climatological conditions. Test campaigns have been performed in

- Vantaa, Finland
- FMI Jokioinen, Finland
- Penang, Malaysia
- CHMI, Libus, Czech Republic
- UK Met Office, Camborne, UK

In addition, a large number of concept-level and R&D soundings have been made in various locations in Finland, USA, and Australia.

Figure 15 shows a commonly used test rig, which carries four radiosondes, two RS41s and two RS92s. The setup enables a direct difference comparison between the RS41 and RS92 radiosonde models, and a characterization of radiosonde type-related reproducibility, by performing an RS41-RS41 and RS92-RS92 comparison. In some test soundings the test rig included additional independent reference instruments.



Figure 15: Test rig at CHMI Libus

9. TEMPERATURE MEASUREMENT RESULTS

The most recent large-scale RS41/RS92 sounding test campaign was performed in Camborne, UK, in November 2013. 30 ascents, with four radiosondes each, two RS92s and two RS41s, were launched from the Met Office radiosonde station in Camborne during November 2013. The RS92 software and model versions were the same as those used in the WMO intercomparison of high quality radiosonde systems, Yangjuang, China, 2010 [3] and the design of the trial followed the methodology of WMO intercomparisons. The following presents some characteristic results from the data set. In addition, the UK Met Office has

provided a scientifically independent report [4] from the data produced by the trial.

9.1 Temperature Reproducibility, Night Time

Figure 16 presents a night time sounding example of temperature differences between four radiosondes, RS41, RS41_2, RS92, and RS92_2. For the analysis, RS41 was used as a reference. During the 90 minutes flight the balloon reached an altitude of about 32 kilometers. Throughout the flight the difference between the two RS41 Radiosondes was generally within 0.03 °C, not exceeding 0.1 °C at any second in this sounding. Result for RS92 radiosondes show also good agreement but with less precision than RS41 at lower altitudes.

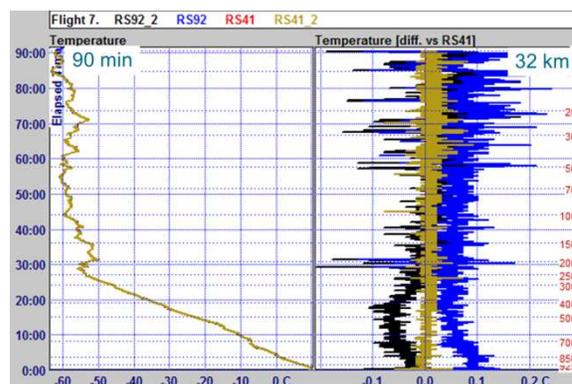


Figure 16: Night time sounding example, Camborne test

Statistics for RS41-RS41 and RS92-RS92 pairs in ten night time soundings is presented in **Figures 17** and **18**. Standard deviation between differences for RS41-RS41 pairs at 30 km is 0.025 °C and at 10 km 0.015 °C. This is about 60% of the deviation for RS92.

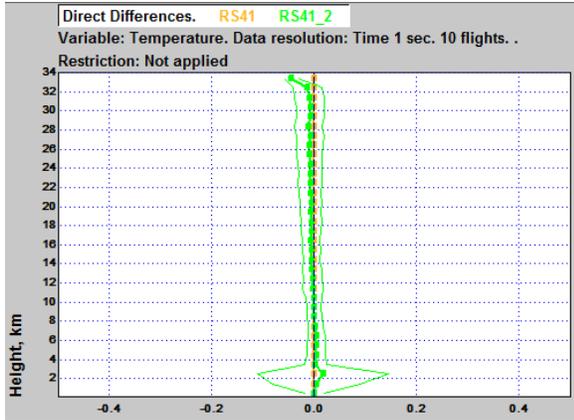


Figure 17: RS41 direct differences and standard deviation, night time, Camborne test. The average difference between the two RS41 radiosondes is indicated by the bold line and the standard deviation of difference by the thin lines.

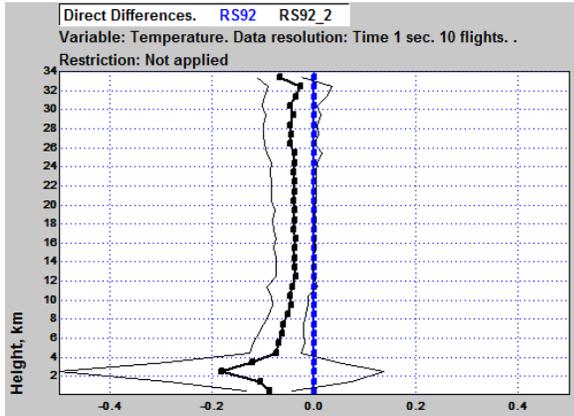


Figure 18: RS92 direct differences and standard deviation, night time, Camborne test

9,2 Temperature reproducibility, daytime

During the day time the temperature sensor is prone to intense solar radiation in a thin air at high altitudes, causing sensor heating. This solar radiation error is compensated by mathematical means in the ground system calculation. In spite of the compensation the residual uncertainty and deviation of the measurement remains higher than at night time conditions.

Figures 19 and **20** show results of RS41 and RS92 temperature measurement reproducibility of 20 soundings. For both radiosondes the deviation increases at higher altitudes. This is due to the increased solar radiation effect. At 30 km altitude RS41 demonstrates improved measurement reproducibility, about two thirds of what is measured with RS92. At lower altitudes the relative difference is bigger, the reproducibility of RS41 being about one third of what is measured with RS92.

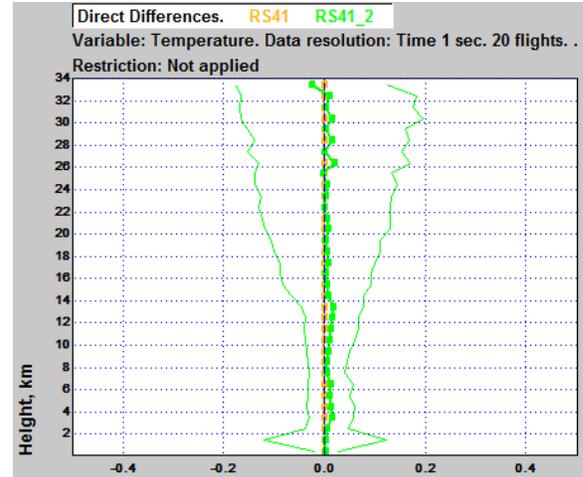


Figure 19: RS41 direct differences and standard deviation, day time, Camborne test

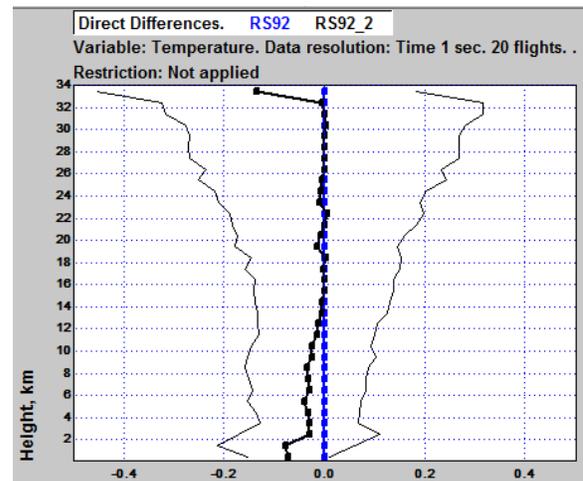


Figure 20: RS92 direct differences and standard deviation, day time, Camborne test

9.3 Temperature direct differences, RS92-RS41

Direct differences of temperatures between RS41 and RS92 radiosondes were compared of 10 night time soundings and 20 day time soundings. **Figure 21** presents the differences calculated from the night time soundings. RS41 data serves as a reference. Difference between two RS41 radiosondes RS41_1 and RS41_2 are very small. RS92 radiosondes deviate from RS41 and from each other a bit more, differences being typically less than 0.05 C and at low cloud region less than 0.2 C.

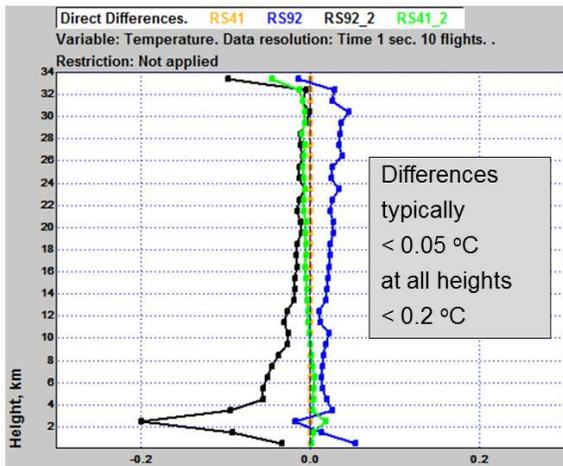


Figure 21: RS92-RS41 direct differences, night time, Camborne

Figure 22 presents the mean direct differences of 20 soundings at day time conditions. At day time the direct differences between RS41 and RS92 radiosondes were typically less than 0.1 C.

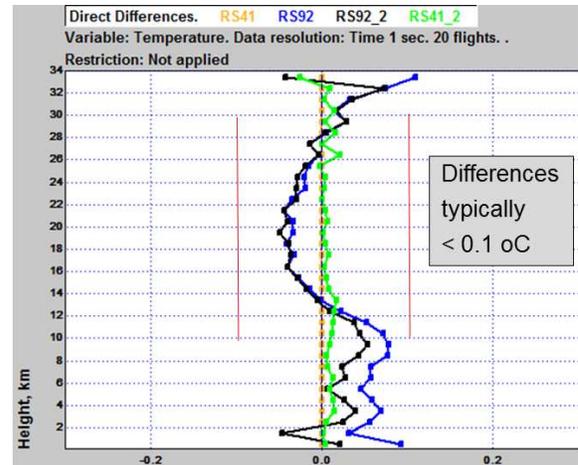


Figure 22: RS92-RS41 direct differences, day time, Camborne

Temperature measurement results in the Camborne test are well aligned with the results of the test performed in CHMI, Libus, Czech Republic, during fall 2013, [5]. In this test, the direct differences in day time were higher than at night, but still lower than 0.2 °C. At night, the standard deviation in temperature was from 0.02 to 0.09 °C for both types of radiosondes. Day time standard deviations progressed from 0.02 on surface up to 0.2 °C in 34 km for RS41 radiosonde, and from 0.08 to 0.4 for the RS92 radiosonde. At all heights RS41 standard deviation varied between 50-70% compared with the standard deviation of RS92.

In tropics environment the average temperature differences between RS41 Radiosonde and RS92 Radiosonde in day time were < 0.2 °C and in night time < 0.1 °C. Both day and night time the reproducibility of RS41 Radiosonde was at lower level compared to RS92 [5]

10. HUMIDITY MEASUREMENT RESULTS

Sounding campaigns for RS41/RS92 comparison have been conducted in various climatological conditions. For radiosonde humidity measurement testing tropical atmosphere offers probably the most challenging environment covering a wide range in water vapour pressure, in temperature, and in solar radiation. For this reason the results discussed here are mostly from the tropics.

10.1 Humidity night time direct differences, RS92-RS41

In tropical night-time soundings the detected differences have been < 2.5 %RH (**Figure 23**), [6]. Test results at higher latitude soundings have shown RS41 – RS92 differences of $< 1 - 2$ %RH at night-time soundings.

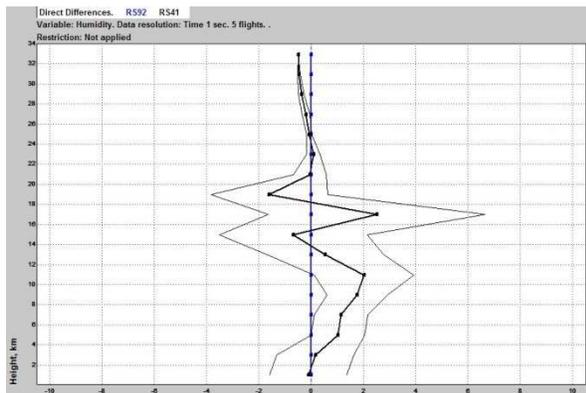


Figure 23: RS92-RS41 direct differences, night-time, tropics

10.2 Humidity daytime direct differences, RS92-RS41

Test results at higher latitude soundings have shown RS41 – RS92 differences of < 2 %RH at day time. Largest difference between RS41 and RS92 humidity measurement can be seen in tropical day time conditions. **Figure 24** presents direct difference mean result of ten soundings, with RS41 as a reference. At tropopause region at 17 km, RS41 measured about 5%RH higher relative humidity when compared to RS92.

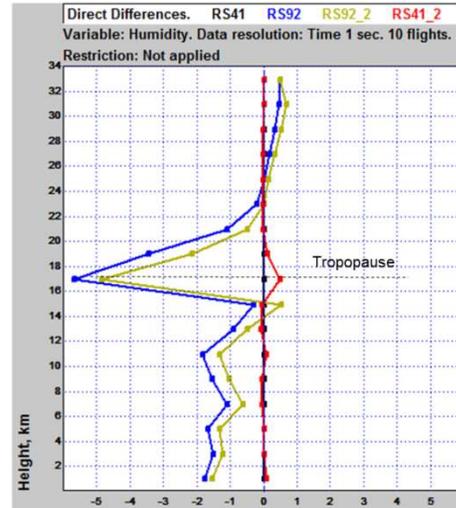


Figure 24: RS92-RS41 direct differences, day time, tropics

Figure 25 shows a sounding example from Malaysia at lat. 5° N. In lower altitudes RS41 and RS92 measures humidity details with good agreement. However, at altitudes above 16.3 km RS41 shows 10 – 15 %RH higher relative humidity values. The difference is largely due to dissimilar approaches in compensating the heating effect of solar radiation on humidity sensor. RS92 Radiosonde relies on SW-correction, whereas in RS41 Radiosonde the measurement of actual humidity sensor temperature produces accurate humidity result directly, without a need for SW-based solar radiation correction.

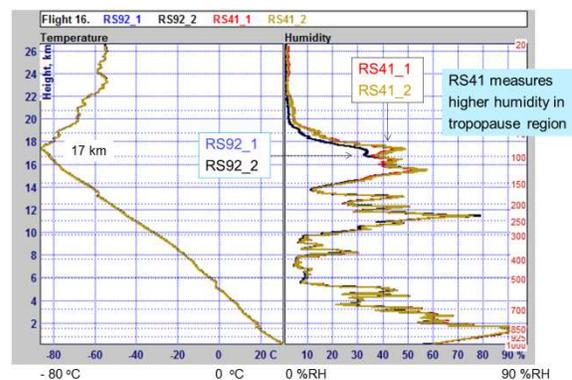


Figure 25: Tropical sounding profile elaborating differences in humidity measurements of RS92 and RS41.

10.3 RS41 Humidity measurement against Cryogenic Frostpoint Hygrometer CFH

RS41 Radiosonde humidity measurement has also been tested against independent external reference. As an example, **Figure 26** presents and a sounding test result from Malaysia.

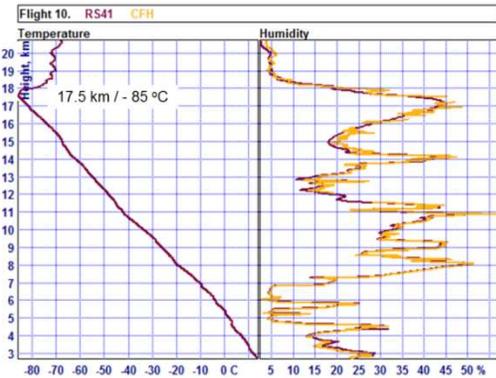


Figure 26: RS41 humidity measurement against Cryogenic Frostpoint Hygrometer (CFH).

10.4 Humidity reproducibility

Statistics for RS41-RS41 night-time and day time soundings in tropics are presented in **Figures 27** and **28**. For both night-time and daytime the measurement reproducibility remains below 0.5 %RH up to 8 km being highest at daytime tropopause, about 1.5 %RH. Standard deviations of differences for RS92 are broader [6], at night-time about 1.5%RH in the first kilometer and around 2%RH at day time in tropopause region.



Figure 27: RS41-RS41 humidity reproducibility in tropical night time atmosphere

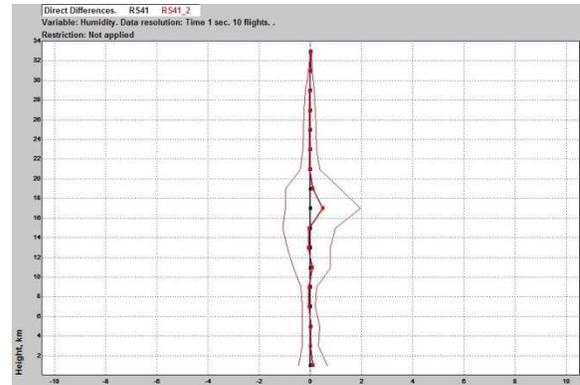


Figure 28: RS41-RS41 humidity reproducibility in tropical daytime atmosphere

At sounding campaigns held at high and mid latitudes RS41 humidity measurement has resulted in reproducibility maximum values ranging from 0.6 to 1 %RH and typical values ranging from 0.4 to 0.7 %RH.

11. PRESSURE AND HEIGHT MEASUREMENTS

RS41-SG uses the Global Positioning System (GPS) for observations of height, pressure, horizontal location and wind. The Vaisala RS41 GPS receiver has a new design compared with the Vaisala RS92 series. The calculation algorithms in MW41 use custom signal processing, including methods such as filtering designed for typical radiosonde ascent rates. Ionospheric modeling is used to minimize the impact of atmospheric effects on measurement.

The GPS-based pressure measurement method has been validated in WMO intercomparisons. Atmospheric pressure is derived from GPS height, surface pressure, and radiosonde temperature and humidity observations. The method assumes hydrostatic conditions. The method is similar but reverse compared to the method of calculating height from pressure sensor, as shown in **Figure 29**. RS41 GPS-based pressure measurements have been validated with RS92 GPS and sensor measurements. This chapter shows comparison results with RS92 sensor measurement, which is the most common used operational method.

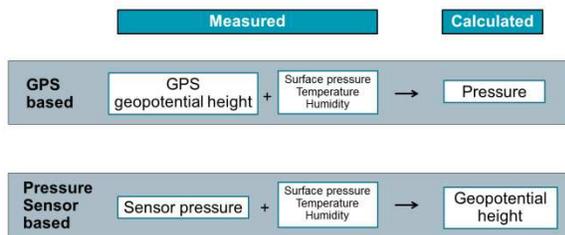


Figure 29: GPS based and pressure sensor based techniques for measuring geopotential height and atmospheric pressure with radiosonde.

11.1 Pressure reproducibility

GPS-based pressure measurements are more accurate than sensor measurements in the upper atmosphere. This is due to the very high accuracy of the GPS height measurement through all height ranges. Pressure sensor measurements are less accurate at low pressures. The performance difference is evident in **Figure 30**, which shows the pressure reproducibility in twin soundings for RS41-SG radiosondes using GPS, and RS92-SGPD radiosondes using pressure sensor. Results are from 31 flights (GPS) and 34 flights (sensor) from sounding campaigns in Finland and Malaysia. In these sounding campaigns two separate local GPS antennas were installed at the ground station to ensure that the two radiosondes measured independent GPS height measurements.

The average differences between RS41 and RS92 measurements in these campaigns were 0.3 hPa or less in the lower atmosphere and 0.2 hPa above 30 km.

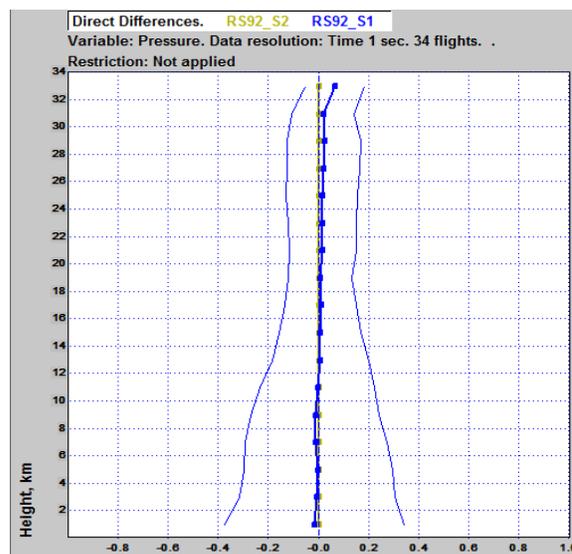
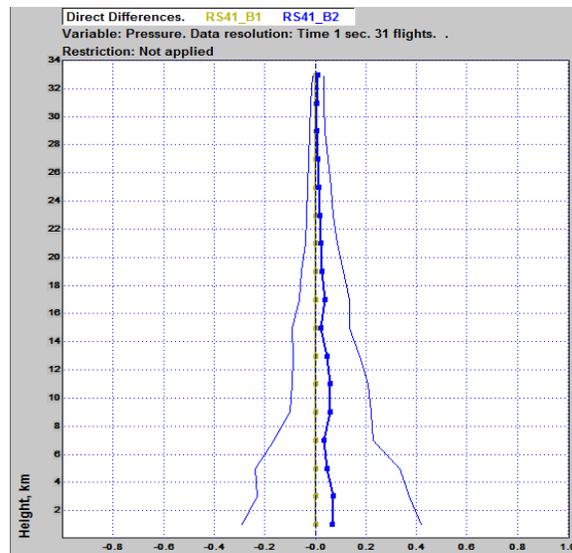


Figure 30: Reproducibility of pressure measurement using GPS (above) and sensor pressure (below). Showing average differences and standard deviation of differences (thin lines) between two radiosondes in rig soundings.

11.2 Height comparison, RS92 – RS41

Table 3 shows a comparison of GPS and sensor based geopotential height measurements in a set of rig soundings, with two RS41-SG and two RS92-SGP

radiosondes hanging from each rig. The average differences remained at under 20 gpm up to 20 km altitude, and at under 50 gpm up to 32 km. Standard deviations for the GPS measurement are much smaller than for sensor measurement. In this campaign the two RS41-SG radiosondes used the same local GPS antenna. In tests using independent antennas the observed standard deviations have been 6 gpm or less.

Standard pressure level heights show a very high agreement between the two measurement methods, **Table 4**, better than for pressure or height measurements separately. This result follows from the connection between the pressure and height observations, as depicted in **Figure 29**.

Geopotential Height

	Average Difference gpm	Standard Deviation gpm	
	Sensor vs. GPS	RS41 GPS based	RS92 Sensor based
Up to 10 km	< 10	< 2	< 7
Up to 20 km	< 20	< 2	< 20
Up to 32 km	< 50	< 3	< 102

Table 3: Comparison of geopotential height between RS41 (GPS) and RS92 (sensor). Results are from 26 flights in Camborne, UK.

Standard Pressure Level Height

	Average Difference gpm	Standard Deviation gpm	
	Sensor vs. GPS	RS41 GPS based	RS92 Sensor based
850 hPa	-0.2	1.3	1.9
100 hPa	5.5	2.8	9.3
20 hPa	-0.6	7.8	14.9

Table 4: Comparison of standard pressure levels of 850, 100 and 20 hPa between RS41 (GPS) and RS92 (sensor). Results are from 20 soundings in Finland and Malaysia.

11.3 RS41 with pressure sensor

The RS41 radiosonde will also be available with pressure sensor in future. This provides data redundancy from both GPS and sensor pressure, for e.g. non-hydrostatic situations. Sensor-based measurements can be valuable in research applications and in climatological data series, which can benefit from data redundancy and consistent use of direct pressure measurements. For the RS41

Radiosonde with the pressure sensor, Vaisala DigiCORA® Sounding System MW41 will provide both GPS and pressure sensor based measurement data simultaneously in usable XML format.

12. WIND MEASUREMENT

RS41 wind measurement method uses GPS technology and is similar to RS92. Validation results from measurement campaigns show no change in accuracy and data availability.

CONCLUSIONS

Vaisala Radiosonde RS41 and Vaisala DigiCORA® Sounding System MW41 introduce a new generation of sounding products, using state-of-art sensor design and with special attention to ease of use. These factors contribute to high consistency and accuracy of measurements.

Based on performed reproducibility testing Vaisala RS41 Radiosonde shows improved temperature and humidity measurement precision, compared with Vaisala Radiosonde RS92.

Observed direct differences between RS41 Radiosonde and RS92 Radiosonde temperatures are moderate, typically in the order of 0.1 °C, up to 0.2 °C.

Observed direct differences between RS41 Radiosonde and RS92 Radiosonde humidity are in the order of 1 – 3 %RH. In tropical day time conditions RS41 Radiosonde measured on average 5 %RH higher humidity than RS92 Radiosonde in tropopause region. The difference is related to the accurate on-chip temperature measurement in RS41 Radiosonde.

GPS-based pressure method in Vaisala Radiosonde RS41-SG is a WMO tested observation method, suitable for operational use. At higher altitudes, RS41 Radiosonde GPS based height and pressure measurement provide improved accuracy compared with RS92 Radiosonde pressure based measurement.

Test results so far demonstrate that Vaisala Radiosonde RS41 will provide improved

measurement accuracy and data consistency to atmospheric humidity, temperature and pressure measurement.

References

[1] Vaisala Radiosonde RS41 Measurement Performance, White Paper

[2] JCGM 100:2008. Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement

[3] WMO Intercomparison of High Quality Radiosonde Systems, Yangjiang, China, 12 July – 3 August 2010

[4] Edwards, D., G. Anderson, T. Oakley, P. Gault, 2014: UK MET Office Intercomparison of Vaisala RS92 and RS41 Radiosondes

[5] Vaisala RS41 Trial in the Czech Republic, Vaisala News 192/2014, pages 14 – 17

[6] Comparison of Vaisala Radiosondes RS41 and RS92, White Paper