Comparison of Vaisala Radiosondes RS41 and RS92

WHITE PAPER

VAISALA

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CHAPTER 1

Introduction

The purpose of this document is to report the key differences and results of comparison soundings for the new Vaisala Radiosonde RS41 and the current Vaisala Radiosonde RS92.

Radiosonde data is crucial for many important applications, e.g. weather forecasting, climatology, and atmospheric research. Therefore the implications of changes in the Vaisala radiosonde model are of great interest.

Vaisala Radiosonde RS41 introduces improvements to the data accuracy and consistency. RS41 is also very easy to operate, an important feature contributing both to efficiency and quality of soundings operations. Simple and error preventive design ensures consistency of observations and is therefore very relevant to data quality in everyday use. Key parameters contributing to ease of use and error prevention are presented in Chapter 2.

Both RS41 and RS92 radiosonde performances have been thoroughly characterized. Key performance figures in a comparable format are presented in Chapter 3.

Results of comparison soundings for RS41 and RS92 at two different locations, representing both tropical (Malaysia, lat. 5° N) and high latitude (Finland, lat. 60° N) atmospheres, are shown in Chapter 4 for temperature and in Chapter 5 for humidity. The focus in this document is in statistical average differences and differences in data reproducibility between the two radiosonde models in these locations.

RS41 and RS92 comparison soundings have been carried out also in other locations. Results of RS41 and RS92 intercomparison test conducted by the Czech Hydrometeorological Institute at Praha-Libus station (WMO#11520) are presented in [8] Analysis by UK Met Office of RS41 and RS92 intercomparison conducted at Camborne station (WMO#03808) is presented in [9].

The RS41-SG measurement performance is presented thoroughly in [1]. In the paper, improvements in RS41 data precision throughout the whole soundings profile and comparisons against independent references are presented, demonstrating the accuracy of RS41 radiosonde data.

RS41-SG pressure and geopotential height are derived from GPS. Summary of differences compared to sensor-based RS92-SGP measurements are presented in Chapter 6. More comprehensive description of GPS-based pressure measurement is presented in [2].

Wind measurement comparison results are presented in Chapter 7.

Data continuation aspects of climatological time series are discussed in Chapter 8.

CHAPTER 2

Key Improvements in RS41

Sensor technologies in RS41 and practices in operational sounding preparations have changed compared to RS92, contributing to improvements in accuracy and data consistency.

Ease of use and human error prevention have been clear focus areas in RS41 and the related soundings systems. Both contribute to constant quality and are thus an important part of RS41 performance in everyday use.

Key improvements in RS41 are visualized in **Figure 1**.

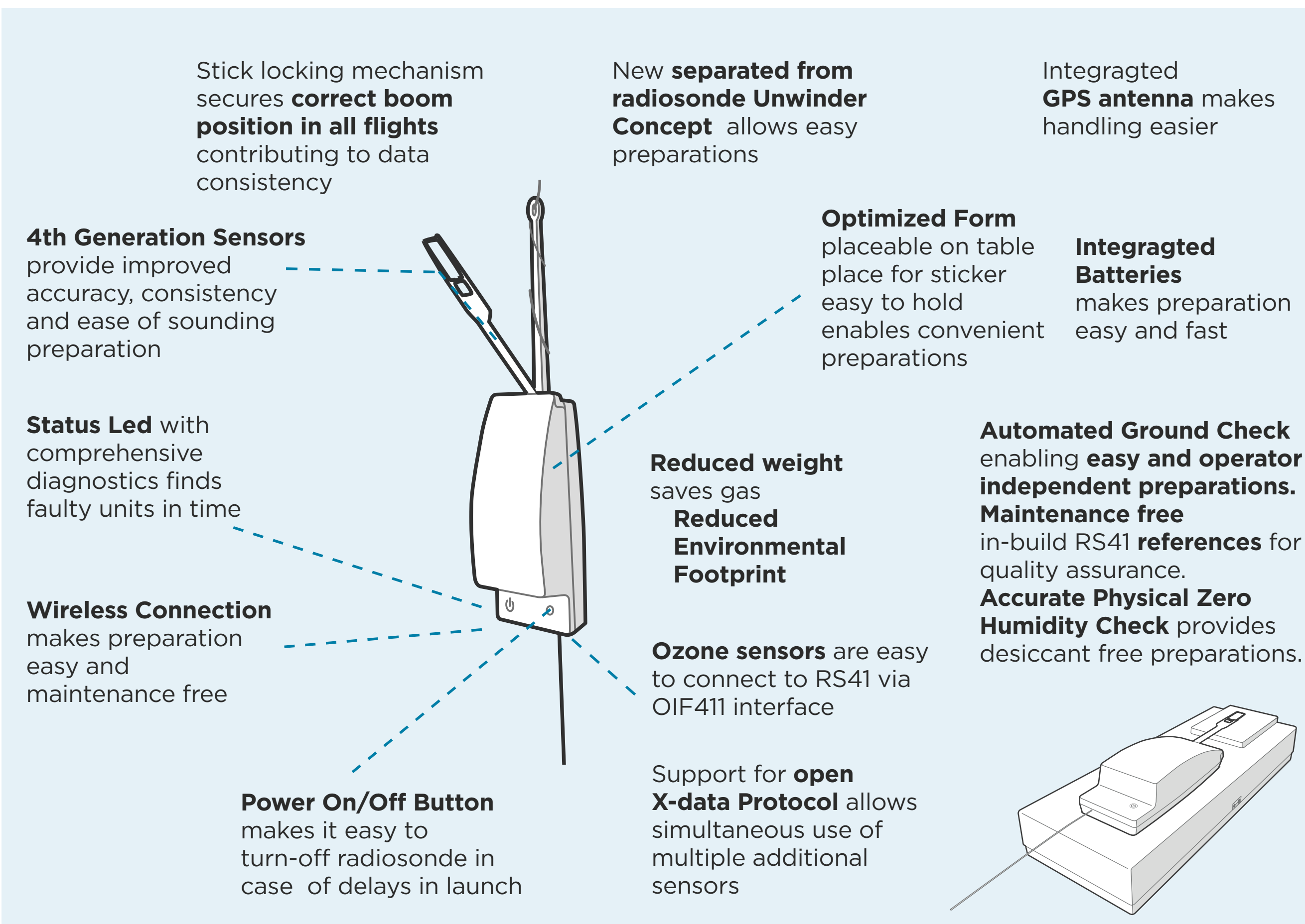

Figure 1. *Key improvements in RS41.*

CHAPTER 3

RS41 and RS92 Comparison Tables

Key performance figures in comparable format are presented in **Tables 1-5**. More details can be found in technical datasheets [6] [7] and performance white papers [1] [2].

Temperature	**RS92-SGPD**	**RS41-SG**
Sensor type	**Capacitive wire**	**Platinum Resistor**
Combined uncertainty in sounding 1)	0.5 °C < 16 km 0.5 °C > 16 km	0.3 °C < 16 km 0.4 °C > 16 km
Reproducibility in sounding 2)	0.2 °C > 100 hPa 0.5 °C < 100 hPa	0.15 °C > 100 hPa 0.3 °C < 100 hPa
Repeatability in calibration 3)	0.15 °C	0.1 °C
Response time (63.2%, 6m/s flow, 1000hPa)	0.4 s No time lag correction.	0.5 s Time lag correction applied, negligible residual errors.
Ground Check	Corrected against Pt100 reference.	No correction needed. In-built temperature check to find faulty units.

Table 1. *Comparison of RS92 and RS41 temperature measurement specifications.*

Humidity	**RS92-SGPD**	**RS41-SG**
Sensor type	**Thin-film capacitor, heated twin sensor**	**Thin-film capacitor, integrated T sensor and heating functionality**
Combined uncertainty in sounding 1)	5 %RH	4 %RH
Reproducibility in sounding 2)	2 %RH	2 %H
Repeatability in calibration 3)	2 %RH	2 %RH
Response time (63.2%, 6m/s flow, 1000hPa)	< 0.5 s, +20 °C, < 20 s, -40 °C	< 0.3 s, +20 °C < 10 s, -40 °C
Ground Check	Corrected against 0%RH humidity generated by desiccants.	Corrected with RS41 in-built Physical Zero Humidity Check.

Table 2. *Comparison of RS92 and RS41 humidity measurement specifications.*

Pressure	RS92-SGPD	RS41-SG
Sensor type 5)	**Silicon, Capacitive sensor**	**GPS derived**
Combined uncertainty in sounding 1)	1.0 hPa > 100 hPa 0.6 hPa < 100 hPa 0.6 hPa < 10 hPa	1.0 hPa > 100 hPa 0.3 hPa < 100 hPa 0.04 hPa < 10 hPa
Reproducibility in sounding 2)	0.5 hPa > 100 hPa 0.3 hPa < 100 hPa 0.3 hPa < 10 hPa	0.5 hPa > 100 hPa 0.2 hPa < 100 hPa 0.04 hPa < 10 hPa
Geopotential Height		
Combined uncertainty in sounding 1)	Derived from Pressure	10 gpm
Reproducibility in sounding 2)	Derived from Pressure	6 gpm

Table 3. *Comparison of RS92 and RS41 pressure and geopotential height measurement specifications.*

Wind Speed and Direction	RS92-SGPD	RS41-SG
Velocity uncertainty 6)	0.15 m/s	0.15 m/s
Directional uncertainty 6)	2 deg	2 deg

Table 4. *Comparison of RS92 and RS41 wind measurement specifications.*

Feature	RS92-SGPD	RS41-SG
Weight 4)	280 g	109 g
Dimensions	220 x 80 x 75 mm	272 x 63 x 46 mm
Battery type	Alkaline, nominal 9V	Lithium, nominal 3V
Battery capacity	135 min	> 240 min
Transmitter standard	EN 302 054	EN 302 054
Transmitter power	60 mW	Min. 60 mW
Telemetry range t(with RB31 antenna)	350 km	350 km
Measurement cycle	1 s	1 s

Table 5. *Comparison of RS92 and RS41 other key specifications.*

1) 2-sigma (k=2) confidence level (95.5%) cumulative uncertainty.

2) Standard deviation of differences in twin soundings, ascent rate above 3 m/s.

3) Standard deviation of differences between two successive repeated calibrations, k=2 confidence level.

4) Weight does not include unwinder and other possible extra rigging, such as parachute.

5) GPS-based pressure and geopotential height are also available as an optional calculation method with RS92-SGP. Here the comparison focus is in a sensor-based method, as that has been the one most commonly used with RS92 radiosonde.

6) Standard deviation of differences in twin soundings, wind speed above 3 m/s in directional uncertainty.

CHAPTER 4

Temperature Measurement

RS41 vs. RS92 differences in temperature measurements in sounding conditions were evaluated with experimental tests. Soundings were made in two locations, representing both tropical (Malaysia, lat. 5° N) and high latitude (Finland, lat. 60° N) atmospheres, to get an understanding of the results in different conditions. Example profiles in **Figures 4.1 to 4.3** describe typical atmospheric conditions during the tests.

During the test soundings campaign, each flight carried two or more radiosondes hanging in a rig, making the comparison of radiosondes both accurate and time synchronous. Statistical analyses of the comparisons were made using the RSKOMP radiosonde comparison software, approved and recommend by WMO/ CIMO [5].

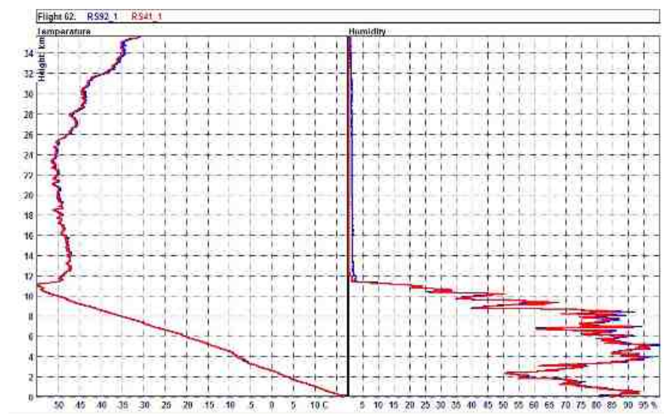

Figure 4.2. *Example temperature and humidity profile of a high latitude daytime sounding. Tropopause is at about 11 km height and temperature drops down to -55°C.*

Typical Atmospheric Conditions During the Tests

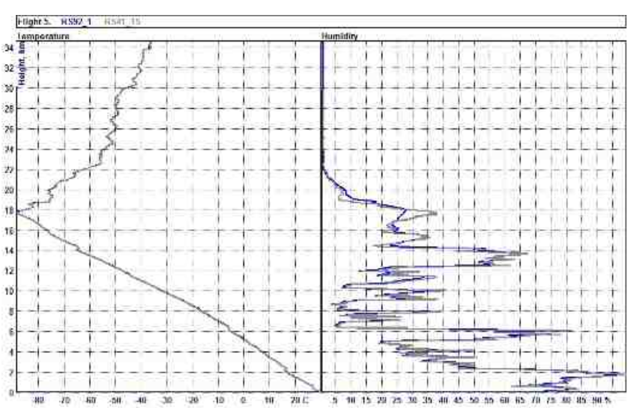

Figure 4.1. *Example temperature and humidity profile of a tropical daytime sounding. Tropopause is at about 18 km height and temperature drops below -80°C.*

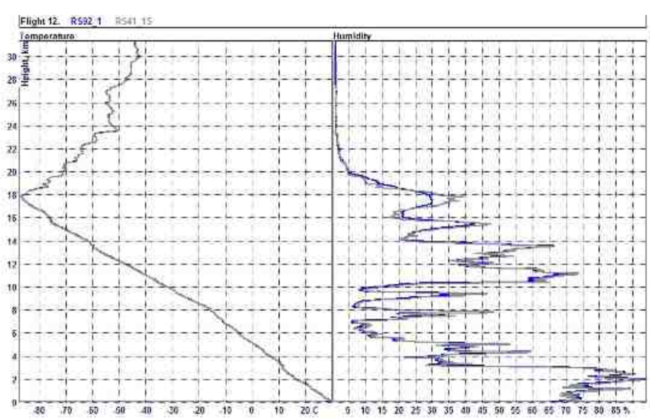

Figure 4.3. *Example temperature and humidity profile of a tropical night time sounding.*

Comparison Results of Daytime Soundings

The average difference in daytime RS41 and RS92 temperature measurements is < 0.1°C throughout the soundings in high latitude conditions, and up to 29km in tropical conditions.

Comparison Results of Night Time Soundings

Temperature measurements of RS41 and RS92 have negligible differences in night time soundings, < 0.05°C up to 26 km and < 0.1°C throughout the profile. This is demonstrated in **Figure 4.6** in tropical conditions, representing a wide temperature range of -80°C to +30°C.

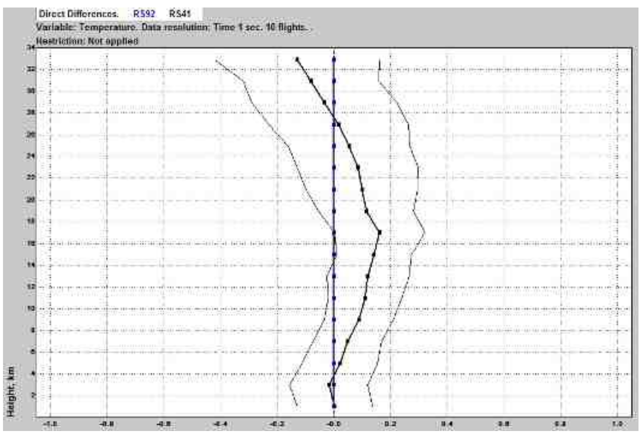

Figure 4.4. *RS92 vs. RS41 temperature differences in tropical daytime atmosphere, using RS92 as the reference. Showing average differences and standard deviation of differences (thin lines).*

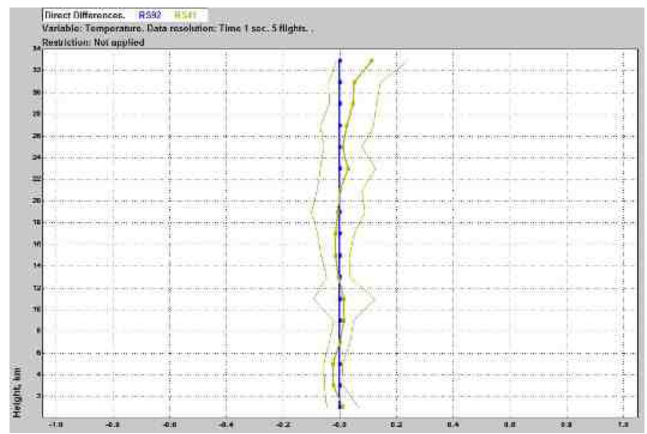

Figure 4.6. *RS92 vs. RS41 temperature differences in tropical night time atmosphere.*

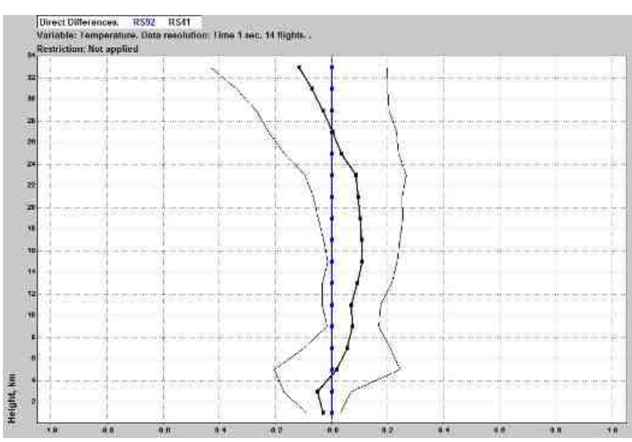

Figure 4.5. *RS92 vs. RS41 temperature differences in high latitude daytime atmosphere.*

Comparison Results of Data Reproducibility

Reproducibility is defined as the measurement deviation between two similar radiosondes in a rig sounding. Good reproducibility indicates excellent consistency of data in operational use.

Following figures present day- and night time reproducibility for both RS92 and RS41 in tropical atmosphere, representing the widest range of temperature and humidity conditions. RS41 reproducibility is better than RS92 in all atmospheric conditions. Improved consistency is mostly due to renewed sensor technology and optimized sensor boom and RS41 mechanics.

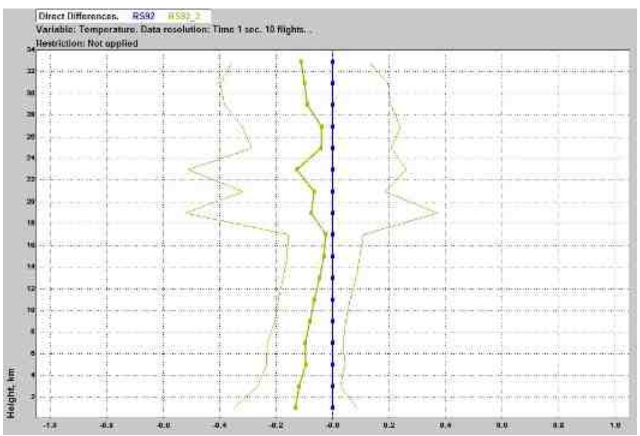

Figure 4.7. *RS92-RS92 temperature reproducibility in tropical daytime atmosphere.*

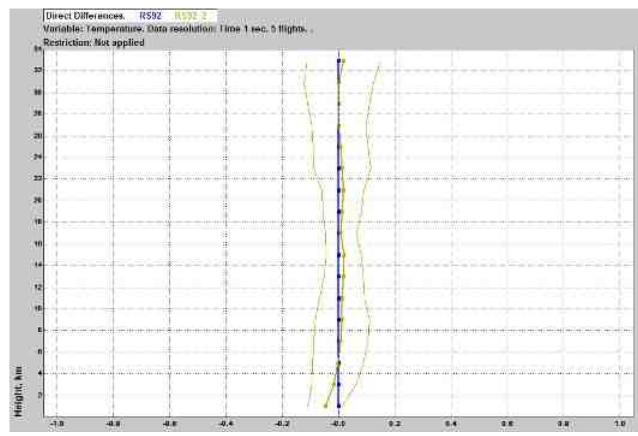

Figure 4.9. *RS92-RS92 temperature reproducibility in tropical night time atmosphere.*

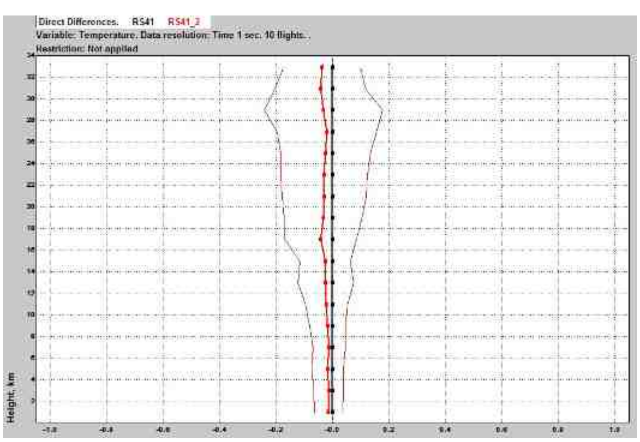

Figure 4.8. *RS41-RS41 temperature reproducibility in tropical daytime atmosphere.*

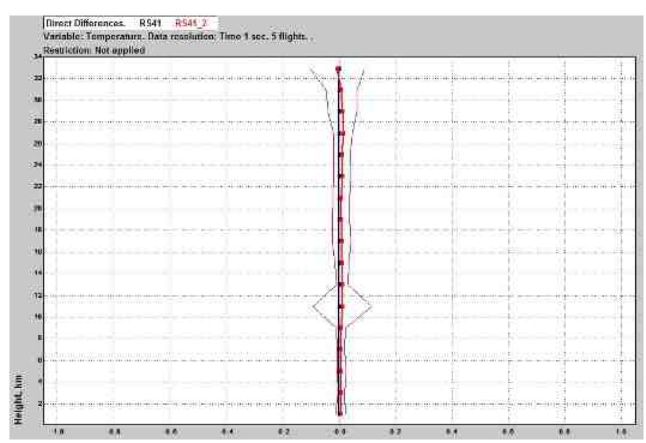

Figure 4.10. *RS41-RS41 temperature reproducibility in tropical night time atmosphere.*

CHAPTER 5

Humidity Measurement

RS41 vs. RS92 differences in humidity measurement in sounding conditions were evaluated with experimental sounding tests. Soundings were made in two locations, representing both tropical (Malaysia, lat. 5° N) and high latitude (Finland, lat. 60° N) atmospheres, to get an understanding of the results in different conditions.

During the test soundings campaign, each flight carried two or more radiosondes hanging in a rig, making the comparison of radiosondes both accurate and time synchronous. Statistical analyses of the comparisons were made using the RSKOMP radiosonde comparison software, approved and recommend by WMO/ CIMO [5].

The improved humidity measurement in RS41 provides better precision in every stage of the profile, and thus clouds and other important fine structures of the atmosphere are detected very precisely. More details are described in [1].

Typical Atmospheric Conditions During the Tests

Example profiles in **Figures 4.1 to 4.3** in Chapter 4 describe typical atmospheric conditions during the tests.

Comparison Results of Daytime Soundings

The average difference in daytime RS41 and RS92 humidity measurements is small, < 2 %RH, in high latitude conditions. In tropical conditions the difference is greater due to the improvements in RS41 humidity measurement. For example, uncertainty originating from solar radiation is greatly reduced as a result of the renewed humidity measurement concept [1].

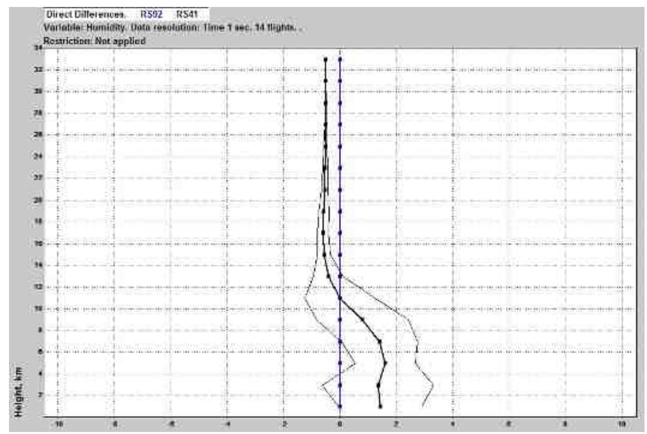

Figure 5.2. *RS92 vs. RS41 humidity differences in high latitude daytime atmosphere.*

Comparison Results of Night Time Soundings

The average difference in night time RS41 and RS92 humidity measurements is small, < 2%RH. This is demonstrated in the figure below in tropical conditions, representing a wide temperature range with high humidity conditions.

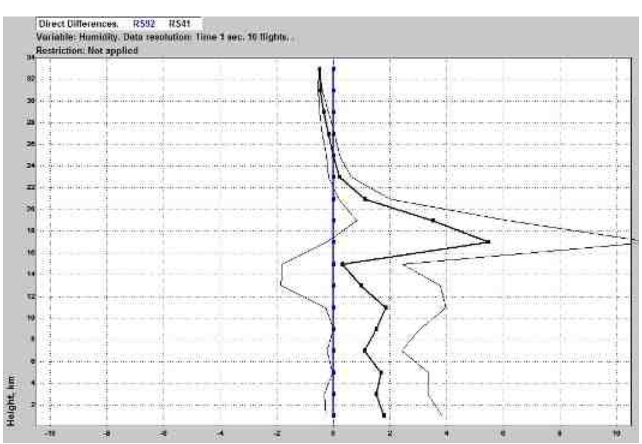

Figure 5.1. *RS92 vs. RS41 humidity differences in tropical daytime atmosphere. Showing average differences and standard deviation of differences (thin lines).*

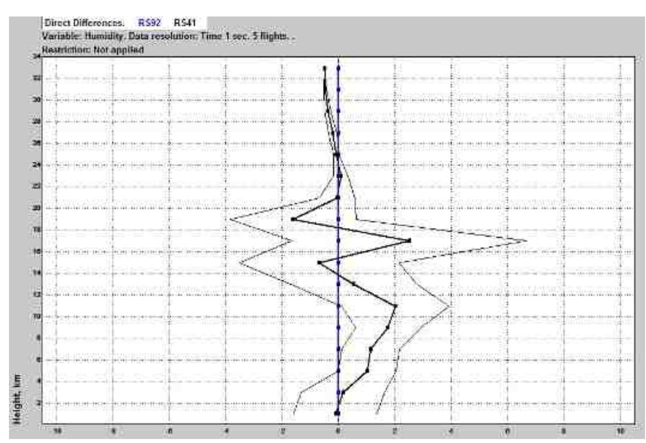

Figure 5.3. *RS92 vs. RS41 humidity differences in tropical night time atmosphere.*

Comparison Results of Data Reproducibility

Reproducibility is defined as the measurement deviation between two similar radiosondes in a rig sounding. Good reproducibility indicates excellent consistency of data in operational use.

The following figures present day- and night time reproducibility for both RS92 and RS41 in tropical atmosphere, representing the widest range of temperature and humidity conditions. On average, RS41 reproducibility is better than that of RS92 in all atmospheric conditions.

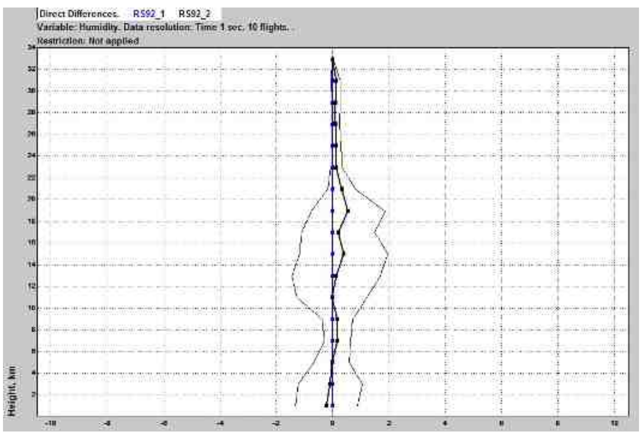

Figure 5.4. *RS92-RS92 humidity reproducibility in tropical daytime atmosphere.*

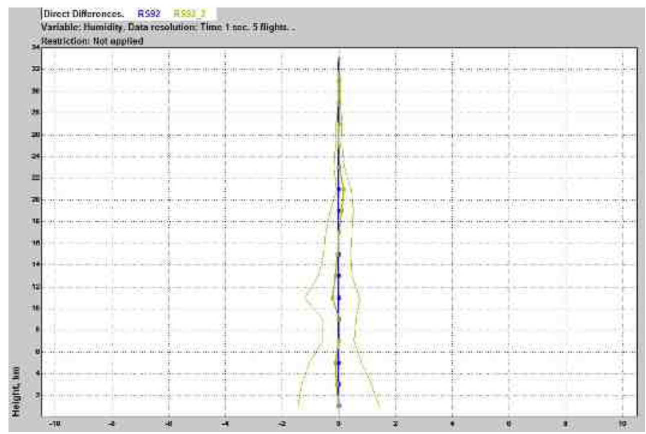

Figure 5.6. *RS92-RS92 humidity reproducibility in tropical night time atmosphere.*

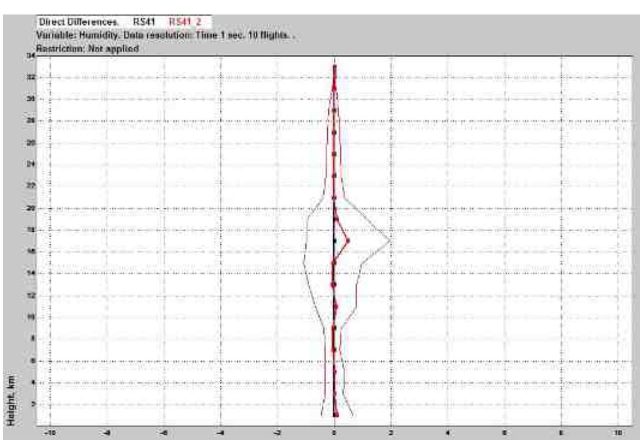

Figure 5.5. *RS41-RS41 humidity reproducibility in tropical daytime atmosphere.*

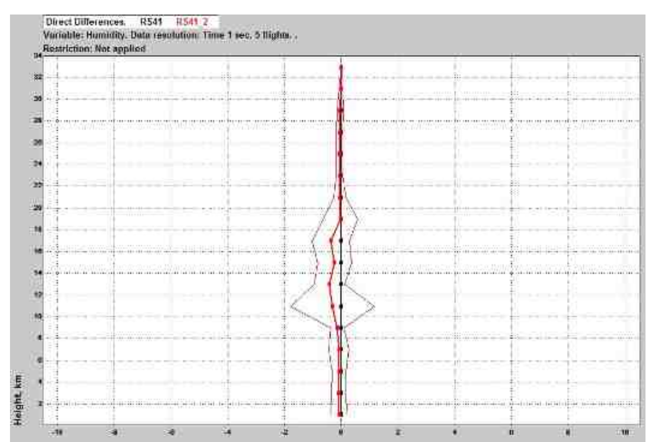

Figure 5.7. *RS41-RS41 humidity reproducibility in tropical night time atmosphere.*

CHAPTER 6

Pressure and Geopotential Height Measurement

The Vaisala Radiosonde RS41 provides high-quality GPS-based height and pressure measurements. Vaisala Sounding System MW41 uses custom GPS signal processing and Vaisala has optimized the algorithms for performance in radiosonde application. Good quality height measurements are essential for accurate atmospheric pressure observations.

The Vaisala RS41 GPS receiver has a new design compared with the Vaisala RS92 series. The RS41 GPS antenna is a robust, high-efficiency integrated antenna. The GPS-based measurements in the RS41 are described in detail in reference [2].

Comparison Results

The RS41 GPS-based height and pressure measurements were compared with RS92-SGP sensor measurements in sounding campaigns in Malaysia (lat. 5° N) and Finland (lat. 60° N), to cover different satellite geometries and site environments.

Table 6 presents a summary of standard pressure level heights between GPS-based observations in RS41 and pressure sensor observations in RS92. The two measurement techniques compare well with small height differences in standard pressure levels.

Figure 6.1 compares GPS-based pressure with sensor-based pressure in the RS41 and RS92, respectively. The two measurement methods are well in alignment, with average differences < 0.3 hPa near ground and < 0.2 hPa above 30 km.

Standard pressure level	RS41 - RS92 average differences in height	RS41 - RS92 standard deviation of differences in height
	GPS-based height and pressure in RS41, sensor-based in RS92 (n = 20)	
850 hPa	-0.2 gpm	2.1 gpm
100 hPa	5.5 gpm	4.9 gpm
20 hPa	-0.6 gpm	7.8 gpm

Table 6. *Differences in standard pressure level heights of 850, 100, and 20 hPa between RS41 and RS92 radiosondes.*

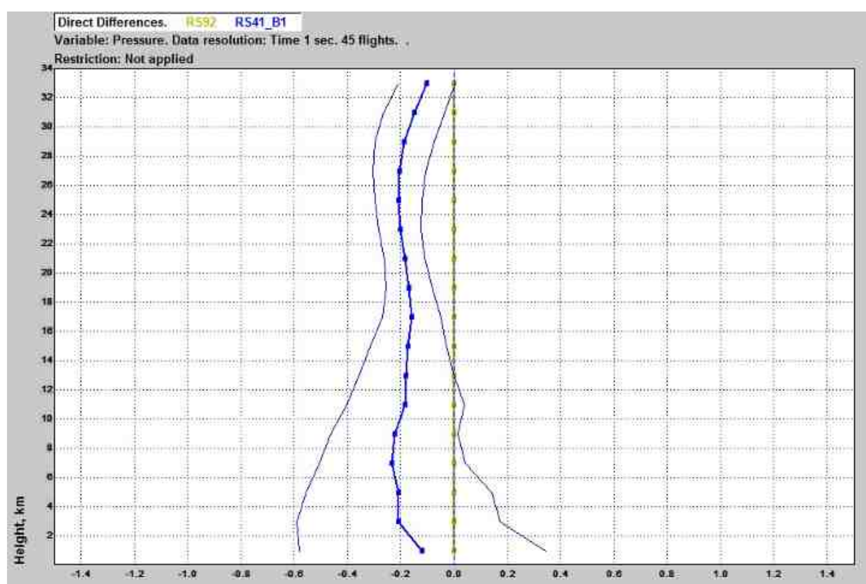

Figure 6.1. *Comparison of GPS-based pressure from the RS41 and sensor-based pressure from the RS92 radiosonde, using the RS92 as the reference. Showing average differences and standard deviation of differences (thin lines).*

CHAPTER 7

Wind Measurement

Vaisala Radiosonde RS41 uses Global Positioning System (GPS) for high-quality wind speed and direction measurements. Vaisala Sounding System MW41 computes results using custom signal processing, updated from Vaisala Sounding System MW31. The measurement performance of the RS41 is similar to RS92, as shown in **Table 7**.

Wind Speed and Direction	RS92-SGPD	RS41-SG
Velocity uncertainty	0.15 m/s	0.15 m/s
Direction uncertainty	2 deg	2 deg

Table 7. *Comparison of RS92 and RS41 wind measurement specifications.*

CHAPTER 8

Data Continuity

Climate change is a pressing scientific problem and a major worldwide societal and political challenge. Fundamental to all facets of the climate debate is the need for an extremely accurate, precise and representative record of atmospheric changes – especially temperature, water vapor and precipitation, which need to be measured over multi-decadal timescales and on geographical scales ranging from local to regional and global [3].

In addition to introducing more precise instruments for operational and research use, it is imperative to guarantee continuity of observation datasets. Accordingly, Vaisala has established a public, web-based database that will provide radiosonde-related information faciliating the homogenization of climatological time series [3].

All relevant changes in sensor design, procedures and related software have been documented in www.vaisala.com since the launch of RS92 radiosonde in 2003 [4].

Data Continuity from RS92 to RS41

The impact of radiosonde model switch from RS92 to RS41 on climatological time series is estimated to be moderate. The improved accuracy of RS41 data does not affect average measurement values as much as it affects the consistency or reproducibility of the data. So far, the tests indicate that the most significant impact on average values will be seen in humidity measurements of tropical atmosphere, especially in the humid conditions of the upper troposphere.

The statistical differences between RS92 and RS41 are described in Chapters 4 - 7 by experimental sounding results. The information will also be available in www.vaisala.com to ensure an open end-data-user access to this important metadata.

Data Continuity as RS41 is in Operational Use

Vaisala intends to offer the best possible tools for climate research, including accurate measurement instruments with carefully estimated uncertainty budgets, as well as tools and the metadata for managing data continuation.

Vaisala commits to announcing all RS41 product changes that could affect the homogeneity of climatological data series in www.vaisala.com.

References

[1] Vaisala Radiosonde RS41 Measurement Performance White Paper

[2] GPS-Based Measurement of Height and Pressure with Vaisala Radiosonde RS41 White Paper

[3] Climate Monitoring and Research, Vaisala Contributes to Earth's Climate Knowledge, 2009, Vaisala Reference C210061EN-A

[4] www.vaisala.com > Sounding Systems and Radiosondes > Sounding Data Continuity

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[7] Vaisala Radiosonde RS41 Datasheet

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

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

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