VAISALA

TECHNICAL PAPER

Comparison of Radiosonde Data from Vaisala Sounding Systems MW51 and MW41

1 Introduction

The purpose of this document is to report the results of comparison soundings between the Vaisala Cirrus™ Sounding System MW51 and the Vaisala Sounding System MW41. The MW51 is designed to ensure consistent high-quality measurements using Vaisala RS41 Upper Air Radiosondes, and provides a smooth transition path from older Vaisala sounding systems.

The MW51 implements largely the same advanced algorithms for computing temperature, humidity, pressure and wind, but with improvements in the applied corrections and data filtering, an upgraded software platform and a newly designed sounding processing subsystem. The MW41 was used as a reference model in the comparison.

The data used in the comparison were obtained from soundings carried out at a high latitude location (Finland, Lat. 60° N) by Vaisala staff between fall 2022 and winter 2023. The results described in this document are applicable to all RS41 models with a GPS receiver (RS41-SG, RS41-SGP, RS41-SGM and RS41-NG), except for the sensor pressure which is applicable specifically for RS41-SGP. The test method and system setup are described in Chapter 3. Individual results for temperature, humidity, pressure, and wind observations are described in the following sections.

2 Executive summary

A summary of the measurement performance evaluation is presented in Table 1. The results show that there are no relevant or unpredicted differences between the data processing streams of the two sounding systems, despite the changes in implementation technologies. The average and random differences are typically very small compared to the radiosonde measurement accuracy, other than expected differences observed, arising from improved filtering and measurement correction in the MW51 (e.g., U time-lag correction). Hence, a sounding system upgrade will not cause significant changes in the observed data.

The test results can be affected by factors including different ground check corrections, different receiver systems, timing differences between the systems, and the resolution of the statistical analysis software. There will therefore be small differences between the resulting measurement values caused by the test setup.

Besides the validation of measurement performance, data availability analysis indicated an improvement in valid telemetry percentage in the MW51 sounding system.

Measurement	Accuracy of RS41 in sounding[1]	System comparison: average difference	System comparison: random differences (k=2)
Temperature	0.3 °C (0-16 km) 0.4 °C (above 16 km)	0.01 °C <0.03 °C	0.02 °C <0.05 °C
Humidity	4 %RH	<0.11 %RH[2] <0.5 %RH[3]	<0.5 %RH[2] <3.9 %RH[3]
Pressure (silicon, capacitive sensor)[4]	1.0 hPa (> 100 hPa) 0.6 hPa (< 100 hPa)	0.00 hPa 0.00 hPa	<0.01 hPa <0.01 hPa
Geopotential Height (GPS derived)	10 gpm	<0.8 gpm	<5.0 gpm
Pressure (GPS derived)	1.0 hPa (>100 hPa) 0.3 hPa (100 – 10 hPa) 0.04 hPa (<10 hPa)	<0.07 hPa <0.02 hPa 0.00 hPa	<0.4 hPa <0.07 hPa 0.01 hPa
Wind	0.15 m/s (reproducibility)[5]	<0.01 m/s	<0.08 m/s

Table 1: Summary of comparison results between MW51 and MW41 sounding systems.

1. *Combined uncertainty with k=2 confidence level (~95%).*
2. *After the tropopause.*
3. *Maximum differences observed at higher troposphere, around the tropopause, related to improved U time-lag correction in MW51.*
4. *RS41-SGP models only.*
5. *Standard deviation of differences in twin soundings, encompassing about 68% of the dispersion of the results.*

3 Method of comparison and system setup

The two sounding systems were used in parallel and received the data from the same RS41-SGP radiosonde at the same time, as shown in Figure 1. In this way, the comparison was about the difference between the two systems and not about the repeatability of the radiosonde data. Both systems used the same omnidirectional RM32 UHF antenna [1] and GA31 GPS local antenna [2]. The MW51 controlled the antenna direction. In addition, the systems shared the same RI41-B ground check set so that the differences in data due to ground check were minimized. The exact procedure is explained in Reference [3].

Table 2 summarizes the system configurations during the test. The MW41 was deployed with software version 2.17 and used the SPS311G sounding processing subsystem. The MW51 was used with the Vaisala DigiCORA® software version 5.4 and the new SPS511 sounding processing subsystem.

	MW51	MW41
SW version	DigiCORA 5.4	2.17
Sounding processing subsystem	SPS511	SPS311G
GPS local antenna	GA31	GA31
UHF telemetry antenna	RM32	RM32

Table 2: Configuration of the tested MW51 and MW41 sounding systems.

The analysis consists of 18 total soundings. After the data was collected, the DigiCORA files from the MW51 and the MWX files from the MW41 were extracted into ASCII files and the data was time synced using GPS time stamps. It must be emphasized that the statistical analysis of GPS-derived measurements is based on a reduced sample of 10 soundings, all done after a revision in the DigiCORA software used in MW51. The other measurements are unaltered by this change.

Statistical analysis was made using the RSKOMP radiosonde comparison software. WVIEW executable was used to display and inspect each flight, individually. The statistical plots shown in the following chapters are generated by WSTAT using one-second data resolution, as provided by the radiosondes themselves, and the analysis was completed over 1 km height bands.

Each plot displays the average and random differences between the two sounding systems. The random differences are described as two standard deviations of the differences and plotted as thinner lines, showing the boundaries of where approximately 95% of the differences in the data fall and representing the expected performance for that radiosonde in most cases.

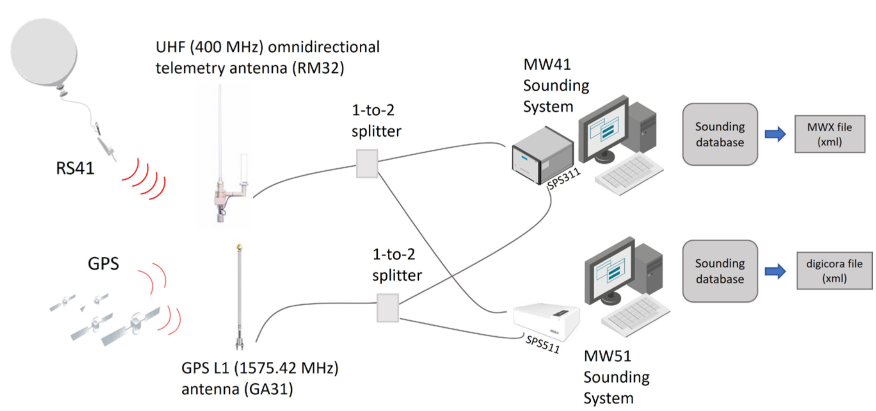

Figure 1: System diagram showing hardware configuration for the two systems used in the comparison.

4 Temperature measurement

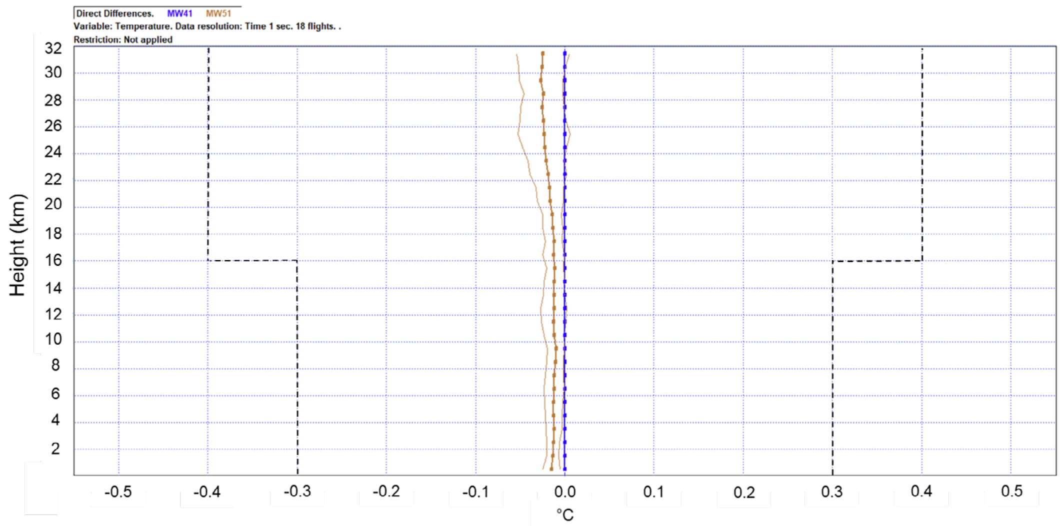

Figure 2: MW51 temperature measurement comparison against MW41, used as a reference. The average differences between the two sounding systems are indicated by the bold line, and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the accuracy of RS41 radiosonde in sounding.

The temperature measurements in the comparison were taken from the resistive platinum sensor in the RS41 radiosonde. This sensor type ensures reference-class linearity and stability. The comparison results are shown in Figure 2. The graph shows the average difference ("Direct Differences" in RSKOMP) and the standard deviation of the differences as a function of height for all flights. These indicate, respectively, the level of persistent differences and random variations between the two sounding systems.

The average differences were 0.03 °C or less and the standard deviations 0.05 °C or less at all heights. The combined uncertainty in sounding of the RS41 temperature measurement is 0.3 °C (0-16 km) and 0.4 °C (above 16 km). There are therefore no significant differences between the temperature results of the two systems. The Vaisala Cirrus™ Sounding System MW51 implements the same advanced algorithms for temperature calculation as the MW41 sounding systems, although including updated correction methods. Consequently, the small bias observed arises from minor differences in the applied corrections. An example of temperature profile and difference between the sounding systems is shown in Figure 3.

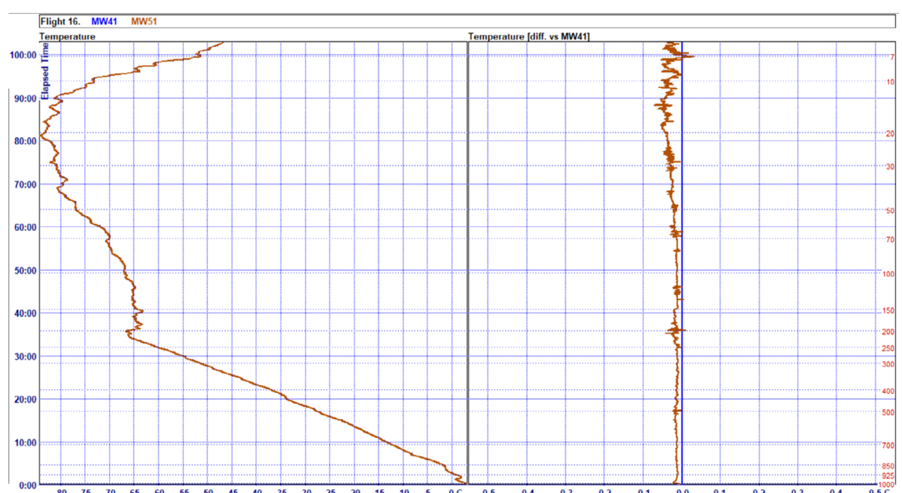

Figure 3: Example of temperature profile in sounding and difference between the systems.

5 Humidity measurement

The humidity measurement of the RS41 radiosonde is based on proven capacitive polymer technology. The sensor design integrates humidity and temperature sensing elements with a heating resistor, enabling active de-icing during sounding. Automated pre-flight reconditioning and zero humidity check procedures effectively remove possible chemical contaminants and storage drifts, laying the foundation for excellent humidity measurement accuracy. The effects of solar radiation are compensated by the on-chip temperature measurement, resulting in enhanced measurement accuracy throughout the profile.

The humidity comparison results are shown in Figure 4. The average and random differences observed were 0.16 %RH or less and 1.0 %RH or less, respectively, through most of the sounding height levels and thus well within the 4 %RH total uncertainty in sounding of the RS41 humidity measurement. Yet, larger average differences up to 0.52 %RH were found in the upper troposphere and when approaching the tropopause following a region of relatively high humidity, where the random differences between the two systems were up to 3.9 %RH. The increase in random differences observed indicates the region where the impact of the MW51 adjusted response-time model of the humidity sensor is largest with respect to the MW41.

An example of humidity profile and difference between the sounding systems is shown in Figure 5. The larger differences between the two implementations

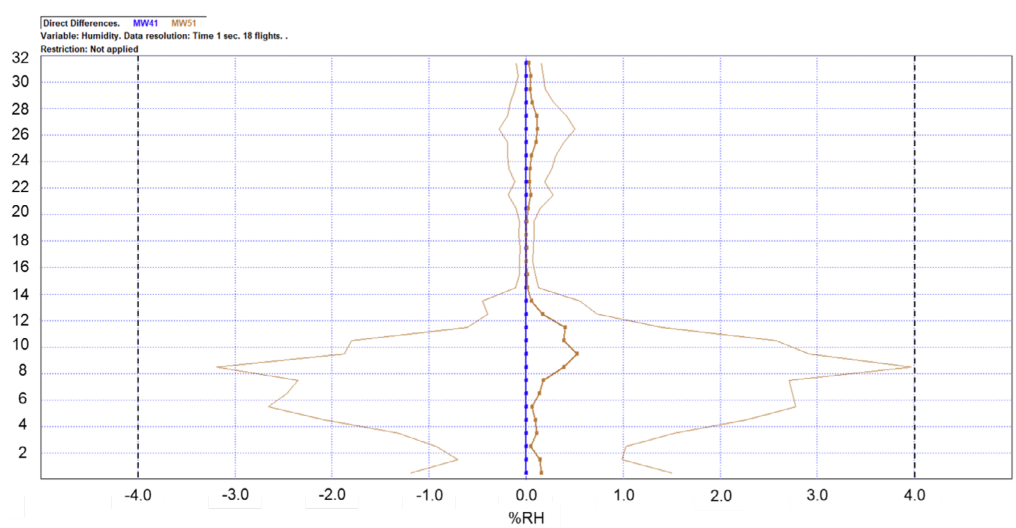

Figure 4: MW51 humidity measurement comparison against MW41, used as a reference. The average differences between the two sounding systems are indicated by the bold line and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the accuracy of RS41 radiosonde in sounding.

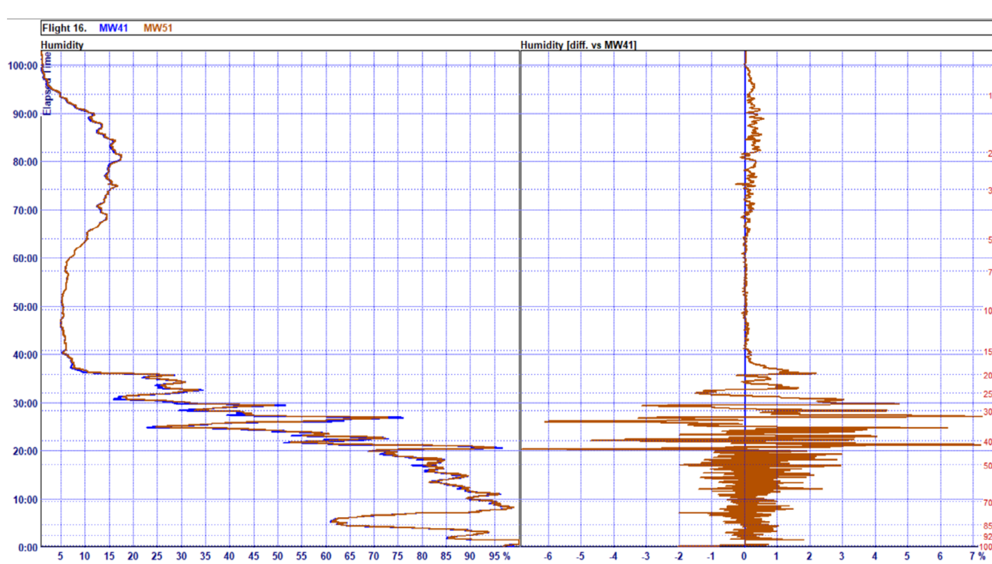

Figure 5: Example humidity profile in sounding and difference between the sounding systems.

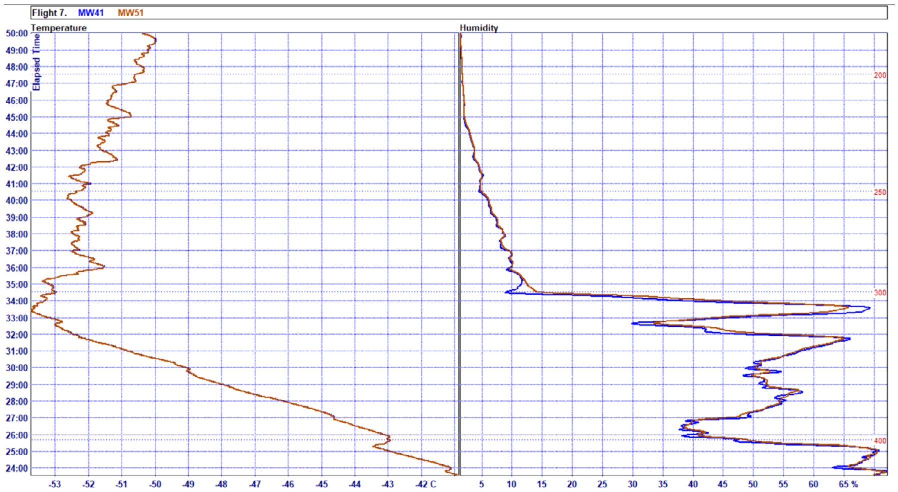

Figure 6: Example of large differences between humidity measurement around the tropopause in the two sounding systems, caused by different filtering and time-lag correction implementation. Such differences rapidly drop after the tropopause.

in the mid-high troposphere arise from the optimized smoothing of the MW51 data, which ensures better timing and alignment with raw data and mitigates pendulum-originated oscillations.

The new filtering pipeline also significantly reduces overshooting in the fast step-like humidity changes that may occur in the sounding, such as during the rapid drying around the tropopause. An example of such behavior is shown in Figure 6. In both cases, the differences between the two systems rapidly lower to 0.1%RH or less, after the tropopause.

6 Pressure measurement

The RS41-SGP provides pressure data redundancy: By default, the pressure is reported from the silicon sensor measurements, and pressure results calculated with the GPS-based method, assuming hydrostatic equilibrium in the atmosphere and ideal gas law, are also available in the Vaisala Sounding System MW51/MW41 database.

The GPS-based method measurement is well-proven and recommended by World Meteorological Organization (WMO) for synoptic observations, while the direct pressure sensor measurement in RS41-SGP may provide a more reliable measurement of the true atmospheric pressure when there are significant local deviations from hydrostatic conditions, such as near frontal zones and storms.

Pressure sensor

The pressure comparison results are shown in Figure 7. The average differences were negligible and the standard deviations were less than 0.01 hPa at all heights. The total uncertainty in the sounding of the RS41-SGP pressure sensor measurement is 1.0 hPa in the pressure range 1080-100 hPa, reducing to 0.6 hPa in the pressure range 100-3 hPa. There are no significant differences between the pressure results of the two systems.

GPS-based geopotential height and pressure

The GPS-based pressure measurement applies to all RS41 radiosonde models equipped with a GPS receiver. The MW51 and MW41 sounding systems use custom signal processing for location and GPS-based pressure and wind measurements. Vaisala has optimized the

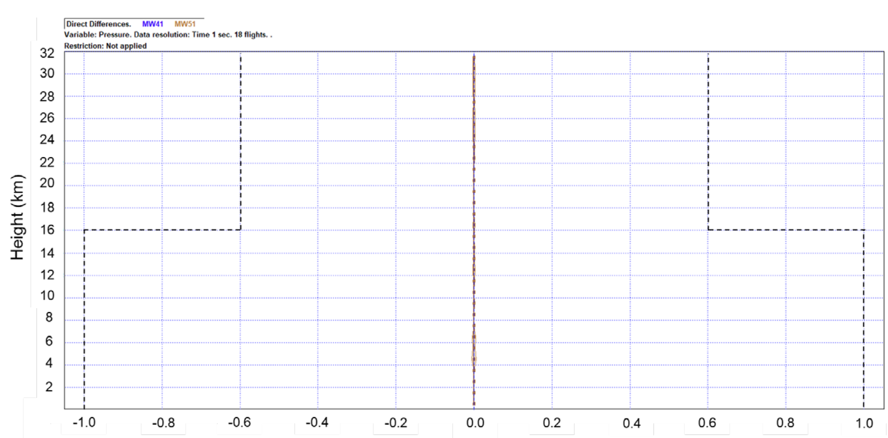

Figure 7: MW51 pressure measurement (sensor-based) comparison against MW41, used as reference. The average differences between the two sounding systems are indicated by the bold line and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the accuracy of RS41 radiosonde in sounding. The average differences were negligible and the standard deviations were less than 0.01 hPa at all heights.

algorithms for radiosonde applications. High-quality height measurements are essential for accurate atmospheric pressure observations.

The algorithms include methods such as filtering designed for typical radiosonde ascent rates. Ionospheric modeling is used to minimize the impact of atmospheric effects on measurement. In addition, fixed stations combine GPS measurements from the radiosonde and the local GPS receiver to produce differential GPS corrections. These eliminate many common GPS positioning errors.

It is worth noting that, although the sounding systems share the same GPS antenna, both have their own GPS receivers. This can potentially cause some differences in the calculated positions as the systems may not be tracking the same locally observed satellites, or different rejection limits for weak GPS signals may be applied.

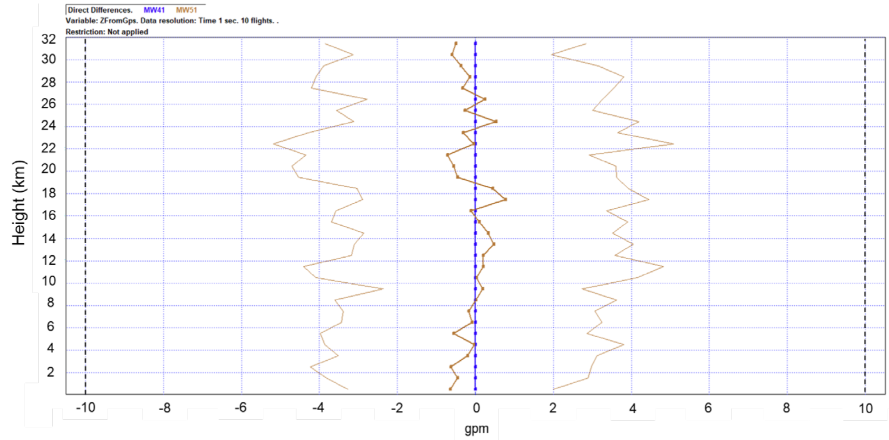

Figure 8: MW51 geopotential height measurement (GPS-based) comparison against MW41, used as a reference. The average differences between the two sounding systems are indicated by the bold line and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the accuracy of RS41 radiosonde in sounding.

The geopotential height comparison results from all soundings are shown in Figure 8. The average differences observed were 0.8 gpm or less and the random differences less than about 5 gpm at all heights, hence well within the total uncertainty of the RS41 in sounding of 10 gpm.

The GPS-derived pressure measurements between the two sounding systems are shown in Figure 9. The average differences in the lower troposphere were 0.07 hPa or less and the random differences less than about 0.4 hPa, but steadily decreased with increasing height. There are no significant differences between the pressure results of the two systems when compared against the RS41 specifications in Table 1.

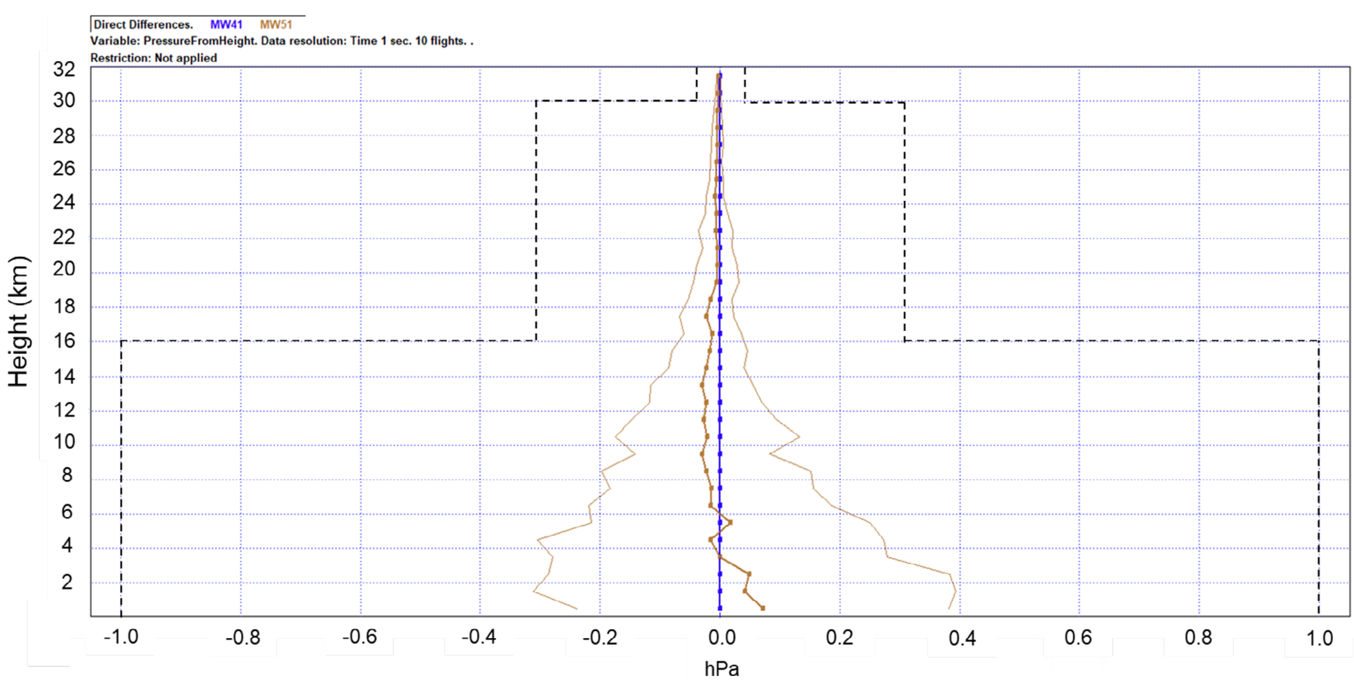

Figure 9: MW51 pressure measurement (GPS-based) comparison against MW41, used as a reference. The average differences between the two sounding systems are indicated by the bold line and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the accuracy of RS41 radiosonde in sounding.

7 Wind measurement

Wind measurements in both sounding systems are based on the same GPS signals received by the RS41 and similar processing, and do not depend on the GPS-derived location of the radiosonde. The comparison of N-S and E-W wind velocity components are shown in Figure 10 and Figure 11, respectively. The average difference in velocity is negligible and the standard deviation is equal or less than about 0.08 m/s, up to an altitude of about 29 km. The larger dispersion in random differences observed during the sounding arises from occasional data filtering interpolation of wind layers and inherent differences caused by different filtering implementations between the software versions, which become more effective at the end of radiosonde ascent and the subsequent descent transition.

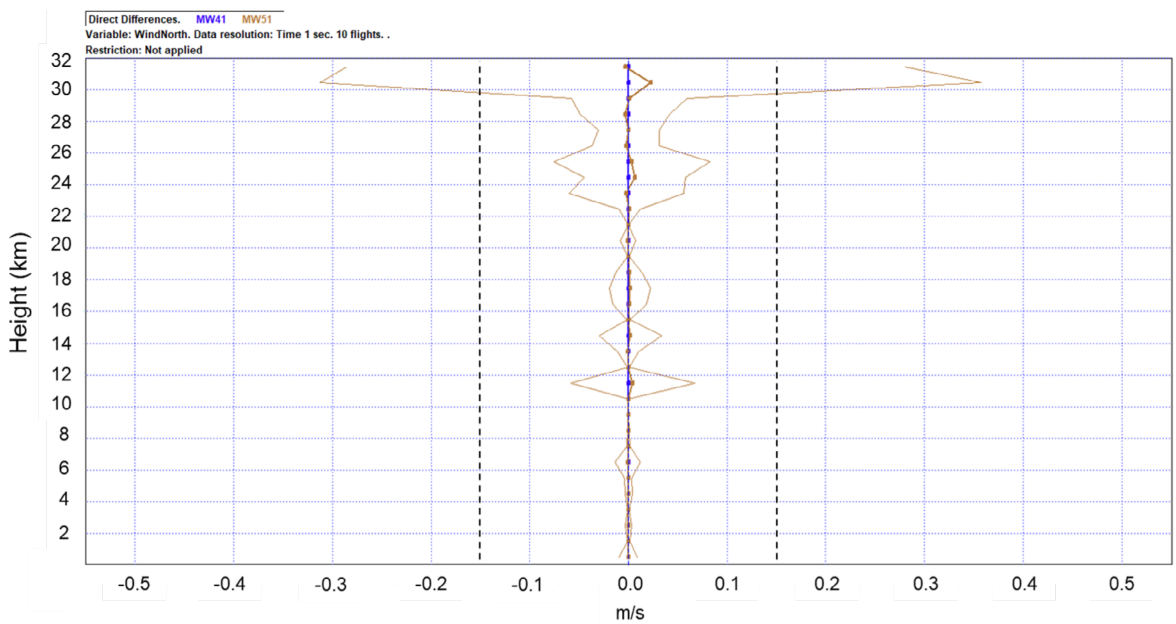

Figure 10: MW51 N-S wind velocity comparison against MW41, used as a reference. The average differences between the two sounding systems are indicated by the bold line and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the reproducibility of RS41 wind measurements in sounding, as one standard deviation of differences in twin soundings.

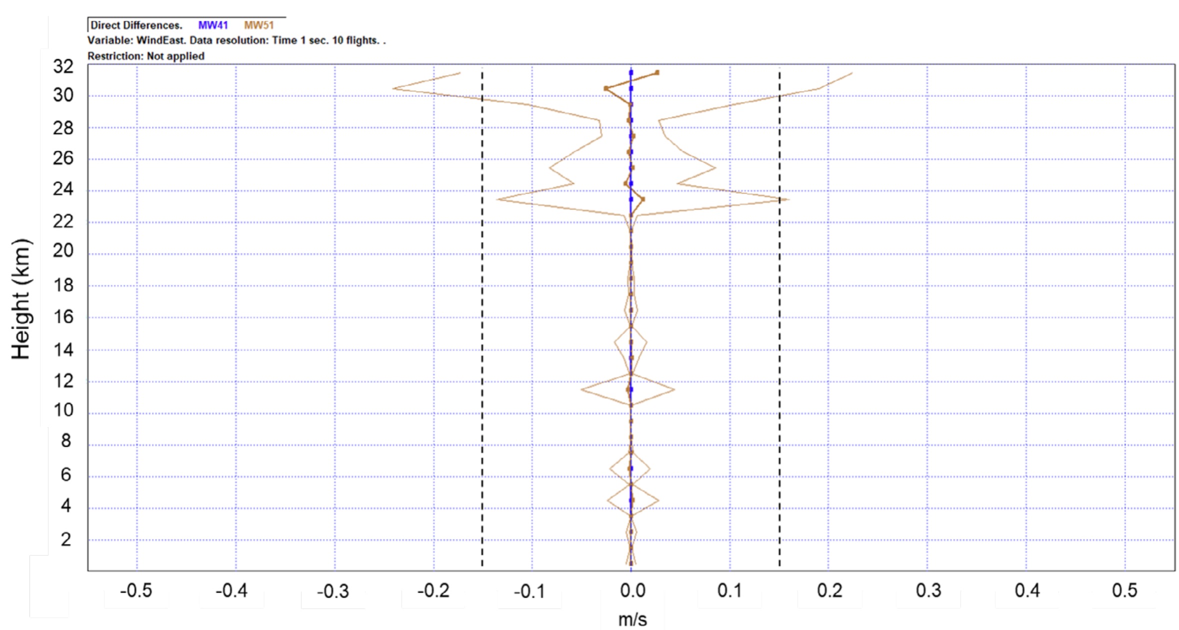

Figure 11: MW51 E-W wind velocity comparison against MW41, used as a reference. The average differences between the two sounding systems are indicated by the bold line and the two standard deviations of differences are indicated by the thin lines. The black dashed lines show the reproducibility of RS41 wind measurements in sounding, as one standard deviation of differences in twin soundings.

8 Data availability

The data availability comparison between the two sounding systems was performed by measuring the amount of valid telemetry at the end of sonde ascent, for the entire dataset (18 soundings). This additional variable is calculated as a percentage value from the total number of received frames, initialized only after the radiosonde has recognized balloon release, and the number of erroneous and missing frames.

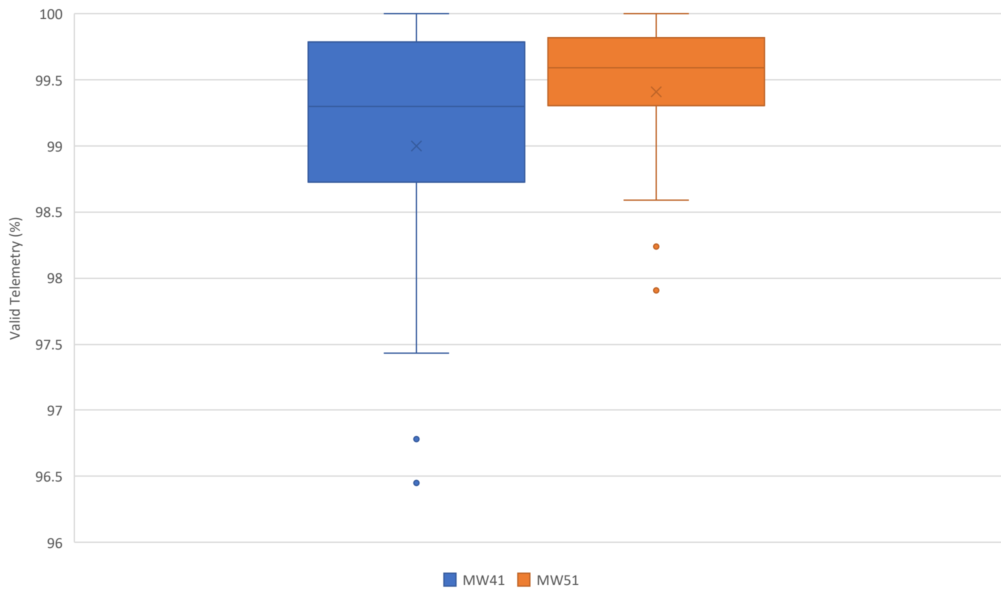

Figure 12: Valid Telemetry (%) comparison between the sounding systems. The cross represents the mean of data, the inside line is median, and the box width is determined by interquartile range.

The comparison shown in Figure 12 indicates that the MW51 ensures a slight improvement in the mean valid telemetry (99.4 % and 99.0 % for MW51 and MW41, respectively), and reduced dispersion in the distribution of values, which demonstrates the multiple reliability improvements of the new purpose-built radio receiver in the Sounding Processing Subsystem SPS511.

[1] Telemetry Antenna RM32, Vaisala Reference B210657EN-E

[2] GPS Antenna GA31, Vaisala Reference B210466EN-D

[3] RS41 Ground Check Procedures, Vaisala Reference B211539EN-C

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