Vaisala Radiosonde RS92 Performance in the WMO Intercomparison of High Quality Radiosonde Systems

/ YANGJIANG, CHINA 2010

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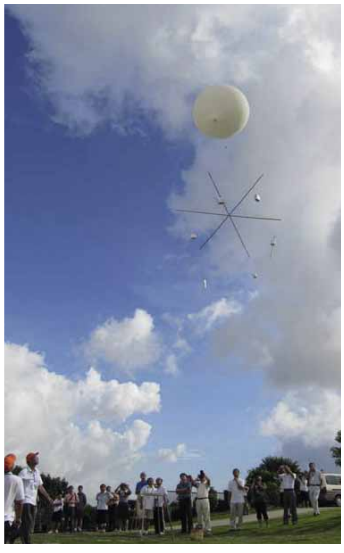

VAISALA

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1. Introduction

1.1 Executive Summary

The 8th WMO High Quality Radiosonde Intercomparison was held between July 13 and August 1, 2010 in Yangjiang, China. The Vaisala Radiosonde RS92-SGP and Vaisala DigiCORA® Sounding System MW31 participated in the intercomparison, achieving very good overall results in all measurement parameters. Eleven radiosonde manufacturers participated in the intercomparison, making this the largest measurement campaign in the history of modern radiosonde intercomparisons.

The Vaisala Radiosonde RS92-SGP performs very well in temperature measurement. This high level of performance is maintained in demanding conditions, such as those experienced after emerging from clouds, without exhibiting degradation due to evaporative cooling. In particular, the excellent humidity measurement of the RS92-SGP is shown in the intercomparison. When compared to a Cryogenic Frostpoint Hygrometer (CFH), which can be considered the de facto standard for upper-air water vapor measurement, the RS92 shows remarkable agreement in the relative humidity profiles obtained by the two instruments. The Vaisala Radiosonde RS92-SGP's geopotential height, pressure, and wind measurements - all based on the observations from the onboard GPS receiver- are all extremely accurate, demonstrating highly consistent performance in all intercomparison soundings.

The performance evaluation of the Vaisala Radiosonde RS92 is presented in **Table 1**. The RS92's average score was 4.96. The scoring limits are further discussed in Chapter 7.

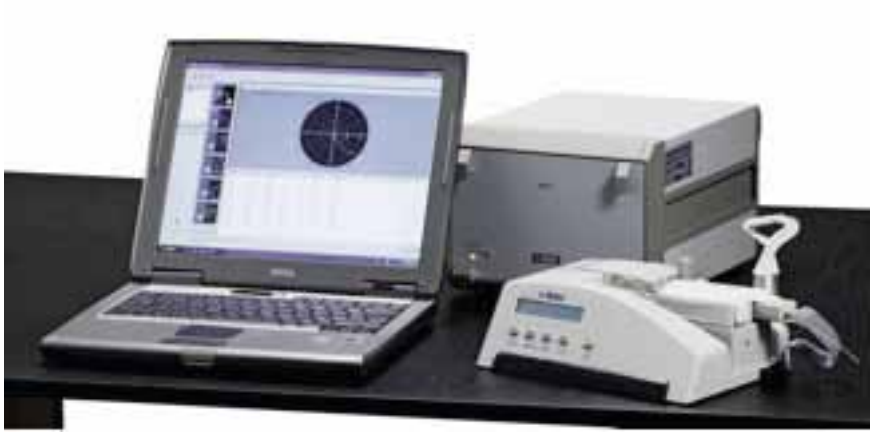


Figure 1. *The Vaisala DigiCORA Sounding System MW31 and Vaisala Radiosonde RS92-SGP*

Vaisala	Score	Accuracy limit for score*
Temperature, Night, Height < 16 km	5	0.3 °C
Temperature, Night, Height > 16 km	5	0.6 °C
Temperature, Day, Height < 16 km	5	0.3 °C
Temperature, Day, Height > 16 km	5	0.6 °C
Protection for Evap. cooling errors	Yes	
Humidity, T > -40 °C, Night	5	3 %RH
Humidity, T > -40 °C, Day	5	3 %RH
Humidity, T < -40 °C, Night	5	5 %RH
Humidity, T < -40 °C, Day	4.5	5 ... 10 %RH
Height, P > 100 hPa	5	10 m
Height, P < 100 hPa	5	20 m
Pressure, P > 100 hPa	5	1 ... 0.3 hPa
Pressure, P < 100 hPa	5	0.1 ... 0.04 hPa
Wind, troposphere	5	0.5 m/s
Wind, stratosphere	5	0.5 m/s
2 years in operation	Yes	
Used in	global	

*Proofs that Vaisala accuracy is at least this good.

Table 1. *Summary of the Vaisala Radiosonde RS92's performance as measured in the Yangjiang intercomparison.*

1.2 Applications of Radiosonde Data

Radiosonde data is used in a variety of meteorological applications. The technical solutions used in the Vaisala Radiosonde RS92 ensure that data it provides is highly accurate and suitable for its intended end use as illustrated in **Table 2**.

Today, the forecasts produced by numerical weather prediction models provide perhaps the most important information about synoptic-scale weather events. From a numerical weather prediction perspective, it is important that the input data does not exhibit biases, as it is assumed that any errors in the data are random. One example of a source of bias is the evaporative cooling effect after emerging from clouds, which leads to abnormally low temperatures above clouds. This can have an effect on the assimilation of temperature data into the weather model, reducing the positive impact that the radiosonde data would otherwise have, and therefore affecting the quality of the weather forecast. The Vaisala Radiosonde RS92 features a special hydrophobic coating applied to the temperature sensor to reduce the effects of this evaporative cooling.

Another example of a source of bias in radiosonde measurement is the chemical contamination of humidity sensors during storage, a typical phenomenon that happens with thin-film polymer sensors. This can cause dry bias in the humidity observations, resulting in humidity values that are too low and therefore hindering accurate cloud detection. The Vaisala Radiosonde RS92 implements a reconditioning procedure to ensure that any chemical contaminant that may have accumulated on the humidity sensor during storage is removed before the radiosonde is launched, thereby ensuring that the humidity observations are as accurate as possible. See reference 4 [4].

Radiosonde data is also used operationally to verify the performance and accuracy of outputs from numerical weather prediction models. For this particular use, it is important that the radiosonde reference data is of high quality so that the uncertainties that may be in the weather model can be identified with high confidence.

Atmospheric profile information is also directly assessed by meteorologists in order to monitor the upper-air conditions. These profiles allow meteorologists to determine the stability of the atmosphere and identify the presence of conditions for the formation and dissipation of fog or clouds, temperature inversion layers, vertical wind shear, and depth of convection, for example. These events can be forecast in the short term from radiosonde profiles, so it is important to have correct and reliable data on which to base the forecasts. The Vaisala Radiosonde RS92's sensors ensure that all the details of the atmospheric profiles are accurately measured and are available to meteorologists.

Climate change has revealed the importance of long-term, accurate meteorological observations. As water vapor is the most important greenhouse gas, it is important that accurate measurements are available in order to monitor how the concentration varies over years and decades. The suitability of the Vaisala Radiosonde RS92 for long-term climate monitoring was once again established in the WMO Radiosonde Intercomparison Final Report. For climate monitoring in particular, it is proposed that a radiosonde must have a performance score of at least 4 in all climate variables in order to be qualified for GCOS Upper Air Network (GUAN) use.

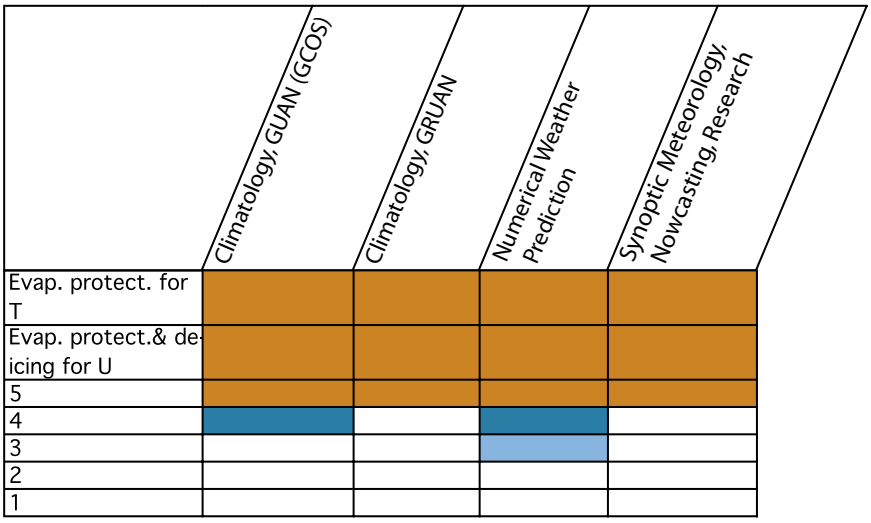


Table 2. *Vaisala Radiosonde RS92 data can be used effectively in a wide range of applications, indicated in orange in the table. GUAN = GCOS Upper Air Network, GCOS = Global Climate Observing System, GRUAN = GCOS Reference Upper Air Network. For GRUAN good product documentation and understanding of measurement uncertainties are also required.*

2. Temperature Measurement

The Vaisala Radiosonde RS92-SGP's thin-wire temperature sensor features very fast response time with small solar radiation correction; a typical solar radiation correction is 0.7 °C at an altitude of 10 hPa. The sensor is also protected with a hydrophobic coating to reduce the effects of evaporative cooling after emerging from clouds, for example.

The intercomparison also introduced the latest DigiCORA software (version 3.64), which contains newly developed algorithms for RS92-SGP temperature and humidity measurement. These algorithms are further explored in a Vaisala News article [2]. The information can also be found on the Vaisala Sounding Data Continuity pages [3].

The statistics of the temperature measurement performance comparisons, and the advantages of using a hydrophobic coating on top of the temperature sensor, are illustrated in the following sections.

2.1 Intercomparison Statistics for Radiosonde Temperature Measurement

The launch schedule at the intercomparison was four to five launches per day in order to capture radiosonde performance in both daytime and nighttime conditions. **Figure 2** through **Figure 5** shows the excellent performance of the RS92 in both situations.

In daytime conditions, high solar radiation intensity combined with varying cloud conditions and low atmospheric pressure set demanding requirements for accurate upper tropospheric and stratospheric temperature measurement. **Figure 2** presents the systematic bias between simultaneous temperatures of tested radiosonde models in daytime soundings. A considerable variation between radiosonde models can be detected from 14 km at the upper part of the soundings, ranging from -0.7 °C to 1.0 °C from the reference line at 32 km. The Vaisala Radiosonde RS92-SGP temperature measurement result is good, within -0.03 to 0.17 °C from ground level to 32 km. Corresponding estimates for random error are presented in **Figure 3**. The RS92-SGP showed highly consistent measurement, with random error of less than 0.2 °C throughout the profile.

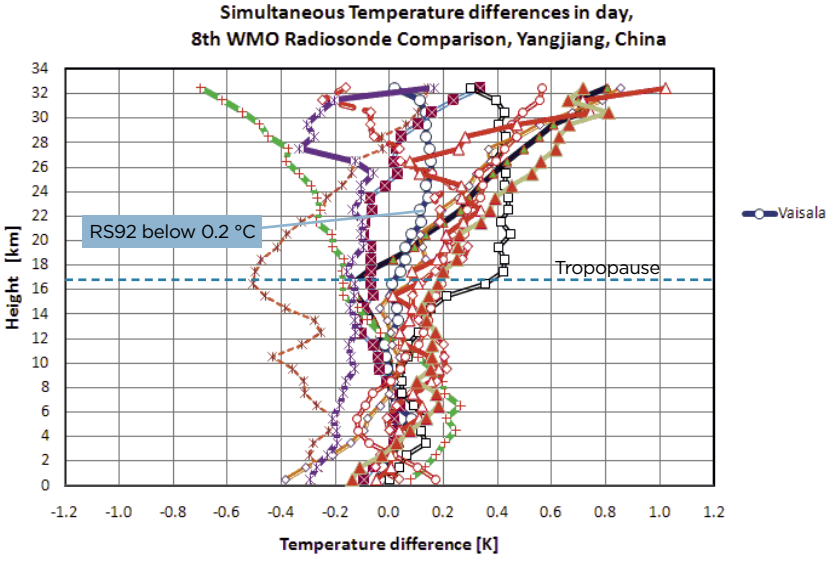


Figure 2. *Systematic bias between simultaneous temperatures (K) in the day, with reference adjusted above 16 km to take into account estimate of day-night differences in geopotential height analysis. Source: WMO Final Report, Fig. 7.1.3 [1]*

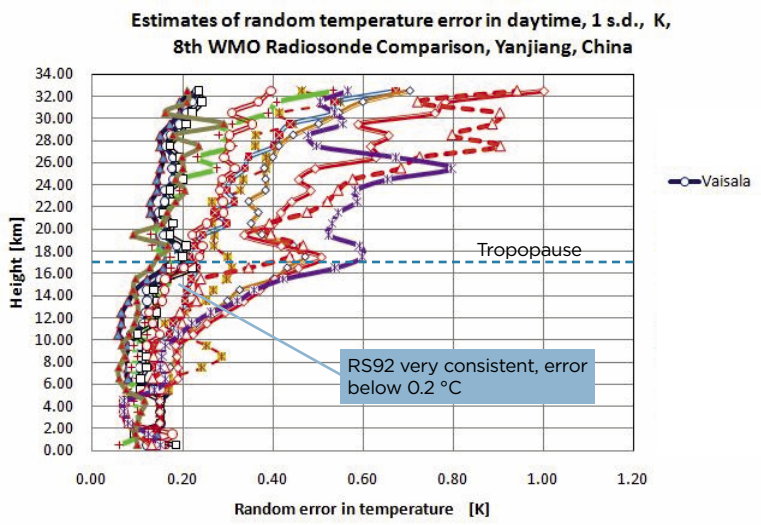


Figure 3. *Estimated random errors in temperature measurements in the day Source: WMO Final Report, Fig. 7.1.4 [1]*

Even though solar radiation does not effect measurements in nighttime conditions, good sensor properties are required to make the measurement insensitive to long-wave radiation, which is largely dependent on earth surface and cloud conditions. The good nighttime performance of the RS92-SGP can be seen in **figures 4** and **5** which show nighttime comparison result. Larger variation for some radiosonde models in the intercomparison can be seen in the tropopause region, at 16 km.

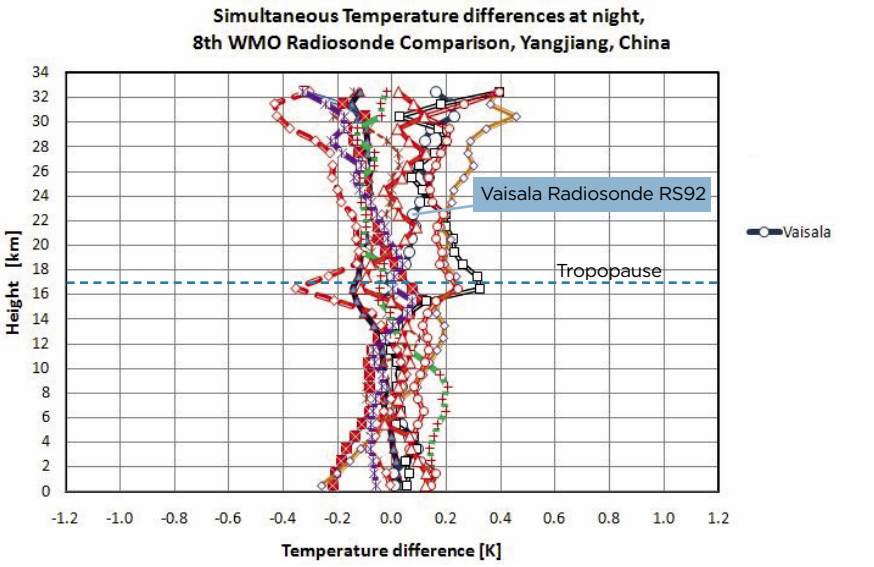


Figure 4. *Systematic bias between simultaneous temperatures (K) at night. Source: WMO Final Report, Fig. 7.1.1 [1]*

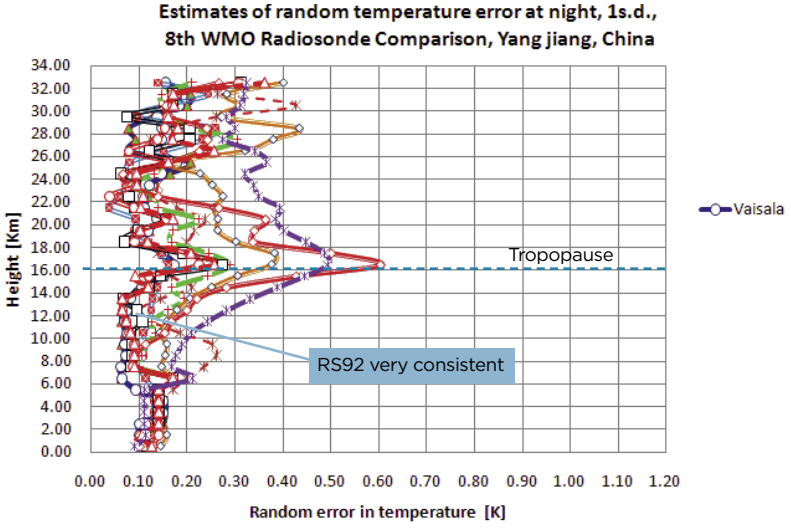
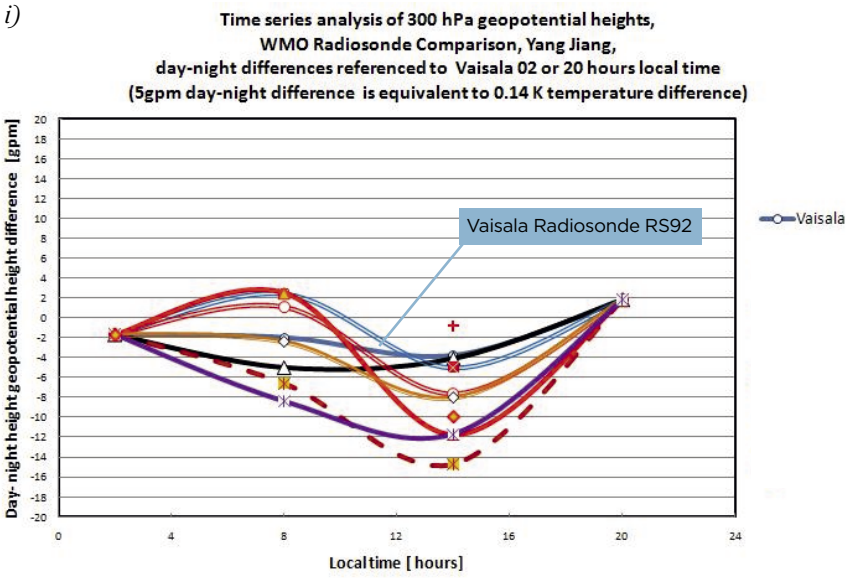


Figure 5. *Estimated random error in temperature measurements at night. Source: WMO Final Report, Fig. 7.1.2 [1]*

2.2 Temperature Day-Night Difference Analysis Using Geopotential Height

The temperature measurement performance difference between day and night is further compared in **Figure 6**, where the observed geopotential heights for two different pressure levels observed during the day and night are compared. The qeopotential height difference between two specified pressure levels is a good approximation proportional to the mean layer temperature between the pressure levels. The Vaisala Radiosonde RS92-SGP shows very good agreement between daytime and nighttime observations indicating that the temperature sensor is performing consistently under different solar radiation conditions. If a radiosonde system were to exhibit biases in temperature observations, the test would show altitude differences between daytime and nighttime observations of geopotential height. These differences are usually due to insufficient temperature sensor solar radiation correction, which results in errors in geopotential heights.

i)



ii)

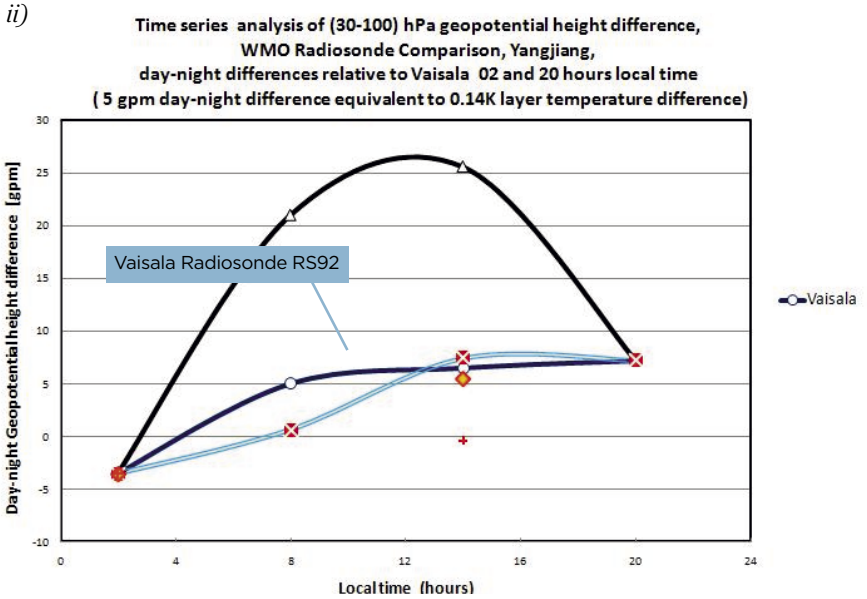


Figure 6. *Results of time series analysis of day-night bias in geopotential heights for pressure levels of (i) 300 hPa, (ii) (30-100) hPa.*
Source: WMO Final Report, Fig. 7.1.15 a) and c) [1]

2.3 Evaporative Cooling

When a radiosonde emerges from a cloud into a drier layer, the accumulated water from the surface of the wet temperature sensor starts to evaporate, causing the sensor to cool and show abnormally low temperature values. The Vaisala Radiosonde RS92-SGP minimizes the effects of this cooling by utilizing a hydrophobic coating on the temperature sensor, which prevents water from accumulating on the sensor in the first place. This ensures that the temperature values provided by the Vaisala radiosonde are reliable for use in further applications, such as assimilation into numerical weather prediction models, as noted in the Final Report [1].

In the China intercomparison, and also in the previous intercomparison in Mauritus in 2005, the success of the hydrophobic coating used in the RS92 was clearly visible. As an example, **Figure 7** shows RS92 measurements of temperature inversion at correct altitude at cloud top.

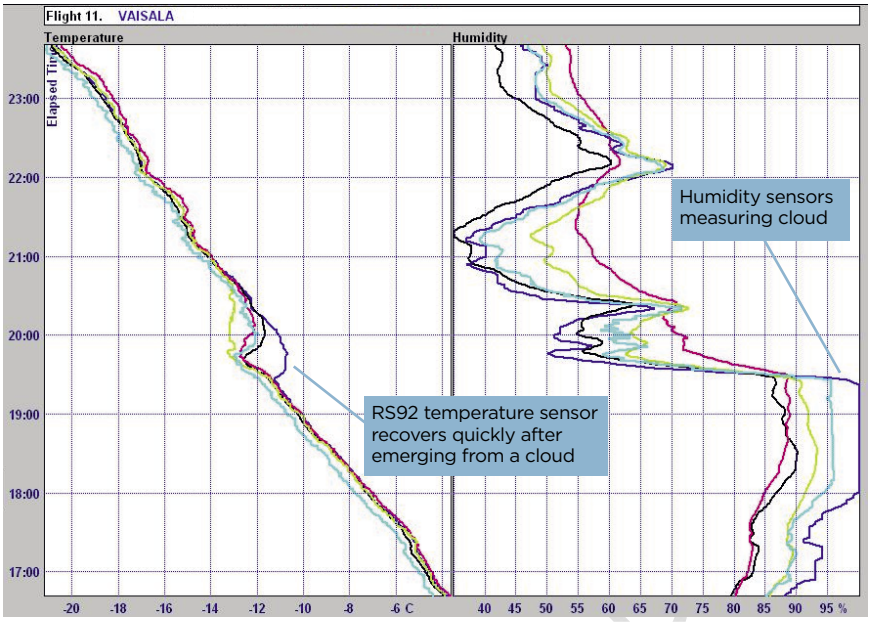


Figure 7. *For figure text and group reference description refer to source: WMO Final Report, Fig. 7.1.16 (b) [1]*

3. Humidity Measurement

As noted in the Final Report [1], humidity is still the most difficult parameter to measure properly, and it is a demanding task to ensure that the observed values exhibit low biases in all conditions, both during the day and at night. Together with the improved humidity computation algorithms, as described in the references at the end of this paper [2], the RS92-SGP achieved excellent humidity measurement performance in the intercomparison's operational Quality Radiosonde Systems (QRS).

The factors, actively removed from RS92-SGP, causing the errors identified by the report include:

- water vapor/ice contamination during ascent
- chemical contamination, which affects sensor performance

The Vaisala Radiosonde RS92 has two thin-film polymer humidity sensors optimized for radiosonde use. The sensors are pulse heated to prevent them from freezing. Another advanced feature of the RS92's humidity measurement is the reconditioning process of the humidity sensors before launch. This process ensures that any chemical contaminant that may have accumulated on the humidity sensor during storage is removed before the radiosonde is launched, thereby ensuring that the humidity observations are as accurate as possible.

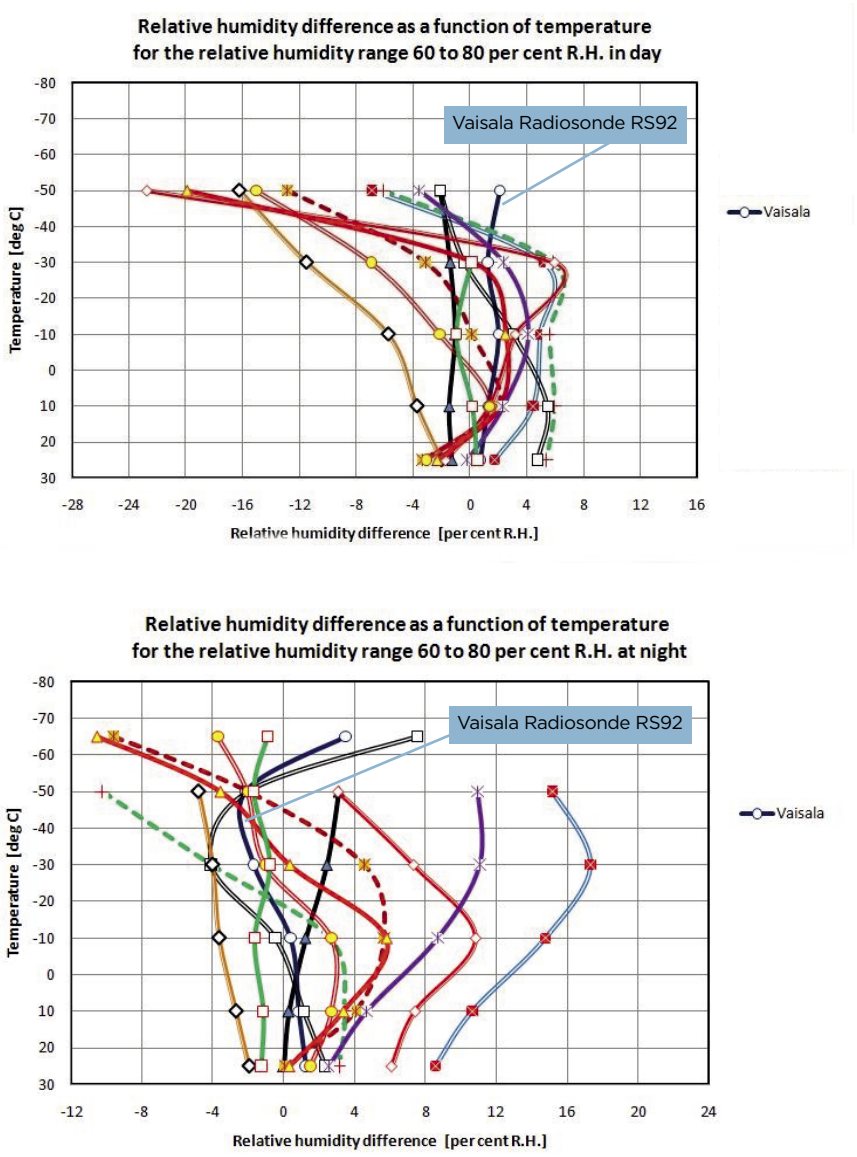


Figure 8. *Systematic bias (%) of relative humidity sensors from all QRS flights for the 60–80 % R.H. band (daytime at the top and nighttime at the bottom). Source: WMO Final Report, Fig. 8.1.4 [1]*

3.1 Intercomparison Statistics for Radiosonde Humidity Measurement

The systematic biases for relative humidity have been thoroughly analyzed in the intercomparison report in several bands. The results from the 60–80 percent R.H. band are shown in **Figure 8**. As noted in the report, the improvements in the RS92's solar radiation compensation lead to very good results, producing measurements that are within 2 percent of the reference data, both during the day and night.

The day-night differences as a function of relative humidity for the entire humidity range (5-95 % R.H.) are summarized for all the QRS systems in the intercomparison report. As illustrated in **Figure 9**, the Vaisala Radiosonde RS92 shows very consistent daytime and nighttime measurement right up to the coldest temperature (-75 °C).

3.2 Humidity Day-Night Difference Analysis, Integrated Water Vapor

The day-night difference of the radiosonde humidity measurement was also compared against integrated water vapor (IWV) data from nearby GPSMET stations. The results further indicate the good reproducibility of the RS92 humidity measurement between daytime and nighttime conditions. As seen in **Figure 10**, the IWV values derived from RS92 humidity profiles are highly consistent during the day and at night when compared to GPS IVW.

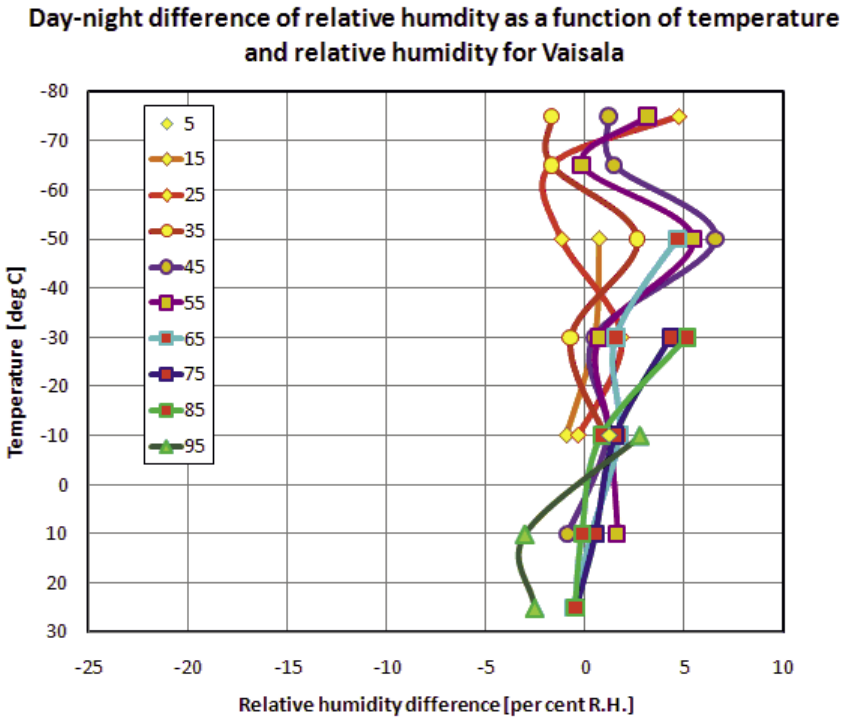


Figure 9. *Day-night difference in systematic bias of relative humidity plotted against temperature for relative humidity bands centered 10 % R.H. apart. Source: WMO Final Report, Fig. 8.1.13 [1]*

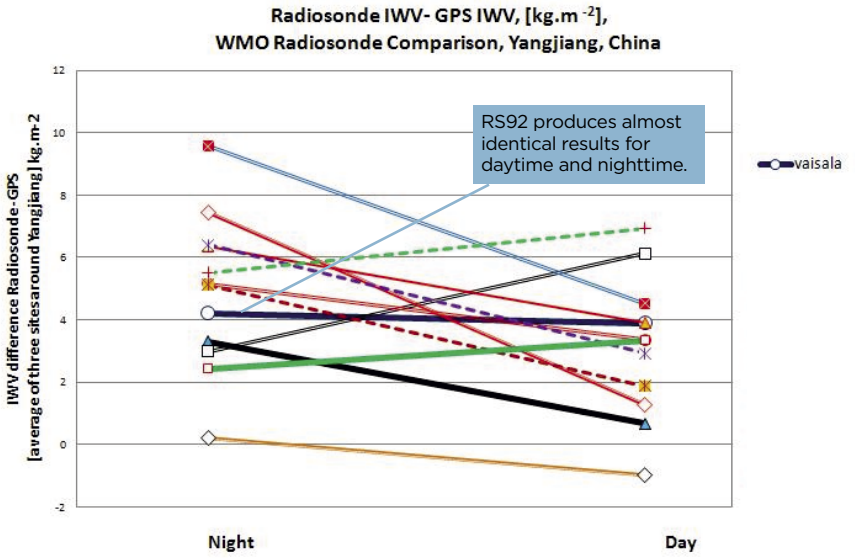
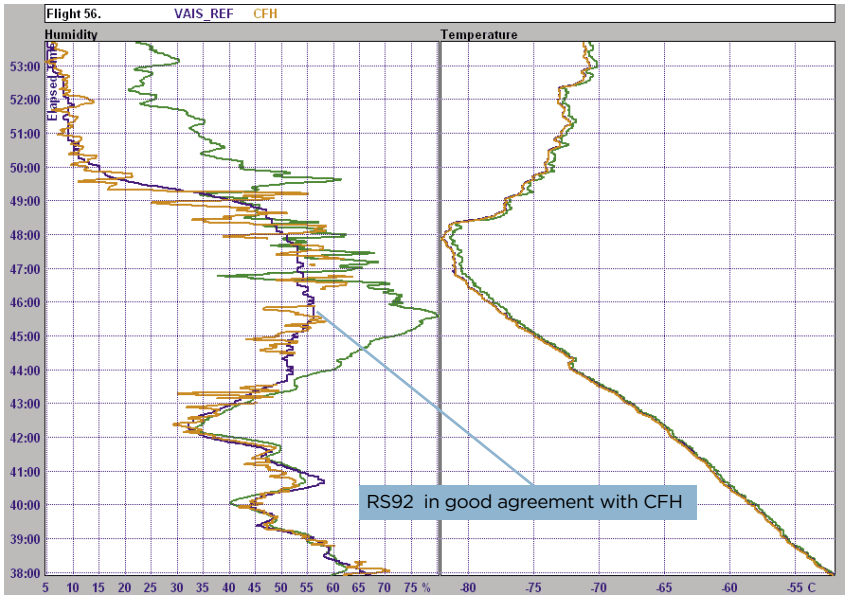


Figure 10. *Results of systematic bias in comparisons of integrated water vapour from each radiosonde type with simultaneous Yangjiang, Enping and Yangchun GPS integrated water vapour measurements.*
Source: WMO Final Report, Fig.8.4.2 [1]

3.3 Comparison of RS92 Against Cryogenic Frostpoint Hygrometer (CFH)

The Vaisala Radiosonde RS92 humidity sensor was compared against the Cryogenic Frostpoint Hygrometer (CFH, Vömel et al., 2007a), which is capable of measuring water vapor in the troposphere and lower stratosphere. The instrument can be consired the de facto reference standard for upper-air water vapor measurement. The comparison shows very good agreement between the sensors. This is largely thanks to the technical solutions in the RS92's sensor, the exposure that allows free ventilation during sounding as well as the algorithms used to produce the humidity values. The results of the comparison are presented in **Figure 11**. As stated in the report: "Based on these results, we can conclude that the Vaisala RS92 version tested in China shows systematic errors of less than 2 %RH and random errors of ~5% from the surface to the lower stratosphere."

Another example of good agreement between RS92 and CFH is shown in **Figure 12**.



(b) Comparison with Vaisala and CFH on Flight 56

Figure 11. *Profiles of RH differences between the RS92 and CFH. Source: WMO Final Report, Fig. D6.3 [1].*

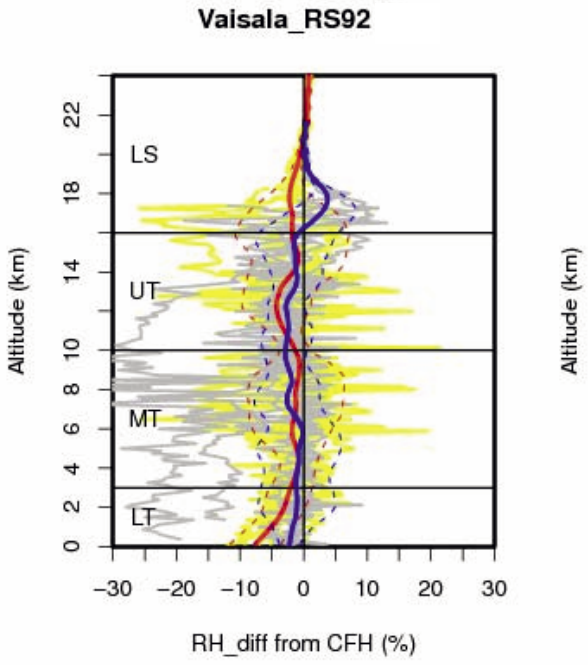


Figure 12. *Profiles of RH differences between the RS92 and CFH. Individual profiles are shown in yellow for daytime and grey for nighttime soundings; daytime mean differences in solid red, and nighttime mean in solid blue; standard deviations are shown with dashed lines. Source: WMO Final Report, Fig. 8.2.5 [1]*

3.4 Humidity Fine Structure

The relative humidity profilers in Yangjiang contained several detailed structures of the atmospheric conditions. Below are a few examples of the recorded performance of the Vaisala Radiosonde RS92 humidity measurement in these conditions. The figures show that thanks to the free-ventilated structure of its humidity sensors, active de-icing during flight, and improved algorithms; the RS92 is able to measure the different details of the atmospheric humidity profiles with very high accuracy.

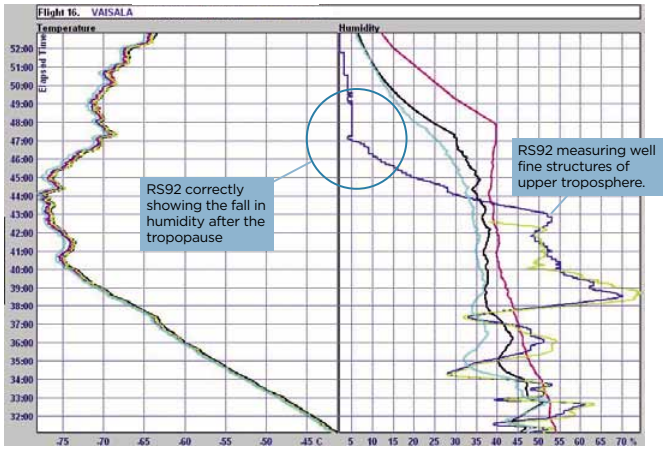


Figure 13. *For figure text and group description refer to source: WMO Final Report, Fig. 8.1.19 (a) [1]*

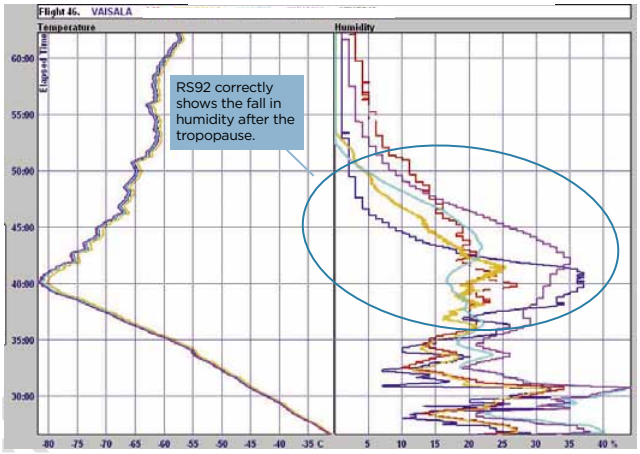


Figure 14. *Temperature and relative humidity as a function of time on a nighttime flight with dry conditions in the upper troposphere and no detectable cloud. Source: WMO Final Report, Fig.8.1.24 (a) [1]*

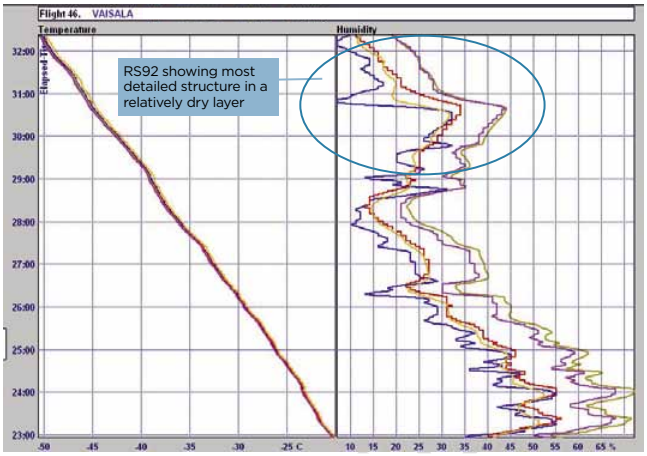


Figure 15. *Sample of detailed vertical structure from a single nighttime flight. Source: WMO Final Report, Fig. 8.1.16 (b) [1]*

4. Wind Measurement

Nowadays most radiosondes use GPS to measure wind speed and direction, as it is considered to be the most reliable and accurate technology for wind measurement. The Vaisala Radiosonde RS92-SGP incorporates a 12-channel code-correlating GPS receiver that uses differential GPS calculation in the ground receiving system. Together with the effective wind pendulum removal algorithm, this provided very good results in the intercomparison.

Figure 16 and **17** shows an example of the RS92-SGP's reliable performance. The RS92-SGP shows very small systematic difference and standard deviation in the intercomparison relative to the group references.

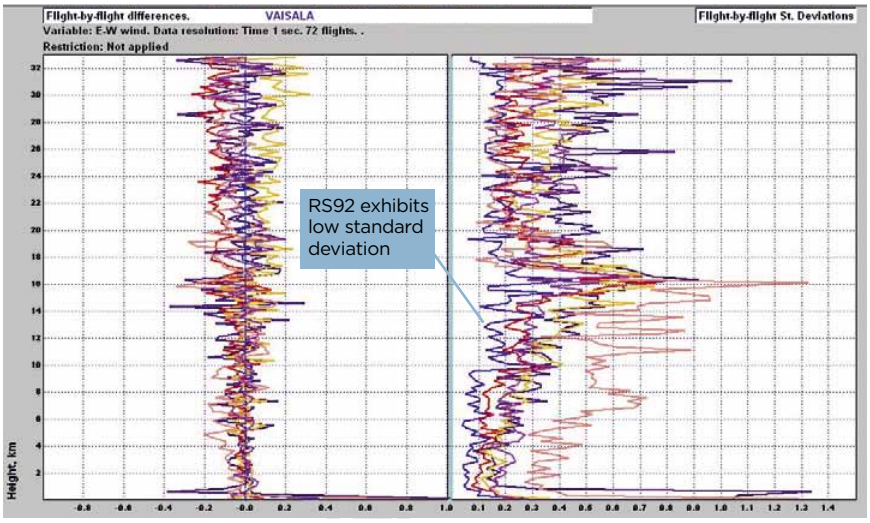


Figure 16. *For figure text and group reference description refer to source: WMO Final Report, Fig. 11.3.3 [1]*

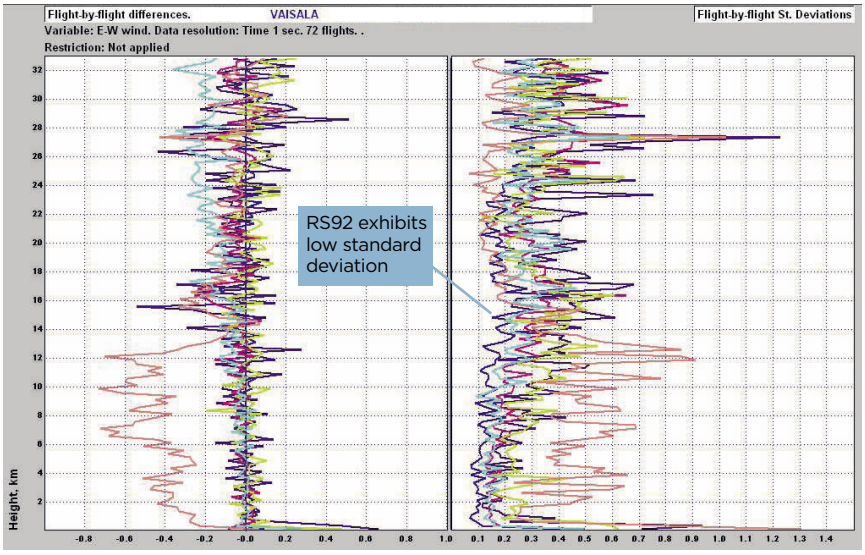


Figure 17. *For figure text and group reference description refer to source: WMO Final Report, Fig. 11.3.4 [1]*

5. Geopotential Height Measurement

The Vaisala Radiosonde RS92-SGP can measure geopotential height using either its pressure sensor or GPS. In the intercomparison the RS92's GPS was used for all flights, with the geometric height being converted to geopotential height.

As with GPS-based wind measurement, the measurement of geopotential height was also highly accurate. **Figure 18** and **Figure 19** show the statistical results of the geopotential height comparisons, indicating the highly consistent performance of the Vaisala Radiosonde RS92-SGP.

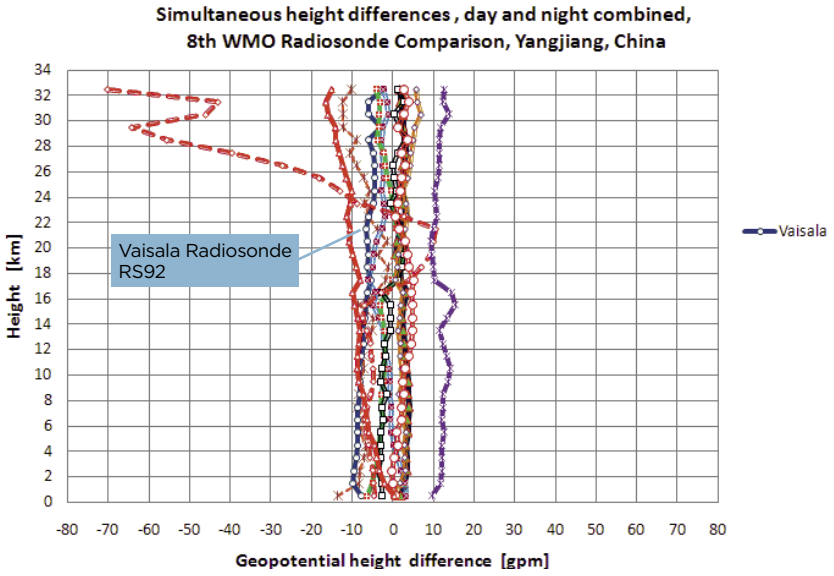


Figure 18. *Systematic bias between simultaneous geopotential heights [gpm], daytime and nighttime measurements combined. Source: WMO Final Report, Fig. 9.3.1 [1]*

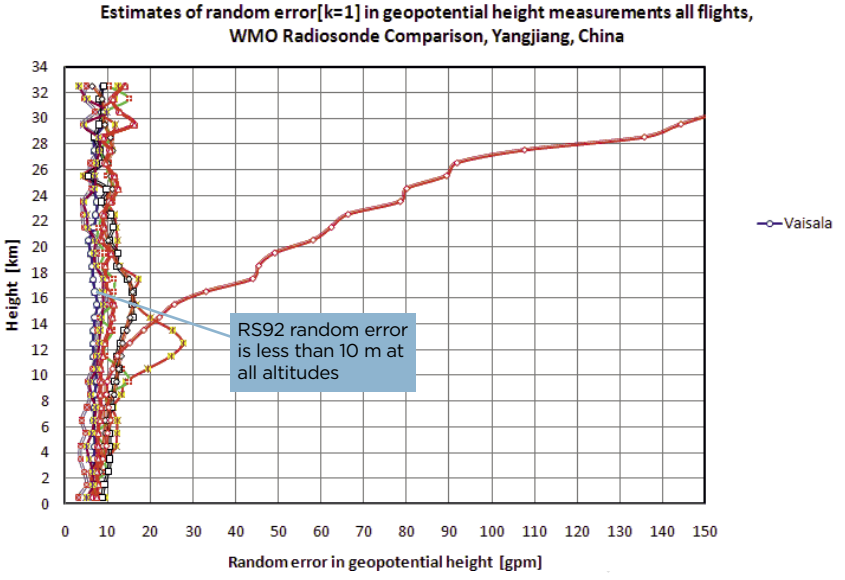


Figure 19. *Random error (k=1) of geopotential heights [gpm] measurements, daytime and night time measurements combined.*
Source: WMO Final Report, Fig. 9.3.2 [1]

6. Pressure Measurement

With the Vaisala Radiosonde RS92-SGP, pressure can either be measured using a silicon pressure sensor or derived from GPS height. In the intercomparison, the Vaisala Radiosonde RS92-SGP used GPS to measure the pressure, as was the case with all but one of the systems being compared. The consistency between the compared GPS pressure measurements was good, especially in the lower stratosphere, as shown in **Figures 20** and **21**.

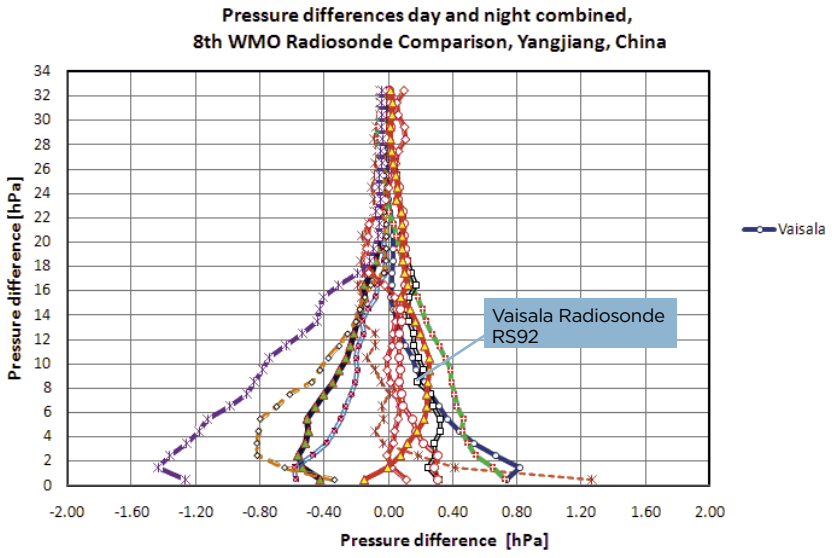


Figure 20. *Systematic bias between simultaneous pressures [hPa], day-time and night-time measurements combined. Source: WMO Final Report, Fig. 10.3.1 [1]*

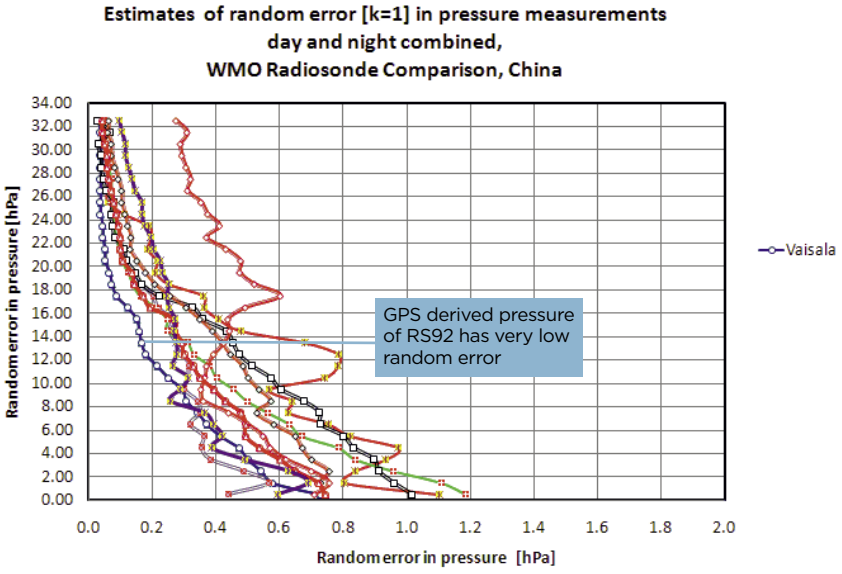


Figure 21. *Random error [k=1] of pressure [hPa] measurements, day-time and night-time measurements combined. Source: WMO Final Report, Fig. 10.3.2 [1]*

7. Performance Ratings

The Vaisala Radiosonde RS92's average score was 4.96 **(Table 3).** In addition, the RS92 is the only radiosonde that incorporates working protection against evaporative cooling. This protection ensures that the Vaisala Radiosonde RS92-SGP provides very good data accuracy for a wide range of meteorological applications. The accuracy limit values are taken from the intercomparison report, based on the score that the RS92-SGP received.

Complete Table of scores is available in the Final Report [1]. An explanation of the different scores, as applied in the WMO Final Report, is included in **Table 4**.

As the results indicate, the Vaisala Radiosonde RS92-SGP provides excellent quality radiosonde data, and this data is suitable for a wide range of applications, such as numerical weather prediction models, climatology, and synoptic meteorology.

Vaisala	Score	Accuracy limit for score*
Temperature, Night, Height < 16 km	5	0.3 °C
Temperature, Night, Height > 16 km	5	0.6 °C
Temperature, Day, Height < 16 km	5	0.3 °C
Temperature, Day, Height > 16 km	5	0.6 °C
Protection for Evap. cooling errors	Yes	
Humidity, T > -40 °C, Night	5	3 %RH
Humidity, T > -40 °C, Day	5	3 %RH
Humidity, T < -40 °C, Night	5	5 %RH
Humidity, T < -40 °C, Day	4.5	5 ... 10 %RH
Height, P > 100 hPa	5	10 m
Height, P < 100 hPa	5	20 m
Pressure, P > 100 hPa	5	1 ... 0.3 hPa
Pressure, P < 100 hPa	5	0.1 ... 0.04 hPa
Wind, troposphere	5	0.5 m/s
Wind, stratosphere	5	0.5 m/s
2 years in operation	Yes	
Used in	global	

*Proofs that Vaisala accuracy is at least this good.

Table 3. *Summary of Vaisala RS92-SGP performance as measured in the WMO intercomparison.*

	Temperature deg C, P > 100hPa	Temperature deg C, P < 100hPa	Humidity %RH, T > -40 deg C	Humidity %RH, T < -40 deg C	Height, P > 100hPa	Height, P < 100hPa	Pressure, P > 100hPa	Pressure, P < 100hPa	Wind speed m/s, P > 100hPa	Wind speed m/s, P < 100hPa	
5	0,3	0,6	3	5	10	20	1.. 0.3	0.1... 0.04	0,5	0,5	As good as can be expeted for GRUAN at the moment
4,75											
4,5											
4,25											
4			5	10							Better than operational requirements of CIMO Guide, but still needs some improvement to become ideal for GRUAN
3,75											
3,5											
3,25											
3	0,5	1	7.5*	15*	15*.. 60	100.. 120	1.. * 1.5	0.5..* 0.2	1	1,5	Just meets the operational requirements of the CIMO guide, *revised ones
2											Close to the accuracy requirements of operations in the CIMO guide
1	1	2	20	30	40.. 200	300	3.. 4	1.5.. 0.6	3	5	Minimum acceptable performance given current available technology
CIMO requirements WMO-No8, 2008	0,5	1	5	5	1.. 0.5%	-	1.. 2	2 %	1	2	For reference CIMO requirements as in WMO Guide nro.8 For GUAN it is recommended that for important climate variables score at least an overall category 4 is met.
Protection for Evap.cooling errors											Working protection is very important for weather forecast use.

Table 4. *Scoring categories used in Tables 1, 2 and 3 for evaluating QRS performance in Yangjiang [5]*

References

[1] Nash J., Oakley T., Vömel H. and Wei LI, 2011, WMO Intercomparison of High Quality Radiosonde Systems, Yangjiang, China, 12 July – 3 August 2010, Instruments and Observing Methods Report No. 107, World Meteorological Organization, 248 p.

[2] Vaisala News 185: Improved Measurement Accuracy of Vaisala Radiosonde RS92, January 2011.

[3] Vaisala Radiosonde RS92 Sounding Data Continuity, available at http://www.vaisala.com/en/products/soundingsystemsandradiosondes/soundingdatacontinuity/Pages/default.aspx

[4] Währn J., Rekikoski I., Jauhiainen H., Hirvensalo J.: New Vaisala Radiosonde RS92: Testing and Results from the Field, Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, American Meteorological Society, 2004.

[5] WMO Final Report, information combined from following tables and annexes: Table 12.2, Table 12.3, Table 12.4, Table 12.5, Table 12.6, Table 12.7; Annex E: Accuracy Requirements for Upper-Air Measurement, Extract from WMO Guide to Meteorological Instruments and Methods of Observation (WMO-No.8, 2008), Annex 12.A.: Accuracy Requirements (standard error) for Upper-Air Measurements for Synoptic Meteorology, Interpreted for Conventional Upper-Air and Wind Measurements.

Vaisala's additions in figures marked as blue color.

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