New Vaisala Radiosonde RS92: Testing and Results from the Field

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1. NEW VAISALA RADIOSONDE RS92 PRODUCT FAMILY

Vaisala Oyj (Vaisala) strives continuously to serve the meteorological community with innovative solutions for measuring the environment. Vaisala radiosondes are a cornerstone in the monitoring of upper-air pressure, temperature, humidity, wind velocity and direction as well as additional measurements such as ozone and radioactivity. The quality, accuracy and reliability of upper-air in-situ measurements correlate directly with the quality of weather forecasting and the timeliness of weather bulletins. The traceability of radiosonde measurements to international standards is necessary in order to maintain faith in the observation time series and the conclusions drawn from the data. Vaisala's answer to the new and demanding requirements of radiosonde users is given in the form of the new Vaisala RS92 radiosonde family. The RS92 radiosonde family was introduced at the AMS 2003 annual meeting at Long Beach CA in February 2003.

The key performance indicators for the RS92 radiosonde are: continuous wind data availability with code correlating GPS (global positioning system) and Loran-C windfinding and a high level of PTU (pressure, temperature, humidity) measurement performance. The high level of PTU measurement performance is a result of a number of improvements, particularly in humidity measurement. The “reconditioning” of the Vaisala HUMICAP® humidity sensor eliminates the dry bias phenomenon in operational soundings.

This paper concentrates on reviewing the characteristics of the new Vaisala RS92 radiosonde family in operational use and discusses the progress that has been made by radiosonde users in adopting the RS92 in place of older radiosonde models.

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Figure 1. *The new Vaisala RS92 GPS radiosonde with its modular mechanics.*

2. RS92 GPS WINDFINDING: DESIGN TARGETS, RESULTS AND SPECIFICATIONS

The operational targets for the RS92 GPS receiving and calculation system were determined at an early stage of RS92 development. These targets formed the basis for the design of the radiosonde and also set the requirements for the manufacturing process. The operational targets were:

- 100% wind data availability in terms of GPS tracking and calculation capability
- 100% production quality of the radiosonde GPS receiver
- Fastest possible signal acquisition time and Time-To-First-Fix (TTFF) with cold start conditions, i.e. without any initialization of the radiosonde GPS receiver

- GPS receiver must have high immunity against external interference caused by e.g. radar
- Sufficient position and velocity determination accuracy for all conditions and for all customers

Analysis of these targets resulted in design and production-related specifications. The means of meeting the specifications were analyzed in order to find the optimal technical solution for each target and performance specification. The most important performance specifications, operational targets and the means of meeting the performance specifications are shown in Table 1.

Table 1. *RS92 GPS system operational targets, performance specifications, means of meeting the performance specifications*

Operational target	Design and production related specifications	Means of fulfilling the specifications
100% GPS tracking and calculation	High operational margin in receiver tracking capability High tolerance against external disturbances Measurements and calculation results always valid and reliable	HW and SW design focuses on high GPS receiver sensitivity HW and SW design SW design to ensure validity of measurement and calculation results
100% production GPS quality	All components must be approved and specified variation of components must not affect performance Support for reliable testing of the GPS receiver Operational and performance GPS test for all produced units	HW design, careful component selection and verification of component specifications HW and SW design according to DFM/T (Design For Manufacturing/ Testing) GPS production testing system design
Fast GPS signal acquisition and TTFF	At least 4 signals must be acquired in less than 20 seconds in normal conditions without any prior signal information Calculation must produce valid data immediately after satellites are acquired	HW and SW design for a fast search engine that requires no initialization SW design (radiosonde & sounding processor)
GPS receiver immunity to interference	Effective filtering of out-of-band signals Prevention of system jamming	HW design methods to filter interfering signals HW and SW design to enable system recovery in case of malfunction, caused for instance by extremely strong radar pulse
Good position and velocity accuracy	Velocity determination uncertainty less than 0.2 m/s, positioning uncertainty less than 10 m (horizontal) and 20 m (vertical) High accuracy also for moving sounding station	SW design (radiosonde & sounding processor) SW design (sounding processor) to enable independence of the reference GPS receiver

2.1 *Success in reaching the operational targets*

The RS92 GPS models available today are the RS92-SGP, RS92-AGP and RS92-BGP. These models are identical from the point of view of GPS performance, the only difference between them being the transmitter module. The design of the three models is frozen and production has begun. Further development will naturally take place in both the radiosondes and receiving system, but the development model will be a "continuous improvement process". The original operational targets have been reached with the RS92 GPS models now in production.

From the beginning of 2003 to October 2003, a total of 640 RS92 GPS radiosondes have been consumed in test and demonstration soundings. Soundings have been made on every continent and in at least 22 different countries. The RS92 GPS soundings carried out in 2003 can be categorized as follows:

Category	**Pcs**
Total number of test and Demonstration soundings	640
Internal test soundings	250
Customer demos / other customer testing	390
RS92-SGP radiosondes	400
RS92-AGP radiosondes	140
RS92-BGP radiosondes	100

Operational soundings made in Germany are excluded from these figures.

As a result of the soundings already performed, it is possible to draw further conclusions about how successfully the original operational targets have been reached. During the early part of 2003, several modifications were made which further improved the performance of the DigiCORA III sounding system. In the analysis of the results, therefore, only soundings made after July 2003 are included since only those soundings were carried out with the production version of the sounding system. Table 2 summarizes the original operational targets, the results achieved and the conclusions to be drawn.

Table 2. RS92 GPS system: operational targets, results achieved and the conclusions to be drawn.

Operational target	Results achieved	Evidence
100% GPS tracking and calculation	GPS receiver tracking capability has high operational margin and is highly tolerant of different environmental conditions and external interference. Also, shorter strings can be used from GPS point of view without any problems.	As a result of 147 analyzed soundings, 0.1 % of winds were missing due to poor tracking or calculation problems. See Figure 2.
100% production GPS quality	Production testing system reliably identifies units that have decreased sensitivity or otherwise degraded performance.	No GPS defects found in soundings after implementation of the test system. See Figure 2.
Fast GPS signal acquisition and TTFF	In normal conditions, less than 20 seconds' TTFF is achieved without initializing the radiosonde receiver.	Artificial power-up tests with different satellite geometry were performed. Also, TTFF times were calculated from soundings where launch was done directly from the balloon shelter.
GPS receiver immunity to interference	Out-of-band interference immunity is good. In-band immunity is at typical GPS receiver level and is difficult to improve. System recovers quickly even from the heaviest radar pulse (several MW at short distance).	Standard immunity and other EMC tests were done. Also, tests in range of different radar systems were done to test performance in real high interference conditions.
Good position and velocity accuracy	Achieved results are as specified.	Comparison soundings were made to verify position and velocity uncertainty and repeatability in sounding. See Figures 3, 4 and 5.

Figure 2 shows the GPS tracking and wind calculation success rate in soundings made from August 2003 onwards (RS92-SGP, RS92-AGP and RS92-BGP radiosondes). Each value represents the rate of successfully calculated wind levels, divided by all the raw GPS data frames received during the sounding. Errors that occurred during telemetry transmission are excluded. No soundings were disqualified and removed from the sounding database due to malfunctions in the radiosonde or missing data.

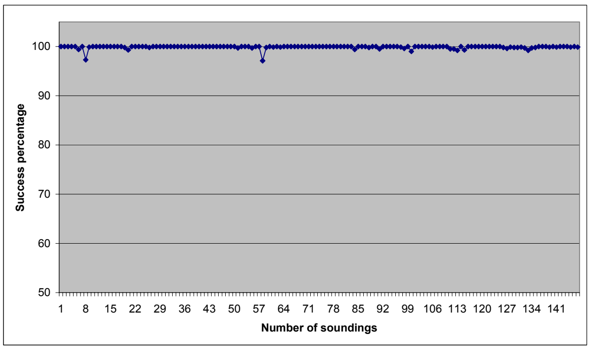

Figure 2. *GPS tracking and wind calculation success rate.*

Figure 3 shows the direct wind speed (velocity) differences of two RS92-SGP radiosondes and one RS80-15G radiosonde launched in a single rig (triple sounding). The reproducibility of wind speed (velocity) in sounding is seen to be excellent for the RS92-SGP radiosondes: there is no systematic difference in the results of the 23 soundings. The RS80-15G tracking problems and interpolation of data cause larger differences than can be seen between the two RS92-SGP radiosondes.

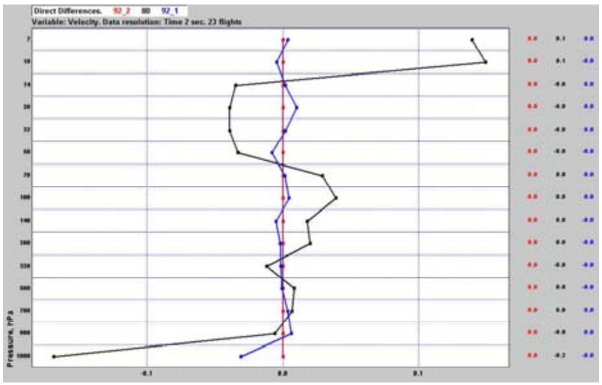

Figure 3. *Wind speed (velocity) direct differences of two RS92-SGP sondes and one RS80-15G sonde.*

Figure 4 presents the wind speed (velocity) standard deviation of differences of two RS92-SGP radiosondes and one RS80-15G radiosonde. The wind speed (velocity) uncertainty in sounding is very small for the RS92-SGP radiosondes. The RS80-15G tracking problems and interpolation of data, especially in the beginning and in the latter part of the sounding, cause a larger deviation than is seen between the two RS92-SGP radiosondes. A total of 23 triple soundings made in May 2003 are included in the analysis.

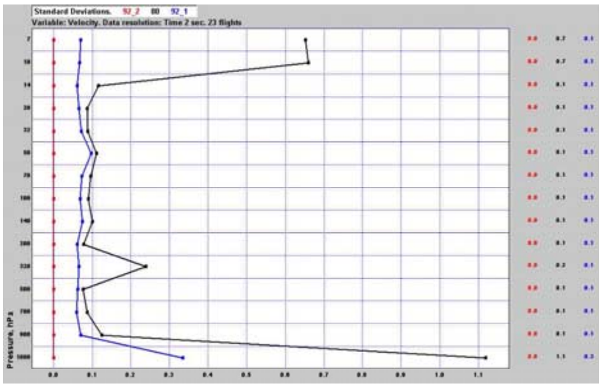

Figure 4. *Wind speed (velocity) standard deviation of differences of two RS92-SGP radiosondes and one RS80-15G radiosonde.*

Figure 5 shows the positioning error of the RS92-SGP measured during a static test at ground level. Please note that the position and velocity accuracy of the GPS is better after the radiosonde is released since the multipath effect (reflected signals) caused by surrounding obstacles and the ground, decreases.

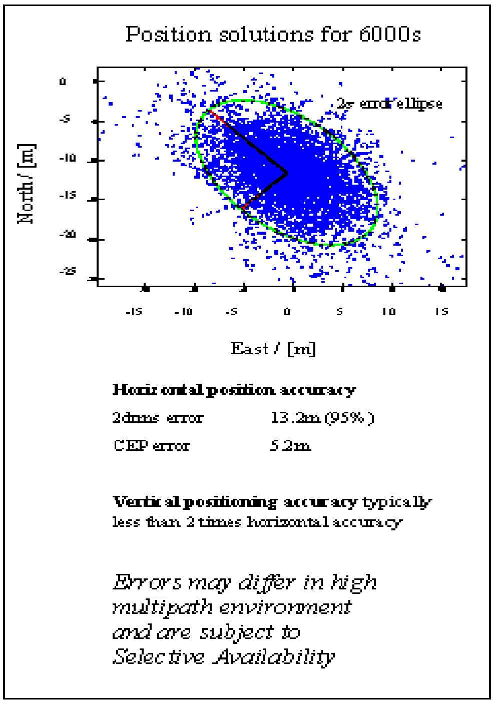

Figure 5. *Positioning error of RS92-SGP system measured in static test at ground level.*

Based on the extensive testing of the RS92 GPS models, both with test series and in operational use, it can be stated that the RS92 GPS radiosondes fulfill the requirements of the most demanding GPS radiosonde users.

3. PROVEN HIGH PTU PERFORMANCE

One of the key focus areas in the development and fielding of the RS92 radiosonde has been to maintain and enhance the performance of the PTU sensors used in the RS90 radiosonde family. The biggest improvement in RS92 PTU performance is in humidity measurement. A new reconditioning procedure has been introduced for the Vaisala HUMICAP® humidity sensor which significantly reduces the so-called “dry bias” phenomenon of humidity measurement.

3.1 Humidity

The new RS92 radiosonde family introduces a higher level of humidity measurement performance. The humidity sensor used in RS92 radiosondes is based on the humidity measurement technology originally introduced with the Vaisala Radiosonde RS90.

The calibration accuracy of the HUMICAP® humidity sensor and its time response capability have been proven in operational use with the RS90 radiosonde. Special attention has now been paid to such factors as sensor stability, calibration accuracy after storage, and the elimination of the possible condensation of water vapor during sounding. As a result, some significant improvements have been made.

3.1.1. Drift at 100% RH level

The stability of the RS92 humidity sensor in high humidity is presented in Figure 6. The humidity sensors were exposed to 100 %RH (+25 °C). The first measurement was done after stabilization of the test chamber conditions. The humidity sensors were measured several times for a period of 62 minutes. The 100 %RH level humidity drift in 62 minutes for the RS92 humidity sensor is around 0.5 %RH. The RS90 humidity sensor drifts several %RH in the same conditions and time period.

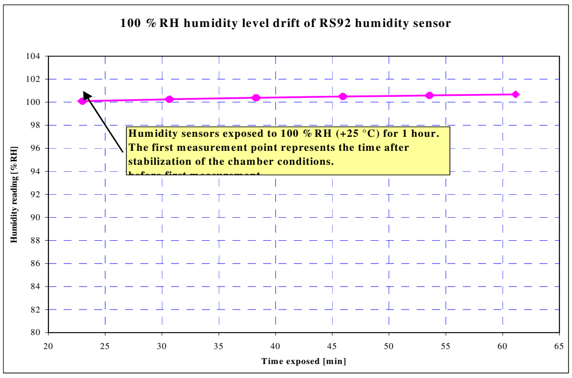

***Figure 6**. 100 %RH level humidity drift of the RS92 humidity sensor. Sample size 16 pcs.*

3.1.2 Elimination of humidity sensor chemical contamination

HUMICAP® is a thin-film polymer humidity sensor which works on the principle of water molecule absorption into the sensor surface. During storage, the humidity sensor can also absorb foreign molecules, e.g. contaminants. These contaminants can produce a bias into humidity measurement if contamination during storage is not prevented or if it is not properly removed prior to flight.

With the RS92 radiosonde, Vaisala introduces a new reconditioning procedure which removes all contaminants from the humidity sensor surface. In this reconditioning procedure, the humidity sensors are heated just before sounding in order to remove possible contaminants from the sensor surface and restore the original calibration accuracy.

The reconditioning process is presented in Figure 7. This test was made using an artificial, highly accelerated chemical contamination environment. According to Vaisala statistics, the worst-case contamination in a real environment leads to a measurement error of less than 5 % RH; a typical level of contamination leads to an error of 0 - 3 % RH.

The blue line in Figure 7 is the error in humidity measurement caused by artificial contamination. The red line is the error for the same humidity sensors after the reconditioning procedure.

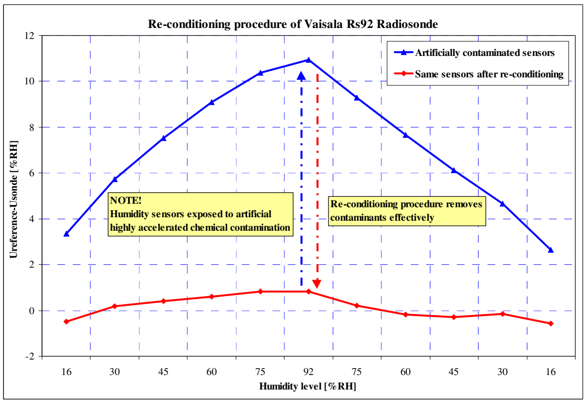

***Figure 7**. Elimination of humidity sensor contamination with reconditioning procedure. Contamination is artificially accelerated and thus does not represent a real storage environment. Sample size 32 pcs.*

In Figure 8 the contamination is assumed to be 3 %RH at 92 %RH after storage. The other values were calculated according to the data in Figure 7. The blue line is the amount of contamination in each humidity level after storage. The purple line is the remaining amount of contamination after the same sensors have been reconditioned.

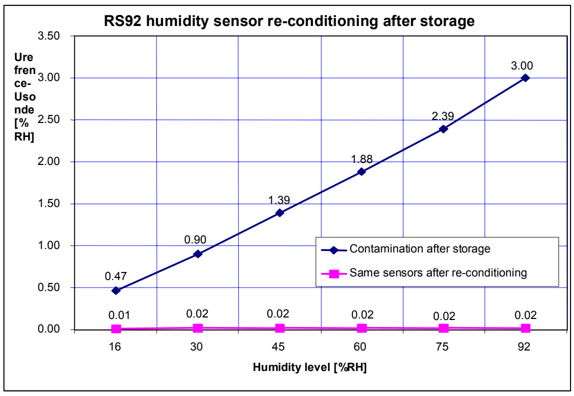

***Figure 8**. Elimination of humidity sensor contamination with reconditioning procedure.*

3.1.3 Optimized timing of sensor heating to prevent sensor icing

The method of using two heated humidity sensors was introduced with the RS90 radiosonde. With two heated humidity sensors, the possible error caused by the condensation of water vapor on the humidity sensor during radiosonde ascent is eliminated and humidity measurement proceeds correctly. This procedure is called "pulse heating".

"Pulse heating" heats one humidity sensor to remove any ice or water condensation from the sensor surface while the other humidity sensor measures relative humidity during the radiosonde's ascent. After the heating cycle, the "cleaned" sensor is cooled down and starts its measuring cycle while the other sensor is heated, and so on. As a result, a clean humidity sensor is always used for measurement.

In RS90 radiosondes, the heating time is the same throughout the sounding. Also, the recovery time is not altered.

To improve humidity measurement accuracy and humidity sensor response time, Vaisala has introduced optimized temperature- dependent pulse heating with the RS92 radiosonde. With the RS92, the heating time and recovery time are both adjusted as a function of temperature measured by the RS92. The pulse heating cycle is now much faster in the lower atmosphere, which significantly reduces the likelihood that water vapor will condense on the humidity sensor surface when the radiosonde emerges from low cloud cover. As a result, the RS92 radiosonde detects the tops of low-level clouds more precisely than was previously possible. This is presented in Figure 9. Also, the cut-off temperature for pulse heating can be lowered to under -40 ºC as compared to the RS90 radiosonde.

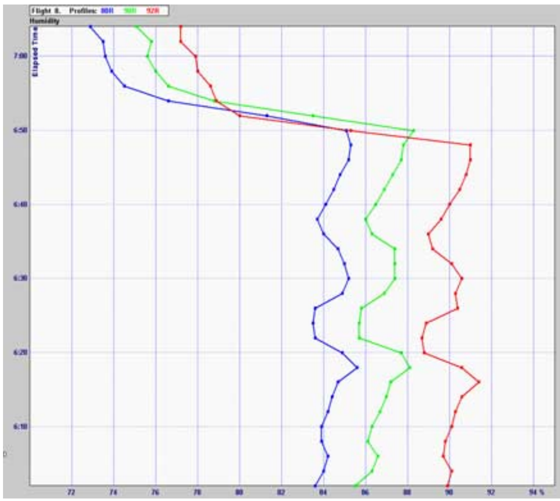

Figure 9. *Example of RS92 humidity measurement performance when it emerges from low cloud. The red line on the right was measured by the RS92, the green line in the middle by the RS90, the blue line by the RS80.*

3.3 Temperature and pressure measurement

The pressure and temperature measurement technology of the RS92 radiosonde family is based on the pressure and temperature measurement technology used in the RS90 radiosonde family.

The temperature and pressure measurement performance of the RS90 radiosonde family have proved to be at a high operational level. The F-THERMOCAP® temperature sensor calibration accuracy, hysteresis, time response and effects of solar and infrared radiation are features that have already been introduced with the RS90 radiosonde. The BAROCAP® pressure sensor has also proven itself in the RS90 radiosonde.

With the RS92 radiosonde, Vaisala continues to offer the same high level of temperature and pressure measurement performance that the RS90 is known for.

4. EXAMPLES OF USER EXPERIENCES WITH RS92 RADIOSONDES

The new RS92 radiosonde family has been well-received by the radiosonde user community. Among the early adopters of the new technology is the "Deutscher Wetterdienst" (DWD), the German Weather Service. The DWD has chosen the RS92 radiosonde and the DigiCORA III Sounding System as the new replacement equipment for its entire German upper-air radiosonde network. The German network uses GPS windfinding technology.

Furthermore, the DWD's AUTOSONDEs are currently being upgraded to fly the RS92. The first operational soundings at the Essen AUTOSONDE site revealed a dramatic improvement in GPS wind data availability with the RS92 GPS radiosonde compared to the previous generation of equipment.

The operational characteristics and performance of the RS92-SGP radiosonde were also evaluated in a test organized by Varde Artillery school, Denmark, from 8.9.03 - 20.9.03. During a two-week test period, almost one hundred soundings were made with a good success rate. The RS92-SGP radiosonde, DigiCORA III Sounding System and GC25 ground check set proved to be operationally mature for a tight sounding schedule of eight soundings per day.

So far, RS92 soundings have been performed successfully in at least 22 countries on every continent. The UK-Met. Office is currently validating the RS92 for operational use in their network.

4.1 *RS92-KL, Loran-C radiosonde validation trial at Praha-Libus, Czech Hydrometeorological Institute (CHMI)*

An important validation trial of the RS92 for operational use was performed at the Praha-Libus upper-air station of the Czech Meteorological Service (CHMI). At the moment, the Praha-Libus station operates mainly with Vaisala RS90 Loran-C radiosondes. The goal of the validation trial was to test a plan to start using Vaisala RS92 radiosondes and the DigiCORA III Sounding System at the Praha-Libus station. The focus was on reviewing possible changes in the aerological data, the homogeneity of the time series, an evaluation of sensor performance and data transmission of two Vaisala ground systems - DigiCORA MW11 and DigiCORA III.

The trial period was from 26th of May to 6th June 2003 consisting of 33 twin-flights and analysis of results. The trial was led by Dr. Pavla Skrivankova, Head of the Upper Air and Surface Observation Department. The radiosondes used in the trial were the RS92-SGP and RS80-15G with GPS windfinding, the RS92-KL with Loran-C windfinding and the RS90-AL with Loran-C windfinding.

Evaluation of the soundings was carried out with binary and ASCII data in 5-second steps. The RS92 was used as a reference versus the RS80 and RS90 radiosondes. Direct differences were compared in a time-scale by means of WMO radiosonde intercomparison software. The heights of standard pressure levels were compared against the ALLADIN model analysis

The ALLADIN model analysis results are shown in Table 3.

Table 3. Results of ALLADIN model analysis.

	RS90-AL	(n=14)	RS92-KL	(n=14)
P[hPa]	Mean [m]	STD dev. [m]	Mean [m]	STD dev. [m]
500	-5.4	8.9	-7	7.2
300	-2.4	8.1	-2.7	6.6
200	1	11.3	2.4	8.2
100	-6.2	12.4	-3.5	10.6
50	-12.7	14.5	-9.4	12.9

	RS80-15G	(n=14)	RS92-SGP	(n=14)
P[hPa]	Mean [m]	STD dev. [m]	Mean [m]	STD dev. [m]
500	-6.4	7	-6	6.4
300	-7.4	10.1	-3.4	8.7
200	-10.9	9.6	-3.4	5.9
100	-15.9	10.9	-6.7	7.3
50	-21.8	10.1	-12.3	9.3

The conclusions drawn from the CHMI tests were: The PTU differences between the RS92 and RS90 are smaller than the variance between the RS92 and RS80; the RS92 radiosonde performs better than the RS80 and is comparable with the RS90 PTU performance; the RS92 pre-flight preparation with ground check set GC25 was found to be comfortable.

As a summary of the conclusions, it was stated that upgrading to the RS92 GPS radiosonde should improve wind measurement and reduce the failure rate. The suggestion is to start using the RS92 at the Praha-Libus station.

5. SUMMARY

The Vaisala RS92 radiosonde family is a major improvement over current upper-air instrumentation. The RS92's improved GPS and PTU measurement capability will provide meteorological data users with better and more reliable upper-air in-situ data. To make the benefits of the RS92 widely available, Vaisala is ready to assist radiosonde users in replacing their older radiosonde models with the equivalent RS92 models. Convenient upgrade packages are available for Vaisala DigiCORA® sounding systems.

By making the transition from the RS80 radiosonde to the RS92 radiosonde, the meteorological community gains a higher level of PTU measurement performance, continuous wind data availability, and a growth path into the future of radiosonde-based meteorological observation.

6. REFERENCES

Hirvensalo, J., Währn, J., Jauhiainen, H.

New Vaisala RS92 GPS radiosonde offers high level of performance and GPS wind data availability, February 2003, Long Beach CA; American Meteorological Society, 2003.