VAISALA RS92 RADIOSONDES OFFER A HIGH LEVEL OF GPS PERFORMANCE WITH A RELIABLE TELEMETRY LINK

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ABSTRACT

Upper-air observational data gathered with radiosondes benefits from continuous instrument development. Accurate and reliable measurement of GPS winds as well as robust telemetry link performance is needed to meet the requirements of the meteorological community and the applications it works with.

Vaisala's code correlating GPS windfinding technology was developed specifically for upper-air weather observation and has proven to be highly reliable in operational use. It is implemented in custom ASIC (Application Specific Integrated Circuit) electronics that provide advanced levels of performance. In addition to conventional autonomous GPS positioning technology, it utilizes differential measurements to further improve measurement accuracy.

The digital RS92 radiosondes utilize a narrowband downlink which meets the requirements of the ETSI EN 302 054-1 European standard. Meeting the requirements of this standard is a basic operational requirement for all digital radiosondes used in the European community area. The best data transmission performance of the RS92 radiosonde is achieved by using the new Vaisala "Software Defined Radio" receiver that is built into the DigiCORA MW31 ground equipment. This receiver utilizes modern digital signal processing technology to replace the signal path sections conventionally utilized in analog electronic components. As a result, more robust performance is achieved which is also consistent from unit to unit.

The RS92 radiosonde is designed to be fast and easy to launch manually and also automatically from Vaisala AUTOSONDE unmanned sounding stations. The RS92 radiosonde along with the latest DigiCORA® MW31 sounding system represents the most modern solution for upper-air weather observation.

1. INTRODUCTION

The RS92 radiosonde has received operational testing in many different geographical locations around the world. Its performance has proved to be reliable. Several reports have been published on the PTU, GPS and telemetry performance and more information will soon be available along with the WMO's analysis of the Mauritius 2005 WMO Radiosonde Intercomparison. This article concentrates on presenting an up-to-date report on the RS92's telemetry link and GPS windfinding performance.

2. VAISALA RS92-SGP RADIOSONDE DATA LINK UTILIZING THE NEW SOFTWARE DEFINED RADIO-BASED DigiCORA SOUNDING SYSTEM

There is a fully digital telemetry link between the Vaisala Radiosonde RS92-SGP and the Vaisala Sounding Subsystem SPS311 (component of the DigiCORA MW31 Sounding System), which incorporates Vaisala's new Software Defined Radio technology. This telemetry link enables the use of modern digital modulation methods, error correction algorithms and telemetry diagnostics. The result is improved bandwidth efficiency, reliable data transmission, improved diagnostic cababilities and more consistent unit-to-unit operation. Furthermore, future receiver upgrades can be accomplished by updating the software only.

2.1. Software Defined Radio technology

Vaisala's Software Defined Radio technology consists of a low-noise antenna amplifier which resides in the antenna, a 400 MHz receiver unit and a receiver processor unit.

In the 400 MHz RF unit, the entire 400...406 MHz meteorological frequency band is first translated to an intermediate frequency (IF) band of 16...22 MHz. The IF signal is then sampled by a high-performance analog-to-digital converter using a sampling rate of 64 Msamples/second. All further processing of the signal – filtering, downconversion to baseband, demodulation, error detection/correction and telemetry analysis – is done in the receiver processor unit by digital down converters (DDCs) and a powerful digital signal processor (DSP).

When compared to conventional analog RF receiver technology, the new technology offers significant advantages including accurate and flexible digital signal processing, software-configurable digital filters, modern digital modulation techniques and efficient error detection and correction methods.

RB31 400 MHz telemetry antenna with low noise antenna amplifier

SPS311 Sounding Processor Subsystem

SPS311 Sounding Processor Units

Figure 1. The Vaisala Sounding Processing Subsystem SPS311 with Software Defined Radio

2.2. Vaisala RS92-SGP telemetry link and error coding

The RS92-SGP's telemetry link performance is a sum of the performance of its subcomponents: GFSK-modulation, Reed-Solomon error correction coding, data validation and the performance characteristics of the software defined radio receiver.

The RS92-SGP radiosonde transmits a narrowband GFSK (Gaussian Frequency Shift Keying) modulated signal which carries 2400-bit data frames at a data rate of 2400 bits / second. The radiosonde data frame is divided into several sub-blocks, each followed by a check sum. In addition, each data frame is protected with Reed-Solomon check bytes that are used for error correction. Data is scrambled to achieve a uniform distribution of ones and zeros and to avoid long sequences of the same value.

In the receiver end, the demodulated baseband data is descrambled and the Reed-Solomon error correction algorithm is applied. The data is then validated using the checksums. With the selected error correction coding, 4.7% of the symbols can be erroneous without causing the system to lose data. The relative coding gain is approximately 5 dB. A more detailed description of the Vaisala Software Defined Radio technology is presented in a separate document (Åkerberg 2004).

2.3. Telemetry link performance

The RS92-SGP telemetry link using the Software Defined Radio was tested in Tenerife in November 2004 at the Izana Observatory of the Spanish National Institute of Meteorology. The observatory has many characteristics that make it interesting for testing meteorological devices. In addition to this, it is suitable for testing telemetry link performance because it offers the possibility of exposing the test system to controllable levels of TV and other telemetry link interference.

The telemetry noise circumstances in which the soundings were made are presented in Figure 2. The spectrum snapshot on the left shows the situation when the receiving antenna was placed in a location that was shielded from telemetry noise. The spectrum snapshot on the right shows the type of severe link interference that was experienced when the receiving antenna was placed in a location that was not shielded from telemetry noise. The base noise level is some 10-20 dB higher in the section of the band the radiosondes were tuned to. Test soundings were performed as single-flight soundings and multiple-flight rig soundings.

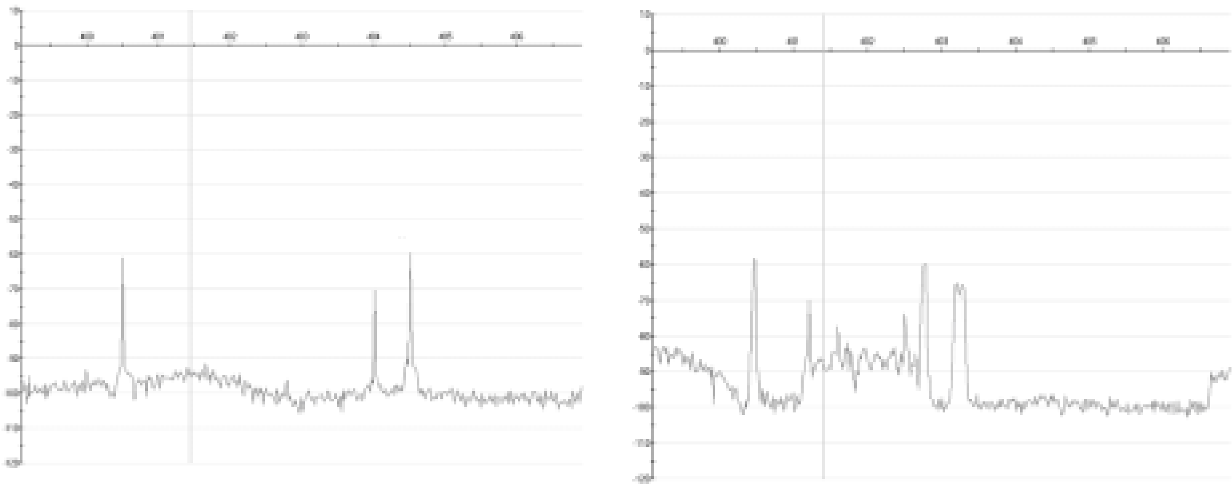

Figure 2. Frequency spectrum snapshot examples: at left - shielded; at right - unshielded

2.3.1. Comparison of performance: SPS311 with Software Defined Radio vs. SPS220 with analog receiver

In the test, there were two configurations of the receiving ground equipment: one configuration comprised the new SPS311 with software defined radio, the other configuration comprised the SPS220 and its analog receiver. The results of the soundings made with the RS92-SGP in the presence of severe telemetry link disturbance are presented in Table 1. The Channeling Ratio [%] is a measure of the PTU data availability as reported by the Vaisala DigiCORA MW31 Sounding System. The Valid Raw Wind [%] was reported by the DigiCORA MW31 Sounding System. The Frame Error Ratio (FER) is the ratio of erroneous data frames to all data frames. The erroneous data frames were data frames that could not be repaired by the Reed-Solomon error correction.

The reason for the termination of each test sounding was increasing pressure: a normal type of termination. The results were good for both systems but the combination of the RS92-SGP and SPS311 gave a better result. This can be seen in the Channeling Ratio [%] and Valid Raw Wind [%]. The wind conditions caused the RS92-SGP/SPS311 soundings to be the longest ones.

	Type	Channeling Ratio [%]	Valid Raw Wind [%]	FER [%]	Range [km]	Height [km]
1	**RS92-SGP / SPS311 SW-radio**	**100**	**100**	0.1	127	31
2	**RS92-SGP / SPS311 SW-radio**	**100**	**99**	0.4	55	30
3	**RS92-SGP / SPS311 SW-radio**	**100**	**100**	0	109	28
4	**RS92-SGP / SPS311 SW-radio**	**100**	**100**	0	89	30
5	**RS92-SGP / SPS220 radio**	**94**	**89**	NA	61	33
6	**RS92-SGP / SPS220 radio**	**98**	**96**	NA	70	32

Table 1. The soundings made with the RS92-SGP in the presence of severe telemetry disturbance. Tested with the SPS311 equipped with software defined radio and SPS220 with analog radio receiver.

2.3.2. Performance comparison: Vaisala RS92-SGP and SPS311 with software defined radio VS. Vaisala RS80-15G and SPS220 with analog radio receiver

In order to compare the performance of the RS80-15G radiosonde vs. that of the RS92-SGP radiosonde in conditions of severe telemetry link disturbance, the direction of the Vaisala UHF Antenna RB31 was turned upwards manually. Thus in addition to the telemetry link disturbance experienced, the telemetry range was also manually restricted by limiting the antenna radiation pattern. Table 2 shows the difference in telemetry performance of the Vaisala Radiosonde RS92-SGP with the Vaisala Sounding Processing Subsystem SPS311 vs. that of the Vaisala Radiosonde RS80-15G with the Vaisala Sounding Processing Subsystem SPS220. The test was made with the two radiosondes attached to one rig. The reason for termination of the soundings was a "No PTU" signal, which indicated that the limiting factor was telemetry.

The results show that in sounding conditions featuring telemetry link disturbance, the telemetry performance of the combination of the RS92-SGP radiosonde and SPS311 with software defined radio was clearly better than that of the RS80-15G and SPS220 combination. This can be seen in Table 2 from the longer sounding range and altitude achieved. As a conclusion, it can be stated that the RS92-SGP and SPS311 combination offers good immunity to telemetry noise and an increased margin for telemetry errors in long-range soundings with little telemetry disturbance.

	Type	Range [km]	Height [km]
1	**RS92-SGP / SPS311 SW-radio**	**56**	**15**
	RS80-15G / SPS220	**13**	**8**
2	**RS92-SGP / SPS311 SW-radio**	**44**	**12**
	RS80-15G / SPS220	**12**	**6**
3	**RS92-SGP / SPS311 SW-radio**	**31**	**9**
	RS80-15G + SPS220	**8**	**7**

Table 2. The comparison of RS92-SGP + SPS311 and RS80-15G + SPS220 in conditions of severe RF disturbance. A limited antenna radiation pattern was also introduced to restrict the telemetry range artifically.

2.3.3. Vaisala RS92-SGP / DigiCORA MW31 telemetry link performance in Mauritius WMO Radiosonde Intercomparison

The combination of the RS92-SGP radiosonde and DigiCORA MW31 / SPS311 with software defined radio was used in the Mauritius WMO Radiosonde Intercomparison that was conducted in February 2005. Figure 3 plots the percentage of received frames from the Mauritius soundings. The reliability of the data transmission was very high; on average it was 99.2% while median was 99.9%.

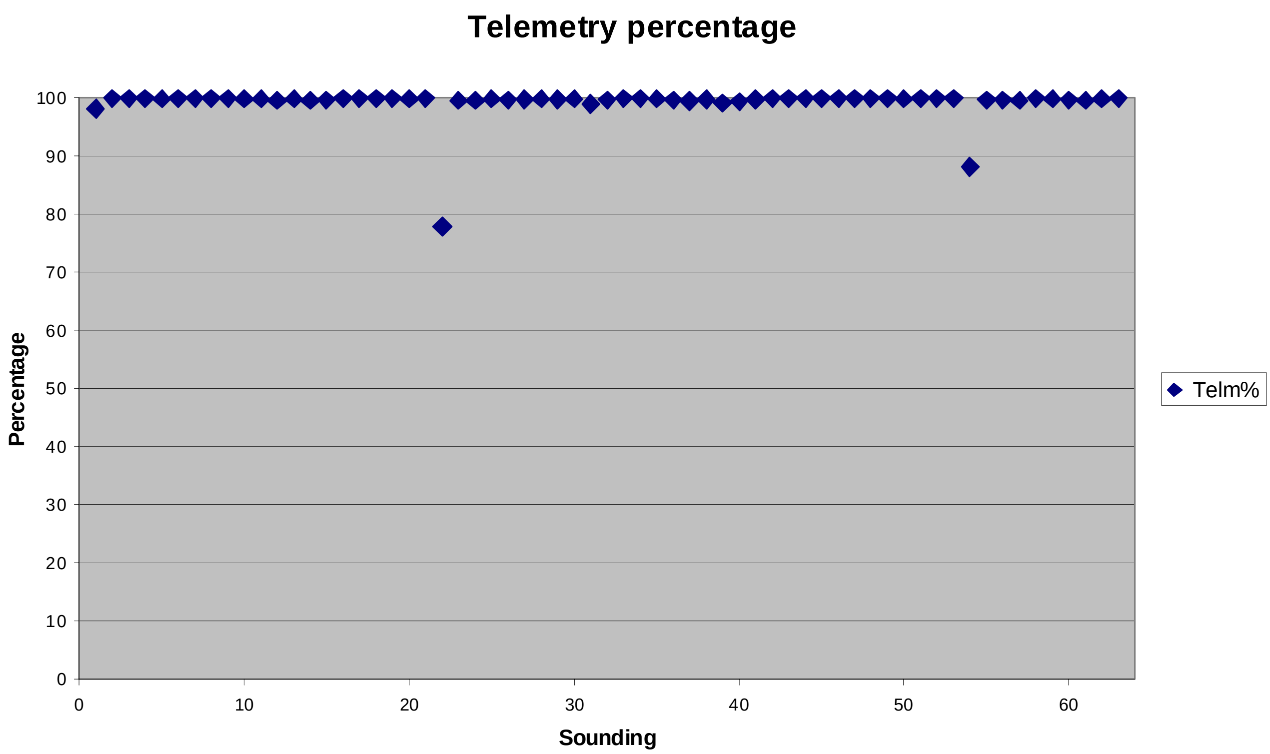

Figure 3. Telemetry performance of RS92-SGP / SPS311 with software defined radio in the Mauritius WMO Radiosonde Intecomparison of February 2005. Percentage of received frames, average 99.2% and median 99.9%

3. VAISALA RS92 GPS WINDFINDING PERFORMANCE

The GPS windfinding of RS92 GPS radiosondes is based on code correlating GPS (ccGPS) technology (Währn, 2004). This technology offers excellent accuracy and better immunity to external interference compared to previous codeless GPS windfinding solutions.

3.1. Wind measurement accuracy

Due to the lack of a good reference, the absolute accuracy of wind measurement in the test soundings cannot be determined. However, it is possible to compare the wind measurement performance of the radiosondes flown on the same sounding rig. The windfinding repeatability of the RS92 radiosonde was presented at the CIMO UASI-1/IOC-1 meeting on March 3, 2004. It was reported that the wind direction measurement repeatability (1-σ stdev) was generally better than 2 degrees and, in fast changing layers over a shorter period, better than 6 degrees. The repeatability for wind speed measurement was better than 0.2 m/s. More recent test data show a similar level of windfinding performance.

A multiple radiosonde sounding test was performed in Tenerife in November 2004 at the Izana Observatory. Figures 4 and 5 show the typical wind direction and wind speed measurement performance with three RS92 radiosondes flown on the same rig.

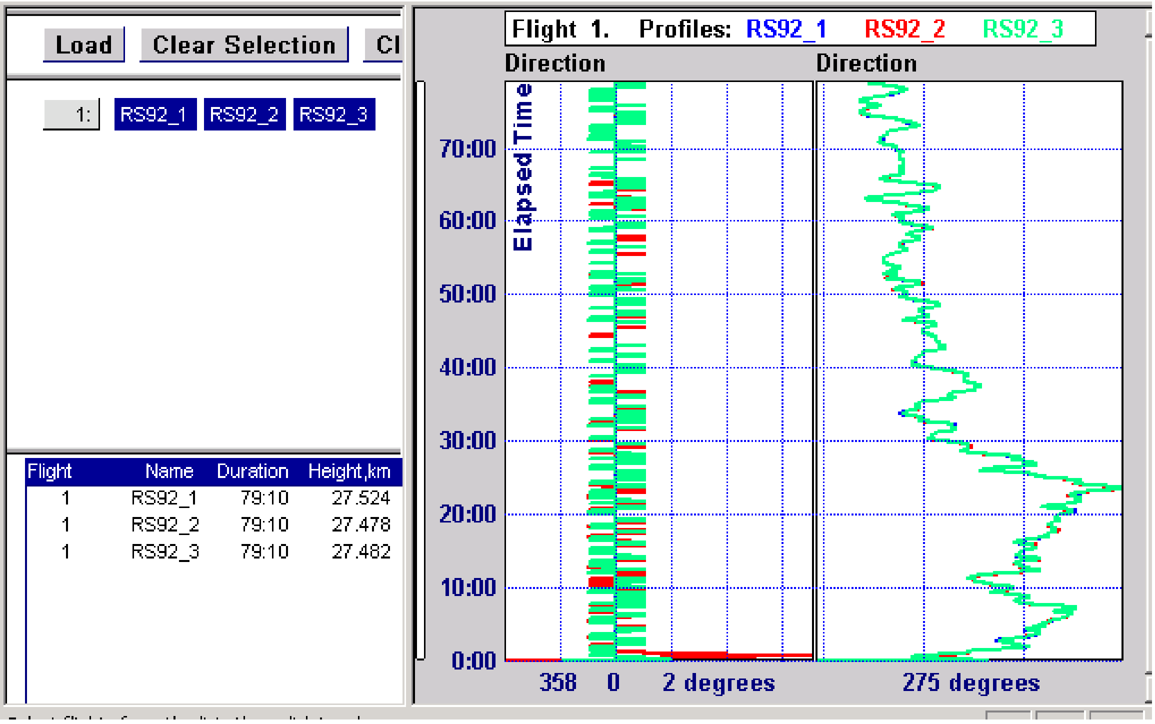

Figure 4. Triple sounding test result: wind direction

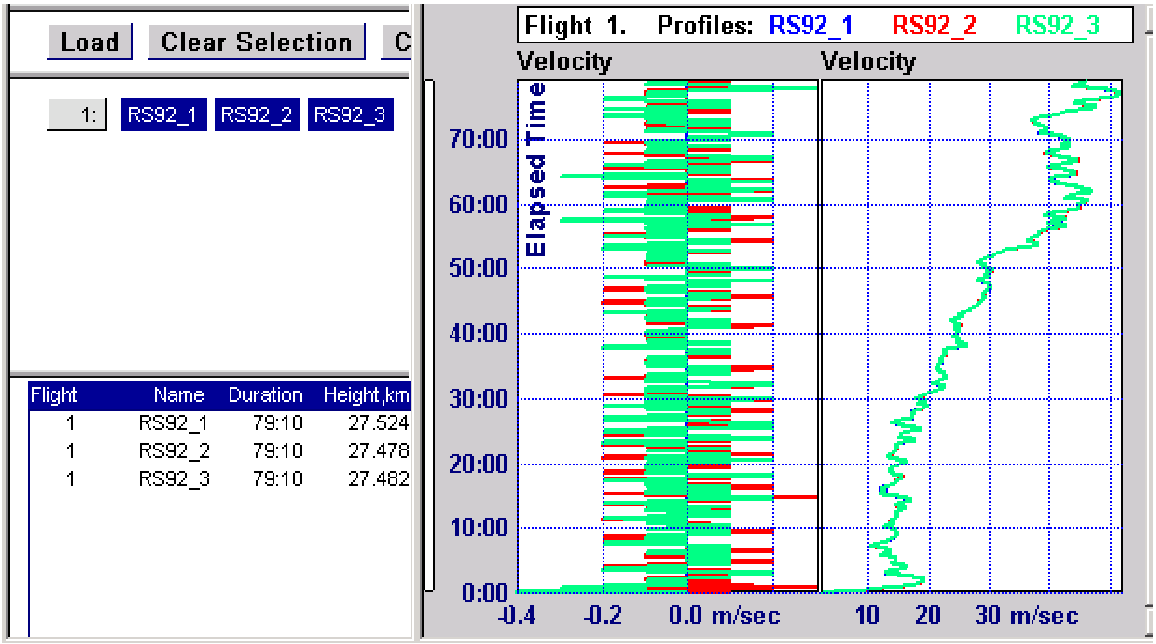

Figure 5. Triple sounding test result: wind speed

3.2. Wind data availability in operational use

Table 3 summarizes the GPS wind data availability of RS92 radiosondes flown in Europe's Region VI as extracted from European Region VI TEMP messages. The category "Missing winds to PTU top (%)" was calculated by dividing the total sum of reported missing wind meters by the total sum of reported wind meters to PTU Top. The result was scaled to a percentage by multiplying the division result by 100. The analysis covers all the observations made in 2004 with RS92 GPS radiosondes in the WMO Region VI Europe. The results show an excellent (almost 100%) success rate for windfinding reliability. Considerable improvement is seen when compared to the results achieved with older, codeless GPS technology.

TEMP messages, Region VI Europe, Year 2004 **Vaisala RS92 GPS sondes**			
Month	**Missing winds to PTU top (%)**	**Month**	**Missing winds to PTU top (%)**
Jan	1.8	July	0.6
Feb	0.1	August	0.3
March	0.3	September	0.7
April	0.1	October	0.4
May	0.2	November	0.2
June	0.1	December	0.1

Table 3. RS92 GPS wind data availabilty shown as a % of missing wind data

3.3 RS92-SGP wind data availability in the WMO Mauritius Radiosonde Intercomparison

The GPS wind data availability of the RS92-SGP radiosonde has been evaluated based on the large data set generated in the WMO Mauritius Radiosonde Intercomparison. Figure 6 plots the average number of GPS satellites that was tracked by the RS92 GPS radiosondes: on average, 11 satellites were tracked. Not all of the tracked satellites were used in the GPS wind calculations, however. For example, the weather station and radiosonde GPS receivers may have tracked different satellites during the course of a particular sounding, and satellites below a certain angle of elevation were not used. GPS wind calculation requires at least four satellites to be tracked and this was the case in 99.95% of the received GPS frames. When this figure is combined with excellent figures for telemetry performance, it can be seen that the RS92-SGP offered excellent wind data availability performance in the WMO Mauritius Radiosonde Intercomparison.

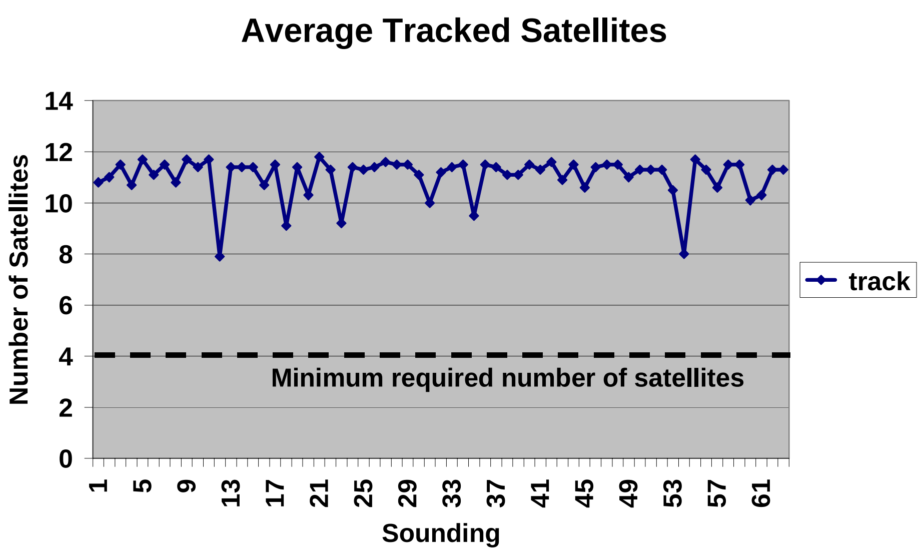

Figure 6. Average tracked satellites

3.4 Vaisala DigiCORA MW31 GPS height calculation

GPS velocity and location computations are made by the Vaisala DigiCORA MW31 ground equipment. The Vaisala DigiCORA sounding software provides autonomous radiosonde GPS navigation but is also capable of using the local GPS receiver as a differential base station.

Differential GPS calculation provides better accuracy when GPS positioning is used to calculate the GPS geopotential height. Future releases of the DigiCORA MW31 sounding software will provide a GPS height calculation with accuracy comparable to the accuracy of height computed from PTU. The algorithm, utilizing WGS84 specifications, was used in the Mauritius WMO Radiosonde Intercomparison.

The GPS height algorithm was also tested in the Tenerife sounding test. Figure 7 shows an example of the differences in GPS and PTU height measurements that were seen in Tenerife. Typically the difference will be a few meters up to 100 hPa. The larger difference that starts to be seen below the 100 hPa level is estimated to be due to measurement inaccuracies in the pressure sensor: even a small bias in pressure measurement can give rise to differences in the height calculation. This is seen in Figure 8, which shows the results of the same sounding used for Figure 7 but with a simulated -0.1 hPa constant pressure offset. In the Tenerife tests, the typical difference between the PTU and GPS heights was seen to be about 100 meters at 10 hPa, which reveals the very good accuracy of the pressure sensor.

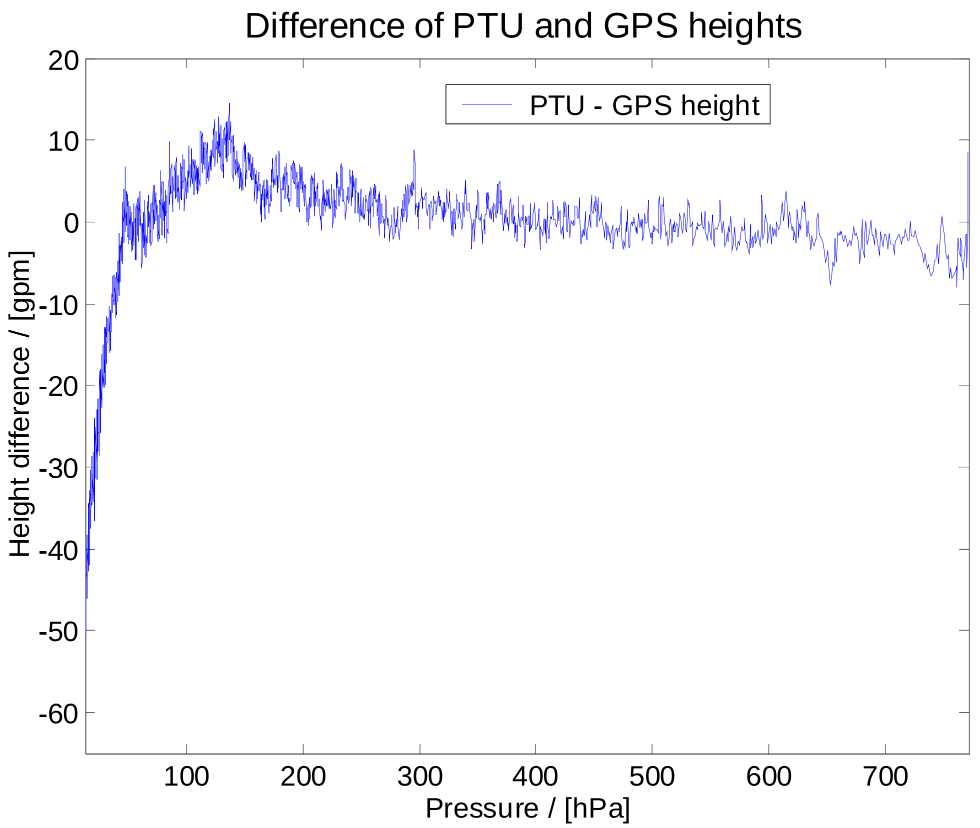

Figure 7. Difference between PTU and GPS heights

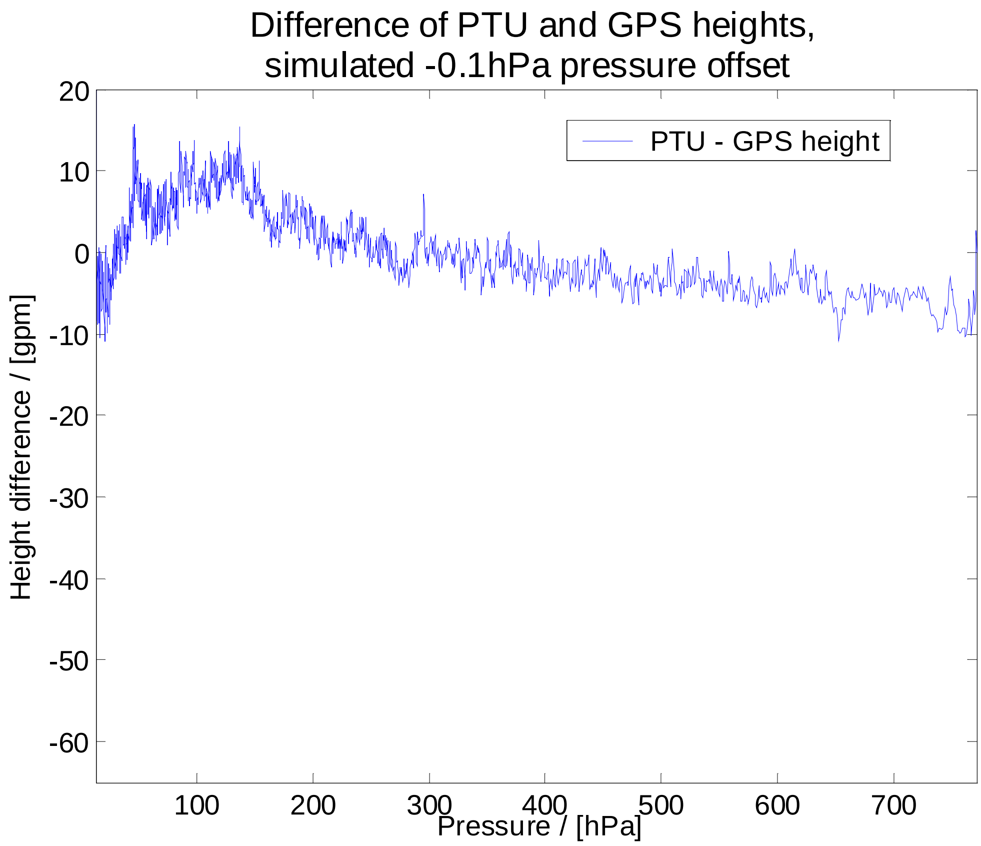

Figure 8. Differences between PTU and GPS heights, simulated with –0.1 hPa pressure offset

To test the repeatability of the GPS height calculation, multiple radiosondes were tested in a rig attached to a balloon. Figure 10 shows an example of the typical performance of three radiosondes measuring the same altitude. Figure 11 provides a close-up showing noise level in more detailed time scale. The excellent result for repeatability is due to the DigiCORA ground equipment's use of differential GPS-height calculation algorithms.

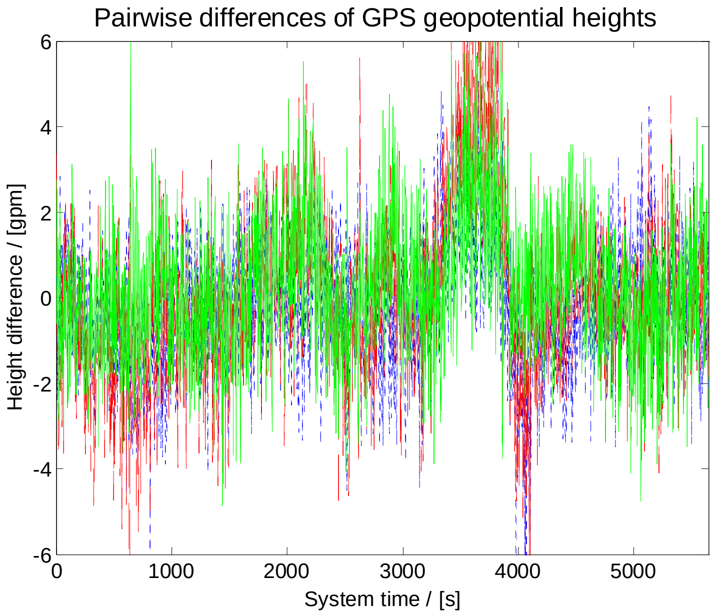

Figure 10. Radiosonde-pair differences of GPS geopotential height from a triple sounding

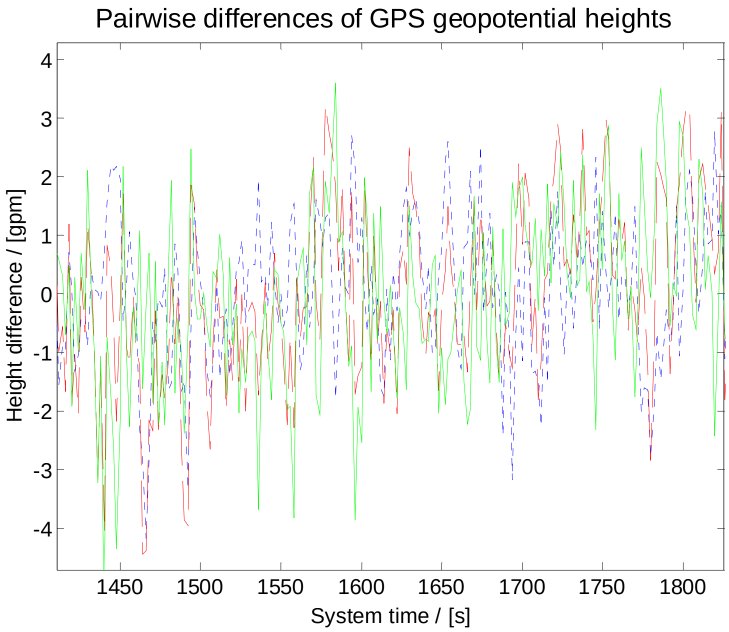

Figure 11. Radiosonde-pair differences of GPS geopotential height from a triple sounding, close-up

4. SUMMARY

Recent tests of the Vaisala RS92-SGP radiosonde and DigiCORA MW31 Sounding System equipped with the SPS311 (featuring software defined radio technology) have revealed very good results for telemetry performance and GPS windfinding performance. This system offers a digital telemetry link and receiving equipment featuring modern software defined radio technology that increases the reliability of the telemetry link by making it more immune to external disturbances experienced in the transmission band. The GPS technology of the system was designed specifically for radiosonde applications. The same is true of the differential algorithms used by the DigiCORA MW31 ground equipment. Taken together, these two facts ensure highly accurate wind speed/direction calculation in soundings made with RS92 GPS radiosondes.

5. REFERENCES

Åkerberg J.: State-of-the-art radiosonde telemetry, Eight Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, American Meteorological Society, 2004

Währn J., Rekikoski I., Jauhiainen H., Hirvensalo J.: New Vaisala Radiosonde RS92: testing and Results from the field, Eight Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, American Meteorological Society, 2004