APPLICATION OF VAISALA DRYCAP® SENSOR IN UPPER TROPOSPHERE AND LOWER STRATOSPHERE HUMIDITY MEASUREMENTS

Terhi Lehtola[1], Petteri Survo[1], Heikki Turtiainen[1] and Rigel Kivi[2]

[1]*Vaisala Oyj, PB 26, 00421 Helsinki, Finland, tel. +358 9 89491, e-mail terhi.lehtola@vaisala.com*
[2]*Finnish Meteorological Institute, Arctic Research, Sodankylä, Finland*

ABSTRACT

Vaisala has launched a program to develop an operational reference grade radiosonde for climate change studies, targeting especially the needs of the planned GCOS Reference Upper Air Network. The program concentrates first on upper-air measurements of humidity.

The first prototype of the operational reference radiosonde, Vaisala RR01, is based on the Vaisala Radiosonde RS92 sensors and Vaisala DRYCAP®, a new capacitive sensor capable of measuring extremely low humidity levels in upper troposhere and lower stratosphere. The highly sensitive sensor material can be applied for humidity measurement in the range from -30 to -90 ℃ frost point temperature, thus supplementing well the standard RS92 Vaisala HUMICAP® sensor.

Field testing of the RR01 prototype began in the FMI Arctic Research Centre in December 2009. In January-March 2010 RR01 participated in the LAPBIAT2 campaign together with several other upper atmospheric measuring instruments. In the flight tests RR01 has showed consistent performance with excellent repeatability and negligible radiation error. More work is needed to clarify the observed +1…+3 ℃ bias against the CFH (Cryogenic Frostpoint Hygrometer), as well as to develop all-weather capability. However, on the whole Vaisala DRYCAP® has demonstrated great potential for a new upper atmosphere humidity measurement technology.

1 VAISALA REFERENCE RADIOSONDE PROGRAM

In January 2009, Vaisala made a corporate commitment to develop an operational reference-grade radiosonde for climate change studies, especially targeting the needs of the planned WMO GCOS Reference Upper Air Network, or GRUAN /1/. Collaborating with the international scientific community, the program focuses first on upper-air measurements of humidity - the most abundant and subsequently the most important greenhouse gas in Earth's atmosphere.

Even before the program launch, Vaisala had started internal field trials to apply Vaisala DRYCAP® sensor technology to stratospheric humidity measurements. External testing began in autumn 2008, when Vaisala participated in the LUAMI campaign in the DWD Lindenberg Observatory with an early prototype /2/. The actual reference radiosonde development project was started in spring 2009, and the first test results were reported at the Annual Meeting of the American Meteorological Society in January 2010 /3/. The field testing then continued in the LAPBIAT2 campaign in the FMI Arctic Research Centre, Sodankylä /4/; preliminary results of RR01 performance there are reported here. Also, the National Center of Atmospheric Research (NCAR) in Boulder, Colorado, has started evaluating the RR01.

In addition to developing precise reference instruments, it is imperative to guarantee the continuity of standard observation datasets. Accordingly, Vaisala has established a public, web-based database that will provide RS92 radiosonde-related information which affects the interpretation of climatological time series /5/; similar information is provided for the climate reference radiosonde /6/.

2 RR01 DESIGN

The prototype of the operational reference radiosonde, Vaisala RR01, consists of Vaisala Radiosonde RS92 and Vaisala DRYCAP® humidity sensor module (figure 1). DRYCAP® (formerly known as APS) is a capacitive thin-film sensor capable of measuring extremely low humidity levels in upper troposphere and lower stratosphere. The sensor was originally developed for measuring ultra-dry gases in industrial applications. The highly sensitive sensor material can be applied for humidity measurement in the range from -30 to -90 °C frost point temperature, thus supplementing well the standard RS92 Vaisala HUMICAP® sensor.

Figure 1. Vaisala Reference Radiosonde RR01 prototype.

Since the DRYCAP® sensor is operated at a constant temperature (+45 °C), the response time of the sensor is not affected by ambient temperature and furthermore, the overall accuracy is improved as there is no need for temperature corrections. Another consequence of the constant sensor temperature is that the primary measured variable for the sensor is water vapor pressure (Pw) rather than relative humidity.

The capacitance of the sensor is measured by the sensor module electronics and converted into frost point temperature using post-processing software after the sounding has been terminated. Frost point readings of the sensor module are factory calibrated against a chilled mirror reference with traceability to NIST standards down to -90 °C.

Autocalibration procedures substantially reduce sensor drift during a sounding, thus assuring excellent repeatability. A wind shield is incorporated in the sensor mechanics to attenuate turbulent flow around the sensor and stabilize the sensor temperature. Furthermore, a radiation shield for the wind shield was tested during some flights.

The reference humidity module, including the Vaisala DRYCAP® sensor, measuring electronics and batteries (powering both the sensor module and the radiosonde), is attached in place of the standard RS92 battery pack. The module connects electrically to the RS92 add-on sensor interface. It is worth mentioning that as a part of the reference radiosonde program, the technical details and message protocol of the interface have been made public by Vaisala. This will allow, in addition to Vaisala's own sensors, also third-party sensor modules to be connected to RS92.

3 RR01 MEASUREMENTS IN THE LAPBIAT2 CAMPAIGN

Vaisala RR01 was flown together with other instruments with Aerostar 19 k balloons. The instruments were attached to a horizontal plastic rod and CFH, a chilled mirror hygrometer, was in the payload during some flights. CFH (Cryogenic Frostpoint Hygrometer) is typically used as a reference instrument due to its fundamental measurement principle /7/. Other instruments flown are reported in the paper of R. Kivi et al. /4/.

Three different types of wind shields for the RR01 were tested during the campaign, all made of stainless steel, see Figure 2. Type 1 is a light weight, low cost wind shield. Type 2 is aimed for better performance in condensing conditions as it has larger mass and an accordingly larger heat capacity. A mushroom shaped type 3 is potentially more feasible in various weather conditions. In all the types of wind shield, the ventilation takes place through eight holes of two millimeter diameter situated in the upper part of the shield structure.

A radiation shield has a cylindrical structure and is made of sheet metal and placed around the wind shield, with approximately 5 mm larger radius than the wind shield, see Figure 2. To avoid contaminating the sensor mechanics with moisture, the radiation shield is thoroughly ventilated through the open top part and six large elliptical holes in the bottom part. The radiation shield was used during some flights to examine the possible effects caused by solar radiation, which warms up the wind shield, especially at altitudes above the tropopause.

Figure 2. The tree different types of wind shields and a radiation shield (on the right) used during the LAPBIAT2 campaign.

An example of the frost point temperature results from a sounding with two RR01 attached to the same balloon is shown in Figure 3. One of the two RR01 radiosondes, labeled 16, was equipped with a radiation shield while the other, labeled 12, had no shield. Based on the results shown in Figure 3, the radiation shield does not seem to have an effect on the frost point results.

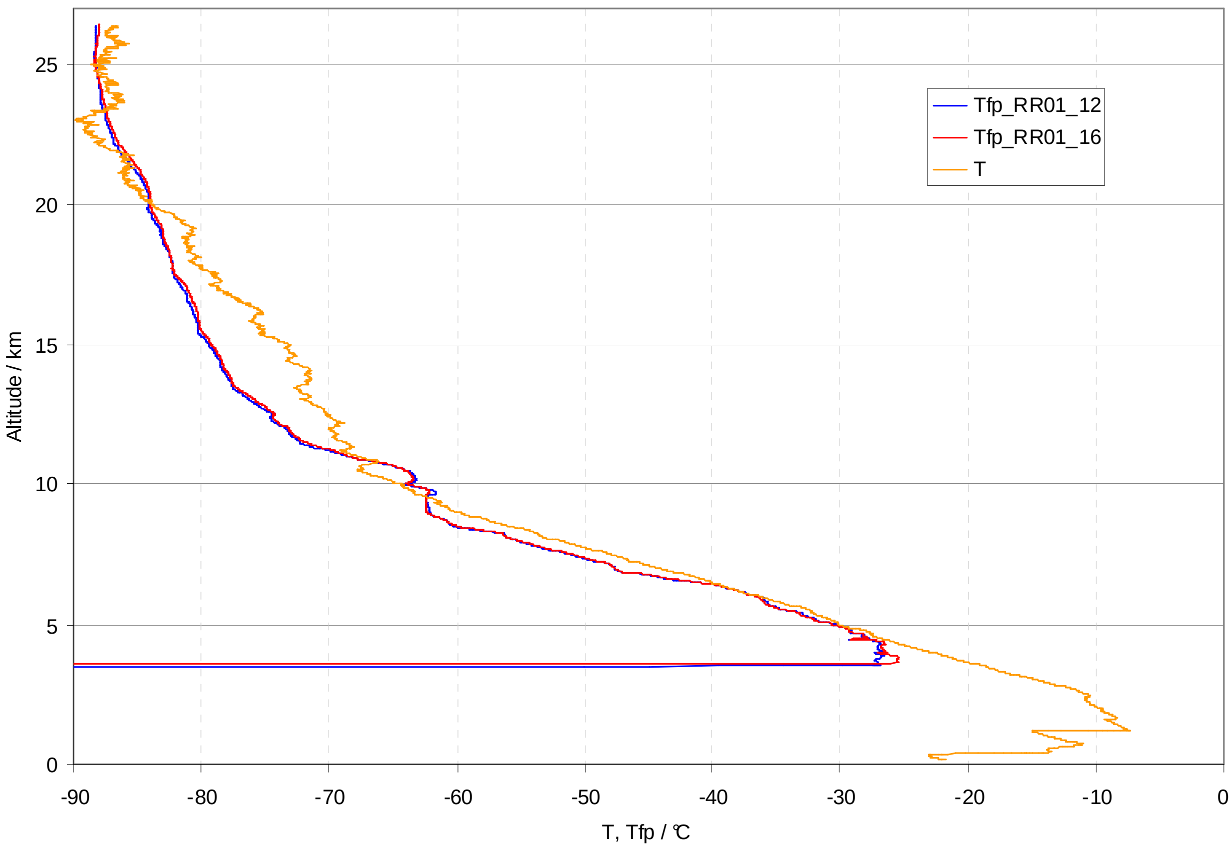

Figure 3. Frost point temperature results of RR01 with (16, blue line) and without (12, red line) a radiation shield. Temperature readings, measured by RS92, are drawn with a yellow line.

Results of RR01 and CHF in another typical sounding are shown in Figure 4. It is clear that in spite of a small, substantially constant difference, the RR01 detects the same atmospheric humidity features as CHF.

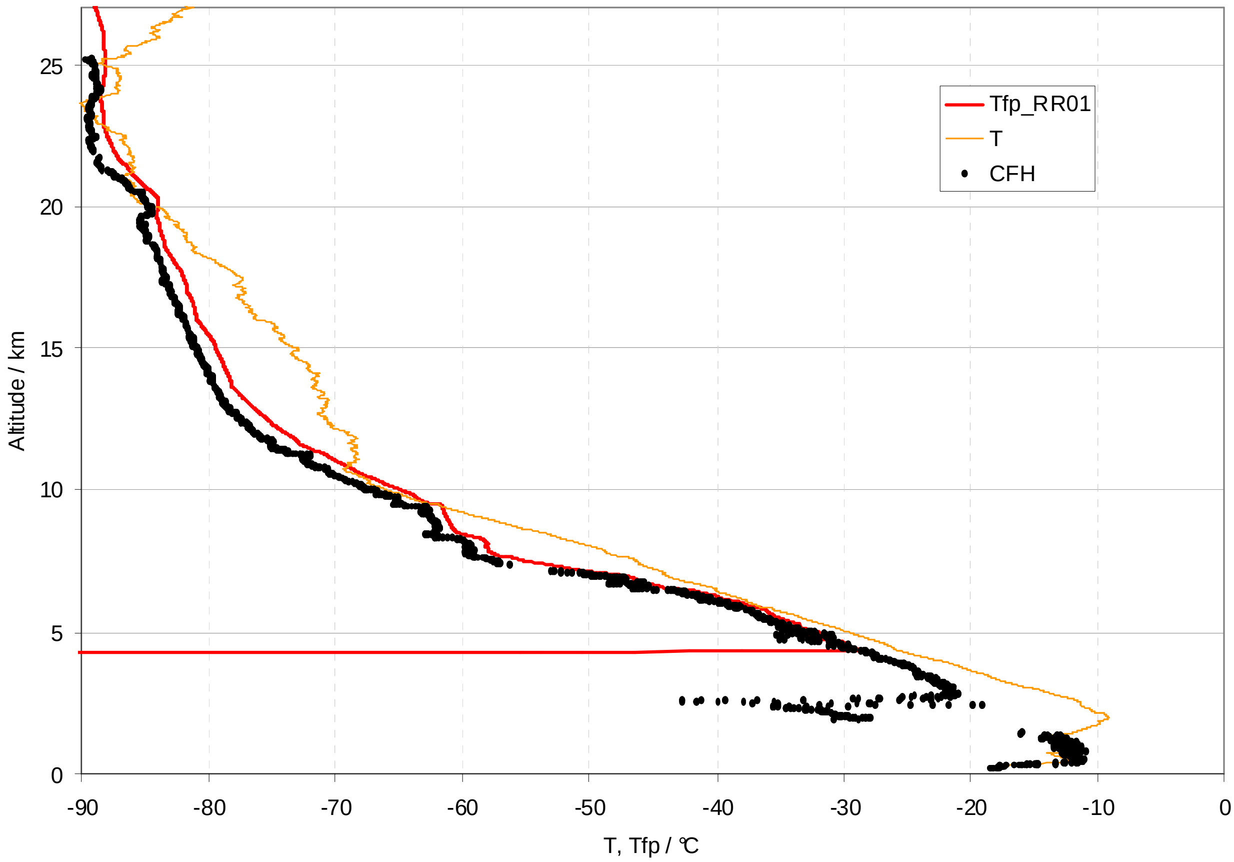

Figure 4. Frost point temperature results of RR01 (red line) and CFH (black dots) during a night- time sounding. Temperature readings, measured by RS92, are drawn with a yellow line.

The differences between the frost point temperature readings of RR01 and CFH during several soundings are summarized in Table 1. Data is collected from three altitude intervals where CFH readings were within ± 0.5 ℃ of -80, -82, -84 and -86 ℃. If CFH failed or was not used during the sounding, CFH data from the previous sounding was used instead, assuming that moisture conditions in the stratosphere had remained constant.

Table 1. Observed differences between frost point temperatures measured by RR01 and CFH at frost point range -80..-86℃.

Date 2010	**Time UTC**	**CFH data from sounding**	**RRD100 ID**	**wind shield type**	**radiation shield**	**day/night**	**Difference at -80℃Tf**	**Difference at -82℃ Tf**	**Difference at -84℃Tf**	**Difference at -86℃Tf**
17.01.	19:47	the same	F0160005	1	no	night	1.9	1.9	2.0	2.1
22.01.	19:08	the same	F0160015	1	no	night	1.9	1.7	1.6	1.3
23.01.	17:30	the same	F0160013	1	no	night	1.4	1.2	0.8	1.2
24.01.	23:58	the same	F0160001	1	no	night	1.2	1.0	0.7	0.6
25.01.	18:13	the same	F0160011	1	yes	night	2.3	2.6	2.4	2.8
28.01.	16:44	the same	F0160019	1	yes	night	5.4	4.8	3.5	4.1
02.02.	12:27	the same	F0160009	2	no	day	2.3	2.3	2.0	2.0
02.02.	12:27	the same	F0160010	3	no	day	2.6	2.6	2.3	2.0
23.01.	9:42	night 22.01.	F0160012	1	no	day	1.5	1.3	1.4	1.2
23.01.	9:42	night 22.01.	F0160016	1	yes	day	1.7	1.6	1.5	1.5
28.01.	9:07	night 27.01.	F0160017	1	yes	day	1.7	1.9	1.8	2.4
28.01.	9:07	night 27.01.	F0160018	1	no	day	1.9	2.1	2.1	2.6
						Average	2.2	2.1	1.8	2.0
						StDev.	1.1	1.0	0.8	0.9
						StDev. when F0160019 excluded	0.4	0.5	0.6	0.7

From the results of dual RR01 soundings (F0160012, F0160016) and (F0160017, F0160018), it can be seen that the RR01 results of a given sounding are essentially the same regardless of the presence of the radiation shield. Plotting the results measured at frost point -84 ℃ and comparing the results daytime versus night-time, see Figure 5, it seems that no notable differences in the average frost point temperature values exist in this respect either. To summarize these two observations it can be concluded that unlike the most conventional moisture sensors, the measurement results of Vaisala DRYCAP® humidity sensor module of RR01 have a negligible radiation error.

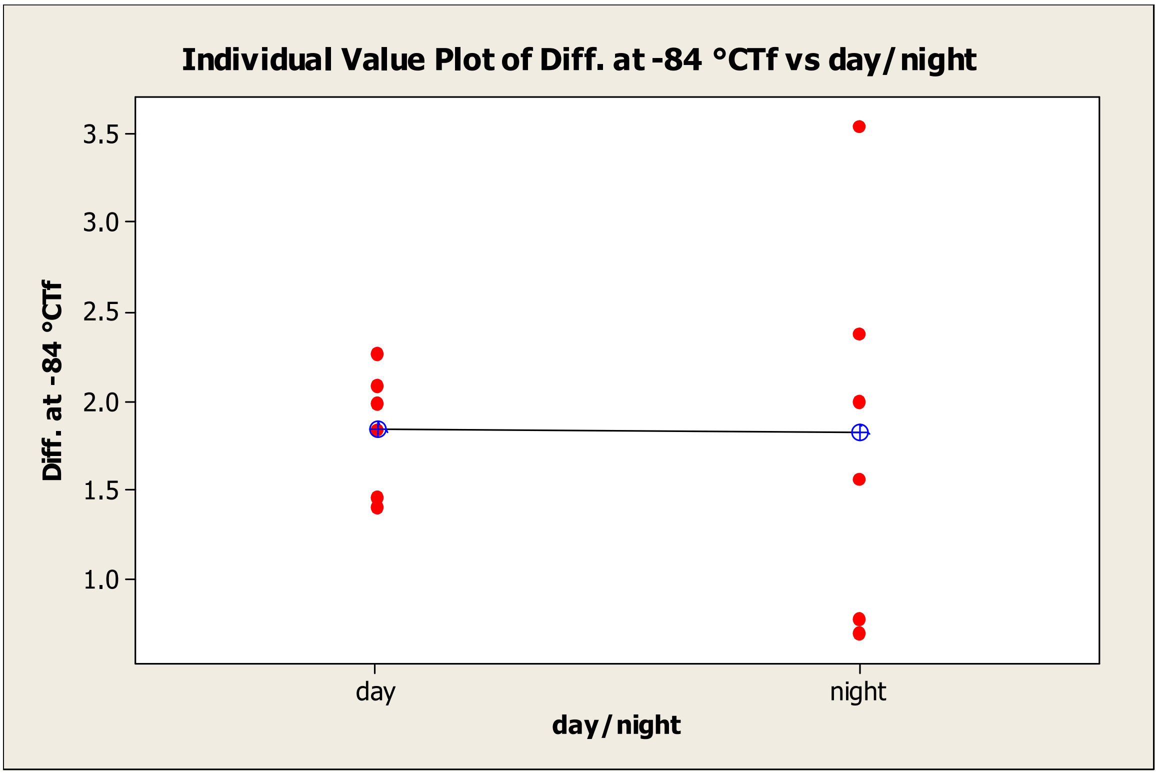

Figure 5. Frost point temperature reading differences between RR01 and CFH with respect to time of sounding.

4 DISCUSSION

Data analysis of the numerous soundings conducted during LAPBIAT2 campaign revealed that frost point temperature readings obtained from the RR01 module are practically free from radiation induced error. That is not surprising, considering the sensor mechanics. Firstly, the metallic wind shield acts also as a radiation shield, protecting the sensor chip from solar radiation. Secondly, due in part to the metallic wind shield material and in part to the good ventilation of the sensor structure, the warming-up of the wind shield structure at the stratosphere does not induce a substantial proportion of desorption originated water vapor to be detected by the sensor. This is the case at least if the conditions in the troposphere have been non-condensing during the sounding.

Another observation about the RR01 results was the excellent repeatability. In all three dual soundings (i.e. two individual RR01's launched with the same balloon) the results agreed better than 0.3 ℃ in terms of the measured frost point temperature.

The results of the LAPBIAT campaign also verified the earlier observations that there is a systematic difference between the frost point temperature readings of RR01 and CFH, RR01 showing typically 1 to 3 ℃ higher values. The cause of the difference could not be identified during the campaign. However, the excellent repeatability of the RR01 demonstrates the great potential of the Vaisala DRYCAP® sensor as a new frost point temperature measurement technology for upper troposphere and lower stratosphere.

References

1 Seidel, D., 2009. Reference Upper-Air Observations for Climate: Rationale, Progress, and Plans, Bulletin of the American Meteorological Society, March 2009.

2 Immler, F. and the LUAMI team, 2010. Results from the Lindenberg Upper-Air Method Intercomparison (LUAMI). WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2010), Helsinki, Finland, 30 August - 1 September 2010.

3 Turtiainen, H, H. Jauhiainen, J. Lentonen, V. P. Viitanen, P. Survo, and W. F. Dabberdt, 2010. Upper atmosphere humidity measurement with the APS sensor—1st progress report on the Vaisala Reference Radiosonde Program. 15th Symposium on Meteorological Observation and Instrumentation, Atlanta, GA, 17–21 January 2010.

4 Kivi, R., et al., 2010. LAPBIAT Atmospheric Sounding Campaign in Janauary-March 2010: Upper-Air and Remote Sensing Observations of Water Vapor. WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2010), Helsinki, Finland, 30 August - 1 September 2010.

5 http://www.vaisala.com/weather/products/datacontinuity.html

6 http://www.vaisala.com/weather/applications/referenceradiosondeprogram.html

7 Vömel, H., D. E. David, and K. Smith (2007), Accuracy of tropospheric and stratospheric water vapor measurements by the cryogenic frost point hygrometer: Instrumental details and observations, J. Geophys. Res., 112, D08305, doi:10.1029/2006JD007224.