# 7.1 UPPER ATMOSPHERE HUMIDITY MEASUREMENTS WITH THE APS SENSOR - 1st PROGRESS REPORT ON THE VAISALA REFERENCE RADIOSONDE PROGRAM

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## 1. INTRODUCTION

In 2007, World Meteorological Organization's (WMO) Global Climate Observing System (GCOS) laid out the need for a GCOS Global Reference Upper-Air Network, or GRUAN. They concluded (WMO, 2007) that shortcomings in the current upper-air measurement network do not satisfy the accuracy and detail of observations needed to specify climate variability and changes above the Earth's surface. This deficit greatly impacts the ability to accurately assess and predict climate change, and hence has potentially serious consequences in areas of high relevance to society.

The overall goal of GRUAN is to establish 30-40 stations that will use reference grade radiosondes in addition to other instrumentation to represent climate around the world /1/. While the current radiosondes support normal weather observation needs rather well, they do not provide sufficiently accurate information for climate and climate-change needs. An improved radiosonde is needed to meet GRUAN's upper-air climate requirements of precision and accuracy.

In January 2009, Vaisala made a corporate commitment to take on this important development challenge by launching an internal program to develop an operational reference-grade radiosonde that could be used in GRUAN and other applications where enhanced radiosonde sensor performance is required. The program is being implemented in close collaboration with the meteorological research community, and the benefits will be is shared equally with all countries. Vaisala has also set aside commercial gain from this program in keeping with its Corporate Social Responsibility Program.

Water vapor is the most abundant and most important greenhouse gas in Earth's atmosphere. However, it is also one of the most difficult parameters to measure with high precision and accuracy, especially in the upper troposphere and stratosphere where conditions are extremely cold and dry. Therefore, the program is focusing initially on improved upper-air measurements of humidity.

Following internal field trials, external testing began in autumn 2009 in cooperation with several international research partners. The first test results are reported here.

## 2 REFERENCE RADIOSONDE DESIGN

The first prototype of the operational reference radiosonde, Vaisala RR01, is based on the Vaisala Radiosonde RS92 sensors and Vaisala's DRYCAP® humidity sensor (formerly known as APS), a new capacitive sensor capable of measuring extremely low humidity levels in upper troposhere and lower stratosphere.

The DRYCAP® technology 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 frostpoint temperature, thus supplementing well the standard RS92 Humicap sensor.

The primary measurand of the DRYCAP® sensor is water vapour pressure (Pw), which is then converted to frostpoint temperature. The sensor is operated at constant temperature above the ambient (+45 °C), resulting in faster response time, improved accuracy (no need

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for temperature correction) and simple calibration process. On-flight autocalibration procedure removes drift.

The sensor is factory calibrated against a chilled mirror reference with traceability to NIST standards, currently down to -80 ℃ and soon to be extended to -90 ℃.

Fig. 1. Vaisala Reference Radiosonde RR01 prototype.

## 3. TEST RESULTS

### 3.1 FEASIBILITY STUDY

The first extensive test of the DRYCAP® sensor in a radiosonde application took place in summer 2007. The test flights in the FMI Sodankylä Observatory, northern Finland, displayed good agreement with the Cryogenic Frostpoint Hygrometer (CFH), generally considered to be the most accurate instrument available for upper troposphere and lower stratosphere humidity measurements /2/.

The observed differences between the DRYCAP® and the CFH were typically less than 1 K (see fig. 2). The test conditions were favourable, with dry lower troposphere. As such the tests verified the basic accuracy and repeatability of the DRYCAP® sensor, but more work was needed to evaluate the performance in more demanding conditions.

### 3.2. THE LUAMI CAMPAIGN

The next test took place in autumn 2008 in the LUAMI campaign, organized by the DWD Lindenberg Observatory.

Compared to the first tests, the LUAMI campaign was more challenging: the atmosphere was much more humid, including rainy and foggy conditions. Four of the 13 soundings the DRYCAP® sensor participated were made during rain or fog, and showed large deviations. Suspected reason is "moisture contamination" (wetting or condensation, and consequent formation of ice on the sensor shield or nearby surfaces in the lower atmosphere). In the stratosphere, the accumulated ice begins to evaporate, causing observation error.

Even in the successful flights, compared to CFH the DRYCAP® showed on the average appr. 2 ℃ higher frostpoint temperatures. This is at least partially believed to be attributed to moisture contamination problem and remains to be one of the major challenges for stratospheric humidity measurement.

### 3.3 RR01 FLIGHT TESTS

The Vaisala Reference Radiosonde Program was launched in January 2009, and has now provided the first prototype: Vaisala RR01 (fig. 1). Compared to the laboratory prototypes, RR01 is a full scale production prototype featuring
- Re-designed DRYCAP® sensor electronics
- Refined embedded calculation and autocalibration algorithms
- New mechanical design and factory calibration process suitable for volume production
- Post-processing software package.

In addition, systematic field testing and evaluation program has been started together with research partners. The first RR01 tests took place in December 2009 in the FMI Sodankylä Observatory. The results continued to exhibit consistent performance, but with slightly lower bias compared to the CFH than in the LUAMI campaign - this is believed to be due to the new, improved calculation algorithm. The test flights included several twin soundings to test the repeatability of RR01, with good results (see figures 3 and 4).

Further test results are expected from the LAPBIAT2 campaign, currently under way in the Sodankylä Observatory /3/.

## 4. CONCLUSIONS

The Vaisala reference radiosonde (RR01) has entered the prototype phase. RR01 is based on Vaisala RS92 radiosonde sensors and DRYCAP® sensor technology, capable of measuring extremely low humidity levels. Compared to the current reference grade instruments RR01 will be considerably easier to operate and less expensive, thus enabling more frequent climatological soundings.

The first sounding tests show that measurement accuracy and repeatability are at a high level when verified against the cryogenic frostpoint hygrometer (CFH).

Vaisala, together with its research partners is continuing development of RR01 humidity sensor, focusing next on further improvement of the it's accuracy and all-weather-capability (performance in humid conditions).

In parallel, the program is also proceeding to develop more precise measurements for other atmospheric parameters. Development will continue until the climate science needs (including lower tropospheric requirements) are satisfied for humidity, temperature, pressure and wind soundings.

In addition to developing precise reference instruments, it is imperative to guarantee continuity of standard observation datasets. Accordingly, Vaisala has established a public, web-based database that will provide RS92 radiosonde-related information that affects the interpretation of climatological time series /4/. Similar information will be provided for the climate reference radiosonde /5/.

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3 http://www.sgo.fi/lapbiat/

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

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

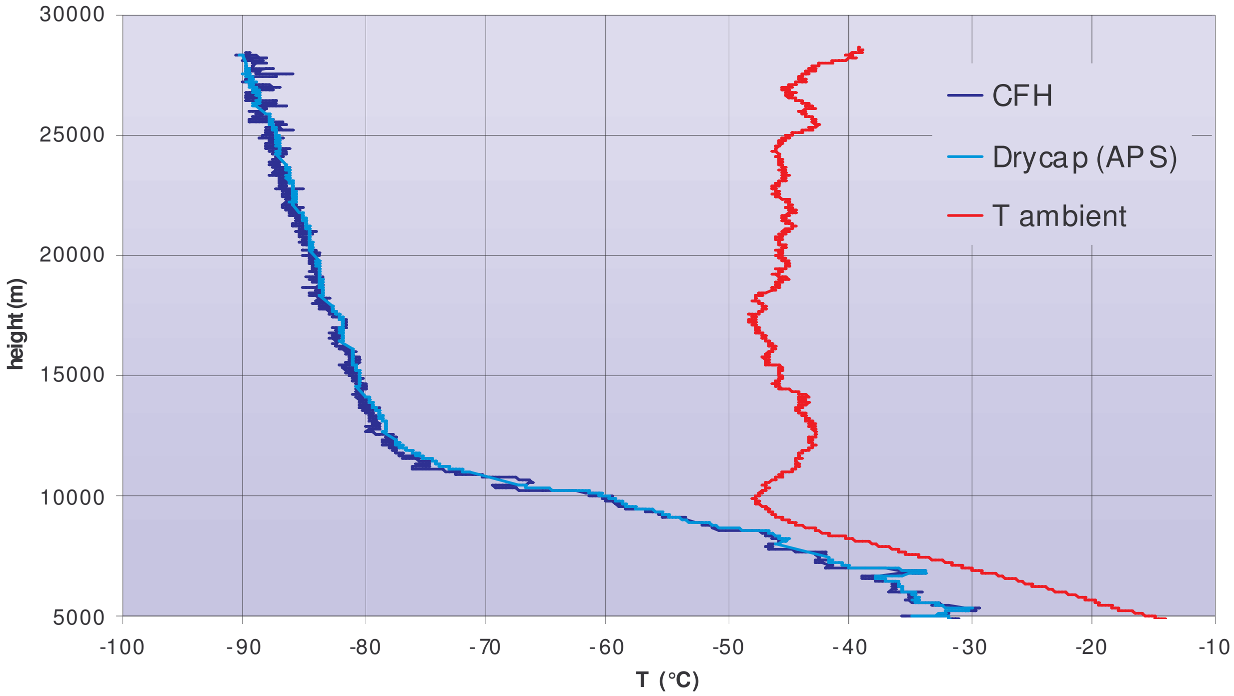


Fig 2. First test results of the DRYCAP® sensor: comparison against CFH in July 2007.

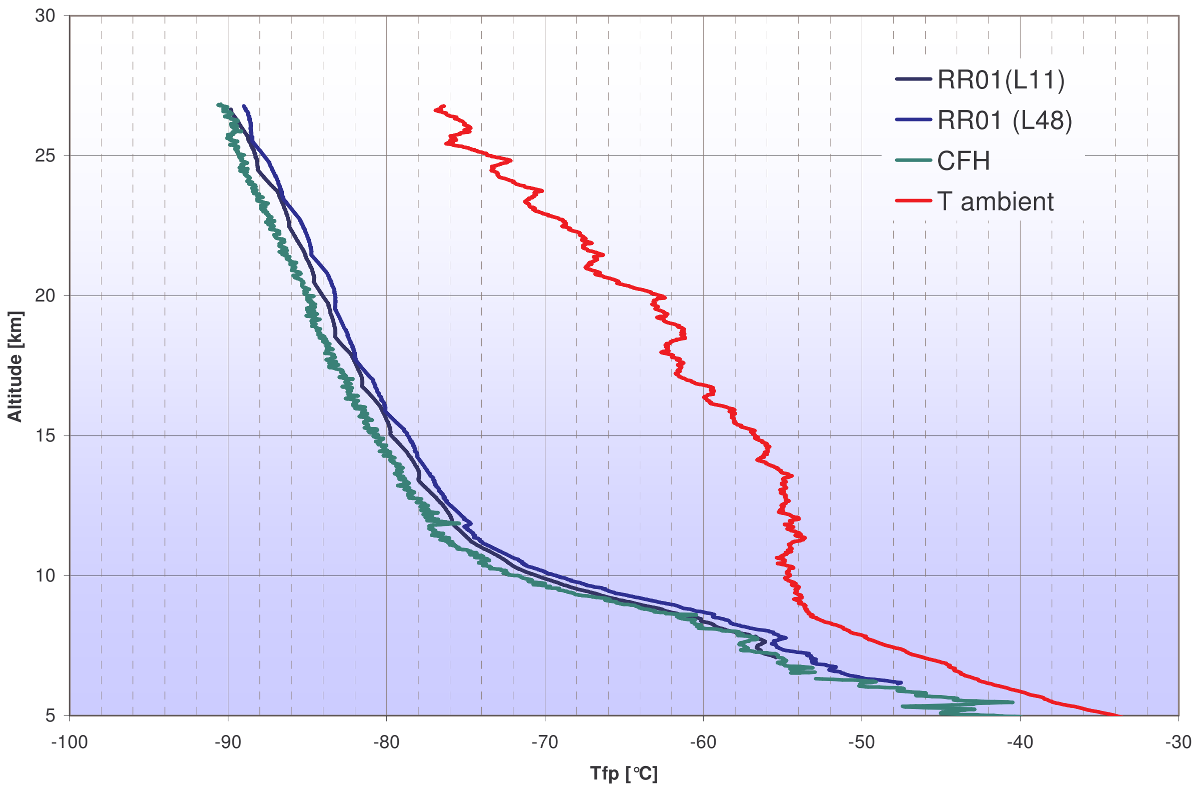


Fig. 3. RR01 nighttime sounding test, Sodankylä Dec 13, 2009 (two RR01's and a CFH).

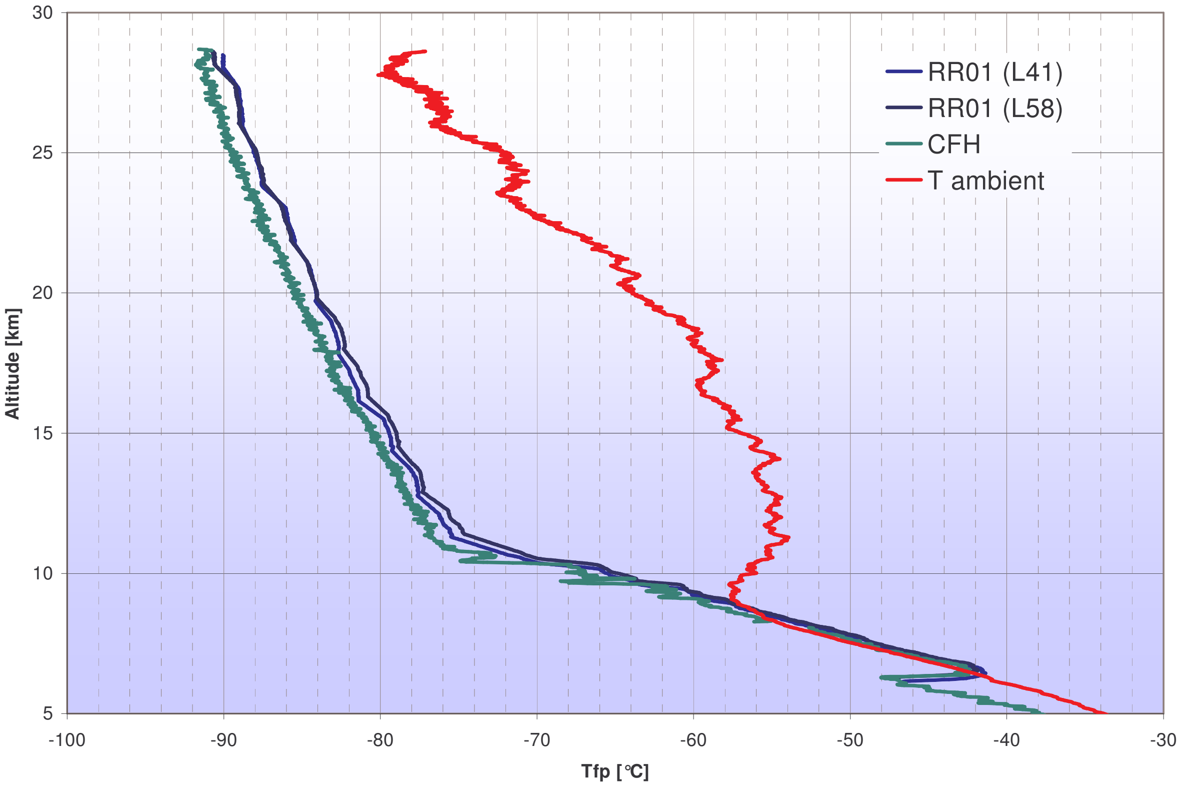


Fig. 4. RR01 daytime sounding test, Sodankylä Dec 14, 2009 (two RR01's and a CFH).