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Arbeitsbericht MeteoSchweiz Nr. 229

Transition from VIZ/Sippican to ROTRONIC –

A new humidity sensor for the SWISS SRS 400 Radiosonde

R. Philipona, G. Levrat, G. Romanens, P. Jeannet, D. Ruffieux and B. Calpini

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CHAPTER 1 Executive summary

This report describes the implementation of a new humidity sensor for the Swiss radiossonde SRS 400 to improve humidity profile measurements. Since the introduction of the SRS 400 radiosonde in 1990, MeteoSwiss uses a fast response carbon resistive hygristor of the US company VIZ/Sippican. With rising demands on the quality of atmospheric water vapour measurements for numerical weather prediction models and climate change observations, the VIZ/Sippican hygristor does not respond to the increasing requirements any more. MeteoSwiss and Meteolabor, the manufacturer of the SRS 400, therefore decided to investigate solutions for a possible substitution of the VIZ/Sippican carbon hygristor. The goals set forth for the new sensor were to improve humidity profile measurements in the lower and mid troposphere and to have a cost effective solution. Another constraint was to find a sensor that fits in the electronic design of the SRS 400 radiosonde.

In close collaboration between MeteoSwiss, Meteolabor, and Rotronic a Swiss manufacturer of humidity sensors, a high performance capacitive humidity sensor was developed and tested over the last three years. An advanced prototype, the Rotronic HC2, was successfully tested during the Lindenberg Upper-Air Methods Intercomparison (LUAMI) during fall 2008. Final adjustment on the sensor and the electronics of the SRS 400 were made during winter and spring 2009. Beginning of May 2009 the latest version of Rotronic humidity sensor type HC2 version B1.5.1 has finally been put in operation with the Meteolabor SRS 400 radiosonde at the aerological station Payerne.

The report shows investigations made on the VIZ/Sippican hygristors and relates to the different problems found with the old sensor over the years. It then shows the LUAMI test results obtained with the new capacitive humidity sensor and finally shows results from pre-operational measurements at Payerne. In a general view the new capacitive sensor shows striking improvements over the old hygristor and compares very well with sensors used on international radiosondes in the lower and middle troposphere. In the upper troposphere at very low temperatures the sensitivity of the new sensor is rather low and improvements are aimed for. The new sensor also shows much better agreement with GPS measured integrated water vapor.

For financial and logistic reasons MeteoSwiss decided to keep the SRS 400 (analog sonde) or its sister sonde the C34 (digital sonde) in operation until ca. 2012. This strategy is linked to the current project Rad4Alps, the renewal of the weather radar sites in Switzerland. Therefore this transition VIZ/Sippican to Rotronic is an intermediate solution for the years 2009 to 2012, and the final renewal of the radiosonde site of the MeteoSwiss aerological station Payerne is postponed for at least 2012.

CHAPTER 2 Introduction

Since its introduction in 1990 the SWISS radiosonde SRS 400 measures atmospheric humidity profiles with the “VIZ/Sippican” resistive carbon hygristor. With rising demands on the quality of atmospheric water vapour measurements for numerical weather prediction models and climate change observations, the VIZ/Sippican hygristor does not respond to the increasing requirements any more. Also, the manufacturer company Sippican announced a possible discontinuity of the production of the specific hygristor for the SRS 400. In view of these problems and facts, MeteoSwiss, in collaboration with Meteolabor, the manufacturer of the SRS 400, decided to investigate solutions for a possible substitution of the VIZ/Sippican carbon hygristor with a high performance capacitive humidity sensor, which may more favourably respond to present day quality requirements on atmospheric humidity profile measurements. Another constraint was to find a sensor that fits in the electronic design of the sonde.

The measurement principle of a capacitive humidity sensor is based on the dielectric properties of a polymer plastic material and their changes in function of relative humidity. Polymers are hygroscopic and tend naturally and fast to be in equilibrium with the surrounding air. According to the absorbed water content the dielectric constant of the polymer changes and hence the capacitance of the sensor, which with respect to ambient air temperature, becomes a direct measurement of relative humidity. An additional sensor measuring air temperature allows determining the dew point temperature.

Two sensor types were preselected and suggested by Meteolabor for possible use on the SRS 400, the HY41 sensor of the Austrian E+E company and the HygroClip Type S sensor of the Swiss Rotronic company. Both sensors are fast capacitive humidity sensors suitable for atmospheric profile measurements. MeteoSwiss finally choose the Rotronic sensor, which promised easier adaptation with only minor changes on the SRS 400 radiosonde. Rotronic built a specific programmable interfacing module which responds to the specifications required for the adaptation on the SRS 400. First investigations started in 2006 and several sensor types were tested on a large number of sounding flights at the MeteoSwiss aerological station Payerne.

In 2008 a new prototype of Rotronic the version HC2 was first tested on the experimental Meteolabor digital sonde SRS-C34, and in the same year flown at the international radiosonde campaign LUAMI in Lindenberg, Germany. During this campaign the HC2 turned out to be a very reliable sensor and the results in comparison with other humidity sensors flown on international radiosondes were very satisfactory. A second generation of HC2 sensors has then been built for the operational analog SRS 400 sonde. Sounding tests during the first month of 2009 allowed resolving final technical problems with respect to the operational radiosonde data acquisition system at Payerne.

Beginning of May 2009 the latest version of Rotronic humidity sensor type HC2 version B1.5.1 has finally been put in operation with the Meteolabor SRS 400 radiosonde at the MeteoSwiss aerological station Payerne. In order to guarantee a good overlap between the old and the new humidity profile measurements, VIZ/Sippican sensors are still flown once a week during a noontime double sounding. These double soundings will continue for at least one year. Furthermore regular intercomparisons are made with SnowWhite and RS92 radiosondes and the new Rotronic HC2 sensor.

CHAPTER 3 The SWISS radiosonde SRS 400

3.1 Introduction

The Swiss radiosonde SRS 400 used at the MeteoSwiss aerological station Payerne was introduced in 1990 and is manufactured by the Swiss company Meteolabor. The features of this sonde include copper-constantan thermocouples of 0.05 mm diameter, a full range water hypsometer, and a carbon hygristor for the relative humidity measurement in the troposphere up to 200 hPa (see Fig. 3.1).

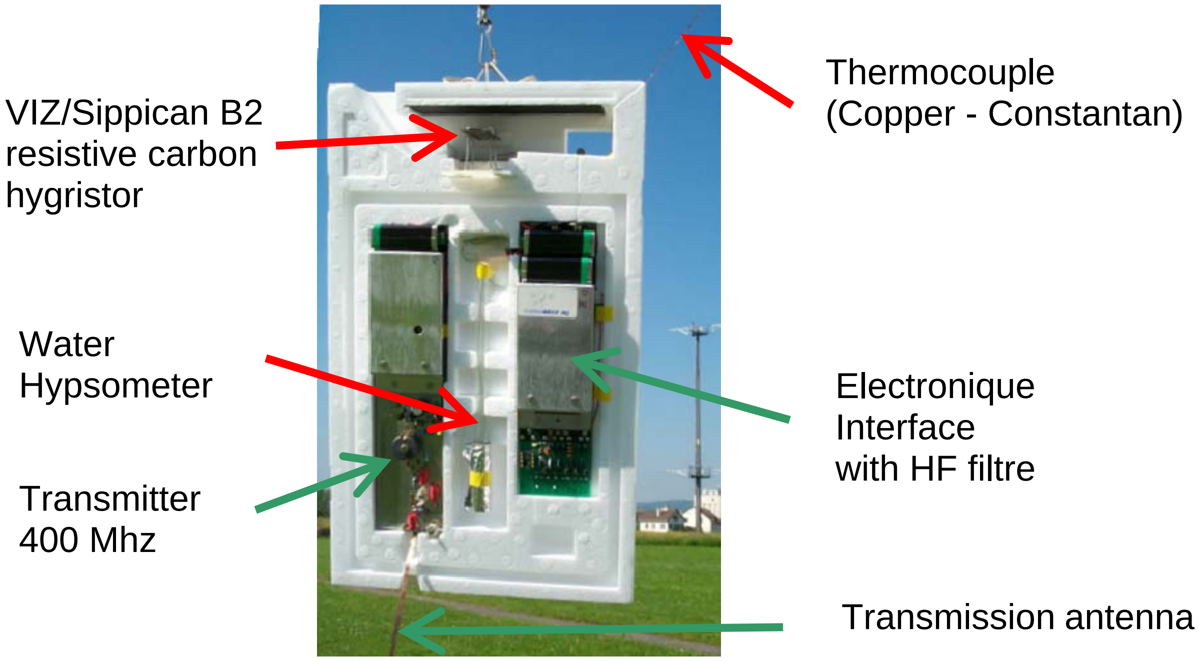


Figure 3.1 SRS 400 radiosonde from Meteolabor, Switzerland

The SRS 400 has been equipped with a resistive hygristor for the humidity measurement produced by the VIZ company (USA). The VIZ company was bought by Sippican in 1997 [Elliott et al., 2002; Christy and Norris, 2006], which further developed the manufacturing process of these hygristors, and later on transferred the production to a factory in Mexico, supposedly without changing the specifications. A few months after the switch to hygristor lots produced by Sippican in Mexico, MeteoSwiss encountered serious problems with a lot of hygristors that were rejected by the quality control during the pre-flight check. Since then, many investigations, tests and analyses have been made on the behaviour of the VIZ/Sippican hygristor at MeteoSwiss.

3.2 VIZ / Sippican humidity sensor

The humidity sensor of the operational SRS 400 radiosonde is a fast response carbon resistive hygristor of the US company VIZ/Sippican (Premium humidity sensors ACCU-LOK® P/N 1386-663). Originally conceived for the VIZ-radiosonde, it had been implemented on the Swiss radiosonde SRS 400. According to our purchase procedure, we normally ordered several thousand hygristors, allowing a three to five year operation. Lots of several hundreds of hygristors were characterized by a unique calibration factor (so-called Lock–In value). Hygristors produced by the VIZ factory in the USA have been in use until mid of March 2001. Then, the new Sippican version produced in Mexico was introduced. The physical aspects of these hygristors were standard of VIZ/Sippican, but the calibration procedure was modified. The accuracy specified by the manufacturer over the range of 5 to 100 % relative humidity (RH) was ± 2 % rms (repeated calibration method over the temperature range from –35 °C to 40 °C). Figure 3.2 displays the sensor response functions, used at Payerne between 1997 and 2003. VIZ and later on Sippican have introduced several times slight changes in these response functions, which were systematically taken into account at Payerne. For example, Sippican determined individual lock-in factors and defined 2 additional calibration factors H1 and H2 shifting the response functions in the high, respective low, humidity range, which were put in operation at Payerne in 2003. As can be seen in Fig. 3.2, resistive hygristors are strongly temperature dependent and nonlinear. It is known that carbon hygristors have a large response time below –40 °C and almost no sensitivity below – 60 °C.

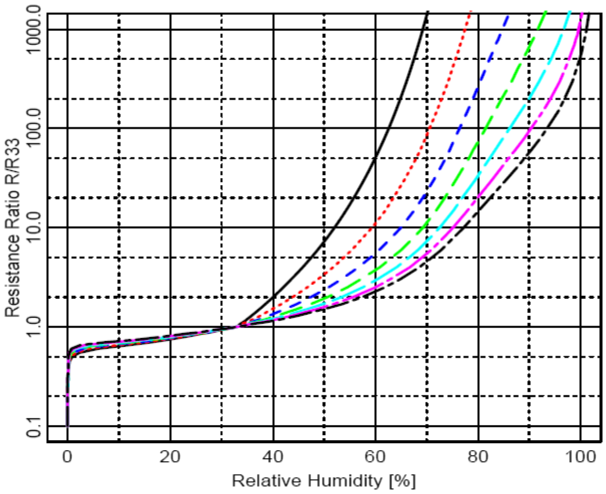


Figure 3.2 Response functions used for the processing of the VIZ/Sippican hygristor measurements. The vertical axis represents the ratio between the resistance measured in flight (R) and the resistance measured in the calibration chamber at 33 % RH and 25 ^{o}C (lock-in: R33). The continuous black line to the left of the figure applies to air temperatures of - 60 ^{o}C, the next dotted red line to -45 °C, etc., and finally the last dash dotted black line applies to +30 ^{o}C.

The first Sippican hygristors from the production in Mexico (lot 7210D) were put in operation at Payerne mid of March 2001. They revealed no special operational problems and even seemed to exhibit better dynamical behavior at low atmospheric humidity (VIZ hygristors seldom measured relative humidity below 20 %). These new hygristors in fact occasionally measured humidity values below 1 % RH (minimum accepted by the calculation procedure) over thick layers in the middle troposphere. Their humidity measurements in the pre-flight calibration chamber stayed within the large rejection limits of ±15 % RH.

The second lot 7210B brought serious problems, as the hygristors were almost systematically rejected by the pre-flight check. The differences between the reference and the hygristor climbed to values ranging between 6 to 18%. We changed the relative humidity limit of the pre-flight check from 15% (never reached between 1992 and 2000) to 20%. After thorough testing of the reference hygrometers of the pre-flight calibration chamber as well as the whole data acquisition system, we investigated several hygristors from different lots delivered by Sippican in the calibration chamber. They exhibited rather large differences compared to the reference hygrometer. Three hygristors from each of nine different lots were then shipped back to Sippican for factory tests. End of October 2001, Sippican reported us the following results of their investigations:

"*The problem was in our process of obtaining calibration Lock-In values for these lots of hygristors. With the testing of your returned samples and our failure analysis investigations, we have determined that all lots with the exception of Lot 7210 can be linearly adjusted to obtain accurate RH readings. We would like to propose that an adjustment of +15% be made to the existing Lock-in value and a sample of lots be tested to verify that your results are within your acceptable range.*"

The +15% Lock-in adjustment was then applied accordingly and a procedure was established in order to enable a systematic check of all suspect lots [Jeannet et al., 2003].

The hygristor is placed in an air duct in the upper part of the SRS sonde, where the temperature was supposed to hardly differ from the outside air temperature (see Fig. 3.3), while recent experiments in 2008 showed that the slight difference in these temperatures has to be accounted for. The ascent speed of the sonde, and hence the air ventilation speed for the sensor, is on the order of 5 m/s.

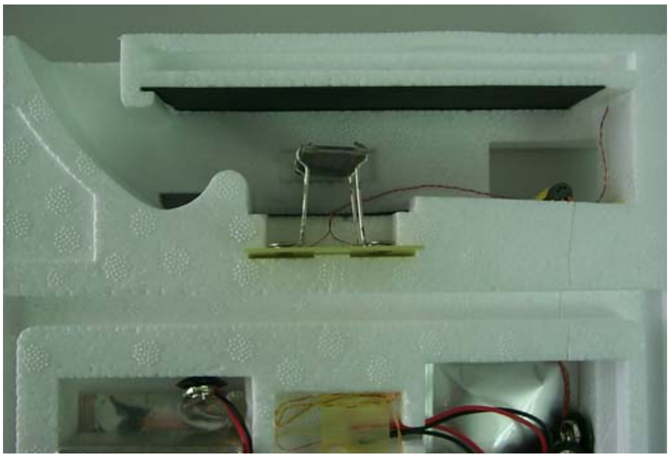


Figure 3.3 VIZ/Sippican hygristor placed in the upper part of the Swiss radiosonde. The air inlet is on the left on top of the sonde. The air outlet is on both sides of the sonde on the right. Rain drops are kept from the hygristor by a ballistic obstacle and can escape on one side of the sonde.

Sippican has now developed a new capacitive humidity sensor for its new radiosonde and is presently only producing resistive hygristors for customers still using their old sonde (e.g. part of the US upper air network) as MeteoSwiss

3.3 Analysis of pre-flight humidity checks

As our original operating procedure did not archive the final results of the pre-flight humidity checks, we re-processed the raw data files of 195 soundings from the years 1998 to 2002 and we started archiving routinely pre-flight measurements by end of September 2002. The large archived data set now contains the lot number, the lock-in value, the reference temperature, the sonde temperature, the reference humidity and the sonde humidity for each of the pre-flight checks. Most of the selected cases before September 2002 are from dual soundings, where both sondes were equipped with resistive hygristors, or the hygristor of the second sonde was replaced by a chilled mirror hygrometer.

Figure 3.4 shows the relative humidity differences between sonde and reference measured in the pre-flight calibration chamber at temperatures between 20 and 25 °C, for all lots taken into account in this analysis. The first two lots on the left of the figure, marked with blue triangles and violet circles were manufactured in the USA by the VIZ company (first 125 cases from soundings between March 1998 and mid of March 2001, with hygristors delivered in 1996). The following lots, beginning with the brown circles, were all manufactured by Sippican in Mexico. The two cases marked with blue plus signs correspond to the first lot showing problems in mid-July 2001. Soon after the re-calibration performed by Sippican, we introduced the adjustment factor of +15 %, first for the lot 7223B put in operation 24th of November 2002 (pink squares). The measurements marked with blue triangles belong to the replacement lot manufactured in February 2002, which does not need a lock-in value any more. As can be seen some of the Sippican lots deviate systematically from the zero line and most of them are characterized by a larger dispersion than the lot used in 1998. The individual Sippican hygristors belonging to the different lots that have been corrected with the +15% lock-in value deviate within a broad range going from -10 to + 15 % RH from the reference hygrometer (without lots 7210A-B). The replacement lot (no 7327) is shifted against positive humidity differences.

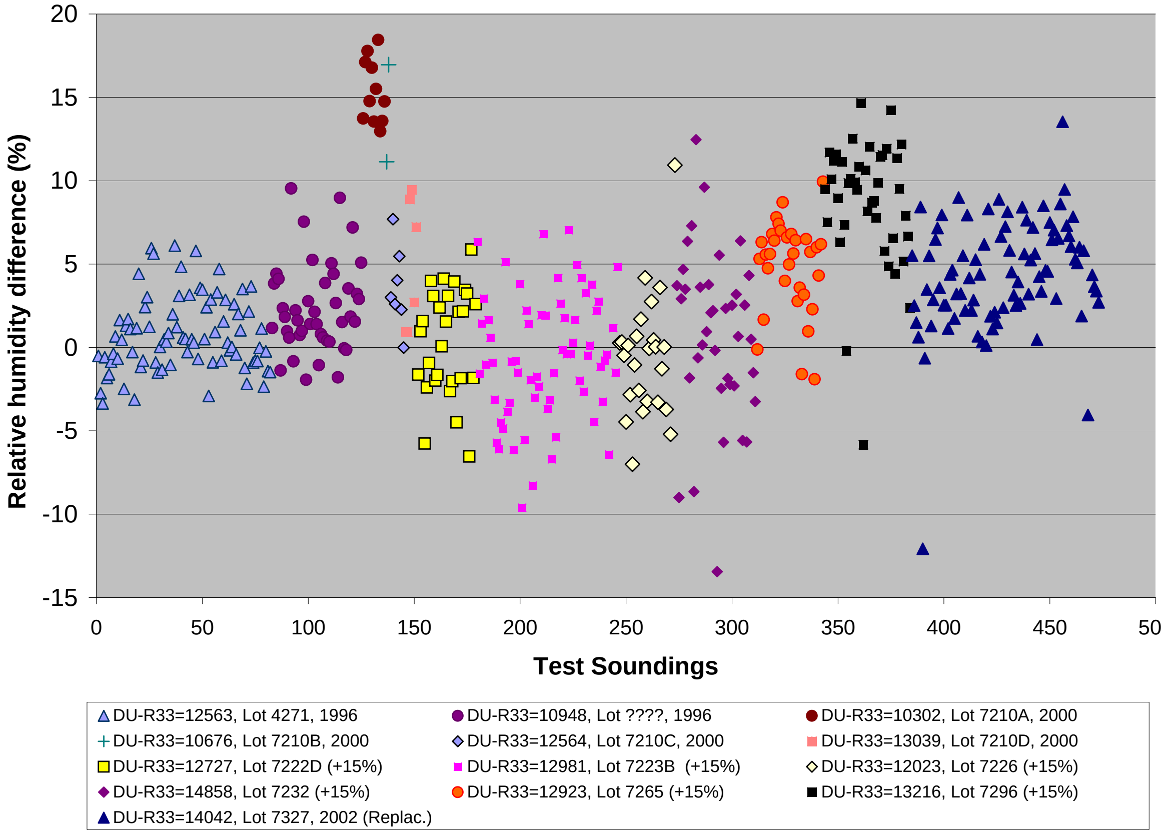


Figure 3.4 Relative humidity differences between sonde and reference measured in the pre-flight calibration chamber. The first 125 soundings shown here were equipped with hygristors manufactured by VIZ, the following ones by Sippican. The soundings are ordered with increasing lot number. Soundings with numbers 150 to 380 refer to hygristors with the +15% lock-in adjustment.

Figure 3.5 shows the differences of relative humidity between sonde and reference in percent for lots produced between 1996 and 2008. At the end of 2002 the + 15 % adjustment factor was introduced. In the newer lots after 2005 additional calibration factors H1 and H2 were introduced (individual lock-in factor, H1 and H2 constant within a lot). Note that the problem encountered in 2001-2002 was a special and very serious one, but the fundamental limitations of the resistive hygristors have not been removed by the new factors H1 and H2. In addition, the lots used in the very last years showed strongly changing H2 factors questioning the long-term stability of the production and calibration processes at the Sippican factory.

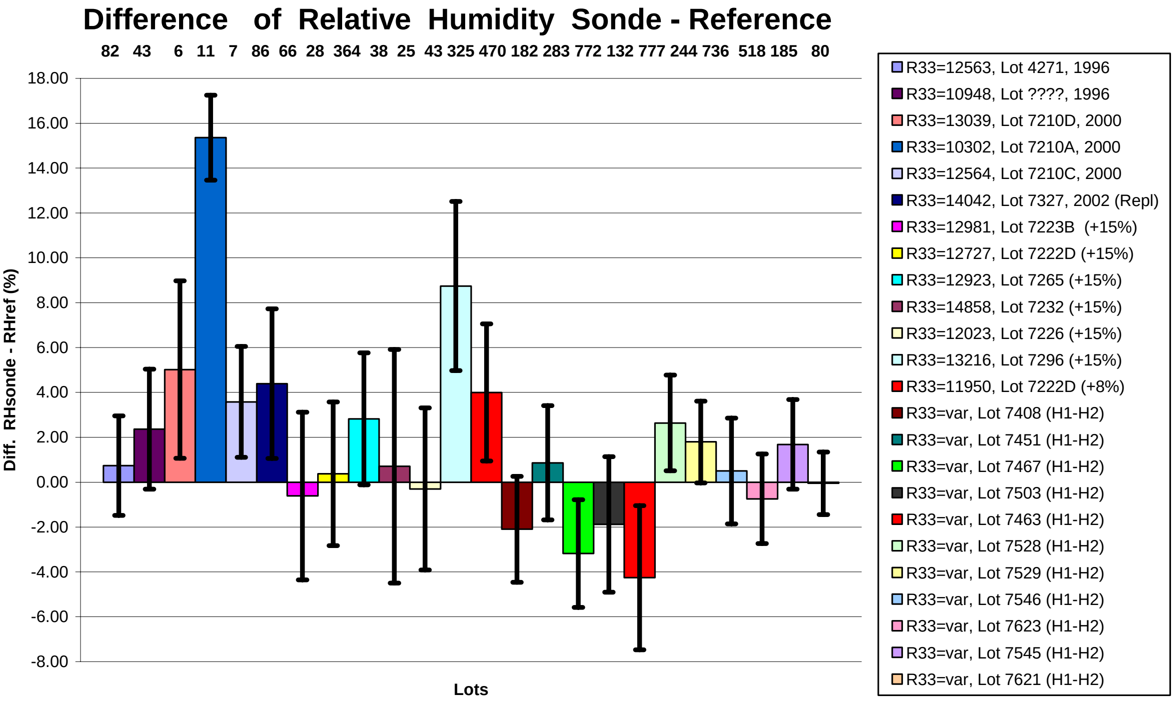


Figure 3.5 Differences of relative humidity between sonde and reference (pre-flight check) in percent for lots produced between 1996 and 2008. Figures above indicate the number of hygristors per lot.

3.4 Precision during flight measurements

Numerous dual soundings that have been performed for several years allow an analysis of the reproducibility of the VIZ/Sippican hygristors. Two identical ground-receiving systems receive simultaneously the measurements of two meteorological sondes attached to the same balloon. The measurements of the two sondes are synchronized in the data acquisition. Such dual soundings had been performed at Payerne primarily to compare the performance of different ozone sondes.

The US national weather service uses the root mean square of the differences (RMSD) and frequency distributions of the time and pressure-paired meteorological measurement differences to test dual flights [Bower, 2002]. These dual flights must meet the following accuracy requirement for humidity: RMSD and 95 % of differences < 5% from +50 °C to -60 °C.

Figure 3.6 left applies to hygristors produced by VIZ in 1996. The mean differences are close to zero, as it is expected for a rather large collective of dual humidity profiles performed with an identical sensor type. Hence, the RMS and the standard deviation are almost identical. The RMS slightly varies between 2 and 4.5 % RH in function of the altitude. No clear altitude dependency can be observed, but the smallest values are found in the lower troposphere. The mean RMS amounts to approximately 3 % RH. The 95% values amount to nearly twice the RMS and vary between 4 and 9.5 % RH.

Figure 3.6 right relates to hygristors from the different lots manufactured by Sippican in winter 2000/2001. Although the collective is even larger then on the left graph, the mean differences are not so close to zero. The main feature of this figure is a strong increase of all types of differences. Above 2 km altitude, the mean difference exceeds 5 % RH and stays mostly between 7 and 8 % RH. The 95 percent of the individual differences reaches 15 % above 4 km altitude. The fact that these dual soundings mix hygristors from different lots certainly lowers the functional reproducibility, but this should not be the case if the calibration fulfills the accuracy specified by the manufacturer.

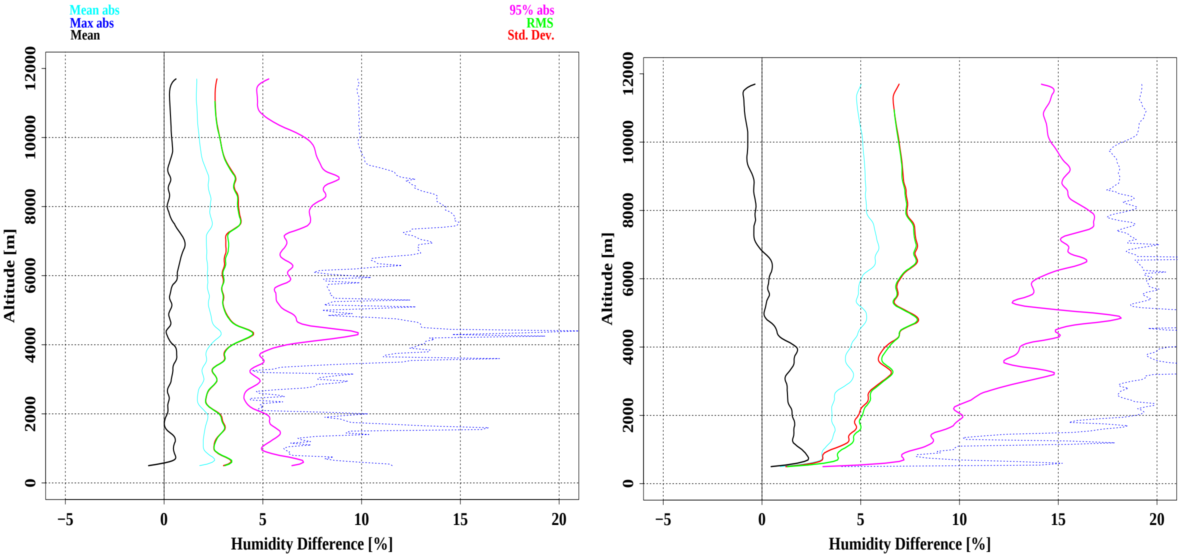


Figure 3.6 Statistical parameters of the differences between the relative humidity measured by two VIZ hygristors for 39 dual soundings performed during 1998 (left, VIZ_USA) and 55 dual soundings performed during 2001 and 2002 (right, Sippican_Mexico). Mean difference (Mean, black), the mean of the absolute differences (Mean abs, light blue), the maximum of the absolute differences (Max abs, dark blue), the standard deviation of the mean difference (Std Dev, red), the root mean square difference (RMS, green), as well as the percentile 95% of the individual absolute differences (95% abs, purple).

3.5 Comparison to different humidity sensors

Dual or even triple soundings were performed to compare the measurements of different humidity sensors. Figure 3.7 shows two flights performed in the framework of the international TUC campaign at Payerne [Ruffieux et al., 2006] that compare measurements from a VIZ/Sippican hygristor, a Snow White chilled mirror hygrometer and a Vaisala Humicap hygristor. Several corrections have been applied to the different sensors. The corrections applied to the three humidity sensors improve their results as most corrections are mainly related to systematic errors in their data processing. These corrections most frequently increase the relative humidity values and bring them closer to one another. In the high humidity range, the slight difference between the environment air temperature and the hygristor temperature is responsible for a slight underestimation of the measured humidity values (uncorrected values).

In the boundary layer, the continuity between the surface measurements and the first levels after launch is generally improved. The agreement between the three sensors is generally good in the lower free troposphere. The statistical correction applied to the VIZ/Sippican hygristor improves noticeably the mean agreement with the two other sensors, but still represents a rather crude correction in different situations. First, above a freezing low stratus the humidity measured by the hygristor stays afterward blocked with almost constant values (see right graph). Second, in the upper troposphere carbon hygristors generally lower their sensitivity at temperatures below -30 °C (left and right graph).

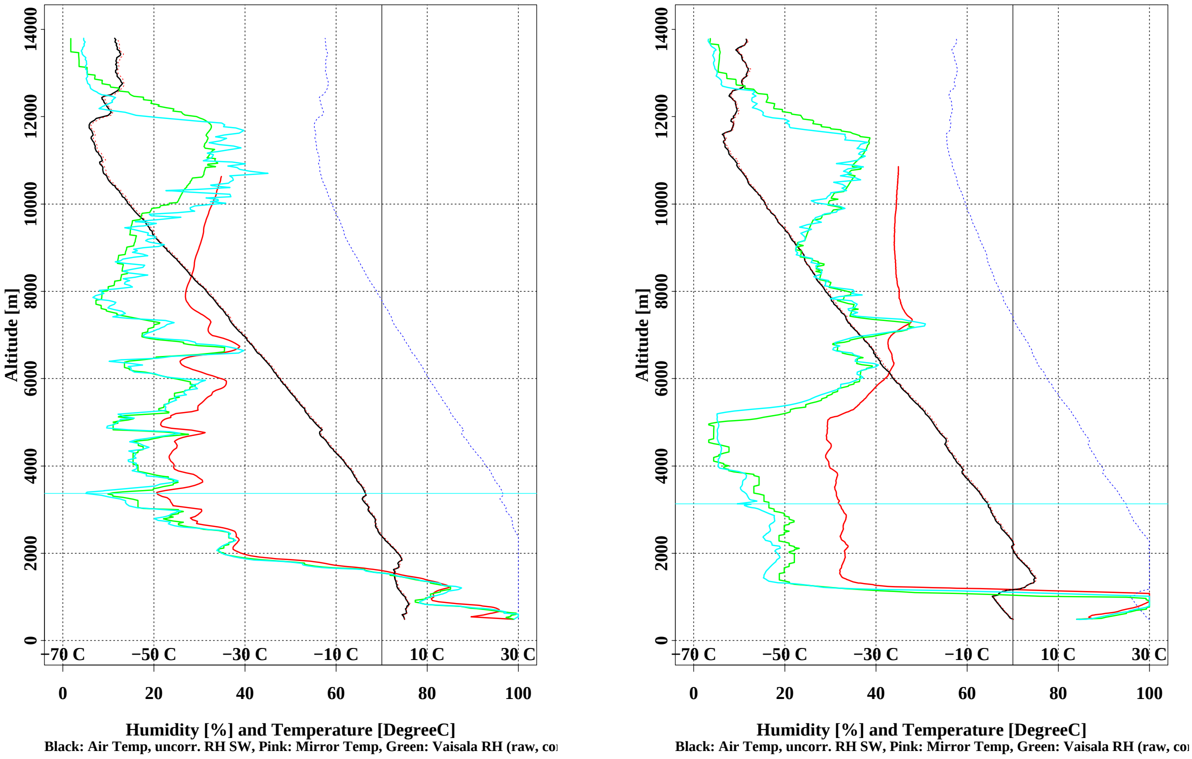


Figure 3.7 Corrected humidity profiles of 3 sondes launched with the same balloon
- « Snow White » hygrometer - SRS VIZ/Sippcan hygristor - Vaisala Humicap A hygristor
as well as - saturation over ice (dotted) - SRS temperature
The horizontal bleu line depicts the transition from dew to frost on the hygrometer mirror.

3.6 Integrated water vapor – VIZ/Sippican hygristor compared to GPS

VIZ/Sippican humidity measurements during winter time and within layers of low temperature and low humidity were often rather high. During such periods integrated water vapor (IWV) measured by the sonde often exceeds IWV determined from GPS measurements. Figure 3.8 shows several days in January 2006 with the sonde values above GPS values. Overall, we found that IWV from the VIZ/Sippican sonde shows rarely values below 5 mm. However, during spring and summer with high humidity, IWV from the VIZ/Sippican is often rather low compared to GPS measurements.

The observed overestimation of IWV by the VIZ/Sippican sensor is mostly explained by the artefact underlined in Fig. 3.7 (figure on the right): The ascent of the sensor through stratus or heavy cloud layers often induces saturated and artificially too high RH measurements (typically around 20 to 30% RH) even though the sensor may fly into very dry layers above clouds with RH below 10%.

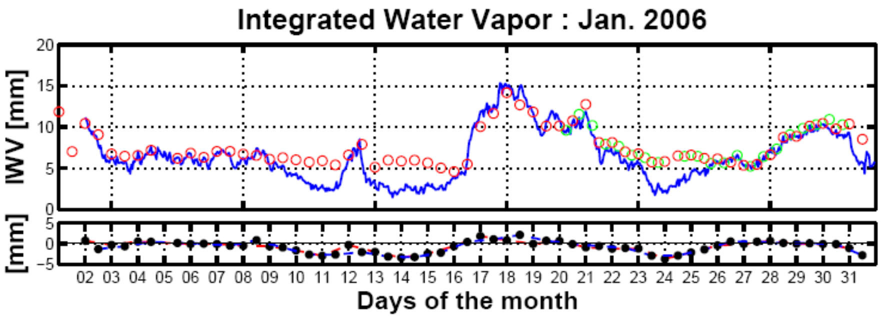


Figure 3.8 Comparison between hourly integrated water vapor (IWV) determined with GPS (blue curve) measurements and the soundings (red and green dots).

3.7 Summary

From the different investigations and analyses performed at MeteoSwiss on VIZ/Sippican hygristors, we conclude that the quality and the reproducibility of hygristors delivered to Payerne by the Sippican company between 2000 and 2002 considerably lowered, in contrast to hygristors manufactured by the former VIZ company. This results from pre-flight investigations but also from the analyses of numerous dual soundings. The manufacturing of the hygristors by Sippican has apparently not been as stable as by the former VIZ company. In the following years, the addition of supplementary calibration factors by Sippican, which we put in operation at Payerne, did not significantly remove the fundamental limitations of these resistive hygristors, which are also documented in several publications.

Double or triple soundings comparing resistive hygristors with chilled mirror hygrometers show deficiencies on resistive hygristors particularly above freezing stratus clouds and low temperatures below -30°C. Also, integrated water vapor values show that during periods with very low humidity VIZ/Sippican hygristors do not reach low enough values and during high humidity they often rather underestimate the effective IWV.

CHAPTER 4 Evaluation of a new humidity sensor

4.1 Introduction

In 2006 MeteoSwiss decided for a prolongation of the SRS 400 radiosonde until at least 2012. Considering the different problems encountered with the VIZ/Sippican hygristor it was decided to test the feasibility for a possible adaptation of a new humidity sensor on the SRS 400. The goals set forth for the new sensor was to improve humidity profile measurements in the lower and mid troposphere and to have a cost effective solution. Beside resistive humidity sensors, which have been used in the past on radiosondes, different types of capacitive humidity sensors are now available on the market and have been applied on different radiosondes.

4.2 Resistive hygristors

The VIZ/Sippican humidity sensor is a carbon resistive hygristor, which consists of a polystyrene foil which is coated with a carbon dotted hygroscopic thin film. As shown in Figure 4.1 the foil is molded between two electrodes. Relative humidity variations modify the dimensions of the hygroscopic film thereby modifying the electric resistance between the two electrodes.

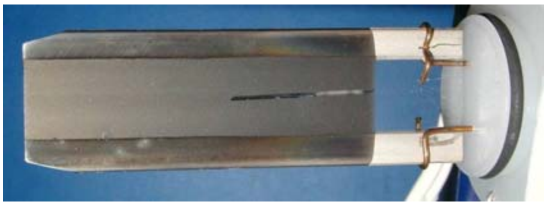


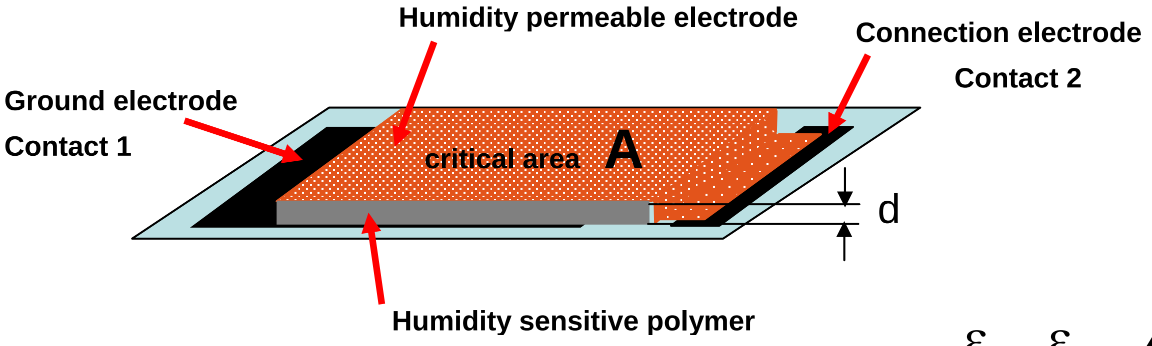
Figure 4.1 Carbon resistive hygristor

Relative humidity changes from 30 % to 90% produce very large resistance increases. However, as the sensitivity varies strongly nonlinear with humidity and temperature (see Figure 3.2), measurements have to be carried out over a very wide range in order to calibrate the sensor. Sensitivity and output range of the sensor can be controlled by changing the electrode spacing or geometry.

4.3 Capacitive humidity sensors

The physical measurement principle of a capacitive polymer humidity sensor is based on the characteristics of a hygroscopic material, which is used as the dielectric medium of a capacitor. The water content in the polymer is in equilibrium with the relative humidity of the atmosphere being measured. According to the water content the dielectric constant of the dielectric medium changes and hence the capacitance of the sensor, which becomes a direct measurement of relative humidity.

By virtue of its constructional characteristics, the capacitance value almost linearly depends on the value of relative humidity. The high nominal capacitance and good sensitivity enables simple and stable evaluation electronics. The used polymer is resistant against dew formation and usual chemicals.



$$C\,(RH) \approx \frac{\varepsilon_o \quad \varepsilon_p \quad A}{d}$$

Figure 4.2 Capacitive polymer sensor in thin-film technology

For aerological profile measurements sensors are needed with very small thermal response times and, first and foremost, very short humidity response times. Capacity polymer sensors have become increasingly popular for measuring humidity as they can be manufactured with an appropriate design and sufficiently good response speed thanks to effective process management in production (see schematic in figure 4.2). *A* is the active surface and *d* the thickness, therefore the best capacity (RH) sensor is (1) as thin as possible (shortest response time and highest RH sensitivity) and (2) with a large enough area *A*. To find the best compromise has been the challenge of the 2006–2008 development.

4.4 Rotronic humidity sensor

Humidity sensors from the Swiss company Rotronic have been used at MeteoSwiss for surface humidity measurements for many years. Over the last three years several Rotronic hygromer humidity sensors have been tested in collaboration between Meteolabor, Rotronic and MeteoSwiss on a number of aerological flights starting from Payerne. For their Type S model Rotronic first built the necessary electronics interface to adapt to the data acquisition of the SRS 400 (see figure 4.3).

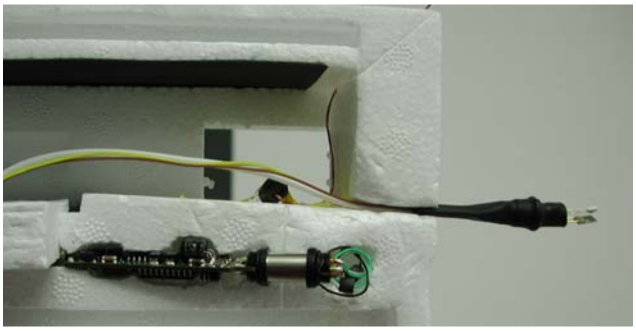


Figure 4.3 Rotronic Type S capacitive polymer humidity sensor and electronics interface to adapt to the SRS 400 data flow.

4.5 Test flights with Rotronic C-94-M-SK humidity sensor

A number of test flights were made with the Rotronic type C-94-M-SK 1st and 2nd generation (Figure 4.4 left and right). These prototypes had several physical problems and were not robust enough for the large temperature changes during aerological flights. The problem was primarily related to the rigidity of the polymer foil (attempts with quite large surface A) which let to fractures at low temperatures.

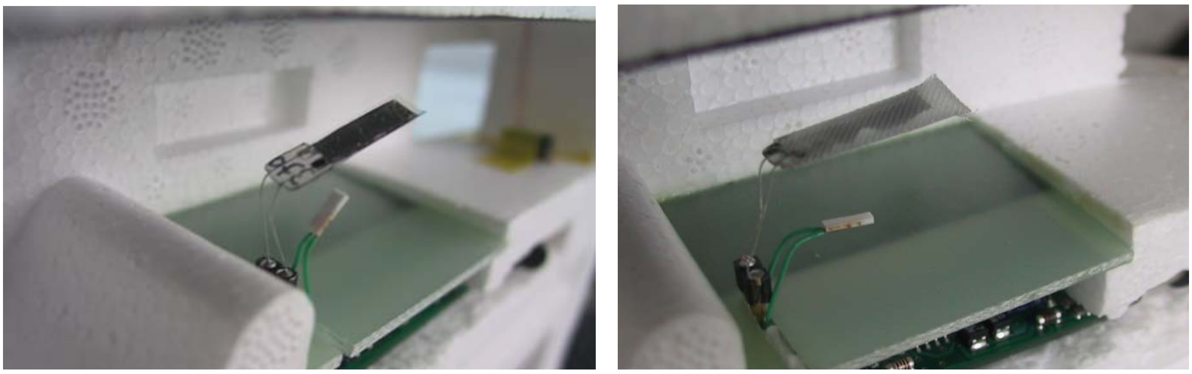


Figure 4.4 Rotronic type C-94-M-SK 1st generation (left) and 2nd generation (right)

4.6 Rotronic type HC2 sensor for experimental SRS-C34 radiosonde

A first generation of Rotronic type HC2 sensors (see figure 4.5) was built and first tested with the Meteolabor digital SRS-C34 radiosonde. The HC2 sensor is very thin (d = a few µm) and the active area A is 32 mm^2. It measures relative humidity with the larger sensor plate (above) and air temperature with the small sensor plate (below). The configuration in the SRS-C34 sonde was such that the HC2 temperature measurement was used to make internal corrections of the relative humidity, which was measured by the humidity sensor. An additional thermocouple temperature sensor mounted inside the ventilation channel, close to the humidity sensor, allowed determining the dew point temperature. The dew point temperature and the measured outside air temperature finally allowed to determine outside relative humidity.

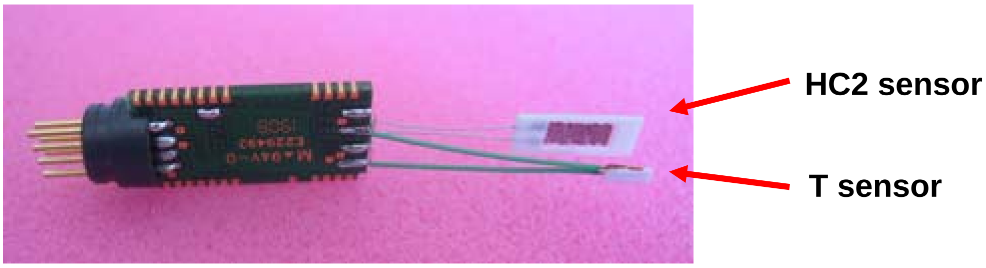


Figure 4.5 Rotronic HC2 1st generation

This configuration has been extensively tested during the LUAMI campaign in Lindenberg in November 2008 (see results in Chapter 5). More than 20 sondes were flown day and night with the SRS-C34 radiosonde and the ARGUS 37 radiosonde system. The ARGUS 37 is a portable radiosonde system that has been developed for research purposes by Meteolabor. Acquisition of radiosonde data are made very easy with a simple helix antenna and a portable computer. The digital SRS-C34 is a high quality radiosonde with the same temperature sensor and hypsometer as the sensors of the analog SRS 400 radiosonde. The sonde has a GPS sensor and several additional analog voltage channels that allow operating additional sensors and instruments.

4.7 Rotronic type HC2 sensor for operational SRS 400 radiosonde

The operational Swiss radiosonde SRS 400 has no additional voltage channel available for a separate temperature measurement inside the ventilation channel. Hence, the HC2 sensor has to deliver dew point temperature using its own temperature sensor. Dew point temperature is therefore calculated inside the HC2 and delivered as final measurement to the SRS 400. Relative humidity is finally determined with the outside thermocouple temperature measurement of the SRS 400.

Figure 4.6 Rotronic HC2 2nd generation (left), (right)

Hence the procedure applied in the operational radiosonde SRS 400 is different from the procedure in the experimental SRS-C34 sonde. Rotronic in collaboration with Meteolabor therefore developed a 2nd generation HC2 sensor. To improve the temperature measurement the arran Rotronic final HC2 version B1.5.1gement of the temperature sensor has been changed on the HC2 to minimize thermal flow thru the wiring to and from the detector. The 2nd generation HC2 version B1.5.1 sensor shown in figure 4.6 is the latest version developed by Rotronic and is now used on the operational SRS 400 radiosonde. Test flights made during March and April 2009 have shown that relative humidity measurements with the HC2 ver. B1.5.1 on the SRS 400 radiosonde are of same quality as the measurements with the HC2 measurements on the SRS-C34 made during the LUAMI campaign.

CHAPTER 5 Rotronic HC2 test sounding results

5.1 The LUAMI campaign

The Lindenberg Upper-Air Methods Intercomparison (LUAMI) was designed to improve the understanding of remote sensing (including the water vapor Raman Lidar at the Meteoswiss aerological station Payerne) and in-situ methods on measuring the basic atmospheric variables, with a strong focus on humidity. The campaign also aimed at testing the suitability of a large variety of methods of observations for their deployment in operational networks including the GCOS Reference Upper-Air Network (GRUAN). During the observational phase (4 – 22 November 2008) ground-based remote sensing, air-borne observations, and in-situ soundings were applied as intense as possible to provide a large dataset.

The basic concept of in-situ soundings during LUAMI followed the guidelines for radiosonde intercomparisons from CIMO. Radiosondes from different manufactures as well as reference instruments (see table 5.1) were attached to a rig and launched with one balloon. Up to 4.5 kilogram payload could be launched simultaneously. Radiosonde- and meta data were collected as soon as possible after the launch by the GRUAN lead centre and made available to all participants using a common data format (.ldf) and a ftp server.

Table 5.1 Radiosondes and sensors flown during LUAMI

Abbreviation	*Type / method*	*weight /g*	*Organisation / Company, Country*	*number*
		Commercial radiosondes		
RS-92 SGP	PTU - GPS	280	Vaisala Oyj, Finland	76
DFM-06	PTU - GPS	90	GRAW Radiosondes GmbH, Germany	24
BAT-4G	PTU - GPS	200	InterMet Systems, South Africa	25
SRS-C34	PTU - GPS	620	Meteolabor AG, Switzerland	29
		Reference- and Research radiosonde sensors		
RS-90 FN	FN Reference	380	RAO, Lindenberg, DWD, Germany	7
RS-92 FN	method			9
SW	Frostpoint mirror	550	Meteolabor AG, Switzerland	21
FLASH	Lyman-Alpha-Hygrometer	980	RAO / CAO Moscow, Russia	4
CFH	Frost-point mirror	990	RAO, Lindenberg, DWD, Germany, University Colorado, Boulder/USA	6
APS	Polymer sensor	600	Vaisala, Finland	12
COBALD	Backscatter sonde	500	ETH Zürich	7

5.2 HC2 humidity sensor flights during LUAMI

The LUAMI campaign ideally served to test the Rotronic HC2 humidity sensor. Meteolabor AG in collaboration with MeteoSwiss took part at the LUAMI intercomparison with their mobile radiosounding system ARGUS 37 and the digital SRS-C34 sonde. The 16 channel SRS C34 measures temperature with the standard Meteolabor thermocouple sensor and uses the Meteolabor hypsometer as well as GPS windfinding to determine pressure and geopotential height. With its modular design the SRS-C34 was used with various humidity sensors, like the capacitive polymer humidity sensors Rotronic HC2, the SnowWhite frostpoint mirror, the Lyman-Alpha hygrometer FLASH and the COBALD backscatter sonde.

Although several reference and research radiosondes were deployed during the campaign we decided to investigate the Rotronic HC2 soundings by comparing them to measurements from two commercial radiosondes, the Vaisala RS92 and the GRAW DFM. During LUAMI 32 SRS-C34 sondes where launched, of which 20 flights were made with HC2 sensors.

5.3 Temperature and time lag corrections

During LUAMI the HC2 sensor was mounted inside the ventilation channel of the SRS-C34 and was connected to an analog voltage port which resulted in a relative humidity measurement. A separate thermocouple measuring air temperature inside the ventilation channel was mounted very close to the HC2. This temperature measurement and the relative humidity of the HC2 were used to calculate the dew point temperature inside the ventilation channel. The outside relative humidity was finally calculated using the correct air temperature measured with the outside thermocouple. The outside relative humidity was then further corrected by applying specific time lag corrections for the HC2 sensor.

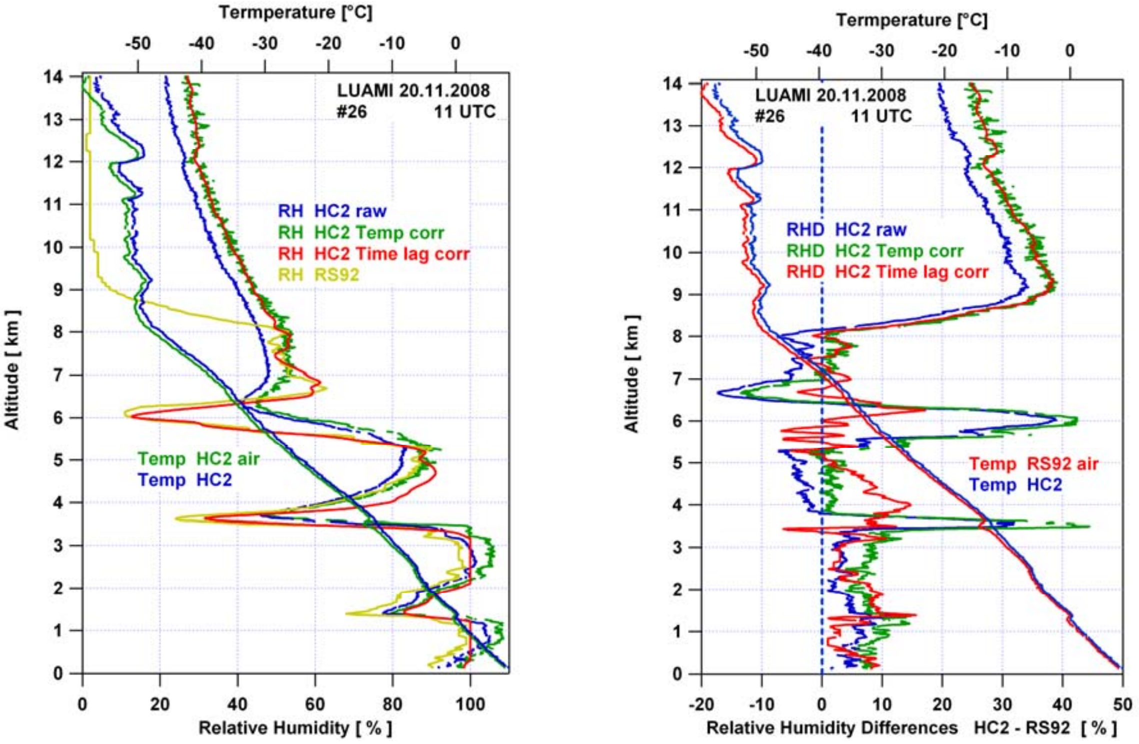


Figure 5.1 Typical temperature and time lag corrections on HC2 relative humidity measurements during a single flight (#26) experiment (left). Relative humidity differences HC2 – RS92 (right).

Figure 5.1 shows temperature and time lag corrections on the HC2 humidity measurements for the LUAMI flight #26. Relative humidity measured with the HC2 sensor in the ventilation channel (blue) is shown in the left graph as well as the temperature corrected relative humidity using outside temperature (green). Time lag corrections (red) are further applied on the temperature corrected HC2 relative humidity. This red curve corresponds to the final best estimate of the RH profile obtained with HC2.The right graph shows differences between HC2 raw, HC2 temperature corrected and HC2 time lag corrected relative humidity and the RS92 measurements.The different steps are each compared to the relative humidity reading of the RS92 sonde. Temperature differences between the ventilation channel and the outside air temperature of 0.5 to 1°C make up for relative humidity differences of a couple of percent. However, considerably larger relative humidity corrections of 10 to 20 percent are involved with the time lag correction during large and rapid relative humidity changes. Temperature and time lag corrections improve the HC2 relative humidity measurements.

5.4 Performance of the HC2 sensor during LUAMI

Of the 20 Rotronic HC2 flights performed during LUAMI, 14 soundings had all data available from the different sondes that allowed intercomparisons between RS92, GRAW and HC2 radiosonde measurements. For the intercomparison we used the official final results of altitude, pressure, air temperature and relative humidity that is available from the LUAMI data center for the individual sondes. We used the WRSKOMP software from Sergey Kurnosenko to interpolate the data with respect to altitude and to compute additional values like the water vapor mixing ratio and precipitable water for further statistical analysis.

Four typical soundings, two daytime (#20 and #22) and two nighttime (#19 and #23) were chosen to show the dynamic behavior and the concordance of relative humidity measurements of the HC2, the RS92 and the GRAW sonde, from the surface to the lower stratosphere (Fig. 5.2). Relative humidity variations from almost 100 to 0 percent during the four flights show large and very rapid changes under decreasing and increasing humidity. Consistent results between the three sondes are found from surface, or ambient temperature, to about –35°C, which corresponds to an altitude of 7 to 8 km. In this range differences between HC2 and RS92 are within 5 percent, except for rapid humidity changes, and they are very similar to differences between HC2 and GRAW. For temperatures below -35°C however, several flights clearly show much reduced sensitivity to humidity changes for the HC2, particularly with respect to rising humidity in high altitude cirrus clouds. Around and above the trospospause the HC2 rarely responds to humidity changes.

In figure 5.3 we show the Water Vapor Mixing Ratio (WVMR) for the same four soundings and we also show the percentage difference of the HC2 – RS92 versus RS92 and the HC2 – GRAW versus GRAW mixing ratio. Within the first 5 to 6 km the agreement between HC2 and the two other operational sondes is quite satisfactory with percentage differences within 5 percent as long as the WVMR is not subject to rapid changes or to very low humidity values. Above 6 km larger percentage differences are observed particularly in cases were the WVMR gets very small. In the upper troposphere and towards the tropopause the WVMR gets very small and percentage differences of the WVMR are not relevant at these altitudes. The graphs of the four flights show that the HC2 humidity sensor is in quite good agreement with the RS92 and the GRAW sensor as long as the water vapor mixing ratio has values higher than typically 0.5 gr/kg of dry air..

For the same four soundings we also show the absolute differences of the water vapor mixing ratio in [g / kg] and we show the precipitable water (PW) in [mm] water column (Fig. 5.4). The four soundings show a very large range of precipitable water going from a very dry sounding (flight #20) with less than 5 mm of total precipitable water to the rather wet case (flight #19) with more than 25 mm of water integrated over the whole profile.

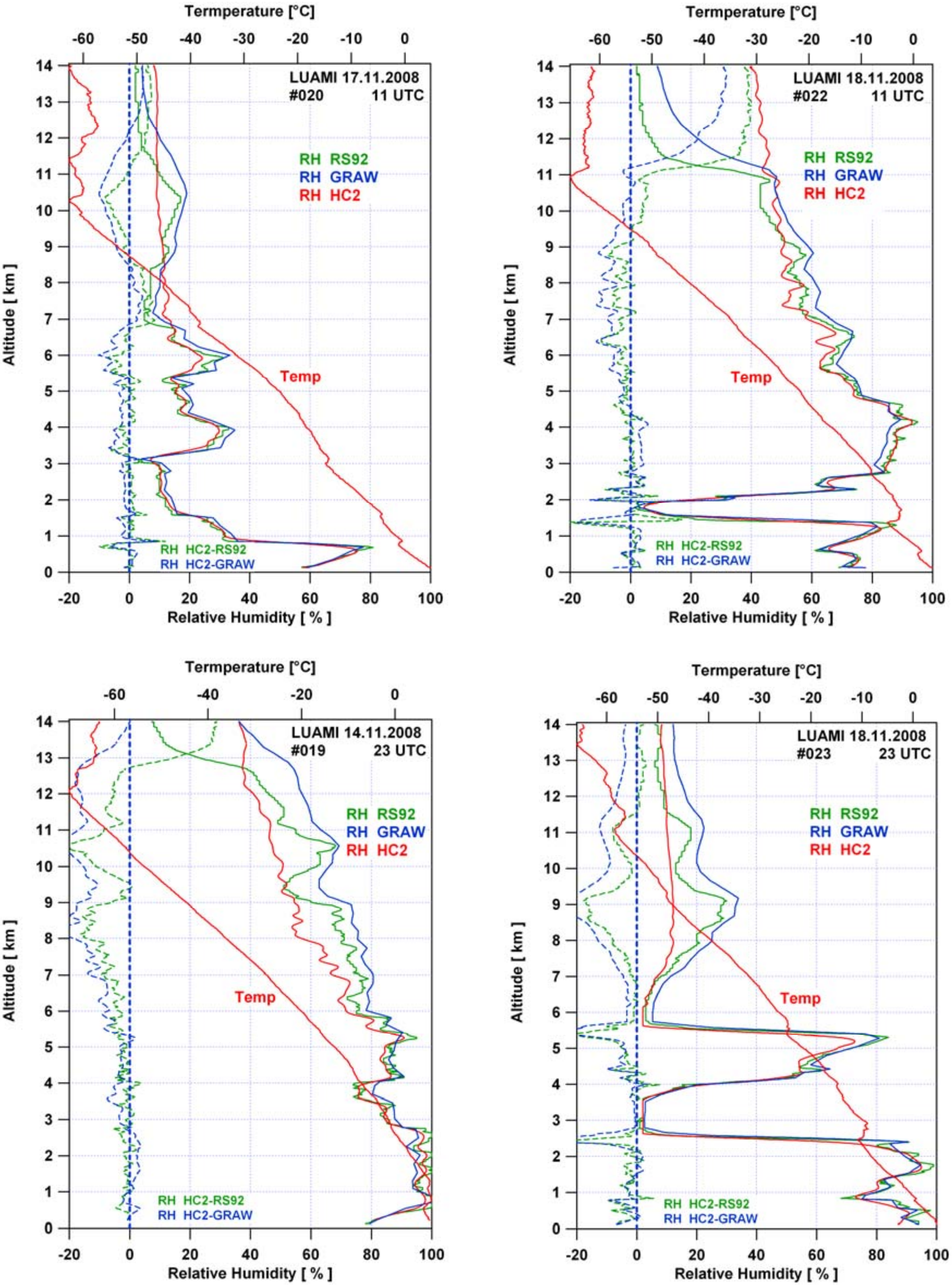


Figure 5.2 Daytime and nighttime relative humidity profiles during LUAMI. Daytime (flight #020 and #022 above) and nighttime (flight #19 and #023 below) humidity profiles measured by RS92 (green), GRAW (blue) and HC2 (red) humidity sensors. Consistent relative humidity is measured by the three sondes with variations from 0 to 100 percent. Differences HC2 - RS92 respectively HC2 - GRAW are within 5% for temperatures above -35°C and except for rapid and large humidity changes. For temperatures below -35°C the HC2 sensor shows much reduced sensitive to humidity changes. Around and above the tropopause the HC2 shows almost no sensitivity.

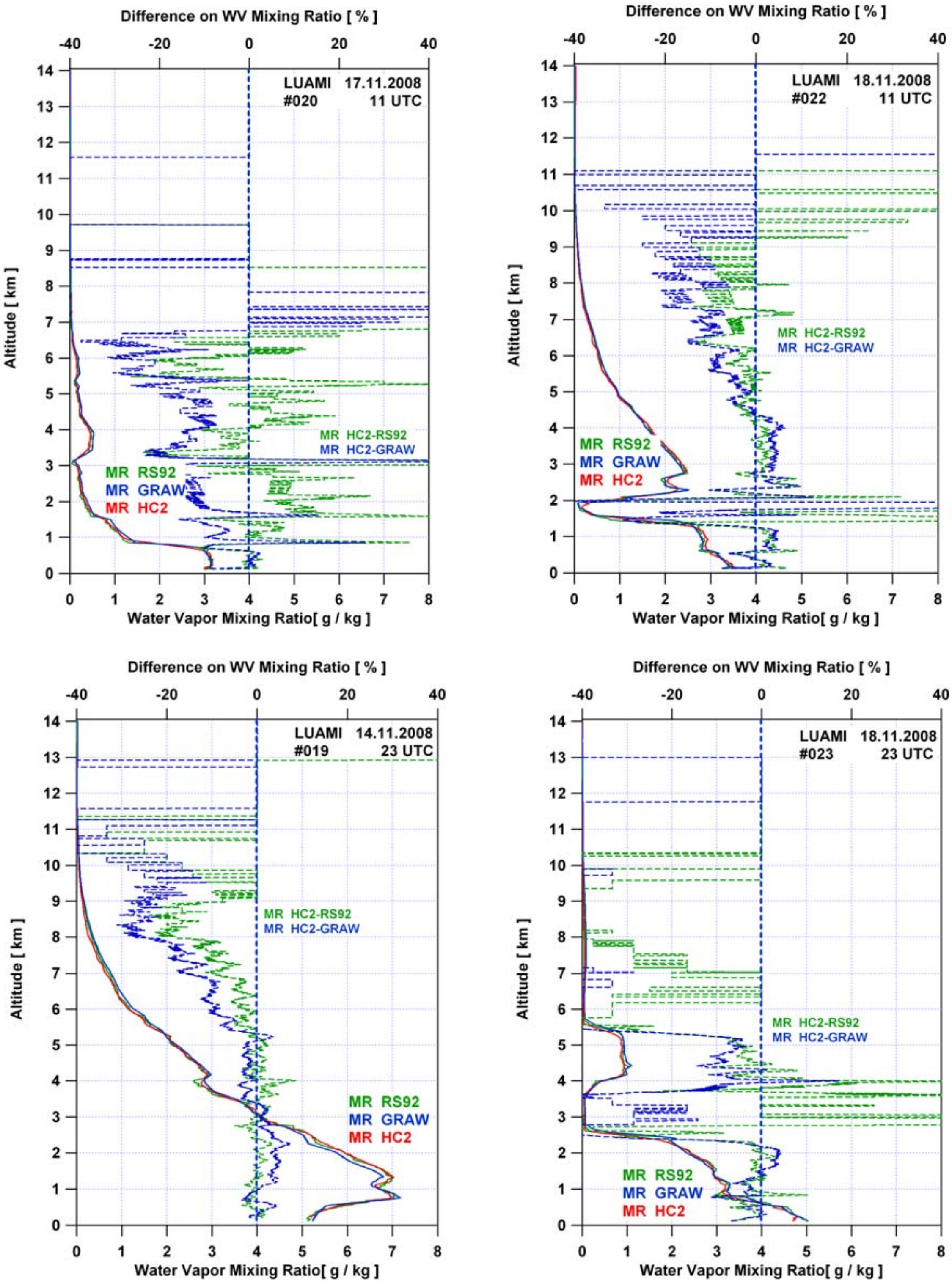


Figure 5.3 Water vapor mixing ratio profiles and differences between the three sensors. Water vapor mixing ratio for daytime (flight #020 and #022 above) and nighttime (flight #19 and #023 below) soundings measured by RS92 (green), GRAW (blue) and HC2 (red) humidity sensors. Mixing ratio percentage difference HC2 – RS92 and HC2 – GRAW show good agreement within 5 percent up to 5 to 6 km except for very low WVMR values. In the upper troposphere WVMR values become very small and mixing ratio percentage differences are not relevant.

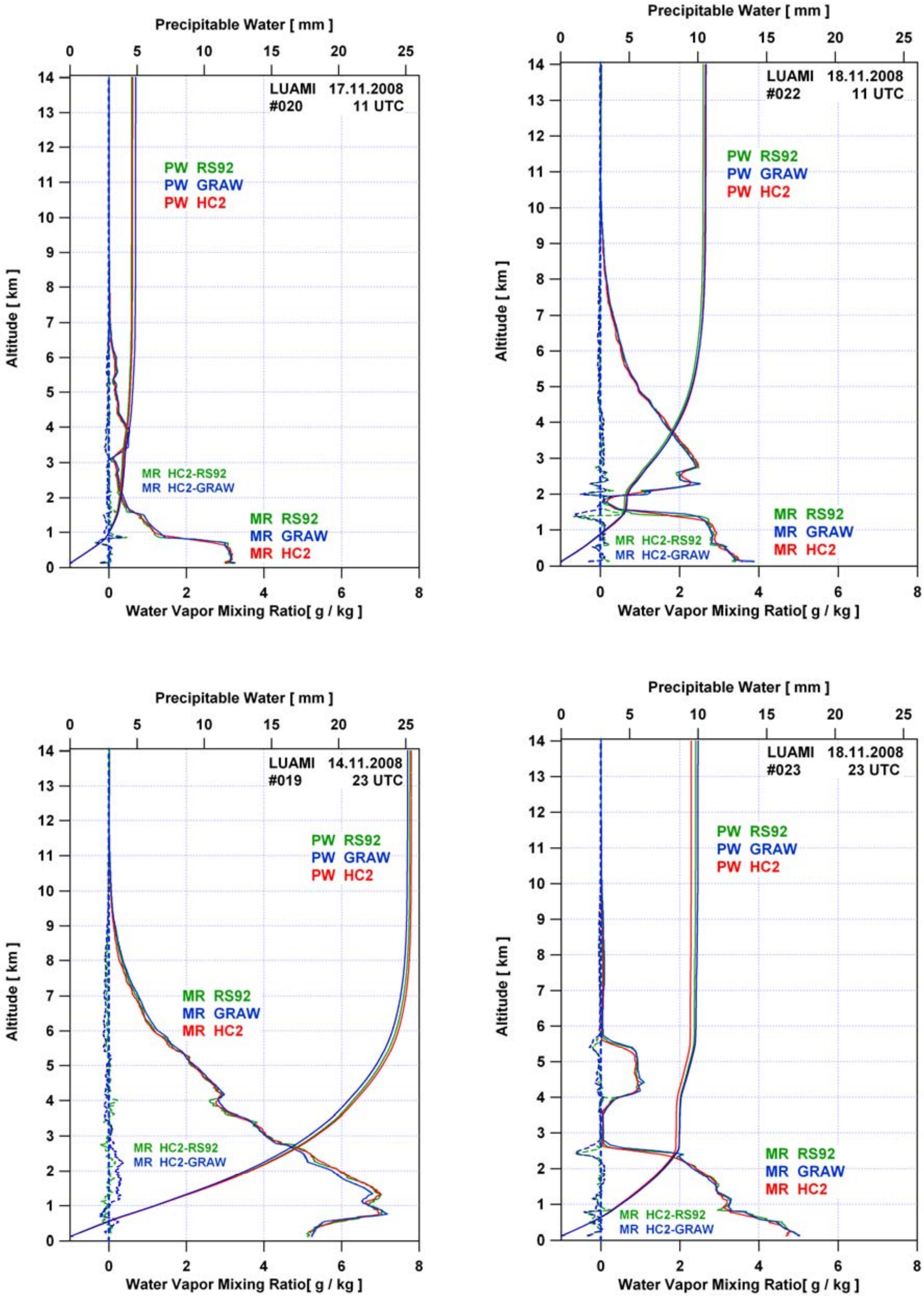


Figure 5.4 Absolute differences of water vapor mixing ratio and precipitable water for daytime (flight #020 and #022 above) and nighttime (flight #19 and #023 below). Absolute differences in [g / kg] and precipitable water in [mm] are shown for the same four flights. The four soundings show a very large range of precipitable water going from about 5 to 25 mm.

Table 5.2 shows percentage differences of precipitable water measured by the different sondes. Average values of the differences of all 14 LUAMI soundings are given at different altitudes. Average differences are on the order of 3 percent. Due to the fact that over all the soundings 63 percent of the precipitable water is below 2000 meter and 95 percent below an altitude of 6000 meter the percentage error is often higher a low altitudes. This result underlined that in very different moisture conditions, HC2 gives a total precipitable water (total integrated water content) that agrees with the 2 other sensors GRAW and RS92 to a difference of less than 3%. This result is later in this report compared with the VIZ/Sippican sensor (see page 29).

Table 5.2 Differences of precipitable water between different sondes at different altitudes

	Average differences [%]		
Altitude	**HC2-RS92**	**HC2-GRAW**	**GRAW-RS92**
2000	3.51	3.21	0.36
4000	3.11	1.84	1.32
6000	2.90	0.98	1.98
8000	2.69	0.52	2.24
10000	2.62	0.38	2.31
12000	2.65	0.38	2.34
14000	2.68	0.35	2.39
16000	2.67	0.34	2.40

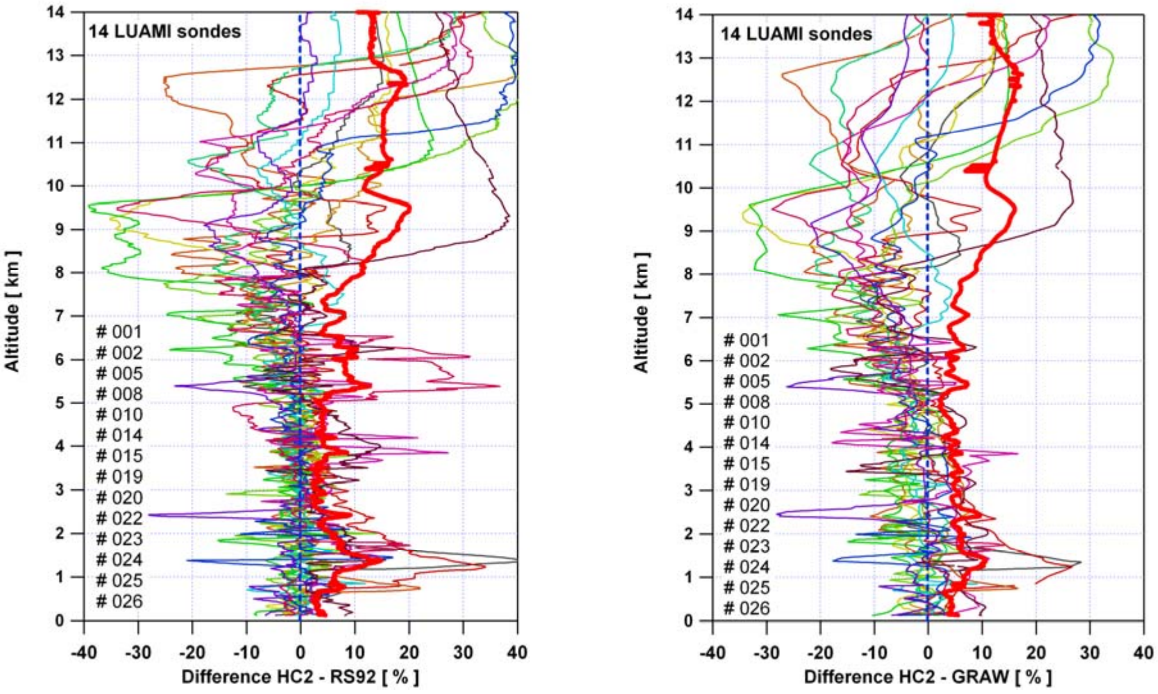


Figure 5.5 Relative humidity differences of HC2 – RS92 (left) and HC2 – GRAW (right) of 14 soundings during LUAMI. The red bold curve is the standard deviation of the differences of the 14 assents.

In figure 5.5 we finally show relative humidity differences HC2 - RS92 and HC2 - GRAW for all 14 LUAMI assents for which data off the three sensors were available. The red bold curve represents the standard deviation of the differences of all 14 soundings. Above temperatures of about -35°C (below altitudes of 7 to 8 km) the overall agreement is on average around 5 percent between HC2 and RS92 and GRAW. However, below -35°C (above 8 km altitude) average deviations go up to 20 percent and for individual soundings differences up to 30 percent can be observed, and this is clearly due to the reduced sensitivity of the Rotronic HC2 humidity sensor.

5.5 HC2 pre-operational test soundings at Payerne

The very encouraging good results obtained with the Rotronic humidity sensor HC2 1st generation during the LUAMI intercomparison let us to the next step, testing the second generation HC2 B1.5.1 with the operational SRS-400 sonde of MeteoSwiss at Payerne. Unlike the digital SRS-C34 with the mobile ARGUS 37 flight system, which has several additional input channels, the analog SRS-400 sonde with the operational BASORA tracking antenna system, has only one analog input channel to measure humidity. Hence, the HC2 B1.5.1 sonde had to be programmed such that its output signal directly provides the dew point temperature inside the ventilation channel. With the dew point temperature and the air temperature measurement the outside relative humidity is calculated. Hence, even thought the HC2 sensor used with the SRS-400 is the same humidity sensor as the one used during the LUAMI campaign, the reprogramming and the adjustments which had to be made to directly measure the dew point temperature caused several problems which had to be resolved.

During February and March 2009 several test flights were made with the HC2 version B1.5.1, and with this same version pre-operational flights were conducted during April. In order to demonstrate that the quality of the humidity measurements with the operational analog SRS-400 sonde is equal to the quality of the measurements with the digital SRS-C34 during LUAMI, four of the pre-operational flights were analyzed similarly as the four flights shown for the LUAMI campaign. The four pre-operational flights were conducted in parallel with RS92 sondes and also in parallel with the VIZ/SIPPICAN humidity sensor, which is the operational sensor of MeteoSwiss.

Figure 5.6 shows relative humidity measurements and the differences of the relative humidity HC2-RS92 and VIZ-HC2. The differences of relative humidity for all the four flights show better agreement between HC2 and RS92 than between the old VIZ/SIPPICAN sensor and the RS92 sonde. As in LUAMI all flights show that in contrast to the RS92 the HC2 sensor is not sensitive below -35 °C or at altitudes above about 8 km. Overall the comparisons between HC2 and RS92 look very similar to the measurements during LUAMI and the measurements show that the quality of the humidity profile is clearly improved in comparison with measurements of the present operational VIZ/SIPPICAN sensor.

The water vapor mixing ratio shown in figure 5.7 reveals similar aspects as the results from LUAMI (Fig. 5.3). The mixing ratio differences are reasonable only up to about 5 to 6 km. With the WVMR becoming very small higher up the percentage differences are getting large. Nevertheless the four graphs of figure 5.7 show clearly that the HC2 sensor compares considerably better with the RS92 than the VIZ/SIPPICAN sensor.

Precipitable water in figure 5.8 shows values from about 6 to 14 mm for the total water column for the four flights. Differences of precipitable water between the VIZ/SIPPICAN sonde and the RS92 are considerably larger than between the HC2 and the RS92 sonde. If we consider the LUAMI and the Payerne measurements the differences of precipitable water between HC2 and RS92 are again on the order of ±3 percent (see Table 5.2 and Table 5.3).

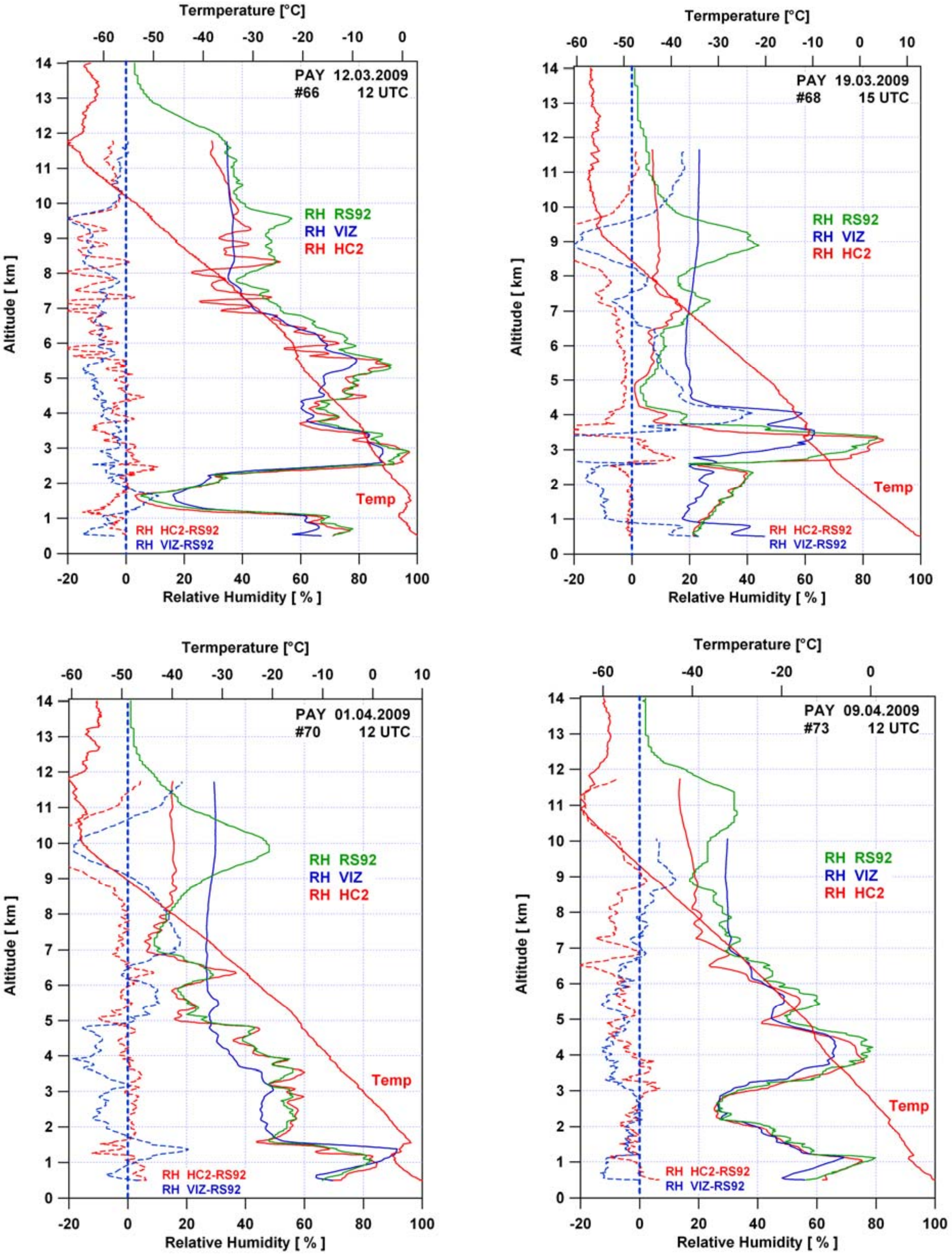


Figure 5.6 Daytime relative humidity profiles during pre-operational flights at Payerne. The four graphs show relative humidity profiles and differences between different sensors HC2-RS92 and VIZ-RS92. Agreement between the HC2 and RS92 is quite good for temperature above -35°C (altitudes below 8 km). Above about 8 km the HC2 sensor shows very similar results as during the LUAMI campaign with apparently strongly reduced sensitivity. The VIZ/SIPPICAN sensor shows larger deviations from RS92 measurements.

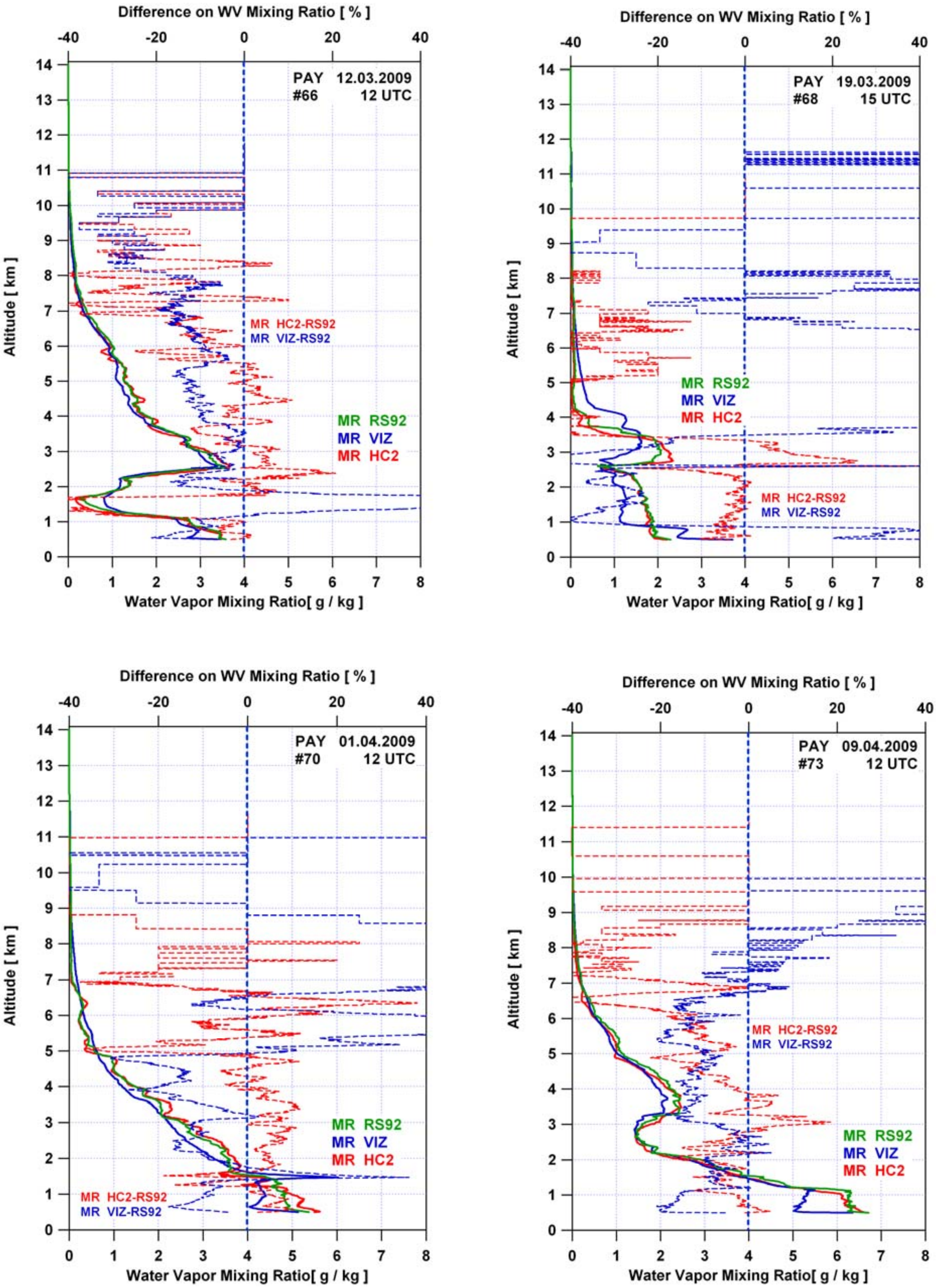


Figure 5.7 Water vapor mixing ratio profiles and differences between the three sensors.

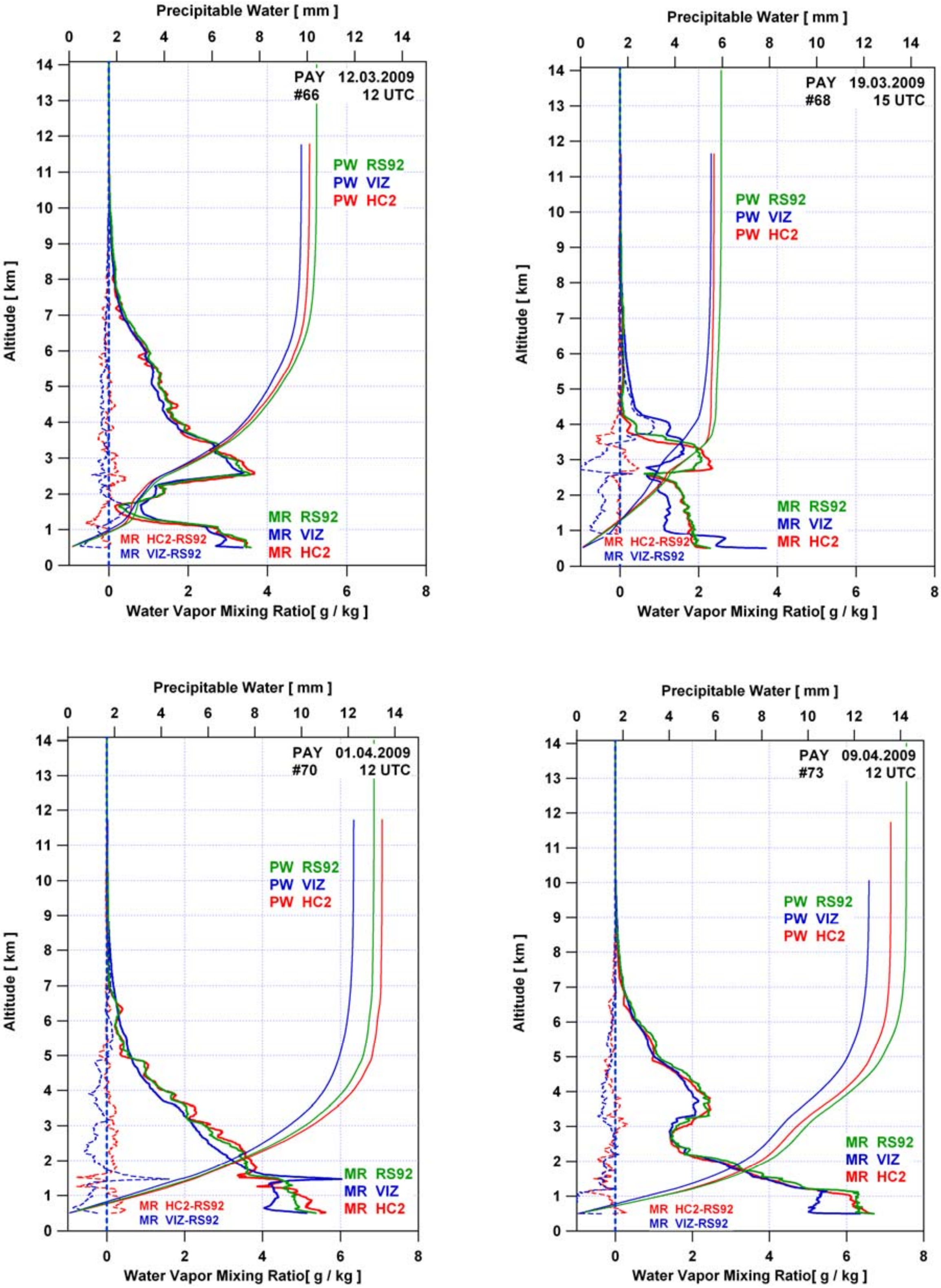


Figure 5.8 Absolute differences of water vapor mixing ratio and precipitable water.

Table 5.3 Differences of precipitable water between HC2 and RS92 as well as VIZ and RS92 at different altitudes

	Average differences [%]	
Altitude	**HC2-RS92**	**VIZ-RS92**
2000	-3.27	-7.85
4000	-1.28	-9.45
6000	-1.92	-7.99
8000	-2.30	-7.78
10000	-2.45	-7.84

Table 5.3 shows percentage differences of precipitable water measured by the different sondes. Average values of the four pre-operational soundings are given at different altitudes. Average differences are on the order of -3 percent between the HC2 and RS92. The difference between VIZ and RS92 is at least twice as large.

CHAPTER 6 Transition from VIZ/Sippican to Rotronic

6.1 Operational use of Rotronic HC2 since May 2009

Final pre-operational soundings and tests with the Rotronic humidity sensor type HC2 version B1.5.1 on the SRS 400 were successfully made during April 2009. Last fine tunings on the operation equipment and on data acquisition systems were made. Software changes and updates had to be made on programs computing temperature and time lag corrections. A first set of sensors for operational use was prepared by Meteolabor and shipped to Payerne. In-house instruction courses were provided to the radiosonde operators.

On Monday 4 May 2009 the first official operational sounding was performed at UTC 12:00 using the new Rotronic HC2 capacitive humidity sensor on the Swiss SRS 400 radiosonde. During May, the operational radiosounding with the new sensor was working at Payerne without significant problem. However, a new software version was introduced in the beginning of June with a more robust smoothing procedure of the raw and final profiles.

6.2 Overlap double sounding VIZ/Sippican and Rotronic

In order to guarantee a smooth overlap between the old and the new humidity profile measurements, VIZ/Sippican sensors are still flown once a week during noontime double soundings (Fig. 6.1). These double soundings will continue for at least one year and will be regularly checked and analysed with respect to performance and possible deviations. These double sounding measurements also help to improve long time series of humidity profile measurements from Payerne, which are presently under investigation in order to produce a homogenized series of measurements from 1990 to 2009.

To further track and check the quality of the new radiosonde in relation to internationally used radiosondes, monthly double or triple flights will be performed to compare HC2 humidity profiles with profile measurements from Meteolabor SnowWhite and Vaisala RS92 radiosondes. We also will participate with the new sensor on upcoming international radiosonde intercomparisons (WMO-CIMO).

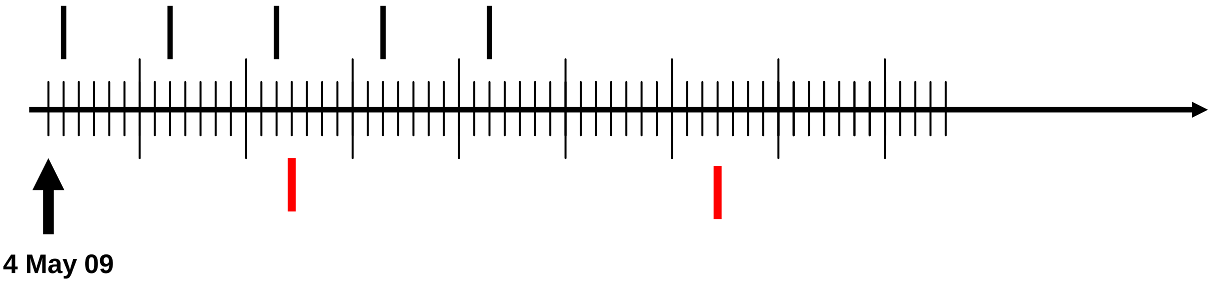


Figure 6.1 Schematic of periodic double and triple soundings. Regular night 00:00UT and day 12:00UT soundings are perfomed with the Rotronic sensor since 4 May 2009. Weekly double soundings VIZ/Sippican and Rotronic are made every Tuesday at 12:00UT (thick black lines). Monthly

tripple soundings are performed with SnowWhite, RS92 and Rotronic during night time (thick red lines).

6.3 Integrated water vapor – VIZ/Sippican versus Rotronic

In Figure 6.2 we show comparisons of hourly Integrated Water Vapor (IWV) measured by GPS wet delay analysis and soundings. The blue curve represents the GPS data, the red dots, the values estimated from the sounding at 00 & 12 UTC. The figure above shows measurements during April 2009 with the old VIZ/Sippican hygristor on the SRS 400 radiosonde. Below are measurements during June 2009 with the Rotronic sensor on the SRS 400. The old sensor shows considerably more variations in April than the new sensor in June if compared to GPS measurements.

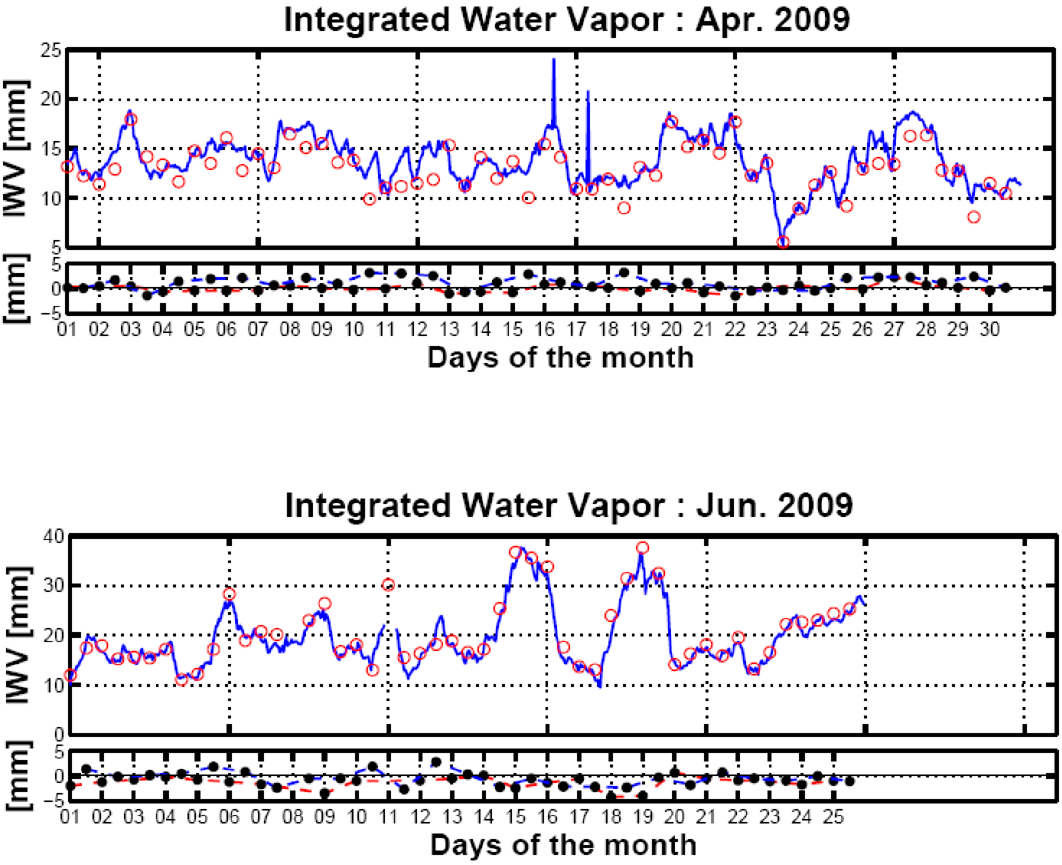


Figure 6.2 Radiosonde SRS 400 with VIZ/Sippican humidity sensor during April 2009 (above), and Radiosonde SRS 400 with Rotronic HC2 humidity sensor during June 2009 (below).

CHAPTER 7 Summary and concluding remarks

7.1 Summary

This report describes the implementation of a new humidity sensor on the Swiss SRS 400 radiosonde. While the original VIZ/Sippican resistive hygristor, which was in use on the SRS 400 since its introduction in 1990, did not fulfil any more the anticipated quality requirements, MeteoSwiss in collaboration with Meteolabor decided to use in the future a new high performance capacitive sensor from the Swiss humidity sensor manufacturer Rotronic. The new sensor was successfully tested during the international radiosonde campaign LUAMI and during a large number of test flights at the station Payerne. In a general view the new capacitive sensor shows striking improvements over the old hygristor and compares very well with sensors used on international radiosondes in the lower and middle troposphere. In the upper troposphere at very low temperatures the sensitivity of the new sensor is rather low and improvements are aimed for. The new sensor also shows much better agreement with GPS measured integrated water vapor.

On Monday 4 May 2009 the first official operational sounding was performed at UTC 12:00 using the new Rotronic HC2 capacitive humidity sensor on the Swiss SRS 400 radiosonde. Since that day MeteoSwiss Payerne delivers twice a day at 0 and 12 UTC the RH radiosonde profile using the HC2 sensors. For more than two month the operational radiosounding with the new sensor is now already in place at Payerne without any significant problems.

7.2 Conclusions

In order to guarantee a smooth overlap between the old and the new humidity profile measurements, VIZ/Sippican sensors are still flown once a week during noontime double soundings. These double soundings will continue for at least one year and will be regularly checked and analysed with respect to performance and possible deviations. The double sounding measurements also help to quality control and improve long time series of humidity profile measurements from Payerne, which are presently under investigation in order to produce a homogenized series of measurements starting in 1990.

To further track and check the quality of the new radiosonde in relation with internationally used radiosondes, monthly double or triple flights will be performed to compare HC2 humidity profiles with profile measurements from Meteolabor SnowWhite and Vaisala RS92 radiosondes. We also intend to participate with the new sensor on upcoming international radiosonde intercomparisons.

CHAPTER 8 References

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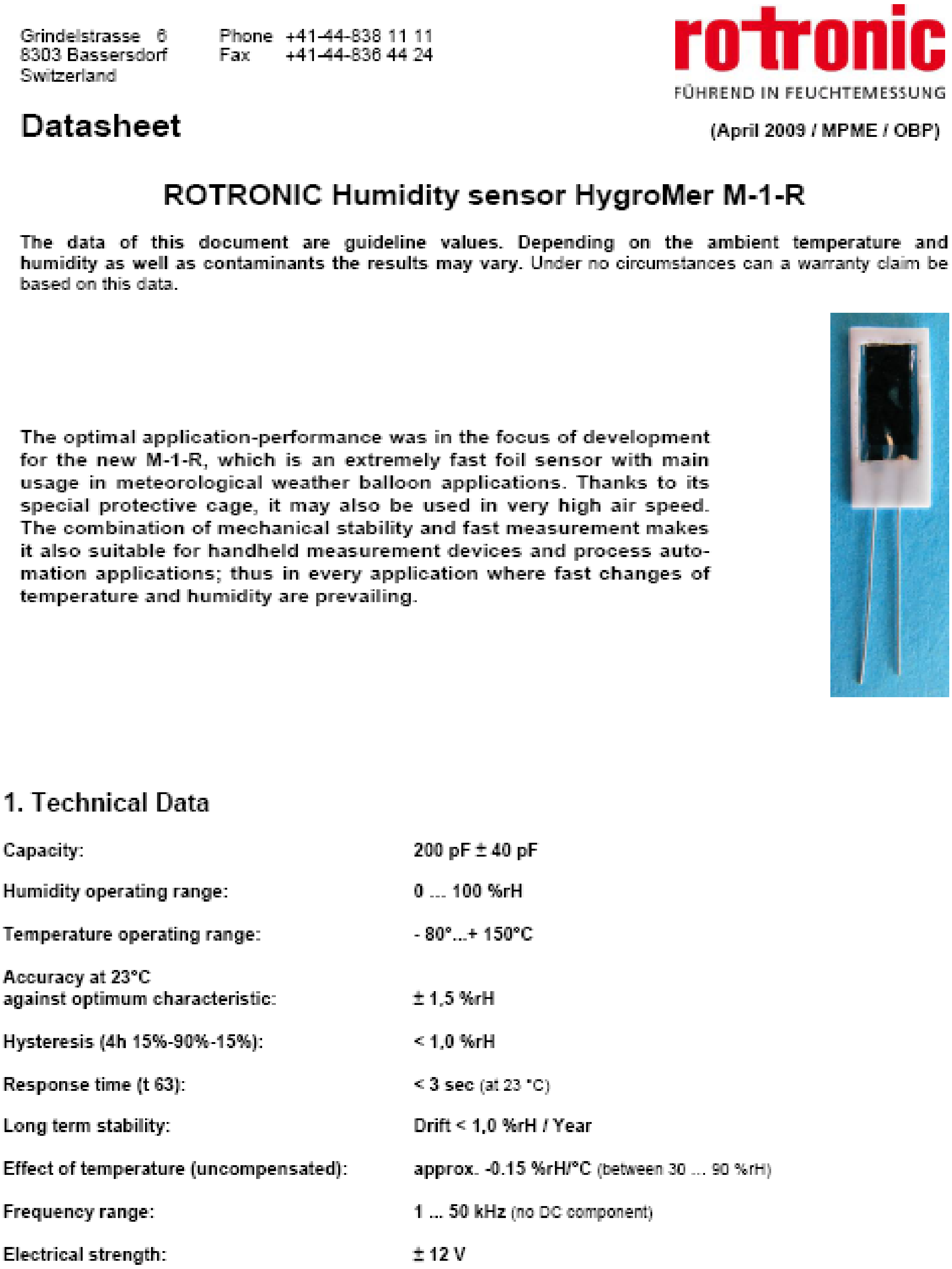
CHAPTER 9 Appendix

A Rotronic humidity sensor data sheet



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rotronic
FÜHREND IN FEUCHTEMESSUNG

Datasheet

(April 2009 / MPME / OBP)

ROTRONIC Humidity sensor HygroMer M-1-R

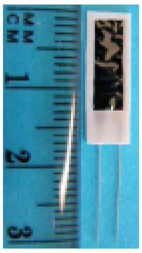
The data of this document are guideline values. Depending on the ambient temperature and humidity as well as contaminants the results may vary. Under no circumstances can a warranty claim be based on this data.

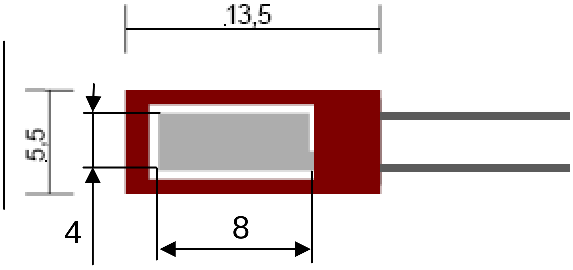
The optimal application-performance was in the focus of development for the new M-1-R, which is an extremely fast foil sensor with main usage in meteorological weather balloon applications. Thanks to its special protective cage, it may also be used in very high air speed. The combination of mechanical stability and fast measurement makes it also suitable for handheld measurement devices and process automation applications; thus in every application where fast changes of temperature and humidity are prevailing.

1. Technical Data

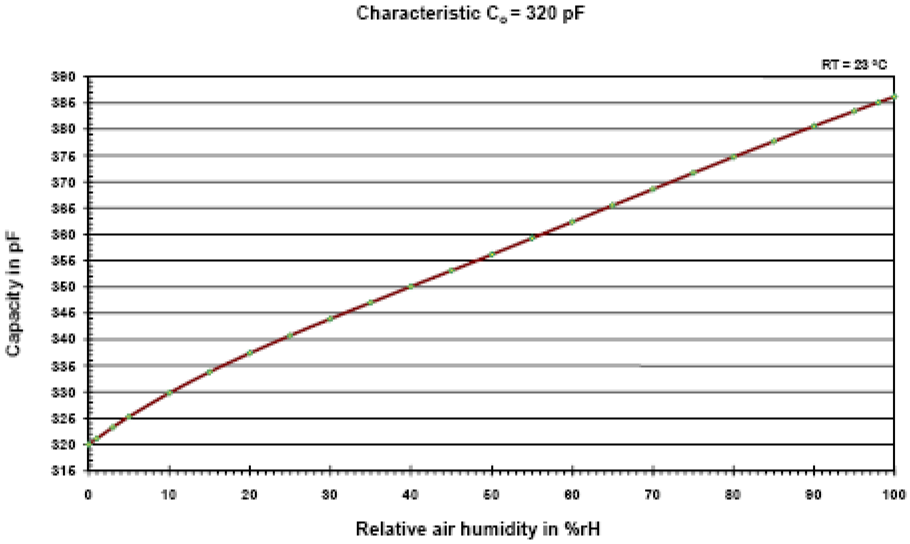
Capacity:	200 pF ± 40 pF
Humidity operating range:	0 ... 100 %rH
Temperature operating range:	- 80°...+ 150°C
Accuracy at 23°C against optimum characteristic:	± 1,5 %rH
Hysteresis (4h 15%-90%-15%):	< 1,0 %rH
Response time (t 63):	< 3 sec (at 23 °C)
Long term stability:	Drift < 1,0 %rH / Year
Effect of temperature (uncompensated):	approx. -0.15 %rH/°C (between 30 ... 90 %rH)
Frequency range:	1 ... 50 kHz (no DC component)
Electrical strength:	± 12 V

2. Dimensions





3. Characteristic curve



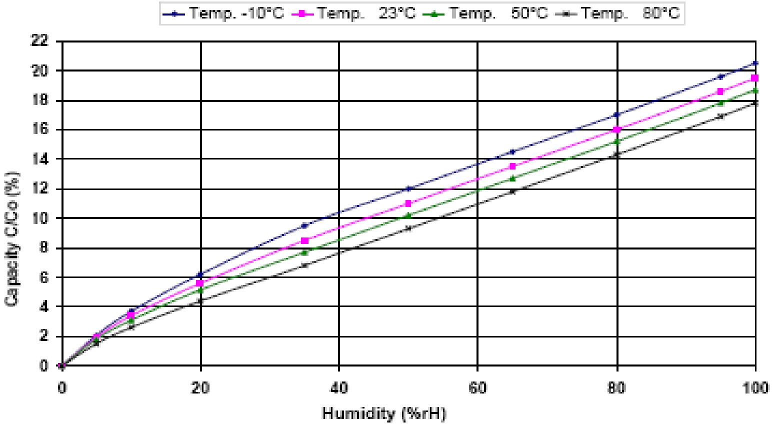
4. Characteristic polynomial

Polynomial 5 Grades with:

$Y = A_0 + A_1*x + A_2*x^2 + A_3*x^3 + A_4*x^4 + A_5*x^5$

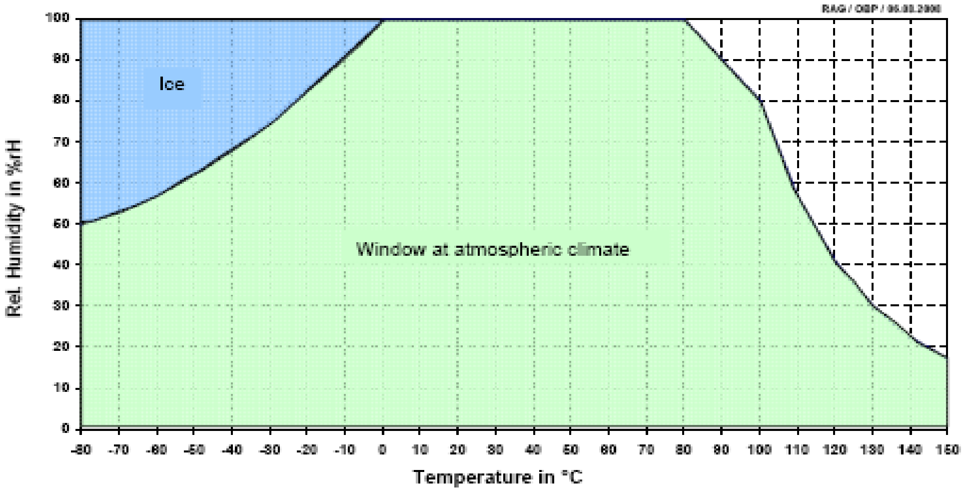
A0 =	3.20000E+02
A1 =	1.14009E+00
A2 =	-1.90440E-02
A3 =	3.22862E-04
A4 =	-2.54735E-06
A5 =	7.44984E-09

7. Temperature dependence:



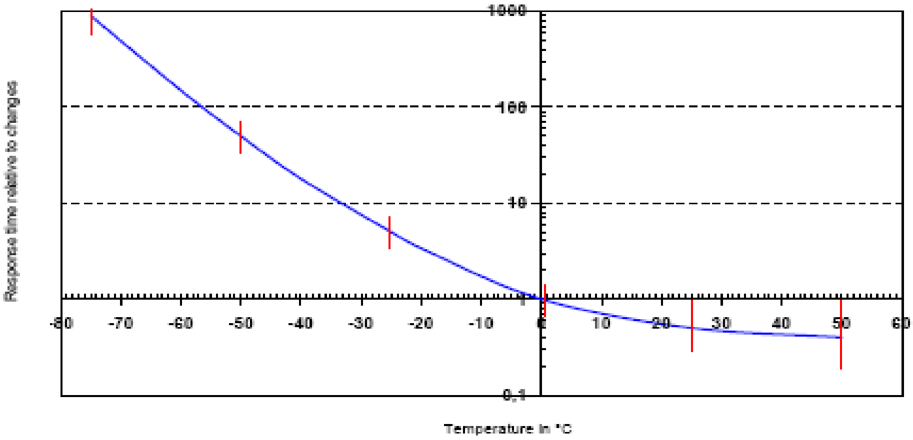
8. Temperature, humidity window

Temperature, humidity window: M-1-R / M-3-R

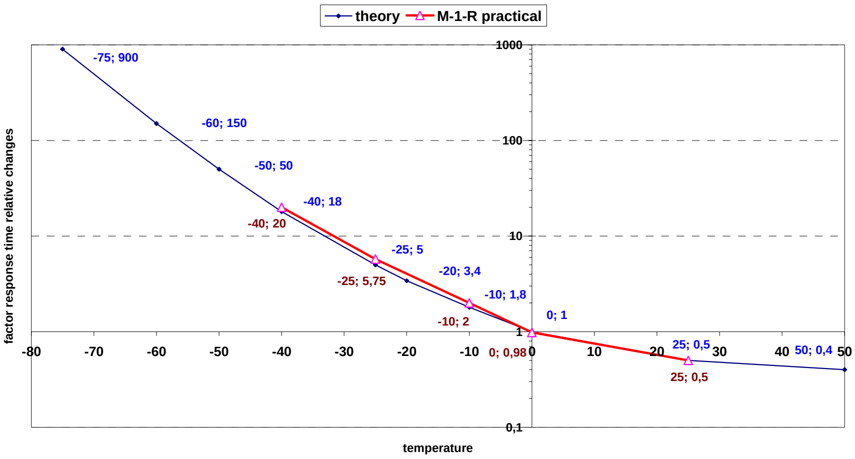


9. Response over temperature range

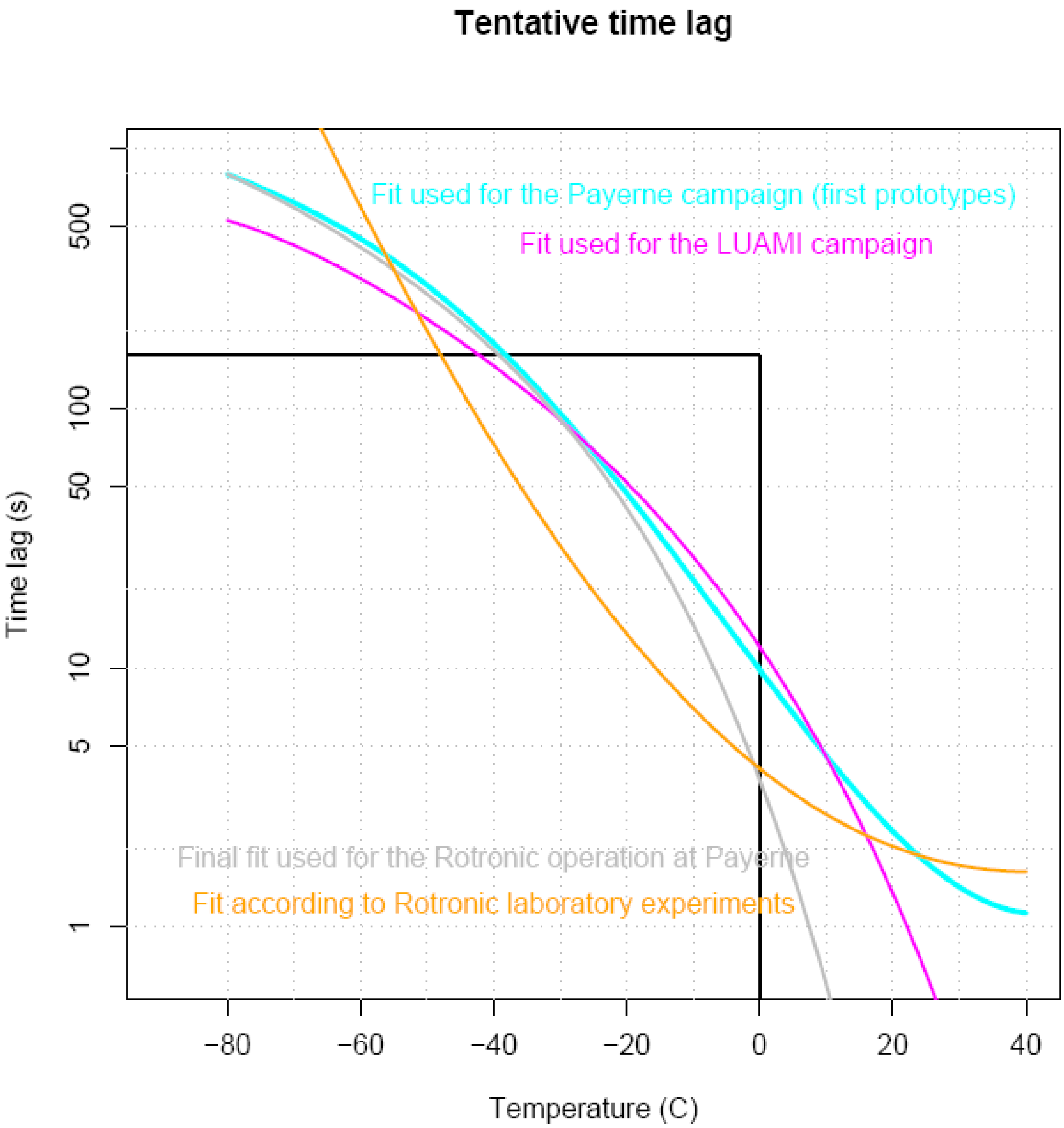
Response time M-1-R weather balloon sensor above relative temperature
value on the basis 1s at 0°C



Response time M-1-R sensor at different temperatures
Relative changes related to: 1s at 0°C



B Different time lag fits used with the Rotronic HC2 sensor



The black rectangle illustrates the temperature and time lag ranges where the time lag correction is applied to the Payerne operational sounding. Above 0°C, no time lag correction is performed as well as no interpolation of the original humidity measurements. In this way a cumulative effect of smoothing and time lag correction is avoided. Above altitudes where the time lag reaches 160 seconds, the time lag is linearly brought to zero over an altitude range of 1.5 km. This reduces overshooting effects of the time lag corrections by very long time lags and slowly brings the final RH profile to the original one.

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