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Vaisala Leads the Way Towards Understanding Humidity Conditions in Cold and Humid Atmospheres

The Technical Research Centre of Finland (VTT) and the Finnish Meteorological Institute (FMI) have recently carried out measurements in arctic severe weather with the heated Vaisala HUMICAP® Dewpoint Transmitter HMP243, and compared the results with those achieved with more conventional probes. The results have been published in the Boundary-Layer Meteorology journal.

The data indicate that problems that have hampered all previous humidity measurements under such conditions can be solved with the HMP243. Furthermore, contrary to a cooled-mirror sensor, the HMP243 shows saturation with respect to ice during snowfall, as one would expect.

Collecting data at freezing temperatures

While measuring humidity is generally quite accurate, problems arise in severe weather, particularly at freezing temperatures. The main reason is that the probe will ice up due to sublimation, after which its reading will be fixed to the humidity that corresponds to the frost point [1, 2]. It is also important to understand humidity in cold temperature and high humidity conditions, in order to understand and predict the icing of wind turbines and instruments, hoarfrost, cloud physical processes and the global heat balance of the Earth in the polar areas.

The widely used Vaisala Humidity/Dewpoint Transmitter HMP233 is based on the Vaisala HUMICAP®, a capacitive polymer film probe sensitive to relative humidity. The HMP243, on the other hand, uses a different measurement principle. While the humidity sensor element is a capacitive polymer film based on the HUMICAP®, the device is fundamentally different in that the probe itself is heated a few degrees above the ambient air temperature in order to prevent sublimation. A Pt100 thermo-element is attached to the humidity sensor head for measuring its temperature T_s. The device includes a separate unheated thermometer installed far away from the heated probe. The unheated thermometer measures the ambient air temperature T_a, which makes it possible to calculate the relative humidity RH. On the new Vaisala production line, the corresponding product is the Vaisala HUMICAP® Humidity and Temperature Transmitter HMT337.

The measurements discussed, which can be seen in more detail in the Boundary-Layer Meteorology journal, were carried out on two mountain fells in Lapland. The sites were partly manned during the measurements, so that the instruments could be carefully monitored and ice occasionally cleaned from the radiation shields of the hygrometers. Manual observations were also made of the liquid water content and droplet size of the icing clouds using the rotating multicylinder method [5]. Video recordings and Labko LID ice detectors [6] were used, which made it possible to detect events of rime icing and snowfall.

Instrument comparisons

The correspondence of RH as measured with the HMP233 and HMP243 on Olostunturi fell is shown in Figure 1. Strikingly, points with RH ≥ 100%, that is, air at or above saturation with respect to water, are completely absent from the data of the HMP233. They are abundant, however, in the data of the HMP243. This suggests that the HMP243 is able to detect in-cloud conditions and icing situations contrary to the conventional sensor.

Secondly, the HMP233 and HMP243 measured RH in excellent agreement up to RH around 60% at Olostunturi. This shows that the instruments measure consistently and that their calibrations, at least in this range of RH, are good. Problems arise at higher humidity levels and become more serious close to RH = 100%. Apparently, the points in Figure 1 where the HMP243 shows a much higher RH are due to ice cover on the sensor of the other probe. Such ice cover may persist a long time after its formation even at low subsequent humidity, unless the air temperature rises above 0 °C. Consequently, a conventional capacitance probe shows too high RH when still iced up, even though the air is no more saturated with respect to ice, and a too low value when being iced up in air that is actually supersaturated with respect to ice. In the latter case the reading is fixed at RH_i = 100%. Here RH_i is the relative humidity (as a percentage) with respect to ice

$$RH_i(T_a)=[e_w/e_{sat,i}(T_a)]100$$

where $e_{sat,i}(T_a)$ is the saturation water vapor pressure with respect to ice at the temperature T_a.

Figures 2 and 3 show the relative humidity with respect to ice, RH_i versus air temperature T_a as measured with the HMP233 and HMP243 respectively. Figure 3 reveals a very different picture from Figure 2. Because of the measurement principle that prevents sublimation on the probe, the HMP243 appears to measure properly, both in supersaturated conditions as well as in dry air that follows such conditions. Consequently, Figure 3 shows thousands of data points where RH_i > 100%, whereas there are only a few such points measured at any temperature with HMP233 in Figure 2. From the simultaneous icing observations and measurements of cloud microphysical properties, we know that the supersaturated conditions measured with the HMP243, but not those measured with the HMP233, are real.

The results thus indicate that the HMP243 with heated probe is able to avoid the errors associated with icing on conventional hygrometers.

Vaisala probe more accurate than the WMO recommended standard

As the new field data strongly supports the validity of the humidity measurements of the HMP243, one would expect that it would agree well with the data measured with a cooled-mirror hygrometer, which is recommended as standard by the WMO [7]. However, Figure 4 demonstrates that this is not the case at all at low temperatures.

The results in Figure 4 indicate that at cold temperatures there is something seriously wrong with the humidity measurements of either the HMP243, the cooled-mirror hygrometer, or both. This question was investigated further by separating in the data the cases of in-cloud icing, no icing, and snowfall based on the ice detector output and the video recordings. This is shown in Figure 5. An important ob-

Following [3], the principle of the HMP243 is as follows:

The relative humidity RH (as a percentage) is defined by WMO with respect to water, i.e.

$$RH(T_a)=[e_w/e_{sat,w}(T_a)]100 \qquad (1)$$

where e_w is the water vapor pressure in air and $e_{sat,w}(T_a)$ is the saturation water vapor pressure with respect to water at the temperature T_a. From (1), the ambient water vapor pressure is

$$e_w=[RH(T_a)/100]e_{sat,w}(T_a) \qquad (2)$$

On the other hand, because (1) is valid at any T, it may be applied at the temperature T_s of the heated polymer sensor as well, so that

$$e_w=[RH(T_s)/100]e_{sat,w}(T_s) \qquad (3)$$

From (2) and (3) it follows that

$$RH(T_a)=[e_{sat,w}(T_s)/e_{sat,w}(T_a)]RH(T_s) \qquad (4)$$

The HMP243 probe determines $RH(T_s)$, since it measures the heated sensor's capacitance C and temperature T_s directly and the response function $C(RH,T_s)$ for the sensor is well known from experiments. Using the measured T_a and T_s the saturation water vapor pressures in (4) can be determined since the function $e_{sat,w}(T)$ is known. Thus, the ambient relative humidity $RH(T_a)$ can be calculated from (4).

The ingenious use of (4) as the measurement principle of HMP243 escapes the problems of sublimation because (4) is valid at any temperature of the sensor head. Consequently, the humidity probe as a whole can be heated sufficiently to keep T_s well above T_a, so that the probe is ice-free at all times, and yet still obtain an accurate RH value for the undisturbed ambient air. ●

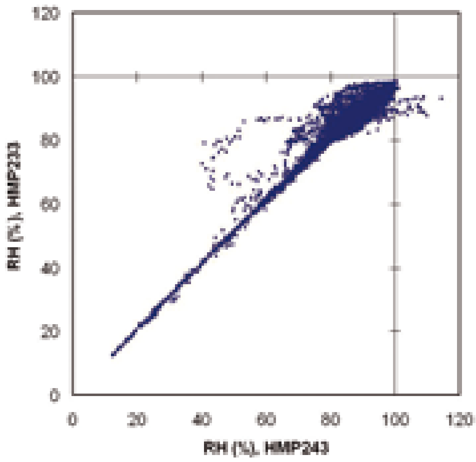

Figure 1: Correspondence of the relative humidity RH as measured with the HMP243 and HMP233. The linear correlation coefficient is 0.967.

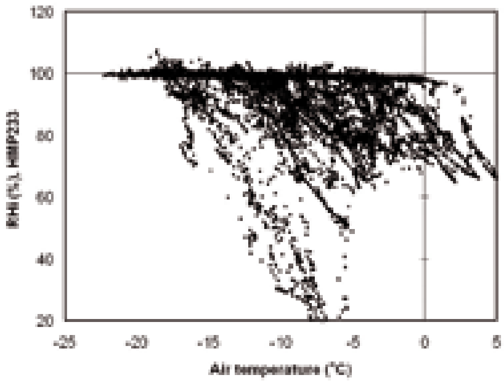

Figure 2: Relative humidity with respect to ice RH_i as measured with the HMP233 versus air temperature.

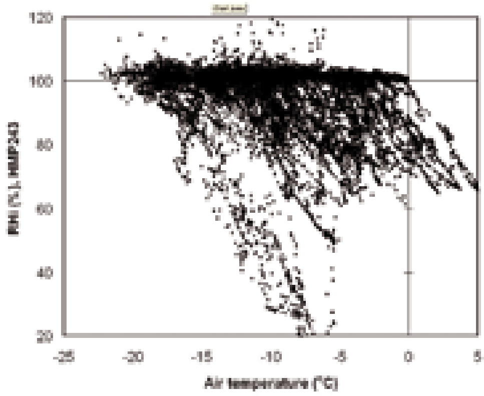

Figure 3: Relative humidity with respect to ice RH_i as measured with the HMP243 versus air temperature.

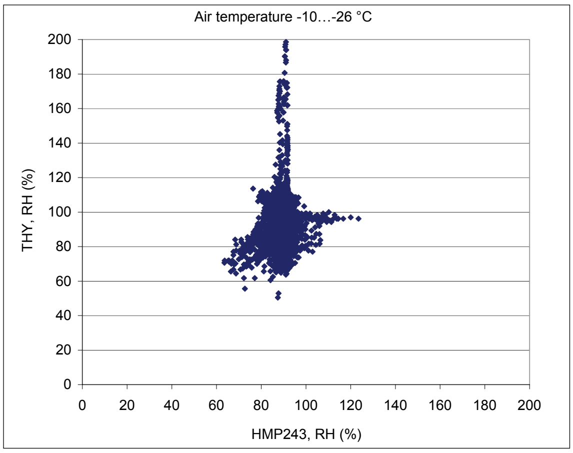

Figure 4: Correspondence between relative humidity as measured with a cooled-mirror hygrometer and the HMP243 when the air temperature is below -10 °C.

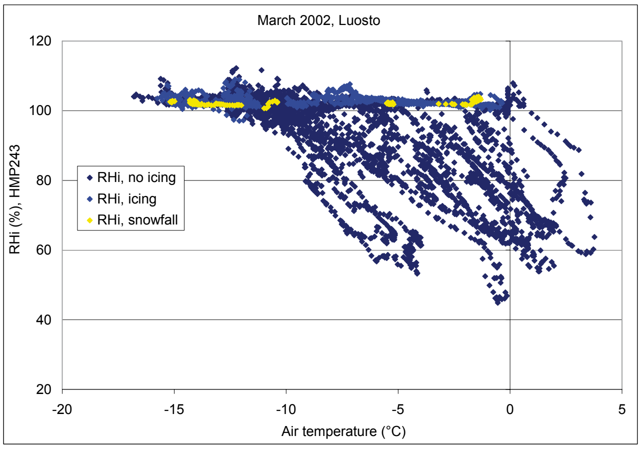

Figure 5: Relative humidity with respect to ice RH_i versus air temperature as measured with the HMP243. Icing events are shown in blue and snowfall events in yellow. (Figure by K. Säntti, Finnish Meteorological Institute).

servation is that the HMP243 shows values very close to saturation with respect to ice during snowfall at all temperatures. Such equilibrium is to be expected, because, in snowfall, the concentration of ice particles is high and their surface area to bulk volume ratio is large. The corresponding data for the cooled-mirror hygrometer did not show this behavior, suggesting that results measured with the Vaisala HUMICAP® Dewpoint Transmitter HMP243 reflect the real humidity conditions under these circumstances better than the sensor recommended as a humidity measurement standard by the WMO.

Possible reasons for the poor behavior of the cooled-mirror device include the observation in laboratory experiments [8] that, in humid air between 0 and -20 ºC, supercooled dew may form on the mirror rather than frost, making the interpretation of the measurements prone to errors. Furthermore, the concept that the temperature at the time of nucleation on a cold surface necessarily corresponds to the equilibrium frost point has recently been shown to be questionable [9]. Thus, it appears that Vaisala's heated humidity probe HMP243/HMT337 is more suitable for measurements in arctic conditions than cooled-mirror hygrometers. ●

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