Development of a double cap on the humidity sensor in radiosondes for improving ventilation

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ABSTRACT: Although a protective cap on the humidity sensor of radiosondes is an effective tool to prevent the sensor from wetting by rain and/or clouds, the cap is thought to be responsible for poor ventilation and thereby induces a time delay in the measurement of relative humidity in upper air. In the present study, a new type of the protective cap having a double cap configuration has been developed for improving the ventilation of air. The double cap consists of an outer cap and an inner cap with holes and windows on the top and sides of each cap, respectively, that are designed not to face each other, between two caps for blocking the penetration of water droplets. The wetting of the double cap was tested by artificial water droplets as well as during flying tests on rainy days and the humidity sensor in a double cap was not wet in both cases. In addition, the response of sensors to indoor humidity changes as well as during balloon-borne measurements was found to be faster in the case of double caps than conventional closed caps, suggesting the enhancement of ventilation when using the double cap. The present study provides an efficient way to improve the performance of humidity sensors of radiosondes by simply modifying the design of protective caps.

KEY WORDS radiosonde; relative humidity; humidity sensor; double cap; ventilation

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1. Introduction

Precise measurements of atmospheric temperature and relative humidity (RH) are of great interest in relation to weather prediction, climate change and safety issues. The observation of temperature and humidity profiles in the upper air mostly relies on balloon-borne measurements using radiosondes that are flown from the ground to lower stratosphere (∼35 km) (Seidel et al., 2011). Most of the radiosondes are equipped with polymeric thin film capacitors as humidity sensors (Smit et al., 2013). Although these sensors show an excellent price-performance, they have a weakness such as sensor icing indicated by biased measurements and a lack of sensitivity especially when they are wet passing through rain and/or clouds (Nash et al., 2011). Therefore, most of the polymeric humidity sensors in radiosondes are equipped with protective caps to prevent wetting (Nash et al., 2011). However, during the last World Meteorological Organization (WMO) intercomparison of high quality radiosonde systems, protective caps on humidity sensors were thought to be partly responsible for poor ventilation, delaying the response time of humidity sensors (Nash et al., 2006, 2011). To resolve these two seemingly contradictory issues, the prevention of wetting and the enhancement of ventilation through protective caps, a new design of protective caps for humidity sensors is studied.

Here, a new type of protective cap for the humidity sensor in radiosondes is developed for facilitating ventilation and thereby enhancing response time of the sensor while preventing the sensors from wetting. The new cap is designed to be a double cap configuration having an inner cap and an outer cap with holes and windows in a zigzag fashion between two caps. The enhanced response time of humidity sensors in radiosondes wearing the double cap was studied by changing well-controlled RH using a humidity generator as well as by balloon-borne measurements.

2. Methodology

2.1. Design of the double cap

The main objective of the new design of the double cap is the enhancement of ventilation through the cap, while protecting humidity sensors from wetting when it rains and/or when they pass through clouds. To achieve these seemingly contradictory goals at the same time, a double cap having an inner cap and an outer cap with holes on the top and windows on sides was newly designed, as shown in Figure 1(a). The holes and windows of the inner cap are designed to face the walls on the outer cap, and vice versa. For example, there are four holes near the edge of the top of the outer cap that are misaligned with a hole at the centre of the top of the inner cap (Figure 1(b)). In addition, four windows of the outer cap and the inner cap are designed not to face each other. In this way, water droplets are expected to be blocked by the wall of the inner cap even though they pass through the holes or windows of the outer cap without reaching the humidity sensor. To test the effect of wetting of the humidity sensor, artificial raindrops were made using a sprayer and poured intensively onto the double cap in which the humidity sensor is replaced by a piece of litmus paper (Figure S1, Supporting Information). The equivalent precipitation of the artificial rain
was about 10 mm$^{-1}$. No discernible wet spot was observed suggesting that the double cap sufficiently plays a protective role against the penetration of water drops. Due to the holes and windows, the ventilation of air including water vapour through the double cap is expected to be more facilitated than that through the conventional closed cap.

2.2. Fabrication of double caps

A 3D printing technique was used for the fabrication of the prototype of the double cap. The inner cap and the outer cap were fabricated either separately or jointly during a single process in the 3D printer (FORTUS 400mc, Stratasys). The physical dimension of the outer cap was designed to be the same as that of the conventional caps used for Jinyang radiosondes (RSG-20) for compatibility. The walls of the double cap were fabricated by laterally integrating four lines with the minimum width (0.127 mm) by the 3D printer. The thickness of the walls was measured to be about 0.5 mm, indicating that the manufacturing error is insignificant ($0.127 \times 4 = 0.508$). The diameters of the outer cap and the inner cap are 15 and 11 mm, respectively, and the heights of the outer cap and the inner cap are 14 and 11 mm, respectively. The widths of the windows in the outer cap and the inner cap are about 4 and 3 mm, respectively, with a height of 8 mm for all windows. The size of the holes in both the inner and outer caps is 3 mm in diameter.

2.3. Response to changes of RH

In order to test the efficacy of the double cap on the response of humidity sensors in radiosondes, the capacitance change of humidity sensors was read upon humidity changes from 20 to 80% RH and vice versa. For the capacitance readout, an impedance analyzer (HP 4192A) was used at 25 kHz by a LabVIEW program. For the generation of desired humidity, a divided-flow-type humidity generator was used to create humidity changes from 20 to 80% RH and vice versa. The capacitance of the radiosonde humidity sensor with a closed cap or a double cap was measured during humidity change at 25 kHz, which is slightly higher than the manufacturer’s recommendation (20 kHz). As a result, it was found that the capacitance of the humidity sensor with the double cap changes more rapidly than that with the conventional closed cap during both hydration (from 20 to 80% RH) and dehydration (from 80 to 20% RH) as compared to the conventional closed cap.
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Figure 3. Comparison measurements for studying temperature variations inside the caps due to their role as a heat source. The thermistor of the radiosondes was first equipped with a cap or no cap and the temperature from two radiosondes was compared in cases that there is (a) no cap on both thermistors, (b) a white double cap and no cap on each thermistor, (c) a black double cap and no cap on each thermistor and (d) a white double cap and an old cap on each thermistor.

shown in Figure 2(a) and (b), respectively. When the response time is defined as the time taken to reach 90% of the total capacitance change upon humidity changes for 5 min based on the way the experiments were conducted, response times of the humidity sensor with the double cap and the closed cap are $24.0 \pm 0.9$ s and $37.1 \pm 0.8$ s, respectively, during hydration (from 20 to 80% RH) and $25.4 \pm 0.8$ s and $35.6 \pm 0.9$ s, respectively, during dehydration (from 80 to 20% RH). This observation implies that the response time of the humidity sensors of radiosondes can be enhanced by simply changing the design of the protective caps.

3.2. Temperature changes by protective caps

It is a pre-requisite to exclude other factors that can possibly affect humidity measurements. One major issue is that since any cap may act as a heat source, the temperature inside the cap might be different from the temperature in a humidity sensor without a cap. For instance, if the temperature of a humidity sensor is higher than the actual air temperature, the measured RH is biased low. In this regard, a series of comparison study was conducted on sunny days with caps equipped on the temperature sensor (thermistor) of Jinyang radiosondes to study how the temperature inside each cap is changed. First, it was checked that the difference in temperature measurements between individual thermistors with no cap is negligible (Figure 3(a)). However, when the double cap was used, the temperature measured by the thermistor inside the cap was higher than the temperature without a cap (Figure 3(b)). In order to find if the origin of this observation is due to a solar radiation effect (Ruffieux and Joss, 2003; Philipona et al., 2013), a white cap was coloured black and used for a comparison study (Figure 3(c)). Consequently, the temperature inside the black double cap was measured to be higher than that with no cap. The higher the altitude was, the larger the temperature difference became, suggesting that the solar radiation plays a significant role in heating the cap and thereby increasing the inside temperature. The temperature inside a double cap and an old cap was then compared and it was found that there is essentially no temperature difference, indicating that both caps act as a similar heat source (Figure 3(d)). The difference between two measured temperatures at 15 km in Figure 3(d) is $0.69 ^\circ C$, which is close to the individual difference between thermistors ($0.55 ^\circ C$ in Figure 3(a) and is much smaller than $3.71$ and $8.50 ^\circ C$ in Figure 3(b) and (c), respectively. Therefore, it is safe to exclude the effect of heat dissipation of humidity sensors on humidity measurements when the double cap and old cap are used for comparison. However, it should be noted that measurements of the temperature of humidity sensors, followed by proper compensation, are necessary for more accurate humidity measurements in future (Luo et al., 2014).

3.3. Humidity measurements with the double cap and the old cap

In an effort to confirm if the double cap is effective in the prevention of wetting, one of the humidity sensors was allowed to be partially wet on purpose during a flying test on a rainy day by using only an outer cap and the other sensor was equipped with an old cap (Figure 4). In this control experiment, the measurement behaviour of a humidity sensor can be identified when the sensor is wet by rain. As a result, the measured humidity by the humidity sensor with only an outer cap was found to be evidently higher than that with an old cap. Since this observation occurred especially after passing through a high humidity region (about 5–7 km) on a rainy day, a plausible explanation is that the sensor with the outer cap became wet and indicated higher humidity than what it should be.
Based on the above control experiment, flying tests for studying the effect of the double cap on humidity measurements were conducted on rainy days as well as sunny days during August and September in 2014 in Daejeon, South Korea (see Section 2). The typical behaviour of flying tests on rainy days shows that the humidity measured by a sensor with a double cap generally follows that with a conventional cap as shown in Figure 5(a). This observation is contrasted with the case with the outer cap only by the fact that the measured humidity did not stay higher. This suggests that the humidity sensor with a double cap was not wetted by rain. More importantly, the measured humidity with the double cap showed a faster response than that with the old cap during flight as indicated by arrows in Figure 5(b). As indicated by a steep rise (I), a moderate rise (II) and a steep drop (III), those humidity changes occurred faster in humidity measured by the sensor with the double cap. These are typical behaviours when the response time of humidity sensors is improved (Shimizu et al., 2014). A similar behaviour was also observed in humidity measurements on sunny days in which the overall humidity stayed below 70% RH (Figure 6). When the measured humidity was suddenly dropped as indicated by an arrow (I), the sensor with the double cap responded more quickly than that with the old cap. This observation also indicates that the double cap facilitates ventilation better than that through the conventional cap.

4. Conclusions

A new type of the protective cap for humidity sensors in radiosondes was developed. The new protective cap has a double cap configuration consisting of an outer cap and an inner cap with holes and windows that are designed not to face each other to protect the sensor from wetting while improving the ventilation. Humidity sensors with a double cap were tested by pouring artificial raindrops intensively and it was found to be safe from wetting. Moreover, humidity sensors with the double cap showed faster responses to indoor humidity changes than those with an old cap. During flying tests, humidity sensors with a double cap were not wet on rainy days and showed faster responses than sensors with an old cap especially when the humidity sharply changed on both rainy and sunny days. The present study can be an important advance in improving the response time of humidity sensors by simply modifying the design of protective caps.
Future studies should focus on quantification of the improvement in sensor responses during airborne tests. Equally important, the quantification should be made based on traceability to SI units that can be achieved by radiosonde calibrators (Sairanen et al., 2014) that meet the uncertainty requirements of the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) (GCOS, 2007, 2013).

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Supporting information

The following material is available as part of the online article:

Figure S1. Wetting test of humidity sensors with and without a double cap. (a) The humidity sensor was first replaced by a piece of litmus paper to facilitate an eye examination after wetting test. (b) The artificial rain was allowed to fall heavily on the litmus paper inside the double cap (top) and with no cap (bottom). (c) After the wetting test, the litmus paper was not wet when it was covered by the double cap while it was completely wet when there was no cap.

Figure S2. Photographs taken during flying tests at the front yard of KRISS. (a) Two radiosondes equipped with an old cap and a double cap each (red arrows) were attached together and (b) flown by a single balloon. Flying experiments were conducted during August and September 2014.

References


