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TECHNICAL PAPER

Vaisala Radiosonde RS41 E-models

1 Introduction

The first part of this document describes the Vaisala BioCover™ material. Test results are given for the estimated disintegration times of the cover, insulation, fasteners and unwinder pin in different environments. The unwinder string material is also biodegradable, and the properties of the string, Vaisala BioTwine™, are discussed separately in the white paper "Vaisala Radiosonde RS41 Unwinder with BioTwine™" B212511EN-A.

Furthermore, as will be shown in the second part, the measurement accuracy of the radiosonde is not affected at all by the change of the cover mechanics. All specifications and previously-published performance white papers of Vaisala Radiosonde RS41 therefore still apply.

Biodegradable cover, insulation, fasteners and string pin

The BioCover parts, which includes the cover and insulation, are based on natural fibers, starch and selected additives, and are natural, biobased, biodegradable and plastic-free. No harmful chemicals are used in the manufacturing process of the cover and insulation parts.

The fasteners for the cover assembly and string pin are made of plastic-free biodegradable material which belongs to the polyester family — the end product of a microorganism metaboly fed with starch originating, for example, from corn. The polymer is extracted with a water-based solution, so no chemicals are used in production. The reinforcement fibers originate from cellulose.

The biodegradation process for the cover, insulation parts, fasteners and unwinder pin starts with oxidation and hydrolysis which break down the polymer chains into shorter pieces. This then changes to enzymatic cleaving of different microorganisms. The resulting small sugar molecules are used by the microorganisms in their metabolism. Unquestionably, no microplastics are formed since none of the materials contain any non-biodegradable plastic.

Cover and insulation disintegration time estimates

Tests conducted in different environments show that the cover and insulation materials disintegrate in compost, freshwater, grassy terrain and marine environments, shown in Figure 1.

Figure 1. Test environments for cover and insulation materials: home compost (upper left), freshwater (upper right), grassy terrain (lower left) and Baltic Sea (lower right).

Environment	Cover	Insulation
Home compost	8 months	4 months
Baltic Sea	17 months	< 1 month
Freshwater (T <5 °C)	50 months	8 months
Grassy terrain	27 months	3 months

Table 1. Predictions of complete disintegration times in different environments.

As listed in Table 1, the home compost test gave estimations of 8 months for the cover and 4 months for the insulation to reach complete disintegration. The Baltic Sea test dissolved the insulation material within the first month, whereas the cover has a complete disintegration time of 17 months. The freshwater test was carried out in cold climate (T <5 °C). The estimated complete degradation takes 50 months for the cover and 8 months for the insulation. The grassy terrain test gave estimations of 27 months for the cover and 3 months for the insulation to reach complete disintegration. Note that these estimations are rough predictions, and in practice the rate can vary significantly during the process due to local conditions.

The Baltic Sea test indicates that the insulation material would disintegrate quickly in the ocean due to the higher salt concentration, which acts as an electron acceptor for microorganisms and can accelerate the biodegradation process. However, marine environments can also have very slow biodegradation processes if they lack the nutrients needed by microorganisms. The same applies to the cover as well, making it difficult to predict complete disintegration and biodegradation times in the ocean.

Fasteners and string pin disintegration time estimates

Environment	Fasteners and string pin
Home compost	15 months
Freshwater (T <5 °C)	19 months
Grassy terrain	5 years

Table 2. Predictions for complete disintegration times for fasteners and string pin material.

The tests carried out in different environments were similar to the cover parts (see Figure 1). As listed in Table 2, the fasteners and string pin disintegrate in compost, freshwater and grassy terrain environments. For fasteners and string pin, the compost test gave an estimation of 15 months to reach complete disintegration. The freshwater test was carried out in a cold climate (T <5 °C) and the estimated complete degradation is 19 months. The grassy terrain test gave an estimation of 5 years to reach complete disintegration.

Change to BioCover and BioTwine

The RS41 design and infrastructure set the style and dimensions for the cover change. Due to the characteristics of biodegradable materials and the constraints in the molding technique, some minor modifications have been made but the dimensions of the radiosonde body are almost the same as the standard RS41 with Expanded polystyrene (EPS) covers. When set side by side, the EPS cover version and the BioCover version share the same look (see Figure 2).

In the RS41 E-model, the radiosonde cover mechanics have been replaced but the proven, high quality sensors and electronics ensure that the performance remains at the high level of the standard RS41. The cover change does not influence the manufacturing flow either, and the calibration of the sensors remains the same with SI traceable references.

From the operator's point of view, the change is visible, but the operation remains simple and user-friendly as before. RS41 E-models are compatible with the Vaisala Autosonde® AS41. However, the new dimensions will require an adapter for fitting to the Vaisala Ground Check Device RI41 and an additional part to the Vaisala Autosonde® AS15 tray. Those changes are communicated in detail as they are available.

Impact to environment

The reduction in environmental impact after service is due to the reduced use of plastics in radiosonde mechanics and string. The standard EPS version of RS41 with unwinder contains a total of 59.9 g of non-biodegradable plastics including covers, snaps, gaskets, battery holder, string pin, unwinder string and unwinder body. With BioCover and BioTwine, the unwinder body and battery holder remain with non-biodegradable plastics while other parts are changed to biodegradable. Non-biodegradable plastics are reduced from 59.9 g to 20.5 g, or 66 % (39.4 g).

A Life Cycle Assessment (LCA) was completed for RS41 E-models having one functional unit: radiosonde, unwinder, 350 g balloon and helium from cradle to use. The total energy consumption is 168 megajoules (MJ), 46 MJ of which is renewable energy. Greenhouse gas emissions are 6.24 CO_2 -eq, which is equal to driving 32.5 km with an average medium-sized car.

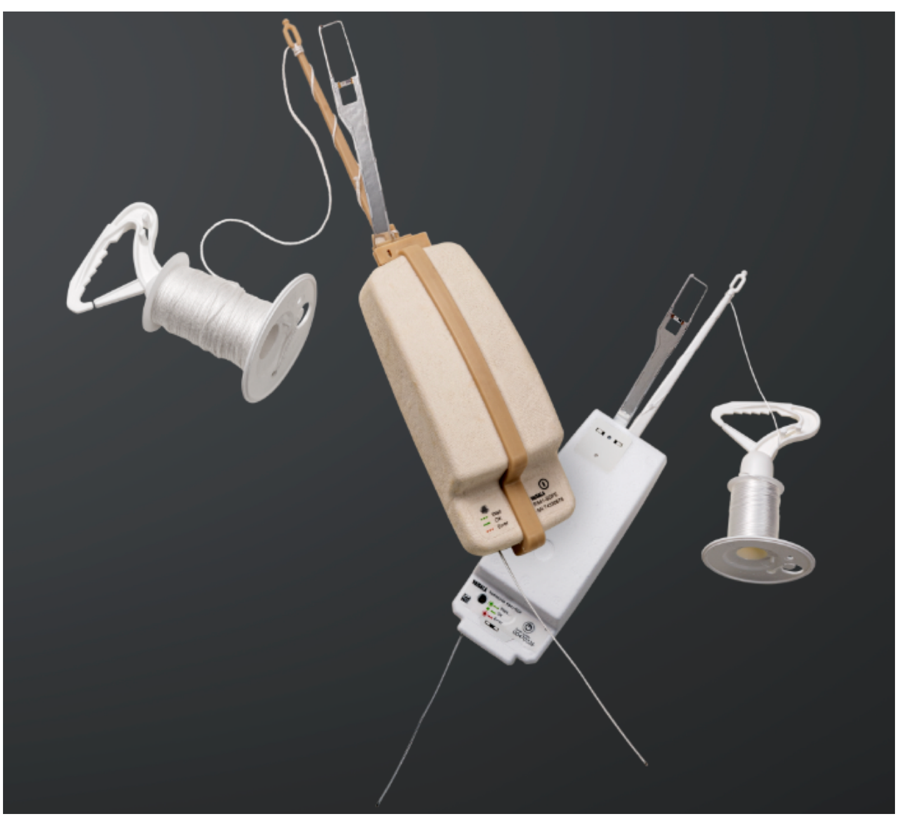

Figure 2. RS41 E-model with BioCover and BioTwine (left) and standard RS41 with EPS cover and non-biodegradable string (right).

2 Comparison Data

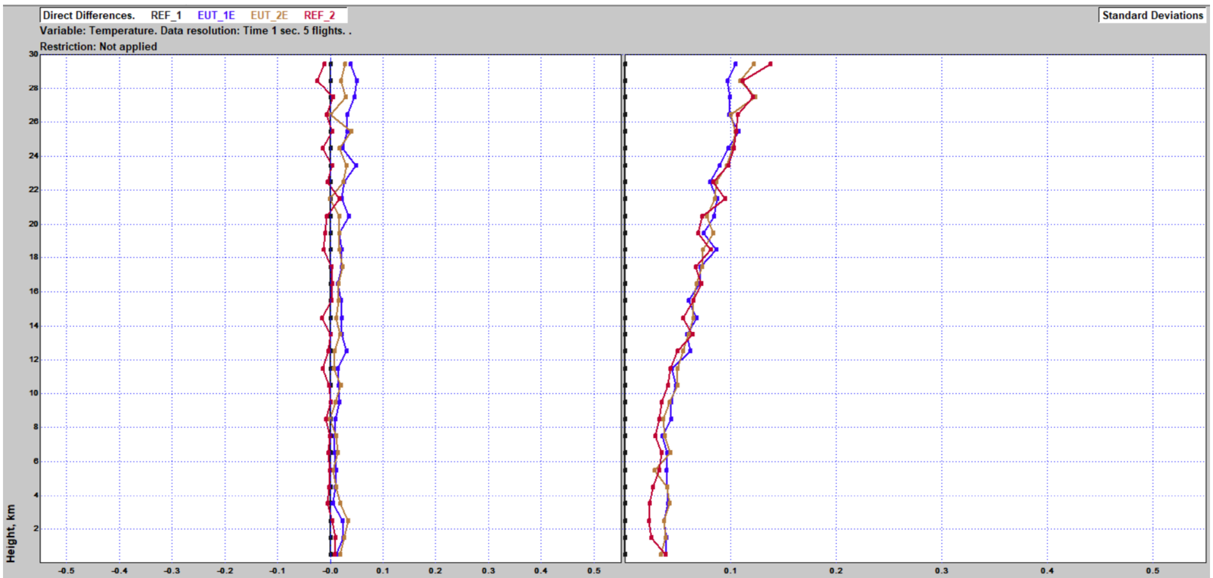

Figure 3. The average differences and reproducibility of temperature measurement in five daytime comparison soundings in high latitude.

The comparison data for EPS cover RS41 vs. BioCover RS41 is presented. To include different site environments and satellite geometries, soundings were carried out in two locations: Australia (tropical latitude 12° S) and Finland (high latitude 60° N). In Finland, four radiosondes were attached to a rig, that is, 2 x RS41 with EPS covers and 2 x RS41 with BioCover. In Australia, two radiosondes were attached to a rig, that is, one RS41 with EPS cover and one RS41 with BioCover. Each radiosonde was tied to the radiosonde mounting points using the standard string.

Temperature

The reproducibility of the Radiosonde RS41 temperature measurement has been analyzed in Finland (high latitude), shown in Figure 3. The data in the figure is from daytime soundings in various weather conditions. In the figure, the average differences between the four RS41 radiosondes is indicated in the left pane and the standard deviation of difference in the right pane. REF_1 and _2 indicate radiosondes with EPS covers, and EUT_1 and_2 indicate radiosondes with BioCover.

The results show the cover type does not influence the temperature measurement performance. The average differences between the different cover versions are small and of the same magnitude as between radiosondes having similar covers. The standard deviation of the measured temperature differences in a sounding increases gradually with altitude, starting at the level of 0.04 °C on the ground and ending at the level well below 0.15 °C at 30 km.

The average differences of the Radiosonde RS41 temperature measurement has been analyzed in Australia (tropical latitude) for daytime and nighttime soundings, shown in Figure 4 and Figure 5. REF indicates radiosondes with EPS covers, and EUT indicates radiosondes with BioCover.

The results show the temperature measurements agree well in both daytime and nighttime soundings.

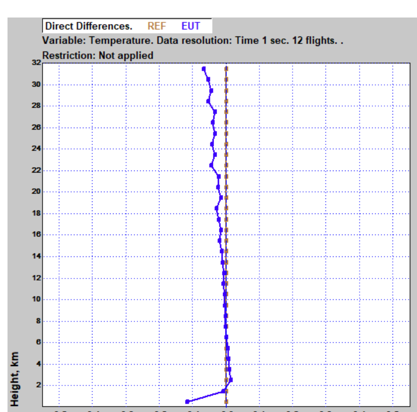

Figure 4. The average differences of temperature measurements in twelve daytime comparison soundings in tropical latitude.

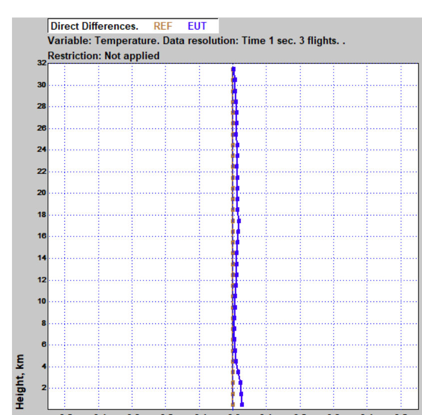

Figure 5. The average differences of temperature measurements in three nighttime comparison soundings in tropical latitude.

Humidity

The reproducibility of the Radiosonde RS41 humidity measurement has been analyzed in Finland (high latitude), shown in Figure 6. The data in the figure is from daytime soundings in various weather conditions. In the figure, the average differences between the four RS41 radiosondes is indicated in the left pane and the standard deviation of difference in the right pane. REF_1 and _2 indicate radiosondes with EPS covers and EUT_1 and_2 indicate radiosondes with BioCover.

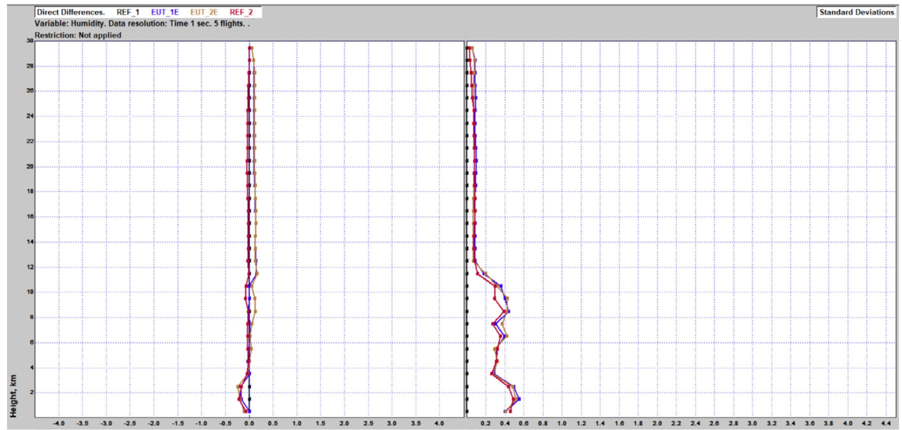

Figure 6. The average differences and reproducibility of humidity measurement in five daytime comparison soundings in high latitude.

The results show the cover type does not influence the humidity measurement performance. The average differences between the different cover versions are small and of the same magnitude as between radiosondes having similar covers. The humidity differences in a sounding are typically less than 0.3% relative humidity (RH) and the reproducibility is on the level of 0.6% RH.

The average differences of the Radiosonde RS41 humidity measurement has been analyzed in Australia (tropical latitude) for a combination of daytime and nighttime soundings, shown in Figure 7. REF indicates radiosondes with EPS covers, and EUT indicates radiosondes with BioCover.

The results show the humidity measurements agree nicely, and the average differences are moderate even in the extremely cold tropical tropopause with fast temperature and humidity changes.

Geopotential height

The reproducibility of the Radiosonde RS41 geopotential height measurement has been analyzed in Finland (high latitude), shown in Figure 8. The data in the figure is from daytime soundings in various weather conditions. In the figure, the average differences between the four RS41 radiosondes is indicated in the left pane and the standard deviation of difference in the right pane. REF_1 and _2 indicates radiosondes with EPS covers and EUT_1 and_2 indicates radiosondes with BioCover.

The results show the cover type does not influence the geopotential height measurement performance. The average differences between the different cover versions are small and of the same magnitude as between radiosondes having similar covers. The performance is uniformly good at all heights, with averaged differences of 0-1.5 geopotential meter (gpm) and standard deviations of less than 4.5 gpm.

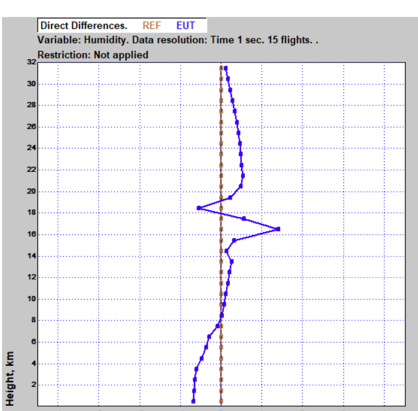

Figure 7. The average differences of humidity measurement in fifteen daytime and nighttime soundings in tropical latitude.

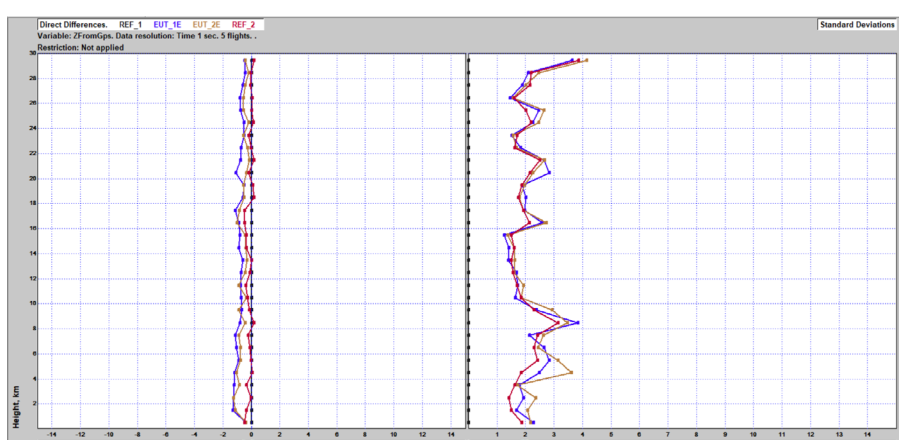

Figure 8. The average differences and reproducibility of geopotential height measurements in five comparison soundings in high latitude.

The average differences of the Radiosonde RS41 geopotential height measurement has been analyzed in Australia (tropical latitude) for a combination of daytime and nighttime soundings, shown in Figure 9. REF indicates radiosondes with EPS covers, and EUT indicates radiosondes with BioCover.

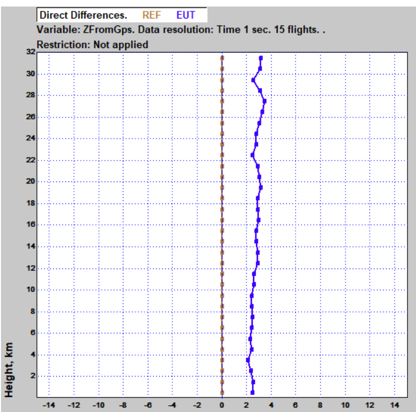

Figure 9. The average differences of geopotential height measurements in fifteen daytime and night-time soundings in tropical latitude.

The results show that there is a small bias in geopotential height measurements, well below the 10 gpm uncertainty value for sounding.

Pressure

The reproducibility of Radiosonde RS41 GPS-based pressure measurements have been analyzed in Finland (high latitude), shown in Figure 10. The data in the figure is from daytime soundings in various weather conditions. In the figures, the average differences between the four RS41 radiosondes is indicated in the left pane and the standard deviation of difference in the right pane. REF_1 and _2 indicate radiosondes with EPS covers and EUT_1E and_2E indicate radiosondes with BioCover.

The results show that the cover type does not influence the GPS-based pressure measurement performance. The average differences between the different cover versions are small and of the same magnitude as between radiosondes having similar covers. The random differences in pressure decrease rapidly as a function of altitude, following the exponential decrease in atmospheric pressure. The observed standard deviations are below 0.3 hectopascal (hPa) near the ground and <0.04 hPa at altitudes above 28 km.

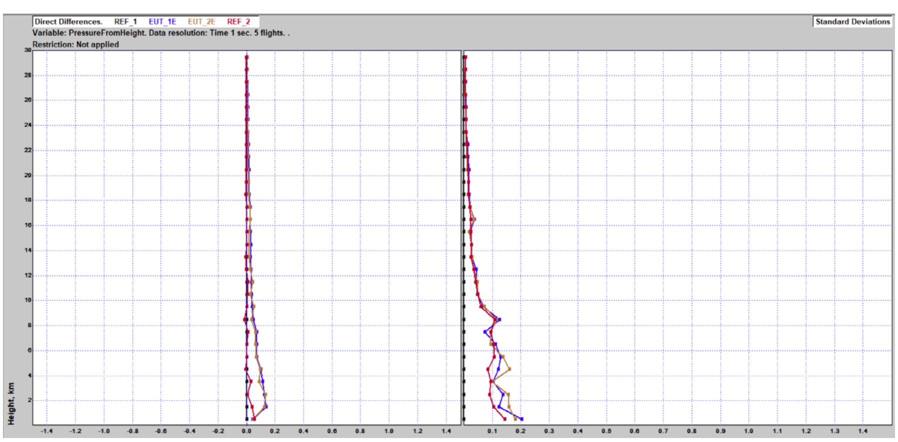

Figure 10. The average differences and reproducibility of pressure measurements in five comparison soundings in high latitude.

The average differences of the Radiosonde RS41 pressure measurement has been analyzed in Australia (tropical latitude) for a combination of daytime and nighttime soundings, shown in Figure 11. REF indicates radiosondes with EPS covers, and EUT indicates radiosondes with BioCover.

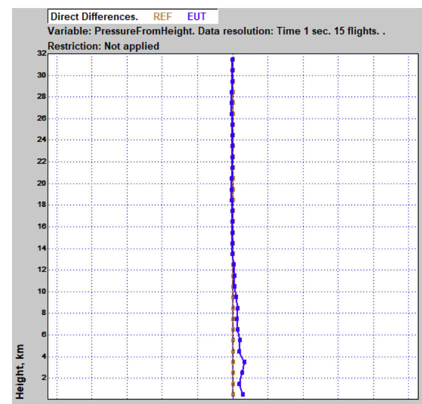

Figure 11. The average differences of pressure measurements in fifteen comparison soundings in tropical latitude.

The results show that the pressure measurements were practically identical.

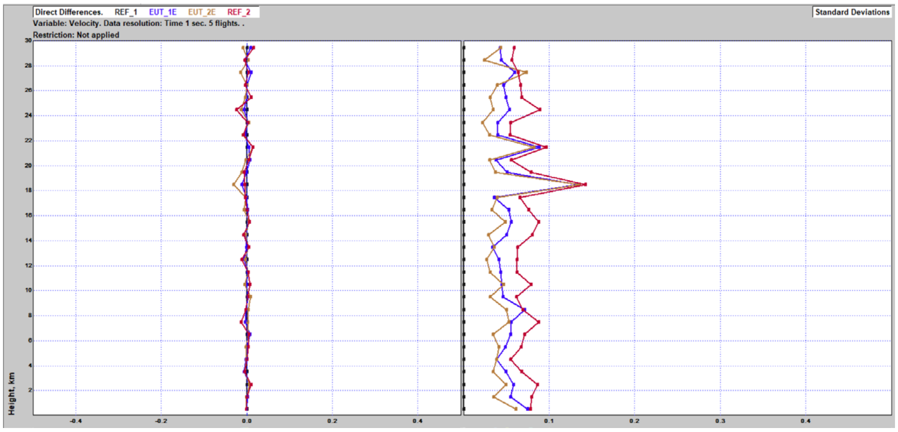

Figure 12. The average differences and reproducibility of wind velocity in five comparison soundings in high latitude.

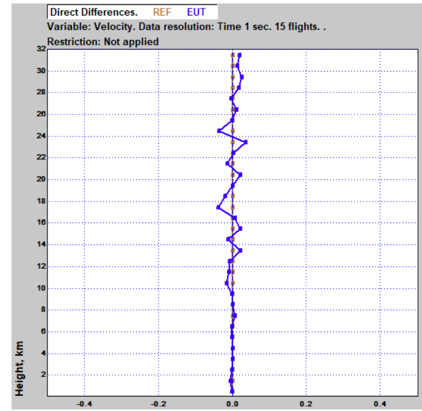

Figure 14. The average differences of wind speed measurements in fifteen comparison soundings in tropical latitude.

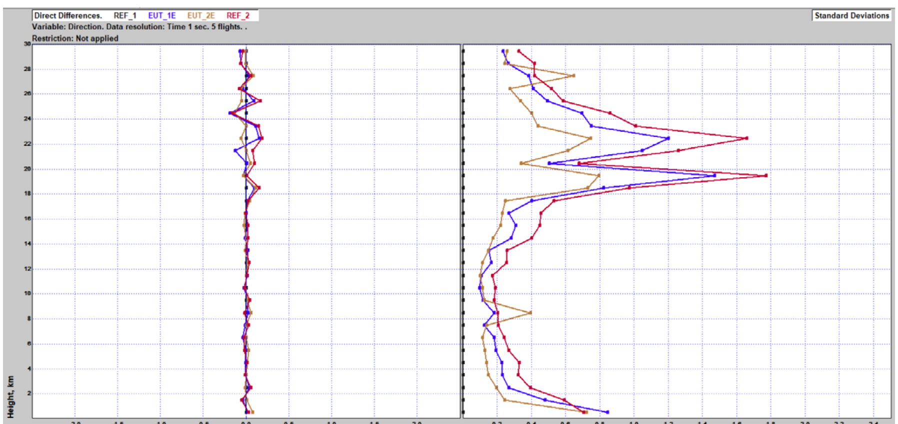

Figure 13. The average differences and reproducibility of wind direction in five comparison soundings in high latitude.

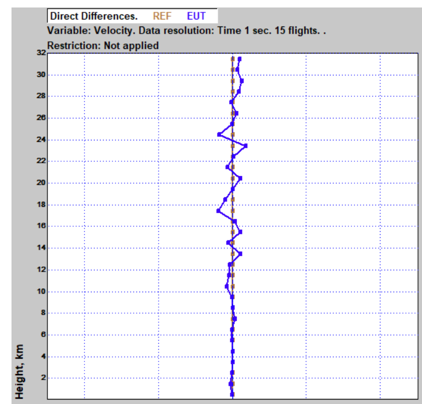

Figure 15. The average differences of wind direction measurements in fifteen comparison soundings in tropical latitude.

Wind measurement

The reproducibility of the Radiosonde RS41 wind measurements has been analyzed in Finland (high latitude), shown in Figure 12 and Figure 13. The data in the figures is from daytime soundings in various weather conditions. In the figures, the average differences between the four RS41 radiosondes is indicated in the left pane and the standard deviation of difference in the right pane. REF_1 and _2 indicate radiosondes with EPS covers and EUT_1E and_2E indicate radiosondes with BioCover.

The results show that the cover type does not influence the GPS-based wind measurement performance. The average differences between the different cover versions are small and of the same magnitude as between radiosondes having similar covers. The reproducibility for wind speed is on the level of 0.15 meters per second (m/s) and for wind direction 2 degrees.

The average differences of the Radiosonde RS41 wind measurement has been analyzed in Australia (tropical latitude) for a combination of daytime and nighttime soundings, shown in Figure 14 and Figure 15. REF indicates radiosondes with EPS covers, and EUT indicates radiosondes with BioCover.

The results show that the wind speed measurements agreed well, being below the uncertainty value of 0.15 m/s. Wind direction measurements were practically identical.

3 Summary

Radiosonde RS41 E-models include BioCover, patent-pending plastic-free and biodegradable radiosonde cover and insulation, and BioTwine, plastic-free and biodegradable unwinder twine. With the change to BioCover and BioTwine, the non-biodegradable plastic content is decreased by 66% (39.4 g) compared to the standard EPS cover version with non-biodegradable unwinder string and pin. This is a significant change to the environmental footprint of sounding operations.

As shown by the comparison flight data in Chapter 2, the change has no impact on RS41 measurement performance. All specifications and previously published performance technical and white papers fully apply. In addition, sounding operations remain the same: accurate, reliable, simple and user-friendly.

The change will also be communicated on www.vaisala.com, having no effect on the RS41 data continuity.

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