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Atmospheric Measurement Techniques Discussions

Interactive comment on "Performance of WVSS-II hygrometers on the FAAM Research Aircraft" *by* A. K. Vance et al.

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We would like to thank the referee for taking the time to consider this paper and provide the comments to which we reply, below:

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Referee_2: "p. 8645 l. 23-25: Be more concise about how rounding increases uncertainty for higher humidity."

Original text: "...(2) the WVSS-II measurements in question are compromised by the restrictions imposed by the manner in which they are encoded for transmission (Bedka et al., 2006)."

Proposed replacement: "...(2) the WVSS-II measurements in question are truncated for transmission (two-digit mantissa, one digit exponent) which "can add substantial error to the moisture reports exceeding 10 k/kg" (Bedka et al., 2006)."

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Referee_2: p. 8646 l. 22: How do you determine whether the inlet is inside or outside the aircraft boundary layer?

Response: For this we have relied on data from the aircraft manufacturer in a confidential report. As a result, there is little we can add to this, and nothing that an independent worker could verify. We realise that this situation is not ideal, and are willing to consider any suggestions which the you might care to make.

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Referee_2: p. 8648 l. 21: Why was the heater of the sample chamber disconnected?

Response: The sample chamber was disconnected by DWD prior to its transfer to the Met Office, as it was believed that adequate adiabatic heating would arise in the Rosemount inlet to render the sample heater superfluous and that it's disconnection would permit a more uniform temperature field in the cell, and enhance accuracy. The effect (if any) of the disconnected sample heater is something which we intend to cover in next year's WVSS2 paper.

Original text: "...with the exception that wvssR had the heater of its sample chamber disconnected;..."

Proposed replacement: "...with the exception that wvssR had the heater of its sample chamber disconnected by DWD prior to its transfer to the Met Office as it was believed that adequate adiabatic heating would arise in the Rosemount inlet to render the sample heater superfluous and that it's disconnection would permit a more uniform temperature field in the cell, and enhance accuracy."

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Referee_2: p. 8649 l. 5-9: If desorbing water was the reason for the higher lower limit one would expect a (probably very slow) decrease in the water vapor signal. Do you see something like that? Could it also be a small leak or an issue of the plumbing material?

Response: The WVSS2 was not connected to the PTB system for long enough to provide a useful comparison and, in addition, the PTB was carried out at substantially higher pressures, so the drying out would be expected to be slower. Although we did not have access to a leak tester for this part of the experiment, from monitoring the pressure of evacuated parts of the system, we are confident that there were no significant leaks in the plumbing, from monitoring pressure rise.

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Referee_2: Sec. 3: Did you check that you don't dismiss systematically specific temperature or pressure conditions when determining the offsets?

Response: It rather depends on what you mean by systematic dismissal. None of the selection criteria specifically exclude data at specific temperatures or pressures but will, preferentially, thin out the data under certain conditions. For example, the requirement that the chilled mirror instruments be stable will reject much more data at low temperatures than high, due to their slower response at low temperatures, and these will tend to be found at lower pressures but where the chilled mirrors are stable (or appear to be from the criteria described) data will be included. The selection criteria, particularly the 90% rejection limit, have been varied and it observed that although the spread of the data varies, the means and medians do not. From this we believe that our selection procedure does not introduce any artificial bias.

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Referee_2: p. 8650 l. 9: What does "meaningful" mean here? From the lower panel in

Fig. 7 I would think that a meaningful offset can only be determined for higher humidity, maybe above 0.4 g/m3. Does your filter retain values over the complete range or is it more a "high humidity" offset?

Original text: "This value, to some extent arbitrary, is a compromise arrived at by inspection, between retaining sufficient data for meaningful comparison and maximising the rejection of poor data."

Response: At the start of section 5 we note that in the case studies, including the one illustrated in figure 7, "the offsets calculated for the bulk comparison (Sect. 4) and described in Sect. 3, have not been applied." The offsets do include data from the majority of the range, but the majority of the data tend to be in the mid-to-high range.

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Referee_2: Sec. 4: In my opinion, the statement that instruments show good agreement within the IQR (e.g. p.8651, l.18 & 25) is not appropriate to judge the quality of the measurement or instrument, respectively since the IQR cannot be treated similar to an error bar. To assess the quality of the data, one has to acknowledge systematic deviations as well as scatter of the data. With the presented approach, if you have a certain systematic deviation, a larger scatter can make your data "better", however the data quality is in fact worse. I suggest discussing scatter and systematic deviation separately and to avoid the term "agree within the IQR".

Response: This is a perfectly valid point but we would point out that we are not intending that the IQR be used as an error bar. The problem exists with field data that there is an inherent spread due to the uncontrolled nature of conditions which can makes difficult to assess performance of different instruments or, indeed, make meaningful measurements with any available instrument. We have chosen to use the five percentiles to describe the spread of the data as we believe this is more helpful to the target audience than a single-figure error bar. While it is true that one could choose to interpret greater scatter as 'better' but we feel that readers are more likely to in-

terpret such situations as indicative of conditions in which reliable measurement was inherently problematic.

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Referee_2: Sec. 4 / Sec. 6: Although focusing on their relative performance: Since apparently all instruments tend to over read at low humidities, did you check (e.g. using RHi) if the measured values are in a reasonable range?

Response: Could you possibly clarify this question? We are a little confused about the statement" apparently all instruments tend to over read" as, if this was the case, we would be unable to tell on account of having no instrument left to compare against.

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Referee_2: p. 8652 l. 1-3: Could you comment on possible reasons for a positive bias of the GE below 250K?

Response: While it is important that instruments' capabilities and limitations are understood, we feel it is beyond the scope of this particular paper to delve into the causes of bias in the other instruments.

Original text: "...approximates to a mirror temperature of around 230 K; this is typical of the frost points encountered when the ambient temperature is around 250 K, supporting FAAM's suspicions of a possible positive bias below 250 K."

Proposed replacement: "...approximates to a mirror temperature of around 230 K; this is typical of the frost points encountered when the ambient temperature is around 250 K, supporting FAAM's suspicions of a possible positive bias below 250 K due to desorption of retained water from internal surfaces."

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Referee_2: p. 8652 l. 13: Same as above, can you comment on reasons for the over reading of the WVSSF? Could desorption of water from the aircraft skin cause such a

behavior?

Original text: "...flush inlet samples air approximately 5 mm from the skin of the aircraft, the performance..."

Response: The understanding the reasons for the difference in bias between the two WVSS2s is important, but is also quite an involved exercise and, we feel, well beyond the scope of this paper. It seems likely that desorption from the skin will contribute at times but the reasons are likely to extend beyond this. Part of the process of addressing the issue involves operating each instrument on each inlet and with the sample heaters both connected and disconnected; these data are still being gathered. The possibility of discussing the causes of inter-WVSS2 differences was considered, but it was felt that a cursory treatment in this paper would not be helpful, and that the subject warranted its own paper; this is planned for the coming year.

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Referee_2: Sec. 5.2: Could you comment on the uncertainty of the mean volume radius? During the second cloud penetration there could be another issue since, in contrast to all other penetrations, the wvssR signal even exceeds the wvssF+LWC signal. Could this is a part of the cloud with a significant amount of smaller particles below the detection limit of the CDP?

Response: We suspect that errors in the CDP-derived mean volume radius are unlikely to be significant in this context as larger uncertainties are expected to arise elsewhere. There is some concern that the Rosemount inlet may shatter larger drops, resulting in smaller droplets, more likely to enter the instrument. The relationship between droplet size in undisturbed air and that which exists within the Rosemount head is not known. In addition to this, flow modelling suggests that the size spectrum at the location of the CDP may be significantly different from that at the location of the Rosemount inlet. As the data are inconclusive, however, we propose to simplify section 5.2, as follows:

Original text (p. 8654, ll. 6-19): "It should be noted, however, that the mean volume radius at which the departure from the total water values occur varies. In all penetrations but the second one, there appear to be a gradual transition between approximately 5 and 10 [mu]m but in the second cloud penetration there is a relatively rapid transition from about 7.5 to 10 ?m, where the wvssR might be expected to report total water content. When the mean volume radius is larger than this, the wvssR reports between the total water and vapour only values, as seen elsewhere, but when the mean volume radius drops below 5 [mu]m there appears to be an enhancement, with the wvssR reporting higher values than the estimated total water content. Although this would suggest that the susceptibility of this inlet to liquid increases as droplet size reduces, Vance et al. (2011) shows an example of susceptibility to liquid droplets of around 20 [mu]m radius. It is therefore not possible to draw conclusions about the importance of droplet size, from these data but, but it is clear that the wvssR is likely to ingest and evaporate liquid cloud droplets whereas the wvssF is not. This is, perhaps, not surprising as it has been noted that Rosemount

Proposed replacement: "It should be noted, however, that the mean volume radius at which the departure from the total water values occur varies. Vance et al. (2011) shows examples of susceptibility to liquid droplets of around 20 [mu]m radius but no susceptibility to cloud with a modal radius of $\sim$8 [mu]m. It is therefore not possible to draw conclusions about the importance of droplet size, from these data but, but it is clear that the wvssR is unreliable in liquid cloud as it can ingest and evaporate some liquid cloud droplets whereas the wvssF does not. This is, perhaps, not surprising as it has been noted that Rosemount

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Referee_2: Sec. 5.3: Since humidity is rather high in Fig. 7: are you sure that this was a pure cirrus and not a mixed phase cloud? Especially at high peaks in total water, it seems that the wvssR comes close or even exceeds values of the wvssF while being lower the rest of the time. This could indicate that the wvssR signal is sometimes

altered by liquid particles. Do you know the cloud temperature?

Response: The data shown in Figure 7 are from cirrus cloud where the high peaks in total water coincide with 'embedded fall-streaks'. The location of the measurements was actually chosen to be where there was inhomogeneity in the cirrus cloud. The temperature during the time period shown was between -28 degC and -20 degC, and the cloud phase is expected to be ice. In-situ cloud imaging probes do not show any liquid water during this time. We would thank the reviewer for drawing our attention to the possible enhancements in the wvssR. Sometimes in high total water peaks the wvssR does come close or exceed the wvssF, the total number concentration of ice particles is much higher in these regions and, hence, the greater potential to add evaporated ice water to the wvssR signal similar to the situation in liquid cloud.

Original text (p8654 l. 27 - p. 8655 l. 26): "The upper panel shows absolute humidity from the five instruments: wvssF (black), wvssR (red), Buck (green), GE (blue) and TWC (purple) which has been calibrated against the wvssR in cloud free conditions. Four "steps" in the humidity data can be seen, corresponding to four race-tracks at different altitudes. Although small offsets (removed for the bulk intercomparison, above) are apparent between the two WVSS-II and the two chilled mirrors they can be seen to report the same basic conditions. It is clear from the oscillations (particularly visible in GE data) that the chilled mirrors are not stable for most of the period. The TWC is, of course, reporting humidity arising from all phases. The large increases in total water correspond to the aircraft passing through fall streaks embedded in the cirrus. In these regions the density of ice particles is significantly higher than the background. This lower background ice concentration is evident as "noise" on the TWC trace between the fall streaks. The four hygrometers show no response to the fall streaks. The lower panel shows a comparison of wvssR (red) and wvssF (grey) to the Buck during this period in terms of absolute humidity, analogous to the plots in Figs. 2-4. As previously noted, the offset removed for the bulk comparison is apparent, as is the gradual over reading of the wvssF but no differences attributable to the presence of ice are

apparent."

Proposed replacement: "The upper panel shows absolute humidity from three instruments: wvssF (black), wvssR (red) and TWC (purple) which has been calibrated against the wvssR in cloud free conditions; in the interests of clarity, the Buck an GE have been omitted as they were clearly not stable during this period. Four "steps" in the humidity data can be seen, corresponding to four race-tracks at different altitudes. Although small offsets (removed for the bulk intercomparison, above) are apparent between the two WVSS-II and the two chilled mirrors they can be seen to report the same basic conditions. The TWC is, of course, reporting humidity arising from all phases. The large increases in total water correspond to the aircraft passing through fall streaks embedded in the cirrus. In these regions the density of ice particles is significantly higher than the background. This lower background ice concentration is evident as "noise" on the TWC trace between the fall streaks. Although the situation is substantially less conclusive than in the case of liquid water there is some suggestion that ice particles may be evaporating in the wvssR and producing enhancements in some of the fall streaks. The lower panel shows a comparison of wvssR (red) and wvssF (grey) to the Buck during this period in terms of absolute humidity, analogous to the plots in Figs. 2-4. As previously noted, the offset removed for the bulk comparison is apparent, as is the gradual over reading of the wvssF but no differences attributable to the presence of ice are readily apparent."

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Referee_2: Fig. 2 / Fig. 3: Both figures show a similar branch at humidities between 0.3 and 3 g/m3 with large positive values indicating a significant under reading of the Buck CR-2. Do you know the reason for that?

Response: In p 8651 l 13-15 we state that "It is immediately clear that the criteria used to select data, although strict, do still permit the inclusion of some "bad" data; in the interests of preserving objectivity, however, no attempt to remove these has been

made." This is branching is a prime example of this. It was felt that, in context, it was sufficiently obvious that the upper 'branch' constituted bad data (as referred to on p 8651) that no further comment was necessary.

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