

Interactive comment on “Comparisons of temperature, pressure and humidity measurements by balloon-borne radiosondes and frost point hygrometers during MOHAVE 2009” by D. F. Hurst et al.

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Replies to Reviewer #2

{Reviewer Comment} There is a small problem that the campaign overview article (Leblanc et al.) already represents some of the main conclusions of the sonde manuscript reducing the informative value of the soundings paper itself.

{Author Reply} I have forwarded your comment to the editor with a request for assis-

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tance in this task. The editor was asked if he would contact the overview author and urge him to comply with your request. To date I have heard nothing back from the editor on this topic.

{RC} As noted by referee 1 the paper is sometimes cumbersome to read... If the authors could find a more compact and maybe a little less detailed way to discuss the results it would make a great service to readability of the manuscript.

{AR} A substantial effort will be made to make the manuscript easier to read. We have introduced two new tables to improve the clarity of the presentation and to reduce clutter. One presents manufacturer-specified and combined uncertainties for radiosonde measurements and the other presents the percentages of measurement differences that exceed the combined measurement uncertainties of the radiosondes.

{RC} What comes to World Meteorological Organization it of course arranges periodically the “official” intercomparisons of the operational radiosondes, lastly in Yangjiang, China in August 2010. The same sondes or at least the same manufacturer’s products (CHF, Vaisala RS92 and Internet) as a year earlier in Mohave participated in the latest WMO campaign too (WMO, Instruments and observing methods report no. 107). It would be interesting to have a comment about the similarities and differences of the two campaigns and their results, especially as one of the coauthors also participated in the WMO campaign and the report (e.g. at the summary section).

{AR} We feel that adding this discussion to the current manuscript would only exacerbate the problem of it already being too “wordy” and complicated. Also, our understanding is that the WMO study employed the South African version of the iMet-2 radiosonde, which is very different from the North American iMet-1-RSB radiosonde launched during MOHAVE 2009.

{RC} 2.1 Radiosondes PTU differences were compared against the manufacturer–quoted error estimates but manufacturer’s own hardware and software was not always used. In case of iMet radiosonde the ground system was not Internet’s own but a ra-

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diomodem connected to user's acquisition/analysis software. How might these affect the comparison results e.g validity of manufacture specs. (In case of Vaisala the RH dry bias correction was mentioned and quantified roughly.)

{AR} The manufacturer's (Vaisala) DigiCORA system and software were used for the RS92 radiosondes. The only corrections applied to RS92 data by the manufacturer's software were solar radiation corrections to temperature measurements during the two daytime flights (all other flights were at night). RH data from the RS92 sondes were exported in raw form and corrected off-line using the algorithms presented in Miloshevich et al. [2004 and 2009]. For Imet sondes, our off-the-shelf hardware (radio receiver and modem) and custom data acquisition software do nothing more than receive and store the data packets telemetered by the sondes. Unless the manufacturer's software applies some corrections to the raw data that we are unaware of, their system and ours will basically record and store the same data. Since this manuscript was submitted back in April, solar radiation corrections for the IMET temperature measurements have become available. We have now applied these corrections to the IMET temperature data for the two daytime flights (TF027, TF040) and have recomputed the RS92-IMET differences and statistics for T and RH.

{RC} 3.1 Temperature The authors find a negative bias of half a degree in the iMet readings against Vaisala RS92. Is that specific to this campaign or more common feature of iMet-1 temperature sensor? CHF team should have a lot of experience flying iMet sondes and RS92 together. Aforementioned WMO campaign reports a positive bias in Intermet's next version iMet-2 which participated in Yangjiang. Again it would be interesting to hear expert opinion on this apparent contradiction.

{AR} We feel that the suggested discussion is outside the realm of this manuscript, especially since the iMet-2 you refer to is manufactured and calibrated in South Africa. We are under the impression that InterMet North America and InterMet South Africa are not connected by over-arching leadership, hence the two companies tend to do things in quite disparate ways. Furthermore, the calibration and implementation of sensors on

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the iMet-1-RSB may be quite dynamic, meaning that sondes purchased two years ago are likely to be different from those manufactured today, even though the model number remains the same. This is certainly true for the iMet pressure and RH sensors. Thus, it is difficult to make generalized comments about "common features" of the iMet-1-RSB sensors as they were implemented during different campaigns conducted a year or two apart.

{RC} 3.2 Pressure There is an interesting comment in the Yangjiang WMO report that the GPS altitudes are becoming so accurate that there might be not necessary to use pressure gauges at all in the future radiosondes. Have authors thought about this possibility of converting radiosonde GPS altitudes to pressures? Could be interesting to try that and discuss briefly. Something new or at least novel.

{AR} This comment prodded us to examine the iMet GPS altitude data and use them to back-calculate atmospheric pressure, using the hypsometric equation. The results are quite conclusive; the GPS-based pressures are in agreement with the directly measured pressures, except for sondes contributing to the anomalous pressure difference profiles (Figure 5). Comparisons of the measured pressures and the GPS-based pressures allows us to confidently identify the poorly performing radiosonde(s) in each anomalous difference profile. This was a very good suggestion and we will incorporate the use of GPS-based pressures into the manuscript.

{RC} 3.3. Relative humidity The environment in Mohave is quite dry and maybe this makes it possible to have sensible RH from higher altitudes by radiosondes too. Nevertheless, when a manufacturer says that the error in RH measurements can be 5% RH does it not mean that instrument is virtually useless in the stratosphere? Further, in these cold temperatures time lag increases rapidly so that no correction is able to correct the readings. What actually is the altitude in these conditions that radiosondes still could provide useful RH measurements? Does RS92 for example detect the hygropause?

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{AR} These are tricky questions because the answers largely depend on the level of uncertainty that can be tolerated in the RH measurements. The RS92 sensor does respond to changes in RH, even at temperatures as low as -90°C, and a time-lag correction can be applied. However, the relative uncertainties in the corrected data increase substantially from 14% at 5% RH to >50% at lower stratospheric values of 1% RH. In this sense, the RS92 can detect the hygropause because highly accurate RH values are not required. Miloshevich et al. [2009] indicated a reasonable altitude limit of about 18 km for the validity of RS92 RH corrections, but further work now extends the correction algorithms to higher altitudes, albeit with substantial increases in relative measurement uncertainties. In this manuscript we apply an altitude ceiling of 20 km for the comparisons of corrected RS92 (and other) RH measurements because the necessarily small RH differences above 20 km tend to bias the difference statistics towards zero.

{RC} Curiously RS92-RS92 differences tend to be on the negative side although not statistically significant e.g. figs. 12 and 13. Was there a systematic way of naming one RS92 as a primary and another one secondary (e.g. position in the rig or sgp-vs. k-type)? I am thinking of possible small effect of rest of the payload to humidity environment, for example.

{AR} When two RS92 sondes were flown on the same balloon, the RS92-K sondes from JPL (14) were always designated as the primary sondes, and either the RS92-K (11) or RS92-SGP (3) from Goddard were designated as the secondary sondes. A negative bias infers that the JPL sondes measured lower RH values than the Goddard sondes. There were no consistent physical differences in the mounting locations of primary and secondary radiosondes on the CFH/FPH/ozone/sonde payloads and no consistent RH biases between the three pairs of JPL –K and Goddard –SGP sondes flown together. Four of the Goddard sondes used in dual RS92 soundings were significantly older (~1 yr) than the rest (~ 2 months), but difference profiles for the newer/older and newer/newer sonde pairs are intertwined (Figure 10). That leaves differences in

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RH sensor reconditioning and zero humidity ground checks as candidates for the bias, since JPL and Goddard used separate ground check units for their sondes. But as you indicate this bias is not statistically significant, so we consider it unnecessary to dredge through the detailed logs of of sonde ground checks and sensor reconditioning to (hopefully) find a culprit. It could be as simple as slight differences in the dryness of the two GC-25 dessicant beds used to perform the zero humidity checks, or it could be much more complex. We will mention in the manuscript that the consistency of ground checks and RH sensor reconditioning is an important factor in obtaining reproducible results from two different RS92 sondes.

{RC} 3.4 Water vapor mixing ratios At the end of the section authors emphasize the importance of accurate pressure data to VMR computation from frost point hygrometer measurements. Since both RS92 and iMet have GPS receivers I return to my previous point of trying calculate pressure from the GPS altitudes. Also the payload might have its own GPS locator and anyway the payload is expensive enough to justify having a good GPS unit attached to it if sonde GPS is not good enough for this purpose. What would be your comment or experience on this point in general?

{AR} Without a doubt the GPS capabilities of the iMet and RS92-SGP assist us in tracking the payloads and, if possible, retrieving them after flights. The GPS altitude data from the two types of sondes also agree quite well, implying high data quality. The problem in calculating accurate pressure values from the GPS-based altitude (i.e., geopotential pressure) is that the hypsometric equation depends on the small, incremental, measured changes in GPS altitude, temperature and RH that occur between radiosonde time stamps. Sensor biases and noise can create sizeable errors in the calculated geopotential pressures, much as they can when calculating geopotential heights. Both methods rely on well-established anchor values (launch site elevation and pressure for geopotential heights and geopotential pressures, respectively) but then must calculate the incremental changes in these values from the small measured changes in temperature, RH, and pressure (for geopotential height) or GPS altitude

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(for geopotential pressure).

{RC} Section 3.5 (Altitude calculation comparison) Here the user made programs were compared against the Vaisala Digicora program. The lack of use of GPS data in this analysis is surprising. Why was it not used? {AR} We have now included GPS altitudes from the iMet sondes (there were only 5 RS92-SGP sondes launched during the 26 balloon flights) to gauge the quality of the geopotential heights calculated by the DigiCORA software and by our custom iMet software. The differences between the GPS altitudes and geopotential heights (now included in Figure 18) are consistent with the differences between the two sets of geopotential heights. The iMet geopotential heights more closely match the GPS altitudes than do the RS92 geopotential heights. This discussion will be added to manuscript.

Interactive comment on Atmos. Meas. Tech. Discuss., 4, 4357, 2011.