NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

TECHNICAL NOTE 7

Investigation of RH Calibration Method

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Updated July 2016

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Investigation of RH Calibration Method

Introduction

Rotronic MP101(a) air temperature and relative humidity sensors are deployed on OCS moorings, on both the ATLAS and Flex systems. In conditions of high humidity, the sensors at times report values very different from each other. This report describes the investigation of the current method of performing calibrations on relative humidity sensors at PMEL, and whether this method ensures measurement accuracy, especially in an environment of >95%RH.

Historical Data

For multiple years, OCS moorings at KEO and Papa have been deployed with dual ATRH sensors, side by side. To date, there are a total of eight years worth of comparison data from both sites. Differences in reported RH values between the two sensors on each mooring were compared, subtracting the values measured by the ATLAS sensor from the values measured by the Flex sensor. It was found that fewer than 25% of all measurements differed by more than the stated accuracy specifications for RH on OCS moorings, of ±2.7%RH (Lake, et al., 2003). Figure 1 shows a sample comparison from one deployment.

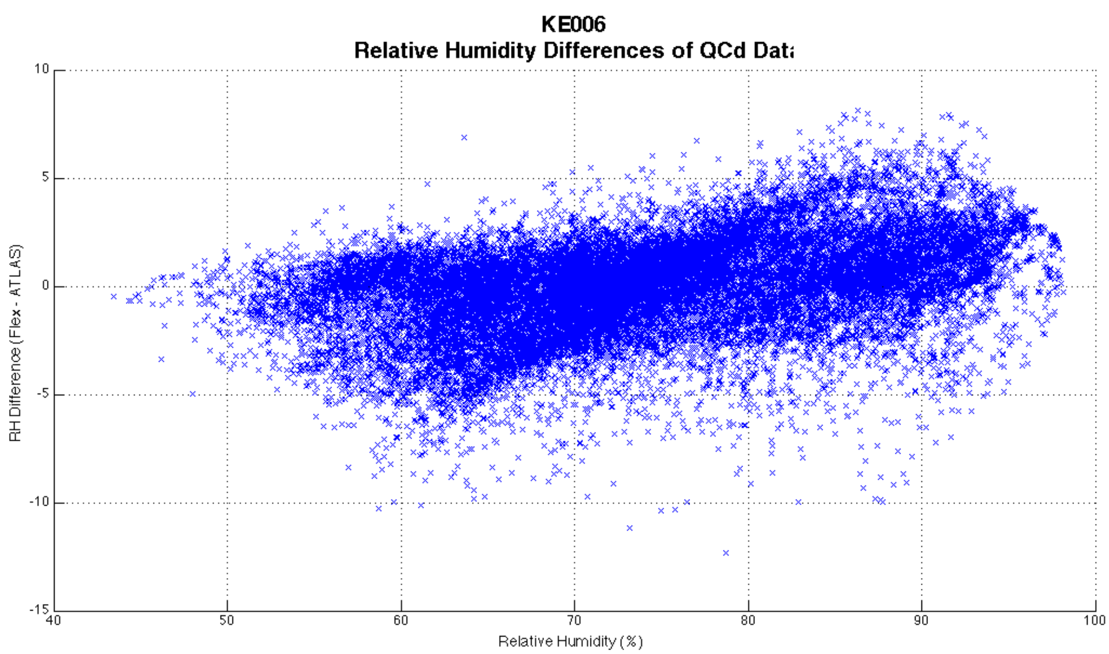

Figure 1: Example of comparison of side by side ATRH sensors on an OCS mooring. Plot shows Flex – ATLAS difference vs. average relative humidity.

The RH accuracy specified by Lake, et al. is based on an RMS value of pre deployment and post recovery calibration differences. The percentage of differences measured on OCS buoys that fall outside this spec are consistent with the RMS accuracy.

To determine if sensor consistency was worse in a particular range of humidity, difference data were binned by average humidity into 11 groups, each spanning 5%RH. It can be seen in Figure 2 that the sensor agreement was the worst in the range of 90-95%RH. In that range, less than 70% of the differences fell within the stated accuracy specification. Above 95%RH, the agreement improved, as the sensors became saturated, causing differences to converge.

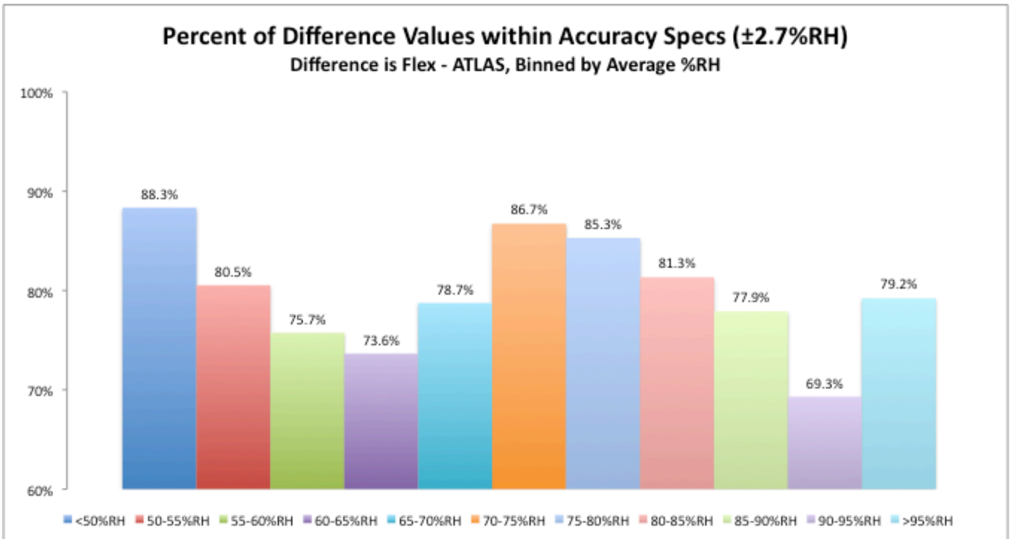

Figure 2: Percentage of differences between side by side RH measurements on eight OCS moorings that fall within stated accuracy specifications, binned by average %RH. Differences computed as Flex – ATLAS.

A similar side by side comparison of Rotronic MP101 sensors was conducted in a joint study between WHOI, PMEL, JAMSTEC, and Brookhaven National Laboratory (Payne, et al., 2002). The method used in that study was to compare individual sensor measurements to the composite average relative humidity calculated from all individual measurements. Using this comparison method on OCS data, the Flex and ATLAS sensor differences from the average fall within the accuracy limit of ±2.7%RH in 97.8% of all measurements in the years compared[1]. These comparisons are shown in Figures 3 & 4.

[1] Data from PA003 were not included, due to a large shift in ATLAS sensor output mid-deployment. This sensor failed the post-recovery calibration.

[2] Chamber temperature setting for calibration is based on manufacturer's recommendation in MP101 manual. Phone call

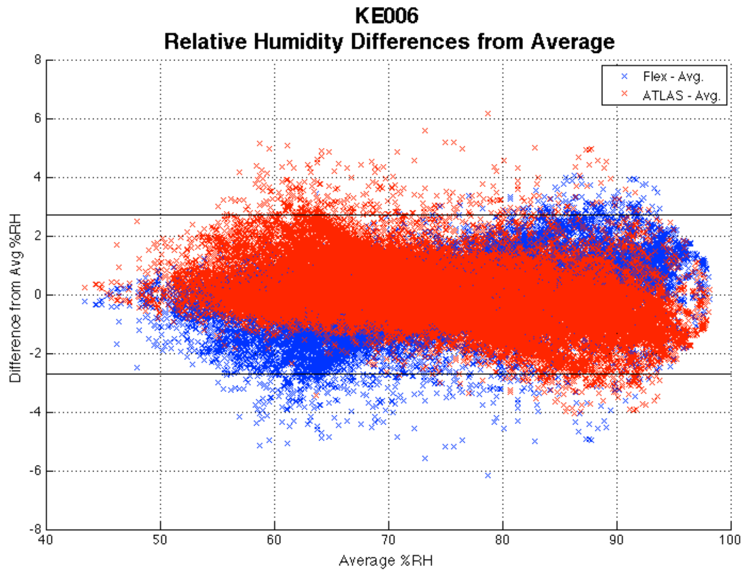

Figure 3: Example of comparison of side by side ATRH sensors on an OCS mooring. Plot shows Flex/ATLAS – Average difference vs. average relative humidity.

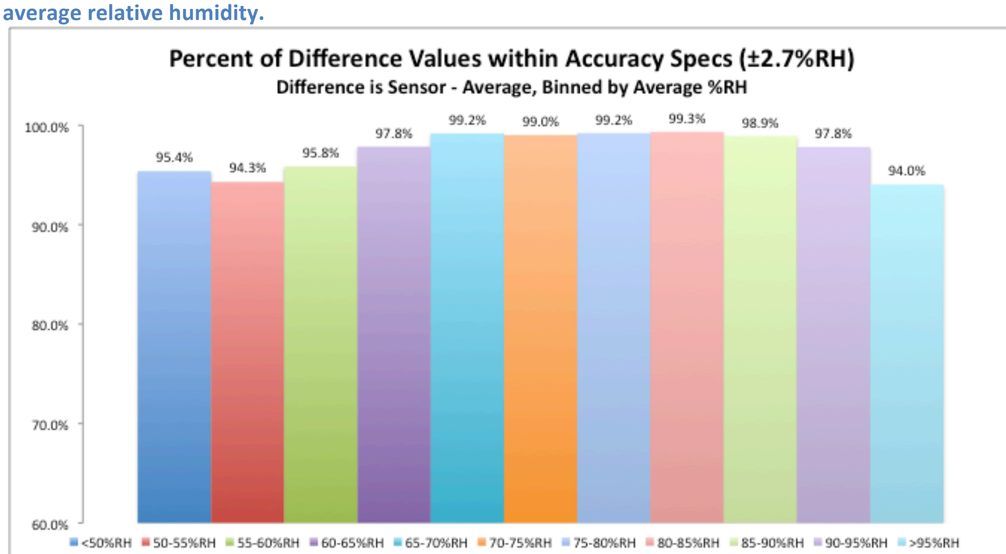

Figure 4: Percentage of differences between side by side measurements on seven OCS moorings that fall within stated accuracy specifications, binned by average %RH. Differences computed as Flex/ATLAS – Average.

In comparison to the composite average, the sensors agree very well in the range of 60 – 95%RH. At the high and low ends, agreement is slightly worse. At the low end, this is likely due to the limited number of measurements at low humidity. A few bad data points have a large influence on the percentage. Above 95%RH, the greater disagreement between the sensors is likely due to different saturation levels and equilibration rates.

Sensor performance above 95%RH is difficult to monitor in a controlled setting, due to limitations of lab equipment. The calibration method used at PMEL was investigated, to determine whether a higher-order polynomial correction should be applied to the data, or if comparison points above 95%RH could improve the correction.

Calibration Method

Thecalibration method for RH sensors used at PMEL is well established, tested, and documented by Lake, et al. (2003). For OCS moorings, humidity sensor calibrations are checked at six set points, every

10%RH from 45%RH to 95%RH. A Thunder Scientific Model 2500 Humidity Generator is used for the test, with the chamber temperature set to 25°C[2]. Calibration software records the actual humidity in the chamber, and the reported values from the sensors, once per minute at each set point.

For both pre-deployment and post-recovery calibrations performed for testing described in this report, an equilibration time of 100min was used at the first four set points, 160min at the 85%RH set point, and 220min at the 95%RH set point. Experience has shown that the sensors require longer equilibrium time at higher chamber values. The final ten readings at each set point are averaged together. The sensor averages are compared to the chamber averages, and a linear fit is calculated. These linear coefficients are applied as corrections to raw sensor output in the field. A sensor fails a calibration if the maximum linear fit residual is greater than ±1%RH.
Figure 5 shows RH calibration checks from one sensor (S/N 112220) prior to deployment (left), and again after a year at sea (right). The post recovery check resulted in a maximum linear fit residual greater than 1%RH, which is considered a failure. Both a linear and quadratic fit are shown for each the Pre Deployment and Post Recovery calibration checks. The second order polynomial equation fits the data points slightly better in the Post Recovery run, but the difference is small for Pre Deployment. A higher order fit from pre deployment calibrations would not be likely to improve corrections to measurements in the field.

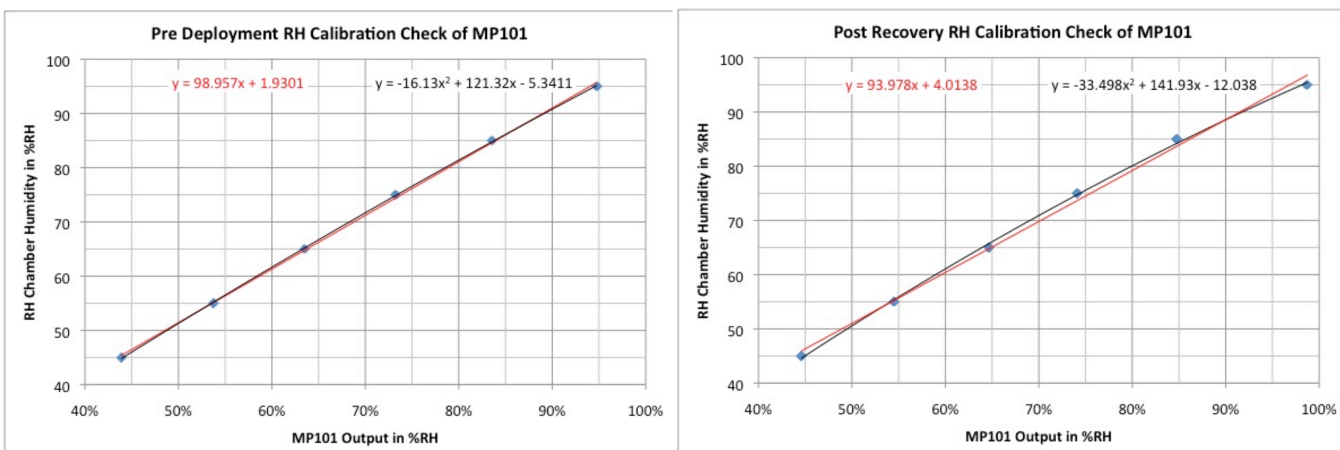

Figure 5: Linear and polynomial corrections applied to raw sensor output, pre deployment and post recovery.

Plotting all data from the calibration performed above vs. time, as shown in Figure 6, the MP101 output increases throughout the equilibration period. Though the linear fit is only calculated from the final ten minutes at each set point, the sensor may not yet have reached a steady level when this average is computed. For the post recovery check, if the protective filter is clogged with salt, the clogged pores could restrict airflow so the sensor is still adjusting to the higher humidity while the chamber is holding steady. In the past, equilibration times were extended for post recovery calibration checks. Equilibrium at the first four set points was held for 220min, 85%RH was held for 280min, and 95%RH for 340min. These extended equilibration times for post recovery checks will be reinstated. Differences in filter clogging and sensor equilibration times in the field would contribute to differences between measurements of two sensors.

[2] Chamber temperature setting for calibration is based on manufacturer's recommendation in MP101 manual. Phone call to Rotronic tech support on 7/20/2012 verified that temperature during calibration *should not* have an effect on RH readings in the field.

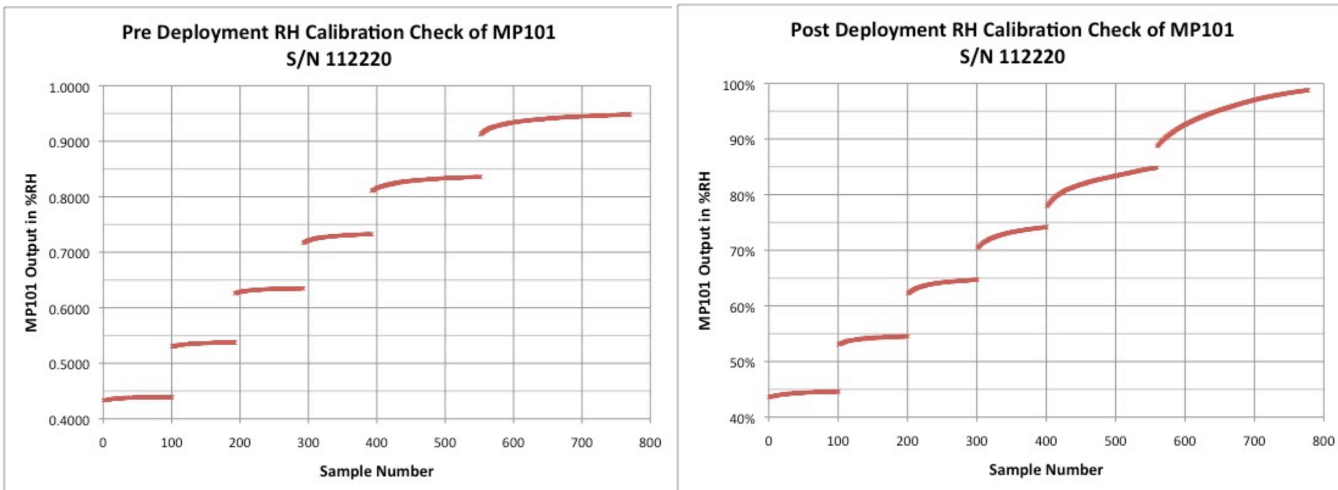

Figure 6: Raw MP101 output during calibration check, pre deployment (L) and post recovery (R). Sensor equilibration times increase when filter is clogged with salt and dirt after a year in the field.

Extended Calibration Range

The Thunder Scientific Model 2500 Humidity Generator used for calibrations at PMEL has a stated operating limit of 95%RH. MP101 sensor performance was previously not checked above this level. Jeff Bennewitz at Thunder Scientific was contacted regarding the possibility of operating the chamber at 98%RH. His recommendation was to purchase a custom copper manifold for use in the chamber. The manifold mounts directly to the test chamber input. The probe to be tested would be placed in the open end of the manifold, along with the temperature probe from the calibration chamber. This should allow a higher humidity within the manifold, with no risk of damage to the chamber.

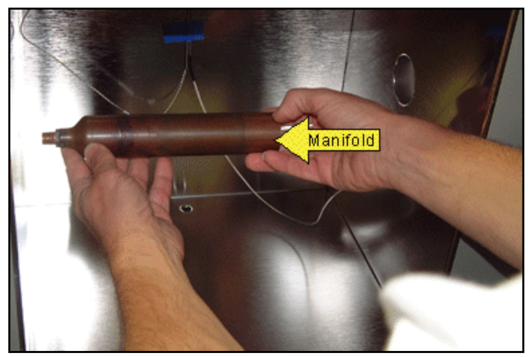

Figure 7: Copper manifold for Thunder Scientific humidity chamber. (Photo courtesy T.S.)

The manifold for the RH calibration chamber was received at PMEL in August 2012. A humidity level of 98%RH could not be achieved, but several MP101 sensors were tested to 97%RH at 25°C. Raw output data are shown in Figure 8. The units with S/N's 58365 and 118816 had not been deployed since their previous servicing. Sensor 104889 was deployed for a year on the PA005 mooring, and passed the post recovery calibration. No servicing was done on that instrument prior to this test. Unit 112220 failed its post recovery calibration after being deployed on the KE009 mooring for eight months, so that RH sensor and filter were replaced prior to this test, and the sensor was adjusted to RH standards.

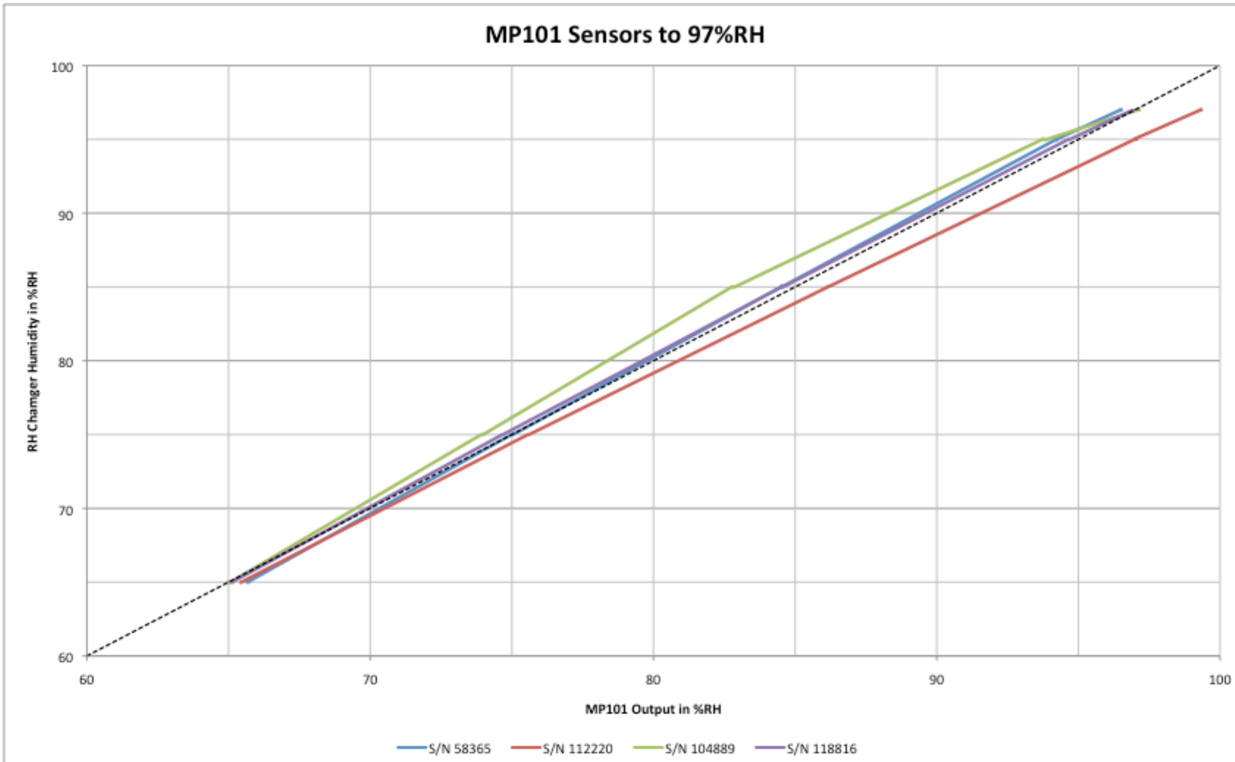

Figure 8: Raw output from MP101 sensors tested from 65% to 97%RH at 25°C.

In Figure 8, it can be seen that the linearity of the sensor output does change slightly above 95%RH. The line tips toward higher measured humidity levels, which might account for some of the problems noted in field measurements above 95%RH. The effect is very small in the sensors that have not been deployed. It is possible that sensor performance degrades over time in the field.

For sensor S/N 104889, the raw data output from the above test to 97%RH was plotted, along with the data corrected by the linear fit from that run. For comparison, the linear fit from the original post recovery check to 95%RH was applied, as well as the pre deployment linear fit. The plots of the resulting output are shown in Figure 9.

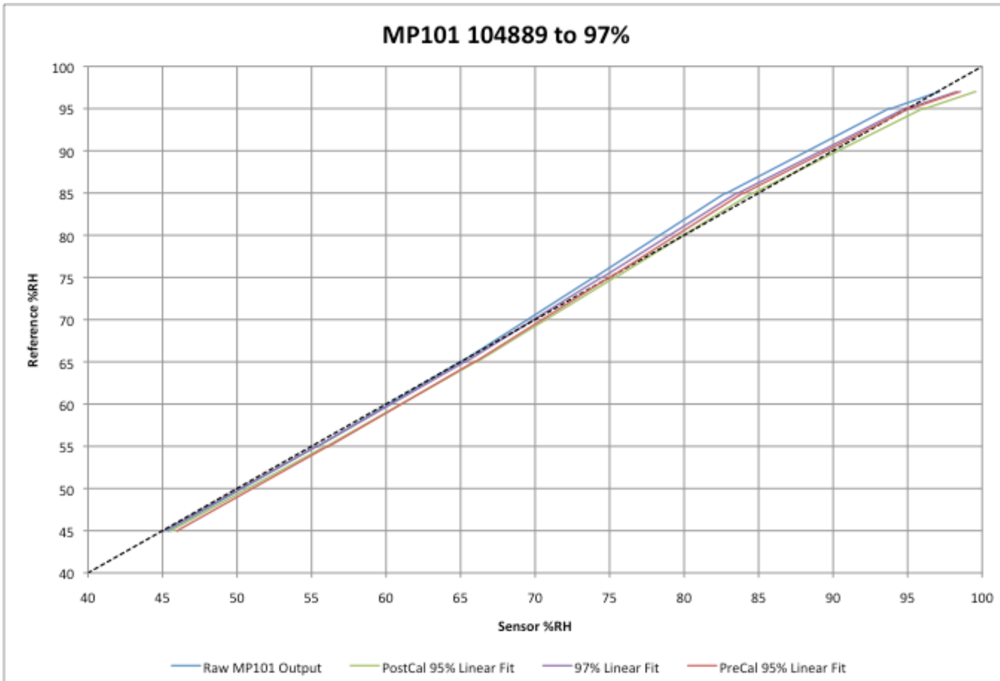

Figure 9: One sensor tested to 97%RH with various corrections applied to the raw data.

The measurements corrected using the linear fit from the 97%RH post recovery calibration test (purple line) agree very well with the pre deployment linear fit that was run to 95%RH (red line). Extending a pre deployment linear fit calibration to include data above 95%RH does not seem likely to significantly improve the humidity measurements at higher levels of humidity, based on the limited number of instruments tested.

Temperature Effects

During the multiple calibration tests performed above, it was noted that the chamber temperature was set to 25°C. Since OCS moorings are deployed at high latitudes, temperatures can be much lower than this. The effect of temperature on sensor RH readings was investigated by varying the temperature within the test chamber between calibration runs.

To explore the effects of temperature on raw sensor output, instruments 58365, 104889, and 118816 were put in the chamber together, and were tested at three RH set points; 45%, 75%, and 95%. Separate calibration checks were conducted, with the chamber temperature set to 10°, 15°, 20° and 25°C. Raw sensor output was found to vary with temperature, as shown in Figure 10. These measurement differences at different temperatures were generally larger than those expected due to uncertainty in the calibration process, which was estimated by Lake et al. to have a repeatability of approximately 0.42%RH. This was the RMS of standard deviations computed over all set points used in the Lake et al. evaluation.

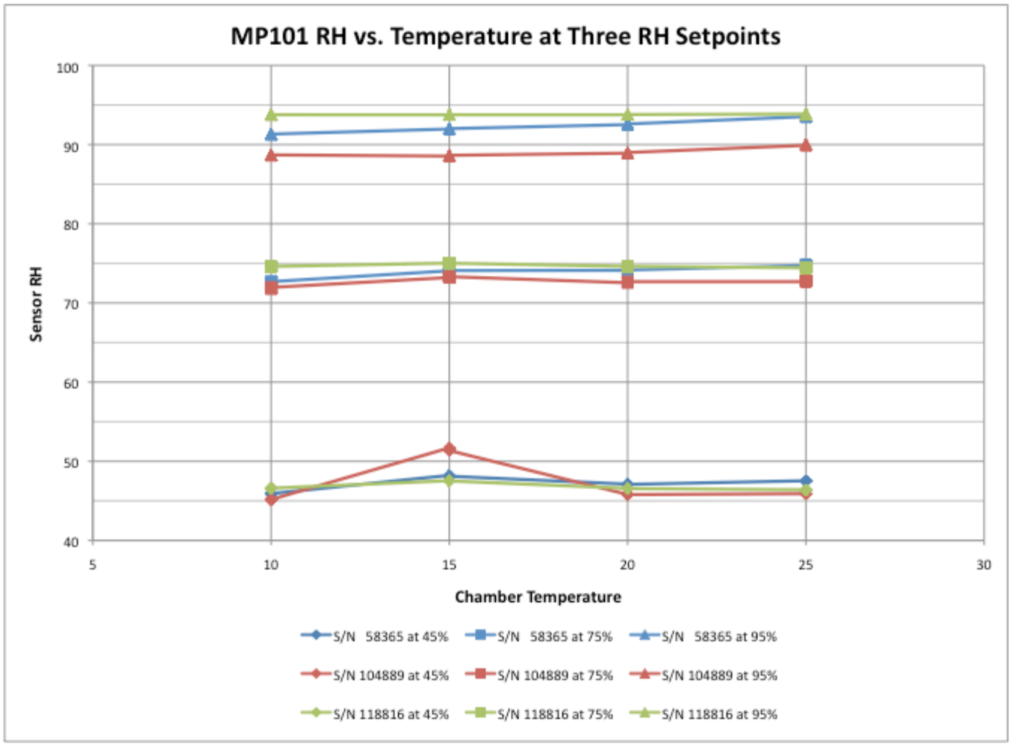

Figure 10: Raw MP101 output at three RH set points, with varying temperature.

The linear fit correction for each sensor calculated during the 10°C run was applied to the raw data from each temperature setting. The same was done with the 25°C correction. The maximum residuals for the linear fit data compared to the actual chamber reading are shown in the tables below.

10°C Linear Fit Applied

Temperature Set Point	Max Residual S/N 58365	Max Residual S/N 104889	Max Residual S/N 118816
10°C	0.51	0.67	0.33
15°C	2.73	7.17	1.23
20°C	1.51	1.08	0.23
25°C	2.62	1.24	0.32

25°C Linear Fit Applied

Temperature Set Point	Max Residual S/N 58365	Max Residual S/N 104889	Max Residual S/N 118816
10°C	2.42	1.82	0.50
15°C	1.29	6.39	1.22
20°C	0.76	1.60	0.42
25°C	0.50	0.42	0.58

The fit residuals indicate that it would be best to perform the calibration at a temperature that is closest to the nominal temperature at the deployment site. The residuals seem to be highest at 15°C, and Figure 10 does show that sensor output at 45%RH particularly, is skewed at 15°C.

These temperature test results were shared with Rotronic Instrument Corp., the manufacturer of the MP101 probe. David Love of Rotronic requested that these probes be sent to him, so that he could repeat the testing. Figure 11 shows the results of his test (DL) and those performed at PMEL (JK). Plots are the difference of the raw MP101 output from the standard vs. temperature, at three RH levels.

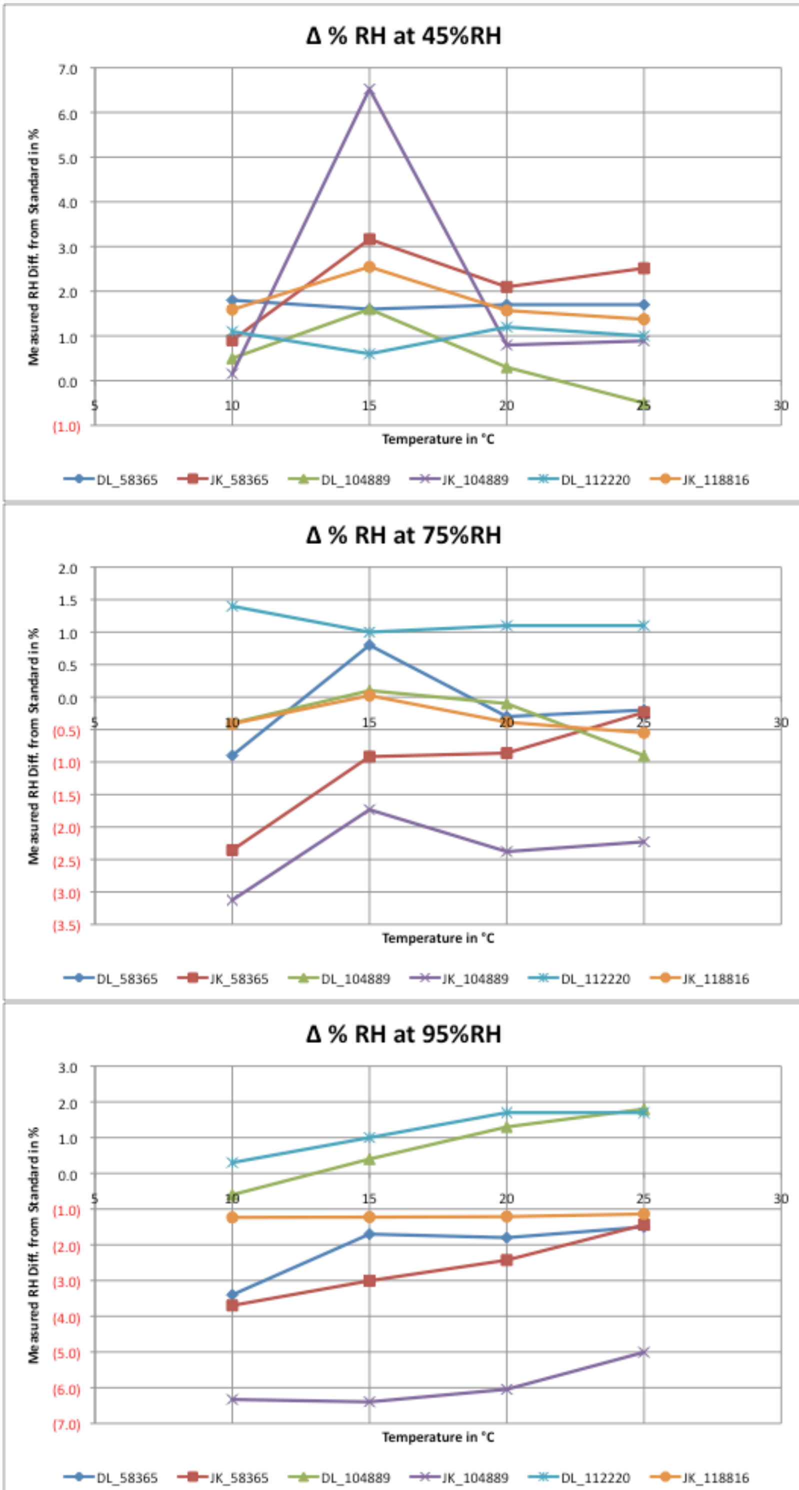

Figure 11: Difference of raw MP101 output from standard vs. temperature, at three RH set points. Testing done at Rotronic labeled DL_*; testing done at PMEL labeled JK_*.

Sensor variability with temperature is not consistent between sensors, or across the RH range. In a follow-up discussion with Mr. Love from Rotronic on November 30, 2012, it was his belief that this is due to the nature of analog sensors. Internal components tend to drift over time. They may drift in different directions, and at different rates. This leads to differences in measurements between instruments. His recommended solution was to switch to the new digital sensor being offer by Rotronic, the HygroClip HC2-S3.

Digital Sensor

The Rotronic HycroClip HC2-S3 has recently been introduced to the PMEL sensor pool as an alternative to the MP101. This is a digital sensor from the same manufacturer, with similar or improved stated accuracy specifications and response time.

Several HygroClip sensors were tested in the same way as the MP101; to 97%RH at 25°C, and across a range of temperatures. When tested to 97%RH, the HygroClip performance, with the linear fit correction applied, compared very well to the RH chamber values, as shown in Figure 12. Sensor output appears linear throughout the calibration range, so that a higher-order fit is not necessary.

The tested sensors were brand new. Further performance testing should be done when instruments have been deployed in the field for at least a year.

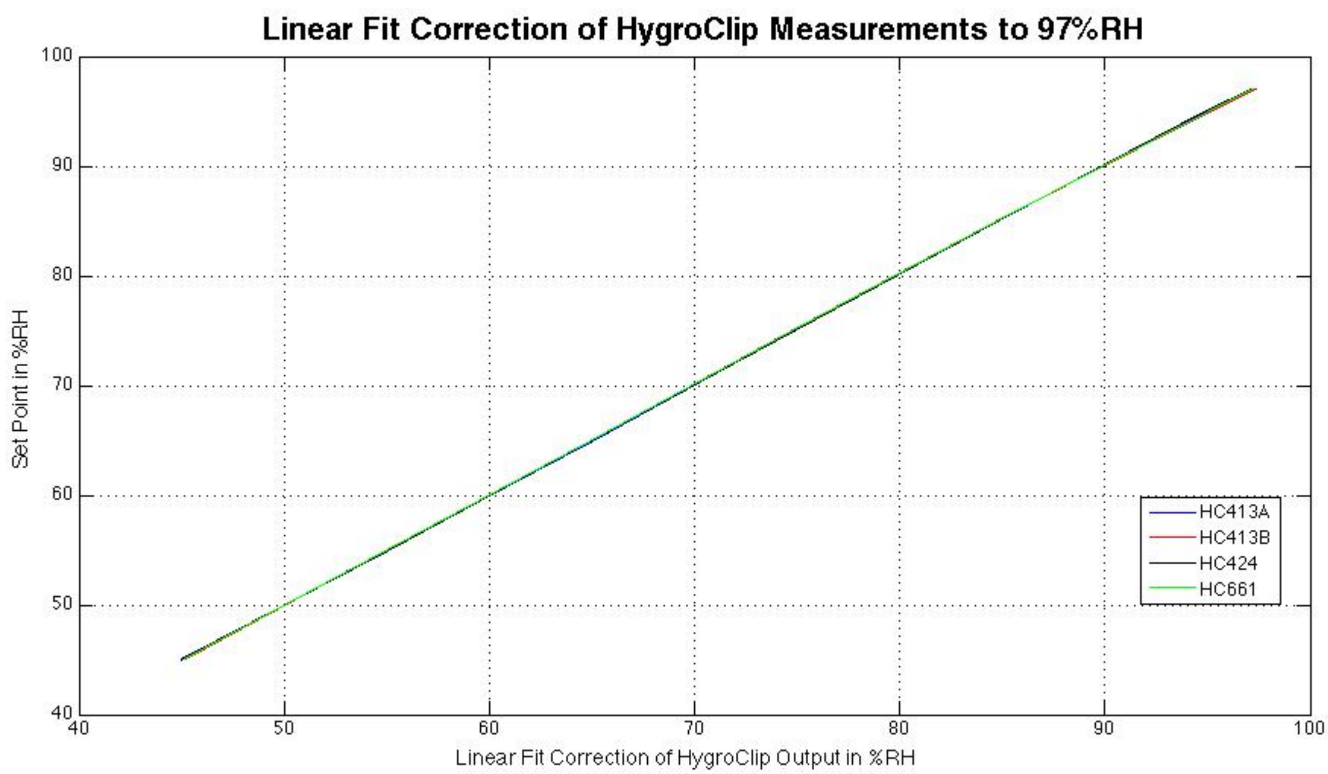

Figure 12: Calibration results from four HygroClips with linear correction applied.

A small study of several HygroClip sensors indicated that their raw output also varied with temperature. Though much better than the variability of the MP101, the HygroClip output at 95%RH in the chamber at 10°C could be nearly 2% different than at 25°C, as seen in the plots in Figure 13. The calibrations to determine linear fit coefficients for these sensors should also be performed at a temperature closest to what is expected in the field.

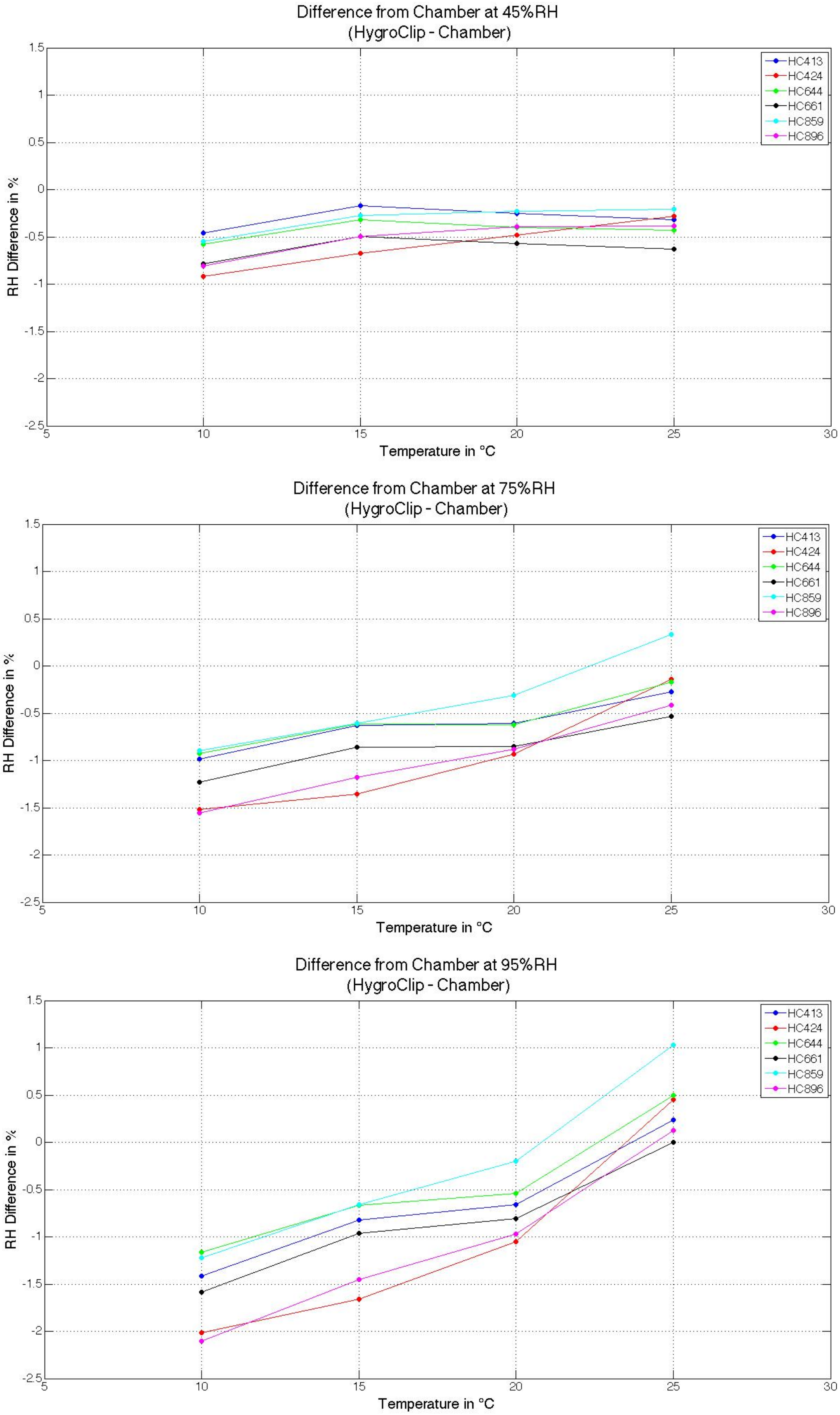

Figure 13: HygroClip difference from chamber vs. temperature, at three RH set points; 45%RH (top), 75%RH (middle), 95%RH (bottom). Raw sensor output shows clear dependence on temperature, particularly at higher humidity.

Sensor Aspiration

In previous studies, it was theorized that the amount of sensor aspiration could affect temperature and relative humidity readings. Solar heating of the gill plates used to house the sensors could bias the temperature measurements, and also the relative humidity. This bias would be more apparent in low wind conditions. In the data sets studied here, winds do not appear to affect the differences measured in RH between the two sensors. Figure 14 shows the Flex – ATLAS difference in RH versus the measured wind speed for one mooring, with no correlation.

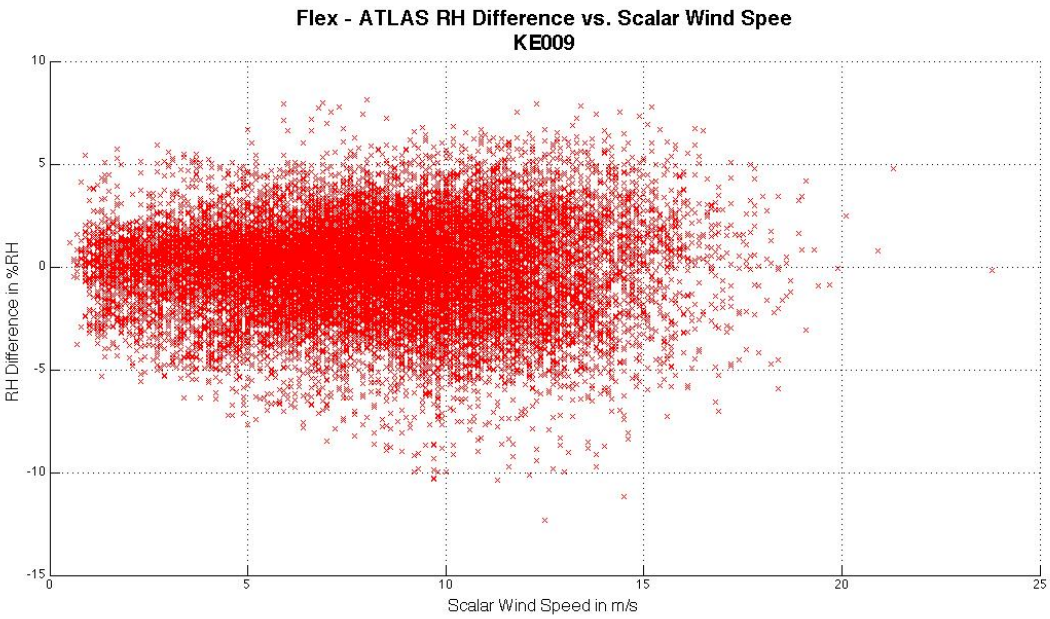

Figure 14: Flex - ATLAS RH Difference vs. Scalar Wind Speed at KE009. No apparent correlation.

Differing amounts of filter clogging toward the end of the deployment was also investigated as a possible source of measurement discrepancy. In Figure 15, any measurement difference that fell outside of the ±2.7%RH specification was plotted in an absolute scale, versus deployment time for one mooring. The differences remain fairly consistent throughout the deployment.

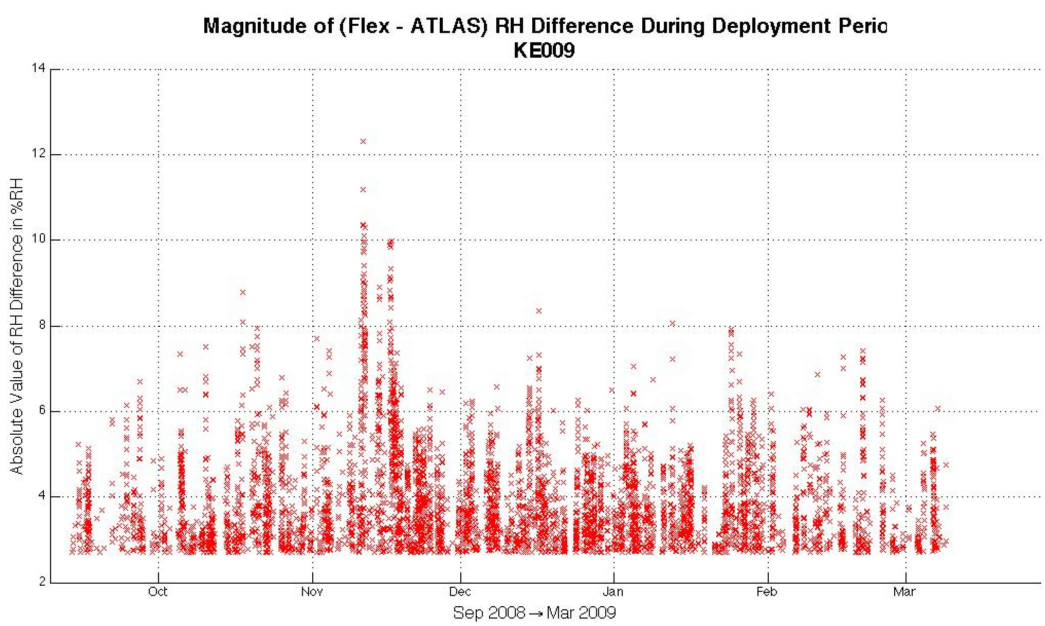

Figure 15: Absolute value of Flex - ATLAS RH Difference outside of ±2.7% spec over entire deployment period.

Original Conclusions & Recommendations (September 2013)

The original concern of this study was MP101(a) air temperature and relative humidity sensor performance above 95%RH. It was found that 97.8% of all measurements from side by side sensors differ from the combined average relative humidity by less than ±2.7%RH. Above 95%RH, the difference increases slightly, but based on the testing done in this investigation, the accuracy of relative humidity measurements is a function of the sensor, not the calibration method used at PMEL.

The Rotronic MP101(a) analog ATRH instruments exhibit slight non-linearity over the RH calibration range used at PMEL, and also display high variability in RH measurements with temperature. When deployed in the field, filters become clogged, slowing sensor response times. Internal components also drift over time, affecting measurement accuracy.

Test results indicate that a first-order linear fit to 95%RH is sufficient for pre deployment calibrations. Though sensor performance is seen to alter in the post recovery calibration, where a higher-order fit is better, this cannot be predicted in the pre deployment calibration. Linearity of sensor output above 95%RH does not change significantly to warrant extending the calibration range to 97%RH.

To improve post recovery calibration linear fits, the equilibration times used at each set point will be extended. Allowing the sensor more time to adjust to the humidity level before readings are recorded, will help to reduce inaccuracies in post recovery corrections introduced by clogged and dirty filters. It will have no effect on sensor performance in the field.

The unexpected dependence of sensor output on ambient temperature should be addressed by slightly altering the calibration method. Rather than performing all calibrations at a standard temperature of 25°C, it is recommended that the sensors be calibrated at the mean or median temperature expected for the deployment site (Appendix). At this time, there is no means to perform a calibration over a range of temperatures and apply those corrections to the data.

The digital HygroClip has shown slightly better performance than the analog MP101 in lab testing. This sensor should be tested for accuracy and reliability in the field. If performance is at least as good as the MP101, with less drift over time, it should be considered as a replacement to the outdated analog technology of the MP101.

Update – July 2016

Field deployments of instruments calibrated at the lower temperatures recommended in the September 2013 version of this report showed drastic differences between measurements made by instruments on the same mooring (Figure 16). Removing the calibration coefficients showed improvement in comparisons of the raw data, indicating that the calibrations were introducing errors into the measurements.

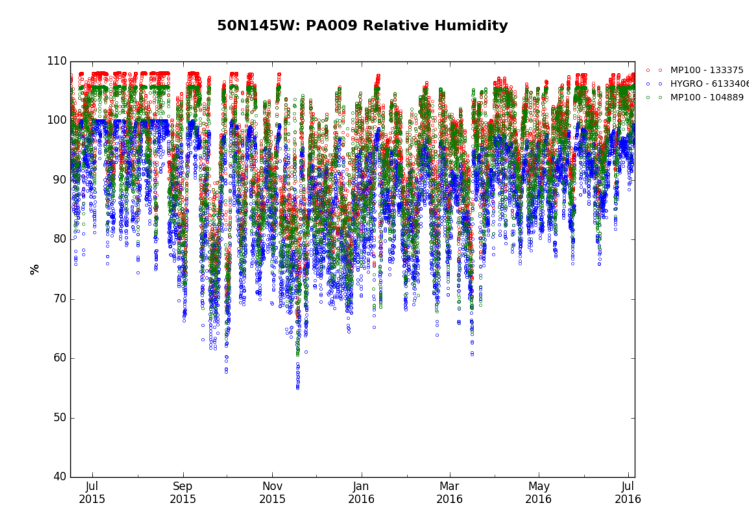

Figure 16: Example of large differences in measured RH from three sensors on the same mooring. (MP101 = Red & Green, HygroClip = Blue)

Comparison of Calibration Coefficients from Different Temperatures

In order to investigate the differences between calibration corrections derived from different temperature set points in the RH chamber, five ATRH sensors were installed on a test platform at PMEL (3 HygroClips, 2 MP101s). Due to a logging problem with one system, the sensors did not all log data simultaneously. A swap was made on 2/12/16 in order to collect data from all sensors.

Instruments Installed on Test Platform

	Logging Dates	
Sensor	**Start Date**	**End Date**
MP_58365	1/14/16	3/8/16
HC_61334171	1/14/16	3/8/16
HC_61365505	1/14/16	2/12/16
MP_118816	2/12/16	3/8/16
HC_20044582	2/12/16	3/8/16

RH calibrations at 7°C and 25°C were performed on each sensor prior to installation on the test platform. Raw data were logged during the test, to allow application of the calibration coefficients in post processing, for comparison. Figure 17 shows the average of the raw measurements (green) from all sensors, as well as averages made with cold (7°C, blue) and warm (25°C, red) coefficients applied. Large changes were seen in the resulting data, particularly with cold calibration coefficients applied.

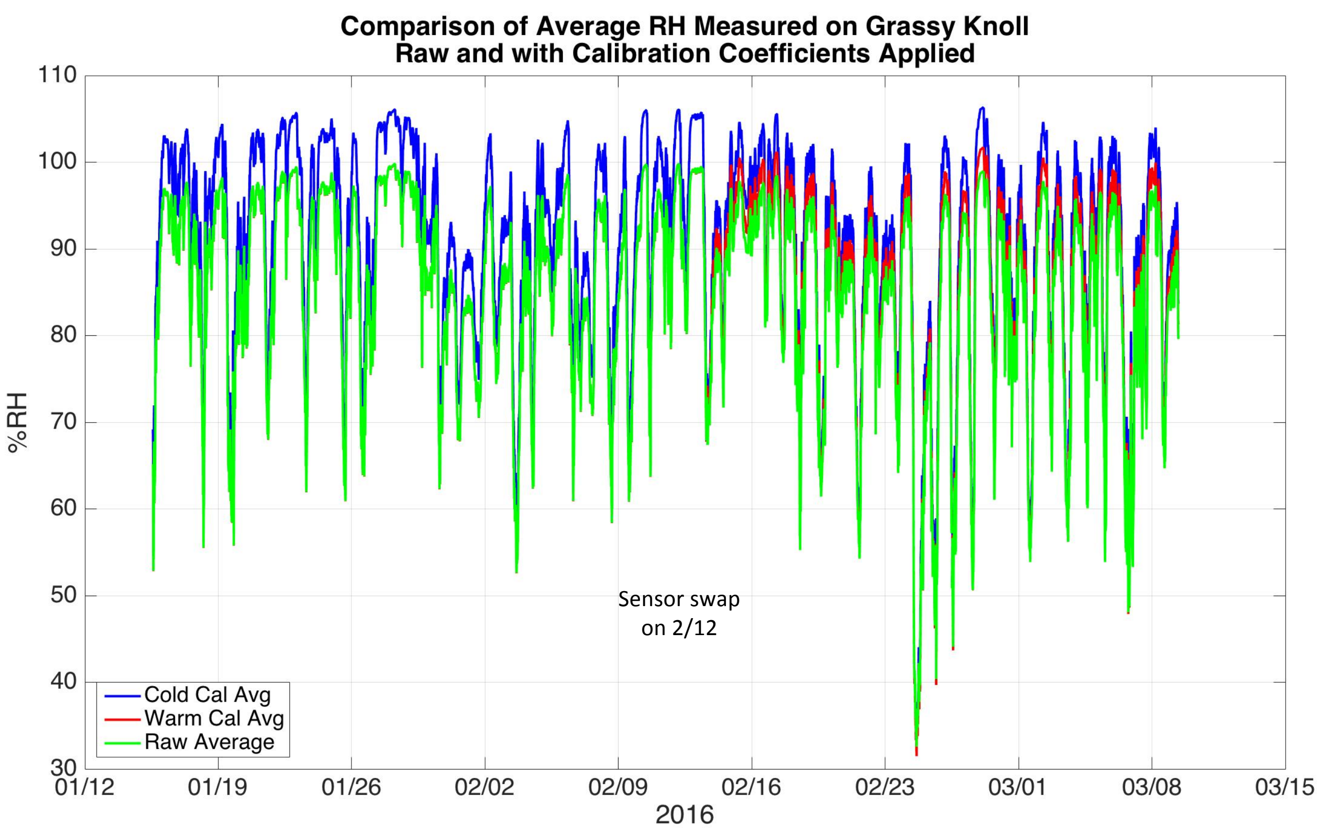

Figure 17: Average RH measured by multiple sensors on a test platform. Raw data (green) were logged, and then calibration coefficients from cold (blue) and warm (red) RH calibrations were applied.

Considering data from the sensors individually (Figure 18 a-e), the application of the coefficients from the cold calibration pushed the measured RH values over 100%RH for all five instruments. It is now believed that temperature gradients within the RH chamber during the calibrations caused the probes to experience different RH levels than the chamber reference, introducing large errors in the correction coefficients. In separate testing, it was shown that temperatures measured by the sensors in the RH chamber were warmer than the chamber's temperature set point by up to 1.5°C throughout the calibration run. Since temperature directly affects RH, performing RH calibrations at low temperatures will be abandoned.

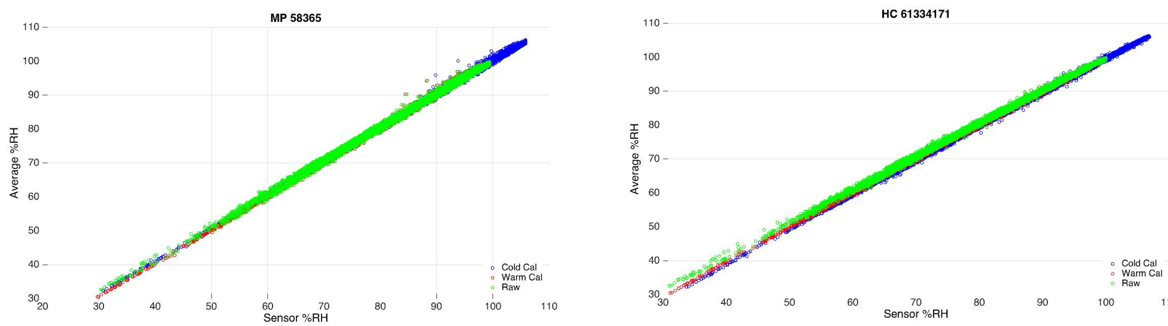

Figure 18 a, b: MP101 58365 (L) & HC 61334171 (R) logged 1/14 – 3/8/16. Plots show Average RH (from all sensors) vs. Sensor RH.

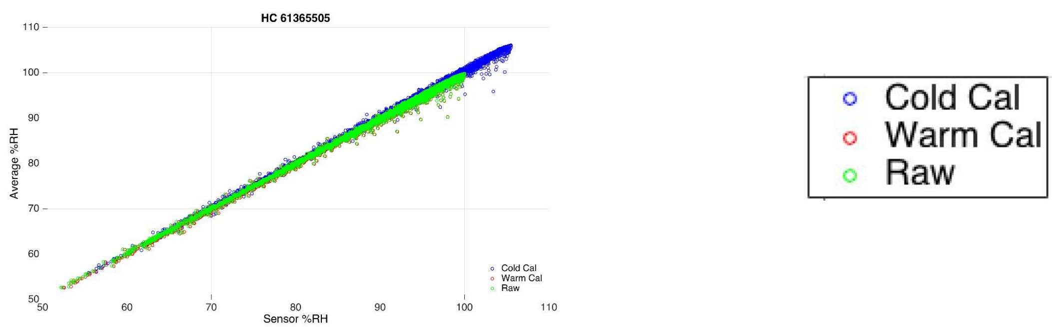

Figure 18 c: HC 61365505 logged 1/14 – 2/12/16. Plot shows Average RH (from all sensors) vs. Sensor RH.

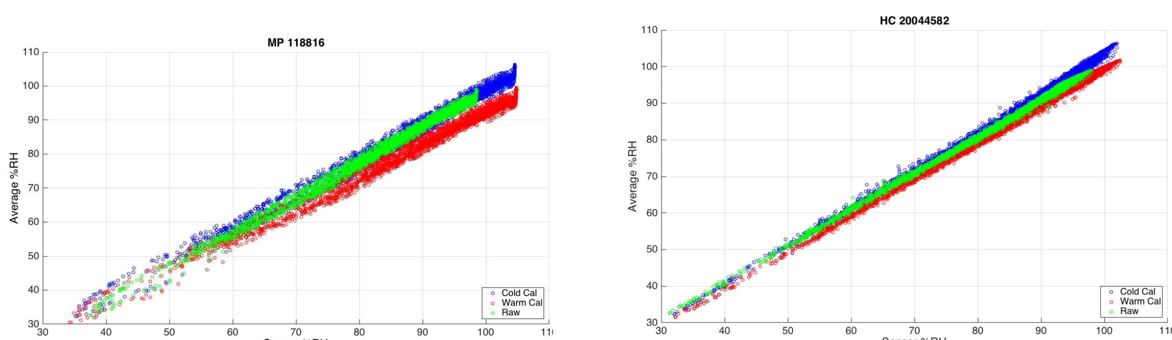

Figure 18 d, e: MP101 118816 (L) & HC 20044582 (R) logged 2/12 – 3/8/16. Plots show Average RH (from all sensors) vs. Sensor RH.

In two cases, shown in Figure 18 d & e, the coefficients from the warm calibration also caused the instrument readings to go over 100% RH. MP101 118816 (Figure 18 d) was deemed to have a bad sensor, even though it fell within PMEL standards of "passing" its RH calibration.

The HygroClip 20044782 (Figure 18 e) that read high with the warm coefficients applied was new, and had never been deployed before this test. Calibrations at 25°C performed on 12/21/15, and 3/29/16 showed that the sensor readings were low at the 95%RH set point, which would cause the applied correction coefficients to push the measured values higher. In the field test, in real conditions over 95%RH, the measured values were over-corrected, to readings over 100%.

This sensor was newer than the other two HygroClips used for this test, coming from a newer generation of sensors from Rotronic. It is possible that this was just a bad sensor, or there may be unknown changes in the newer versions. Care should continue to be taken to fully test HygroClip sensors until the manufacturer has created a stable version.

Updated Conclusions – July 2016

OCS will revert to performing all RH calibrations at 25°C, which is near room temperature in the PMEL calibration room (measured at 24.6°C). It is hoped this will minimize temperature gradients in the RH chamber, which can affect the RH readings and introduce errors into the correction coefficients applied to data in the field.

Through comparisons of multiple instruments, it was also shown that a sensor could be bad, even if it meets the PMEL standards of passing its RH calibration. To try to catch problems like this, close inspection will be made of measurements made by all OCS sensors during standard pre-shipment testing performed at PMEL. Any outliers will be investigated, and sensors replaced if necessary.

References

Lake, B.J., S.M. Noor, H.P. Freitag, M.J. McPhaden (2003): Calibration procedures and instrumental accuracy estimates of ATLAS temperature and relative humidity measurements. *NOAA Tech. Memo. OAR PMEL-123*, Pacific Marine Environmental Laboratory, Seattle, Washington, 23 pp.

Payne, R.E., K. Huang, R.A. Weller, H.P. Freitag, M.F. Cronin, M. J. McPhaden, Y. Kuroda, N. Ushijima, R.M. Reynolds (2002): A comparison of buoy meteorological systems. *UOP Technical Report 02-05*, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 67 pp.

Acknowledgements

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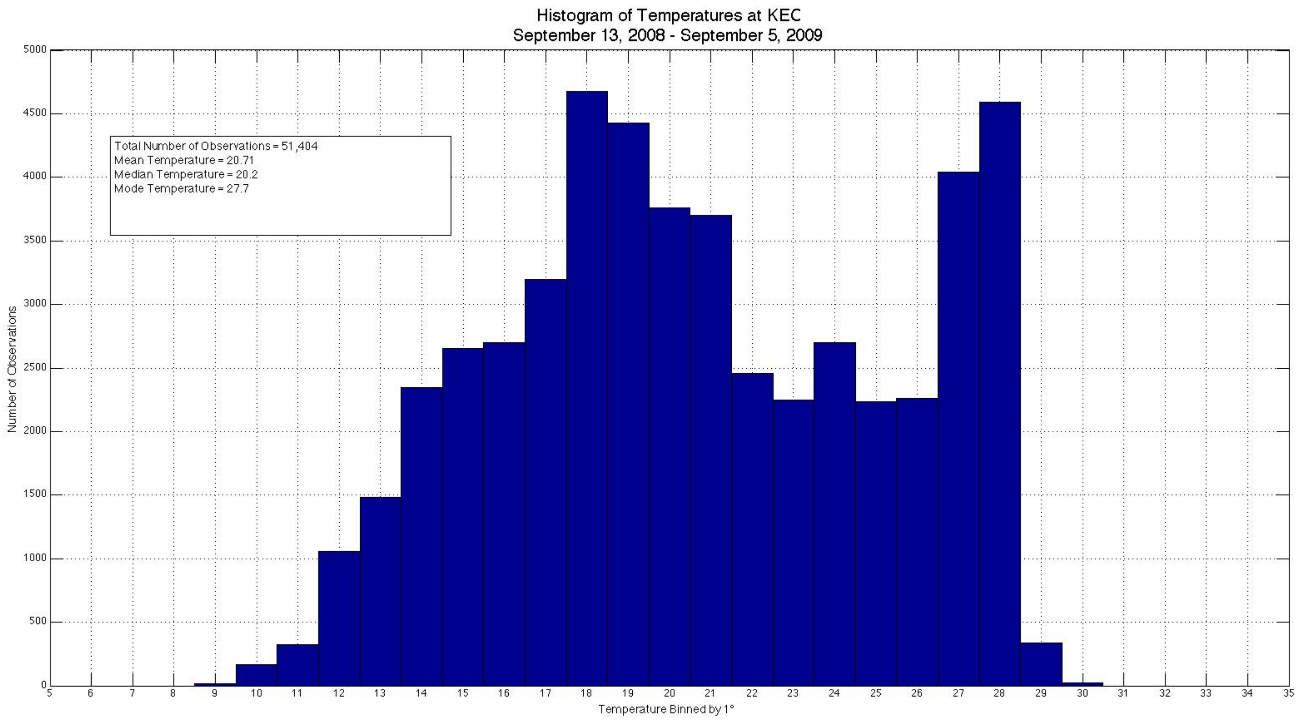
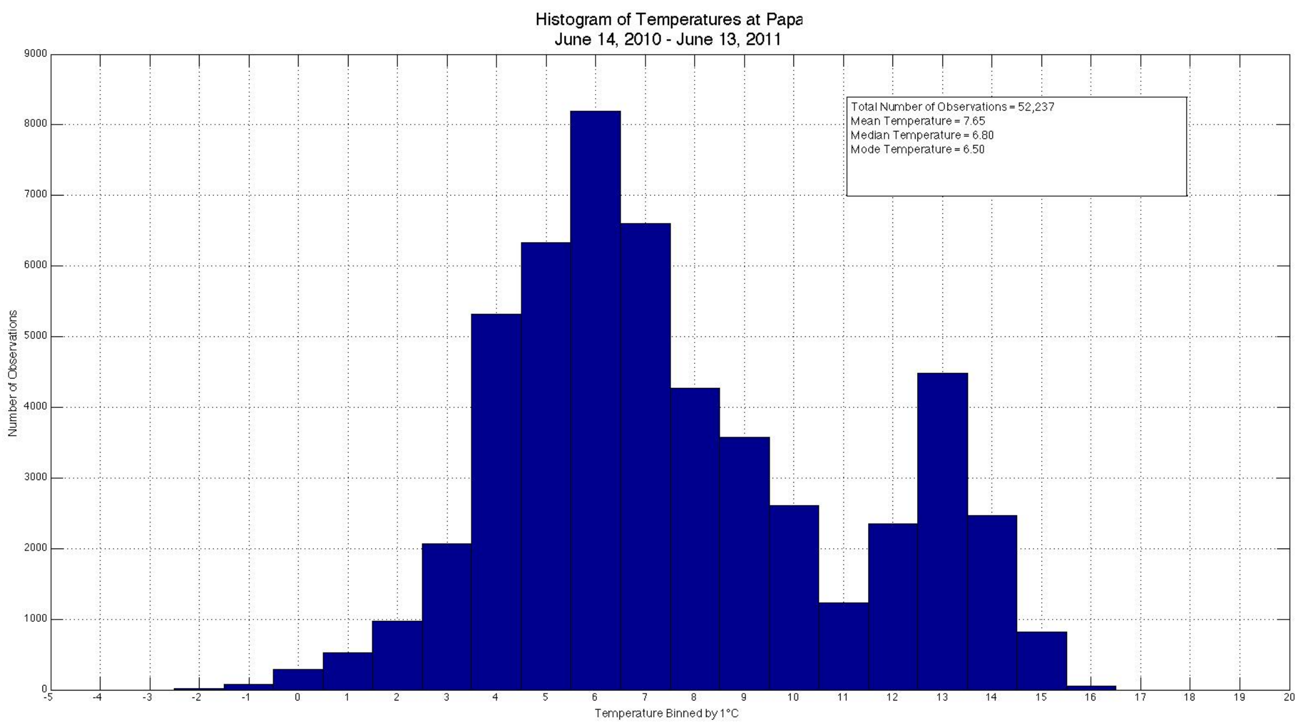
Contributed by: Jennifer Keene, UW JISAO, OCS

Appendix: RH Calibration Temperatures for KEO and Papa Sites





From: Meghan F Cronin <meghan.f.cronin@noaa.gov>
Date: February 21, 2013 3:53:34 PM PST

Please use 7C for Papa RH cals, and 21C for KEO RH cals.
(NOTE: The RH chamber could not routinely achieve and hold 95%RH at 7°C, so the Papa calibration temperature was increased to 10°C.)

UPDATED JULY 2016 – The temperature set point for all RH calibrations will be 25°C, to match the temperature in the calibration room.