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Malcolm Porterfield
Accelerometer Drift Study

Introduction:

Accelerometers are energy transducers that convert mechanical energy into an electrical signal. That electrical signal is proportional to the amount of mechanical stress the accelerometer was subjected to. Knowing this proportionality allows the electrical signal to be interpreted as an acceleration. There are three types of sensing technologies utilized in capacitors: piezoelectric, piezoresistive and capacitive. In this study, all of the accelerometers utilized are of the piezoelectric type and purchased from one particular vendor, MEGGITT. The piezoelectric effect is the phenomena by which a material generates an electrical charge when subjected to a mechanical stress. A piezoelectric accelerometer will not generate an electrical charge when placed in a static acceleration field because no stress will be placed on the piezoelectric element. However if the acceleration field is dynamic, the piezoelectric element will generate an electrical charge. So the types of accelerations these accelerometers are measuring are dynamic in nature, such as vibrations. Knowledge of dynamic acceleration is useful in characterizing the structural response of some object.

The sensitivity of an accelerometer is the ratio of its electrical output to mechanical input. The more sensitive an accelerometer is, the greater the value of the electrical output to a given mechanical input. An accelerometer's sensitivity is known to drift over time. The objective of this study is to quantify this drift. Questions to answer are: does the accelerometer become more or less sensitive over time and by how much. This is important to understand because this will establish a time frame of when readings from the accelerometer can be utilized. The larger this time frame is the better because that would preclude the need to purchase accelerometers frequently, which saves on costs. This would further bolster the relationship between MEGGITT and LANL if it is found that MEGGITT produces accelerometers that can be used for a relatively long period of time. This would create less uncertainty in picking a vendor for accelerometers.

Data Analysis Methodology:

The change in sensitivity of each accelerometer as a function of calibration date will be plotted. The sensitivity values are reported from the calibration certificate furnished by either MEGGITT or LANL. The purpose of this plot is to observe if any accelerometer's sensitivity falls out of a ± 10% uncertainty range over the course of its calibration history.

A plot of the normal distribution of the initial sensitivities of all the accelerometers alongside a normal distribution of the final sensitivities for all the accelerometers will allow for an understanding of how the average sensitivity of the accelerometers change over time. Are the accelerometers becoming more or less sensitive as time passes and what is the relative variance in these sensitivity readings?

A correlation plot between the initial and final calibration sensitivities for each accelerometer will be plotted to understand how a particular accelerometer's sensitivity changes over time. Ideally a perfect correlation will be observed indicating that an accelerometer does not drift from its original sensitivity value over time.

A plot of the percentage sensitivity change as a function of time from the initial calibration for each accelerometer will reveal how much each sensor deviates from its initial measured calibration. The formula used will be:

$$\%\ Change\ in\ Sensitivity = \frac{Initial\ Sensitivity - Subsequent\ Sensitivity}{Initial\ Sensitivity} \times 100\% \qquad (1)$$

The times from the initial calibration will be rounded to the nearest year in order generate enough data to create a normal distribution curve for each year past the initial calibration. That plot will allow for the determination of the number (percentage) of sensors that will deviate by a given percentage from their initial calibration.

The change in sensitivity between calibrations will be plotted as a function of the change in temperature between those same calibrations. This plot will quantify how a change in temperature relates to a change sensitivity. A corresponding plot for relative humidity will also be made. Ideally neither temperature nor humidity will play a part in affecting the sensitivity of the accelerometers.

A normal distribution of the sensitivities measured by MEGGITT versus the sensitivities measured by LANL will be able to reveal if there is some type of systematic bias in the sensitivity measurements depending on which institution does the calibration. The sensitivities measured would ideally be independent of the institution.

Finally, a plot of the percentage change in accelerometer sensitivity as a function of what institutional exchange took place will be presented. In other words, if the accelerometer is passed from LANL to MEGGITT does the sensitivity appear to change by a consistent amount?

Equipment Definitions:

- 50 accelerometers were utilized in this study
- 40 Accelerometers are the MEGGITT 7250AM1-10 model
- 10 Accelerometers are the MEGGITT 7250A-10 model
- The only difference between the 7250AM1-10 model and the 7250A-10 model accelerometers is the 7250AM1-10 model utilized solder pins as output terminals while the 7250A-10 model utilized a 6-40 UNF connector as the output
- Both accelerometer models are of the piezoelectric type using Endevco's Piezite ® Type P-8 Crystal element with integral electronics and are hermetically sealed
- Both Accelerometer models were rated with a sensitivity of 10 mV/g ± 10% (meaning an overall range of sensitivity from 9 mV/g to 11 mV/g)
- Each initial calibration was performed by MEGGIT and the reported sensitivity on each calibration was performed at 100 Hz frequency and a 10 g peak
- The uncertainty of the measured initial sensitivity at 100 Hz frequency was ±1.2% at a confidence level of 95% k=2 (two standard deviations)
- Each of the 50 accelerometers went through various conditions and calibrations (some accelerometers underwent two calibrations while others underwent three, some were utilized in multiple tests while others were left idle for extended periods of time, some accelerometers were only calibrated by MEGGITT while others were calibrated by both MEGGITT and LANL, etc.)

Results and Discussion:

Figure 1a displays the sensitivity of each accelerometer as a function of time. The red dashed lines indicate the ±10% bounds for the acceptable sensitivity for each accelerometer and the black dashed line indicates the intended sensitivity (10 mV/g) for each accelerometer to attain. According to Figure 1a none of the accelerometers have a sensitivity outside of 10% bound. 13 accelerometers have at least one reported sensitivity above 10 mV/g, meaning the majority of accelerometers only have sensitivities below 10 mV/g skewing average accelerometer sensitivity below 10 mV/g. Figure 1b is a snapshot of Figure 1a focused on the accelerometers with sensitivities below 10 mV/g and only two calibration dates. Figure 1c is also a snapshot of Figure 1a but is instead focused on accelerometers with sensitivities below 10 mV/g and *three* calibration dates. The accelerometers in Figure 1b appear to be equal in the amount of accelerometers that drift positively and negatively while the majority of accelerometers in Figure 1c tend to drift positively in calibrations 2 and 3 but calibration 1 could be higher or lower than calibration 3 which determines if the entire trend is concave or convex.

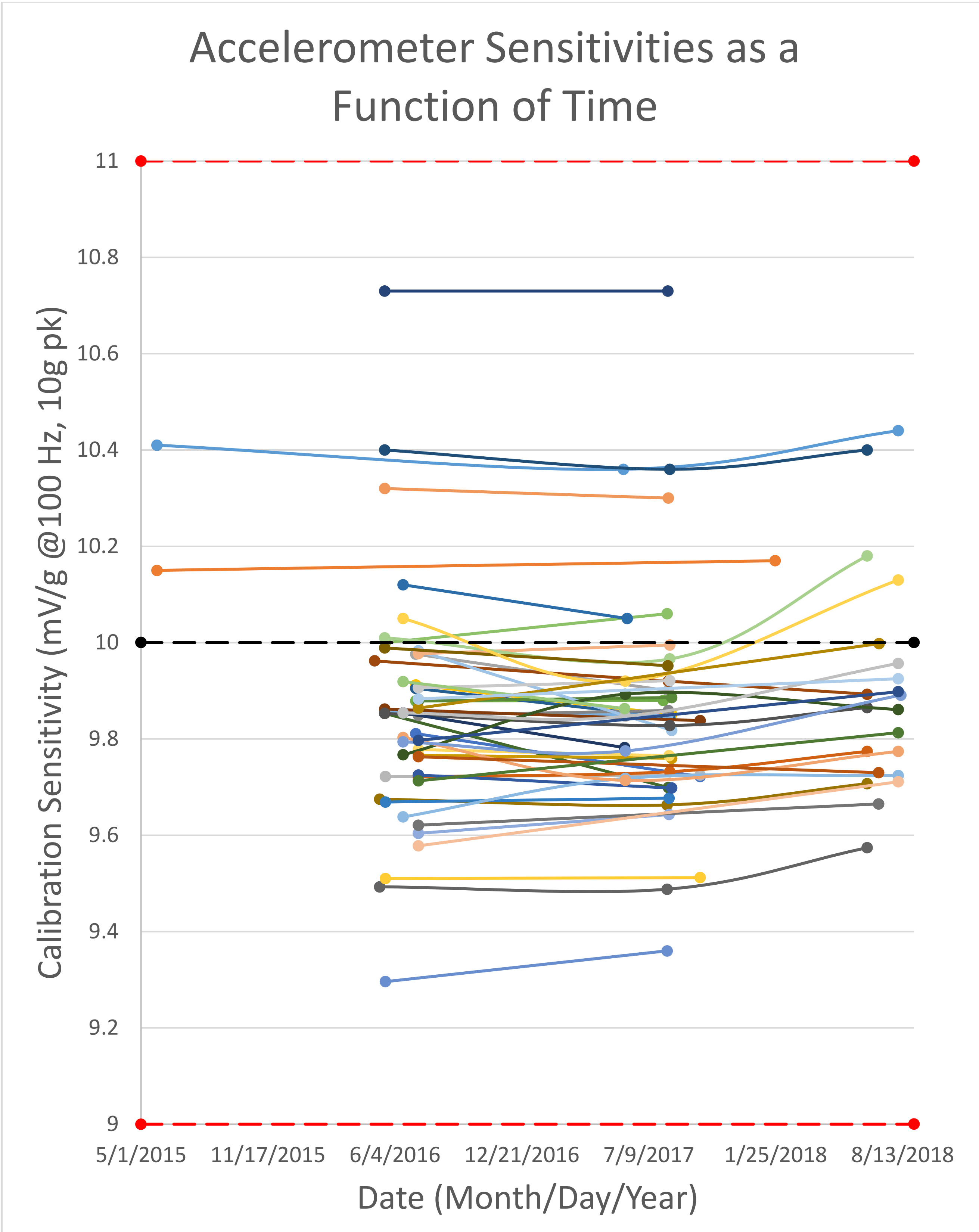

Figure 1a (The variation in the accelerometer's sensitivity as time progresses forward)

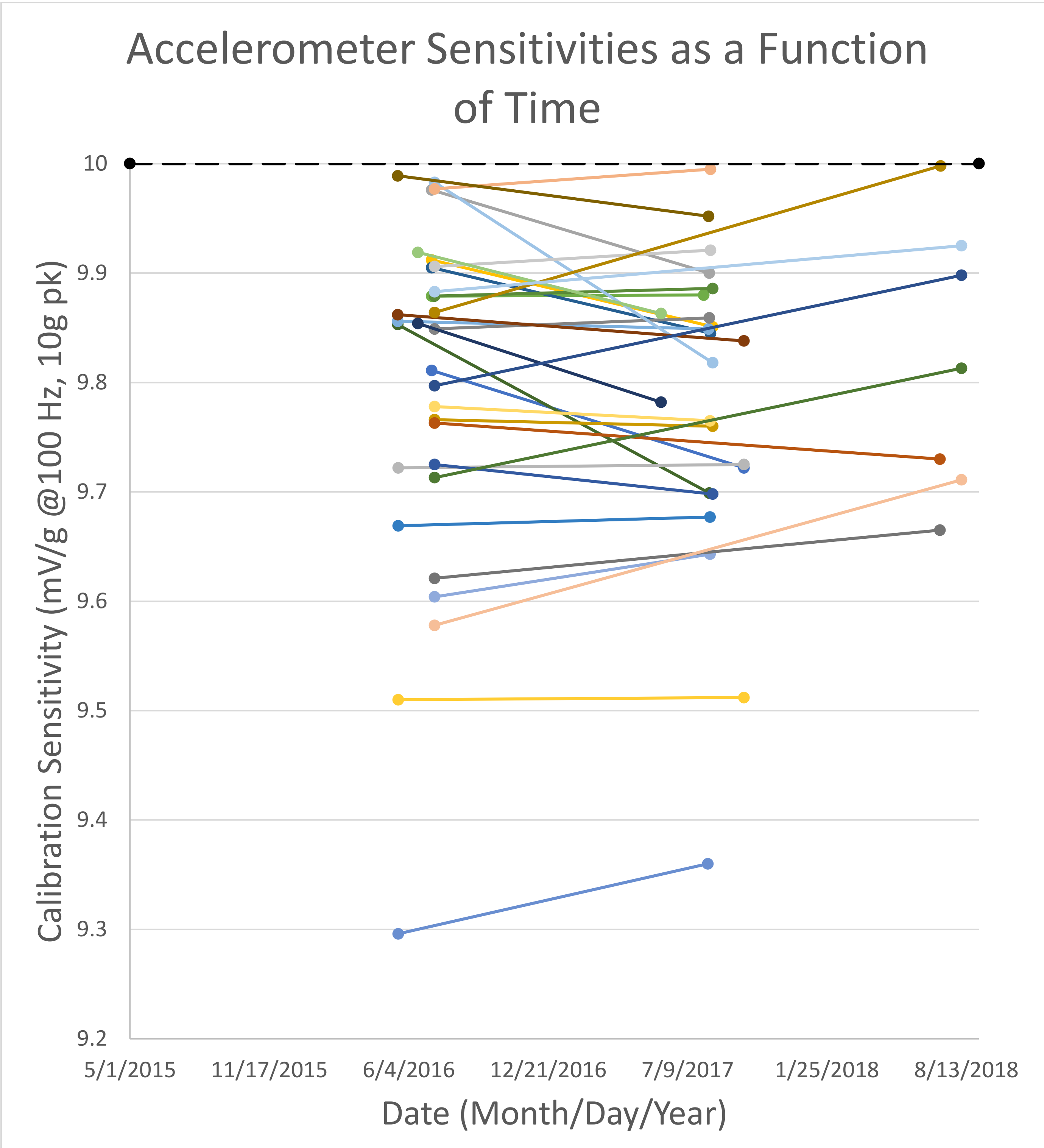

Figure 1b (The variation in the accelerometer's sensitivity as time progresses forward zoomed on two calibration dates)

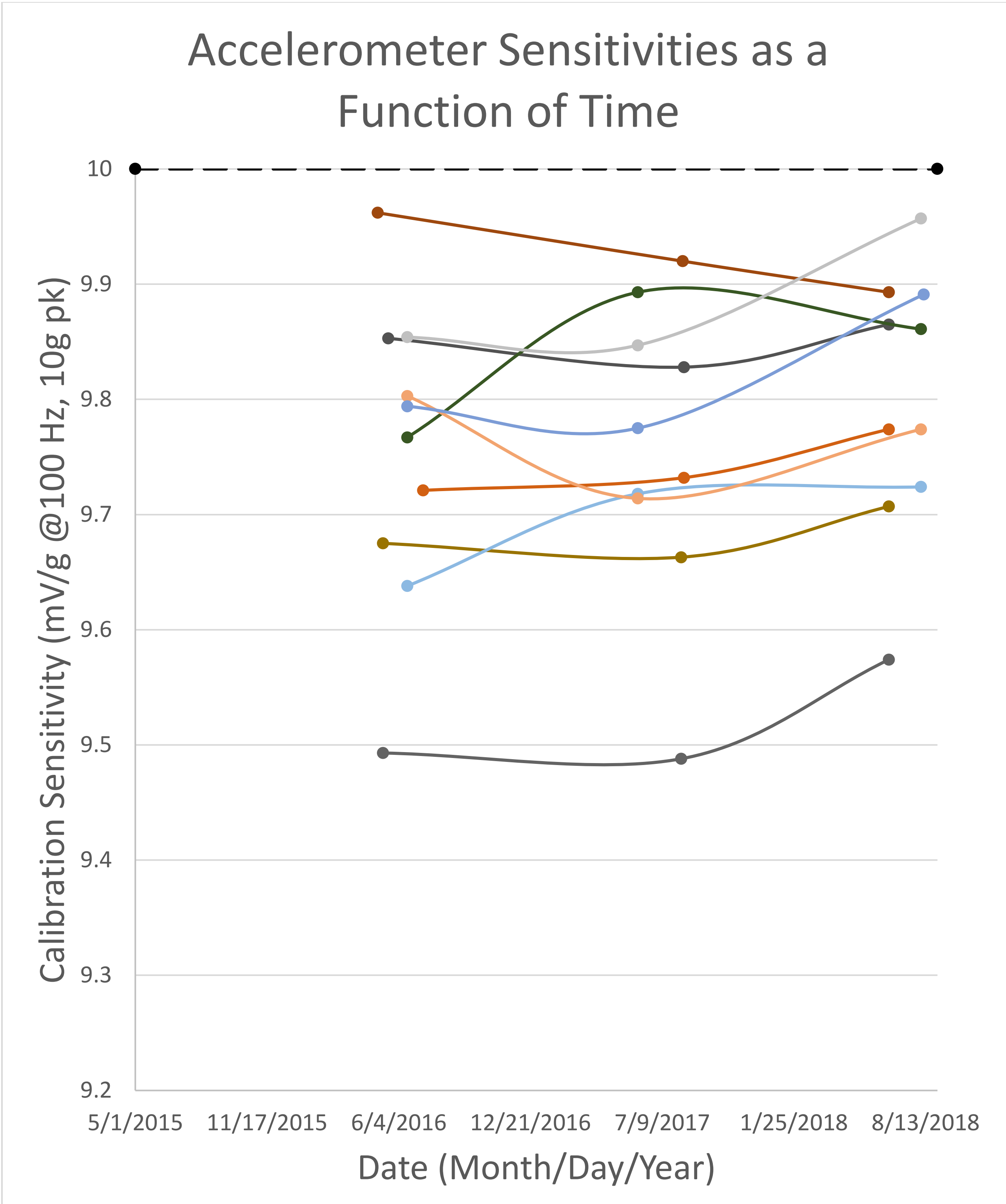

Figure 1c (The variation in the accelerometer's sensitivity as time progresses forward zoomed on three calibration dates)

Figure 2 is the normal distribution curve (taken to three standard deviations) of the sensitivity of all accelerometers at their initial calibration date and final calibration date. The three vertical lines indicate (going from left to right) the lower bound, intended target and upper bound for the sensitivity of the accelerometer respectively. The mean and standard deviation for each distribution is displayed in Table 1. There is a drift in both the mean and standard deviation of sensitivity values as time progresses. Utilizing the initial date as the accepted value there is a 0.1157% drift in sensitivity and a -2.3033% drift in the standard deviation. This would indicate that as time progresses accelerometers increase in sensitivity and have less of a variance in said sensitivity.

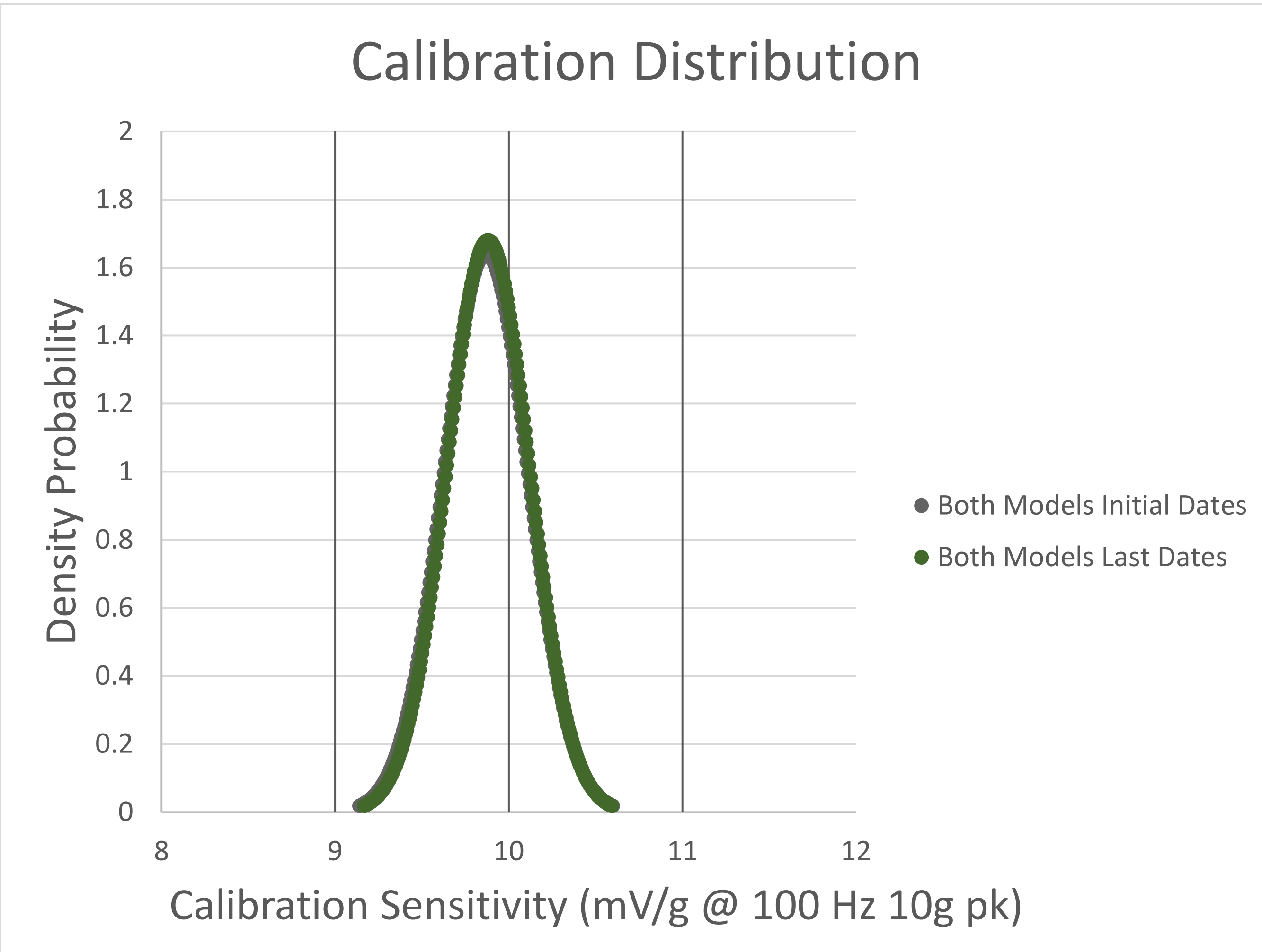

Figure 2a (Initial and final calibration normal distribution for all accelerometers)

Distribution	Mean Sensitivity (mV/g @100 Hz 10g pk)	Standard Deviation (mV/g @ 100 Hz 10g pk)
Both Models Initial Calibration Date	9.86898	0.242980598
Both Models Last Calibration Date	9.8804	0.237384

Table 1 (Mean and standard deviation of initial and last calibrations for all accelerometers)

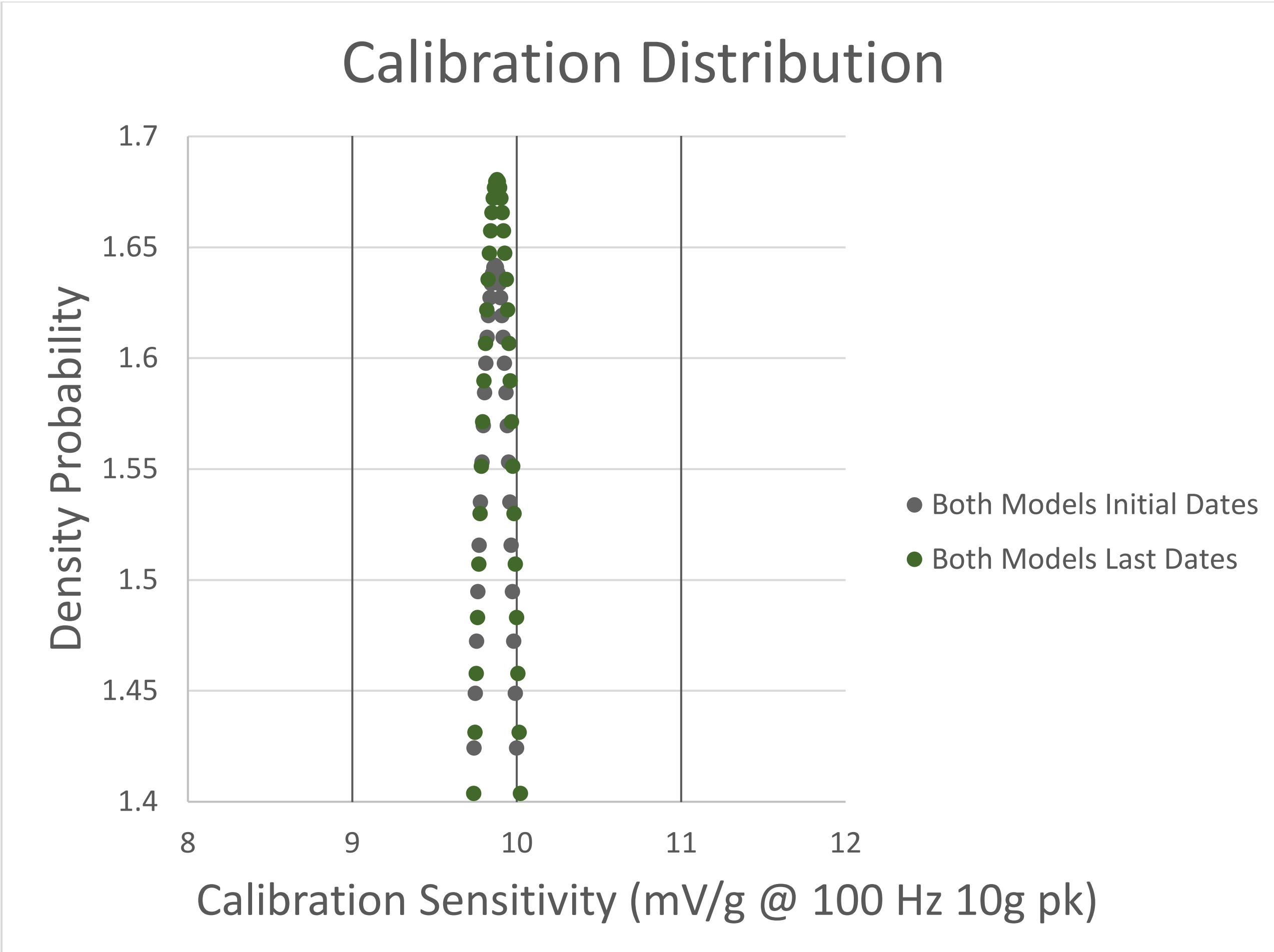

Figure 2a (Initial and final calibration normal distribution for all accelerometers zoomed in)

Figure 3 is a correlation plot between the first and last dates of calibration for each accelerometer. The dotted gray reference line represents a perfect correlation meaning for example, an initial calibration sensitivity of 9.7 mV/g corresponds to a last calibration sensitivity of 9.7mV/g. The dashed black line indicates the +1.2% uncertainty in initial sensitivity calibration and the red dashed line indicates the -1.2% uncertainty in initial sensitivity calibration. How these lines were generated is that for example, from an initial calibration sensitivity of 9.7mV/g the +1.2% uncertainty point is calculated as 9.7 + (0.012 x 9.7) = 9.8164 and the -1.2% uncertainty point is calculated as 9.7 - (0.012 x 9.7) = 9.5836. The general formula is:

$$\pm p_{1.2\%} = X \pm (0.012 \times X) \tag{2}$$

Where X is the point on the perfect correlation plot.

Generally Speaking, most points fall within the uncertainty bound indicating that for each accelerometer, each final calibration sensitivity does not drift greater than 1.2% from the initial calibration reading.

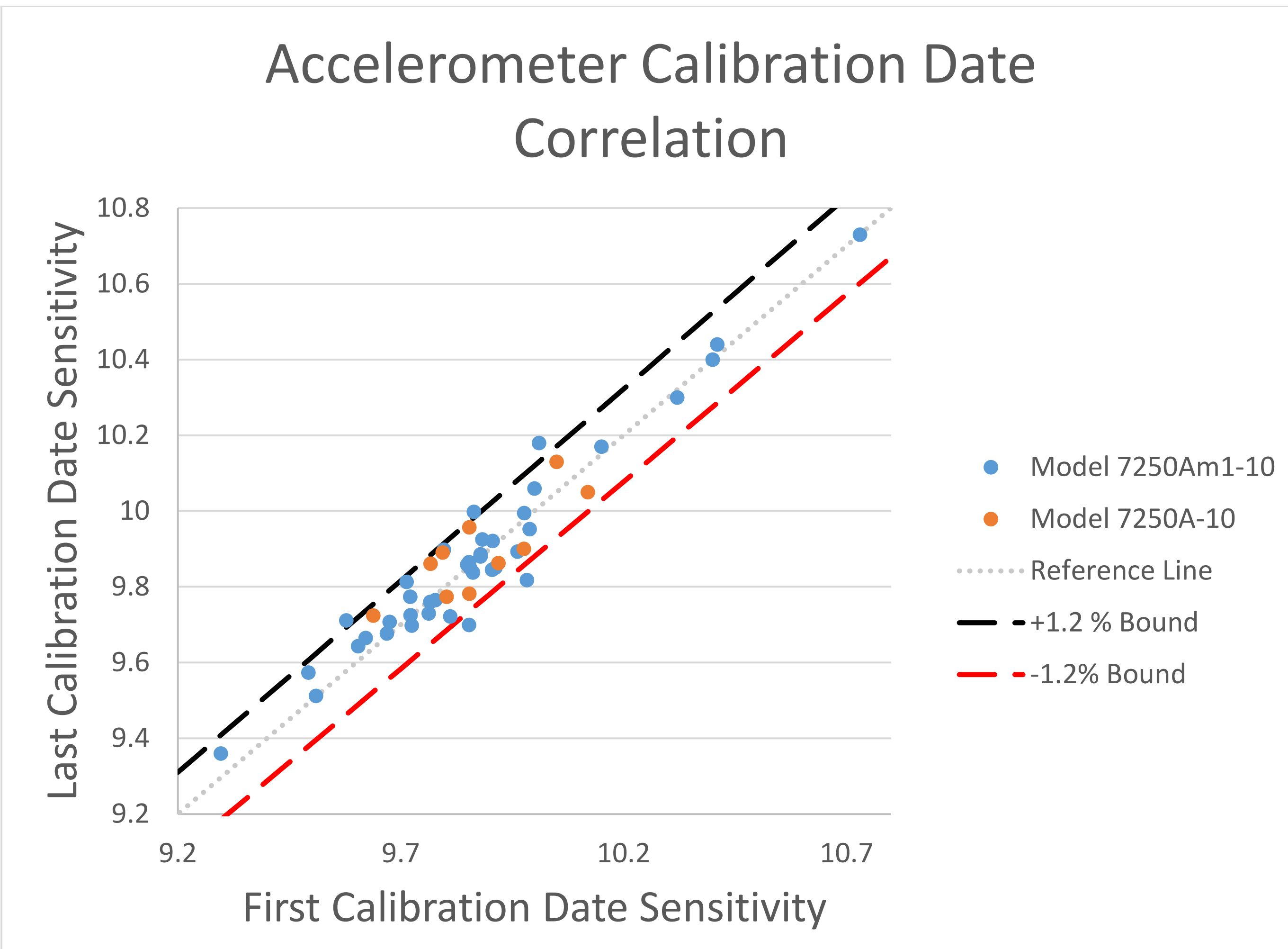

Figure 3 (First and last date calibration correlation)

Figure 4 depicts the percentage change in sensitivity for each accelerometer as a function of time from the initial calibration. The dotted lines indicate ±1.2% deviation from the initial calibration date. Figure 4 shows that the majority of accelerometers do not deviate more than 1.2% from their initial sensitivity (in total 7 accelerometers drifted out of the 1.2% bound in years 1 and 2 combined). For accelerometers that venture out of the ±1.2% bound, at 1 year from initial calibration most accelerometers tend to fail at the lower bound and at two years from initial calibration, all accelerometers fail at the upper bound. Accelerometers that drifted out of the 1.2% bound only did so once, meaning that if an accelerometer was out of the 1.2% bound at 1 year from calibration, it was not also out of bound 2 years from calibration. That indicates a nonlinear trend in the drift in accelerometer sensitivity as time progresses.

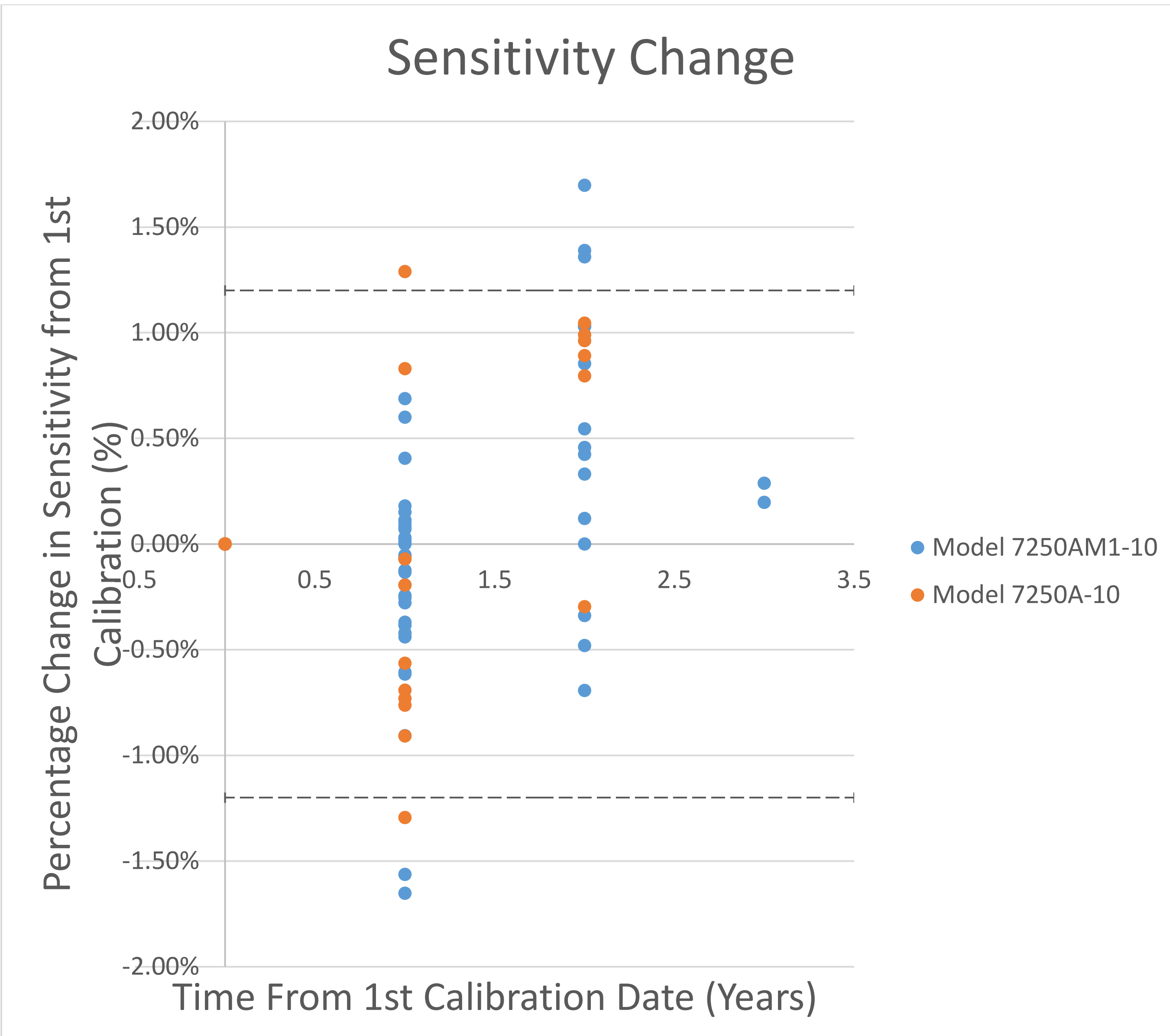

Figure 4 (Accelerometer percentage change as a function of time)

Figure 5 is a normal distribution (taken to two standard deviations) of absolute percentage change in calibration sensitivity from the initial calibration date. The mean and standard deviation are tabulated in table 3. There is a shift from year 1 to year 2 in the average percentage deviation from the initial calibration date of approximately 70% (if we take the year 1 mean as the accepted value). The standard deviation from year 1 to year 2 changes by approximately 1.45%. Thus it is more likely to find an accelerometer outside of the 1.2% bound in year two than in year one, leading to the conclusion that the accelerometers do experience a drift in their sensitivity as time progresses. The 95^{th} percentile for year 1 is approximately 1.2241% and the 95^{th} percentile for year 2 is approximately 1.5415%, this is an approximate 26% change in the location of the 95^{th} percentile from year 1 to year 2.

Assuming a linear trend:

$$95^{th} = 1.2241 + (0.26 \times t) \tag{3}$$

Where t is the time in years from the first subsequent calibration date (i.e. t+1 years from the initial calibration), by year 15, the 95^{th} percentile would be at a value of approximately 4.8641% indicating that after 15 years, 95% of the accelerometers would drift less than 5% from their initial calibration sensitivity. Assuming a linear trend for the variance in standard deviation, that would lead to a bound of:

$$Standard\ Deviation\ (t) = 0.004339293 + (0.0145 \times t) \tag{4}$$

However it was determined from Figure 4 that the percentage change in accelerometer sensitivities was most likely not a linear trend. Given the relatively few amount of data points past two years, a linear trend is all that could be determined with any type of confidence, but given the scarcity of data it is most likely wise to not extrapolate the data beyond two additional years let alone 15.

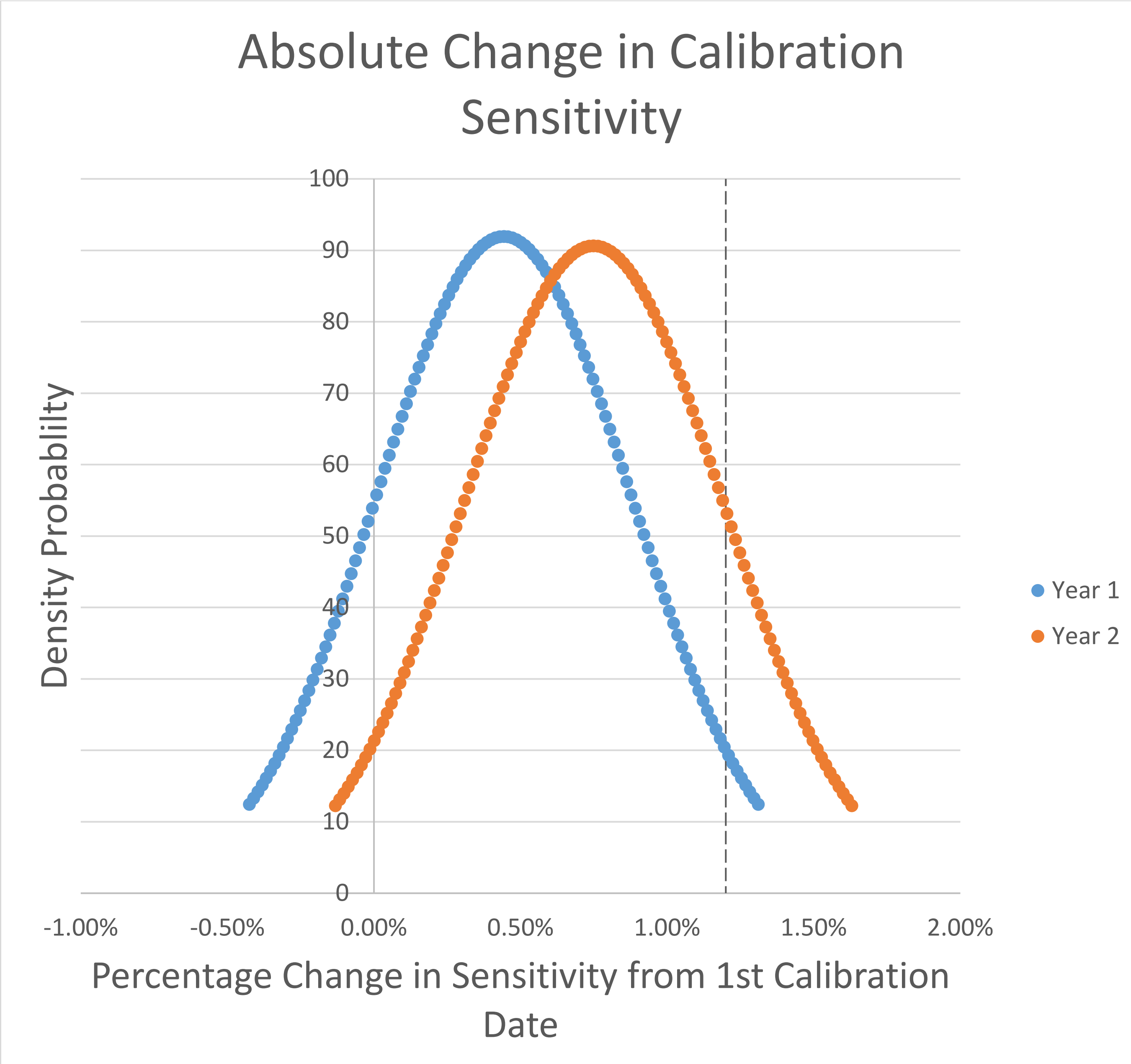

Figure 5 (Normal distribution of accelerometer sensitivity percentage change)

Distribution	Mean Percentage Change (%)	Standard Deviation (%)
Year 1	0.44	0.75
Year 2	0.004339293	0.004402098

Table 2 (Mean and standard deviation in accelerometer percentage change)

Figure 6a depicts the change in sensitivity of each accelerometer as a function of the change in temperature. Generally speaking, it appears that a positive change in temperature corresponds to a positive change in sensitivity and a negative change in temperature corresponds to a negative change in sensitivity. The trend line depicted in Figure 6a is a 6th order polynomial that provides the best fit for the data, a coefficient of determination value of 0.3807. The formula for this trend line is given in equation 5:

$$\Delta Calibration = 0.0008\Delta T^6 + 0.0004\Delta T^5 - 0.0082\Delta T^4 - 0.0077\Delta T^3 + 0.0249\Delta T^2 + 0.0487\Delta T - 0.0017 \quad (5)$$

Figure 6b depicts the change in sensitivity as a function of the change in temperature for each of the accelerometers that fell outside of the ±1.2% bound. Only the points where the accelerometer fell outside of the ±1.2% bound are displayed. There are not enough data points to come to any decisive conclusions however approximately 71% of the accelerometers that fell outside of that bound adhere to the general trend in temperature observed for all of the accelerometers.

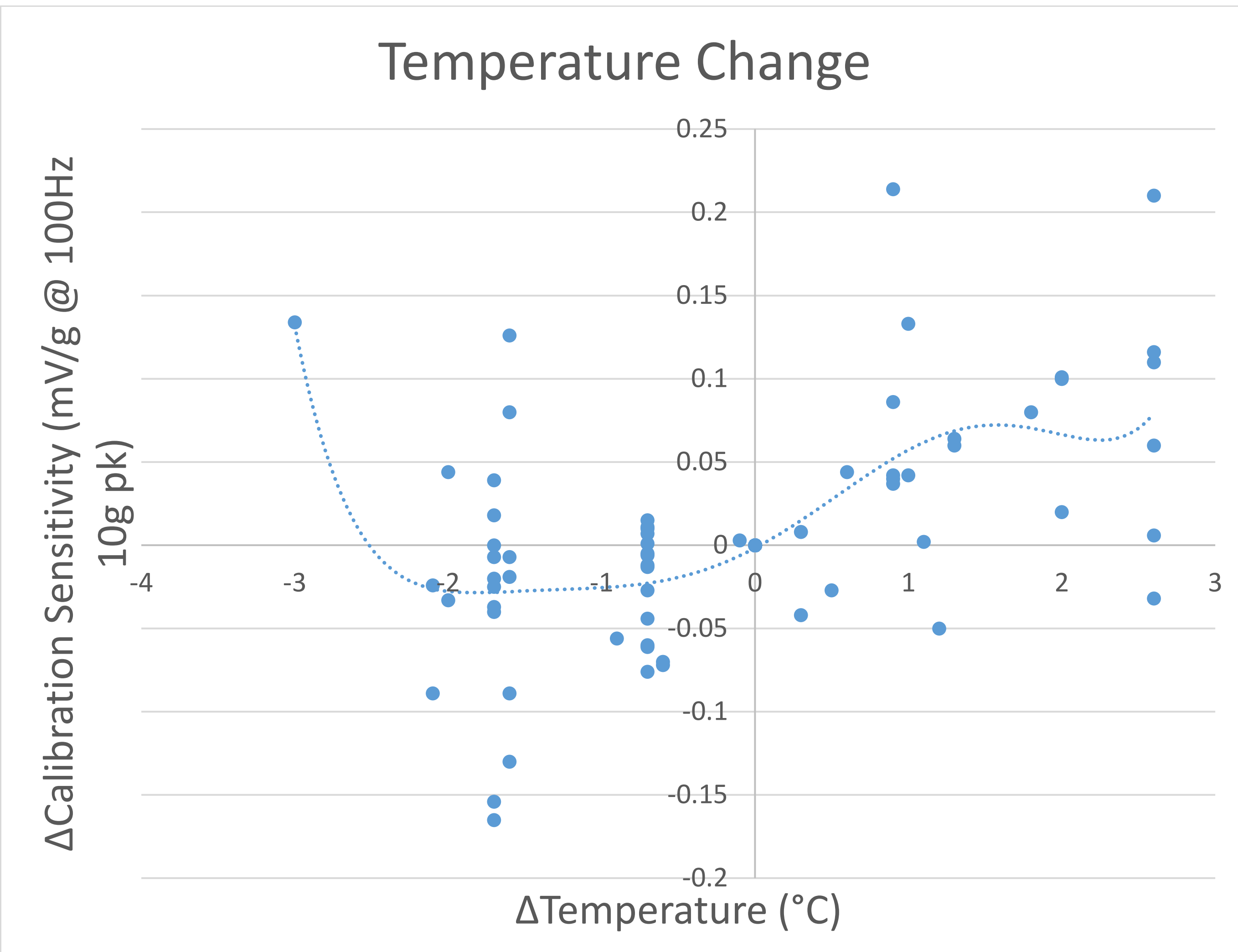

Figure 6a (Change in sensitivity as a function of change in temperature)

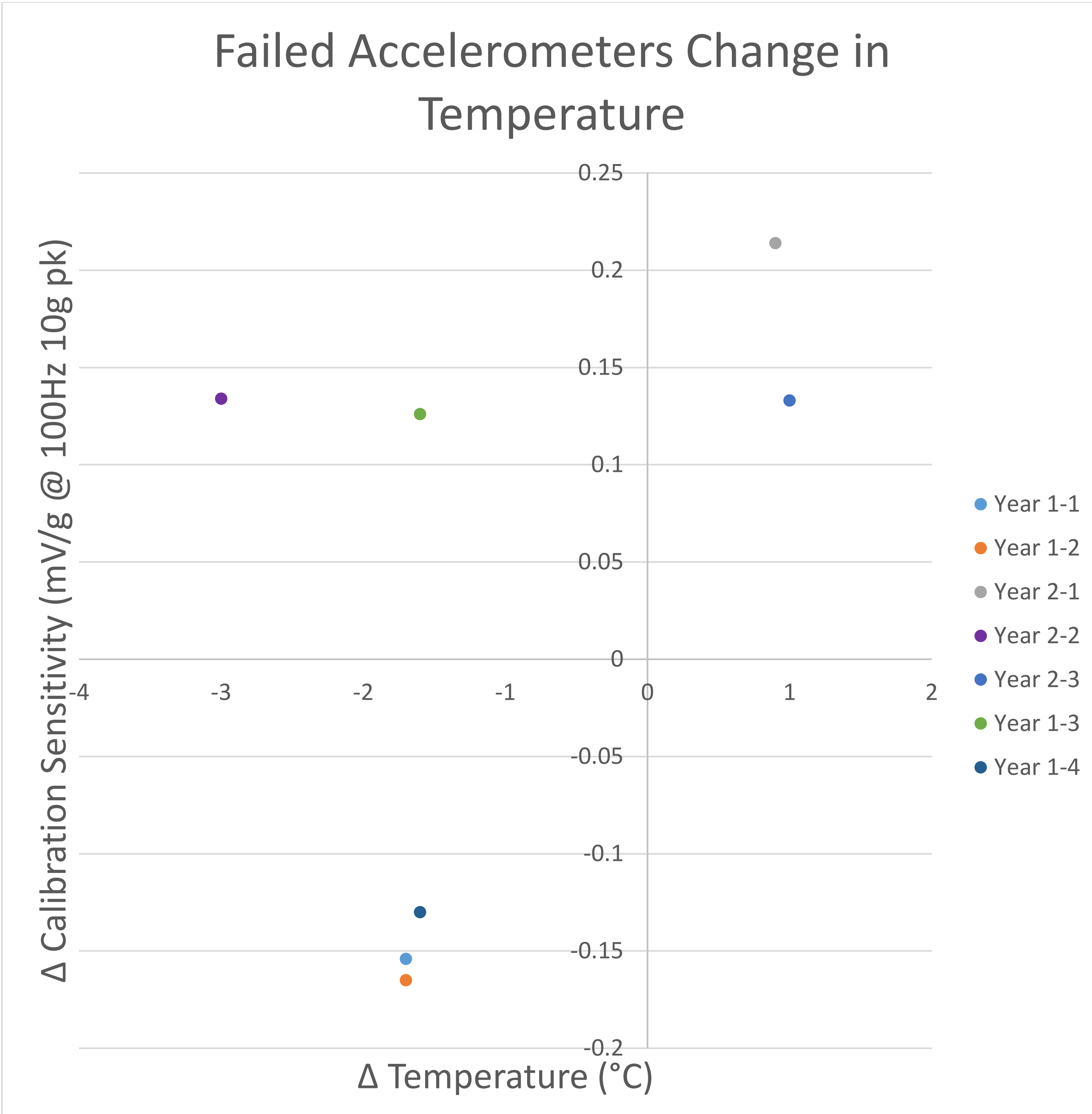

Figure 6b (Change in sensitivity as a function of change in temperature for accelerometers that fell out of the ±1.2% bound)

Figure 7a depicts the change in sensitivity of each accelerometer as a function of the change in relative humidity. As with the changes in temperature, generally speaking a positive change in relative humidity corresponds to a positive change in calibration sensitivity and a negative change in relative humidity corresponds to a negative change in calibration sensitivity. A 6th order polynomial is also used to fit the data in Figure 7a though the coefficient of determination in this case is 0.2636. The equation for this polynomial is given by equation 6:

$$\Delta Calibration = 2\times10^{-10}\Delta RH^6 + 7\times10^{-9}\Delta RH^5 - 6\times10^{-7}\Delta RH^4 - 1\times10^{-5}\Delta RH^3 + 0.0003\Delta RH^2 + 0.0053\Delta RH - 0.0036 \quad (6)$$

Figure 7b depicts the change in sensitivity as a function of the change in relative humidity for each of the accelerometers that fell outside of the ±1.2% bound. Only the points where the accelerometer fell outside of the ±1.2% bound are displayed. Again approximately 71% of the accelerometers that fell outside of that bound adhere to the general trend in relative humidity observed for all of the accelerometers.

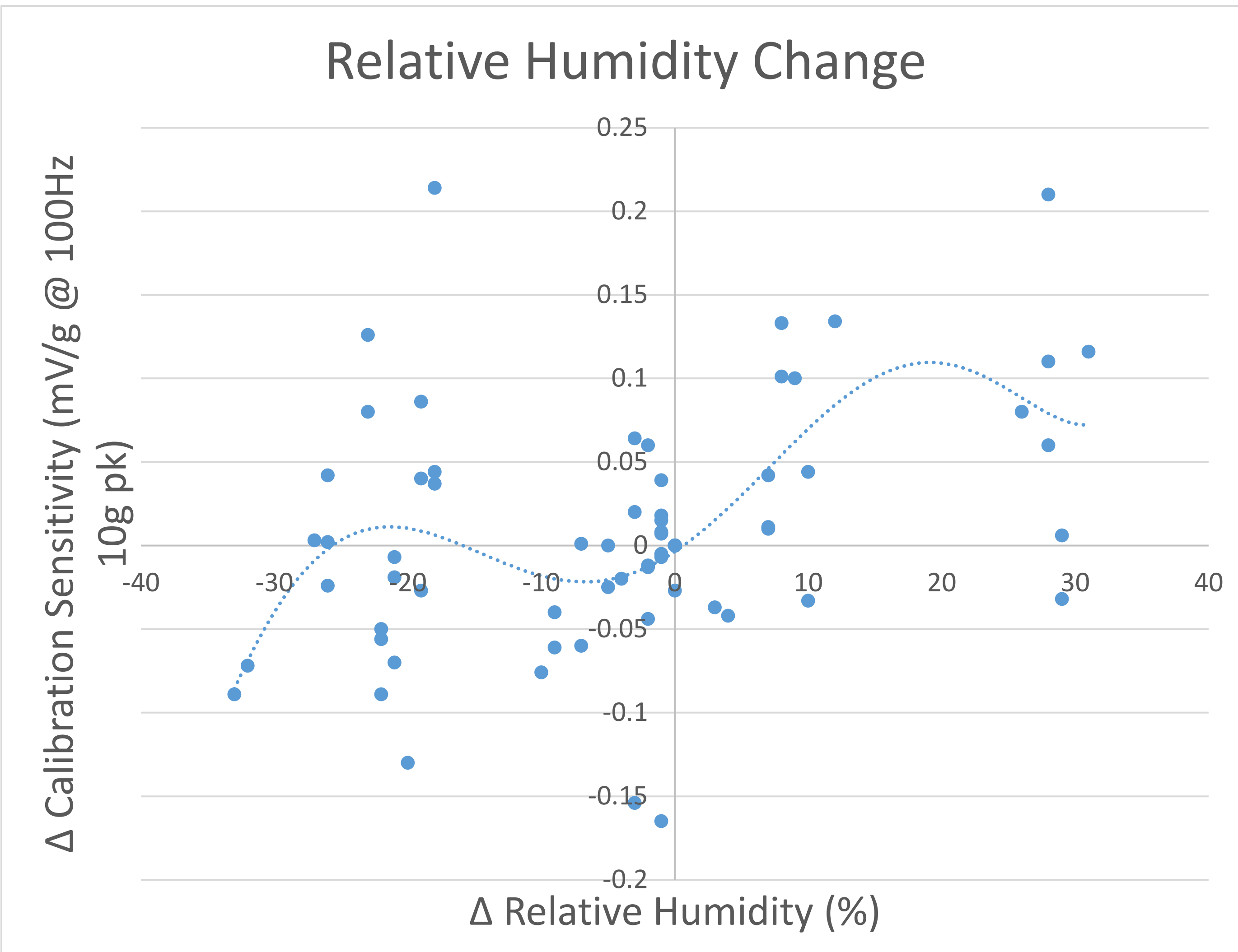

Figure 7a (Change in sensitivity as a function of change in relative humidity)

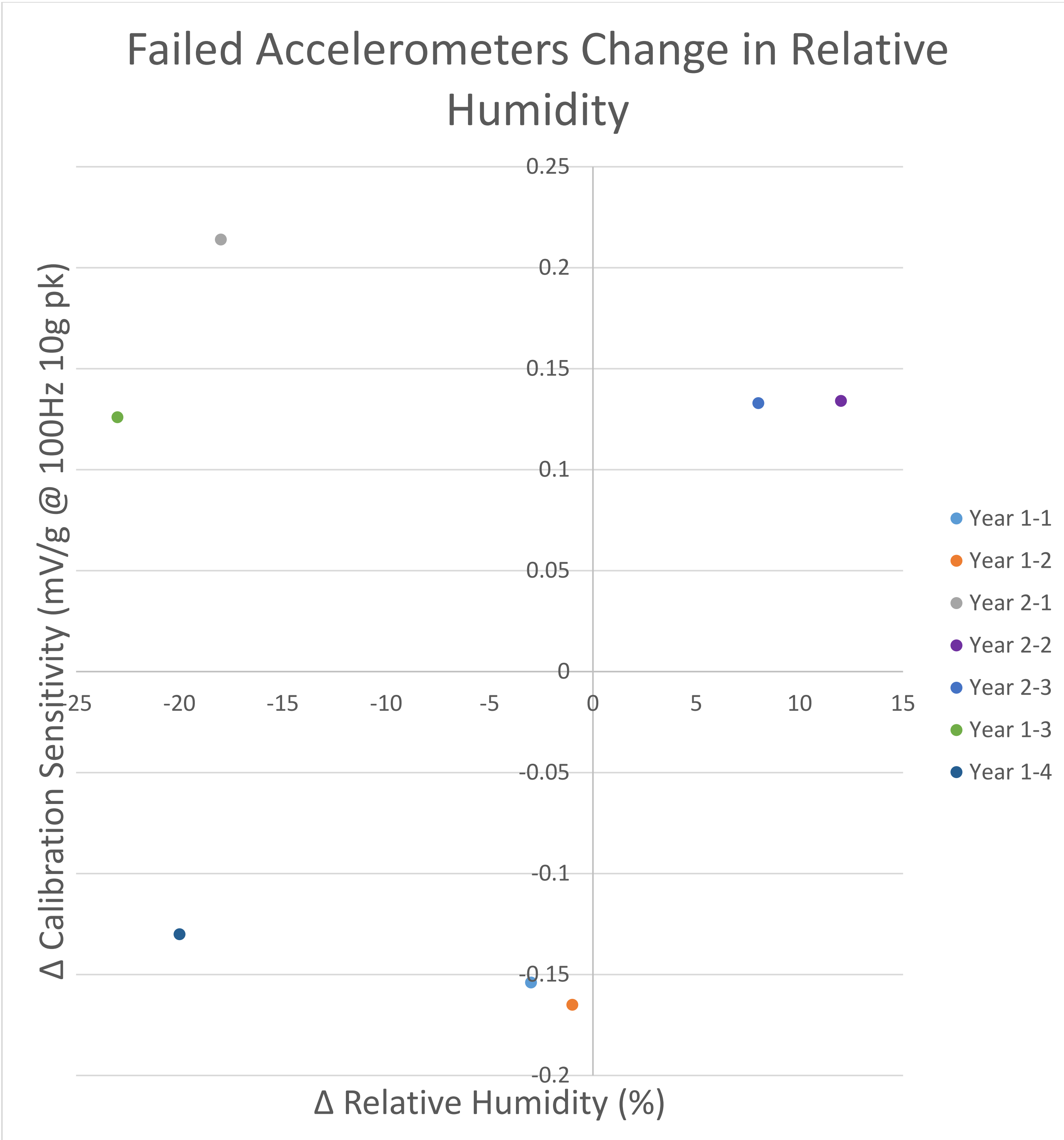

Figure 7b (Change in sensitivity as a function of change in relative humidity for accelerometers that fell out of the 1.2% bound)

Figure 8 depicts a normal distribution (taken to three standard deviations) of the sensitivity of each accelerometer depending on the institution that performed the calibration (MEEGGITT of LANL). The variance in mean sensitivity (using MEGGITT as the accepted value) is approximately 0.108% and the variance in standard deviation is approximately 2.88%. MEGGITT calibrations appear to report higher sensitivities and lower spreads than LANL calibrations.

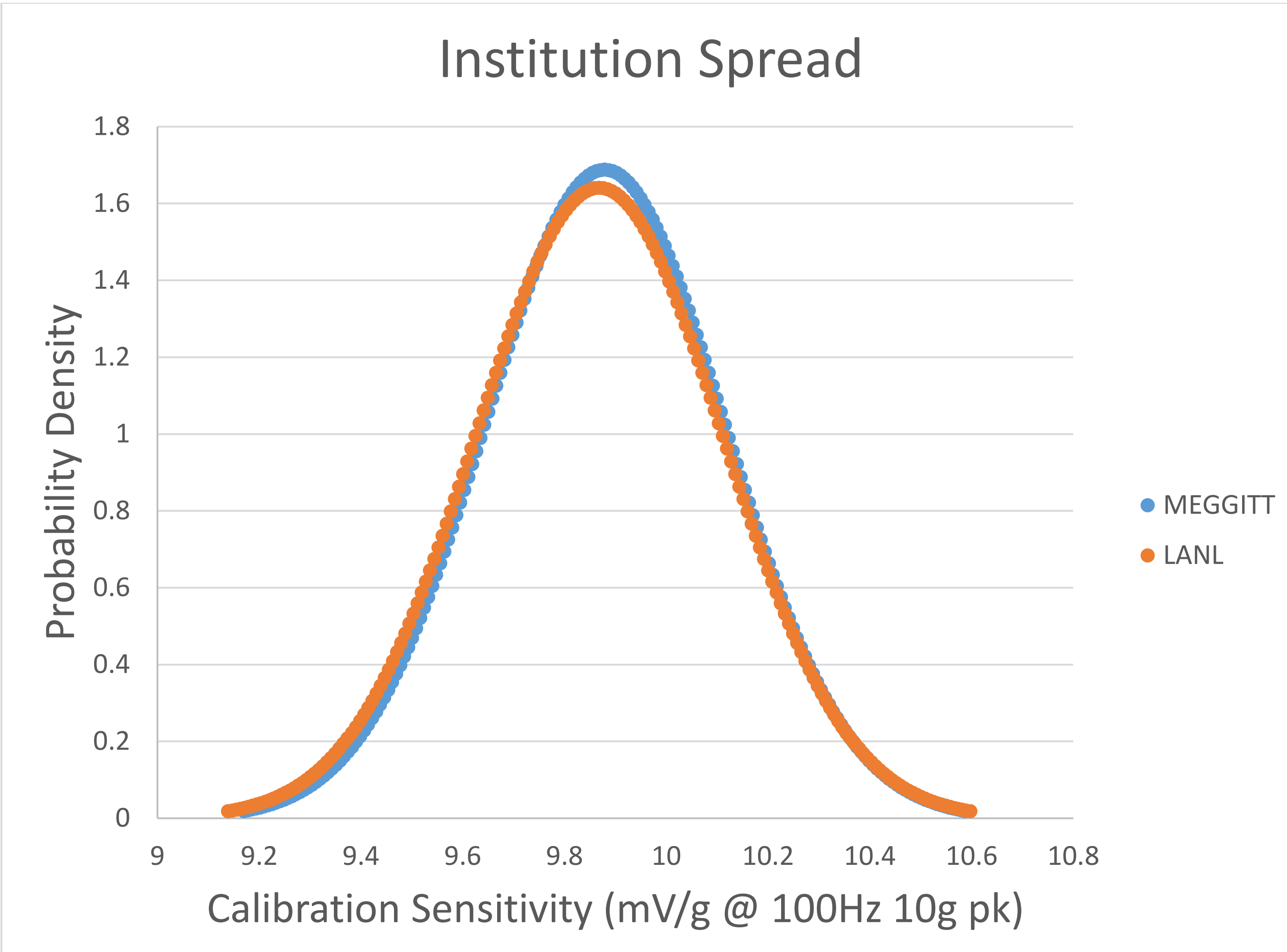

Figure 8 (Normal distribution of accelerometer sensitivities based on institution)

Distribution	Mean Sensitivity (mV/g @100 Hz 10g pk)	Standard Deviation (mV/g @ 100 Hz 10g pk)
MEGGITT Calibration	9.878828	0.236342
LANL Calibration	9.86816	0.243149

Table 3 (Mean and standard deviation in accelerometer sensitivity based on institution)

Figure 9a depicts the percentage change in absolute sensitivity from the initial calibration date as a function of the exchange between which institute handled the accelerometer (MEGGITT always performed the first calibration). For example, after the initial calibration of a given accelerometer, if LANL completed the second calibration that is an exchange from MEGGITT to LANL. If LANL also handled the third calibration that is an exchange from LANL to LANL. Figure 9b depicts the whole tree of calibration exchanges for particular accelerometers. Interestingly enough, there were only four exchange patters observed. 36 accelerometers only under two calibrations with 29 accelerometers being exchanged from MEGGITT to LANL and the remaining 7 being exchanged from MEGGITT to MEGGIT. Of the 3 calibration accelerometers, when the last two exchanges took place from LANL to MEGGITT there was a trend of decreasing percentage change while when the last two exchanges took place from LANL to LANL there was trend of increasing percentage change. Of the 7 accelerometers that fell out of the ±1.2% bound, 5 of them were calibrated by LANL.

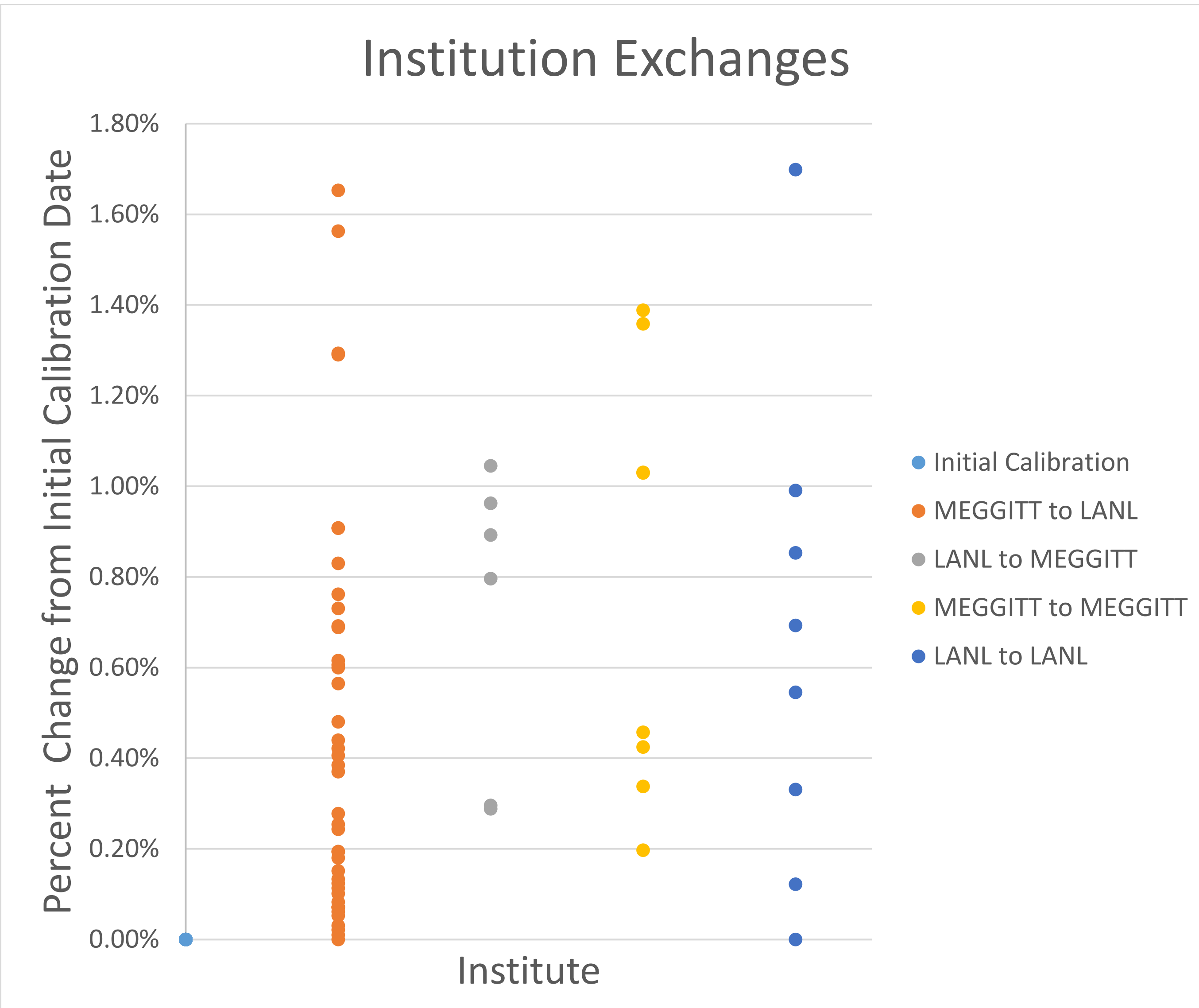

Figure 9a (Percentage change as a function of institution calibration)

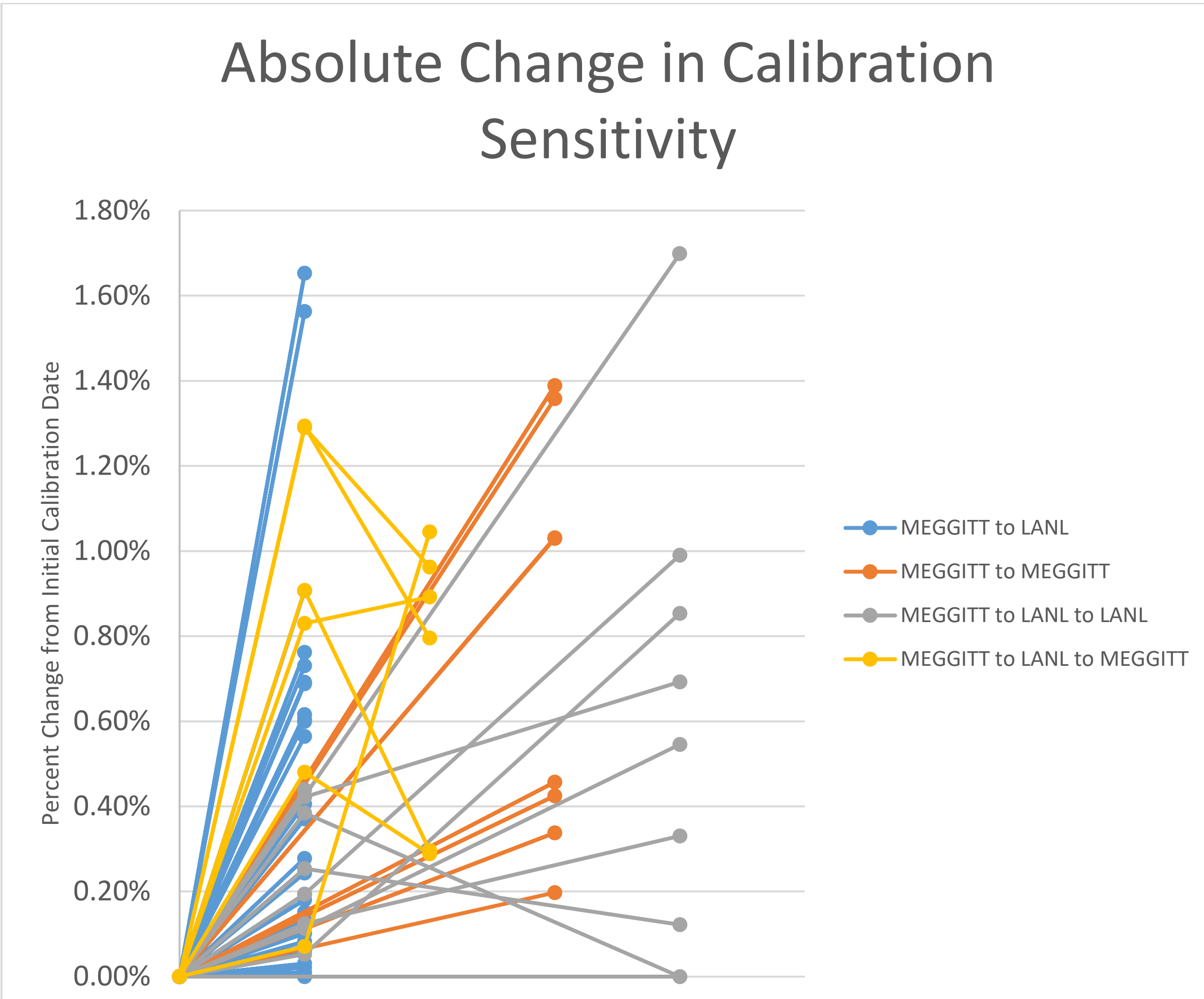

Figure 9b (Percentage change as a function of institution calibration per sensor)

Conclusions:

50 accelerometers were examined in this study. The drift in their sensitives were measured as functions of time, temperature, relative humidity and institution performing the calibration.

Time:
Accelerometers experience a drift in their sensitivity as time progresses. The sensitivity appears to increase as time progresses according to Figures 2a and 2b. There is not enough evidence to conclude what type of drift the accelerometers experience (linear, exponential, polynomial, etc.). Within two years from the initial calibration most accelerometers do not drift more than 1.2% from their initial sensitivity reading. All accelerometers studied stay within the 10% bound for nominal sensitivity.

Temperature and Relative Humidity:
Both changes in Temperature and changes Relative humidity appear to be positively correlated with changes in sensitivity. The correlation between sensitivity and temperature appears stronger than the correlation between sensitivity and relative humidity.

Institution:
The variance in sensitivity readings between institutions does not appear to be significant, however a majority of the sensors that left the 1.2% bound were measured by LANL.

To improve this study and be more confident about the behavior of accelerometers, utilizing more accelerometers would be beneficial however if more calibrations were done on these accelerometers over a longer period of time, that would really allow for a better prediction of the performance of these accelerometers over time. If it is possible to control temperature and relative humidity when calibrating these accelerometers, it would go a long way in determining how these parameters directly influence the sensitivity of the accelerometer (which one is more dominant or are both of them equal partners). The inclusion of a third party in the calibration of these accelerometers would help to eliminate any conflicts of interest that may exist between MEGGITT and LANL.

Overall from this study, one can be confident in the readings these accelerometers provide for two years from the initial calibration. Any further extrapolation would be prone to large error because it is unknown how accelerometer sensitivity trends with time.