Investigating Inaccurate Pressure Data from the UNR Weather Station

Abstract

This paper examines measurements from the Vaisalla PTB101B pressure sensor over the month of March, 2015. Data taken from this type of sensor was analyzed from three separate northern Nevada weather stations. These stations are located at Slide Mountain (SM); the University of Nevada, Reno (UNR); and the Reno Desert Research Institute (DRI). The UNR station was scrutinized under the pretense that it was not recording accurate measurements. The consequences of extrapolating further atmospheric quantities from the inaccurate data was demonstrated. Specifically, it was found that the mean virtual temperature for the layer of atmosphere between the UNR and DRI weather stations had unusual fluctuations compared to other layers. Furthermore, these values were abnormally large, with spikes as high as 2,445 Kelvin. Although analysis of the data indicates that there is an issue, it is not a viable means to diagnose the actual source of the problem; however, several causes of error are still outlined.

I. Introduction

Barometric pressure is a fundamental measurement for qualitatively and quantitatively describing the atmosphere. For this study, the pressure data from three separate sites in the Reno-Tahoe area of Nevada were examined. This data comes from weather stations located at Slide Mountain (SM); the University of Nevada, Reno (UNR); and the Reno Desert Research Institute (DRI). There are several methods for measuring pressure. Barometric instruments may utilize a resistor configuration known as a Wheatstone Bridge, or employ some of the properties of certain semiconductors [5]. Regardless of the method, these devices take advantage of what is known as the piezoresistive effect. This is the name given to the observed phenomenon of when a material's electrical resistance changes due to a mechanical stress/strain applied to it. The stations mentioned above contain a Vaisalla PTB101B pressure sensor. The manual for this sensor states that it uses the "BAROCAP® silicon capacitive absolute pressure sensor", meaning that silicon is the material to be considered in the pressure circuit [5]. Silicone is a semiconductor, meaning that electrons in its valence band are a relatively small energy level away from its conduction band, as shown in ***Figure 1***. Electrons that are "stuck" in the valence band resist the flow of other electrons, causing the material to

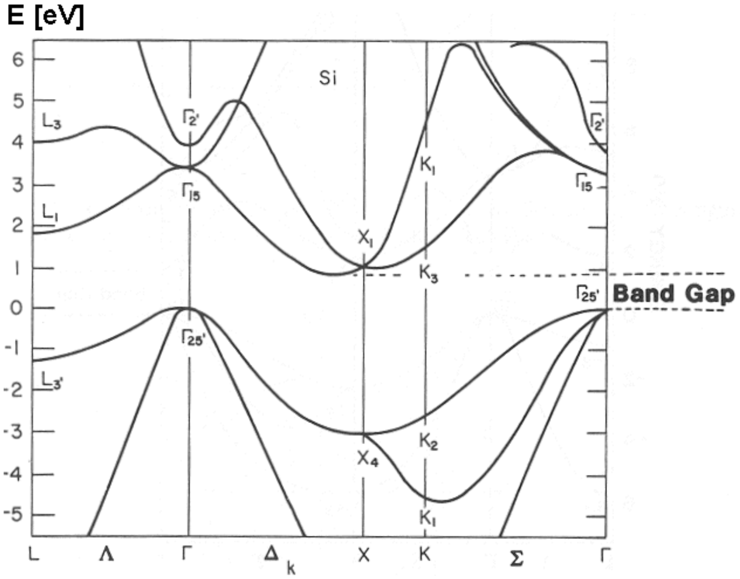

Figure 1: The band structure of Silicon [9]

behave like an insulator. However, electrons that have been excited to the conduction band leave holes through which an electric current can flow, and the material becomes a conductor.

There are two ways to get electrons to “jump” the gap. The first is to make the gap much smaller. For a crystal, this is achieved by a deformation of the lattice structure in such a way that the reciprocal lattice changes the overall potential energy of the electrons. Using this potential in Schrodinger’s equation will change the allowable energies of each electron accordingly [1]. Thus, the band gap can increase or decrease based on the deformation. Even with a reduced band gap, electrons still need energy to transition to higher states. The number of available energy levels that an electron can fill is given by the Fermi-Dirac distribution [4]:

$$f(E) = \frac{1}{\exp\left[\frac{E - E_F}{kT}\right] + 1} \tag{1}$$

The important thing to note about ***Equation (1)***, is the function’s dependence on temperature ***T***. This shows that as temperature increases, the probability that an electron will be found at a given energy level also increases. So the second way to excite electrons across the gap is to simply heat up the material. This introduces a temperature dependence, which will be revisited later on. The resistive load (determined by the semiconductor) in the pressure circuit ultimately effects its output voltage. It is from this voltage that calculations are performed to extrapolate the magnitude of the barometric pressure.

Once pressure measurements are collected, the data can be used to calculate other quantities pertaining to the atmosphere. This stresses the importance of having accurate data, as incorrect values will yield a different description of the atmosphere than what may actually be occurring. One such calculation that can be performed is the virtual temperature of a layer of atmosphere. Air is actually composed of many gases. Through the ideal gas law, one can extrapolate the density of given volume of air at a certain temperature. If water vapor is introduced into the system, then the density of the same volume of air at the same temperature will change. To make the densities equal again, the temperature of the dry air parcel can be raised. The raised temperature at which the densities are equal again is the virtual temperature [2]. The average of this value over a specified layer of atmosphere is formulated as:

$$< T_V >= \frac{g}{R_D} \cdot \frac{z_2 - z_1}{\ln{(P_1/P_2)}} \tag{2}$$

Where, g = 9.81 m/s, R_D = 287 J/Kg/K, z_i are the different altitudes given in meters, with corresponding pressures of P_i given in mbar. The air in Northern Nevada region is dry, especially in the winter months. Because of these conditions, the mean virtual temperature only provides a small correction to the average temperature of a given layer of atmosphere. For this reason, the average temperature of a layer can be used to estimate how reasonable a result from ***Equation (2)*** is. This is an important point, and is discussed in the measurements section below.

It is also important to mention that atmospheric pressure undergoes tidal shifts. It oscillates about a certain value with a period on the scale of a solar or lunar day. The source of these tides comes from heating of the air by the sun. The sun is only up for half the day, and so the solar semidiurnal tide is given by:

$$S_2(P) = 1.16 \cdot \sin^3(\theta) \cdot \sin(4\pi t + 158°)\ mbar + Negligible\ Term\ mbar \qquad (3)$$

Where, ***t*** is the time of day and ***θ*** is the colatitude of the location. The total tidal pressure is then then:

$$P_{Tidal} =< P_{Calculated} > +S_2(P) \qquad (4)$$

The importance of this calculation is to show the periodicity, and amplitude at which pressure can fluctuate throughout the day due to these tidal forces [3].

One also has the ability to forgo a direct pressure measurement at a given site by utilizing the following formula:

$$P_1 = P_2 \cdot \exp\left[\frac{2g}{R_D} \cdot \frac{z_2 - z_1}{T_1 + T_2}\right] \qquad (5)$$

Where, ***g*** = 9.81 m/s, $\boldsymbol{R_D}$ = 287 J/Kg/K, $\boldsymbol{z_i}$ are the different altitudes given in meters, with corresponding temperatures of $\boldsymbol{T_i}$ given in Kelvin.

II. Measurements

Data was collected from the SM, UNR, and DRI weather stations for the month of March, 2015. The barometric pressure at each site was plotted for the entire month in ***Figure 2*** shown below.

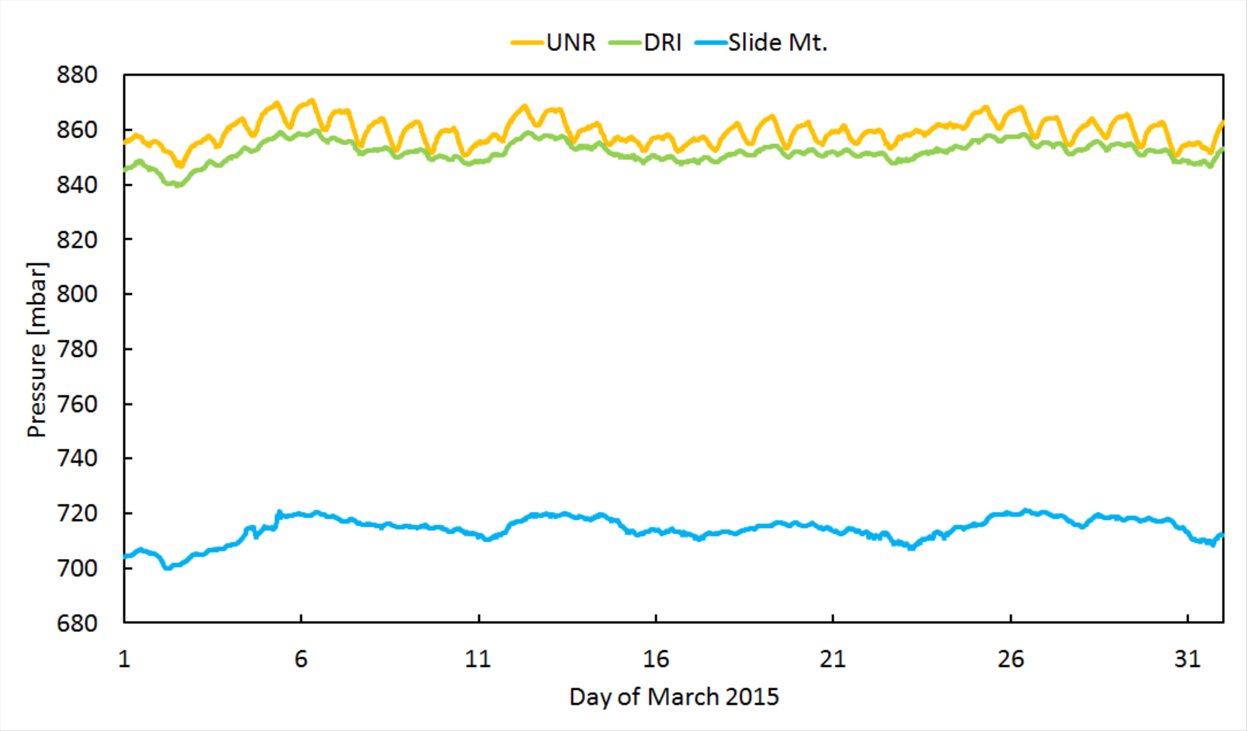

Figure 2: The pressure readings from the UNR, DRI, and SM weather stations. Data was recorded every 10 minutes.

The SM weather station is at an elevation of 2,941 meters, whereas the DRI and UNR stations are at 1,508 and 1,365 meters respectively [6][7][8]. Because air is less dense higher up in the atmosphere, measurements performed at greater elevations will yield lower pressures. ***Figure 2*** appears to accurately represent this principal. However, an oddity stands out with the UNR pressure measurements. Though spikes in each data set are common throughout the month, UNR appears to suffer from the largest jumps. ***Figure 3*** examines this in more detail by looking at the daily average of these values.

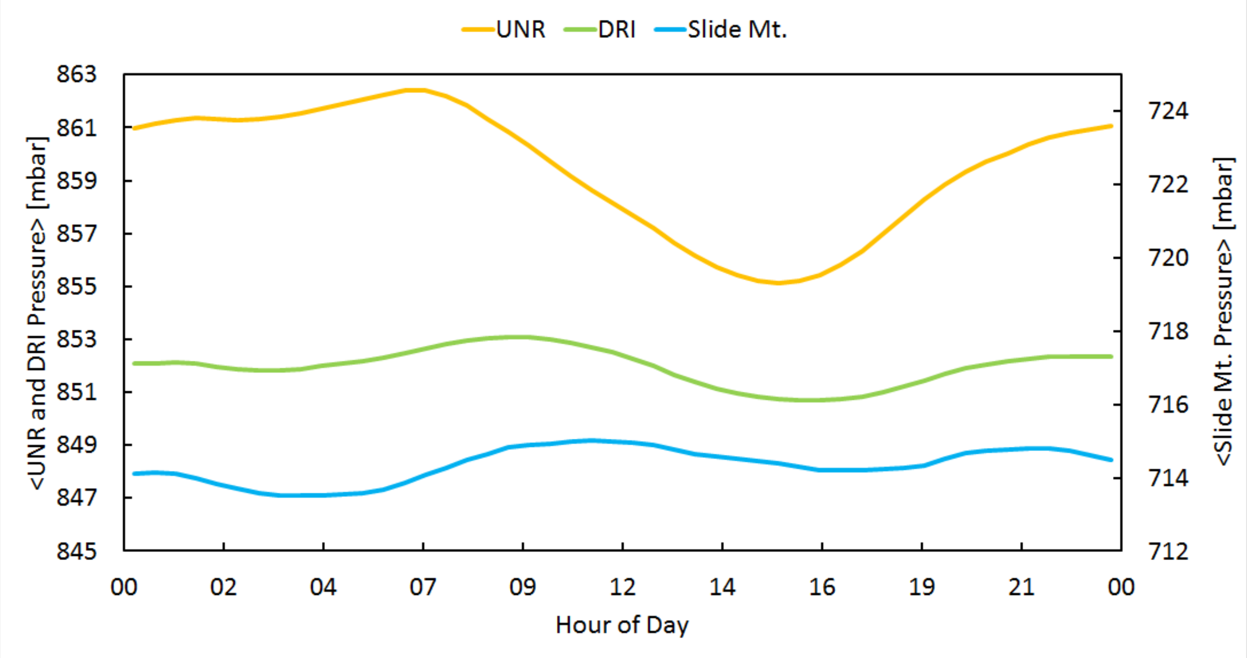

Figure 3: The daily average pressure values from each site.

The dramatic fluctuation in pressure at the UNR station can be seen in more detail. As stated earlier, fluctuations in pressure are expected due to tidal forces acting on the atmosphere. The calculated pressure at UNR was used as a reference to find these tidal pressures. These values were attained through ***Equations (3), (4)*** and ***(5)***. Both are compared to the measured values, shown in ***Figure 4***.

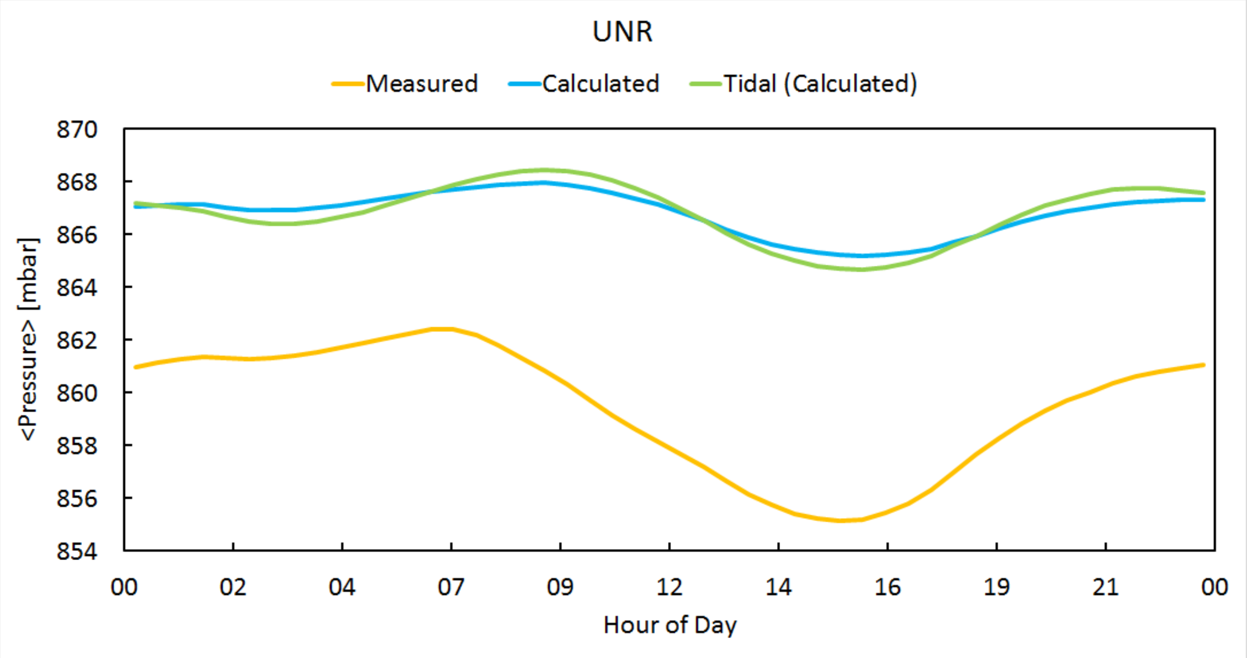

Figure 4: The tidal pressure, calculated pressure, and measured pressure (all for the UNR site) are all shown on the same axis.

It appears that the calculated pressure better fits the tidal oscillation curve than the measured values do. Furthermore, there is a discrepancy in the amplitude of both the calculated and measured pressures. The measured values fall about 6 mbar short of what is expected. It is reasonable to ask to what extent does the difference matter. To help answer this, a typical calculation of the mean virtual temperatures was performed by using the data along with ***Equation (2)***. ***Figure 5*** best tells the story.

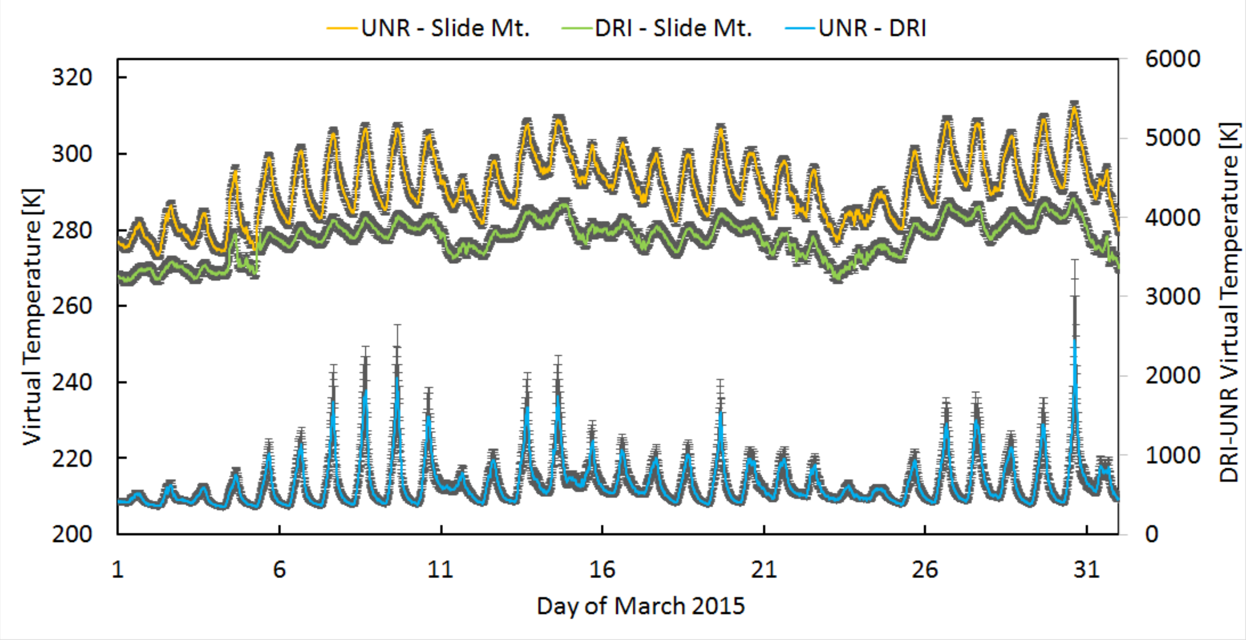

Figure 5: The mean virtual temperatures of the layer of atmosphere between each site. Calculations were performed using the measured UNR pressure. The error bars were calculated by propagating the error in pressure measurements. This error is quoted in the PTB101B manufacturer's manual as being ± .5 mbar [5].

As mentioned above, the mean virtual temperature should roughly represent a layer of atmosphere's average temperature. It is highly unlikely that the layer of atmosphere between UNR and DRI ever reached a maximum temperature of 2,445 Kelvin with an average error of 82 K, as indicated by ***Figure 5***. The difference between the mean virtual temperature and the average temperature of the layer are illustrated in ***Figure 6***.

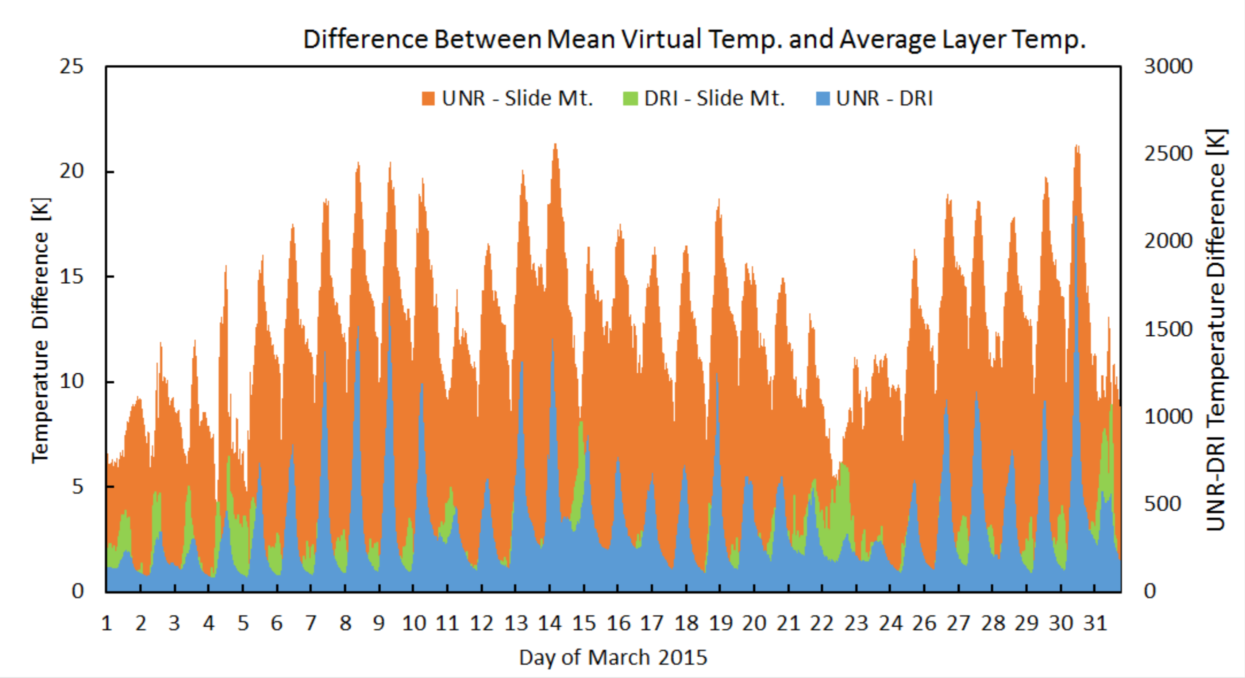

Figure 6: The difference between the mean virtual temperature and the average temperature of a given layer of atmosphere. Calculations were performed using the measured UNR pressure.

It is clear that the differences in these values, particularly between UNR and DRI, are quite large, ranging in thousands of degrees. Even the UNR to Slide Mt. layer differs by up to 20 °C.

For comparison, the mean virtual temperature was redone using the calculated pressure at the UNR site. These new values are shown in ***Figure** 7*.

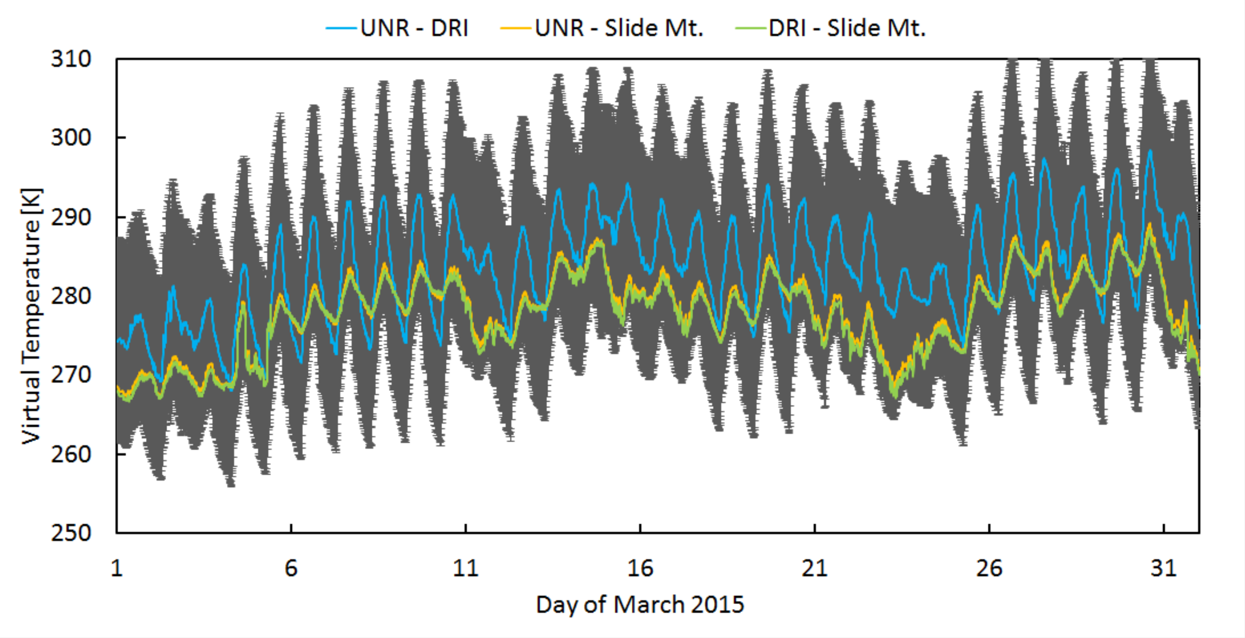

Figure 7: The revised mean virtual temperatures of the layer of atmosphere between each site. Calculations were performed using the calculated UNR pressure.

Although the UNR-DRI error in this calculation seems large because of the scale, it is actually smaller than the errors given in the previous calculation, at an average value of only 13 K. It is large when considering air temperature, but these values are still more believable, as shown by their difference from the average air temperature in the corresponding layer (***Figure 8***).

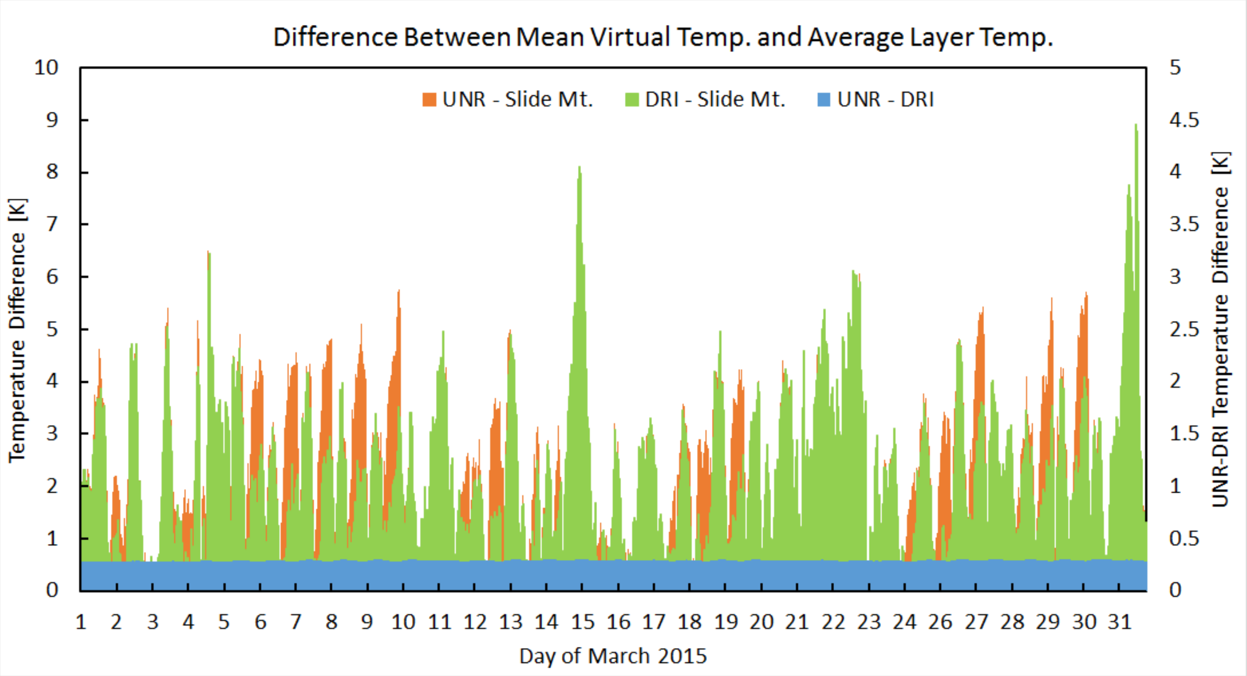

Figure 8: The revised difference between the mean virtual temperature and the average temperature of a given layer of atmosphere. Calculations were performed using the calculated UNR pressure.

Here, all the differences are under 9 °C, and the difference for UNR to DRI is now so small that in requires the secondary axis to be seen. This indicates that the calculated pressure values are more agreeable with what is expected.

The differences in temperatures shown above appear almost periodic. There are definite peaks and troughs in the data. This indicates that the discrepancy changes throughout the day, reaching a maximum during warmer hours. The same conclusions might then be said about discrepancies in the pressure measurements at UNR compared with their calculated counterparts. These differences were plotted as a function of temperature, shown in ***Figure 9***.

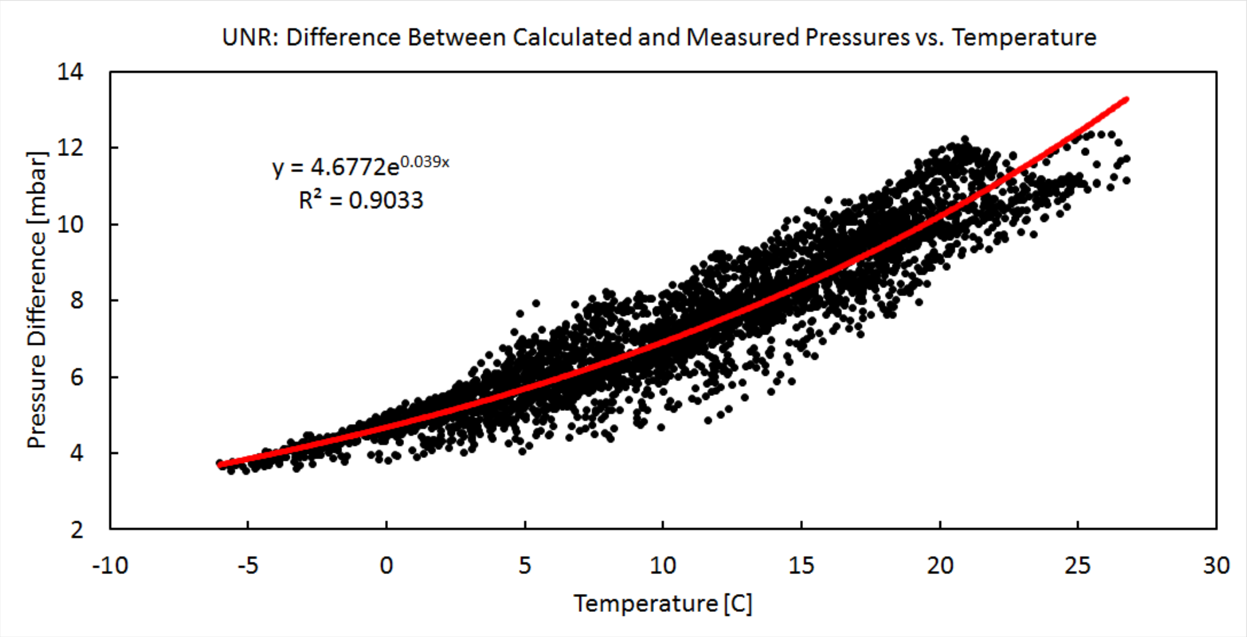

Figure 9: The difference between the calculated UNR pressure and the measured UNR pressure as a function of temperature. A fit curve of the data is shown in red.

Looking at the graph reveals a strong correlation between the pressure difference and surrounding air temperature. Furthermore, the discrepancy seems to follow a trend which is exponentially proportional to the temperature, suggesting that warmer conditions may lead to more inaccurate measurements.

III. Conclusions

The Vaisalla PTB101B pressure sensor being utilized on the University of Nevada, Reno weather station is reporting inaccurate barometric pressure readings. Analysis of data from March, 2015 shows that the average daily pressures are lower than what is expected by about 6 mbar. However, the manufacturer reports that the measured uncertainty should not exceed .5 mbar. Although there are many reasons that this could be happening, data shows that there is a strong temperature dependence in the discrepancy. This agrees with the fact that the resistivity of silicon in the pressure circuit also has a temperature dependence. The program that converts the output voltage into a pressure reading may not be accounting for this dependence. The sensor itself may be suffering from a manufacturing defect, or could have sustained damage at some point as well.

In the future, it would be beneficial to perform the same analysis for dates as early as available, generating a time series that spans over several years. This can provide insight as to when the errors in the pressure measurement may have begun. A definite change in the data may correlate to a date when a systematic change was made. Suspicious events might include moving the weather station, updating hardware on the station, and/or updating data processing software on the station.

References

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