Analyzing Measurements from a Temperature Inversion

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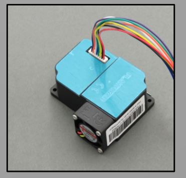
Abstract

A temperature inversion is a weather condition in which the atmosphere undergoes a trend different from normal. Temperature normally decreases with an increase in altitude, but under the condition of a temperature inversion: temperature increases with altitude. This weather condition is formed by radiational cooling of Earth's surface which causes a cold layer of air to be trapped under a warm layer of air. This atmospheric condition tends to have a stronger influence closer to the Earth's surface. At a certain altitude the effects of a temperature inversion are no longer present in the atmosphere. Dry, cloud-free nights are preferred conditions for a temperature inversion to occur. On these nights, radiation from the Earth is more likely to transmit to space instead of getting absorbed by the atmosphere. This allows the cooling process to occur. Pollutants, such as PM2.5 and PM10 particles, tend to get trapped in the atmospheric regions where temperature inversions occur due to the confinement of a difference in temperature layers. This raises concern for a possible increase in the concentration of pollution near the surface in the planetary boundary layer during temperature inversions.

The night of August 29, 2019 in Beltsville, MD was clear and cloud-free setting up conditions for the development of a nocturnal temperature inversion. On the morning of August 30th, 2019 at the Howard University Beltsville Campus, repeated ascent and descent profile measurements of temperature and particulate matter (PM) were made using a home-made tethersonde system. A standard weather balloon that carried a radiosonde, to measure temperature, and low-cost PM sensor were attached to the tethersonde by high-strength fishing line. This project analyzes the trends of the temperature inversion. It compares the temperature data to models provided by NOAA and it also analyzes PM2.5 concentration data recorded on the day of the experiment.

Methods

From original experimentation, the instrumentation attached to the weather balloon captured 30 vertical profiles of different atmospheric variables. There were a total of 15 ascent profiles where the weather balloon gained altitude and 15 descent profiles where the weather balloon decreased in altitude. Analysis of particulate matter data, iMet Radiosonde data, and High-Resolution Rapid Refresh (HRRR) data was done for this study. The programming language used to analyze the atmospheric data was Wolfram Mathematica. Data analyzed from this study included profiles from a PMS-3003 sensor (top right), a BME280 sensor, an HRRR dataset provided by NOAA, and an iMet-1 Radiosonde from InterMet Systems, Inc. The picture to the bottom right is an image of the weather balloon and instrumentation on the day of experimentation.

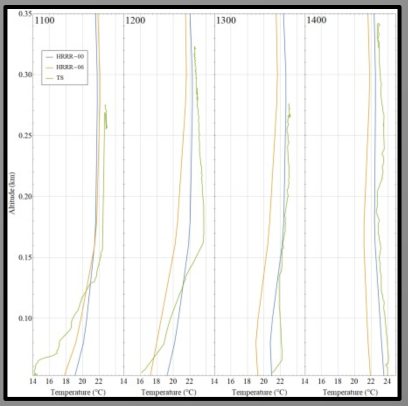


Picture retrieved from: https://www.researchgate.net/figure/Intermet-iMet-1-RS-radiosonde-used-for-FPH-flights-at-Boulder_fig10_285629102.

Picture retrieved from: HUBC

HRRR and Radiosonde Comparisons

The graph to the right depicts the HRRR temperature data after the initialization of 0000 UTC and 0600 UTC against the HUBC (TS) temperature data at four set hours. For the first three sets of plot lines, the forecast data do not correspond well to the HUBC data. The model forecasts are on average cooler than the HUBC data. In order to compare the temperature measurements, the RMSE of the full altitude range of all data was taken for all times. The HUBC average RMSE was 22.03; the 0000 forecast was 21.29 and the 0600 forecast was 20.45. Generally, the measurements from the 0000 model were closer to the HUBC data. The temperature difference between the maximum and minimum altitude of the HUBC and model forecast is displayed to the bottom right. On average, the HUBC data had more drastic temperature changes over the full altitude with an average temperature difference of 4.68 °C compared to the 0000 model's 2.69 °C and 0600 model's 3.29 °C.

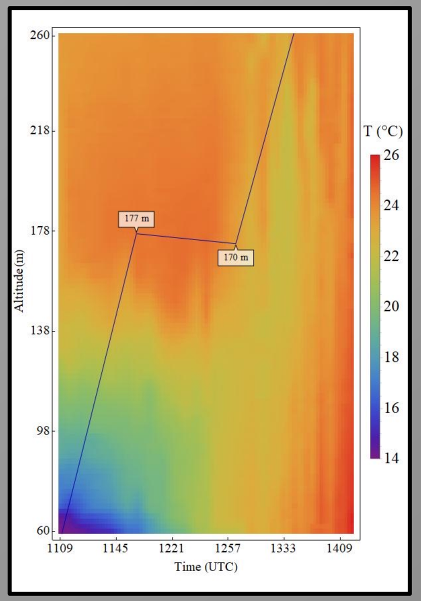


Temperature Difference Between Min and Max Altitude

	HRRR 0000	HUBC	HRRR 0600
1100	+4.40 °C	+8.65 °C	+5.98 °C
1200	+3.54 °C	+6.43 °C	+4.56 °C
1300	-1.05 °C	+2.18 °C	+1.73 °C
1400	-1.76 °C	+1.46 °C	-0.89 °C

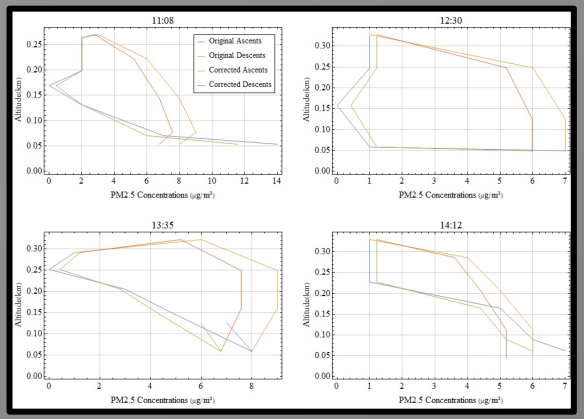
Temperature Inversion Color Map

By interpolating the measured temperature data at a vertical resolution of 2 meters and 2 minutes, the color map to the right illustrates the evolution of the temperature inversion that occurred on August 30th at HUBC. The inversion can be observed at the blue area in the lower left corner of the map during the first two hours where there is approximately a 7 °C increase in temperature within the lowest 100m of the atmosphere . The last two hours display the dispersion of heat from the temperature inversion as the condition starts to break down into a more normal atmospheric trend. This dispersion is represented by the vertical mixing of the yellow and orange color. PBL height forecasts (taken from the HRRR model forecast) were also depicted on this graph. The PBL exhibits a behavior of keeping the warmer temperatures above it and continuing that trend throughout.



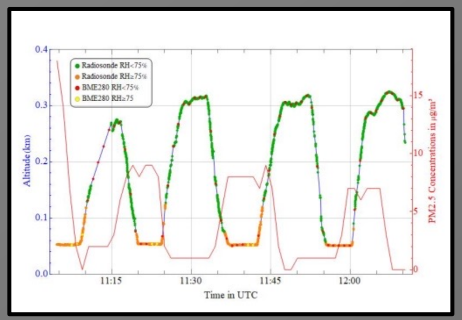
PM2.5 Concentration Measurements

The graph to the right depicts the PM2.5 concentrations during 4 adjacent ascents and descents of the weather balloon. The ascents and descents were separated by approximately 10 minutes therefore one would expect that the measured profiles of PM2.5 would be similar. Instead, there is a large disagreement where the ascent data has an average of 2.55 µg/m³ while the descent data has an average of 5.53 µg/m³.



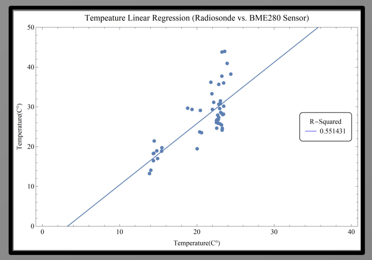
The common trend of high PM2.5 concentrations corresponding to lower altitudes may have been a result of insufficient ventilation of the container used to package the PMS-3003. Without sufficient ventilation, the air that the PMS-3003 is measuring may not be the same as the air at the height of the weather balloon which may have resulted in the observed hysteresis of the measurements.

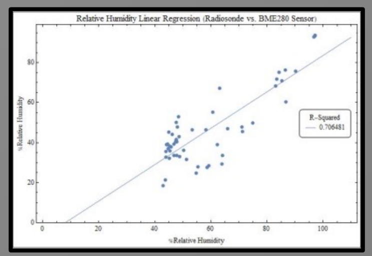
The graph to the right displays the altitude and PM2.5 concentration measurements for three cycles of experimentation. A BME280 sensor and iMet were both used to record the RH values. High RH values (RH≥75%) are represented by yellow and orange points while low RH values (RH<75%) are represented by red and green points. Measurements acquired when the RH was ≥ 75% in general indicate higher PM2.5 concentrations. This effect was present throughout the experiment period. These high RH values may have introduced hygroscopic growth to the PM2.5 particles and increased them in size at the high RH values resulting in increased PM2.5 concentrations.



Radiosonde and BME280 Sensor Comparison

To the right are two graphs depicting the linear regressions comparing the temperature and relative humidity measurements of the BME280 and the iMet. The correlation coefficient between the two devices for the temperature measurements was 0.55, indicating a considerable difference between the temperature measurements between both devices. While the relative humidity correlation coefficient was relatively higher than the temperature (0.706), its difference was still illustrated throughout experimentation enough to consider it an issue. With these differences in measurements, we plan to use these findings to improve the packaging of the PMS-3003 and BME280 which may have attributed to the temperature and relative humidity differences.





Summary & Discussion

The data from this analysis were retrieved from original experimentation of a weather balloon launch on August 30th, 2019, at HUBC. The instrumentation attached to the weather balloon recorded a temperature inversion and those data were used for this study to analyze different trends from those data.

It was shown that the PM2.5 concentration data recorded by the PMS-3003 was inconsistent with the atmospheric data recorded by the iMet. While the PM2.5 concentration displayed measurements that corresponded with increases in altitude or decreases with altitude, these results may have been skewed by high RH and temperature levels. The packaging of the PMS-3003 caused poor ventilation during experimentation which may have introduced the increased RH levels that were recorded by the BME280 that were not recorded by the iMet. The drastic differences in the RH and temperature levels between the lower altitudes and the higher altitudes may have changed the readings from the BME280 sensor and the PMS-3003 sensor so that it was not consistent with the atmospheric measurements from the iMet.

Future Work

The PM2.5 concentration data recorded by the PMS-3003 was unreliable due to hygroscopic growth induced by high RH values. This made it difficult to analyze any possible effects the temperature inversion had on the particle matter count. In future experimentation, it would be helpful to engineer an enhanced packaging method for the particle sensor and the BME280 sensor that improves the ventilation of the container. This way the sensors will not be influenced by very high or low temperature and RH values. Also, introducing newer models for both sensors and a more compact layout of both models would also suit future experimentation.

References

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