Analyzing the Breakup of a Temperature Inversion

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Abstract

Under normal circumstances, temperature decreases as altitude increases, but overnight radiative cooling of the surface can result in the temperature increasing with altitude instead, this is known as a temperature inversion. The cooling window is the largest when the skies are clear with little to no clouds and since the Earth's surface has a higher heat capacity than the molecules in the atmosphere, it tends to cool more rapidly. When skies are clear and the atmosphere is stable, the surface of the Earth cools quite rapidly and conduction causes the atmosphere to lose energy by being in contact with the surface. Also, the higher you are from the surface, the influence from it decreases and that's how an increase in temperature with height develops. These all contribute to the development of a nocturnal temperature inversion.

Pollutants released from the surface can often be trapped under the inversion point (the point where the structure of temperature reverts to its normal behavior) due to the stability of the atmosphere. The structure of temperature begins to breakup as the surface of the Earth heats up in the early morning.

This project analyzes the breakup of a temperature inversion that was captured on August 30th, looking at how solar heating influences variables such as the structure of temperature and particle count and how our data compares to models from NOAA.

Setup

This image is of the iMet radiosonde with a PMS-3003 particle sensor attached to it. The sensor was put in a Ziploc bag to protect it from any harm.

This image shows what was being launched repeatedly up and down. The red plastic attached to the circular cardboard is the parachute, the weather balloon is up top and the sonde is at the bottom

This is the tethersonde contraption, the item that was used to repeatedly reel the weather balloon either up or down.

This is a wide view of the full setup. Next to the tethersonde is a table which held the laptop, receiver, and logbook.

Methods

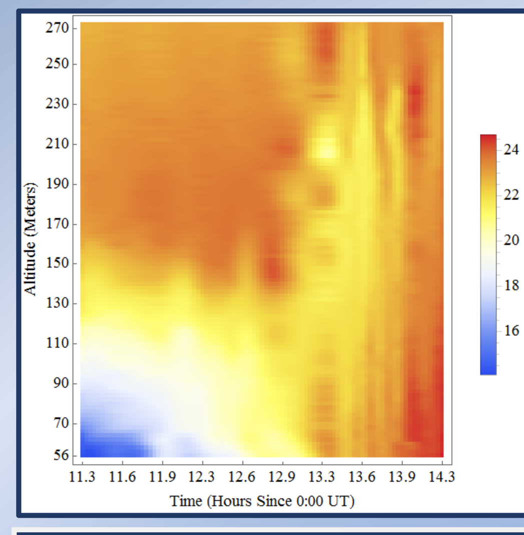
Preparation

1. The particle counter was prepared to allow for its sensitive components to be protected and was secured to the radiosonde.
2. The tethersonde was prepared with a parachute, drill, weather balloon, strings attaching to the weather balloon, a radiosonde, and a particulate matter sensor.
3. SkySonde Client and SkySonde Server were used to receive data packages from the radiosonde in real time.

Execution

1. Experimentation began as all the equipment was switched on.
2. The tethersonde was used to reel in and out the string attached to the equipment, causing the radiosonde to capture multiple profiles of the atmosphere
   - Each ascent and descent were separated by five-minute intervals until the last hour of experimentation.
   - The tethersonde captured thirty profiles of data over the course of three hours as the temperature inversion broke up.
3. After the last descent, the equipment was switched off and carefully transported inside the lab where it could be stored and where the weather balloon could safely deflate.

Temperature Inversion Color Map

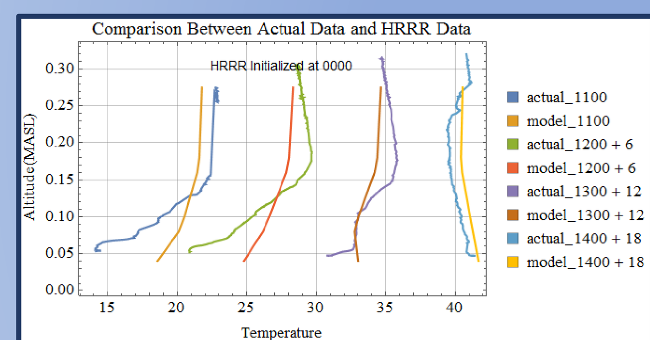


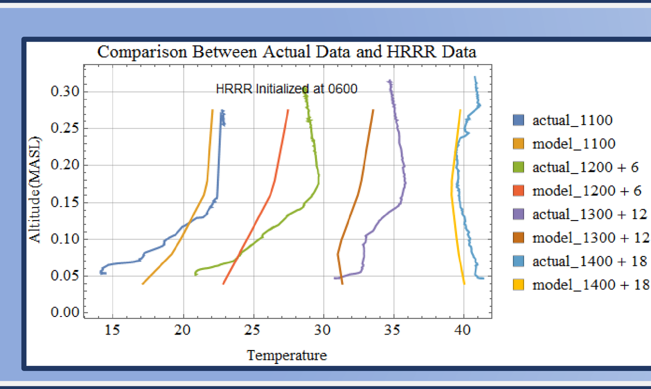
This figure displays a color map representing the breakup of this temperature inversion over the course of experimentation. The plot was made by doing a couple of interpolations of the actual data to get it into a vertical resolution of 2 meters and 2 minutes.

The effects of solar heating are quite evident in this plot as the increase in temperature with altitude changes after a certain amount of time and becomes a decrease in temperature as altitude increases. The yellow flares are most likely a result of data dropouts.

HRRR Data Comparisons

The High-Resolution Rapid Refresh (HRRR) data is a NOAA real-time 3-km resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized by 3km grids with 3km radar assimilation. Radar data is assimilated in the HRRR every 15 min over a 1-h period adding further detail to that provided by the hourly data assimilation from the 13km radar-enhanced Rapid Refresh. (National Oceanic & Atmospheric Administration, 2020) We obtained two HRRR datasets from NOAA's Dave Turner to compare to our data. The two datasets were initialized at two different times, 0000 UT and 0600 UT.

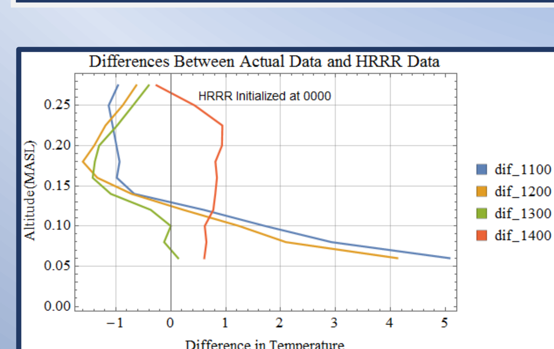




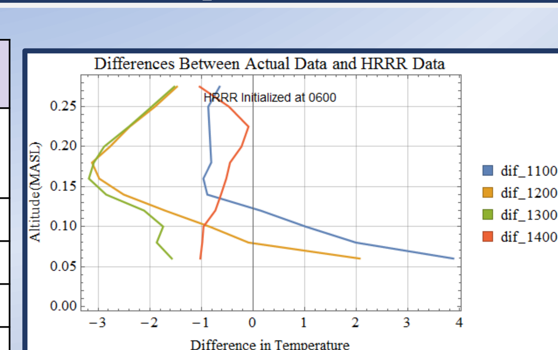
These two graphs are more of a visual comparison rather than a calculated comparison of the data sets. On the left is the comparison between the actual data and the HRRR data initialized at 0000, the right is the comparison when initialized at 0600.

The model at 0000 does not portray the strong structure of the temperature inversion as captured in our data for the first two hours. The HRRR data and the actual data begins to agree much more in the later hours. The inversion points also line up at around the same spot for each of the hours.

The model initialized at 0600 appears to capture the structure of the inversions quite accurately, compared to the one initialized at 0000. The first and the last hours are the most accurate but the two in between are far off. The inversion points still align up, but the temperature values are far off, even by 3 degrees at some points.



Root Mean Square of Differences Between the Actual Data and the Modeled Data		
Time (UT)	**RMS when initialized at 0000 (°C)**	**RMS when initialized at 0600 (°C)**
1100	2.00419	1.50567
1200	1.71545	2.1718
1300	0.883697	2.36241
1400	0.725924	0.71812



The three figures above show mathematical comparisons between the model and the actual data. The two graphs are calculated differences for each of the temperature values in each profile. When the model was initialized at 0000, the differences appear to be quite high near the surface for the first two hours and they agree at higher altitudes, as well as for the next two hours. This is almost the same case for the model initialized at 0600 except that at 1200 and 1300 UT, there is a large difference between the datasets throughout the whole profile. The table in the middle show root mean square values of these differences. Since the values are lower when the model was initialized at 0000, it indicates that that data was more accurate than the one initialized at 0600. The only time where the root mean square of the differences where greater initialized at 0000 than at 0600 was at hour 1100 UT.

Influence on Particulate Matter

his table shows the average amount of particle count above and below the inversion point and its standard deviation. An inversion point is the point in each profile where the temperature begins to decrease as altitude increases like normal. The average particle count below the inversion point was 4.44 microns, above the inversion point it was 3.41 microns. Due to the atmosphere being stable during an inversion, particulates are often trapped under that inversion point and the data somewhat indicated this. Due to the miniscule difference between the averages below and above the inversion point, we cannot draw towards a definitive conclusion.

Average Particle Count Above and Below the Inversion Point		
	Mean	**Standard Deviation**
Above	3.409	2.796
Below	4.444	3.033

Summary & Discussion

A tethersonde was launched to capture 30 different profiles of the atmosphere during the event of a temperature inversion on August 30th. The data from the radiosonde and particle counter that was launched from the tethersonde was then transferred onto Mathematica to be processed.

Our data shows an expected amount of particulates above and below the inversion point since there was a higher average below the inversion point than above, but the difference is not significant enough to draw towards a definitive conclusion. When comparing the differences of the two models, it appears that the model initialized at 0000 was more accurate than the one initialized at 0600. Logically, the model initialized later should perform better than that at an earlier time but in this case, the opposite happened.

Future Work

In the data, there were a couple of kinks and times where there was a loss of data, which affected interpolations done in the data processing. It would be beneficial to have multiple datasets, to conduct the experiment more than twice in a week to do comparisons and more valuable analyses. It would also be beneficial to do a couple of test trials before the actual experiment to make sure that when the actual experiment is done, there are little to no flaws. There was an issue with the radiosonde package moving too much in the air, it would be trivial to engineer a solution for wind influence in results.

References

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