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ANALYSIS OF DESCENT METEOROLOGICAL DATA FROM NWS RAOB FLIGHTS

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ABSTRACT

Weather balloons carry radiosondes aloft from 92 stations across the United States, and around 500 locations worldwide twice daily. Radiosonde in the United States measure atmospheric pressure, temperature and relative humidity as well as calculate wind speed and direction at 1 second intervals, from balloon release until flight termination (usually balloon burst). No data are collected after flight termination, yet the radiosonde is still transmitting data as it descends through the atmosphere. Meteorological data collected from the radiosonde during descent would allow for a second sample of the atmosphere at the same pressure levels at a different location and different time. This additional sampling of the atmosphere could either verify unusual or potentially erroneous data from the ascent sounding, or could show short term changes in the atmosphere. Either way, this additional data could benefit the accuracy of the numeric weather prediction models.

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1. Introduction

Radiosonde observations (RAOBs) are supported by the National Weather Service (NWS) from around 92 locations across the United States and US Territories twice per day, with flight observation times of 00 UTC and 12 UTC. Special observations are conducted as needed. Presently, the National Weather Service employs 3 models of radiosondes for most of their locations, the Lockheed Martin/Sippican LMS-6 1680 MHz, the Lockheed Martin/Sippican LMS-6 403 MHz and the Vaisala RS92-NGP (RWS Users Guide and ERS 01-2019), and the National Weather Service Buffalo utilizes the LMS-6 1680 MHz radiosonde. The LMS-6 radiosonde measures pressure with a capacitance aneroid cell, which has an accuracy of about 0.5 hPa (with decreasing accuracy aloft), with a measuring range of 1060 to 6 hPa (NWSM 10-1401). Temperature is measured by a thermistor, having an accuracy of +/- 0.3° C in the troposphere, with a rapid response time (usually less than 4 seconds) (NWSM 10-1401). For relative humidity, a hygristor is used by the LMS-6, which has an accuracy of +/- 5%, and the sensor response can exceed 2 minutes below -30° C (NWSM 10-1401). A radiosonde is suspended roughly 100 feet below hydrogen or helium filled balloon, and measures temperature, relative humidity, pressure and GPS (Lat./Lon./height) at one second intervals, as it ascends. Data are transmitted from the radiosonde to a tracking dish known as the Telemetry Receiving System (TRS) near the release point. Wind data are computed from the change in position of the radiosonde using the one second GPS data. A Signal Processing System (SPS) converts the received signal into Met data and computes "unsmoothed" and "smoothed" U and V wind. This data is then sent to the Radiosonde Work Station (RWS) computer that resides in the NWS Office, which further processes the data, and computes dew point, lapse rates, among other elements. A solar correction is computed by the RWS to correct the temperature error when the thermistor is exposed to solar radiation (RWS Users Guide). This solar correction can approach or even exceed 1° C (NWSM 10-1401). Note: all of the temperature data used in this technical attachment are raw, with no solar correction applied.

The RWS is the primary interface that the observer uses to quality control data from the RAOB before the transmission of the WMO Coded Messages. The RWS computer will identify significant changes in the temperature or relative humidity data and flags these as significant levels. These significant levels, along with the mandatory levels are transmitted via the SBN as the Mandatory, Significant and Above Level Messages. These messages contain data that is the primary data input into the numeric weather prediction models.

RAOBs for the 00 UTC and 12 UTC soundings are launched within time window extending from H-60 minutes to H+29 minutes, where H is either 00 or 12 UTC. Once the RWS detects a balloon burst or, on rare occasions a radiosonde failure, the RAOB is terminated and the ABV messages are generated. Operationally no data are collected after flight termination, despite the radiosonde still transmitting data. However, after flight termination, it is possible to restart the RWS software in live flight mode, and reacquire the signal of the descending radiosonde. After the descent radiosonde signal is lost, data can be extracted from the SPS log file.

During the summer of 2012, the NWS Springfield MO collected descent data from a few soundings and compared it to the ascent, using the Vaisala RS-92 radiosonde. Some concerns noted from those descent cases noted by Bill Blackmore at NWS Headquarters are:

1. The descent speed of the radiosonde (e.g. did the parachute fully deploy). This could impact accuracy of the wind data.
2. The radiosonde design, the RS-92 will permanently shut down the RH sensor once it reaches -60° C. (Descent cases discuss here use the LMS-6 radiosonde, that does not shut down the RH sensor)
3. After balloon burst, the flight train and balloon remnants could become tangled around the sensors and contaminate the temperature and RH sensors.
4. The RWS Software would need to be rewritten to accommodate the descent data.
5. Descent data collection may require a shift in working hours for employees doing the UA RAOB.

With that being said, Petersen (2016) showed RAOB data resulted in a 15% reduction in error of 24-hour temperature forecasts. Additionally, Ratnam et al. (2014) noted "The radiosonde descent profile provides reliable data of the meteorological parameters and can be used for scientific studies". Therefore, if implemented, radiosonde descent data could provide an additional ground truth dataset to improve forecasting models, especially the model runs other than the 00 UTC and 12 UTC runs. Lastly, with respect to the descent speed and its impact on wind computation (e.g. did the parachute deploy as designed), further research could refine wind computation algorithms, possibly by developing multiple computation algorithms based on overall descent rate (e.g. a different algorithm would be used for a fully deployed parachute, another for a partially deployed parachute, etc.).

With this background the descent data was collected at WFO BUF over a three-year period to better understand the characteristics of descent data and what value it might provide. The following sections will show the data and methods used, discuss the results and detail conclusions. Lastly, some ideas for future work are provided.

2. Data and Methodology

Between August 2013 and January of 2016, data was collected after flight termination from 207 synoptic and special RAOBs at the NWS Buffalo Office. The descending radiosondes were tracked until the signal was lost, usually due to the loss of line of sight from the curvature of the Earth. Depending on distance from the release point, the height of the last data point received from the descent sounding was anywhere from ground level to 11,700 m above ground level.

After flight termination, the tracking equipment was left on to obtain data from the radiosonde as it descended back to Earth. Since the tracking equipment was in the "flight mode", the SPS was ingesting the radiosonde data, as well computing smoothed and unsmoothed winds, and storing this in a log file. This log file, as well as the log file from the ascent, were decoded and converted to a ".csv" file, using a program developed by David Church, a Forecaster at the NWS Buffalo. These log files contain the one second meteorological data transmissions from the radiosonde, as well as the computed winds. The winds are computed using proprietary software at the SPS, and the output consisted of "smoothed" and "unsmoothed" U and V wind components, measured in meters per second. SPS Log files were converted for both the radiosonde ascent and the descent, and data were compared at 50 m height increments. If the height level did not fall exactly on one of these 50 m levels, the next higher 1 second height was used. This would show a slightly positive difference between the ascent and descent pressure data, as is seen in Fig. 9. For temperature, pressure and humidity, the difference between the ascent value and the descent value was computed every 50 m, these values were then averaged. For wind data, the U and V unsmoothed and smoothed winds were averaged over the flight, then a difference between the ascent and descent average wind component computed.

The University of Wyoming, Dept. of Atmospheric Science, has a balloon trajectory forecast on their website. This trajectory forecast uses the GFS and will output either a .kml file or a text file showing the forecasted flight path and landing point. In the text output, GFS forecasted temperature, relative humidity and pressure, as well as U and V wind components are displayed, however the forecasted met data in both the ascent and the descent are nearly identical. These forecasts do a fair job in forecasting the actual path of the RAOB, however the sounding flights have a tendency to drift further than this forecast.

The 100-foot flight train, with the radiosonde on the bottom, acts as a large pendulum, as the balloon ascends, and this swaying action would introduce significant error into the wind data. This is evident in the raw and smoothed position data right after release shown in Fig. 1. Therefore, the position data needed to be "smoothed" in order to properly compute the actual winds. A comparison of the smoothed and the unsmoothed position data is shown in Fig. 1 and Fig. 2.

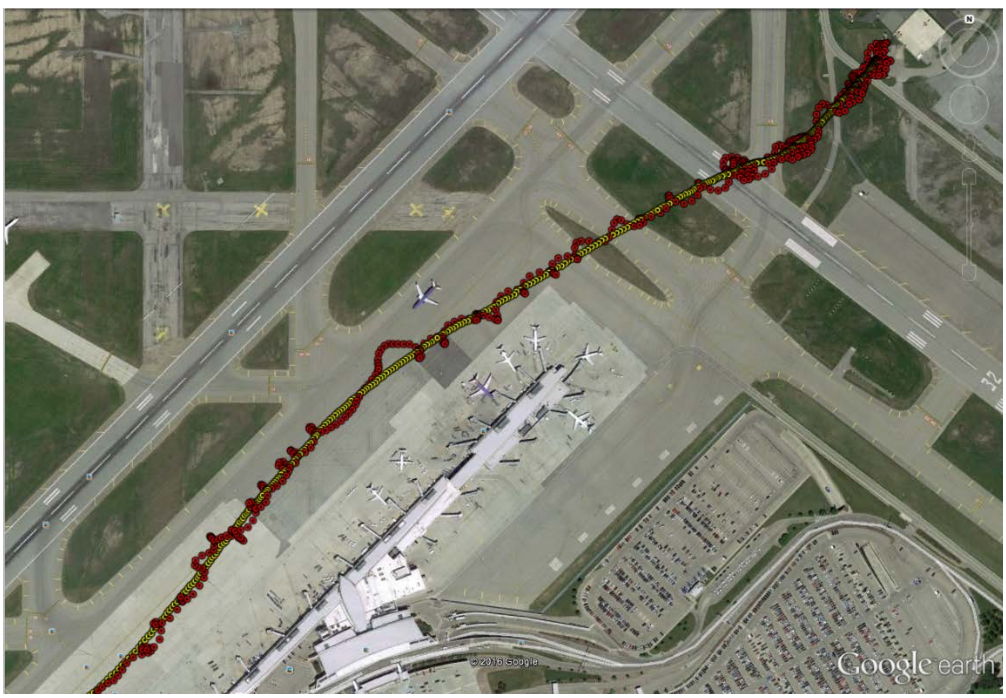


Figure 1. Unsmoothed (red dots) path actually taken by the radiosonde. Note the spiral path, which is due to the "pendulum" action of the radiosonde and flight train. The yellow dots represent the smoothed position.

Figure 2. A further demonstration of the difference between the unsmoothed (red) and the smoothed (yellow) position data. In this case, the radiosonde hit the ground, and was thrown into a vehicle that drove north on Transit, turning west onto Genesee. Note how the unsmoothed position closely follows the curves of the road, while the smoothed data points smooth out the curves in the road.

Each of the 207 flights was placed into one of 6 categories based upon how far away from the release point the last data point from the descent is. Those categories are the last data point is: 0 to 30 km, 30 to 75 km, 80 to 110 km, 110 to 150 km, 150 to 225 km and greater than 225 km. These categories were selected in an attempt to differentiate between different average wind speeds aloft. Flights falling into the first category would have an average wind that was very light, and the radiosonde could be tracked to within a few meters of the surface. The stronger the average winds the further away the last data point is, and the higher the final data point received. These categories were selected to see if the strength of the average wind impacts the difference in the wind speed and direction between the ascent and the descent.

A second comparison was made between the ascent and descent data and NAM model data that is initialized from the RAOB data. Since the radiosonde measures relative humidity, and the NAM outputs dew point, the radiosonde RH was converted to dew point for comparison. (McNoldy Temperature, Dew Point and RH Calculator) However great differences were noted when comparing the ascent RH and the descent RH, so the RH data was not compared to NAM model data in this paper. The data from the ascent was compared to the corresponding synoptic model run, and the descent data was compared to the nearest site of either BUF, ROC or ART 2 hours later, using the same model run. Finally, the difference between the difference between the ascent vs. the 0-hour model data and the descent vs. the 2-hour model forecast was computed. This was done in an attempt to remove any model initialization errors that may have occurred. These flights were broken down into 4 categories based upon the descent rate. **Note: During ALL flights a parachute is used, and every effort is made to ensure that the parachute properly deploys after balloon burst.** The reason that descent rate was used is that the wind computations are developed based upon the size and shape of the balloon. After the balloon burst the state of the flight train is unknown, but can be approximated based on the descent rate. Therefore, the descent rate was broken down into the categories outlined in Table 1.

Table 1. The number of flights in the descent rate categories used to compare to the NAM model data.

Descent rate	**Number of flights used**
<10 m/s	6

10 to 15 m/s	4
15 to 18.5 m/s	4
>18.5 m/s	6

3. Results

a. Temperature/RH/Pressure

Of the 207 RAOBs, the average last pressure of the descent was 722.09 mb, with an average loss height of 2625.9 m above the ground level. Nearly all of the descent flights were able to sample the jet stream at a different location, generally between an hour and a half and two hours later (Table 2). Additionally, the vast majority of these descent soundings made it down to the mid-levels of the atmosphere. While few of these descent soundings were able to re-sample the low-level inversion within a few meters of the surface, mid and upper level winds and temperatures obtained from these soundings would provide valuable data to the numeric weather prediction models.

Table 2. The percentage of the 207 descent RAOBs that include the various Mandatory Pressure Levels.

Mandatory Pressure Level	Percentage of descent RAOBs that include the Mandatory Pressure Level
150 mb	100%
200 mb	99.5%
250 mb	98.6%
300 mb	97.6%
400 mb	93.2%
500 mb	87.9%
700 mb	67.1%
850 mb	38.6%
925 mb	15.9%

When the ascent temperature is compared to the descent temperature, the values are very similar, especially below the tropopause. Above the tropopause, fluctuations in temperature result in some slightly larger differences. These fluctuations can be seen in Fig. 3 and Fig. 4, which are examples of the 12 UTC temperature in blue and the descent temperature in red. The gap in the descent temperature from around 30 mb to around 50 mb in Fig. 3 is due to the time needed to lock back on to the radiosonde after the 12 UTC flight termination. Upper level winds were very light this day, and the radiosonde came down about 2.4 km away from the release point. Note how well the temperatures match up in the lower levels, as the 12 UTC sounding and the descent were able to sample nearly the same locations in the atmosphere. In Fig. 4, the last data point was 342 km away, so the descent was sampling a different location in the atmosphere, however the descent temperature was very similar to the ascent below the tropopause. The variance in the temperatures above the tropopause and the smaller sample size below may skew the temperature differences in the last 2 categories of Table 3. Table 3 shows the average difference in the pressure, temperature and humidity, with the average difference in temperature only -0.1° C, which is just the difference between a positive and a negative temperature in the WMO coded messages (odd tenths of a degree Celsius values for temperature, represent a negative temperature, while even is positive) (NWSM-10-1401). Table 4 shows the standard deviation in the differences, and again shows slightly larger deviation the further away the radiosonde travels. Figures 6, 7 and 8 compare the ascent and the descent temperatures at the 500 mb, 300 mb and 100 mb mandatory levels. Of the 3 mandatory levels, the largest difference between the ascent and descent is at 100 mb, this is due to being at or above the tropopause.

Temperature fluctuations are much greater above the tropopause than below. Overall, there is a very good correlation in the descent temperature when compared to the RAOB.

Differences in pressure are due to the selection of the 50 m height level in the individual RAOBs. Since the radiosonde transmits every second, the chance that the height of the data falls exactly on the intended height is low, and the 1 second data point above the intended height is used. Therefore, the pressure will have a positive bias. However, the standard deviation is low.

When comparing the relative humidity ascent data to the descent data, the descent relative humidity was skewed downward. An example of this is shown in Fig. 5. Note how the moist layers in the ascent around 220 mb, 270 mb, 325 mb, 375 mb and 450 mb are skewed downward in the descent. This was observed in many of the 207 descent cases that were looked at. One would think that with the orientation of the RH sensor boom (RH sensor chip under a cup oriented downward) that the atmospheric humidity should impact the sensor quicker in the descent than the ascent. The actual delay may be due to icing or other contaminants preventing the sensor from properly sampling the atmospheric moisture. Additionally, if the relative humidity sensor encounters a cloud or precipitation layer, the reported RH can exceed 100%. Therefore, the descent relative humidity data should be used with caution.

Table 3. This table shows the average differences in meteorological data between the ascent and descent for all 207 flights sorted by the distance from the release point to the last data point.

Average Differences between Ascent and Descent			
Last data point	Pressure	Temp.	RH
0 to 30 km	0.19	-0.11	3.11
30 to 75 km	0.25	-0.04	0.07
80 to 110 km	0.38	-0.06	3.29
110 to 150 km	0.21	-0.12	1.74
150 to 225 km	0.31	-0.28	2.33
>225 km	0.24	-0.26	3.18
Avg. All	0.19	-0.11	3.11

Table 4. The standard deviation in the difference between the ascent and descent met elements.

	Average Standard Deviation		
Last data point	Pressure	Temp.	RH
0 to 30 km	0.42	0.80	10.26
30 to 75 km	0.37	0.90	10.43
80 to 110 km	0.45	0.88	13.32
110 to 150 km	0.45	0.95	10.44
150 to 225 km	0.46	0.99	9.67
>225 km	0.41	1.33	6.77
Avg. All	0.43	1.01	10.02

b. Wind Data

Taking a look at the differences in the U and V wind components, it was originally thought that the unsmoothed winds would have the greatest differences, and the smoothed the least. Surprisingly the smoothed wind speeds have a slightly larger difference in the last three categories than the first three. Additionally, it was originally thought that with the last categories (last data points furthest away), the average wind speed would be much greater, so the likelihood of the descent sampling a much different wind speed or direction than the ascent would be greater. The differences in wind speed, though, are actually somewhat similar; at least much more similar than expected (Fig. 10). Plotting the differences in the wind U and V wind components in all of the flights in each of the flight categories, the differences between the ascent and the descent smoothed winds in the majority of the cases is 1 m/s or less (Fig. 11). The exception is in the >255 km last data point category, where the difference in the U direction was a bit greater in both the unsmoothed and the smoothed datasets. During these flights, average wind speeds are very high, and a jet max is likely nearby. The ascent and the descent would sample this jet max in different locations, resulting in a larger difference. Interesting to note, this is not very evident in the other last data point categories. When comparing the ascent U and V winds to the descent U and V components, the ascent vs descent winds are much closer at 300 mb (Figs. 14 & 15) than at 100 mb (Figs. 16 & 17) and 500 mb (Figs. 12 & 13), however, even at 100 mb and 500 mb, differences are limited to a few meters per second.

The descent data were compared to the NAM model for 20 flights with varying descent rates, at the point BUF, ROC or ART whichever location was closest to the majority of the flight descent. Comparing all of the data levels where descent flight wind data and model wind data were available for all 20 flights, it is found that differences in winds in the majority of the 20 flights, for smoothed wind data, is 2 m/s or less (Fig. 18). The 20 flights were separated into 4 categories based on descent rates, as it was originally thought that a faster descent rate would result in a slow bias with respect to wind speed, as it was observed that with the faster descent rates, when compared to the University of Wyoming forecasted descent tracks, they would not travel as far as forecasted. The descent rates of 5 m/s to 10 m/s (6 flights), 10 m/s to 15 m/s (4 flights), 15 m/s to 18.5 m/s (4 flights) and greater than 18.5 m/s (6 flights) were selected. However, when the descent rates were compared to the 2-hour forecasted NAM data, the faster descent rates actually showed a slightly higher positive smoothed wind speed in both the U and the V directions (Fig. 19).

It was thought that the descent rate may impact the computation of the winds on the descent (e.g. if the descent rate is faster, the wind computation algorithm would show a slow bias in the descent data). Looking at all 20 flights (Fig. 20), the majority of the smoothed U and V winds fell with 2.1 m/s of the bias corrected model winds. Looking at the 4 descent rate categories outlined above, there is not a noticeable impact of the descent rate on the wind computations (Fig. 21).

An example of a flight where there was a larger difference in the ascent vs descent wind speed is shown in Fig. 22. In Fig. 22, both the actual flight (dots) and the U of WY trajectory forecast (triangles) are plotted, with the ascent in green and the descent in red. Note the length of the actual descent, which fell from ~130 mb to ~609 mb in 13 minutes and 50 seconds. This would lead to an average descent rate of around 12.5 m/s. For comparison the ascent rates are 4.58 m/s to 5.8 m/s, and values over 8.3m/s should be closely watched due to the possibility of pressure sensor failure (NWSM 10-1401).

Table 5 determines model bias by subtracting the University of Wyoming forecast winds from the observed smoothed and unsmoothed winds in the ascent, then doing the same for the descent. Finally, subtracting the difference in the ascent from the difference in the descent. This was done to try to remove any initialization error the GFS may have had. The 12 UTC flight on 8/9/2014 (forecasted flight path in Fig. 23) had 1 second ascent and descent wind component values that were very similar. For the trajectory forecasts, only a 12-hour forecast from the 00 UTC GFS model was used, and this was to ensure synoptic RAOBs were used for model initialization. The trajectory forecast for the Jan 3 2014 12 UTC RAOB (large difference in winds) averaged about 5 m/s too strong in the V direction, however, the model did much better with the Aug 9

2014 12 UTC (small difference in winds) case, as seen in Table 6.

Table 5. A comparison of the descent wind data to the ascent wind data, and to model wind data on Jan 3 2014 at 12 UTC. The forecast data is a 12-hour forecast using the 00 UTC Jan 3 2014 GFS from the University of Wyoming. This flight had one of the higher differences between the ascent and descent winds. The flight path is shown in Fig. 17.

	Observed – Forecast Ascent				Observed – Forecast Descent				Observed Ascent – Observed Descent			
	Unsmoothed		Smoothed		Unsmoothed		Smoothed		Unsmoothed		Smoothed	
Pressure	U	V	U	V	U	V	U	V	U	V	U	V
600mb	7.6	-0.5	0.8	-1.1	1.3	8.1	2.3	10.9	6.3	-8.6	-1.5	-12.0
550mb	2.1	-0.7	-1.3	-0.2	2.0	10.8	3.2	14.0	0.1	-11.5	-4.5	-14.2
500mb	0	5.5	1.5	1.5	1.0	19.7	1.5	18.3	-1.0	-14.2	0	-16.8
450mb	-5.5	9.6	-0.1	7.4	0.1	22.9	0.6	21.3	-5.6	-13.3	-0.7	-13.9
400mb	-2.6	11.2	-1.1	13.1	0.5	27.4	3.4	23.8	-3.1	-16.2	-4.5	-10.7
350mb	-1.3	8.7	0.5	12.8	3.5	26.5	4.5	26.3	-4.8	-17.8	-4.0	-13.5
300mb	2.4	7.2	-1.2	8.9	3.8	23.2	3.6	21.9	-1.4	-16.0	-4.8	-13.0
250mb	1.2	7.7	1.4	7.8	2.5	16.5	1.4	18.9	-1.3	-8.8	0	-11.1
200mb	-0.7	7.0	0.6	6.9	4.3	5.1	1.2	10.5	-5.0	1.9	0.6	-3.6
150mb	1.6	1.3	1.3	1.5	0.3	11.1	1.8	9.8	1.3	-8.8	-0.5	-7.3
Avg.	0.48	5.70	0.24	5.86	1.93	17.13	2.35	17.57	-1.45	-11.33	-2.11	-11.60
St Dev	3.48	4.23	1.10	5.17	1.54	7.98	1.26	5.94	3.56	5.72	2.07	3.78

Table 6. A comparison of the descent wind data to the ascent wind data, and to model wind data on Aug 9 2014 at 12 UTC. The forecast data is a 12-hour forecast using the 00 UTC Aug 8 2014 GFS from the University of Wyoming. This flight had one of the lower differences between the ascent and descent winds. The flight path is shown in Fig. 18.

	Observed – Forecast Ascent				Observed – Forecast Descent				Observed Ascent – Observed Descent			
	Unsmoothed		Smoothed		Unsmoothed		Smoothed		Unsmoothed		Smoothed	
Pressure	U	V	U	V	U	V	U	V	U	V	U	V
900mb	0.4	6.4	0	0.6	0.9	2.3	0.8	1.3	-0.5	4.1	-0.8	-0.7
850mb	1.3	-3.4	2.0	0.9	0.3	0.5	0.7	0.5	1.0	-3.9	1.3	0.4
800mb	1.6	3.5	1.9	1.3	-0.8	0.3	-0.8	0.8	2.4	3.2	2.7	0.5
750mb	-0.2	7.1	-1.0	1.5	0.9	0.4	1.0	1.4	-1.1	6.7	-2.0	0.1
700mb	-2.1	7.9	0.4	2.2	-0.3	1.1	-0.2	1.7	-1.8	6.8	0.6	0.5
650mb	-1.1	3.5	-0.2	0.2	0.5	-0.4	1.2	0.1	-1.6	3.9	-1.4	0.1
600mb	2.9	-2.7	-0.2	1.4	1.7	1.4	1.8	0.6	1.2	-4.1	-2.0	0.8
550mb	-3.8	0.9	-1.0	-0.2	1.3	-0.7	1.8	0.2	-5.1	1.6	-2.8	-0.4
500mb	-0.8	-2.8	-1.6	-2.3	1.5	-0.6	1.0	-0.9	-2.3	-2.2	-2.6	-1.4
450mb	4.7	3.6	0	-1.0	2.6	0	2.4	-0.1	2.1	3.6	-2.4	-0.9
400mb	3.2	-2.9	0.4	-0.7	2.4	-3.4	2.5	-4.7	0.8	0.5	-2.1	4.0
350mb	1.4	-6.9	2.5	-3.1	4.2	-3.7	3.2	-2.3	-2.8	-3.2	-0.7	-0.8
300mb	0.6	0.8	4.5	3.6	5.7	-2.0	5.1	-4.7	-5.1	2.8	-0.6	8.3
250mb	3.7	-4.0	2.1	-0.2	4.0	-1.3	3.1	-3.2	-0.3	-2.7	-1.0	3.0
200mb	-2.5	-5.4	-3.2	-5.5	-3.0	-2.6	0.8	-0.1	0.5	-2.8	-4.0	-5.4
150mb	3.3	4.0	0.7	1.2	2.1	3.8	-0.6	1.9	1.2	0.2	1.3	-0.7
100mb	2.9	2.3	0.1	2.1	1.2	2.1	0.3	0.6	1.7	0.2	-0.2	1.5
70mb	-3.0	-0.8	-2.9	-0.6	-1.6	2.3	-2.5	3.9	-1.4	-3.1	-0.4	-4.5
Avg.	0.69	0.62	0.25	0.08	1.31	-0.03	1.20	-0.17	-0.62	0.64	-0.95	0.24
St Dev	2.52	4.44	1.90	2.14	2.10	2.06	1.73	2.26	2.24	3.61	1.68	2.97

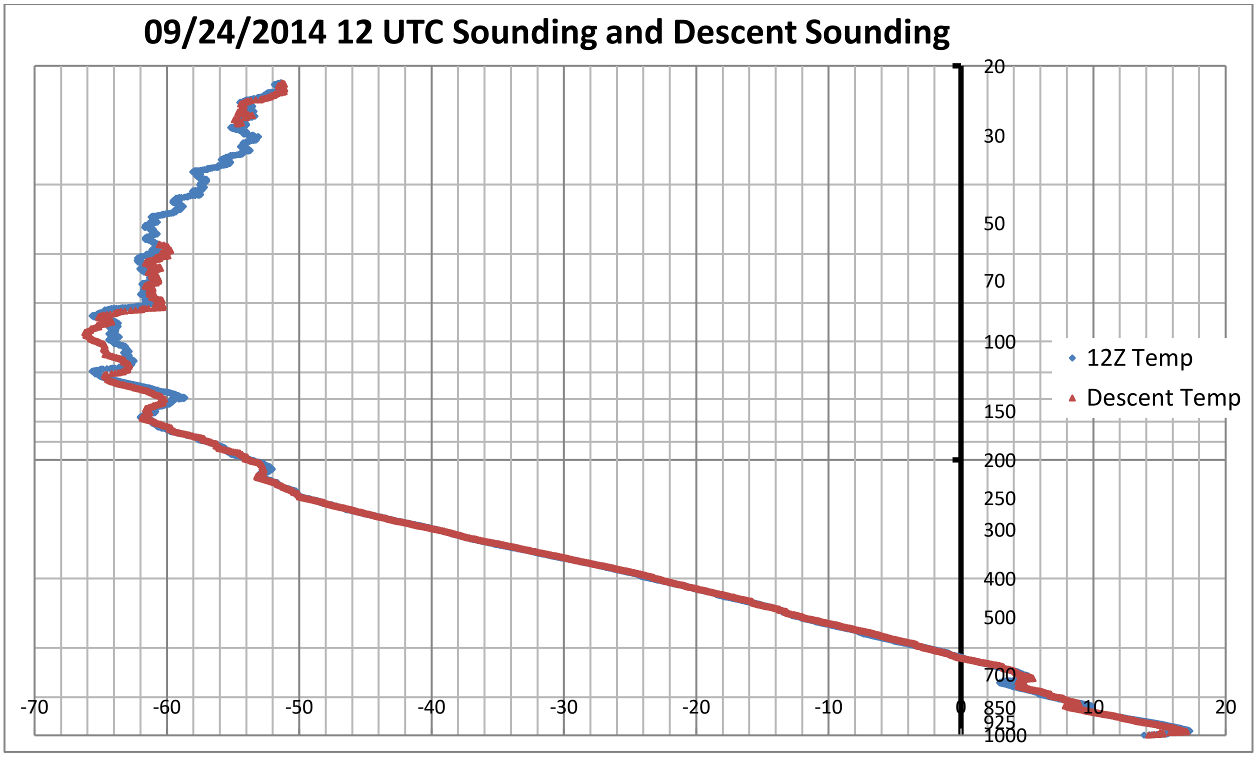


Figure 3. Ascent vs. descent one second temperature plotted vs. log pressure from a radiosonde that came down about a mile and a half from the release point.

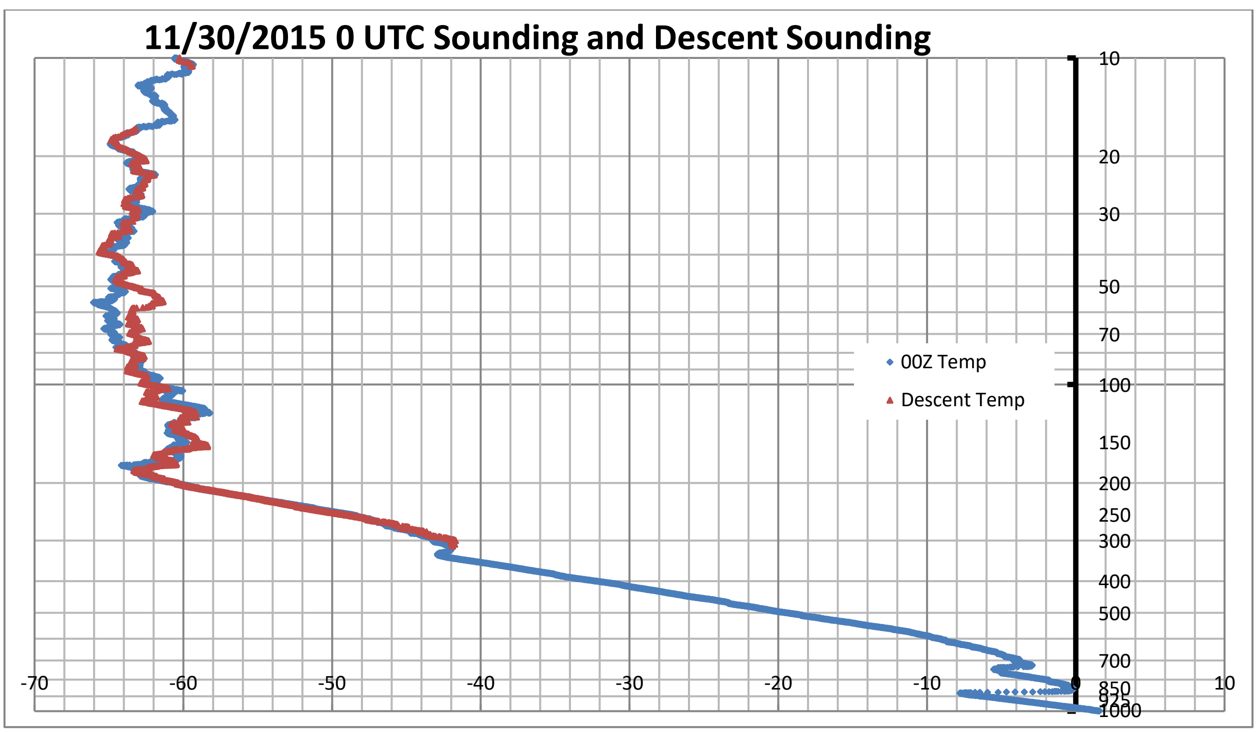


Figure 4. Ascent vs. descent one second temperature plotted vs. log pressure from a radiosonde

that came down far away. Note the last data point is just below 300 mb and is about 212 miles away from the Buffalo release point.

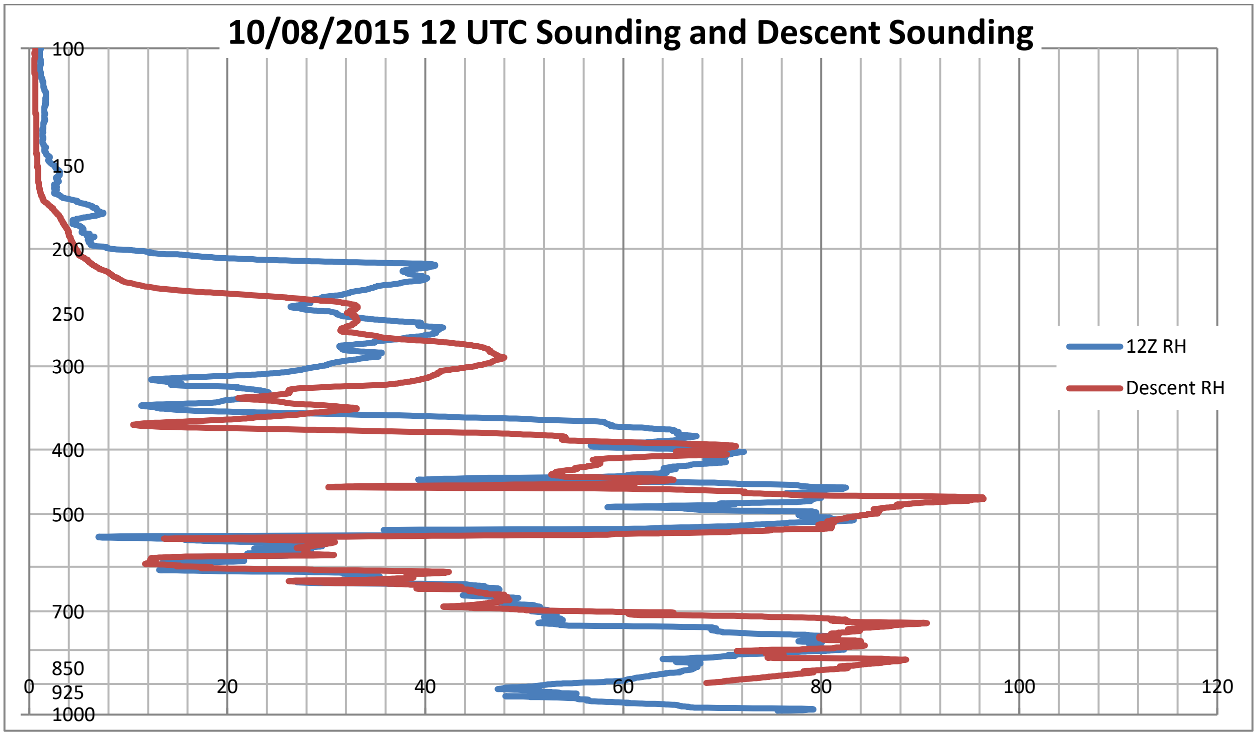


Figure 5. Ascent vs. Descent 1 second relative humidity data. Interesting to note, in nearly all of the descent cases the moist layers, especially the higher layers, are shifted downward.

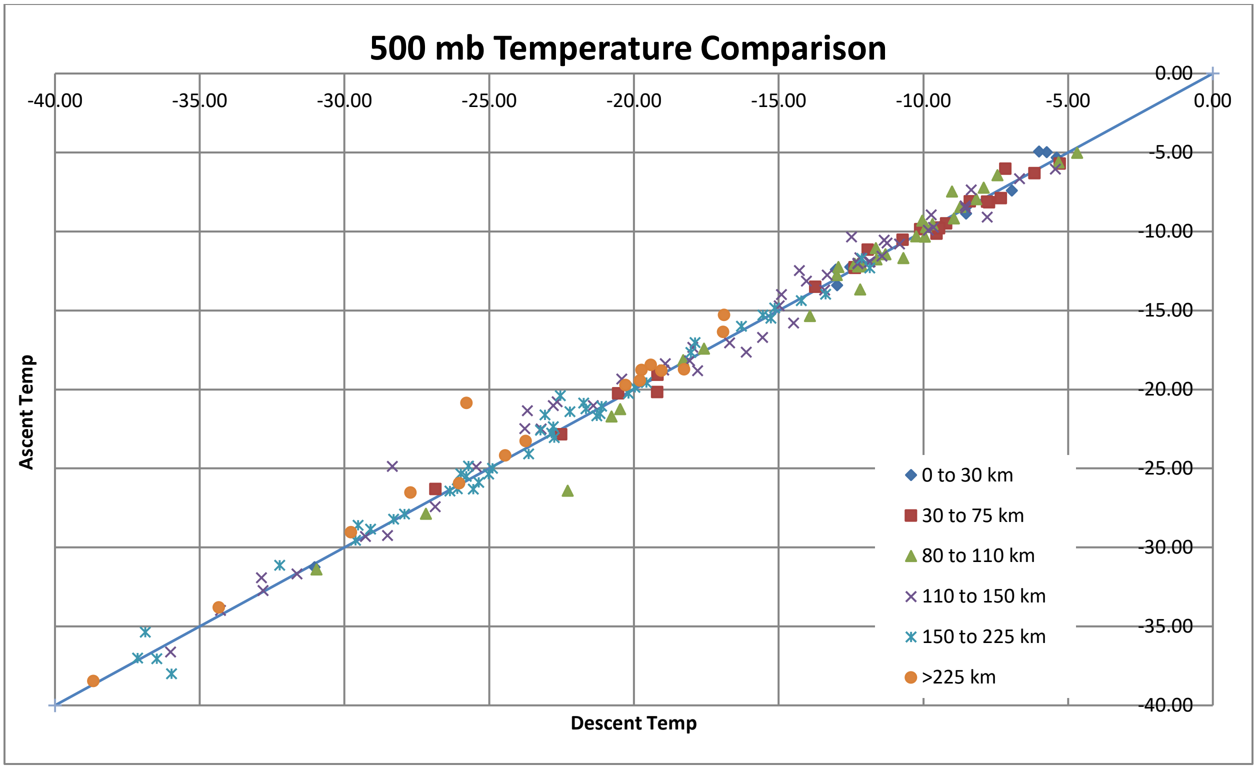
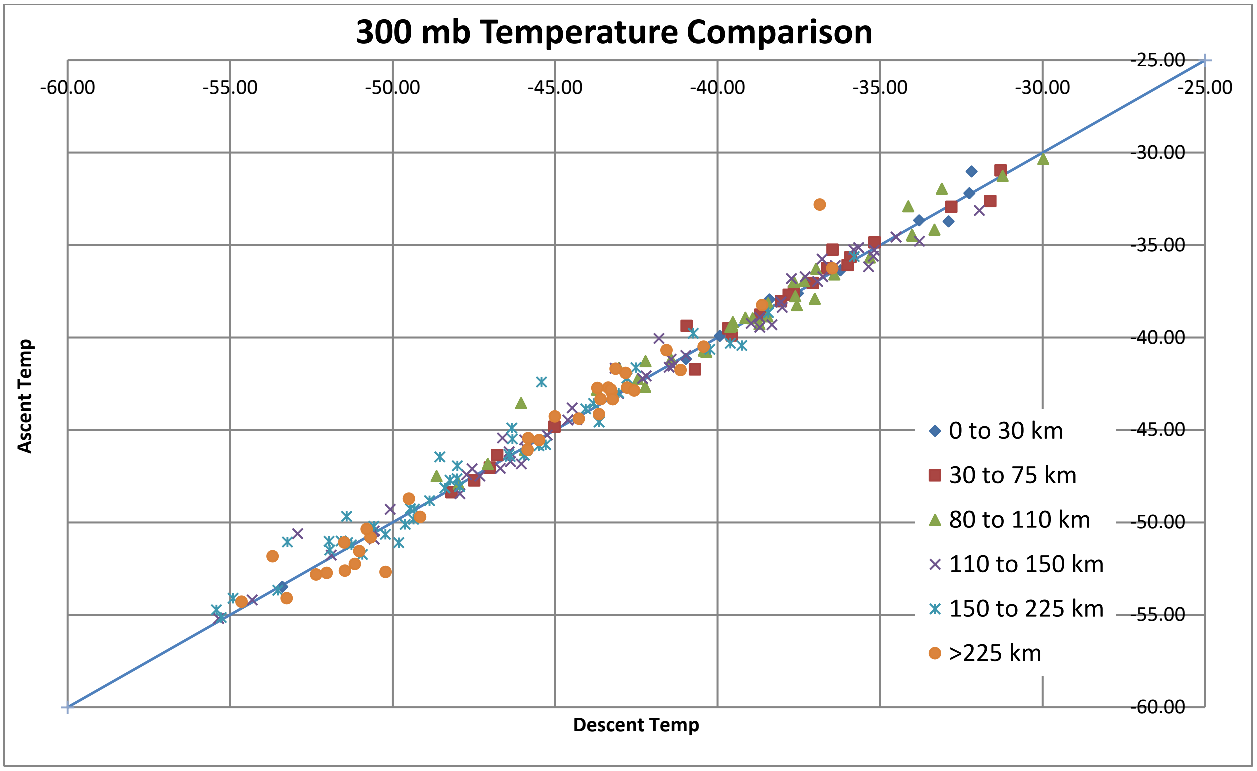
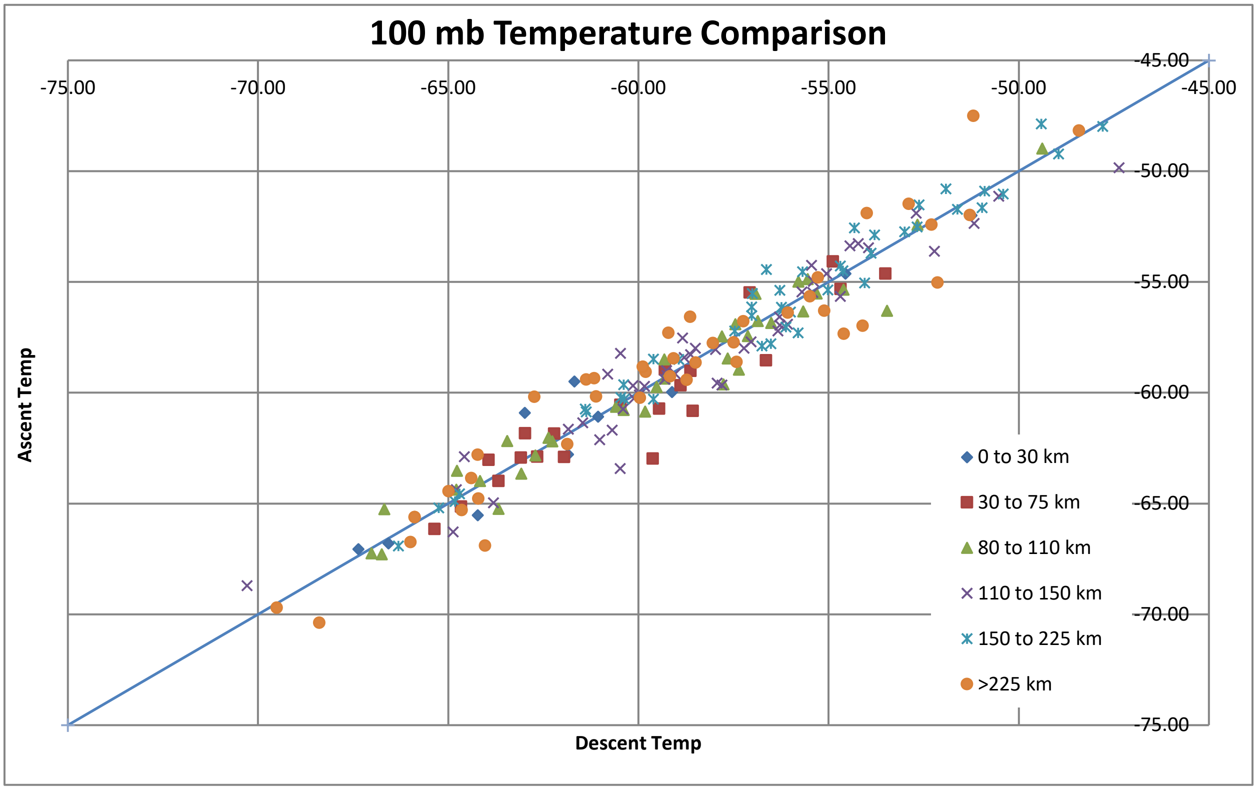


Figure 6. Ascent vs. Descent temperature at 500 mb.





Figures 7 & 8. Ascent vs. Descent temperature at 300 mb and 100 mb, showing very similar temperatures especially at 300 mb.

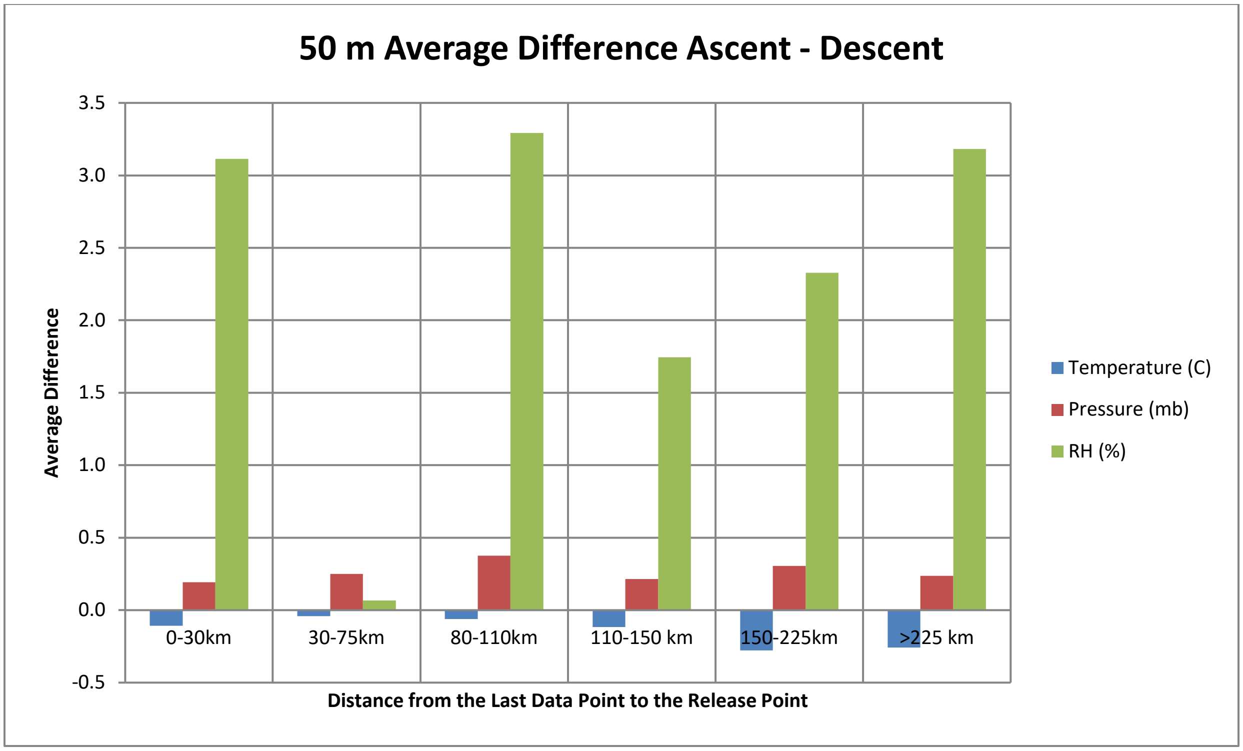


Figure 9. Differences in the temperature, pressure and relative humidity with respect to last data point categories.

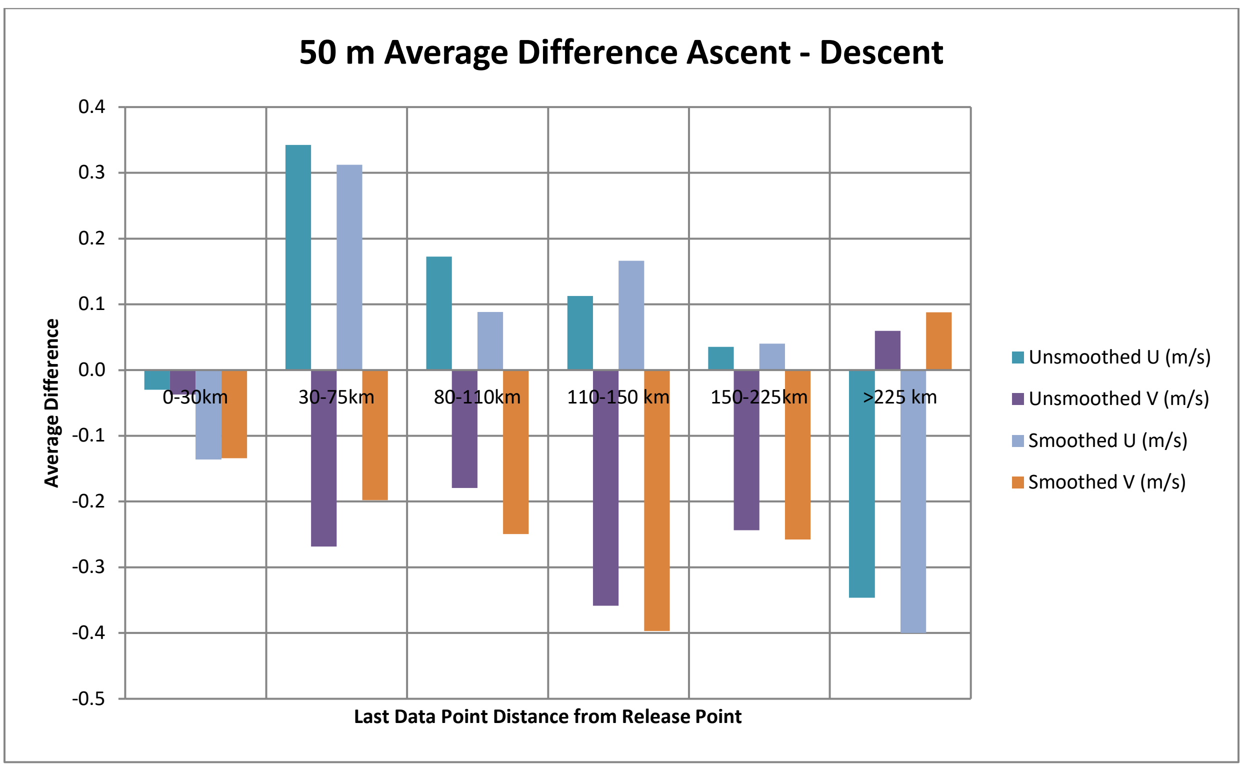


Figure 10. Differences in both the smoothed and unsmoothed U and V wind components, taken at 50 m increments during the flight for each of the last data point categories. Flights in the

categories where the last data point is further from the release point are only sampling the higher level winds.

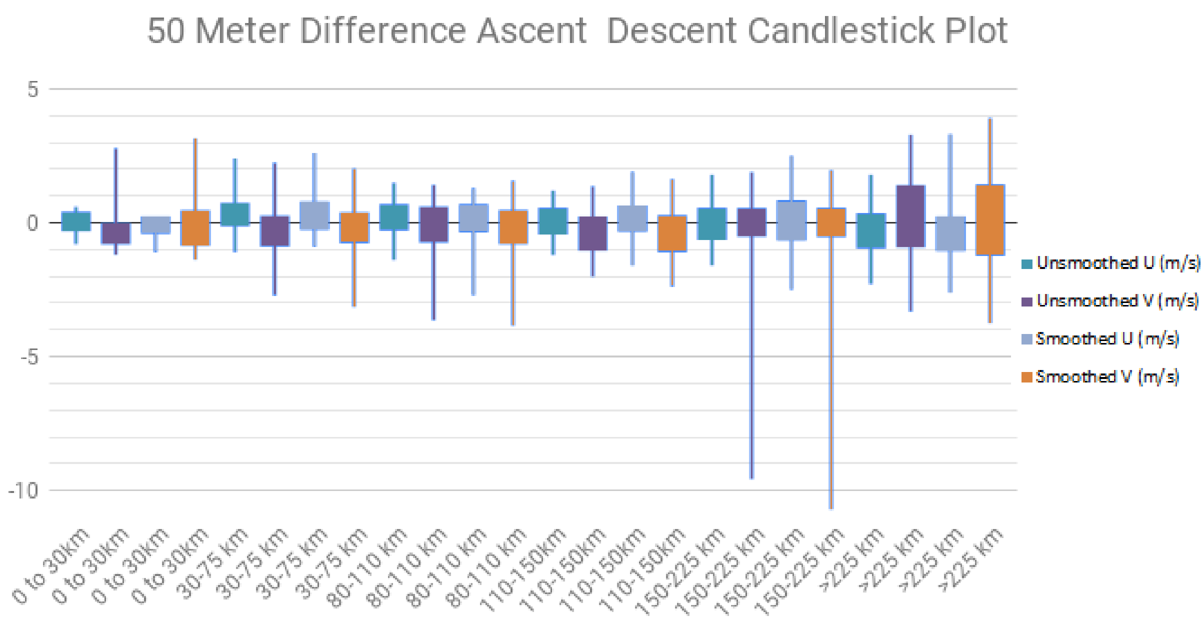
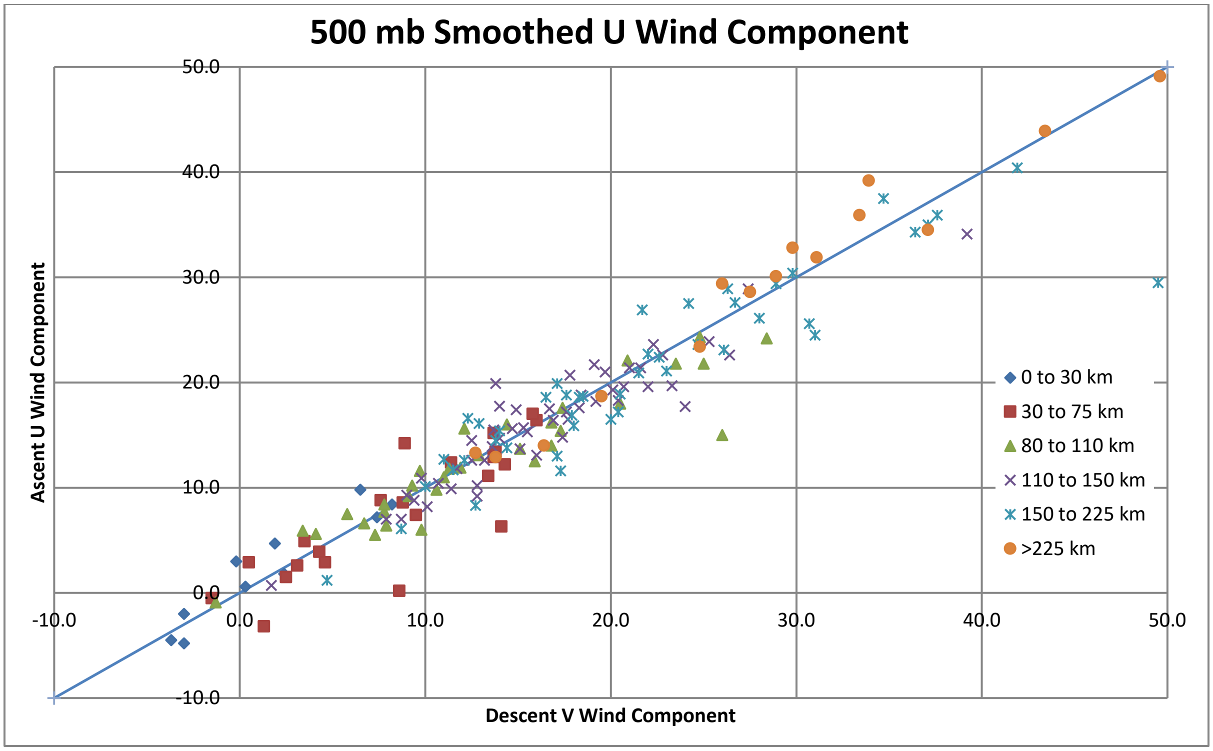
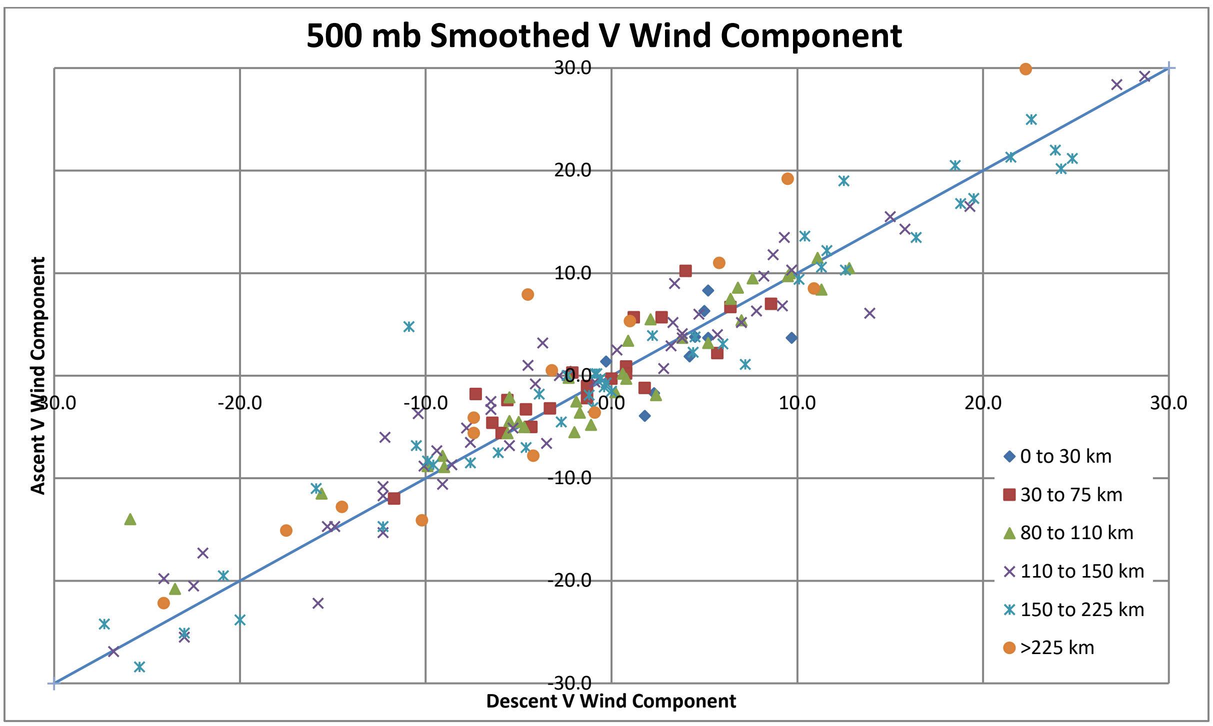
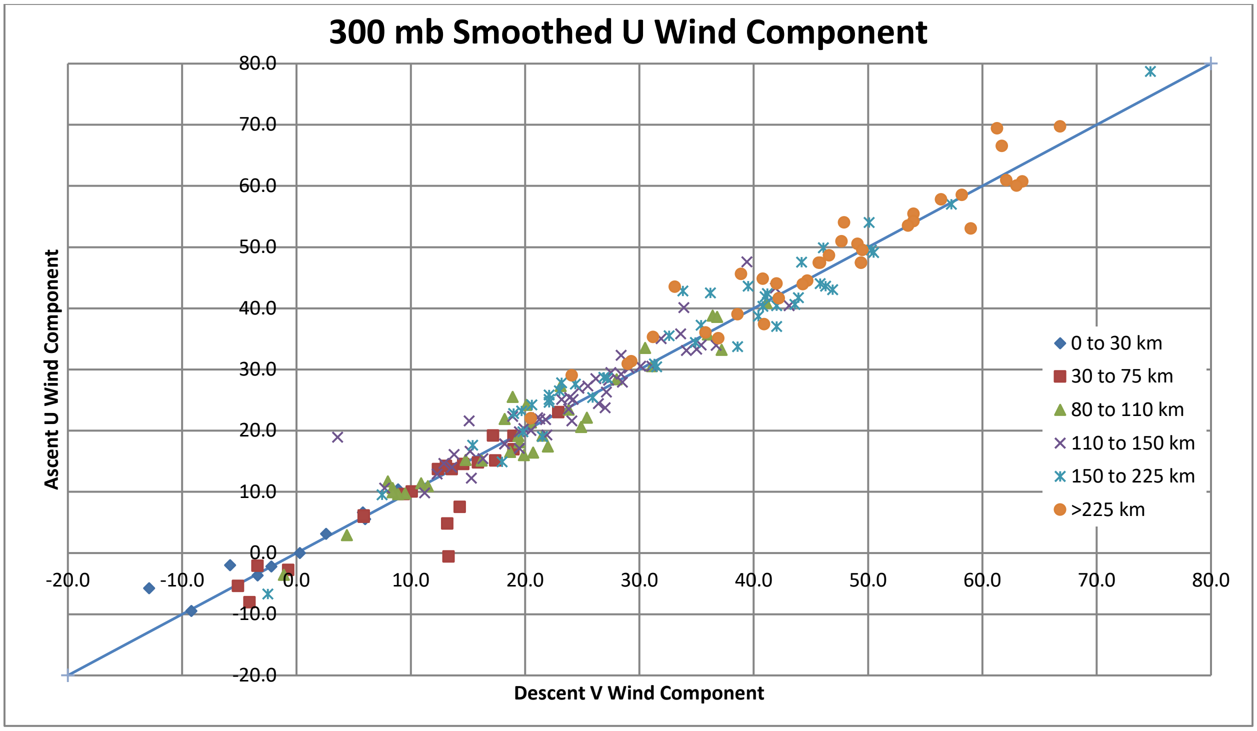


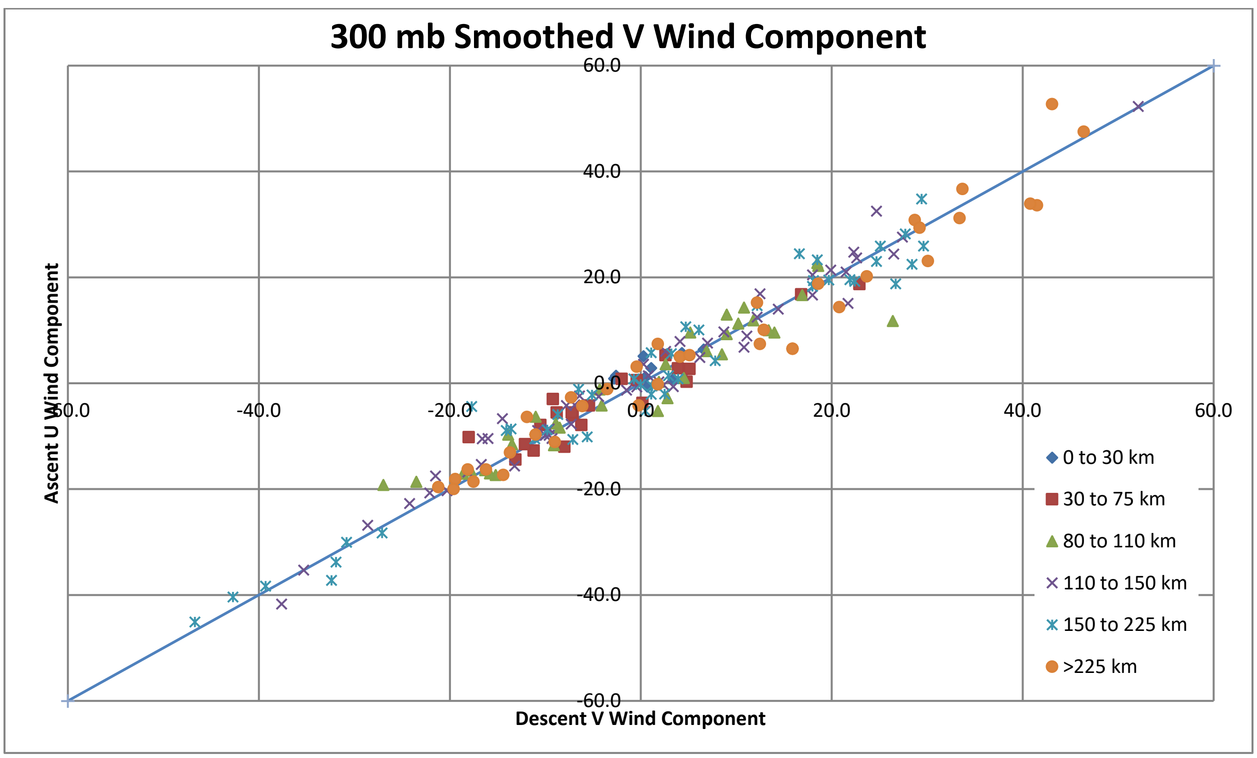
Figure 11. Same dataset as in Fig. 10, however, instead of showing an average of the flights in the last data point category, every flight is shown as a Candlestick plot. Interesting to note the spread in the U (east/west) component in the >225km last data point category. Since the last data point is so far away, upper level winds are strongest and the spread is presumably from the sampling of the jet max at a different in the ascent vs the descent. Aside from a few outliers, differences in wind speed in the descent compared to the ascent are primarily less than 2 m/s.



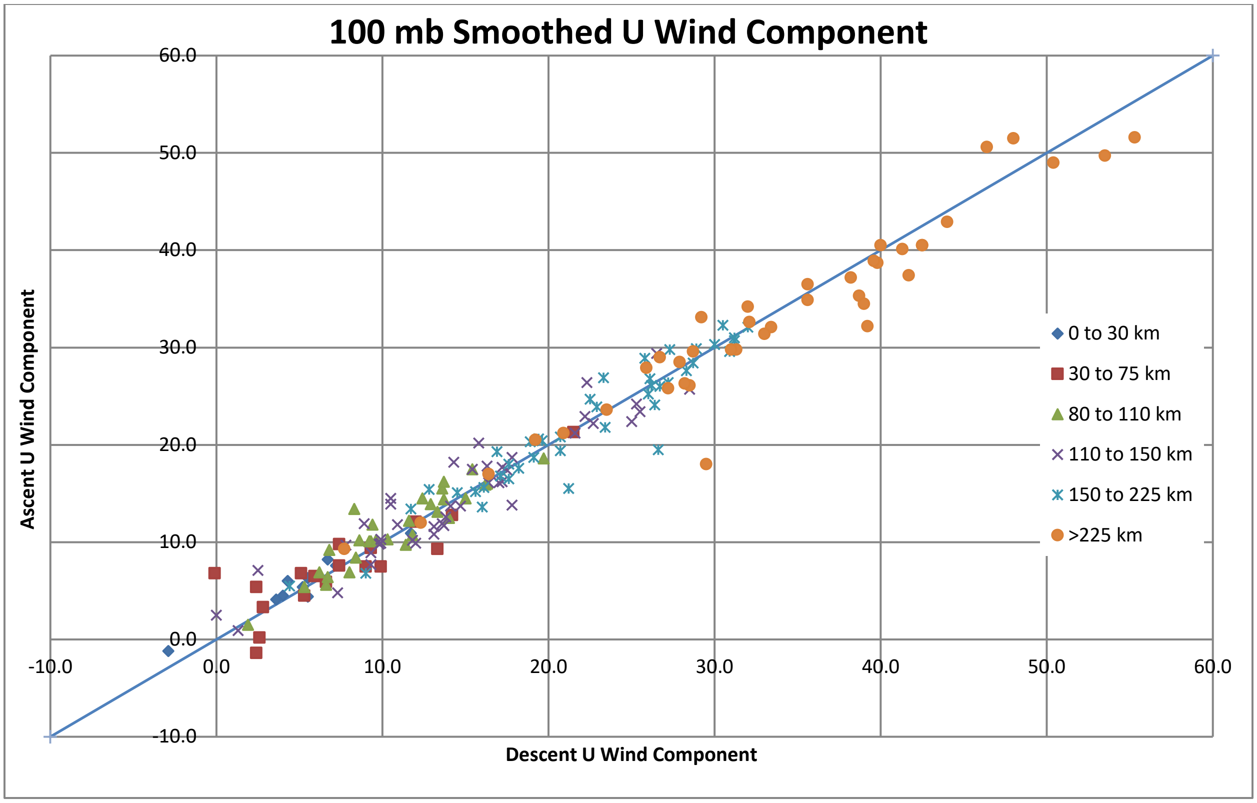


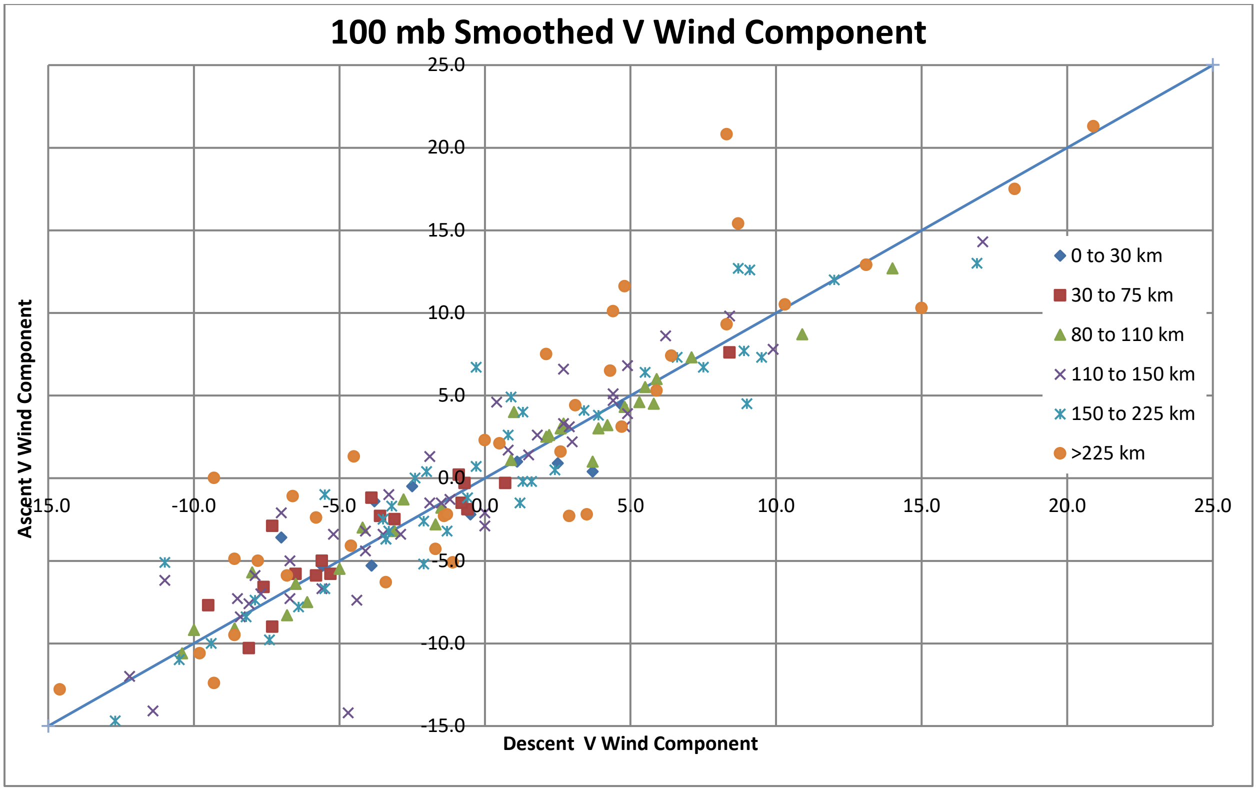
Figures 12 & 13. Smoothed U and V wind components from all 207 flights during the ascent and the descent plotted at 500 mb. Different symbols represent the last data point categories, and the blue line is X=Y.





Figures 14 & 15. Smoothed U and V wind components from all 207 flights during the ascent and the descent plotted at 300 mb. Different symbols represent the last data point categories, and the blue line is X=Y.





Figures 16 & 17. Smoothed U and V wind components from all 207 flights during the ascent and the descent plotted at 100 mb. Different symbols represent the last data point categories, and the blue line is X=Y.

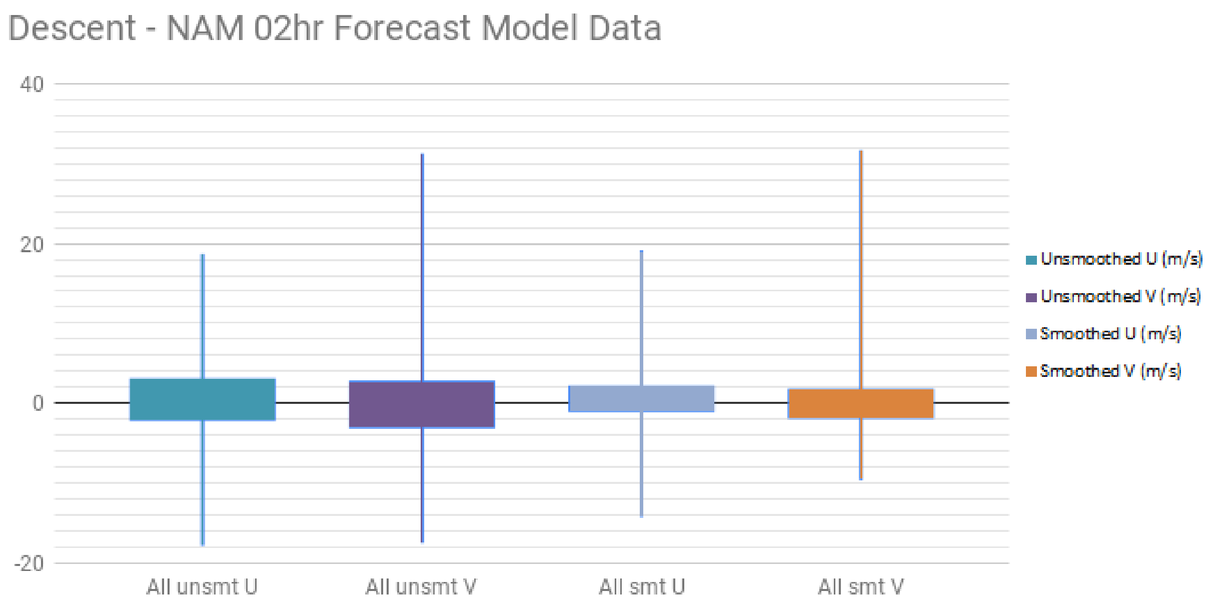


Figure 18. Candlestick plot showing the difference between the NAM 2-hour model forecast and the descent data. Twenty flights were used in this comparison with varying descent rates, and were compared at all levels where data from the NAM and data from the descent were available.

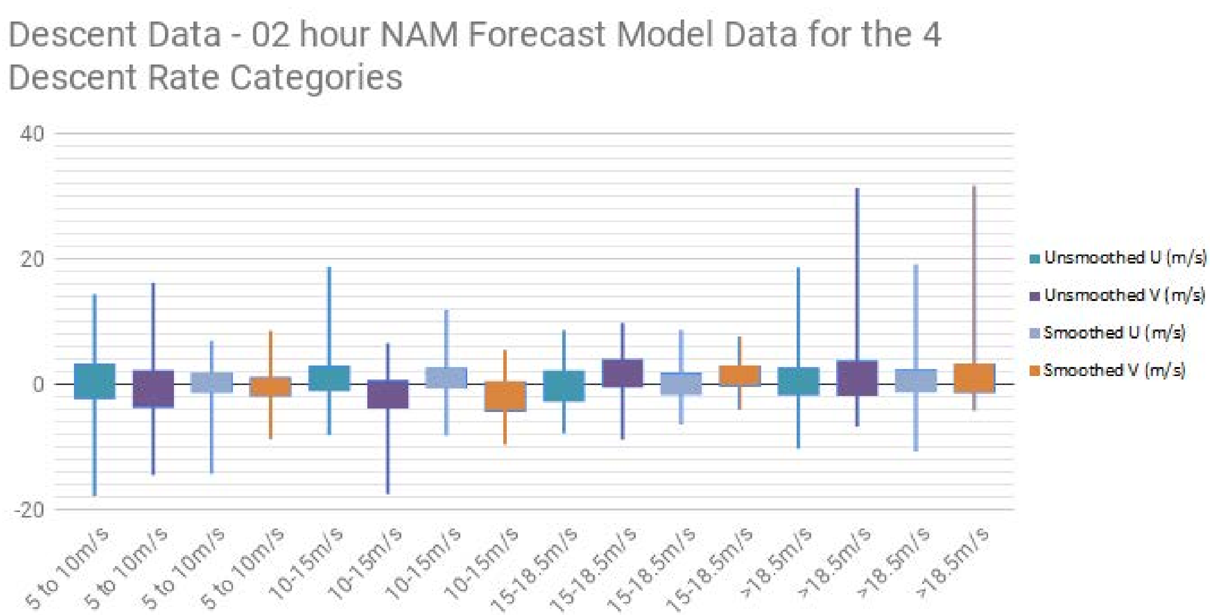


Figure 19. Candlestick plot showing the difference between the descent data and the 2-hour NAM model forecast wind data. A total of 20 flights were used in this comparison with 6 flights with descent rates of 5 to 10 m/s and greater than 18.5 m/s, and 4 flights with descent rates of 10 to 15

m/s and 15 to 18.5 m/s. These categories were selected to determine if descent rates had any impact on wind computations compared to NAM model data.

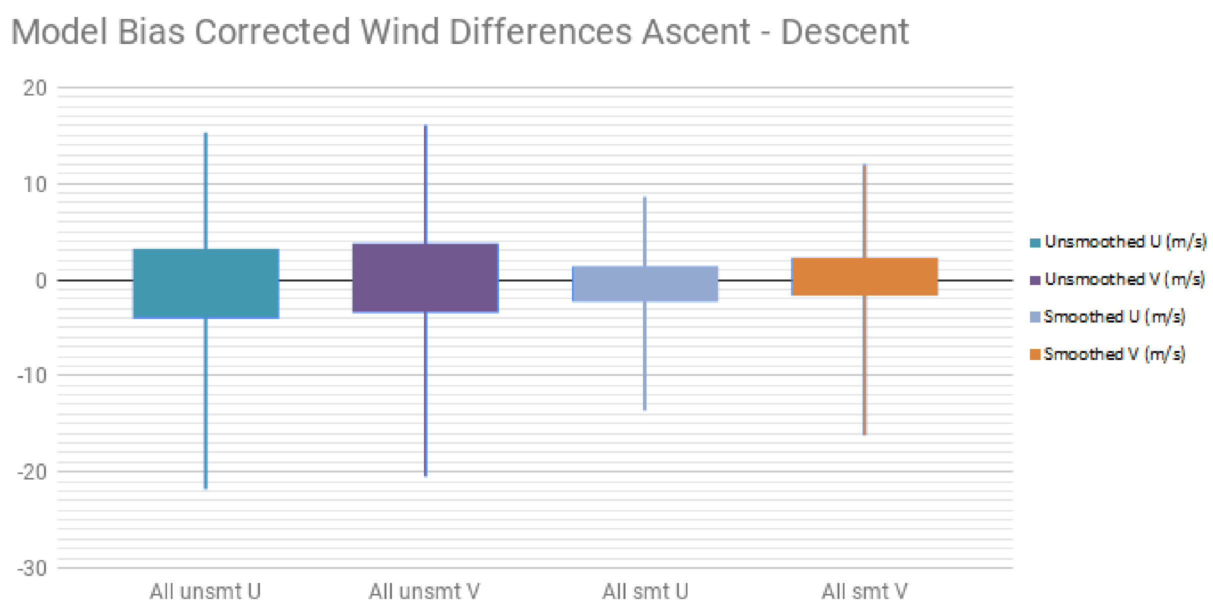


Figure 20. Candlestick plot showing the difference between the NAM 0-hour model forecast and the ascent minus the difference between the NAM 2-hour model forecast and the descent. This method was used in an attempt to eliminate any model bias on the wind speed and direction. Twenty flights were used in this comparison with varying descent rates, and were compared at all levels where data from the NAM and data from the descent were available. Note the difference in the minor gridlines between Fig. 18 and Fig. 20, with 2 m/s and 1 m/s used respectively.

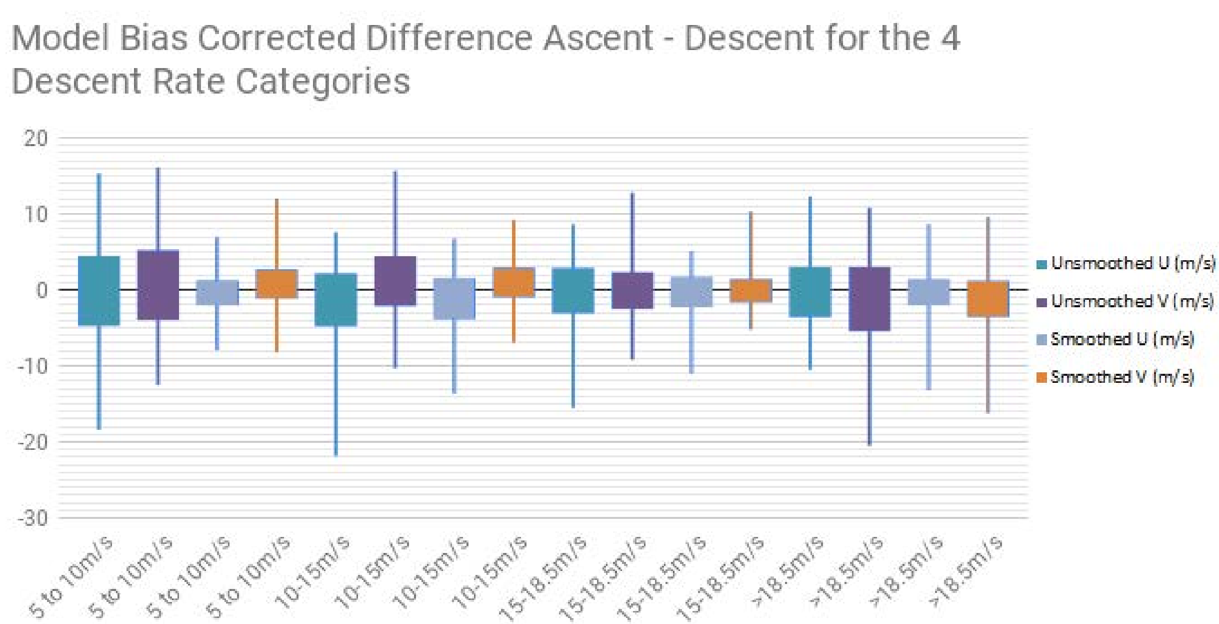


Figure 21. Candlestick plot showing the difference between the NAM 0-hour model forecast and

the ascent minus the difference between the NAM 2-hour model forecast and the descent, for 4 different categories based upon the descent rate. The same flights were used in this chart as were used in Fig. 19, with the model bias removed. Overall the results are better for the smoothed U and V winds than in Fig. 19. Note the scale difference with the minor gridlines at 2 m/s in Fig. 19 and 1 m/s in Fig. 21.

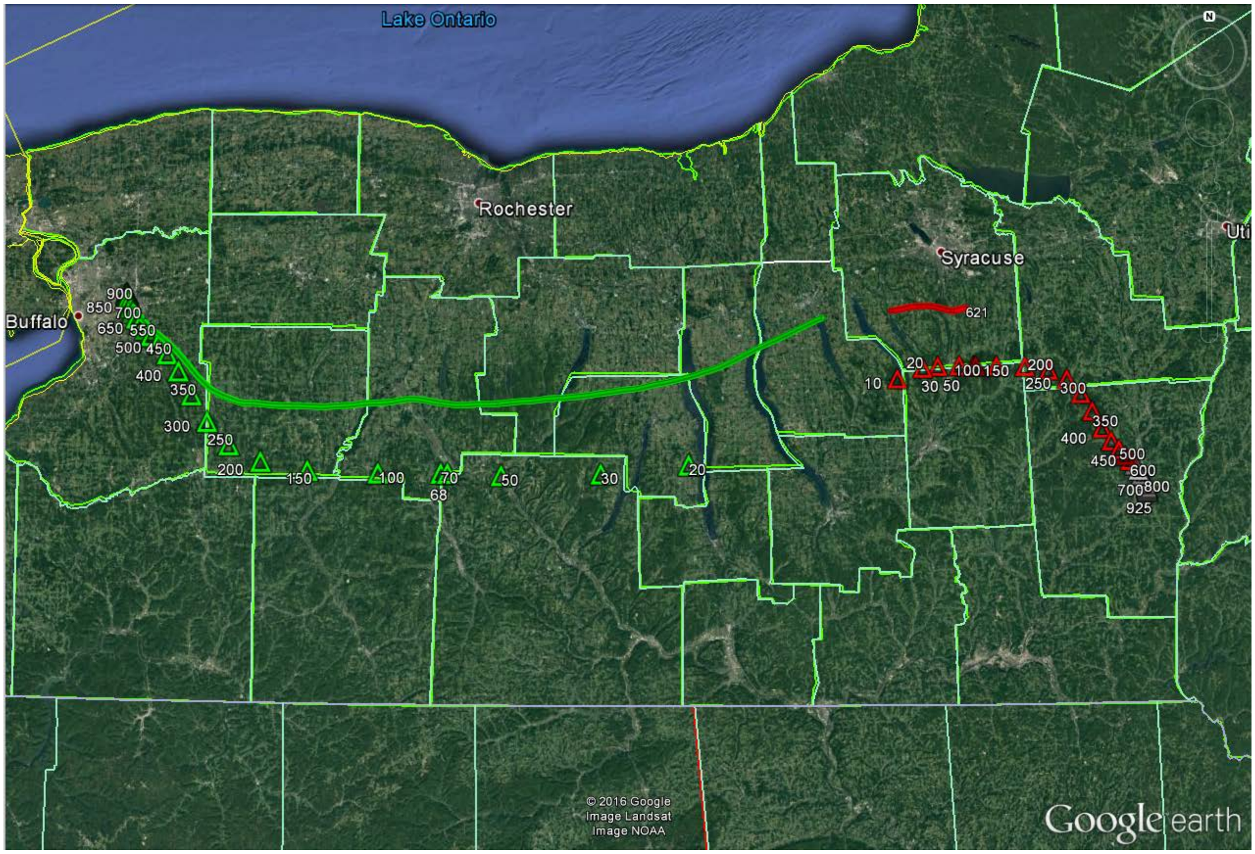


Figure 22. The RAOB on Jan 3 2014 at 12 UTC, showing the actual 1 second position of the ascent (green dots) and descent (red dots), as well as the forecast flight trajectory ascent (green triangles) and descent (red triangles). The forecast trajectory is courtesy of the University of Wyoming Atmospheric Sciences website, and is a 12-hour forecast from the 00 UTC Jan 3 2014 GFS run. Pressure levels of the forecast data points are labeled, as is the last data point from the actual descent. This flight had a large difference between the wind values when comparing the ascent to the descent and, as seen the in image, a fair discrepancy between the actual and forecasted track.

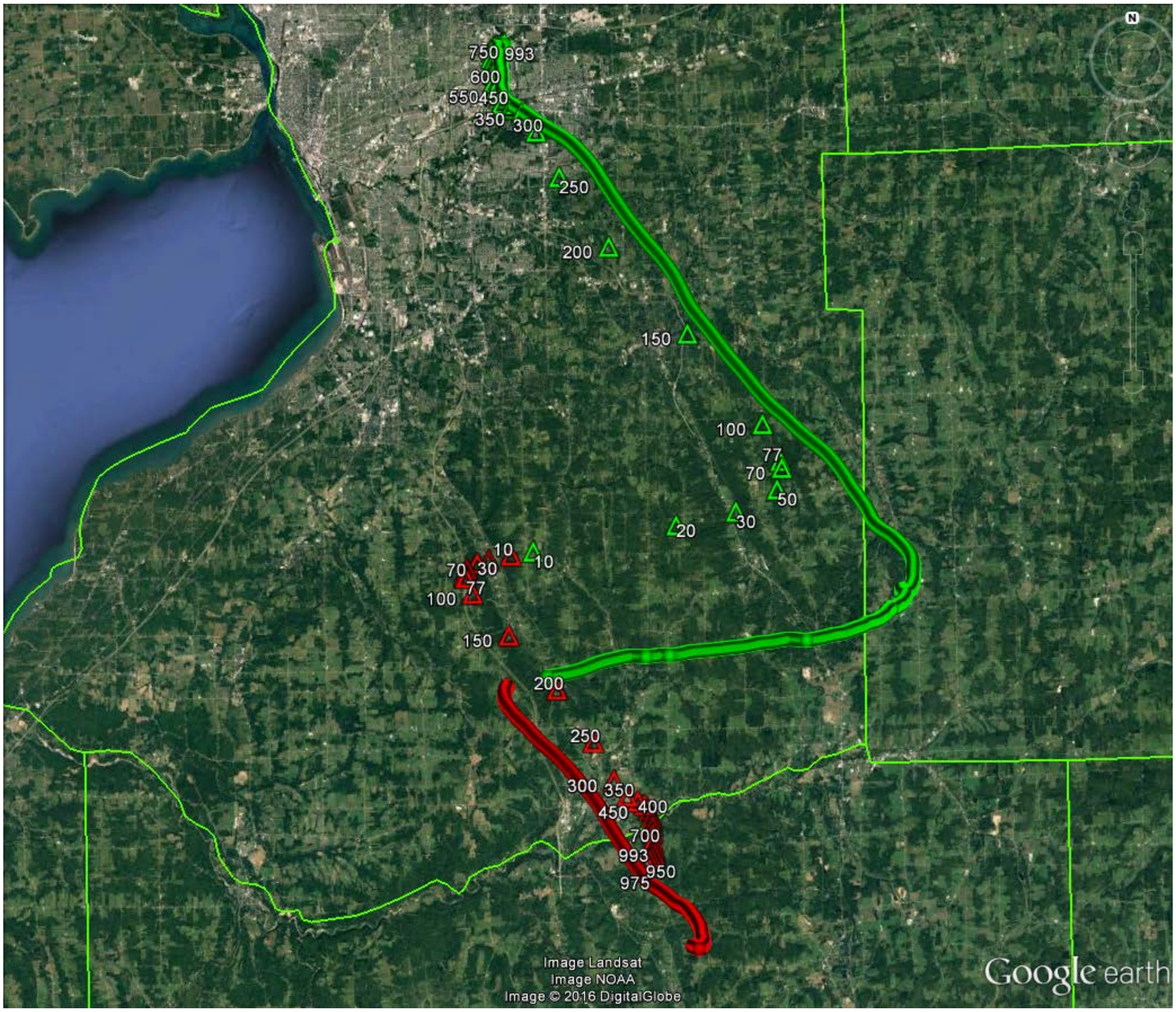


Figure 23. This is the RAOB from 8/9/2014 at 12 UTC. The observed 1 second position of the radiosonde is in the small dots, while the 12-hour trajectory forecast from University of Wyoming and the 8/9/2014 0 UTC run of the GFS is represented by the triangles, with the pressure levels labeled. Green represents the ascent, while red is the descent.

4. Conclusions

The accuracy of RAOB descent temperature data correlates very well with the ascent temperature data, with an average difference of only -0.16° C for the 207 RAOBS included in this study. Based on this study descent temperature data would provide additional data to the Numeric Weather Prediction Models and could improve accuracy. As seen in Petersen (2016), RAOBs result in a reduction in error for a 24-hour temperature forecast of 15% +/- 5% of the Numeric Weather Prediction Models. Additionally, this data could be used to identify erroneous data (e.g. super adiabatic lapse rates from evaporative cooling on the temperature sensor) and improve the accuracy of the data archive.

Relative Humidity data should be used with caution, as moisture profile features trend lower in the descent data than in the ascent data. Additionally, RH values exceeding 100% are reported by the radiosonde when interacting with cloud layers and precipitation.

Descent wind data looks promising as well, however some errors are introduced into the descent wind data due to a more rapid descent rate when the parachute does not deploy properly (as stated earlier, every effort is made by the RAOB Observer to avoid this). This error could be corrected by developing a correction factor to be applied to the data, with values based upon the descent rate.

One thing to consider with respect to the accuracy of the wind data is, for the balloon descent, the size and shape of the flight train is known (e.g. balloon size, train length and resulting pendulum action, etc.). Since the state of the flight train is known for the ascent, the winds can be accurately computed (e.g. a wind of xx m/s would move a 6-foot diameter balloon xx meters). However, one of the challenges of the descent is that the exact state of the flight train is not entirely known. Questions we need to ask are; did the parachute properly deploy? If so, is the wind calculation accurate, as, in theory, it would take a lighter wind to move the radiosonde say 10 m than if the parachute did not deploy properly. Would this even significantly impact the wind calculation? If so, could an algorithm apply a correction factor to the wind speed based upon the descent speed, etc. (Note: Upper Air Observers at the NWS in Buffalo ALWAYS use a parachute and check to ensure they open properly and are free of defects before release).

When compared to the 2-hour NAM forecast, the majority of the smoothed winds were within 2 m/s of the NAM forecasted winds, so the descent winds definitely show promise.

With nearly 88% of the descent flights gathering data down to 500 mb, and over two thirds including the mandatory 700 mb pressure level, descent soundings would provide additional information on upper level features at the same standard pressure levels, but at a different location and time. This additional data could be used to better sample jet stream winds and upper level low pressure systems and shortwaves. Descent RAOB data is definitely worth looking into as a low-cost way of obtaining quality data that could improve Numeric Weather Prediction Model performance as well.

5. Further Study

Per concern number 1 from Mr. Blackmore at NWSHQ in the Introduction, further refining of the wind computation algorithm could provide a more accurate descent wind. Descent data could be collected from several flights where the upper air release points are very close. An example would be Davenport, IA (KDVN) and Lincoln, IL (KILX). In times of northwest flow, descent wind data could be collected from the KDVN RAOBs, then compared to the ascent winds from the synoptic RAOB from KILX. Compare the winds based upon the descent rates of the KDVN data, then refine the algorithm based on different descent rates (this would determine if the parachute was operating as designed or failed). Data used for this study may be found at https://www.weather.gov/media/erh/Data_Analysis_2.xlsx.

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