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CLIMATOLOGICAL STUDY OF THE SHORT-TERM VARIATION OF THE 0°C, -10°C, AND -20°C ALTITUDE LEVELS OVER THE FLORIDA SPACEPORT

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Executive Summary

For evaluation of the potential of cloud electrification, it is necessary to know the altitude of the 0, -10 and -20 degree Celsius levels. Cape Canaveral Air Force Station has recorded balloon launch data back to 1989. In support of rocket launches, often multiple balloons are launched within minutes of each other in the 4-6 hours leading up to launch. In the past, temperature data from sondes was typically available every hour or so through the launch countdown, allowing for frequent updates of these critical temperature thresholds. Recently, launch customers are relying on Jimsphere and wind profiler data that do not have a thermodynamic component in the latter 4-6 hours of a countdown. This study compares the altitude differences of the 0, -10 and -20 degree Celsius levels from consecutive balloon pairs not to exceed 6 hours apart. The analysis uses 9685 soundings from 1989 to 2013. Approximately 5% of the time the altitude of the temperature level in question (0, -10, -20 degrees C), varies by more than 500 feet (operationally significant threshold) within 6 hours. This study analyzes the altitude variability as a function of several meteorological parameters, such as change in sonde type, dew point depression, and solar zenith angle. Additionally, the study concludes with impacts to launch operations.

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Introduction

The 45th Weather Squadron (45 WS) is the U.S. Air Force unit that provides weather support to America's space program at Cape Canaveral Air Force Station (CCAFS) and National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC). (Harms et al., 1999). A major part of the 45 WS support to launch is evaluating and forecasting the Lightning Launch Commit Criteria (LLCC) (Roeder et. al., 1999). The LLCC protect against natural and rocket triggered lightning strikes to the in-flight rocket (Roeder et. al., 2006). Launching through electrified clouds resulting in triggered lightning is a primary weather hazard to spaceflight operations (Merceret et. al., 2010). Evaluation of the LLCC requires knowing the altitude of the 0°C, -10°C, and -20°C temperature levels. In the past, to support rocket launches, multiple low-resolution rawinsondes were released every hour or so through the launch countdown window allowing for frequent updates of these critical temperature levels. Recently, however, launch customers have been relying on high-resolution Jimspheres and Doppler Radar Wind Profiler (DRWP) data that do not have a thermodynamic component in the latter 4 to 6 hours of a countdown. Therefore, frequent updates of the altitudes of the critical temperature levels would not be available, leading to the question of how much those altitudes might change given the new longer latency between measurements. Surprisingly, no information was available on temperature altitude changes vs. time, and certainly not specifically for the Florida Spaceport. Therefore, to better assess the impact on LLCC evaluation, the 45 WS asked the Applied Meteorology Unit (AMU) to determine the probability of a 500 foot or more change in the altitude of these temperature levels in less than 6 hours so that it could be determined if additional low-resolution radiosondes should be released nearer to launch time. The 500 foot or more value was chosen because is close to the operational limit of the radar, so changes greater than that are technically detectable and 6 hours was chosen because 6 hours prior to T-0 is a typical time for when a low-resolution rawinsonde is released during a launch countdown.

Historical Data

The AMU looked at rawinsonde data that had been previously downloaded for other AMU projects with a period of record of January 1989 through July 2013. Only the warm season months (May through September) had at least one pair of daily rawinsondes launched less than 6 hours apart during this period. Also in 2001, the Eastern Range switched to Global Positioning System (GPS) tracked sondes from radar tracked sondes. The data from the radar tracked sondes showed much more variability than the GPS tracked sondes. To eliminate the variability from uncertainty of radar tracking vs. GPS tracking, only the GPS-tracked data were used. This analysis used 3,198 pairs of soundings from warm seasons for years 2001 to 2013. Time series of the 0°C, -10°C, and -20°C temperature level altitude changes by year are shown in **Error! Reference source not found.** , 2, and 3.

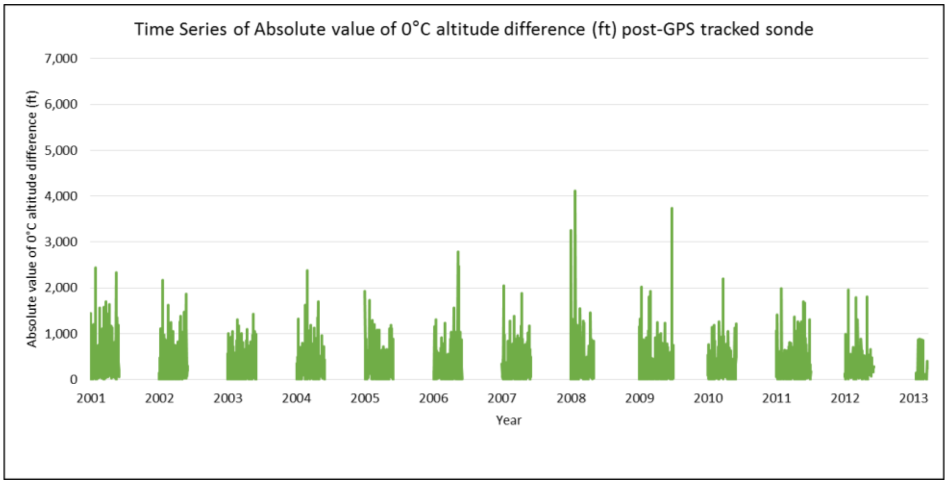

Figure 1. Time series of the 0°C temperature level altitude changes by year (2001 to 2013 warm season)

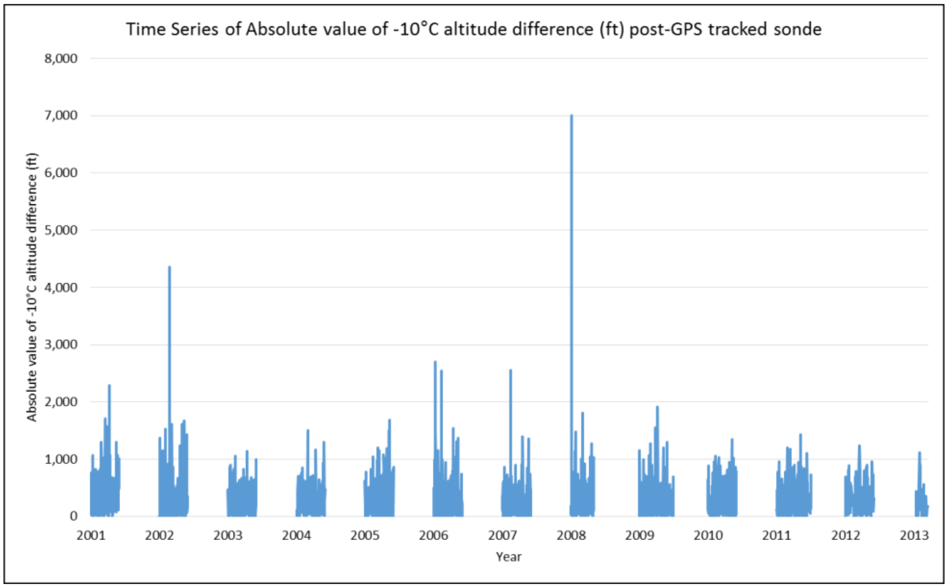

Figure 2. Time series of the -10°C temperature level altitude changes by year (2001 to 2013 warm season)

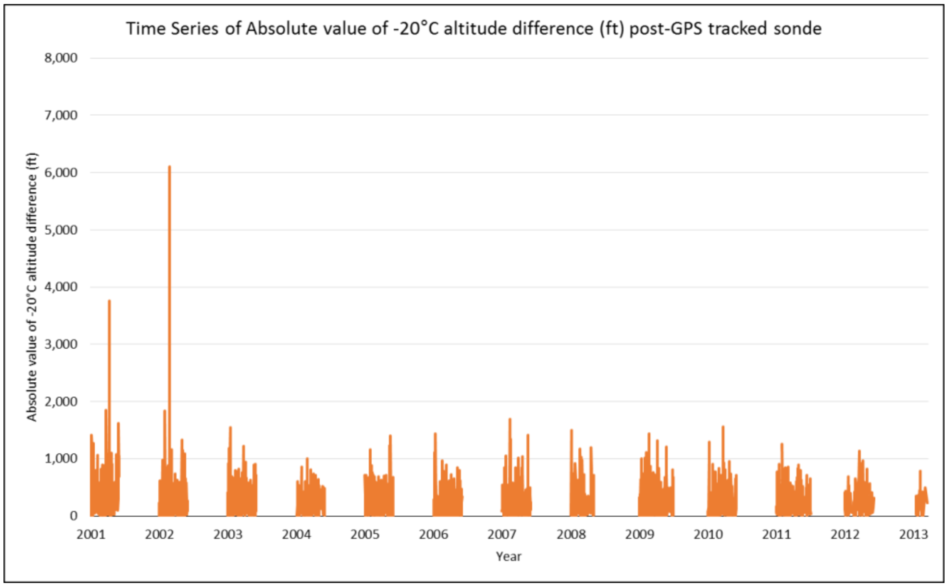

Figure 3. Time series of the -20°C temperature level altitude changes by year (2001 to 2013 warm season)

Results

In order to accurately calculate the probability of a particular change of altitude for 0°C, -10°C, and -20°C temperature levels, the distribution of the absolute value of the altitude differences had to be determined. The AMU plotted percentile curves of the absolute value of the altitude differences (in feet) for the GPS-tracked rawinsondes at each of the desired temperature levels. These percentile curves are shown in Figures 4, 5, and 6.

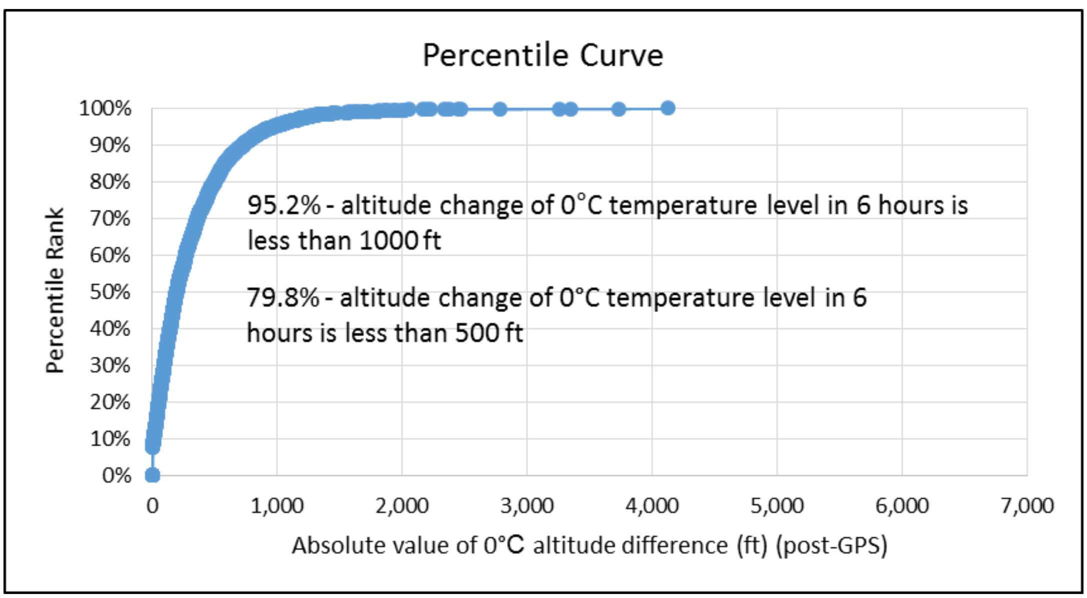

Figure 4. Percentile curve for the absolute value of the 0°C altitude difference (in feet) of post-GPS tracked sondes.

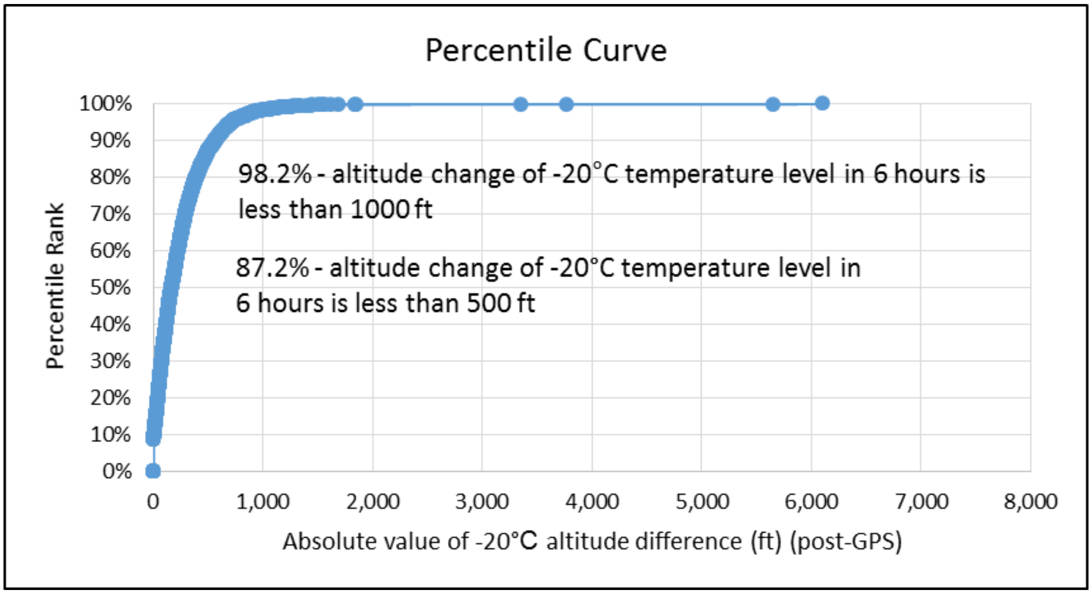

Figure 5. Percentile curve for the absolute value of the -10°C altitude difference (in feet) of post-GPS tracked sondes.

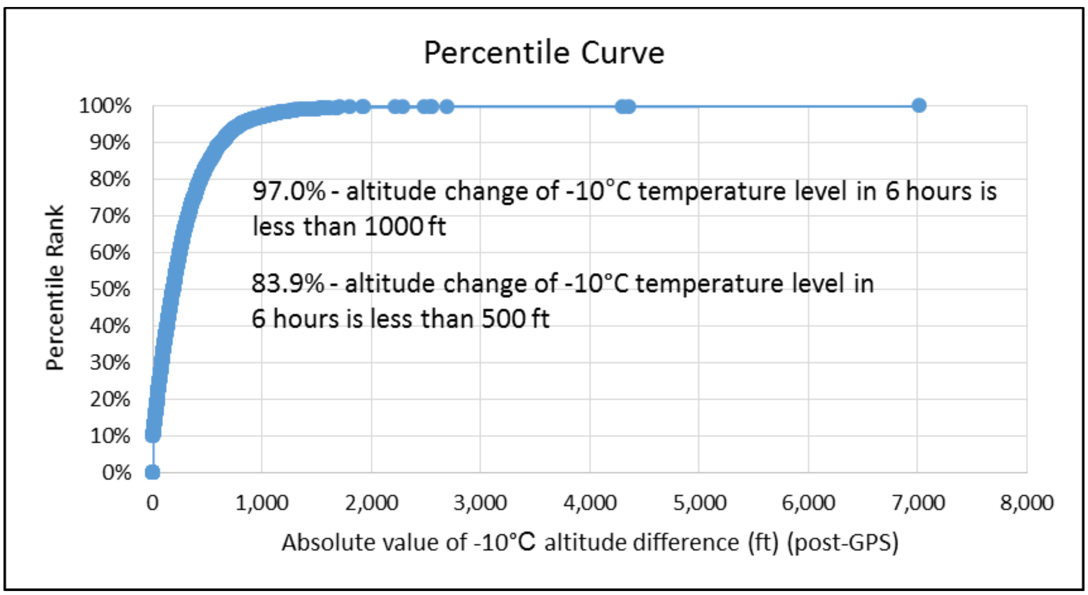

Figure 6. Percentile curve for the absolute value of the -20°C altitude difference (in feet) of post-GPS tracked sondes.

Because the ultimate goal was to have an equation to calculate the probability of a given altitude difference within a given time interval for each of the temperature levels, the AMU performed goodness-of-fit tests for each of the percentile plots for the most common distributions (e.g. normal, log-normal, exponential, Weibull, gamma, logistic, extreme values). Unfortunately, the goodness-of-fit test failed for all of the attempted distributions. The AMU was able to perform Monte Carlo resampling analyses to verify the percentages, however.

Next the AMU performed regression analyses with several variables easily obtained from the rawinsonde data sets. The first regression performed attempted to find a relationship between the absolute value of the 0°C, -10°C and -20°C altitudes differences and the hours elapsed between released balloons. The hypothesis was that the absolute value of the altitude difference would be directly proportional to the time difference between the released balloons. The best case (for the -10°C temperature level) showed that the time elapsed between balloons only accounted for about 6% of the variation of altitude difference. The time elapsed regressions for the 0°C, -10°C, and -20°C altitudes are shown in Figures 7, 8, and 9.

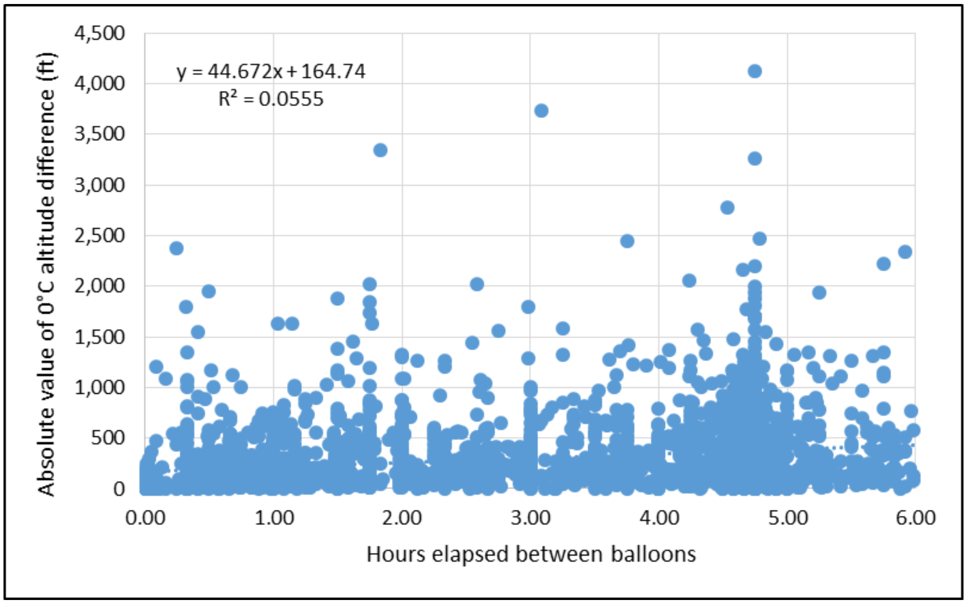

Figure 7. Linear regression results for the hours elapsed between balloon releases and the absolute value of the 0°C altitude difference (in feet) of post-GPS tracked sondes.

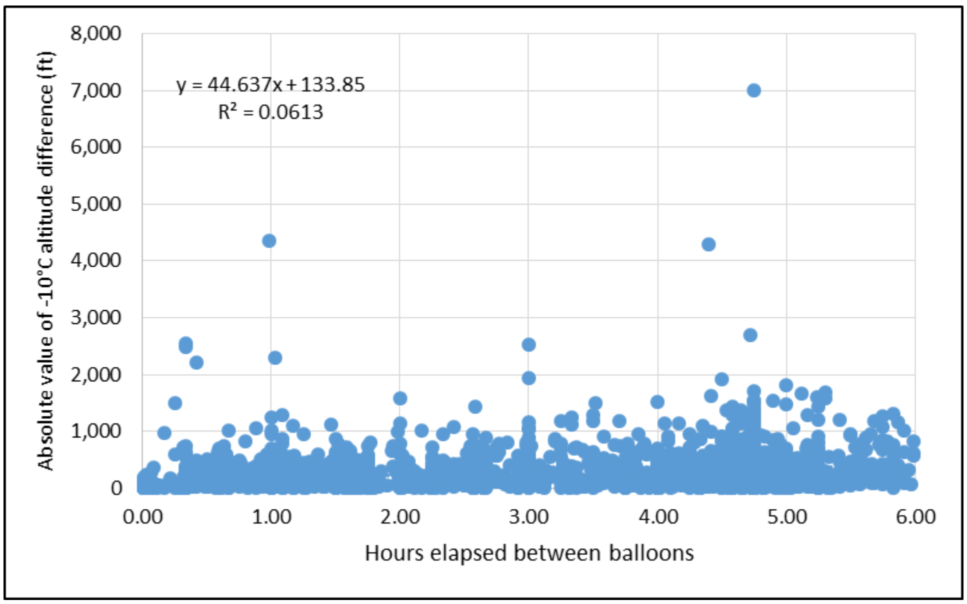

Figure 8. Linear regression results for the hours elapsed between balloon releases and the absolute value of the -10°C altitude difference (in feet) of post-GPS tracked sondes.

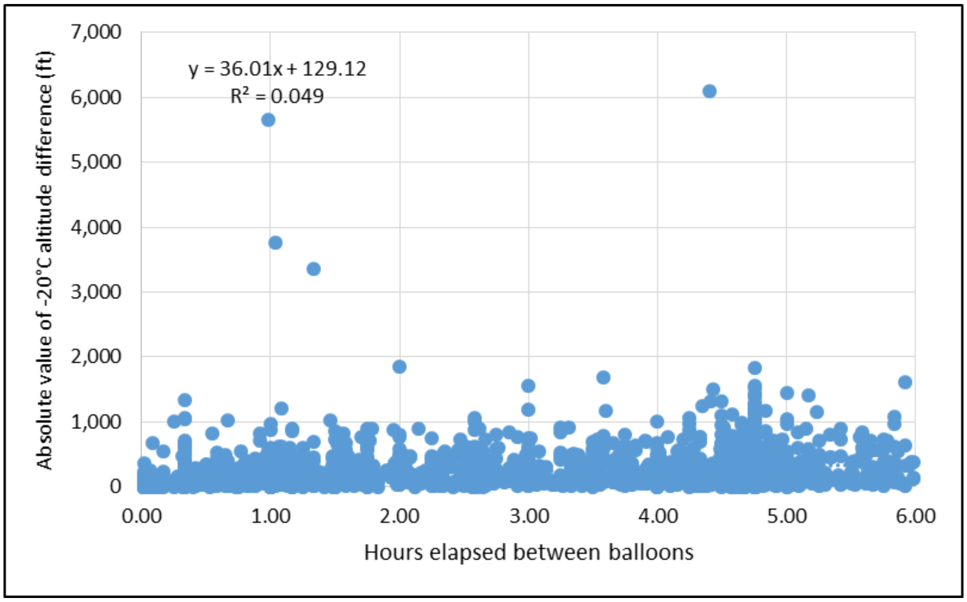

Figure 9. Linear regression results for the hours elapsed between balloon releases and the absolute value of the -20°C altitude difference (in feet) of post-GPS tracked sondes.

Finally, the AMU attempted to find a relationship between the altitude differences of the selected temperature levels and some proxy variables for clouds and solar heating. The rationale being that if the balloon ascended into a cloud (by proxy, various dew point depression measurements) or ascended during max solar zenith (by proxy, solar heating) that one of these may have correlated to greater temperature differences. The dew point depression of the later rawinsonde, the maximum dew point of the pair of rawinsondes, the dew point depression difference between the pair of rawinsondes, and the solar zenith angle of the later rawinsonde were regressed against the absolute value of the 0°C, -10°C and -20°C altitude differences in the attempt to find a correlation. The best case (for the 0°C temperature level) showed that the maximum dew point between the pair of rawinsondes only accounted for about 1.5% of the variation of altitude difference. Figures 10, 11, 12, and 13 show the correlation results for the above variables for the 0°C altitude levels. The results for the other temperature levels are similar but not shown here.

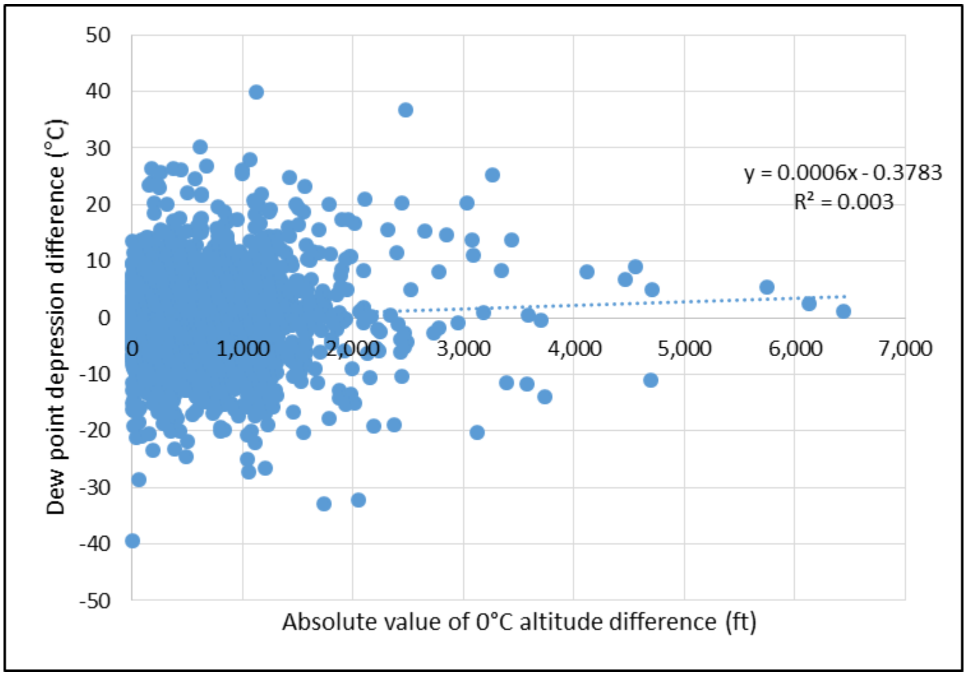

Figure 10. Linear regression results for the absolute value of the 0°C altitude difference (in feet) and the dew point depression difference of the rawinsonde pair.

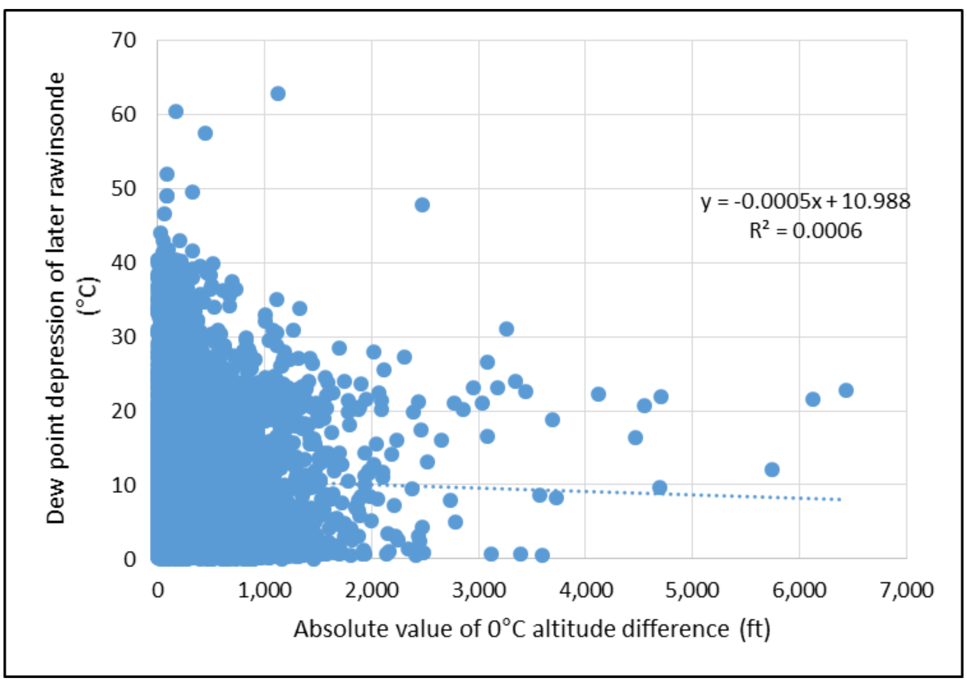

Figure 11. Linear regression results for the absolute value of the 0°C altitude difference (in feet) and the dew point depression of the later rawinsonde.

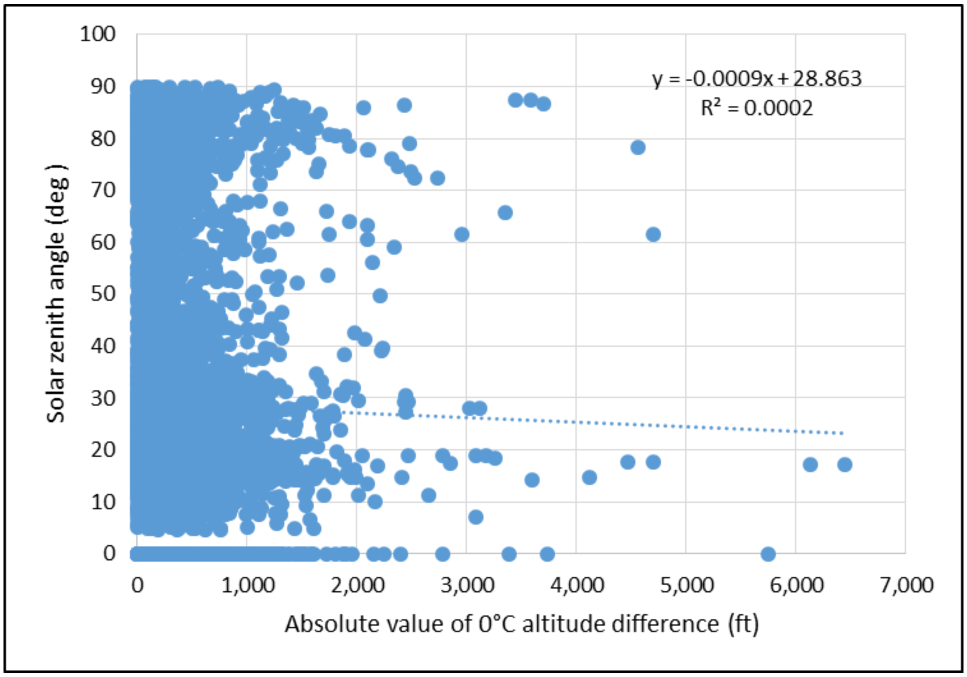

Figure 12. Linear regression results for the absolute value of the 0°C altitude difference (in feet) and the solar zenith angle of the later rawinsonde.

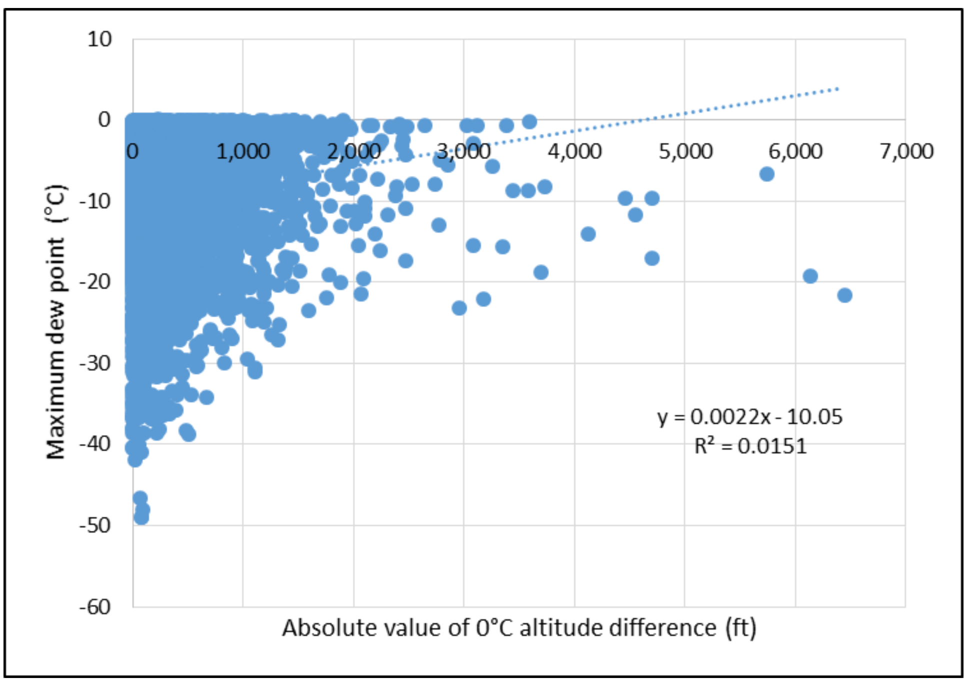

Figure 13. Linear regression results for the absolute value of the 0°C altitude difference (in feet) and the maximum dew point of the rawinsonde pair.

Future Work

The AMU would like to update the period of record to include the warm seasons for 2013 (the above analysis was only through mid-July of 2013) through 2016 and repeat the analysis for more Rawinsonde Observation (RAOB) release differences (e.g. 8 hr, 10 hr, 12 hr,…,24 hr). Another possible action would be to perform some non-linear regression and some spectral analysis and autocorrelation on the time series data to see if any patterns or correlations emerge. Also, the data should be reviewed for outliers that might be excluded from the analysis. Finally, previous data on multiple sondes released at the same time, such as when testing new sonde designs, should be pursued to measure the variability of the temperature altitudes—how much of the change in altitude is due to change in time and how much is due to precision of the measurement? Unfortunately, performing a new study to determine temperature altitude variability is unlikely to occur. The ultimate goal would be to develop a tool that the 45 WS Launch Weather Officer (LWO) could use to provide the probability of exceeding a user-specified temperature level for a selected month.

Conclusion

The AMU was requested to determine the probability of a 500 foot or more change in the altitude of the 0°C, -10°C, and -20°C temperature levels in less than 6 hours. The AMU determined that the probability of short-term changes of 500 feet or more (< 6 hours) of the 0°C, -10°C, and -20°C temperature levels were 20.2%, 16.1%, and 12.8%, respectively. The probability of short term changes of 1000 feet or more of the 0°C, 10°C, and -20°C temperature levels were 4.8%, 3.0%, and 1.8%, respectively. Unfortunately, there was very little correlation of change in altitude of temperature levels with time, dew point depression, dew point depression difference, maximum dew point, or solar zenith angle. However, because the short term changes in the altitude of a particular temperature level was larger than the Launch Weather Team anticipated, the AMU recommended the team request the release of a low-resolution rawinsonde closer to T-0. Since it takes the rawinsonde about an hour to reach maximum altitude, the low-resolution rawinsonde should be released around T-2 hours to allow time for interpretation and in case there is a sonde failure, allowing time for another sonde release.

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List of Acronyms

45 WS	45th Weather Squadron
AMU	Applied Meteorology Unit
CCAFS	Cape Canaveral Air Force Station
DRWP	Doppler Radar Wind Profiler
GPS	Global Positioning System
KSC	Kennedy Space Center
LLCC	Lightning Launch Commit Criteria
LWO	Launch Weather Officer
NASA	National Aeronautics and Space Administration
POR	Period of Record
RAOB	Rawinsonde Observation