

The Utility of 1000 - 500 mb Thickness and Weather Type as a Rain-Snow Divide: A 30-Year Study at Albany, NY

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Abstract

Winter synoptic conditions that produce snowfall with bitterly cold temperatures create both social and economic hazards in the capital city of Albany, NY. Sometimes these systems are forecasted in error to produce rain or mixed precipitation. It is beneficial for meteorologists to better understand the commonly used 5400 and 1300 GPM line to better forecast rain versus snow events. Other studies have looked into the use of the 5400 GPM (540 dm) line but none have assessed the validity of this boundary with respect to weather type characterization at Albany. This study aims to determine the reliability of the widely referenced guides for depicting the rain-snow line, and improve forecast aids for the vertical atmosphere during winter precipitation events. The mean daily 500, 850, 925 and 1000 mb heights and weather type frequency of the Spatial Synoptic Classification between November and March of 1980 - 2012 are analyzed. Results indicate that the standard vertical boundaries are inaccurate indicators of a rain versus snow event in Albany. More reasonable rain-snow cut offs for the 1000 - 500 and 1000 - 850 mb thicknesses are 5222 and 1262 GPM. For the 1000 - 925 mb level, 606 GPM is a helpful aid of identifying the rain-snow boundary. Further scrutinizing by weather type indicates that the rain-snow boundary also varies depending on what air mass/weather type is present on a given day. For instance, when the most prominent weather type is observed over Albany (Dry Polar), at the 1000 - 850 mb and 1000 - 500 mb layers, a boundary of 1242 GPM and 5152 GPM is found to be most representative. Results indicate only for the rarest of winter weather types observed over Albany, Moist Tropical, are the standard cut offs useful. Determining the reliability of this precipitation indicator at a specific station, like Albany, could enable meteorologists in other regions of the country to draw parallels between weather type, precipitation, and thickness in their forecast zones.

Keywords

Thickness, Geopotential, Weather Type, Air Mass, Northeast US, Spatial Synoptic Classification, Snow, Rain

1. Introduction

In the Northeast, major winter storms that produce large snow totals cost cities like Albany, NY a great deal. Some are increasing in severity as a result of the changing global climate [1] [2] [3]. The 14 March 2017 storm at Albany set a new daily record with 43.18 cm of snowfall; the largest ever snow storm in the month of March. The 2018 annual snow contract highlights the cost of handling these events, as the city was approved for the amount of \$1,403,721 for snow removal [4]. Accurate prediction of these storms is a difficult task, but perhaps a greater challenge for Albany forecasters comes with deciphering between events that produce snow and those with rain, and/or mixed precipitation. Community frustration arises, understandably, as the timing of roadway preparations can be misaligned with commuter needs. Forecasters also feel the repercussions of their community member's distrust by just "getting it wrong". Two prominent examples are when residents expect the first predicted snowstorm of the year to come and nothing manifests and when a strongly hyped mid-winter snowfall event is predicted but weakens before reaching the city, producing some mixed precipitation and rain rather than snow.

Both situations poise atmospheric scientists to test whether a strong predictor exists for distinguishing between rain and snowfall events. Of course, forecasting is clearly not that simple. Forecasting agencies utilize a number of techniques to describe synoptic set-ups, such as the interpretation of model guidance and soundings, to predict the timing, duration and amount of snowfall at a particular location. Yet meteorologists do present just such a method for rain-snow distinction to students of the field in introductory and advanced synoptic forecasting and atmospheric dynamics courses. Across the atmospheric sciences, the 5400 GPM line (or the 540 dm line, as used by government forecasting agencies) is a widely referenced guide for depicting the rain-snow line, sometimes referred to as the transition region, on a given day. The value is indicative of the thickness of the 1000 - 500 mb layer and is based in mathematical theory explained by the governing Hypsometric equation. This fundamental equation shows that thickness of any atmospheric layer is dependent on the mean temperature of that layer. As such, greater thickness values are characterized by warmer air temperatures (like that accompanying rain at the surface) and lower thicknesses by colder layer temperatures (like the cool conditions related to snowfall). Meteorologists then impose a general interpretation of the 5400 GPM line as the specific layer thickness that distinguishes an atmosphere of a low-elevation city cold enough to produce precipitation as snow (<5400) or warm enough for rain

(>5400) [5] [6].

The primary goal of this research is to determine whether the 5400 GPM (and 1300 GPM) line can be a valid indicator for distinguishing rain versus snow events at Albany. Where inappropriate, a better thickness line will be suggested. Preliminary upper air analyses helped establish a hypothesis that the 5400 GPM and 1300 GPM thicknesses are too high to be regularly useful at Albany in winter and a lower line is probably more representative of the transition region. Further, there may be large variations in the transition region based on what air mass dominates a precipitation event. Generally, transitional and moist weather types, versus dry ones, should produce more snowfall with lower thicknesses. Greater thickness relates to warmer air columns and likely warmer surface air mass domination.

A more specific goal of this research aims to increase the utilization of air masses/weather types in understanding the environment of Northeast snowfall events as the data are readily available and easy to use. The study will be performed for Albany, NY over 30 winter seasons. Baseline thickness values will be established for all days on record and compared to thicknesses identified only during differing precipitation events. Weather type (air mass) variations will also be compared to find differences in snow day synoptic thicknesses. The amount of variability between the thickness layers will also be compared to determine whether atmospheric conditions during snow events are vertically consistent.

Given the frequency and range of strengths in winter storms at Albany, NY it is necessary that local meteorologists continue to better develop an understanding of the air masses that produce different precipitation types and amounts for the region. Testing the validity of the 5400 GPM thickness with respect to varying air masses that are present during winter seems useful and could reduce forecast errors of rain versus snow events. Determining the reliability of this precipitation indicator at a specific station, like Albany, could enable meteorologists in other regions of the country to draw parallels between air masses, precipitation and thickness in their forecast zones. One may find that the 5400 GPM line is only a useful divide between liquid and solid precipitation during certain air mass types. If those are relatively infrequent, it makes forecasting winter precipitation on those days somewhat easier.

This research aims to add guidelines about the vertical atmosphere during winter precipitation events at Albany, NY for forecasting agencies. The work is most useful when applied in conjunction with all other present forecasting techniques. Certain atmospheric weather patterns will inevitably lend to setbacks in obtaining accurate precipitation, thickness and air mass data inputs. Weather systems suppressing precipitation south of the Northeast region may be particularly difficult to forecast whereas a large ridge over the region producing higher thickness values that would not support snowfall may be easier to handle. Weather model biases toward certain cold or warm surface set-ups should also be well understood. For example, a weather model may possess a cold bias in temperature forecasts in regions of higher elevation such as the Catskill and

Adirondack Mountains than is present in the Mohawk Valley in Central New York.

2. Rain-Snow Transition

The transition line for precipitation change is normally located with the surface, or the 85 kPa, low center (with snow north and rain to the south) [7]. According to [7], the transition region is related to closeness of the shoreline so that, when present, inland locations will be colder than the transition southward, especially when there is snow-covered ground. Typically, the line is located offshore, but if strong onshore winds occur, the transition region could be pushed more inland. In the eastern US the most common location for this is associated with cold air leeward of the Appalachian Mountains and with warm air aloft. With mountainous areas, the transition region would be located at increasing elevation, with below freezing conditions. Nearer to sea level, the air is generally warmer and the transition region lies between the higher and lower elevations. Forecasting the transition region for storm events is challenging due to the fact that the location is always evolving [7]. Studies show that there is a correlation between precipitation phase and temperature. According to [8], when air temperatures are below 0°C, precipitation as snow occurs around 100% of the time. As the temperature increases to 1°C, this percentage decreases slowly, but then declines rapidly to about 20% as temperatures approach 2°C. In the case of lower elevations, the phase transition occurs over a wide range of temperatures from -2° to 4° Celsius, which occurs over land, with half the frequency occurring around 1.2°C. Further, significant pressure dependence is only found at very advanced elevations, not near sea level.

Other commonly examined thickness profiles are the 1000 - 850 mb level and 850 - 700 mb layers. The information associated with these lower atmospheric profiles may tell meteorologists about the maximum daytime temperatures, snow probability, and thermal advection [5] [6]. With respect to the 1000 - 850 mb layer, a commonly used guide for depicting the rain-snow line on a given day is the 1300 GPM thickness. Identification of thinner warm or cool layers frequently becomes another source of information for agencies to identify frozen precipitation events. NWS offices have advised that use of the 5460 GPM may be a better measure for snow prediction for elevations at or above 1 km (3700 ft) [9]. [10] pointed out a major difficulty for forecasters in using such techniques, in that quantitative knowledge of the average heights and thicknesses (and mean departures in these values of one or more standard deviations) during snow events is often unknown. The variability of atmospheric thicknesses present at the time of snowfall may also be a source of uncertainty, adding complexity to the forecasting process. An additional setback, even with model guidance, stems from the ability to resolve the mean temperature of a layer above a location with soundings that are limited in spatial coverage.

Several investigations have been aimed at reducing error when forecasting snow events in the Northeast through model guidance of multiple synoptic me-

eteorological parameters at once. For instance, [11] found that NAM model parameters, including saturation, moist symmetric instability and frontogenetical forcing, increased the 12-hour prediction accuracy of snowfall from heavy, banded and even weaker snowfall events. It is interesting to note that air masses are infrequently, if ever, used in the process of predicting snowfall though they represent cohesive thermal and moisture conditions across spatially expansive areas. The large surface extent of homogenous conditions found in air masses means that they could be important for filling in data gaps between sites where radiosonde data are collected. With this in mind, air mass, or weather type, indices have been potentially underutilized alongside information from soundings which could be used by forecasters to develop the necessary, quantitative knowledge of layer thicknesses and variability during snow events.

3. Spatial Synoptic Classification

The Spatial Synoptic Classification (SSC) is an index that provides a daily weather type calendar back regularly to 1950, often earlier, at >300 locations across the U.S. Use of the SSC in a transition region forecast may add information to that currently used by forecasting agencies to improve the foundation of winter prediction at different cities [12]. It serves as a useful update to the ways of Bergeron classification in broad areas.

In his 1928 dissertation, Tor Bergeron took an analytical approach to understanding air masses [13]. His research focused on source regions to describe six air mass types. Bergeron argued that, as an air mass moves from one location to another, the weather variables remain relatively stable. Thus, it was only necessary to consider the weather variables at the source region in order to determine the variety moving to a new location as well as future positions [14]. The six air mass types under Bergeron's classification include: continental arctic (cA), continental polar (cP), continental tropical (cT), maritime polar (mP), and maritime tropical (mT) [15].

The way in which meteorologists classify air masses remains rooted in the work of Bergeron, while changing with time. Many other perspectives regarding how air masses can be identified exist. These contributions included both manual and automated classification systems, or in some cases, a hybrid system that combines both means of characterization [15]. Among these is the Spatial Synoptic Classification (SSC), a scheme that classes days into six unique synoptic air mass types. Rather than looking at source region this system examines surface weather observations to determine the surface weather type at a location. Based on characteristic weather types, seed days were created and assigned individually to each of the stations with weather data every day of the year. This enabled the ability to compare observed conditions and seed day conditions, allowing for an identification of weather typing in a given region [15].

The SSC defines six weather type (loosely, also the near-surface "air mass" conditions; those found nearest the ground) categories: dry polar (DP), dry moderate (DM), dry tropical (DT), moist polar (MP), moist moderate (MM),

and moist tropical (MT). The DP is analogous to that of Bergeron's cP air mass, which is represented with air that is cold and dry. With a DP present, winds predominantly blow from the north, bringing the cold air from the uppermost North American continent. The DM is not synonymous with a Bergeron classification type, however, is associated with slightly more mild, dry air than that of the DP. In the United States, DM air is often found on the leeward side of the Rocky Mountains; a region of adiabatic heating. The warmest summer air is associated with DT dominance, which is comparable to that of Bergeron's cT air mass. This air comes from the dry deserts of the south western United States. MP conditions are comparable to Bergeron's mP; chillier and humid, often accompanied with precipitation. This air mass is most commonly found in upstate New York during lake effect snow fall events. The MM set-up is warmer than that of an MP and is also more humid. MT types are like that of the Bergeron mT air, in that the air is very humid and warm, typically coming from the tropics. Finally, a Transitional (TR) stage is included in the scheme, which is used on a day when there is not a single air mass present, but rather a shift from one air mass to another [13].

4. Methods & Analysis

4.1. Study Region & Data

In order to examine thickness variations by air mass type during winter snow days at Albany, NY, the atmospheric sounding data from the KALB weather station (42.44°N, 73.47°W) are acquired. Mean daily 500, 850, 925, and 1000 mb heights (in m, then converted to GPM) are calculated by averaging the observations from 00Z and 012Z for the November to March 1980 - 2012 period [16]. Mean daily thicknesses for the 925 - 1000 mb, 850 - 1000 mb and 500 - 1000 mb levels are then computed from the height data. These thickness levels are selected as they are the most common levels examined when winter snowfall forecasts are issued. Note that the authors recognize the 700 - 1000 mb thicknesses as another critical level analyzed in winter snow forecasts, excluded only as the scope of this research was to examine an initial three-layer variation.

Daily SSC air mass data are collected for analysis alongside thicknesses for the same 30 - year period of winter [12]. The air mass frequency for the period of record is displayed in **Figure 1**, and illustrates that some air mass types occur more or less often than others. The DM and DP air mass are the most frequent winter air masses, while the DT and MT are substantially less frequent.

Daily total snowfall data (cm) are collected from the United States Historical Climatology Network (USHCN) station at Albany [17]. Rainfall data are also gathered to distinguish general winter precipitation days (snow and rain) from non-snow or non-precipitation days. The types of winter days analyzed in this research are: 1) all days, or, all days in the record), 2) snow days, or, days in which precipitation had fallen *only* in the form of snow, 3) rain days, or, days in which precipitation had fallen *only* in the form of rain, 4) mixed precipitation

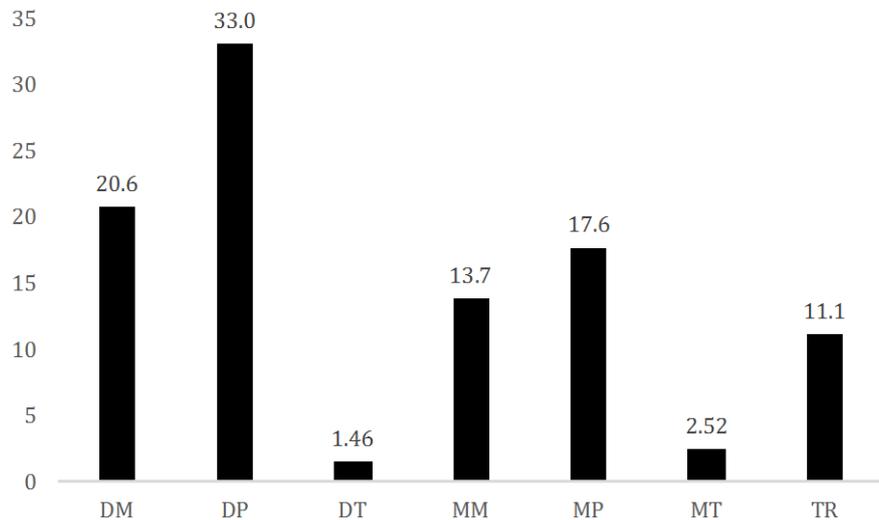


Figure 1. Period of record winter air mass frequency (%) at Albany, NY.

days, or, days where precipitation had fallen in the form of snow *and possibly* other forms of precipitation, and 5) non-precipitation days, or, days where no precipitation had fallen in the form of rain or snow.

4.2. Baseline Analysis

In order to understand the relationship between precipitation type and atmospheric thickness at Albany, a baseline analysis of mean daily thickness is computed for the period of record. To do so, the pressure (mb) and mean daily heights (GPM) are analyzed, alongside daily rainfall (m) and snowfall amounts (m). The twice-daily pressures are gathered at four atmospheric heights: 500 mb, 850 mb, 925 mb, and 1000 mb. The pressures are then averaged to determine the mean daily pressure.

The difference between the 925 mb and 1000 mb mean daily heights is computed and represents the daily thickness of the 1000 - 925 mb layer of the atmosphere. A difference is then calculated for the 1000 - 850 mb and 1000 - 500 mb layer in the same manner (**Figure 2**). Afterward, low-quality data are removed by utilizing the modified z-score method. In utilizing these statistics, any z-score value less than -3.5 and greater than 3.5 is classed as an outlier. With the removal of all missing and erroneous data, 2997 days at the 1000 - 925 mb level, 4703 at the 1000 - 850 mb level, and 4725 days at the 1000 - 500 mb level are found to be high quality data for further analysis. For the three layers, average thicknesses are computed for five categories of days. These categories are: 1) all days, 2) mixed precipitation, 3) snow, 4) rain, and 5) non-precipitation days. The categories are then compared for substantial differences in thickness.

Once average thickness is calculated for each day in all three layers, the difference between 1000 - 850 mb and 1000 - 500 mb is measured (**Figure 3**). These differences indicate the nature of atmospheric layer variation, or, the extent to which the layers vary together during days with different types of precipitation.

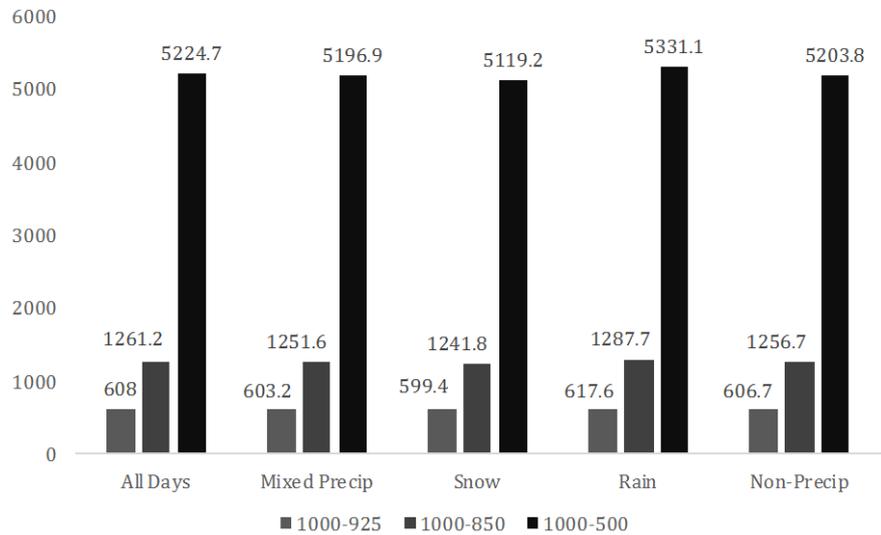


Figure 2. Period of record mean thickness (GPM) for all atmospheric layers examined during the precipitation regimes.

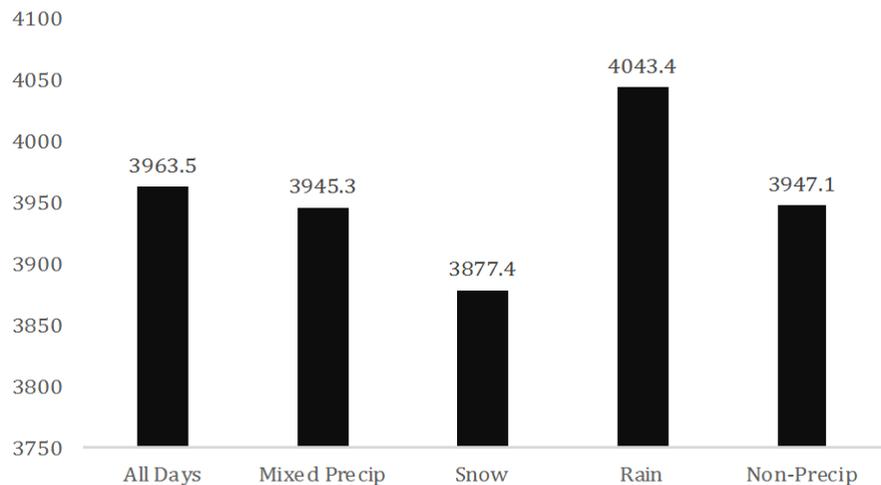


Figure 3. Period of record mean thickness differences (GPM) for all layers and precipitation regimes.

4.3. Air Mass Frequency Analysis

After obtaining the 1000 - 925 mb, 1000 - 850 mb, and 1000 - 500 mb thickness averages, as well as the difference between the two layers, the same methods are utilized to obtain daily thickness and thickness differences based on SSC surface air mass/weather type. To do this, the data for each category are separated based on daily air mass type at Albany. Mean daily thickness is calculated for the three thickness layers. The total number of days in each precipitation category by air mass is noted for the purpose of determining practical significance. Standard deviations are further calculated for the categories most prevalent in each air mass type.

With determining a new rain-snow cutoff for each thickness level and weather type, it is necessary to determine the statistical significance of the findings. To do

that, the two proportion z-test method is utilized, and allows the authors to determine the confidence interval for the newly determined cut offs. When using this method, population 1 (x_1) represents the number of days below 5400/1300 GPM in a given air mass, population 2 (x_2) represents the number of days below 5400/1300 GPM in winter, total number in population 1 (n_1) represents the total number of days in a given air mass, and the total number in population 2 (n_2) represents the total number of days in the period of record. In some cases, if a weather type contained less than 100 days, the significance was not tested, and therefore this weather type was deemed insignificant.

Next, the differences from the baseline and air mass thickness analyses are determined. To do this, the baseline average for each category is subtracted from the daily air mass thickness mean. The differences are divided into two categories, as percentages; air mass averages > baseline values, and air mass averages < baseline values. When graphed, the values > 0 represent those > baseline, while values < 0 represent those < baseline. For example, the DT air mass has no pure rain or pure snow days. To determine if the category is above or below the baseline, the computation: $((\text{air mass value} - \text{baseline value}) / \text{baseline value}) * 100\%$ is used. If the zero thickness value (representing the number of days for pure rain and pure snow) is added in for the air mass value, a percent difference from the baseline will be obtained.

5. Results

5.1. Baseline

After computing the average thickness of the 1000 - 850 mb and 1000 - 500 mb layers, a baseline indicator is determined for each precipitation category. Using those thicknesses, a new boundary can be identified. Then, an analysis of each of the seven SSC air mass types (utilizing the same methodologies as the baseline) allows for the identification of new divides for each air mass type. This analysis shows that the rain-snow cut off at Albany, NY is different than the standard 5400 GPM boundary that is often used for forecasts with the 1000 - 500 mb thickness layer. The widely used 1300 GPM thickness boundary is also not a good representation of the 1000 - 850 mb thickness layer at Albany. Better rain-snow cut offs are the 5222 GPM and the 1262 GPM. This examination discovers that for every precipitation type experienced at Albany, the average thickness is less than 5400 GPM and 1300 GPM (**Table 1** and **Table 2**). From

Table 1. Departure (GPM) from 5400 GPM for each precipitation regime.

Precipitation	Departure
All	-175.3
Mixed Precip	-203.1
Rain	-68.9
Snow	-280.8
Non-Precip	-196.2

Table 2. Departure (GPM) from 1300 GPM for each precipitation regime.

Precipitation	Departure
All	-38.8
Mixed Precip	-48.4
Rain	-12.3
Snow	-58.2
Non-Precip	-43.3

this finding, it can be concluded that the atmosphere studied above Albany is generally cooler than expected in winter.

The results of this research naturally follow general hypsometric equation expectations. With respect to the 1000 - 500 mb baseline analysis and the 1000 - 850 mb baseline analysis (see [Figure 2](#)), it can be observed that thickness increases in both layers during rain events and decreases (both layers) during snow events. The smaller the departure from the 5400 and 1300 GPM line, the thicker the 1000 - 500 mb and 1000 - 850 mb layer, respectively. This is further emphasized in observed differences between the thickness layers (see [Figure 3](#)). For instance, the difference between the two levels of the atmosphere produces a value of 3877.4 GPM for the snow category, while the rain category results in a value of 4043.4 GPM. Thus, it can be inferred that the numerical value of the snow thickness difference is primarily due to the colder temperatures experienced during snow events, as compared to rain events.

5.2. 1000 - 850 mb

For the 1000 - 850 mb layer, the 1300 GPM thickness line is widely used by meteorologists as a rain-snow boundary within this layer of the atmosphere. Depending on the air mass type present, utilizing this layer has proven sometimes unnecessary, except for predicting days with snowfall. Instead, a simple analysis of the 1000 - 500 mb boundary should suffice. For the air masses most prominent in the Albany area, an analysis of both layers will provide meteorologists with a better, more accurate boundary. For example, during times of meandering frontal boundaries, there are transitions in air masses. This set up makes forecasting more difficult, primarily because the atmosphere is dimensional. Looking at different layers of the atmosphere allows meteorologists to depict sub-freezing air versus freezing air, and therefore, resulting precipitation types.

In Albany, DP is the most prominent winter air mass (see [Figure 1](#)), and is the weather type responsible for much of the snowfall in this region. With an occurrence of 1564 days (out of a total 4725 days in this dataset), it is critical that meteorologists are able to distinguish between a snow and rain event. For each of the precipitation types experienced in Albany, the average thickness is less than 1300 GPM for the DP air mass type ([Figure 4](#)). Additionally, there is also substantial variation and notable departure (%) from the average thickness calculated in the baseline analysis ([Figure 5](#)). This illustrates that, when further

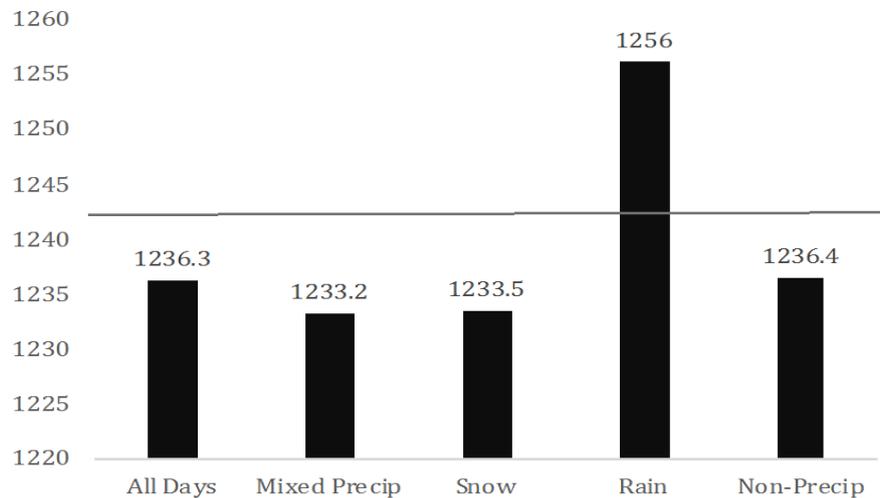


Figure 4. Period of record 1000 - 850 mb mean thickness (GPM) of DP at Albany in winter.

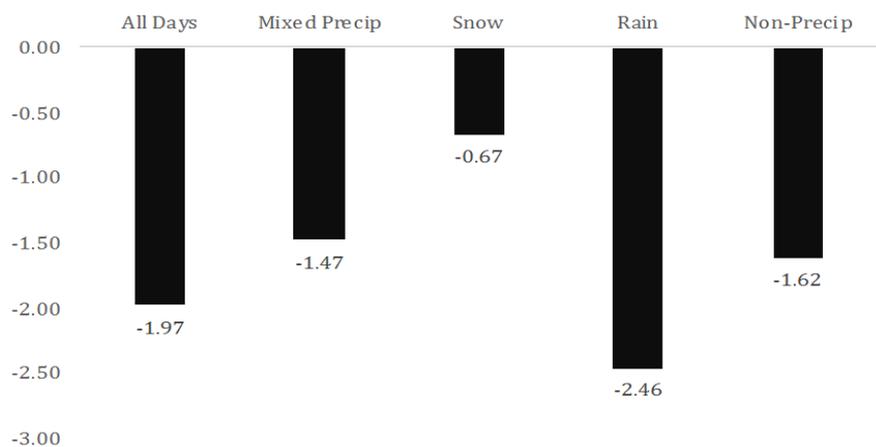


Figure 5. Period of record 1000 - 850 mb mean thickness differences (%) of DP at Albany in winter.

scrutinizing based on air mass type, the boundary for rain and snow is going to be different depending on what air mass is present. Furthermore, by computing the standard deviation, and thus, determining the typical thickness ranges of the rain and snow categories, a new boundary is determined. In the case of a DP air mass, a new boundary of 1242 GPM is considered to be more representative (>99% confidence level).

That the average thickness, among both the rain and snow precipitation categories of the DP air mass, is lower than that of the general 1300 GPM cut off, is a consistent theme among the most prominent air mass types at Albany. For instance, the MP air mass is the third most prominent variety at Albany, however, like that of the DP, this kind is associated with a substantial amount of Albany's winter time snowfall. Again, each of the precipitation categories has an average thickness of less than 1300 GPM (**Figure 6**). Perhaps the most probable cause of low average thickness values with respect to MP days (more specifically, in the

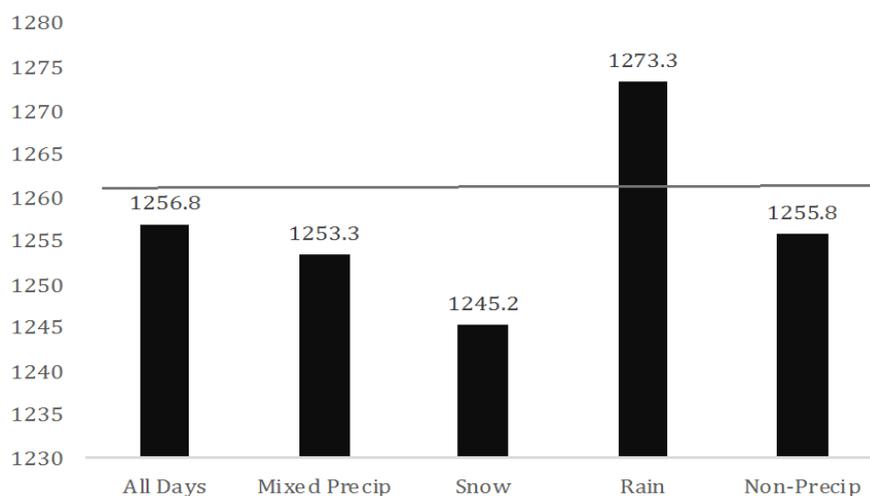


Figure 6. Period of record 1000 - 850 mb mean thickness (GPM) of MP at Albany in winter.

pure snow precipitation category), is the influence of a Hatteras Low. It seems reasonable to think that if the Low pressure center remains offshore, and there is a Canadian High to the north that will supply cold air to the entire column of the atmosphere, then precipitation will fall in the form of pure snow in east central NY. With that, a boundary of 1261 GPM is deemed appropriate during these air mass days (>99% confidence level). Furthermore, according to the research results, any thickness value above (greater than) this boundary will produce rain, and any value below (less than) will produce snow.

The DM air mass is the second most frequent air mass at Albany (962 days out of a total 4703 days in the 1000 - 850 mb analysis), though with less practical significance than DP and MP air mass days for predicting snowfall. However, while this particular air mass is not associated with much accumulating snow or even many pure snow days, given its wintertime frequency, it is important to be able to establish a rain-snow boundary. Similar to that of each of the preceding air mass types, the DM has very low mean thicknesses associated with each precipitation category, compared to that of the standard 1300 GPM cut off for rain versus snow (**Figure 7**). When forecasting during a DM day, a thickness value of 1269 GPM would serve as a good indicator of a rain versus snow event (98% - 99% confidence level). In other words, if a DM air mass is present during the winter months, a thickness value greater than 1269 GPM should indicate a rain event, whereas a value less than 1269 GPM would indicate snow.

The same methodologies are used to determine the rain-snow cut off of the remaining SSC air mass types. Furthermore, appropriate boundaries for the DT, MM, MT, MT+ (a sub-division of MT, representing a set of the warmest and most moist days of MT), and TR air mass types are 1299 GPM, 1281 GPM, 1269 GPM, 1296 GPM, and 1263 GPM, respectively. The only case in which the 1300 GPM thickness boundary would serve as a valid rain-snow cut off, would be on days in which an MT++ air mass (a warmest, most moist sub-division of MT) is

present. When a tropical air mass is present, snow is so extremely rare, and instead, days without precipitation or precipitation in the form of pure rain are most common. It seems intuitive. Nevertheless, given the purpose of this study, in the event that an MT++ air mass is present, the 1300 GPM serves as a valid indicator of a snow event, were one to ever happen at Albany under the influence of this particular air mass (**Figure 8**). With that, if precipitation is present, then any value greater than 1300 GPM would result in rain, and any value less than 1300 GPM would result in snow. The authors even support a higher value of 1331 GPM as a fine cut-off based on this analysis. Since there are fewer than 100 days in this dataset, a confidence interval cannot be calculated.

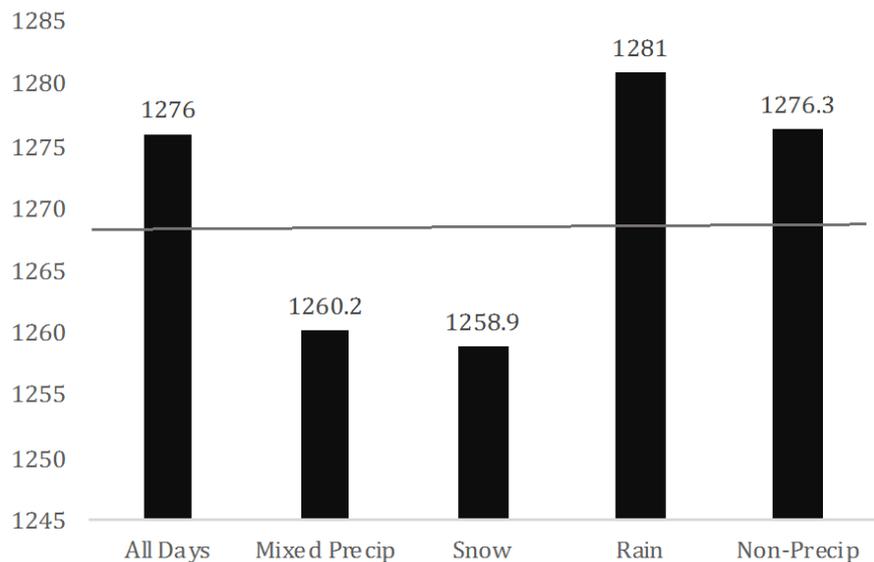


Figure 7. Period of record 1000 - 850 mb mean thickness (GPM) of DM at Albany in winter.

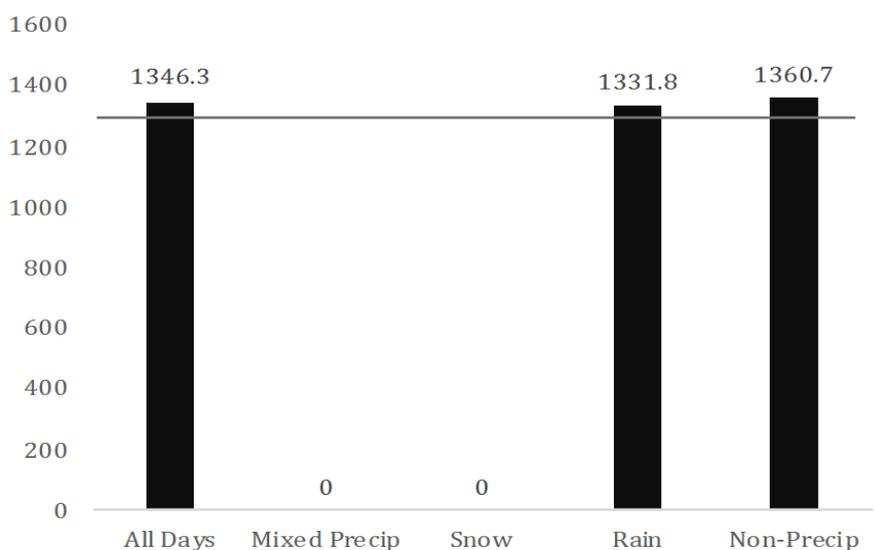


Figure 8. Period of record 1000 - 850 mb mean thickness (GPM) of MT++ at Albany in winter.

5.3. 1000 - 500 mb

When analyzing the 1000 - 500 mb layer, the 5400 GPM thickness line is most commonly used as a rain-snow boundary by forecasters and meteorologists. The results of this research indicate that the utilization of the 5400 GPM is not valid for all of the various weather types that pass through Albany. While the 5222 GPM line shows here to be a more adequate predictor of a rain versus snow event, further analysis has determined that each air mass type requires a unique rain-snow cut off.

For example, the most prominent air mass type for this particular layer of the atmosphere is the SSC classified DP air mass (occurring 1560 days, out of a total 4725 days). Similar to that of the 1000 - 850 mb layer results for the DP air mass, the average thickness of each precipitation regime that is associated with this air mass is less than 5400 GPM (**Figure 9**). The average thickness value that is associated with liquid precipitation is nearly 5224 GPM, while the average thickness accompanying the pure snow category is almost 5000 GPM. These low thickness values represent departures (%) of approximately -2 and -0.5 , respectively, from the 1000 - 500 mb baseline values (**Figure 10**). By computing the standard deviation of the snow and rain categories, the median between the first standard deviation of both precipitation types is calculated. With that, a new rain-snow cut-off of 5152 GPM is determined for the DP air mass (95% confidence level). A thickness greater than 5152 GPM would result in precipitation in the form of rain, while a thickness less than 5152 GPM would result in snow.

The MP air mass, which is present on 833 days out of a total of 4725, is associated with average thicknesses less than 5400 GPM. Each precipitation category of MP has an average thickness less than 5300 GPM (**Figure 11**). Nor'easters are a common winter time weather phenomenon that can be observed during days in which an MP air mass is present. This may be the case when the synoptic Low pressure center of a mid-latitude cyclone remains off the east coast, and a High

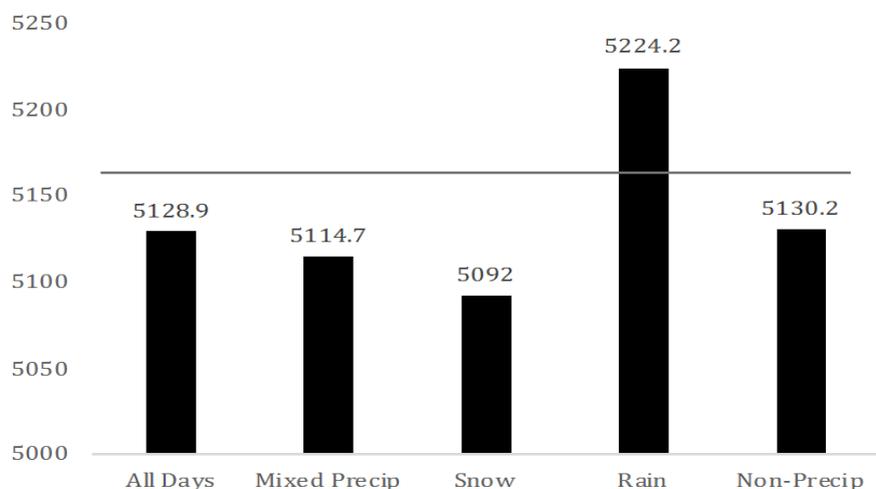


Figure 9. Period of record 1000 - 500 mb mean thickness (GPM) of DP at Albany in winter.

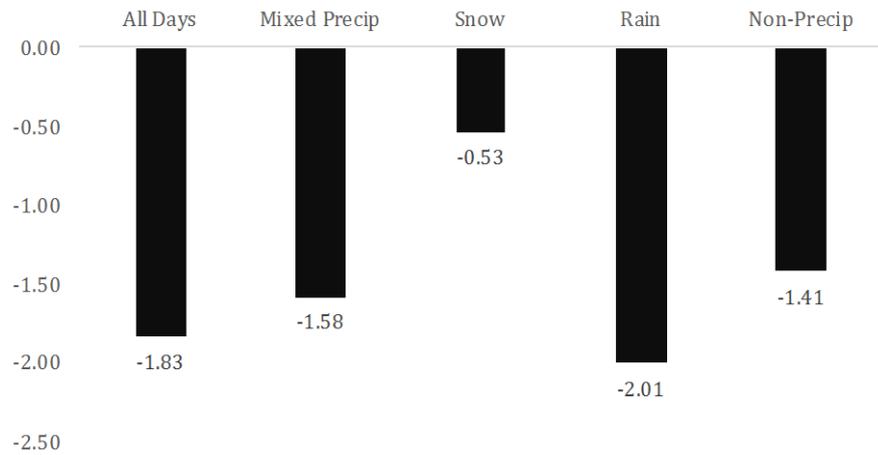


Figure 10. Period of record 1000 - 500 mb mean thickness differences (%) of DP at Albany in winter.

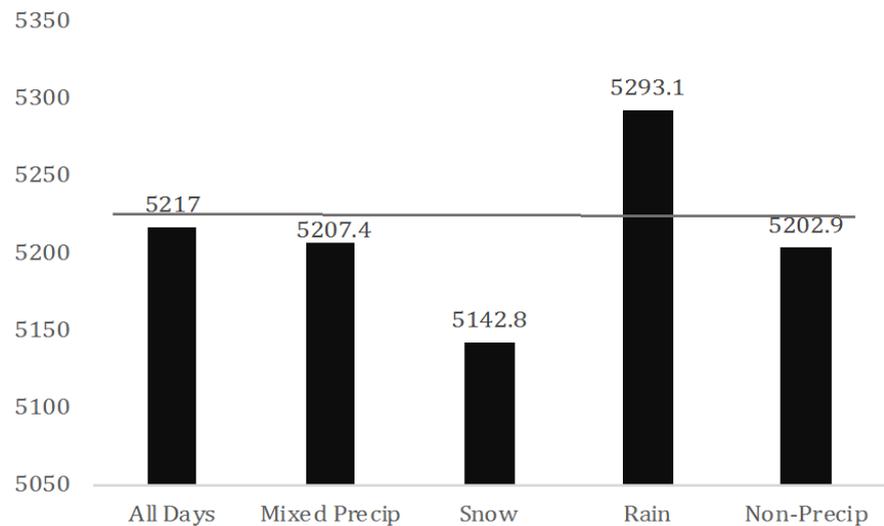


Figure 11. Period of record 1000 - 500 mb mean thickness (GPM) of MP at Albany in winter.

pressure is situated to the north. MP is linked with substantial amounts of snowfall. In New York State's capital district it is, therefore, critical to be able to define a thickness cut-off that gives forecasters a better understanding of the type of precipitation that will fall. With that, a thickness boundary of 5225 GPM will serve as a better rain-snow indicator when an MP air mass is present (>99% confidence level). If the 1000 - 500 mb thickness is less the 5225 GPM at Albany, then precipitation will fall in the form of snow. Conversely, if the thickness is greater than 5225 GPM, then it will rain.

The 1000 - 500 mb thickness pattern associated with the DM air mass is similar to that of the 1000 - 850 mb thickness, in that the average thickness of each precipitation category is again, less than the commonly used 5400 GPM boundary (Figure 12). Though there are fewer pure snow days that are present when DM is situated over Albany, it is the second most frequent winter time air mass

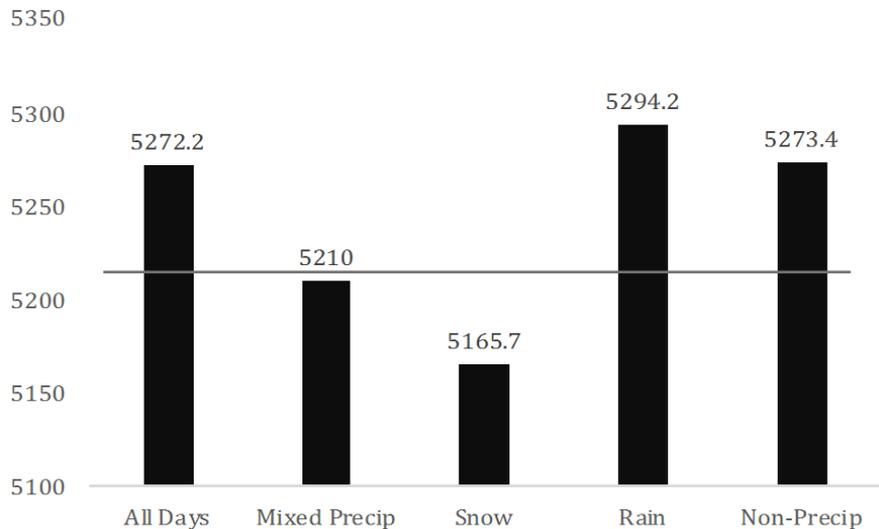


Figure 12. Period of record 1000 - 500 mb mean thickness (GPM) of DM at Albany in winter.

in the city. With that, an accurate rain-snow cut off is imperative. Furthermore, the median between one standard deviation of both the average rain and snow categories is calculated, and reveals that 5212 GPM serves as a better depiction of a rain versus snow event (98% - 99% confidence level). When the thickness is greater than 5212 GPM, precipitation will fall in the form of rain, however, when the thickness value is less than 5212 GPM, snow will fall.

The remaining air mass types have less practical significance, as the frequency of each at Albany is substantially lower. With that, however, a new rain-snow boundary for the DT, MM, MT, MT+, and TR weather types are 5337 GPM, 5255 GPM, 5257 GPM, 5305 GPM, and 5219 GPM, respectively. Each of the rain-snow boundaries for the seven SSC types can also be found in the conclusions that follow. It is important to note that, similar to that of the 1000 - 850 mb layer, the 5400 GPM line can be used as a sufficient rain-snow cut off in the presence of MT++ (Figure 13). Tropical air masses are extremely rare during the winter months (119 total MT days in this data set, including MT+ and MT++) and even on days in which MT is present, snow days are very rare. In fact, there were zero pure snow days associated with any of the tropical air mass types (including DT) throughout this 30 - year study.

5.4. 1000 - 925 mb

The 1000 - 925 mb layer is analyzed as a means of understanding potential reasons for such low thickness values at both the 1000 - 850 and 1000 - 500 mb layers of the atmosphere. Figure 2 shows why the authors suggest the use of 606 GPM as a possible transition predictor for this level. However, it was analyzed for more information as well. An investigation of the surface to 925 mb allows the authors to assess phenomena like cold air damming. Given the location of Albany (situated where the Hudson Valley meets the Mohawk Valley, with the

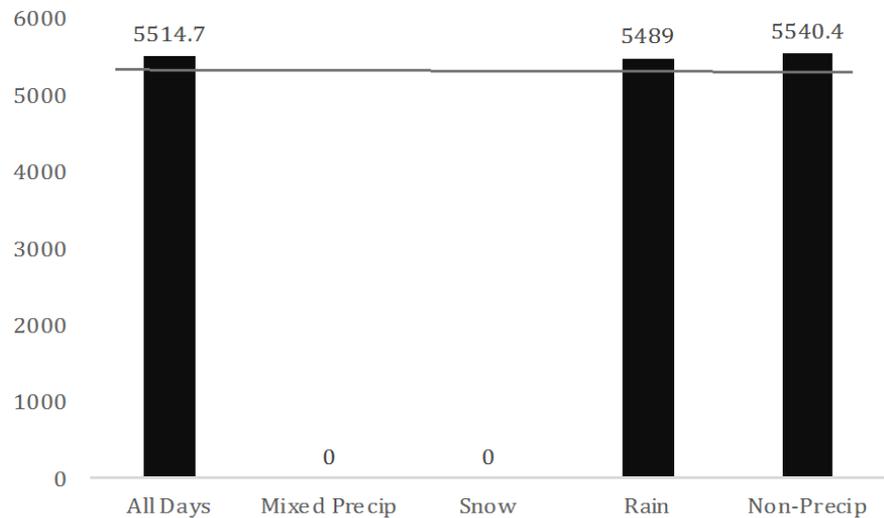


Figure 13. Period of record 1000 - 500 mb mean thickness (GPM) of MT++ at Albany in winter.

Adirondack Mountains to the North, Catskill Mountains to the South, and the Green Mountains to the East), it is hypothesized that the unusually low winter time thicknesses at Albany may be attributed to cold air getting trapped within the valley. The most probable scenario of when this would occur, would be when a High pressure center is located over the Great Lakes, and a Low pressure can be found off of the Northeast coast.

However, composite analysis indicates that cold air damming is not necessarily responsible for the extremely low thickness days. Instead, after examining both the top 10 (and top 20, not shown below) lowest thickness days and creating a surface pressure anomaly composite map, a Low pressure center can be found to the north of Albany (**Figure 14**). In contrast, the top 10 highest thickness composite reveals a Low pressure center that has likely moved off the northeastern coast, and an area of higher pressure in the region, south, and to the west. The pressure anomaly composite of the top 20 highest thickness days varied only in that the Low pressure appeared yet to move through the northeast region.

6. Conclusions

This research examines three atmospheric thickness layers, and the explicit use of the 5400 GPM line as a valid rain-snow indicator at Albany, NY. It is determined that the boundary can only accurately work with tropical air mass presence. Yet these are extremely rare precipitation producers over NY in winter. The 5222 GPM line is a more useful guide for the city. However, depending on the dominant weather type during precipitation, slight variations may be most beneficial for forecasters, as depicted in **Table 3**. The outcome of this analysis finds that subtle clues about the surface air mass present during an expected precipitation event will be useful in government and private forecasting of rain

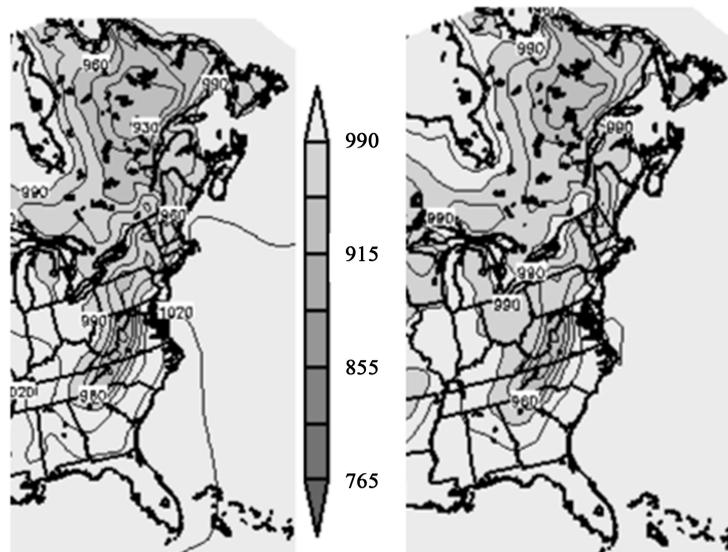


Figure 14. Surface pressure anomaly composite maps of the top 10 lowest (left) and top 10 highest (right) thickness days examined since 1980. Made with 20th century daily reanalysis data (v3) at the NOAA PSL [18]. Top 10 lowest days occurred in the following years: 1982, 1983, 1985, 1994, 1995, 1997, 2009 and 2010. Top 10 highest days occurred in these years: 1981, 1985, 1994, 2000, 2001, 2003, 2007, and 2008.

Table 3. Suggested cut-offs for the rain-snow line to be used at Albany, NY. Presented by SSC surface air mass/weather type (including MT+ and MT++, sub-divisions of MT) for both the 1000 - 500 mb layer and the 1000 - 850 mb layer.

Weather Type	Best Cut-Off (GPM)	
	1000 - 500 mb	1000 - 850 mb
DM	5212	1269
DP	5152	1245
DT	5337	1299
MM	5255	1281
MP	5225	1261
MT	5257	1269
MT+ (++)	5305 (5489)	1296 (1331)
TR	5219	1263

or snowfall. This is valuable information for the public at the beginning and ending of a snow season in upstate NY, impacting travel, work, and extracurricular interests.

This investigation also finds that information about the shallower 1000 - 850 mb layer (and use of a 1262 GPM thickness) gives indications about the type of precipitation that will fall at Albany. When used in conjunction with the deeper layer to 500 mb, and with surface weather type information, predictions may see fewer errors on tough forecasting days. **Table 3** can even be referenced as a quick guide in weather offices daily in wintertime after SSC weather type data

for the day at KALB are released. Furthermore, the methodologies applied here could be directed at other cities across the country, specifically those in the Northeast US with comparable synoptic conditions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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