A Study on Snow Density Variations at Different Elevations and the Related Consequences; Especially to Forecasting.

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ABSTRACT

With observations becoming more common and forecasting becoming more accurate snow density research has increased. These new observations can be correlated with current knowledge to develop reasons for snow density variations. Currently there is still no specific consensus on what are the important characteristics in snow density variations. There are many points of general agreement such as that temperature and relative humidity are key factors. How to incorporate these into snowfall prediction is the key. Once there is more substantiated knowledge, more accurate forecasts can be made. Finally, the last in the chain of events is that society can plan accordingly to this new data. Better prediction means less work, less time, and less money spent. This study attempts to determine if elevation is an important characteristic in snow density variations. It also looks at computer models and how snow density is used in conjunction with these models to make snowfall projections. The results seem to show elevation is not an important characteristic. The results also show that model accuracy is more important than snow density variations when using models to make snowfall projections.

1. Introduction

The density of snow is a very important topic in winter weather. This is because the density of snow helps determine characteristics of a given snowfall. For example, if there are two 2 inch snowfalls and one of them is not as dense, the less dense snowfall will be more likely to blow and drift. This could then possibly cause whiteout conditions, which would be hazardous to driving. The glossary of meteorology by the American Meteorological Society defines snow density as the ratio of the volume of meltwater that can be derived from a sample of snow to the original volume of the sample. Snow densities are typically on an order of 70 to 150 kg m^{-3}, but can be lower or higher in some cases.

The fact that snow densities can vary makes them one of the most important characteristics of snowfall prediction. This means that each individual snowfall has a different density, and thus different water equivalence. The American Meteorological Society glossary defines water equivalence as the depth of water that would result from the melting of the snowpack or snow sample. Since the density of water can be assumed to be a constant 1000 kg m^{-3}, the depth of the water that results from melting snowpack is much less that the depth of the snowpack itself. This shows an interesting correlation between precipitation in the summer and winter. In the summer, a big rainstorm could give 2 inch precipitation totals. If the 2 inches of rain were instead to fall as snow, there would be approximately 20 inches of snow if an average snow density of 100 kg m^{-3} were assumed. Since most snowstorms do not come close to this snowfall amount, we can see that usually the amount of liquid present is much less in the winter.

In general, forecasting precipitation is not an exact science. Models are used as a tool to help forecasters make decisions about how much precipitation to forecast. These models output Quantitative Precipitation Forecasts (QPFs), which give an amount of precipitation expected for a given location. QPFs are getting better with time, but are still by no means absolutely correct. Even if they are approximately correct, snow density variations present problems when trying to estimate a snow-to-liquid-equivalent ratio (SLR) [*Baxter et al.,* 2004]. For example, assume a QPF of 1 inch. If temperatures were cold enough for snow then snow density will be the determining factor in how much snow is received. If the snow were very dense, there might only be 6 inches of snow. But if the snow was very light, there might be as much as 14 inches of snow. Thus making a good forecast is just one part of predicting snowfall totals.

Another concern in relation to snow density is the snow water equivalent (SWE). This refers to the water equivalent of snow on the ground [*Schmidlin et al.,* 1995]. SWE is different from SLR in that SLR is used mainly as a simple ratio. SLR normally assumes a specific snow density so that a certain ratio may be applied to given situation. SWE can be seen as a verification of SLR. If an SLR for a given location was assumed to be correct, then the SWE for that snow should verify it. The assumption in the last situation is that there is no snow on the ground. If there was already snow present then the measurement for SWE would be a combination of the new snow and snow that already fallen. These different snowfalls would have different snow densities and thus a SLR could not be applied. SLR is used more for prediction and verification of individual snowfalls [*Baxter et al.,* 2004]. Conversely SWE is used more for nowcasting and daily measurements of the snowpack [*Rasmussen et al.,* 2003]. Nowcasting is the same as forecasting but provides information for only a small amount of time ahead of the current time. Snow density can then be calculated from SWE by dividing it by the snow depth [*Schmidlin et al.,* 1995]. SWE is also usually measured daily by different organizations including the United States National Weather Service and the U.S. National Resources Conservation Service (NRCS). The United States National Climate Data Center does automated control on the National Weather Service data [*Schmidlin et al.,* 1995]. The NRCS uses a network called SNOTEL, which stands for snowpack telemetry, to make its observations. The observations are needed because SWE is important for many reasons. Knowledge of SWE is helpful in snow removal, potential runoff, hydrological and engineering applications, and climate change studies [*Schmidlin et al.,* 1995].

Snow density was long neglected as a topic of research because a ten-to-one ratio of snow to liquid water was assumed. This assumption derived from a late nineteenth century Canadian study and was implemented in the United States around the same time [*Roebber et al.,* 2003]. Even back then this ratio was warned to be an average and not true for every case [*Roebber et al.,* 2003]. A few studies were done during the mid 1900's, but there was another lull in research until recently. One reason for snow density not being studied much in the past is that until the 70's Doppler radars and other types of observation equipment were not in place. Now that there is a comprehensive observation network and ways to verify these observations using radar and satellite, more comprehensive studies can be done. Another reason for snow density not being studied much is that forecasting has only currently become a bigger topic because of better modeling and computer technology. Now that forecasting has improved researchers are trying to understand the underlying errors involved. Thus snow density is now being studied because it is an important characteristic to making better snowfall forecasts.

The importance of snow density, as previously described, and the lack of specific knowledge of what changes it are the main motivations for this work. Especially with the lack of many studies on how elevation changes snow density. Thus, this paper uses the author's weeklong stay at Storm Peak Laboratory (SPL) near the summit of Mount Werner in Steamboat Springs, Colorado as a time to study the effects of elevation on snow density. The goal then was to develop a dataset to test the hypothesis that elevation is a defining characteristic in snow density. Environmental variables must also be looked at to make accurate determinations of why a certain amount of snow fell. In addition data from a few other selected snow events are presented to further test the hypothesis. Also, measurements of accumulated snow were taken at SPL to see how density differs after a snow event is over and if it leads to any additional conclusions about the density of the actual snow event. A final related hypothesis is that snow density variations are the most important factor in making snowfall forecasts from model projections.

2. Methodology

The testing of the hypotheses was mainly done at the Storm Peak Laboratory in Steamboat Springs, Colorado from March 11th thru the 17th. Storm Peak Laboratory is located near the top of Mt. Werner at 10,500 feet or 3200 meters. Storm Peak Laboratory is run by Dr. Randolph Borys and is a subsidiary of the Desert Research Institute. The trip to Storm Peak Laboratory (SPL) was funded by the University of Wisconsin and was led by Dr. Greg Tripoli. SPL has an abundance of equipment to use in measuring different types of winter weather and thus was a good place for my experiment.

Figure 1. Trail map of Steamboat Springs Ski Resort. Locations denoted are SPL (black arrow at top), Bar-UE Pumphouse (red arrow in the middle of the mountain to the left of the red sign), and Top of the Gondola (purple circle and arrow on the right middle side of the picture).

The set-up for the experiment was as follows. Four locations along the windward side of the mountain (where the ski area is located) were selected as suitable sites for measuring snow density. The locations were the base of the mountain or ski resort (6,900ft., 2103m.), the top of the Gondola (9,100ft., 2773.7m), the BAR-UE pumphouse(9,160ft., 2792m.), and the SPL lab(10,500ft., 3200m). The SPL lab location was only used for measuring accumulated snow since no more boards were available for use. To measure new snow two other locations at the top of the mountain were used. The locations were the actual Storm Peak (10,359ft., 3157m.) and the Mt. Werner summit (10,569ft., 3221.4m). These locations were operated by a fellow colleague Andy Thut. At both the bottom three locations and the two locations manned by Andy Thut flat plywood boards were placed on top of the snowpack. These boards were flat and white so that they were suitable for snow collection. To make sure snow was not blown onto these boards, the immediate surrounding area was cleared of snow so that the boards were located on mini-plateaus. The boards were kept in place by a long wooden stick which ran through a hole in the board and into the ground. The three locations I manned were picked because mesonet data, which recorded temperature and relative humidity, was available for these sites. Measurements of new snow depth in centimeters and snow water equivalence in millimeters were taken in order to calculate a new snow density value (kg m^{-3}). New snow density represents a ratio of snow water equivalency to new snow depth [*Schmidlin et al.,* 1995]. Depth and SWE measurements were completed with a Snowmetrics T1 sampling tube and hanging spring scale.

Figure 2. Snow Density sampling kit provided by SPL. Includes scale, sampling tube, and shovel.

Using these measurements a simple calculation of ((SWE/new snow depth) * 1000) was used to derive new snow densities. This calculation worked because the spring scale converts the weight of the sample into water equivalence. Once a measurement was taken the board was cleared so that old snow did not mix with any future accumulating snow. Andy's calculations were a little different because this spring scale was not used. Instead, he used the volume and mass to calculate density. Accumulated snow measurements were also taken at specific times. The same amount was taken at each station so that the densities could be compared exactly.

One other snow events were analyzed. The other event was a three day event over the central Plain states and Ohio Valley. This event occurred March 19th thru 21st of 2006. Data was taken from the Interactive Weather Information Network (IWIN) of the National Weather Service. Again snow depth and water equivalence were used as the variables to calculate snow depth. The National Weather Service uses gauges to measure snow accumulation and water content. These gauges are very similar to what I used in my study. As always there is a possibility the gauges are individually biased, but assuming these biases are small the measurements are very good for comparison with my measurements in Colorado.

4. Results

The big problem when running an experiment that relies on observations is that there might be no observations to take. This is especially true on studies that observe over a small time scale. Thus when the group arrived on March 11th is was already too late in the day to begin observations even though it was snowing. It was too late because in order to get back to the lab a lift that closed at 3:15 had to be taken up. Thus for the locations not at the top the boards could not be placed until March 12th. The top locations could be set up on the 11th because a snowmobile could be used to get to these locations. By the time the boards were set up on the 12th it was too late to take any measurements that day. Finally, on March 13th the day after a big snow the boards could be used. This did not work out though because the portable scale was not working. This may have been due to the fact it got covered by snow during a fall on the slopes. The only other day when snow had accumulated at the three locations not at the top was March 16th, and on that day the base measurement had been tampered with. On March 17th, accumulated snow was measured at the three locations I operated. To supplement the data of these locations the two locations manned by Andy Thut were used. For these locations reliable data was available for the 13th and 17th of March. The following is a table that includes the SPL data plus the other snow event. In addition figures depicting actual and predicted precipitation for March 12th-13th, 2006 are included for comparison.

Table 1(a) – New Snow measurements

Place	Elevation (m)	Date/ Time	Snow Depth (mm)	Water Equivalence (mm)	Snow density (kg m^{-3})	Temp. (°C)	Relative Humidity (percent)
Storm Peak	3157	March 13th, 9am (MT)	352.4	NA	79.1	Avg. over-night temp. -16	Avg. 92
Mt. Werner	3221.4	Same as above	Missing data	NA	141.1	Same as above	Same
Storm Peak	3157	13th at 1:15 pm (MT)	38.1	NA	40.7	Avg. temp. since 9am -13.5	Avg. 85
Mt. Werner	3221.4	Same as above	33.8	NA	40.4	Same	Same
Storm Peak	3157	13th at 4:30 pm	46	NA	29.6	Avg. temp. since	same

		(MT)				1pm -14	
Mt. Werner	3221.4	Same as above	38.1	NA	52.5	Same	Same
BAR-UE	2792	16th at 9am (MT)	16	3.5	218.75	Avg. temp from day before -10.3	Avg. from day before when snowed 95
Top of Gondola	2773.7	16th at 11am (MT)	42	10.5	250	Same	Same
Grand Island, NE	567	Sum of Daily totals for March 19th-21st, 2006	548.6	54.1	98.6	NA	NA

Hastings, NE	588	Same	538.5	46.2	85.8	NA	NA
Kearney, NE	663	Same	428.2	47	109.8	NA	NA
Cincinnati, Ohio	168.8	Daily total for March 21st, 2006	71.1	3.1	43.6	NA	NA
Dayton, Ohio	239	Same	20.3	2	98.5	NA	NA
Moline, IL	178	Same	66	1	15.2	NA	NA
Cedar Rapids, IA	222.8	Same	25.4	1	39.4	NA	NA
Springfield, IL	182.9	Same	139.7	7.9	56.5	Avg. -1.6	NA
Peoria, IL	209.1	Same	127	10.2	80.3	Avg. -0.5	NA

Table 1(b) Accumulated snow measurements (Same variables)

BAR-UE	2792	March 16th, 2006	76.2	12	157.5	NA	NA
Top of Gondola	2773.2	Same	76.2	13	170.6	NA	NA
Base	2103	Same	76.2	14	183.7	NA	NA
BAR-UE	2792	March 17th, 2006	76.2	13	170.6	NA	NA
Top of Gondola	2773.2	Same	76.2	13	170.6	NA	NA
Storm Peak	3157	Same	304.8	48	157.5	NA	NA
Mt. Werner	3221.4	Same	304.8	56	183.7	NA	NA
SPL	3200	Same	304.8	70	229	NA	NA

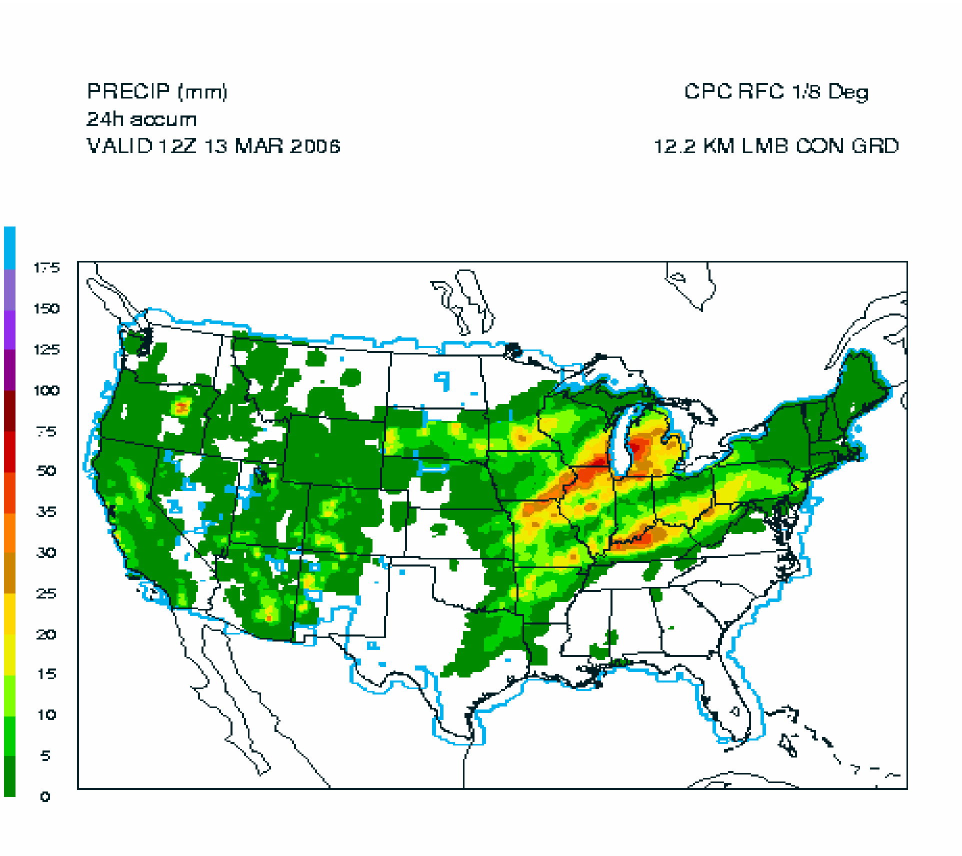

Figure 3. 24 hour accumulated precipitation from March 12th, 2006 at 12Z to March 13th, 2006 at 12Z. Map courtesy of the Climate Prediction Center.

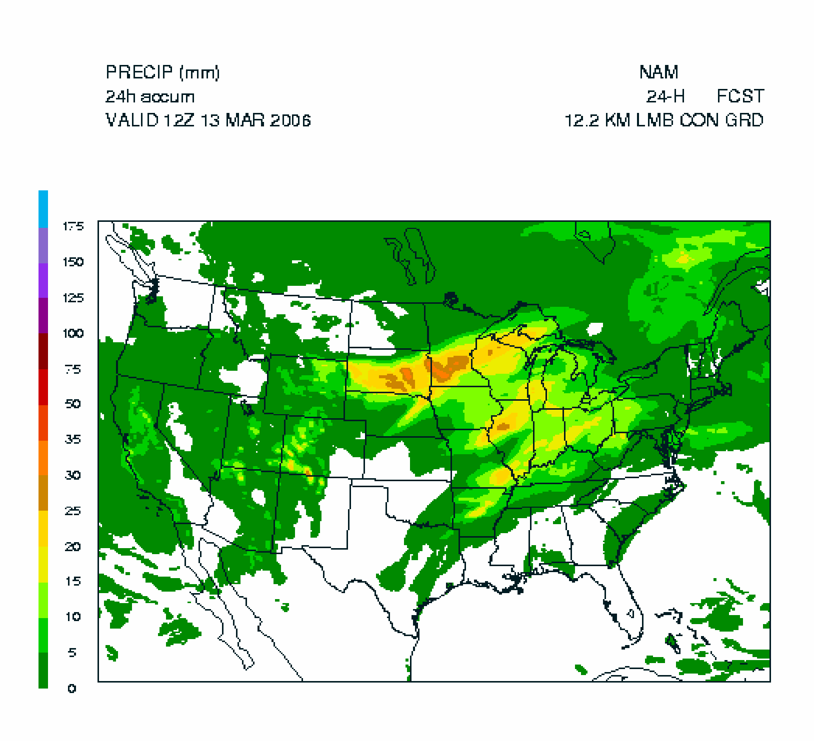

Figure 4. 24 hour forecasted precipitation by the NAM model 12.2km grid (known formerly as the ETA model) valid at 12Z on the 13th of March, 2006.

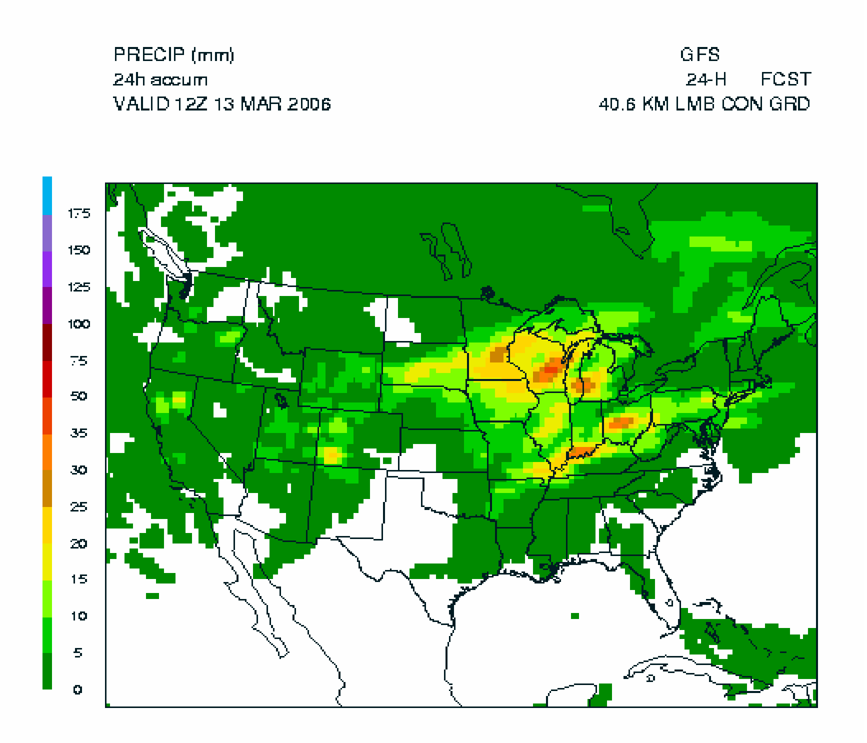

Figure 5. 24 hour forecasted precipitation by the GFS model (formerly known as the AVN model) on a 40.6km grid valid at 12Z on the 13th of March, 2006.

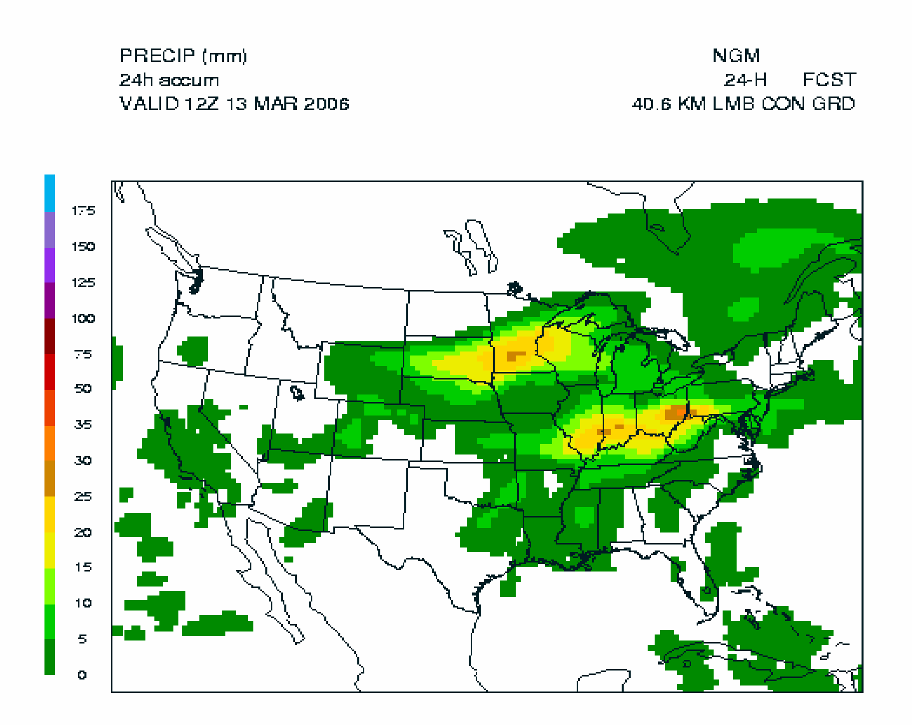

Figure 6. 24 hour forecasted precipitation by the NGM model on a 40.6km grid valid at 12Z on the 13th of March, 2006.

5. Discussion

The results presented in Tables 1a. and 1b. show some interesting things. The first thing to look at is the direct relationship between snow density and elevation and if there is one present. Looking at the data from the SPL trip first it is hard to see any correlation between elevation and density. Two of the Mount Werner observations do not seem to fit the rest of the data. The two are the measurements taken at 9am and 4:30pm on March 13th. The 9am measurement of snow density is substantially larger then the density observation taken at the same time at Storm Peak, which is relatively close in both horizontal distance and vertical elevation to the Mt. Werner site. Also, the 4:30 density measurement on Mt. Werner was up from the previous measurement, which differs again from Storm Peak. At Storm Peak the density of the new snow was lower then the previous measurement. These stations do not differ that much, so both Mt. Werner measurements are questionable. The only thing that can be inferred from both of these places on the 13th is that relative humidity and temperature do seem to have a pronounced effect on snow density. This is seen from the Storm Peak measurements. When the relative humidity decreased from an average of 92 percent to 86 percent the snow density decreased. This relative humidity decrease was probably associated in some way with the temperature increase. Because there was less moisture there was less perceptible water in the second snow of the day. Less water will make a snow less dense since water is heavier then snow. Elevation is possibly a cause for the high densities seen on the 16th at BAR-UE Pumphouse and the top of the Gondola. One reason besides elevation that the densities were especially high was probably the fact that the snow was from the evening before. This extra time allowed for settling and compaction. But there is also a slight density change between the two sites. The difference between the two sites and the fact that both sites had much greater densities then the mountain top seems to imply that snow density decreases with height.

The data from the March 19th thru 21st snow event does not really correlate with the thought that snow density decreases with elevation. Temperatures and relative humidity’s are not available for this event. Thus there is no outside information to help explain any differences. Nebraska received the most snowfall from this event. Both Grand Island, NE and Hastings, NE received over 20 inches while Kearney, NE received 16.7 inches. These were some of the highest totals recorded in Nebraska. These three cities are very close in proximity. Kearney is the farthest away and is about 50 miles from both Hastings and Grand Island. Kearney is to the west and has the highest elevation of the three cities. In this storm the snow that fell in Kearney had a higher density then the other two places. This seems to contradict that density decreases with height. Conversely Hastings which has a slightly higher elevation then Grand Island has a lower density then the

Grand Island snowfall. These three cities show that elevation was probably not very important in determining the density of the snowfall in this storm. Also, when comparing other places that are close in this storm like Cincinnati and Dayton, Moline and Cedar Rapids, and Springfield and Peoria, the place with the higher elevation always had a higher snow density.

Another way to try to make some deduction on how elevation affects snow density was done by using accumulated snow. The first thing that stands out is that the accumulated snow is generally denser. This is likely due to compaction and other ground processes. Also, the data from March 16th shows a clear distinction between height and density. The March 16th data shows a decrease in density with height. There is again opposing data this time from March 17th, which except for the Storm Peak measurement shows an increase in snow density with height. Thus, the results are inconclusive on the effect of elevation on snow density.

Snow density variations also have effects on how to use model projections to predict snowfall. This idea can be looked at in relation to the snow that fell at the Steamboat ski area on the night of March 12th. Figures 3 thru 6 help to show how models compare in QPF forecasts. Figure 3 is a map of the actual precipitation that occurred during the 24 hour period of March 12th at 12Z to March 13th at 0Z. Figure 4 shows how much precipitation the North American Model (NAM) forecasted for the same period. Figure 5 is the same but for the Global Forecast System (GFS) model and figure 6 is the Nested Grid Model (NGM) model. All three models do not exactly predict the actual amounts of precipitation. The NAM has the smallest grid spacing meaning that it has a best resolution of the three. The other two models have grid spacing more then double the NAM. Thus, the NAM should normally forecast precipitation events for small areas better then the other two models. This is true for the period of time being discussed. Over the United States the NAM forecasted precipitation map correlates the most with actual precipitation map. The NGM is the worst forecast especially over the mountain's west side where mountainous terrain creates small pockets of oragraphically enhanced precipitation. These figures show that even though snow densities are still not exactly known for different locations models first must make accurate QPF forecasts for Snow to Liquid ratios to even be correctly used. Thus snow density is important in translating QPF'S, but not very important in the model's correctness for a precipitation forecast.

Another model that is not shown in any figure is the University of Wisconsin - Nonhydrostatic Modeling System (UW-NMS) model developed by Dr. Greg Tripoli. For Steamboat the model was run over a higher resolution to see the topography present. Unlike most models, the UW-NMS uses a conversion to convert QPF to a snow amount. This conversion calculates a snow ratio based on a few variables like air temperature and temperature of the soil. For the night of March 12th, the model did very well in predicting the amount of snow. There was approximately 15 inches of snow overnight at the Storm Peak Lab. The UW-NMS model predicted 14 inches. The fact that it is a mesoscale model and was done over small grid spacing helped it predict the snowfall well (Model

Information courtesy of Dr. Greg Tripoli).

This case study does not present enough data and significant results to be either correlated with or contradicted with previous work. Other studies though can be compared and contrasted to see what current research is concluding. The trend of recent research has been to move away from the old average ratio of ten-to-one and come up with a better standard. In order to do this, researchers first have had to determine what causes fluctuations in snow density. The only way to do this has been to go out and use observations to support new conclusions. In these case studies many variables were identified as playing a key role in snow density. The limited results from this study did not delve into the large amounts of variables shown to be involved in snow density. In such a limited study it would have been hard to prove which factor stood out in determining snow density.

One study includes a summary of the processes that influence snow density. The processes are in-cloud processes that are associated with the shape and size of the ice crystals, subcloud processes that modify the ice crystal as it falls, ground level compaction due to prevailing weather conditions**,** and snowpack metamorphism [*Roebber et al.,* 2003]. Inside the cloud the shape of the ice crystal is determined by the surrounding air temperature and the degree of supersaturation with respect to ice and liquid [*Roebber et al.,* 2003]. The types of crystals that result are plates, dendrites, needles, columns, and others. Each crystal shape has a different density, but as ice crystals fall through the cloud they experience different environmental conditions and thus the final crystal is a combination of types [*Roebber et al.,* 2003]. Crystal size depends on how much time spent in the cloud and the degree of supersaturation [*Roebber et al.,* 2003]. Some crystals will grow relative to their neighbors leading to many small particles of low density being swept out of the cloud [*Roebber et al.,* 2003]. If an ice crystal falls through a cloud of supercooled water droplets, on the other hand, this will lead to rimed crystals (graupel) and very high snow densities [*Roebber et al.,* 2003]. After ice crystals leave the cloud sublimation and melting occur over short distances [*Roebber et al.,* 2003]. Low level temperature and relative humidity are central to these processes [*Roebber et al.,* 2003]. Finally, once on the ground compaction can occur. Wind can move ice crystals around causing surface compaction, which will increase snow density [*Roebber et al.,* 2003]. Also, the weight of the snowfall can further compress the snowpack [*Roebber et al.,* 2003]. It has been found that there are ways to try to eliminate these last influences by shading the observations from the wind and taking the measurements quickly so as not to allow for much compaction [*Wetzel et al.,* 2004]. This was done in Steamboat by putting the sites in places shielded from the direct wind. But afterwards it was realized that the sites were not shielded enough on extremely windy days like March 15th when winds where gusting to over 50mph at the top of the mountain.

Through all the case studies, temperature and relative humidity seem to be the dominate factors influencing snow density. The first and major emphasis of snow density research has been to take observations of certain places over a period of time to determine the characteristic snow density of that place. For example a study by *Judson and Doesken* [2000] attempted to determine the density of freshly fallen snow in the central Rocky Mountains. Their study found that snow densities were lower at lower elevations. Another study by *Wetzel et al.* [2004] also looked at snow density in this area, but their goals were different. *Judson and Doesken* [2000] only wanted to determine snow density. *Wetzel et al.* [2004] were bolder and looked at how snow density fits into the grand scheme of snowfall prediction in mountainous regions. But during the course of the study, *Wetzel et al.* found that snow densities are lowest at the highest elevations. This directly contradicts the *Judson and Doesken* [2000] study. But the *Judson and Doesken* [2000] study was done over a larger spatial scale. Moreover, observed density differences over a large region should not be analyzed in the same manner as small scale studies because of differing influence related to synoptic and mesoscale (storm system origin) conditions, as well as microscale influences (complex topography).

Another study by *Baxter et al.* [2004] looked at thirty year climatology of snow to liquid equivalent ratio in the contiguous United States. This goal of this study was to create a better set standard for different locations using climatology. The study developed varying standards and proposed explanations for these standards based on the kind of conditions usually experienced in a certain place. The overall conclusion though, was that climatology while a good standard could be put to even better use in creating an algorithm for snow to liquid equivalence. This idea has already been put to use but not exactly in the way the Baxter study proposed. One recent study by *Roebber* and colleagues [2004] used data from many events but not long term climatology. This study used the data to create an Artificial Neural Network (ANN), which predicts the expected snow density when separated into three classes: light, average, and heavy. This network uses technology that “learns”, sort of like humans do, and adapts to data that it does not immediately recognize. This network has proven to beat both climatology’s and the National Weather Service’s “new snowfall to estimated meltwater conversion” table. As shown the ANN is an advancement over others, but still has errors of its own and is not perfect. In an even more recent paper that discusses the data from the ANN, snow ratio was found to increase as the liquid equivalent decreases [*Ware*, 2006]. Some other empirical techniques exist to diagnose snowfall in the absence of explicit snow density forecasts, but there is an argument over whether these techniques have any value in real world applications [*Roebber et al.,* 2003]. Empirical techniques use large scale observations like where the flow is coming from and where the greatest rising motions are to predict the amount of snow expected. The techniques used by the Baxter and Roebber studies take a historical approach to looking at data and propose mathematical solutions using the data to the problem of predicting snow density. Their solutions differ from each other, but the studies arrive at these solutions from similar viewpoints. These two studies differ from the direct observational approach, which was shown by the Judson and Doesken and Wetzel studies. These studies are beneficial because they can directly show variations specific to an event, but are hard to really apply on a large scale like the Baxter and Roebber studies attempt to do. Both types of studies have valid results and use for the future.

6. Conclusion

Snow density is a topic in meteorology that is still yet to be fully understood. Many of the mechanisms by which snow density varies have been found, but the way these mechanisms cause the variations is still up for debate. My work included only a small amount of research. It did not really find a correlation between elevation and snow density. Since there were not many observations no definite conclusions can be made, but it seems that elevation is not an important characteristic in determining snow density. Also, this study showed that snow density while important for translating QPF'S, is not as important as the model's correctness of a precipitation forecast for snowfall projections. But if others continue this type of work, in the future different studies may be combined into a larger more comprehensive study. This last statement has yet to be accomplished. In reality, the only way to get a real data comparison for a large scale conclusion is to combine research from different places. This paper is an example of how to use research in the context of other research to compare and contrast results. If more results are compared then more conclusions can be drawn. Once better knowledge of the spatial and temporal characteristics of snow density and its derivatives, like snow water equivalence and snow depth, becomes known then further advances in numerical weather prediction can be made (*Brasnett,* 1999). Snow density is not just needed to convert QPF'S into snow forecasts. Snow density of accumulated snow is also needed to parameterize the melting process in hydrological computations (*Brasnett,* 1999). Also, future advancements will allow operational meteorologists to better predict snowfall and to snow hydrologists in figuring out water amounts present in a certain area. Better prediction will allow for money and lives to be saved [*Judson and Doesken,* 2000]. Snow density has become a bigger topic recently and if there is continued research, much more will soon be known about a key factor in the lives of many people around the globe during the winter months.

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http://www.emc.ncep.noaa.gov/mmb/ylin/pcpverif/daily/
National Resources Conservation Service
http://www.nrcs.usda.gov/about/organization/regions.html

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