Cloud Image Report 2

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Flow Visualization

The intent of this image was to capture a compelling image of a cloud formation. The assignment was for the Flow Visualization course at the University of Colorado. Any type of cloud formation could be photographed for this assignment, so long as the photographer found the formation interesting. In the previous cloud image assignment, I was able to catch a very dynamic formation of clouds cascading over the Flatirons due to Chinook winds. For this second assignment, I wanted to capture a calmer, peaceful photograph of clouds, so I waited for a day where the clouds were well lit, and the winds were fairly calm. On March 23, 2012 I was on my way to work at 7:30 in the morning (Mountain Standard Time) when I saw a calm collection of clouds over my house. I took a photo of the clouds and edited the photograph for submittal in class. The intent was to capture the cloud formation and to explain how it came about.

The visualization technique for the image was entirely natural. The image was taken from Table Mesa and Broadway in Boulder, Colorado. The image was captured at 7:30 in the morning, just when the sun was rising in the East of Boulder. The camera was pointed to the East, which allowed the clouds to be lit up from the other side of the photographer by the sun. This caused the light, thin clouds to come out vividly white, and the darker clouds to become greyer as the cloud thickened. The camera is held parallel to the horizon and tilted up about 45 degrees to catch more of the clouds in the sky, and to minimize the trees and houses in the shot.

The clouds in the image are categorized as altocumulus clouds. The altocumulus clouds are characterized by their fluffy characteristics, the spaces found between the clouds in the sky, and the cloud base height being 2,400-8,100 meters. (Pinney, 2011) The altocumulus clouds are typically seen in the early morning when the winds are very calm, if present at all. (Pinney, 2011) Indeed, on the morning the shot was taken, the outside environment was a little chilly but the winds were hardly noticeable.

To determine the height of the clouds in the photograph, a skew-T plot was used to find the atmospheric conditions at the time of the photograph. The skew-T plot used for the photograph is shown below in Figure 1:

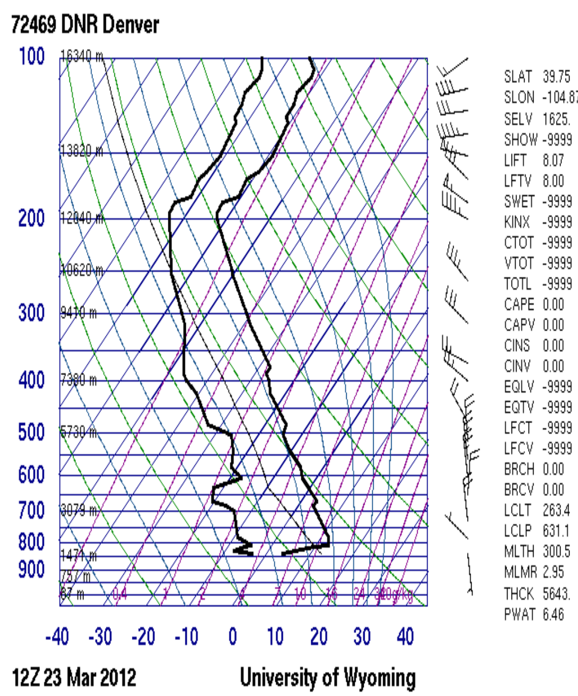

Figure 1: Skew-T plot for Denver Colorado at 00:00 UTC, 23 Feb, 2012

A skew-T plot is a means of comparing pressures and temperatures at different heights. Only two skew-T plots are available per day (one at 5 A.M., and one at 5 P.M., non-daylight savings time, Mountain Standard Time). Fortunately, the photo was shot at 7:30 AM, meaning that the skew-T data shown in Figure 1 is not too far off from the time the photo was taken. However, the data is for Denver, rather than Boulder, so some of the data may be inaccurate for a location 40 miles away. This also accounts for why the data readings do not begin until about 1471 meters. The skew-T plots are based off of a sea-level baseline, and since Denver is a mile above sea level, there is no data to be plotted below 1471 meters.

The temperature axes in the plot are skewed diagonally to the right as the pressure decreases, hence the name of the "Skew-T" plot. The bold black line on the right hand side is the temperature of the atmosphere, and the bold black line on the left is the dew point at that same height. The thin black line in the middle is the average cooling profile with increase in height, indicating the stability of the atmosphere.

If the slope of the cooling profile is less than that of the atmospheric temperature line, the atmosphere is stable at that height. If the slope is steeper, the atmosphere is unstable at that particular height. Since the slope of both the temperature and the dew point lines change with height, there are sections of the atmosphere which may be stable, and sections which are unstable. (Haby, date unknown) For the data in Figure 1, the cooling profile appears to have a lower slope than the atmospheric temperature at all points above the ground. This indicates the atmosphere was stable at all points in the atmosphere during this particular time of day.

When the temperature and dew points are close together at a given height, clouds have a good chance to be created. In Figure 1, the lines get relatively close at 4,000-5,730 meters, meaning the height of the clouds seen in the photograph is likely around that height. This fact is further verified using the following equation to predict cloud base height using temperatures at a given height: (Rosenfeld, 2009)

$$\mathbf{H_{cloudbase}=(((T-DP)/2.44\ {}^{\circ}C)x304.8\ m)+H_{temp}} \quad (1)$$

$$\mathbf{H_{cloudbase}=(((12-(-3))/2.44)x304.8\ m) + 1471\ m}$$

$$\mathbf{H_{cloudbase}=3344.7\ m}$$

In Equation (1), T is the actual temperature at the height in question, DP is the dew point at the same height, and the +Htemp is the height above the ground where the temperatures are recorded. In this example, the numbers are based off of the 1471 meter readings in Figure 1, since those are the lowest recorded readings. Equation 1 indicates that the cloud base should be somewhere around 3500 meters relative to sea-level, or about 2 kilometers off the ground in Colorado. This agrees fairly well with the data in Figure 1. Although there is a difference in about 500 meters for the two estimates, the 40 mile difference in location between Boulder and Denver, and the 2-3 hour difference between the photograph and the skew-T plot data accounts for the variance in the two results. Both results indicate that the cloud base is formed around where altocumulus clouds should be expected for such a day. (Pinney, 2011) In fact, it was fortunate that the weather was calm enough for the altocumulus clouds to be so stable at the time of the photograph. Many times in the springtime, altocumulus *lenticularis* clouds are expected around the Flatirons area, due to the cold fronts moving in, and the winds caused by the change in weather. (Banta and Cotton, 1981)

The altocumulus clouds are predominantly formed of liquid vapor, but in temperature ranges from -40 to 0 degrees Celsius, a mixture of ice crystals and liquid water droplets can co-exist in the same cloud formation. (Carey, et al. 2008)

The ice crystals can only form in clouds if the temperature is below freezing. At the time this photograph was taken the temperature was approximately 8.9 degrees Fahrenheit (as determined from the University of Colorado Boulder Weather archive). This is above the freezing point of water. While it is true that temperatures decrease with increasing height through the troposphere, the cloud base was not at adequate temperature, based off the following equation (Kittle, 1980):

$$\frac{dT}{dz} = -\frac{mg}{R}\frac{\gamma - 1}{\gamma} = -9.8°\mathrm{C}/km$$

Where R is the specific gas constant, γ is the heat capacity ratio, (equal to 7/5 in dry-air conditions [Kittle, 1980]) m is the average mass of the air, and g is earth normal gravity. Using this equation, and the calculated height of the clouds (~2 km), the temperature of the clouds is approximately -11 degrees Celsius. This is well below freezing, therefore there is likely a water vapor and ice crystal mixture within the clouds.

When there are ice crystals present in the clouds, the ice can act as prisms to the sun behind the clouds. This prism effect has the ability to create a spectrum of colors emanating from the clouds themselves. These are typically seen in the thinner, cirrus clouds, where the light diffraction is not blocked by the thicker clouds. An example of this type of light diffraction is shown below in Figure 2.

Figure 2: Example of Light Diffraction due to Ice Particles in Clouds (From North by Northwest Archive: http://northbynwa.com/category/its-science/)

Note that the cumulus clouds in Figure 2 show little rainbow diffraction, except for a bit at the edges. While such phenomena is somewhat frequent across Colorado, the image in question of altocumulus clouds does not show any type of color diffraction, even on the edges. This is primarily due to the altocumulus cloud type. The clouds are too thick for the light to penetrate through and diffract in the dramatic fashion seen in Figure 2. The cirrus clouds in Figure 2 are very thin, and allow for good color visibility, whereas the altocumulus clouds in the image discussed above show shades of white, grey, and black, but no rainbow colors. This diffraction dynamic would have been nice to capture, but was not achieved during this shot. If the clouds had been thinner on the outside portions of the clouds, it is feasible that a rainbow might have been visible.

The weather stayed fairly constant throughout the rest of the day. The temperature continued to increase on a day-to-day basis for the next week. This indicates that the atmosphere was fairly stable and calm after the image was taken, which allowed for the altocumulus clouds to be serene and calm as they were taken.

To capture an adequate field of view of the clouds, it was necessary to get a large field of view. However, in achieving this large field of view, a set of trees had to be included in the image. In order to make the trees work with the image, rather than distracting from it, the camera was set up to capture a large depth of field, keeping both the trees and the clouds in sharp focus. From the relative size of the trees and the approximate 2 km. height of the clouds, the individual cloud sizes varied from 100 meters with the small clouds, to as much as 1 km in length on the large clouds on the right side of the photo.

The picture was taken at an ISO of 100, a focal length of 6.3 millimeters, an f stop value of 7.1, and a shutter speed of 1/400 second. The image was captured in jpeg format with 7.1 megapixel resolution (the maximum resolution for the Sony Cybershot DSC-S700) with a width of 2304 pixels, and a length of 3072 pixels. The original image can be viewed in the Appendix. The picture was cropped down to 2140 pixels by 2468 pixels, and Gimp© was used for editing. In editing, the color saturation was turned up by +20. The blue and green hue were increased by +15 and +35, respectively. The color saturation and color hue alteration made the blue sky more vivid. This did not change the image too much from the original, since the original image looked pretty good as it was.

This image reveals a serene scene where stable altocumulus clouds float peacefully above the front range of Boulder. The image was taken at a time of day where the blue sky was visible between the clouds, which made for a vivid contrast between each cloud. Originally, the image did not look as striking as it looked in real life. The solution was to increase the color sharpness and blue shades with Gimp©. Overall, not much editing was required, which was nice, since the previous cloud image took quite a bit of time to edit (see previous cloud report). The physics of the cloud formation are well understood, and the data obtained seems to match up fairly well with the dynamics shown in the photo. It would have been nice to capture a shot with some more color, as seen in Figure 2, but the characteristic altocumulus formation looks good in a simple, serene way. It would be interesting to see how the time of day might have affected the overall photo. A nice addition would be to take many images of the same spot over a longer period of time to fully understand the wind and atmospheric dynamics that propagate the clouds through the sky. Overall, I am pleased with this image, and I learned a fair amount of cloud dynamics through the whole process.

Bibliography:

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Appendix:

Figure A: Original Image, as seen before any post-processing modification