Cloud Image Report 1

Joshua Hecht

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Flow Visualization

The intent of this image was to capture a compelling image of a cloud formation for the Flow Visualization course at the University of Colorado. The photographer could choose any cloud they desired. Originally, images were of puffy clouds on a sunny day, but the photographs were not very striking. A different opportunity arose on Wednesday, February 22, 2012, when wind was blowing out of the west of Boulder, Colorado with gusts of 60 miles per hour and up. The sun was starting to set over the Flatirons in the west, and the wind was carrying waves of clouds over the mountains. A photograph was captured at a moment where two sets of clouds were about to meet, and a thin strip of blue sky was able to peek through the closing gap. The intent was to capture this cloud dynamic and to explain how it came about.

The visualization technique for the image was entirely natural. The image was taken from 30th and Colorado in Boulder, Colorado. The image was captured at 4:30 in the afternoon, just when the sun was approaching the top of the Flatirons. The image was lit up from the other side of the clouds by the sun. This allowed the top portions of the clouds to come out white and vivid, since they were being directly exposed to the sun. The clouds were quite thick so the light did not penetrate to the bottom of the cloud, where the clouds in the image appear significantly darker. The camera is rotated at a slight angle relative to the horizontal, about 10 degrees, which creates a diagonal break in the blue sky between the clouds. The camera is tilted about 30 degrees upwards to catch more of the clouds in the sky, and to line up the blue sky break in the center of the image.

The clouds in the image are categorized as altocumulus lenticularis 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 clouds on the upper portion of the image have a billowy and spread out shape, whereas the clouds over the Flatirons are smooth and curled. The lower cloud is a lenticularis cloud, formed by the wind creating a smooth face on the cloud surface perpendicular to the wind direction. To verify the height of the cloud base formation 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:

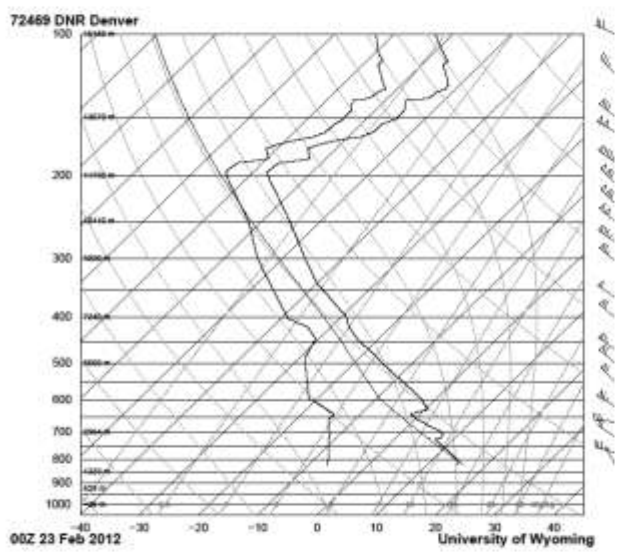

Figure 1: Skew-T plot for Denver Colorado at 00:00 UTC, 23 Feb, 2012

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 4:30 PM, (MST) 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. 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 right 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 steeper slope than the actual temperature line around 6,000 meters. This indicates the atmosphere was likely unstable at that height.

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 6,000 meters, meaning the base 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)

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

$$\mathbf{H_{cloudbase}=(((24\text{-}1)/2.44)x304.8\ m) + 1400\ m}$$

$$\mathbf{H_{cloudbase}=4273.1\ m}$$

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 1400m readings in Figure 1, since those are the lowest recorded readings. Equation 1 indicates that the cloud base should be somewhere around 4500 m. This agrees fairly well with the data in Figure 1. Although there is a difference in 1,500 meters for the two estimates, the winds coming off the Flatirons cause significant turbulence in the atmosphere and the cloud location, which accounts for the variance in the two results. Both results indicate that the cloud base is formed around where cumulus clouds should be expected for such a day. In fact, for 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)

There are other types of clouds that may be expected with this type of weather. One example is stratocumulus clouds, which are likely to appear if the atmosphere was stable. (Pinney, 2011) However, the cooling profile shown in Figure 1 demonstrates that at 6,000 meters, the atmosphere was unstable, leading to the altocumulus lenticularis clouds to be formed over and around the Flatirons. Therefore, the data found from the skew-T plots matches up very well with the actual formation of clouds on the day in question.

The altocumulus clouds on the bottom part of the image are curled down from the peak of the cloud at its highest altitude, due to the wind being launched over the Flatirons and cascading back down. These type of winds are called “Chinook winds” and cause a downwards draft of winds as the Flatirons drop off. The wind coming over and around the Flatirons carries the atmosphere, and the clouds within the atmosphere along for the ride up and over the Flatirons. The downwards motion of the wind carries the clouds downwards, making a smooth surface of the cloud where the wind is flowing over the cloud formation. (Ives, 1950) The dynamics of the Chinook winds can be visualized in Figure 2:

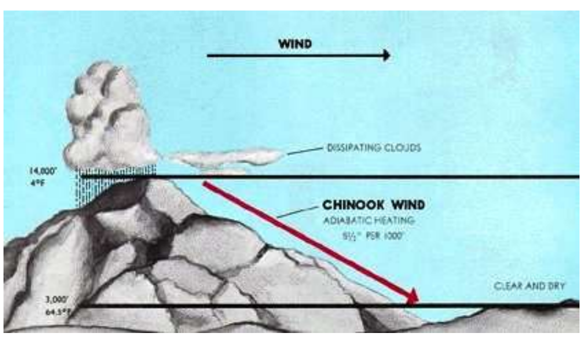

Figure 2: Example of Chinook Wind Dynamics (From U.S. FAA AC 00-61, Chapter 6, Figure 41. Adiabatic warming of downward moving air produces the warm Chinook wind.)

While Figure 2 shows a 14,000 foot mountain, as opposed to the smaller Flatirons, the dynamics are the same. The wind is forced down over the mountains, and the clouds are kept at a layer just above where the top of the mountain is located. Indeed, this is exactly what is shown in the lower portion of the image, where the clouds appear much smoother than those in the upper portion of the image, since the wind is cascading down and around the clouds. The clouds are kept above the top of the Flatirons, due to the adiabatic heating that is undergoing as the wind cascades down the mountain. The fact that the clouds are caused by topography (the Flatirons) categorizes the clouds as orthographic clouds. The weather was very windy the entire day, and quite cold. About 2 hours after the photo was taken, significant precipitation started to occur in the form of snow. The snow indicates that the water was building up in the cloud, and that the snow was getting closer and closer to the surface. Indeed, looking at the skew T plot shows that at altitudes lower than 6,000 meters, the dew point and temperature were not close enough together to allow for precipitation. However, since the cloud formation was already so close to the ground, and the winds were cooling down the atmosphere, the cloud formation point was getting lower and lower to the ground. After a couple hours, the atmospheric temperature cools down enough so that it equals the dew point of the atmosphere, causing precipitation. This process is actually exactly what happened on the day in question.

To capture an adequate field of view of the clouds, it was necessary to get a large field of view. The camera was set up so the waves of clouds coming over the Flatirons were captured in the same image as the billowy clouds directly overhead. The clouds were at a height of approximately 6,000 meters and the set of clouds coming over the Flatirons were located approximately 2 miles away.

The distance and field of view calculations are taken from approximating distances using the calculations and figures from Google Maps ©.

From the size of the Flatirons in the original image, the field of view was likely about 2 miles across, and the image covers cloud heights up to about 5-8 miles up. 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 1/640 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 2304 pixels by 1864 pixels, and Photoshop Lightroom© was used for editing. In editing, the exposure was decreased by -.85, the clarity was increased by +50, the lights were increased by +15, the darks were decreased by -15, the highlight and shadows hues were significantly turned up to give the most contrast possible, and the image was finally sharpened by 25. This significantly changed the image, for the original white clouds with the blue break in the sky turned into a vivid yellow and brown image, highlighting the blue break in the sky as a dark brown strip in between two vivid clouds.

This image reveals some very unique fluid dynamics found within the atmosphere in the front range area of Colorado. With the unique topography of Boulder, the springtime brings about Chinook winds over the top of the mountainside, which catch the clouds forming above and around the mountain. The image captures these Chinook winds catching an altocumulus lenticularis cloud, and creates a swirling effect around the outsides of the cloud. The image was taken at a time of day where some blue sky was visible between the clouds, which makes for a unique contrast between the different types of clouds. Originally, the image did not have enough definition to make the clouds look striking. The solution was primarily found with Photoshop©, where some creative cropping and editing brought out the colors and shades of the clouds in an old-school vintage fashion. In the future, it would be nice to have an image which did not require so much editing. 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. There remains a mystery in the image regarding how long the clouds took to meet up, and eliminate the break in the sky imaged in the photo. However, the photo was taken at an ideal time, and the intent of the image was fully realized in understanding how such a formation came about. In the next set of images, it would be interesting to see how the time of day might have affected the overall photo. Perhaps more photos must be taken over a longer period of time to fully understand the wind and atmospheric dynamics that propagate the clouds through the sky.

Bibliography:

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Appendix:

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