Boulder Stratus Fractus Cloud Formation

Clouds 1 Assignment

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MCEN 5151: Flow Visualization
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February 24, 2014

The second assignment for Flow Visualization (MCEN 5151), entitled “The Photography of Clouds”, is the first of two assignments where students are required to take photos of clouds that both have an artistic appeal and display a visible fluid phenomenon. The first of the two photos is required to be taken between January 10th and February 19th, meaning that the clouds will be ones commonly found during the cold weather of the winter season. With my photo, I wanted to photograph a dissolving (or fracturing) cloud so it would be reminiscent of waves or fire. When I eventually ended up locating a fractus cloud, I took many pictures of it as it dissolved so that I could capture the right shape to achieve the desired effect.

My photograph (seen on title page) was taken in east Boulder near Baseline and 55th Street in an open field in the late afternoon of February 15th, at 4:27 pm. The cloud formation was in front and slightly south of the flatirons, so the camera lens was facing just south of west. The cloud formation that I focused on was low hanging, so the camera was only about 25^{o} above horizontal for the final photograph used. The temperature in Boulder at the time the photograph was taken was 39^{o} F and there was a low northeast surface wind of 8 mph.

There are two cloud types in the image. In the upper half of the image, we see what appear to be translucent clouds covering the sky. These are likely cirrostratus, which can be deduced from observing that they are high up in the sky, light in color and transparent rather than opaque. The other most likely candidates are altostratus and cirrocumulus, however if either of these were in the sky that day, different conditions would likely have been observed. Altostratus clouds tend to be more opaque and block out the sun and cirrocumulus do not form as smooth and continuous as cirrostratus, so neither are as likely as cirrostratus. The atmosphere was stable as well (discussed in more detail later), which is further evidence of some form of high level stratus clouds. The main focus of the image, though, is placed on the dissolving cloud in the forefront, which I concluded to be a stratus cloud of the fractus species. To determine the genus of cloud, weather data from the day the photo was taken as well as from previous and subsequent dates needed to be gathered. This information was found using skew-T diagrams provided by the University of Wyoming’s Department of Atmospheric Science and general weather/cloud graphs from WeatherSpark.

A skew-T diagram is a graph that allows users to view the temperature and dew point as a function of altitude. The wind speeds at various altitudes are also shown and the chart provides an adiabatic line as well, which is useful when looking at the convective available potential energy (CAPE number) to determine atmospheric stability. The skew-T diagram for February 15th at 6:00 pm is shown below in **Figure 1**.

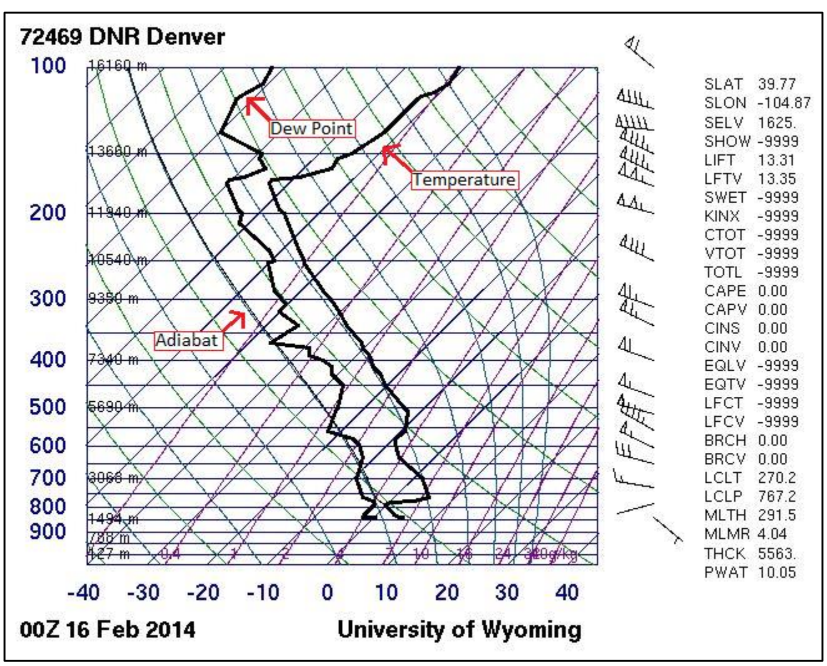

Figure 1: Skew-T diagram for Denver, CO at 6:00 pm on Feb. 15th, 2014.[1]

From the skew-T diagram, we gather a few very important pieces of information. Firstly, we can see that the CAPE number is 0.00 (shown on the right column of the figure). This means that the temperature line (the bold line on the right, labelled in **Figure 1**) is above the adiabat (dark blue bold line, labelled in **Figure 1**) at all times. If the temperature line were to dip below the adiabat at any level in the atmosphere, the atmosphere would be said to be unstable, and the CAPE number would become greater than zero, with the magnitude depending on the area below the adiabat and above the temperature line. Another important piece of information is gathered from the distance between the dew point line (bold line on the left, labelled in **Figure 1**) and the temperature line. As these lines approach each other, the likelihood of a cloud forming at that particular level in the atmosphere is increased. The reason clouds form as these two lines come together is because as the temperature of the air is cooled, its ability to hold water vapor is decreased. When air is cooled to the dew point temperature, it becomes saturated with water, causing vapor to be released. After being released, some of the vapor can condense into water droplets and form a cloud.[3] Condensation resulting in cloud formation can only occur if the water particles are able to condense onto an air parcel, though. Air parcels can ascend into the atmosphere by four main mechanisms: convection, frontal uplift, orographic uplift and convergence.[4] Depending on the mechanism, different types of clouds can be formed. This information, when used in conjunction with the atmospheric conditions provided by WeatherSpark (shown in **Figure 2** below) allow us to hypothesize what type of cloud is present in the image.

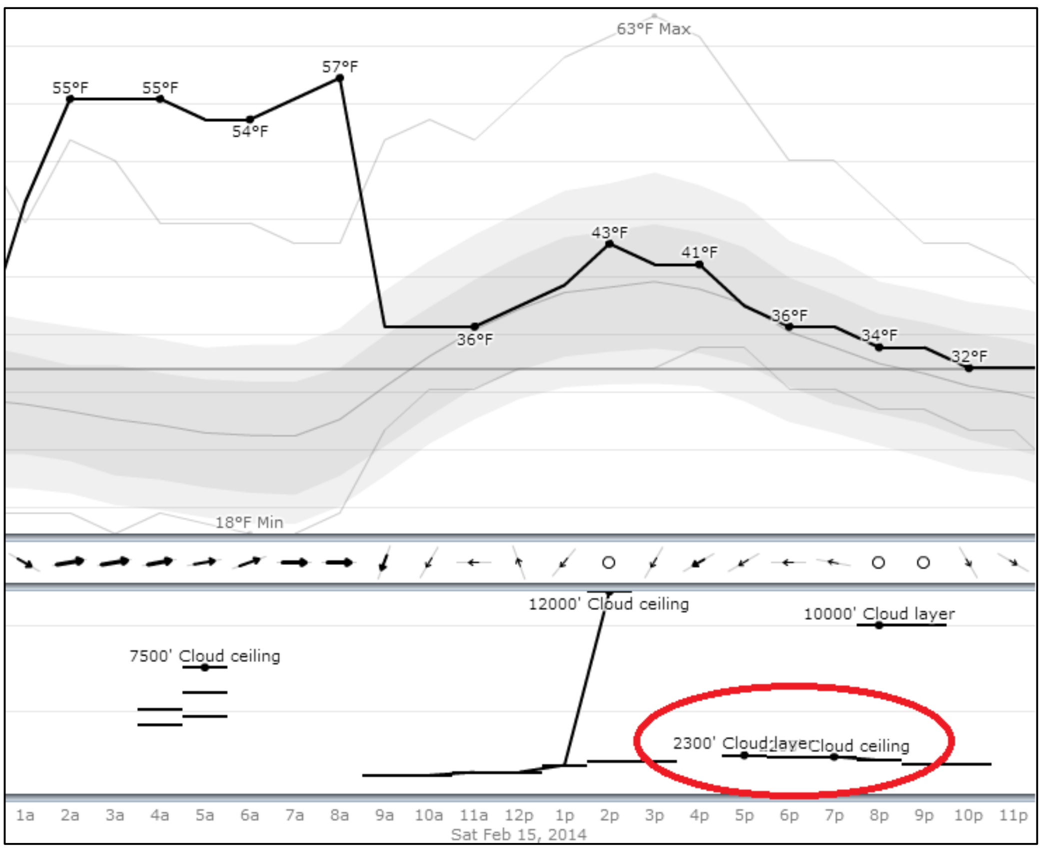

Figure 2: Temperature, wind and cloud ceiling data from Weather Spark.[6]

The data in **Figure 2** (and other information gathered from WeatherSpark) informs us of the temperature, surface wind speed/direction, precipitation, humidity (84% at the time the picture was taken) and cloud ceiling. The most meaningful piece of information here is the cloud ceiling, which tells us how high the clouds were at the time the photo was taken. From the graph, we see that around the time the image was taken, the cloud ceiling was at around 2300 feet above ground level. Looking back at **Figure 1**, we see that the temperature and dew point lines get very close at around 1500 meters (roughly 5000 feet) above ground level. Because neither of these charts give us the exact information we need at the precise time and location required, some gauging is necessary. Using this information, I believe it is safe to say that the cloud ceiling was somewhere between 2300 and 5000 feet above ground level in at the time and location the photo was taken. This suggests that the cloud is some form of low cloud, which form below 6500ft, or 2000m (**Figure 3**). This limits the genus possibilities to stratus, stratocumulus and cumulus (no precipitation, so cumulonimbus and nimbostratus are not potential candidates).[5] It is known that the atmosphere was stable, which is evidence in support of stratus and stratocumulus cloud types. Lastly, we can see obvious fracturing of the cloud occurring in the image, and because there is no fractus species of stratocumulus, I selected stratus as the most likely genus of cloud.

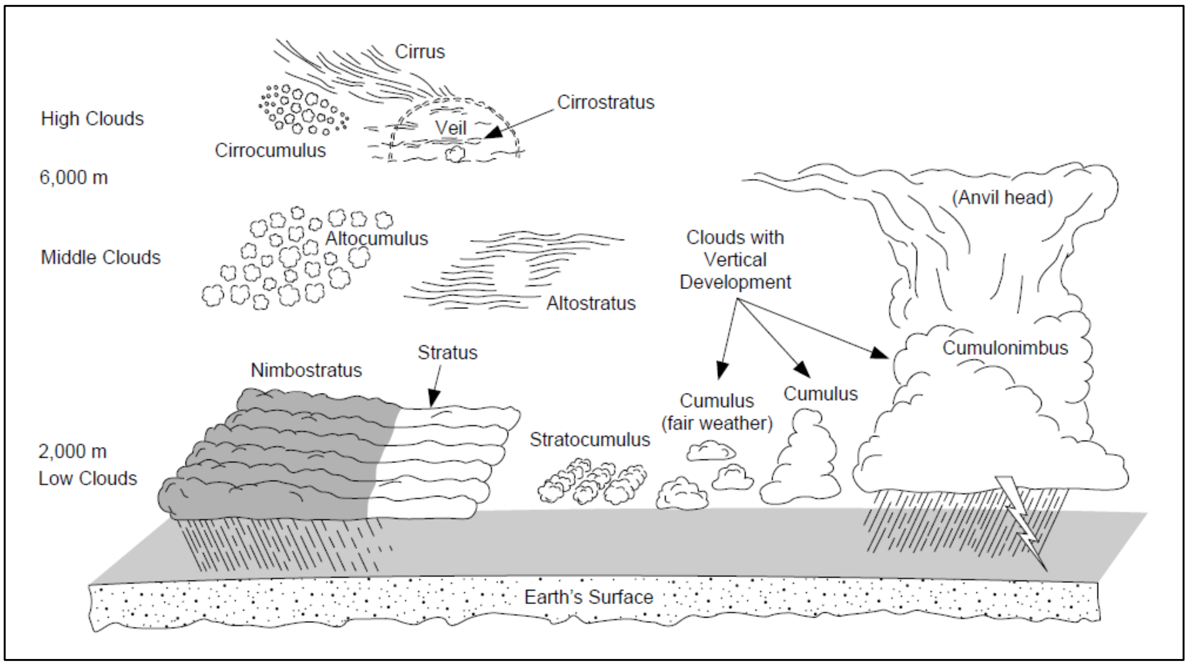

Figure 3: Cloud types and levels in atmosphere.[5]

To further support that the cloud is of the stratus genus, the temperature history for the Boulder area was consulted (Weather Spark). It was discovered that the date of February 15th was in the middle of what appeared to be a warm front, with cold fronts in front and behind. There was no precipitation on the day the photo was taken, and little to no precipitation on the days immediately before and after the 15th. Because stratus clouds are likely to form in the stable, calm conditions between fronts, this further reinforces the claim that the clouds are stratus (though stratocumulus are likely to form in these conditions as well).

I determined the stratus cloud in the image to be of the fractus species. A simple look at the cloud is evidence to this, as it is obviously breaking apart and dissolving at a significant rate. Knowing the species of cloud is important, but it is also important to understand why this particular cloud might be dissolving. There are several potential reasons why a stratus cloud, like the one I photographed, might start to fracture. These include turbulence and shear caused by high winds, as well as the tendency of clouds to dissolve as they descend. High, turbulent winds can lead to fractus clouds because they can shear a small portion of the cloud off from a large group. When a small part of the cloud is broken off from the group, it is easier to start raising the temperature of the condensed water in the cloud to a high enough level that it goes above the dew point. This leads to unsaturated air, which in turn causes the water molecules to rapidly convert to the vapor form. As the molecules evaporate into vapor, they become more energized and move faster than the surrounding liquid water. These faster moving vapor molecules, as they move around and collide with liquid molecules, are what cause the visible fracturing and branching of the cloud, much like what we see occurring in the image.

Clouds can also begin to fracture as they descend. As the air descends, various changes in the atmosphere occur, including an increase in pressure and temperature (seen on the skew-T diagram, **Figure 1**). This leads to a similar mechanism as was previously described, where the molecules become more energized, evaporate, and the cloud begins to "branch" and fracture. From the skew-T diagram, we can see that the wind speeds at the 2300-5000ft levels in the atmosphere are fairly low, which suggests that the fracturing of this stratus cloud is caused by descending air rather than turbulent winds. Stratus cloud fracturing in general, regardless of the mechanism, when it occurs in the atmospheric boundary layer (lowest part of the atmosphere), has been associated with the transition from non-Brownian to Brownian-type fluctuations that liquid water molecules experience as they change from liquid to vapor.[2]

Now that we have classified both the genus and species as stratus and fractus, respectively, the last piece of classification information desired is the variety of cloud. For stratus clouds, there are three potential candidates: opacus, translucidus and undulatus. Unlike genus and species, clouds can belong to multiple varieties at the same time. An opacus cloud is one that is opaque, and blocks out the sun. A translucidus cloud is one that is transparent enough that light from the moon or sun would be able to penetrate through to the earth. An undulatus cloud is one that is broken up into individual spots or layers. We do not see any of the undulatus type of behavior in the cloud from the photograph, so we can safely say that it is not an undulatus variety of stratus fractus. Because it is very opaque and could easily block out the sun, I concluded it to be a stratus fractus cloud of the opacus variety. The previously identified cirrostratus cloud is likely of the nebulosus species because of its featureless appearance, but because this cloud is not the focus of the image, much time will not be spent on its precise classification.

The distance between the camera lens and the stratus fractus opacus cloud in the image was roughly 10000ft, with a field of view of roughly 5000ft by 7500ft. As was previously mentioned, the cloud was low hanging, so the angle of the lens above horizontal was only about 25^o, and the photo was taken at ground level (i.e. not on top of a building, rock formation, hill, etc.). The full camera specs are shown in **Table 1** below. A digital DSLR camera with a standard zoom lens was used to take the photo. The zoom was utilized to give the appearance of being very close to the cloud. Because it was daytime and the camera was being pointed in the direction of the sun, the ISO was turned very low and a fast shutter speed and high f-stop were used. This allowed me to take the photo without getting any blown out areas.

Table 1: Camera settings

Camera Body	Canon EOS Rebel T2i
Camera Lens	Canon EF 28-135mm IS USM standard zoom
Shutter Speed	1/160
ISO	100
Aperture (f-stop)	22
Focal Length	80mm
Pupil Diameter	3.64mm
Pixel Dimensions	5184 x 2962 (unedited image 5184 x 3456)

The photo was digitally altered utilizing both Adobe Lightroom and Adobe Photoshop. Lightroom was used to adjust the contrast, increase the highlights, darken the blacks, turn the photo black and white and crop the image slightly to the appropriate size. The image was only cropped in the vertical direction, decreasing the pixel height from 3456 to 2962 so that the final dimensions were 5184 x 2962 pixels. By increasing the contrast, I was able to bring out details in the clouds that were hard to see before the adjustment was made. The choice to change the photo to B&W was made for two main reasons. First, there was a slight lens flare on the original image that was undesirable. Turning the photo black and white eliminated this. It also allowed me to change the hue, saturation and additional contrast settings to bring out more detail in the clouds without making the image appear unnatural. The image was then moved into Photoshop to get rid of some spots that appeared due to dust on my lens. The dodge tool was also used on some of the branches of the fracturing cloud so that they would stand out better against the grey background, which originally was of a similar shade (see **Figure 4**). By doing this, viewers are able to see the details in the fracturing pieces of the cloud much easier.

Figure 4: Original image, before any post-processing

I believe that the intent of the image was realized. I noticed that fracturing clouds looked like fire or waves crashing on rocks, and I wanted to capture that look. The photo that I was able to get does exactly that, while also clearly illustrating the physics of a cloud breaking apart. This image shows me that even common cloud types like stratus clouds can be beautiful under certain circumstances. If I were to retake this photo, I would do my best to eliminate the cloud in the upper right of the image. While it does not do the image a terrible amount of harm, I feel as though it is a bit distracting and takes the viewer's eye away from what I really want them to be looking at, which is the stratus fractus cloud as it dissolves. Aside from that, I do not think there is anything that I would change. I like the photo a lot, and in the end it turned out much better than I imagined it would.

References

[1] "Atmospheric Soundings." *Atmospheric Soundings*. N.p., n.d. Web. 18 Feb. 2014. <http://weather.uwyo.edu/upperair/sounding.html>.

[2] Ivanova, K., M. Ausloos, E. E. Clothiaux, H. N. Shirer, and T. P. Ackerman. "Breakup of Stratus Cloud Structure Predicted from Non-Brownian Motion Liquid Water Fluctuations." *Tenth ARM Science Team Meeting Proceedings* N/A (2000): N/A. Print.

[3] Krollova, Sandra. "Cumulus and Stratus Clouds Microstructure." *Centre of Excellence for Air Transport* 6.5 (2011): 143-148. Print.

[4] Russell, Andrew, Hugo Ricketts, and Sylcia Knight. "Clouds." *Physics Education* 42.5 (2007): 457-465. Print.

[5] Shaw, Glenn E.. "Clouds and Cloud Formation."*Clouds and climate change*. Sausalito, Calif.: University Science Bks., 1996. 2-8. Print.

[6] "WeatherSpark Beta." *Beautiful Weather Graphs and Maps*. N.p., n.d. Web. 18 Feb. 2014. <http://weatherspark.com/#!graphs;a=USA/CO/Boulder>.

LOUDY ARCTIC BOUNDARY LAYER