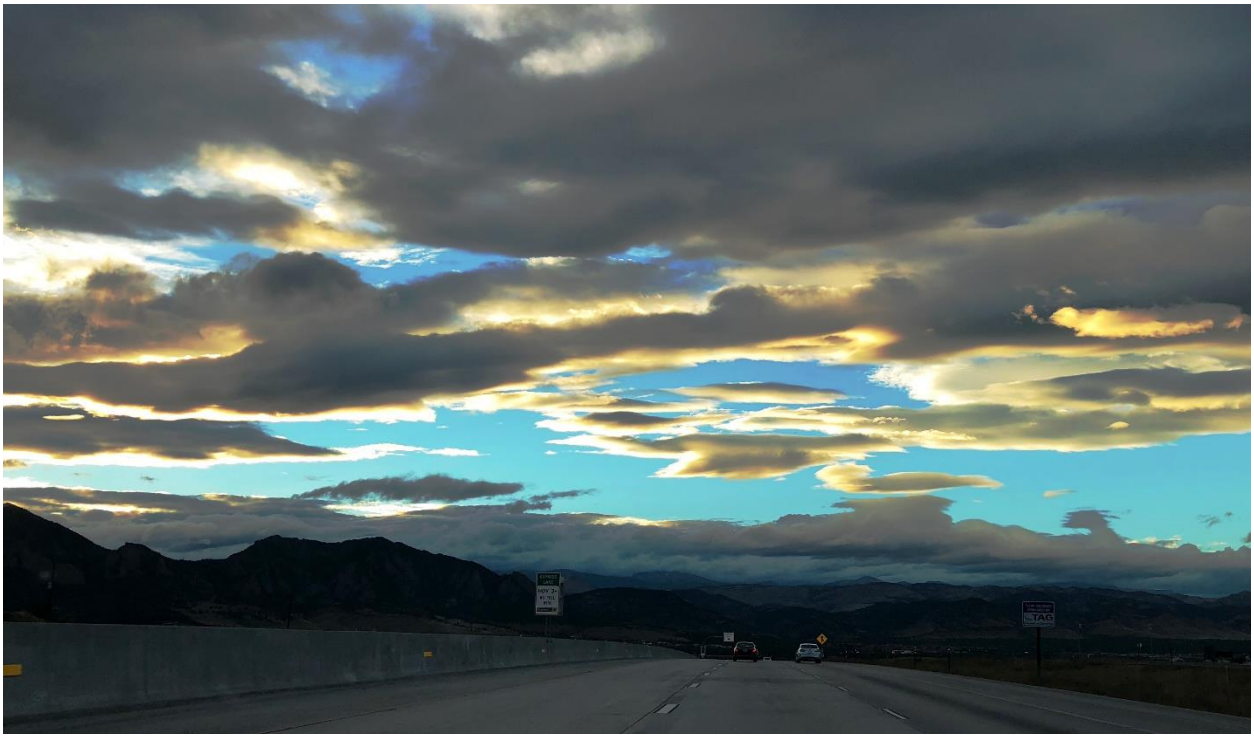

Formation of Stratocumulus and Föehn Clouds Over Boulder

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Introduction

Cloud formations are an aspect of everyday life that many people take for granted and tend to not know anything about the physics or science behind them. For this assignment, we were tasked with capturing the beauty of clouds around us. Luckily, Colorado and particularly Boulder, tend to generate some incredible and very unique cloud formations. I am relatively new to identifying and capturing clouds so I wanted to capture something unique to the Boulder valley. As one of my friends was driving us back from Louisville, I was able to capture a great image of clouds just after the sunset on a warm October day.

Experimental Setup

There was no controlled experimental setup for this image. Unfortunately, we are not able to control the weather; however, we can do our best to capture its beauty. This image was captured at 6:25pm on October 2, 2018.

Cloud Physics

As shown in the image, the clouds captured in the foreground of the image are classified as Stratocumulus. Stratocumulus clouds are formed in stable atmospheres. Stratocumulus clouds are typical puffy clouds that form at distances around 6,000 to 10,000 ft above the surface of the Earth. By utilizing the Skew-T data shown in Figure 1, we can analyze approximately what height we believe these clouds are present at.

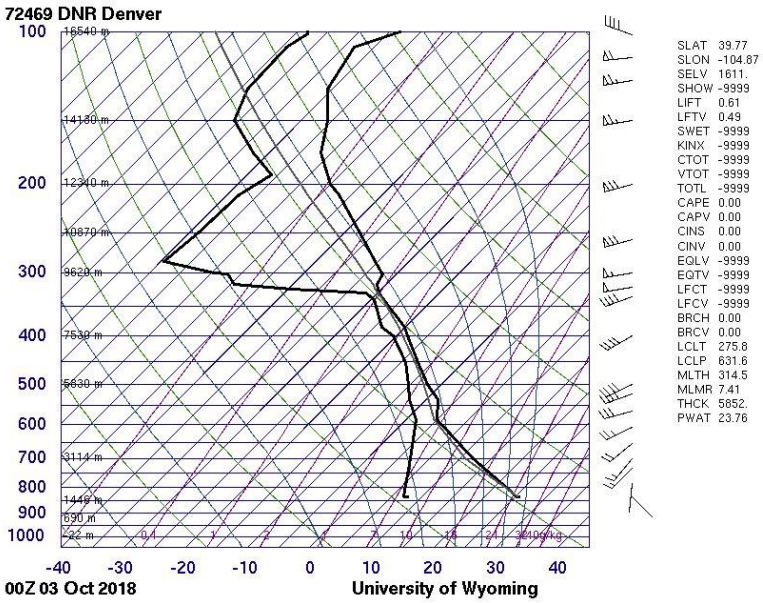

Figure 1: *Skew-T data from Denver International Airport at 6pm on October 2, 2018*[1]

The Skew-T plot shows a variety of atmospheric information; for the purpose of this report we will focus on the following items. The dark black line on the right half of the plot shows the atmospheric temperature, while the dark black line on the left half shows the due point. It is important to note that when the temperature and dew point become close to one another, the likelihood of a cloud forming at this location is high. This is because that at this altitude, the atmospheric temperature is close to the required temperature to generate moisture (dew point). From Figure 1, this appears to be anywhere from roughly 4,000 meters to 10,000 meters above sea level. This data translates to the likelihood of clouds forming around 6,500 to 26,200 ft above the surface in Boulder CO. In addition to the Skew-T data, a Ceilometer reading was obtained for this day. Ceilometers typically work by emitting a strong beam of infrared or ultraviolet light (or this can be a laser depending on the application) at the cloud ceiling overhead. The reflected light by the base of the clouds is then received by a photocell that can estimate the height and thickness of the clouds.[2] This data can be seen in Figure 2 below.

[1] "University of Wyoming Atmospheric Sounding Data." Atmospheric Soundings. October 2, 2018. http://weather.uwyo.edu/upperair/sounding.html.
[2] Morris, VR. "Ceilometer Instrument Handbook." *US Department of Energy*, 2016. doi:10.2172/1036530.

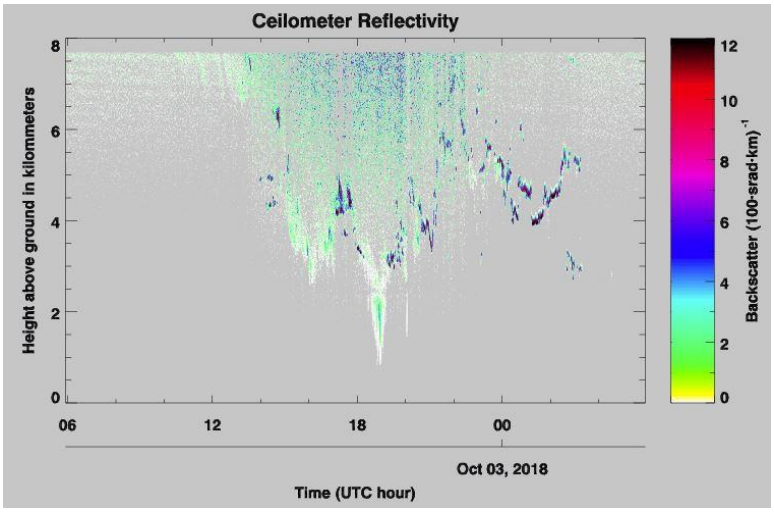

Figure 2: *Ceilometer Reflectivity Data*[3]*. Note that the time the image was captured was at 00 (UTC hour) on Oct 03, 2018.*

Both sets of data support the assumption that the clouds within the foreground of the image are Stratocumulus. In addition to the height of the clouds, the Skew-T also depicts the stability of the atmosphere through the CAPE value on the right side of Figure 1. When this value is equal to zero, the atmosphere is stable. This CAPE value also suggests that the clouds are Stratocumulus in nature.

The more unique portion of this image, is the cloud formation lurking in the background, trapped behind the foothills. This cloud front is known as a Föehn cloud wall. Föehn clouds are generated by a Föehn wind blowing over the mountains and down the front face of the foothills. A Föehn wind is a generic term for a warm, strong, and often very dry wind that descends in the lee of a mountain barrier.[4] These types of winds typically associate with a weather system moving across a mountain range. This is true, just 3 days after this picture was taken, the weather in Boulder got much colder as shown in Figure 3.

[3] "Ceilometer Reflectivity." Skywatch Observatory. October 2, 2018. http://skywatch.colorado.edu/.
[4] Weatheronline.co.uk. "Föhn (foehn) Wind." WeatherOnline. https://www.weatheronline.co.uk/reports/wxfacts/The-Foehn-foehn-wind.htm.

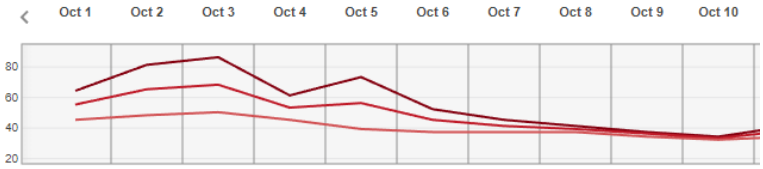

Figure 3: *Weather trends in Boulder, CO for the week following October 2, 2018. Note that the lines represent Maximum, Mean and Minimum temperatures for each day.*[5]

This wind direction is a very common occurrence in Boulder due to the nature of the valley that we live in. As shown by the wind indicators on the Skew-T in Figure 1, the wind at all altitudes is blowing almost directly east, suggesting that a Föehn cloud wall is probable to occur. As the Föehn clouds continue to collect on the back side of the mountain, they will typically stay stationary with periodic clouds breaking off and forming throughout the valley. The lines of Stratocumulus clouds seen in the image are likely formed from the Föehn cloud. This linear nature of the clouds has a specific suffix, these clouds are called Stratocumulus Lenticularis.

Photographic Technique & Post Processing

This assignment required little precision and was really a "push-here-dummy" type shoot, I just let the clouds do all of the work. The camera that was used to take this photograph was an iPhone X. This experiment did not require extremely quick shutter speed; however, the default shutter speed of iPhone's is 1/350 seconds. The shot was conducted through a clean car window. No additional lighting was required. The camera settings used were as follows:

Photo Dimensions	4032 x 3024 Pixels
ISO Speed	ISO - 20
F-Stop	f / 1.8
Exposure Time	1 / 350 sec
Flash Mode	No Flash
Focal Length	4 mm

Table 1: *Camera Settings*

[5] "Boulder Muni, Boulder, CO, CO History." Weather Underground. October 2018. https://www.wunderground.com/history/monthly/us/co/boulder-muni,-boulder,-co/KBDU/date/2018-10.

Colorado generates some beautiful sunsets, and this was no exception, in post-processing I essentially just tweaked the color curve to make the background blue pop. I preformed my post-capture editing through Gimp. Figure 2 shows the color curve utilized to generate the editing progression seen in Figure 3. The raw image had an extremely wide field of view that captured a large number of distracting elements. After color correction was completed, I cropped the image into a nice landscape orientation that removed the extremely long foreground of highway as well as distracting elements to the right of the image. This allowed the central focus of the image to be on the clouds, rather than the highway or other distractions.

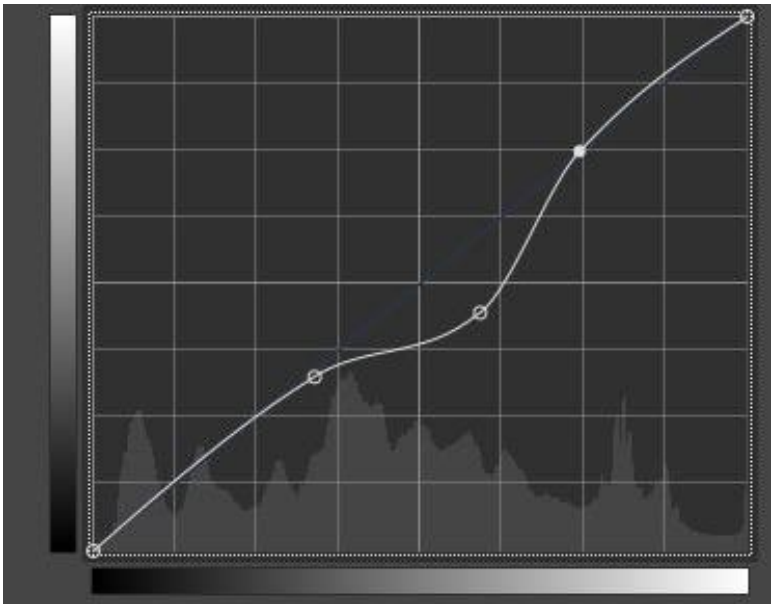

Figure 2: *Color correction curve utilized to generate the final image.*

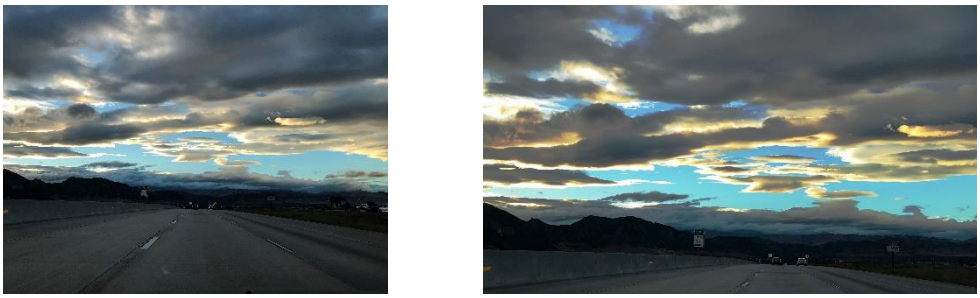

Figure 3: *Image progression after editing. Raw file is shown on the left, final edited photo on the right.*

Visualization Technique

This image required no visualization techniques, nature is beautiful this way!

Results

Overall the clouds assignment allowed me to really understand what happens when clouds form and why certain clouds form on certain days. This assignment has had me checking the sky almost every day now to identify whether or not I think the atmosphere is stable and/or what types of clouds are visible that day. The resulting image that I was able to capture was very nice; however, I do wish that I would have been able to capture this beautiful cloud formation in setting that had less man-made objects. For the second clouds image I will likely find a location that is much more scenic.