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MCEN 4151: Flow Visualization
03 December 2016

Clouds 2 – 2016 Report

Figure 1: Final Image

Image Context

For the image seen in Figure 1, the purpose was to take a picture of clouds for the class *Flow Visualization*. This was the second cloud assignment, and I'd taken photos on a few prior days to be able to choose from when I saw this cloud formation. The image was taken from the 8th floor of the Engineering Center at the University of Colorado Boulder—I'd taken photos there a few times before, so I knew it would be a good spot to view the cloud formation. What I didn't anticipate was the complexities of the clouds I would observe including the Kelvin-Helmholtz Instability.

Image Circumstance

As mentioned, this photo was taken from the 8th floor of the Engineering Center Office Tower at the University of Colorado Boulder. The image is looking southwest at Green Mountain which contains the well-known Flatirons—they are not visible within the silhouette of the mountain in this image. Figure 2 shows an aerial perspective of the camera's view. Green Mountain was around 2.5 miles from the location of the camera and at a greater elevation so the camera was angled slightly upwards. The image was taken on November 14th at 4:05pm MT. At 4:05pm the sun had a heading of 240° WSW from Boulder with an altitude of 6°. Sunset wasn't technically until 4:45pm (Time and Date, n.d.), but the picture shows it had just set behind the mountain, so this information helps give a better understanding of the perspective of the image.

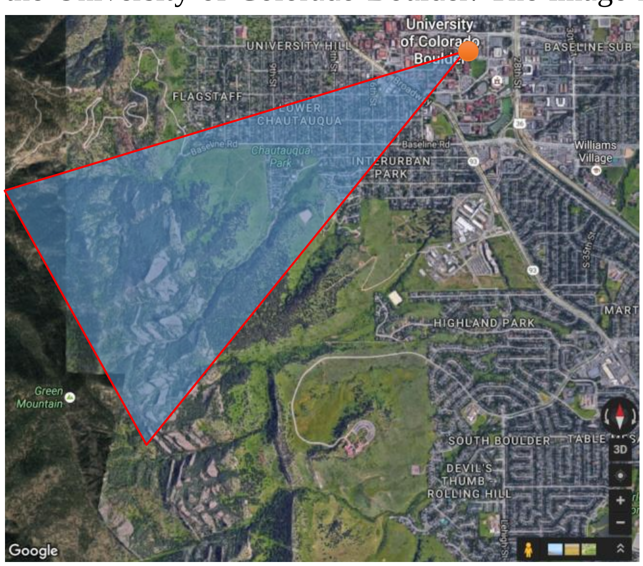

Figure 2: Map of Image View

Clouds Visualization

In Figure 1 there are several different cloud types and phenomenon present. The most obvious cloud is the orographic cloud stretching across the photo over the peak of Green Mountain. Green Mountain has an elevation of 8150 feet which converts to 2484 meters. Looking at the skew-T diagram in Figure 3 shows the possible presence of clouds around 5800 meters which is higher than the large cloud mass appeared. The skew-T was taken 2 hours later on the plains east of Boulder—so it may not be completely accurate—but since the clouds don't appear to be readily present in the skew-T it leads to the conclusion that they are orographic. Additionally, there were not many other clouds in the sky at the same altitude besides this mass. Orographic clouds like these are formed when moist air is pushed over a land obstruction and expand to its saturation temperature due to the increase in altitude and increase in air speed which by Bernoulli's Principle equates to a decrease in pressure (Paperin, Orographic Clouds, 2012). The skew-T diagram also shows a CAPE of 0.00 which indicates the atmosphere was stable and confirms observations of the surrounding sky. Given this, the most prominent cloud mass can further be classified as a stratocumulus due to its appearance and altitude referencing Figure 4.

There are also clouds background which are fairly easy to classify. The clouds on the left half of the image, visible above the mass in in the foreground and between it and Green Mountain, were higher than the stratocumulus strand. They appeared to fall close to the 5800-meter point that the skew-T first shows the greatest chance of clouds. Since these clouds were still above the front range, they were likely orographically formed with the extra expansion necessary to condense to clouds. 5800 meters is around 19000 feet which is in the region of altostratus—this matches the appearance of the clouds.

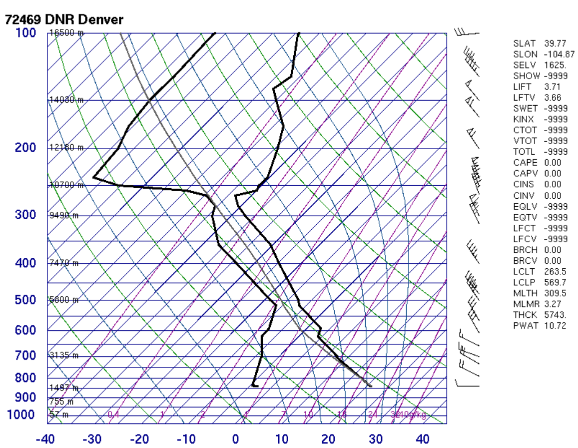

Figure 3: Skew-T plot from Denver International Airport on 11/14/16 at 6pm (Wyoming, 2016)

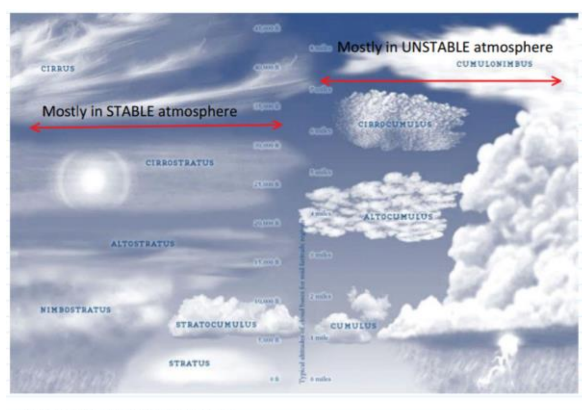

Figure 4: Cloud Regions (Pretor-Pinney, 2006)

The last cloud phenomenon to comment on is the presence of the Kelvin-Helmholtz Instability. There are two major waves present directly over the peak of the mountain. This instability is created along the boundary layer of two air masses when they are independently moving at different speeds. The friction forces between the two masses and lower pressure of the faster mass, by Bernoulli's Principle, draws the clouds up in a form reminiscent of crashing ocean waves (Paperin, Kelin-Helmholts Instability Cloud Structure, 2012). Figure 5 shows the progression of the instability over a couple minutes with the chosen photo as the middle image. The one prior shows two waves beginning to form and the final image shows them curling over and breaking apart to rejoin the cloud mass. The cloud formation was slowly moving along the front range in a SSE direction which the Skew-T diagram doesn't confirm, but that could be due to the dislocation and timing of the sounding to this photo. The direction of the waves supports the direction being southward.

Figure 5: Progression of Kelvin-Helmholtz Instability

Photographic Technique

The original image is shown below in Figure 6 which was taken on a Canon EOS Rebel T3i DSLR. The image was zoomed in with a focal length of 42mm which resulted in a field of view of approximately 1.25 miles across, along the ridgeline 2.5 miles away. Other settings include an aperture of f/5, ISO of 200, and shutter speed of 1/2500 sec. This fast shutter speed and low ISO were permitted due to the sun being behind the mountains but still illuminating the clouds. This created the natural silhouette of the mountain to provide foreground but still highlight the clouds in the image. The original image had a size of 5184 x 3456 pixels which was vertically cropped to 5184 x 2048 pixels for the final image in order to focus on the Kelvin-Helmholtz Instability while maintaining rule of thirds. The image was also processed in Adobe Photoshop by first sharpening the image in order to provide a bit more distinction of the cloud outlines, and then modifying the curves according to Figure 7 for increased contrast.

Figure 6: Original Photo

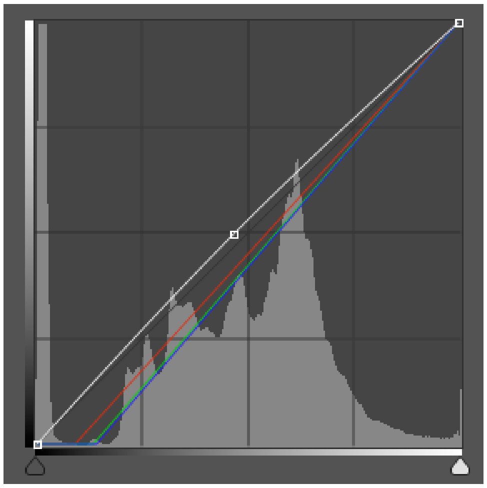

Figure 7: Image Curves Adjustments

Conclusion

In conclusion this image reveals several cloud types with the presence of stratocumulus and alto stratus clouds as well as several phenomena with the presence of orographic clouds and the ever elusive Kelvin-Helmholtz Instability wave cloud. I've never noticed a Kelvin-Helmholtz wave, so I was stunned with this image when the instability occurred out of nowhere during my shoot. The effect of the sun just setting to create the mountain silhouette with clouds still well exposed added to my appreciation of this image and it exceeding my intent. Additionally, the image came out with great focus, and although it was taken through a dirty, scratched window, the effects are not visible. In the future I hope to capture more Kelvin-Helmholtz Instabilities over wider ranges, and setting up a time-lapse would add a cool affect to visualize the transformation.

References

Paperin, M. (2012). *Kelin-Helmholts Instability Cloud Structure*. Retrieved from Cloud Structures.

Paperin, M. (2012). *Orographic Clouds*. Retrieved from Cloud Structures: http://www.brockmann-consult.de/CloudStructures/orographic-clouds-description.htm

Pretor-Pinney, G. (2006). *The Cloudspotter's Guide.* Penguin.

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Wyoming, U. o. (2016, November 14). *Weather.* Retrieved from Department of Atmospheric Science: http://weather.uwyo.edu/upperair/sounding.html