# Mountain Wave Clouds

First Clouds Assignment
MCEN 5151-001: Flow Visualization
University of Colorado Boulder
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Image shows mountain wave clouds (cumulus fractus), cirrus clouds, and crepuscular rays.
The image was taken on October 14, 2020 at 17:53 in Boulder, Colorado (40° 0.5' N 105° 15' W).

**Author**: Matthew McCallum

**Instructor**: Jean Hertzberg

## 1. Introduction

This report will outline the situation that this image was taken in, the type of clouds in the image, the weather occurring at the time of the image, and describe the photographic technique used to take this image. This image was taken for the first clouds assignment for the "Flow Visualization" course (MCEN 5151) at CU Boulder. The image shows clouds that formed above the famous Boulder Flatirons.

## 2. Image Circumstances

The image was taken on October 14, 2020 at 17:53 in Boulder, Colorado in between the CU Boulder Main Campus and the CU Boulder East Campus (40° 0.5' N 105° 15' W) at an altitude of 1605 meters. The camera is pointed west and is angled upwards 30° (these two values are approximate as they were not recorded when the image was taken).

## 3. Image Discussion

There are three main components to this image: the mountain wave clouds, the cirrus clouds, and the crepuscular rays.

The mountain wave clouds are the ones that take up most of the image. These clouds form because of the waves generated by the air flowing over a disturbance such as a mountain range. These waves move the atmosphere up and down as it flows downwind of the mountains. When the flow reaches a peak, it can cool down below the dew point which allows for clouds to form. An interesting result of the clouds only forming at the peak of these waves is that, since the wave are stationary relative to the mountain range, the clouds do not move across the sky. This can be seen by looking at **Figure 1** and noticing that the clouds are still in the same position in the sky, even though this image was taken a few minutes after the main image. Another indication that these are mountain wave clouds can be seen in **Figure 2** where more clouds can be seen forming at the peak of the next wave. Mountain wave clouds formed by a mountain range such as in this case generate cumulus clouds and, in this case, they are

**Figure 1** Image taken of the clouds to the right of the main image

**Figure 2** Image taken of the clouds behind the main image

**Figure 3** Image taken of the clouds to the left of the main image

specifically cumulus fractus clouds. Cumulus clouds are the typical fluffy low altitude clouds that most people think of when they picture a cloud. The subset of cumulus clouds called cumulus fractus are cumulus clouds that are more ragged than standard cumulus clouds and do not have flat bottoms.

The cirrus clouds are the ones that can be seen in the gaps between the mountain wave clouds. Cirrus clouds are thin, wispy clouds that form at high altitudes. They are formed by bands of falling ice crystals and often form thin hair like structures. In the main image the bands can be seen mostly on the right half of the image, and larger sheets of cirrus clouds can be seen mostly on the left half of the image.

The crepuscular rays are the lines of light that are shining over the mountain wave clouds. These rays are caused by the tops of the clouds blocking out the sunlight differently due to their random shapes. This causes there to be parts of the atmosphere that are in shadow right next to parts that are in direct sunlight. This can be seen because the sunlight bounces off particles in the atmosphere, showing the bright regions, and the bright regions are well contrasted with the regions that are in shadow.

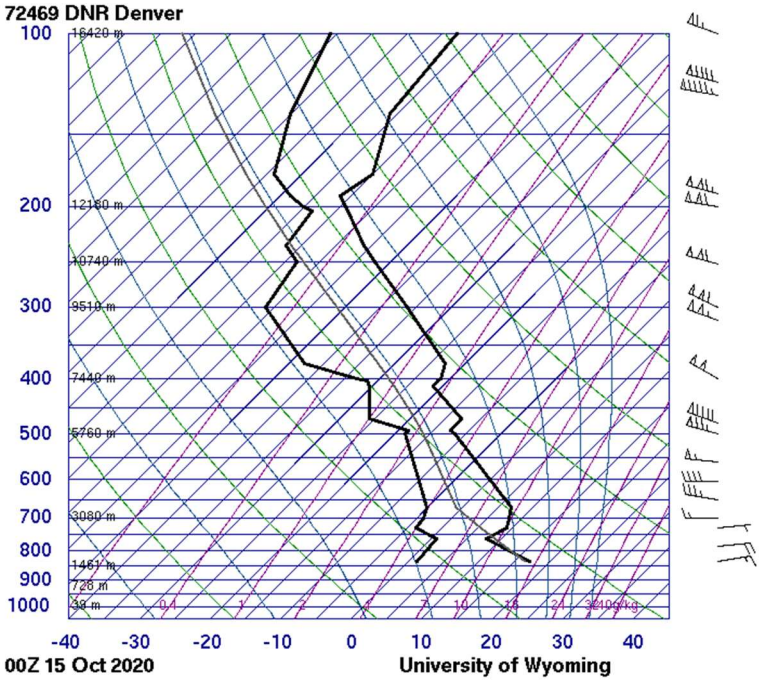


**Figure 4** The skew-T plot of the atmosphere above Denver within a few hours of the main image being taken (The CAPE value is 0)[1]

Looking at **Figure 4**, it can be seen at what two altitudes the clouds in the main image were forming at. The lowest pinch on the graph is at around 2.4 km. Boulder's altitude is around 1.6 km, and cumulus clouds form at under 2 km in altitude. Therefore, this is likely that the mountain wave clouds were forming at around 800 m in altitude. Cirrus clouds form between 5 and 13.7 km above sea level, so the pinch at around 12.1 km above sea level is likely where the cirrus clouds are forming. There was no precipitation around the time that the image was taken, which is expected from the atmosphere being stable (stability is known because the CAPE value was zero).

**5. Photographic Technique**

The image did not require any fine tuning of the settings, so the camera settings were left on auto. The setting that the image was taken with were:

| | |
|---|---|
| **Camera:** | Samsung SM-G960U (Galaxy S9) |
| **Aperture:** | f/2.4 |
| **Exposure:** | 1/927 |
| **Focal Length:** | 4 mm |
| **ISO:** | 50 |
| **Width:** | 4032 pixels |
| **Height:** | 3024 pixels |

The image was edited using Darktable and only had 1 edit performed. The bottom of the image was cropped out to remove most of the ground from the image (though some of the mountains and trees can still be seen). This was done to keep the focus of the image on the clouds by removing the distracting components such as the houses.

Due to the large distance from the camera to the clouds, the focus of the camera was effectively at infinity. This means that the distance to the clouds is not needed to take the image, but it can still be approximated. The mountain wave clouds were at an altitude of about 800 meters and the camera was angled upwards by about 30 degrees, therefore, the mountain wave clouds were about 1600 meters away from the camera. The cirrus clouds were at an altitude of about 10.5 kilometers and the camera was angled upwards by about 30 degrees, therefore, the cirrus clouds were about 21 kilometers away from the camera. This much larger distance is due to the fact that since the camera was at a low angle, the cirrus clouds that can be seen are much further away across the ground.

**6. Image Commentary**

This image does a great job of showing the amazing scenery that can be seen in Boulder, Colorado. There are many days like this where there are amazing looking clouds over the Flatirons, this image was just one of the several days where I was able to capture images like this. A way that could make an image like this better would be to take one around the start of the year. At that time of year, the Flatirons are covered in snow and provide a wonderful backdrop that would likely add to the beauty of the clouds above them. Though capturing an image of the Flatirons and clouds without having a lot of distractions from buildings and trees on the ground would be difficult. It would require either finding a good place on the ground with minimal obstructions towards the Flatirons, or a place above the obstructions on the ground.

## References

[1] University of Wyoming Department of Atmosphereic Science, http://weather.uwyo.edu/upperair/sounding.html

[2] Gavin Pretor-Pinney, *The Cloud Spotter's Guide.* Perigee Press, 2006

## Appendix

**Figure 2** Unedited image of the clouds