Altocumulus Cloud Formation Above Rocky Mountains

Wesley Caruso

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Figure 1: Final Image

1 Introduction

The image shown in Figure 1 was taken for the first clouds assignment in the MCEN-5151 Flow visualization course at CU Boulder. The purpose of this assignment was to examine properties of cloud formations in different layers of the atmosphere. For this assignment, many hours were spent exploring Colorado in search of a cloud formation that was both scientifically interesting and aesthetically captivating.

2 Geographic Location Data and Setup

This image was captured on January 26, 2018 at 5:04 pm at the Boulder Reservoir West Trailhead in Longmont, Colorado at $40°05'05.2"N$ and $105°13'31.3"W$. This location had been observed over a span of two days during sunset to capture the cloud formations above the Rocky Mountains. Both days presented great cloud formations, although the first day had a more stable atmosphere and resulted in a better aesthetic appeal. The image was captured facing 250 degrees due west toward the Gold Hill mountain peak at an elevation of 5280 feet and approximately 9.75 miles horizontal distance from the Rocky Mountains. The photo was setup aiming below the parallel horizontal plane of the ground at an angle of about five degrees in order to frame the mountain tops in the middle of the photo.

3 Conditions and Cloud Formation

Clouds form in different shapes, sizes, and colors displaying interesting properties based on the various weather conditions at a location. This photo focuses on Altocumulus cloud formations in a stable atmosphere above the Rocky Mountains. The clouds featured in this image were deemed Altocumulus due to the stable atmospheric conditions present at the time of capture, as well as based off the definition of the cloud formation. Alto comes from the Latin root *altus* meaning high, and *cumulus* meaning heap. Altocumulus clouds are known as mid-level clouds and are typically found between elevations of 6500 and 27000 feet [4].

Prior to the photo being taken, the forecast predicted a chance of light precipitation in the Boulder area, although there was no rainfall present. This likely was an attribute to the formation of the Altocumulus clouds since light precipitation can occur for this cloud type to form. At the time the photo was taken, it was thirty degrees Fahrenheit with overcast weather and wind gusts in the westward direction of approximately eight miles per hour. The surrounding area of Boulder had a few inches of snow remaining from a previous snowfall earlier that week and there was no immediate foresight of a front approaching within a 48 hour period. The following day at sunset, the sky contained Stratus clouds which did not resemble the Altocumulus ones in this image with wind speeds of around 17 miles per hour, likely causing the Stratus cloud formation.

Altocumulus clouds typically form due to mid level atmospheric disturbances and wave propagation which can be caused by mountains, such as the Rocky Mountains featured in this image [3]. Along the ridge of the mountains, these cloud formations continued for as far as could see, but directly above and behind the spot the image was taken, there were no clouds in sight. This indicates that wave propagation caused by the mountains was heavily responsible for the formation of these cloud patterns. The skew T diagram, obtained from the University of Wyoming's Department of Atmospheric Science website, provides important data on the atmospheric conditions when the image was captured.

During the time frame this photo was taken, the atmospheric conditions were stable as indicated by the CAPE value on the skew T diagram in figure 2. The CAPE value stands for convective available potential energy, which is the amount of energy of an air parcel as it travels up an adiabatic line. A CAPE value of zero indicates a stable atmosphere while any other value indicates an unstable atmosphere. For cloud formation, there needs to be an excess of moisture in the air with the relative humidity exceeding one hundred percent to begin expulsion of moisture from an air parcel.

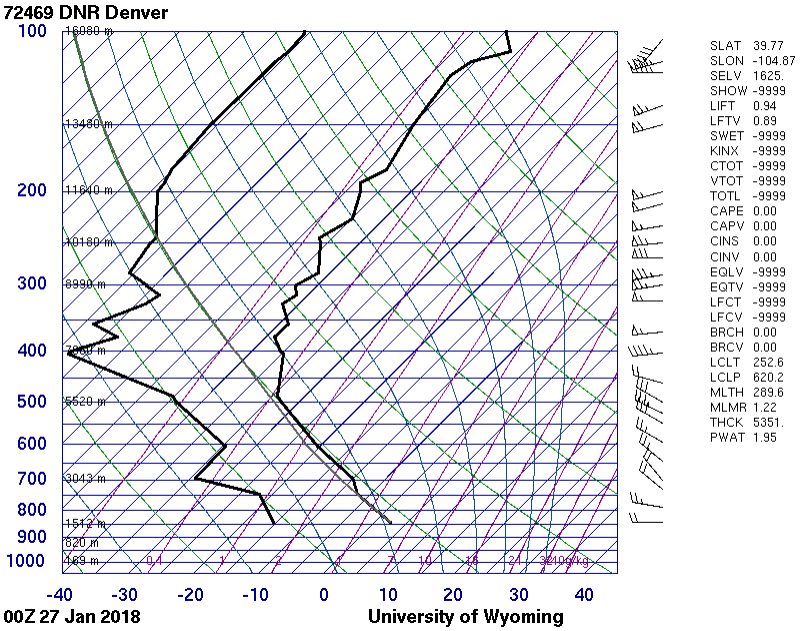

Figure 2: Skew T diagram from time period of photo captured

In a skew T diagram, the LCL detects when Altocumulus clouds begin to form when the top of the boundary layer reaches the bottom of the LCL zone [1]. Using the LCLT and LCLP values of 252.6 Kelvin and 620.6 hPa respectively, further information can be found about the atmospheric conditions. By starting at the -20 degree Celsius isotherm line on the Skew T diagram and following it to the intersection point of the 620.6 LCLP point, the approximate base cloud height can be determined. From the skew T, the lower bounds of cloud formation for the Altocumulus clouds were estimated using the LCL to be 13000 feet.

This Altocumulus cloud formation can also be described by the air flow present in the surrounding area. When air from the Denver and Boulder area travelled westward toward the mountains due to the wind of eight miles per hour, the surface warmed air was lifted up along the mountains and displaced at higher altitudes. During this process, the air parcels condensed as they began to cool during this convective process. The surface warmed air, which contained more moisture than the air parcels at higher elevations, replaced the cold air in the upper altitudes and caused condensation to occur and form Altocumulus clouds.

Another useful estimator is the convective condensation level, which was found by using the surface dew point and following a parallel saturation line until it intersects the temperature line. This value, also known as the CCL, is approximately located at a altitude of 14000 feet. Thus from the CCL and LCL it was determined that the approximate base layer for Altocumulus cloud formation was between 13000 and 14000 feet and could reach up to 18000 to 20000 feet with potential to go higher. Using the relative field of view from the image, calculated in the next section, the distance between the ground and the clouds ranges from a height of 12000 to 18000 feet in elevation. This matches up with the skew T diagram which describes possible cloud formation between 8000 and 20000 feet based on the dew point and temperature lines being closer together. Other clouds that could be expected are Stratus clouds, had there been stronger winds with a few other environmental conditions. The justification for this was the observation from the following day where the wind speed was between two and three times as fast resulting in Stratus clouds above the Boulder area spreading toward the mountain regions.

4 Photographic Technique

The rule of thirds was used to compose the photo and find a balance between the water, mountains, and clouds that suited the framing of the image. The distance from the camera to the clouds was a linear distance of about 51480 feet (9.75 miles) which was calculated on Google Maps using the geographical distance of

where the photo was taken to the Gold Hill mountain peak as featured in the image. A 24.2 megapixel Nikon D3400 DSLR was used to photograph the clouds using the settings listed in table 1. The ISO was set low to 200 in order to obtain a cleaner image with less noise since typically an increase in ISO value results in a grainier photo. An aperture of 6.3 was chosen for this capture because it suited the light environment best along with a shutter speed of 1/250 second to reduce motion blur.

ISO	200
Focal Length	40mm
EV	0
Aperture	6.3
Shutter Speed	1/250 s
Mode	Manual

Table 1: Nikon D3400 Camera Settings

The original image, figure 3, was captured at 6000x4000 pixels and cropped in Photoshop to 5784x3854 pixels in order to center the intended focus in the middle of the frame. When capturing any image, especially a sunset or sunrise, steady shots are necessary in order to change camera settings without having to re-frame the entire shot. Therefore, a camera tripod is very useful for this situation and was used to align the mountains and the horizon as closely as possible. The focus subject of this image was the light rays breaking through the clouds as depicted in figure 1. Additionally, the image was slightly rotated to correct the alignment of the horizon with the frame of the photo. The field of view was calculated using the variables from table 2 and the equations that follow. First, the angle of view, θ, was calculated from equations 1 and 2, then those values were used to compute an estimated field of view of 30400 feet horizontally and 20100 feet vertically, shown in equations 3 and 4 [2].

θ	angle of view	computed
s	focus distance	51480
h	frame dimension	0.9448x0.6299 in
f	focal length	1.57 in
m	lens multiplication factor	1.53x

Table 2: FOV Variables

$$\theta_{horizontal} = 2\arctan\frac{h(s-f)}{2sf} = 2\arctan\frac{0.9448(51480-1.57)}{(2)(51480)(1.57)} = 32.9^\circ \tag{1}$$

$$\theta_{vertical} = 2\arctan\frac{h(s-f)}{2sf} = 2\arctan\frac{0.6299(51480-1.57)}{(2)(51480)(1.57)} = 22.1^\circ \tag{2}$$

$$FOV_{horizontal} = 2(s)(m)\tan\frac{\theta}{2f} = (2)(51480)(1.53)tan\frac{32.9}{(2)(1.57)} = 30400ft \tag{3}$$

$$FOV_{vertical} = 2(s)(m)\tan\frac{\theta}{2f} = (2)(51480)(1.53)tan\frac{22.1}{(2)(1.57)} = 20100ft \tag{4}$$

Figure 3: Original Image

5 Image Revelation

This image captures the scientific and aesthetics of cloud formations. Clouds can display amazing properties in any condition, and with the introduction of a light source such as a sunset, the colors that are present can be captivating. While framing this image, the water was kept in the photo for an additional perspective to give a sense of depth to how far away the mountains were. The colors were left unaltered since darkening the photo would have silhouetted the mountains and lightening the photo would have saturated the light rays from the sunset too much. The colors captured when the photo was taken seemed too enticing to alter. These observations could be further developed by analyzing the same spot throughout sequential days and observing the effects of weather and atmospheric conditions on cloud formation. Overall, this image demonstrates the formation of Altocumulus clouds in a stable atmosphere during a winter sunset.

References

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[3] Nenes Research Group. *Clouds*. University Lecture. 2016.

[4] Damao Zhang et al. "Spatial scales of altocumulus clouds observed with collocated CALIPSO and CloudSat measurements". In: *Atmospheric Research* 149 (2014), pp. 58–69. ISSN: 0169-8095. DOI: https://doi.org/10.1016/j.atmosres.2014.05.023. URL: http://www.sciencedirect.com/science/article/pii/S0169809514002324.