Lenticular Kelvin-Helmholtz Clouds

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Flow Visualization: The Physics and Art of Fluid Flow

Project 3: Clouds First

Introduction

Upon learning about fluctus clouds in lecture, I was interested in trying to capture the cloud type. But, due to the fleeting nature of the phenomenon, I realized the chances of me catching one were slim. Thus, I was thrilled that while trying to photograph the annular eclipse the morning of October 14th, I looked up and saw one. I quickly grabbed the camera and snapped maybe five to six photos back to back before the waves dissolved. The picture we're discussing is the first of the pictures I took.

Location

The photo was taken on October 14th, 2023 at 9:43am MST (15:43 UTC) from Sunrise Amphitheater near the top of Flagstaff Mountain in Boulder, Colorado. The peak of Flagstaff mountain is approximately 2128 meters (6983 ft) above sea level.

I was facing South, shooting about 50-60 degrees above the horizon.

Cloud Discussion

The clouds pictured appear to be altocumulus lenticularis clouds with the Kelvin-Helmholtz, or 'fluctus' clouds. The sky was very clear, spotted with the occasional clouds like the ones pictured. The clouds also have wave features besides the Kelvin-Helmholtz waves; referred to as undulatus features, or gravity-waves

Lenticular clouds form when stable, moist air gets carried by winds over obstructions on the surface of the Earth, such as mountains. When the moist air drops in temperature as it crests over the mountain, it may hit a dew point, forming clouds. If no other obstructions are encountered, the waves of air may oscillate as damped harmonic oscillators giving way to the undulatus feature we also observe. Clouds driven by surface features are known as orographic clouds.

Kelvin-Helmholtz waves form when the velocity of the wind and cloud parcels at the top of the cloud is greater than the velocity at the bottom of the cloud. The higher velocity at the top scoops the top of a cloud up and over forming the rolling wave pattern. This also matches the environment necessary for the other cloud features we observe here

Fig 1. Unedited, uncropped image

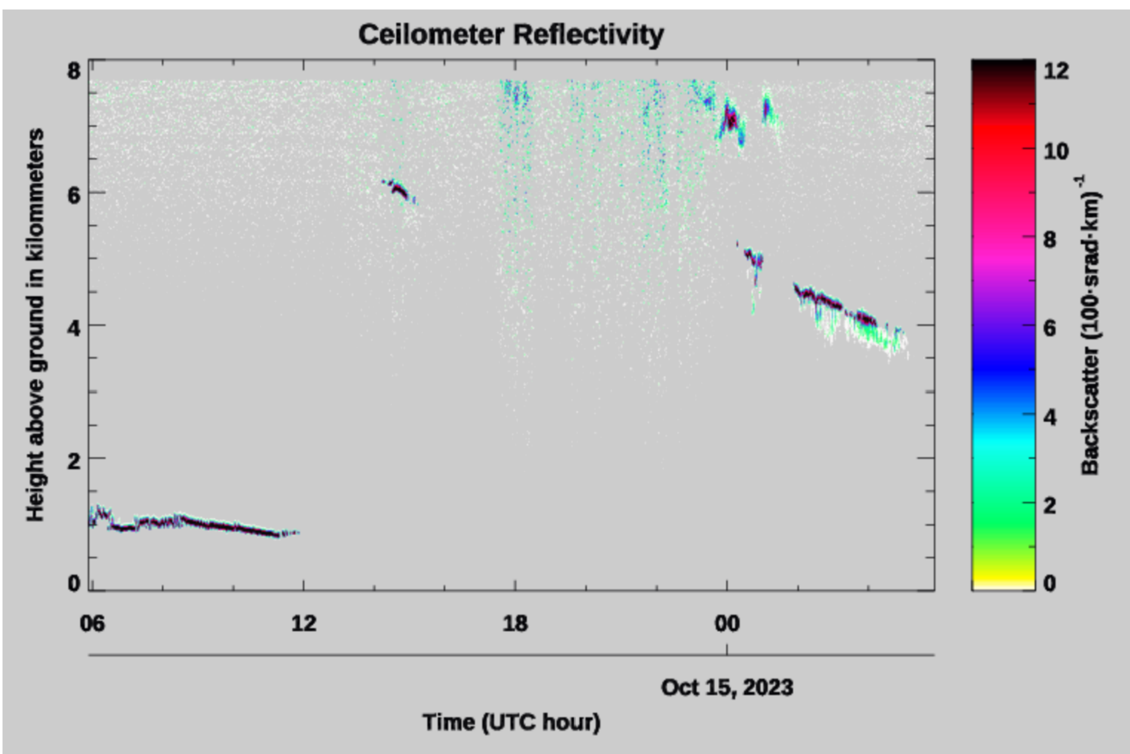

Fig 2. Ceilometer Reflectivity[1]

The photo was taken at 15:43 UTC and as we can see in the ceilometer (Figure 2) there is a significant blip of reflectivity right around that time at a height of approximately 6 kilometers above the ground in Boulder, Colorado. Comparing this estimate to the Skew-T diagram (Figure 3), The dew-point line (the left black line) and the temperature profile (the right black line) come closer together around 7 kilometers. Considering that Skew-T is from Grand Junction, Wyoming and not Boulder, Colorado, the similarity of these values seems reasonable.

We can see from the CAPE value being 0.00 in the Skew-T diagram (Figure 3) that the atmosphere was altogether stable. This fits with the hypothesis that the clouds were altocumulus lenticularis as those clouds exist in stable atmospheres. We can also see in the symbology to the right of the diagram that the velocity of the wind was increasing with altitude. This also supports the necessary conditions for Kelvin-Helmholtz waves.

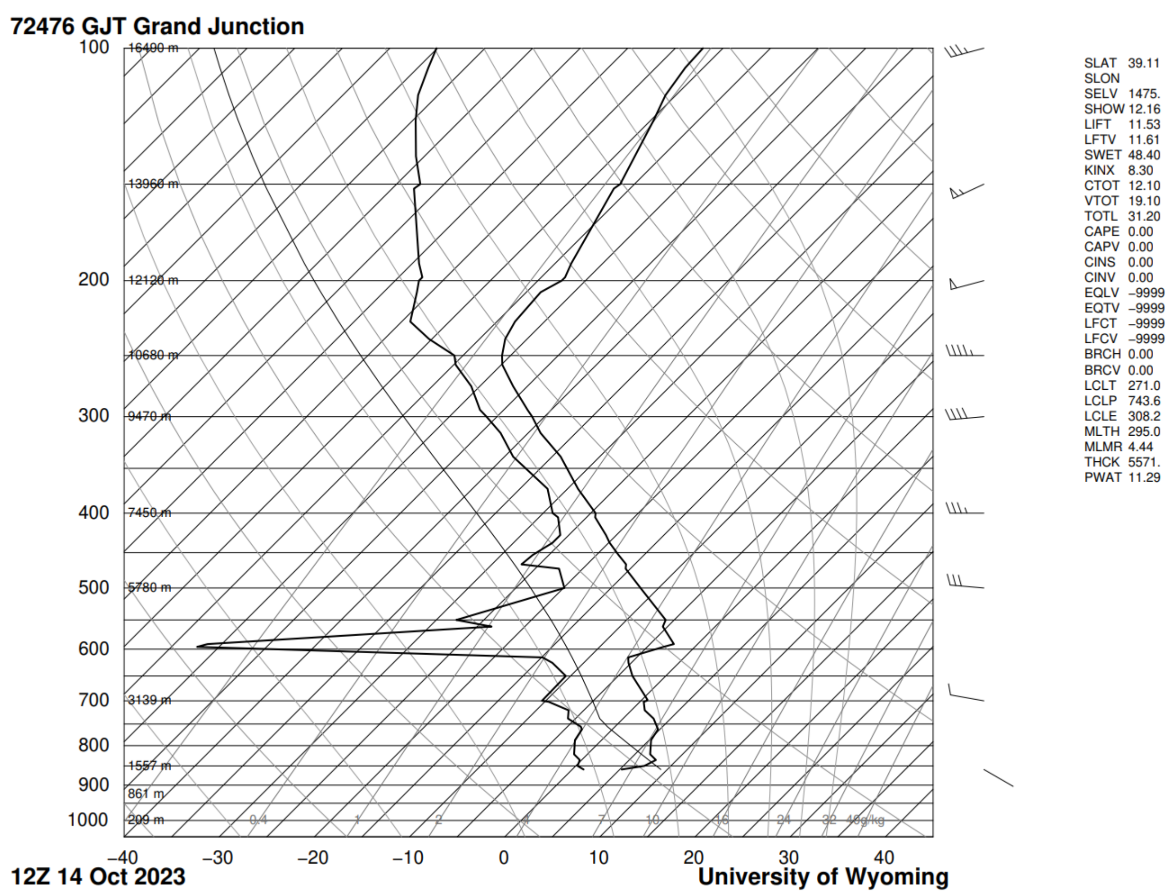

Fig 3. Skew T[3]

Considering a surface weather map (Figure 4), We can see that Colorado was a high pressure center, which also supports the dynamics observed, where clouds of lower temperature are falling, just after coming over the crest of the front range mountains. No front appear to be approaching which also supports the stability of the observed atmosphere.

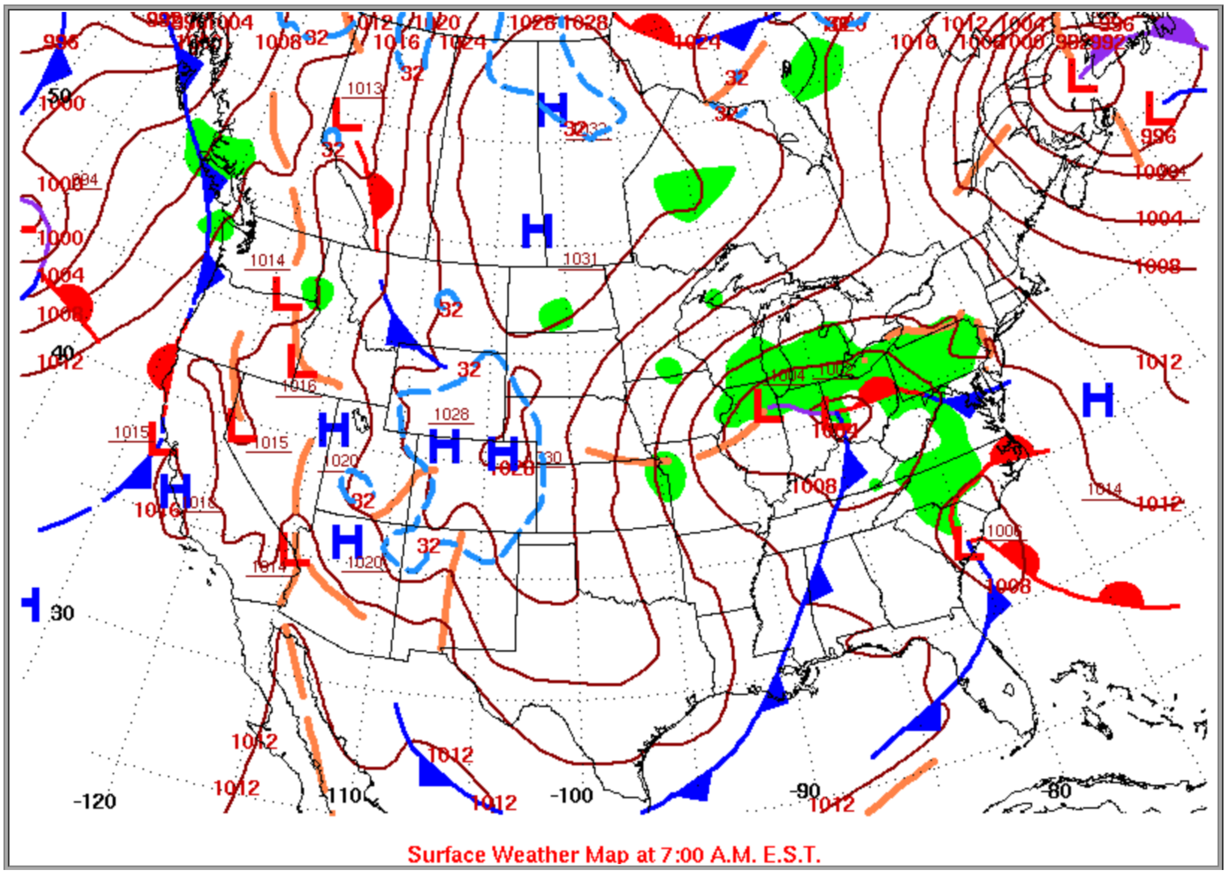

Fig 4. Surface weather map[2]

Photography

The scale of the clouds in question I would roughly estimate to approximately 10 kilometers or so. This estimate comes from calculating the distance in the simple trigonometry equation below, where h is the height in meters, and d is the distance from the camera in meters.

$$d = \frac{h}{sin(60°)} = \frac{6000}{0.866} = 7000\,m$$

Thus, I estimate the cloud to be approximately 7 kilometers away. The width of each lenticular cloud seemed much larger than the distance, thus my estimate of 10 kilometers.

The original photo's dimensions are 5202 x 3564px. The final edited and cropped images dimensions are 1300 x 834 px.

The camera specifications and settings I used are as so:

Camera Make and Model	Canon EOS Rebel T6
F-Stop	F/8
Exposure Time	1/4000s
ISO	400
Focal Length	75mm
Maximum Aperture	4.125

To edit the image, I mostly adjusted the contrast through boosting whites and highlights, reducing the blacks, and increasing the saturation to maintain a nice blue color. All edits were done in Adobe Lightroom.

When it came to cropping the photo, I wanted to focus on the Kelvin-Helmholtz waves as that phenomenon is so fleeting.

Adjusted Setting	**Adjusted Percentage**

Contrast	+50
Highlights	+46
Whites	+59
Blacks	-59
Texture	+22
Clarity	+37
Saturation	+50

Here we can see the stages of editing the photo:

Fig 5. Unedited photo. The same image as Figure 1

Fig 6. Edited photo, uncropped

Fig 7. Edited, cropped photo

Conclusion

I'm very pleased with the outcome of my photo. I did not expect to be able to capture the elusive Kelvin-Helmholtz waves and so I feel this photo came together serendipitously. I feel that the photo demonstrates the Kelvin-Helmholtz wave physics well and the unedited picture shows much more phenomena than I had initially thought before writing this report. I feel the scale of the clouds could be estimated more precisely, but I'm not certain how that could be accomplished easily. Perhaps in the future this is something to consider.

Works Cited

1. Department of Atmospheric and Oceanic Sciences (ATOC). *Skywatch Observatory*, University of Colorado, Boulder, https://skywatch.colorado.edu/. Accessed 27 October 2023.
2. National Centers for Environmental Prediction, Weather Prediction Center. *Daily Weather Maps*, US Department of Commerce, 9 March 2019, https://www.wpc.ncep.noaa.gov/dailywxmap/index_20231014.html. Accessed 27 October 2023.
3. Oolman, Larry, and University of Wyoming, Department of Atmospheric Science. “Atmospheric Soundings.” *Wyoming Weather Web*, https://weather.uwyo.edu/upperair/sounding.html. Accessed 27 October 2023