Clouds First: Sunrise Swirls
Fluctus Kelvin-Helmholtz Instability Clouds

Photo Taken at 6:51am on September 29, 2023, in Boulder, Colorado

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MCEN 4151: Flow Visualization

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1 BACKGROUND

This image was taken September 29, 2023, just east of CU Boulder's campus, facing west toward the Flatirons. This captures fluctus clouds showing the rare Kelvin-Helmholtz instability in clouds as the sun rises at 6:50am. This is the first cloud assignment of the MCEN 4151: Flow Visualization Fall 2023 course. The clouds appear as beautiful waves in the sky and capture a rare fluid phenomenon so high above the treetops and buildings. The photo was taken early in the morning, allowing the orange sunrise colors to shine. Although many photos were taken of these specific clouds, this was the best of the clouds.

2 CIRCUMSTANCES OF IMAGE

This photograph of stunning clouds was taken near the University of Colorado Boulder's campus. At the intersection of Aurora Avenue and 28th Frontage Road, this image was captured in Boulder, Colorado. The elevation of the photographer was at 5,341 feet above sea level. The photographer stood with the camera facing directly west to the geographic landmark of the Flatiron rock formations. The angle from horizontal of the image was about 40 degrees, as showing in Figure 1 below. Finally, the image was taken at 6:51am on September 29, 2023.
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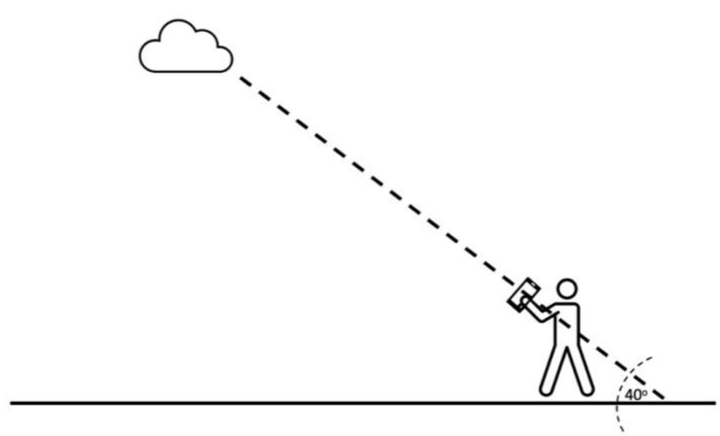

Figure 1: Angle of photographer toward the clouds when photo was taken.

3 PHYSICS OF THE FLOW

The clouds in this image are fluctus clouds formed by a Kelvin-Helmholtz instability. This special kind of cloud creates a wave pattern in the sky and is formed by a "vertical shear between two air streams" [2]. The wind blows faster at the higher altitude and slower at the lower altitude, creating a wave. The Kelvin-Helmholtz instability is not only found in clouds, but also in other fluids when there are two types of fluid and different velocities. The image I have captured very clearly looks like waves in the sky, so I can be certain it is this fluid physics phenomenon demonstrated by clouds. On this September morning, the rest of the sky had some small cirrus clouds further in the distance. Additionally, the wave-like formation of clouds was strongest in the center of a longer line of clouds across the horizon. An image capturing more of the sky can be seen in Figure 2.

Figure 2: An extended image of the sky on September 29, 2023. It is clear to see the Kelvin-Helmholtz instability fading toward the edges of this image.

Furthermore, it was a very windy day that day adding to the shear winds that created this interesting cloud formation. Generally, the weather was very similar the days before and after, but this day was windier than either the 28^{th} or 30^{th} of September. The clouds did not look the same on the days leading up to or following the date this picture was taken. As the day progressed after the morning that this photo was taken during, the sun came out even more and fewer clouds remained in the sky. There was no snow or rain within the hours before and after this picture.

Although these clouds are demonstrating an instability, the atmosphere was most likely stable during this photograph. I think the clouds are above my elevation, and even still much higher than the peaks of the Flatirons. Given this, I estimate the altitude of my clouds to be around 6,000 meters. The skew-T diagram can be seen below in Figure 3.

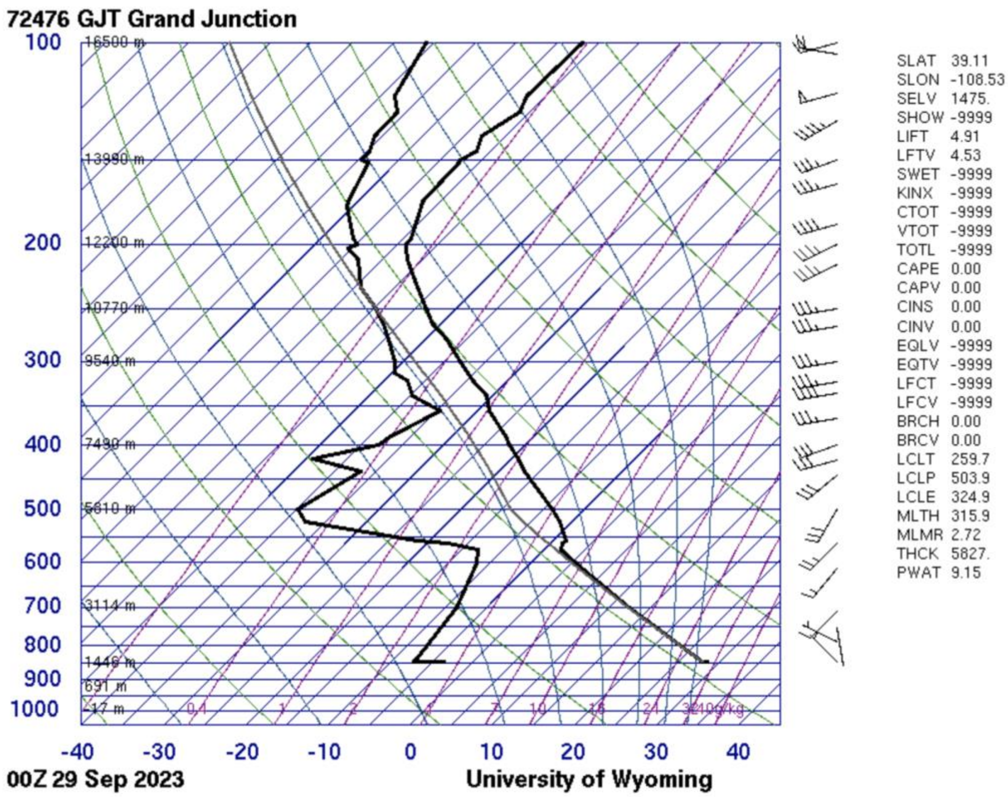

Figure 3: Nearest Skew-T diagram at the time my cloud photo was taken.

Based on the Skew-T diagram, I think my clouds were about 5,810 meters in the sky because there is clearly a bump that can describe where my clouds are. Based on my estimations, this is around what I expected and observed. The Skew-T describes the types of clouds I saw well.

As mentioned above, the physics that led to this formation of these fluctus clouds was two separate winds of different temperatures shearing. The warmer air on top against the cooler air on the bottom creates a wave shape due to the layers having different densities. [3] Furthermore, the speed of the upper wind is faster contrasted with the slower, lower wind generating the curl-like formation. Although a beautiful display of physics, these clouds do not last long due to the evaporation of the upper layer.

Although rare, others have also captured this phenomenon. [4]

4 VISUALIZATION AND PHOTOGRAPHY TECHNIQUES

The photographic technique is marked boundary [1]. The image clearly shows the distinction between the clouds and the sky as a marked boundary. I was drawn to taking this image because of the interesting clouds and the different layers of background produced with the wispy orange cloud layer between the sky and the Kelvin-Helmholtz clouds. I was trying to capture as much of the cloud and as little of the buildings and trees in the foreground. Despite this, the field of view was just capturing a little of the building and tops of the trees.

The photo was taken using the iPhone 14 Pro with the 24mm lens, the aperture of f1.78, the shutter speed was 1/164s, and ISO 50. This iPhone camera is a digital camera. The original photo was 4,016 x 3,016 pixels. The edited photo was 3,841 x 1,871 pixels. The aspect ratio of the edited picture is much larger. See Figure 4 below for the edited and unedited photos.

Figure 4: The unedited, raw image can be seen on the left in comparison with the edited photo on the right.

The key editing done to this photo was as follows: the brilliance was turned up, the highlights muted while the shadows were enhanced, the contrast was decreased, the black point was raised to bring darkness to the trees and the building, and finally, saturation and warmth were added.

5 CONCLUSION

In my opinion, this image is truly stunning, it captures such a beautiful flow described by physics while also being visually interesting. I like how the orange contrasts with the deeper blue and gray sky behind it. I also admire the highlights that pop out in the center of each peak of the cloud. One thing I would have liked to see in this photo was a bit sharper distinction of each of the cloud formations, making each “wave” pop out of the image even more. Despite this, I still think this photo shows the fluid physics quite well and is easily identifiable. The only remaining question I have is why is this phenomenon uncommon? In the future, I would like to improve some of the framing and centering in order to capture only the cloud and not the buildings and other background items in the photo. Overall, the Kelvin-Helmholtz instability shown in these clouds is gorgeous and a beautiful display of fluid flow in nature. I am very proud of this photo and believe I achieved the desired intent of capturing a pretty and physically interesting cloud. I will constantly be examining the sky for other clouds like this one as it is a glowing display of nature.

6 REFERENCES

[1] Hertzberg, Jean. "Flow Vis Guidebook." *Flow Visualization*, 13 July 2023, www.flowvis.org/Flow%20Vis%20Guide/overview-3-lighting/.

[2] "Kelvin-Helmholtz Cloud." *Met Office*, www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/clouds/other-clouds/kelvin-helmholtz#:~:text=An%20extremely%20rare%20phenomenon%2C%20where,but%20usually%20at%20higher%20levels. Accessed 30 Oct. 2023.

[3] Oblack, Rachelle. "What Is a Kelvin-Helmholtz Cloud?" *ThoughtCo*, ThoughtCo, 11 Mar. 2019, www.thoughtco.com/kelvin-helmholtz-clouds-3443792.

[4] P. Dalin, N. Pertsev, S. Frandsen, O. Hansen, H. Andersen, A. Dubietis, R. Balciunas, A case study of the evolution of a Kelvin–Helmholtz wave and turbulence in noctilucent clouds, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 72, Issues 14–15, 2010, Pages 1129-1138, ISSN 1364-6826, https://doi.org/10.1016/j.jastp.2010.06.011.