MORNING FLUCTUS

CLOUDS FIRST, FALL 2023

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MCEN 5151 – Flow Visualization

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INTRODUCTION

On September 29th, I walked outside of my house to a *fluctus* floating just above my neighbor's trees. I captured this image as a part of the Clouds First assignment of the Fall 2023 iteration of MCEN 5151 – Flow Visualization at the University of Colorado – Boulder. Through this image, I hoped to capture the rare waveform of a Kelvin-Helmholtz instability in the clouds. My artistic intent was to photograph the movement and the somewhat cartoonish form of *fluctus* clouds. The shape of a *fluctus* reminds me of how a child draws ocean waves. In this image, I aimed to isolate the clouds and give the effect that someone was drawing waves in the sky with clouds.

CIRCUMSTANCES

I photographed this *fluctus* in Niwot, Colorado (40.1039° N, 105.1708° W) at 7:00 am on September 29, 2023. Niwot is located about 5190 ft. above sea level. I was facing 211 degrees southwest with my camera pointed at an elevation of 37 degrees above horizontal. This elevation was necessary to avoid capturing some of the taller trees, roofs, and a few powerlines in my images. Over about 10 minutes, I captured numerous photos of the *fluctus* before the waveform dissipated into an altostratus cloud.

CLOUD IDENTIFICATION AND PHYSICS

In this image, we see an *altostratus fluctus*, which is a Kelvin-Helmholtz instability formed in altostratus clouds ("Clouds 5," n.d.; Pretor-Pinney, 2007). A Kelvin-Helmholtz instability emerges when the air above the cloud moves at a different velocity than the air below the clouds ("Kelvin–Helmholtz Instability," 2023). This causes a velocity shear (Helmholtz, 1868; "Kelvin–Helmholtz Instability," 2023).

Fluctus clouds can form in the various layers of the atmosphere (e.g., from stratus, cirrus, and altostratus clouds) (WMO, n.d.-b). In this image, we see the *fluctus* form in altostratus clouds. These could also be altocumulus clouds. However, due to the cloud structure, height of the cloud base, and the stability of the atmosphere evident in the Skew-T diagram, Dr. Tian from NCAR and I think these are altostratus. I estimate this *fluctus* cloud base height is around 5000m, as shown in the Skew-T diagram and based on the relative size of the *fluctus* (i.e., less than two fingers in height). This cloud base height supports the belief that the *fluctus* clouds in this image are within the altostratus altitude range.

On the morning of September 29th, the rest of the sky was mostly clear with a few areas of *altostratus undulatus* clouds stretching across the southern sky (WMO, n.d.-a). This is supported by the ceilometer data from September 29th (shown below). Few clouds were to the north of the camera. The clouds were mostly pink and orange with a light blue/grey sky, as seems typical during fall mornings in Colorado.

The Skew-T diagram shows a blip around 5000m above sea level, which is where I estimate clouds and the photographed *fluctus* should appear. I corroborated this cloud height estimation using

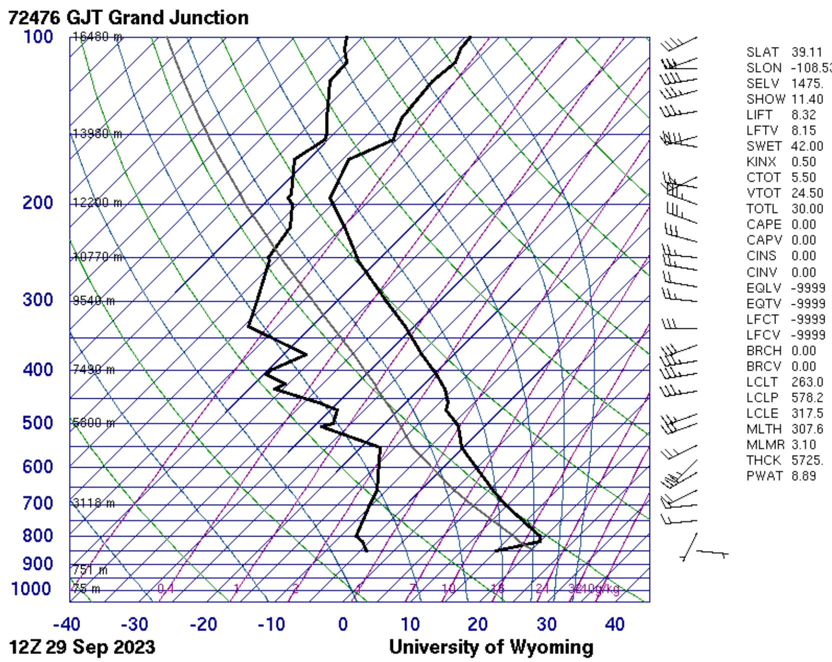

FIGURE 1: SKEW-T DIAGRAM FOR 29 SEPTEMBER 2023 AT 12Z OR 6AM MDT.

the "finger method" suggested by Dr. Hertzberg and the Gavin Pretor-Pinney (Pretor-Pinney, 2007). The ceilometer reflectivity also shows a few clouds starting at 4000-5000 meters around 12pm noon UTC (~6am Mountain time). The *fluctus* was smaller than two finger widths, suggesting it occurs in the middle altitude range (between 2000 – 6000m). The wind was moving to the west-southwest at 35 knots. Although the *fluctus* is an instability, the atmosphere is generally stable as is evident from the CAPE of 0.00. We can also estimate this by sending a parcel up the nearest dry adiabat line on the Skew-T diagram("Clouds 3," n.d.). The neighbors are steeper, warmer, and less dense than the parcel on the dry adiabat, suggesting that the atmosphere is stable around the *fluctus* cloud.

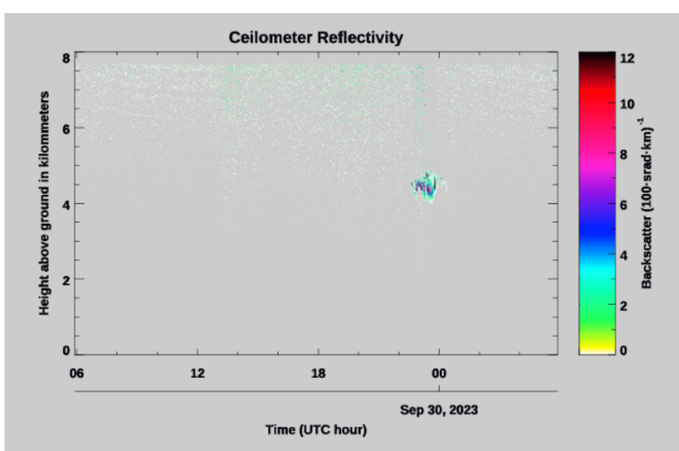

FIGURE 2: CEILOMETER DATA FOR 29 SEPTEMBER TO 30 SEPTEMBER

I believe the proximity of this *fluctus* to the mountains indicates that these are orographic clouds – clouds with features affected by the terrain. Downstream of the mountains, layers of distinct wind speeds are more likely ("Clouds 5," n.d.). This windspeed can vary dramatically across each layer of the atmosphere, causing strong shearing between each layer of wind speeds("Clouds 5," n.d.). Here the wind directly above the cloud is moving at a different speed than the wind in the cloud and below the cloud. The Skew-T diagram shows dramatically faster winds above the clouds (35 knots to the west-southwest) than below the estimated cloud height (25 knots to the west-southwest but slightly more south). The higher speeds above the cloud base could cause shearing of the upper portion of the clouds. Here, the wind across the top of the cloud appears to drag across the upper portion of the cloud, causing vortices across the top edge of the cloud. In my image, it looks like the wind is moving to the left of the image toward the south-southwest, shearing the upper portion of the cloud to the left.

Photographic Technique

I captured this image on an Olympus OMD E-M10 Mark II camera with an Olympus Digital 40 – 150mm 1:4-5.6 ED lens. This lens is a bit longer than the kit lens and allowed me to take a raw image without many distracting elements in the frame. With the longer lens set at 108 mm, I captured a field of view above the trees and power lines that surround my house. Due to the moderately early morning hour, the sun was not yet very bright. I used a low ISO setting (100) to avoid noise. However, I think this contributes to the darkness of my original image. I employed an exposure of 1/160 in order to compensate for my lower ISO setting while being fast enough to freeze the dynamics of the cloud without motion blur. The cloud dissipated after about 7-10 minutes, which meant I had very little time to experiment with different settings. For this reason, I used my camera in "P" mode, which means that the camera automatically selected the exposure and F number for me. I also employed the automatic focus setting with manual adjustments (AF + MF) to increase my efficiency. While I generally try to use my own settings (in M mode with manual focus), I did not have an abundance of time to experiment with these settings in capturing this cloud. In the original image, I used an aspect ratio of 16:9, which helped capture the full length of the fluctus without cropping too much off the top and bottom of the image.

Table 1: Camera and Image Settings

Camera	Olympus OMD E-M10 Mark II
Lens	Olympus Digital 40-150mm 1:4-5.6 ED lens
Focal Length	108 mm
Focus Distance	53.24m
ISO Speed Rating	ISO 100
Exposure	1/160
F number	f/5.1
Camera Modes	P – exposure and F number chosen for me.
Raw Image Size	4608 × 2592
Edited Image Size	4573 × 2418
Edited Resolution	72 pixels/inch

Post-Processing

FIGURE 3: BEFORE EDITING

FIGURE 4: AFTER EDITING

To edit this image, I used DarkTable to crop a small portion off the bottom where a few errant tree limbs were visible. I also cut a bit off the left side of the image to better center some of the waves. Since the original image was rather washed out, I increased the contrast – using the rgb curve setting and tone setting – as shown below. My intent with these edits was to show the clouds with similar color that I saw that morning. My original photograph washed out the pinks and oranges that were so vibrant the morning I took this photo. My editing decisions were mostly guided by my memory of the sky that morning combined with a desire to show the crisp edges of the *fluctus*.

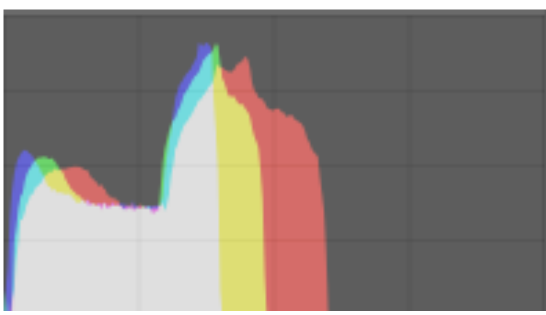

FIGURE 5: BEFORE EDITING

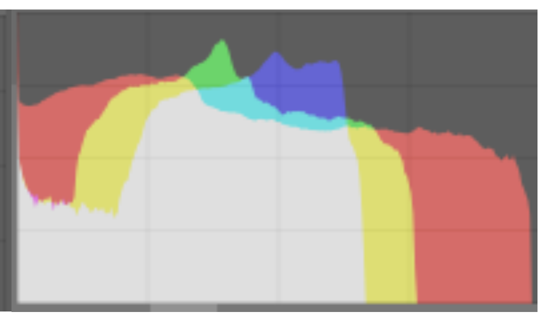

FIGURE 6: AFTER EDITING

After increasing the contrast, I noticed the clouds appeared rather grainy. I played with some of DarkTable's built in denoising algorithms, lens correction, haze removal, and hot pixel settings to smooth the image a bit, bring out the edges of the clouds, and correct any hot pixels. These changes made the clouds much clearer. The contrast changes brought out the wispy portion of the cloud on the left side. With these edits, I hoped to make the waves and edges of the *fluctus* look more robust and defined.

CONCLUSION

I find this image of a *fluctus* cloud striking. To me, *fluctus* clouds resemble a child's drawing of a wave in the sky. As fluid dynamicist, I was thrilled to see and capture an image this rare Kelvin-Helmholtz instability. I was also ecstatic that the cloud emerged well over any roofs, powerlines, and trees that would have distracted a viewer from the stark contrast of the waves. In editing this image, I struggled to improve the color contrast without making the image too grainy. While I like the new exposure and color contrast of the image, the noise you can see in the blue and the artificial (though unintentional) vignetting effect at the edges of this image bother me. After much experimentation with editing, I believe the vignetting and noise are tradeoffs for increasing the contrast of the image. Overall, I am pleased with the edited version of this image despite these flaws. I feel fortunate to have photographed such a rare phenomenon.

Acknowledgements

I would like to dedicate this image to my grandfather, who passed away during the drafting of this report. I walked outside on the morning of September 29th in order to check on him and make him breakfast. I would not have seen this *fluctus* without him.

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