Multi-Layered Mountain Wave Clouds

Gabriel Bershenyi[1]
University of Colorado, Boulder

Figure 1: Mountain wave clouds over Boulder's Flatirons formation

I. Introduction

THIS photographic experiment was intended to capture an image of clouds that demonstrated an interesting atmospheric phenomenon while also presenting artistic beauty. The experiment was part of an assignment called "The Photography of Clouds" for the Flow Visualization class at the University Of Colorado Department Of Mechanical Engineering. This specific image is an attempt to capture the mountain wave clouds that commonly form over the peaks of Colorado's Front Range. As the air moves from west to east across the mountains, it is forced up to flow over the mountain range. As the moving air rises, it cools and water forms a stationary cloud.

[1] Student, MCEN 5151 - Flow Visualization: The Physics and Art of Fluid Flow

After the air passes over the obstacle, it descends and the temperature increases above that of the local dew point. In this image, Boulder's Bear Peak (left) and Green Mountain (right) provide the obstacle to cause a series of mountain wave clouds.

II. Image Conditions

The image captured for this experiment was taken from the 4th floor of the Engineering Center at the University of Colorado. The image faces south by southwest toward Eldorado Mountain, Bear Peak, and Green Mountain from left to right. The image was captured at 12:57MST on 15 February 2013. Based on this time, the solar elevation angle can be calculated at 36.6 degrees above the horizon.[6] The photo was taken one day after a moderate snow storm.

The height of the clouds can be estimated by using spacecraft imagery of the region near the time of the image. An image from the MODIS camera on the Terra spacecraft was used for this purpose. The 7-2-1 spectral bands (620-670 nm, 841-876 nm, and 2105-2155 nm) help to differentiate between the ground-based snow, which appears blue in the false-colored image, and the atmospheric clouds, which appear white.[5] The full size image has a resolution of 250m per pixel, so one can calculate the altitude of cloud layers by counting the pixels between their edges and shadows and using the equation,

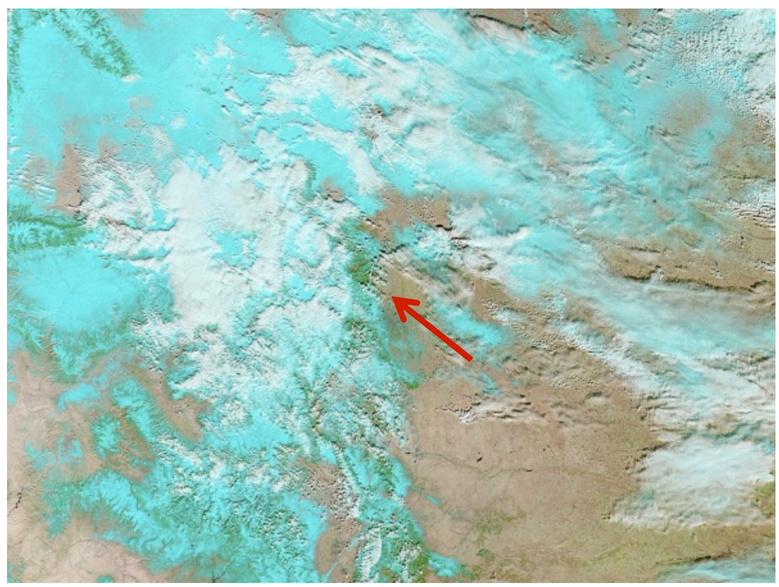

Figure 2: MODIS Terra Boulder subset, bands 7-2-1, 2013/02/15-10:45MST [7]

$$altitude = baseline + \tan(solar\ elevation) \cdot shadow\ length$$

Using multiple clouds similar to those in the image, the altitudes of the two layers were estimated at 3500m and 5000m. The two altitudes roughly agree with the two spots in Figure 3, the Skew-T diagram, where the local dew point approaches the local temperature to indicate possible cloud formation. Based on this diagram, the altitude of the higher cloud layer can be estimated at 5500m.

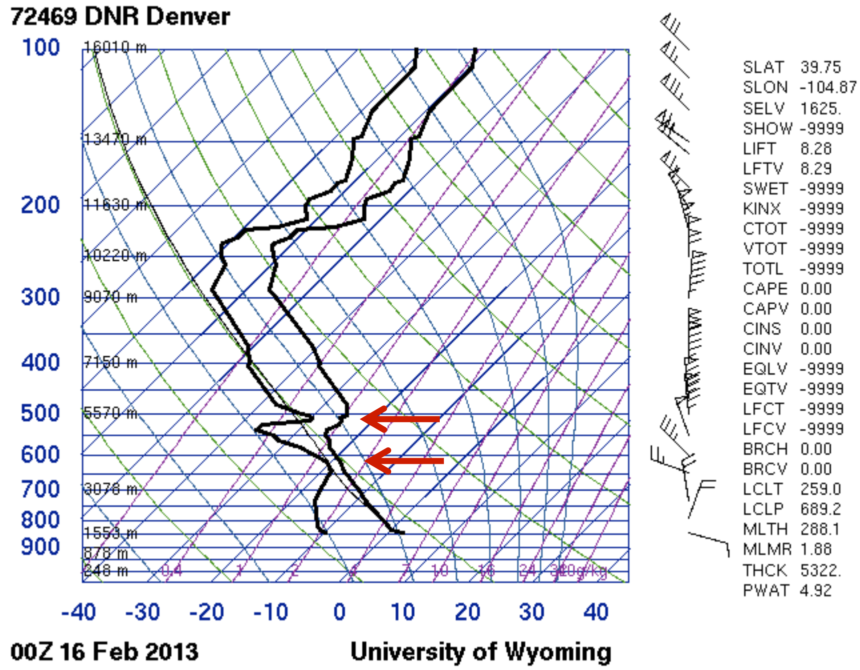

Figure 3: Skew-T Diagram[1]

III. Cloud Analysis

The clouds imaged for this experiment are examples of stratocumulus and altocumulus lenticularis clouds formed by the mountain lee effect. As discussed earlier, this effect forms clouds as air is lifted and then lowered to form a wave pattern similar to gravity waves seen as ripples in water.[2] These clouds must form in a stable atmosphere, which can be seen by the Convective Available Potential Energy (CAPE) measurement of 0 in Figure 3.[1,2] The stable atmosphere means that the uplifted air will fall back toward its original level, warming as it falls until the water begins to evaporate and the cloud terminates.[3]

The upper cloud level in this photograph can be identified as altocumulus lenticularis based on their altitude and smooth shape. The smooth shape of the cloud is due to the fact that the moving air must deflect less at high altitudes than the air crossing the object at lower altitudes. The stratocumulus cloud in the upper left of the image is a good example of the opposite level of turbulence and shear that occurs in layers closer to the ground.[2] This cloud was observed with a high degree of internal rotation, which was evidence of more turbulent conditions at lower levels. In separate images, one can see the featured cloud moving across an angle the size of the disk of the sun in 11 seconds. With its estimated range of 3000m, this translates to a speed of roughly 2.5m/s (6mph). As it moved, the cloud visibly dissipated. This is expected as the cool stable air sinks back toward its original height and adiabatic warming causes evaporation.[3] The red arrow pointing toward Boulder in Figure 2 helps to show that the stratocumulus clouds formed close to the front range and then dissipated as the air moved east over the planes.

IV. Photographic Technique

The image was captured using a Panasonic DS20 point-and-shoot digital camera. The image was recorded with a focal length of 4.5mm, an aperture of f/9, an exposure time of 1/640s, and an ISO sensitivity of 100. In order to capture the brightly lit cloud in the upper left in great detail, the exposure bias was set to -2. This allowed the cloud backlit by the sun to show its full detail.

Figure 4: Original Image

The image was processed using Gimp photo editing software from its original state as seen in Figure 4. The image was first cropped from an original size of 4608x3456 pixels to 3916x2816 in order to eliminate the edges of buildings that did not add to the artistic quality of the image. The color was then adjusted using the transfer function curves to increase the brightness of medium brightness pixels. This was enough to brighten an originally dark image, and increase the contrast between the clouds and the surrounding sky.

V. Conclusion

The image accomplishes its two goals of presenting an example of mountain wave clouds and showing artistic beauty. The greatest accomplishment of this image is to show the turbulence present in the air at the level of the stratocumulus clouds. The artistic beauty of this image was found in the juxtaposition of the fleeting clouds against the endurance of the mountains. The shortcomings of this image came in the attempts to balance the conflicting desires of preserving detail in the extremely bright cloud backlit by the sun, while enhancing the brightness of the rest of the image. This goal should be possible given more time and experience with photo editing software.

Acknowledgments

The author would like to thank Zach Wehner, Wayne Russell, and Colin Stewart for their consultation on photographic technique.

References

[1] "Atmospheric Soundings." Atmospheric Soundings. University of Wyoming, 16 Feb. 2013. Web. 28 Feb. 2013.

[2] Cruette, Denise. "Experimental Study of Mountain Lee-waves by Means of Satellite Photographs and Aircraft Measurements." *Tellus* 28.6 (1976): 499-523. Print.

[3] Doyle, James D., and Ronald B. Smith. "Mountain Waves over the Hohe Tauern: Influence of Upstream Diabatic Effects." *Quarterly Journal of the Royal Meteorological Society* 129.588 (2003): 799-823. Print.

[4] "MODIS Spectral Bands." Spectral Bands. National Snow & Ice Data Center, n.d. Web. 28 Feb. 2013.

[6] "NOAA Solar Position Calculator." NOAA Solar Position Calculator. National Oceanic and Atmospheric Administration, n.d. Web. 28 Feb. 2013.

[7] "Rapid Response Visualization | EOSDIS - Earth Data Website." Rapid Response Visualization | EOSDIS - Earth Data Website. National Aeronautics and Space Administration, 16 Feb. 2013. Web. 28 Feb. 2013.