Assignment 5 – “Clouds 2”

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1 Objective

The objective of the image was to visualize atmospheric fluid dynamics by observing clouds. This was accomplished by photographing a cloud over Boulder Canyon from the University of Colorado Boulder Campus. The setting sun provided interesting shadows, allowing for an aesthetically pleasing photograph while accomplishing the objective of flow visualization.

2 Photographic Setup

The photograph was taken near the south entrance of the Benson Earth Sciences Building facing westward. Several clouds were visible at the time, and the photographed cloud was selected due to the shadows created from lighting at a low angle and the shape of the cloud. Specifically, the contours of the mountains are paralleled in the shape of the cloud. The time of the photograph was approximately 3:30 pm, September 28th 2007. The photo was taken with a Canon Digital Rebel XT with an 18-55 mm lens using a polarizing filter to obtain maximum cloud contrast.

The submitted photo was first acquired as the RAW image shown in Figure 1. The photograph was taken with a focal lenth of 18mm, an f-stop of 8.0, an ISO setting of 100, and a 1/200th second exposure. The RAW image was processed to a color filtered black and white image, similar to the red filter with black and white film method used by Ansel Adams (Figure 2). The color filter applied minimized the intensity of the blue channel to darken the sky. For Figure 3, the contrast was enhanced, the small white cloud in the lower right corner was removed, and the image was cropped to draw attention to the shape of the cloud.

3 Discussion

The cloud photographed in figure 3 was directly over Boulder Canyon and is a very good example of a lenticular cloud (altocumulus standing lenticularis)[1]. From the sounding data in the Skew-T plot (Figure 4), the height of the cloud is approximately 12000 ft, based on the narrowing of the dewpoint

Figure 1 - Original RAW image of the submitted photo

Figure 2 – Filtered Black and White image from Figure 1

Figure 3 – Enhanced contrast image from cropped image of Figure 2 and small cloud removed from lower right hand corner

and temperature curves. At this altitude, the wind is blowing east and slightly northeast, which is likely the cause of the fragmented left edge (southern) observed in the cloud. The atmosphere is stable at this elevation, as determined by comparing the slopes of the dry adiabatic curve and the temperature curve, which contributes to the well defined structure of the cloud.

Lenticular clouds can be formed by standing waves from wind blowing over mountains or mountain ranges. In this particular case, the Boulder Flatirons are somewhat different than a typical mountain range due to the asymmetry of the features. Many mountain ranges may be approximated in 2-d as a parabolic or sinusoidal profile, but this is not true of the Boulder Flatirons. This

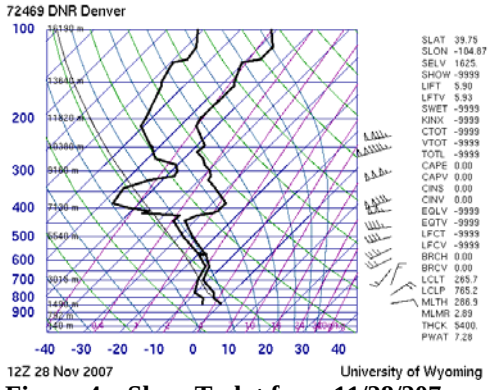

Figure 4 – Skew T plot from 11/28/207

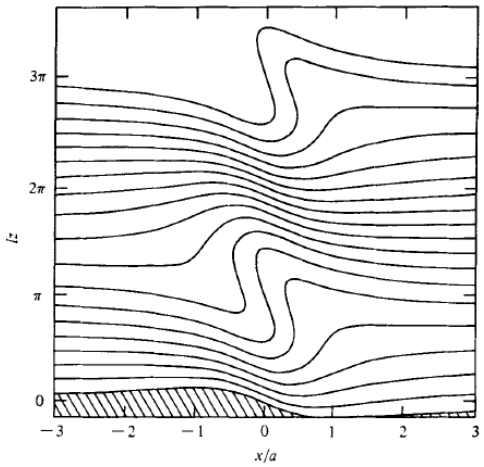

Figure 5 - Southward view of the Boulder Flatirions from Google Earth with flow

special case of obstacle asymmetry was solved analytically by Lilly and Klemp. The 2-d geometry combined with an inviscid fluid is well suited to complex analysis and the resulting stream functions are shown in Figure 5 [2]. The stream functions illustrate the fluid flow responsible for the recognizable lens shape observed of the photographed cloud, as well as the common characteristics exhibited by all lenticular clouds.

4 References

1. World_Meteorological_Organization, *International cloud atlas*. 1975, Geneva : Secretariat of the World Meteorological Organization.
2. Lilly, D.K. and J.B. Klemp, *Effects of Terrain Shape on Non-Linear Hydrostatic Mountain Waves.* Journal of Fluid Mechanics, 1979. **95**(NOV): p. 241-261.