Cloud Phenomena 2

"Highlights and Shadows"

Bronwyn Hayworth
November 17, 2004
Professor J. Hertzberg
Professor A. Sweetman

As I emerged from my Thermal Systems Design class at slightly after 6:00 pm on Thursday October 14th 2004, I immediately dropped my books and grabbed my camera. There were several amazing examples of rotor clouds formed by trapped lee waves illuminated by the setting sun. Although these clouds are rather typical over Boulder, Colorado, the interaction of the clouds with the setting sun created a very dramatic, but ephemeral sight. Thus, I chose to submit these images for the second cloud photography assignment for the Flow Visualization course because they provide wonderful examples of cloud phenomenon and are also very aesthetically pleasing. In general, the cloud visualization assignments have focused on capturing images of interesting cloud phenomenon and revealing the physics causing or dictating the phenomenon. My personal intent for this cloud assignment was to capture a different phenomenon than my previous cloud visualization attempts. In addition, I also wanted to capture something that made a different aesthetic statement. My prior set of cloud images focused on low fog in the mountains and its interaction with the land. The phenomenon in those images was significantly more muted and portrayed an entirely different feeling than the current images, which are vibrant and more robust. Three images that I feel particularly fulfill my intents for this project were chosen for submittal. The first image captured features several rotor clouds extending east from the Continental Divide. The clouds are also framed by the north side of Flagstaff Mountain and by the Gamow and Jila Physics towers.

Figure 1: First cloud image at sunset over the north side of Flagstaff Mountain

The second image was shot while facing further south toward the summit of Bear Mountain (above the Flatirons). This image provides a different aspect from which to view the clouds

Figure 2: Second image of clouds at sunset

The third image depicts the same phenomenon several minutes later after the sun has moved further down over the horizon. Thus, the fading light illuminates different features of the clouds. The mountains in the image are the south side of Flagstaff Mountain and the saddle between Flagstaff and Bear Mountain.

Figure 3: Third image of rotor clouds at sunset

All three sunset images were captured while facing west from the walkway in front of the south facing doors of the Benson Earth Sciences building on the University of Colorado at Boulder campus. A map of this location is provided below. Please note that distance in this image is not to scale and the foothills are approximately 2-4 miles west of this point on campus.

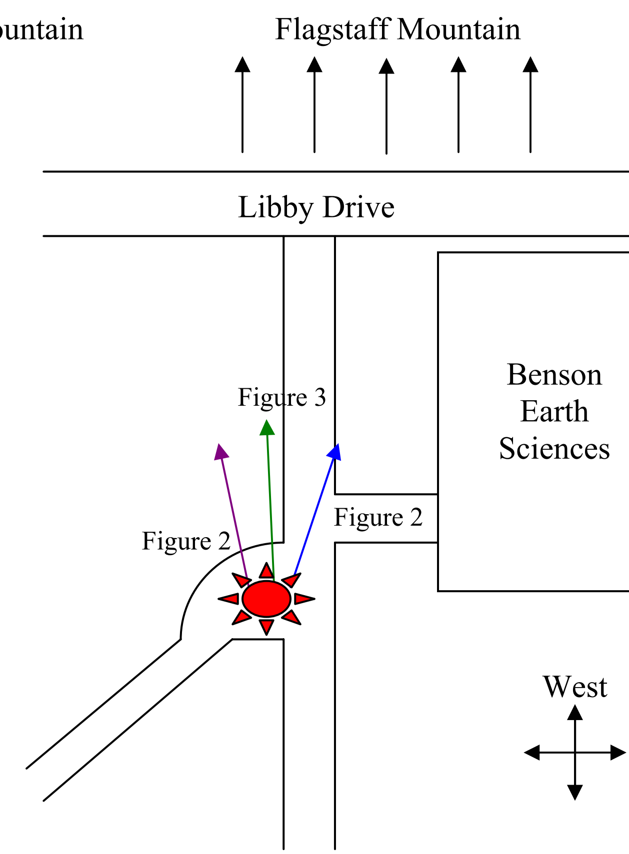

Figure 4: Location from which images were shot from.

According to http://www.weatherunderground.com/US/CO/Broomfield.html, the local temperature of Broomfield, a town near Boulder, was 15°C with 39% humidity. Wind was coming out of the west at 9 km/hr on the ground level and visibility was 32.2 kilometers. In addition, more atmospheric data for October 14th, 2004 in Denver, Colorado was obtained from http://weather.unisys.com/upper_air/skew/skew_KDNR.html. A skew T plot, which describes the vertical conditions present in the atmosphere, was obtained to help identify any potential atmospheric circumstances that related to the development of the specific cloud phenomena observed. The plot is created twice a day by releasing a weather balloon into the atmosphere and recording temperature, wind, humidity and elevation data.

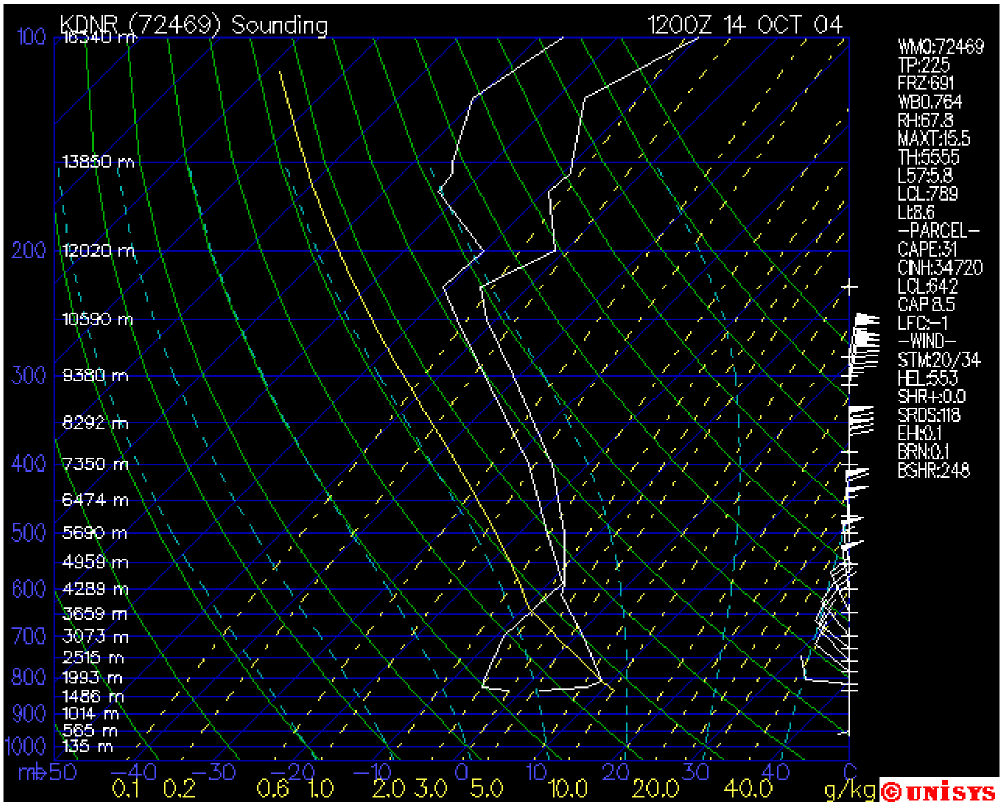

Figure 5: Skew T plot for atmospheric conditions for October 14th 2004

According to Unisys, a skew T plot is developed "By using the concept of an air parcel, lifting it or lowering it and comparing the resulting parcel conditions to the conditions of the surrounding environment as defined by the balloon sounding." A very basic analysis of the above Skew T plot follows. The yellow line in the figure denotes the trajectory of an air parcel as it moves vertically through the atmosphere. The white lines represent the dew point and temperature profiles, from left to right, respectively. When the white lines are to the left of the yellow line, the conditions are unstable, whereas when the white lines are to the right of the yellow line, the conditions are stable. Therefore, this diagram shows that the lower atmosphere is slightly unstable while the upper atmosphere is stable. The unstable air generally accelerates upwards and leads to the creation of thunderstorms. The wind barbs (shown on the right side of the diagram) illustrate the increasing velocity of the wind with elevation.

A general classification of stratus was given to the rotor clouds captured because of their generally "flat" appearance and relatively low elevation off the ground. These clouds were further classified by comparison with examples in the Hazardous Mountain Winds and Their Visual Indicators publication posted online at http://www.faa.gov/and/AC0057/AC0057.HTM by the United States Department of Transportation. A remarkable image found in this publication illustrates cloud phenomenon very similar to the phenomenon captured in Figures 1 through 3. Oddly enough, the sunset images and the image below both show the same general geographic vicinity.

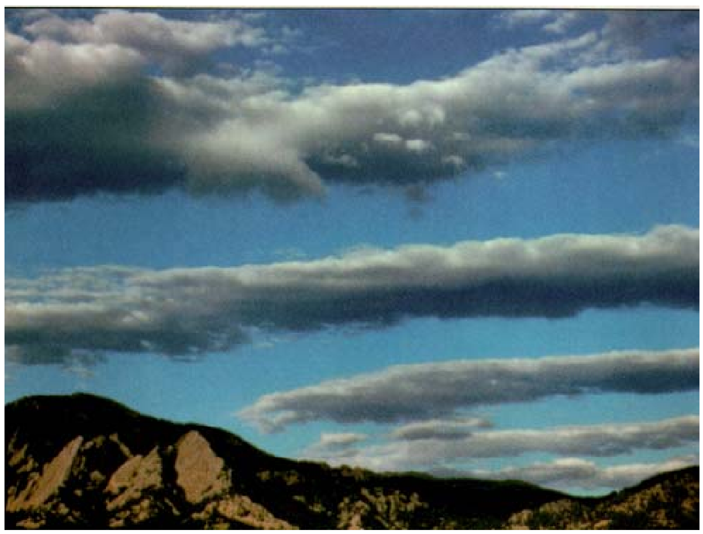

Figure 6: Image of rotor clouds from Hazardous Mountain Winds, Figure 6-11a

According to the Hazardous Mountain Winds Publication, these clouds are "associated with vertically suppressed, trapped lee waves" and are created when strong wind shear above the level of the ridges, in this case, most likely from the Continental Divide, confines the wave energy of the air to a certain altitude. The Hazardous Mountain Winds Publication also specifically states that, "Trapped lee waves are most likely to occur when the wind crosses a narrow mountain range, with a layer close to ridge level and upstream of the mountain that has strongly increasing wind speed with height and high stability, capped by a layer of strong flow and low stability." Visually this can be illustrated as

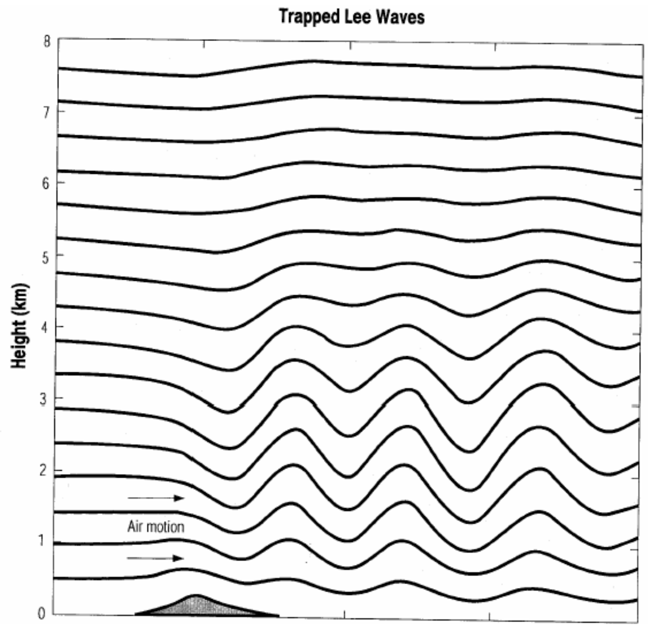

Figure 7: Illustration depicting trapped lee waves from Hazardous Mountain Winds, Figure 5-6

The scenario described in the excerpt almost completely depicts atmospheric conditions on the day the images were captured. For instance, the presence of high wind speed in the upper levels of the atmosphere is verified by the Skew T plot for this day. In addition, the clouds were most likely originating from slightly east of the Continental Divide as the westward wind moved air over the mountains.

Another aspect of these clouds is determined by the rotation in each individual cloud. A good illustration showing the rotation of these vertically suppressed, trapped lee wave clouds is taken from Figure 6-11b from the Hazardous Mountain Winds Publication. It depicts not only the rotation of the individual clouds, but also the pattern of cloud development.

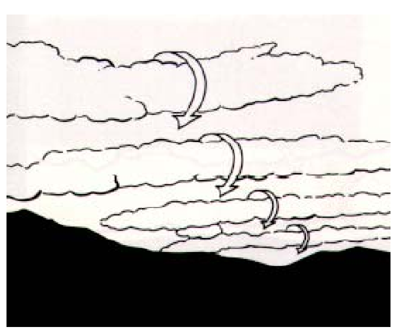

Figure 7: Illustration of vertically suppressed, trapped lee wave clouds

In this case, the rotation of the clouds was very slight and was only evident after examining the clouds for a longer period of time than the images were exposed for. The rotation was most likely a function of different wind speeds above and below the cloud as well as the air moving down the slope of the foot hills and coming in contact with the flat floor of the valley and then going through a hydraulic jump. Figure 5-9 in Hazardous Mountain Winds, explains the location of rotor cloud formation very well.

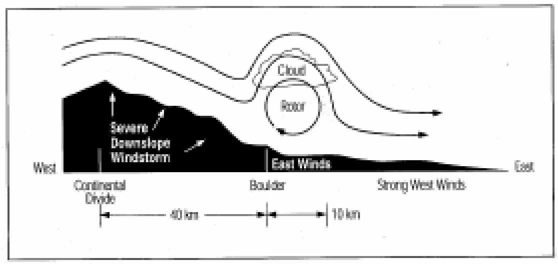

Figure 8: Formation of Rotor Clouds associated with trapped lee waves.

In addition, the book also draws the conclusion that as the "raggedness" of the cloud increases, the general amount of turbulence also increases. Figures 1 through 3 are relatively smooth and therefore, the amount of turbulence present is probably low.

In these images, the flow doesn't seem to be changing as fast as the light is. However, from ground wind velocity measurements, the speed of the clouds is approximately 9 km/hr which translates into 2.5 m/s. Therefore, in the time that the shutter is open, the clouds move approximately .030 m, .053 m and .050 m for Figure 1, Figure 2, and Figure 3, respectively. The smallest resolvable feature is probably half of a meter. This was determined by examining the size of the trees on the ridge in the background. Although, the physical size of a pixel is 0.0003527 meters for these images, the information recorded in the area of a square pixel corresponds to a much larger area because of the distance at which the images were taken from. Thus, the amount the phenomena move during the exposure is negligible compared to the smallest resolvable feature.

No specific visualization techniques were employed to obtain these images. However, the boundary of the clouds against the clear sky created a contrast that helped to capture the images. In addition, the reflection of the light from the sun off of the water droplets in the clouds helped to create the myriad of colors present in the images. The only light used was that of the setting sun.

All images were captured on a 4.0 effective megapixel Nikon Coolpix 4300 digital camera. The camera was set to automatic focus in the long-distance, landscape mode. The camera settings applied to capture the images were as follows:

Table 1: Camera settings

Settings	Figure 1	Figure 2	Figure 3
Original File Size	1116 kB	1155 kB	1092 kB
Digital Zoom	x1.0	x1.0	x1.0
Focal Length (mm)	f24.0	f24.0	F24.0
Aperture Setting	F4.9	F4.9	F4.9
Shutter Speed (sec)	1/84.1	1/44.3	1/46.9
ISO Equivalency Number	100(Auto)	100(Auto)	100(Auto)
Final Dimensions (pixels)	2272 x 1704	2272 x 1704	2272 x 1704
Final Image Field of View	1 km x 3 km	1 km x 2 km	1 km x 2 km

The field of view for each of the images was highly approximated because of the large region photographed and the inability to determine the exact length scales. For this project, the colors of the images remained very true to the actual phenomenon that was observed. Therefore, the only Photoshop or other post processing technique applied was to adjust the coloring of several light-colored, distracting elements in the foreground. Figure 1 was not altered in any manner.

These images reveal a very typical cloud formation over Boulder, Colorado and further investigation yielded the physics behind the creation and movement of these clouds. Overall, I really enjoy both shooting and observing these photographs because the dramatic elements are very attractive. In addition, I believe the clouds and the color reflecting off of the sun produce a texture that is rather uncommon in the natural world. Nonetheless, I have several regrets with these images. First of all, I would have liked to capture the images from an angle more elevated over the foreground from a location such as the photographers point on Highway 36 as one heads west and descends into the Boulder Valley. In addition, I would have also liked to have had a video camera nearby to capture time-lapse footage. However, I realize the feasibility of having all of these devices at my disposal at any given moment is unrealistic. I also recognize the fact that cloud phenomenon and particularly cloud phenomenon interacting with natural light is very fleeting and any chance to capture images from any vantage point requires intense patience or genuine luck.   This sunset was unlike any other I have every seen and I do feel very fortunate to have captured any images of it at all. My intent was fulfilled because I captured a cloud phenomenon that was very different from my last cloud visualization project and the images obtained are equally striking in their own way. Overall, I believe that the more experience I obtain taking pictures of clouds, the better at photographing them I will become. In conclusion, I have resolved to point my camera and my eyes skyward more often.