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Cloud Image 1

Flow Visualization   MCEN 4151

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Introduction

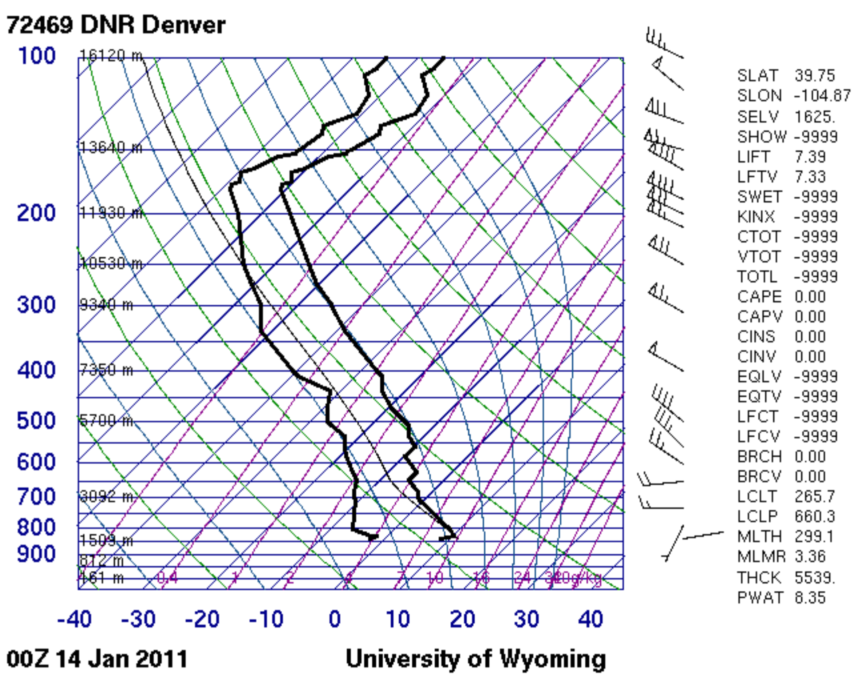
The intent of this image was to capture the best possible image of clouds forming over the mountains. I have always been fascinated by the way that clouds can show us how air flows over the mountains. Since air is clear, it is not so easy for us to see what it is doing. Clouds are the best way to visualize the large patterns of motion of the atmosphere.

Circumstances of the image

This photo was taken from the 11th floor of the Duane Physics tower on the CU Boulder campus. The windows were washed thoroughly with a window cleaner and dried to remove any spots from sullying the image. The camera was facing West/Northwest and angled just a few degrees above parallel to the horizon. The photo was taken on 1/13/2011 at 16:51 when the sun had just barely set over the Front Range.

Physical explanation of the clouds

Below is a skew T plot for Denver CO at 00Z on February 14th, or 6pm on February 13th in Denver (University of Wyoming, 2011). This is the closest time and location for these clouds.



The line on the left represents the dew point temperature and the line on the right represents the actual temperature at each altitude. As the altitude increases, the temperature decreases until reaching the tropopause where the temperature remains approximately constant. On this Skew T plot the tropopause can be seen at about 13,000 meters or about 8 miles. The green lines are dry adiabats: what would happen to the temperature of a dry parcel of air as if it were raised in altitude. The fact that the slope of the decreasing temperature line is not as steep as the dry adiabat indicates that if a parcel of air rose along the dry adiabat, it would be colder than the air around it and it would therefore fall back down due to density. A stable atmosphere is one in which a rising parcel of air would sink again. The atmosphere at the time the photograph was taken was stable.

When the dew point temperature line and the actual temperature line intersect, this indicates that the conditions are right to form clouds. On this plot, the dew point temperature and the temperature lines do not meet, indicating that no clouds were forming above Denver at 6 pm.

When the atmosphere is stable, and the Skew T plot does not predict clouds at any elevation, observers can expect to see orographic clouds and not much else.

The large gray solid looking cloud toward the bottom of the photograph is an Altocumulus lenticularus opacus (Pretor-Pinney, 2006). This is an orographic cloud, also known as a mountain wave cloud.

Air flowing from west to east encounters a large obstacle (a mountain). The mountain forces the air upward. The pressure of the atmosphere decreases further away from earth’s surface much the same way as water pressure increases the deeper one swims toward the bottom of a pool or lake. Therefore, when the air rises it experiences less and less pressure. As it experiences less pressure, it expands. When a parcel of air expands it does work on its surroundings, much the same way as an expanding piston cylinder in a car’s engine does work on the car to make the car move. Conservation of energy tells us that to do work on the surroundings, a system must take energy from somewhere. The expanding piston cylinder in the car’s engine takes the energy from the combustion of fuel. The expanding parcel of rising air takes that energy from the kinetic energy of the air molecules, the temperature of the air.

So as the air rises, it drops in temperature. As that air cools, eventually it gets cold enough for the water vapor in the air to condense. Observers can see the air condensing at the beginning of the lenticular cloud. When the atmosphere is stable, the air that has been pushed up by the mountains is now colder than the air around it. Because of density, this air sinks again. When the air sinks, it experiences greater pressure, the temperature rises, and the water vapor evaporates. Observers can see the air evaporating at the tail end of the lenticular cloud. Thus, as air rushes through the cloud at high velocities, the cloud stays in place above the mountain.

This particular cloud stayed in the same place over time, a characteristic of orographic clouds. It also has the distinct lens shape of lenticular clouds. It has a unique long two-humped shape. The two humps in the clouds mirror two mountain peaks underneath. The hump on the left is formed from air rising over Green Mountain (the mountain the Flatirons live on); the hump on the right is formed from air rising over Anemone Hill (the mountain that hikers can climb from Settler’s Park).

Another photo taken from the same location with the same zoom showed the mountains in the photo as well. This photo is pictured below. The distance was estimated between the summit of Green Mountain and Anemone Hill. The distance between these peaks in the photo was compared to the distance between the actual mountain peaks of 1.6 miles (calculated from the scale on the Google Terrain Map pictured below). This ratio gave a distance across the entire frame of the photo of 2.3 miles. Because the photo used for the calculations had the same zoom and was taken from the same location, the main photo also shows a horizontal distance of about 2.3 miles.

On the right is a photograph of the clouds. On the left is a Google topographic map of the same location. Location 1 is the summit of Green Mountain. Location 2 is the summit of Anemone Hill. The balloon labeled A on the Google map is the location the photograph was taken from.

The elevation of Green Mountain is 8120 ft (Google Terrain Maps). Because these orographic clouds are likely located directly above these mountains, the elevation of the clouds can be estimated using the mountain elevation and the same ratios used to determine the horizontal distance in the photo. The bottom of the large lenticular cloud was estimated to be at an elevation of about 9800 ft. The top of the cloud was estimated to be at about 11,500 ft. This means the cloud is about 1700 feet from bottom to top at its thickest point. This ratio was also used to estimate that the horizontal distance from the camera to the clouds was about 1.9 miles.

At the elevations the clouds were observed, the wind speeds reported in the Skew T plot were 18-22knots, or 20-25 miles per hour. However, the speed of the wind passing through the lenticular clouds is probably greater from being accelerated over the mountain.

The image also shows some Cirrus fibratus radiatus lit up by the setting sun in the center of the photograph, which look like straight parallel streaks (Pretor-Pinney, 2006). These clouds are formed from ice crystals because they form high in the atmosphere where temperatures are colder. Cirrus clouds typically appear between 16,500 and 45,000 ft (Pretor-Pinney, 2006), or between 3.1 and 8.5 miles. Even though the temperature and dew point temperature lines do not meet on the Skew T plot, the closest they come is near the bottom of the tropopause at an elevation of about 8 miles. The Skew T plot for 6 am in Denver on the morning of the 13th also did not show the temperature and dew point lines meeting (University of Wyoming). Photographs taken from earlier that same day show similar but larger Cirrus formations that did not extend very far East past the mountains.

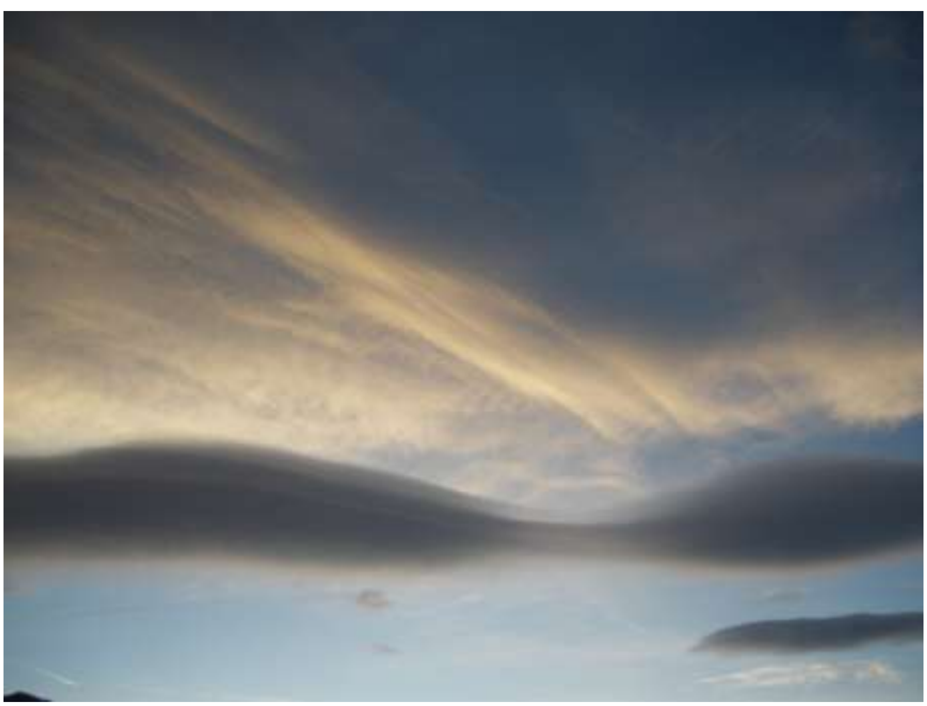
Cirrus clouds can often be the predictors of a change in weather on a synoptic scale, like a cold or warm front moving in (Pretor-Pinney, 2006). On January 13th, a high pressure system had just moved. A low pressure system came into Boulder around the 9th, which brought snow and high temperatures around 17 degrees F and low temperatures around 2 degrees F. By the 13th however, a warm front had moved in; the high temperature was 55 and the low was 33 degrees F (Weather Underground, 2011). It is possible that these cirrus clouds were being brought about by the coming warm front.

However, because neither the Skew T plot for 6 am nor the Skew T plot for 6 pm showed synoptic scale cloud formation, and because the photographs from all day on the 13th showed cirrus formations only near the mountains, it is more likely that these particular cirrus clouds are orographic. The very top of the same air mass that was being pushed upward to form the Altocumulus lenticularus may have formed these Cirrus clouds.

Photographic Information

The photo was taken with an Olympus FE-340 8.0 megapixel digital camera. The shutter speed was 1/50 sec with an aperture value of f/3.5. The ISO speed rating is 64. The focal length is 6.3 mm. The original image was 2048 by 1536 pixels. The zoom lens was on its widest possible angle. The field of view was estimated to be about 2.3 miles and the horizontal distance from the camera to the clouds was estimated to be about 1.9 miles, as described previously.

The final image was cropped to be 2048 by 1308 pixels. The contrast was boosted by using the Curves tool in Photoshop, making the dark pixels darker and the light pixels lighter. This contrast helps to see the fine outlines of the lenticular clouds. Below is the image before any cropping or photo processing.



Discussion

I really wish that I had taken a photo of these clouds with the mountains at the bottom of the photo. Then it would be very obvious just from the photo that they are orographic. I think that the silhouette of the mountains would have really aided the composition of the image, too. I took some photos with the mountains in the shot earlier, when the clouds were not as interesting. I'm not sure why I didn't think to include the mountains in a shot when the clouds became more spectacular.

I think this cloud is a particularly fine specimen of an Altocumulus lenticularis because of its peculiar two humped shape, mirroring the topography below. While the Altocumulus lenticularis species may be cliché in Boulder, I find them to be the most fascinating of clouds. I have always been intrigued by the way that clouds are affected by geographical formations. It just goes to show that air is just another fluid.

Works Cited

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