Flow Visualization
MCEN 5228

Assignment: Clouds 2
Presented To: Dr. Jean Hertzberg
Ben Bishop
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The two cloud assignments assigned through Dr. Jean Hertzberg in the Mechanical Engineering Department at the University of Colorado at Boulder served as a creative way to observe a variety of atmospheric conditions, as well as to create a pleasurable diversion from other engineering works. In the first cloud assignment, I captured a Cumulus fractus cloud rising in the midst of sunset, displaying a full spectrum of color in its radiance. For the second assignment I wanted to capture the same warmth and radiance in black and white, much like the cloud images of Ansel Adams and Alfred Stieglitz. Stieglitz, a German engineer by profession, pursued cloud photography as a form of artistic expression, claiming that the abstract shapes found within clouds contained transcendental meaning that could be projected as inner states, emotions, and ideas within humans (Metropolitan Museum, 2009). His collection *Equivalents*, photographed in 1926, captured images which portrayed many of the common human emotions. Those containing both abstract cloud shapes brightly backlit by the sun were labeled as happy, uplifting, and elegant (DailyMotion, 2009). My image submitted for the *Clouds 2* assignment uses the sun to create a full contrast range in a darkened image, similar to the photos previously mentioned. However, this photo zooms in much closer to the Altocumulus and Altostratus clouds in order to clearly reveal the atmospheric conditions at that altitude; mixing artistic expression with science.

The photo was taken in Boulder, Colorado slightly southwest of the intersection of Baseline Rd. and 38th St., just to the north of Bear Creek Apartments. The circumstances surrounding the image as it was taken are shown in Figure 1, below.

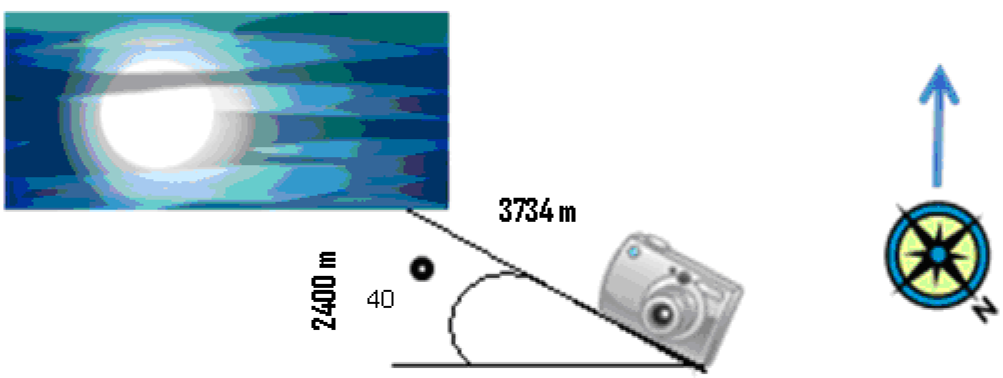

Figure 1: Diagram of Photographic Direction and Elevation

At 3:34 PM on April 8th, 2009, the sun began to quickly converge on the mountain peaks, placing it about forty degrees above the horizontal from the Baseline - 38th intersection. The angle was measured by taking the distance to the nearest telephone pole (approximately 17 feet) and the height of the lowest telephone line (approximated at 20 feet above the camera, which was raised five feet off of the ground due to the height of the photographer) which needed to be overcome for a clear image. The arctangent, then, of (17feet)/(20feet) is about 40 degrees. From this same location the sun was located to the southwest, hidden slightly behind the clouds that became the subject of the image.

To determine the type of cloud, the cloud shape, elevation, and potential weather characteristics were compared with that of the International Cloud Figure Code; an identification chart portraying various cloud types and traits documented by Purdue University's Department of Earth and Atmospheric Sciences. The puff-shaped, dominant clouds seen throughout the image are Altocumulus perlucidus. These are high-altitude clouds recognized by their patch-like appearance, with the perlucidus form in particular usually appearing darker grey rather than white in color. The altocumulus clouds are smaller than the related stratocumulus clouds, but remain larger than cirrocumulus. Their presence signifies convection at their altitude. These clouds, which contain water and ice, will likely bring precipitation within fifteen to twenty hours if the prevailing winds remain steady from Northeast to South. If the wind is from another direction, the clouds will solely bring overcast (Purdue University, 1958). The clouds in the left portion of the image holding no particular shape, serving more as a backdrop, are Altostratus translucidus. Altostratus clouds are characterized by a thin layer of gray clouds covering the whole sky which the sun can shine through. They are caused by a large air mass that is lifted and then condensed, usually by an incoming frontal system bringing cold weather. Like the Altocumulus, they are made of ice and cause precipitation within ten to fifteen hours if the prevailing winds remain steady from Northeast to South. The prefix "alto" for both of these cloud types classify them as "middle" clouds, occurring at heights between 2,400 and 6,100 meters, with their suffixes, respectively, meaning "heap" and "layer" (Purdue University, 1958). The surrounding sky was speckled with the same cloud types, but Cumulus clouds with vertical growth were seen peaking over the mountains to the West. These are fair-weather clouds which often indicate afternoon showers, transforming into Cumulonimbus clouds (Purdue University, 1958). The weather characteristics for each of the clouds followed the weather patterns of the week. April 8th was fairly warm with sunny skies. The following days were intermixed with cold weather and small snow flurries. Figure 2, below, shows the Skew-T plot for the day, giving a graphical representation of the atmospheric conditions.

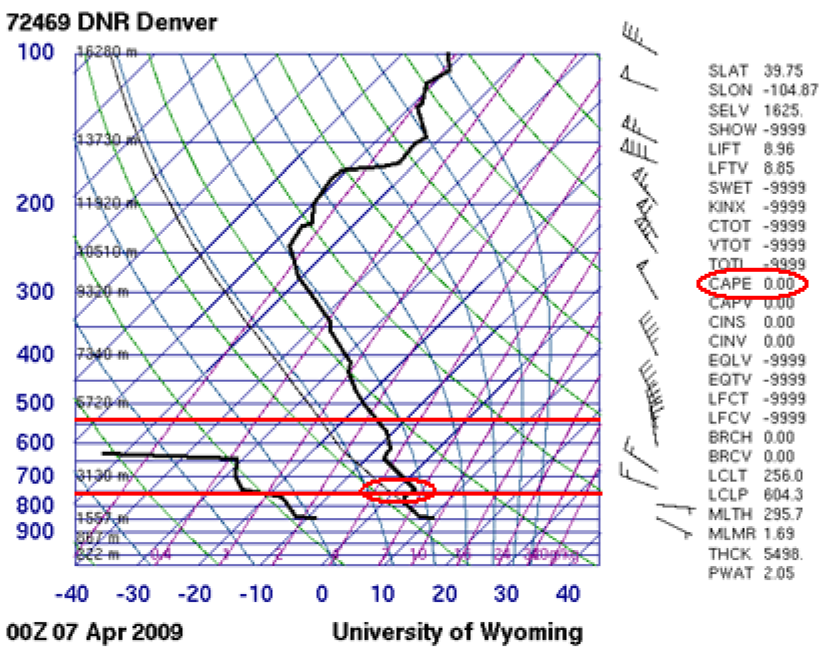

Figure 2: SKEW-T Diagram for 18:00 April 8, 2009 from Denver (U. of Wyoming, 2009)

The SKEW-T plot displays the atmospheric conditions at 18:00 on April 8th, 2009 when the photo was taken. The data was collected from a weather balloon released from Denver (the nearest data collection point) and shows the local temperature (right line), the Dew Point (left line), and the adiabatic line (faint black curve in center). The plot shows that the majority of the atmosphere is stable. The circled area, around 2400 m, shows a potential area of instability, where the adiabatic line is close to the right side of the temperature line. This is the altitude in which the clouds would be most likely to occur. To confirm the stability: pick a spot on the temperature line and trace that point upwards parallel to the adiabatic line. If that point lies left of the temperature line, the actual parcel lapse rate is less than the adiabatic lapse rate (subadiabatic) resulting in what is known as "atmospheric stability." In addition, the CAPE sounding index is an acronym for the Convective Available Potential Energy. Also circled in red in Figure 2, it is an index which assigns a numerical value to the stability of the atmosphere on a given day. It is meant to be used as a quick reference only for it neglects details seen in each elevation. In general, however, a positive value means there are areas of instability in the atmosphere. It can be seen in Figure 2 that the CAPE value is zero, showing that the atmosphere is mostly stable, but may be close to unstable in some regions since the value is encroaching upon positive values (Hertzberg, 2009). Thus, Stratus clouds, occurring in times of stability, and Cumulus clouds, occurring at times of instability, are a possibility.

The pressure at any point in the atmosphere is the pressure needed to support the weight of everything above that point. The given pressure is dependent upon temperature, given by the Perfect Gas Law. As a parcel of air moves upwards, it does work on its surroundings as it expands and exchanges negligible amounts of heat, resulting in an adiabatic process. Because the reverse situation is also possible, it is a reversible, adiabatic process assuming that no mixing occurs. By making substitutions into the fluid's Barometric Equation:

$$\frac{dP}{dz} = -\rho g \qquad (1)$$

Where P is pressure, z is altitude, rho is density of the surrounding air and g is the acceleration due to gravity, one can determine that

$$\frac{dT}{dz} = \frac{-gM}{C_p} \quad \text{(De Nevers, 90-93)} \qquad (2)$$

by eliminating the change in pressure term and substituting the remainder of the Perfect Gas Law in for rho. In equation 2, T is temperature, z is altitude, g is the gravitational acceleration, M is the molecular weight of air (approximately equivalent to 28.96 g/mol) and C is the heat capacity of the gas at constant pressure. The parcel, when moved upwards, will follow the adiabatic lapse rate and be colder than the ambient air as it expands and does work on the neighboring air parcels, causing it to eventually sink with negative buoyancy after it expends its energy. The parcel will then warm up as work is done on it by the surrounding parcels, causing it to once again rise. This is a stable situation which normally results in Stratus clouds.

The dew point, the temperature at which the ratio of the vapor pressure of water to the atmospheric pressure is equal to the mol fraction of water vapor in the gas, is the point in which contained moisture in the atmosphere will begin to condense. This ratio can be expressed as:

$$\frac{p_{watervapor}}{P} = molfraction \quad \text{(De Nevers, 197)} \qquad (3)$$

When the dew point line (temperature) is close to the temperature line (right line in Figure 2), the air temperature is close to the dew point, meaning a cloud is likely to form. In Figure 2, the elevation most likely to create a cloud was around 2400 m, where the lines are closest together. This meets the criterion for middle-level Cumulus clouds and Straus clouds. The wind conditions are found on the right hand side of the SKEW-T plot. At the given elevation of 2,400 m, winds can be seen coming from West by Northwest at 15 knots (17.3 mph). Just above that, winds reach speeds up to 45 knots (51.8 mph). In addition, the book A Physical Introduction to

Fluid Mechanics by Alexander J. Smits discusses that clouds, like air motion, are generally turbulent. According to Smits, typical characteristics of a cloud are a depth of 500 m, internal motion of 5 m/s, and a kinematic viscosity of 10^{-5} m^2/s. This results in a Reynolds number of 2.5E8 (Smits, 2000). At 15 knots (7.7 m/s), the individual cloud particles would be able to move 3.85E-3 m within the 1/2000 s exposure time.

It should be noted that the data shown is representative of a sample taken in Denver (28 miles from Boulder) two and a half hours after the photograph was taken. Also, because the CAPE shows evidence of the atmosphere being close to having instabilities, an Altocumulus cloud is not extraordinary under the generally stable circumstances.

The image was taken with a digital Sony DSC-H10. The Sony digital camera used comes equipped with a flash range of (0.2-7) m wide x (0.9 to 5.6) m tall and a Carl Zeiss Vairo-Tessar 10x zoom lens. For an estimated field of view of 300 m, the camera was zoomed in to a focal length of 11.8 mm to capture all of the clouds approximately 3734 meters away at a forty degree angle. The aperture, then, was set to f/3.5. The high ISO setting of 125 was countered with a short exposure time of 1/2000 seconds. This was still a very bright image since the lens was aimed directly at the sun. Adobe Photoshop was used to darken the image. This was done using the *curves* function. First, the curves function related to all of the colors was used to gain a full range of contrast. Then, the individual colors (red, green, and blue) were taken out of the photo partially to give the image a black and white look, with a yellow hue around the sun. The original photo, measuring 3264 pixels wide x 2448 pixels high was cropped to 2910 pixels wide by 1257 pixels wide. This focused the image on half of the sun and extended the rest of the image until the full contrast range could be seen; a full gradient from light to dark.

Though I would not assign the emotion happiness to this image, as Alfred Stieglitz might have done, I would say it reveals mysticism and wonder. I am pleased with the image for multiple reasons. The range of contrast portrayed in the photo through the obvious gradient moves one's eyes over the photo; each section revealing a new piece: at first the viewer encounters the Altostratus clouds and is then transitioned to the more intriguing Altocumulus. This photo also reveals how those two types of clouds are linked and work in unison at the edge of a cold front to bring cold weather through convection and precipitation. The convection is obvious in the photo, seen in the wispiness of the cloud shapes and the overall small size of the clouds. The next step would be to apply color filters to the lens, like Adams did, to achieve a pure contrast spectrum without the use of external software. The orange filters used on his camera seemed to create an even better range of contrast more naturally. Also, the lack of further editing resulted in final images of higher resolution, which is what I would have liked to achieve in my photo. However, the physics, as well as the warm feeling achieved through the first assignment, were brought out in this photo, even without the color. What other human emotions or transcendental thought could be inspired by a simple cloud photo?

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