Flow Visualization
MCEN 5228

Assignment: Clouds 1
Presented To: Dr. Jean Hertzberg
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2/25/09

"A cloud does not know why it moves in just such a direction and at such a speed...It feels an impulsion...this is the place to go now. But the sky knows the reasons and the patterns behind all clouds," (Thinkexist.com). The previous is the thought of author Richard Bach in his 1936 novel Jonathan Livingston Seagull. Clouds are indeed at the mercy of the atmosphere surrounding them; deciding where they travel to and the length of their existence. The "Clouds 1 Assignment" for Dr. Jean Hertzberg's Flow Visualization class at the University of Colorado at Boulder stimulated each photographer to look to the clouds and digitally capture the patterns of the atmosphere; the physics behind the clouds. In taking the photographs it was my intent to capture the phenomena in its natural state, where color alterations and digital enhancements would not have to be employed to emphasize the sky's beauty and abstractness. In addition, my goal was to individually capture initial cloud formation or dissipation well illuminated by the sun. In this case, that aim was achieved with the image of a Cumulus cloud dissipation at sunset.

Boulder, Colorado served as the location for the photograph, taken from the northern fields adjacent to Bear Creek Apartments at the southernmost point on 30th Street. The diagram below depicts the circumstances surrounding the image as it was taken.

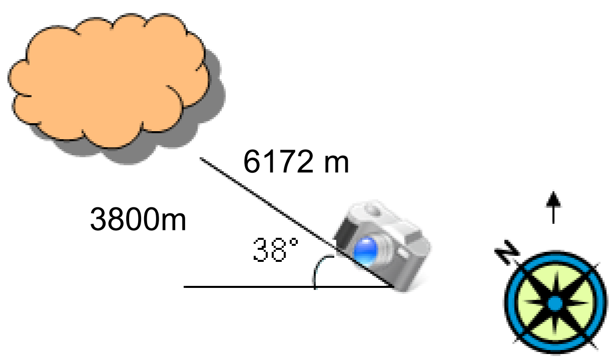

Figure 1: Diagram of Photographic Direction and Elevation

The only view from the field not hindered by obstacles faced northeast, towards the city of Longmont. From a five foot elevation the camera was tilted 23 degrees up, capturing the entire cloud in the field of view since the cloud itself was stationed very low in the atmosphere (around 3800 m). The final image, then, was taken on January 21, 2009 at the onset of sunset where the colors and lighting were most vibrant; at 17:12 Mountain Standard Time. This resulted in the available lighting coming straight from the West orographically, both from the sun and from atmospheric diffraction; where the varying colors illuminate from.

In comparison with the International Cloud Figure Code compiled by Purdue University's Department of Earth and Atmospheric Sciences, the photographed cloud reveals characteristics similar to that of Cumulus fractus. That classification of cloud is defined as being fair weather clouds that resemble Cumulus clouds broken up by high winds. These clouds also release no precipitation unless winds remain steady from the Northeast direction, bringing cold arctic winds that cause instability within the cloud (described later). The final image shows only the crest of one of these clouds, while the negative space is speckled with the remnants of other cloud portions of the same classification.

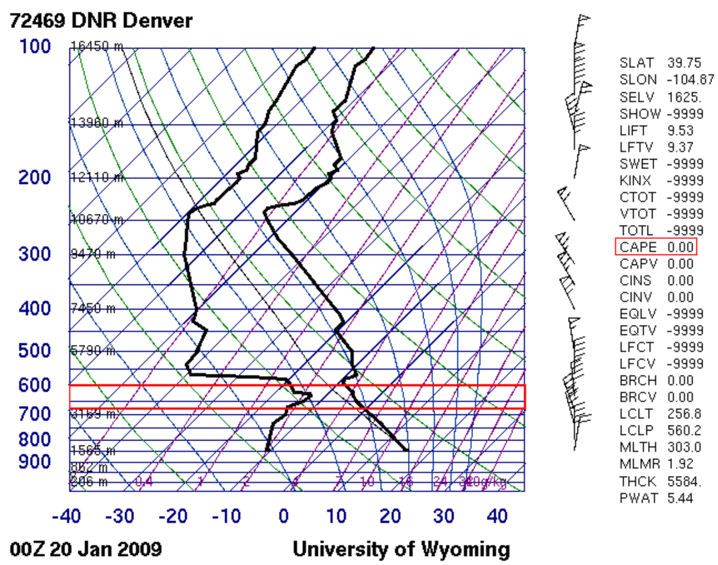

Figure 2: SKEW-T Diagram for 18:00 January 21, 2009 from Denver (U. of Wyoming)

The SKEW-T plot shown above displays the atmospheric conditions of the atmosphere at 18:00 on January 21, 2009; the day 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, including the Cumulus fractus elevation around 3800 m. 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. Boxed 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). Thus, a Cumulus fractus is a possibility in the given atmosphere.

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:

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

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

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

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:

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

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 3800 m (12,467 ft), where the lines are closest together. This meats the criterion for a low-level cumulus cloud, such as the majority of Cumulus fractus. The other criterion, high winds, can be seen on the right hand side of the SKEW-T plot. At the given elevation, winds can be seen coming from North by Northwest at 20 knots (23mph). Just above that, winds reach speeds from 40 to 55 knots (46 to 63 mph). These high winds meet the standards for forming a Cumulus fractus cloud. 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, 435-436). This, in addition to the high winds prevalent around the cloud, gives it the turbulent appearance around the cloud's outer edges.

It should be noted that although the SKEW-T plot gives evidence of atmospheric stability resulting in Stratus clouds, the data shown is representative of a sample taken in Denver (28 miles from Boulder) an hour after the photograph was taken. Also, because the CAPE shows evidence of the atmosphere being close to having instabilities, a Cumulus cloud is not extraordinary under the circumstances.

The image was taken with a Sony digital DSC-H10. Since the image was taken with dwindling light, flash was used and an ISO setting of 125 helped the sensitivity capture the colorations, balancing the short shutter speed of $\frac{1}{8}$ of a second and an aperture value of f/3.5. From the geometry in Figure 1, the object distance was approximately 6172 m. Including the focal length of 0.0063 m, the distance from the object to the lens could be calculated to be 0.0063 m. Since the cloud was so far away, the field of view is estimated to be around 300 m, resulting in an image (original and final) of pixel dimensions 3264 x 2448. Photoshop was used to enhance the coloration distribution in the cloud. The curves function was used, augmenting the brightness of the image and strengthening the blue hue to further contrast the cloud from the surrounding space.

The image fulfilled my intent of capturing a dissipating cloud illuminated with natural lighting; in this case, a Cumulus fractus at sunset. The image reveals natural dissipation due both in part to high winds and the heating of the individual air parcels, furthering its temperature from the dew point. What I like about the image is the transformation from a Cumulus (usually deemed unstable) to a more stable formation; an event I do not notice on a regular basis. This is due to the cold winds from the North chilling the parcels to make them sink and stabilize. In addition, I like its abstract shape, much like a bird, which reveals a section of turbulence located centrally in the cloud with a more stable set of "wings." On the right side of the image there seems to be a segment of blurriness. However, I do not know if this is due to the shutter speed or if it is naturally occurring. I would like to improve on the balance between my shutter speed and sensitivity to prevent such cases. However, I believe the image remarkably captures the physics of air parcel stabilization and reaction to external atmospheric conditions in an artistic fashion, showing both depth and contrast gradients.

References

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