Clouds Assignment 2
Flow Visualization
University of Colorado
Tracy Eliasson

Context and Purpose

The image, depicting clouds over the Boulder Flatirons, was made as part of the second Clouds assignment for the Flow Visualization course at the University of Colorado. The image reveals the layers and texture in altocumulus stratiformis duplicatus. The duplication of layers became visible because of the late day sun angle.

Flow Apparatus

The "flow apparatus" for this experiment is the November Colorado Sky. The image was made on November 15, 2007. It was taken from the corner of Hawthorn Place and Hawthorn in Boulder Colorado. The camera was placed on the ground for stability and pointed in a South West direction. The community garden at this corner allows for sunset views obstructed only by the Flatirons. Figure 1 shows the Skew-T Data for the afternoon of November 15th. The atmosphere was unstable at low altitudes (below 2700 m) and stable above that. Weather on the 15th and following days was warm for the season. There was a mass of clouds in the same location for several days and was followed by

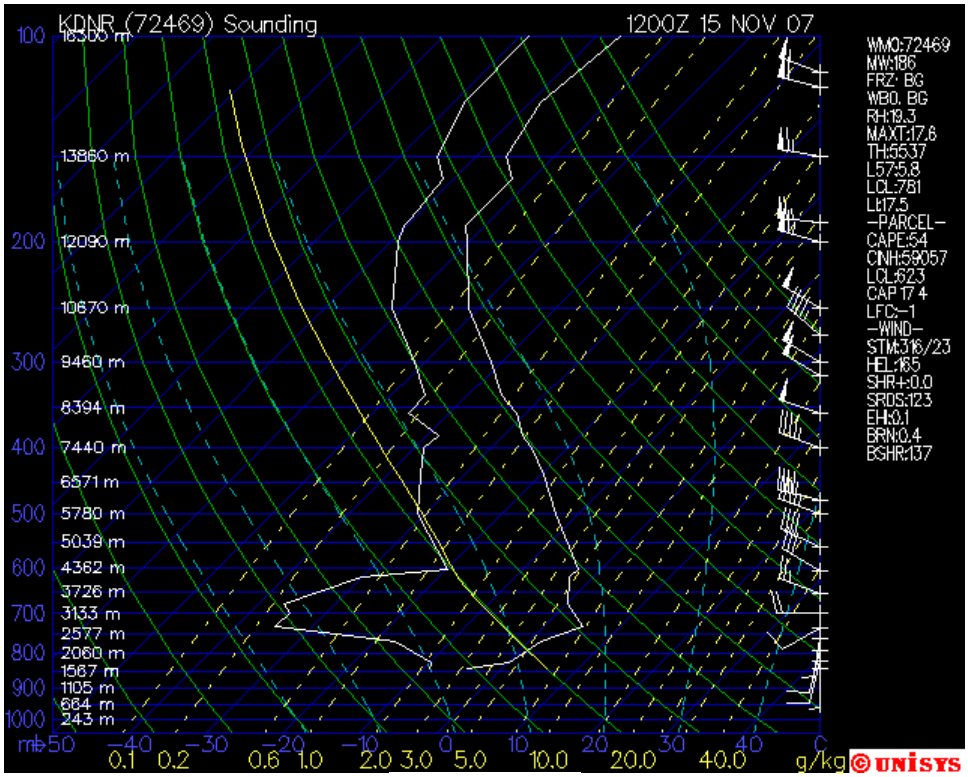

Figure 1

snowfall several days later. The photographer first noted these clouds at about 2:00 pm and again at 3:15 pm. It was not until dusk that the duplicatus nature of the formation was made visible by late day sunlight. The clouds are at a high elevation in a stable atmosphere. Clearly the clouds are at a higher elevation than the peaks also pictured. These peaks are Green Mountain and Bear Peak with elevations of 2482 meters and 2634 meters[1] respectively. Altocumulus clouds are typically found at the middle Etage which ranges from 2000 to 7000 meters[2]. The author estimates that these clouds are at an elevation between 5000 and 7000 meters. The extent of these clouds was massive. They stretched north and south of Boulder along the Front Range, easily covering a length of 60 or more miles. The height (vertical extent) of these clouds is estimated to be several hundred feet per layer. Four layers are visible. The Skew-T plot indicates wind speeds at this elevation between 32 and 48 knots[3]. The Reynolds number (calculated in Appendix B) is estimated to be on the order of 10^8. This indicates turbulent flow. The clouds have been classified as altocumulus stratiformis duplicatus because they appear as sheets of white rounded masses of clouds. Another classification that was considered was stratocumulus, but the cloud International Cloud Atlas indicates that stratocumulus "almost always has dark parts"[4] which these clouds did not exhibit. Cloud formation is likely related to a cold front moving in from over the mountains and pushing out the warm air from previous days. There is much discussion in the literature of the effect of mountains on cloud formation. One such reference, "On the Influence of the Alps on a Cold Font", documents similar bands of clouds in the presence of both a cold front and a mountain range.[5]

Visualization Technique

The visualization technique for this cloud formation was related to lighting. These clouds were first spotted mid afternoon. At that time the cloud band appeared as a thick mass of clouds stretching along the foothills of Boulder. The layers of clouds and separation between layers were not visible. Late day sun allowed for a light angle that lit up the structure and layers within the clouds.

Photographic Technique

The field of view for this image is estimated to be 3000 meters by 2000 meters. The estimated cloud elevation, 6000 meters, was uses as an estimate for distance to the subject. The field of view of the original image was estimated as 4800 meters wide by 3200 meters high[6]. The final image size, cropped from an original image of 3872 pixels by 2594 pixels, is 2416 pixels by 1616 pixels. The focal length utilized is 28 mm. The shutter speed was 1.3 seconds. The aperture setting is F/3.8. Detailed camera setting data as reported by Nikon is included as

---

[1] http://www.topozone.com/states/Colorado.asp?county=Boulder&feature=Summit
[2] International Cloud Atlas. World Meteorological Organization. Chapter 11. 1956.
[3] http://weather.unisys.com/upper_air/skew/details.html
[4] International Cloud Atlas. World Meteorological Organization. Chapter 11. 1956.
[5] Hoinka, Klaus P., Hagen, Martin, Volkert, Hans. & Heimann Dietrich. (1989). On the Influence of Alps on a Cold Font. Tellus, Series A (Dynamic Meteorology and Oceanography), 42A, 140-164.
[6] http://www.tawbaware.com/maxlyons/calc.htm

Appendix A. The photograph was captured with a Nikon D80 digital camera. The image has been processed in Photoshop Elements. Unfortunately the original image was taken at dusk without a tripod. Although the author attempted to use the ground as a tripod results were not ideal. Motion blur of the skyline in the original image was very distracting. At the suggestion of another classmate a second image of the mountains was made from the same location with minimal focus blur. Measurements on were made in order to scale and rotate the 2nd image so that the mountains could be inserted into the image with the clouds. Note, motion blur of an arguably unacceptable level still exists in the clouds, but the distracting element (blurry skyline) has been fixed. Other adjustments include 1) afore mentioned cropping 2) Image level correction of foreground to give it the appearance of being taken at dusk (actual image time was about 10:00 AM). 3) Image level adjustment of the sky in order to bring the contrast up to an optimal level for viewing.

Revealed:

The image reveals a clouds formed by a typical winter weather pattern in Boulder, Colorado. I like that this image opened my eyes to weather patterns and other clouds for days and even weeks after the image was made. I also like that the image is not cluttered with houses, buildings, and electrical wires. It is difficult to make a landscape photograph like this from within the city limits. Although Photoshop was utilized in order to get the full effect the image captures what I remember of the scene. In the future landscape photographs made at dusk will utilize a tripod. I've learned that choosing the least blurry of 30 images is not necessarily going to produce an image of acceptable quality. Also in the future I have learned that although an image looks good on one monitor it may not look good on others. It is smart to view the final image with several contrast settings before public display in order to raise confidence that the image will show well then the time comes.

Appendix A: Shooting Data

Nikon D80
2007/11/15 18:16:09.4
Compressed RAW (12-bit)
Image Size: Large (3872 x 2592)
Color
Lens: 28-135mm F/3.8-5.6 D
Focal Length: 28mm
Digital Vari-Program: Auto
Metering Mode: Multi-Pattern
1.30 sec - F/3.8
Exposure Comp.: 0 EV
Sensitivity: ISO 400
Optimize Image:
White Balance: Auto
AF Mode: AF-A
Flash Sync Mode: Not Attached
Flash Mode: Built-in, i-TTL-BL
Color Mode: Mode Ia (sRGB)
Tone Comp.: Auto
Hue Adjustment: 0°
Saturation: Auto
Sharpening: Auto
Image Comment:
Long Exposure NR: Off
High ISO NR: Off

Appendix B: Reynolds Number Calculation

The Reynolds Number, Re, is a dimensionless number used to understand if a flow is in turbulent or laminar regime.

Re = $v*L/\nu$ where:
v = flow velocity
L = characteristic length of the flow
ν is the kinematic viscosity

Property	**Estimate**	**Estimated Minimum**	**Estimated Maximum**
Flow Velocity, v	20.5 m / sec	16 m / sec	25 m / sec
Characteristic Length, L	76 m	60 m	90 m
Kinematic Viscosity, ν	1.2 x 10^-5 m^2/sec [7]	1.08 x 10^-5 m^2/sec	1.32 * 10^-5 m^2/sec
Reynolds Number, Re	1.28 X 10^8	8.89 X 10^7	1.7 X 10 ^ 8

[7] McDonald, A., Fox, R., *Introduction to Fluid Mechanics*, John Wiley & Sons, Inc, New York, (1992).