MCEN 5141: Flow Visualization
Clouds First

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1 Introduction

This project was intended to serve as an opportunity to enhance understanding of flow visualization techniques through the imaging of everyday cloud formations. The ultimate goal was to generate an image that was aesthetically pleasing, while also indicative of the atmospheric fluid flow conditions that generated the subject cloud.

A variety of photos were taken over an eleven week period in the Denver, Colorado metro area and the resultant photo appears on the title page of this document.

2 Image Details

2.1 Circumstance

Over the course of the project several hundred photos of different cloud types were taken from various locations in the Denver metro area. Details pertinent to the photo ultimately chosen to represent the project are as follows:

Date	29 August 2015
Time	7:39pm MST (0139Z)
Location	N40°7′27.15″ W104°55′59.01″ (Firestone, CO)
Sightline Azimuth	260°
Sightline Elevation	0°

2.2 Weather

All of the clouds captured in the image belong to the *cirrus* family of cloud types. Portions of the formation could be further classified as *cirrus fibratus*, meaning composed of thin threads or fiber-like structures, and *cirrus uncinus*, exhibiting fibers with hooked or curved ends [3].

The portion of the visible sky not captured in the image was largely devoid of clouds, with rare exceptions being small cirrus formations, possibly remnants of aircraft contrails. In the days prior to the image skies were generally clear although they exhibited a marginally larger amount of cloud formations than were observed on August 29th. The same was true of the following few days.

On the day the image was taken, Colorado experienced the passing of a high pressure ridge accompanied by a very weak warm front. These conditions typically bring dry air masses with very low dew points resulting in little to no low level cloud cover. However, high level clouds frequently form under these conditions as the warm air mass behind the front is forced up over the top of the relatively dense cool air mass that it is displacing (See Figure 1).

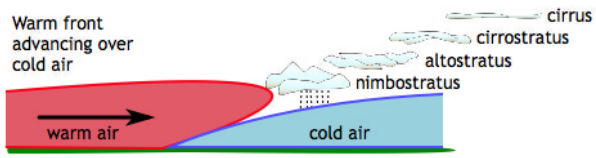

Figure 1: Warm Front Boundary [2]

In this way, relatively dry air can be lifted and cooled beyond its dew point, forming high level clouds under relatively stable atmospheric conditions. This is likely the mechanism which generated the imaged cirrus formations.

In an effort to confirm this, a *skew-T* diagram generated by weather balloon sounding was analyzed. Figure 2 shows the 30 Aug 2015, 00Z (29 Aug 2015, 6:00pm MST) sounding launched from Denver International Airport (KDEN).

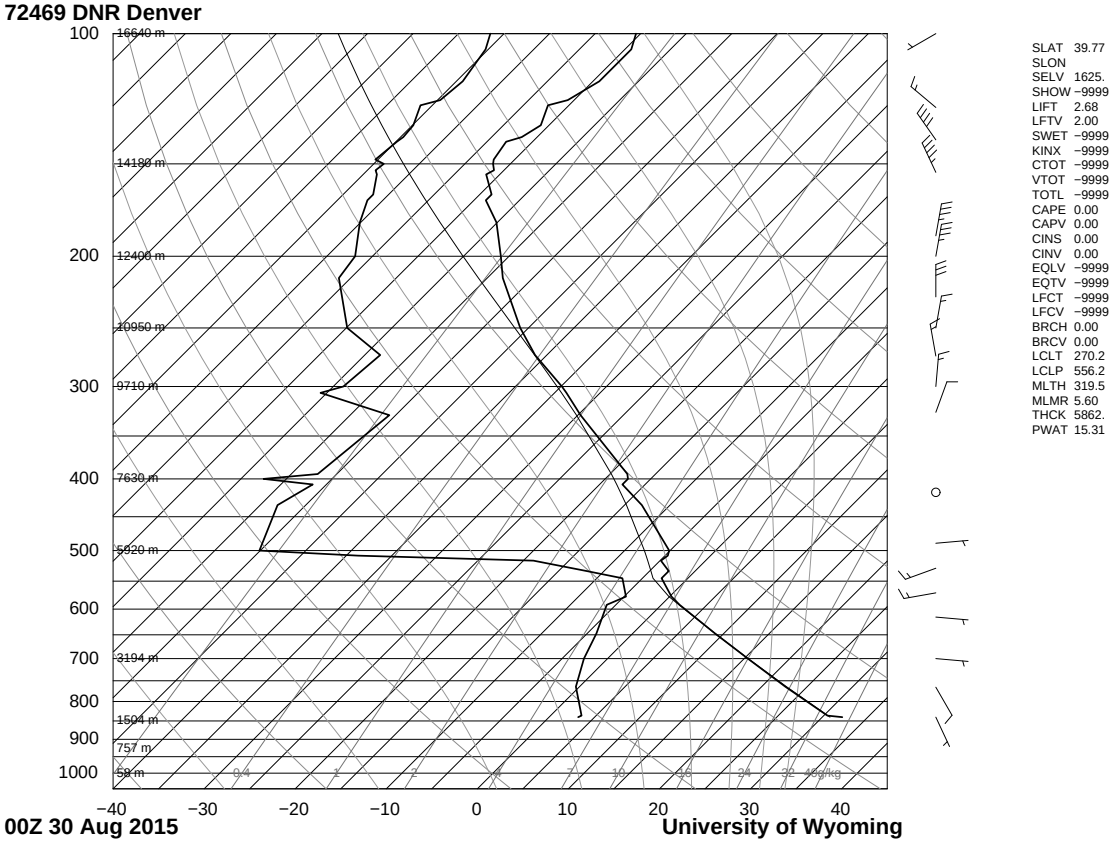

Figure 2: Skew-T Diagram [5]

The skew-T diagram confirms that the atmosphere was stable at the time, exhibiting zero Convective Available Potential Energy (CAPE). The relative dryness of the air mass is also

apparent given the large separation between air temperature and dew point lines through most of the strata. However, dew-point and temperature come within a few degrees Celsius of one another at approximately 20000ft MSL. This is the region most likely to generate condensate. Also of note, the imaged clouds are clearly moving with the winds on a bearing of approximately 085°. The skew-T diagram shows that there is only one distinct band of easterly winds in the entire strata, and it coincides with the converging dew-point/temperature region around 20000ft.

To further confirm the altitude of the clouds, a Meteorological Terminal Aviation Routine Weather Report (METAR) for KDEN, which includes observed sky condition, was referenced for the date of the image. It indicates clear skies with the exception of a single cloud layer at 23000ft MSL [4].

2.3 Camera

The image was captured from an Apple iPhone 5 with the following parameters, and can be seen in original form in Figure 3:

Aperture	f/2.4
Shutter Speed	1/198 sec.
ISO	50
Focal Length	4mm
Resolution	3264 × 2448

Figure 3: Raw Image

In post-production, the foreground of the original image was cropped using Adobe Photoshop and the contrast was adjusted to darken the remaining 'skyline' and increase the contrast range in the sky. The resultant image is shown on the title page.

3 Conclusion

Over the course of this project several images of clouds were obtained that could be considered more aesthetically pleasing than the final image chosen, however, their composition limited clear information about the fluid dynamics of the air mass involved. The photo presented here nicely balances aesthetics with the desire to capture fluid flow information. Most simply, the clouds in the image show the direction of winds at their altitude (in this case, easterly). However, they also highlight the turbulence inherent within most atmospheric flows.

Although only captured by chance, the aircraft contrail seen in the image illustrates the artificial formation of a 'cloud' by the same basic process that created the natural cirrus. Water vapor condenses on particulate matter in the aircraft exhaust and freezes creating the contrail. Although particulate matter is not strictly necessary for cirrus formation, many formations are aided by particles present in the upper atmosphere.

References

[1] National Weather Service Weather Prediction Center. Archived Daily Weather Maps. http://www.wpc.ncep.noaa.gov/dailywxmap/pdf/DWM3515_color.pdf. Accessed: 2015-10-12.

[2] Center for Multiscale Modeling of Atmospheric Processes. Clouds: Fronts. http://www.cmmap.org/learn/clouds/howForm5.html. Accessed: 2015-10-12.

[3] National Weather Service Online School for Weather. Cloud Classifications. http://oceanservice.noaa.gov/education/yos/resource/JetStream/synoptic/clouds_max.htm. Accessed: 2015-10-12.

[4] Plymouth State Department of Meteorology. Archived Surface Text Observations. http://vortex.plymouth.edu/myo/sfc/textobs.html. Accessed: 2015-10-12.

[5] University of Wyoming Department of Atmospheric Science. Upper Air Data: Soundings. http://weather.uwyo.edu/upperair/sounding.html. Accessed: 2015-10-12.