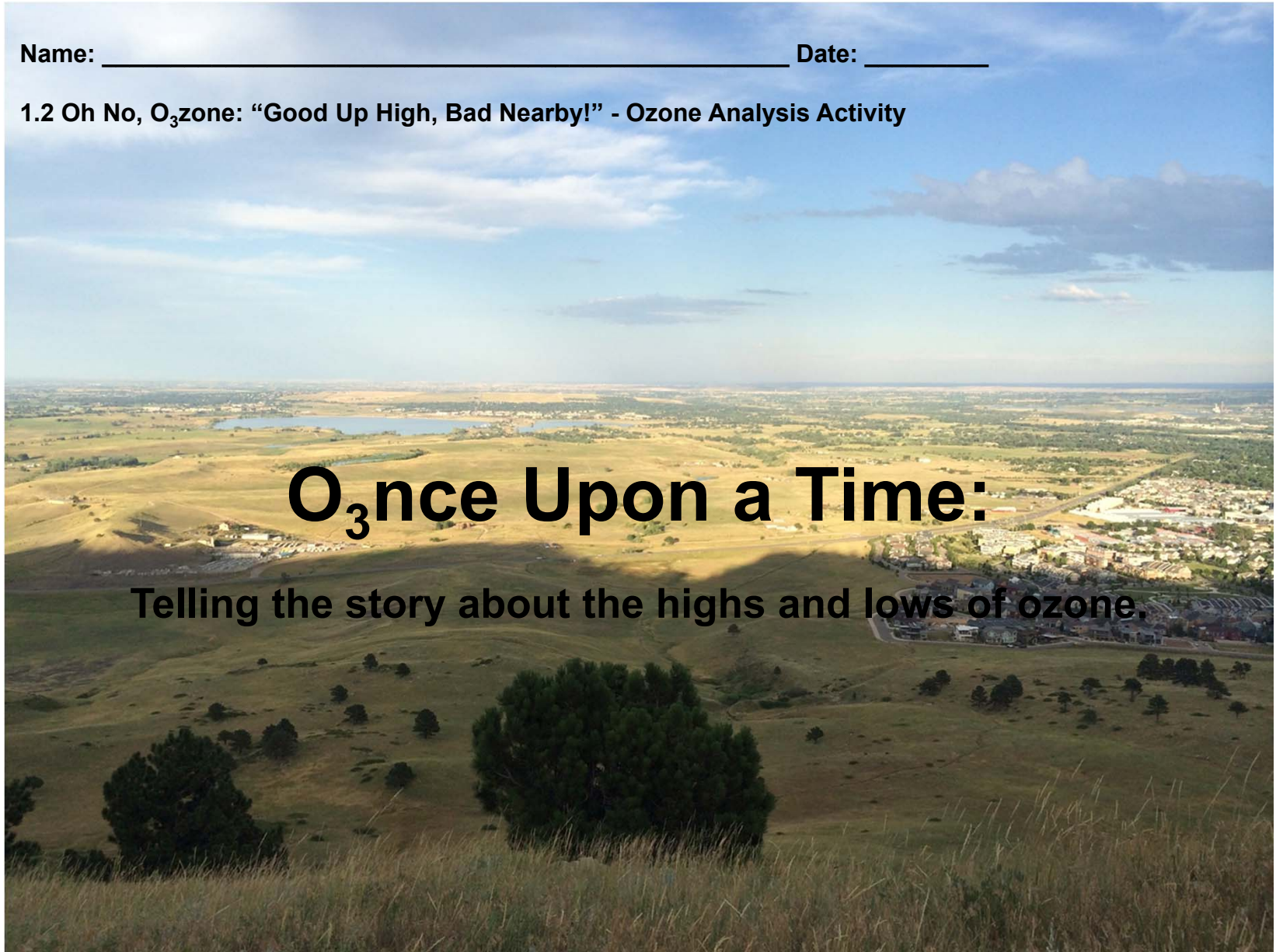


Name: _____ Date: _____

1.2 Oh No, O₃zone: “Good Up High, Bad Nearby!” - Ozone Analysis Activity

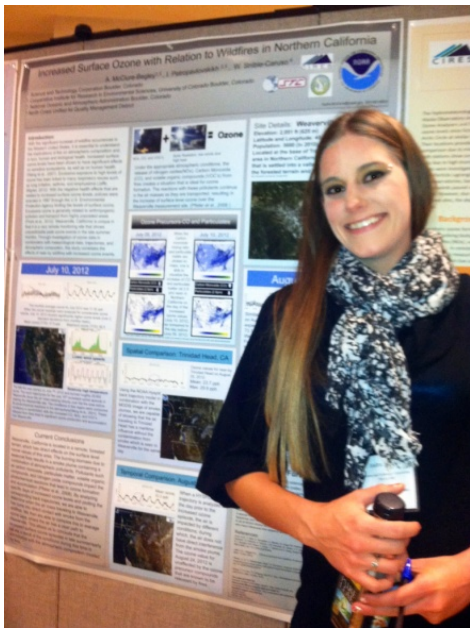
O₃nce Upon a Time:

Telling the story about the highs and lows of ozone.



The Protagonist: Atmospheric Scientist

Audra McClure-Begley (CIRES, University of Colorado-Boulder & NOAA-Global Monitoring Division)



Audra was born in Boulder, Colorado and raised on a small farm outside of Columbia, Missouri. She began working for NOAA-Global Monitoring Division, Ozone and Water Vapor group after receiving her Bachelors degree from the University of Colorado-Boulder.

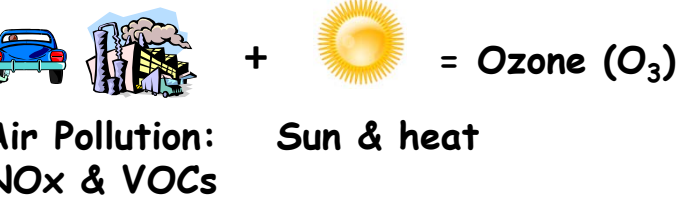
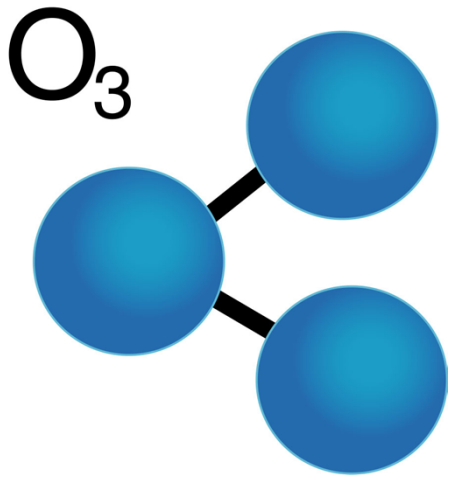
She enjoys hiking, horseback riding, rock-climbing, camping, and being outdoors; which makes the hikes to mountain monitoring stations (Niwot Ridge) a day of doing what she loves most. An avid skydiver with little to no fear of heights, the 300 meter climbs up the Boulder Atmospheric Observatory (BAO) tower in Erie, CO to monitor the ozone are no big challenge.

Her work and research is driven by the desire to improve public understanding of air quality and ozone production-relating to the effects ozone has on ecosystems. She shares her life with her Service Dog, Rhea, and a variety of other pets.



The Antagonist: Ground-level Ozone

a.k.a O_3 or just plain “ozone”



When people hear the word “ozone” they usually think of the ozone layer that is located high in the atmosphere, about 25 km above Earth’s surface, in the stratosphere. The ozone layer protects life on Earth from harmful UV radiation from the Sun.

Ground level ozone is a “secondary pollutant” meaning it is not directly emitted into the air but is formed from other pollutants, mainly volatile organic compounds (VOCs) and nitrogen oxides (NOx), that are emitted into the air.

The main factor that causes the formation of ground-level ozone pollution is sunlight. Ozone typically peaks during the summer months when sunlight is more intense and daylight is longer.

At Earth’s surface, ozone is a toxic and damaging pollutant to living things. Ground level ozone affects plants, including crops, by damaging their leaves.

In humans, breathing ozone decreases lung function and irritates the linings of the lungs that can then worsen existing respiratory diseases such as asthma and bronchitis.. Ozone is an oxidant and breathing it has been described as getting “sunburn” in your lungs.

Introduction: Air Quality Monitoring Stations



- **Boulder Atmospheric Observatory (BAO)**
 - Located on the Front Range plains in Erie, Colorado
 - 40.05 N, 105.00 W
 - 1584 meters above sea level (masl)
- **Niwot Ridge C1 (NWR)**
 - Located in the mountains about 35 km west of Boulder, Colorado
 - 40.05 N, 105.54 W
 - 3035 masl
- Both monitoring stations experience seasonal maximum ozone values during the summer and minimum ozone values during the winter.
- Ozone levels follow a diurnal (daily) cycle. This is characterized by low levels of ozone during the nighttime that is followed by daytime build up of ozone resulting in high levels of ozone during the late afternoon.

Scene I: Boulder Atmospheric Observatory (BAO) - Erie, CO



Erie, Colorado has co-located tower ozone measurements to understand the vertical dynamics of ozone. Tower climbs require proper gear, training, and a good team of co-workers.

Pictured from left to right: Tom Legard, Audra McClure, and Jon Kofler.



Climbing the 300 meter tower allows for gorgeous views of the front range area.



A view from above of the Boulder Atmospheric Observatory site. (Surface ozone instrument)

Scene II: Niwot Ridge (C1) - Mountain Research Station, CO

Collaboration with University of Colorado-INSTAAR

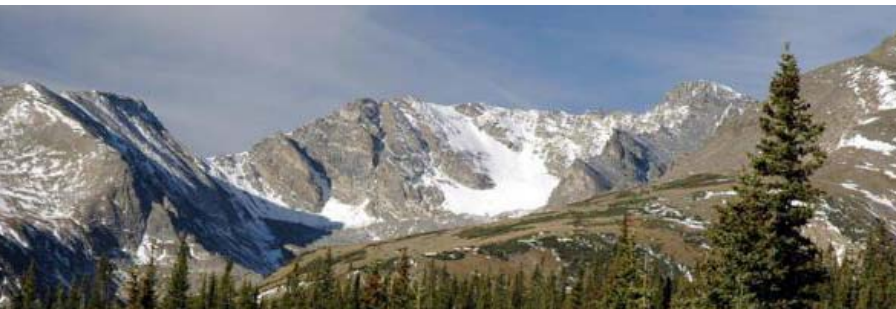


The Niwot Ridge, C1 monitoring station is located nestled in the trees-co-located with halocarbon and meteorological instruments.

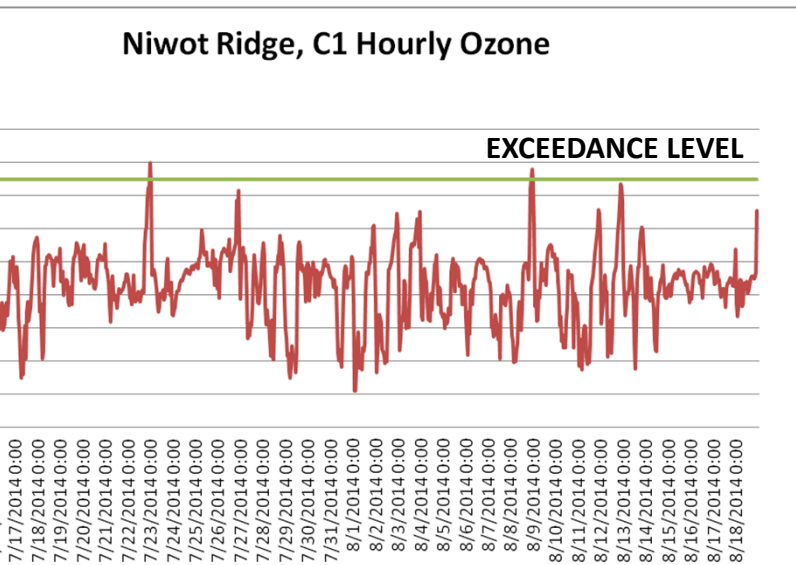
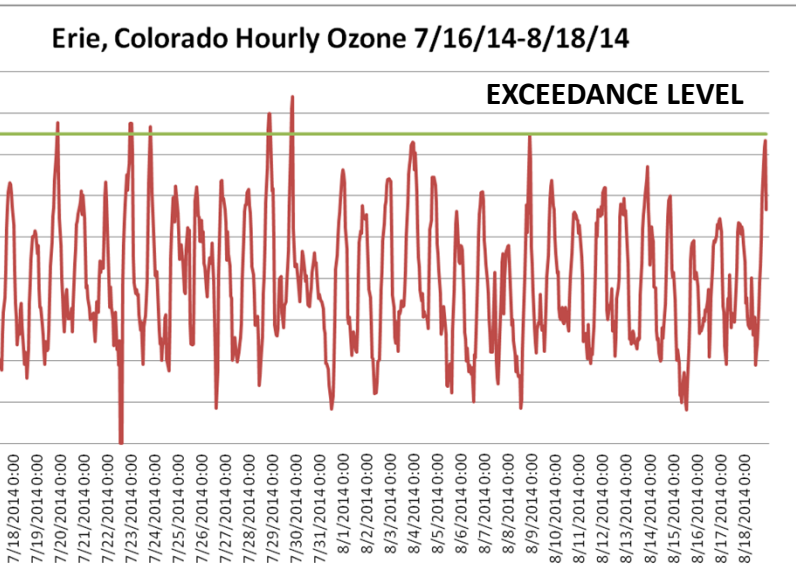
Access to the monitoring site is limited to prevent contamination of air samples and other research projects. A long hike in the forest is the preferred method for reaching the site.



The hike to the Niwot Ridge monitoring station allows for scenic mountain views



The Plot: Exceeding Safe Levels of Ozone



1. Observe the graphs and tell the story of how ground-level ozone values changed throughout the summer in 2014.
 - a. What do the x and y-axes measure?
 - b. What does the red line represent? What are its maximum and minimum values?
 - c. What does the green line represent?
 - d. How many times in each location does the red line meet and/or extend above the green line? Why is this of importance to air quality?
2. Write a paragraph that describes the patterns in the data that are backed up with the scientific evidence provided in the graphs. Be creative and scientifically accurate!
 - a. X-axis: ozone values, parts per billion (ppb), Y-axis: days
 - b. Red line: ozone values change over time
 - c. Green line: ozone value 75 ppb, this level and above is an exceedance of EPA air quality regulations of safe levels of ozone.
 - d. BAO (Erie, CO): 6 incidents of ozone exceedance, Niwot Ridge: 2 incidents of ozone exceedance.



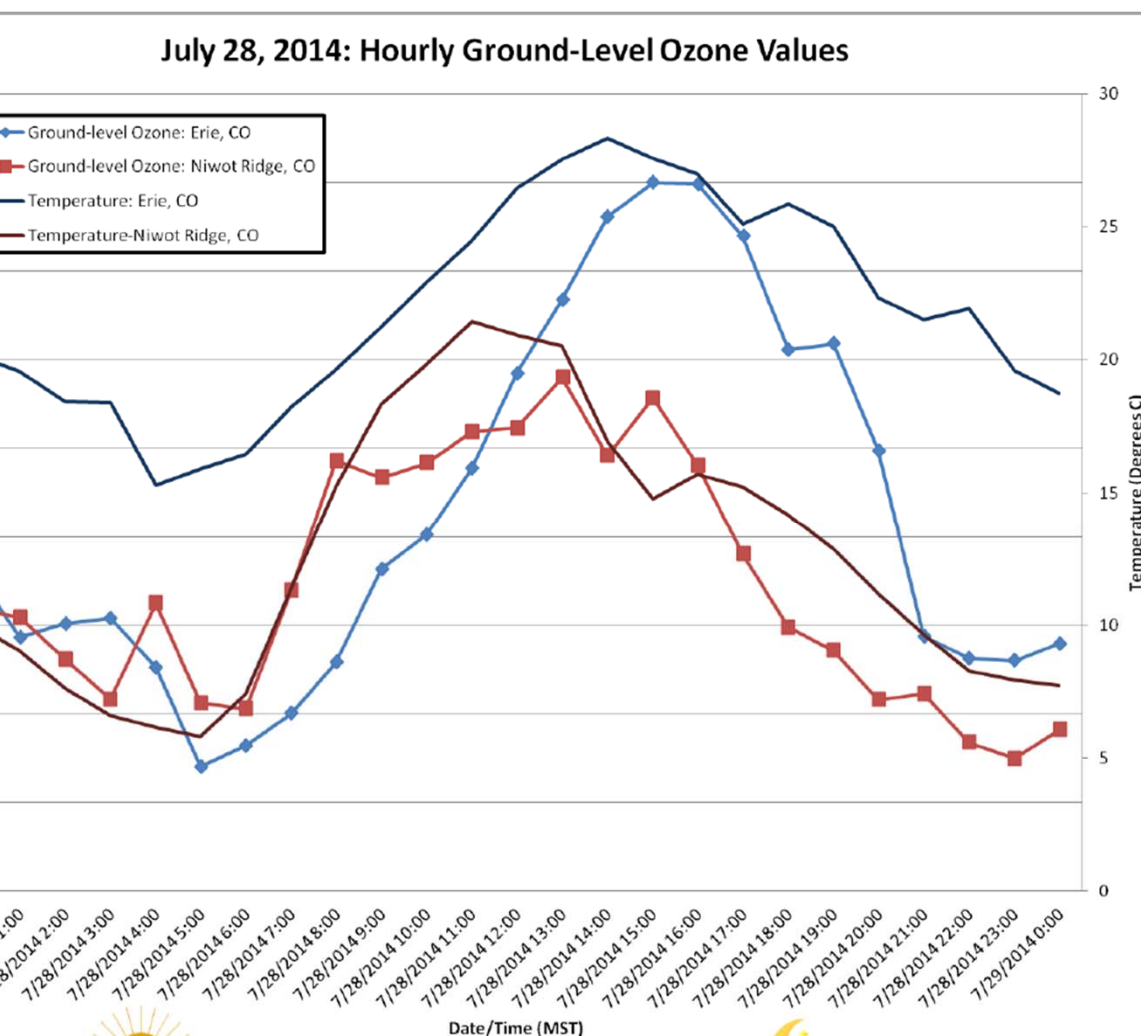
Air Quality Index for Ozone

(based on 8-hr average concentrations)

Index Values (Conc. Range)	Air Quality Descriptors	Cautionary Statements for Ozone
0 – 50 (0-59 ppb)	Good	No health impacts are expected when air quality is in this range.
51 – 100 (60-75 ppb)	Moderate	Unusually sensitive people should consider limiting prolonged outdoor exertion
101 – 150 (76-95 ppb)	Unhealthy for Sensitive Groups	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion
151 – 200 (96-115 ppb)	Unhealthy	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children should limit prolonged outdoor exertion.
201 – 300 (116-374 ppb)	Very Unhealthy	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.

Chapter 1: High Ozone Factors - July 28, 2014

Values at Erie, Colorado exceeded the 75 ppb air quality standard on July 28, 2014. However, the near-by Niwot Ridge did not record high ozone values. The dominant wind direction was from the North, which pushed the air-mass in a westerly direction. This kept the mountain measurement site out of the polluted air mass path.



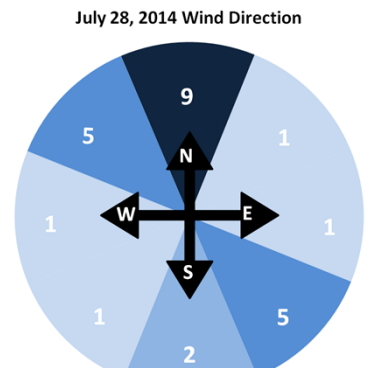
Weather & Wind Conditions

Sunny day, clear skies.

The prevailing wind direction was to the north, which prevented the high-levels of ground-level ozone pollution from being pushed west into the mountain areas. The lower ozone levels recorded at the Niwot Ridge (C1) monitoring site confirm this.

Note: wind direction indicates the direction where wind originates not direction it is blowing.

(wind from N blows S)



Chapter 1: Tell the story...the heat is on!

Analyze the BAO and Niwot air monitoring station graphs and review the day's weather conditions. Then tell the story of the factors that relate to the day's ozone values.

What do the x and y-axes measure? Axes labels/scale/units?

What is the temperature pattern? What are its maximum and minimum values? When do they occur?

What is the ozone value pattern? What are its maximum and minimum values? When do they occur?

What is the relationship between temperature and ozone?

How does sunrise and sunset relate to temperature and ozone values?

In which directions is the wind mainly blowing?

Did BAO and/or Niwot Ridge experience an exceedance of safe ozone values (75 ppb and above)? Explain why or why not by comparing and contrasting the above scientific data and summarizing its main evidence. According to the EPA Air Quality Index (AQI), what was the air quality rating at BAO and Niwot Ridge?

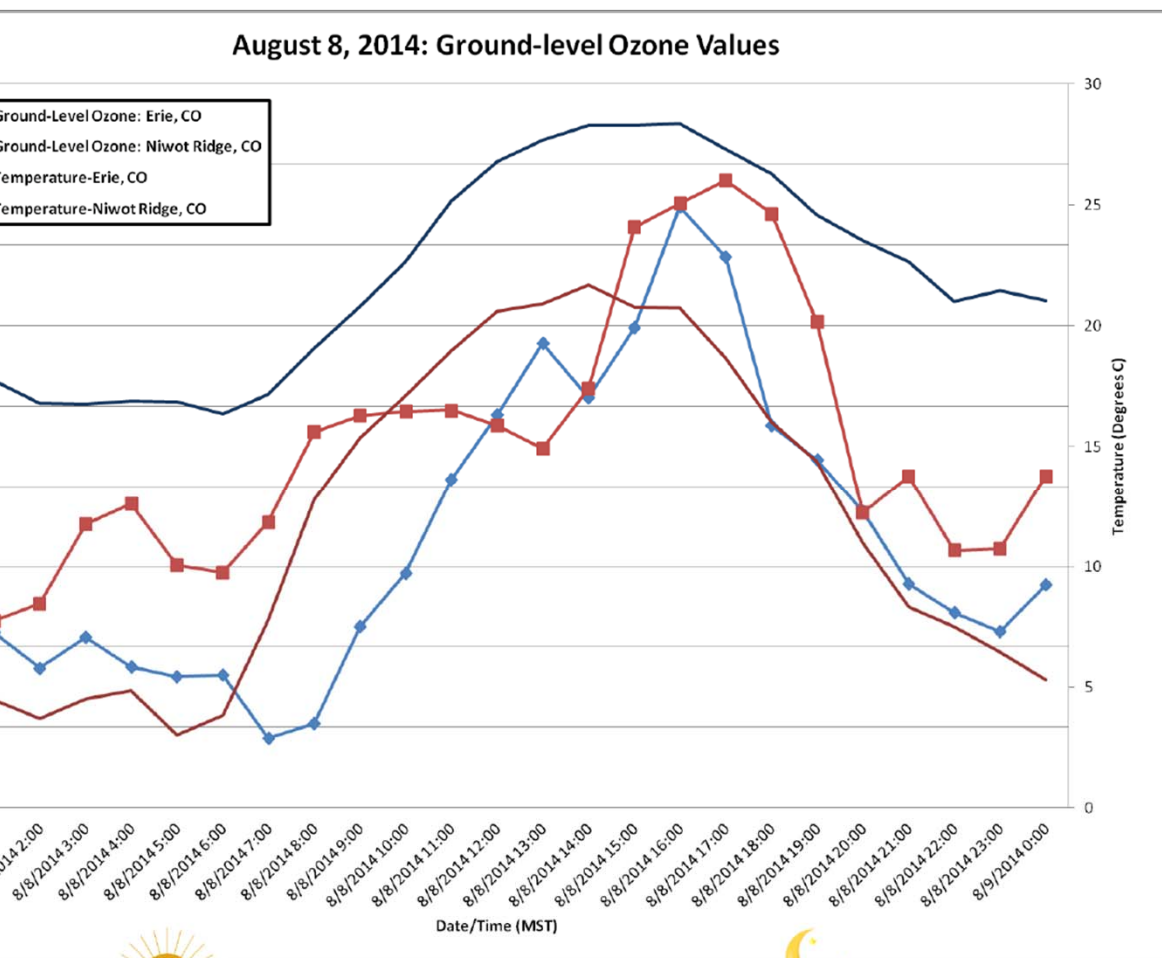
2. Write and illustrate a paragraph that describes the patterns in the data that are backed up with the scientific evidence provided in the graphs. Be creative and scientifically accurate!

- a. X-axis: ground-level ozone values, Y-axis: hours
- b. Temperature increases from sunrise until mid-day and then decreases until sunset. BAO: min. temp 15C at 4:00 (4 am), max. temp 28C at 14:00 (2 pm). Niwot: min. temp. 6C at 5:00 (5 am), max. temp. 22C at 11:00 (11 am).
- c. Ozone values increase from sunrise until mid-day and then decrease until sunset. BAO: min. O₃ 14 ppb at 5:00 (5 am), max. O₃ 80 ppb at 15:00-16:00 (3-4 pm). Niwot: min. O₃ 15 ppb at 23:00 (11 pm), max. O₃ 59 ppb at 13:00 (1 pm).
- d. Temperature leads ozone values. Ozone values follow temperature.
- e. As the Sun rises, temperatures and ozone values increase until mid-day. As the Sun starts setting from mid-day until sunset, temperatures and ozone values decrease.
- f. Wind is from the north blowing in a southerly direction.

2. BAO had an exceedance of safe ozone values (80 ppb) but Niwot did not (59 ppb). The main reason is because Erie is located along the front Range in Erie, CO and there are more sources of NO_x (vehicle exhaust) and VOC (industry, Oil Gas wells, etc.) air pollution than up in the mountains. Also, the wind blew the ground-level ozone pollution to the south not to the west towards Niwot Ridge. The air quality at BAO was rated as "unhealthy for sensitive groups (orange)" and at the

Chapter 2: Ozone and Upslope Wind - August 8, 2014

The values at both stations exceeded the 75 ppb level of ozone exceedance, but why? The Niwot Ridge station peaks in ozone values about one hour after the peak of ozone at Erie, Colorado. This can be attributed to the time it takes for the polluted air mass to be transported up the mountain slope to the high elevation monitoring site. Ozone episodes in the high elevation Rocky Mountains have added concern for alpine ecosystem functioning, including forest health and biodiversity in the mountains.



Weather & Wind Conditions

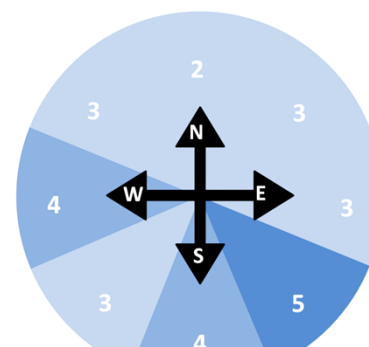
Sunny day, clear skies.

In contrast, the direction of the wind pushed the ground-level ozone west into the mountains. The higher ozone levels recorded at the Niwot Ridge (C1) monitoring site confirm this.

Note: wind direction indicates the direction where wind originates not direction it is blowing.

(wind from SE blows NW)

August 8, 2014 Wind Direction



Chapter 2: Tell the story...going with the flow!

Analyze the BAO and Niwot air monitoring station graphs and review the day's weather conditions. Then tell the story of the factors that relate to the day's ozone values.

What do the x and y-axes measure? Axes labels/scale/units?

What is the temperature pattern? What are its maximum and minimum values? When do they occur?

What is the ozone value pattern? What are its maximum and minimum values? When do they occur?

What is the relationship between temperature and ozone?

How does sunrise and sunset relate to temperature and ozone values?

In which directions is the wind mainly blowing?

Did BAO and/or Niwot Ridge experience an exceedance of safe ozone values (75 ppb and above)? Explain why or why not by comparing and contrasting the above scientific data and summarizing its main evidence. According to the EPA Air Quality Index (AQI), what was the air quality rating at BAO and Niwot Ridge?

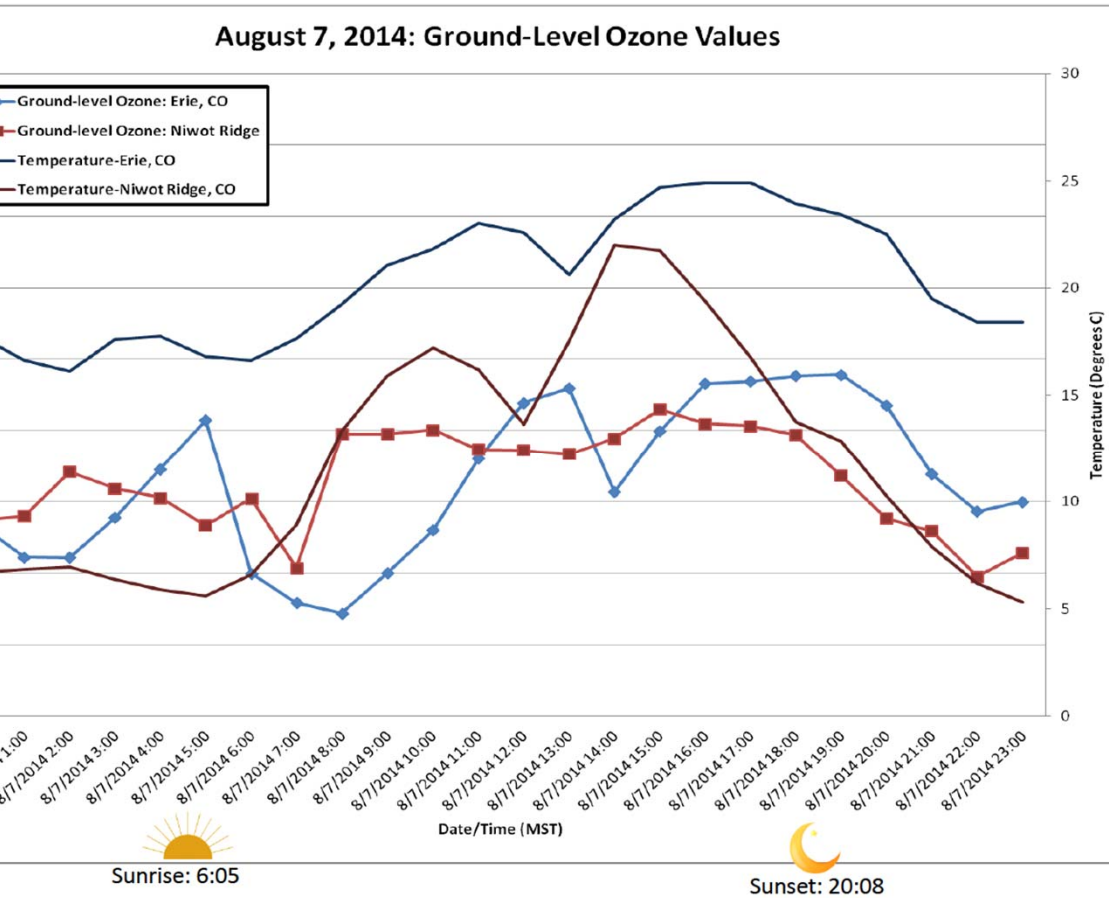
2. Write and illustrate a paragraph that describes the patterns in the data that are backed up with the scientific evidence provided in the graphs. Be creative and scientifically accurate!

- a. X-axis: ground-level ozone values, Y-axis: hours
- b. Temperature increases from sunrise until mid-day and then decreases until sunset. BAO: min. temp 17C at 6:00 (6 am), max. temp 28C at 16:00 (4 pm). Niwot: min. temp. 7C at 0:00 (12 am), max. temp. 22C at 14:00 (2 pm).
- c. Ozone values increase from sunrise until mid-day and then decrease until sunset. BAO: min. O₃ 9 ppb at 7:00 (7 am), max. O₃ 76 ppb at 17:00 (5 pm). Niwot: min. O₃ 20 ppb at 0:00 (12 am), max. O₃ 78 ppb at 16:00 (6 pm).
- d. Temperature leads ozone values. Ozone values follow temperature.
- e. As the Sun rises, temperatures and ozone values increase until mid-day. As the Sun starts setting from mid-day until sunset, temperatures and ozone values decrease.
- f. Wind is from the north blowing in a southerly direction.

2. Both BAO (76 ppb) and Niwot Ridge (78 ppb) had an exceedance of safe ozone values. The main reason is because the air pollution generated in the Front Range from NO_x (vehicle exhaust) and VOC (industry, Oil Gas wells, etc.) was converted by sunshine into ground-level ozone. BAO experience an ozone exceedance first it is nearest to the sources of ozone and the wind then blew the ozone pollution upslope in a westerly direction into the foothills towards the Niwot Ridge monitoring station, which occurred an hour after BAO recorded its ozone exceedance. The air quality at BAO and Niwot were both rated as "unhealthy for sensitive groups (orange)".

Chapter 3: Ozone and Clouds - August 7, 2014

The basic formula for ozone production is $\text{NO}_x + \text{VOC} + \text{Sunlight} = \text{Ozone}$. Clouds prevent UV solar radiation from reaching the ground, preventing the formation of molecules that would react in sunlight to form ground-level ozone. August 7th had higher cloud coverage and lower ozone values compared to August 8th, which had clear skies, warmer temperatures, and higher ozone values.



Compare & Contrast Ozone & Temperature Data:

1. Maximum ozone value at BAO: 48 ppb
2. Maximum ozone value at Niwot Ridge: 42 ppb
3. Maximum temperature at BAO: 25 C
4. Maximum temperature at Niwot Ridge: 22 C
5. Did the BAO (Erie, CO) air monitoring site record unsafe ozone values (above 75 ppb)?
Yes No
6. Did the Niwot Ridge air monitoring site record unsafe ozone values (above 75 ppb)?
Yes No

Chapter 3: Tell the story...undercover!

analyze the BAO and Niwot air monitoring station graphs and weather description. Then tell the story of the factors that relate to the day's ozone values.

August 7, 2014 was a cloudy day. How did the lack of sunshine affect the ozone values at BAO and Niwot Ridge? Explain with evidence.

Based on this and previous weather data, is the Sun an important fact in the formation of ground-level ozone? Explain with evidence.

Did BAO and/or Niwot Ridge experience an exceedance of safe ozone values (75 ppb and above)? Explain why or why not by comparing and contrasting the above scientific data and summarizing its main evidence. According to the EPA Air Quality Index (AQI), what was the air quality rating at BAO and Niwot Ridge?

2. Write and illustrate a paragraph that describes the patterns in the data that are backed up with the scientific evidence provided in the graphs. Be creative and scientifically accurate!

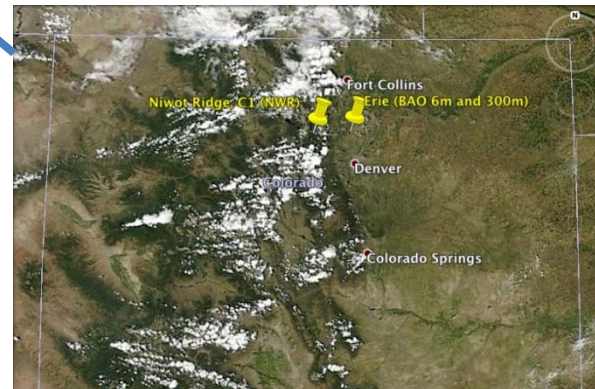
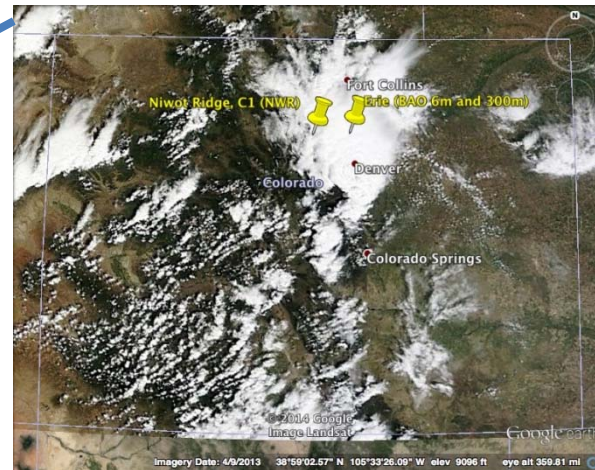
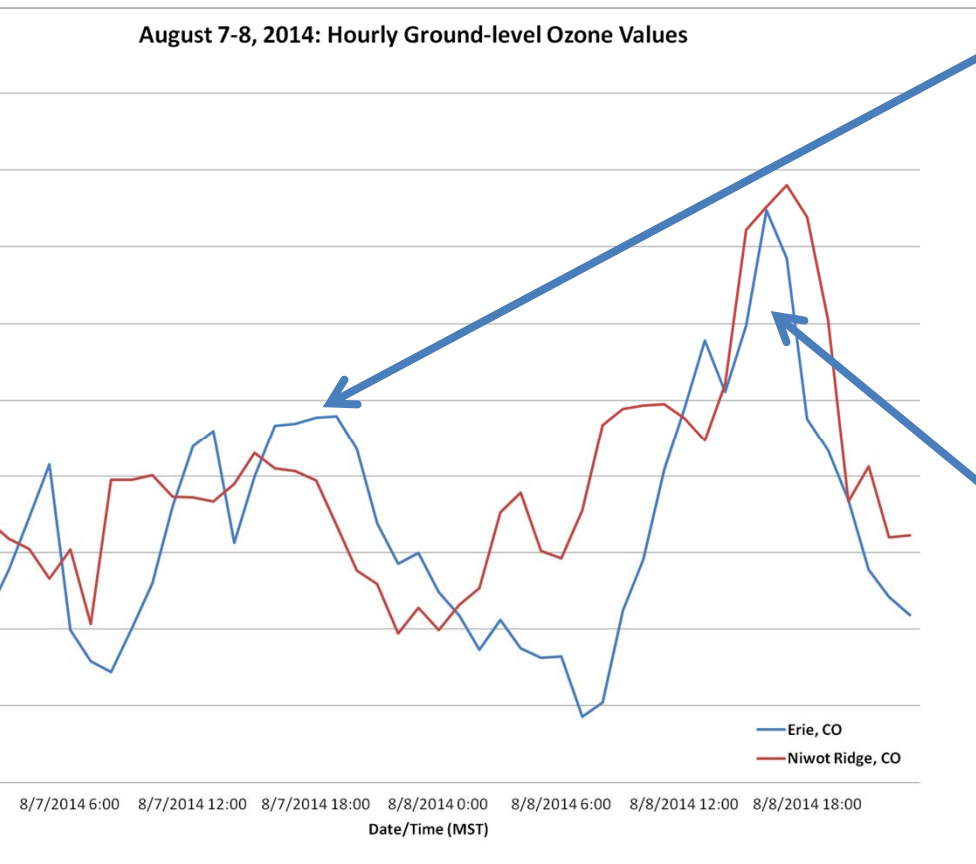
- a. On August 7, the lack of sunshine did affect the ozone values at BAO and Niwot Ridge. They were lower even though the temperature at both locations were similar on August 8 and July 28, 2014.
- b. The Sun is the source of energy that causes the chemical reaction that creates ozone. At night when the Sun is not shining, ozone values are at their lowest.

2. Both BAO (48 ppb) and Niwot Ridge (42 ppb) did not have an exceedance of safe ozone values. The lack of sunshine did not favor the formation of ground-level ozone. According to the EPA Air Quality Index (AQI), both locations had a "good (green)" rating for air quality.

The Climax: Ozone - August 7 & 8, 2014

General formula for ozone production consists of $\text{NO}_x + \text{VOC} + \text{Sunlight} = \text{Ozone}$. Clouds prevent all UV solar radiation from reaching ozone-forming molecules that would react in sunlight to form ground-level ozone. August 8th had high ozone values and clear skies. However, the previous day- August 7th, had relatively low ozone and high cloud cover.

Representative Satellite Images:



Conclusion

Analyze the BAO and Niwot air monitoring station graphs and satellite images. Then tell the story of the main factors that determine ozone values.

What is the basic “formula” for ozone production?

How does the amount of sunlight effect ozone values?

How does time of day effect ozone values?

How does temperature relate to ozone values?

How does wind effect ozone values?

Compare and contrast the above scientific data and summarize the key factors that contribute to high values of ground-level ozone and those that result in low values of ground-level ozone.

Extend your learning by using your creativity to communicate the science of ground-level ozone!

Use your story as a script to film a video, record a podcast, present a poster, post a webpage or blog, create a graphic comic strip, etc. The skies the limit!

2. Write and illustrate a conclusion that describes the factors that determine ground-level ozone values. Provide scientific evidence from the graphs, images, and descriptions to support your conclusion . Be creative and scientifically accurate!

- a. $\text{NO}_x + \text{VOC} + \text{Sunlight} = \text{Ozone}$
- b. The greater the amount of sunlight the greater the greater the amount of ground-level ozone that is formed.
- c. Ozone levels peak at mid-day when the sunlight is most abundant. Ozone values are higher during the day when the un is shining than at night when the Sun is not shining.
- d. The warmer the temperature the higher the ozone values
- e. Wind can blow ozone pollution into and out of an area depending on its direction.

The End!