Course Description:
Air pollution and adverse air quality in general continue to be an issue in many regions around the world, as the global population increases and increasingly residing in urban areas, in which emissions and exposure are intensified. A knowledge of the physical processes behind air pollution—both the chemistry and meteorology—are essential for devising effective policies to combat adverse air quality. This class will examine these physical processes and will also touch upon the U.S. national and international regulatory regime that has evolved to address air pollution.

Prerequisites:
- Calculus 2
- General Chemistry
Scheduled class time:
Tuesdays and Thursdays: 2pm to 3:20pm in WBB 517

Instructor
Course Instructor
Prof. John C. Lin
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For Appointments
Prof. John Lin
Office: 721 WBB
Often right after class is a good time to talk briefly.
Otherwise just e-mail me to set up a time!

Course Objectives
• Introduce the chemistry underlying air pollution
• Obtain ability to carry out chemical calculations
• Understand meteorological phenomena leading to adverse air quality
• Learn about scientific instruments and measurements that quantify air pollution events
• Examine air quality data and carry out a small research project
• Think about regulatory framework and policy decisions to improve air quality

Rough Schedule and Topics that Will be Covered in Class
(NOTE: schedule could be subject to change, depending on the pace of the class and other events)

Class 1: Introduction
Class 2: Fundamental Chemistry Concepts
Class 3~4: Atmospheric composition and structure
Class 5~7: Aerosols and the wintertime particulate matter (PM) problem in Salt Lake Valley
Class 8: Lab Tour
Class 9~10: Tropospheric ozone
Class 11: U.S. Clean Air Act and state implementation plans and “exceptional events”
Class 12: Wildfires and dust
Class 13~14: Stratospheric ozone depletion ("ozone hole")
Class 15~16: Atmospheric transport and air pollution
Class 17~20: Greenhouse gases, TRAX-based observations of greenhouse gases & air quality
Class 21: Carbon cycling in the Western U.S.
Class 22: Urban greenhouse gas and pollutant emissions
Class 23: Midterm Exam
Class 24~26: Modeling of air quality; climate-air quality nexus
Class 27~29: In-class oral presentations of final projects

**Grading**

Problem Sets: 40%
Midterm Exam: 25%
Research Project: 30%
Class Participation: 5% (attendance and participation)

**Extra Credit**

Throughout the course of the semester, we will read scientific papers that illustrate the concepts introduced in class. These papers are an integral part of the course. This will be an opportunity for you to get familiar reading the “primary literature”—i.e., the papers in which new science is published. Volunteers will be solicited to present the paper to the class. Each volunteer will receive extra credit for this additional effort!

**Textbook**

- Lecture notes

**Late Policy**

Score gets halved each additional day after the deadline. For instance, if an assignment is late by 3 days, then even if it garnered a perfect 100% score, it will be marked down by a factor of $1/2^3=1/8$, or $100%/8=12.5%$.

**Center for Disability Services**

If you will need accommodations in the class, please give reasonable prior notice to the Center for Disability Services: [http://disability.utah.edu/](http://disability.utah.edu/)
Faculty and Student Responsibilities
All students are expected to maintain professional behavior in the classroom setting, according to the Student Code, spelled out in the Student Handbook. The Code prohibits cheating on tests, plagiarism, etc. Students should read the Code carefully and know they are responsible for the content.

Scheduling Accommodations:
Except in cases of sudden illness or emergency, you shall in advance of any absence arrange with the instructor to make up materials. If you miss an exam or assignment due to illness, you must provide medical documentation (i.e., letter from doctor) in order to make up missed work.

This syllabus is not a legally-binding contract. The instructor reserves the right to make modifications when the student is given reasonable advance notice.
ATMOS 3100: Atmospheric Chemistry & Air Pollution
Spring Term 2017
Class Project General Guidelines

I. Grading (% of Total Grade)
   Project proposal: 2%
   Oral Presentation to the Class: 8%
   Written Paper: 20%

II. Topic
   I ask you to carry out an independent piece of “mini-research project” based on the TRAX observations of meteorology, air quality, and greenhouse gases in the Salt Lake Valley.

   Please send me an one-pager describing your topic by the end of March. Make sure you describe the research question you are trying to answer using the TRAX data. This serves as your project proposal.

III. Project Components

   1) Project Proposal
      Send an one-page document describing your topic by the end of March. Make sure you describe the research question you are trying to answer using the TRAX data.

   2) Oral Presentation
      Prepare for an oral presentation of ~10 minutes, carried out during class time at the end of the term.

   3) Final Paper
      The final paper, with a write-up of the model changes and the analysis results, is due at the end of the term. It will have a length of ~12 pages, in total (including references, figures, tables).
Evaluator's Name:  
(names will be removed when evaluation forms are distributed to fellow students)

-----------------------------------------------------------------------------------------------------------
ATMOS 3100  Project Oral Final Presentations Evaluation Form

Name(s) of Presenter(s):  

Clarity of Delivery (1 to 2):  
• Are the ideas clearly communicated to the audience?
• Does the presenter make eye contact with the audience? Does s/he provide emphasis on important points with appropriate physical gestures or changes in voice strength or tone?
• Did the presenter clearly answer the audience's questions?

Clarity of Electronic Presentation(1 to 3):  
• Are the slides readable? easy to follow?
• Do the electronic slides help support the presentation? Or are they distracting?
• Is the progression of slides logical? Are the slides focussed on the topic of discussion?

Scientific Background (1 to 3):  
• Has enough scientific background been provided for the audience to understand the presentation?
• Do the attendant data/graphics support the statements made?
• Are the presented scientific explanations sound?
• Did the presenter provide a scientifically sound answer to the audience's questions?

General Comments:
(1) [total: 40%] Analyzing dataset of personal observations on TRAX

Since everyone took the TRAX and collected ridership data (number of people taking TRAX) in their train cars, we will analyze this dataset! The data can be found in the Excel spreadsheet entitled “TRAX_PS3_student_data_for_PS4”.

First of all, only focus on data collected between Stadium station and West Jordan City station (since everyone collected observations between those stations).

a) [8%] Average number of passengers at each station

Calculate the average number of passengers in each car, at each station along the Red Line, regardless of which hour of the day it was sampled.

Paste the table of average number of passengers at each station in your answer.

b) [8%] Diurnal cycle of ridership

Determine the average number of passengers at each hour of the day (regardless of which station). Generate a graph of the average number of passengers at different hours of the day and include it in your answer.

c) [15%] Average “removed emissions” due to transit use
Average the number of passengers at each hour of the day, across all the stations between Stadium and West Jordan City. Now, assume that these passengers would all have taken their personal vehicles and drove the same distance. How much emissions of CO₂ and NOₓ have been removed from the road by virtue of the fact that these folks took TRAX instead of driving? Clearly state the assumptions and simplifications you had to make to carry out this calculation. Name the data sources that you used to carry out this calculation (e.g., Google Maps, Wikipedia, other specific websites).

d) [9%] Other than the fact that the observations by eye used in the dataset are inaccurate, name 3 other shortcomings in the calculation in c) that would degrade the accuracy of your calculation. If you had more time and resources to improve the accuracy, how would you address the 3 shortcomings you mentioned?

(2) [total: 30%] Box Models
We saw some examples of “box models” of carbon amounts and flows in class. Now, construct your own box model of carbon in the Salt Lake Valley.
a) Draw a box model of carbon flows in the Salt Lake Valley. Use at least 7 boxes. Label the boxes and draw arrows to represent flows of carbon between the boxes. No need to put numbers on the boxes—just think about how you would select the boxes.
b) Explain what is meant by each arrow (flow of carbon between boxes). In other words, what is the physical meaning of each arrow?
Let us explore the carbon fluxes affecting atmospheric CO$_2$ levels, using the Global Carbon Atlas (http://www.globalcarbonatlas.org/). This is the same website that we examined in the computer lab.

a) [10%] Let's see how the anthropogenic emissions from different nations have changed over time. Click on the “Emissions” link on the Global Carbon Atlas, to get to the following page (http://www.globalcarbonatlas.org/?q=emissions).

Gather the CO$_2$ emissions for the following 5 political entities:
1) USA; 2) China; 3) India; 4) Russian Federation; 5) EU28

Generate a Table in which the CO$_2$ emissions of each of the 5 political entities is reported in the following two ways:
1. MtCO$_2$ per year;
2. Percentage of the total emissions from the 5 political entities (sum of emissions from USA, China, India, Russian Federation, and EU28) in a particular year contributed by each political entity above


b) [10%] We will now examine a different component of the carbon cycle—the terrestrial biospheric flux. Click on the “Research” link, and choose “Land models” to plot land fluxes. Select the CLM4CN model on the lefthand bar, which indicates output from the Community Land Model (CLM). Also choose “Monthly mean” under “Averaging period”. Choose January 2010 under “Time Period” to get the average monthly terrestrial flux for January 2010. Click “Create Map” on the top lefthand corner to generate the map.

You should get a map like this:
Next, to get a sense of the “typical” flux simulated by the model from a “representative deciduous forest” from the New England area, pick 2 gridcells to the west of Boston, MA. (This would be the gridcell in Central Massachusetts, between the cities of Springfield and Worcester).

To facilitate this, you can export the result to a KMZ file, which can be opened in Google Earth. See screenshot above (top righthand corner of screenshot) for how to export KMZs (“Export to kmz”).

If this carbon flux from Jan 2010 in this gridcell is representative of the ENTIRE U.S. and for the ENTIRE YEAR, what would the flux be? Convert the flux to Mt CO₂/year. Compare that number against total U.S. Emissions in 2010, in a).

Note: the units are in gC/m²/year, so you need to account for the differences in molecular mass between C (molecular mass=12) and CO₂ (molecular mass =44).

c) [10%] Do the same calculation as in b), but choose July 2010—also for the same gridcell.
Problem Set #3
Due Date: Thursday, March 23rd, 2017

(1) [total: 36%] We compare here some features of the Chapman mechanism at 20 km and 45 km altitude. Adopt temperatures of 200 K at 20 km altitude and 270 K at 45 km altitude. The reactions in the Chapman mechanism are:

\begin{align*}
O_2 + h & \rightarrow O + O \quad \text{(R1)} \\
O + O_2 + M & \rightarrow O_3 + M \quad \text{(R2)} \\
O_3 + h & \rightarrow O_2 + O \quad \text{(R3)} \\
O_3 + O & \rightarrow 2O_2 \quad \text{(R4)}
\end{align*}

with rate constants:

\begin{align*}
k_2 &= 1 \times 10^{-33} \text{ cm}^6 \text{ molecule}^{-2} \text{ s}^{-1} \\
 k_3 &= 1 \times 10^{-10} \text{ s}^{-1} \\
 k_4 &= 8.0 \times 10^{-12} \exp(-2060/T) \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}
\end{align*}

where \( T \) is temperature

a) [6%] What is the air density [molecules/cm\(^3\)] at 20 km and 45 km? Apply the Barometric Law, with a scale height of 7 km.

b) [6%] Determine an expression for the chemical lifetime (\( \tau \)) of O atom, based on R2. We neglect R4 here because R4 is much slower than R2.

c) [6%] Calculate the lifetime of the O atom at 20 km and 45 km altitude. HINT: make use of your answers in a). Can the O atom be assumed in chemical steady state throughout the stratosphere?

d) [6%] Assuming steady state for O atoms, calculate the ratio \([O]/[O_3]\) at 20 km and 45 km altitude. Can we assume \([O_3][O_3] \approx [O] [O]\) throughout the stratosphere?

e) [6%] Show that the mass balance equation for odd oxygen (\( O_x = O_3 + O \)), ignoring transport terms, can be written:

\[
\frac{d[O_x]}{dt} = \frac{2}{\text{P}} - \frac{k[O_x]}{\text{P}^2}
\]

where \( \text{P} = 2k_1[O_2] \) is the \( O_x \) production rate and \( k = 2k_3k_4 / k_2 C_{O_2} n_a \)

\( C_{O_2} \) is the \( O_2 \) mole fraction; \( n_a \) is the air density
f) [6%] Express the lifetime of O₅ as a function of k and [O₅]. If 
[O₅]=3.0×10^{12} \text{ molecules cm}^{-3} \text{ at 20 km and } [O₅]=0.25×10^{12} \text{ molecules cm}^{-3} \text{ at 45 km, calculate the lifetime of O₅ at 20 km and 45 km altitude.}

(2) [total: 28%]
When researchers are determining how solar and terrestrial radiation affect the atmosphere's temperature profile, they divide the atmosphere up into many layers, each with its own properties (that depend on the mixture of gases). In Lecture #7, we examined the energy balance for the case with only a single atmospheric layer. In this problem, we examine another simplified case, where there are only 2 atmospheric layers. Assume radiative equilibrium. Similar to the example in class, we assume that the atmosphere does not absorb solar radiation (mostly in the visible wavelengths), but both atmospheric layers absorb terrestrial radiation (mostly in the infrared) completely. The following is a figure of this model:

Values of constants:
Planetary albedo (αₚ) = 0.3; Solar constant S₀ = 1367 W/m²;
Stefan-Boltzmann constant (σ) = 5.67 \times 10^{-8} \text{ W m}^{-2}\text{K}^{-4}

a) [7%] What is Tₑ, the emission temperature?
b) [7%] What is $T_a$, the temperature of the first atmospheric layer?

c) [7%] What is $T_b$, the temperature of the second atmospheric layer?

d) [7%] What is $T_s$, the temperature of the surface?

(3) TRAX red line experience [36%]
This is a special kind of “assignment”, in which you are asked to take the TRAX red line and experience light rail. This experience will hopefully help you interpret the TRAX-based air quality observations and give you ideas about what to do for your class project.

NOTE: All full-time students at the University of Utah should be able to take the TRAX for free using your U-card. Remember to tap on when you get on the train platform before your board the train, and tap off on the platform after you hop off the train.

Fill out the worksheet following the first page of instructions. Specifically, I ask you to make note of the following as the train makes its way through Salt Lake Valley:

1. time (in HH:MM format)
2. number of people in the train car
3. elevation
4. busyness of traffic
5. surrounding buildings and landscape

Remember to also answer the following questions on the last page:

a) What do you like about taking TRAX?

b) What do you NOT like about the TRAX experience?

c) Are you taking TRAX on a regular basis?

d) If not taking TRAX on regular basis, what would convince you to take TRAX more regularly?
Experience the Utah Transit Authority's “TRAX” light rail system on the Red Line and make some observations along the way!
You only need to fill out the worksheet in a single direction. Start at your ride from one of the stations on the University of Utah campus of your choosing: University Medical Center, Fort Douglas, University South Campus, or Stadium station. Ride it all the way to West Jordan City Center. For extra credit (additional 10%), go all the way to the last stop of the red line (Daybreak), and inI ask you to make note of the following as the train makes its way through Salt Lake Valley:
   (1) time (in HH:MM format)
   (2) number of people in the train car
   (3) elevation
   (4) busyness of traffic
surrounding buildings and landscape clude a picture FROM YOUR OWN CAMERA (or smartphone) of the Daybreak TRAX station to the problem set submission.

Budget ~60 minutes for a roundtrip ride to West Jordan City Center from the Univ. of Utah campus, and 2 hours for an one-way ride to Daybreak (if you are going for extra credit).

The route map (also included as Appendix) and schedule are available at:  

Bon Voyage!

*NOTE: All full-time students at the University of Utah should be able to take the TRAX for free using your U-card. Remember to tap on when you get on the train platform before your board the train, and tap off on the platform after you hop off the train.*
Start your trip from one of the stations on the Univ. of Utah campus below:

<table>
<thead>
<tr>
<th>Time (HH:MM)</th>
<th># of People in Train Car</th>
<th>Elevation of station relative to bottom of Salt Lake Valley (high, medium, low)</th>
<th>How Busy is Traffic Around Station?</th>
<th>Describe Surrounding Buildings &amp; Landscape</th>
</tr>
</thead>
<tbody>
<tr>
<td>University Medical Center</td>
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<tr>
<td>Fort Douglas</td>
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<tr>
<td>University South Campus</td>
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<td>Stadium</td>
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<td>900 East</td>
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<td>Library</td>
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<td>Courthouse</td>
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<tr>
<td>Ballpark</td>
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<tr>
<td>Central Pointe</td>
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<tr>
<td>Meadowbrook</td>
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<tr>
<td>Murray Central</td>
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<tr>
<td>Fashion Place West</td>
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<td></td>
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<tr>
<td>Bingham Junction</td>
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<tr>
<td>West Jordan City Center</td>
<td></td>
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<tr>
<td>5600 W. Old Bingham Highway</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daybreak Parkway</td>
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</tr>
</tbody>
</table>

Bonus: ride all the way to the last stop.
Fill out two additional stations until the end of the Red Line, to the "Daybreak Parkway" station. Budget an additional 30 minutes, one-way.
What do you like about taking TRAX?

What do you not like about the TRAX experience?

Are you taking TRAX on a regular basis?

If not taking TRAX on regular basis, what would convince you to take TRAX more regularly?
Computer Lab: Spatiotemporal patterns of greenhouse gases and air pollutants across Salt Lake City, UT observed from the TRAX light rail train.

In this computer lab we will investigate the spatiotemporal patterns of carbon dioxide (CO₂), methane (CH₄), particulate matter (PM₂.₅), and ozone (O₃) across Salt Lake City, UT, using data that was collected with instruments mounted on top of a TRAX light rail car.

**NOTE:** These data are unpublished, so please do not distribute them outside of the class.

The TRAX project had a pilot phase in August 2014 (those data are not included here) and the main project began in December 2014. The data are in a raw state and have not been fully calibrated, however they are good enough to do initial analyses on for the purposes of our class.

The trains run most days and you can take a look at the real-time data on these websites:

- [https://air.utah.edu](https://air.utah.edu)
- [http://meso1.chpc.utah.edu/mesotrax/](http://meso1.chpc.utah.edu/mesotrax/)

Take a look at these websites in your free time, or if you are ahead of the group during the lab.

**1.) Getting set up**

We will be using R to analyze this data and plot it in Google Earth. We’ll be working in the Documents folder, but if you want to put the data in another folder you can (just remember where you put it!).

First, download the data file from CANVAS. Now, open the Finder and click on your Documents folder, then go to your Downloads and open the zip file, then drag the contents to your Documents folder.

Now, in Finder, open the Documents folder, right-click on the “TRAX_CANVAS.r” file and select “Open With -> R”. (If you double clicked it, the file will open in a different application, so just go back and try again.) This is the R script that we will be using to analyze and plot the data.

Once we’re all at this point we can proceed. If you get here first, help your neighbor!

**2.) Plotting the CO₂ annual average**

In the R code, set the starting and ending dates to ‘2014-12-01’ and ‘2015-11-30’ (lines 12 & 13). They should look like this:

```r
  t_start <- as.Date('2014-12-01', tz='MST')
  t_end   <- as.Date('2015-11-30', tz='MST')
```

Also make sure the species is set to ‘co2’ (line 23), and the train line is set to ‘rd’ (Red) (line 27).
species <- 'co2'
line <- 'rd'

Once you have checked these lines, select all of the code (command-A) and press (command-return). (command-return) executes the selected code in R.

A couple of windows will open up. One is a Timeseries plot showing you all of the data that has been plotted. This is a nice way to do a sanity check to make sure the correct data has been selected. The other window that pops up is in Safari. This shows you a map of Salt Lake City with the data plotted on it with color representing the concentration levels. This is a really useful display, but Google Earth is cooler (I think).

Now use the Finder to go to the Documents folder and you will see a new folder called “Output”. Open this folder and you will see a KMZ file with a filename like “TRAX_rd_co2_2014-12-09...kmz”. Right click on this file and select “Open With -> Google Earth”. This should display the CO2 annual average in Google Earth along the TRAX Red line!

In Google Earth you use the mouse wheel to zoom in and out and the compass navigation in the upper right hand corner to change the direction you are looking.

Go back to R and in the code, change the train line to ‘gr’ (line 27)

line <- 'gr'

and run the code again by selecting all (command-A) and then executing it (command-return).

In Finder a new KMZ file will be created. Right click on this one and open it in Google Earth. Now you should be looking at the CO2 annual average from both the red and green TRAX train lines.

Questions: What are the sources of CO2 that you can identify? Are there any sinks that you can see? What about the transport?

3.) Plotting the O3 summertime average

Go back to the code and change the species to ‘OZNE’ (line 23) and then set the date range to be during the summer, from '2015-05-01' to '2015-09-30' (lines12-13).

t_start <- as.Date('2015-05-01', tz='MST')
t_end <- as.Date('2015-09-30', tz='MST')

species <- 'OZNE'

Run the code for the Red line:

line <- 'rd'

and then run it again for the Green train line:

line <- 'gr'

Now, in Finder, open the two new KMZ files that you just created in Google Earth. In Google Earth, click the checkmark next to the CO2 kmz files that you were just looking at. This hides them from view so you can look at the new ones.

Questions: What are the sources of O3 that you can identify? What are the sinks that you can see? How does transport affect the summertime average?
4.) Plotting PM$_{2.5}$ during a wintertime persistent cold air pool (PCAP, aka “inversion”)

Go back to the code and change the species to ‘PM25’, the train line to ‘rd’, and the date range to a 4-day period during a wintertime persistent cold air pool (aka inversion), from ‘2015-01-08’ to ‘2015-01-11’.

```r
t_start <- as.Date('2015-01-08', tz='MST')
t_end <- as.Date('2015-01-11', tz='MST')
species <- 'PM25'
line <- 'rd'
```

The train was only on the Red line during this time period, so there is no data from the Green train line. Now open open this KMZ to look at the spatiotemporal average.

**Questions:** What is the National Ambient Air Quality Standard (NAAQS) for PM$_{2.5}$ currently for a 24-hour period? What is the spatial extent of the area in violation of NAAQS? How did sources, sinks, and transport affect the spatial pattern of PM$_{2.5}$ during this persistent cold air pool? What about topography? If you were going to open a retirement home for older folks who might be sensitive to air pollution, where would you put it?

5.) Plotting the CH$_4$ (methane) annual average

Go back to the code and change the species to ‘ch4’, use the same date range as you did for CO$_2$ (above), and run the code for both the Red and Green lines.

```r
t_start <- as.Date('2014-12-01', tz='MST')
t_end <- as.Date('2015-11-30', tz='MST')
species <- 'ch4'
line <- 'rd'
```

and run it again for the Green train line:

```r
line <- 'gr'
```

**Questions:** What were the sources, sinks, and transport that affected CH$_4$? Are there any facilities near the CH$_4$ plumes that might be responsible for the CH$_4$ plume?

6.) Examine only a select range of hours

Next we can select the data from a few hours of the day, averaged across a lot of days. Let’s start with the annual average CO$_2$ on the Red line (use the same settings as above). Then, uncomment the code on line 16. To uncomment the line, all you have to do is remove the pound sign ('#') so it looks like this:

```r
HHsel<-(12,13,14)  #select subset of hours
```

You should also change the color scale. Do this by changing the range from 410-450 to 410-470. The line of code should look like this:

```r
'co2'  = c(410, 470),  #[ppm]
```
Now run the code for both the Red and Green train lines. The KMZs that are produced will show you the average CO2 during the hours of 12, 13, and 14 (i.e., the middle of the day). Next, re-comment line 16 (by replacing the ‘#’ at the beginning of the line) and uncomment line 17 and re-run the code for both the Green and Red train lines. This will show you the data averaged during hours 20-22 (8pm-10pm).

What causes the differences between CO2 in the middle of the day vs. the evening?

Finally, do this same exercise for O3. Adjust the date range according to look at the summer and the color scale from 27-45 ppb to 18-55 ppb (line 40). How is the spatial pattern of O3 different during the day vs the evening? What causes this difference?

7.) Play around with the data!

Change the dates, the species, and the train lines as you see fit. Can you find anything interesting in the data?