ESS C113/213: Homework 2
Due Jan. 26, 2018

1. Tropospheric Ozone
In the LA Basin and other urban areas, ozone forms mainly from the reaction of NO_2 with sunlight, and its concentration is determined by a steady-state reaction relationship between NO, NO_2 and O_2:

$$NO_2 + O_2 \leftarrow\rightarrow NO + O_3$$

Seinfeld (1989) proposed a relationship to estimate the equilibrium abundance of O_3 in such environments:

$$O_3 \text{ (ppmv)} = 0.021\ [NO_2]/[NO]$$

a) Use this relationship to estimate the abundance of ozone when 18 ppbv NO_2 and 15 ppbv NO are present (ppbv = parts per billion by volume; ppmv = parts per million by volume).

b) Convert this abundance to the Air Quality Index (AQI) scale (http://airnow.gov/index.cfm?action=resources.conc_aqi_calc), assuming a constant abundance over an 8-hour period.

c) How much ozone would be enough to trigger a "red" or "unhealthy" air quality?

d) Find the current ground-level ozone AQI for Los Angeles, and convert it to ppm Ozone. You can find this data online at http://www.airnow.gov, or at our local air quality management district's site (http://www3.aqmd.gov/webappl/aqdetail/AirQualityParameterData.aspx?Stationid=70091&AreaNumber=2&res=1280; click on the "Historical Data" button). Please note the date of the observation, and its location (i.e., Santa Monica, LA inland, Northwest Coastal L.A. County, San Bernardino, etc.).

e) According to Schlesinger, figure 3.10, what (roughly) would the ozone concentration be in a forested area during the growing season, if NO_2 = 18 ppbv, NO = 15 ppbv, and the total of all other reactive nitrogen species is 4 ppbv? Why is this different from urban air?

2. CFC's and Stratospheric Ozone

We learned in class that enough air moves from the troposphere to the stratosphere each year to replace about 75% of the stratosphere's mass, indicating a mean residence time of 4/3 years for air in the stratosphere (this is an oversimplification because the upper stratosphere doesn't mix very well with the lower stratosphere, but let's keep things simple for now).

a) Given that the troposphere has 4 times the mass of the stratosphere, what is the mean residence time of air in the troposphere?

The widespread use and release of chlorofluorocarbons into the atmosphere has led to the rapid seasonal loss of ozone in the stratosphere. This follows, at least in part, from the inertness of CFC molecules in the troposphere. Freon-11 ($CFCl_3$) has a mean atmospheric lifetime of about 52 years. This means that:

$$dF/dt \approx -(1/52)F \quad \text{(in per-year units)}$$

where "F" is the molecular abundance of $CFCl_3$.

b) Show that the expression:

$$F(t) = F_{initial}\, e^{-t/52}$$

is a solution to this differential equation.

c) If your (hypothetical, obsolete) refrigerator springs a tiny leak and releases 1000 molecules of Freon-11, how many will survive 5 years to enter the stratosphere at least once?

Production of CFC's was essentially ended in the 1990's by the Montreal Protocol (http://en.wikipedia.org/wiki/Montreal_Protocol; you don't have to read it, this link is just for kicks). Assume that production and release stopped completely by 1995 (see Fig. 1).

d) On Fig. 1b, plot the expected trend in CFC-11 concentration from 1995 to 2015, if production stopped completely in 1995. Does the trend match observed concentrations?

e) Given the mean lifetime of CFC-11 in the atmosphere, and assuming production ceased in 1995, in what year will is concentration expected to fall below its average 1978 abundance?

f) (Graduate students only) In reality, the release of CFC-11 has continued even after production ceased, because of ongoing leaks, especially from old foam that was manufactured using CFCs as the "blowing agent" to inflate the foam bubbles, and from old air conditioning and refrigeration equipment (https://unfccc.int/files/methods/other_methodological_issues/interactions_with_ozone_layer/application/pdf/cfc1100.pdf). This means that CFC-11 is still being added to the air, i.e., $dF/dt \approx -(1/52)F + S$, where S is the rate of release to air. Because $S > 0$, CFC concentrations will not decline as quickly as predicted by the simper decay equation from (a) and (b) above. If we assume that S is constant, show that the following expression is a solution to the new differential equation:

$$F(t) = (52)(S)(1 - e^{-t/52}) + F_{initial}\, e^{-t/52}$$

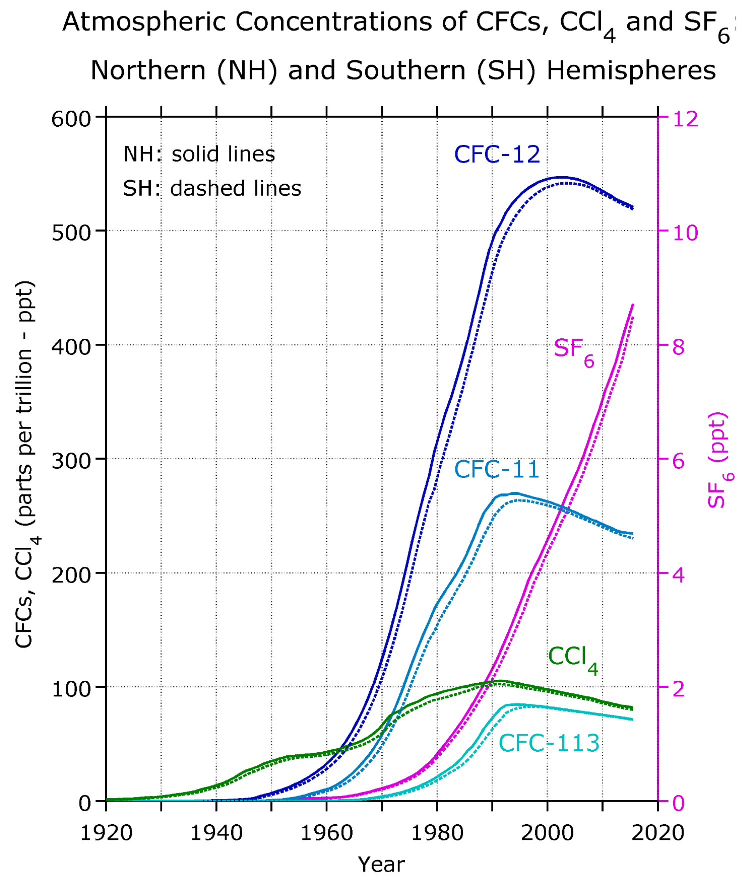

Figure 1. Concentrations of $CFCl_3$ in air. a) historical concentrations in the southern (dashed) and northern (solid) hemispheres, in pptv. Data from the "Atmospheric CFC, CCl4, and SF6 Historical Update" (Bullister, 2015); http://cdiac.ornl.gov/oceans/new_atmCFC.html
b) recent globally averaged concentrations (1978-2015). Data set from NOAA Earth System Research Laboratory Global Monitoring Division. http://www.esrl.noaa.gov/gmd/hats/combined/CFC11.html