OCN/ESS/ATM S 588 Global Carbon Cycle and Greenhouse Gases
Problem Set 1 – due in class on January 20, 2008

1. Global climate forcing: past and future

In this exercise you will examine the past and future evolution of greenhouse gases and calculate their associated radiative forcings. You can do this exercise using Excel, MatLab or any program that you are familiar with. Two files (greenhouse_gases_1850-2006 and future_gases_2000_2100) contain tabulated values for observed greenhouse gas concentrations between 1850 and 2000 (based on ice-core and atmospheric observations) and projections to 2100 (for a 'middle of the road' IPCC scenario A1B). These files are available on the course web site in Excel (.xls), text (.txt) , or Matlab (*.m) formats. Download your favorite format.

a) Generate a plot for each well-mixed greenhouse gas (CO_2, CH_4, N_2O, CFC-11, CFC-12) showing the observed and predicted concentrations between 1850 and 2100 based on the A1B IPCC scenario.

b) Table 1 below presents greenhouse radiative forcings (in W/m^2) for a given change in mixing ratios. In the case of CFC-11, for example, F = 0.264(x-x_0) where x is the current CFC-11 mixing ratio in ppbv (see note at the end of the problem set on mixing ratios) and x_0 is the mixing ratio of CFC-11 at some point in the past.

Table 1. Greenhouse gas radiative forcings

Gas	Radiative forcing
CO_2	$F = f(c) - f(c_o)$, where $f(c) = 4.996 \ln(c + 0.0005c^2)$
CH_4	$F = 0.0406(\sqrt{m} - \sqrt{m_o}) - [g(m, n_o) - g(m_o, n_o)]$
N_2O	$F = 0.136(\sqrt{n} - \sqrt{n_o}) - [g(m_o, n) - g(m_o, n_o)]$, where $g(m, n) = 0.5 \ln[1 + 2 \times 10^{-5}(mn)^{0.75}]$
CFC-11	$F = 0.264(x - x_o)$
CFC-12	$F = 0.323(y - y_o)$

c, CO_2 (ppm); m, CH_4 (ppb); n, N_2O (ppb); x/y, CFC-11/12 (ppb).

[Table from Hansen et al., PNAS, vol. 97 (18), 9875-9880, 2000]

Use the functions in Table 1 to calculate the radiative forcing in W/m^2 associated with a 1% change (relative to 2000 concentrations) in the concentrations of CO_2, CH_4, N_2O, CFC-11 ($CFCl_3$) and CFC-12 (CF_2Cl_2).

c) A useful index to evaluate the radiative impact of increasing greenhouse gas X is the *greenhouse efficiency*, a_x. It is defined as the radiative forcing of greenhouse gas X normalized per unit molecule change divided by the radiative forcing of CO_2 per unit molecule change:

$$a_x = (\Delta F_x/\Delta[X])/(\Delta F_{co2}/\Delta[CO_2])$$

where ΔF_x is the radiative forcing associated with a change Δ[X] in the mixing ratio of greenhouse gas X (in ppbv). Calculate the greenhouse efficiencies of CH_4, N_2O, CFC-11 and

CFC-12 based on the radiative forcing associated with a 1% increase in their concentrations that you calculated in A). Comment on the values you obtain.

d) Use the functions in Table 1 to calculate the radiative forcing for year 2005 (relative to year 1850) associated with the observed concentrations of well-mixed greenhouse gases CO_2, CH_4, N_2O, CFC-11 and CFC-12. Compare to the values from the IPCC's technical summary (Figure TS.5).

e) On a single page, make a plot showing all the individual forcings (using 1850 as the reference year) of these greenhouse gases starting in 1850 until 2100. Comment on the trends you obtain.

f) Do you agree with the statement that non-CO_2 greenhouse gases have been the primary drivers for climate change throughout most of the 20^{th} century? Explain. Does this statement apply for climate change in the 21^{th} century?

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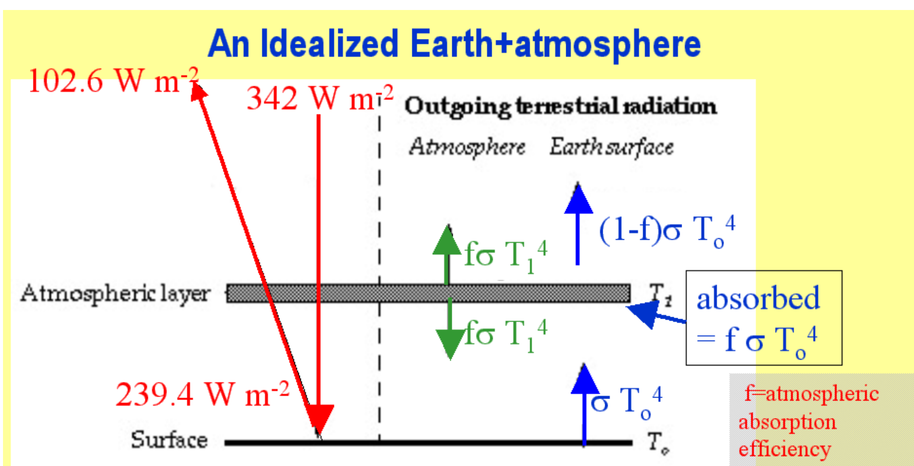
2. Layer model for the atmosphere

a) Consider the simple 1-layer model of the Earth's atmosphere that we used in class. In this model, the atmospheric layer is transparent to solar radiation and absorbs a fraction f = 0.77 of terrestrial radiation. Calculate the temperature of the surface T_0 and the atmosphere T_1. (see class notes for all the input variables). $\sigma = 5.67 \times 10^{-8}$ W m^{-2} T^{-4}



b) If the 1 layer model above represents the preindustrial (1850) atmosphere, how do the temperatures T_0 and T_1 change with a 3 W m^{-2} greenhouse gas radiative forcing estimated by the IPCC (*hint: first solve for Δf assuming no initial change in temperature*). Is this consistent with the observed temperature increase (look at figure TS.6 in the IPCC technical summary)? How would you make the calculation more realistic?

Note on mixing ratios: The mixing ratio C_x of a gas X is defined as the number of moles of X per mole of air. It is given in units of mol/mol, or equivalently in units of v/v (volume of gas per volume of air) since the volume occupied by an ideal gas is proportional to the number of molecules. Mixing ratios of trace gases are typically given in units of parts per million volume (*ppmv* or simply *ppm*), parts per billion volume (*ppbv* or *ppb*), or parts per trillion volume (*pptv* or *ppt*); 1 ppm = 10^{-6} mol/mol; 1 ppb = 10^{-9} mol/mol; 1 ppt = 10^{-12} mol/mol.