Exercise 1:

General questions/short exercises:

a) **(3points)** Are the following loss processes first-order?

A. Uptake of CO2 by the biosphere
B. Photolysis of gases in the stratosphere
C. Scavenging of aerosol particles by precipitation

b) **(3points)** Consider a 2-box model with the two boxes being the troposphere (1000-150 hPa) and the stratosphere (150-1 hPa). The lifetime of air in the stratosphere is 2 years. What is roughly the lifetime of air in the troposphere?

c.) **(3points)** If the Earth were twice its distance from the Sun, by how much would its effective temperature decrease?

d.) **(3points)** A chemical species is removed from the atmosphere by chemical reaction with a lifetime of 2 years, and by deposition with a lifetime of 6 months. What is its atmospheric lifetime?

Exercise 2:

Briefly comment on following statements: (true, not true, explain why?)

a). **(3points)** The equilibrium temperature of Venus is lower than that of Earth, even though Venus is nearer to the sun.

b) **(3points)** Mixing ratios of CO2, krypton-85, and other gases emitted mainly in the northern hemisphere DECREASE with altitude in the northern hemisphere but INCREASE with altitude in the southern hemisphere.

c) **(3points)** The presence of a cloud cover tends to favor lower daytime temperatures and higher nighttime temperatures.

d.) **(3points)** The colors of stars are related to their temperatures whereas the colors of the planets are not.

e.) **(3points)** Low clouds emit more longwave radiation than high clouds of comparable thickness.

f.) **(3points)** On a clear, still night (other factors being the same) the surface temperature drops more rapidly when the air above is dry than when it is moist, even before dew begins to form.

g.) **(3points)** Pressure in the atmosphere increases approximately exponentially with depth, whereas the pressure in the ocean increases approximately linearly with depth.

Exercise 3:

Consider a simplified planet-atmosphere system where a thin atmospheric layer is at some distance from the surface of the planet. The albedo of the planet's surface is A. The surface perfectly absorbs infrared (longwave) radiation; i.e. it can be considered a blackbody in this wavelength region. There is no scattering of sunlight in the atmosphere, so the albedo of the atmosphere by itself is 0. The transmissivity of the atmosphere is τ_s for sunlight and τ_i for infrared radiation. The average incident solar radiation per surface area of the planet is Q. (For clarification: of the incident radiation Q the fraction $\tau_s Q$ is transmitted through the atmosphere, and the fraction $(1-\tau_s)Q$ is absorbed.)

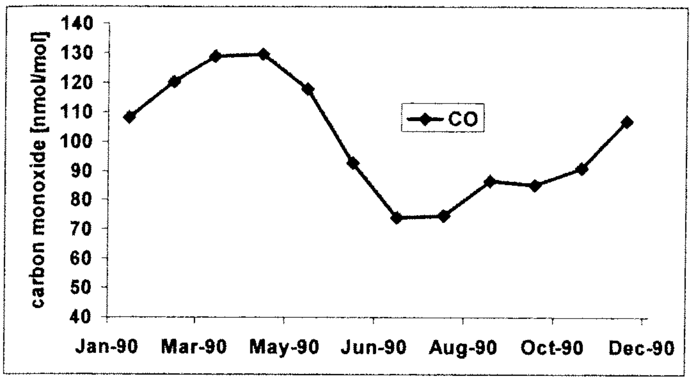
a) **(16points)** Show that the surface temperature T_0 of the planet is given by following relation:

$$\sigma T_0^4 = Q\left[\frac{1+\tau_s}{1+\tau_i}\right](1-\tau_s A)$$

b) **(6points)** Using the relation above show that for some choices of τ_s, τ_i, and A the surface temperature is lower than the equilibrium temperature T_E of the planet. (This would be a sort of negative greenhouse effect).

Exercise 4: Lifetime of carbon monoxide

For the year 1990 the Dutch based Emission Database for Global Atmospheric Research (EDGAR, www.rivm.nl/edgar) estimated a global emission of carbon monoxide of 974 Tg due to anthropogenic activity. You may assume that all these emissions occur in the Northern hemisphere and that there is no seasonal variation in the source strength. The Figure gives monthly average CO mixing ratios for 1990 at the Manua Loa observatory in Hawaii. The observatory is at a remote location in the Pacific Ocean and the mixing ratios can be regarded to be representative for the northern hemisphere. The graph shows a strong seasonal variation of CO. The main reason for this is that the atmospheric lifetime of CO changes in the course of the year. To keep the example simple, do not consider any exchange between the Northern and the Southern hemisphere. You may assume that the northern hemisphere is a well mixed box and that the system is in steady state.



1) **(5points)** Before you start calculating, answer following questions: How is lifetime defined? How is steady state defined? What is the monthly anthropogenic emission rate of CO during summer and winter?

2) **(5points)** Calculate the atmospheric inventory of CO during summer (use the minimum mixing ratio of Fig 1) and in winter (use the maximum mixing ratio of Fig 1).

3) **(5points)** Assuming steady state and no natural sources of CO what would you estimate to be the lifetime of CO in summer and in winter? Is the steady state assumption justified?

4) **(5points)** There are also large natural sources of CO, mostly coming from the photochemical degradation of methane and biogenic hydrocarbons (isoprene, and monoterpenes). The natural source of CO is about 1000 Tg/year in the Northern hemisphere, but it is stronger during summer (~160 Tg/month) than during winter (~40 Tg/month). Refine your estimate of the CO lifetime during summer and winter. Is the steady state assumption justified?

{*useful quantities:* molecular weights: carbon 12 g/mol, oxygen 16 g/mol, dry air 28.96 g/mol; mass of atmosphere: 5.2E18 kg; mean surface pressure: 984 hPa; Earth's radius: 6371 km, surface area of a sphere $A=4r^2\pi$}

Exercise 5:

It has been suggested hat hydrogen in the Earth's primitive atmosphere led to the production of CH_4 by the reaction

$$CO_2(g) + 4H_2(g) \xleftrightarrow{k_{eq}} CH_4(g) + 2H_2O(g)$$

a) **(10 points)** The equilibrium constants k_{eq} for this reaction at 300 and 400 K are 5.2 x 10^{19} and 2.7 x 10^{12} bar^{-2}, respectively. If the partial pressures of H_2O, CO_2, and H_2 in the primitive atmosphere were taken to be 3.0 x 10^{-2}, 3 x 10^{-4}, and 5.0 x 10^{-5} bar, respectively, what are the equilibrium pressures of CH_4 at 300 and 400 K?

b) **(5points)** The equilibrium constants k_{eq}=$k_{forward}$/$k_{backward}$. At 400 K $k_{forward}$ is large, but at 300 K it is immeasurably small. Is it likely that this reaction was responsible for the conversion of much H_2 into CH_4 in the primitive atmosphere? Why, or why not?

Exercise 6

(10 points) In the year 2000 a total amount of 8.5x10^{12} kg of fossil fuels has been burned. Assuming that 50% of the emitted CO_2 accumulates in the atmosphere, what is the averaged increase of the CO_2 mixing ratio (in ppm) in the atmosphere? Assume that 80% of the weight of fossil fuels is carbon; the molecular weights of C, O, and air are 12, 16, and 29 g/mol respectively. (Mass of atmosphere: 5.2E18 kg)