PROBLEMS

7. 1 Climate response to changes in ozone

Simulations with a general circulation model (GCM) have been used to investigate the climate sensitivity to large changes in atmospheric ozone. Explain qualitatively the results below.

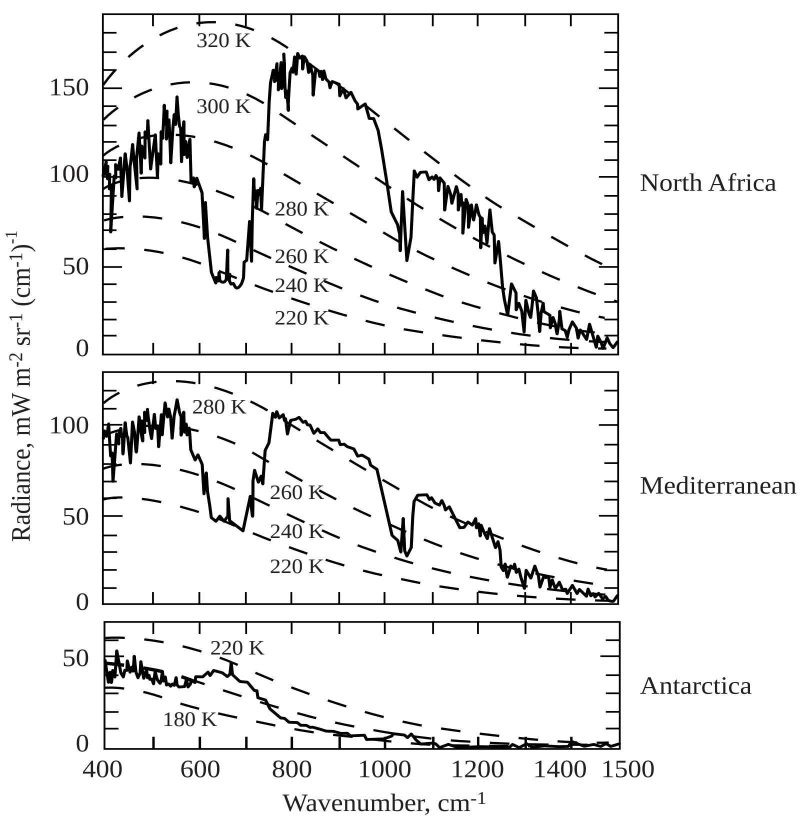
1. A simulation in which all O_3 above 30 km altitude is removed shows a large tropospheric warming (+1-3^{o}C) and a very large stratospheric cooling (up to -80^{o}C).

2. A simulation where all O_3 in the upper troposphere is removed shows a 1^{o}C cooling of the Earth's surface, while a simulation where the same amount of O_3 is removed but in the lower troposphere shows no significant temperature change.

[Source: Hansen, J., et al., Radiative forcing and climate response, *J. Geophys. Res.*, *102*, 6831-6864, 1997.]

7. 2 Interpretation of the terrestrial radiation spectrum

The Figure below shows terrestrial emission spectra measured from a satellite over northern Africa, the Mediterranean Sea, and and Antarctica. The spectra are reported as a function of wavenumber, which is the inverse of wavelength.



1. Estimate from the spectra the surface temperature of each region.

2. Explain the dips at 600-700 cm^{-1} (14-16 μm) and 1000-1050 cm^{-1} (9.5-10 μm) in the emission spectra for the Sahara and Mediterranean Sea. Why do these dips become bumps in the emission spectrum for Antarctica?

7. 3 Jupiter and Mars

1. Jupiter is 7.8×10^8 km from the Sun. Its albedo is 0.73.

1.1 Calculate the effective temperature of Jupiter assuming that the Sun is the only energy source.

1.2 Observations indicate an effective temperature for Jupiter of 134 K. This temperature is maintained in part by heat from gravitational accretion and chemical reactions within the planet. How does the magnitude of Jupiter's internal heat source compare to the source from solar radiation?

2. Mars is 2.3×10^8 km away from the Sun; its albedo is 0.15. Its only source of heat is solar radiation.

2.1. Calculate the effective temperature of Mars.

2.2. The temperature observed at the surface of Mars is 220 K. What do you conclude about the Martian atmosphere?

7. 4 The "faint Sun" problem

Sedimentary deposits in rocks show that liquid water was present on Earth as early as 3.8 billion years ago, when solar radiation was 25% less than today according to current models of the evolution of the Sun. Consider the simple greenhouse model described in this chapter where the atmosphere is represented as a thin layer transparent to solar radiation and absorbing a fraction f of terrestrial radiation. Assume throughout this problem a constant planetary albedo A = 0.28 for the Earth.

1. If the greenhouse effect 3.8 billion years ago were the same as today (f = 0.77), what would be the surface temperature of the Earth? Would liquid water be present?

2. Current thinking is that a stronger greenhouse effect offset the weaker Sun.
Let us try to simulate this stronger greenhouse effect by keeping our 1-layer model for the atmosphere but assuming that the atmospheric layer absorbs 100% of terrestrial radiation. Calculate the resulting surface temperature. What do you conclude?

3. We can modify our model to produce a warmer surface temperature by representing the atmosphere as *two* superimposed layers, both transparent to solar radiation and both absorbing 100% of terrestrial radiation. Provide a physical justification for this 2-layer model. Calculate the resulting surface temperature.

4. It has been proposed that the strong greenhouse effect in the early Earth could have resulted from accumulation in the atmosphere of CO_2 emitted by volcanoes. Imagine an Earth initially covered by ice. Explain why volcanic CO_2 would accumulate in the atmosphere under such conditions, eventually thawing the Earth.

[To know more: Caldeira, K., and J.F. Kasting, Susceptibility of the early Earth to irreversible glaciation caused by carbon dioxide clouds, *Nature, 359,* 226-228, 1992.]

7. 5 Planetary skin

Consider a two-layer model for the Earth's atmosphere including:

- a "main" atmospheric layer of temperature T_{main} that is transparent to solar radiation and absorbs a fraction $f = 0.77$ of terrestrial radiation;
- a "thin" atmospheric layer of temperature T_{thin} above this main layer that is transparent to solar radiation and absorbs a small fraction $f' << 1$ of terrestrial radiation. This layer is often called the "planetary skin".

Calculate the temperature T_{thin}. This temperature represents the coldest temperature achievable in the Earth's atmosphere in the absence of absorption of solar radiation by gas molecules. Explain briefly why.

7. 6 Absorption in the atmospheric window

The water vapor dimer absorbs radiation in the 8-12 μm atmospheric window. The resulting optical depth for an elemental atmospheric column of thickness dz is $d\delta = k\rho dz$, where ρ is the mass density of air and $k = 1\text{x}10^{-11}P^2_{H2O}$ m^2 per kg of air is an absorption coefficient for the water vapor dimer; P_{H2O} is the water vapor pressure in Pascals.

1. Explain why k varies as the *square* of the water vapor pressure.

2. Assuming a scale height of 4 km for the water vapor *mixing ratio*, a surface air density ρ_o of 1.2 kg m^{-3}, and $p_o = 1\text{x}10^3$ Pa for the water vapor pressure in surface air, calculate the total optical depth from absorption by the water vapor dimer. How efficient is the dimer at absorbing radiation in the 8-12 μm window?