

Answers to questions test 1 Climate Dynamics 18 April 2011.

Problem 1

(a) All gases that absorb radiation also emit radiation. Only those that absorb in the long-wave spectral interval are called greenhouse gases.

According to the figure, this is the case for all 6 constituents that are shown, i.e. water vapour, carbon dioxide, oxygen and ozone, methane and nitrous oxide.

(b) The atmospheric window is found in the wavelength-interval 8-13 micrometres.

Problem 2

(a) The climate of the Netherlands if the obliquity were equal to zero would be devoid of seasons, with constant daily mean temperatures somewhere in between the normal temperatures observed at present in March and September.

Problem 3

(a) The precipitable water, PW , is found by integrating the equation for ρ_v from the bottom to the top of the atmosphere (at $p=0$). This yields

$$PW = \rho_{v,g} H_v = 0.024 \times 3000 = 72 \text{ Kg m}^{-2}.$$

(b) This water vapour is coming from evaporation over the subtropical Indian Ocean and transported to India by the trade winds. The trade winds over the Indian ocean during the monsoon are part of the winter Hadley cell. They cross the equator from the southern hemisphere and pick up a lot of moisture by evaporation from the ocean.

Problem 4

See section 2.18 and box 2.10. Your answer must at least explain the albedo effect of clouds, the greenhouse effect of clouds and the effect of cloud top height on the radiative forcing.

Problem 5

(a) The optical thickness of the upper 10 hPa (1000 Pa) of the atmosphere is

$$\tau = q_{CO_2} \sigma_{CO_2} \Delta p / g = 0.0004 \times \left(\frac{R}{R_a} \right) \times 0.3 \times 1000 / 9.8 = 0.0004 \times \left(\frac{287}{188} \right) \times 0.3 \times 1000 / 9.8 = 0.0187 < 1.$$

(R and R_a are the specific gas constants of, respectively, air and carbon dioxide). Therefore, the stratosphere is optically thin.

NOTE: The specific gas constants of air and carbon dioxide should have been given.

(b) The net long wave emission coefficient of the stratosphere is

$$\varepsilon = 1 - \exp(-\tau) = 1 - \exp(-0.0187) = 1 - 0.9815 = 0.0185.$$

(c) The *approximate* radiation balance of the uppermost 10 hPa of the atmosphere, assuming that the long-wave absorption/emission coefficient, ϵ_{strat} , of this layer is much smaller than 1, is

$$(1 - \alpha_p)(Q - S_{\text{strat}}) + S_{\text{strat}} = (1 - \alpha_p)Q + \alpha_p S_{\text{strat}} = (1 - \alpha_p + 0.01\alpha_p)Q = (1 - 0.99\alpha_p)Q \equiv \sigma T_e^4$$

where $Q = S_0/4$, α_p is the planetary albedo (determined by cloud cover and ground albedo), $S_{\text{strat}} = 0.01Q$ is the Solar irradiance that is absorbed by this layer and T_e is the emission temperature, defined according to the above formula.

The stratosphere absorbs a very small fraction of the upwelling long-wave irradiance coming from the atmosphere and the Earth's surface below (see answer to 5b). We may therefore assume that this upwelling radiation is approximately equal to σT_e^4 and that a fraction, ϵ_{strat} , of this upwelling radiation is absorbed by the stratosphere.

In equilibrium, therefore, the stratosphere absorbs S_{strat} from above, $\epsilon_{\text{strat}}\sigma T_e^4$ from below, and emits $\epsilon_{\text{strat}}\sigma T_{\text{strat}}^4$ downwards and upwards. This is consistent with the following equation.

$$S_{\text{strat}} + \epsilon_{\text{strat}}\sigma T_e^4 = 2\epsilon_{\text{strat}}\sigma T_{\text{strat}}^4,$$

or

$$\begin{aligned} T_{\text{strat}} &= \sqrt[4]{\frac{(\epsilon_{\text{strat}})^{-1} S_{\text{strat}} + \sigma T_e^4}{2\sigma}} = \sqrt[4]{\frac{(\epsilon_{\text{strat}})^{-1} 0.01Q + (1 - 0.99\alpha_p)Q}{2\sigma}} \\ &= \sqrt[4]{\frac{1.243Q}{2\sigma}} = \sqrt[4]{1.243} \times T_{\text{skin}} \approx 1.056 \times 215 = 227 \text{ K}. \end{aligned}$$

(d) From (c):

$$T_{\text{strat}} = \sqrt[4]{\frac{(\epsilon_{\text{strat}})^{-1} S_{\text{strat}} + \sigma T_e^4}{2\sigma}}$$

This equation confirms that the temperature of the stratosphere decreases with increasing value of ϵ_{strat} .

Problem 6

(a) The Earth's surface is not in radiative equilibrium because non-radiative fluxes contribute to the energy budget.

(b) The planetary albedo is given by the ratio of the reflected Soalar radiation at the top of the atmosphere divided by the incoming Solar radiation at the top of the atmosphere, i.e. 102/341.

(c) The cloud albedo is calculated simply by dividing the reflected solar radiation (79 W m^{-2}) by the solar radiation that reaches the cloud tops ($0.6 \times 341 \text{ W m}^{-2}$). This yields 0.386.

(d) Two constituents that take care of about half of the absorption of 78 W m^{-2} of the incoming solar radiation are water vapour and ozone.