

Answers to Study Questions - Topic 5

1. (a) The highest yearly total K_{Ex} (extraterrestrial irradiance) is found at the Equator ($\theta = 0^\circ$) with $13.2 \text{ GJ m}^{-2} \text{ year}^{-1}$. This means that there is an energy gradient from the Equator to the Poles (lowest input with $5.5 \text{ GJ m}^{-2} \text{ year}^{-1}$ at the Poles $\theta = 90^\circ$) that creates a global circulation exchanging energy from low to high latitudes (ocean currents, general atmospheric circulation).
 (b) The highest daily total K_{Ex} is found at the poles with $47 \text{ MJ m}^{-2} \text{ day}^{-1}$ during the summer solstice. This is because the solar irradiance reaches the poles during the full 24h cycle.
 (c) For Montreal, the highest instantaneous $K_{Ex} \approx 1200 \text{ W m}^{-2}$ is found on the day of the summer solstice (Jun 22) at 12 LAT. The lowest value (0 W m^{-2}) during any night.
2. Using the energy conservation equation (reading package, equation 2.12) we know that radiation of wavelength λ incident upon a substance must either be *transmitted* through it, be *reflected* from its surface, or be *absorbed*:

$$\Psi_\lambda + \alpha_\lambda + \zeta_\lambda = 1 \quad (1)$$

If the body is opaque, then $\Psi_\lambda = 0$ and:

$$\begin{aligned} \alpha_\lambda + \zeta_\lambda &= 1 \\ \alpha_\lambda &= 1 - \zeta_\lambda \end{aligned} \quad (2)$$

so the reflectivity is $\alpha_\lambda = 1 - 0.75 = \underline{0.25}$.

3. We use Equation (1) and solve for absorptivity:

$$\zeta_{\text{PAR}} = 1 - (\Psi_{\text{PAR}} + \alpha_{\text{PAR}}) \quad (3)$$

This results in $\zeta_{\text{PAR}} = 1 - (0.08 + 0.11) = 0.81$. Hence, the fraction of the incident radiation of $800 \mu\text{mol s}^{-1} \text{ m}^{-2}$ that is absorbed is 81%:

$$0.81 \times 800 \mu\text{mol s}^{-1} \text{ m}^{-2} = \underline{648 \mu\text{mol s}^{-1} \text{ m}^{-2}}$$

4. We use the bulk transfer formula from Lecture 5 and rearrange for the transmissivity Ψ_a :

$$K_{\downarrow} = K_{Ex} \Psi_a^m \quad (4)$$

$$\Psi_a = \left(\frac{K_{\downarrow}}{K_{Ex}} \right)^{\frac{1}{m}} \quad (5)$$

K_{Ex} has been calculated for the same time and location in the Study Question Set 4 (Question 5) and is $K_{Ex} = 560 \text{ W m}^{-2}$ (for the calculation see Answers of Study Question Set 4). We further need the optical air mass number m which is:

$$m = \frac{1}{\cos Z} = \frac{1}{\sin \beta} \quad (6)$$

we use $\beta = 23.55^\circ$ and $\sin \beta = 0.411$ from Study Question Set 4, Question 4 and get $m = 2.502$. We insert this in Equation (5):

$$\Psi_a = \left(\frac{298 \text{ W m}^{-2}}{560 \text{ W m}^{-2}} \right)^{\frac{1}{2.502}} = \underline{0.78} \quad (7)$$

5. We use $\Psi_a = 0.78$ from Question 4 and solve the bulk transfer formula:

$$K_{\downarrow} = K_{Ex} \Psi_a^m \quad (8)$$

K_{Ex} at 10:00 is calculated according to the procedure in Study Question Set 4 and is 644 W m^{-2} , and the optical air mass number is $m = 2.178$ ($Z = 62.67^\circ$), hence:

$$K_{\downarrow} = 644 \text{ W m}^{-2} \times 0.78^{2.178} = \underline{372 \text{ W m}^{-2}} \quad (9)$$