# 第 4 次作业

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# Homework 4

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# 1 Question 1

If the top 100 m of ocean warms by 5°C during a 3-month summer period, what is the average rate of net energy flow into the ocean during this period in units of W m$^{-2}$? If the atmosphere warms by 20°C during the same period, what is the average rate of net energy flow into the atmosphere? (Hartmann, 2016, p. 129)

## 1.1 Solution

If the top 100 m of ocean warms by 5°C during a 3-month summer period, the average rate of net energy flow into the ocean during this period is

$$G_\mathrm{o} = \frac{\partial E_\mathrm{o}}{\partial t} = \frac{c_\mathrm{w}\rho_\mathrm{w}d_\mathrm{w}\Delta T_\mathrm{w}}{\tau} = \frac{4218\times 10^3\times 100\times 5}{90\times 24\times 3600}\mathrm{W\ m^{-2}} = 271\ \mathrm{W\ m^{-2}}. \tag{1.1}$$

If the atmosphere warms by 20°C during the same period, the average rate of net energy flow into the atmosphere is

$$G_\mathrm{a} = \frac{\partial E_\mathrm{a}}{\partial t} = \frac{\overline{C}_\mathrm{a}\Delta T_\mathrm{a}}{\tau} = c_\mathrm{p}\frac{p_\mathrm{s}}{g}\frac{\Delta T_\mathrm{a}}{\tau} = 1004\times\frac{10^5}{9.81}\times\frac{20\ \mathrm{W\ m^{-2}}}{90\times 24\times 3600} = 26.3\ \mathrm{W\ m^{-2}}. \tag{1.2}$$

# 2 Question 2

The blackbody emission from the surface can be linearized about some reference temperature $T_0$. $\sigma T_\mathrm{s}^4 \approx \sigma T_0^4 + 4\sigma T_0^3(T_\mathrm{s} - T_0) + \cdots$. And the sensible cooling of the surface can be written as $\mathrm{SH} \approx c_\mathrm{p}\rho C_\mathrm{D}U(T_\mathrm{s} - T_\mathrm{a}) + \cdots$. Calculate and compare the rates at which longwave emission and sensible heat flux vary with surface temperature, $T_\mathrm{s}$. In other words, if the surface temperature rises by 1°C, by how much will the longwave and sensible cooling increase? Assume that $T_0 = 288$ K, $T_\mathrm{a}$ is fixed, $\rho = 1.2$ kg m$^{-3}$, $c_\mathrm{p} = 1004$ J kg$^{-1}$ K$^{-1}$, $C_\mathrm{D} = 2\times 10^{-3}$, and $U = 5$ m s$^{-1}$. (Hartmann, 2016, p. 129)

## 2.1 Solution

We have

$$\mathrm{d}\left(\sigma T_\mathrm{s}^4\right)\big|_{T_\mathrm{s}=T_0} = 4\sigma T_0^3\ \mathrm{d}T_\mathrm{s} \tag{2.1}$$

and

$$\mathrm{d}(\mathrm{SH})|_{T_\mathrm{s}=T_0} = c_\mathrm{p}\rho C_\mathrm{D}U\ \mathrm{d}T_\mathrm{s}. \tag{2.2}$$

So, if the surface temperature rises by 1°C, the longwave and sensible cooling will increase by

$$\Delta\left(\sigma T_\mathrm{s}^4\right) \approx \mathrm{d}\left(\sigma T_\mathrm{s}^4\right)\big|_{T_\mathrm{s}=T_0} = 4\sigma T_0^3\ \mathrm{d}T_\mathrm{s} = 4\times 5.67\times 10^{-8}\times 288^3\times 1\ \mathrm{W\ m^{-2}} = 5.4\ \mathrm{W\ m^{-2}} \tag{2.3}$$

and

$$\Delta(\mathrm{SH}) \approx \mathrm{d}(\mathrm{SH})|_{T_\mathrm{s}=T_0} = c_\mathrm{p}\rho C_\mathrm{D}U\ \mathrm{d}T_\mathrm{s} = 1004\times 1.2\times\left(2\times 10^{-3}\right)\times 5\times 1\ \mathrm{W\ m^{-2}} = 12\ \mathrm{W\ m^{-2}}, \tag{2.4}$$

respectively.

# References

Hartmann, D. L. (2016). Chapter 4 - The Energy Balance of the Surface. In D. L. Hartmann (Ed.), *Global Physical Climatology (Second Edition)* (pp. 95-130). Elsevier. https://doi.org/10.1016/B978-0-12-328531-7.00004-9