



## 第 4 次作业

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## Homework 4

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## 目 录

摘要 .....	i
Abstract.....	i
1 Question 1 .....	1
1.1 Solution .....	1
2 Question 2 .....	1
2.1 Solution .....	1
References .....	2



## 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  $\text{W m}^{-2}$ ? 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

$$G_o = \frac{\partial E_o}{\partial t} = \frac{c_w \rho_w d_w \Delta T_w}{\tau} = \frac{4218 \times 10^3 \times 100 \times 5}{90 \times 24 \times 3600} \text{ W m}^{-2} = 271 \text{ W m}^{-2}. \quad (1.1)$$

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

$$G_a = \frac{\partial E_a}{\partial t} = \frac{\bar{C}_a \Delta T_a}{\tau} = c_p \frac{p_s}{g} \frac{\Delta T_a}{\tau} = 1004 \times \frac{10^5}{9.81} \times \frac{20 \text{ W m}^{-2}}{90 \times 24 \times 3600} = 26.3 \text{ W m}^{-2}. \quad (1.2)$$

## 2 Question 2

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

### 2.1 Solution

We have

$$d(\sigma T_s^4)|_{T_s=T_0} = 4\sigma T_0^3 dT_s \quad (2.1)$$

and

$$d(SH)|_{T_s=T_0} = c_p \rho C_D U dT_s. \quad (2.2)$$

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

$$\Delta(\sigma T_s^4) \approx d(\sigma T_s^4)|_{T_s=T_0} = 4\sigma T_0^3 dT_s = 4 \times 5.67 \times 10^{-8} \times 288^3 \times 1 \text{ W m}^{-2} = 5.4 \text{ W m}^{-2} \quad (2.3)$$

and

$$\Delta(SH) \approx d(SH)|_{T_s=T_0} = c_p \rho C_D U dT_s = 1004 \times 1.2 \times (2 \times 10^{-3}) \times 5 \times 1 \text{ W m}^{-2} = 12 \text{ W m}^{-2}, \quad (2.4)$$

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>