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Due: Monday, 10 March, 2003; 14:00

Problem II.1: Winter Cooling – Without Sea Ice

Consider an oceanic mixed layer of depth $D = 100\text{m}$ underneath an atmosphere with constant surface temperature $T_A = -20^\circ\text{C}$. The time-varying mixed layer temperature is $T(t)$; it is initially at temperature $T(0) = 5^\circ\text{C}$ and is cooled according to the law,

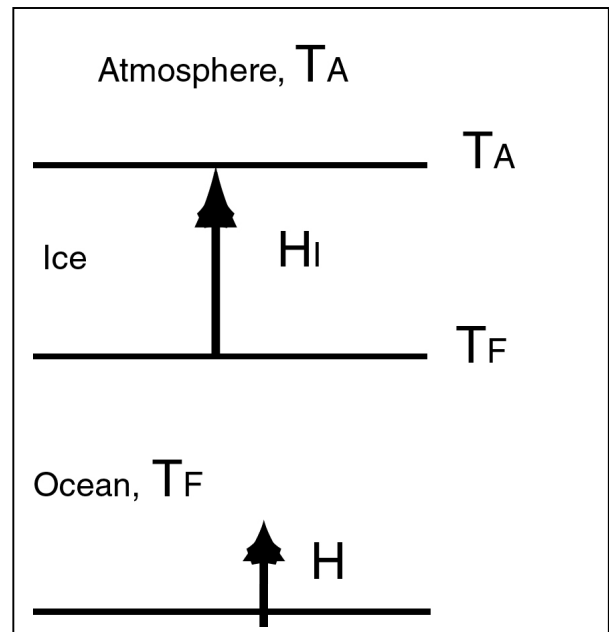
$$H_T(t) = \lambda(T_A - T(t)), \tag{1.1}$$

where $\lambda = 35\text{Wm}^{-2}\text{K}^{-1}$ is the air-sea heat exchange coefficient. Calculate the time-evolution of mixed layer temperature and heat loss, assuming that sea ice never forms. (That is, we accept that water can be supercooled – imagine the freezing temperature were at -100°C). What is the e-folding cooling timescale? Sketch your solution for $T(t)$, as well as that for $H_T(t)$.

[30 %]

Problem II.2: Winter Cooling – With Sea Ice

Consider the ocean-sea ice-atmosphere system sketched in the figure. The atmosphere and the top of the sea ice are at temperature $T_A = -20^\circ\text{C}$, while the ocean and the bottom of the sea ice are at freezing point temperature, $T_F = -2^\circ\text{C}$. Ice thickness is denoted h . The ocean is heated from below at a rate of 20Wm^{-2} . The upward heat flux through the ice, H_I , is given by $H_I = \frac{k}{h}(T_F - T_A)$, where k , the conductivity through sea ice, is $2\text{W m}^{-1}\text{K}^{-1}$.



(a) What is the steady-state ice thickness? [15 %]

(b) Why is T_F not equal to 0°C ? [5 %]

(c) Given these atmospheric and oceanic temperatures, estimate what the instantaneous oceanic heat loss to the atmosphere would be without the presence of sea ice. Use a typical value for the thermal air-sea interaction coefficient. Discuss the difference between the ice-free and ice-covered cases, using the results from II.1 [10 %]

(d) Assume that air temperature falls from $+5^{\circ}\text{C}$ to -5°C over a 500 m deep lake and a 500 m deep part of the ocean. Freshwater has its density maximum above freezing; does this cause a difference in how these two water bodies freeze over? (*Hint*: Argue precisely but qualitatively – no maths required).

[10 %]

(e) Returning to the system depicted in the figure, assume it is in the steady state calculated in (1), and assume that the heat flux from below, H , suddenly stops. How long does it take until ice thickness doubles? (*Hint*: The latent heat of freezing and melting, per unit volume of ice, is $L_F = 3 \times 10^8 \text{Ws m}^{-3}$).

[30 %]