1. There are numerous methods for determining reservoir evaporation using various measurements. This problem assumes the water surface of the reservoir has an area of 10^6 m^2 (1 km^2) with a steady flow rate of water into the reservoir of 0.2 m^3 s^{-1}.

(a) The steady flow rate leaving the reservoir is 0.15 m^3 s^{-1}. What is the daily evaporation rate in [mm day^{-1}]?

$$ER = \frac{4320\,\frac{m^3}{day}}{10^6\,m^2} \times \frac{100cm}{m} = \boxed{0.432 mm/d}$$ ✓

$$Q_{in} = 0.2\,\frac{m^3}{s} \qquad Q_{out} = 0.15\,m^3/s$$

If steady state, mass in = mass out, water incompressible,

so $V_{in} = V_{out}$

$$Q_{in} - Q_{out} = 0.05\,m^3/s \times \frac{60s}{1min} \times \frac{60min}{1hr} \times \frac{24hr}{day}$$

4320 m³/day

(b) The steady state dissolved salt concentration in the flow entering the reservoir is 300 g m^{-3} and the steady state dissolved salt concentration leaving the reservoir is 400 g m^{-3}. What is the daily evaporation rate in [mm day^{-1}]?

Mass in = mass out

$$Q_1 C_1 = Q_2 C_2$$

$$(300 g/m^3)(0.2 m^3/s) = Q_2 (400 g/m^3)$$

$$Q_2 = 0.15 m^3/s$$

So evaporation rate is the same as before ✓

$= \boxed{0.432 mm/d}$

(c) Over a day the average heat input to the reservoir is 0.125 kJ m^{-2} s^{-1} and the entering and exiting water temperatures are the same. What is the daily evaporation rate in [mm day^{-1}]?

Heat In = Heat Out + Accum.

$$0.125\,kJ/m^2 s \times 10^6 m^2 \times 24 \times 60 \times 60 = \left(1000\,\frac{kg}{m^3}\right)\overset{Le}{\left(2500 kJ/kg\right)} \times 10^6 m^2\, h \times \frac{100cm}{1m}$$

$= \boxed{0.432 mm/day}$ ✓

10

2. A vessel contains air and water vapor at 101.3 kPa total pressure and a temperature of 20°C. Water is at its saturation vapor pressure of $p_w^* = 2.34$ kPa.

(a) What is the mass concentration of water vapor in the vessel [g m^{-3}]?

$\boxed{0.017 \frac{kg}{m3}}$ ✓

$$\rho_{wa} = \frac{n_w MW}{V} = \frac{P_w\, MW}{RT} = \frac{2.34\times10^{3}\,Pa \times 18\times10^{-3}\,\frac{kg}{mol}}{(8.314\,J/mol\cdot K)(293K)}$$

(b) Dry air has a molecular mass of 28.97 g mole^{-1} and water has molar molecular mass of 18 g mole^{-1}. What is the total gas density at 101.3 kPa total pressure and 20°C with water at its saturation vapor pressure?

$$\rho_g = \rho_{wa} + \rho_{dry\ air}$$ ✓ ✓

$$\rho_d = \frac{P_d\ MW}{RT} = \frac{(\overset{-2.34}{101.3}\times10^{3}Pa)\times 28.97\times10^{-3}}{(8.314\,J/mol\cdot K\,(293K)}$$ (−2)

$$\rho_g = 0.017\frac{kg}{m3} + 1.2\frac{kg}{m3} = \boxed{1.217\frac{kg}{m3}}$$

$$\rho_d = 1.2\ kg/m^3$$

(c) The water-saturated air at 20°C and 101.3 kPa also has fog droplets (condensed liquid water) with a mass concentration of 0.06 g m^{-3}. Will this fog change the density of the air calculated in part (b)?

it will change it by $6\times10^{-5}\frac{kg}{m^3}$, which is not significant. ✓

2. (cont.)

(d) What heat is required to clear the fog [kJ m^{-3}]?

H_{in} = Heat Accum.

yes.

$$H = \boxed{(2500\ kJ/kg)(0.06\ kg/m^3)} + (\underset{1840\ J/kg \cdot K}{C_{pw}})\overset{\Delta T}{(80)}(0.06\ kg/m^3)$$

-2

$$H_{in} = 150\ kJ/m^3 + 8.86\ kJ/m^3 = \boxed{159\ kJ/m^3}$$

(e) What is the resulting temperature of the air in (d) after the fog is removed (±2°C is fine)?

$$150\ kJ/m^3 = \overset{kg/m^3}{\rho_{wa}} \times V \times C_{pw} \Delta T + \rho_{Da} \times V \times \underset{1386\ J/kg \cdot K}{C_{pDw}}$$

$$0.0314\ \Delta T + 1.2\ \frac{kg}{m^3} \times \frac{1386\ kJ}{1000\ kg\ K}\ \Delta T$$

$$150\ kJ/m^3 = (0.0314 + 1.6632)\ \Delta T$$

$$\Delta T = 88.5$$

$$\boxed{T_f = 108.5°C}$$

a little large ?

-1

/5

3. Photosynthesis occurs within leaves with the overall reaction of

$$CO_2 + H_2O = CH_2O + O_2$$

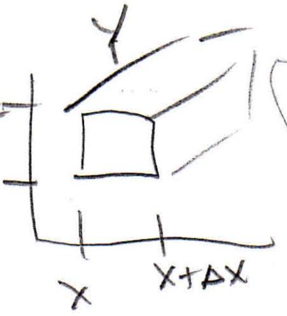
where CH_2O is a simplified formula for organic matter. The CO_2 comes from the atmosphere and the H_2O comes from the soil and the molecular oxygen, O_2, is released to the atmosphere. The exchange of the gaseous constituents occurs in a leaf boundary layer that is of thickness δ where the air is assumed to be stagnant.

(a) Show by a water mass balance over a differential control volume that water mass concentration in the air within the leaf boundary layer is described by

$$\frac{\partial \rho_{wa}}{\partial x} = D_{wa}\frac{\partial^2 \rho_{wa}}{\partial x^2}$$

t ?

where D_{wa} is the molecular diffusivity of water vapor in air.



mass in = Mass Out + Acc.

$F_A(x) \times \Delta z\, Y\, t = F_A(x+\Delta x)\, \Delta z\, Y\, t + \Delta(\rho_w)\, \Delta z\, Y\, \Delta x$

$-\dfrac{F_A(x+\Delta x) - F_A(x)}{\Delta x} = \dfrac{\Delta \rho}{\Delta t}$

$\lim_{\Delta x, \Delta t \to 0}$

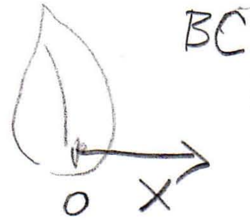
$F_A = -D_M \dfrac{\partial \rho_{wa}}{\partial x}$

$+ \dfrac{\partial D_{wa} \partial^2 \rho_{wa}}{\partial x^2} = \dfrac{\partial \rho}{\partial t}$

✓

(b) What is the steady state water mass concentration in air within the leaf boundary layer if the relative humidity is 100% at the leaf surface and $\rho_{wa,b}$ in the bulk atmosphere?

Steady-State $\dfrac{\partial \rho_{wa}}{\partial t} = 0$



BC ρ_{wa}^* @ x=0 ✓

$\rho_{wa,b}$ ✓ @ x = δ at edge of BL

$\rho_{wa} = C_1 x + C_2$

$\rho_{wa,b} = C_1 L + \rho_{wa}^*$

$\rho_{wa} = \dfrac{\rho_{wa} - \rho_{wa}^*}{\delta} x + \rho_{wa}^*$ ✓

(c) Sun shines on the dark leaves leading to a temperature of the leaf of T_L that is greater than the ambient air temperature, T_{air}. What is the steady state air temperature profile in the leaf boundary layer?

$T_{LB} = \dfrac{T_{air} - T_L}{\delta} x + T_L$ ✓

3. (cont.)

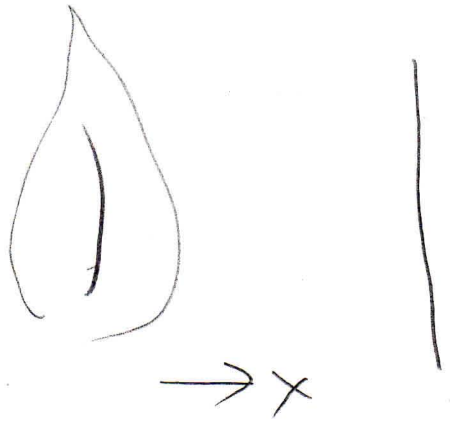
(d) What is the expression for the heat flux magnitude and direction for the conditions in (c)?

$$F_Q = -\alpha \frac{d(\rho c_p T)}{dx}$$

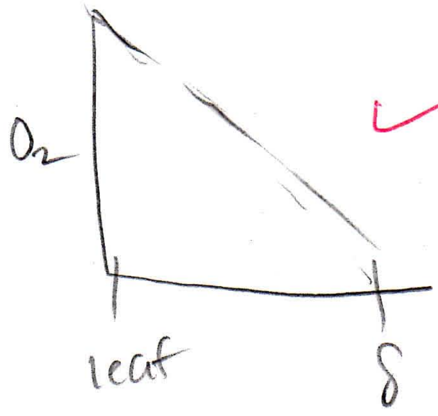
$$F_Q = -\alpha_{BL} \frac{T_{air} - T_L}{\delta} \times \rho c_p = \boxed{-\alpha_{BL} \rho c_p \left[\frac{T_{air} - T_L}{\delta}\right]}$$

✓

(e) Sketch the approximate profiles of CO_2 and O_2 in the leaf boundary layer when the leaf is actively photosynthesizing.



✓

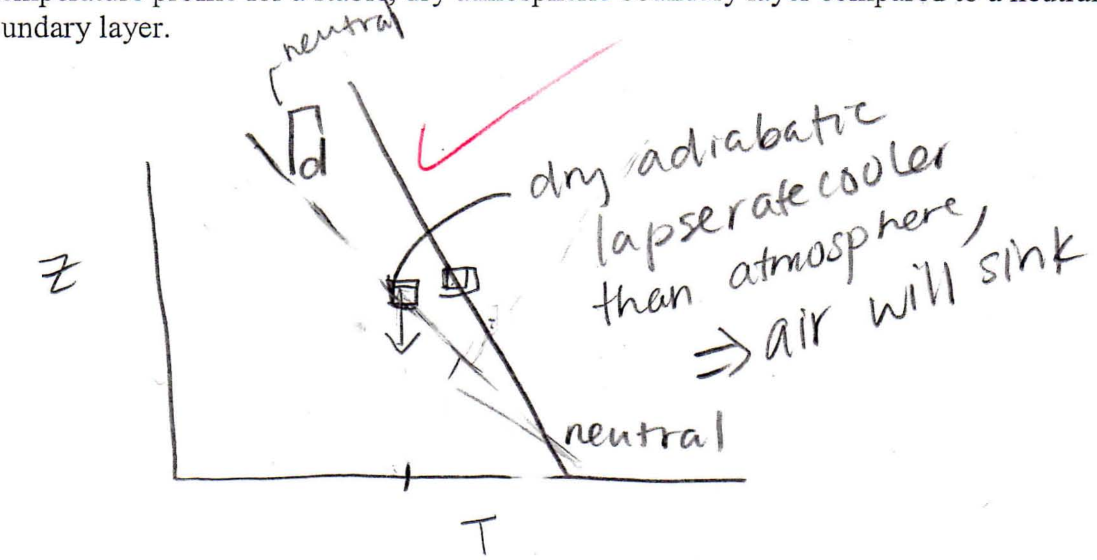


✓

10

4. The dry atmosphere has an adiabatic lapse rate of $\Gamma_d = -10^{\circ}\mathrm{C\ km^{-1}}$.

(a) Sketch the temperature profile for a stable, dry atmospheric boundary layer compared to a neutral atmospheric boundary layer.

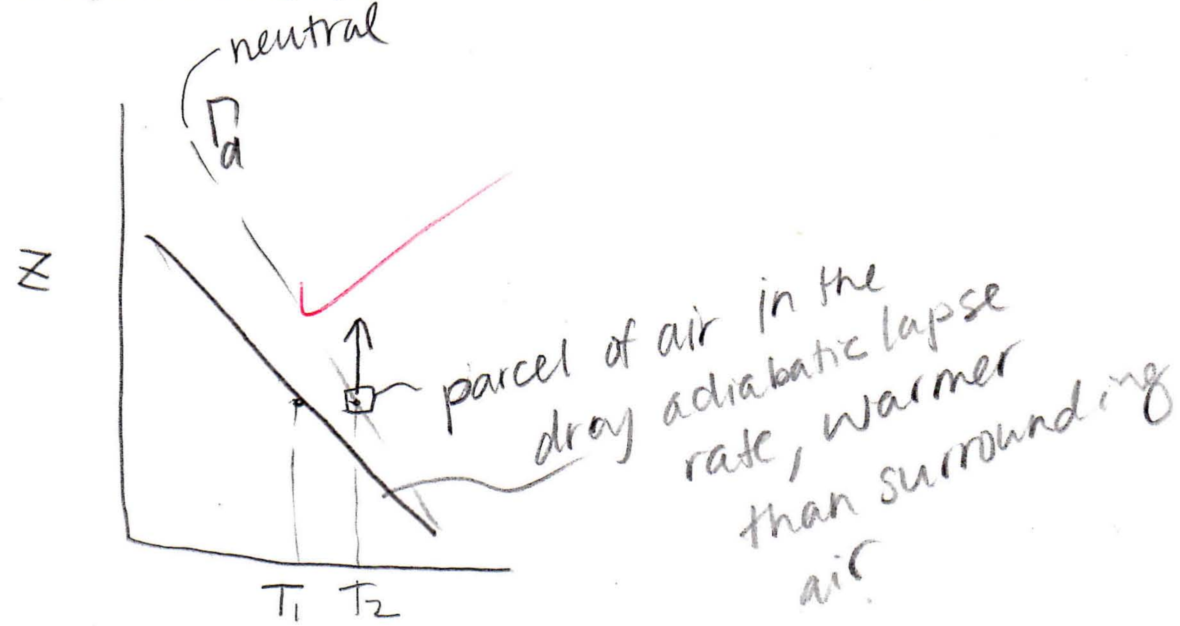


dry adiabatic lapserate cooler than atmosphere, ⇒ air will sink

(b) What time of the day would you expect to find a stable atmospheric boundary layer and why?

At night, air cools off & sinks.

(c) Sketch the temperature profile for an unstable, dry atmospheric boundary layer compared to a neutral atmospheric boundary layer.



parcel of air in the dray adiabatic lapse rate, warmer than surrounding air

4. (cont.)

(d) What time of the day would you expect to find an unstable atmospheric boundary layer and why?

~~An~~ In the afternoon, air is warm and rises & mixes w/ surrounding air.

✓

(e) In respect for the weather today, describe mechanistically Santa Ana winds (also called Diablo winds, Chinooks, föhn)

Air, which was originally under cooler conditions, holding less water, gets heated up as it moves↓ giving rise to hot, dry winds.

w/ neglible additions of water

moves downward ?

-2

/ -2