ESS 223: Problem Set 2

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1 Problem 1

a) Plot the net radiation in the two sites. Why might it differ between the two sites?

Net radiation is the result of shortwave radiation down minus shortwave radiation up, plus longwave radiation down minus longwave radiation up. Therefore, one way R_n might differ between these two sites is because of a difference in albedo, where higher albedo (such as at Vaira Ranch) would result in more reflected shortwave radiation up and therefore lower R_n.

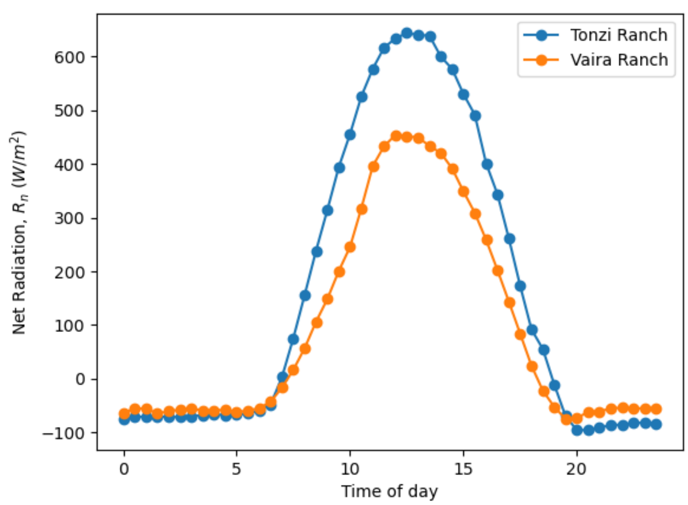

Figure 1: Net radiation (R_n) at two FLUXNET sites.

b) Why does the sign of the R_n change between nighttime and mid-day?

R_n is negative at night because downward shortwave radiation (from the sun) stops, but longwave radiation continues to be emitted from the Earth's surface.

c) Which of these two sites do you expect to have the greatest ET rates on this day?

I would expect Tonzi Ranch to have higher ET rates on this day because (a) R_n is greater, and (b) the vegetation is taller (trees vs grass) which translates to higher aerodynamic resistance, which effectively makes the denominator of the Penman-Monteith equation smaller, and therefore ET larger.

d) Which of these two sites do you expect to have the greatest atmospheric specific humidity on this day?

Specific humidity is defined as the mass of moist air divided by the mass of moist and dry air together. If ET rates are higher at Tonzi Ranch, I would expect the specific humidity to be higher there as well, due to the increase in moist air mass from water transported by the trees as Tonzi Ranch to the atmosphere.

2 Problem 2

a) What is the vapor pressure deficit, in hPa? What is the vapor pressure deficit in millibar?

The VPD is 8.17 hPa. Millibar is equivalent to hPa. (See code for steps.)

b) For the typical day whose measurements you have, what is the aerodynamic resistance for each plant?

The aerodynamic resistance is 35 and 22 s/m for options 1 and 2 respectively. Aerodynamic resistance was calculated as a function of wind speed and vegetation height (see code for math).

c) For the typical day whose measurements you have, what would the ET (in mm day-1) be for each of these plant choices? Use the Penman-Monteith equation.

ET would be 3.15 and 2.51 mm/day for Option 1 and Option 2, respectively. The Penman-Monteith equation was used to calculate LE, which was converted to mm/day of ET by dividing by the lambda ($2.54e6$ J/kg) and converting to days (86,400 s/day). Full calculation is in the code.

3 Problem 3

During rainfall, evapotranspiration is usually fairly low. Name two possible reasons.

- During rainfall, VPD is close to 0 because the vapor pressure (e) is very close to the saturation vapor pressure (e*) and VPD is defined as the difference between e* and e.
- Radiation is low because it is probably cloudy, and therefore incoming shortwave radiation is likely being reflected off of those clouds.
- There is water on the plant leaves, which changes their conductance and also probably impacts stomatal closure in general.

4 Problem 4

a) What is the relative humidity inside the hospital building if the air is brought from outside and heated to the required temperature, but not humidified?

e* for the inside and outside temperatures can be determined from the Clausius-Clapeyron as 24 and 3.7 hPa respectively. Because $RH = e * -e$, we can determine that the new RH if outside air is brought in without being humidified would be 12%. (See code for math.)

b) Consider a hospital building with 1500 m3 volume. It has a humidifier system that vaporizes 4 liter/hr of water. How many hours should the humidifier be in operation to increase the relative humidity of the indoor air to the regulation limit?

The humidifier will need to run almost 5 hours per day. We have a target vapor pressure (corresponding to 75% RH and e* of the inside temperature) of 18.16 hPa, and an actual, unhumidified vapor pressure of 2.97 hPa. We can calculate the mass of water needed as $mass_water = (e/P)/mass_air$ where e is the vapor pressure, P is the pressure (given as 1000 mb) and the mass of air is given as 1.2 kg. The difference in the mass of water between our target and actual vapor pressures, multiplied by the volume of the room, results in 19 liters of water which need to be added, and which will take approximately 5 hours to be added given the rate of humidification. (See code for math.)

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import math

def main():
    tonzi = pd.read_csv('TonziSample.csv')
    vaira = pd.read_csv('VairaSample.csv')

    #Problem 1A: Plot Rn
    plt.plot(tonzi['TimeOfDay'], tonzi['Rn'], '-o', label =
'Tonzi Ranch')
    plt.plot(vaira['TimeOfDay'], vaira['Rn'], '-o', label =
'Vaira Ranch')
    plt.legend()
    plt.xlabel('Time of day')
    plt.ylabel('Net Radiation, $R_n$ ($W/m^2$)')
    plt.savefig('problem1a_rn.png')

    # Problem 2
    print('\n\nPROBLEM 2\n')
    Rn = 280 #W/m^2
    rho_water = 1000 #kg/m3
    rho_air = 1.2 #kg/m3
    T_air = 20 #c
    u = 1 # m/s
    RH = 65 #%
    h = 2 #m, height of met station
    gamma = 0.67 #mb C (psychrometric constant)
    g = 25 #W/m2 (ground heat flux)

    # Problem 2a: Calculate VPD

    def clausius_clap(T_air):
        """
        Returns e_sat given T_air in C.
        """
        e_star = 6.1094*math.exp((17.625*T_air)/(T_air +
243.04))
        return e_star

    def calc_vpd(T_air, RH):
        """
        Returns VPD in units of hPa
        given T_air in C and RH in decimal or percent.
        """
        # Convert to percent if given whole number
```

```
        if RH % 1 == 0: RH /= 100
        e_star = clausius_clap(T_air)
        return e_star * (1-RH)

    vpd = calc_vpd(T_air, RH)
    print(f"Problem 2a: VPD (hPa) = {round(vpd,2)}")


    # Problem 2b: Calculate aerodynamic resistance for each
plant
    gs_1 = 30
    gs_2 = 60
    h_1 = .30 #m
    h_2 = 1 #m

    def calc_aero_resistance(h, u):
        # h in m, u in m/s
        log = (2 - 0.7*h) / (0.1*h)
        denom = 0.41 * 0.41 * u
        return math.log2(log) / denom

    ra_1 = calc_aero_resistance(h_1, u)
    ra_2 = calc_aero_resistance(h_2, u)

    print(f"Ra (s/m) Option 1: {ra_1}")
    print(f"Ra (s/m) Option 2: {ra_2}")

    # Problem 2c: Calculate ET

    def calc_s(T_air):
        # Slope of Clausius-Clapeyron
        num = 17.625 * (T_air + 243.04) - 17.625 * T_air
        denom = (T_air + 243.04)**2
        return num/denom

    def calc_penman_monteith(Rn, G, T_air, h, u, RH, gamma,
rho_air, rho_water, r_s):
        r_a = calc_aero_resistance(h, u)
        vpd = calc_vpd(T_air, RH)
        s = calc_s(T_air)
        num = s * (Rn-G) + ((rho_air * 1005) / r_a)*vpd
        denom = s + gamma * (1 + (r_s/r_a))
        latent_heat = num/denom
        et = latent_heat / 2.45
        return et
```

```
    et_1 = calc_penman_monteith(Rn, g, T_air, h_1, u, RH, gamma,
rho_air, rho_water, gs_1)
    et_2 = calc_penman_monteith(Rn, g, T_air, h_2, u, RH, gamma,
rho_air, rho_water, gs_2)

    print(et_1)
    print(et_2)
    lam = 2.54e6
    sec_per_day = 86400

    print(f"Daily ET, option 1: {et_1 / lam * sec_per_day} mm/
day")
    print(f"Daily ET, option 2: {et_2 / lam * sec_per_day} mm/
day")


    ## Problem 4
    print('\n\nPROBLEM 4\n')
    t_inside = 20.6 #c
    rh_inside = 0.75 #%
    t_outside = -6.7 #c
    rh_outside = 0.8 #%
    rho_air = 1.2 #kg
    pressure = 1000 #mb

    # A) RH inside hosptal if air is brought
    # from outside and heated to temp,
    # but not humidified

    # RH = e/e*
    e_star_outside = clausius_clap(t_outside)
    e_outside = rh_outside * e_star_outside
    e_star_inside = clausius_clap(t_inside)
    print(f"E_star {e_star_inside, e_star_outside}")
    rh_inside = e_outside / e_star_inside
    print(f"RH in hospital if air not humidified:
{round(rh_inside*100)}%")

    # B) Hospital with 1500 m3 volume.
    # Humidifier vaporizes 4 liters/hr water.
    # How many hours should it be running to increase RH to 75%

    e_target = 0.75 * e_star_inside
    e_actual = rh_inside * e_star_inside
    print(f"Target vapor pressure (e) for 75% RH:
{round(e_target,2)} hPa")
    print(f"Unhumidified e: {round(e_actual,2)} hPa")
```

```
    print(f"Difference in vapor pressure: {round(e_target -
e_actual,2)} hPa")

    def mass_of_water(e):
        mass_air = 1.2 # kg
        P = 1000 # hPa
        mass_water = (e/P) / mass_air
        return mass_water

    water_target = mass_of_water(e_target) * 1500
    water_actual = mass_of_water(e_actual) * 1500
    print(water_target, water_actual)

    water_needed = (mass_of_water(e_target) -
mass_of_water(e_actual)) * 1500
    print(f"Litres of water needed: {round(water_needed)}")
    print(f"Hours of humidifier operation: {water_needed/4}")


if __name__ == '__main__':
    main()
```