Assignment 4
GOES 300
Lague Term 1 2024

Boundary Layers, Stability, and Plant-Atmosphere Interactions

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Instructions: Please return your answers including all calculations, graphs and discussions in a well-structured report (PDF format). Please copy-paste images from questions into your report when you are asked to draw on the images. Alternatively, you may write your answers directly on this pdf (but please ensure answers are legible).

Label the report document with your name, your student number, the course and year. Marks are indicated in square brackets. This assignment is worth 10% of your final grade. There are 8 questions and 65 points.

Unlike the previous assignments, this assignment does not require the use of python/excel/R; you may use these, or a calculator, to complete calculations if you wish.

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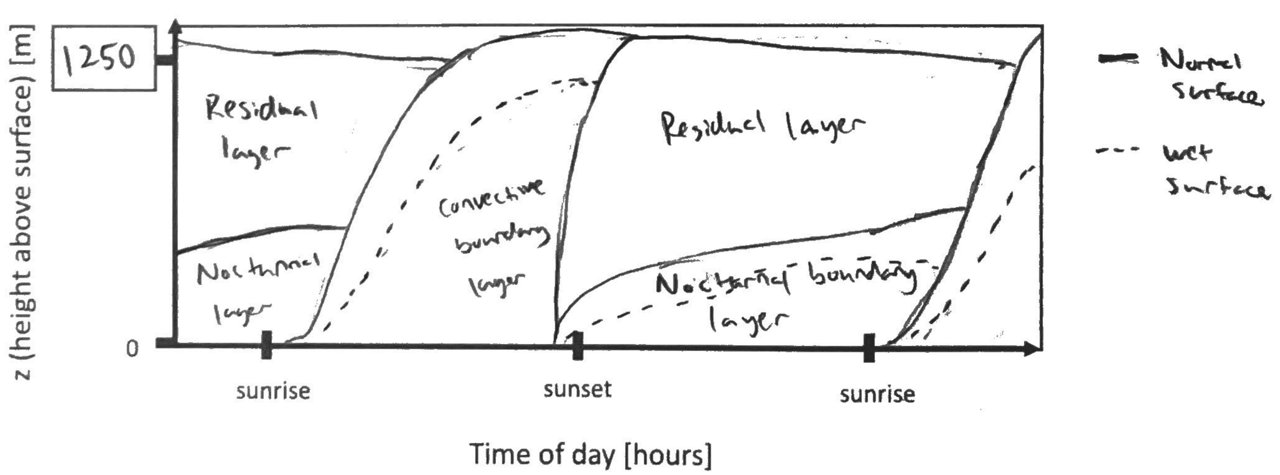
1. [8]
   Draw the day-night evolution of the depth of the atmospheric boundary layer over a typical land surface (e.g. a grassy field) [2], and fill in the box on the upper end of the y-axis [1] (approximate value is fine); label the convective boundary layer, the residual layer, and the nocturnal boundary layer [3]. Using a different colour (or different type of line), draw how the boundary layer would look different if the surface were much wetter (e.g. a bog) [2].



Rubric:

[2] for approximately correct day/night heights
[3] 1 per label of convective, residual, and nocturnal boundary layers
[2] for approximately correct day/night heights over wetter surface

2. [6]
Use the ideal gas law to calculate the density ρ_1 and ρ_2 of two parcels of air, both at 1000 hPa (sea level pressure) [4]. The temperature T_1 of the first air parcel is 10°C, and the temperature T_2 of the second is 15°C. Which parcel would rise above the other, and why [2]?

ρ_2 will rise above ρ_1 because ρ_2 is less dense. Hotter air is less dense than colder air.

Rubric:
[2] for approach/ideal gas law implementation
[2] for correct densities (hint: watch your units)
[2] for correct answer + reason

$$P = \rho R_s T \qquad R_s = 287\ J kg^{-1} K^{-1}$$

$$\rho = \frac{P}{R_s T} \qquad \rho_1 = \frac{1000\ hPa}{287\ J kg^{-1} K^{-1} (283.15\ K)} \qquad \rho_1 = \frac{100000\ Pa}{81264.05\ J kg^{-1}}$$

$$\rho_1 = \frac{100000\ kg\, m^{-1} s^{-2}}{81264.05\ kg\, m^2 s^{-2} kg^{-1}} \qquad \rho_1 = 1.23\ kg\, m^{-3}$$

$$\rho_2 = \frac{100000\ Pa}{287\ J kg^{-1} K^{-1} (288.15\ K)} = \frac{100000\ Pa}{82699.05\ kg\, m^2 s^{-2} kg^{-1}} \qquad \rho_2 = 1.02\ kg\, m^{-3}$$

3. [8]
The following satellite image was captured by Landsat 7 on September 15, 1999, showing von Karman vortices near Alexander Selkirk Island in the South Pacific. Using concepts covered in lecture:

a. Indicate direction of mean wind (draw an arrow on the image). [1]

b. Briefly describe the conditions that lead to the formation of these von Karman vortices. Are they always present in this location? [4]

The flow of atmospheric air around obstacles like islands or isolated mountains can lead to von Karman vortices. They are not always present because the flow direction has to be exact and there also has to be clouds present. The disturbance of flow from these hills / mountains causes the vortices.

c. Write the equation for the Freude number. Estimate the approximate value of the Freude number based on the flow visible in the image. [3]

$$Fr = \frac{\pi U_0}{NH}$$

$Fr \Rightarrow 0$ when the flow is around an obstacle like a mountain or hill which in this case is the Von Karman Vortices.

Rubric:
a – [1] for correct direction
b – [3] for conditions, [1] for if they're always present or not
c – [1] for equation, [2] for approximate value estimate

4. [6]
In the process of photosynthesis, energy is extracted from photons in the PAR range. To assimilate one mole of CO2, it requires an energy of 469 kJ. The same amount is released back during respiration (metabolism, decomposition of organic matter). We call this energy flux density the net biochemical energy storage ΔQ_P. Consider a location where at noon, net radiation Q* is 600 W/m2. A flux tower measures net vertical exchange of CO2 to be -4.01 µmol/m2/s (i.e. 4.01 µmol/m2/s into the surface); this reflects plant uptake of CO2 through photosynthesis.

a. [4] Calculate ΔQ_P

$$\Delta Q_P = \emptyset \, NEP$$

$NEP = -4.01 \ \mu mol \ m^{-2} s^{-1}$

$\emptyset = 469 \ kJ \ mol^{-1}$

$$\Delta Q_P = -4.01 \cdot 10^{-6} \ mol \ m^{-2} s^{-1} \cdot 469000 \ J \ mol^{-1}$$

$$\Delta Q_P = -1.88 \ Wm^{-2}$$

Negative sign saying energy being stored into biochemical bonds via photosynthesis.

$$\Delta Q_P = 1.88 \ Wm^{-2}$$

b. [2] What fraction of Q* is ΔQ_P? Is this a substantial part of the surface energy budget? Discuss your answer.

$$\frac{1.88}{600} = 0.00313$$

No, it is not a substenial part of the energy budget because most of the energy from Q* is distributed to other heat fluxes. However ΔQ_P serves an important role in photosynthesis and carbon sequestion.

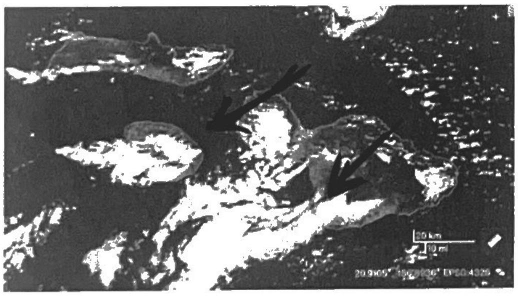
Rubric:

a – [2] approach, [1] numerical answer, [1] units

b – [1] numerical answer, [1] discussion.

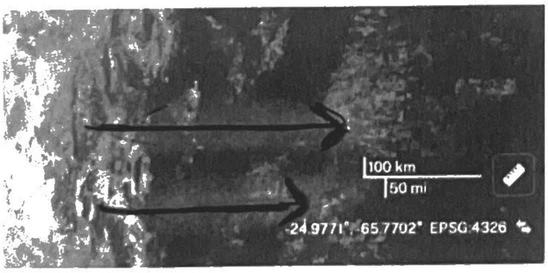
5. [3] Each of the following examples has a sharp gradient in topography. Based on distribution of vegetation, say something about the direction of the mean winds.

   a. Hawaii

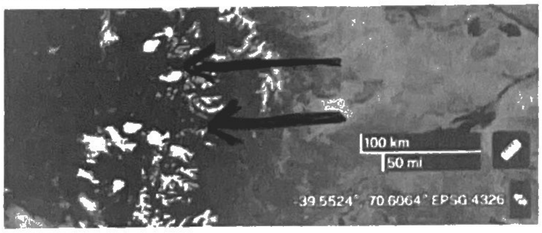


Assuming that all the locations are orographic (large mountains), so winds are forced over the mountains which leads to precipitation on the wind-ward side and a rain shadow in the downwind (leeward) side. The wind would be coming from the areas that are less dry and have more vegetation on the side. (arrows drawn where wind is coming from)

   b. South America:



   c. South America:



6. [12]
What shape would you expect flow for each of the following Richardson numbers, and why? Are there eddies? Describe/discuss what is physically driving the motion in each case.

a. $R_f = 50$ Stable

The flow is stable and dominated by thermal suppression. Little to no turbulence and mixing as the flow is very laminar. No eddies because the flow is very stable and laminar.

b. $R_f = 0.7$ neutral

The flow is marginally stable, with shear and buoyancy force competing. There is turbulence as areas with higher shear forces is more unstable. Eddies are small-scale but still able to form with low vertical mixing.

c. $R_f = -0.5$ neutral

The flow is slightly unstable as thermal suppression becomes weak and turns into weak thermal production. Mechanical production can increase causing more turbulence in the flow. Eddies are taller due to turbulence and buoyancy forces acting.

d. $R_f = -3$ unstable

The flow is very unstable as thermal production become big. The flow experiences strong overturning and mixing. Mechanical production is tiny compared to thermal production so turbulence is strong. Eddies form are large and unstable as mixing and turbulence are both high.

Rubric:
[1] per shape, [2] per reasoning

7. [12]

The August-Roche-Magnus equation for calculating the saturation vapour pressure p (in kilopascals, or kPa) of water in air as a function of temperature T (in degrees C) is:

$$p_v^* = 0.61094 \exp\left(\frac{17.625T}{T + 243.04}\right)$$

Relative humidity (RH) can be calculated as the ratio of actual water vapour to saturation water vapour pressure (RH = p_v / p_{sv}). Assuming a relative humidity of 60%, follow the below steps to use the linearized Penman model to estimate evaporation from a saturated surface where the surface temperature is T_0 = 25 degrees C and the air temperature is T_a = 20 degrees C.

a. [2] Calculate the saturation vapour pressure for both the surface temperature p^*_0 and the air temperature p^*_a.

$$p^*_0 = 0.61094 \exp\left(\frac{17.625(25)}{25 + 243.04}\right) = 3.162 \text{ kPa}$$

$$p^*_a = 0.61094 \exp\left(\frac{17.625(20)}{20 + 243.04}\right) = 2.333 \text{ kPa}$$

b. [2] Assuming 60% relative humidity, calculate the actual vapour pressure in the air, p_a.

$$RH = \frac{p_a}{p^*_a} \qquad p_a = RH \cdot p^*_a$$

$$p_a = 0.6 \cdot 2.333 \qquad p_a = 1.4 \text{ kPa}$$

c. [2] The ideal gas law tells us that pV = (m/M)*RT, where R is the ideal gas constant (8.31 J/K/mol), m is the mass of water present in a parcel of air and M is the molar mass of water (18.02 grams / mol). Rearrange this equation for ρ^*_a= m/v = ______, a density in kg/m³.

$$pV = \frac{m}{M}RT \quad \frac{V}{m} \cdot p = \frac{mRT}{MV} \quad \frac{V}{m}p = \frac{RT}{M} \quad \frac{V}{m} = \frac{RT}{pM}$$

$$\frac{m}{V} = \frac{pM}{RT}$$

d. [2] Substituting the saturation vapour pressure from (a) into the p term lets you solve for the saturation vapour density. Do this for the surface, and for the air, and calculate the actual vapour density of the air.

$\rho^*_a = 0.0173 \frac{kg}{m^3}$

$\rho^*_o = 0.023 \frac{kg}{m^3}$

$\rho_a = 0.0104 \frac{kg}{m^3}$

$\rho^*_a = \frac{2.333\ kPa \cdot 18.02\ g\ mol^{-1}}{8.31\ J K^{-1} mol^{-1} \cdot 293.15\ K} = \frac{2333\ kg\ m^{-1} s^{-2} \cdot 0.01802\ kg\ mol^{-1}}{8.31\ kg\ m^2 s^{-2} K^{-1} mol^{-1} \cdot 293.15\ K}$

$\rho^*_o = \frac{3.162 \cdot 18.02}{8.31 \cdot 298.15} = \frac{56.97924}{2477.6265} = 0.023$

$\rho_a = \frac{1.4 \cdot 18.02}{8.31 \cdot 293.15} = 0.0104$

e. [1] Calculate the vapour density deficit vdd_a.

$vdd_a = \rho^*_a - \rho_a$

$vdd_a = 0.0173 - 0.0104$

$vdd_a = 0.0069 \frac{kg}{m^3}$

f. [1] Calculate the linearized change in saturation vapour density with temperature, s:

$$s = \frac{\Delta \rho_v^*}{\Delta T}$$

$S = \frac{0.023 - 0.0173}{298.15 - 293.15} = 0.00114$

$S = 0.00114$

$\rho^*_{vo} - \rho_{va} = s(T_o - T_a) + vdd_a$

$0.023 - 0.0104 = s(5) + 0.0069$

$s = 0.00114$

g. [2] Assume an aerodynamic resistance for heat of r_{aH} = 100 s/m. Assume the ground heat flux is 20 W/m^2. Assume net radiation is 400 W/m^2. Estimate the latent heat flux.

8. [10]
Identify a microclimate (you may find one on/off campus, or use something like GoogleEarth). Make sure it has a distinctly different microclimate nearby (e.g. opposite sides of a hill, or opposite sides of a tree), to allow for easy comparison between two locations for the following questions.
   a. [1] Provide an image your microclimate.

Attached to the Submission

   b. [5] Speculate on how each term of the surface energy budget in your microclimate is modulated by the physical surface properties of the microclimate.

Grass has higher albedo meaning reflected solar radiation is higher. Reduces Q*. Open canopy in grassland allow for shortwave and long wave exchange with atmosphere. Forests tend to trap waves amongst their leaves. Grass land also have shallower roots, smaller leaves, leading to lower transpiration rates and causes lower latent heat flux.

   c. [4] Discuss the aerodynamic properties of your microclimate. Use terms and concepts from class to discuss how physical attributes of your microclimate interact with flow in the atmosphere (2 point per attribute paired with a discussion of the physics).
   For example:
      i. if you choose a hill, talk about how tall the hill is and how flow moves around your hill based on wind speed – relate to the Freude number.
      ii. Or, if you choose a grass/forest transition, talk about the aerodynamic roughness and discuss how wind speeds and momentum production change.
      iii. Or, talk about the Richardson number and how vertical motions over your microclimate might differ from neighbouring regions.
   This is not an exhaustive list.

Rubric:
a – [1] for photo
b – [1] per term of the surface energy budget
c – [2] per topic + relation to physical attributes of the system.

Wind speeds from a smooth to a rough surfaces slows as it reaches the forest boundary. It doesn't happen immediately due to intertia. Forest edges are very susceptible to damage due the high winds that hit it and is forced to slow down due to trees in the path of the flow. So the edge of forest is taking out that energy and slowing it down. The bottom of the wind profile decreases in speed as it hits rough surface. The Reynolds stress which are turbulent flows convective movement of momentum are highest when mean wind and roughness is high (at exchange point of rough & smooth surfaces)


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Image © 2024 Airbus
Lily of the Valley Trail (13)
Trail (13)
Google Earth
1985
Imagery Date: 7/24/2021
49°15'43.91" N 123°13'20.26" W elev 311 ft eye alt 1454 ft