McGill University
Knox / GEOG 321 / April 26, 2024
Climatic Environments

Final Examination

Name	Student #	
Signature	*for marking only* Marks	Grade

Write answers directly into space provided. Additional pages are not allowed and will not be marked. Scores are indicated in square brackets. The total score is 100 (Part A: 24, Part B: 16, Part C: 18, Part D: 42). Read all instructions in the beginning of each part carefully. Time allowed: 180 min.

Part A: Multiple choice questions

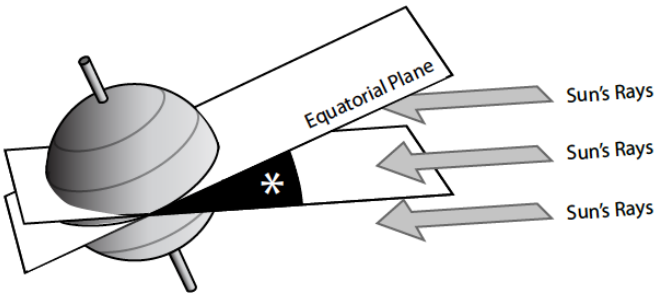
Solve <u>all</u> multiple choice questions. Check only one box per question. If you check none or multiple boxes, your answer will be invalid. Total: 24 marks (24% of the exam).

1. What does the term z_d in the logarithmic wind law below represent [2]

$$\overline{u} = \frac{u_*}{k} \ln(\frac{z - z_d}{z_0})$$

◯ Roughness length
◯ Friction velocity
◯ Zero-plane displacement
◯ Measurement height

2. What is the name of the angle (*) in the following figure? [2]



◯ Solar azimuth ◯ Declination ◯ Latitude ◯ Hour angle

3. Which term is <u>not</u> part of net ecosystem productivity (NEP)? [2]

◯ Gross Primary Productivity
◯ Heterotrophic respiration
◯ Heat of assimilation of carbon
◯ Ecosystem respiration

4. Which term is <u>not</u> part of the water balance of a land-surface? [2]
◯ Evapotranspiration
◯ Run-off ratio
◯ Change in storage
◯ Precipitation

5. Which term describes the friction velocity u_*? [2]

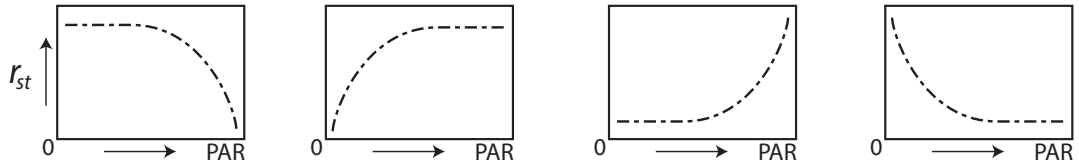
◯ τ^2 ◯ $K_M\, \partial u/\partial z$ ◯ $\sqrt{-\overline{u'w'}}$ ◯ $K_M\, \overline{u'w'}$

6. Which expression describes the latent heat flux density (Q_E) in $\mathrm{W\,m^{-2}}$? [2]

◯ $\rho_v\, L_v\, E$ ◯ $\rho_a\, c_p\, \partial\theta/\partial z$ ◯ $L_v\, \overline{w'\rho_v'}$ ◯ $\rho_a\, c_p\, \overline{w'T'}$

7. Which statement on turbulence in the atmospheric surface layer (SL) is correct? [2]
   - ◯ All turbulence in the SL is produced by buoyancy.
   - ◯ The typical size of eddies decreases with height above ground.
   - ◯ Mechanical production of turbulence dominates in the SL.
   - ◯ The turbulent kinetic energy in the SL increases with stability.

8. How does stomatal resistance of a leaf (r_{st}) change with PAR? [2]



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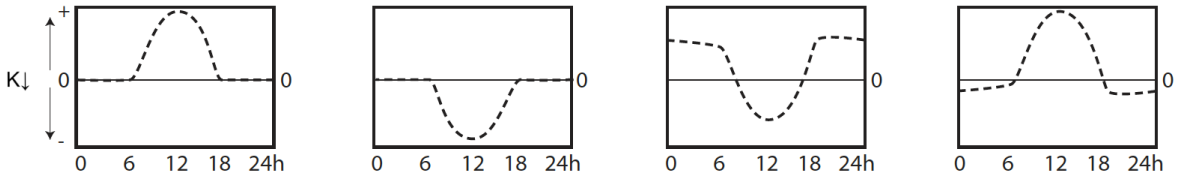
9. How do you expect incoming shortwave radiation ($K\downarrow$) to change with time over a 24h period? Assume summer, clear skies and a grass surface on UBC Totem Field. [2]

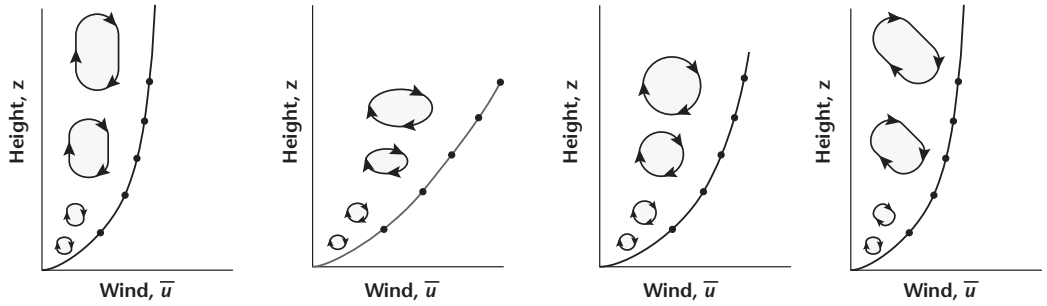


◯ ◯ ◯ ◯

10. UBC researchers have installed the following instrumentation above a forest clear-cut. What variable can be measured using this instrumentation? [2]

   - ◯ Evapotranspiration (E).
   - ◯ Net all-wave radiative flux density (Q^*).
   - ◯ Soil heat flux density (Q_G).
   - ◯ Interception (P_I).

11. Which sketch shows the eddy shape and the wind profile under stable conditions? [2]



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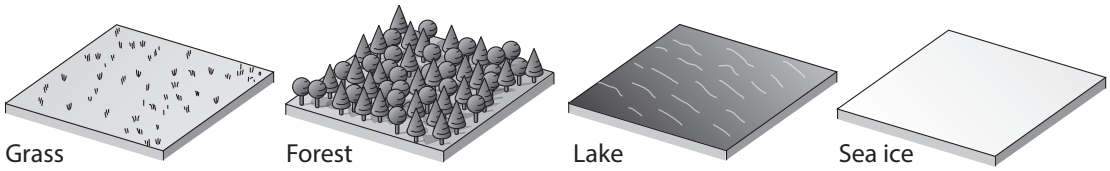
12. Which of the following surfaces has the largest aerodynamic roughness length z_0? [2]



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Part B: Terminology questions

Answer <u>all</u> of the following short answer questions in 5 words or less, or provide a formula. Note: simply state the correct terminology, equation, or range (with units). Do not write in full sentences. Total: 16 marks (16% of the exam).

1. Name a term of your choice that is part of the surface energy balance equation. [2]

2. Which wavelengths of the electromagnetic radiation spectrum fall within the shortwave band? [2]

3. What is the most effective transfer mechanism for sensible heat in the atmospheric boundary layer? [2]

4. What is the name of the term $\sqrt{\overline{T'^2}}$ if T is air temperature? [2]

5. List a method of your choice that can be used to measure evapotranspiration of a crop. [2]

6. Write down the Reynolds decomposition for any variable of your choice. [2]

7. How do you call an event in a turbulent flow that transports excess momentum from a high velocity region to a low velocity region? [2]

8. Name a process that can produce turbulence in the atmosphere. [2]

Part C: Define and Compare Terms

Answer only three of the following five questions. For each of the three questions you choose to answer, briefly define each term and explain the differences between the two terms in italics. Only the first three questions with witting will be marked.. Total: 18 marks (18% of the exam).

1. Define *advection* and *entrainment* and briefly explain the difference between these two terms. [6]

2. Define *throughfall* and *stemflow* and briefly explain the difference between these two terms. [6]

3. Define *convective boundary layer (CBL)* and *stable boundary layer (SBL)* and briefly explain the difference between these two terms. [6]

4. Define *atmospheric boundary layer depth* and *damping depth* and briefly explain the difference between these two terms. [6]

5. Define *respiration* and *transpiration* and briefly explain the difference between these two terms. [6]

Part D: Problem questions

Answer only three out of the following five questions. Again: the first three questions with any answer written into the space provided will be marked, hence solving more than three questions is not to your advantage. Total: 42 marks (42% of the exam).

1. Stomatal resistance r_s is key control affecting land-atmosphere exchange. (a) Define in your words what r_s describes? (b) What are the units of r_s, and (c) list four environmental controls that affect r_s and describe with words or draw a diagram showing how an increase in each environmental control would impact r_s. [14]

2. The questions below are related to the Fourier heat conduction equation in 1-D:

$$T(z,t) = \underbrace{\overline{T_o} + \Delta T_0 \times \exp\left[-z\left(\frac{\omega}{2\kappa}\right)^{1/2}\right]}_{\text{TermA}} \times \underbrace{\sin\left[\omega\, t - \left(\frac{\omega}{2\kappa}\right)^{1/2} z\right]}_{\text{TermB}}$$

Note that you do not need this equation to answer the questions below, but you might find it helpful when answering some of the questions.

(a) Describe or draw how the amplitude of the temperature wave varies with depth. [3]

(b) At a depth of 10 cm in the soil, is the amplitude of the diurnal wave larger or smaller in a soil with a large thermal diffusivity (κ_s)? [2]

(c) Describe how the phase shift (time lag) varies with depth. [3]

(d) Is the phase shift at a depth of 30 cm larger or smaller for soils with a large κ_s? [2]

(e) Approximately how far down does the surface temperature wave move down into the soil in response to radiative forcing at the (i) daily and (ii) annual time period? [4]

3. A typical eddy covariance set-up to measure terms of the surface energy balance (SEB) - such as the one you saw in the lab - is capable of measuring the following turbulent fluctuations: u', v', w', T' and ρ_v', where u, v and w are the components of the three-dimensional wind vector (in $\mathrm{m\,s^{-1}}$), T is temperature (in K) and ρ_v is the absolute humidity (in $\mathrm{g\,m^{-3}}$). (a) How many unique covariances can you form between the variables measured? Write all unique covariance terms down. (b) List two covariances of your choice that relate directly to terms of the SEB. For those, provide an equation how the covariance translates to the terms of the SEB. [14]

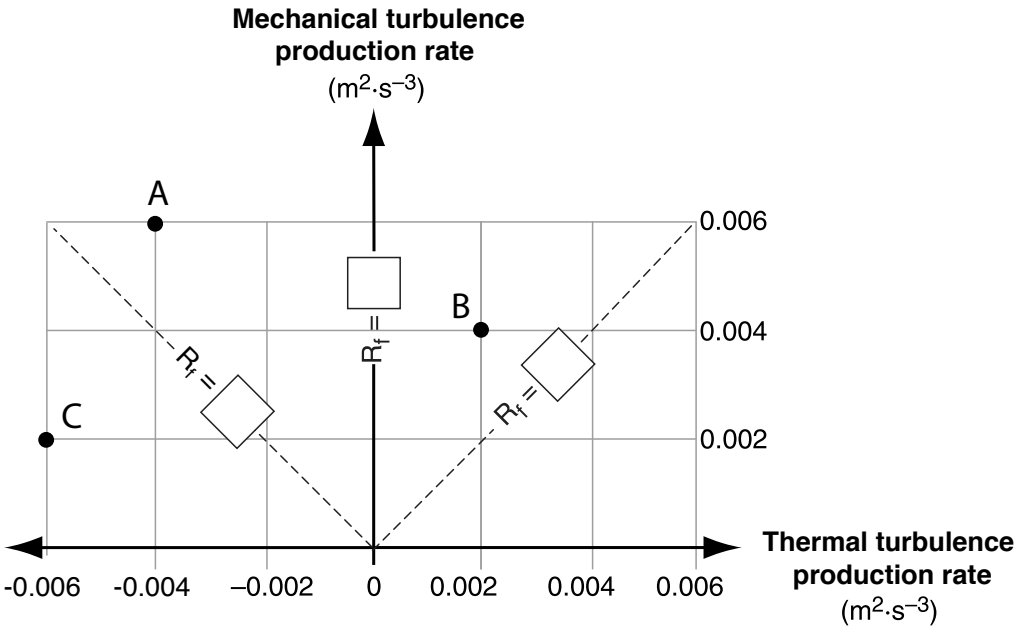
4. The graph below illustrates the concept of the flux Richardson number (Rf).

(a) What does Rf describe? [5]

(b) Indicate in the graph, where you expect a laminar flow, and where you expect a turbulent flow? [2]

(c) Which point, A, B, or C, experiences highest turbulent kinetic energy (TKE)? [3].

(d) Insert into the three boxes the proper Rf values [6]



5. Demonstrate or describe how the energy balance, water balance and carbon balance are linked. Make sure to include all terms in the energy, water and carbon balance. You can explain how they are linked using words or equations, but make sure to *define all symbols*. [14]

[End of Exam - 12 pages]