Midterm Examination

Name	Student #

Signature	*for marking only* Marks	Grade

Write answers directly into the space provided. Additional pages are not allowed and will not be marked. There are 7 pages. Make sure you have all. Marks are indicated in square brackets. Total possible marks are 102 (Part A: 36, Part B: 24, Part C: 42). Time allowed - 80 min.

Part A: Multiple choice questions

Solve __all__ multiple choice questions. Check only one box per question. If you check none or multiple boxes, your answer will be invalid and you receive zero points.

1. In which of the following times is the Sun always at its highest point at noon (12:00) in Montreal? [4]

   ◯ LMST   ◯ EST   ⊗ LAT   ◯ UTC

2. Which layer of the atmosphere is primarily influenced by the Earth's surface? [4]

   ◯ Stratosphere   ◯ Mesosphere   ⊗ Troposphere   ◯ Thermosphere

3. How is net long-wave radiation defined? [4]

   ◯ $L\uparrow/L\downarrow$ ⊗ $\varepsilon_o L\downarrow -\varepsilon_o \sigma T_o^4$ ◯ $(1-\alpha)L\downarrow$ ◯ $L\downarrow(1-\varepsilon_o)+\varepsilon_o\sigma T_o^4$

4. A researcher is studying two different surfaces: a dry, sandy desert and a wet, vegetated field. On a particular day, the net radiation (Q*) for both surfaces is the same. The sensible heat flux (Q_H) for the desert is 200 W m^{-2}, and the latent heat flux (Q_E) for the field is 150 W m^{-2}. Which of the following statements is true regarding the Bowen ratios (β) of the two surfaces? [4]

   ⊗ The Bowen ratio for the desert is higher than that for the field because the desert has a higher sensible heat flux.
   ◯ The Bowen ratio for the field is higher than that for the desert because the field has a higher latent heat flux.
   ◯ The Bowen ratios for both surfaces are equal because the net radiation is the same.
   ◯ The Bowen ratio for the desert is lower than that for the field because the desert has a lower latent heat flux.

5. Which of the following is NOT a mode of energy transport in the Earth-Atmosphere system? [4]

   ◯ Conduction   ◯ Convection   ⊗ Reflection   ◯ Radiation

6. What is the dominant cause for the production of turbulence over an array of buildings at night? [4]

   ◯ Isotropy   ◯ Sensible heat   ⊗ Form drag   ◯ Thermal admittance

7. Consider two different surfaces: a snow-covered field and a dense forest. The snow-covered field has a high albedo, while the dense forest has a low albedo. If both surfaces receive the same amount of incoming solar radiation, which of the following statements is true regarding the net shortwave radiation (K*) received by each surface? [4]

⊘ The net shortwave radiation received by the snow-covered field is higher than that received by the dense forest.

⊗ The net shortwave radiation received by the dense forest is higher than that received by the snow-covered field.

⊘ The net shortwave radiation received by both surfaces is the same because the incoming solar radiation is equal.

⊘ The net shortwave radiation received by the snow-covered field is equal to the reflected shortwave radiation from the dense forest.

8. What characterizes the flow within the laminar boundary layer (LBL)? [4]
⊘ Turbulent flow with eddies.
⊗ Smooth flow with parallel streamlines.
⊘ Chaotic flow with cross-stream components.
⊘ Random flow with no distinct layers.

9. Reynolds averaging is a technique used in fluid dynamics to separate the instantaneous measured velocity into mean and fluctuating components. Given the instantaneous velocity u, it can be expressed as:

$$u = \bar{u} + u'$$

where $\bar{u}$ is the mean velocity and u' is the fluctuating component.

Which of the following statements is true? [4]

⊗ The mean of the fluctuating component u' over time is zero.
⊘ The mean of the fluctuating component u' over time is equal to the mean velocity $\bar{u}$.
⊘ The mean velocity $\bar{u}$ is always greater than the fluctuating component u'.
⊘ The fluctuating component u' is always positive.

Part B: Short answer questions.

Answer only three out of these four short answer questions. Note: 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.

1. Briefly describe the concept of *thermal admittance* and its relationship to other thermal properties of soil. Don't forget to include the units of thermal admittance. Briefly explain its significance in soil temperature variations. [8]

Thermal admittance (μ) is a measure of a material's ability to accept or release heat (or definition similar to what is covered in Lect 11). The units are J m^{-2} K^{-1} s$^{-1/2}$ [1 point definition, 1 point units].

It is defined as the square root of the product of thermal conductivity (k) and heat capacity (C) [1 point for describing or writing the equation]:

$$\mu = \sqrt{kC}$$

Thermal Conductivity (k) is the ability of a material to conduct heat [1]. Note, units do not need to be included.

Heat Capacity (C) The amount of heat required to raise the temperature of a unit volume of the material by one degree Kelvin [1]. Note, units do not need to be included.

Significance in Soil Temperature Variations [3 total - 1.5 for a description of high thermal admittance and 1.5 for a description of low thermal admittance]. Examples could include the following:

Heat Exchange Efficiency:

Soils with high thermal admittance can efficiently exchange heat with the atmosphere. This means they can quickly absorb heat during the day and release it at night, leading to smaller temperature variations. [1.5]

Soils with low thermal admittance have less efficient heat exchange, resulting in larger temperature variations as they cannot quickly absorb or release heat. [1.5]

Surface Temperature Stability:

High thermal admittance leads to more stable surface temperatures. For example, wet soils or soils with high moisture content have higher thermal admittance, which helps moderate temperature fluctuations. [1.5]

Low thermal admittance, such as in dry soils, results in more extreme temperature fluctuations because the soil cannot buffer the heat changes effectively. [1.5]

2. Identify and briefly describe the *four* main components of the *surface energy balance equation*. Also, indicate the units of each of the terms. [8]

   The explanations should be close to the following:

   - Net Radiation ($Q*$ or Rn) [1]: This is the difference between incoming and outgoing radiation at the surface. It includes both shortwave (solar) and longwave (terrestrial) radiation. [1] Note students need to include both shortwave and longwave in their answer otherwise -1 point.
   - Sensible Heat Flux (Q_H or H) [1]: This represents the heat transfer between the surface and the air due to temperature differences. It is the energy used to heat the air. [1]
   - Latent Heat Flux (Q_E or LE) [1]: This is the energy associated with the phase change of water, such as evaporation/transpiration/evapotranspiration or condensation. It is the energy used to change the state of water. [1]
   - Ground Heat Flux (or soil heat flux) (Q_G or G) [1]: This is the heat transfer into or out of the ground. It represents the energy that is conducted into the soil or substrate. [1] Note that the heat is transfered via conduction. If they say convection as in Q_H or Q_E then -0.5 point.

   The surface energy balance equation can be expressed as:
   $Q* = Q_H + Q_E + Q_G$

3. Briefly describe the factors that contribute to the *mechanical* production of turbulence in the atmospheric boundary layer. [8]

   Mechanical turbulence in the ABL is caused by instabilities arising from strong mean velocity gradients [2] (need to note something about differences in wind speed with height or direction), which in turn are caused by:

   - (Surface) skin friction [1]. Air layers are slowed by skin friction at surface, hence layers above have different speed [1]
   - Form drag (obstacles) [1]. Obstacles block flow and pressure differences cause overturning and flow separation [1]. Note as long as the description is along those lines you can give them 1 point.
   - shear flow [1]. Two air layers with different speeds and/ or direction [1]

4. Assuming that a surface has an emissivity ($\varepsilon_{o,LW}$) of 0.8, what is the absorptivity of the surface in the long-wave band ($\zeta_{o,LW}$), and how much of the incoming long-wave radiation ($L\downarrow$) is reflected from the surface assuming that $L\downarrow$ is 100 W m^{-2} [8]?

   $\varepsilon_{o,LW} = \zeta_{o,LW}$ [2], hence $\zeta_{o,LW} = 0.8$ [2].

   Also, $\varepsilon_{o,LW} = \zeta_{o,LW}$, hence $\alpha_{o,LW} = 0.2$ (i.e., $(1 - \varepsilon_{o,LW})$) [2].

   Hence reflection in the LW is: $(1 - \varepsilon_{o,LW})L\downarrow = \alpha_{o,LW}L\downarrow = 0.2$ x 100 W m^{-2} = 20 W m^{-2} [2]. Note -1 point is units are missing

Part C: Problem questions

*Answer **three** out of the following four questions. Again: the first four questions with any answer written into the space provided will be marked, hence solving more than four questions is not to your advantage.*

1. How do the components of the surface energy balance (i.e. Q_H, Q_E, Q_G) change after a grassland that experienced drought finally receive rain?

   (a) In the table below, compare the components of the surface energy balance. Fill-in the boxes below with (=,<, or >). Briefly explain each postulated change (or explain why no change is expected). [9]

Dry grassland		Wet grassland	Brief explanation
Q_H	>	Q_H	During the drought, Q_H is typically high because the dry soil and vegetation lead to higher temperatures and more heat being transferred to the air. After the rain, Q_H decreases as the soil and vegetation cool down due to the added moisture and reduced temperature gradients.
Q_E	<	Q_E	During the drought, Q_E is low because there is limited moisture available for evaporation. After the rain, Q_E increases significantly as the added water from the rain evaporates, transferring energy from the surface to the atmosphere in the form of latent heat.
Q_G	<	Q_G	During the drought, Q_G is relatively low because the dry soil has a lower heat capacity and less energy is conducted into the ground. After the rain, Q_G increases as the wet soil has a higher heat capacity and more energy is conducted into the ground.

   Include [3] marks per term. [1] for the correct sign (=,<, or >) and [2] for the correct explanation.

   (b) How would that impact the bowen ratio β (i.e. would you expect the bowen ratio to be higher, lower or stay the same and why) [5]?

   The bowen ratio ($\beta = Q_H/Q_E$) [2 point for the equation] would be lower after the dought since Q_E would be higher and Q_H would be lower [3].

2. The graphs below shows how soil thermal conductivity (k) varies with increasing soil water content for a *mineral* and an *organic* soil (θ_w).
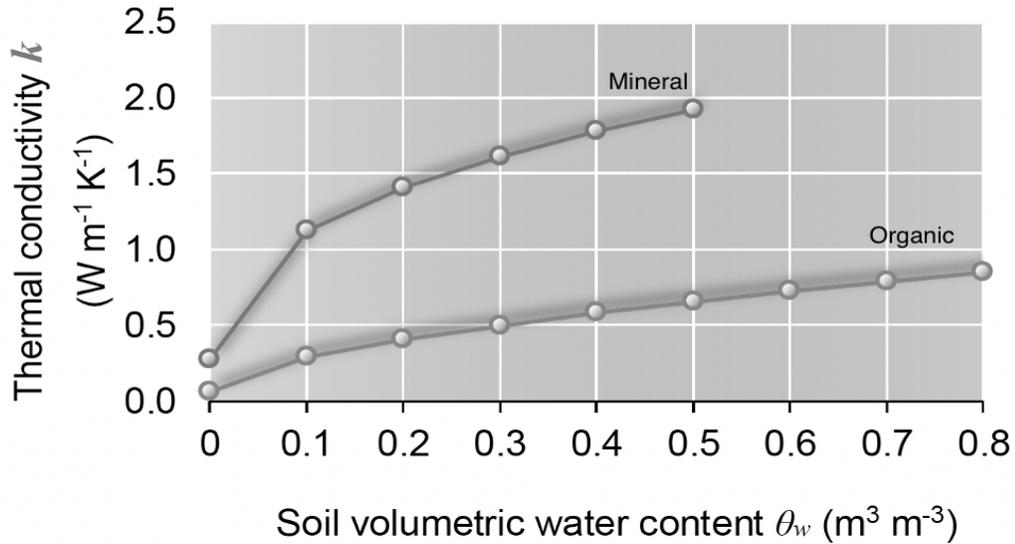
(a) Indicate which line correcponds to the mineral soil and which one corresponds to the organic soil. Note that you can label them directly on the graph. [4]

See figure above

(b) Justify your answer in (a). [6]

Mineral matter is a good conductor [2], hence it has a higher thermal conductivity than organic matter [2]. Organic soils have a higher porosity and hence the grater pore space means lower thermal conductivity as air is a very poor conductor [2]. Note they could also include values such as 'Air has low thermal conductivity (0.025 W/m·K), much lower than soil minerals (2-5 W/m·K) or water (0.6 W/m·K).'

(c) Briefly discuss and explain the relationship between k and θ_w. [4]

There is a non-linear relation exists between k and soil water content [1]

Adding water to dry soil initially causes k to increase rapidly – rapid increase in area of contacts between soil particles resulting from water film. [2]

As more water is added, k increases less rapidly – area of contacts increases more slowly per unit of water added (i.e. diminishing returns). [1]

3. Net radiation ($Q*$) can be written as:

$$K{\downarrow}(1\text{-}\alpha) + \varepsilon_o L{\downarrow} - \varepsilon_o \sigma T_o^4$$

(a) Which terms in this equation are related to surface properties? [6]

α (albedo) [2], ε_o [2] (surface emissivity), and T_o^4 (surface temperature) [2].

(b) Which surface properties in the net all-wave budget tend to partially offset each other? What is the implication for $Q*$? [4]

α [1] and T_o^4 [1]. These two terms offset each other since if the surface has a lower albedo it will absorb more radiation (i.e. $K{\downarrow}(1\text{-}\alpha)$, but this in turn will typically result in a warmer surface and hence $\varepsilon_o \sigma T_o^4$ will be larger (i.e. greater emitted longwave radiation). Therefore, increase absorption of shortwave radiation will be offset by higher longwave emission, lessening the range in $Q*$ [2].

(c) Which terms are controlled by solar geometry and the atmosphere? How do clouds impact these terms? [4]

$K{\downarrow}$ [1] and $L{\downarrow}$ [1]. Clouds decrease $K{\downarrow}$ [1] and increase $L{\downarrow}$ [1], thereby reducing extremes.

$\rightarrow$ Lecture 9 slide 8.

4. In class, we discussed the spectral reflectivity of leaves and how we can use this information in remote sensing applications. Below are two spectra, one is from a green leaf and one is from an autumn leaf.
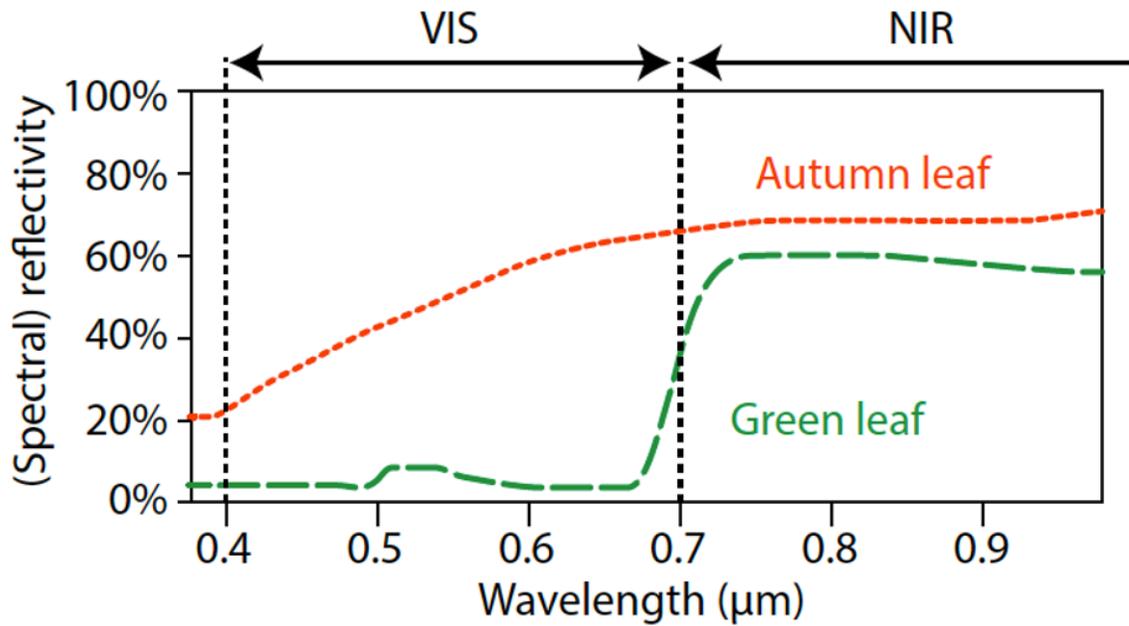
(a) How would you label the y-axis of the graph? [2]

Can say 'Spectral reflectivity' or just 'reflectivity' or α_λ to get full marks. Note that 'Albedo', 'Reflectance', and 'reflection coefficient' are incorrect and result in zero marks.

(b) Identify which wavelengths along the x-axis correspond to visible (VIS) and near infrared (NIR) portion of the electromagnetic spectrum. Also, which wavelengths correspond to Photosynthetically active radiation (PAR)? [3]

VIS = 0.4 to 0.7 μm [1]; NIR = 0.7 μm to end of graph (and beyond) [1]; PAR = 0.4 to 0.7 μm (same as VIS)[1]. Note -1 point total if units are missing

(c) Attribute the green and autumn leaf to the corresponding curves (A or B), and briefly justify your choice. [3]

Get [1] for correct choice (see graph) and [2] for the correct explanation (i.e., the green leaf follows the typical reflectivity pattern with a peak in the green and NIR [1], while the autumn leaf doesn't follow the typical reflectivity pattern of a healthy leaf [1]).

(d) Briefly say how the difference in the curves may benefit the remote sensing of land surfaces. Would the green or autumn leaf have a greater normalized difference vegetation index (i.e., NDVI)? Briefly justify your choice. [6]

We can measure reflectivity in the VIS and NIR and based on the difference determine whether vegetation is healthy (e.g. different values of NDVI) [4].

The green leaf [1] would have the greater NDVI value since there's a greater difference between NIR and red wavelengths [1] (or vice versa for the autumn leaf).

They can also include the equation for NDVI = (NIR-RED)/(NIR+RED) and justify it using approximate values from the graph.