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 8 pages. Make sure you have all. Marks are indicated in square brackets. Total possible marks are 100 (Part A: 32, Part B: 28, Part C: 40). 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 ◯ PST ◯ UTC ⊗ LAT

2. Which is the most dominant energy transfer process in well drained soils? [4]

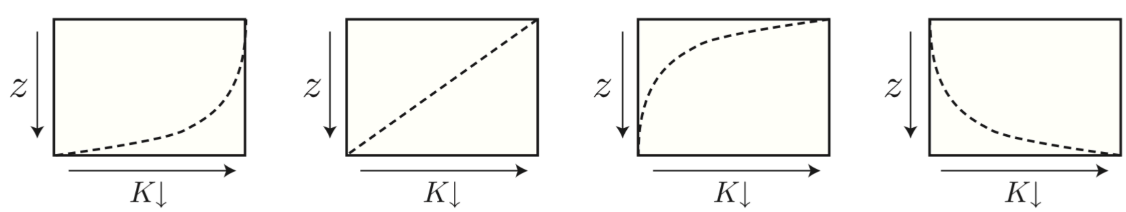
   ⊗ Conduction ◯ Convection ◯ Latent heat ◯ Radiation

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. Which of the following soils has the lowest thermal diffusivity κ [4]
   ⊗ A soil with $k = 0.1$ W m^{-1} K^{-1} and C = 4 MJ m^{-3} K^{-1}
   ◯ A soil with $k = 0.1$ W m^{-1} K^{-1} and C = 0.25 MJ m^{-3} K^{-1}
   ◯ A soil with $k = 1$ W m^{-1} K^{-1} and C = 4 MJ m^{-3} K^{-1}
   ◯ A soil with $k = 1$ W m^{-1} K^{-1} and C = 0.25 MJ m^{-3} K^{-1}

5. How does K↓ change with depth z in a lake? [4]

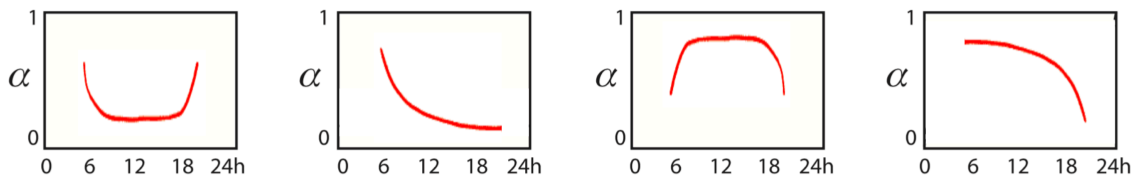


   ◯ ◯ ⊗ ◯

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. For Montreal, how do you expect the albedo of an open water surface to change over a clear-sky day? [4]



⊗ ○ ○ ○

8. Which statement about the laminar boundary layer (LBL) thickness is correct? [4]
○ The LBL thickness shrinks with increasing object size.
○ The LBL thickness increases with increasing wind speed.
⊗ The LBL thickness shrinks with increasing buoyancy.
○ The LBL thickness increases with increasing roughness of the surface.

Part B: Short answer questions.

Answer only four out of these five short answer questions. Note: 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. Briefly explain the difference between *mechanical* and *thermal* production of turbulence. [7]

   Mechanical production of turbulence is caused by *form drag* [1.5], *skin drag* [1.5] (or shear of wind) and transforms *mean kinetic energy* to turbulent kinetic energy [1]. Thermal production of turbulence is caused by *surface heating* (or *buoyancy*) [1.5] and transforms heat* [1.5] to turbulent kinetic energy.

   *alternatively can say: caused by *mean velocity gradients* between *warm air plumes* rising up in the atmospheric boundary layer and ambient air [1].

   → See Lecture 16, slides 7-20.

2. Briefly explain the difference between the *damping depth* in a soil and *thermal admittance*. [7]

   The damping depth in a soil is the depth at with the *surface temperature* [1] wave reaches 37%[1] [2] of the amplitude at the surface. Thermal admittance μ is the ability of a surface or system to accept or release heat [2] following a change in (soil) heat flux ∂QG/∂t[2] [2]

   [1] Can also say to e^{-1} or 1/e.
   [2] Can also say it is a measure of the ability of a surface to accept or release heat since it expresses the temperature change produced by a given heat flux change.

   → See Lectures 12 and 11.

3. Briefly explain the difference between *shortwave* and *longwave radiation*. [7]

   Both refer to electromagnetic radiation, but short-wave radiation is *solar radiation. i.e. emitted by the Sun* [2] and is in the *waveband 0.15 μm* [1] *to 3* μm [1] (or 150 to 3000 nm). Long-wave radiation is mainly emitted from *objects on Earth* [2] *(atmosphere, clouds, land, vegetation, ocean, etc.)*, and is in the *waveband 3 μm to 100 μm* [1].

   → See Lectures 3 and 6.

4. Briefly describe two ways in which the *soil temperature wave* changes with depth as it moves down in response to radiative forcing at the surface, and how the *radiative flux density* changes with depth in water. [7]

   The *amplitude* [1.5] decreases *exponentially* [1.5] and *phase shift (time lag)* [1.5] increases *linearly* [1.5]. The radiative flux density decays *exponentially* [1] with depth.

   → Lectures 12 and 13.

5. Assuming that a surface has an emissivity ($\varepsilon_{o,LW}$) of 0.9, what is the reflectivity of the surface in the long-wave band ($\alpha_{o,LW}$) [3], and how much of the incoming long-wave radiation (L↓) is reflected from the surface assuming that L↓ is 100 W m^{-2} [7]?

   $\alpha_{o,LW}$ = 1 - $\varepsilon_{o,LW}$, hence $\alpha_{o,LW}$ = 1 - 0.9 = 0.1 [3].

   Reflection in the LW is: (1 - $\varepsilon_{o,LW}$)L↓ = $\alpha_{o,LW}$L↓ = 0.1 x 100 W m^{-2} = 10 W m^{-2} [4, with 1 point for the correct units].

   → See Lecture 7 slides 12 and 18.

Part C: Problem questions

Answer ***four*** *out of the following five 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). [6]

Dry grassland		Wet grassland	Brief explanation
Q_H	>	Q_H	Sensible heat flux density will be larger for the dry grassland than the wet grassland since there is less moisture available for evapotranspiration
Q_E	<	Q_E	Latent heat flux density will be lower for the dry grassland than the wet grassland since there is less moisture available for evapotranspiration
Q_G	>	Q_G	Soil heat flux density (or storage flux density in soil) will be larger for the dry grassland than the wet grassland since the dry grassland soil has a larger thermal conductivity, and likely larger temperature gradient between temperatures at the surface vs subsurface. Note that something realistic related to soil thermal properties and the temperature gradient is acceptable.

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

   The bowen ratio (β) would be higher for the dry grassland vs wet grassland [1] since Q_E would be lower and Q_H would be higher for the dry grassland and therefore $\beta = Q_H/Q_E$ [1].

   (c) Name and describe one other term in the surface energy balance that we would need to consider if the grassland were covered in snow [2]?

   Acceptable answers (only need to include one for full marks):

   The net heat storage term (ΔQ_s) then represents the convergence or divergence of sensible heat fluxes within the volume

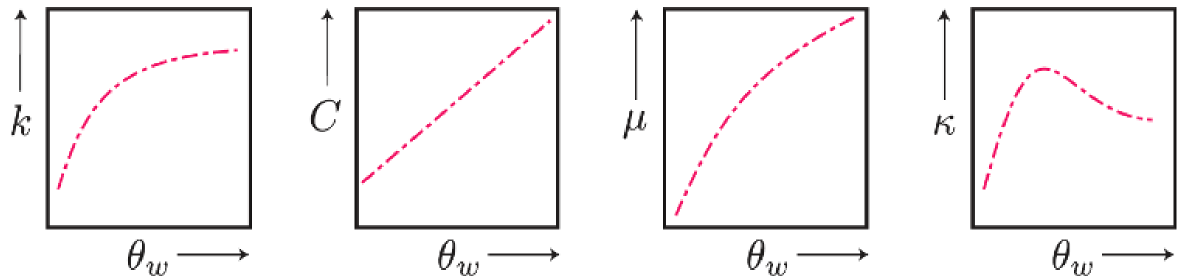
   ΔQ_M which is the latent heat storage change due to melting or freezing.

   Q_R heat supplied by rain if its temperature is greater than that of the snow.

   → See Lectures 3 and 13.

2. The graphs below show how soil thermal properties (i.e., C - heat capacity, k - thermal conductivity, κ - thermal diffusivity, μ - thermal admittance) vary with increasing soil water context (θ_w).

   (a) Indicate which soil thermal property corresponds to each of the graphs. [4]:



   (b) Briefly discuss the shape of each of the curves. [4]

   k (thermal conductivity) is non-linear [0.5] because of non-linear increase of contact area between soil grains as θ_w increases [0.5].

   C is linear [0.5] because of the linear increase of mass of water with increasing θ_w [0.5].

   $\mu = \sqrt{kC}$ and as the product of the two increases always (both get higher) [0.5]. Not linear, because k levels off [0.5].

   μ = k/C increases first, when the increase in k with θ_w is faster than in C [0.5]. Later, the increase in k with θ_w is slow, and C keeps increasing at the constant rate, so μ can decrease [0.5].

   (c) What is the slope of the line in B? [2]

   The slope of the line is the heat capacity of water C_w. This can be seen from the equation: $C_{soil} = C_w\theta_w + C_m\theta_m$ for the mineral soil and $C_{soil} = C_w\theta_w + C_o\theta_o$ for the organic soil. These equations are of the form y = mx + b, where y is C_{soil}, x is θ_w, and b is $C_{m,o}*\theta_{m,o}$, and therefore the slope (m) is C_w.

   → See Lectures 10 and 11.

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? [3]

α (albedo) [1], ε_o [1] (surface emissivity), and T_o^4 (surface temperature) [1].

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

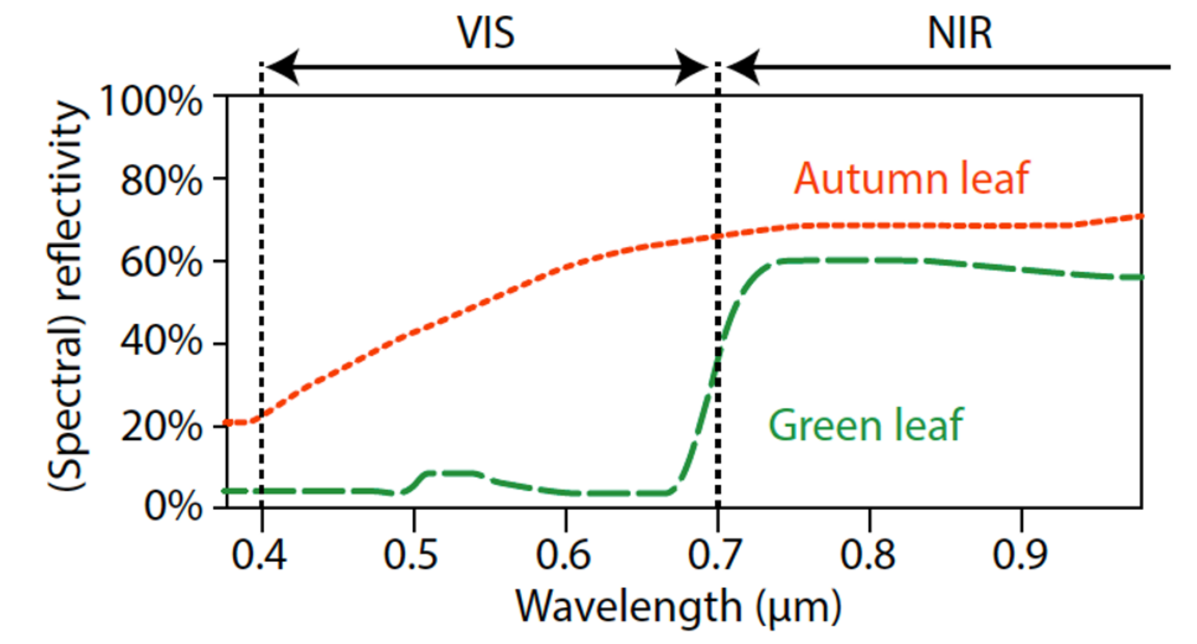
α [1] and T_o^4 [1]. These two terms offset each other since if the surface has a lower albedo it will absorb more radiation (i.e. $K\downarrow(1\text{-}\alpha)$, but this in turn will typically result in a warmer surface and hence $\varepsilon_o \sigma T_o^4$ will be larger (i.e. greater emitted longwave 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? [3]

K↓ [1] and L↓ [1]. Clouds decrease K↓ [0.5] and increase L↓ [0.5], thereby reducing extremes.

→ 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? [1]

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; NIR = 0.7 μm to end of graph (and beyond); PAR = 0.4 to 0.7 μm (same as VIS)

(c) Attribute the green and autumn leaf to the corresponding curves (A or B), and briefly justify your choice. [2]

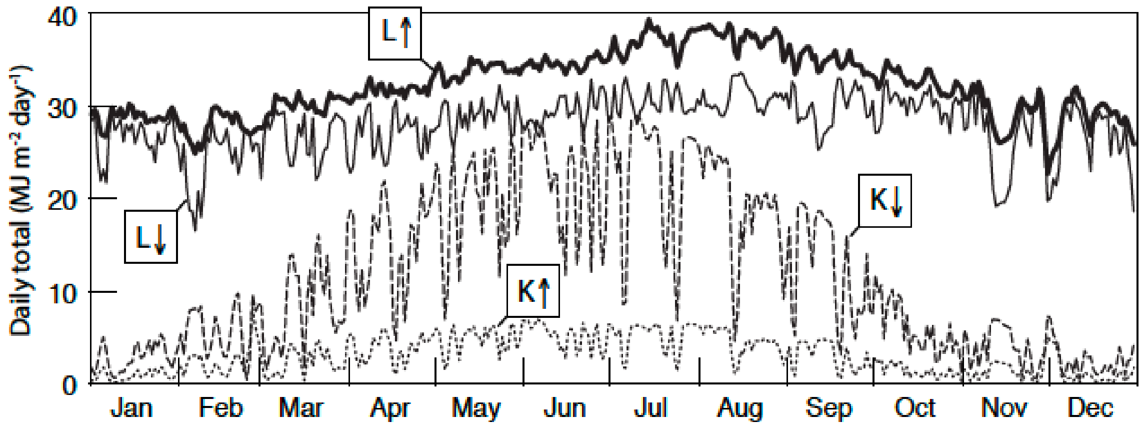
Get [1] for correct choice (see graph) and [1] for the correct explanation (i.e., the green leaf follows the typical reflectivity pattern with a peak in the green and NIR, while the autumn leaf doesn't follow the typical reflectivity pattern of a healthy leave).

(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. [4]

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) [2]. The green leaf [1] would have the greater NDVI value since there's a greater difference between NIR and red wavelengths [1]. They can also include the equation for NDVI = (NIR-RED)/(NIR+RED) and justify it using approximate values from the graph.

→ Lecture 06.

5. The graph below shows the daily totals of all four components of the radiation balance measured at a research station over the course of a year.



(a) Fill in the boxes with the name of the appropriate radiant flux densities, and justify your choice. [6]

Receive [0.5] for each correctly labelled trace.

Receive [1] for each correct justification. Correct justifications include:

$K_{\uparrow}$ shows strong annual course [1]. $L_{\downarrow}$ originates from an atmosphere that is on average cooler than surface [0.5], hence is lower than $L_{\uparrow}$ [0.5]. Always: $K_{\downarrow} > K_{\uparrow}$ [1]. Could also note that $K_{\uparrow}$ is a fraction of $K_{\downarrow}$ and is controlled by the albedo of the surface [1].

(b) What are the instruments that measure each of the components? [2]

We need two pyranometers [1] (one facing up and one facing down) and two pyrgeometers [1] (one facing up and one facing down)(Note: we cannot use a regular net radiometer to separate into the four components, unless you say it is a 4-component net radiometer.)

(c) When during the year (month), is Q* most negative? When is it most positive? [2]

Q* is highest in June or July [1]
Q* is lowest in Nov or Dec or Jan or Feb [1]
Here are the exact values (you cannot calculate this):

Month	Q^* (MJ m^{-2} day^{-1})
Jan	-0.2
Feb	-0.2
Mar	2.6
Apr	6.3
May	10.2
Jun	11.8
Jul	11.2
Aug	8.1
Sep	4.6
Oct	1.9
Nov	-0.4
Dec	-0.9

→ Lecture 8 and Lecture 9 (field visit) and corresponding reading package.

END OF EXAM