The University of British Columbia
Christen / GEOB 300 / October 11, 2013

Answer Key - Midterm Examination 2013

Part A: Multiple choice questions

1. *Name the part of the atmosphere that does <u>not</u> experience a diurnal variation in temperature, humidity and stability. [4]*

   ○ Boundary-layer ○ Troposphere ⊗ Free atmosphere ○ Mixed layer

   The 'free atmosphere' refers to the part of the atmosphere that is not directly coupled with the surface. Its complement is the 'boundary-layer', i.e. the part that does show a diurnal variation in temperature, humidity and stability. The upper part of the daytime well-mixed boundary-layer is also called 'mixed layer' (see later). The 'troposphere' encompasses both, the boundary-layer and the free atmosphere, i.e. troposphere = boundary layer + free atmosphere.

   → Lecture 1, Slide 21

2. *Assume that all of the following surfaces receive the same incoming radiative fluxes. Which surface will experience the highest amplitude in surface temperature T_0 over the course of a day? [4]*

   ○ White concrete ⊗ Black styrofoam ⊗ Black concrete ○ White styrofoam

   To reach a high amplitude (large variation) in surface temperature T_0 we need a surface with a low thermal admittance μ (styrofoam < concrete) and also a surface that has a low albedo α to absorb most of the solar irradiance. <u>Black styrofoam</u> [4] has a low α and a low μ, while white styrofoam has a high α and a low μ, black concrete a low α and a high μ and white concrete a high α and a high μ. A complicating factor is that, given enough turbulence, the high T_0 of the styrofoam will be more readily taken up by the atmosphere, hence <u>also the black concrete</u>, which can store more heat over the course of the day, is counted as a correct answer [4].

   → Lecture 6, Slide 15 and Lecture

3. *Which thermal property has the units* $\mathrm{W\,m^{-1}\,K^{-1}}$*? [4]*

   ○ Thermal diffusivity ⊗ Thermal conductivity ○ Thermal admittance ○ Thermal capacity

   The thermal conductivity is the property that describes the ability to conduct heat by molecular motion across a given temperature gradient (constant of proportionality in Fourier's Law). Its units are energy (J) conducted per second ($\mathrm{s^{-1}}$) and per meter ($\mathrm{m^{-1}}$) for a given gradient in Kelvin ($\mathrm{K^{-1}}$), hence $\mathrm{J\,s^{-1}\,m^{-1}\,K^{-1}} = \mathrm{W\,m^{-1}\,K^{-1}}$.

   → Lecture 11, Slide 12

4. *Which process is <u>not</u> relevant for energy transfer in micrometeorology and microclimatology? [4]*

   ⊗ Interference ○ Convection ○ Radiation ○ Conduction

   'Interference' is a phenomena in physics where waves superimpose, but it does not describe the transfer energy at all. All other terms (convection, radiation and conduction) are relevant for transfer of energy in the Earth-Atmosphere system including the boundary-layer.

   → Lecture 3, Slide 3

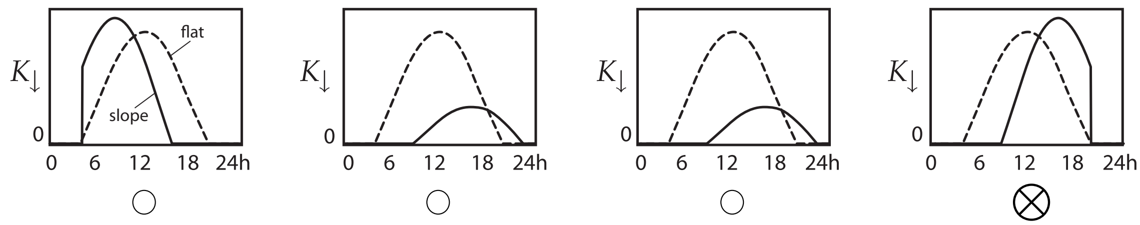
5. *Where do you expect the ratio $S/K_{\downarrow}$ (i.e. of direct-beam irradiance S to total irradiance $K_{\downarrow}$) to be highest [4]?*

   ○ South East Asia ○ Coastal BC ○ Sahara desert ⊗ On the Moon

On the Moon there is no atmosphere. Consequently, no scattering and reflection is possible which means there is also no diffuse irradiance (D). All of $K_\downarrow$ is received as direct-beam (S), i.e. $S/K_\downarrow = 1$. On Earth, $K_\downarrow = S + D$. The fraction $S/K_\downarrow$ is highest in areas dominated by clear-sky weather, such as the Sahara desert. Nevertheless, also under clear-sky conditions about 10% of $K_\downarrow$ reaches the surface as D, and on Earth always $S/K_\downarrow < 1$.

→ Lecture 5, Slide 15

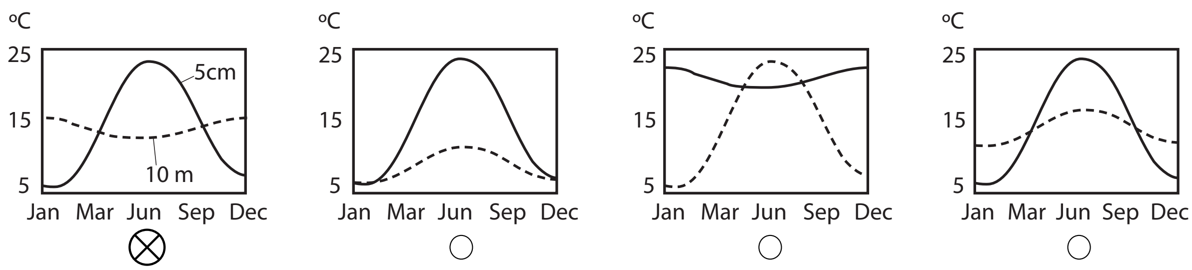
6. *Assume a clear-sky day in Vancouver. How do you expect short-wave irradiance $K_\downarrow$ on a West-facing slope (45° slope angle) to change over the course of a day relative to $K_\downarrow$ on flat surface (dashed line)? [4]*



Short-wave radiation on a West-facing slope will be maximized in the afternoon, so it must be Option 2, 3, or 4. Option 2 and 3 (which are the same!) are not possible, because after sunset there will be no irradiance possible anymore, so the abrupt change in 4 is due to sunset and makes sense. In fact the maximum irradiance on the slope is higher than that on a flat surface, because the rays may hit the surface close to normal to the slope.

→ Lecture 15, Slide 16 for an example, and online-applet.

7. *Which of the following graphs show realistic soil temperature traces at a depth of 5 cm (full line) and at a depth of 10 m (dashed line) over the year in a typical soil in Coastal British Columbia? [4]*



The amplitude of soil temperature T_s waves decreases with depth, while the timing of the maximum is shifted to later in the year. However, the average T_s over the year should be roughly the same (which is not the case in Options 2 and 3). In addition Option 3 is not realistic because the amplitude at 10 m is higher than the amplitude at 5 cm. Option 4 has no phase-shift (which must be substantial), so Option 1 with a half-year of phase-shift is realistic (This is taken from the example on Slide 7, Lecture 13)

→ Lecture 13, Slide 7

8. *Which of the following tables show realistic annual totals of the radiation flux densities for a grassland site in Vancouver (e.g. Totem Field on UBC campus)? [4]*

$K_\downarrow = 4.6$ GJ m^{-2} y^{-1}	$K_\downarrow = 11.4$ GJ m^{-2} y^{-1}	$K_\downarrow = 10.1$ GJ m^{-2} y^{-1}	$K_\downarrow = 4.6$ GJ m^{-2} y^{-1}
$K_\uparrow = 0.8$ GJ m^{-2} y^{-1}	$K_\uparrow = 0.8$ GJ m^{-2} y^{-1}	$K_\uparrow = 11.4$ GJ m^{-2} y^{-1}	$K_\uparrow = 0.8$ GJ m^{-2} y^{-1}
$L_\downarrow = 11.4$ GJ m^{-2} y^{-1}	$L_\downarrow = 10.1$ GJ m^{-2} y^{-1}	$L_\downarrow = 0.8$ GJ m^{-2} y^{-1}	$L_\downarrow = 10.1$ GJ m^{-2} y^{-1}
$L_\uparrow = 10.1$ GJ m^{-2} y^{-1}	$L_\uparrow = 4.6$ GJ m^{-2} y^{-1}	$L_\uparrow = 4.6$ GJ m^{-2} y^{-1}	$L_\uparrow = 11.4$ GJ m^{-2} y^{-1}
○	○	○	⊗

We know for sure that always $K_\uparrow < K_\downarrow$, hence option 3 is not possible. Then, for land-surfaces over a full year, also $L_\uparrow > L_\downarrow$, as the surface is radiatively warmer than the atmosphere, so option 1 and 2 are not realistic. Option 4 remains as the only realistic choice where $K_\uparrow < K_\downarrow$ and $L_\uparrow > L_\downarrow$.

→ Lecture 9, Slide 5

Part B: Short answer questions.

1. *Briefly explain the difference between near infrared radiation (NIR) and thermal infrared radiation (TIR). [7]*

   Both wavebands have wavelength longer than the visible, and hence cannot be seen by the human eye, but NIR is solar radiation [1] [2] in the waveband from 0.7μm to 3μm [2] [1] while TIR is radiation emitted by objects on Earth [3] [3] in the waveband $> 3\mu$m [4] [1]

   → Prerequisites and Lecture 5, Slide 6

2. *Briefly explain the difference between heat capacity and heat flux density. [7]*

   Heat capacity describes the amount of energy needed [2] to warm a unit volume [1] of a substance [5] by one Kelvin [1] [6] while the heat flux density is the amount of heat [or energy] transferred [7] [1] through a unit area [8] [1] per time [9] [1]

   → Lecture 11, Slide 4 / Lecture 3, Slide 5

3. *Briefly explain the difference between Beer's law and Fourier's law in a homogeneous medium. [7]*

   Beer's law describes how monochromatic radiation [2] is transmitted [10] [1] through a homogeneous medium[11] such as snow, water etc., while Fourier's law describes how heat [2] is conducted [2] in a homogeneous medium (by relating a temperature gradient to the heat flux density).

   → Lecture 14, Slide 6 to 8 / Lecture 11, Slide 12.

4. *Briefly explain the difference between solar declination δ and solar altitude β. [7]*

   Both are angles describing the position of the Sun in degrees or radians [1]. Solar declination δ is the angle between the Sun's rays [1] and Earth's Equatorial plane [2]. Solar altitude β describes the angle of the Sun above the observer's horizon [12] [3] (assuming a flat surface).

   → Lecture 4, Slide 8 and 10.

5. *Assume a homogeneous layer of soil between the surface and 10 cm depth. At a given time, Q_G at the surface is 120 $\mathrm{W\,m^{-2}}$ while at 10 cm depth $Q_G = 20\,\mathrm{W\,m^{-2}}$. The soil layer has a heat capacity of $C = 1\,\mathrm{MJ\,m^{-3}\,K^{-1}}$. Assuming those conditions remain the same, in how many seconds has is the soil layer warmed up by 1 K? [7]*

   $$\frac{\Delta Q_G}{\Delta z} = C\,\frac{\Delta T}{\Delta t} \text{ [3, or any other arrangement of same equation]}$$

   $$\Delta t = C\,\frac{\Delta T\,\Delta z}{\Delta Q_G} = 1'000'000\frac{1 \cdot 0.1}{(120-20)} = \underline{1'000}\,\text{sec [4, 2 for values plugged in, 2 for result]}$$

   → Lecture 11, Slides 10 and 11 and Reading Package Lectures 11-13, Equation 7.1

Part C: Problem questions

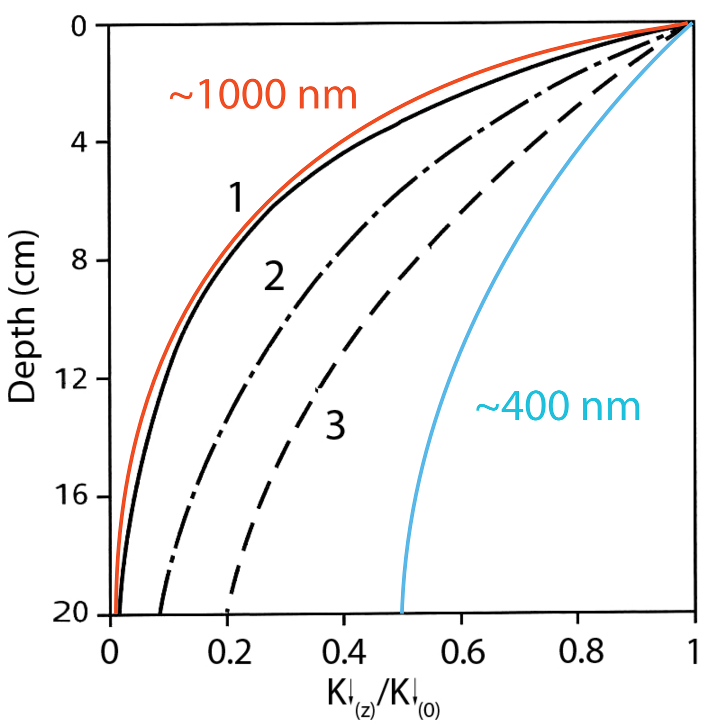
1. *The lines in the graph below show measured vertical profiles of $K_\downarrow$ as a function of depth z in three different snow packs: A fresh snow pack, a mid-winter snow-pack, and an old snow pack in late spring.*

   (a) Attribute the various snow-packs to the curves 1 to 3 to and justify your choice. [3]

   - Graph 3 is the fresh snow pack [1]
   - Graph 2 is the mid-winter snow pack [1]
   - Graph 1 is the old snow pack in late spring [1]

   Explanation [not required]: With increasing age of the snow-pack their density changes and we will also accumulate more impurities such as aerosols. Both effects increase the absorptivity, and hence decrease the transmissivity.

   (b) The graphs show broadband $K_\downarrow$. However specific wavelengths (λ) might behave differently. Sketch directly into the graph expected profiles for radiation at $\lambda \approx 400$ nm and for $\lambda \approx 1000$ nm (for a fresh snow pack). [4]



   400 nm is blue light which is better transmitted, and must be below the line for fresh snow. 1000 nm is much better absorbed, and must be above the line for fresh snow. Both curves must decay exponentially. [2 points for a realistic curve each, no justification needed]

   (c) Which law describes the curves you have drawn (name the law) [3].

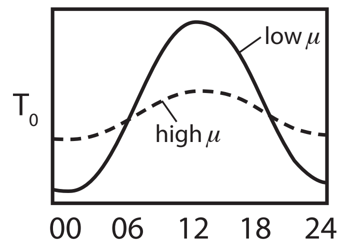
   It is <u>Beer's Law</u>[13] [3] that describes the transmission of monochromatic light through a homogeneous medium.

2. *The thermal admittance of a soil (μ_s) is the thermal property that governs soil surface climates.*

   (a) Give an example of a soil that has a particularly low μ_s and one that has a particularly high μ_s. [4]

   Low μ: A dry organic (e.g. peat) soil [2], High μ: a wet / compacted mineral soil. [2].

   (b) Sketch graphs of the expected surface temperatures T_0 for both soils separately over the course of a clear-sky day (i.e. draw time of day on the x-axis, and T_0 on the y-axis). [3]



Note: Graphs must have roughly same average T_0 over the day.

(c) Which of your two soils might be better suited for agriculture? Justify. [3]

The soil with the high thermal admittance [1], as it is less prone to frost [1] and heat damage to plants.

3. *A recent study published in* Nature Climate Change (Vol 2, 613 - 618, 2012) *reports 'changes in plant growth in an area of around 100'000 km^2, known as the northwestern Eurasian tundra, stretching from western Siberia to Finland. Surveys of the vegetation, using data from satellite imaging, and fieldwork [...] showed that in 8-15% of the area willow and alder plants have grown from shallow shrubs into trees over 2 metres in height in the last 30-40 years'. The study concludes that this 'change from shrubs to forest is important as it alters the albedo (α) effect.'*

   (a) Does the annual α increase or decrease as a result of the plant growth? [2]

   α decreases [2] as a result of plant growth.

   (b) List the two most important reasons why α changes. [4]

   Reason 1: A taller vegetation canopy has more changes multiple reflections and hence lower albedo [1]. Reason 2: Taller vegetation will 'stick out' of a snow cover, hence lower the albedo during times with a shallow snow cover [2].

   (c) Briefly speculate, what is the effect of the altered α effect on soil temperatures and near-surface air temperatures, and the consequence on plant growth. Explain why. [4]

   It will cause a larger absorption of solar radiation (higher Q^*), which will consequently increase soil and air temperatures, and then again enhance tree growth (positive feedback). [4]

4. *This equation describes $L_\uparrow$ of a flat land-surface.*

$$L_\uparrow = \underbrace{\varepsilon\,\sigma\,T_0^4}_{\text{Term I}} + \underbrace{(1-\varepsilon)L_\downarrow}_{\text{Term II}}$$

   (a) What are the radiative processes captured in each of term I and term II? [4]

   Term I describes the emission[14] of long-wave radiation [2] by the surface, while Term 2 describes the reflection[15] of atmospheric downwelling radiation [2] by the surface.

   (b) Which law forms the basis for term I (provide name)? [2]

   The Stefan-Boltzmann Law [2].

   (c) Why do we use ε to describe the process in term II? [4]

   Because the surface is assumed to be non-transparent in the long-wave, hence the reflectivity is equal to 1 - absorptivity [2], i.e. α_λ = 1 - a_λ. Kirchhoff's law[16] [1] states that absorptivity equals emissivity, hence $a_\lambda = \varepsilon_\lambda$. [1]

5. *The graphs show measured radiative fluxes from a network of 11 stations located at various altitudes in the Swiss Alps. Each dot represents a site. The graphs show measured average $K_\downarrow$ and $L_\downarrow$ for clear-sky cases (i.e. simultaneously cloud-free at all sites). All sites measure fluxes on a horizontal surface and are located in open terrain with sky view factors close to 1.*

(a) For both, $K_\downarrow$ and $L_\downarrow$, describe the effect of altitude on flux densities. [2]

$K_\downarrow$ increases with altitude [1] and $L_\downarrow$ decreases with altitude.

(b) Provide a detailed physical explanation for the observed changes in flux density with altitude, separately for $K_\downarrow$ and $L_\downarrow$ [8]

The attenuation of $K_\downarrow$ in the atmosphere depends on the optical air mass number m because the more mass the more is absorbed.[17]. Stations located at higher altitudes have less atmosphere above them (lower m), while stations in the low-land have more atmosphere (higher m). [4]

$L_\downarrow$ is controlled by the apparent temperature of the atmosphere above the sensor. The atmosphere at higher altitudes is c
so according to Stefan Boltzmann the emission, and hence $L_\downarrow$ is less. [4]

6. *The photo shows a set-up to measure solar radiation.*
   (a) What is the name of the instruments labelled (1) and (2)? [4]

   Number (1) is a pyranometer [2], Number (2) is a pyrheliometer.

   (b) Which variables do they measure each? [4]

   The pyranometer (1) measures total solar irradiance[18], the pyrheliometer (1) measures direct-beam radiation only.

   (c) The platform that holds the two instruments can automatically adjust azimuth and tilt. Why? [2]

   This is needed so the pyrheliometer can follow the apparent path of the sun, as it only measures a narrow solid angle [2]. Note: The measurement with the pyrometer is not affected by rotating the platform.

Notes

[1]can also say 'short-wave radiation' or 'radiation emitted by the sun'.

[2]Alternatively - 'longer wavelength than red / visible' or 'beyond the visible' or 'beyond red'

[3]Can also say objects with 'Temperatures found on Earth' or 'long wave radiation'

[4]or from 3 μm to $\approx 100\mu$ m

[5]or 'system' or 'material' etc.

[6]can also say 'amount of energy absorbed (or released) by a unit volume (1 m^3) of a system for a temperature rise (or fall) of 1 K' or equivalent, or provide proper units.

[7]or: 'exchanged', 'transported' etc.

[8]per square metre, or provide units W m^-2

[9]per second, or provide units W m^-2

[10]or absorbed

[11]can also provide equation $I_z = I_0 e^{-k\,z}$ – but need to explain it.

[12]instead of 'horizon' can also say 'observer's ground' or equivalent

[13]can also say Beer-Lambert's Law, or provide correct equation, $I_z = I_0\, e^{(-kz)}$

[14]can also say 'emittance' but not 'emissivity'

[15]can also say 'reflectance' but not 'reflectivity'

[16]Can also describe Kirchhoff's law in words or provide equation.

[17]Can also say: 'Depends on the thickness of the atmosphere' or equivalent. But not: 'it is closer to the sun' – Note, the relative difference in distance to the Sun is at its maximum 2 km vs. 149,600,000 km, which is only 0.000001% !

[18]can also say: 'short-wave irradiance', or 'short-wave incoming flux density' or 'solar incoming flux density'. but not 'short-wave radiation', unless specifying from 2π and upper hemisphere.