Answer Key - Midterm Examination 2010

Part A: Multiple choice questions

1. *Which sensor does measure only direct-beam solar irradiance (S) [4]*

   ⊗ Pyrheliometer ◯ Diffusometer ◯ Pyrgeometer ◯ Pyranometer

   A pyrheliometer measures the direct beam irradiance S by tracking the position of the sun with an absorber disk inside a tube - that has a narrow field of view - just the diameter of the sun - over the course of the day (automatically or manually). A pyranometer measures both, direct-beam and diffuse shortwave irradiance, i.e. $K_{\downarrow} = S + D$ in the entire upper hemisphere. A diffusometer measures D only using a shade disk or shade ring. You can use a pyranometer plus a diffusometer to *indirectly* determine S, i.e. $S = K_{\downarrow} - D$, but the question asks for a single instrument. Finally, a pyrgeometer measures long-wave irradiance ($L_{\downarrow}$).

   → See Field Visit 1 handout and reading package Lecture 10. 78% of the class answered this question correctly.

2. *Under which sky condition is the bulk atmospheric emissivity ε_a lowest? [4]*

   ◯ Fog ◯ High cirrus coulds ◯ Significant haze (forest fires) ⊗ Clear and unpolluted sky

   The atmospheric bulk emissivity ε_a is lowest if there are no water droplets or aerosols that absorb (and hence emit) in the 'atmospheric window' region (and other transmission regions in the EM-spectrum). Water droplets and aerosols are absent in a clear and unpolluted sky where $\varepsilon_a \approx 0.75$. Aerosols increase ε_a in the forest fire haze, and with the two clouds (cirrus, fog) water droplets increase ε_a ($0.75 < \varepsilon_a \leq 1$).

   → See Lecture 8, slides 8, 15 - 17 and reading package Lecture 8. 57% of the class answered this question correctly.

3. *How is spectral reflectivity α_λ defined? [4]*

   ◯ Radiation emitted divided by radiation reflected of a specific wavelength.
   ◯ Radiation reflected divided by radiation transmitted and absorbed of a specific wavelength.
   ⊗ Radiation reflected divided by total incident radiation of a specific wavelength.
   ◯ Radiation absorbed divided by radiation reflected of a specific wavelength.

   The spectral reflectivity α_λ is radiation reflected / radiation incident, i.e. the relative fraction of the total incident radiative flux of a particular wavelength λ that is reflected back. Values for reflectivity range between 0 (no reflection) to 1 (e.g. a perfect mirror).

   → See Lecture 6, slides 3. 90% of the class answered this question correctly.

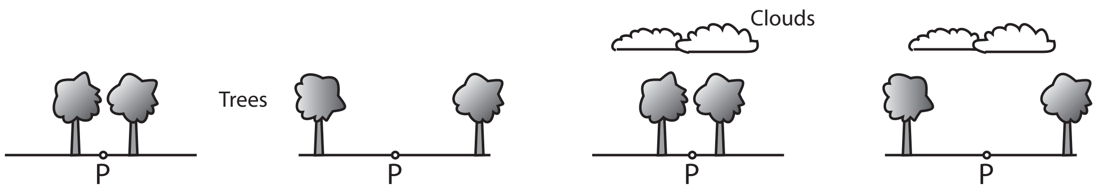
4. *The climatological instrument shown below creates a voltage output that is proportional to the ... [4]*

⊗ Soil heat flux density ◯ Soil volumetric water content
◯ Soil heat capacity ◯ Soil moisture potential

This instrument was passed around in Lecture 12 in class. It is a soil heat flux plate which measures the soil heat flux density Q_G. It is inserted into the soil horizontally at a given depth. It uses a thermopile to measure the difference in temperatures between the upper and lower plate and Fourier's law to convert $\Delta T/\Delta z$ to Q_G using a known k.

→ See Lecture 12, slides 6. 88% of the class answered this question correctly.

5. *In the following diagrams, P is a point on the surface. During night, in which of the four situations do you expect Q^* to be lowest (i.e. most negative) - if everything else is kept constant? [4]*

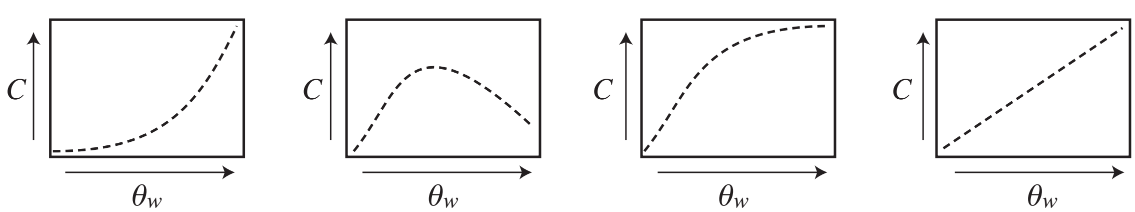


◯ ⊗ ◯ ◯

During night, $Q^* = L^*$, with $L^* = L_\downarrow - L_\uparrow$. $L_\downarrow$ varies according to the view factor of different objects, and their respective temperatures. Sky can be assumed to be always cooler than surface objects. Case 2 has the highest sky view factor ψ_{sky} and hence lowers $L_\downarrow$. Assuming $L_\uparrow$ constant and larger than $L_\downarrow$, then this results in lowest (most negative) Q^*.

→ See Lecture 7, slides 14. 96% of the class answered this question correctly.

6. *How does heat capacity C change with soil volumetric water content θ_w? [4]*

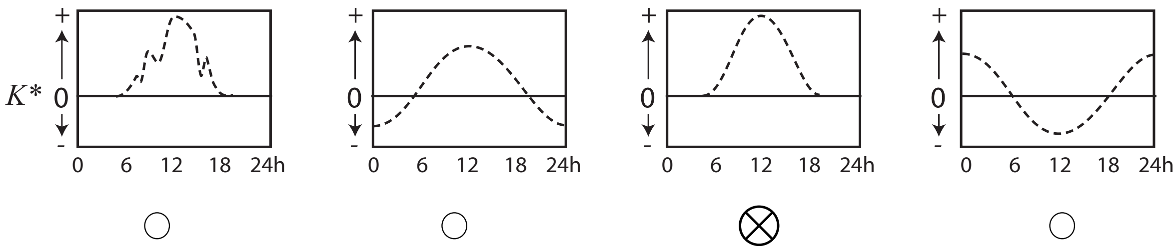


◯ ◯ ◯ ⊗

The heat capacity of a soil C increases linearly with the volume of water added by the amount of C_w, the heat capacity of water. The heat capacity of the air removed, C_a, is very small can be neglected.

→ See Lecture 11, slides 9 and 20 and Reading Package Lecture 11-13. 90% of the class answered this question correctly.

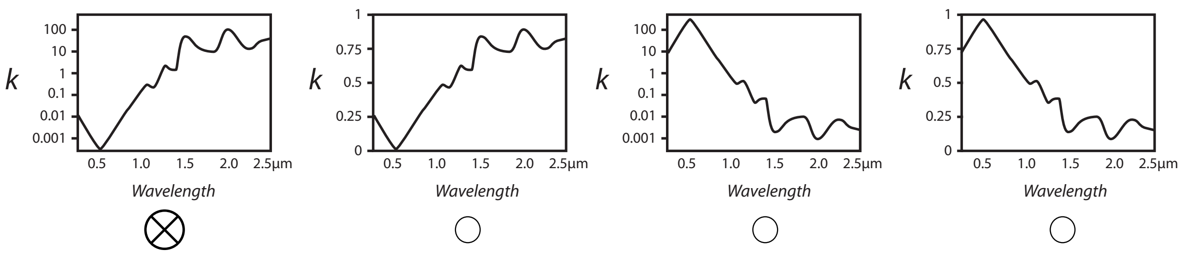
7. *Which of the following graphs shows measurements of net shortwave radiation K^* from a summer clear-sky day measured on Totem Field in Vancouver? [4]*



The diurnal course of K^* on a clear-sky day follows a sinusoidal wave, and is equal zero during night. K^* can never be negative as always, $K_\uparrow \leq K_\downarrow$ (the presence of could disrupt the sinusoidal and reduces it as shown in the leftmost example.

→ See Lecture 5 and 9 or reading package Lecture 6 (Figure 1) for an example. 78% of the class answered this question correctly.

8. *For water, how does the extinction coefficient k change with wavelength? [4]*



The extinction coefficient k is a factor in the exponent of Beer's law i.e. $K_{\downarrow(z)} = K_{\downarrow(0)} \exp(-k\, z)$. The extinction coefficient for water changes in the short-wave by five orders of magnitude (from 0.001 to 100). k is lowest if transmission is high. This is the case in the blue part of the visible spectrum around 500 nm = 0.5 μm.

→ See Lecture 14, slides 8. This was a challenging question and only 20% of the class answered this question correctly.

Part B: Short answer questions.

1. *Briefly explain the difference between* PAR *and* NIR. *[7]*

PAR is photosynthetically active radiation [2] - this is short-wave radiation in the range 0.4μm to 0.7μm ([1]) [1]. NIR is near infrared radiation [2] and is radiation in the range 0.7μm to 3μm ([2]) [1]. PAR can be used by plants in the process of photosynthesis while NIR is not used.[3] [1].

→ See Lecture 5, slides 10, Lecture 6, slide 4 and reading package Lectures 3-4.

2. *Briefly explain the difference between a* cold *and a* wet snowpack *from an energetic point of view.* [7]

A 'cold' snowpack is considerably below 0°C, so that it only contains ice [1]. The only relevant energy exchanges are net-radiation (Q^*) [1], the sensible heat flux to the atmosphere (Q_H) [1] and heat storage change (ΔQ_S) [1]. A 'wet' snowpack contains ice and water [1] and in addition also the exchange of latent heat Q_E [1] and the energy required to melt the snow (ΔQ_M)[4] [1]

→ See Lecture 14, slides 16-17.

3. *Briefly explain the difference between* local mean solar time *(LMST) and* local apparent time *(LAT). [7]*

   Local mean solar time (LMST) is fixed and ensures that on average [1], highest solar altitude is observed at noon [2]. Local apparent time (LAT) is a non-uniform[5] [1] time that ensures that highest solar altitude is always observed at noon [2]. LMST and LAT are related according to the equation of time [1].

   → See Lecture 4, slides 10.

4. *Briefly explain the difference between* frequency *(ν) and* wavelength *(λ) of radiation. [7]*

   Frequency ν refers to the number of crests passing a stationary point [2] in a sine signal per second (in s^{-1} [1]). Wavelength λ is the distance between two crests [2] of the wave (in m) [1]. They are related by the speed of light[6] [1].

   → See Reading Package Lectures 3-4, page 1.

5. *Under a given situation, the atmospheric thermal admittance μ_a is five times larger than the soil thermal admittance μ_s. If the soil heat flux density is $Q_G = 50\,\mathrm{W\,m^{-2}}$, calculate the turbulent sensible heat flux Q_H. [7]*

   Use the heat sharing equation [3] and solve for Q_H:

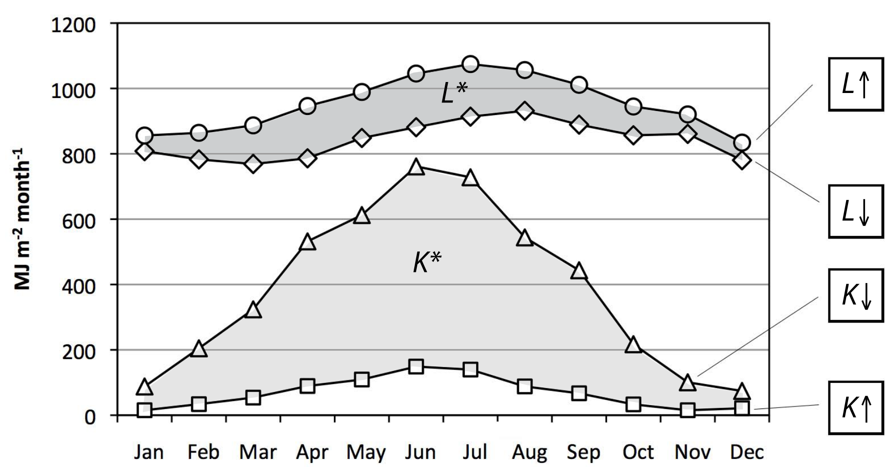
$$\frac{Q_G}{Q_H} = \frac{\mu_s}{\mu_a} \quad \text{and} \quad Q_H = \frac{\mu_a}{\mu_s} \times Q_G$$

$$Q_H = \frac{5}{1} \times 50\,\mathrm{W\,m^{-2}} = \underline{250\,\mathrm{W\,m^{-2}}}\ [4]$$

   → See Lecture 12, slide 14.

Part C: Problem questions

1. *The following graph shows magnitudes of measured monthly totals $K_\downarrow$, $K_\uparrow$, $L_\downarrow$ and $L_\uparrow$ measured in Vancouver (Year 2008). (a) Label the boxes (curves) with $K_\downarrow$, $K_\uparrow$, $L_\downarrow$ or $L_\uparrow$. (b) Determine if the yearly totals of each K^*, L^*, and Q^* are positive or negative. (c) Determine in which month Q^* is highest. [10]*



   (a) Justification (not required): Longwave fluxes are larger in the daily total as they are present 24h a day, while shortwave is restricted to daylight hours (as it comes from sun). Further, in the mid-latitudes, $K_\downarrow$ changes more considerably over the year than $L_\downarrow$ or $L_\uparrow$. $K_\uparrow$ is a 'mirror' image of $K_\downarrow$ (unless albedo changes due to snow). $L_\downarrow < L_\uparrow$ as they are following Stefan-Boltzmann Law and $T_{\text{sky}} < T_0$. [4 marks, one for each correctly labelled term]

(b) $K_\downarrow$ (gain) is always larger than $K_\uparrow$ (loss), hence average and total K^* is positive [1]. $L_\downarrow$ (gain) is always smaller than $L_\uparrow$ (loss), hence average and total L^* is negative [1]. Q^* can be graphically estimated looking at the areas between the curves. The area of K^* is substantially larger (actually it is[7] $+3.8\,\mathrm{GJ\,m^{-2}\,yr^{-1}}$) than the negative area of L^* (K^* $+3.8\,\mathrm{GJ\,m^{-2}\,yr^{-1}}$). So $Q^* = K^* + L^*$ is a large positive term (K^*) minus a term that is moderately negative (L^*), hence the total of Q^* is positive over the year [1] (it is $+2.5\,\mathrm{GJ\,m^{-2}\,yr^{-1}}$)

(c) The month with the highest Q^* is June[8] ($\approx +450\,\mathrm{MJ\,m^{-2}\,month^{-1}}$), as $K^\downarrow$ is highest, and other fluxes are not varying as strong as $K^\downarrow$. [3]

→ See Lecture 9, slide 3 and assignment 1.

2. *In mid-latitude climates, farmers are often keen to retain a deep snow cover over their land during the winter and early spring. List two reasons why this could be an advantage from an agricultural perspective. [10]*

[Any of the statements below result in 5 marks each]

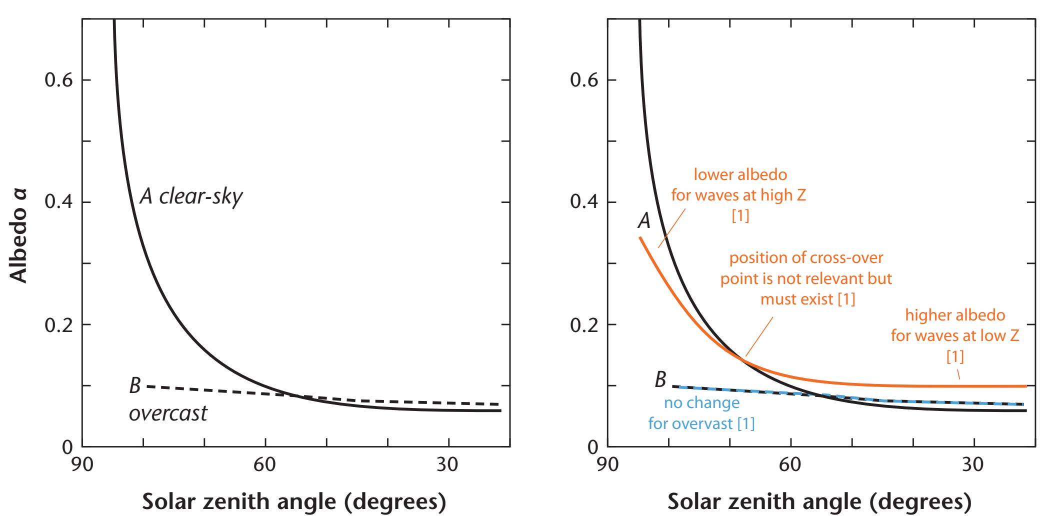
(i) Snow has a low thermal conductivity[9] k which minimizes frost penetration. This in turn thus hastens spring warm-up ready for seed germination as no energy needs to be put into deep-soil warming.

(ii) Snow meltwater may be a significant source of soil moisture / water for the crop in the spring.

(iii) Snow cover may provide thermal protection for early seedlings. Plants within snow are in a conservative if cool environment, but if portions protrude above the surface they are open both to a wider range of temperature fluctuations, and to abrasion by blowing snow and ice pellets.

→ See reading package Lecture 14, page 6.

3. *The graph below shows the measured change of albedo α of a calm water body (lake) as a function of relative solar geometry. (a) Label the x-axis of the graph and briefly justify your choice, (b) The two curves A and B refer to different sky conditions. Label those and briefly justify your choice. (c) Sketch into the diagram two additional curves that show A and B under a situation when the lake's surface experiences waves. Briefly explain your curves. [10]*



(a) Shown is the zenith angle Z [1] as the solar zenith angle approaches 90° specular reflection on water will increase dramatically[10]. [1]

(b) A is clear-sky [1], B is overcast[11] [1]. Justification is that under clear-sky situations short-wave irradiance is highly directed, and specular reflection dominates. For overcast situations, diffuse radiation only is present and not directional [2]

(c) For clear-sky (A): At high solar zenith angles (left), there is a lower albedo compared to a smooth surface due to increased probability of absorption (non-sepcular) on sloped wave surfaces. For low solar zenith angles (right), there is a higher albedo du to increased probability of strong specular reflection on sloped surfaces. [3 in total according to figure], For overcast (B) there is no difference, as radiation is not directional [1].

→ See Lecture 14, slide 12 and reading package Lecture 14.

4. *The figure below shows a mosaic of thermal images from the far-side of the moon taken from a spaceship by NASA on June 23, 2009. These are the first thermal images of the far-side of the moon. The grey-scale represents measured lunar surface temperatures, with white being the hottest (+340 K) and the dark being the coldest (lowest lunar temperature 170K). (a) Briefly explain how a spaceship can remotely measure lunar surface temperatures. (b) The warmest temperatures (+340K = +65° C) are warmer than most surface temperatures on Earth, while the coldest are much lower. Briefly speculate why. (c) Argue why we see topographic features in a band along the centre of the image but not in the upper right or the lower left of the moon (craters are found all across the lunar surface). [10]*

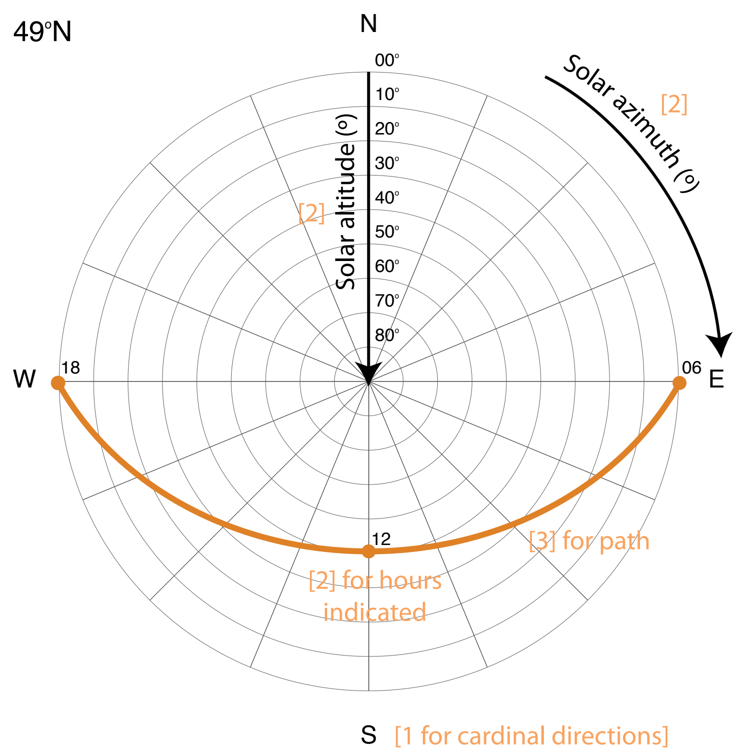
(a) The space probe measured thermal infrared radiation emitted [2] by the lunar surface and uses the Stefan-Boltzmann Law [2][12] to convert to absolute temperatures.

(b) There are several reasons you can mention but all because there is no atmosphere on the moon [1], (i) missing convective energy transfer into an atmosphere (i.e. Q_H) is not possible. The energy balance essentially is $Q^* = Q_G$, (ii) lower lunar albedo (it is 0.12 v.s 0.31 of Earth), (iii) no absorption of radiation in an atmosphere (no greenhouse effect). [any one of i-iii: 2]

(c) This is caused by lunar topography (varying slope angles) that receives solar irradiance at different flux densities according to the cosine-law (sun-facing vs. shadowed slopes of craters). Similar to what we observe on Earth [3]

→ See Lectures 3 (b), 15 (c) and field visit (a).

5. *Draw into the graph below a sun-path diagram valid at the latitude of Vancouver (49° North) for the dates of the equinoxes. Indicate select hours of the day (6h, 12h and 18h in LAT). Label solar latitude and solar azimuth axes and provide units. [10]*



6. *What is special about the the atmosphere in the waveband between 8 and 13 μm of the electromagnetic spectrum? Explain why this is of relevance for the operation of Infrared Thermometers (IRTs)? [10]*

   This region is called 'atmospheric window' [3].

   Absorptivity by atmospheric gases in this range is small, i.e. it is mostly transparent [2] - and consequently through Kirchhoff's Law also emissivity (and the possibility for emission) is low. [2]

   This means the IRTs mostly see the apparent radiative temperature of the surface objects, and not the atmosphere [3] which is desirable.

   → See Lecture 9 slide 9 for a similar example (discussed in class).

Notes

[1]Alternatively 'in the visible part' of the spectrum or equal visible.

[2]Alternatively, beyond the visible but still in the short-wave part of the spectrum.

[3]Alternatively the fact that both are short-wave but one is visible to the human eye while NIR not.

[4]You can also mention Q_R, but not required

[5]You can also say 'it varies' or 'varying time'

[6]Alternatively you can write just $\nu = c/\lambda$

[7]Of course those numbers are not required, just given for the discussion.

[8]If you say July or May you will get 1 mark, if you say between June and July or between May and June you get 2 marks.

[9]Or a low thermal diffusivity *kappa*

[10]alternatively you can say that in mid-latitudes Z cannot be $0°$

[11]or cloudy

[12]you can provide also $T = \sqrt[4]{L_{\uparrow}/\sigma}$