The University of British Columbia
Christen / GEOB 300 / October 10, 2014

Answer Key - Midterm Examination 2014

Part A: Multiple choice questions

1. *What is the correct formulation that defines Q^*? [4]*

   ⊗ $Q^* = K_\downarrow - K_\uparrow + L_\downarrow - L_\uparrow$ ◯ $Q^* = \varepsilon\sigma T^4$ ◯ $Q^* = \varepsilon \frac{K^*}{L^*}$ ◯ $Q^* = Q_H/Q_E$

   Q^* is the symbol for net all-wave radiation, so the combined net effect of shortwave (solar) and long wave (terrestrial) radiation at a surface. Q^* is the net effect of incoming solar irradiance ($K_\downarrow$) minus solar reflectance ($K_\uparrow$) plus incoming long wave radiation from the sky ($L_\downarrow$) minus longwave emittance and reflectance ($L_\uparrow$). Note that the r.h.s. of the second potential answer $\varepsilon\sigma T^4$ is the Stefan Boltzmann Law, and the last choice Q_H/Q_E is the Bowen ratio ($\beta = Q_H/Q_E$ see later in this course).

   → See Lecture 9, slide 4.

2. *Which form of water has the lowest heat capacity C [4]*

   ◯ Liquid water ◯ Ice ⊗ Fresh snow ◯ Old snow

   The heat capacity C describes the energy needed to warm up one cubic metre by one Kelvin ($\mathrm{J\,m^{-3}\,K^{-1}}$). Because it is a volumetric measure, it depends greatly on density. Fresh snow has the lowest density and hence warms most per volume for a given energy input. Fresh snow has a $C \approx 0.2\,\mathrm{MJ\,m^{-3}\,K^{-1}}$, while older, more compacted snow is denser and has a typical value of $C \approx 0.8\,\mathrm{MJ\,m^{-3}\,K^{-1}}$. Ice is even denser with $C = 1.93\,\mathrm{MJ\,m^{-3}\,K^{-1}}$ and liquid water has the higest C with $4.81\,\mathrm{MJ\,m^{-3}\,K^{-1}}$.

   → See Lecture 14, slide 4.

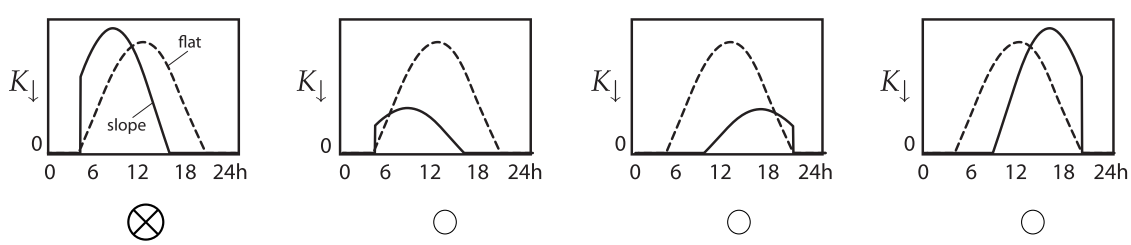
3. *Beer's law describes the transmission of radiation through a homogeneous medium, such as snow or water: $I_z = I_0 e^{-k\,z}$. What is the name of k? [4]*

   ◯ Beer's constant ◯ Transmittance ◯ Absorption coefficient ⊗ Extinction coefficient

   The constant is called the extinction coefficient because it describes how quickly radiation gets extinct (reduced) as it moves into the volume.

   → See Lecture 14, slide 9.

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

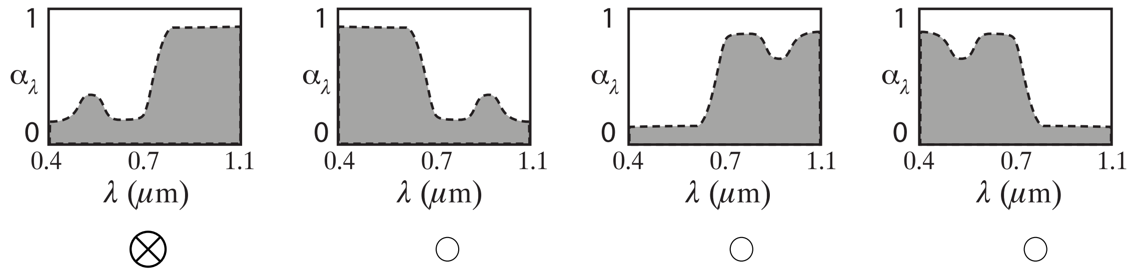


   At sunset an east facing slope immediately receives a substantial amount of irradiance, hence the jump. Later in the afternoon, it will fall into the shadow, and only receive a marginal amount of diffuse irradiance. An inclined slope receives more radiation at peak compared to the flat surface, because the solar beam in the late morning is close to normal to the surface.

   → See Lecture 15, slide 14 and web applet on slope irradiance. [1]

[1] http://ibis.geog.ubc.ca/courses/geob300/applets/slope/

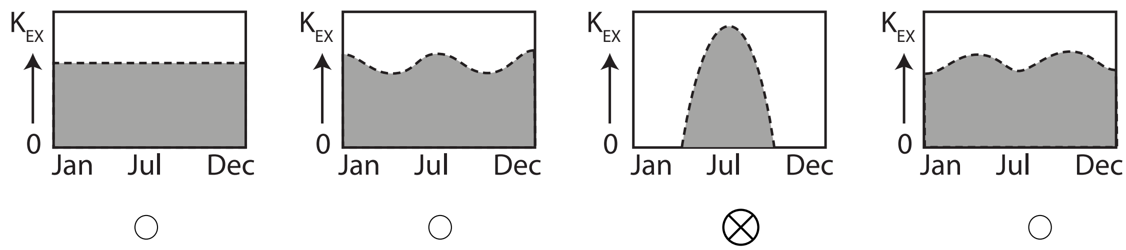
5. *How does spectral reflectivity α_λ of a green leaf change with wavelength λ? [4]*



To appear green, a leaf must reflect more in the green part ($\approx 0.5\mu$m) of the spectrum compared to the red ($\approx 0.65\mu$m) or blue wavelengts ($\approx 0.4\mu$m). This is evident only in the first panel. Another hint is that leaves reflect much more in the NIR ($> 0.7\mu$m) than in the visible part of the spectrum ($< 0.7\mu$m). The reason is that plants use visible light to perform photosynthesis (here absorption is high, reflection is low), but the useless NIR is reflected to avoid overheating the leaves. Only answers 1 and 3 have those characteristics.

→ See Lecture 6, slide 4.

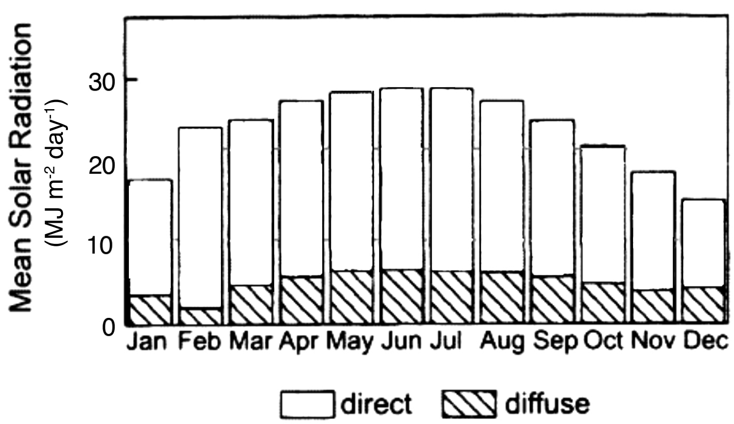
6. *At the North Pole, how does the daily total of extraterrestrial short-wave irradiance K_{EX} change with time of year? [4]*



The north pole experiences half of a year polar night, that means no irradiance at all. This pattern is only evident in the third panel, where K_Ex is zero from later September to late March (equinoxes). By the way, the forth panel is the K_Ex at the equator.

→ See Lecture 14, slide 4 and web applet on extraterrestrial irradiance [2]

7. *The following graph shows the distribution of direct beam and diffuse irradiance for a given station. Where is this station most likely located? [4]*



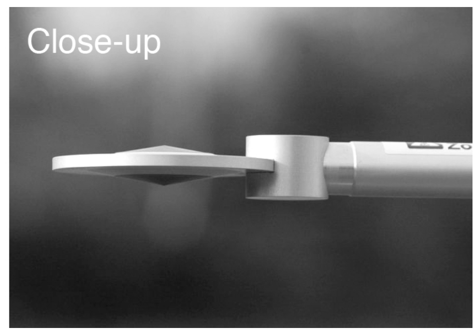
[2]http://ibis.geog.ubc.ca/courses/geob300/applets/latitude/

◯ Manaus, Brazil (3°S, Equatorial Rainforest)
◯ Vancouver, Canada (49°N, Coastal BC)
⊗ Tamanrasset, Algeria (23N°N, Sahara Desert)
◯ South Pole Station, Antartica (90S°N, Ice Shield).

This curve has two characteristics: There is a high fraction of direct beam irradiance plus there is a remarkable annual variability, although in winter (Dec, Jan, Feb) the irradiance is non-zero. It cannot be South-Pole, because South pole would experience, like the North Pole above, half a year of Polar night (from March to October values would be all zero). Vancouver is not possible, because we have much more clouds in winter, so diffuse irradiance would be higher than direct beam irradiance. Manaus on the Equator is not possible because we observe a remarkable annual variability, and at the Equator irradiance would be more or less equal (two peaks in Oct and Mar). Tamanrasset in the Sahara Desert is the most likely choice, as this desert climate has few clouds.

→ See Lecture 5, slide 12 ('Sahara desert' is Tamanrasset, Algeria).

8. *You saw the following meteorological instrument on UBC Totem Field. What is this instrument measuring? [4]*



⊗ Net all-wave radiation Q^*
◯ Net short-wave radiation K^*
◯ Albedo α
◯ Diffuse solar irradiance D

This is a net all-wave radiometer that measured Q^*. You can say so because it has no domes that would filter radiation, and it measures both hemispheres.

→ See Lecture 10 (field visit) and field visit answer key.

Part B: Short answer questions.

1. *Briefly explain the difference between a pyranometer and a pyrgeometer. [7]*

   A pyranometer is an instrument [1] that measures shortwave [2][3] radiation [1][4]. A pyrgeometer is an instrument that measures longwave [2][5] radiation [1].

   → See handout for field visit (lecture 10).

2. *Briefly explain the difference between albedo and reflectance of a surface.* [7]

   The albedo is the (relative) ratio [1] of reflected radiation [1] to radiation incident [1] at a surface [1][6], while reflectance is the (absolute value) flux density of reflected radiation [2] from a surface [1].

   → See Lecture 6, slide 5 and online glossary.

3. *Briefly explain the difference between the atmospheric boundary layer depth and the damping depth in a soil. [7]*

   The atmospheric boundary layer depth is the height in the atmosphere [1] where there is no more a diurnal course of variables [3] (temperature, humidity, ect.)[7]. The damping depth in a soil is the depth at with the surface temperature [1] wave reaches 37%[8] [2] of the amplitude at the surface.

   → See Lecture 1, slide 13 and Lecture 13, slides 14.

4. *Briefly explain the difference between the solar declination and the solar constant. [7]*

   The solar declination is the planar angle [1] between Sun's rays and Earth's Equatorial plane [2], while the solar constant is the actual amount of solar radiation reaching Earth [1] expressed as an average flux density [1] at the top of the atmosphere [1][9] normal to the solar beam [1].

   → See Lecture 4, slide 6 and Lecture 4, slide 25.

5. *The heat capacity C of ice is roughly $2.0\times10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$. Its thermal conductivity k is roughly $2.0\,\mathrm{W\,m^{-1}\,K^{-1}}$. Calculate the thermal admittance μ of ice. [7]*

   The thermal admittance is defined as $\mu = \sqrt{C\,k}$ [3], hence

   $\mu = \sqrt{2.0 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}} \times 2.0\,\mathrm{W\,m^{-1}\,K^{-1}}} = \sqrt{4.0 \times 10^6\,\mathrm{J^2\,m^{-4}\,K^{-2}\,s^{-1}}}$

   $= \underline{2.0 \times 10^3\,\mathrm{J\,m^{-2}\,K^{-1}\,s^{-1/2}}}$[3+1][10]

Part C: Problem questions

1. *The following table shows simultaneous measurements of all components of the radiation balance from two stations in Metro Vancouver on July 15, 2014 at 12:00 PST. July 15, 2014 was a clear day without any clouds. One station listed is Totem Field at UBC (where you have been during the field visit - relatively dry and short lawn ≈5 cm tall), the other station is located in Burns Bog (Delta, very wet peat soil, unmanaged, ≈30 cm tall grasses). At both stations, all components or the radiation balance are measured at 2 m above ground.*

Component	Station 1	Station 2
$K_\downarrow$	890 $\mathrm{W\,m^{-2}}$	885 $\mathrm{W\,m^{-2}}$
$K_\uparrow$	99 $\mathrm{W\,m^{-2}}$	173 $\mathrm{W\,m^{-2}}$
$L_\downarrow$	360 $\mathrm{W\,m^{-2}}$	373 $\mathrm{W\,m^{-2}}$
$L_\uparrow$	495 $\mathrm{W\,m^{-2}}$	550 $\mathrm{W\,m^{-2}}$

   (a) Which station has the higher K^*, which one has the higher L^* at 12:00 [4]?

   $K^* = K_\downarrow - K_\uparrow$

[3] Can also say: solar or from sun
[4] Can also say 'irradiance', or 'incoming radiation' or'hemispherical radiation', or mention 'reflectance'
[5] Can also say: terrestrial or TIR
[6] Alternatively, can write $\alpha = K_\uparrow/K_\downarrow$
[7] Can also say where frictional influences of the surface vanish.
[8] Can also say to e^{-1} or $1/e$
[9] Can also say" In absence of atmospheric effects
[10] 3 marks for calculation, 1 mark for units.

Station 1: $K^* = K_\downarrow - K_\uparrow = 890 - 99 = 791 \mathrm{W\,m^{-2}}$

Station 2: $K^* = K_\downarrow - K_\uparrow = 885 - 173 = 712 \mathrm{W\,m^{-2}}$

Hence, Station 1 has the higher K^* [2][11]

$L^* = L_\downarrow - L_\uparrow$

Station 1: $L^* = L_\downarrow - L_\uparrow = 360 - 495 = -135 \mathrm{W\,m^{-2}}$

Station 2: $L^* = L_\downarrow - L_\uparrow = 373 - 550 = -177 \mathrm{W\,m^{-2}}$

Hence, Station 1 has the higher L^* [2][12]

(b) Based on the measurements above, attribute the stations to 'Burns Bog' and 'UBC Totem Field'. Justify your choice using indicators from selected short-wave and long-wave components measured [6].

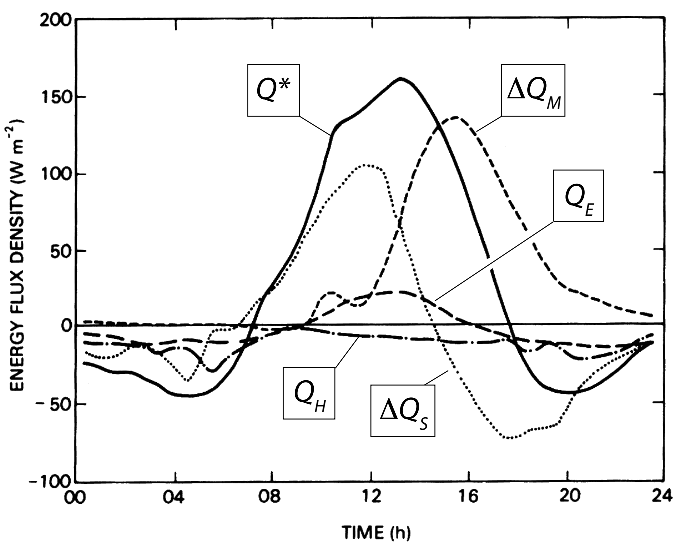
Station 1 is 'Burns Bog', Station 2 is 'Totem field' [2]

The shortwave reflectance ($K_\uparrow$) is much smaller over tall grass and wet peat soil compared to drier and shorter lawn [2].

The longwave outgoing radiation ($L_\uparrow$) is much less over a wet peat soil because it warms less rapidly at day compared to the drier soil at Totem field that warms more rapidly [2].[13]

2. *The graph below shows all terms of the energy balance of a melting snow pack at Bad Lake (Saskatchewan, 51° N) over the course of a day.*

   (a) Q_H is labelled. Label the remaining curves with correct symbols [4]?



[1 Mark for each correct attribution]

(b) What are the major energetic contributors to snow melt at 15:00. Sort them by magnitude. [3]

$Q^* > \Delta Q_S > Q_H$

(c) What are the processes that cause the snow-pack to continue melting at 19:00? [3]

ΔQ_S, Q_E and Q_H, (but not Q^*).[14]

[11] Calculations or numeric value not required
[12] Calculations or numeric value not required
[13] Can also use Stefan Boltzmann Law as argument
[14] Order does not matter for (c)

3. *The following differential equation is valid for temperatures in a soil of homogenous structure.*

$$\frac{\partial T}{\partial t} = -\frac{k}{C_s}\frac{\partial}{\partial z}\left(\frac{\partial T}{\partial z}\right) = -\kappa_s \frac{\partial^2 T}{\partial z^2}$$

(a) Generally, what does this equation describe [2]?

This equation describes how soil temperatures change over time [1] and with depth [1].

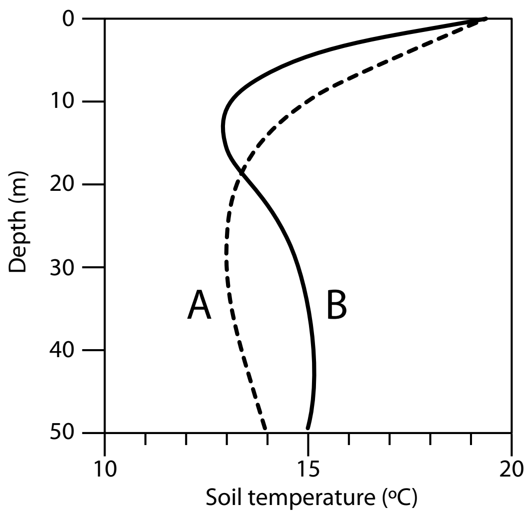
(b) What are the two basic laws or considerations that lead to this formulation? [5]

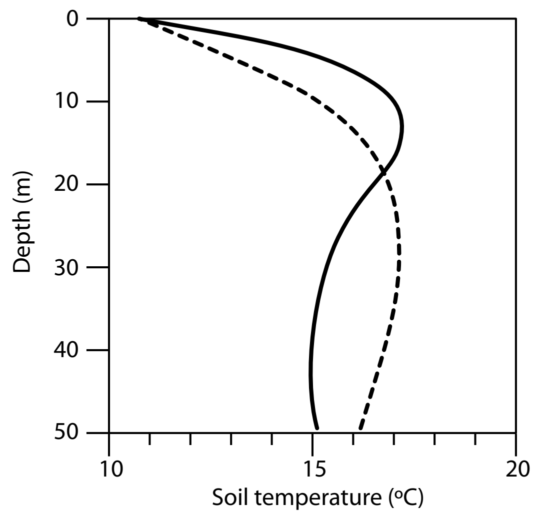
Fourier's Law ($Q_G = -k\partial T, \partial z$) and the heat capacity, i.e. $\partial T/\partial t = C\,\partial Q_G/\partial z$.

(c) Can we use this equation to forecast soil temperatures into the future? Justify, and list any limitations. [3]

We can solve it numerically (i.e. step by step), but not analytically. We need to know the boundary conditions (e.g. surface temperatures).

4. *The left graph shows how soil temperatures change with depth in two different soils at the same time of day with the same energy input / loss at the surface. For all questions, assume homogeneous soil properties and a clear (cloudless) summer day in Vancouver.*





(a) Speculate, <u>when</u> during the day the profiles on the graph were measured. Justify your choice. [3]

They were measured in the morning[15], because the surface is warmest and temperatures decrease with depth in the upper part of the profile.

(b) Which of the two soils, A or B, has the higher thermal diffusivity κ_s? Justify you choice. [3]

Soil A has the higher thermal diffusivity [2], it conducts the wave (warming) more rapidly down (less steep slope near surface). [1]

(c) In the empty panel on the right, sketch how the profiles for soils A and B would approximately look like 12 hours later. [4]

See panel.

[15]can also say 'noon'

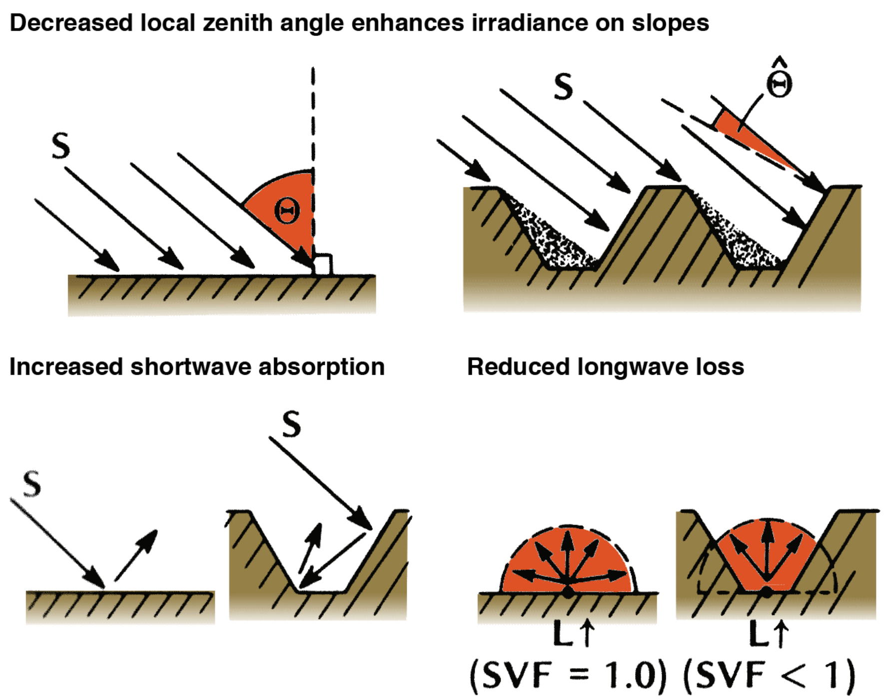
5. *In this field, young raspberry plants have been planted on small ridges (ridge and furrow geometry). In addition, the ridges are covered by an opaque black plastic sheet with holes for the plants.*

   (a) Discuss in detail how the ridge and furrow structure modifies the radiation balance to the benefit of plant growth. [6]

   The furrow and ridge geometry enhances the irradiance of solar radiation on the sloped sides. [2]

   The furrow and ridge geometry enhances shortwave absorption by decreasing the system albedo (multiple reflection) [2]

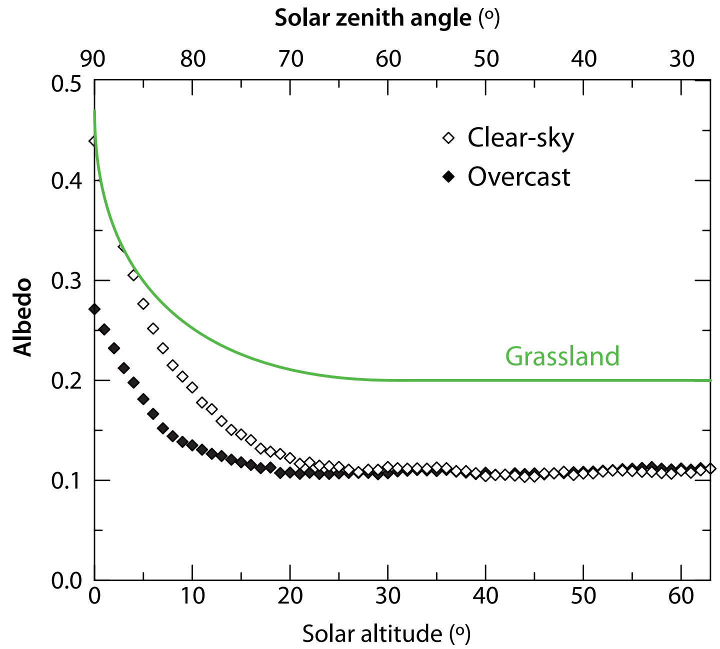
   The furrow and ridge geometry reduces long-wave loss by L^* due to a reduced sky view factor. [2]



   (b) Discuss how the dark plastic sheet enhances the beneficial effects. [4]

   The plastic sheet increases absorption of shortwave radiation due to its <u>low albedo</u> [3] It further limits losses through latent heat flux Q_E [1]

6. *This graph shows albedo α as a function of solar altitude (or solar zenith angle) as measured over an urban surface in the City of Vancouver. The radiometers to measure albedo were mounted on a tall 30-m tower above the city's buildings and trees.*



(a) What causes the curves to behave as observed? [4]

At low solar altitude there is increased specular[16] reflection.

(b) Once curve has been measured during clear skies, the other curve summarizes data from overcast situations. Complete the legend by adding 'clear-sky' and 'overcast' (no justification needed). [2]

Black symbols are overcast, open symbols are clear-sky (Reason is that increased specular reflection happens with direct beam irradiance under clear-sky conditions).

(c) Draw a third line directly into the graph that shows the expected relationship for a short grass surface (e.g. Totem Field) under clear sky conditions [4]

See above. A typical albedo value at high solar altitude is $\approx 20\%$. Curve otherwise behaves similar.

END OF EXAM

[16] Can also say increased 'mirror'-like.