Lab 2: Radiation Measurement Model Answers

How to Evaluate Your Work Using Model Answers

Radiation can vary greatly between lab sections and even within a single lab period. Model answers emphasize the key factors that affect the different types of radiation you measured, and the instruments used to gather the data. They show calculation processes, how to report them, and how to explain the values you measured for both clear (yellow colour coded) and cloudy (blue colour coded) conditions at an enclosed site in early January.

When checking your work, choose the example that most closely matches your lab's weather conditions. At the end of this answer key, the UNBC Weather Station (UNBC Wx Stn) graph shows the conditions that occurred during your lab's observations.

Your answers should follow principles indicated in the model answers, but they must represent the weather conditions /data you observed. When correcting, revise /augment your original answer using your collected data (not numbers from this answer key). Specifically:

1. Calculations should: follow model answer methods but use your data; contain similar levels of reporting detail; and have identical units. But, expect your assignment values to differ as temperature / sky conditions during your measurement period likely differ.
2. The explanations in these Model Answers cover a wide range of radiation conditions and highlight issues to consider under different conditions. Your answers should report and interpret sky and temperature condition details along with any weather that occurred while you took your measurements. Your explanations must relate to your weather conditions. Clarify any confusing points with an instructor as needed.
3. When comparing data between the roof UNBC Weather Station (Wx Stn) and your observations, realize that the roof instruments measure every second and report either a 1-minute or a 10-minute average (depending on which data you used), while your measurements are instantaneous readings. Under rapidly changing sky /weather conditions, these two different data collection methods create quite different results.
4. The site where data was collected for these Model Answers is on the UNBC Prince George campus, in the middle of the drop-off loop located on the east (city-side) of the Teaching and Learning Building (Bld. 10). The radiation values represent mid-morning light conditions in mid-January for two example situations: clear conditions [Table 1a) Jan 15, 2008; in yellow colour-coded tables]; and thick cloud conditions when it was snowing heavily with very low light levels [Table 1b) Jan 14, 2008; blue colour-coded tables].

Radiation Concepts: Your explanation answers should be consistent with these principles

K↓ (incoming solar or shortwave radiation) encompasses direct and diffuse shortwave radiation. As a photon, or wave form of energy, K↓ can be scattered /reflected, absorbed, or transmitted. It is always positive.

K↑ (reflected solar or shortwave radiation that is reflected from a surface) K↑ is always a portion of K↓, so it must be less than K↓. It is always positive.

L↓ or L↑ (longwave or infrared (IR) radiation) depends on the temperature of the object being measured (i.e. sky, clouds, buildings, glass, roads, grass, snow, etc.). IR thermometers detect an object's emitted IR radiation as a temperature. IR thermometer readings of objects are typically warmer (i.e. longwave radiation values are larger) when the ambient air temperature on the day your observations are made is higher (or conversely cooler (longwave values are smaller) when the ambient air temperature is lower).

L↓ (incoming longwave) depends on the temperature of the sky or sky objects. For weather monitoring, L↓ is dominated by the sky condition (clear versus cloud) with much smaller contributions from buildings trees, etc. as our sites are chosen for observing sky conditions. Clouds are much warmer than clear skies resulting in higher L↓ values and sky temperatures. Clouds warm as they absorb the longwave radiation that is emitted by the ground. Thick, low clouds are the warmest; they are also usually the darkest clouds.

L↓ is smaller on clear days (IR thermometer readings are colder) because the surface's longwave radiation can travel higher into the atmosphere before it is absorbed by atmospheric gases or lost to space.

L↑ (outgoing longwave) depends on the temperature of the ground /surface being measured. Ground temperatures vary with ambient air temperatures, the type of surface material which affects the albedo, and the surface's exposure to solar radiation. The exposure of surfaces to sunlight (or shading) is caused by current sky conditions, sun angle, or their location (i.e. near objects that can heat or shade the site). These factors control how much radiation the ground surface can absorb, which affects its temperature and resulting IR emissions.

Q* (net all-wave radiation) integrates all radiation balance components: Q* = (K* + L*) = (K↓ - K↑) + (L↓ -L↑) .

A net radiometer measures Q* as a single instantaneous, integrated measurement of all the radiation components (K↓, K↑, L↓, L↑), so there are no time delay errors in the measurement.

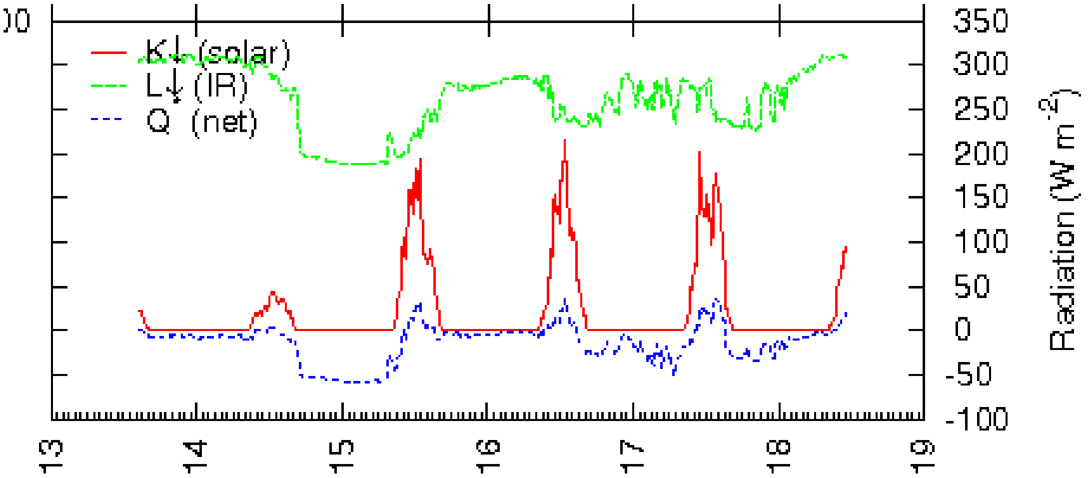
[This is not the case when you determine Q* by measuring the individual radiation balance components (K↓, K↑, L↓, L↑) and then calculating Q* from Q*= (K↓ - K↑) + (L↓ -L↑). This method leads to large errors when sky conditions are changing rapidly.]

This is how integrated, instantaneous Q* measurements appear under:

- clear sky, daylight periods: Q* is dominated by K*.
- night conditions (no solar radiation): K*= 0 so Q*= L*
- cloudy conditions: Carefully consider the sky (and weather) conditions as either K* or L* can dominate. When evaluating your answers to determine the reason for your Q* value, look at the individual ↓ or ↑ components of both the K and L values. Then consider the net effect - are K* and L* positive or negative values?

The UNBC Wx Stn radiation graph can assist when interpreting the radiation components that control Q* as all radiation values (K↓, K↑, L↓, L↑) are plotted on one graph as a time sequence.

Fig. 1: *UNBC Weather Station Radiation, Jan 14 – 17, 2008 showing the simplified data collected at the same time as Tables 1a), 2a), and 1b), 2b) measurements. Notice how Q* responds to the K↓, and L↓ patterns.*



Jan. 14 *is the warm snowy, foggy day with very low light levels.*

Jan 15 *is the clearer, colder day.*

The following pages show model student answers. Answers start with your Table 1 & should look similar.

Model Answers - Observations:

TABLE 1a): Enclosed Site under Clear Weather Conditions

Sample values from a **sunny morning** in mid-January (Jan. 15, 2008) for the drop-off loop outside of the east (city-side) of the Teaching and Learning Building. Under similar sky and ground cover conditions, your enclosed site data should be similar. Calculations show units and method details. Ask your instructor if you aren't sure how to evaluate your answers.

Instrument: *(include type & serial #)*	**Rad'n Component**	**Calibration Coefficient or Value** *(include units)*	**Instrument Output /Reading** *(include units)*	**Calculated Radiation Value in Wm^{-2}** *(show an example of each calculation)*	**Reading Time** **PST**	**Weather Conditions & Comments**
Net Radiometer (REBS 2)	**Q***	For $+ = 8.43 \frac{Wm^{-2}}{mV}$ For $- = 12.73 \frac{Wm^{-2}}{mV}$	-3.1 mV	Use the negative calibration coefficient as the instrument voltage is negative. Q* = [(-3.1 mV)(12.73 Wm^{-2}/mV)] = -39.5 Wm^{-2} = **-40 Wm^{-2}**	10:09	Mostly clear sky, with cirrus clouds; -10^{0}C; very light wind
Pyranometer (CMP #209505)	**K↓**	19.02 $\frac{\mu V}{Wm^{-2}}$	1.22 mV	$K\downarrow = (1.22\ mV)\ (\frac{1000\ uV}{1\ mV})\ (\frac{1\ Wm^{-2}}{19.02 uV})$ $= 64.14\ Wm^{-2} = 64.1\ Wm^{-2} =$ **64 Wm^{-2}**	10:05	Same as above
Pyranometer (CMP #209500)	**K↑**	19.27 $\frac{\mu V}{Wm^{-}}$ which equals 19.27 x 10^{-6} $\frac{V}{Wm^{-2}}$	0.62 mV	E.g. calculation using 19.27 x 10^{-6} $\frac{V}{Wm^{-2}}$ form $K\uparrow = (0.62\ mV)\ (\frac{1\ V}{1000\ mV})\ (\frac{1\ Wm^{-2}}{19.27\times10^{-6}\ V})$ $= 32.17\ Wm^{-2} = 32.2\ Wm^{-2} =$ **32 Wm^{-2}**	10:06	Same as above
IR Radiation Thermometer (ExTech 42512 or Mikron IR Thermometer)	**L↓**	Determine the percentage of the site at each temperature °C; total & convert to energy using Stefan-Boltzmann's law.	Clear sky = 40% @ -48°C Cloud = 45% @ -47°C Building = 10% @ -5 °C Glass = 5% @ -9°C	Calculated temperature as a weighted average: T = [(0.40)(-48)]+ [(0.45)(-47)] + [(0.10)(-5)]+ [(0.05)(-9)] °C = = [(-19.2) + (-21.15) + (-0.5) + (-0.45)]°C = −41.3 °C Convert to Kelvin = (-41.3 °C + 273.15) = 231.85 K Convert to L↓ = σT^4 L↓ = (5.67 x 10^{-8} Wm^{-2} K^{-4})(231.85 K)^4 = 163.84 Wm^{-2} = **164 Wm^{-2}**	10:12	Same as above but with thickening cirrus cloud cover
IR Radiation Thermometer (ExTech 42512 or Mikron IR Thermometer)	**L↑**	Determine the percentage of the site at each temperature °C; total & convert to energy using Stefan-Boltzmann's law.	80% snowy ground @ -15^{0}C 20% snowy ground with gravel @ -11^{0}C	Calculated temperature as a weighted average: T = [(0.80)(-15^{0}C)]+ [(0.20)(-11^{0}C)] = = [(-12) + (-2.2)] ^{0}C = -14.2°C Convert to Kelvin: = -14.2°C + 273.15 K = 258.95 K Convert to L↑ = σT^4 L↑ = (5.67 x 10^{-8} Wm^{-2} K^{-4})(258.95 K)^4 = 254.945 Wm^{-2} = **255 Wm^{-2}**	10:17	Same as L↓ conditions above

Model Answers – Observations continued…

TABLE 1b): Enclosed Site under Snowing Weather Conditions

Sample values from a **heavy snowfall morning** in mid-January (Jan. 14, 2008) for the drop-off loop outside of the east side of the Teaching and Learning Building. Building. Under similar sky and ground cover conditions, your enclosed site data should be similar. Calculations show units and method details. Ask your instructor if you aren't sure how to evaluate your answers.

Instrument: *(include type & serial #)*	**Rad'n Component**	**Calibration Coefficient or Value** (include units)	**Instrument Output /Reading** (include units)	**Calculated Radiation Value in Wm^{-2}** *(show an example of each calculation)*	**Reading Time PST**	**Weather Conditions & Comments**
Net Radiometer (REBS 1)	**Q***	For $+ = 8.50 \frac{Wm^{-2}}{mV}$ For $- = 12.84 \frac{Wm^{-2}}{mV}$	-1.10 mV	Again, use the negative calibration as the instrument voltage is negative Q* = [(-1.10 mV)(12.84 Wm^{-2} /mV)] = -14.124 Wm^{-2} = **-14 Wm^{-2}**	10:30	Heavy snowfall, 100% stratus clouds; temperatures just below freezing; some wind
Pyranometer (CMP #209505)	**K↓**	$19.02 \times 10^{-6} \frac{V}{Wm^{-2}}$ which equals $19.02 \times 10^{-6} \frac{V}{Wm^{-2}}$	0.31 mV	E.g. calculation using $19.02 \times 10^{-6} \frac{V}{Wm^{-2}}$ form $K\downarrow = (0.31\,mV)(\frac{1\,V}{1000\,mV})(\frac{1\,Wm^{-2}}{19.02\times10^{-6}\,V})$ $= 16.30\,Wm^{-2} = 16.3\,Wm^{-2} = \mathbf{16\ Wm^{-2}}$	10:32	Same as above
Pyranometer (CMP #209500)	**K↑**	$19.27 \frac{\mu V}{Wm^{-2}}$	0.21 mV	$K\uparrow = (0.21\,mV)(\frac{1000\,uV}{1\,mV})(\frac{1\,Wm^{-2}}{19.27\,uV})$ $= 10.90\,Wm^{-2} = 10.9\,Wm^{-2} = \mathbf{11\,Wm^{-2}}$	10:33	Same as above
IR Radiation Thermometer (ExTech 42512 or Mikron IR Thermometer)	**L↓**	Determine the percentage of the site at each temperature °C; total & convert to energy using Stefan-Boltzmann's law.	Cloudy sky 100% @ -3°C	Weather conditions make all the L↓ temperatures the same this day. T = (-3 °C)(1.00) Convert to Kelvin = (-3 °C + 273.15) = 270.15 K Convert to L↓ = σ T ^{4} L↓ = (5.67 x 10^{-8} Wm^{-2} K^{-4}) x (270.15K)^4 = 301.997Wm^{-2} = **302 Wm^{-2}**	10:36	Same as above
IR Radiation Thermometer (ExTech 42512 or Mikron IR Thermometer)	**L↑**	Determine the percentage of the site at each temperature °C; total & convert to energy using Stefan-Boltzmann's law.	Snowy ground 100% @ -2^{0}C	Weather conditions make all the L↑ temperatures the same this day. T = (-2 °C)(1.00) Convert to Kelvin = (-2 °C + 273.15) = 271.15 K Convert to L↑ = σ T ^{4} L↑= (5.67 x 10^{-8} Wm^{-2} K^{-4}) x (271.15K)^4 = 306.49 Wm^{-2} = **306 Wm^{-2}**	10:37	Same as above

TABLE 2a): **Weather Station Data Matching Table 1a Observations**

Site: *Roof of the Research Lab Building (data from UNBC Wx Stn website)* **Date:** *Jan 15 2008, 10:30 AM*

Weather conditions: *clear and cold winter weather conditions*

UNBC Weather Station Instrument	**Radiation Component**	***UNBC Station Reading Times** *(match your outdoor measurements as closely as possible)*	**UNBC Station Measurement (Wm^{-2})**
REBS Net Radiometer	**Q***	10:10 am	-3.94 Wm^{-2}
Eppley Pyranometer	**K↓**	10:00 am	97.17 Wm^{-2}
Eppley Pyranometer	**K↑**	10:00 am	57.63 Wm^{-2}
Kipp & Zonen IR Radiometer	**L↓**	10:10 am	199.85 Wm^{-2}
Kipp & Zonen IR Radiometer	**L↑**	10:10 am	237.66 Wm^{-2}

TABLE 2b): **Weather Station Data Matching Table 1b Observations**

Site: *Roof of the Research Lab Building (data from UNBC Wx Stn website)* **Date:** *Jan 14 2008, 10:30 AM*

Weather Conditions: *snowing and warm winter weather conditions*

UNBC Weather Station Instrument	**Radiation Component**	***UNBC Station Reading Times** *(match your outdoor measurements as closely as possible)*	**UNBC Station Measurement (Wm^{-2})**
REBS Net Radiometer	**Q***	10:30 am	-1.44 Wm^{-2}
Eppley Pyranometer	**K↓**	10:30 am	21.27 Wm^{-2}
Eppley Pyranometer	**K↑**	10:300 am	10.30 Wm^{-2}
Kipp & Zonen IR Radiometer	**L↓**	10:40 am	309.45 Wm^{-2}
Kipp & Zonen IR Radiometer	**L↑**	10:40 am	3 13.88 Wm^{-2}

TABLE 3a): Clear Weather Enclosed Site & Roof Data Comparisons:

Weather Conditions: clear, cold winter day (snow covered ground; Jan. 15, 2008)

Site:	**α** (calculated)	**Q*** (measured) Wm^{-2}	**K↓** (measured) Wm^{-2}	**K↑** (measured) Wm^{-2}	**L↓** (measured) Wm^{-2}	**L↑** (measured) Wm^{-2}	**Q***(calculated) Wm^{-2}
Teaching & Learning Building loop	50%	-40	64	32	164	255	-59
Roof	N/A	-3.94	97.17	57.63	199.85	237.66	N/A

TABLE 3b): Snowy Weather Enclosed Site & Roof Data Comparisons:

Weather Conditions: snowy warm winter day (snow covered ground; Jan. 14, 2008)

Site:	**α** (calculated)	**Q*** (measured) Wm^{-2}	**K↓** (measured) Wm^{-2}	**K↑** (measured) Wm^{-2}	**L↓** (measured) Wm^{-2}	**L↑** (measured) Wm^{-2}	**Q***(calculated) Wm^{-2}
Teaching & Learning Building loop	69%	-14	16	11	302	306	1
Roof	N/A	-1.44	21.27	10.30	309.45	313.88	N/A

Sample Calculations Using Clear Weather Data (Jan 15, 2008)

This table is not expected in your answer. It is provided to show the Jan. 15, 2008 Table 1a) data. **Your sample calculations must use your *Table 1* values.**

<table>
<tr><td colspan="5">Site: Drop-off loop on the east (city-side) of the Teaching & Learning Building (Bld. 10)
sky conditions → Mostly clear sky, with cirrus clouds; -10⁰C; very light wind</td></tr>
<tr><td>Q*(measured)
Net Radiometer reading</td><td>K↓
Pyranometer facing sky</td><td>K↑
Pyranometer facing ground</td><td>L↓
Sky object, proportion of sky dome & connected temperature</td><td>L↑
Ground object, proportion of ground view & temperature</td></tr>
<tr><td>-3.1 mV</td><td>1.22 mV</td><td>0.62 mV</td><td>Clear sky: 40% @ -48 ⁰C
Cloud (cirrus): 45% @ -47 ⁰C
Buildings: 10% @ -5 ⁰C
Glass: 5% @ -9 ⁰C</td><td>Snowy ground: 80% @ -15 ⁰C
Snowy ground with gravel: 20% @ -11 ⁰C.</td></tr>
</table>

Example calculations report the measurement, units, and calibrations to show how your work arrives at the final result. Because you are reporting answers in Wm^{-2}, keeping the units as Wm^{-2} in the calculations make your work easier. Contact your instructor if you have questions.

1) **Q*** (measured): Multi-meter reading from the REBS 2 Net Radiometer = -3.1 mV
Convert to Q* using the "bottom" (or negative) calibration coefficient because the millivolt reading is negative. The REBS 2 positive calibration is: 12.73 Wm^{-2} /mV or 12.73 Wm^{-2} = 1 mV.

$$Q^* = (-3.1\,mV)\left(\frac{12.73\,Wm^{-2}}{1\ \ mV}\right) = -39.5\,Wm^{-2} \ = -40\,Wm^{-2}$$

2) **K↓:** Multi-meter measurement = 1.22 mV
Calibration coefficient: 19.02 µV /Wm^{-2} [meaning: 19.02 µV = 1 Wm^{-2} or 1 Wm^{-2} = 19.02 µV]

$$K\downarrow \ = (1.22\,mV)\ \left(\frac{1000\,uV}{1\,mV}\right)\left(\frac{1\,Wm^{-2}}{19.02\,uV}\right)$$

$$= 64.14\,Wm^{-2} = 64.1Wm^{-2} = 64\,Wm^{-2}$$

Alternatively you could do the calculation by converting the microvolt (µV) into its equivalent volts (V), so 19.02 µV /Wm^{-2} becomes 19.02 x 10^{-6} V /Wm^{-2} (or 1 Wm^{-2} = 19.02 x 10^{-6} V).
So the calculation is:

$$K\downarrow \ = (1.22\,mV)\left(\frac{1\,V}{1000\,mV}\right)\left(\frac{1\,Wm^{-2}}{19.02\times10^{-6}\ V}\right)$$

$$= 64.14\,Wm^{-2} = 64.1\,Wm^{-2} = 64\,Wm^{-2}$$

3) **K↑:** Multi-meter measurement = 0.62 mV
Calibration coefficient: 19.27 µV /Wm^{-2} (or 19.27 x 10^{-6} V /Wm^{-2} or 1 Wm^{-2} = 19.27 x 10^{-6} V)

$$K\uparrow = (0.62\,mV)\,(\frac{1000\,uV}{1\,mV})\,(\frac{1\,Wm^{-2}}{19.27\,uV})$$

$$= 32.17\,Wm^{-2} = 32.2\,Wm^{-2} = 32\,Wm^{-2}$$

4) **L↓**: Get data from the table at the top of page 6 (same as L↓ Table 1a) values):

- 40% at -48 ^{0}C (clear sky)
- 45% at -47 ^{0}C (cirrus cloud)
- 10% at -5 ^{0}C (buildings)
- 5% at -9 ^{0}C (glass)

Weighted sky temperature = [0.40 × (-48 ^{0}C)] + [0.45 × (-47 ^{0}C)] + [0.10 × (-5 ^{0}C) + [0.05 × (-9 ^{0}C)]
= [(-19.2) + (-21.15) + (-0.5) + (-0.45)] °C
= −41.3 °C (site temperature)

Convert site temperature in ^{0}C to Kelvin = (-41.3 ^{0}C) + 273.15 K = 231.85 K

Use Stephan Boltzman's Law to determine the radiation emitted by 231.85 K in Wm^{-2}

$$L\downarrow = \sigma T^4 = (5.67\times10^{-8}\,\frac{Wm^{-2}}{K^4})\,(231.85K)^4 = 163.84\,Wm^{-2} = 164\,Wm^{-2}$$

5) **L↑:** Get data from the table at the top of page 6 (same as L↑ Table 1a) values):

- 80% at -15 ^{0}C (snowy ground)
- 20% at -11 ^{0}C (snowy ground with gravel)

Weighted ground temperature = [0.80 × (-15 ^{0}C)] + [0.20 × (-11 ^{0}C)] = -14.2 ^{0}C (site temperature)

Convert site temperature in ^{0}C to Kelvin = (-14.2 ^{0}C) + 273.15 K = 258.95 K

Use Stephan Boltzman's Law to determine the radiation emitted by 258.95 K in Wm^{-2}

$$L\uparrow = \sigma T^4 = (5.67\times10^{-8}\,\frac{Wm^{-2}}{K^4})(258.95K)^4 = 254.95\,Wm^{-2} = 255\,Wm^{-2}$$

6) **α :** The albedo for the snowy ground cover experienced on Jan 15, 2008.

$$\alpha = \frac{K\uparrow}{K\downarrow} = \frac{32\,Wm^{-2}}{64\,Wm^{-2}} = 0.50 \quad \text{(often expressed as a \%)} \rightarrow 50\%$$

7) **Q*** (calculated – determined using the measured components above):

$$Q^* = (K\downarrow - K\uparrow) + (L\downarrow - L\uparrow)$$
$$= [(64 - 32) + (164 - 255)]\ \mathrm{Wm}^{-2}$$
$$Q^* = -59\ \mathrm{Wm}^{-2}$$

Model Answers - Lab Questions & Explanations

1) See the data values for each lab section at the end of this key for measurements made in each lab. Also see Tables 1a, 2a, 3a (clear), or 1b, 2b, 3b (heavy cloud) depending on the weather conditions you experienced for examples similar to yours.

   Ensure your data tables demonstrate good field note taking and have recorded all site, date, and participant information (first and last names), and have noted who did your data recording.

   For each *Sample Calculation* ensure you indicate the equation used, values used, how units change when converting, and the steps involved in obtaining an answer.

2) *What does the albedo indicate; what does it represent, does it vary, why might differences occur?*

   Albedo (α) tells us the fraction of incoming solar radiation that is reflected by a surface (often reported as a percentage). It depends on the reflective properties of the materials at a site. More reflective surfaces are generally lighter coloured (e.g. clean ice) and have higher albedos than less reflective surfaces which are generally darker. Fresh snow can make the ground and resulting albedo more uniform.

   The amount of cloud cover does not affect albedo as the proportion of reflected sunlight remains the same regardless of how much sunlight enters the system. Albedo's change when a surface's material properties change.

   Albedo is always determined from $K\downarrow$ and $K\uparrow$ values that are measured at the same location, at the same time. Albedos greater than 1 are errors; a surface can't reflect more energy than it receives. Similarly, negative albedos do not exist as there is no negative sunlight. If your albedo value is negative or greater than 1, check your math. If your arithmetic is correct, a measurement or method error may be your problem.

3) *When comparing and explaining your Table 3 radiation measurements with the UNBC Weather Station (Wx Stn) radiation values, your answer will vary with the conditions you experienced [as seen in Tables 3a) & 3b)] but, it must follow the logic below, and explain how /why similarities and /or differences occur.*

   Compare and explain:

   a) **Enclosed site $K\downarrow$ and $L\downarrow$ values with UNBC Wx Stn (roof) $K\downarrow$ and $L\downarrow$ values**.
      - **Different measurement strategies:** The roof values are based on measurements taken every second that are averaged and reported for every minute (or every 10 minutes, depending on which data you used). In contrast, your measurements represent a single observation at a particular time. The impact of these different measuring strategies is greatest when sky /weather conditions are changing rapidly (clearing to cloudy; clouds thickening and thinning).
      - **Sky view differences between the UNBC Wx Stn and the enclosed site:** The roof instruments are elevated much higher off the ground and their sky-view is essentially 100% unobstructed. Being elevated can also result in a slightly different temperature. The enclosed site has more obstructing objects creating different object temperatures, shading issues, and heat absorption /emission properties.
      - **Human errors when visually estimating the proportion of different objects /surfaces at the enclosed site for longwave measurements.** (Using fisheye lens photos could make apportioning of site components more accurate as the areas occupied by each object could be quantified.) This is

what the roof top UNBC Wx Stn does using the pyrgeometer (an instrument that integrates all the L↓ radiation into a single L↓ value). It is a more accurate way to measure L↓.

b) **Measured enclosed site Q*with the measured UNBC Wx Stn Q* .**

- **Differences in sky /ground view exposure:** The Wx Stn is nearly 100% unobstructed as it is on a narrow roof, that is elevated about 30 meters above the ground. This allows more K↓ but also changes K↑ and L↑ which depend on albedo (K↑) and surface temperatures (L↑). The roof weather station usually has cooler air temperatures. It also "sees" more ground surfaces though from farther away. At the enclosed site, K↓ is obstructed by buildings, trees and the people while we were measuring. These obstructions increase L↓ values due to their warmer surface temperatures and limit K↓ values. Consequently, the roof and your Q* measurements aren't directly comparable.
- **Different measurement strategies:** The roof Q* values are based on measurements taken every second that are averaged and reported for every minute (or 10 minutes, depending on which data you used). In contrast, your measurements represent a single observation at a particular time. The impact of these different measuring strategies is greatest when sky /weather conditions change rapidly (e.g. clearing to cloudy; clouds thickening and thinning).

c) **Enclosed site calculated Q* (from Q* = (K↓ - K↑) + (L↓ – L↑) with enclosed site measured Q* (from your net radiometer reading).**

- **Different measurement strategies:** Understand that a net radiometer (measured Q*) 'sees' and integrates all the components of the radiation balance into a simultaneous, single measurement, while the calculated Q* from (Q* = K* + L*) is composed of four different measurements, made at slightly different times, using two different types of instruments (and their associated errors).

  Even slightly different measuring times for K↓, K↑, L↓, L↑ data can have a big impact on Q* under variable sky /weather conditions. A calculated Q* is very different from a measured Q* if K↓, K↑, L↓, L↑ measurements are not synchronized. K↓ can have an especially large /rapid impact on Q*. L↓ changes are noticeable but because sky temperature responds more slowly to changing sky conditions, these changes are often smaller, and occurs over longer periods of time.

- **Cumulative errors (whether instrument, method, or human) have more impact on a calculated Q* because there are more readings**. As each instrument has its own associated error, and taking more measurements results in more opportunities for human errors, both of these can decrease the accuracy of your calculated Q* value.

4) **Potential sources of error involved with these radiation measurements:** *Consider the major errors; group them as method errors, human errors, and instrument errors. Ensure your answer accounts for the errors that created your result issues.*

- **Method errors** are inherent in the technique /way a measurement is made; they cannot be eliminated unless the measurement method is changed. Method issues are:
  - ⋆ Taking L↓ and L↑ readings at slightly different times from each other and the Q*, K* readings, when these are intended to represent a single instantaneous measurement
  - ⋆ Not having instrument stands to hold the instruments stable, and at the correct horizon angles and correct heights above the ground. Not using instrument stands also caused

one (or more) people to remain near /obstruct instruments as measurements were taken, and increased human errors.

- ⋆ Using rough estimates (± 5%) to apportion sky view /ground view areas for L↓ and L↑ temperature measurements instead of using fish-eye lens photographs /other quantitative methods.

- **Human errors**:
  - ⋆ people blocking the instrument' s view;
  - ⋆ not leveling instruments properly (horizon's not being correct) which can result in radiation from sources that should not be part of a measurement (i.e. when measuring incoming radiation or Q*, an instrument that is not level may mistakenly include outgoing radiation).
  - ⋆ moving around within the site between readings so that each measurement is not originating at the same spot
  - ⋆ incorrect estimates proportioning object /surface types at each site, and insufficient temperature sampling of each object /surface type for longwave radiation measurements;
  - ⋆ calculation errors
- **Instrument errors** exist for each instrument and are up to 10%. Instrument error details are in the Lab Background Information and should be incorporated in this answer.

5) Relate your measured Radiation Balance values (Q*, K↓, K↑, L↓, L↑) to the outdoor environmental conditions at the time of your measurement (sky, time of day, site, weather variability).

Your answer should follow these patterns and incorporate points from the graphs and explanations for your particular lab days at the end of these model answers.

K↓: Exists only during the day. On a clear day, it is zero at sunrise and gradually increases to a maximum at midday; then K↓ decreases to zero again at sunset. On a cloudy day, the pattern is similar but much reduced as solar radiation is attenuated by varying layers /thickness of cloud. Foggy days further reduce radiation.

K↑: Regardless of sky conditions, K↑ is always a proportion of K↓. It is dependent on amount of incoming solar radiation (K↓) and the albedo (α) which depends on the type of surface. Rain /snow (or even wind on water) can rapidly change the albedo of a surface.

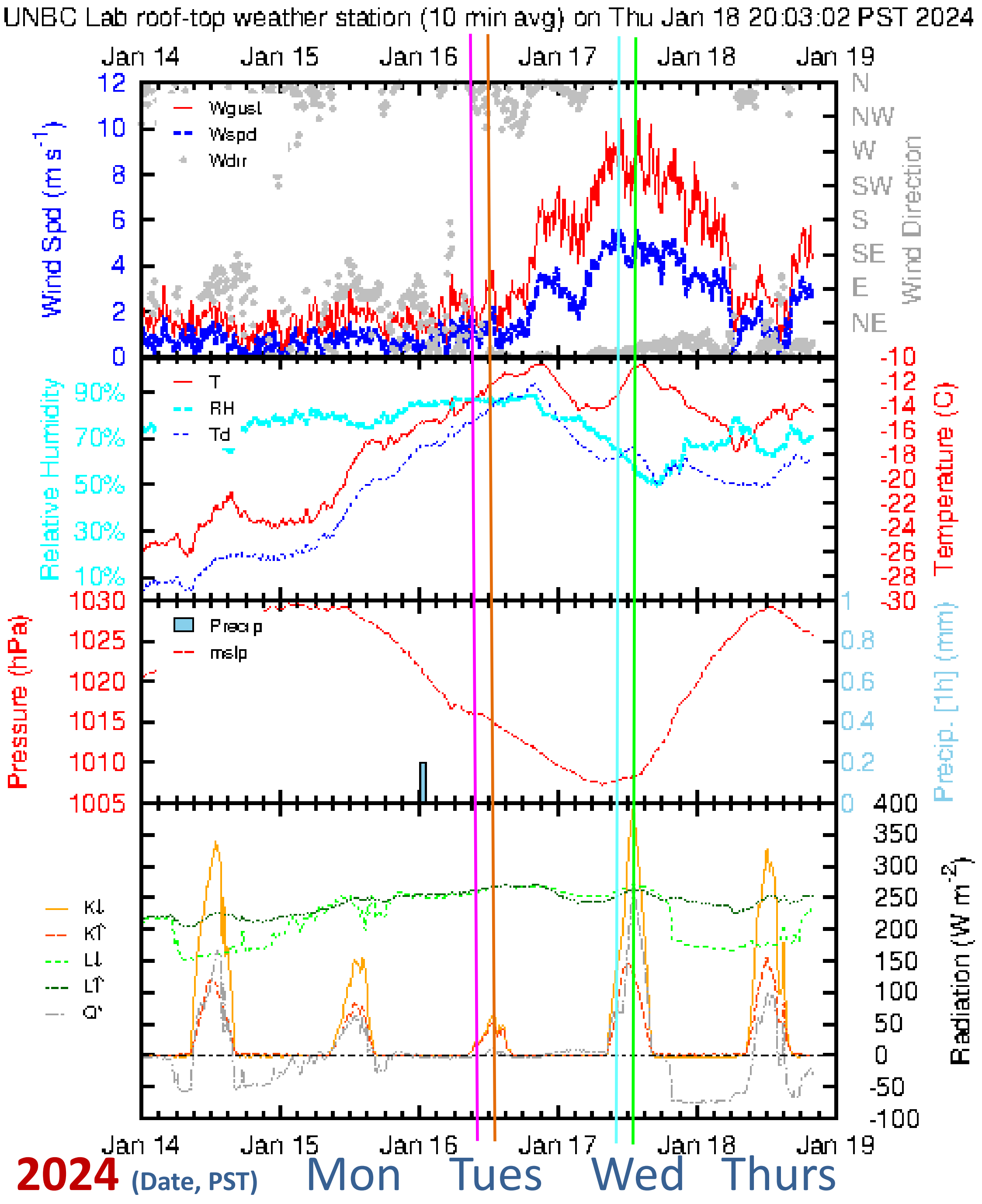
L↑ depends on an object's or surface's temperature which depends on the object's or surface's exposure to solar radiation, daily /seasonal heating variations, and the surface albedo. Generally, L↑fluctuates more than L↓ as surface temperatures change more than sky temperatures.

L↓ depends on sky temperatures. L↓ is smaller under clear skies due to cooler sky temperatures, and greater under cloudy conditions as clouds retain heat and cause warmer sky temperatures. L↓ is determined by the Stephan-Boltzman law which indicates a big change in longwave radiation when there is a small change in temperature. L↓ changes more slowly and varies less than K↓.

Q* variation is dominated by K↓ during daytime regardless of clear or cloudy conditions and follows the pattern of K↓. It is muted in comparison to K↓ due to K↑ and L↑ removing energy. Under cloudy conditions, Q* increases as higher L↓ values contribute to Q*. This is most clearly seen at night when Q* patterns are simplified because there is no shortwave radiation (K↓ =0); thus Q* is usually negative at night.

Fig. 2 UNBS Wx Stn Conditions Tues Jan 16th & Wed Jan 17th 2024. The graph (below) shows the radiation and weather condition during our labs. Tuesday labs experienced steady falling fresh snow, very low light levels due to thicker clouds and overcast sky conditions, and little to no wind. Wednesday labs had clear skies, no observable clouds over our measuring site, and windier conditions. On Wed consider if your measurements where made in the sun or shade as surrounding buildings block the sun when it has low sun angles during the winter. For each graph, different coloured vertical lines indicate each lab time. Look for connections between each form of radiation and the weather patterns, but remember that your measuring site is surrounded by buildings, while the UNBC Wx Stn is unobstructed.

To evaluate your work, match the conditions on your lab day to the appropriate model answer day values. Your answers and calculations should have similar logic and calculation processes. **(See over for a closer look at the radiation parts of this graph.)**



A Closer Look at the Radiation Patterns:

Tuesday had slightly higher L↓values as cloudy skies have higher temperatures so greater longwave radiation (Wm^{-2}). But during lab times on both lab days, L↓ and L↑ values were essentially the same, so L* is about zero and net radiation (Q*) comes from K* (net shortwave, K* = K↓ - K↑) during the day. Once the sun sets, Q* is essentially zero overnight. Use these graphs to evaluate your answers in questions 3 & 5 but remember at the enclosed site, L↓ could be increased because buildings can be warmer than the sky under clear sky conditions.

Each lab's measuring time is shown by a different coloured vertical line. Find yours and compare the plotted radiation to your data values. Look for connections between each form of radiation and also with the weather pattern. See an instructor if you aren't sure how to evaluate your answers for the day your collected data.

UNBC Wx Stn Radiation Data during Lab 2 Measurements