Lab 2: Radiation Measurements

Objectives:

In this lab you will be working outside using a variety of radiometers and infrared thermometers to measure and compare longwave and shortwave radiation. You will also calculate radiation budget components, an albedo, and a radiation balance. Finally, you will analyze the data you collected by comparing measurement differences between open and enclosed sites.

Background:

Key concepts are summarized by the following (also refer to lecture notes):

$$Q^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow \quad \text{(Radiation Balance, or Budget)}$$

$$E = \sigma T^4 \quad \text{(the Stefan Boltzmann Law)}$$

$$\alpha = \frac{K\uparrow}{K\downarrow} \quad \text{(albedo equation)}$$

where:

Q^* = net all-wave radiation

$K\downarrow$ = incoming shortwave radiation

$K\uparrow$ = outgoing (reflected) shortwave radiation

$L\downarrow$ = longwave radiation reaching the surface from the atmosphere or other objects

$L\uparrow$ = longwave radiation emitted by the surface

α = surface albedo

E = either form of longwave radiation energy ($L\uparrow$ *or* $L\downarrow$); which is given in the question details

σ = 5.67×10^{-8} W m $^{-2}$ K $^{-4}$

Equipment and Resources:

1) The roof-top UNBC Weather Station provides real-time meteorological measurements. It is located on the roof of the Research Lab (Building 4). It's data can be accessed from the "UNBC WX" link on the website: http://cirrus.unbc.ca/201/) .

2) Digital multimeters, will be used to read meteorological instrument voltages when making student measurements.

3) The following meteorological equipment will be used for making the lab measurements.
   - **Net all-wave radiation (Q^*)** is measured by a net radiometer. A REBS Q7 Net Radiometer (with an accuracy of ± 10%) will be used for taking student measurements during the lab.

[A Kipp and Zonen CNR4 (a four component net radiometer which measures *K*↓, *K*↑, *L*↓, *L*↑, and computes *Q** to an accuracy of ± 5%) is also part of the roof-top UNBC Weather Station]

- **Shortwave radiation (*K*↓ or *K*↑)** is measured by shortwave radiometers called pyranometers. We will use a Kipp and Zonen CM3 Pyranometer (with an accuracy of ± 10%) for making student measurements during the lab.

  [The roof-top UNBC Weather Station measures *K*↓ and *K*↑ using the Kipp and Zonen CNR4 described above. It also has a Delta-T SPN1 Pyranometer (with an accuracy of ± 5%) which measures incoming total and diffuse shortwave radiation (*K*↓).]

- **Longwave radiation (*L*↓ *L*↑) and radiative temperature which is converted into longwave radiation (*L*↑ or *L*↓).** The radiative temperatures of the sky, ground and various objects will be measured by students using two different types of hand held infrared radiation thermometers (also called IR thermometers). The larger instrument is a Raynger IR radiation thermometer which measures from -25^{0}C to +25^{0}C (with an accuracy of ± 0.5^{0}C). The smaller instrument is a Mikron IR radiation thermometer which measures from -55^{0}C to +500^{0}C (with an accuracy of ± 0.5 ^{0}C). For comparisons, measured temperatures must be converted into *L*↑ *or L*↓ energy values using the Stefan Boltzmann Law.

  Longwave radiation is also measured directly by infrared radiometers called pyrgeometers. Pyrgeometers measure specifically in the infrared portion of the radiation spectrum.

  [The roof-top UNBC Weather Station measures *L*↓ and *L*↑ using the Kipp and Zonen CNR4 described above.]

General Method:

In this lab, you will measure the components of the radiation balance using the previously described instruments. Then you will calculate, compare, and explain your measurements. Your lab instructor will demonstrate how to use each instrument. The Tables in this lab will help organize and record your data. You will work in groups to collect the data but must do your own calculations. All groups will work at the same site until everyone has completed their measurements. Properly situating and orienting each instrument is critical for making good radiation measurements.

Radiometer measurements are output as voltages. These are either converted internally, or calculated manually using each instrument's calibration coefficient. This produces radiation measurements in the units of watts per square meter (Wm^{-2}). When outside, take a calculator so someone in your group can quickly calculate radiation values to check for their "reasonableness". When back in the lab room, we will compare readings with measurements from the roof-top UNBC Weather Station (located on the Research Building roof). Finalize the lab assignment by completing all the lab questions and properly formatting your assignment before turning it in.

Specific Instructions:

Under your instructor's direction you will go outside to a specific Enclosed Site and work as a group to take the various radiation measurements described in this lab. Use *Table 1* to record the data. Closely observe and record the time, sky /cloud /weather conditions when you make **each** measurement. This information will be required to explain your results, and is especially critical when the sky /cloud /weather conditions are changing rapidly between measurements.

Once back in the lab room, report required calculations in Table 1 or the spaces following it. Use *Table 2* to record roof-top weather station data that corresponds to your Enclosed Site measurement times (your lab instructor can help you obtain Weather Station roof data if you are having difficulty using the website). Use *Table 3* to organize values for easier comparison when answering the questions. Answer lab questions on a separate sheet(s). The first page of this assignment is your Table 1 datasheet. If your Table 1 datasheet is too crowded to report the required identifying information, add a title page to the front of the assignment.

1. For *Table 1*:
   a) Identify and describe the site. Record the date and class time.
   b) In the *Instrument* column, record the type and serial number (where applicable) for each of the instruments used in this lab.
   c) Record the *Calibration Coefficient* for the net radiometer and pyranometer (these are located on each instrument). Include the correct units.
   d) Take the readings for each instrument (described in the following specific instructions). Report these under *Instrument Output*. Include the appropriate units.
   e) As you take each measurement, record the time of each reading. Note cloud cover and current weather conditions as you take each observation. Add any other comments, indicating weather variability, etc. as needed.
   f) Inside, after data collection is complete you will use the calibration coefficients to convert the millivolt (*mV*) reading to Wm^{-2}. You will also use the IR thermometer readings to compute the longwave radiation values as discussed below.
   g) Clearly report each measurement value ($Q^*, K\downarrow, K\uparrow, L\downarrow, L\uparrow$) and if there is enough space the required calculation. Spaces are provided following Table 1 for you to report a required sample calculation (properly tracking all units) for each measurement type ($Q^*_{\text{(measured)}}$, $K\downarrow$ or $K\uparrow$, albedo (α), the details of the longwave radiation determinations ($L\downarrow$ and, $L\uparrow$), and $Q^*_{\text{(calculated using } Q^* = (K\downarrow - K\uparrow) + (L\downarrow - L\uparrow))}$.

2. Specific instructions for using each instrument follow: (multimeter connections should be prepared for you in advance of the lab).
   - The net radiometer for measuring Q^* is connected to a multimeter and set to DC *mV* (direct current – millivolts; ask your instructor for assistance if needed). As you carry the instrument ensure the delicate wires are supported or they may break. Test the sensor by moving an infrared (IR) source, such as your hand, near the top (bubble level faces up) of the instrument to see how this affects the reading. Then move your hand over the bottom sensor. Do not knock, set-down or touch the plastic domes as they are easily crushed and damaged. Center the bubble level so the net radiometer is parallel to the ground, and hold it away from your body at ~1.5 m above the ground. Record the Q^* measurement. Convert it from *mV* to Wm^{-2}. For net radiometers, the calibration coefficients are different for positive and negative *mV* readings, (respectively corresponding to dominating downward or upward fluxes). Ensure you record both calibrations and use the appropriate one for your reading. Consider whether your Q^* value makes sense for the current conditions before leaving the measuring site.

- The pyranometer measures shortwave ($K\downarrow$, $K\uparrow$) radiation and is connected to a multimeter set to DC *mV*. Again use the bubble levels to hold the instrument horizontally level at ~ 1.5 m above the ground with the sensor pointing up. Avoid having people obstructing the instrument's *sky view* when taking a measurement. It may take a few minutes to make an accurate reading. Record the measurement. Convert it from *mV* to Wm^{-2}. This is your $K\downarrow$ measurement. Does it make sense for the current conditions?

  Repeat the measuring technique with the pyranometer pointing down, (taking care to ensure it is level and checking that you or others don't obstruct your instrument's view while taking the reading). This is your $K\uparrow$ value.

- Using an IR thermometer, sample the surface temperature several times in different places that represent the different ground materials at your site (i.e. road grit, snow, vegetation, etc.). Record the temperature and corresponding percentage of the total ground surface represented by each temperature value. Remember to consider the instrument's view when estimating the percentage (%) of the surface represented by each material type (this will be further discussed in the lab). Once inside, calculate the weighted average surface temperature for the ground at our site in Kelvins. The temperature is weighted by the fraction of the surface material each temperature measurement represents.

  For example: If you take five temperature measurements (four represent materials that comprised 10% of the ground surface, and one represents 60% of the ground surface), then the weighted average temperature = $0.1T_1 + 0.1T_2 + 0.1T_3 + 0.1T_4 + 0.6T_5$

  Now convert this value to an outgoing longwave flux ($L\uparrow$) by converting the weighted temperature to Kelvin, and then using Stefan Boltzmann's Law to determine $L\uparrow$ in Wm^{-2}.

  Similarly, sample the sky temperature in several places that represent the different sky conditions observed during your measurement time. Consider how the instrument captures sky elements when determining the percentage (%) of the sky represented by each temperature. If non-sky materials such as trees or buildings occupy more than 5% of your sky view, measure them each. Find the weighted average for the sky at your Enclosed Site, and convert this value to its incoming longwave flux ($L\downarrow$).

3. For *Table 2*: Once inside use the computer to link to the *UNBC Roof Weather Station* and record the roof weather station values corresponding to your Table 1 measurement times.

[Note that the *UNBC Weather Station* always records data in Pacific Standard Time (PST), which is one hour behind Pacific Daylight Time (PDT). During PDT you must add 1 hour to the time shown on the website display to synchronize the time.]

4. For *Table 3*, compile the Enclosed Site values (recorded on Table 1: α, $Q^*_{(measured)}$, $K\downarrow$, $K\uparrow$, $L\downarrow$, $L\uparrow$ and $Q^*_{(calculated)}$) with the roof-top UNBC Weather Station values (recorded on Table 2: $Q^*_{(measured)}$, $K\downarrow$, $K\uparrow$, $L\downarrow$, and $L\downarrow$) to make answering the lab questions easier.

Assignment & Lab Questions: {200 marks – use for those who wish to grade their work}

Organize this double turn-in assignment with Tables 1, 2, 3 before your question answers. Don't forget to leave space for corrections. Note, you do not need a title page if you can clearly report your name and your lab instructor's name /lab time in to upper right corner of the first page (in this case Table 1). Answer the questions on lined sheets of paper and attach them (in order) after the completed Tables and example / tracking calculations. {15}

1. Complete the Tables and sample / tracking calculations. Use the spaces provided with the tables to show your example calculations. {80}

2. What does albedo indicate? (In this answer discuss: What property does albedo represent; does it vary? If there are differences why do these occur?) {15}

3. Using the data compiled in *Table 3*, answer the following: {40 total}
   a. How do your measured values of $K\downarrow$ and $L\downarrow$ compare with roof values? Explain. (20)
   b. How does the Enclosed Site Q^* value compare with the net radiation value from the Roof-top Weather Stations located on the Research Lab Building roof? Explain. (10)
   c. How does the calculated value compare with your measured Q^* value? Explain. (10)

4. Discuss the potential sources of errors involved in each of these measurements. {20}

5. Relate each of the radiation balance components you have measured to the outdoor environmental conditions you observed (e.g. clouds, time of day, site conditions, weather variability, etc.. In your answer make sure to comment on how the conditions would produce the observed effect.) {30}

TABLE 1: Enclosed Site – Recorder:_________________________________ Date & Lab Time:________________ __ 40

Group Members (full names):____

Instrument: *(include type & serial #)*	**Rad'n Component**	**Calibration Coefficient** *(include units)*	**Instrument Output** *(include units)*	**Calculated Radiation Value in Wm^{-2}** *(show an example of each calculation)*	**Reading Time**	**Weather Conditions & Comments**
Net Radiometer *type & serial #*	**Q***					
Pyranometer *type & serial #*	**K↓**					
Pyranometer *type & serial #*	**K↑**					
IR Radiation Thermometer *type*	**L↓**	Report the proportion of the site and temperature for each proportion here. (On the back of this page, calculate the weighted average and final radiation value from these values. Show your method and work clearly.)				
		Object	Temperature ^0C	% Coverage		
L↓ sky view sketch						
IR Radiation Thermometer *type*	**L↑**	Report the proportion of the site and temperature for each proportion here. (On the back of this page, calculate the weighted average and final radiation value from these values. Show your method and work clearly.)				
		Object	Temperature ^0C	% Coverage		
L↑ ground view sketch						

Site Description: ____ Group # ___________

Example or tracking of calculations for the Enclosed Site {26 total}

Q^* (5)

K↓ (or K↑for the Enclosed Site; specify which K flux you are reporting as your example calculation) (5)

α (for the Enclosed Site): (3)

Example or tracking of calculations for the Enclosed Site (continued)

L↓ (5)

L↑ (5)

Q* (calculated using Q* = (K↓ -K↑) + (L↓ -L↑) for the Enclosed Site using your measured radiation values) (3)

TABLE 2: SITE 2: Roof of the Research Lab Building (data taken from website) {4}

Date & class time: ________________________________ *Record data times in the table below.*

[Note: UNBC Weather Station Data is always on Pacific Standard Time. Adjust as needed.]

UNBC Roof-top Weather Station Instrument	**Rad'n Compon-ent**	**UNBC Wx Station Data Time** *(match this as closely as possible to your outdoor measurements)*	**UNBC Station Measurement (in Wm^{-2})**
Kipp & Zonen CNR4 Net Radiometer *Taken at the times of the Enclosed Site reading.*	**Q***		
Kipp & Zonen CNR4 Net Radiometer *Taken at the times of the Enclosed Site reading.*	**K↓**		
Kipp & Zonen CNR4 Net Radiometer *Taken at the times of the Enclosed Site reading.*	**K↑**		
Kipp & Zonen CNR4 Net Radiometer *Taken at the times of the Enclosed Site reading.*	**L↓**		
Kipp & Zonen CNR4 Net Radiometer *Taken at the times of the Enclosed Site reading.*	**L↑**		

TABLE 3: Site Comparisons: *(gathered from your other Tables; include your units)* {10 – 1 each based on answer}

Site	**α** (calculated)	**Q*** (measured)	**K↓** (measured)	**K↑** (measured)	**L↓** (measured)	**L↑** (measured)	**Q*** [calculated from your measured values Q*=(K↓-K↑)+(L↓-L↑)]
Enclosed Site							
Roof-top Weather Station (at the times of your Enclosed Site measurements)	**N/A**						**N/A**