TEACHER PAGE – *Trial Version*

** After completion of the lesson, please take a moment to fill out the feedback form on our web site (https://www.cresis.ku.edu/education/k-12/online-data-portal)**

Lesson Title: Data Series – Glacier Mass Balance
Grade: 9-12

Question: How have glaciers changed over the last several decades and what is causing these changes?

Time:
Two 45 minute class periods plus additional time for instruction on Excel if necessary. Lesson can be structured to 20-30 minute segments or as stand-alone activities.

Scope of the Lesson:
This lesson contains basic graphing components, interpretation of information and communication to others of findings depicted on their graph. You may choose to use either the total lesson or bits and pieces depending on student abilities and time constraints. The lesson is also designed so that it can be expanded for advanced students and used as an enrichment activity or a remedial activity.

Use of Microsoft Excel or another computerized graphing program will speed the activity and allow for more than one set of data to be examined. Graph paper and calculator can also be used by the students to get the same results.

If groups are given different data sets, the graphs can be printed or displayed so that the entire class or several groups can merge their information to come up with findings.

Objectives:
Given a set of data students will be able to:

- Create, using Microsoft Excel or another graphing program, an appropriate graph.
- Construct trendlines and interpret slopes.
- Using the graph they construct, be able to answer questions related to the data.
- Interpret the information found on the graph, and present their findings either orally or in a written format.

Standards:

- National 9-12: A2, 3; B1; C1, 2; E1; F2; G4, 5; H1

Vocabulary:

- <u>indicator:</u> *ecology* - a plant or animal species that thrives only under particular environmental conditions and therefore indicates these conditions where it is found
- <u>mass balance:</u> The mass that enters a system must, by conservation of mass, either leave the system or accumulate within the system
- <u>accumulation:</u> the act or process of collecting together or becoming collected
- <u>ablation:</u> the reduction in volume of glacial ice or snow by the combined processes of melting, evaporation, and calving

- <u>water equivalent:</u> a common snowpack measurement, the amount of water contained within the snowpack, the depth of water that would theoretically result if you melted the entire snowpack instantaneously

Background:

When analyzing the current state of local, regional, and global climate, as well as the rate in which such climates are changing, scientists often study components of the earth-climate system whose state of existence is dependent upon certain climatic features. Although these components, known as **indicators**, are present in a variety of forms, bodies of ice are generally considered one of the most important because of their unique properties and sensitivity to the surrounding environment. While larger bodies of ice, such as ice sheets, require many years for noticeable changes to occur, smaller ice bodies, present in the form of glaciers, respond relatively quickly to climate variations. By looking at the average rate at which a glacier grows or shrinks each year, known as the **mass balance** of the glacier, certain aspects of the surrounding climate can be inferred and extrapolated to the larger scale system.

In order for a body of ice such as a mountain glacier to form and be maintained on an annual basis, the overall rate of snow and ice accumulation across the entire ice mass must equal or exceed the overall rate at which the glacier loses ice through **ablation**, or melting, which usually manifests itself through the calving or shedding and subsequent melting of icebergs into lakes or oceans. In the case of a mountain glacier, most ablation can be attributed to the absorption of solar radiation and uptake of heat from the surrounding atmosphere. In fact, these climatic properties have the largest impact on a glacier's long term behavior and hence can be broadly inferred from analyzing changes in ice mass over long periods of time. Through the study of snow and ice that lie near the surface of a glacier, scientists can determine the **annual mass balance**, or the amount of that has been lost or gained throughout the year. A negative balance indicates that the rate of ablation exceeds that of accumulation and that the glacier is shrinking or retreating, while a positive mass balance suggests glacier growth and advancement through greater accumulation. In this manner, scientists use mass balance values to determine the "health" of a glacier as well as the impact that future changes in the local climate may have upon its existence.

In this particular activity, students will examine annual winter and summer mass balance data recorded from 1959-2005 for one of three glaciers, **South Cascade Glacier, Wolverine Glacier**, or **Gulkana Glacier**, a mountain glacier located in the maritime climate of the Cascade Mountain Range in Washington state. Most of the accumulation which occurs at the South Cascade Glacier site is due to snowfall or avalanching of snow onto the glacier surface between the months of October and May when temperatures usually fall to near -10^{o}C (14^{o}F) near the glacier. The most important ablative processes occur, as expected, during the summer months when the local temperature increases to about 20^{o}C (68^{o}F), causing loss of ice through melting and evaporative processes. Analysis of the resulting mass balance values will allow students to determine the behavior of the South Cascade Glacier over the forty six year time period in which data was collected and recognize the changes in climate which caused such behavior to occur.

Materials:

- Computer w/Microsoft Excel (or other graphing software)
- Internet connection
    - http://www.teachersdomain.org/asset/ipy07_int_glacierphoto/
- Data Set – 3 Glacier Mass Balance Summary
    - http://ak.water.usgs.gov/glaciology/all_bmg/3glacier_balance.htm
- Student Worksheet

Engage:

- This activity features six pairs of photographs of Alaskan glaciers (example below) taken up to 100 years apart. Look at each pair of images and observe the different landform features (http://www.teachersdomain.org/asset/ipy07_int_glacierphoto/).

Q1) Describe some general changes you observe between the time of the first photograph and the second.

Q2) What do you find most surprising about the photographs?

Q3) What are some possible explanations for the differences seen in 1941 to 2004?

Q4) What are at least three questions that come to mind when looking at these photographs?

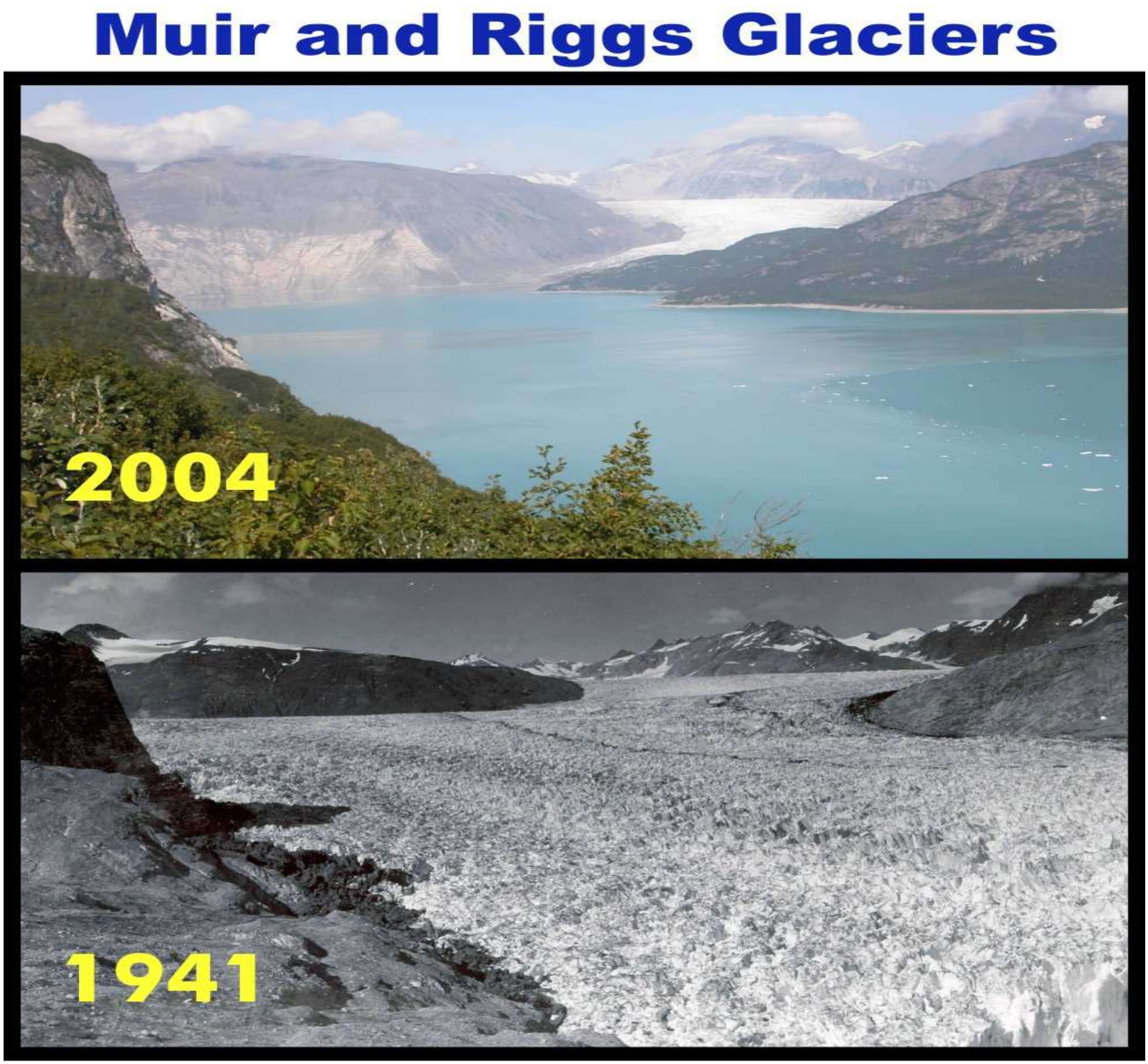

Image 1 - Comparison photos of Muir and Riggs Glaciers in Alaska between 1941 and 2004. During this time, the Muir glacier with was >70 meters thick has retreated out of the frame. Image created by Robert A. Rohde / Global Warming Art (Field, 1941; Molnia, 2004).

Muir glacier, parts of which were greater than 65 meters thick in 1941, has retreated out of the image in 2004 (towards the upper left). The distance to the visible Riggs glacier in 2004 is ~3 km. During this time, the Muir Glacier retreated more than 20 km (Benson and Field 1995).

The Muir and Riggs glaciers are part of the Glacier Bay ice field. In the 1700s, during the little ice age, most of the regional glaciers were merged into a single ice mass that extended ~110 km south of Muir's present location into the Icy Strait of Cross Sound. By 1890, the ice tongue for which Muir was the largest component had already retreated 60 km north (Hall et al. 1995). Tidewater glaciers, i.e. those terminating in channels open to the ocean but sufficiently thick to avoid floating, tend to be unstable when pushed into retreat. If thinned sufficiently, they will start to float off the bottom of the channel and allow sea water infiltration underneath the glacier, which can trigger rapid and prolonged retreat until the glacier reaches a position that is again stable (e.g. Vieli et al. 2002). Because Muir glacier and many other glaciers in the Glacier Bay complex are tidewater glaciers, it is not known how much of the present retreat is a response to recent warming, and how much is the consequence of unstable conditions created by previous warming that has not yet resolved itself (Hall et al. 1995).

Explore:

- Download the data set (see materials section).
- ***NOTE:*** *All mass balance values are in meters of water equivalent.*

Q5) At first glance of the raw data, are the majority of these values for the three glaciers positive or negative? What does this imply about the glaciers?

Q6) What climatic aspect might cause the discrepancy observed between the summer and winter mass balance?

Q7) What would cause this aspect to be different for each season?

- Using the raw data, compute the cumulative mass balance for the South Cascade Glacier.
- Construct a plot of the cumulative mass balance for the South Cascade Glacier from 1959-1982, using the 1959 values as a reference point (i.e. the "zero point").
- Repeat this procedure for 1982-2005 on a separate plot, using 1982 as a reference point.

Q8) Describe the differences between the two plots.

Q9) What do these differences suggest with regard to the mass balance of the glacier?

Q10) How much greater is the rate of mass loss for 1982-2005 compared to 1959-1982?

Explore:

- Construct a graph showing the cumulative mass balance of South Cascade Glacier over the entire time period (1959-2005), using the 1959 value as a reference point.

Q11) What do the calculated values and graph tell us about South Cascade Glacier?

Q12) How are these implications similar or different from those found in questions 7 and 8?

Elaborate:

- Construct a graph of winter mass balance over the entire time period (1959-2005).
- Fit a trendline to the data.
- Repeat this procedure for the summer mass balance.

Q13) Describe the trendline for the winter data.

Q14) Describe the trendline for the summer data.

Q15) Compare and contrast the graph of the winter and summer trendlines.

Q16) What factors might be leading to the observed discrepancy between summer and winter mass balances?

Q17) Determine the overall average mass balance as well as the average summer and winter mass balance.

Q18) What do these values imply?

Q19) What trends do they indicate?

*** * *NOTE* * ***

There are data for three glaciers, **South Cascade Glacier** (1959-2005), **Wolverine Glacier** (1966-2004) and **Gulkana Glacier** (1966-2005), contained in the accompanying Excel Workbook (also found on the web site in the materials section). Assign students different glaciers or divide students into groups to analyze different scenarios. The same questions will apply. Examples and answers are provided for the South Cascade Glacier.

Resources:

- Field, William Osgood. 1941 Muir Glacier: From the Glacier Photograph Collection. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.
- Hall, Dorothy K., Carl S. Benson and William O. Field (1995). "Changes of Glaciers in Glacier Bay Alaska, Using Ground and Satellite Measurements". *Physical Geography* **16** (1): 27-41.
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STUDENT PAGE

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Vocabulary:

- indicator: ____
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- accumulation: ____
- ablation: ____
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When analyzing the current state of local, regional, and global climate, as well as the rate in which such climates are changing, scientists often study components of the earth-climate system whose state of existence is dependent upon certain climatic features. Although these components, known as **indicators**, are present in a variety of forms, bodies of ice are generally considered one of the most important because of their unique properties and sensitivity to the surrounding environment. While larger bodies of ice, such as ice sheets, require many years for noticeable changes to occur, smaller ice bodies, present in the form of glaciers, respond relatively quickly to climate variations. By looking at the average rate at which a glacier grows or shrinks each year, known as the **mass balance** of the glacier, certain aspects of the surrounding climate can be inferred and extrapolated to the larger scale system.

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In this particular activity, students will examine annual winter and summer mass balance data recorded from 1959-2005 for the **South Cascade Glacier**, a mountain glacier located in the maritime climate of the Cascade Mountain Range in Washington state. Most of the accumulation which occurs at the South Cascade Glacier site is due to snowfall or avalanching of snow onto the glacier surface between the months of October and May when temperatures usually fall to near -10^{o}C (14^{o}F) near the glacier. The most important ablative processes occur, as expected, during the summer months when the local temperature increases to about 20^{o}C (68^{o}F), causing loss of ice through melting and evaporative processes. Analysis of the resulting mass balance values will allow students to determine the behavior of the South Cascade Glacier over the forty six year time period in which data was collected and recognize the changes in climate which caused such behavior to occur.

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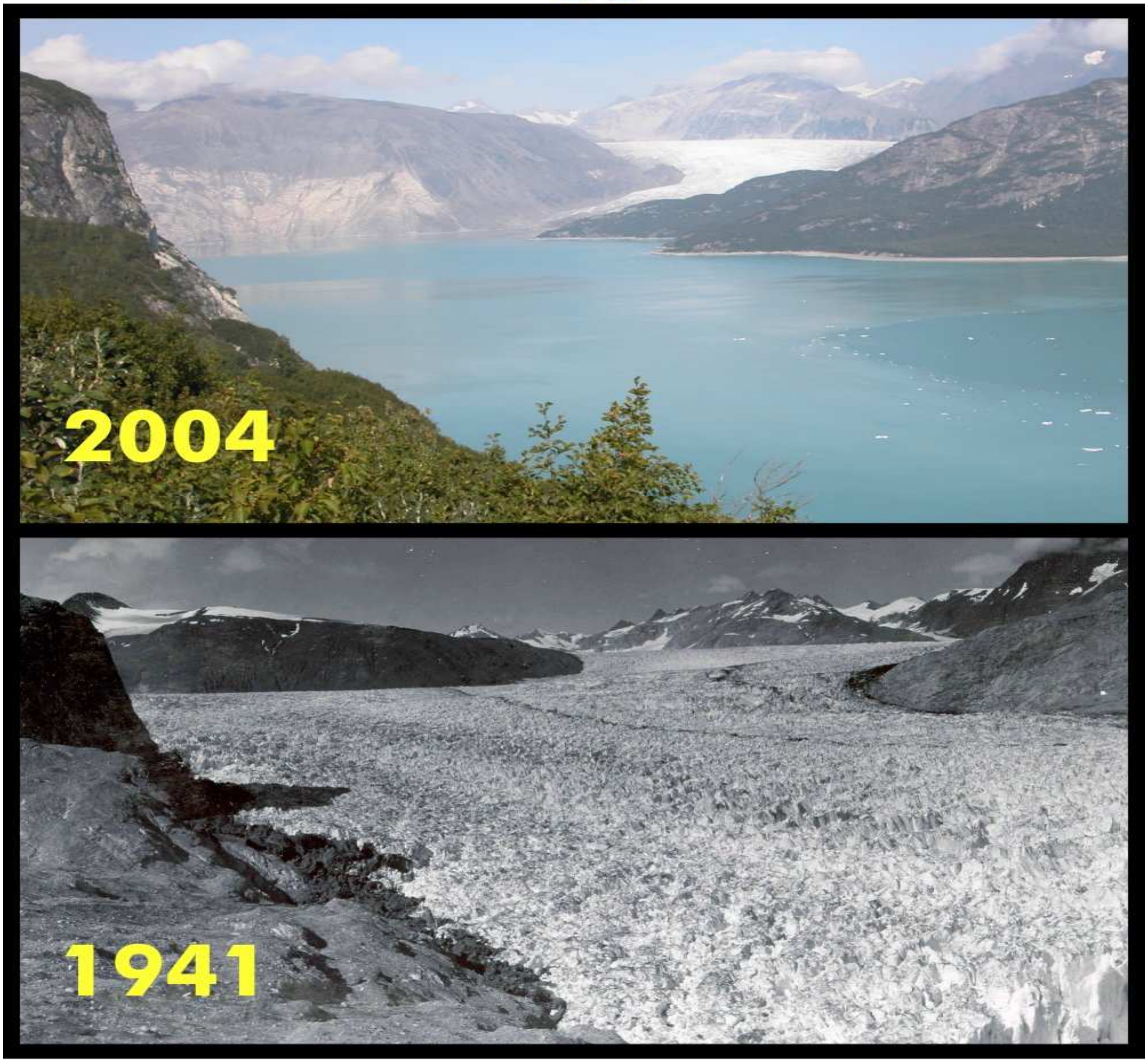
Muir and Riggs Glaciers



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ANSWER KEY (South Cascade Glacier)

Q1) Answers will vary. All reasonable responses should be accepted.

Q2) Answers will vary. All reasonable responses should be accepted.

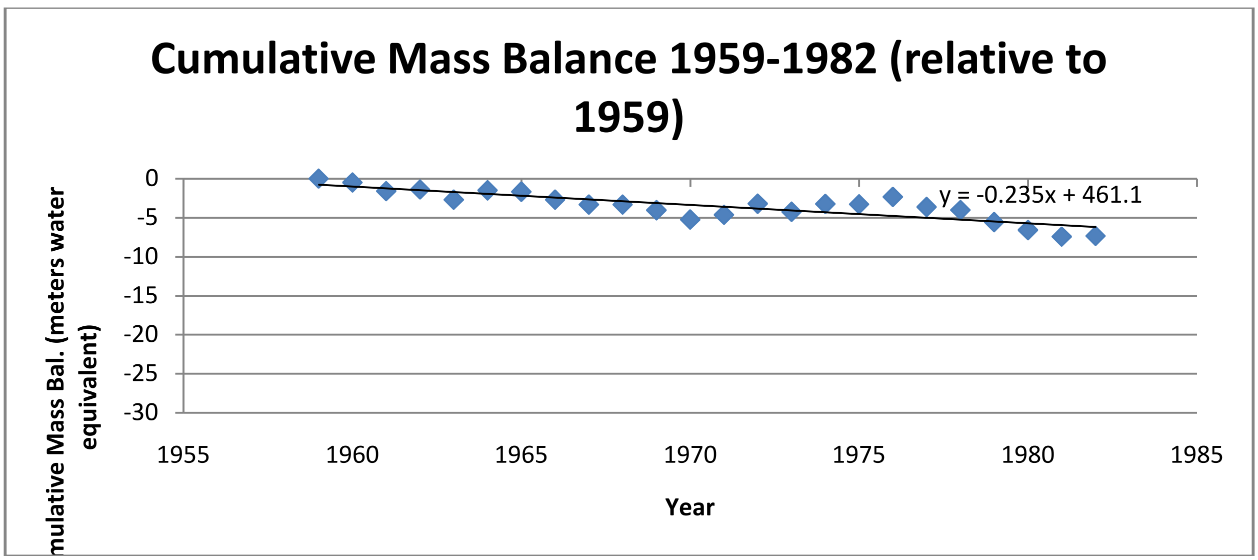
Q3) Answers will vary. Anything scientifically reasonable should be accepted. One example is the temperatures are rising causing more of the glacier to melt.

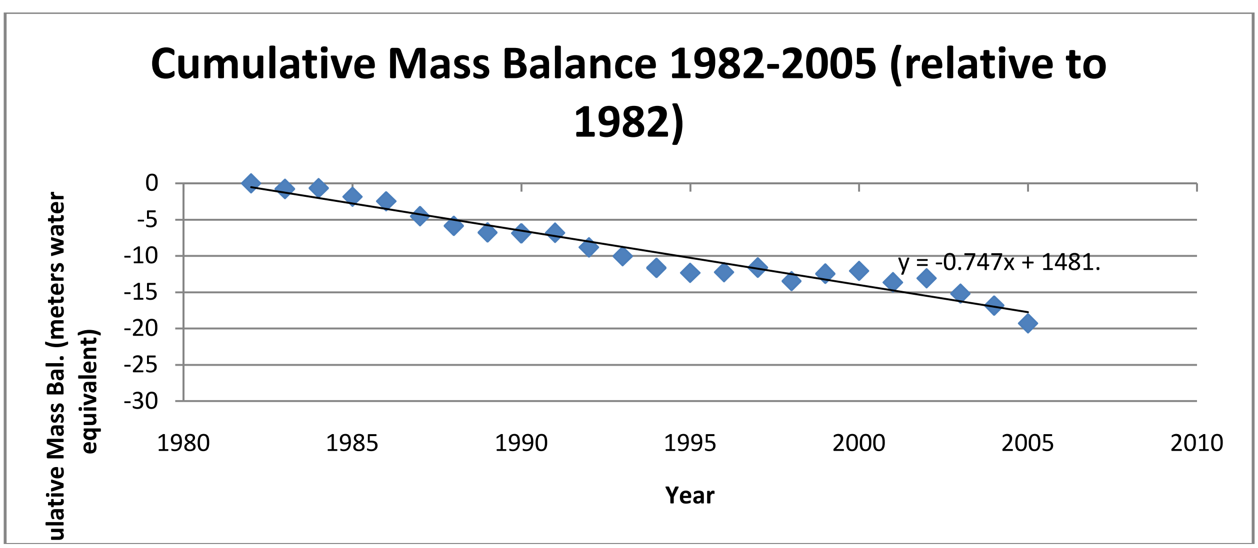
Q4) Answers will vary. Examples: How long will this retreat continue? What is causing the widespread retreat of glaciers? How much rise in sea level do the melting glaciers contribute?

Q5) Most of these values are negative, indicating that the mass of the glacier has been, for the most part, in a state of gradual decrease since 1959.

Q6) The differences in mass balance values observed between these two seasons are due mainly to the warmer temperatures which occur during the summer months.

Q7) This temperature difference is due to several factors such as a higher summer sun angle (causing more direct radiation to be present), increased hours of daylight, and changes in the general weather pattern of the region.





Q8) The plotted 1982-2005 data possesses a 31% steeper slope than the 1959-1982 data.

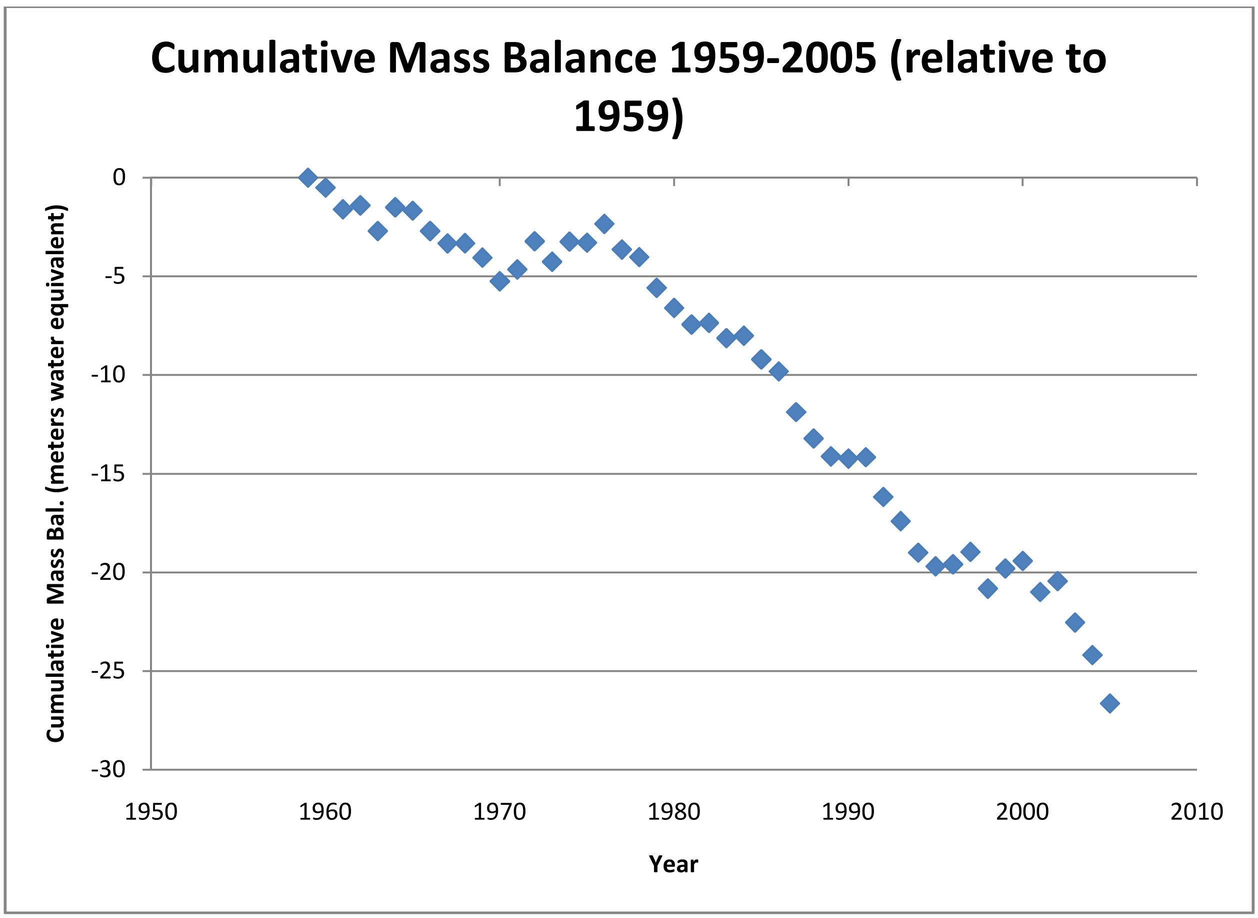
Q9) The steeper slope suggests that the South Cascade Glacier has experienced a greater rate of mass loss since 1982 than in the previous 23 years. Although other factors can also play a role in the melt rate and mass loss of a glacier, scientists believe the most important climatic aspect is the temperature of the air surrounding the glacier.

Q10) The increased rate of mass loss observed after 1982 suggests that the climate surrounding the South Cascade Glacier has been warming at a faster rate during the last 23 years than prior to 1982. Although values may vary slightly due to measurement error, the rate of mass loss for each dataset should be similar to the following values:

$$slope_{1959-1982} \cong -0.235 \frac{mH_20Eq}{year}$$

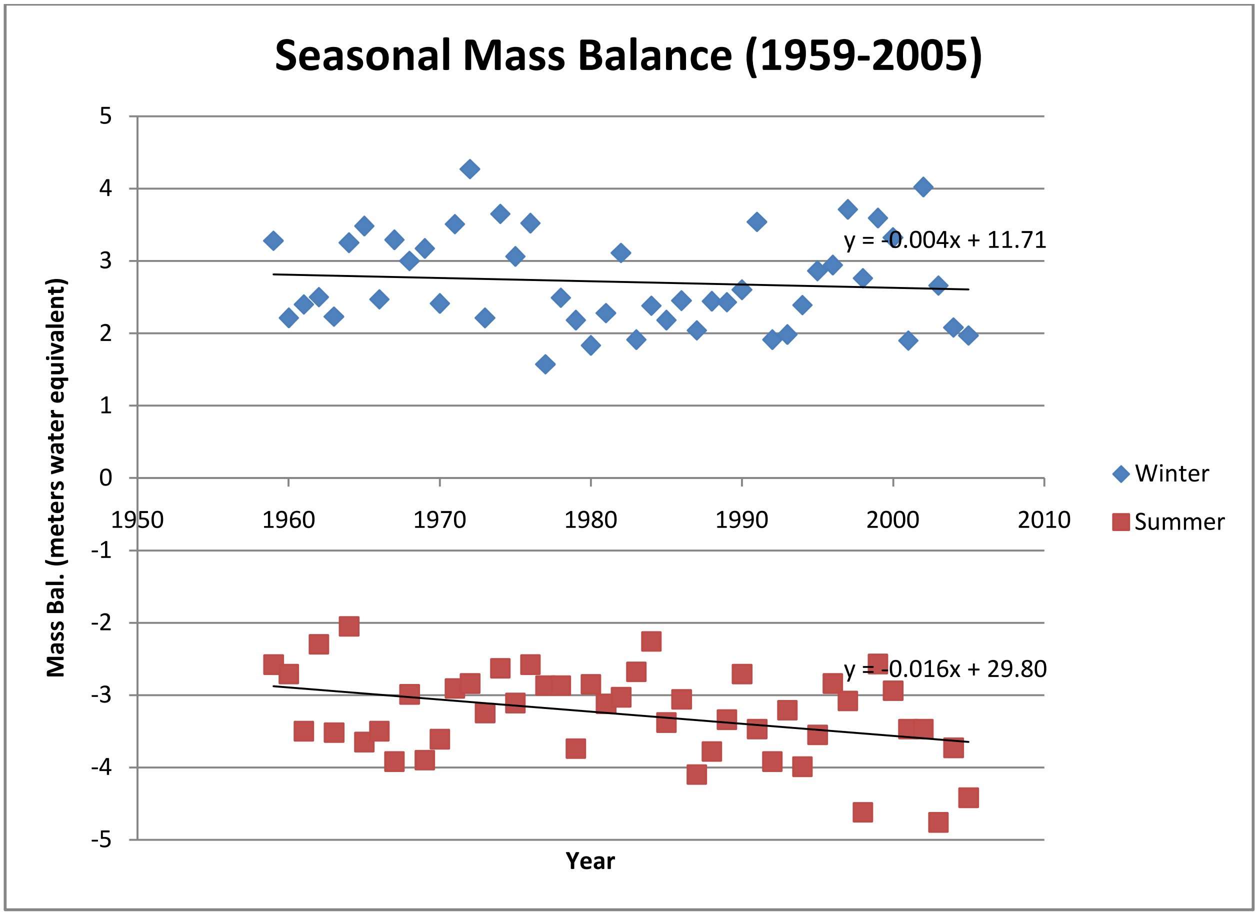
$$slope_{1982-2005} \cong -0.747 \frac{mH_20Eq}{year}$$

Taking the ratio of these two values, the rate of mass loss from 1982-2005 is about 3 times greater than the rate of mass loss from 1959-1982. *NOTE: $mH_20Eq/year$ stands for meters of water equivalent per year.



Q11) When the cumulative mass loss for the entire period is plotted, the rate of glacier mass loss increases after the late 70s/early 80s, as can be seen by an increase in the slope of the plotted data.

Q12) This increase in the rate of mass loss is similar to the conclusions drawn in questions 7 and 8 in which it was determined that the glacier has been losing mass at more rapid rate since 1982 than during the first 23 years of observations.



Q13) The winter trendline is decreasing at a rate of -0.004 meters water equivalent per year.

Q14) The summer trendline is decreasing at a rate of -0.016 meters water equivalent per year.

Q15) Through the application of a linear trendline to the mass balance data, the mass of the glacier has, over time, been decreasing during both seasons. This trend is much more amplified during the summer months, however, as shown by a steeper trendline slope, indicating that most of the observed mass decrease is taking place during the summer.

Q16) The main reasons for increased summer melting are related to simple climatic factors such as a higher sun angle, increased hours of daylight, and warmer temperatures. However, as the trendline indicates, mass loss due to summer melting has displayed an increasing trend since 1959, suggesting that, on average, summer temperatures have warmed. Noticeable loss during the winter has occurred as well, though on a much smaller scale, also suggesting that average winter temperatures have increased. Therefore, it can be concluded that an overall warming trend has been observed over recent decades—one which can be linked to increases in greenhouse gas concentrations.

Q17) Calculated average values of -0.56, 2.71, and -3.26 for the overall net, winter, and summer balances, respectively.

Q18) Since mass balance values are an indicator of the growth and recession of the glacier, the negative overall average implies that the South Cascade Glacier is currently shrinking.

Q19) When the mass balance is analyzed by season, it can be clearly recognized that the current loss of mass is a result of significant melting during the summer months.