Predicting rates of change using Greenland outlet glaciers

You have just learned about marine terminating outlet glaciers in Greenland. Figure 1 below illustrates changes in the combined areas of the 34 widest marine terminating outlet glaciers in Greenland from 2001-2009. (The area is expressed in km² on the left side of the graph and mi² on the right side of the graph.) Satellite technology called MODIS is used to obtain the data necessary to generate this graph.

(1) Explain why the values on the Y-axis are negative numbers.

(2) Approximately how much area change occurred between:

(a) 2001-2002?  ____________ km²
(b) 2001-2003?  ____________ km²
(c) 2001-2005?  ____________ km²

Figure 1. Data from NOAA Arctic Report Card 2009.
(3) Did the area of the marine terminating outlet glaciers in the study change consistently from 2001-2009? Briefly explain your answer, using evidence from the graphed data.

The dashed line in Figure 1 represents the straight line that fits the data best (and consequently, is called a best-fit line!) You are going to use the best-fit line to calculate the average rate of area change from 2001-2009.

(4) If you are looking for the average area change per time, or \( \frac{\text{area change}}{\text{time}} \), in which units should your answer be expressed? Record your answer in the box.

(5) Now, refer back to Figure 1 on the previous page. Which unit is on the Y-axis of the graph? Does this unit correspond to what you wrote in the box above?

(6) Refer back to Figure 1 on the previous page. Which unit is on the X-axis of the graph? Does this unit correspond to what you wrote in the box above?

(7) Another word to express what you're calculating is slope, which is expressed as
\[
\frac{y_1 - y_2}{x_1 - x_2}
\]

Based on what you know about slope and what you did in questions 4, 5, and 6, explain what you need to do to calculate the average area change from 2001-2009.
(8) Calculate the average rate that the area of Greenland’s marine terminating glaciers have changed from 2001-2009.

(9) Using the rate that you just calculated, predict how much the area of Greenland’s marine terminating glaciers will change from 2009-2010. In addition, explain how you came up with your answer, and plot your prediction on Figure 1.

Predicted change in area of Greenland's marine terminating glaciers, 2009-2010:

________________________________________ km²

Explanation of how you came up with your prediction:
(Someone who isn't in this class should be able to read your explanation and understand how to solve a problem like this.)

(Don't forget to plot your prediction on the graph on page 1.)

****If you feel like you need more practice with rates, I recommend that you visit The Math You Need, When You Need It website. This website includes several math tutorials especially for students in introductory geoscience courses. Here's the URL for the tutorial on rates: [http://serc.carleton.edu/mathyouneed/rates/index.html](http://serc.carleton.edu/mathyouneed/rates/index.html)
Next, let’s look at some updated data for 2010 to evaluate your prediction. Figure 2 below illustrates the 5 marine terminating outlet glaciers in Greenland that experienced the greatest cumulative loss in area between 2000 and 2010.

Figure 2. Data from MODIS studies of Greenland, Byrd Polar Research Center
(10) Name one glacier that did not lose area from 2009 to 2010. Explain how you know.

(11) Name one glacier that lost area relatively consistently between 2008 to 2010. Explain how you know.

(12) Which glacier was “the biggest loser” from 2009 to 2010? Explain how you know.

(13) If asked to predict how the data for these five glaciers will look for 2011, how certain would you be in your predictions? Would you be equally certain (or uncertain) for all five of the glaciers? What additional information would be helpful in making 2011 predictions?

(14) Keeping in mind that these are some of the marine terminating outlet glaciers used to make graphs like Figure 1, discuss how certain you are about the prediction that you made in question 9.
(15) Use figure 2 to make a prediction for how the area of each of the glaciers changed in 2011. If you are stuck, refer back to how you made your prediction for figure 1. Feel free to write on figure 2 if it helps you. Record your predictions in the table below. The rest of this page is blank to give you room to make notes and do calculations.

Predicted 2011 area changes for five marine terminating outlet glaciers

<table>
<thead>
<tr>
<th>Glacier name</th>
<th>Predicted area change for 2011 (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Jakobshavn</td>
<td></td>
</tr>
<tr>
<td>Humboldt</td>
<td></td>
</tr>
<tr>
<td>Zachariae</td>
<td></td>
</tr>
<tr>
<td>Petermann</td>
<td></td>
</tr>
</tbody>
</table>
Finally, let’s take a look Figure 3 below, an area change graph that includes 2010. Notice that two points are plotted for 2010: the triangle represents the change in area in 2010 excluding the Petermann Glacier. The square represents the change in area in 2010 including the Petermann Glacier.

Figure 3. Data from NOAA Arctic Report Card 2010

(16) Why do you think that the scientists who made this graph provided a “with Petermann” calculation AND a “without Petermann” calculation for 2010? If you were conducting a study on climate variability in Greenland, which calculation would you use for 2010, and why?
(17) How accurate was your prediction in question 9 if you include the Petermann data?

(18) How accurate was your prediction in question 9 if you do not include the Petermann data?

(19) Below are the updated data from 2011 with the area changes for the five glaciers in figure 2. How accurate were the predictions that you made in question 15?

<table>
<thead>
<tr>
<th>Glacier name</th>
<th>Area change for 2011 (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>+7</td>
</tr>
<tr>
<td>Jakobshavn</td>
<td>-9</td>
</tr>
<tr>
<td>Humboldt</td>
<td>-20</td>
</tr>
<tr>
<td>Zachariae</td>
<td>-19</td>
</tr>
<tr>
<td>Petermann</td>
<td>+13</td>
</tr>
</tbody>
</table>

Data from Arctic Report Card 2011
Based on what you did in this exercise, what are your thoughts on scientists’ ability to predict how the Greenland ice sheet will change in the future? Use evidence from this exercise to support your response.