Appalachian State University
BOONE, NORTH CAROLINA

# Antarctica Ice Melting - Mathematical Modeling Lesson

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**Abstract**

This lesson uses mathematical modeling to approximate the rise in sea level caused by the Antarctica ice sheet melting. Students must formulate questions and assumptions, compute answers, interpret in the context of the problem and then validate their model by assessing the reasonableness and other factors that might also impact the situation. The topics addressed through the mathematical modeling process include unit conversions and the relationship between surface area and volume.

**Antarctica Ice Melting- Mathematical Modeling Lesson**
**Launch Explore Summarize Format**

OBJECTIVES:
After this lesson students will be able to:
Calculate measurement conversions
Understand and utilize the mathematical modeling process

CURRICULUM:
MAT-143 Quantitative Literacy

RESOURCES:
Adapted from activity in "Using and Understanding Mathematics: A Quantitative Reasoning Approach" by Bennett & Briggs (2015)
Activity titled "Global Melting" on page 70

a. **Launch** (10 minutes)

| **Teacher Considerations (Before)** | **Description of Learning Activities** | **Anticipated Student Responses** | **Teacher Guidance (During)** |
|---|---|---|---|
| **Answer the following about planning this phase:**<br>• **How will I engage the students' prior knowledge?**<br>Discuss how to calculate volume of rectangular prisms if necessary. Demonstrate how to cover an area using two measurements. Then build the area up vertically to demonstrate how area and volume are related. Provide the volume formula for students ($V = lwh$) then after discussing the relationship between area and volume have students write an alternate formula using area or surface area instead of *l* and *w*.<br><br>Demonstrate an example of unit conversions (seconds to days) if necessary. Show multiplying the original value by unit fractions to convert between units. You could begin with a numerical fraction | **Write a narrative describing the <u>launch</u> for this lesson.**<br><br>Show the videos.<br><br>Then ask students, "What questions do these videos make you want to ask?" Allow students time to think (on their own) and then share their questions with the class. Write these on the board.<br><br>After all students have voiced their thoughts, focus the class on these questions (or the closest alternatives the | **What are possible student responses/reactions/ solutions/questions (both correct and incorrect)?**<br><br>Students should ask about how much water will be released into the oceans because of the melting or how this will affect sea levels. Also, hopefully students will ask if the volume of ice and water are equivalent. Students | **Possible teacher scaffolding/questions/ Modifications in reaction to anticipated student responses. Ways you intend to build on student responses.**<br><br>Students might need to be prompted to think about the ratio of ice volume to melted liquid volume. Ask them "Do you think air bubbles that form in ice influence the volume of |

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| problem to remind students of how we can simplify fractions being multiplied together by dividing numerators and denominators by common factors. Then show how units can be simplified similarly. Have students practice using the "Converting Units" applet on the National Library of Virtual Manipulatives (http://nlvm.usu.edu/en/nav/topic_t_4.html). Have students create their own problems in the applet, choose the correct unit fraction, and component placement, in order to reach the new required units.<br><br>• **How can I keep from giving away too much of the problem?**<br>Only showing students the videos, editing out the sections that talk about how much the sea level will rise. Making them come up with the questions to be asked, and then making them ask for the needed information.<br><br>• **How can I make it personal and relevant to the students?**<br>Show students these videos:<br>Arctic Ice Death Spiral<br>https://www.youtube.com/watch?v=qUO23Y179pU<br>Antarctica Ice Melt Through Years<br>https://www.youtube.com/watch?v=W2pYHMx5bN8<br>(start at about 0:43- watch through 1:06)<br><br>• **What advantages or difficulties can I foresee?**<br>Students will be much more engaged in this activity than normal unit conversion problems because it is real world and they will have the opportunity to make the problem their own because they must request the information to solve the problem. | students come up with):<br>-What is the total volume of the ice sheet on Antarctica (in cubic kilometers)?<br>-Assuming the ice melts, what will the volume of the water represent?<br>-Suppose the melted ice flows into the seas, and also assume the total surface area does not change (does not spread out over the continents) how much would sea level rise? Have students calculate the rise in km, m, and ft.<br><br>Once the questions have been posed, have students think about the information they will need in order to answer the questions. Make students ask for the needed information. Once they ask you can provide them with this data:<br>-The land area of Antarctica is about 14 million $km^2$.<br>-The average thickness of Antarctica is about 2.15 km.<br>-The oceans' surface area covers about 340 million $km^2$.<br>-When ice melts into water, the resulting water volume is about 5/6 of the original ice volume. | will also probably wonder how much the sea levels will rise because of the increased water. | the liquid once it thaws?"<br><br>Students will probably wonder how much sea levels will rise and will probably think about the extra water spreading out over the continents. In order to simplify the problem at first, and only calculate the increase in depth, students will need to instead assume the extra water does not spread over the continents, increasing vertically over the current surface area of the oceans. Teachers should guide students into this thinking. If students begin asking about how the water will spread as it moves inland discuss how complicated this calculation could become, and instead suggest they think about pouring the water into a fixed area instead. |

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| Getting students to ask the right questions might be difficult. Scaffolding questions to get them thinking in the right direction might be necessary. | Also, students might need:<br>1 km = 1000 m<br>1 m ≈ 3.2808 ft | | |

b. **Explore** (25 minutes)
This is where students work individually or in small groups to solve the problem. This is their chance "to get messy with the math."

| **Teacher Considerations (Before)** | **Description of Learning Activities** | **Anticipated Student Responses** | **Teacher Guidance (During)** |
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| **Answer the following about planning this phase:**<br>• **How will I organize the students to explore this problem? (Individuals? Groups? Pairs?)**<br>Pairs<br><br>• **What materials will students need to encourage diverse thinking and problem-solving?**<br>After students ask for, and obtain, the information above they will have the all the data necessary to solve the problems. Students will need paper and pencils, and their calculators, too.<br><br>• **What advantages or** | **Write a narrative describing the <u>explore</u> for this lesson.**<br>Allow students to work with their partner to solve these questions. Walk around to each group during this time and guide students. (15 min).<br><br>Then, as an entire class discuss the answers found in the groups. (10 min). | **What are possible student responses/reactions/ solutions/questions (both correct and incorrect)?**<br><br>Volume of ice = 30.1 million $km^3$<br><br>Resulting water = 25 1/12 million $km^3$ or ≈ 25.083 million $km^3$<br><br>Rise in sea level ≈ 0.07377 km = 73.77 m ≈ 242.02 ft | **Possible teacher scaffolding/questions/ Modifications in reaction to anticipated student responses.**<br>**Ways you intend to build on student responses.**<br><br>**Specifically, what kinds of questions can I ask:**<br>• **to prompt their thinking if the level of frustration is too high?**<br>Students will probably struggle the most when trying to calculate the rise in sea level question. Remind students of the assumptions discussed during the launch portion of the lesson, and also have students try to visualize or draw representations of what is occurring in the problem.<br><br>If both partners are stuck, have the pair discuss their thinking with another pair of students.<br><br>• **to make them probe further into the problem if the initial question is "answered"?** |

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| **difficulties can I foresee?**<br>Since this activity is meant to be taught before the unit conversion chapter students might struggle with completing the conversions. Also, they might struggle with calculating volume. | | | Does the answer seem reasonable?<br><br>Do the original assumptions make sense? Should they be modified? If so, how would this alter the problem and answers?<br><br>• **to encourage student-to-student conversation, thinking, learning, etc.?**<br>Did your partner get the same answer?<br>Did you both use the same process or reasoning? Explain your thought process to your partner. |

c. **Summarize** (15 minutes)
The purpose of the Summarize section is to bring groups back together and have students explain their solutions while assessing how students are progressing towards the goals of the lesson. The teacher's role is to guide students to the big ideas, to make sure that they have nailed the mathematics. Use the discussion to help you determine whether additional teaching and/or additional exploration by students is needed before they go on to the next lessons.

| Teacher Considerations (Before) | Description of Learning Activities | Anticipated Student Responses | Teacher Guidance (During) |
|---|---|---|---|
| **Answer the following about planning this phase:**<br>• **How can I orchestrate the discussion so the students summarize the thinking in the problem?**<br>Each group can describe how they calculated one of the questions. Then after they describe their approach the teacher can ask for alternate approaches. Make sure students show their conversion | **Write a narrative describing the <u>summarize</u> for this lesson.**<br>After sharing the processes and answers for each of the questions posed in the problem the teacher should ask, "Do you think the assumption that the ocean surface area will stay constant is valid? Why or why not?"<br><br>Allow students time to think individually, or discuss their ideas with their partner. Then have | **What are possible student responses/reactions/ solutions/questions (both correct and incorrect)?**<br>Students should understand that the surface area of the oceans staying constant is not a valid assumption, but was one necessary to simplify the problem and allow for calculating an estimate easily. Students will be interested in solving the more complex problem, but will quickly | **Possible teacher scaffolding/questions/ Modifications in reaction to anticipated student responses. Ways you intend to build on student responses.**<br>The students will probably point out that the surface area of the oceans is not going to stay constant but instead will spread out as sea levels rise. Therefore, the teacher can have students think about how this might change |

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| calculations, and discuss any alternate processes as a class.<br><br>Then the teacher should pose the question, “Do you think the assumption of the ocean surface are staying constant is valid? Why or why not?” Students will have to justify their answers. Then the entire class can discuss how the problem and/or process would have to be modified and what additional information would be needed to solve the new problem.<br><br>• **What generalizations can be made?**<br>Focus students’ attention on the unit conversion process. Discuss the advantages of using unit fractions and showing their work.<br><br>Also, emphasis should be placed upon the modeling process students went through to solve this problem. As a class discuss how during Launch as the students asked questions to gather information needed to solve the problem they were in the **Formulate** stage. Then in pairs they completed calculations in | students discuss their views with the entire class and provide justification for their answers. Discuss how the original model, although correctly solved, is inaccurate because of broad estimations and unaccounted variables.<br><br>Then, discuss how altering the original assumption would require modification of the model, but would create a more reasonable answer. Discuss what new information might be needed to solve the adjusted problem (what is the average height of costal areas; is the average thickness of Antarctica’s ice sheet a good approximation or is there a better estimate).<br><br>Furthermore, discuss other factors which might affect this problem or what other queries might be prompted by discussing this problem. When discussing other factors students might mention Greenland and the Arctic Ocean.<br><br>After discussing how the problem could be re-evaluated, show students the mathematical modeling cycle and discuss how the students went through the modeling cycle during this | realize its complexity when discussing the new information that would be needed.<br><br>Students will explain how parts of the calculation fit within stages of the modeling process. Students might be unsure about the difference between the interpret and the validate stage. Discussing the modeling framework with students will help to illuminate the differences. Also, it will help students understand the types and depth of thinking that will be required to solve modeling questions during future lessons. | the problem. Teachers could ask, “If we introduced new assumptions, such as that the oceans would spread over the continents and not just rise vertically, what new information would you need and how would your computations change?” leading students to think about how they could cycle back around the modeling cycle given the new situation. Students might not consider other factors, such as Greenland or the Arctic Ocean melting, so the teacher can present data about these areas to prompt student thinking.<br><br>**Additionally, what mathematics and processes need to be covered in more depth?**<br>Additional lessons and more time will have to be spent on converting units. More advanced problems, such as converting square yards to square feet, should be investigated.<br><br>This lesson introduces students to the modeling process. Students should learn the steps of the modeling process and the movement between stages. If teachers discuss the modeling framework with the students, the students will better understand |

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| the **Compute** stage. Adding units, discussing reasonableness, and viewing their calculations in terms of the original problem were part of the **Interpret** stage. Lastly, thinking about the validity of the original assumptions, and how new assumptions would alter the answers was part of the **Validate** stage of the modeling process.<br>Discussion how the mathematical modeling process will be a guiding framework and tool for other projects throughout the class.<br><br>• **What advantages or difficulties can I foresee?**<br>This lesson will help students become familiar with the modeling process while being guided by a teacher. Discussing each distinct step in the process, and how the components are linked and continuous, will help students see the connection to real world problem solving skills.<br><br>The unit conversions presented are not very difficult (which is good if this lesson is used to introduce unit conversions). However, students will need | problem. Discuss the components of the modeling process (formulate, compute, interpret, validate) and how students can move between each stage and continue to refine their solutions. Ask students which aspects of the problem they believed fell within each stage. Help students to remember parts of the lesson which contributed to each step of the modeling process.<br><br>Possibly show students the modeling framework and discuss the modeling tasks, along with the components of each step in the process, which they will be presented with in future lessons. Also, discuss how their thinking will be evaluated during each phase of the modeling process.<br><br>Lastly, summarize the process of unit conversion. Possibly present students with some harder problems to complete either in class or for homework. | | the thinking required of them, but further study of the rubric will be necessary during future modeling lessons. |

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| more practice and more challenging problems. | | | |

3. Assessment of Student Learning
   Plan for assessment (both formative and summative) to assess student learning. Some guiding questions to consider:

- What questions are appropriate for my students to do after the investigation?

  Problems from the book about unit analysis to practice converting between units.

  Dan Meyer's "World's Largest Hot Coffee" 3-Act Math Task
  http://mrmeyer.com/threeacts/hotcoffee/
  Students could watch the 3-Act Math Task and answer the questions posed on the site to further practice unit conversions and also the mathematical modeling process.

  A follow-up lesson could require groups to choose one of the "Great Miscalculations" (such as #1 The Mars Climate Orbiter, #2 The Vasa Warship, or #3 The Gimli Glider) (http://www.bbc.com/news/magazine-27509559) to research. Students could describe how the problem was originally miscalculated and then correct the mistake by computing the correct answer.

- What are the goals of the homework/classwork assignment?

  Students will continue practicing unit conversions and will be presented with more complex problems. The homework, and future lesson plan ideas, will also strengthen students' understanding of the modeling process.

- How will students be supported in completing the assignment? Do I provide information and support for students and parents?

  Odd problems from the book have the answer for students to check.

  Dan Meyer's site provides students with all the information they need to solve the problem.

  Students can practice unit conversions with the interactive applet in the National Library of Virtual Manipulatives
  http://nlvm.usu.edu/en/nav/frames_asid_272_g_4_t_4.html?open=instructions&from=topic_t_4.html

Students, and parents, can watch Khan Academy videos on unit conversions (https://www.khanacademy.org/math/cc-fourth-grade-math/cc-4th-measurement-topic/cc-4th-unit-conversion/v/time-unit-conversion).

Class discussions during the subsequent meeting will allow students to ask questions, discuss their processes, learn from their classmates, and practice more under the guidance of the teacher and their peers.

VOSTOK SAMPLES: http://www.daviesand.com/Choices/Precautionary_Planning/New_Data/

**Antarctica Ice Melt – Answer Key**

1. Practice these unit conversions:
   a. 1 week to seconds 604, 800 seconds
   b. 62,000 inches to miles 775/792 miles = 0.97853535 miles
2. What questions do these videos make you want to ask?
   Answers will vary
3. What questions are we going to focus on today?
   a. What is the total volume of the ice sheet on Antarctica (in cubic kilometers)?
   b. Assuming the ice melts, what will the volume of the water represent?
   c. Suppose the melted ice flows into the seas, and also assume the total surface area does not change (does not spread out over the continents)
      i. How much water area is there to spread out over currently?
      ii. How much would sea level rise? Have students calculate the rise in km, m, and ft.
4. What other information is needed to solve the problems? List the information you think would be helpful. I will provide you with the data you request.
   - the area of the Earth's oceans and major seas (either as a total or as individual areas to be added)
   - the volume of the ice sheets overlying land
   - the densities of ice and water, and knowledge that glacier ice is fresh-water ice rather than sea-water ice

**Table 1. Water Areas of the Earth**

| Ocean or Sea | Area (in square kilometers) |
|---|---|
| Pacific Ocean | 166,241,700 |
| Atlantic Ocean | 82,522,600 |
| Indian Ocean | 73,426,500 |
| Arctic Ocean | 14,056,000 |
| Caribbean Sea | 2,512,300 |
| Mediterranean Sea | 2,509,700 |
| Bering Sea | 2,266,250 |
| Gulf of Mexico | 1,554,000 |
| Sea of Okhotsk | 1,528,100 |
| East China Sea | 1,248,400 |
| Sea of Japan | 1,007,500 |
| Hudson Bay | 822,300 |
| North Sea | 575,000 |
| Black Sea | 479,150 |
| Red Sea | 437,700 |
| Baltic Sea | 422,170 |
| Remaining surface water area | 9,522,630 |

Source: *Hammond Citation World Atlas*, Hammond, Maplewood, New Jersey, 1992, p.352.

| | Table 2. Ice Sheet Areas and Thicknesses. | |
|---|---|---|
| **Ice Sheet** | **Area (in square kilometers)** | **Average Thickness (in kilometers)** |
| Antarctica | 11,965,700 | 2.45 |

Source for the Greenland data: Williams, R. S., Jr., and J. G. Ferrigno, editors, Preface, *Satellite Image Atlas of Glaciers of the World: Greenland*, USGS Professional Paper 1386-C, United States Geological Survey, Washington, DC, 1995, p.v.

Source for the Antarctic data: Swithinbank, C., Antarctica, *Satellite Image Atlas of Glaciers of the World: Antarctica* (Richard S. Williams, Jr., and Jane Ferrigno, editors), USGS Professional Paper 1386-B, United States Geological Survey, Washington, DC, 1988, p.B12.

| Table 3. Densities | |
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| **Substance** | **Density (in kilograms per cubic meter)** |
| Fresh water | Approximately 1000 |
| Glacier ice | Approximately 900 (generally between 830 and 917) |

5. What assumptions are we making in order to solve the problem?
    - Approximations and uncertainties in several of the numbers used in the calculations, and hence the answers should be considered as only roughly correct.
    - Strictly speaking, the calculations assume the oceans and seas have vertical sides, with the area covered by water remaining constant throughout the process of sea level rise.

6. How will you approach the problem? What will you do to solve? What equations are you planning on using? Write out the steps you will complete to calculate your answers.
    1. Find total water area from oceans, seas, and other surface water areas from Table 1. This is the area the melting glacier water will spread out over
    2. Calculate the volume of Antarctic ice sheet, by multiplying the ice-sheet area by their average thicknesses provided in Table 2
    3. Convert Antarctic ice sheet volume to the approximate volumes of water that would result if the ice sheets were to melt.
        a. To do this, first calculate the ice mass, by multiplying the ice volume obtained in #2 by the ice density provided in Table 3.
        b. Then, recognizing from the principle of conservation of mass that the mass remains the same when the ice melts, divide by the density of water to obtain the corresponding water volume.
        c. The net calculation is simply a multiplication of the ice volumes by 0.9
    4. Calculate the sea-level-rise answers by dividing the water volumes determined in #3 by the global surface-water area determined in #1, thereby spreading the effect of the ice sheet's water throughout the expanse of the Earth's surface-water area. Answer in m, km and ft

    5. Show all your calculations: Check student work

    6. Write down your answers for questions a, b, and c from above. Make sure to convert your answers into all the units requested above.

    Provides a reasonable first-order estimate of the sea-level-rise response
        a. Total Water Area: 361,132,000 square kilometers
        b. Ice Sheet Volume: 29,315,965 cubic kilometers (Antarctica)

c. Water Volume: 26,384,368 cubic kilometers (Antarctica)
d. Total Water Area Worldwide: 361,132,000 square kilometers
e. The answers are: $\frac{26{,}384{,}368\ cubic\ kilometers}{361{,}132{,}000\ square\ kilometers}$ = 0.0731 km = 73.1 m = 239.8294 ft for the Antarctic ice sheet

7. Do you think the assumption that the ocean surface area will stay constant is valid? Why or why not?
   a. Will spread out over low-lying coastal regions.
   b. As sea levels rise, the area covered by water would increase, which would reduce the magnitude of the rise

8. Elevation above Sea Level:
   Students should identify a few regions/areas that will be completely covered (ie Florida)
   Students should identify if their hometown will be safe or not
9. Are there any other factors which might account for rising sea levels?
   Greenland is another large glacier

| | Table 2. Ice Sheet Areas and Thicknesses. | |
|---|---|---|
| **Ice Sheet** | **Area (in square kilometers)** | **Average Thickness (in kilometers)** |
| Antarctica | 11,965,700 | 2.45 |
| Greenland | 1,736,095 | 1.50 |

10. How could we modify our model to account for these other factors?

Calculate Greenland's ice sheet volume and resulting water volume as well. Add to Antarctica.
Ice Sheet Volume: 2,604,142 cubic kilometers (Greenland)
Water Volume: 2,343,728 cubic kilometers (Greenland)
$\frac{2{,}343{,}728\ \text{cubic kilometers}}{361{,}132{,}000\ \text{square kilometers}}$ = 0.0065 kilometers = 6.5 meters =21.3255 ft for the Greenland ice sheet
6.5 meters + 73.1 meters = 79.6 meters = 261.1549 ft for Greenland and Antarctica together

**DISCLAIMER:**

* No knowledgeable person expects the Greenland and Antarctic ice sheets to disappear completely within the lifetime of anyone alive today, or within the lifetime of any of their children or grandchildren. Hence, the threat of a 79.6- meter sea level rise should not be seen as an immediate concern. Much smaller rises in sea level, however, might well occur and in fact sea level appears to have risen approximately 0.2 meters over the past century. The twentieth-century sea level rise has resulted partly from thermal expansion of the water due to warming and partly from melting of mountain glaciers. It is not certain how much if any of the twentieth-century rise has resulted from changes in the Greenland and Antarctic ice sheets, due to a lack of adequate data. These two ice sheets, however, are the largest potential contributors to sea level rise, and concern has been raised in particular over the possibility that the portion of the Antarctic ice sheet termed the West Antarctic ice sheet, lying largely in the western hemisphere, might be unstable and might decay relatively rapidly, perhaps even causing sea level rises of several meters within 100 years. Although such a decay is not highly probable, it is possible, and if it were to occur, the resulting several-meter sea level rise would cause serious economic and personal consequences to all highly populated low-lying coastal regions.

EXTENSION: MARS CLIMATE ORBITER

Donald G Wiggins says:

"On September 23, 1999, NASA's $125 million Mars Climate Orbiter approached the red planet under guidance from a team of flight controllers at the Jet Propulsion Laboratory. The probe was one of several planned for Mars exploration, and would stay in orbit around the planet as the first extraterrestrial weather satellite. It had been in flight for over nine months, covering more than 415 million miles of empty space on its way to Mars. As the Orbiter reached its final destination, the flight controllers began to realize that something was wrong. They had planned for the probe to reach an orbit approximately 180 km off the surface of Mars – well beyond the planet's thin atmosphere. But new calculations based on the current flight trajectory showed the Orbiter skimming within 60 km of the Martian surface. Now the probe would actually enter the planet's thin atmosphere, something for which it was never designed. The consequences were catastrophic: when the scientists and engineers commanding the probe lost communication, they could only assume that the spacecraft was incinerated by the friction from an atmospheric entry that it was never supposed to make.

What caused this disaster? The problem arose in part from a simple, seemingly innocent, mistake. Throughout the journey from Earth, solar winds pushed against the solar panels of the probe, throwing the spacecraft off course by a small amount. The designers had planned for this, and jet thrusters were turned on by the flight controllers to apply a force, making numerous small corrections to readjust its course. Unfortunately, the **NASA engineers measured this force in pounds (a non-metric unit)**, while the **JPL team worked in Newtons (a metric unit)**, and the software that calculated how long the thrusters should be fired did not make the proper conversion."

http://www.visionlearning.com/blog/2012/09/21/tragedies-in-science-the-crash-of-the-mars-climate-orbiter/

Each time the thrusters turned on they were supposed to provide 1 pound of boost.

NASA reported that on December 26, 1998 the "largest trajectory correction maneuver (TCM) was executed using the hydrazine thrusters. During cruise to Mars, three additional TCM's using the hydrazine thrusters were performed"

http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=1998-073A

- Since 1 pound = 4.45 Newtons what the resulting Newtons applied over the course of the cruise to Mars?
- How large did the mistake grow over the multiple adjustments?

1. A solid rocket booster is ordered with the specification that it is to produce a total of 10 million pounds of thrust. If this number is mistaken for the thrust in Newtons, by how much, in pounds, will the thrust be in error? (1 pound = 4.5 Newtons)

   SOLUTION: 10,000,000 Newtons x (1 pound / 4.448 Newtons) = 2,200,000 pounds.

   10,000,000 pounds - 2,200,000 pounds = 7.800,000 pounds.

   The error is a missing 7,800,000 pounds of thrust.

2. The Mars Climate Orbiter was meant to stop about 160 km away from the surface of Mars, but it ended up within 36 miles of the surface. How far off was it from its target distance (in km)? If the Orbiter is able to function as long as it stays at least 85 km away from the surface, will it still be functional despite the mistake?

   SOLUTION: 36 miles ×1.6kilometers1 mile =57.9km kilometers from surface

   The difference then is (in kilometers): 160 - 57.9 kilometers = 102.1 kilometers away from targeted distance. Hence, the Orbiter is unable to function due to this mistake since it is beyond the 85 km error designed into its function.

Even though the original mistake was not large, the result cost NASA $125 million.

**Antarctica Ice Melt**

1. Practice these unit conversions:
   a. 1 week to seconds

   b. 62,000 inches to miles

2. What questions do these videos make you want to ask?

3. What questions are we going to focus on today?

   a.

   b.

   c.

   d.

4. What other information is needed to solve the problems? List the information you think would be helpful. I will provide you with the data you request.

5. What assumptions are we making in order to solve the problem?

6. How will you approach the problem? What will you do to solve? What equations are you planning on using? Write out the steps you will complete to calculate your answers.

7. Show all your calculations:

8. Write down your answers for questions a, b, c, and d from above. Make sure to convert your answers into all the units requested above.

   a.

   b.

   c.

   d.

9. Do you think the assumption that the ocean surface area will stay constant is valid? Why or why not?

10. Look at a map with contour lines of heights above sea level to see the geographic effects the calculated sea level rises would have.

a. In the event of a complete melting of both Greenland and Antarctica, identify two regions/countries from around the world at risk for loss of land area or perhaps complete submersion.
b. Make a prediction about how greatly sea level rise will affect your chosen region and provide justification for your conclusions.

   i. 1st Region: ______________________

   ii. 2nd Region: ______________________

c. Determine if hometown would be completely safe, at risk or underwater and explain why.

11. Are there any other factors we did not consider which might also cause sea levels to rise?

12. How could we modify our model to account for these other factors? How much does this modification change our answer?