LESSON 17: The Tide is High, but I'm Holding On…
Using ICESat Data to Investigate Sea Level Rise

PURPOSE/QUESTION
Students will calculate and analyze the change of ice mass in Greenland and subsequent sea level rise due to melting ice caps and thermal expansion.

GRADE LEVEL
9-12

TIME TO COMPLETE
(2-3) 50 minute class periods

STANDARDS
See appendix below-page 8

LEARNING OUTCOMES
- Students will learn about how melting land-based ice and thermal expansion of ocean waters contributes to sea level rise
- Students will examine the ice mass of the Greenland ice sheet using ICESat measurements.
- Students will consider impacts of sea level rise in the Chesapeake Bay.

STUDENT OBJECTIVES
- Access NASA ICESat data of the Greenland ice sheet.
- Calculate the change in ice mass for the Greenland Ice Sheet
- Calculate how much the melting of the Greenland ice sheet contributes to the sea level rise around the world.
- Evaluate the impacts of sea level rise on coastal cities and habitats.

TEACHER BACKGROUND
Read ICESat fact sheet: http://icesat.gsfc.nasa.gov/icesat/docs/ICESat_FS_2.pdf

Sea levels are expected to rise between 0.5 m and 2 m during the next century because of climate change. This increase in sea level is primarily due to the thermal expansion of sea water and widespread melting of land-based ice, such as glaciers and ice sheets. The actual rise of sea level will depend on the world's future carbon emissions.

Thermal expansion occurs as the oceans absorb more heat. This expansion increases the overall volume of the ocean, which causes sea levels to rise. According to observations since 1961, the ocean has absorbed more than 80% of the heat from the atmosphere; this temperature increase has been observed down to depths of at least 3000 meters.

Widespread melting of land ice, in particular the Greenland and Antarctica ice sheets, are also contributing to sea level rise. The melting of the entire Greenland ice sheet could result in a sea level rise of around 7 to 8 m, but this would require centuries of warming to take place. Projecting how quickly the ice sheets will melt is difficult because of the complicated nature of ice sheet dynamics. For example, the Greenland ice sheet has been experiencing surface melting due to the rise in temperatures, additional accumulation of snow in interior regions due to the increasing amount of precipitation, and accelerated ice flow as melting water has allowed ice to slide more quickly toward the sea.

The amount of sea-level rise in any specific location is determined by the global rate of sea-level rise and local changes in sea level associated with vertical land motions. Examples include rebounding from the weight of the glaciers from the last Ice Age, land subsidence of river deltas (for example, the sea level of the Mississippi River Delta in Louisiana has increased dramatically due to land sinking/subsidence), and shifts of the Earth's tectonic plates (earthquakes).

Sea-level rise will inundate coastal wetlands, intensify flooding of coastal cities, and affect the fresh water resources for human consumption. Wetlands are essential habitats for wildlife and provide a buffer for inland flooding associated with storm surges due to hurricanes. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), 33% of the coastal wetlands around the world could be inundated by sea-level rise by 2080. Sea-level rise also will cause saltwater infiltration into bodies of fresh water that are essential for wildlife habitats and human consumption.

PREREQUISITES

- Sea level
- NASA's ICESat
- Ice sheet
- Sea ice
- Land ice

MATERIALS & TOOLS

- Computer with Internet
- Color printer (optional)
- Calculator

VOCABULARY

- Thermal Expansion
- Land Subsidence
- Glacier
- Wetlands
- Topography

LESSON LINKS

- NASA's ICESat video
- NASA's ICESat - A Short Tour of the Cryosphere
- NWF Report: Chesapeake Bay and Global Warming – 12 page summary

PART 1 – Ice mass changes in Greenland Observed by ICESat

ESSENTIAL QUESTIONS

1. According to the map, where is Greenland losing ice and where is it gaining ice?
2. (a) What is the average annual net change in ice mass for Greenland during 2003-2007 in units of Gt/year?
   (b) How much total ice mass has been lost over this 5 year time period?
   (c) What is the rate of melting in units of volume of water added to the world's oceans (i.e., convert the rate you calculated in part (a) from mass of water to volume of water using the following conversion: *1 Gt of water = 1 km^3 of water).*
3. At this rate of melting, how long would it take to fill up the Dallas Cowboys stadium, which has a volume of 2.95 x 10^6 m^3?
4. (a) If annual melting from Greenland is spread out over the entire ocean area of 361 million km^2, then how much will sea level rise each year (in units of cm)?
   (b) Using the value found in 4a, how much will sea level rise if this rate continues from 2003-2102 (100 years)?

PROCEDURE

1. Watch video – "ICESat takes worldwide measurements on right side of http://www.nasa.gov/mission_pages/icesat/index.html. Next watch the video – A Short Tour of the Cryoshpere http://youtu.be/ZQTVF29Skmw

2. Examine map to the right of ice mass change over the time period of ICESat observations of the Greenland Ice Sheet (Available at: http://svs.gsfc.nasa.gov/goto?3460).
   a. For 2003-2007, based on ICESat measurements, increased snowfall rates in the interior have caused an **accumulation of ice mass of 35 Gt/year**.
   b. For 2003-2007, based on ICESat measurements, increased melting and changes in the way the ice moves from the interior of the ice sheet toward the edges have caused a **loss of ice mass of 206 Gt/year**.

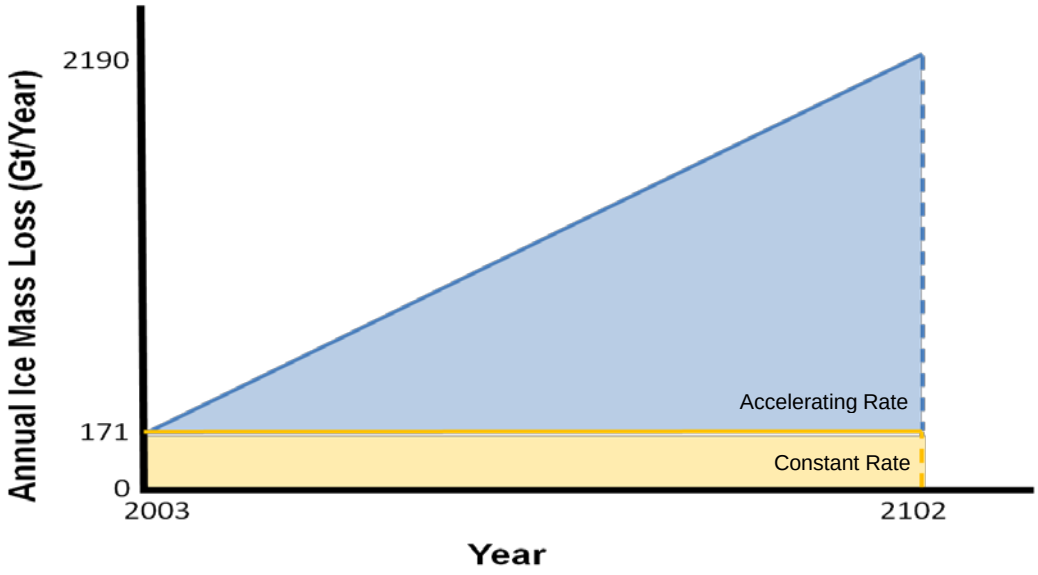
PART 2 – Estimate Future Ice Mass Changes in Greenland

ESSENTIAL QUESTIONS

1. Using the graph below, how much ice mass would Greenland lose from 2003-2102 if the net ice loss continues to accelerate at the current rate?
2. How much would sea level rise in cm by 2102 on average around the world if the amount of ice melted that you computed for Question 1?
3. Climate change is also contributing to sea level rise through thermal expansion of ocean water. For the 21st century, thermal expansion is projected to contribute an average of 3 mm/year to sea level rise. Approximately how much will sea level rise due to thermal expansion from 2003 to 2102?
4. The potential contribution of melting of the Antarctic ice sheet to sea level from 2003 to 2012 is 28 cm. How much could average sea level rise in the coming century be when taking into account thermal expansion and the melting of the Greenland and Antarctica ice sheets?
5. The Greenland ice sheet is estimated to have 2,850,000 Gt of water. If the Greenland Ice sheet melted entirely, how much would sea level rise?

PROCEDURE

1. The rate of melting in Greenland has increased at a rate of 21.9 Gt/year^2 from 1992 to 2009. If the melting continued to accelerate at this rate, then there would be a much larger contribution to sea level rise over the next century. This graph should help you compare the relative ice mass loss with a constant melt rate of 171 Gt/year (orange area) with that of a melt rate starting at 171 Gt/year and accelerating at 21.9 Gt/year^2 (orange + blue areas).



PART 3 – Determining impact of Greenland Ice Mass changes for sea level rise in Chesapeake Bay

ESSENTIAL QUESTIONS

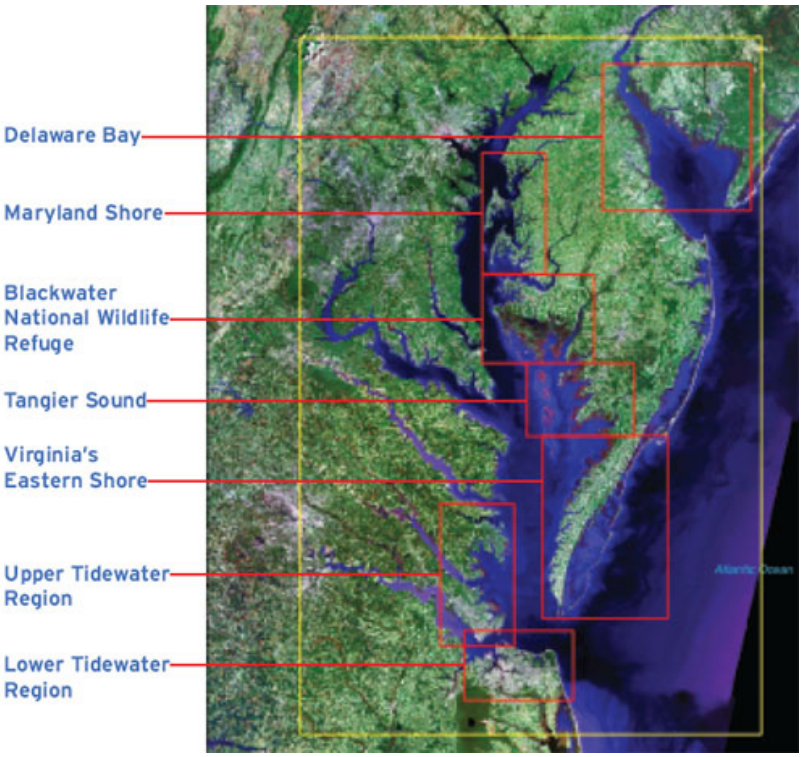
1. Add the contribution from local land subsidence to the estimates of global sea level rise to calculate how much sea level expected to rise in the Chesapeake Bay over the next century?
2. What coastal habitat types will likely be lost in the Blackwater National Wildlife Refuge if sea level in the Chesapeake Bay rises by 70 cm? What impacts would the loss of these habitats have on fish species?
3. What steps can we be taking now to address the impacts of sea level rise on coastal habitats?

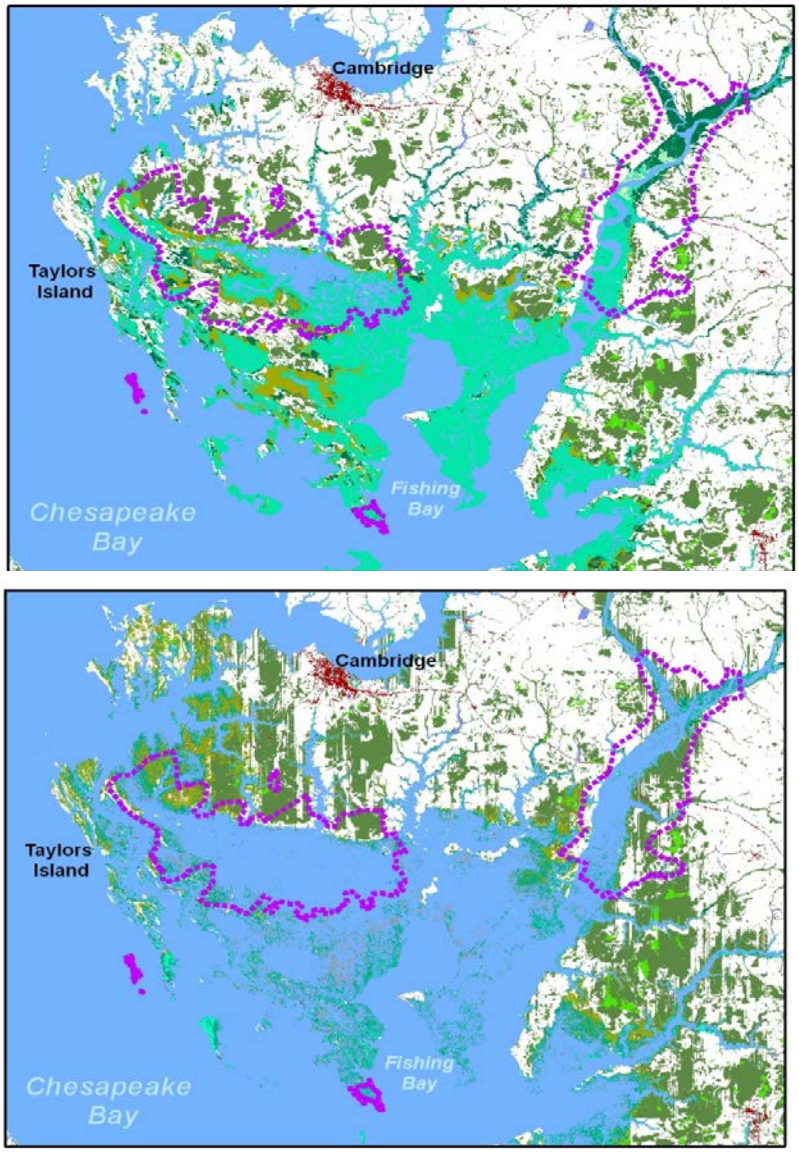
PROCEDURE

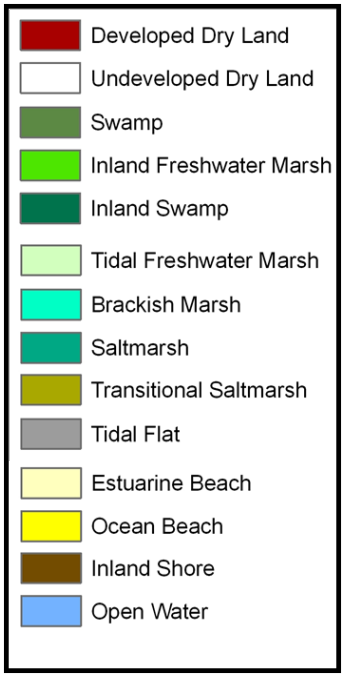
Some locations will experience even more sea-level rise due to changes in the local topography. Over the last century the Chesapeake Bay has seen a 30 cm increase in relative sea-level rise over the 20th century, half due to climate change and half due to naturally subsiding coastal lands. The rate of land subsidence is expected to continue over the next century.

1. Read the NWF report: ***Sea-Level Rise and Coastal Habitats of the Chesapeake Bay: A Summary* - May, 2008,** (12 page summary) Available at http://www.nwf.org/global-warming/effects-on-wildlife-and-habitat/estuaries-and-coastal-wetlands/chesapeake-bay.aspx

2. Study the maps below showing the potential impacts of sea level rise on Blackwater National Wildlife Refuge and surrounding areas. Blackwater National Wildlife Refuge is a crown jewel among Chesapeake Bay's treasured places. Unfortunately, it could be largely underwater by 2100. Dramatic habitat losses are predicted for the refuge and surrounding areas, where global sea-level rise is compounded by high rates of land subsidence due to groundwater withdrawal for agriculture and relatively lower rates of natural accretion in marshes The maps **below show how 70 cm of sea level rise** would impact habitats the Blackwater Refuge area of the Chesapeake Bay. Top image is current coastal habitats and the bottom image is if sea level rises 70 cm.







TOOLS FOR ASSESSMENT

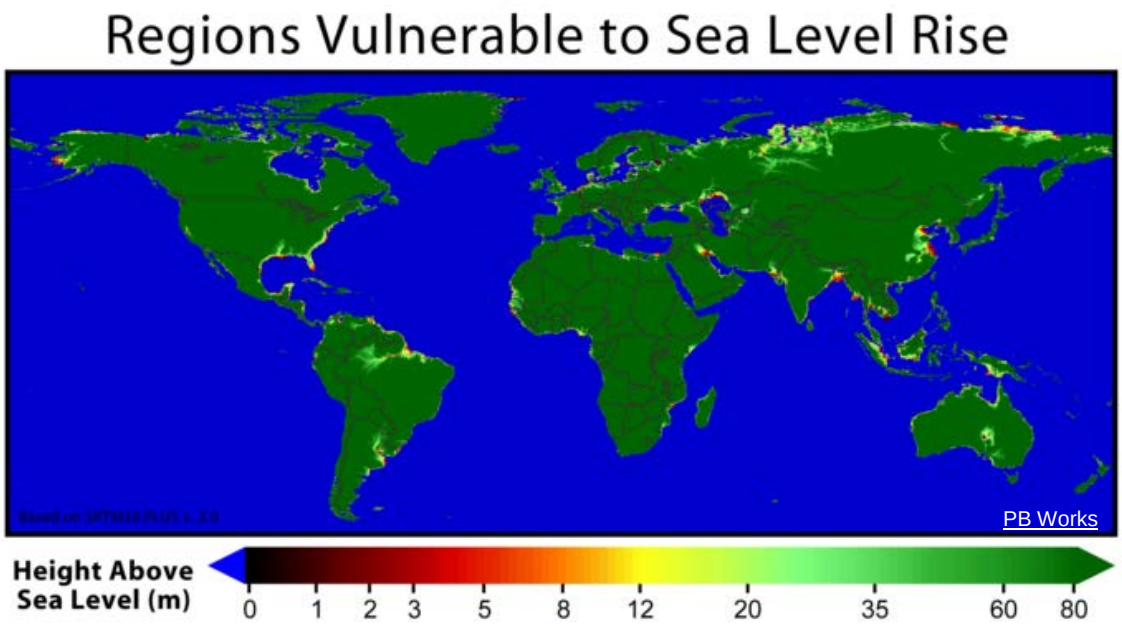
- Science Concept Quiz – found on pg. 13
- Essay – found on pg. 16
- Foldables®
- Student Reading and Science Notebook Assessment Tool – found in the ***Rubrics*** folder.

STUDENT READING RESOURCES

- The Rising Sea Level
- Indian Ocean Sea-Level Rise Threatens Coastal Areas
- Why Does the Greenland Ice Sheet Matter?
- Sea Level Rise Due to Global Warming Poses Threat to New York City
- Fastest Sea-Level Rise in 2,000 Years Linked to Increasing Global Temperatures

WEBSITES FOR FURTHER LEARNING

- Global Climate Change – Sea Level Rise
- USGS Sea-Level Rise, Subsidence and Wetland Loss
- National Snow and Ice Center: Information on Different Kinds of Glaciers
- Global Climate Change – Sea Level Quiz



LESSON 17-APPENDIX

Web Addresses for Hyper Links

Prerequisites

- **Sea level**
  http://mynasadata.larc.nasa.gov/science-glossary/?page_id=672?&letter=S
- **NASA ICESat**
  http://www.nasa.gov/mission_pages/icesat/index.html
- **Ice sheet**
  http://nsidc.org/cryosphere/quickfacts/icesheets.html
- **Sea ice**
  http://www.esr.org/outreach/glossary/sea_ice.html
- **Land ice**
  http://amsglossary.allenpress.com/glossary/search?id=land-ice1

Vocabulary

- **Thermal expansion**
  http://mynasadata.larc.nasa.gov/science-glossary/?page_id=672?&letter=T
- **Land subsidence**
  http://www.ecologydictionary.org/LAND_SUBSIDENCE
- **Glacier**
  http://mynasadata.larc.nasa.gov/science-glossary/?page_id=672?&letter=G
- **Wetlands**
  http://water.epa.gov/lawsregs/guidance/wetlands/definitions.cfm
- **Topography**
  http://en.wikipedia.org/wiki/Topography

Lesson Links

- **NASA's ICESat video – How ICESat Takes Measurements**
  http://www.nasa.gov/mission_pages/icesat/index.html
- **NASA – A Short Tour of the Cryosphere**
  http://youtu.be/ZQTVF29Skmw
- **NWF Report: Chesapeake Bay and Global Warming**
  http://www.nwf.org/global-warming/effects-on-wildlife-and-habitat/estuaries-and-coastal-wetlands/chesapeake-bay.aspx

Websites for Further Learning

- **NASA's Global Climate Change – Vital Signs of the Planet – Sea Level Rise**
  http://climate.nasa.gov/keyIndicators/#seaLevel
- **USGS – Sea Level Rise, Subsidence, and Wetlands Loss – video describes the causes of wetland loss in the Mississippi River Delta.**
  http://gallery.usgs.gov/videos/347#.UIbonm9lE98
- **National Snow and Ice Center: Information on Different Types of Glaciers**
  http://nsidc.org/cryosphere/glaciers/questions/types.html
- **Global Climate Change: Sea Level Rise Quiz**
  http://climate.nasa.gov/launchPages/slqLaunchPage/index.cfm

Student Reading Resources

- **The Rising Sea Level**
  http://earthobservatory.nasa.gov/IOTD/view.php?id=6638
- **Indian Ocean Sea Level Rise Threatens Coastal Areas**
  http://earthobservatory.nasa.gov/Newsroom/view.php?id=44705
- **Why Does the Greenland Ice Sheet Matter?**
  http://earthobservatory.nasa.gov/Features/Greenland/greenland_sidebar.php
- **Sea Level Rise Due to Global Warming Poses Threat to New York City**
  http://earthobservatory.nasa.gov/Newsroom/view.php?id=37546&src=eorss-manews
- **Fastest Sea Level Rise in 2,000 Years Linked to Increasing Global Temperatures**
  http://www.sciencedaily.com/releases/2011/06/110620183242.htm

LESSON 17-STANDARDS

National Science Education Standards

Unifying Concepts and Processes

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement

Standard A – Science as Inquiry

- Abilities to do scientific inquiry
- Understandings about scientific inquiry

Standard D – Earth and Space Science

- Energy in the earth system

Standard E – Science and Technology

- Understandings about science and technology

Standard F – Science in Personal and Social Perspectives

- Natural and human-induced hazards

Standard G – History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

National Education Technology Standards

Standard 1: Creativity and Innovation

- Use models and simulations to explore complex systems and issues
- Identify trends and forecast possibilities

Standard 3: Research and Information Fluency

- Process data and report results

Standard 4: Critical Thinking, Problem Solving, and Decision Making

- Collect and analyze data to identify solutions and/or make informed decisions.

Standard 5: Digital Citizenship

- Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior.

Standard 6: Technology Operations and Concepts

- Understand and use technology concepts
- Select and use applications effectively and productively
- Troubleshoot systems and applications
- Transfer current knowledge to learning of new technologies

National Council of Teachers of Mathematics Standards

Algebra

- Understand patterns, relations, and functions
- Use mathematical models to represent and understand quantitative relationships
- Analyze change in various contexts

Measurement

- Understand measurable attributes

Data Analysis and Probability

- Develop and evaluate inferences and predictions that are based on data

Process

- Connections
  - Recognize and apply mathematics in contexts outside of mathematics
- Representation
  - Use representations to model and interpret physical, social, and mathematical phenomena

Climate Literacy Principles

Principle 2: Climate is regulated by complex interactions among components of the Earth system.
Principle 4: Climate varies over space and time through both natural and man-made processes.
Principle 5: Our understanding of the climate system is improved through observations, theoretical studies, and modeling
Principle 6: Human activities are impacting the climate system.
Principle 7: Climate change will have consequences for the earth system and human lives.

Energy Literacy Principles

Principle 2: Physical Earth processes are the result of energy flow through the earth system.

LESSON 17-ESSENTIAL QUESTIONS ANSWER KEY

Essential Questions-1

1. According to the map, where is Greenland losing ice and where is it gaining ice?
   [Greenland is losing ice primarily around the edges (darkest blues), and it is gaining ice only slightly in parts of inland Greenland (white areas).]

2. (a) What is the average annual net change in ice mass for Greenland during 2003-2007 in units of Gt/year?
   [Average annual net change in ice mass = 35 Gt/year – 206 Gt/year = -171 Gt/year]
   (b) How much ice mass has been lost in total over this 5 year time period?
   [Total ice loss = -171 Gt/year * 5 years = 855 Gt]
   (c) What is the rate of melting in units of volume of water added to the world's oceans (i.e., convert the rate you calculated in part (a) from mass of water to volume of water using the following conversion: 1 Gt of water = 1 km^3 of water).
   [Total volume of water in ice lost from Greenland = 855 Gt water * 1 km^3 water/1Gt water = 855 km^3 of water.]

3. At this rate of melting, how long would it take to fill up the Dallas Cowboys stadium, which has a volume of 2.95 x 106 m^3?
   [Volume of stadium in m^3 = 104000000 ft^3 * (1 m^3 /35.3 ft^3) = 2.95 x10^6 m^3
   Volume of stadium in km^3= 2.95 x 10^6 m^3 * (1 km/1000 m^3) = 2.95 x 10^-3 km^3
   Length of time it would take for Greenland ice melt would fill the stadium =
   .00295 km^3/ (171 km^3/year) = 1.73x10^-5 years
   1.73x10^-5 years * 365 days/year * 24 hours/day * 60 minutes/day = 9.1 minutes]

4. (a) If annual melting from Greenland is spread out over the entire ocean area of 361 million km^2, then how much will sea level rise each year (in units of cm)?
   [Sea level rise from Greenland melting 2003-2007 = (171 km^3 water/ year) / 361,000,000 km^2 water = 4.737x10^-7 km * 100000 cm/km = 0.047 cm/year]
   (b) Using the value found in 4a, how much will sea level rise if this rate continues from 2003-2102 (100 years)?
   [Century of sea level rise from Greenland melting = 0.047 cm/year * 100 years = 4.7 cm]

Essential Questions-2

1. Using the graph below, how much ice mass would Greenland lose from 2003-2102 if the net? ice loss continues to accelerate at the current rate?
   [Answer: Calculate area of the blue triangle to determine ice loss due to accelerating rate
   0.5*(2190 Gt/year – 171 Gt/year) * 100 years = 100950 Gt
   Add to this value, the area of the orange square
   100950 Gt + 171 Gt/year*100 years = 118050 Gt]

2. How much would sea level rise in cm by 2102 on average around the world if the amount of ice melted that you computed for Question 1*?*
   [Sea level rise by 2102 = 118050 Gt * (1 km^3/1 Gt) / 361,000,000 km^2 = 3.27 x 10^-4 km * 10^5 cm/km = 32 cm]

3. Climate change is also contributing to sea level rise through thermal expansion of ocean water. For the 21st century, thermal expansion is projected to contribute an average of 3 mm/year to sea level rise. Approximately how much will sea level rise due to thermal expansion from 2003 to 2102?
   [Sea-level rise due to thermal expansion = 3 mm/year * 100 years = 300 mm = 30 cm.]

4. The potential contribution of melting of the Antarctic ice sheet to sea level from 2003 to 2012 is **28 cm**. How much could average sea level rise in the coming century be when taking into account thermal expansion and the melting of the Greenland and Antarctica ice sheets?
   [Total sea-level rise = Greenland melting + Antarctic melting + thermal expansion = 32 cm + 28 cm + 30 cm = 90 cm]

5. The Greenland ice sheet is estimated to have 2,850,000 Gt of water. If the Greenland Ice sheet melted entirely, how much would sea level rise?
   [Sea level rise by Greenland Icesheet = 2,850,000 Gt * (1 km^3/1 Gt) / 361,000,000 km^2 = 7.89 * 10^-3 km * 10^5 cm/km = 789 cm (or 7.89 m).]

Essential Questions-3

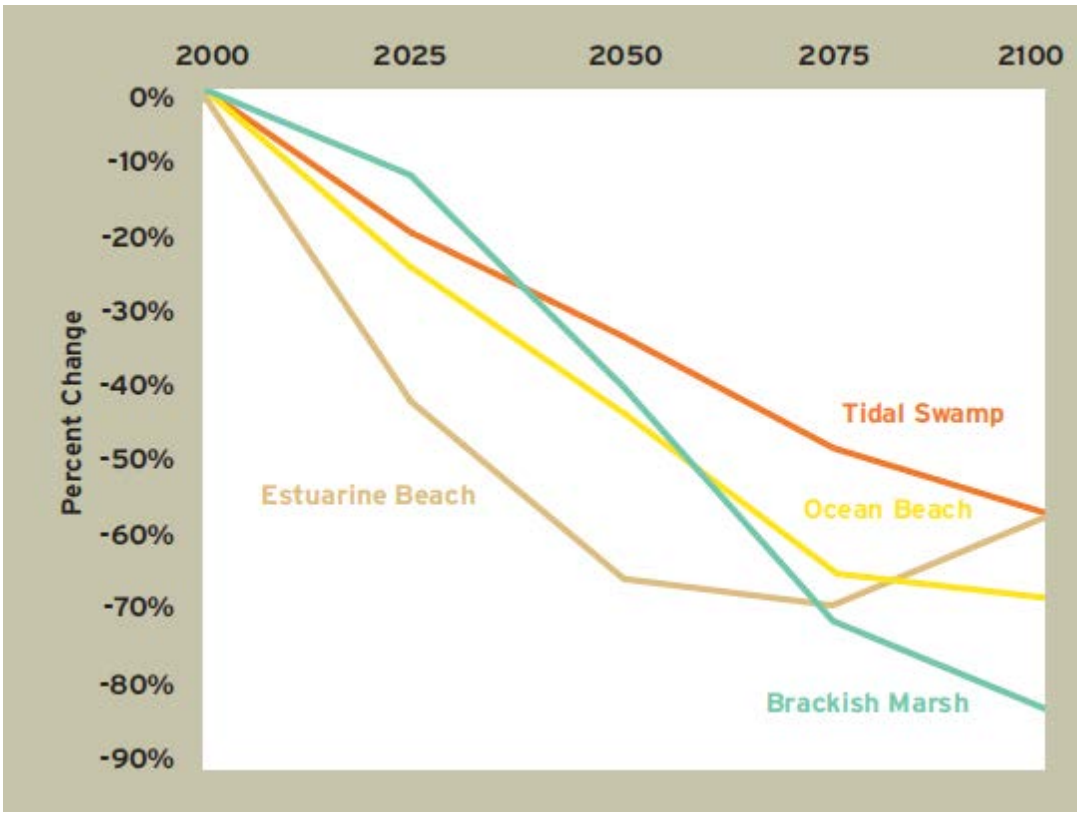
1. Add the contribution from local land subsidence to the estimates of global sea level rise to calculate how much sea level expected to rise in the Chesapeake Bay over the next century?
   [Chesapeake Bay Sea Level Rise (SLR) = Global SLR + SLR due to Local Subsidence = 90 cm + 15 cm = 105 cm = 1.05 m
   How long until reach 70 cm of SLR = 70 cm / (105 cm/100 years) = 73.5 years]

2. What coastal habitat types will likely be lost in the Blackwater National Wildlife Refuge if sea level in the Chesapeake Bay rises by 70 cm? What impacts would the loss of these habitats have on fish species?
   [The site is predicted to lose over 90 percent of its tidal fresh marsh, tidal swamp and brackish marsh, which are converted to saltmarsh and--ultimately--open water. The loss of brackish marsh could be particularly harmful to species that have adapted to these habitats, including rockfish and white perch, as well as anadromous species such as herring and shad, which use brackish marsh habitat as they transition between their freshwater and saltwater life cycles. Similarly, the loss of tidal fresh marshes could affect minnows, carp, sunfish, crappie and bass, which depend on these habitats for shelter, food, and spawning.]

3. What steps can we be taking now to address the impacts of sea level rise on coastal habitats?
   [Reducing carbon pollution to slow the rate of warming and therefore the rate of sea level rise. Preventing development on dry land adjacent to coastal habitats likely to be inundated so that the habitats can slowly migrate inland. Facilitate natural build up and/or artificial replenishment of sediments.]

Name: _____ Date: _____

Science Concept Quiz
Lesson 17: The Tide is High, and I'm Holding On…



According to the, chart habitat types in the Chesapeake Bay region are projected to lose over 50 percents of their area by 2100, with a 27.2 inch rise in global sea level. **What will be some of the impacts on fish and wildlife?**

A. Fish and shellfish populations will thrive due to the major shifts in coastal marshes and loss of beaches.
B. A large number of the regions commercial fish will lose their nursery and spawning grounds.
C. Lose of freshwater marshes would increase the number of waterfowl who are able to migrate using the Atlantic Flyway.
D. A significant change to the areas food web will increase species populations.

_____ points out of 20

I. Answer

A.◯ B.◯ C.◯ D.◯

_____ points out of 15

II. What is the main concept behind the question?

1. Species survival rate
2. Change over time
3. Food web
4. Reading charts and graphs

_____ points out of 25

III. Provide the reasoning for choosing your answer in part II.

_____points out of 40

IV. Why are the other responses in part I not the best answer choice?

1.

2.

3.

4.

Use the rest of this page if more room is needed to fully communicate your thoughts.

Teachers Answer Key

1. B

2. 2

3. Answers will vary. The chart shows how habitats in the Chesapeake Bay will change over time. In the report, Sea-Level Rise and Coastal Habitats of the Chesapeake Bay: A Summary, there are many impacts that predict what will happen to species of fish and wildlife due to these changes over time.

4. Answers will vary.

   A) Fish and shellfish will not thrive due to these changes in their habitat.

   B) This is the correct answer. Changes to coastal marshes will have effects on the region's food web.

   C) Lose of freshwater marshes will decrease the number of birds that rely on the Atlantic Flyway and the Chesapeake Bay as an important stopover and nesting ground in the winter.

   D) A significant change to the areas food web will not have a positive impact on species. Food chains will change, along with the numbers and types of predators, as well as shallow water and beach areas utilized for nesting, spawning, shelter, and food.

Student Name
Teacher/Class
Date

Lesson 17: The Tide is High, but I'm Holding On
Using ICEsat to Investigate Sea Level Rise

What is your opinion based on this statement? Include information in your retort on impacts to human, wildlife, and wild places. Looking to see if you can make a connection to those people who live in inner states.

"I don't live on the coast so why should I care if the ice caps melt and sea level rises?"

What Is the Expectation?

Use new lesson knowledge or student readings to support your position

Visual representations if applicable

Key vocabulary

Evidence of on grade level spelling and grammar usage