Geophysical Information for Teachers (GIFT) Workshop

Hot Topics in Earth Space Science!

December 15 - 16, 2014

The Westin Hotel on Market St.

Franciscan Ballroom

WINDOWS TO THE UNIVERSE

AGU American Geophysical Union

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

Agenda and Bios

AGU-NESTA Geophysical Information For Teachers (GIFT) Workshop 2014

<u>Hot Topics in Earth and Space Science!</u>

The Westin Hotel on Market St.; Franciscan Ballroom

Monday, December 15

7:30 – 8:00 BREAKFAST

8:00 -8:05 **Welcome from AGU** – Bethany Adamec, AGU Education and Public Outreach Coordinator

8:05 – 8:15 **Introductions and Logistics** – Dr. Roberta Johnson, Executive Director, NESTA

8:15 – 9:45 ***Teaching Earth and Space Science using the Next Generation Science Standards*** – Dr. Michael Wysession (Washington University at Saint Louis)

9:45 – 10:00 BREAK

10:00 – 11:30 ***The MAVEN Mission: What We Hope to Learn About the Ancient Atmosphere of Mars***– Lee Pruett (Notre Dame High School), Erin Wood (University of Colorado, LASP), and Dr. Claire Raftery (University of California, Berkeley)

11:30 – 12:15 LUNCH

12:15 – 1:15 **Share-A-Thon 1**

1:15 – 2:45 ***Teaching Climate Using the Third National Assessment*** – Robert Taylor and Laura Stevens (Cooperative Institute for Climate and Satellites, North Carolina)

2:45 – 3:15 Discussion, Closing for Day 1

3:15 Adjourn for Exhibits, Meeting

4:00 – 6:00 Optional Field Trip – ***The Geology of Downtown San Francisco*** – Dr. John Karachewski (EPA) - meet in lobby of Moscone South near luggage check-in

Tuesday, December 16

7:30 – 8:00 BREAKFAST

8:00 – 8:10 Overview of Plans for Day 2, Logistics

8:10 – 8:55 ***NASA Wavelength*** – Cassie Soeffing and Theresa Schwerin (Institute for Global Environmental Strategies)

9:00 – 9:45 ***Earth2Class: A Compendium of Educational Resources for You and Your Students*** – Michael Passow (Lamont-Doherty Earth Observatory)

9:45 – 10:00 Break

10:00 – 11:30 ***Yellowstone National Park as a Hotbed for Inquiry*** - Shelley Olds and Dave Mencin (UNAVCO)

11:30 – 12:15 LUNCH

12:15 – 1:15 **Share-A-Thon 2**

1:15 – 2:45 ***Changing Planet: Earth and Life Through Time*** – Dr. Mark Nielsen (Howard Hughes Medical Institute) and Heather Olins (Harvard University)

2:45 – 3:00 Discussion, Closing, Next Steps

3:00 – 3:15 Workshop Evaluation

3:30 Optional - ***Special Presentation for GIFT Registrants at the NASA Hyperwall*** – Cassie Soeffing (IGES) and NASA scientists from the Earth Science Division, Planetary Science Division, and Heliophysics Division. See the latest scientific research, geared towards educators, in a visually dynamic way on the NASA Hyperwall in the Exhibit Hall.

Speaker and Presenter Biographies

Dr. Pranoti Asher

Dr. Pranoti Asher is the Manager of Education and Outreach at AGU. Prior to joining AGU, she was a faculty member at Georgia Southern University in Statesboro for nearly thirteen years. Among her many achievements at Georgia Southern, Pranoti was the meeting chair for the Southeastern Section of the Geological Society of America meeting held in Savannah in 2007, the Acting Associate Dean of the College of Science and Technology , and a faculty fellow at the University's Center for Excellence in Teaching. She taught introductory and upper division geology courses, mentored and advised students (academic and research), conducted research in geochemistry, igneous petrology, and geoscience education and chaired curriculum and assessment committees to measure student learning outcomes for various courses. She has been recognized with teaching and service awards, including receiving the Association for Women Geoscientists (AWG) Distinguished Service Award in 2004. Pranoti earned her B.S. and M.S. in Geology at the University of Bombay, India, and her Ph.D. in Geological Sciences at the University of Connecticut. In addition to her passion for Geology and Education, she enjoys more esoteric pursuits such as reading mysteries, cooking, gardening, and listening to Celtic music. She is married to Irishman, Planetary Geologist, and AGU Member Michael Shawn Kelley.

Bethany Holm Adamec

Bethany Holm Adamec is a biologist and science education specialist with a particular interest in marine science and hands-on science education for learners of all ages. Bethany is AGU's New Education and Public Outreach Coordinator.

Prior to joining AGU, she was a Science Education Analyst at the National Science Foundation (NSF). Among her activities there were managing and analyzing critical data for undergraduate education programs, coordinating logistical arrangements for professional meetings, leading hands-on science lessons for preschoolers at NSF's Child Development Center, and working across the Foundation with all levels of support staff and management on the Climate Change Education Partnership Program. Her accomplishments during her time at NSF included a Director's Award for Collaborative Integration as a member of the Climate Change Education Working Group. Prior to joining NSF, Bethany taught undergraduate biology labs at American University and was a member of a team of teachers for a summer marine biology field course in Florida for a Washington, DC-based college preparatory school. Before coming to Washington, DC for graduate school, she worked for seven years for Allied Whale, a nonprofit marine mammal research group based in Bar Harbor, ME. Her activities there included assisting in the curation of the Antarctic Humpback Whale Catalog, which identifies and tracks the life history of individual humpback whales in the southern hemisphere. She has traveled to Antarctica, Hawaii, and the Gulf of Maine to study large whales. Bethany earned her B.A. in Human Ecology with a concentration in Marine Mammalogy from College of the Atlantic in Bar Harbor, ME and her M.A. in Biology with a concentration in Marine Mammal Population Genetics from American University in Washington, DC. In addition to her passion for science education, Bethany enjoys hiking, gardening, and training and showing dogs in performance events.

Dr. Roberta Johnson

Dr. Roberta Johnson is the Executive Director for the National Earth Science Teachers Association. Dr. Johnson was a research scientist at the University of Michigan in Ann Arbor, where she started Windows to the Universe, an award-winning Web-based educational tool. Prior to that, she was a Research Physicist at SRI International. Dr. Johnson has served on numerous advisory boards for projects in science education, outreach, and diversity, and has extensive experience advising the National Aeronautics and Space Administration, the National Science Foundation, and a variety of professional societies. She holds a B.S., M.S, and Ph.D. in geophysics and space physics from the University of California, Los Angeles. She is a member of the National Academy of Sciences Climate Change Education Roundtable (2010-2012), and has worked on climate change education and outreach activities over the past 15 years, offering workshops, online courses, web seminars, public events, and online educational resources for the public, students, and educators with support from numerous grants from NASA and NSF. She is married, and has three children.

Dave Mencin

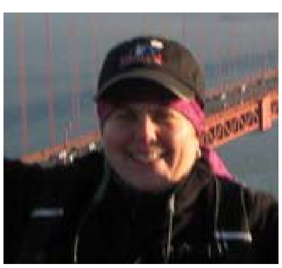
Dave Mencin is a geophysicist who led the team that installed a geodetic network in the Yellowstone region over the last 10 years. His goal as a geophysicist with UNAVACO is to transform human understanding of the changing Earth by enabling the integration of innovative technologies, open geodetic observations and research from pole to pole. After completing his first graduate degree in Nuclear Engineering and moving to Boulder, CO, to study astrophysics in the early 90s, Mencin fell in love with the arcane field of geodesy. As a project manager at UNAVCO, he found true adventure science participating in projects aimed at understanding plate tectonics, volcanoes and earthquakes in nearly 60 countries. These projects have ranged from focused goals like the measurement of the height of Mt. Everest with the Boston Museum of Science and National Geographic to projects spanning entire continents like the recent EarthScope project. Most recently he has focused on Yellowstone. He resides in Lyons, CO, with his wife and two sons.

Mark Nielsen

Science Education Program Officer, Howard Hughes Medical Institute

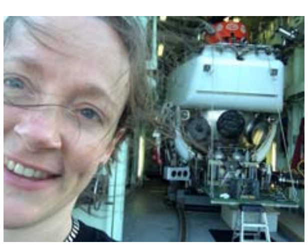
Mark Nielsen is an interdisciplinary earth scientist with experience in geology, oceanography, hydrology, microbial ecology, and engineering. He works with the Educational Media team to produce a wide range of classroom resources, including the Holiday Lectures on Science, the critically acclaimed EarthViewer app, and a variety of short films.

Nielsen earned a PhD in oceanography from Oregon State University. His research focused on using microbial fuel cells to harvest energy from marine sediments. Following his graduate program he was a postdoctoral research fellow at Harvard University working on microbial ecosystems at hydrothermal vents. Prior to focusing on scientific research and education, he was a consulting groundwater geologist for a water-resource consulting firm for five years.



Shelley Olds

Shelley has been teaching about science and technology to interpretive professionals and educators for over 15 years. Shelley is currently Science Education Specialist at UNAVCO, creating free educational materials and museum exhibits that use geodetic data and data products for undergraduate and secondary Earth science courses, developing improved online interface designs for data tools, and leading professional development programs for K-12, college faculty, and park interpreters. Her life-long love of science began at an early age observing stream-life with microscopes and using water & air quality kits to measure pollution. This passion continued into college and she graduated with a B.S. in Earth Science / Geophysics and then combined with her love for teaching as a Master's of Education in Instructional Systems Development. Shelley has been a member of the UNAVCO Education and Community Engagement program since 2006.



Heather Olins

Doctoral Candidate, Harvard University

Heather Olins studies microbial ecology at hydrothermal vents in the deep sea. In addition to geo-biological laboratory and field-based research, she is dedicated to education as a teaching fellow and outreach as a volunteer communicating science to the public with Harvard's Science in the News organization. Olins is nearing completion of her PhD from Harvard University, and has a MA in Earth and Environmental Science from Wesleyan University. Recently she has been a National Science Foundation fellow and a Harvard Horizons Scholar. Before returning to graduate school, she taught middle school Earth and Life Science for three years at the St. Mark's School of Texas in Dallas.

Lee Pruett

Lee Pruett teaches chemistry and AP environmental science at Notre Dame High School in San Jose, CA (an all-girls school), where she's been for the past 5 years. She is passionate about encouraging young women to pursue STEM careers. She co-coordinates the science speaker series at her school and enjoys working on many interdisciplinary and social justice-aligned projects with her colleagues. Before becoming a teacher, she spent 3.5 wonderful years studying climate change as a physical scientist at the United States Geological Survey (USGS) in Menlo Park.

Dr. Claire Raftery

Dr. Claire Raftery is a scientist turned educator, working for the Multiverse group at UC Berkeley's Space Sciences Laboratory. Coming from a background in solar physics, she is never happier than explaining the difference between flares and CMEs with the help of a helium balloon and some twine! Claire has since been involved in a number of NASA missions, both as a scientist and educator. The most recent of these is NASA's MAVEN mission, for which she is the Project Manager of the Education and Public Outreach plan, co-run with the Laboratory of Atmospheric and Space Physics (LASP) at CU Boulder.

Laura Stevens

Laura Stevens is a research scientist with the Cooperative Institute for Climate and Satellites, North Carolina (CICS-NC), based at NOAA's National Climatic Data Center in Asheville, NC. She provides primary science and technical support to the National Climate Assessment Technical Support Unit, including the development of climate data analysis products and research on assessment-relevant topics. Her research involves the analysis of both observational and climate model data sets, which has led to the development of several figures included in the Third National Climate Assessment report. Prior to joining CICS-NC, Ms. Stevens completed a master's degree in atmospheric science at the University of Leeds, UK.

Robert Taylor

Robert Taylor works with the Cooperative Institute for Climate and Satellites, North Carolina (CICS-NC), based at NOAA's National Climatic Data Center in Asheville, NC. He supports outreach, engagement, and education efforts related to the National Climate Assessment. Mr. Taylor also participates in the ongoing development of GIS tools for decision makers as a member of the National Climate Assessment Technical Support Unit. In addition to his work at CICS-NC, Robert is a research assistant with Duke University's Great Smoky Mountains Rain Gauge Network, NASA's Integrated Precipitation and Hydrology experiment (IPHEx) in the southern Appalachians, and UNC Asheville's Sounding-based Experiment on Mixed Precipitation Events, SEMPE. Mr. Taylor studied Atmospheric Sciences and Mathematics at the University of North Carolina at Asheville. Prior to his time in Asheville, Mr. Taylor served as a volunteer coordinator and maintenance manager on a 1500-acre reforestation project in the Payne's Creek National Park on the southern coast of Belize, Central America.

Erin Wood
Erin Wood is the educational coordinator at the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder. She is currently working on the MAVEN team on spectroscopy lessons and Mars Education Ambassadors (MEA) teacher professional development. She co-runs the Colorado National Project Astro, conducts teacher professional development on topics of the Sun and Solar System, and coordinates a Research Experience for Undergraduates (REU) program in solar and space physics, and creates hands-on curriculum for grades 3-12.

Dr. Michael Wysession
Professor Michael Wysession (Washington University in St. Louis) is a leader in the areas of seismology and geophysical education. He has developed several means of using the seismic waves from earthquakes to "see" into the Earth and create three-dimensional pictures of Earth's interior. Wysession is author or co-author of over 20 textbooks ranging from elementary to graduate school levels. Wysession constructed the first computer-generated animation of how seismic waves propagate within the Earth from an earthquake, creating a 20-minute movie that was used in many high school and college classrooms. He is currently lead-PI on a project installing a network of seismometers in Madagascar to better understand mantle dynamics beneath the African Plate. Wysession is the designer and instructor of a 3-day course, *Earth, Moon, and Mars*, which he teaches at different NASA centers. He is currently an editor of AGU's leading journal, *Geophysical Research Letters*. He has authored an internationally acclaimed video course as part of The Teaching Company's Great Courses series (48 lectures on "*How the Earth Works*"), and has just completed a second one (36 lectures on the "*Geologic Wonders of the World*"). Wysession is Chair the NSF-sponsored Earth Science Literacy Initiative, leader of the Earth and Space Science design team for the NRC's *Conceptual Framework for New Science Education Standards,* and team leader for Earth and Space Science in the writing of the new national K-12 science education *Next Generation Science Standards*. Wysession's research and educational efforts have been recognized through several fellowships and awards. He has received a *Science and Engineering Fellowship* from the David and Lucille Packard Foundation, and a National Science Foundation *Presidential Faculty Fellowship*. Wysession received Distinguished Lectureships from the Seismological Society of America and Incorporated Research Institutions of Seismology in 2005, and from the National Association of Geoscience Teachers in 2009. Wysession was awarded the *Innovation Award* of the St. Louis Science Academy and the *Distinguished Faculty Award* of Washington University.

GIFT 2014 Share-a-thon Sign-in

Monday Share-a-thon		
Name	**Subject**	**Signature**
Cliff Treyens	Groundwater	
Kala Perkins	Astronomy	
Nick Haddad	Climate Literacy	
Rob Fatland	Tides	
Sarah Bartholow		
Sarah Crecelius	Langley EPO	
Todd Ellis		
Pat Reiff	MMS	

Tuesday Share-a-thon		
Name	**Subject**	**Signature**
Adam Blankenbicker	National Museum of Natural History’s online content	
Cassie Soeffing	NASA Wavelength	
Mark McCaffrey	NCSE	
Mike Passow	Earth2Class	
Sharon Cooper	Scientific ocean drilling	

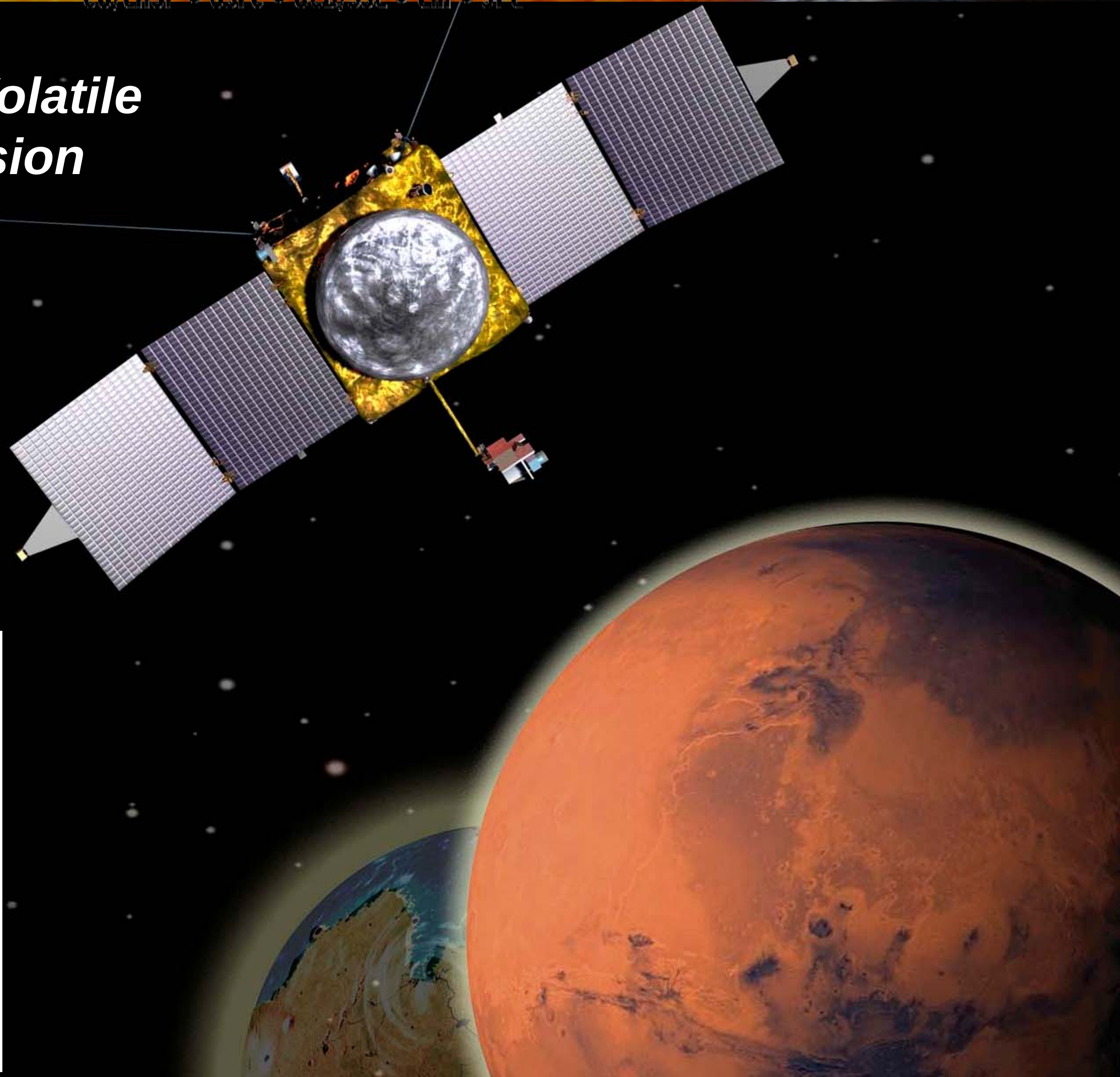
Next Generation Science Standards Update and Discussion – Dr. Michael Wysession, Washington University at Saint Louis

The Scientific Objectives of the NASA MAVEN Mission and Correlating Classroom Activities – Lee Pruett

CU/LASP • GSFC • UCB/SSL • LM • JPL

Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission

LASP-led Mars Scout Mission
Bruce Jakosky, PI
Launch date: 2013



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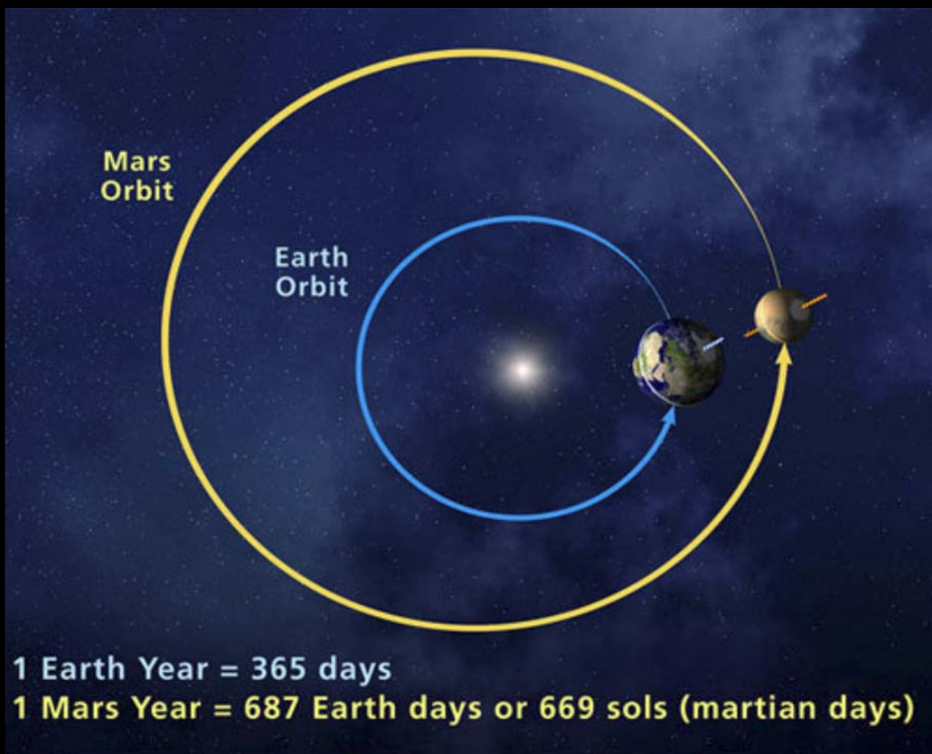
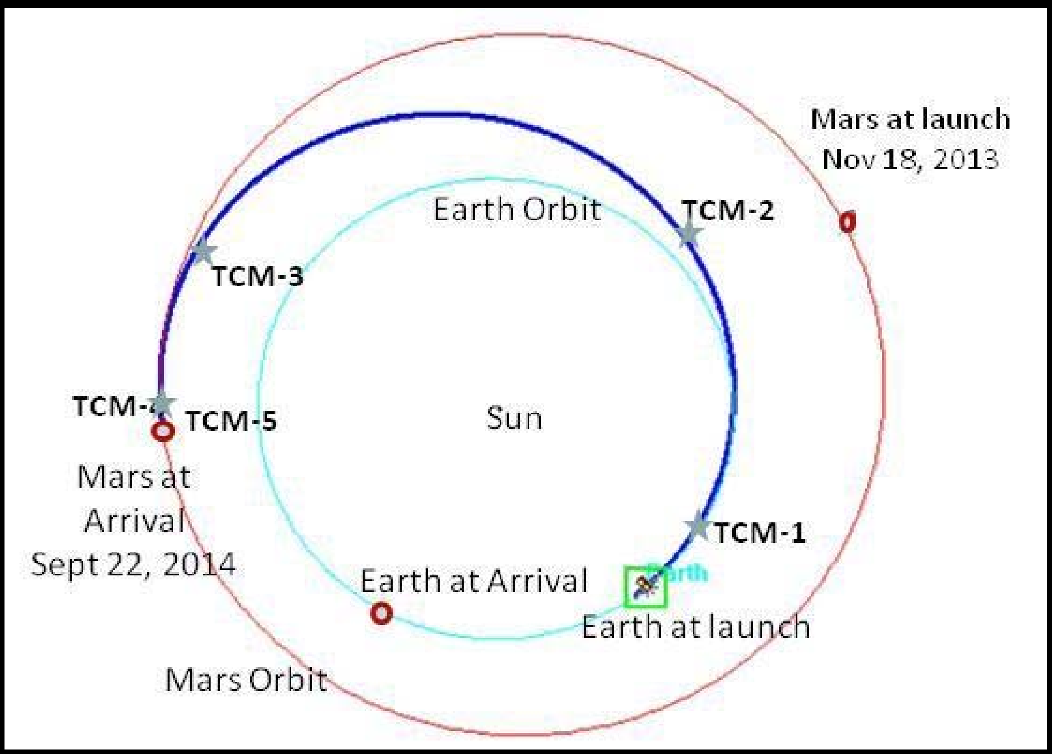
LASP

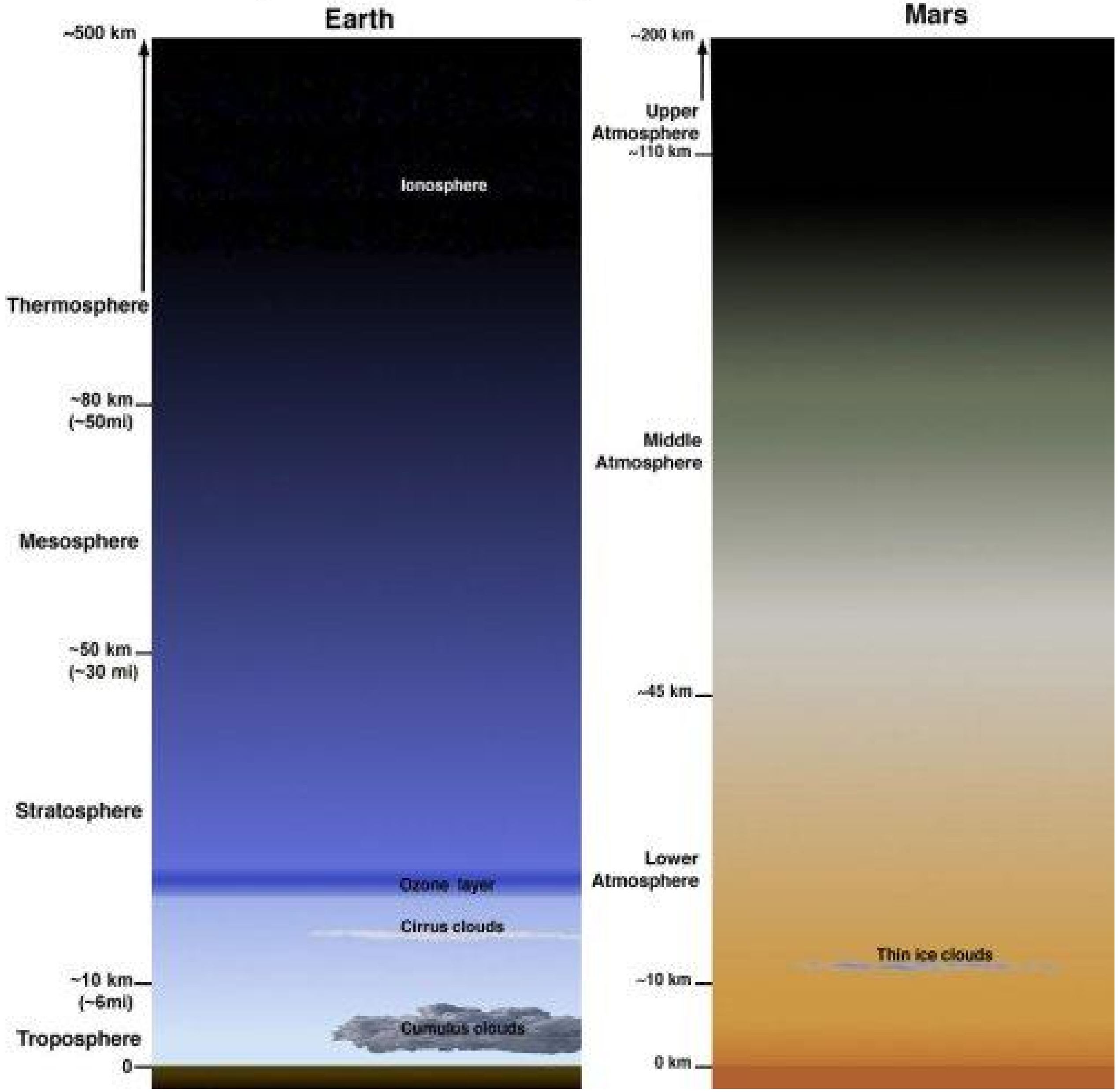
MAVEN FAMILY & FRIENDS NIGHT JULY 15, 2013


Mars
Orbit
Earth
Orbit
1 Earth Year = 365 days
1 Mars Year = 687 Earth days or 669 sols (martian days)


Mars at launch
Nov 18, 2013
Earth Orbit
TCM-2
TCM-3
TCM-4
TCM-5
Sun
Mars at
Arrival
Sept 22, 2014
TCM-1
Earth at Arrival
Earth at launch
Mars Orbit

What is Mars Like Today?

A Comparison of the Atmospheres of Earth and Mars

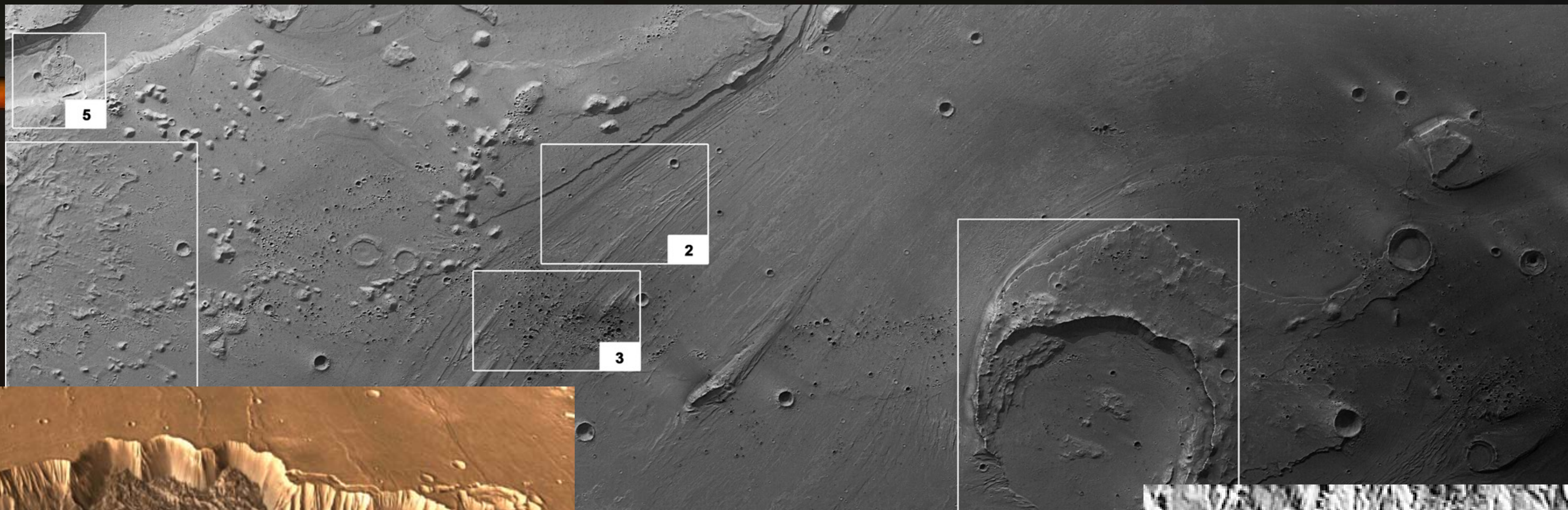


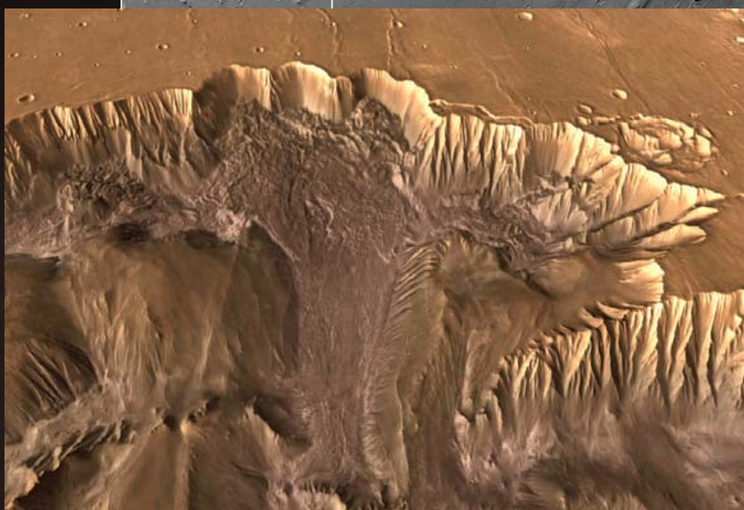
Water Ice is Abundant on Mars Today

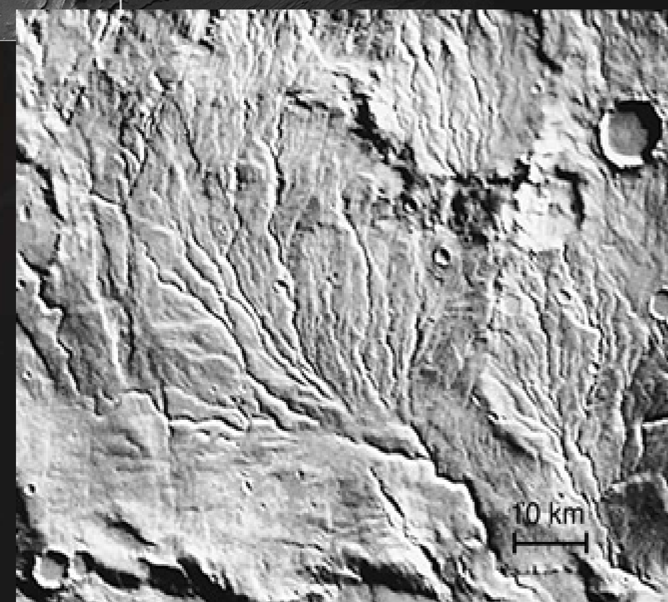
Mars north polar cap is made of water ice.

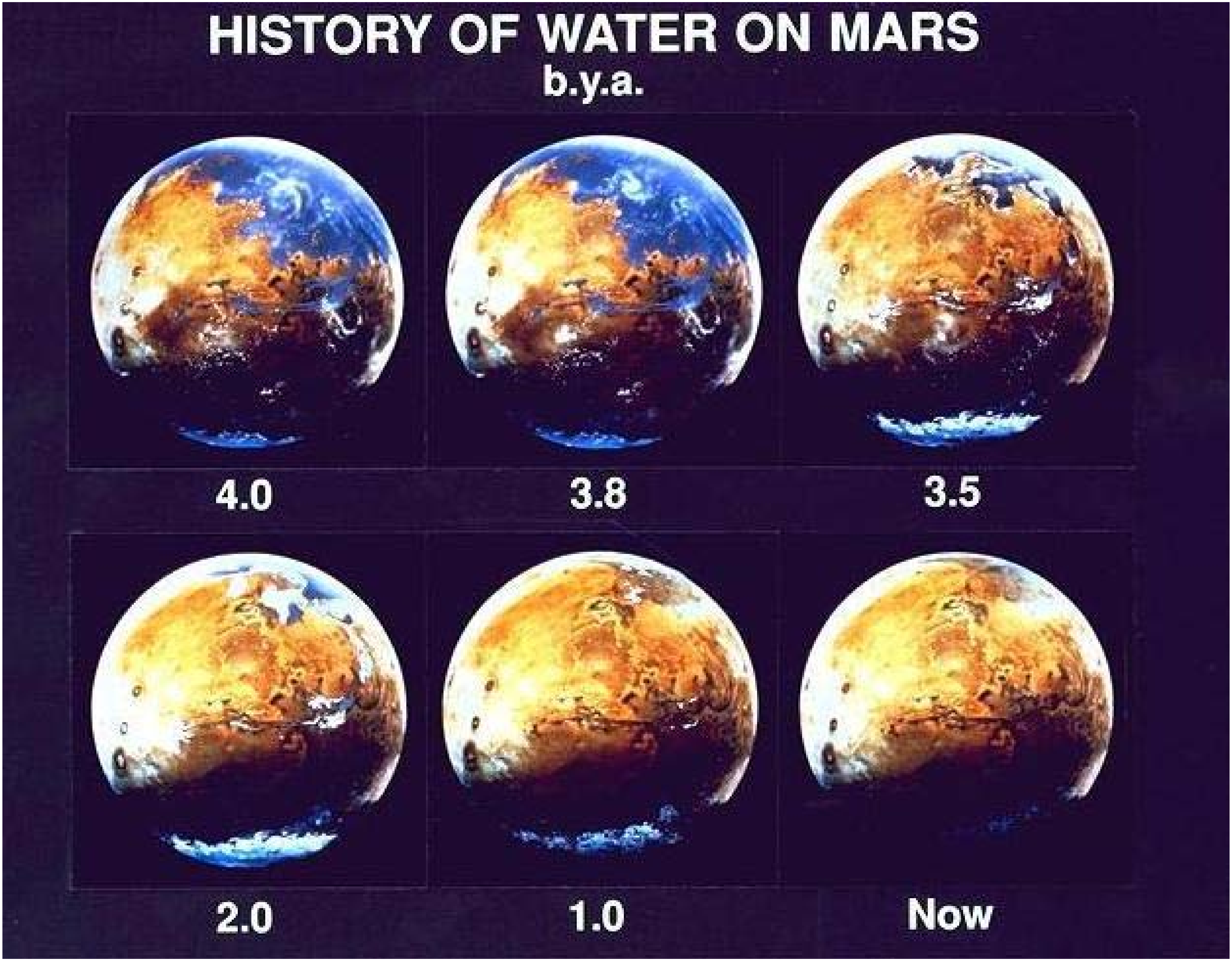
The recent *Phoenix* mission uncovered buried water ice at high latitudes.

Did Mars Have a Watery Past? Surface Features Suggest "Yes"








HISTORY OF WATER ON MARS
b.y.a.
4.0
3.8
3.5
2.0
1.0
Now

If Mars had a thick atmosphere, where it is now?
If Mars had an ocean, where is all the water now?

- Frozen at the poles?
- Not enough!
- Locked underground?
- Not *nearly* enough!

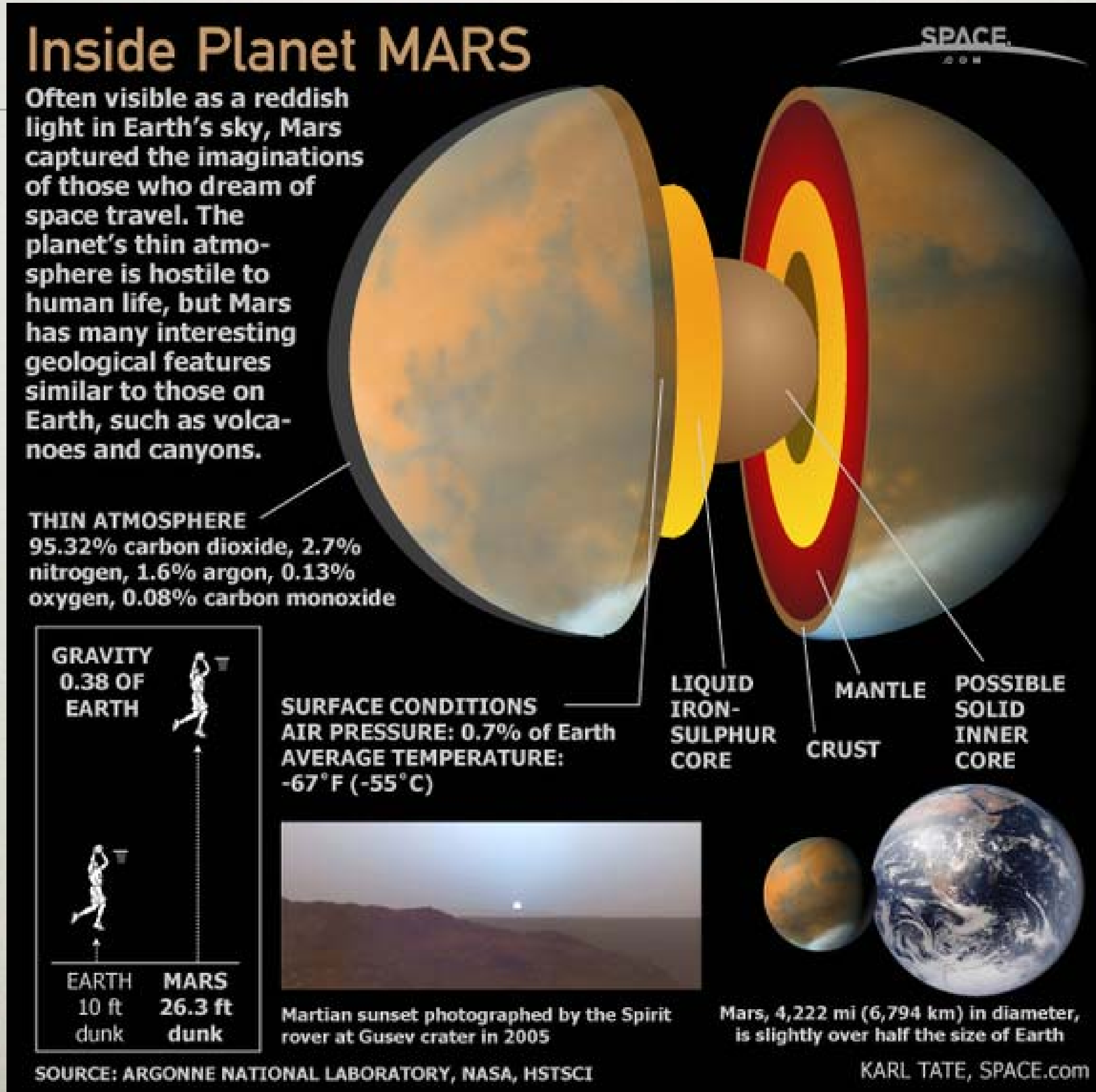
What other possibilities are left?

Artist's conception by Mike Carroll

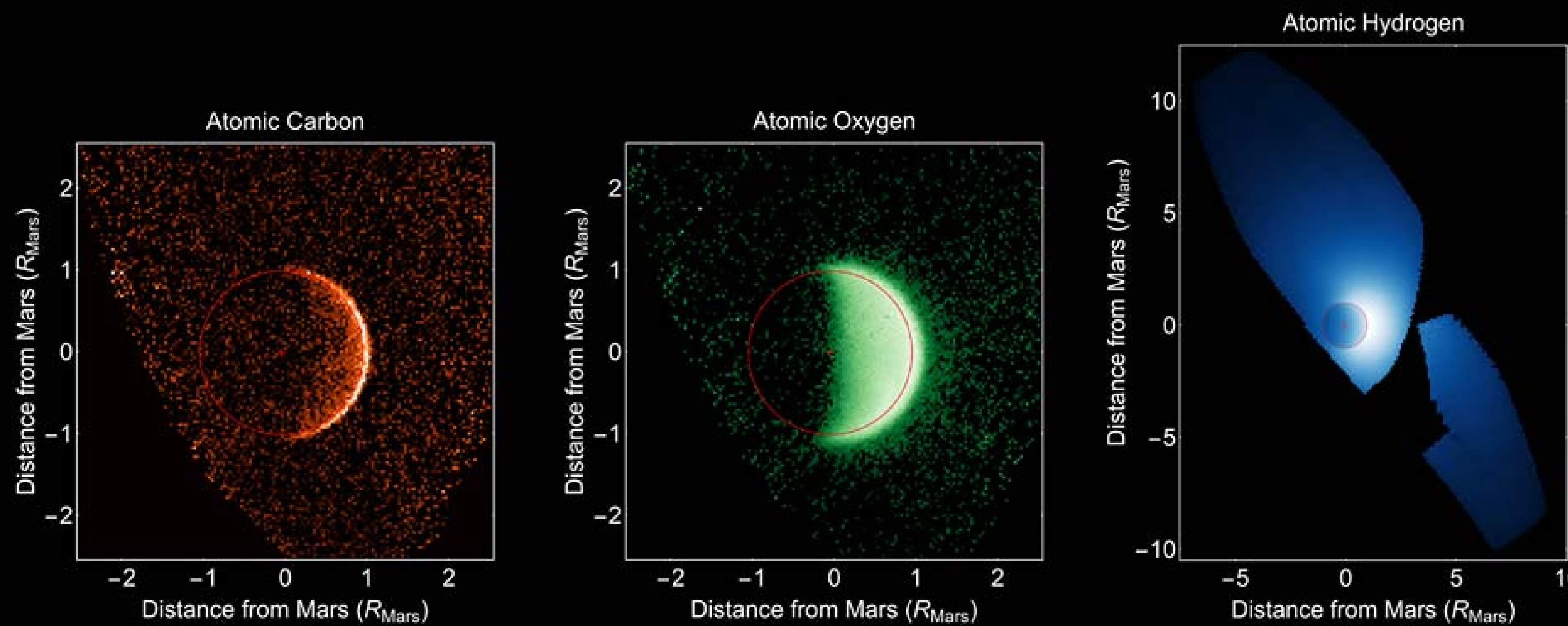
Mars has 2 major problems

- Problem 1: It’s little!
- Problem 2: It has no global magnetic field.

Problem 1: It's little so it has low gravity

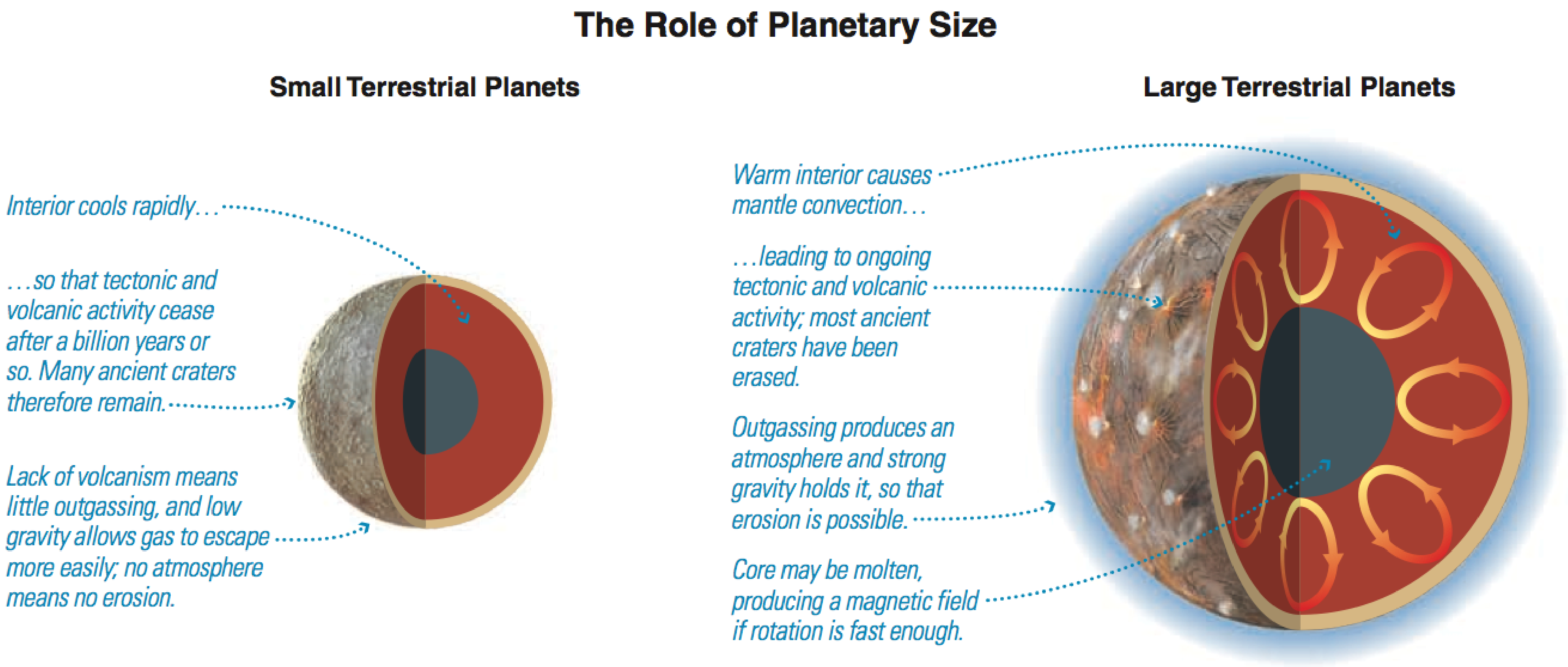


Atmospheric loss BECAUSE of problem 1



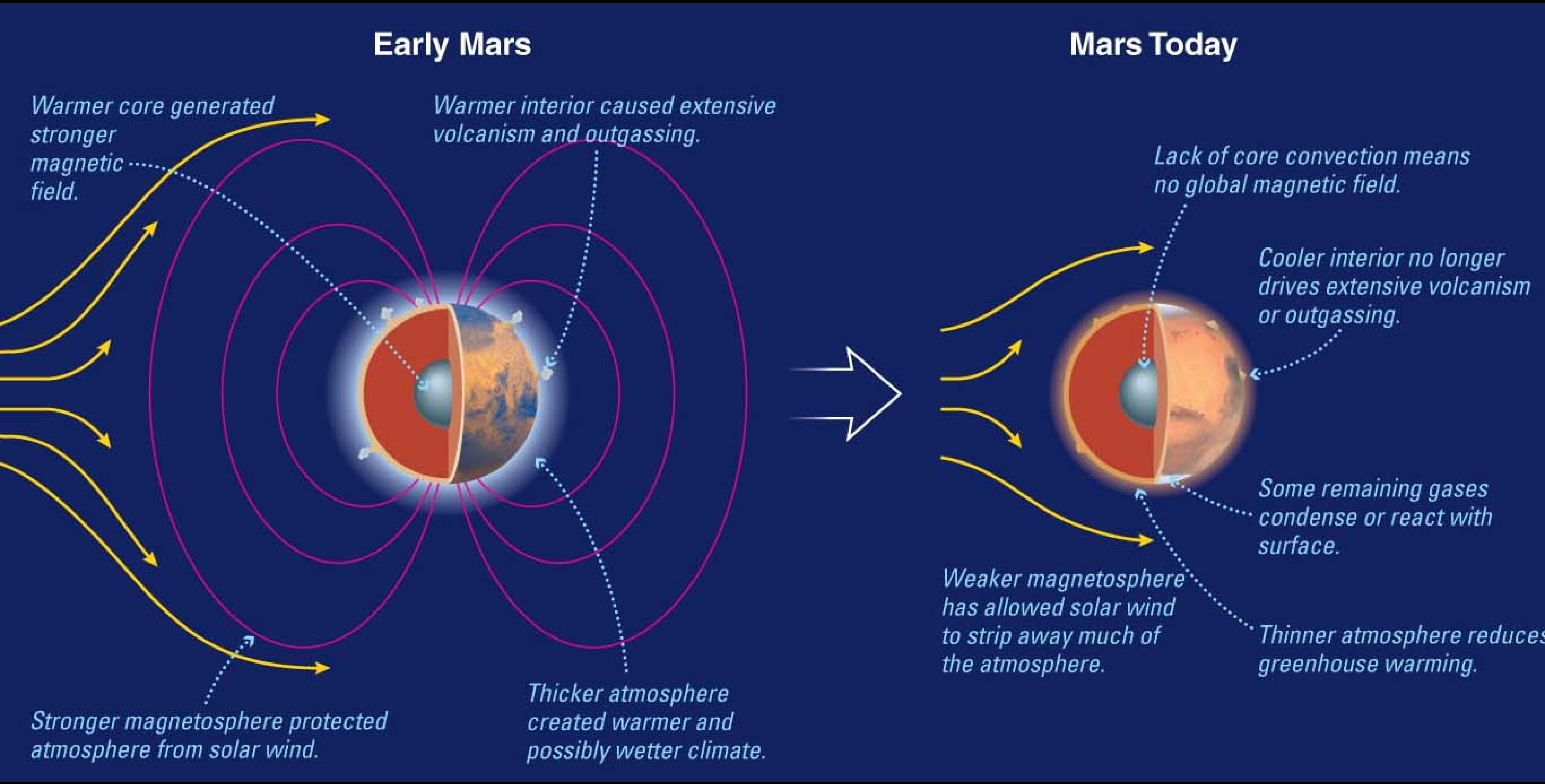
Three views of an escaping atmosphere

Problem 1 leads to Problem 2



- Smaller worlds cool off faster and "harden" earlier
- Larger worlds stay warmer inside, leading to more volcanism and tectonics
- Larger worlds CAN have more erosion because they can create and hold an atmosphere

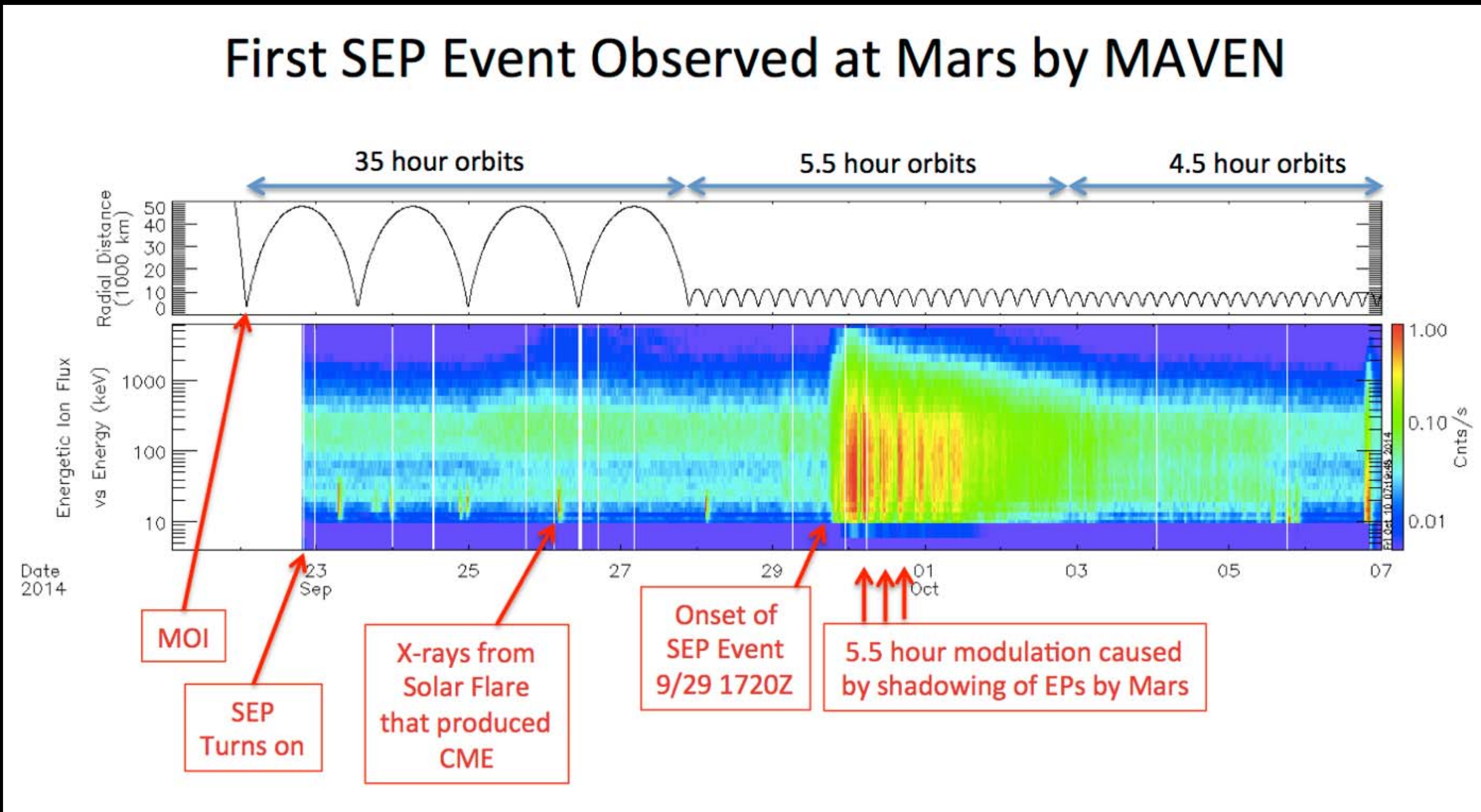
Problem 2: Mars has no global magnetic field



The End of the World – for Martians?

Solar wind blasts planets

Solar energetic particles detected by MAVEN instruments

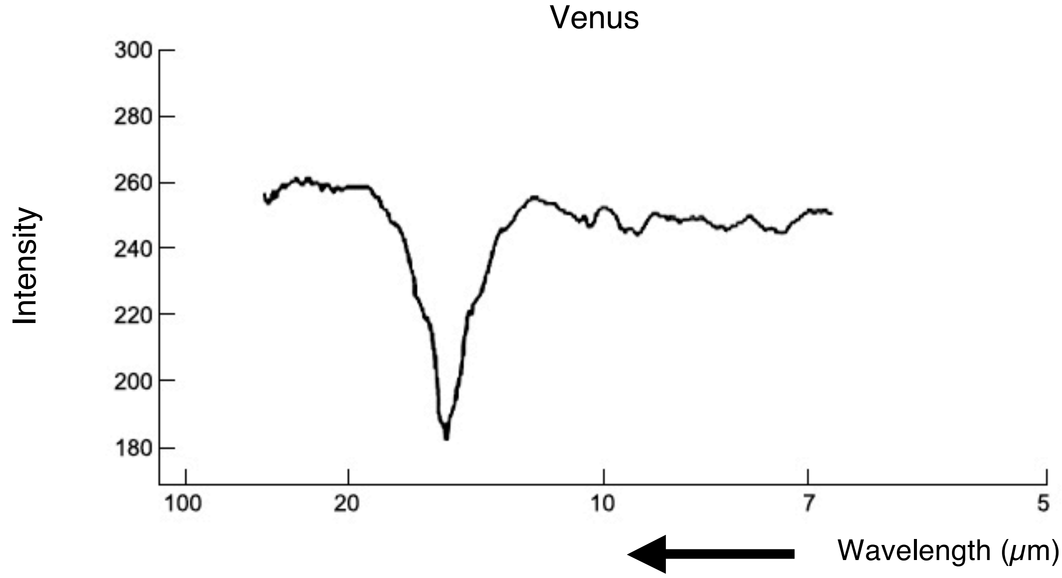


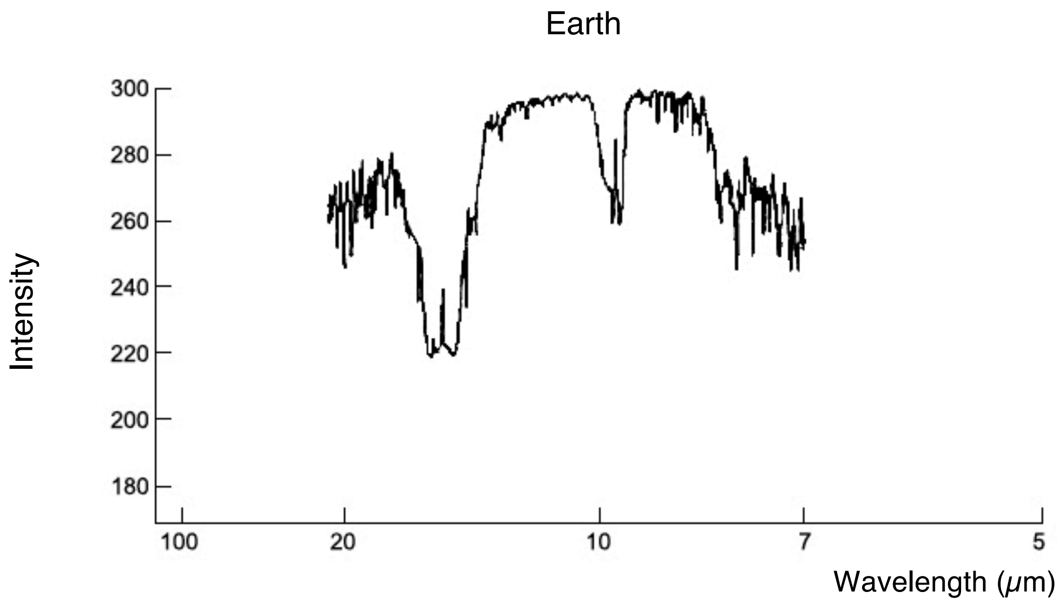
Problem 2: Mars has no global magnetic field

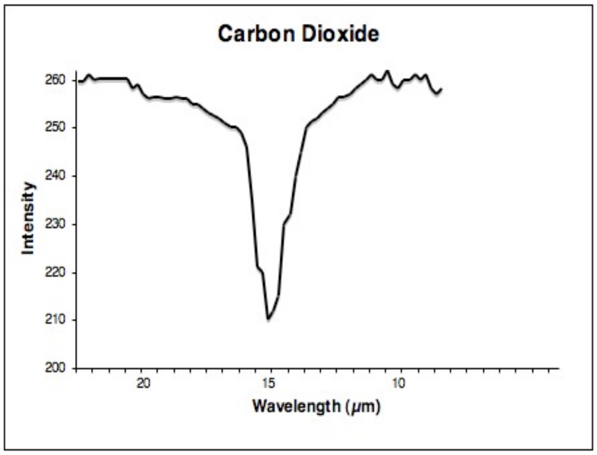
Student directions

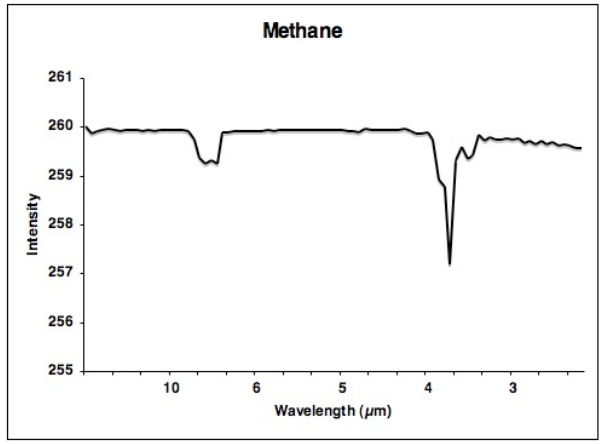
Part 1

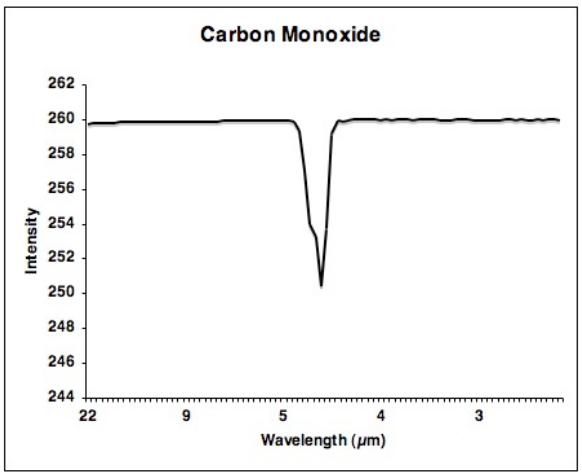
First, let's compare the spectra of Venus and Earth. The spectrum of Venus was taken from the Venera 15 spacecraft with an instrument called the Infrared Fourier Spectrometer in the 1980s. The spectrum of Earth was taken by the Nimbus 4 spacecraft which orbited Earth in the 1970s. Compare the dips in the spectra with known elements on the following page. Be sure to look at the scale very carefully.

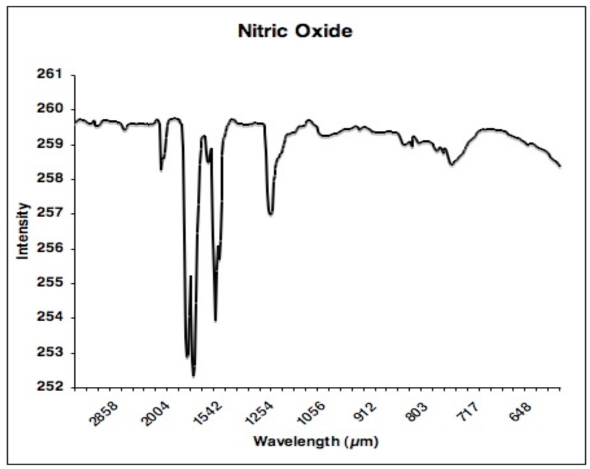


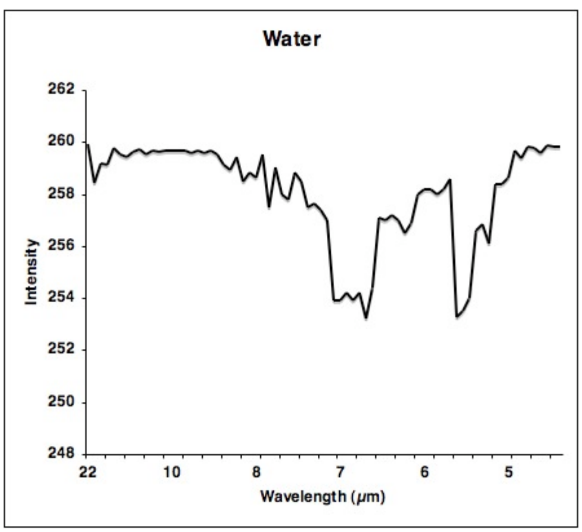


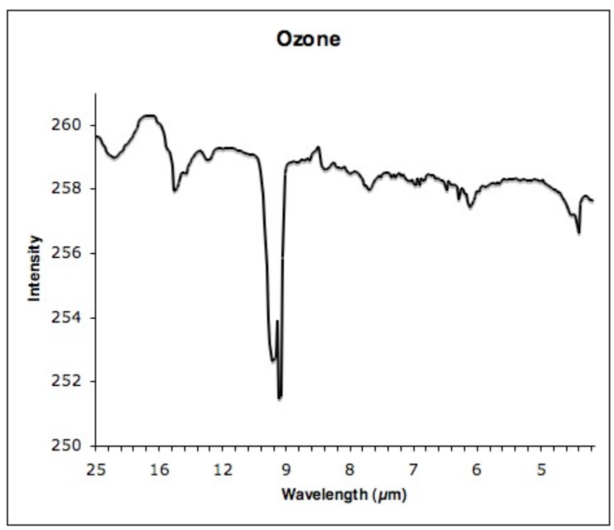

Carbon Dioxide
260
250
240
230
220
210
200
Intensity
20
15
10
Wavelength (μm)


Methane
261
260
259
258
257
256
255
Intensity
10
6
5
4
3
Wavelength (μm)


Carbon Monoxide
262
260
258
256
254
252
250
248
246
244
Intensity
22
9
5
4
3
Wavelength (μm)


Nitric Oxide
261
260
259
258
257
256
255
254
253
252
Intensity
2858
2004
1542
1254
1056
912
803
717
648
Wavelength (μm)


Water
262
260
258
256
254
252
250
248
Intensity
22
10
8
7
6
5
Wavelength (μm)


Ozone
260
258
256
254
252
250
Intensity
25
16
12
9
8
7
6
5
Wavelength (μm)

Goldilocks and the Three Planets

1. Which substances are definitely present in both Earth and Venus' spectra?

2. Which substances are definitely present in only Earth's spectrum?

3. Which substances could be present in Earth's spectrum, but it is difficult to say that they are definitely present? Why?

4. Carbon Dioxide, water, and methane are a few greenhouse gasses. Describe whether or not you see these gasses in the spectra of Venus and Earth.

5. Now, let's do some math! Venus has 90 times more atmosphere than Earth does. About 97% of the total mass of Venus' atmosphere is Carbon Dioxide, but only 0.04% of the total mass of Earth's atmosphere is Carbon Dioxide.
    a. Write an expression for the amount of Carbon Dioxide in the Earth's atmosphere using 'm_e' for the mass of Earth's atmosphere.

    b. Write an expression for the mass of Venus' atmosphere using 'm_e.'

    c. Write an expression for the amount of Carbon Dioxide in Venus' atmosphere using the expression from part b.

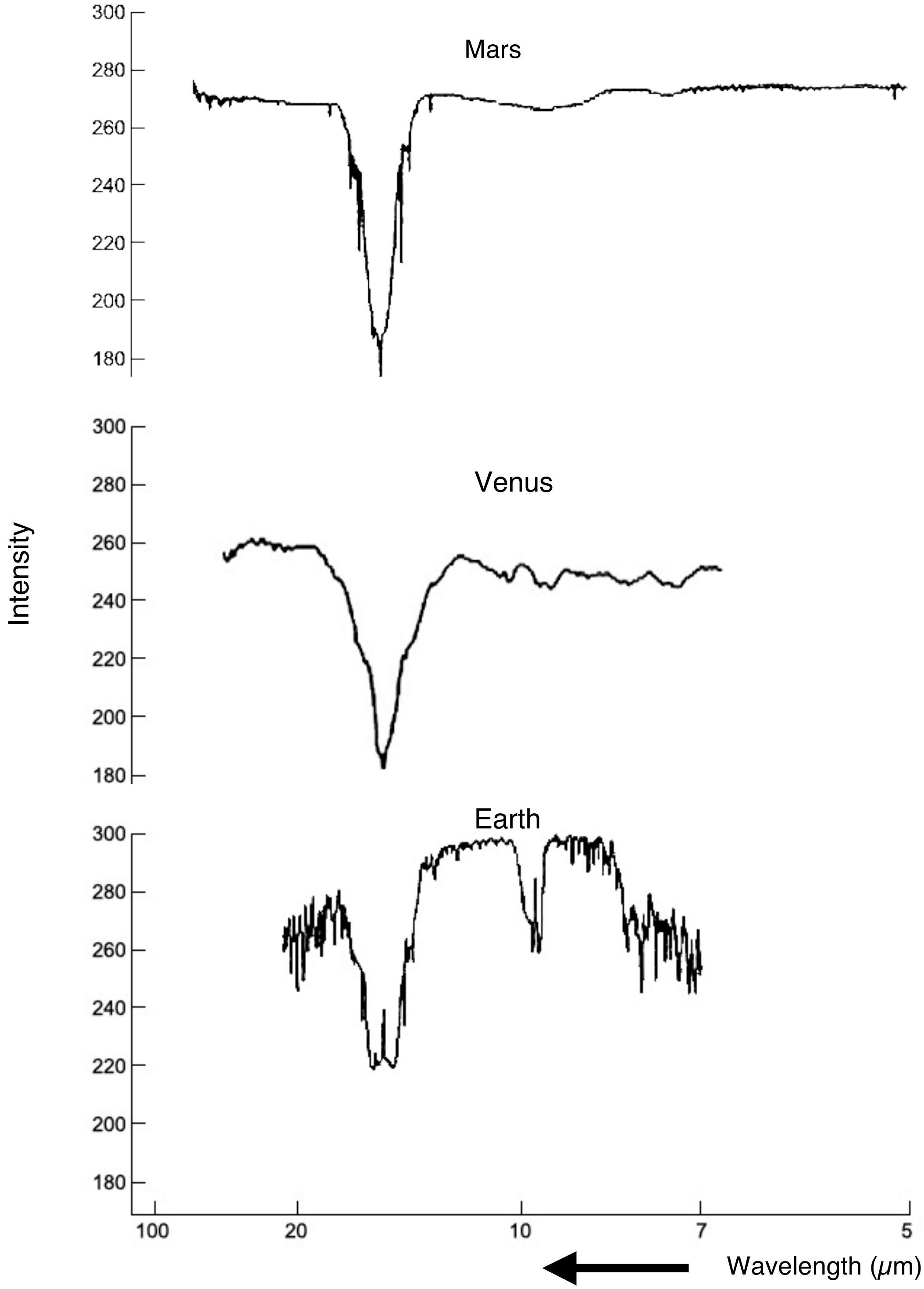
    d. Compare the amount of Carbon Dioxide in Venus' atmosphere to the amount in Earth's atmosphere by dividing the expression from part c by the expression from part a. Round your answer.

6. Using the value from part d above, fill in this blank: Venus has_____ times more Carbon Dioxide than Earth.

7. Venus is very very hot! It can get up to 900 ^{0}F at the surface, hot enough to melt lead!! What conjectures can you make about the cause of Venus' hot temperature?

Part 2

Now, let's look at the spectrum of Mars compared to Earth and Venus. The spectrum of Mars was taken by the Mariner 9 spacecraft in the 1970s.



Project SPECTRA!

Goldilocks and the Three Planets

Put an X in the table below with the substances you know are definitely present.

	Carbon Monoxide	Nitric Oxide	Methane	Water	Ozone	Carbon Dioxide
Venus						
Earth						
Mars						

1. Let's compare Mars and Earth. Mars' atmosphere is much thinner than Earth's, about 0.95% of Earth's atmosphere. About 95% of Mars' atmosphere is Carbon Dioxide. Remember, only 0.04% of the Earth's atmosphere is Carbon dioxide.

    a. Write an expression for the mass of Mars' atmosphere using 'm_e.'

    b. Write an expression for the amount of Carbon Dioxide in Mars' atmosphere using the expression from part a.

    c. Compare the amount of Carbon Dioxide in Mars' atmosphere to the amount in Earth's atmosphere by dividing the expression from part b by the expression from part a from part 1.

2. Using the value from part c above, fill in this blank: Mars has _______ times more Carbon Dioxide than Earth.

3. Even though Mars has more Carbon Dioxide than Earth, it has a much colder average surface temperature of about -70 ^{0}F. Clearly, Mars has more Carbon Dioxide than Earth, but much less than Venus. Why do you think Mars' temperature is so much lower than Earth's? What factors can affect a planet's temperature? Brainstorm with a peer.

Goldilocks and the Three Planets

Middle and High School Grades

Project SPECTRA!

Lesson Summary

Students determine what some of Earth, Venus, and Mars' atmosphere is composed of and then mathematically compare the amount of the greenhouse gas, CO_2, on the planets Venus, Earth, and Mars in order to determine which has the most. Students brainstorm to figure out what things, along with greenhouse gases, can affect a planet's temperature.

Prior Knowledge & Skills

- Experience interpreting data
- Visible light represents only a small portion of all light
- General understanding of energy
- Pre-Algebra or Algebra

AAAS Science Benchmarks

The Nature of Science
The Scientific World View
Scientific Inquiry
The Nature of Mathematics
Mathematics, Science, and Technology
Mathematical Inquiry
The Nature of Technology
Technology and Science
The Physical Setting
The Earth
The Mathematical World
Symbolic Relationships

NSES Science Standards

Science as Inquiry: Understandings about Scientific Inquiry

Earth and Space Science: Energy in the Earth System

NCTM Mathematics Standards

- **Algebra:** Represent and analyze mathematical situations and structures using algebraic symbols

Colorado State Standards

- Mathematics Standards 1.4, 2.2, 2.5
- Science Standard 4, 5

Suggested background reading

Light
Greenhouse Effect

Teaching Time: One to Two 50-minute periods

Materials

Each student needs:
Copy of student directions
Calculator

Advanced Planning

Preparation Time: 10 minutes

1. Print copies of the student instructions.

Why Do We Care?

One reason we care is because Earth is the only planet that has life that we know of in our solar system. Some planets are too cold and some are too hot. Understanding the reasons behind the temperature differences in our solar system is the key to understanding the conditions that make a planet habitable.

LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

Goldilocks and the Three Planets

Grade Level __ (8-10)

Activity Dependency "Using Spectral Data to Explore Saturn and Titan" activity

Group Size 1-2 students

Expendable Cost per Group $0.30

Engineering Connection
In this activity, students compare data taken from spacecraft instrumentation that was designed by engineers to gather data about the atmospheres of planets.

Pre-Requisite Knowledge
Students should have a basic understanding of mathematical comparisons.
Students should be somewhat familiar with algebraic expressions. Students should have some experience with hypothesis.
Students should be comfortable sharing ideas with peers.

Learning Objectives
After this lesson, students should be able to:
- Explain how a mathematical comparison is done
- Constructively argue why inner planets have different temperatures
- Explain how data is a useful tool when creating a theory
- Explain why engineers create tools to collect data

Introduction / Motivation
You've probably heard about the greenhouse effect and global warming, but did you know that if the Earth had no greenhouse gasses, our planet would be colder? Greenhouse gasses act as a blanket that keep us warm because they trap some warm radiation from the Sun. Too much of a good thing can be really bad, though. If we have too many greenhouse gasses in our atmosphere, we could warm the planet up too much. Some nearby planets, Venus and Mars, also have greenhouse gasses. You've heard the story of the three bears. This is the story of the three planets. Venus is much too hot, Mars is much too cold, and Earth is just right to support life. There is more to the story than you might initially think, though, and your job will be to figure out what other things (or variables) beside greenhouse gasses effect the temperature of the three planets.

Engineers built spectrographs for spacecraft that traveled to the planets Venus and Mars. One of the goals was to find out what gasses make up their atmospheres. These spacecraft sent data back to Earth. The spectrographs found the spectra of Venus and Mars by looking at light from the two atmospheres that originally came from the Sun.

Goldilocks and the Three Planets

When you look at a spectrum taken from a spectrometer, you can figure out what is inside of that atmosphere because the dips and peaks in the graph match up to the known dips and peaks of gasses that scientists and engineers have measured in laboratories. You will be using actual data from spacecraft and data taken in a laboratory today to figure out what is inside the atmospheres of Venus, Mars, and Earth.

Vocabulary / Definitions

Incandescent light bulb	A standard light bulb found in most households
Spectrum (plural: spectra)	The pattern light produces as can be seen through a spectrograph
Spectrograph (also Spectroscope)	A tool that allows the components of light to be seen easily with the eye.
Diffraction	When light bends, as through a prism or diffraction grating.
Diffraction Grating	Usually a piece of film designed to act like a prism.

Procedure:

Background

See also background from the "Graphing the Rainbow" activity.

Note: *This lesson can be done as an online flash interactive instead of the paper and pencil version included here. If the appropriate computing speed and version of Flash is not available, an accompanying PowerPoint presentation as well as separate images and movies can be used to augment instruction. For the interactive and associated lesson material, visit the website:* http://lasp.colorado.edu/education/spectra

The greenhouse effect is actually not a bad thing. Greenhouse gasses on Earth, such as H_2O, methane, and CO_2, trap infrared radiation from the Sun that warm the Earth. This acts like a blanket, and Earth would be colder without it. Global warming is a concern in today's society because, as we pump man-made greenhouse gasses into the atmosphere, we trap more and more solar radiation and heat up the Earth.

There are greenhouse gasses on other planets and solar system bodies, too. In this lesson, the students will be looking at the amount of CO2 on Venus, Earth, and Mars. What they will discover is that Venus has the most CO2, Mars has the second greatest amount, and Earth has the least. What should be surprising is that Mars has more CO2 than Earth. Why, then, is Mars so much colder than Earth? Instead of looking at the planets as individual bodies to be studied and analyzed, the solar system must be looked at as a whole. Venus is much closer to the Sun than Earth, has a much thicker atmosphere and more greenhouse gas. CO2 is the most plentiful greenhouse gas in Venus' atmosphere, but it has others as well. Mars, on the other hand, has more CO2 than Earth, but is much farther away and has a very thin atmosphere all together. CO2 is the most plentiful greenhouse gas, but Mars has very little in its atmosphere and only small amounts of other greenhouse gasses. Mars is also much farther from the Sun than Earth. Earth has other greenhouse gasses aside from CO2, and the greenhouse gas that is most plentiful is H2O, water!

Goldilocks and the Three Planets

There is more going on in the solar system than is immediately apparent… Venus is too hot; it is close to the Sun and contains far more greenhouse gas. Mars is too cold; it is far from the Sun and has more CO2 than Earth, but far less of other gasses. Earth is just right; it not only has the perfect amount of greenhouse gas, but it is also just the right distance from the Sun to make life very happy.

Troubleshooting Tips

Students may need assistance with algebraic expressions.

Assessment

Pre-Lesson Assessment
Class Discussion: What kinds of data do spacecraft collect when they travel to other planets? What do engineers need to do to make sure data arrives on Earth? (ans. antenna, computer systems, computer chips, storage devices)

Post-Introduction Assessment
Think-Pair-Share: What are greenhouse gasses good for?

Post-Activity
Writing and illustration:
With a peer, have students create a travel guide explaining:

1. How far Venus or Mars is from the Sun
2. What the surface conditions are like
3. What equipment is needed for the journey and visit
4. Why a person might want to go to that planet

Activity Extensions

Complete the activity "Building a Fancy Spectrograph"

References

Pater, Imke. Lissauer, Jack. Planetary Sciences. New York, NY: Cambridge University Press, 2001.

Owner

Integrated Teaching and Learning Program and Laboratory, University of Colorado at Boulder

Contributors

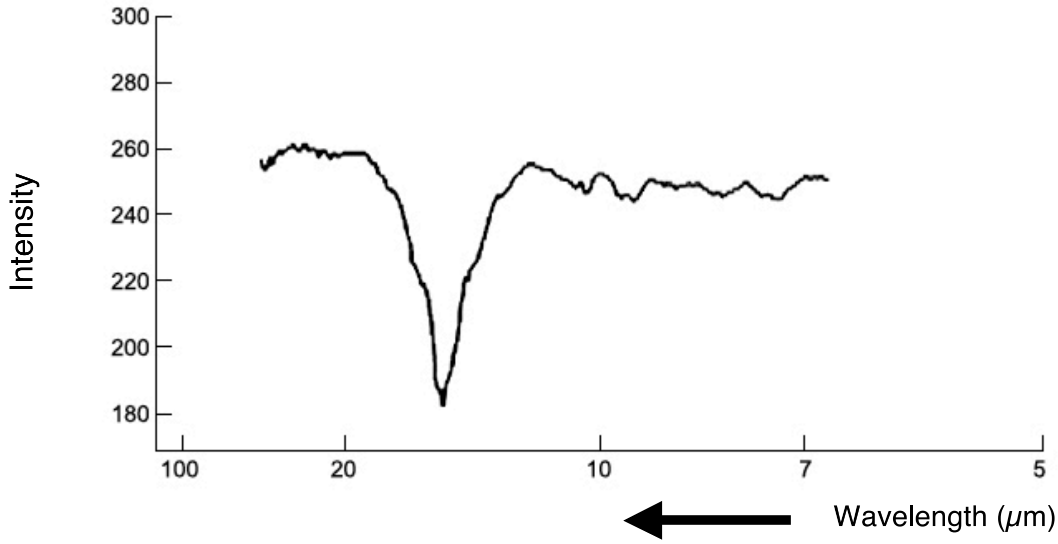
Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder

Student directions

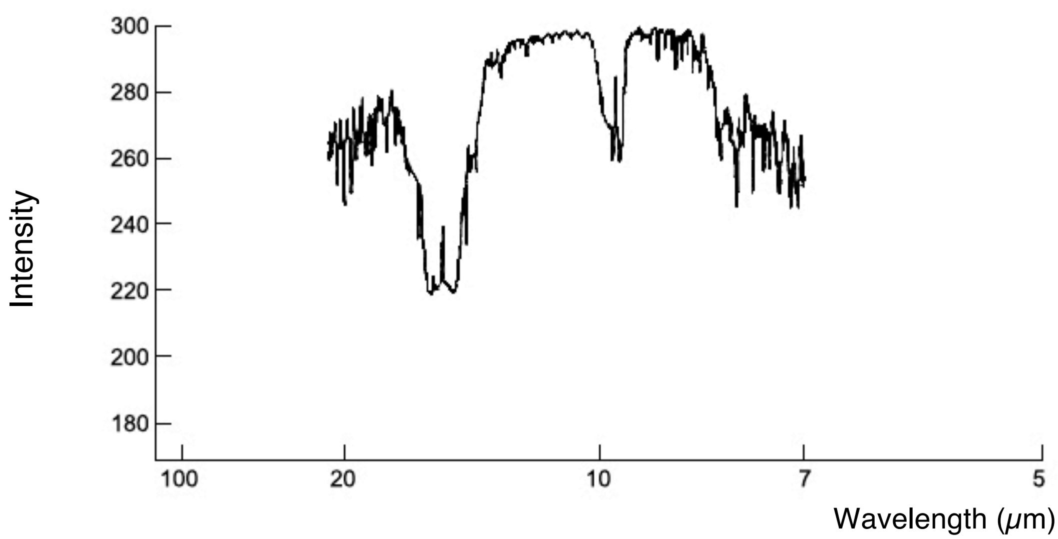
Part 1

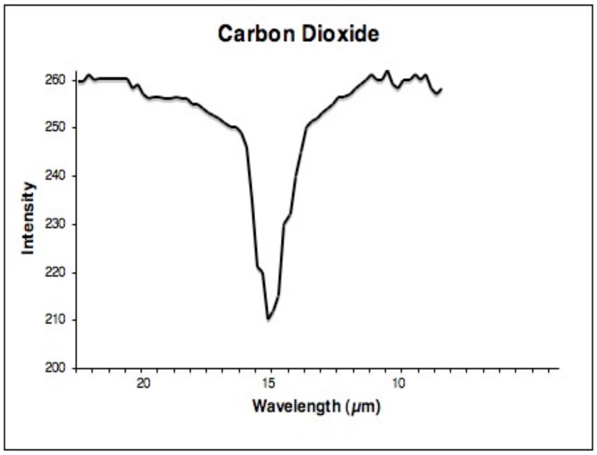
First, let's compare the spectra of Venus and Earth. The spectrum of Venus was taken from the Venera 15 spacecraft with an instrument called the Infrared Fourier Spectrometer in the 1980s. The spectrum of Earth was taken by the Nimbus 4 spacecraft which orbited Earth in the 1970s. Compare the dips in the spectra with known elements on the following page. Be sure to look at the scale very carefully.

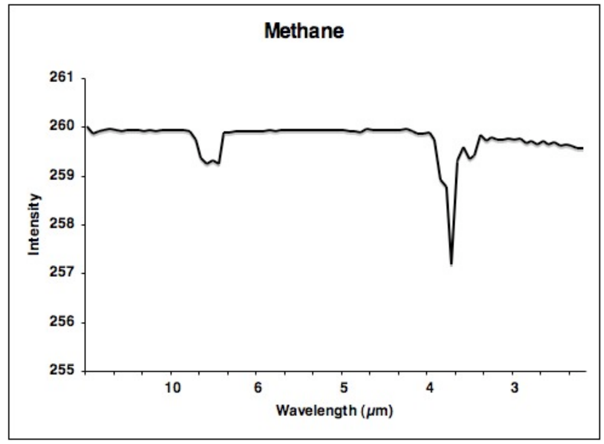
Venus

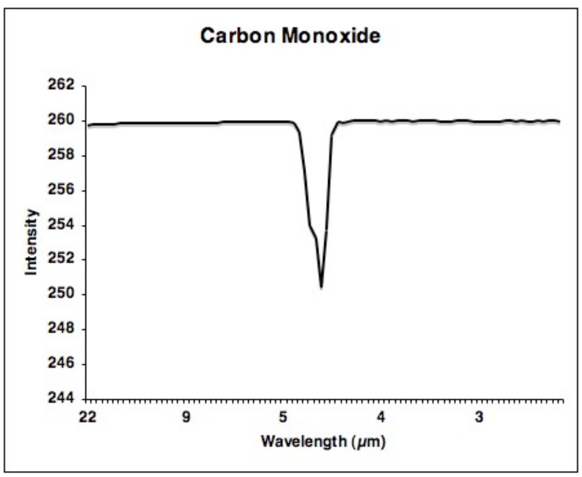


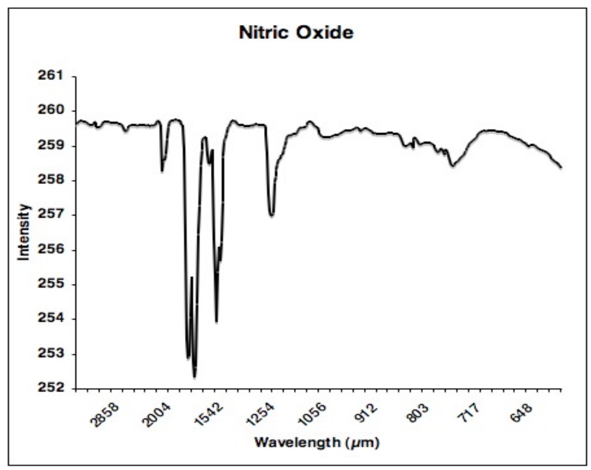
Earth

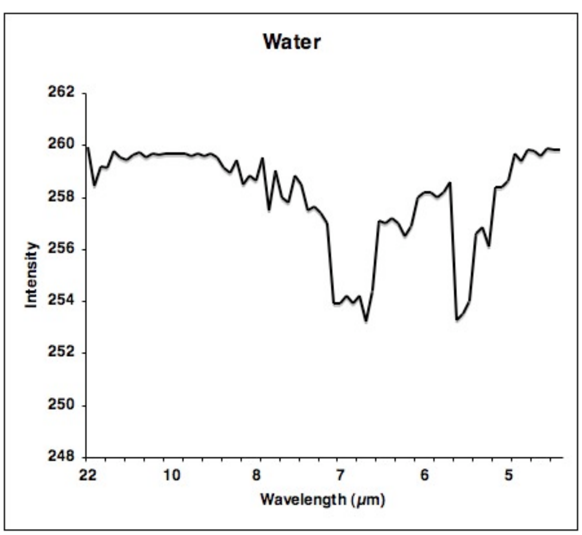


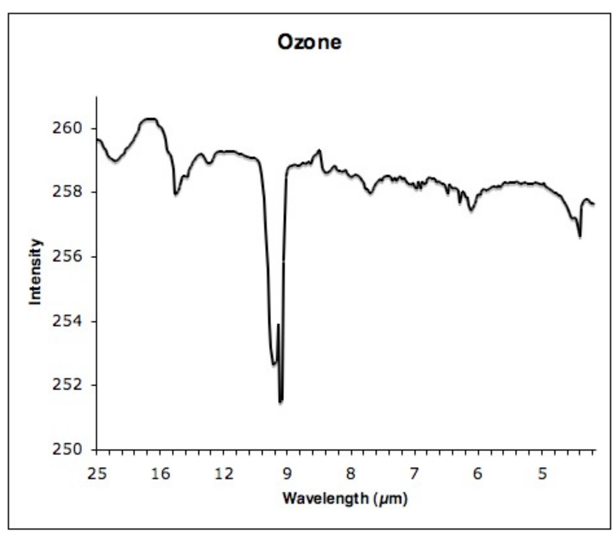

Carbon Dioxide
260
250
240
230
220
210
200
Intensity
20
15
10
Wavelength (μm)


Methane
261
260
259
258
257
256
255
Intensity
10
6
5
4
3
Wavelength (μm)


Carbon Monoxide
262
260
258
256
254
252
250
248
246
244
Intensity
22
9
5
4
3
Wavelength (μm)


Nitric Oxide
261
260
259
258
257
256
255
254
253
252
Intensity
2858
2004
1542
1254
1056
912
803
717
648
Wavelength (μm)


Water
262
260
258
256
254
252
250
248
Intensity
22
10
8
7
6
5
Wavelength (μm)


Ozone
260
258
256
254
252
250
Intensity
25
16
12
9
8
7
6
5
Wavelength (μm)

Goldilocks and the Three Planets

1. Which substances are definitely present in both Earth and Venus' spectra?

2. Which substances are definitely present in only Earth's spectrum?

3. Which substances could be present in Earth's spectrum, but it is difficult to say that they are definitely present? Why?

4. Carbon Dioxide, water, and methane are a few greenhouse gasses. Describe whether or not you see these gasses in the spectra of Venus and Earth.

5. Now, let's do some math! Venus has 90 times more atmosphere than Earth does. About 97% of the total mass of Venus' atmosphere is Carbon Dioxide, but only 0.04% of the total mass of Earth's atmosphere is Carbon Dioxide.
   a. Write an expression for the amount of Carbon Dioxide in the Earth's atmosphere using 'm_e' for the mass of Earth's atmosphere.

   b. Write an expression for the mass of Venus' atmosphere using 'm_e.'

   c. Write an expression for the amount of Carbon Dioxide in Venus' atmosphere using the expression from part b.

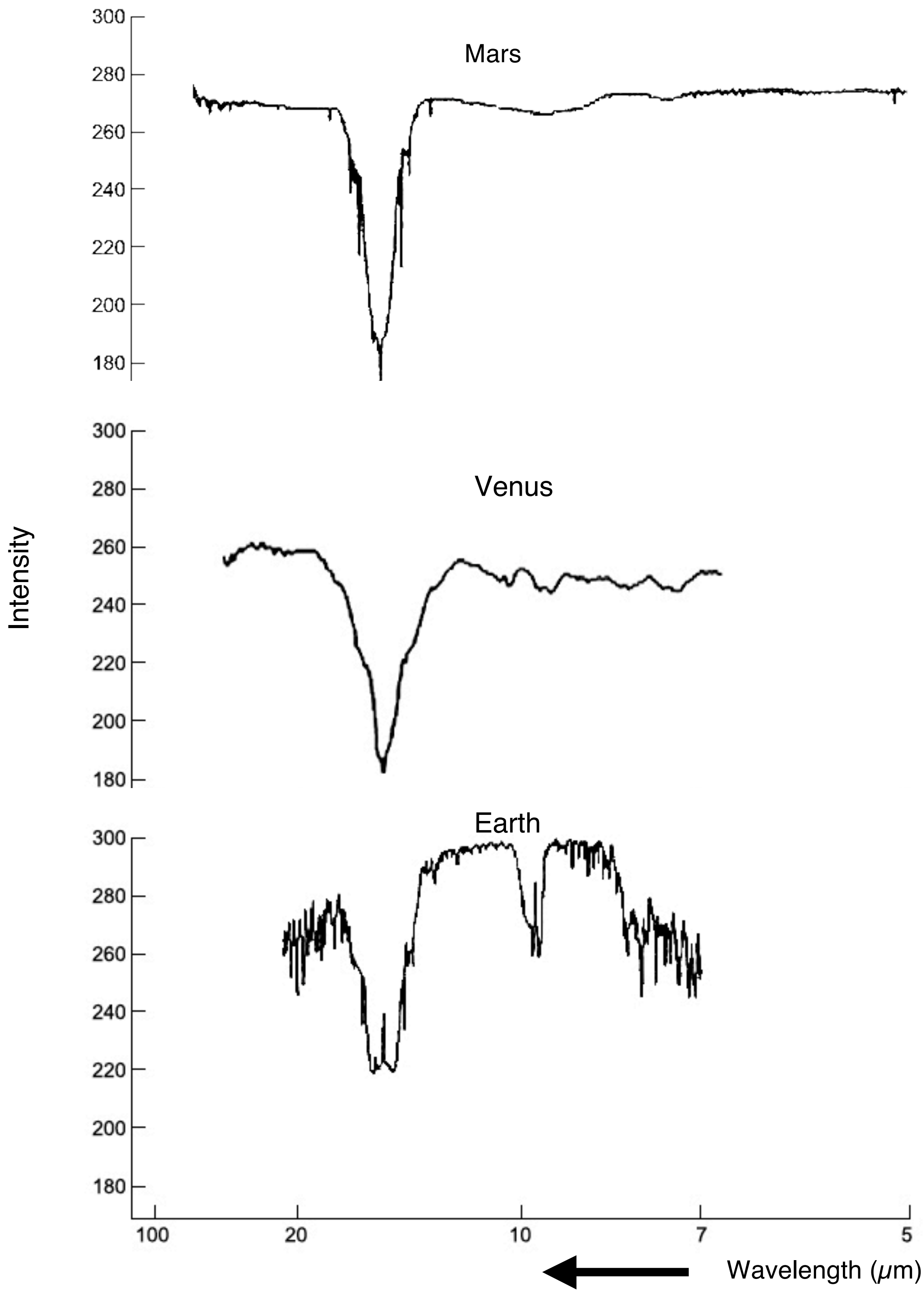
   d. Compare the amount of Carbon Dioxide in Venus' atmosphere to the amount in Earth's atmosphere by dividing the expression from part c by the expression from part a. Round your answer.

6. Using the value from part d above, fill in this blank: Venus has_____ times more Carbon Dioxide than Earth.

7. Venus is very very hot! It can get up to 900 ^{0}F at the surface, hot enough to melt lead!! What conjectures can you make about the cause of Venus' hot temperature?

Part 2

Now, let's look at the spectrum of Mars compared to Earth and Venus. The spectrum of Mars was taken by the Mariner 9 spacecraft in the 1970s.



Project SPECTRA! Goldilocks and the Three Planets

Put an X in the table below with the substances you know are definitely present.

	Carbon Monoxide	Nitric Oxide	Methane	Water	Ozone	Carbon Dioxide
Venus						
Earth						
Mars						

1. Let's compare Mars and Earth. Mars' atmosphere is much thinner than Earth's, about 0.95% of Earth's atmosphere. About 95% of Mars' atmosphere is Carbon Dioxide. Remember, only 0.04% of the Earth's atmosphere is Carbon dioxide.

    a. Write an expression for the mass of Mars' atmosphere using 'm_e.'

    b. Write an expression for the amount of Carbon Dioxide in Mars' atmosphere using the expression from part a.

    c. Compare the amount of Carbon Dioxide in Mars' atmosphere to the amount in Earth's atmosphere by dividing the expression from part b by the expression from part a from part 1.

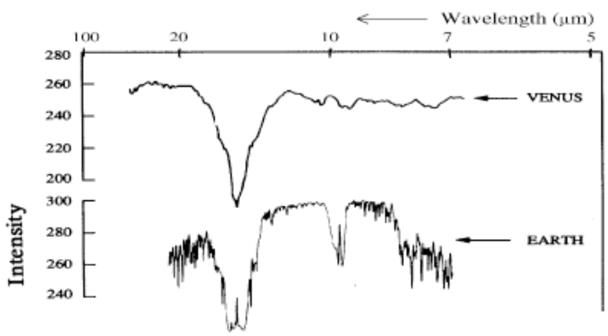
2. Using the value from part c above, fill in this blank: Mars has _______ times more Carbon Dioxide than Earth.

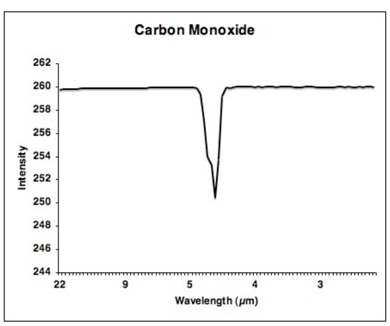
3. Even though Mars has more Carbon Dioxide than Earth, it has a much colder average surface temperature of about -70 ^{0}F. Clearly, Mars has more Carbon Dioxide than Earth, but much less than Venus. Why do you think Mars' temperature is so much lower than Earth's? What factors can affect a planet's temperature? Brainstorm with a peer.

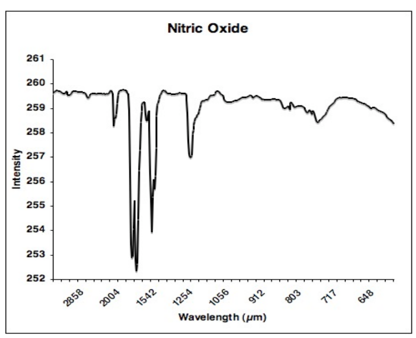
Teacher's Key: Goldilocks and the Three Planets

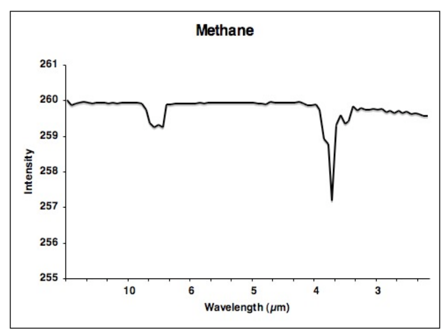
Part 1

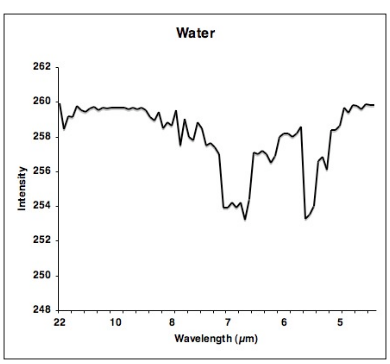
First, let's compare the spectra of Venus and Earth. The spectrum of Venus was taken from the Venera 15 spacecraft with an instrument called the Infrared Fourier Spectrometer in the 1980s. The spectrum of Earth was taken by the Nimbus 4 spacecraft which orbited Earth in the 1970s. Compare the dips in the spectra with known elements on the following page. Be sure to look at the scale very carefully.

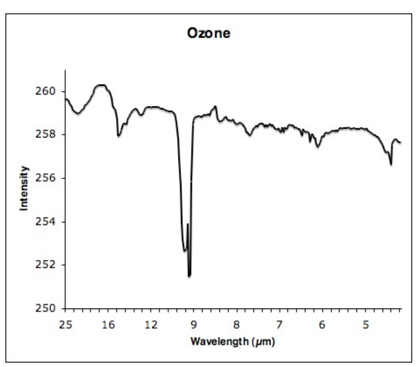


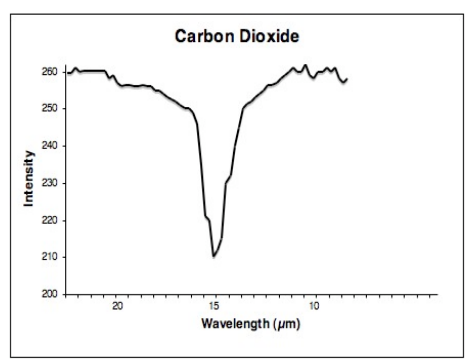












1. Which substances are definitely present in both Earth and Venus' spectra? *Ans: Carbon Dioxide is the only definite substance.*
2. Which substances are definitely present in only Earth's spectrum? *Ans: ozone and water are both present in Earth's spectrum. It is easier to see the ozone, so students may overlook the water (see next question).*
3. Which substances could be present in Earth's spectrum, but it is difficult to say that they are definitely present? Why? *Ans: Water may be present but it is difficult to tell because the wavelength range given for water is partially off of the plot for Earth. We cannot answer whether carbon monoxide or nitric oxide are present because we have not been given enough information. The scale given for these substances do not appear on the plot for Earth. Also, it is difficult to say for sure whether Methane appears in Earth's spectrum because the wavelength range given for methane is partially off of the plot for Earth, and the area where methane could be has quite a few dips and is very close to the end of the plot on the right side. Accept a variety of sensible answers.*
4. Carbon Dioxide, water, and methane are a few greenhouse gasses. Describe whether or not you see these gasses in the spectra of Venus and Earth. *Ans: We see carbon dioxide in both plots. We see water in Earth's spectrum.*
5. Now, let's do some math! Venus has 90 times more atmosphere than Earth does. About 97% of the total mass of Venus' atmosphere is Carbon Dioxide, but only about 0.04% of the total mass of Earth's atmosphere is Carbon Dioxide.
    a. Write an expression for the amount of Carbon Dioxide in the Earth's atmosphere using 'm_e' for the mass of Earth's atmosphere. *Ans: $0.0004m_e$*
    b. Write an expression for the mass of Venus' atmosphere using 'm_e.' *Ans: $90m_e$*
    c. Write an expression for the amount of Carbon Dioxide in Venus' atmosphere using the expression from part b. *Ans: $0.97 \times 90m_e$ simplified $87.3\ m_e$*
    d. Compare the amount of Carbon Dioxide in Venus' atmosphere to the amount in Earth's atmosphere by dividing the expression from part c by the expression from part a. Round your answer. Ans:

    $$\frac{87.3m_e}{0.0004m_e} = 218249.\bar{9}$$

    or *Also acceptable (rounded): 220,000*

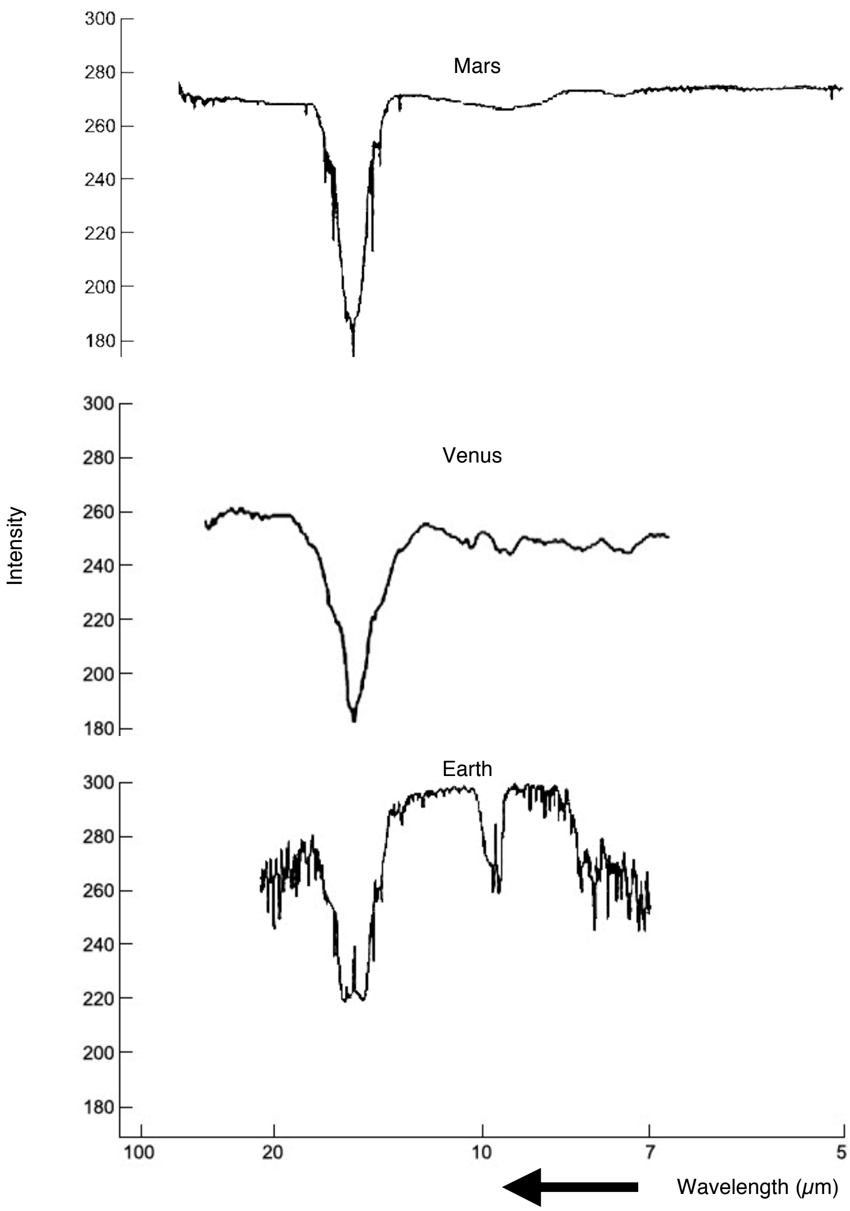
    218,250

6. Using the value from part d above, fill in this blank: Venus has_____ times more Carbon Dioxide than Earth. *Ans: 218,250 or about 220,000 times more Carbon Dioxide than Earth.*

7. Venus is very very hot! It can get up to 900 ^{0}F at the surface, hot enough to melt lead!! What conjectures can you make about the cause of Venus' hot temperature? *Ans: From the calculation, one speculation about Venus' temperature is that it has a very large amount of greenhouse gas that keeps it very hot.*

Part 2

Now, let's look at the spectrum of Mars compared to Earth and Venus. The spectrum of Mars was taken by the Mariner 9 spacecraft in the 1970s.



Goldilocks and the Three Planets

Put an X in the table below with the substances you know are definitely present.

	Carbon Monoxide	Nitric Oxide	Methane	Water	Ozone	Carbon Dioxide
Venus						x
Earth				x	x	x
Mars						x

1. Let's compare Mars and Earth. Mars' atmosphere is much thinner than Earth's, about 0.95% of Earth's atmosphere. About 95% of Mars' atmosphere is Carbon Dioxide. Remember, only 0.04% of the Earth's atmosphere is Carbon dioxide.
   a. Write an expression for the mass of Mars' atmosphere using 'm_e.' *Ans: 0.0095me*
   b. Write an expression for the amount of Carbon Dioxide in Mars' atmosphere using the expression from part a. Ans:

      0.95 x 0.0095me or 0.009025me
   c. Compare the amount of Carbon Dioxide in Mars' atmosphere to the amount in Earth's atmosphere by dividing the expression from part b by the expression from part a from part 1. Ans:

$$\frac{0.009025m_e}{0.0004m_e} = 22.5625$$

or

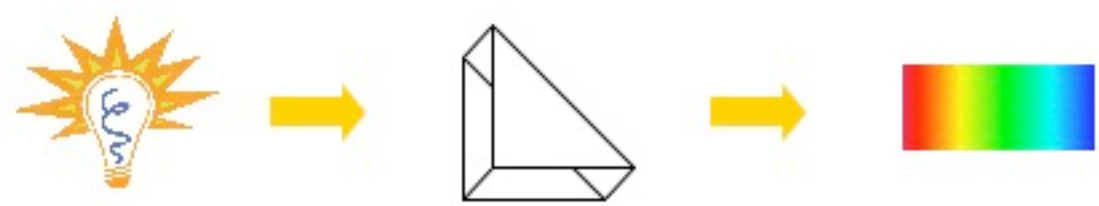
23

2. Using the value from part c above, fill in this blank: Mars has _______ times more Carbon Dioxide than Earth. *Ans: 23*

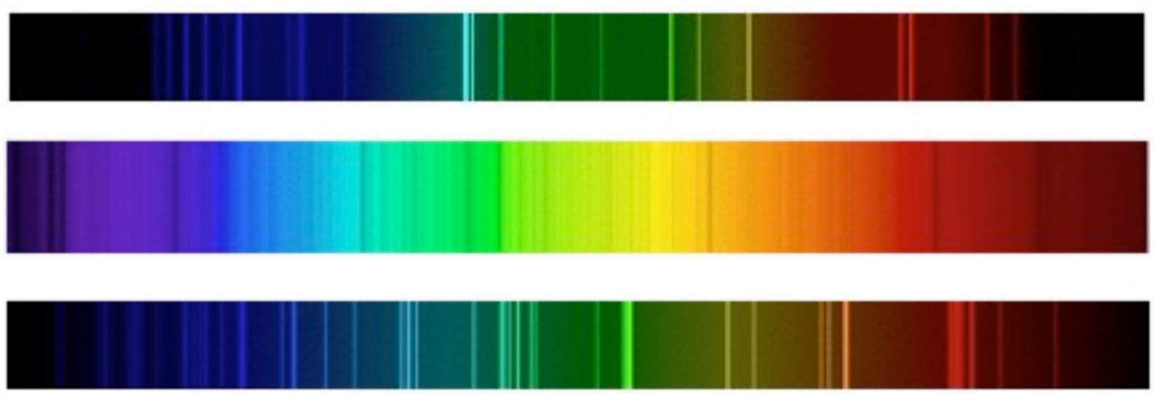
3. Even though Mars has more Carbon Dioxide than Earth, it has a much colder average surface temperature of about -70 ^{0}F. Clearly, Mars has more Carbon Dioxide than Earth, but much less than Venus. Why do you think Mars' temperature is so much lower than Earth's? What factors can affect a planet's temperature? Brainstorm with a peer. *Ans: There are many factors that can affect a planet's temperature. Clearly, the amount of greenhouse gas is an important factor because Venus is so much warmer than Earth… but the distance from the Sun is also very important. Venus not only has more greenhouse gas, but it is also closer to the Sun than Earth. Mars has some more carbon dioxide, but is farther from the Sun than Earth. Mars also has much less atmosphere, and no water, which is also a greenhouse gas. Earth has water, so that contributes to Earth's greenhouse gasses. Since Earth is closer to the Sun and has other greenhouse gasses aside from carbon dioxide, it is warmer than Mars. Accept a variety of answers. Further research can be done on greenhouse gasses on the three planets and planetary temperature.*

Graphing the Rainbow Student Worksheet

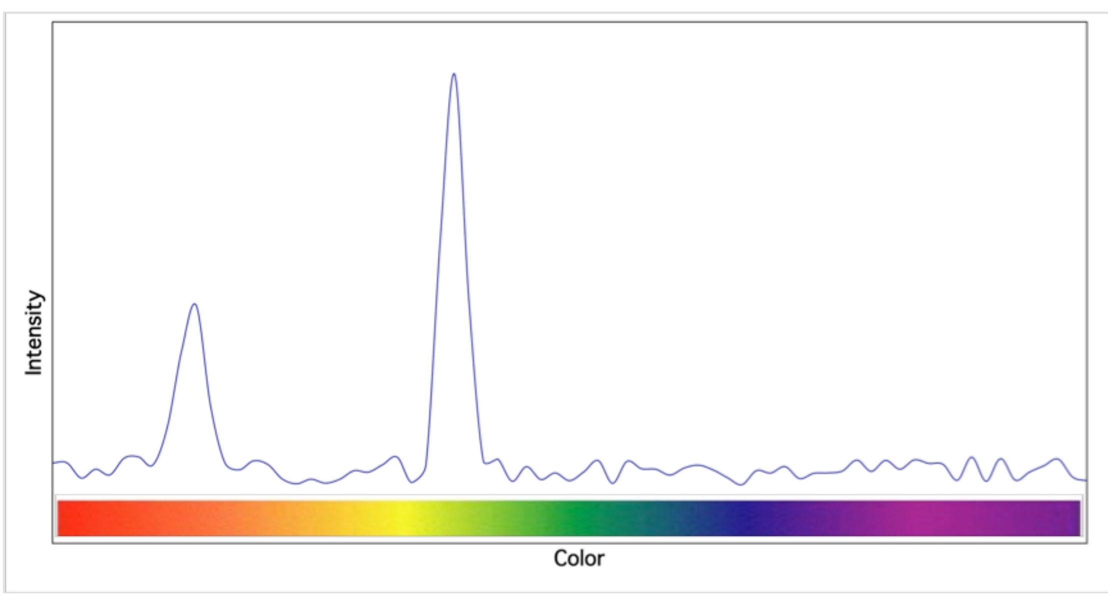
When light from any source—a light bulb, a computer monitor, a planet—passes through a prism or a diffraction grating, it produces a unique rainbow pattern.



The pattern may be mostly bright with a few dark stripes, or dark with a few bright stripes, or some combination.



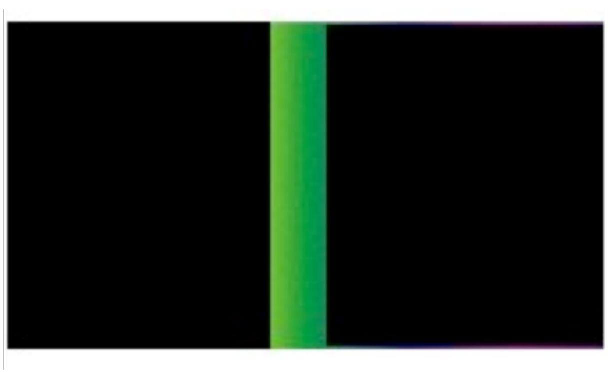
The intensity of each color of light can be plotted on a line graph like the one below.

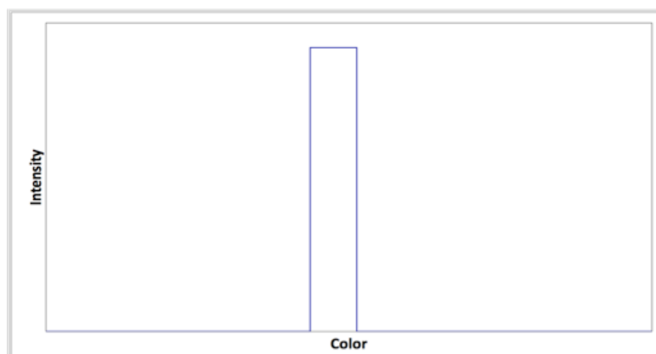


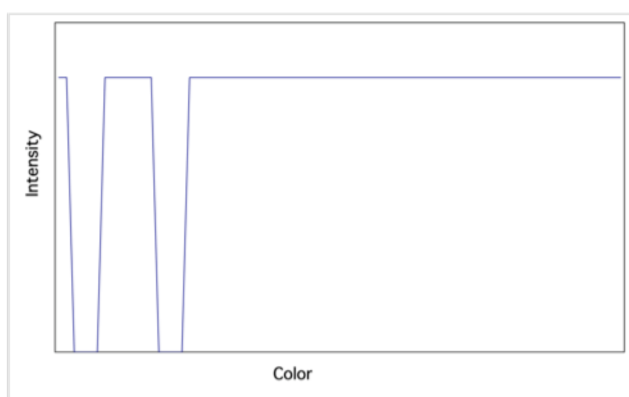
Project SPECTRA!

Graphing the Rainbow

Look at the following examples. Each of the spectra on the left can also be displayed as a line plot, as shown on the right. Bright colors have high intensity, as shown along the y-axis. The first spectrum is called a continuous spectrum. In a continuous spectrum, every color has the same intensity.

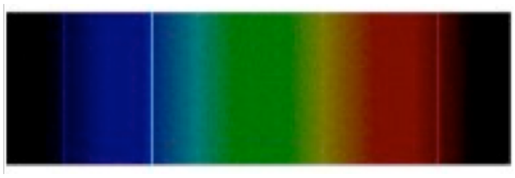


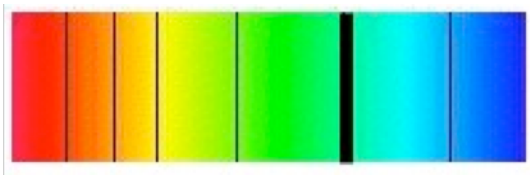


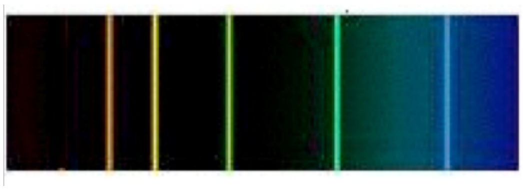


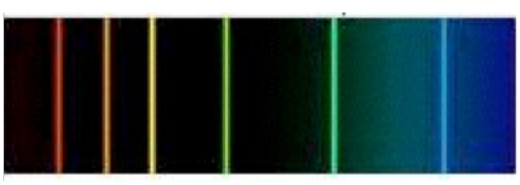
Now, try matching each of the spectra from column A with its corresponding line plot from column B.

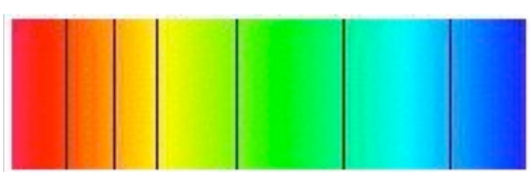
A



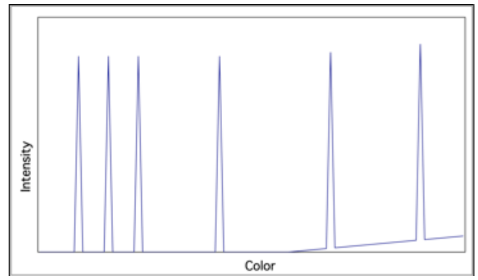


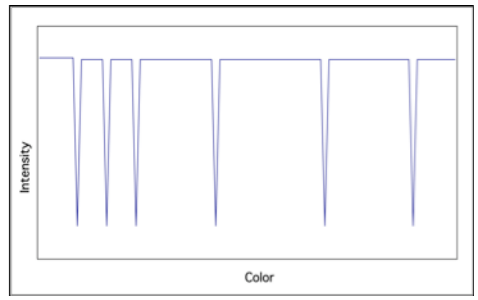


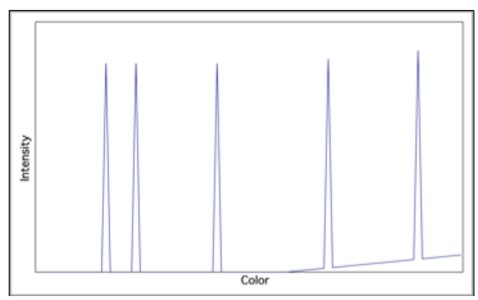


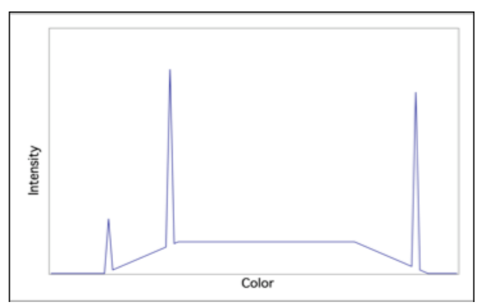


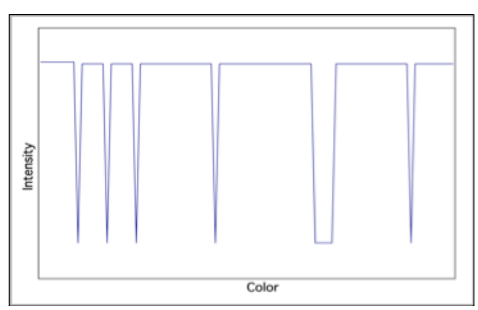
B











Project SPECTRA!

Graphing the Rainbow

Middle School Grades

Lesson Summary

This lesson introduces students to different ways of displaying visual spectra, including colored "barcode" spectra, like those produced by a diffraction grating, and line plots displaying intensity versus color, or wavelength. Students learn that a diffraction grating acts like a prism, bending light into its component colors.

Prior Knowledge & Skills

- Ability to recognize and describe patterns
- Experience interpreting data
- Visible light represents only a small portion of all light
- General understanding of energy

AAAS Science Benchmarks

The Nature of Mathematics

Patterns and Relationships

The Physical Setting

Motion

NSES Science Standards

- **Physical Science:** Transfer of Energy

NCTM Mathematics Standards

- **Geometry:** Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships
- **Algebra:** Understand patterns, relations, and functions

Colorado State Standards

- Mathematics Standards 2.1, 3.1, 3.4
- Science Standard 4

Suggested background reading

Light

Suggestion for modification

Inclusion of lessons on light and the electromagnetic spectrum will make this activity suitable for high school students.

Teaching Time: One 30-minute period

Materials

Each student needs:

- Copy of worksheet

Advanced Planning

Preparation Time: 10 minutes

1. Make one copy of student worksheet before activity.

Why Do We Care?

When passed through a prism or diffraction grating, light is broken up into its component colors. The resulting spectrum will have a characteristic pattern of light and dark that, when analyzed, reveals the composition of the light source. In this activity, students learn how a visual spectrum corresponds to a line plot, which is the way astronomers view spectra to help them determine what astronomical objects are composed of.

Graphing the Rainbow

Group Size 1

Expendable Cost per Group $0

Engineering Connection

Understanding graphs and plots is crucial to engineering, as engineering in astronomy is driven by the need to obtain scientific data. Engineering methods are constantly improved and new types of engineering are created based upon the types of data needed to advance science.

Learning Objectives

After this lesson, students should be able to:

- Explain that light from different sources, when passed through a prism or diffraction grating, can be separated into component colors
- Explain the basic tools engineers use to view spectra
- Explain that those component colors appear in a unique pattern of bright and dark lines
- State two ways to display a spectrum
- Match a "barcode" spectrum with its corresponding line plot

Introduction / Motivation

Do you know how a rainbow is formed? It is created by light, and that light comes from the Sun. When the light passes through water droplets in the clouds, we can see the colors that light from the Sun makes that we cannot normally see with our eyes. All light makes a pattern, and today we will be exploring the patterns that are hidden in light that we cannot normally see unless we have special tools to see them. Any light source, whether it is a light bulb, a computer monitor, a star, or a planet-- when passed through a prism or a diffraction grating-- will display a unique pattern of bright and dark stripes called spectra (the plural of "spectrum").

Prisms and diffraction gratings are tools we can use to see these patterns. Instrumentation developed by engineers can measure exactly how bright each color is, since this is a difficult thing to do with just our eyes. The instrumentation can assign a number value to the brightness that can be plotted on a graph where position on the x-axis (horizontal axis) represents color and the y-axis (vertical axis) represents brightness, or intensity.

Engineers develop instrumentation based upon the properties of light. Engineers create instrumentation to see spectral patterns of light and study the patterns to improve and develop new instrumentation. They usually use diffraction gratings. They also study the processes and the types of light that create specific spectral patterns. Engineers studying space science are interested in helping answer questions about the composition of planetary atmospheres, planetary moons, stars, and gasses within the solar system and universe.

Graphing the Rainbow

Vocabulary / Definitions

Word	Definition
Spectrum (plural: spectra)	The pattern light produces when passed through a prism or diffraction grating, as seen through a spectrograph
Spectrograph	A device that allows one to see a spectrum, which usually has a prism or diffraction grating inside
Diffraction	When light bends around an obstacle or through a small opening like those in a diffraction grating
Diffraction Grating	Usually a piece of film covered with very thin, parallel grooves
Continuous Spectrum	The rainbow that white light is composed in which each color is equally bright
Emission Spectrum	Bright lines that appear through the spectrograph against a dark background
Absorption Spectrum	Dark lines that appear against the continuous spectrum seen through a spectrograph
Light Source	Any object that produces light

Procedure

Background

Students should be familiar with line graphing methods and understand that graphs can be used to represent physical data. Students should have some understanding of the nature of light, i.e. rainbows are formed with light, light can be different colors, etc.

White light, like that produced by an incandescent light bulb (with electricity passing through it) is composed of all of the colors of light in the rainbow combined. It simply looks white with our eyes. A diffraction grating (or a prism) acts to break the light into its component colors. Certain colors "bend" more than others through the grating or prism, which is why the colors line up, like a rainbow.

Light passing through a cool gas will produce what is called an absorption pattern when seen through a diffraction grating or a prism, and dark lines will appear in the continuous spectrum. The dark lines are actually created by the gas absorbing the energy of the light. We can identify the gas based on the distinctive pattern of lines that appear in the spectrum. Conversely, an emission spectrum is seen as bright lines against a dark background, and is produced a hot gas emitting photons. Again, the pattern the gas creates is dependent on the type of gas. A particular hot gas shows emission lines in the exact same places that the same cool gas shows absorption lines. The pattern does not change, but whether you see an absorption or emission pattern through the grating does change depending whether the gas is hot or cool. The resulting spectrum will have a characteristic pattern of light and dark that, when analyzed, reveals the composition of the light source.

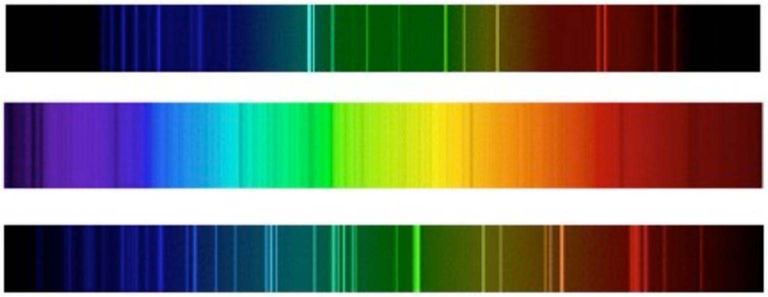


Figure 1
Emission and Absorption spectra
Source/Rights: LASP

With the Students

1. Hand out student worksheet.
2. Using the student worksheet as a guide, demonstrate how a visible light pattern can be graphically represented in different ways. An overhead projection of the second student worksheet page may be beneficial to have on hand.
3. Walk around the room to talk to individual students about the graphs from the student worksheet.
4. Ask students questions about what they see in the plots and why the pictures correspond to a specific graph on the student worksheet.

Troubleshooting Tips

Colorblind and vision-impaired children will have difficulty with this activity. Students with corrective lenses will not have difficulty. Colorblind and blind students can be paired with a student to assist them.

Assessment

Pre-Lesson Assessment

Class discussion: Ask students what they can tell you about light. Probe them for what they already know and understand.

Activity Embedded Assessment

Class Discussion: Ask students why they think the light forms rainbows or patterns when passed through a prism or diffraction grating. Note to teachers: the bending of light through a prism does not have to do with varying speeds of the colors! All colors travel at the same speed.

Worksheet: Have the students complete the activity worksheet; review their answers to gauge their mastery of the subject.

Post-Activity Assessment

Think-Pair-Share activity: Ask students to discuss with a peer about what steps an engineer takes before designing an instrument that studies light. Randomly select groups to share. Discuss ideas as a class.

Graphing: Graphing and plotting are tools all engineers use. Plotting and graphing real world situations allows engineers to analyze whether a tool is working, how to design an effective tool, and can be used to create software to look at data (just like the data in this activity). Ask students to graphically represent a real-world situation, such as driving at a certain speed, at some point coming immediately to a complete stop, and then resuming that same speed. Another example could be a plot representing descending from the top of a flight of stairs to arrive at some distance at the bottom, which could be a distance vs. time plot. Perhaps, have the students represent what it would look like if they stopped on a stair for a very long time. This will establish whether they understand how graphing spectra is a representation of a real situation that occurs with light (as opposed to motion, distance, or some other variable). It will also establish whether the students can apply what they have learned in a different context from this activity. Ask students to come up with their own "real world" graphs, and ask volunteers to explain their graphs to the class.

Activity Extensions

Continue the spectroscopy unit by completing the associated activity, "Using Spectral Data to Explore Saturn and Titan" activity.

References

Fisher, Diane. "Taking Apart the Light." "The Technology Teacher." March (2002).

Owner

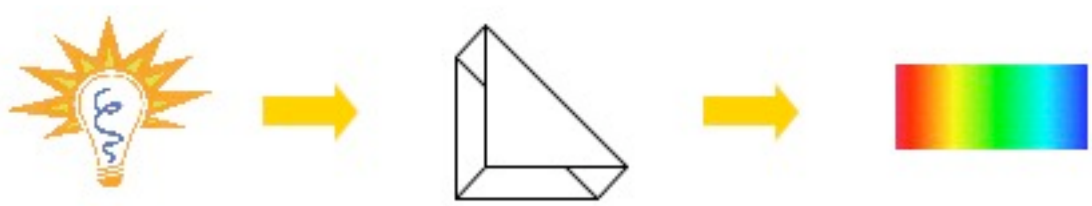
Integrated Teaching and Learning Program and Laboratory, University of Colorado at Boulder

Contributors

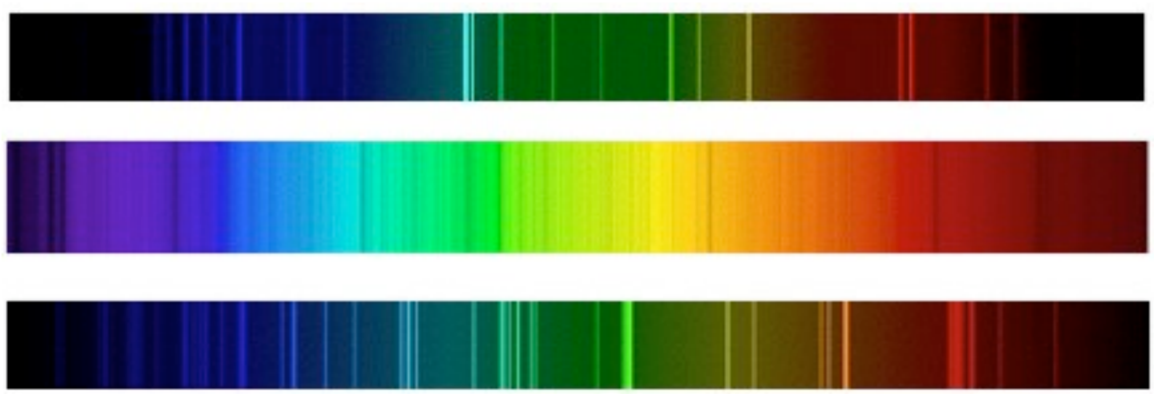
Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder

Graphing the Rainbow Student Worksheet

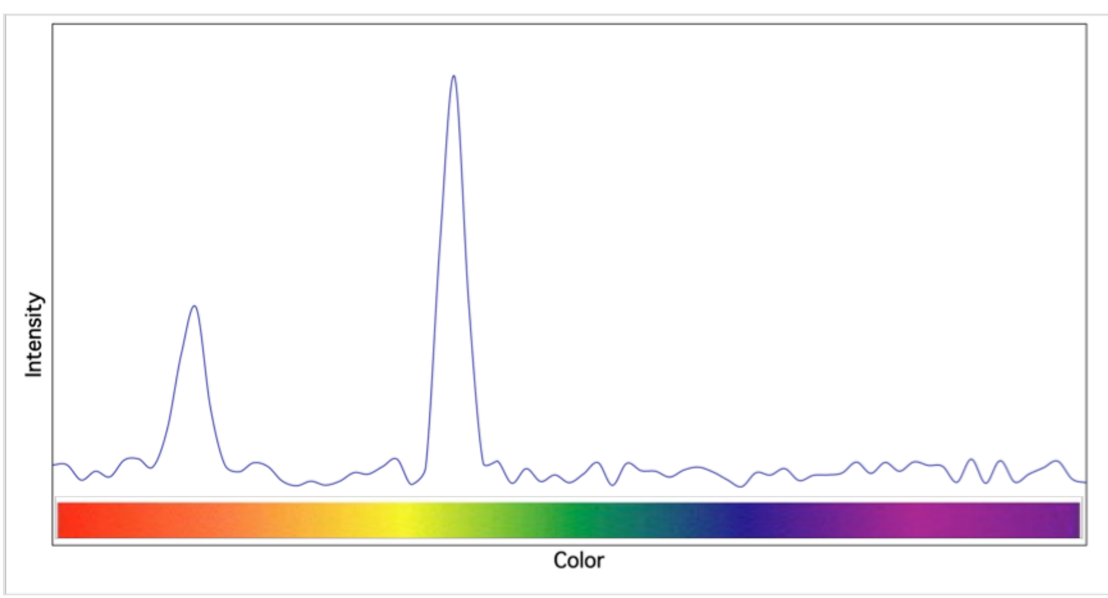
When light from any source—a light bulb, a computer monitor, a planet—passes through a prism or a diffraction grating, it produces a unique rainbow pattern.



The pattern may be mostly bright with a few dark stripes, or dark with a few bright stripes, or some combination.

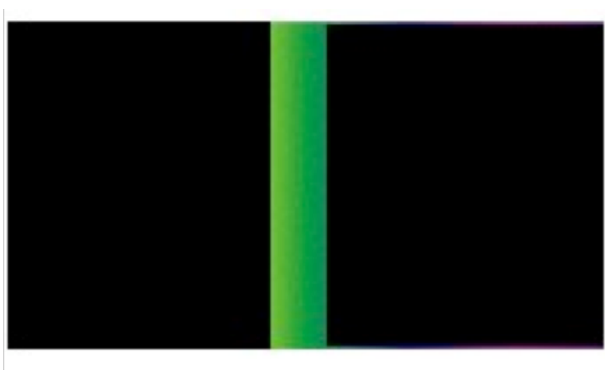


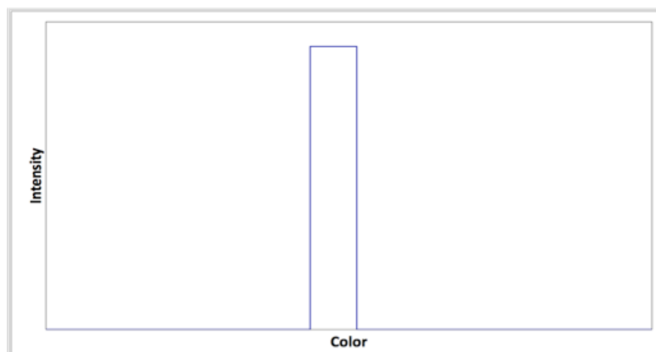
The intensity of each color of light can be plotted on a line graph like the one below.

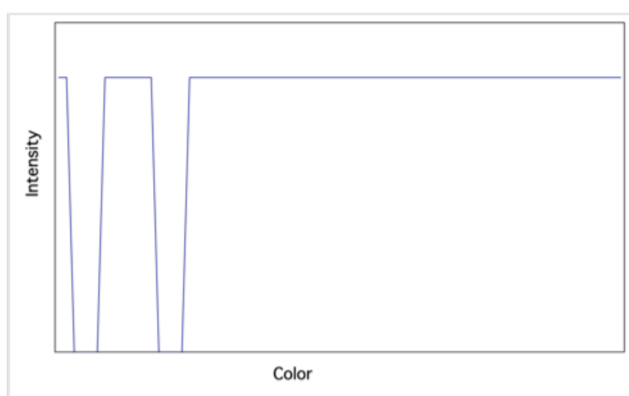


Graphing the Rainbow

Look at the following examples. Each of the spectra on the left can also be displayed as a line plot, as shown on the right. Bright colors have high intensity, as shown along the y-axis. The first spectrum is called a continuous spectrum. In a continuous spectrum, every color has the same intensity.

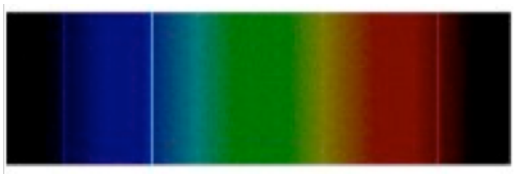


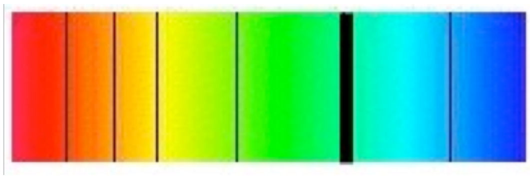


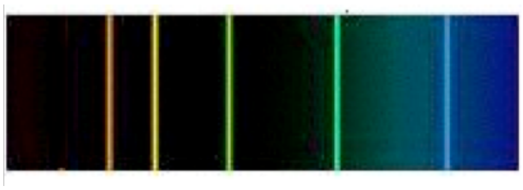


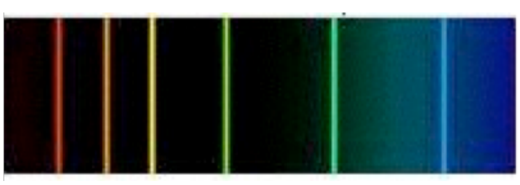
Now, try matching each of the spectra from column A with its corresponding line plot from column B.

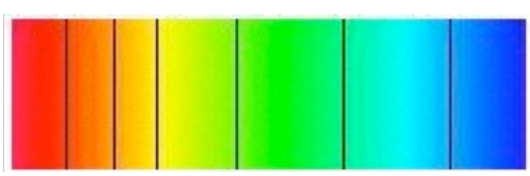
A



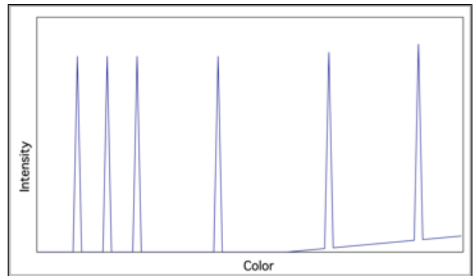


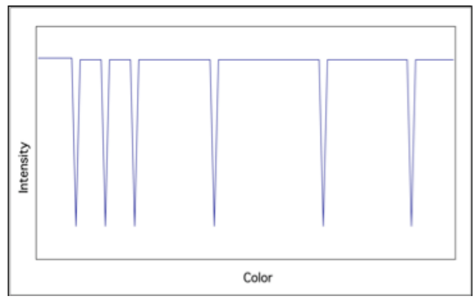


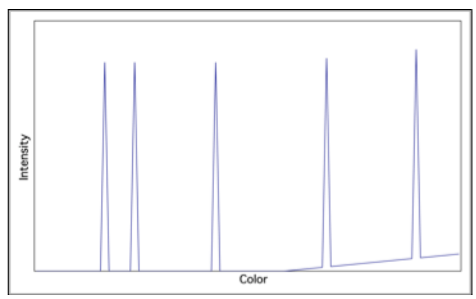


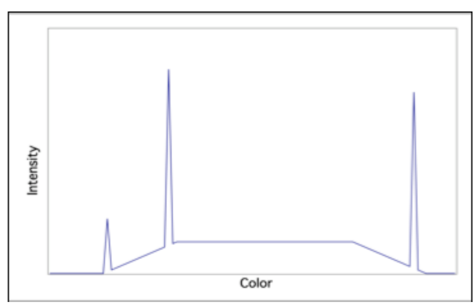


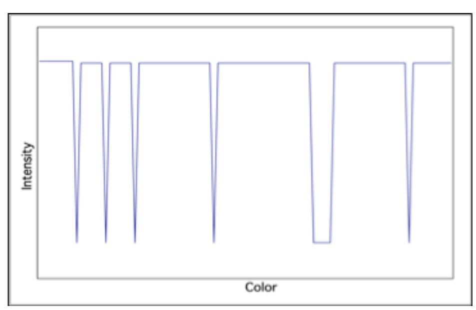
B





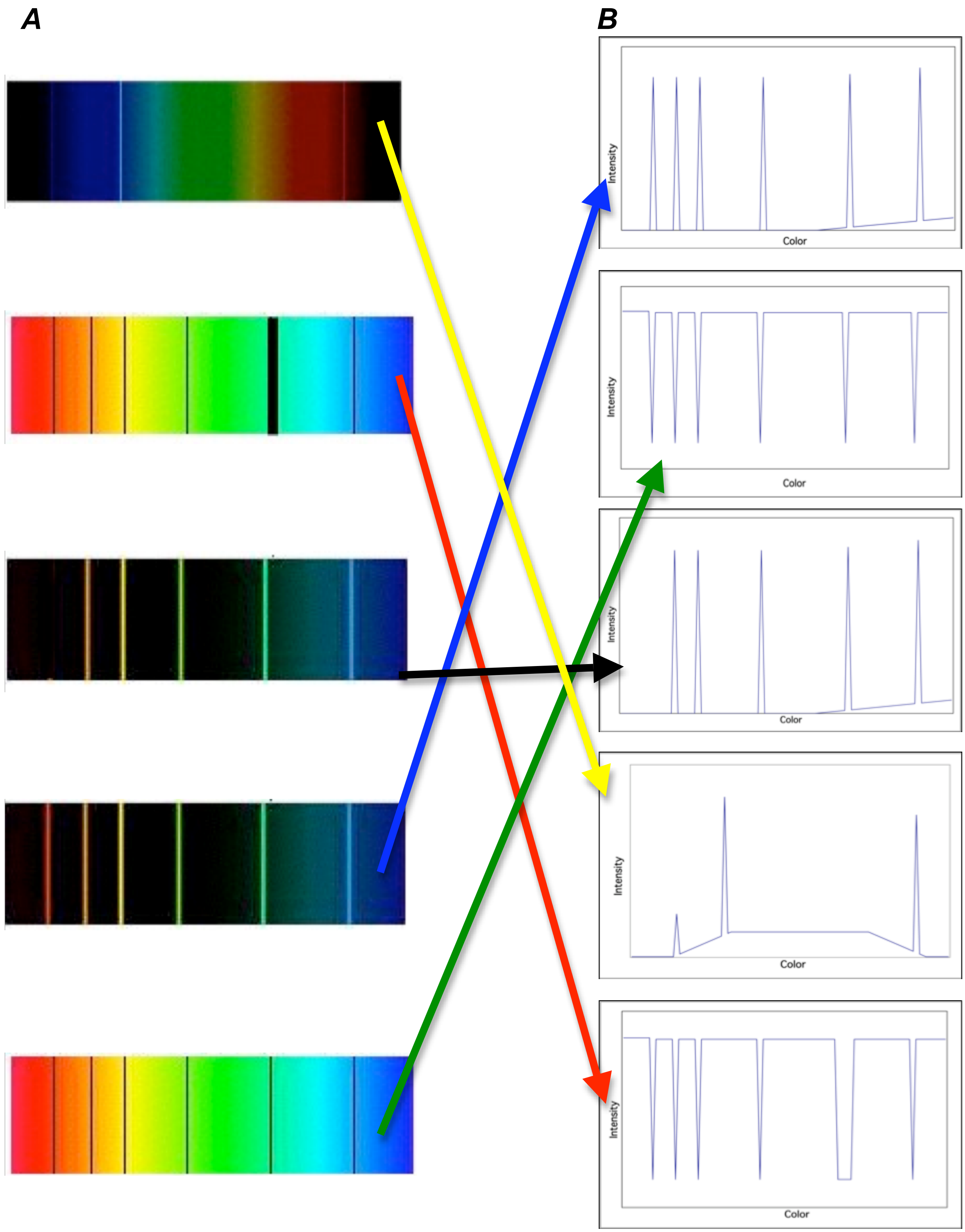






Teacher's Key: Graphing the Rainbow

Now, try matching each of the spectra from column A with its corresponding line plot from column B.



Lesson 6: Mars Match Game

This lesson is adapted from MarsQuest Online's "Earth or Mars?" produced by the Space Science Institute (http://www.marsquestonline.org/tour/welcome/earthormars/index.html).

Purpose: To deepen student understanding of Mars, Mars exploration and the similarities and differences between the Earth and Mars.

Standards

NCTE/IRA Standards for English Language Arts

Standard 5- Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.

National Science Education Standards

Science as Inquiry – Content Standard A

1. Abilities necessary to do scientific inquiry.
2. Understanding about scientific inquiry.

Physical Science – Content Standard B

Properties of objects and materials- objects have many observable properties such as size, and color.

Earth and Space Science– Content Standard D

Properties of Earth materials- Earth materials are solid rocks and soils, water, and the gases of the atmosphere.

Principles and Standards for School Mathematics

Measurement

1. Understand measurable attributes of objects and the units, systems, and processes of measurement.
2. Apply appropriate techniques and tools to determine measurements.

Connections

Recognize and apply mathematics in contexts outside of mathematics.

Overview

Of all the planets in the Solar System, Mars is the most like Earth. Though it currently has no liquid water flowing on the surface, there is evidence that suggests Mars was once warmer and wetter like the Earth. Geologic features revealed by orbiting robotic spacecraft, and secrets uncovered in Martian rocks by robotic rovers on the ground show that long ago Mars and Earth could have looked very much alike.

In this activity, students will compare physical properties of Earth to those of Mars. Students will also become planetary scientists as they investigate images of features on Mars and try to find similar features in images of the Earth.

Understandings

1. Our knowledge and understanding of our Earth and Solar System changes and/or expands as new discoveries are made.
2. Robots gather different information (data) depending on their design and use.
3. Combining the information (data) gathered by a variety of robots gives us a broader and more in-depth understanding of our Earth and Solar System.

Materials

1. Earth vs Mars slide show*
2. Earth/Mars game cards (included)
3. Earth/Mars comparison worksheet (included)
4. Mars Match Game Answer Key, Script (included)

*Slide show can be downloaded from the MarsBots Material section of the Phoenix Mission Website in both Microsoft PowerPoint (PPT) or Adobe Acrobat (PDF) format (http://phoenix.lpl.arizona.edu). ***note: we will make the specific address available as we make final preparations on the learning module.

Time

Ten to 30 minutes for PowerPoint depending on length of class discussion
Thirty to 45 minutes for activity and discussion

Directions

1. Show students the Earth vs. Mars slide show discussing the various differences between Earth and Mars. *Use the script provided in the notes section of the PowerPoint to assist you with the*

discussion.(Select "notes page" print option to print a copy of the PowerPoint presentation notes)

2. After discussing differences, hand out the Earth/Mars comparison images. *Each image from Mars has a matching image of Earth. Students are to look at each image from Mars and identify the Earth image that most resembles the image from Mars. Have students work in pairs for this activity.*

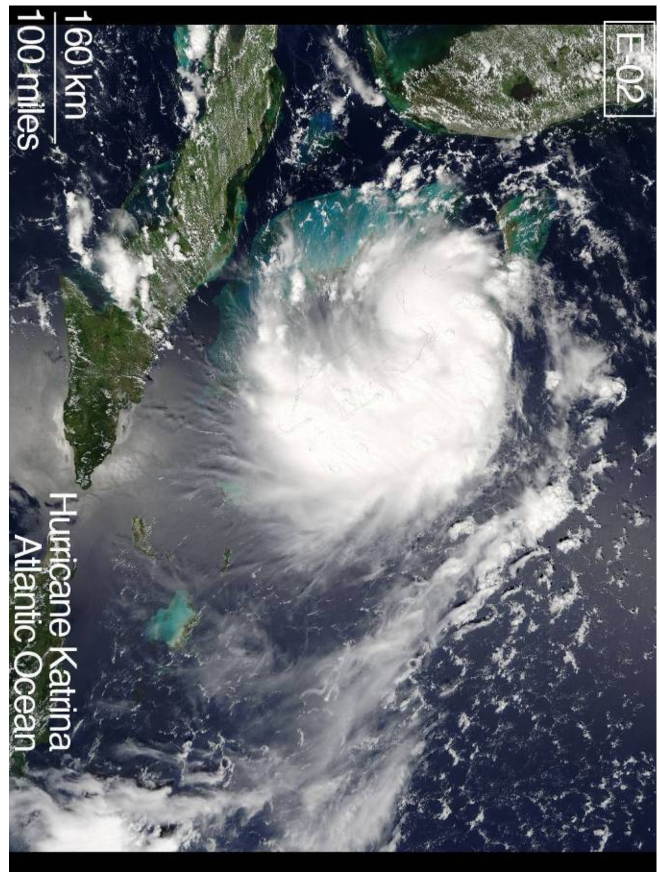
3. Hand out the Earth/Mars Comparison worksheets to help guide students as they make their choices.

4. Talk about how scientists compare features found on the Earth, known to be formed by liquid water, with features on Mars. *While some features seen on Mars could be explained by other processes (e.g. lava flows) others were almost certainly formed by water a long time ago. See the Mars section of the background information at the front of the MarsBots learning module*.

5. Discuss how robotic spacecraft have given us these images of Mars that allow us to see these similarities and differences.

Earth/Mars Comparison game cards

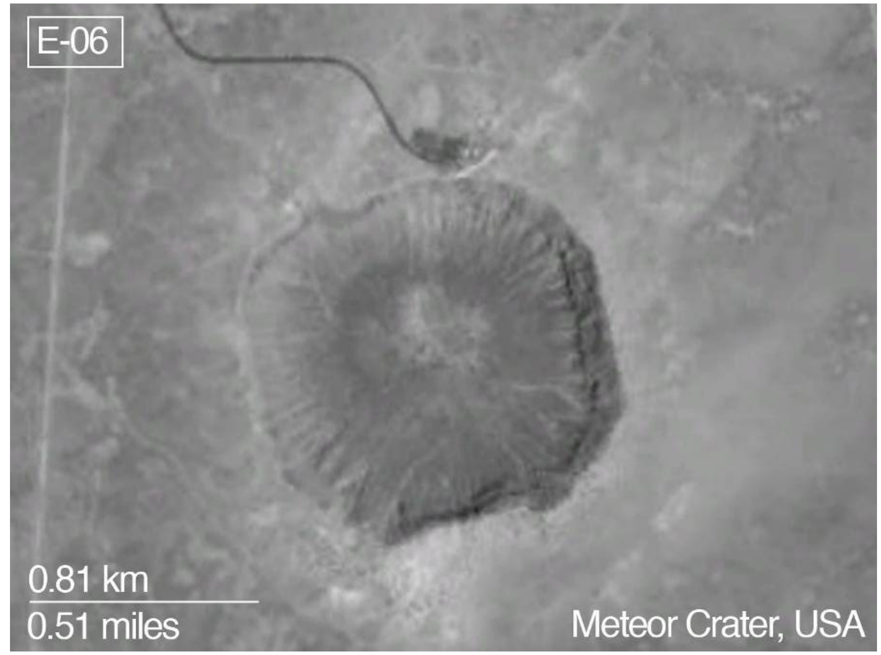
Print pages 37-48 double sided.

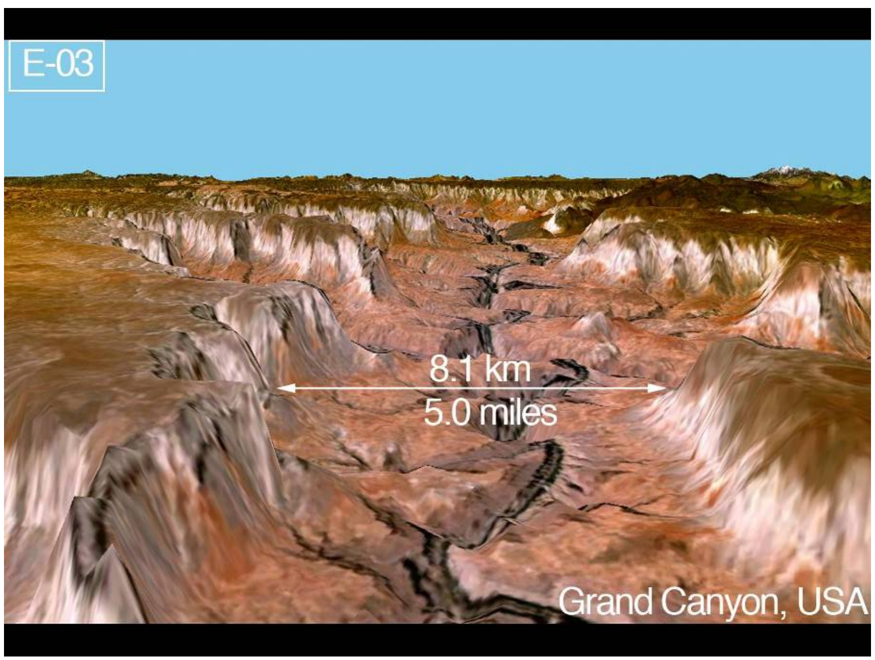


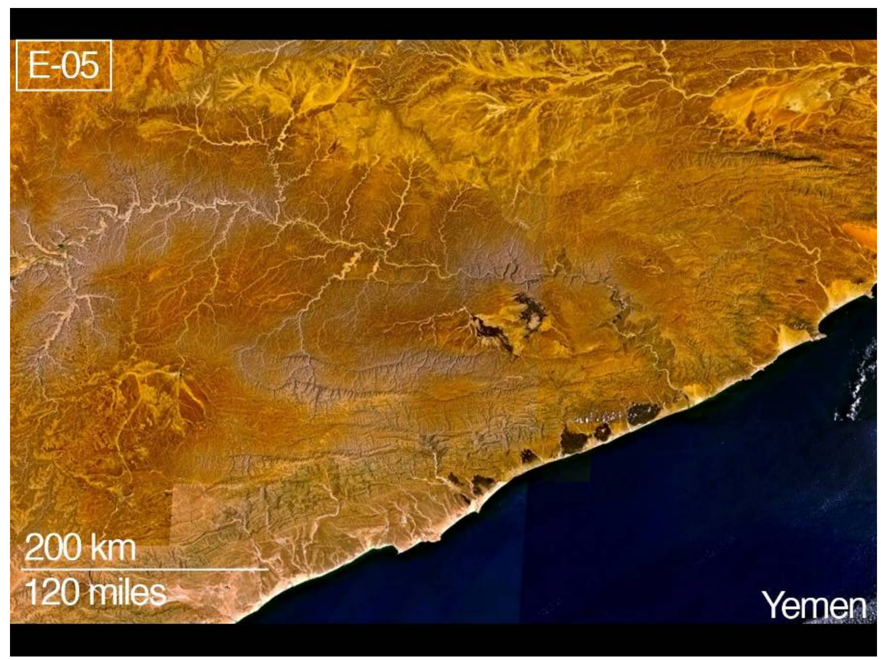
Rivers can change the direction they flow.

Cyclones are large storms on Earth.


E-04
0.27 km
0.17 miles
Amazon River, Brazil


E-06
0.81 km
0.51 miles
Meteor Crater, USA


E-03
8.1 km
5.0 miles
Grand Canyon, USA

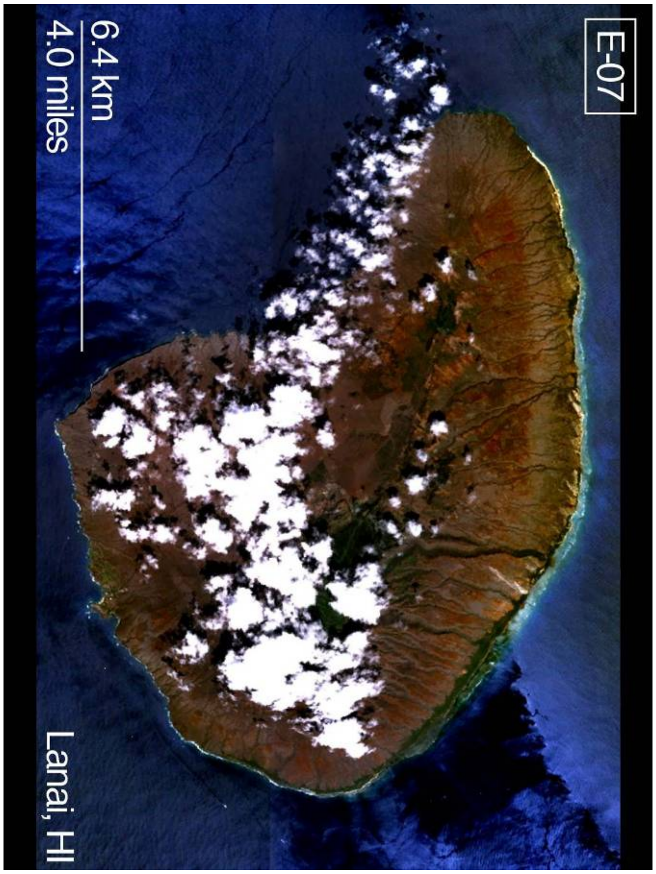

E-05
200 km
120 miles
Yemen

The Grand Canyon can be up to 18 miles across and 1 mile deep.

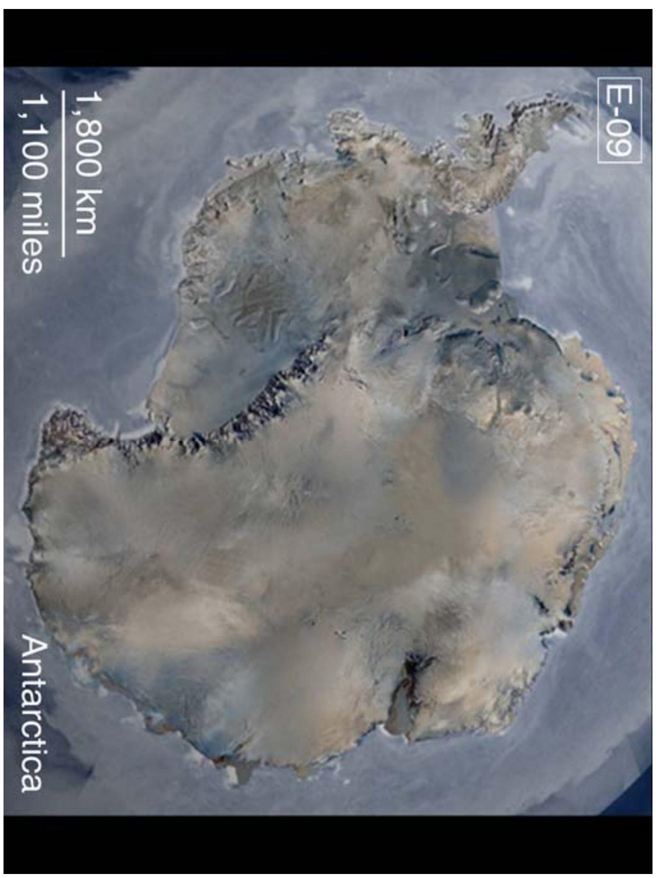
Small streams come together to make one big river.

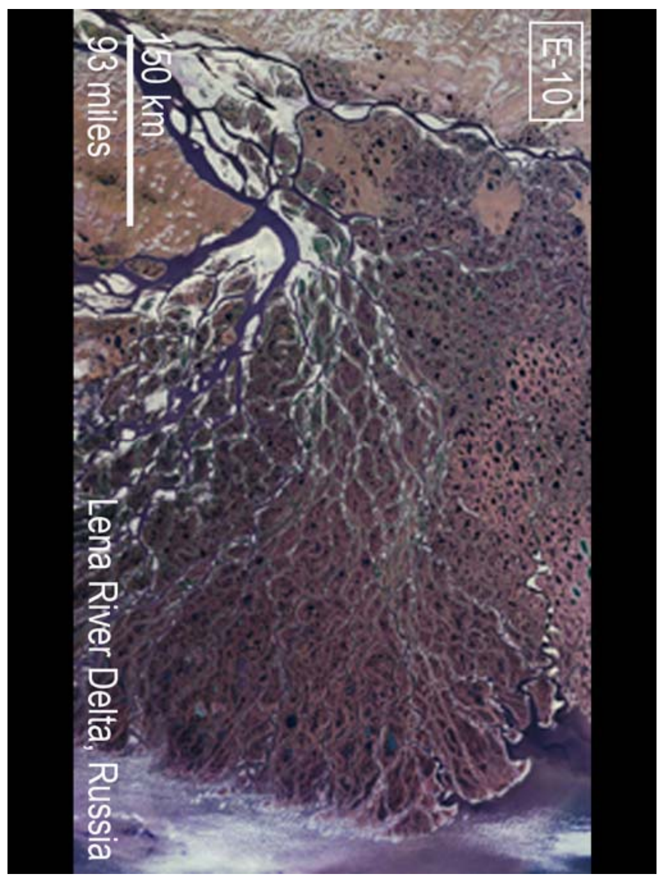
The island in this river did not erode as much as the land around it.

This crater is almost 1 mile across.


E-07
6.4 km
4.0 miles
Lanai, HI


E-08
99 km
62 miles
Grand Canyon, USA


E-09
1,800 km
1,100 miles
Antarctica


E-10
150 km
93 miles
Lena River Delta, Russia

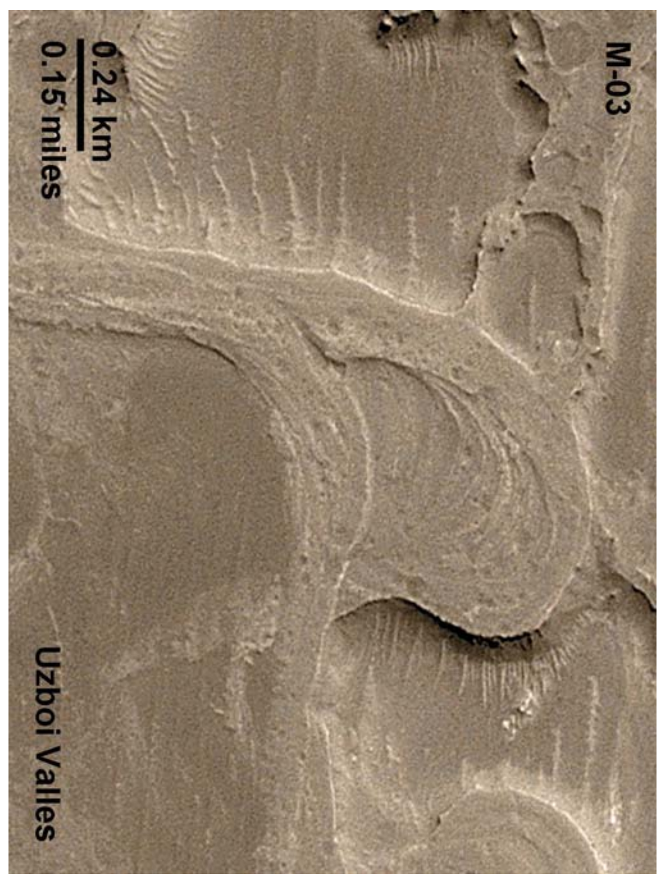
The island of Lanai (Hawaii) is a shield volcano.

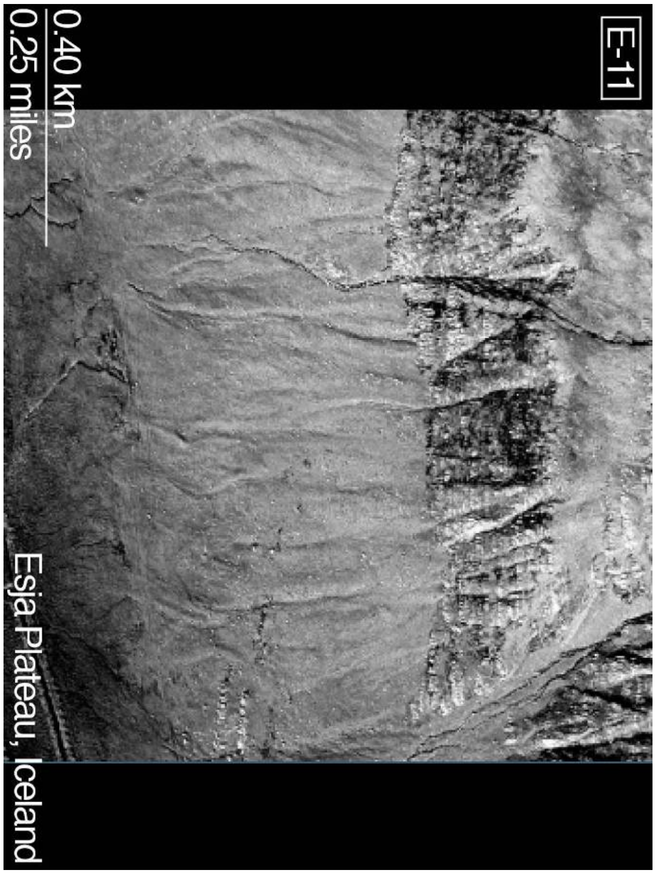
Both the north and south polar caps of Earth are made of frozen water. Most of Earth's fresh water is locked in the southern cap.

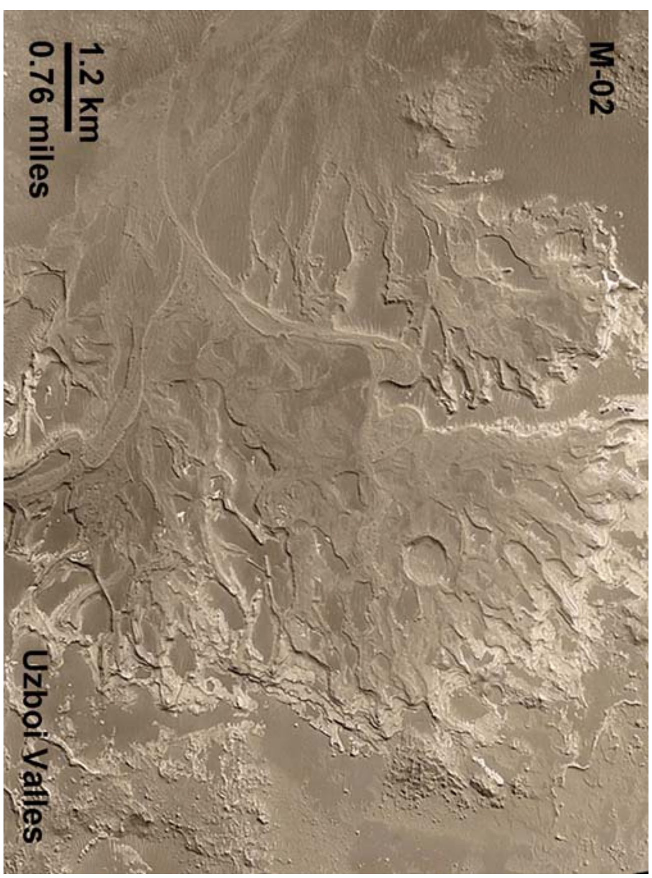
The Grand Canyon is 280 miles long.

Rivers end in lakes or oceans and form deltas.

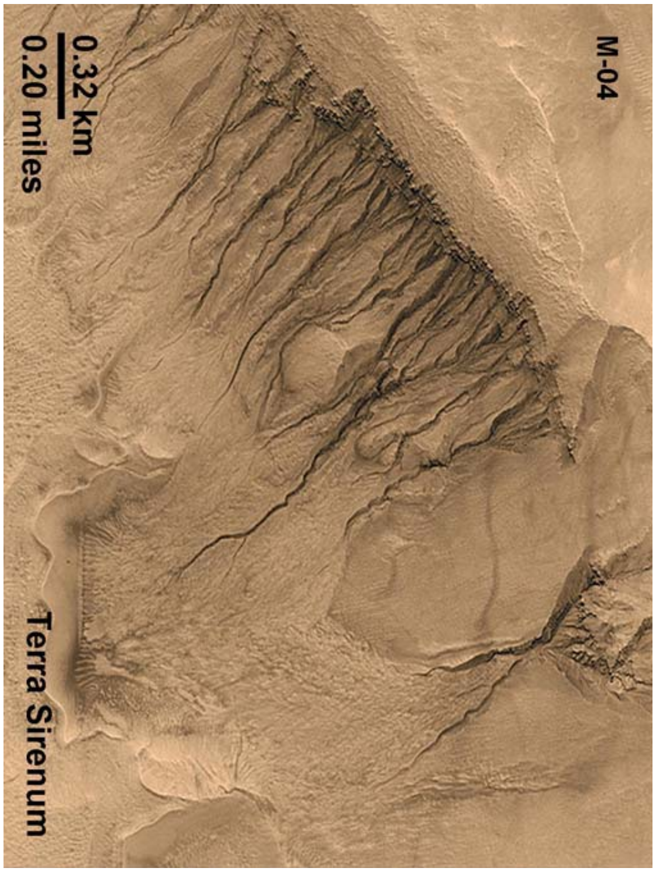

M-01
10 km
6.2 miles
Southern Highlands

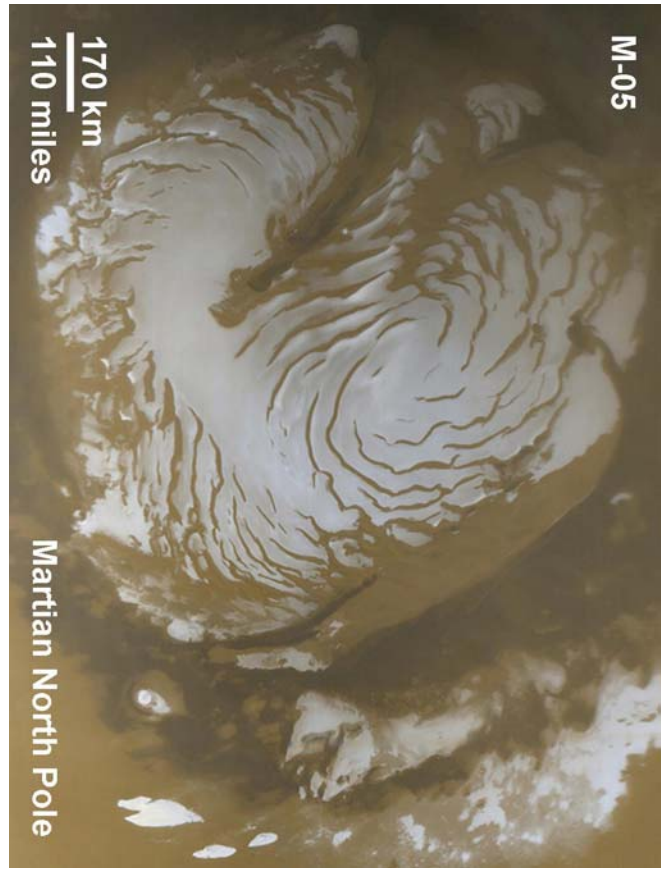

M-03
0.24 km
0.15 miles
Uzboi Valles

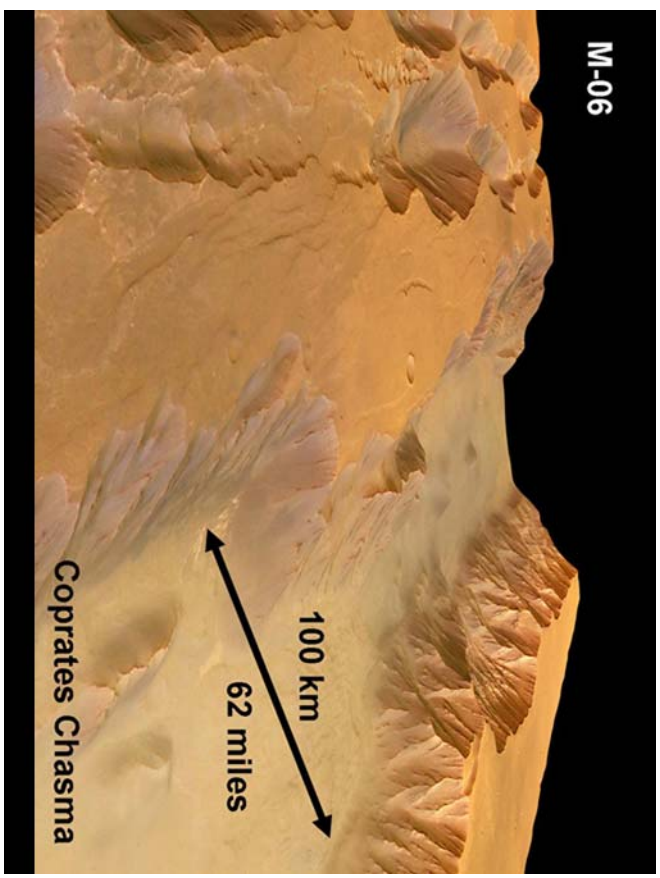

E-11
0.40 km
0.25 miles
Esja Plateau, Iceland

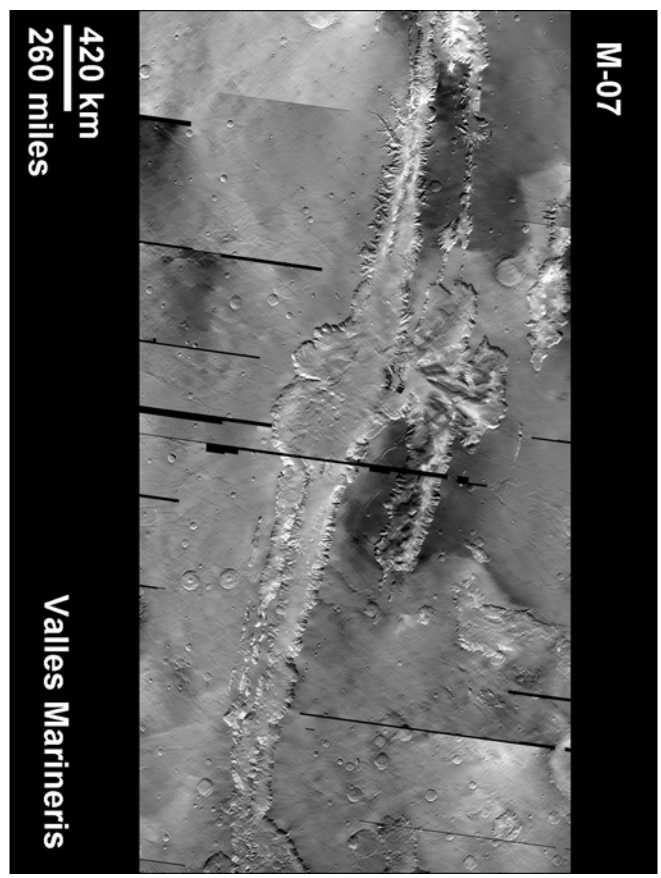

M-02
1.2 km
0.76 miles
Uzboi Valles

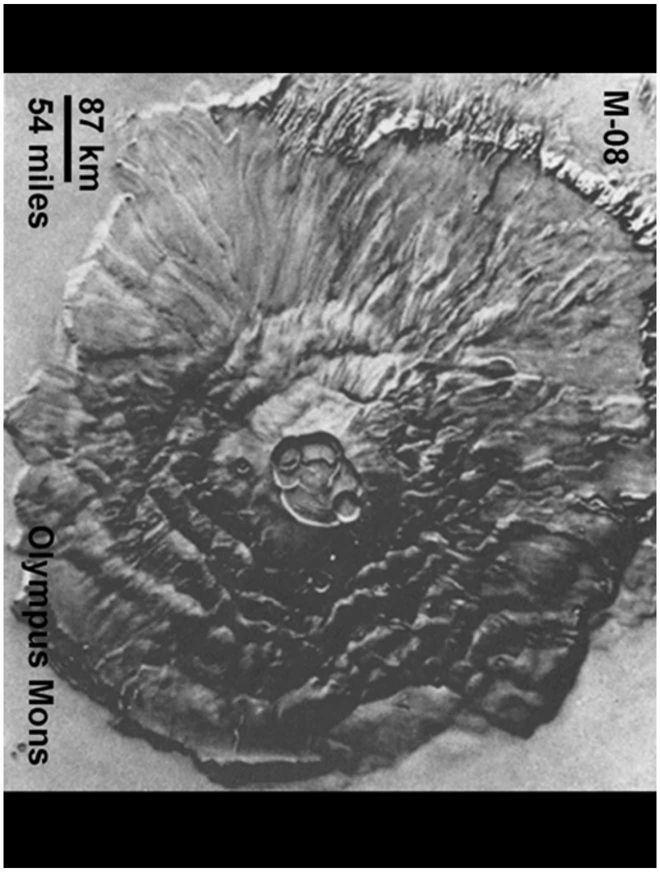
Gullies form on the slopes of hills where there is liquid water.

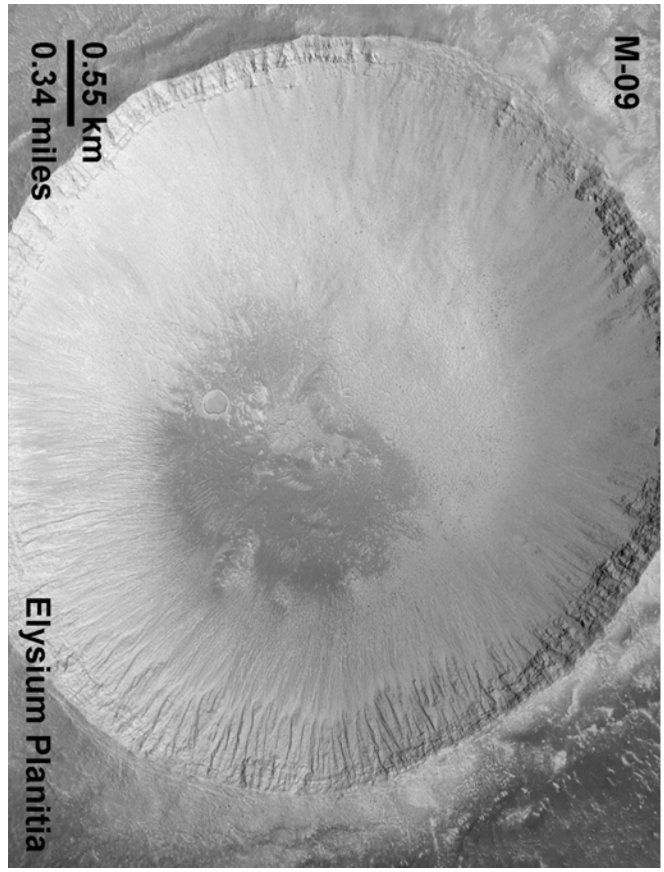

M-04
0.32 km
0.20 miles
Terra Sirenum

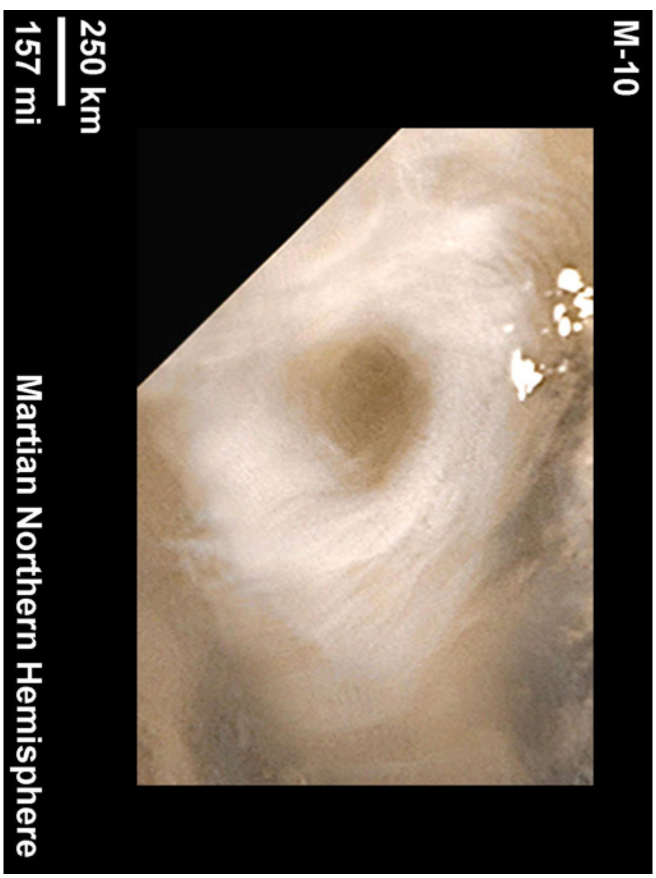

M-05
170 km
110 miles
Martian North Pole

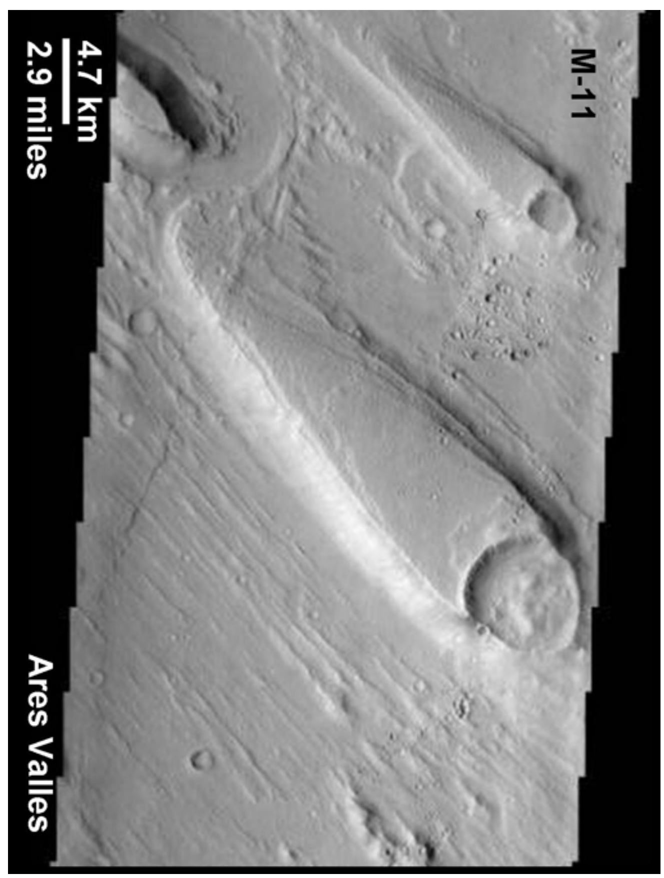

M-06
100 km
62 miles
Coprates Chasma


M-07
420 km
260 miles
Valles Marineris


M-08
87 km
54 miles
Olympus Mons


M-09
0.55 km
0.34 miles
Elysium Planitia


M-10
250 km
157 mi
Martian Northern Hemisphere


M-11
4.7 km
2.9 miles
Ares Valles

Earth/Mars Comparison Worksheet

Use this worksheet to record your observations of the Earth and Mars images. Identify which Mars and Earth images you are comparing by writing the letter of the image on the appropriate line. Next, describe in words both the Earth and Mars image. Using your descriptions of each image, explain why you think the Mars image is a good comparison to the Earth image.

Mars Image ____

Description:

Earth Image ____

Description:

Why these images match:

Mars Image ____

Description:

Earth Image ____

Description:

Why these images match:

Mars Image ____

Description:

Earth Image ____

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Why these images match:

Mars Image ____

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Why these images match:

Mars Image ____

Earth Image ____

Description:

Description:

Why these images match:

Mars Image ____

Earth Image ____

Description:

Description:

Why these images match:

Mars Match Game Answer Key, Script

M-01, E-05 - Tributaries

This feature seen on Mars resembles a series of **tributaries** – small streams or rivers that combine to form larger streams and/or rivers. On Earth, smaller rivers or streams combine into larger and larger rivers. Eventually all these rivers become one single river and empty into a larger body of water such as a lake or an ocean.

M-02, E-10 – River Delta

This feature on Mars resembles a **river delta.** River deltas on Earth form where rivers empty into lakes or oceans. Deltas form as sand and other particles are dropped by the river into the lake or ocean. Over time, the sand and particles build up, eventually blocking the flow of the river. The river then re-directs its flow into the lake or ocean and the process starts over again. This image from Mars is considered strong evidence that liquid water once flowed on the surface of Mars for extended periods of time.

M-03, E-01 – Meandering River

This feature on Mars can be seen in Mars image 03. It is a close-up focusing on what looks like a **meandering river** that changed its direction of flow. The feature can be seen just to the left of center in Mars image 02. On the Earth, rivers redirect themselves over time as seen in the Earth image 01 of the Amazon River. The light blue is the current path of the river - the darker blue next to it shows the path the river took in the past. The same pattern can be seen in the Mars image 03 where the earlier path the water took is cut by the later path.

M-04, E-11 – Gullies

Gullies, like those in Mars image 04, are typically found in mid-latitude regions of Mars. They can be seen in the sides of hill and the walls of craters. Gullies seen on the Earth are typically formed by flowing water, although they may also be formed by landslides. One of the most debated topics in Mars science is whether or not gullies on Mars were formed by liquid water or landslides.

M-05, E-09 – Polar Ice Caps

Like the Earth, Mars has polar ice caps. Mars image 05 shows the northern polar ice cap with its distinct spiral shape. Like the Earth's ice caps, Mars' north and south ice cap are made of frozen water. However, during their respective winters, both the north and south ice cap are covered by a layer of carbon dioxide ice, or dry ice.

M-06, E-03 - Canyons

Mars image 06 shows a perspective of Coprates Chasma. Coprates Chasma is part of the Valles Marineris canyon system. Valles Marineris is as deep as 10 km (6 miles) and as wide as 600 km (372 miles)! In comparison, the Grand Canyon has an average depth of 1.6 km (1 mile) and a maximum width of 29 km (18 miles).

M-07, E-08 - Canyons

The Mars 07 image shows a view of Valles Marineris as seen from orbit around Mars. Valles Marineris stretches over 4000 km (~2500 miles) across the surface of Mars. If you were to put Valles Marineris on the Earth it would stretch across the entire United States! The Grand Canyon in comparison is just 446 km (277 miles) in length.

M-08, E-07 - Volcanoes

Mars has volcanoes like the Earth. Olympus Mons is a type of volcano called a shield volcano. The Hawaiian Islands and the Galapagos Islands are examples of shield volcanoes on the Earth. Most people think of volcanoes as steep, explosive mountains like Mt. St. Helens in Washington. Shield volcanoes, however, are broad, dome-shaped volcanoes that erupt rather quietly. Instead of erupting violently like an explosion, lava oozes out of vent located at and near the top of the volcano then flows down the slopes. Olympus Mons is the largest known volcano in the Solar System. The base of the volcano is as big as the state of Arizona and the top of the volcano is over 26 km (16 miles) high!

M-09, E-06 - Craters

Craters are formed when asteroids or comets slam into another body leaving a large hole in the ground. Craters can be seen scattered on Mars, particularly in the southern hemisphere, and on the Moon, Mercury, and the moons of the outer planets. There are craters on the Earth too, but not as many as we see on other planets like Mars. Why? *Ask the class why they think we don't see many craters on the Earth.* The Earth has been hit just as many times as the Moon, Mars, and Mercury. The difference is that Earth has weather that has eroded away many craters. Meteor crater in Arizona is the best preserved crater on Earth. This crater is small compared to craters on other bodies in the Solar System. It is only 1.2 km (0.75 miles) across. Gusev crater on Mars, for example, is 150 km (93 miles) wide.

M-10, E-02 – Storms

Cyclonic storms exist on both Earth and Mars. Examples of cyclonic storms on the Earth are hurricanes and tornadoes. Cyclonic storms on Mars are not hurricanes or tornadoes but very large dust storms which can engulf the entire planet.

M-11, E-04 – Streamlined Islands

The Mars 11 image shows an area where streamlined islands are believed to have been carved by a catastrophic flood. Water flowed from the upper right of the image to the lower left. These same types of features are seen on the Earth like in the Earth 04 image from the Amazon River.

Teaching Climate Using the Third National Assessment – Dr. Robert Taylor

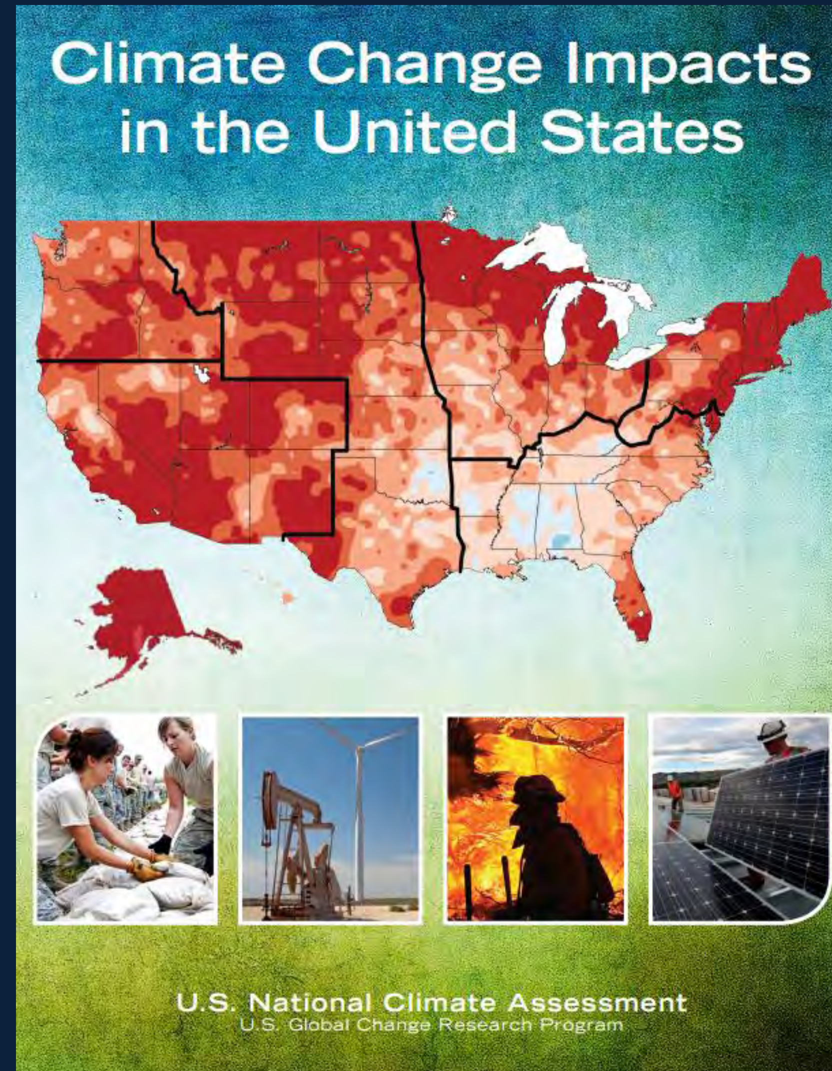
Climate Change Impacts:

Third National Climate Assessment
- and -
Related Resources

ROBERT TAYLOR

LAURA STEVENS

NOAA'S COOPERATIVE INSTITUTE FOR CLIMATE & SATELLITES



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Why does the NCA exist?

- The Global Change Research Act established the US Global Change Research Program to coordinate global change research across the federal government

United States
Global Change
Research Program

Global Change Research Act (1990) Mandate:

"To provide for development and coordination of a comprehensive and integrated United States research program which will assist the Nation and the world to **understand, assess, predict, and respond** to human-induced and natural processes of global change."

13 Federal Departments & Agencies +
Executive Office of the President

Why does the NCA exist?

- The National Climate Assessment is one of the requirements of the Global Change Research Act

GCRA (1990), Section 106:

… not less frequently than every 4 years, the Council… shall prepare… an assessment which –

- integrates, evaluates, and interprets the findings of the Program (USGCRP) and discusses the scientific uncertainties associated with such findings;
- analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and
- analyzes current trends in global change, both human- induced and natural, and projects major trends for the subsequent 25 to 100 years.

The NCA 2014

Inclusive
- 300 authors (academic, private, federal)
- 60 member Federal Advisory Committee
- 13 USGCRP agencies, plus a Technical Support Unit

Public engagement
- Listening sessions around the country
- Request for information, input reports

Future focus on sustained assessment
- Intermediate products planned as well as quadrennial reports

The NCA 2014, continued

New topics covered

Oceans, Coasts, Urban, Rural, Land use

Cross-sector links like Energy/Water/Land

New format (http://nca2014.globalchange.gov)

Digital products and interactive website

Highlights, GCIS, traceable accounts

Extensive Review

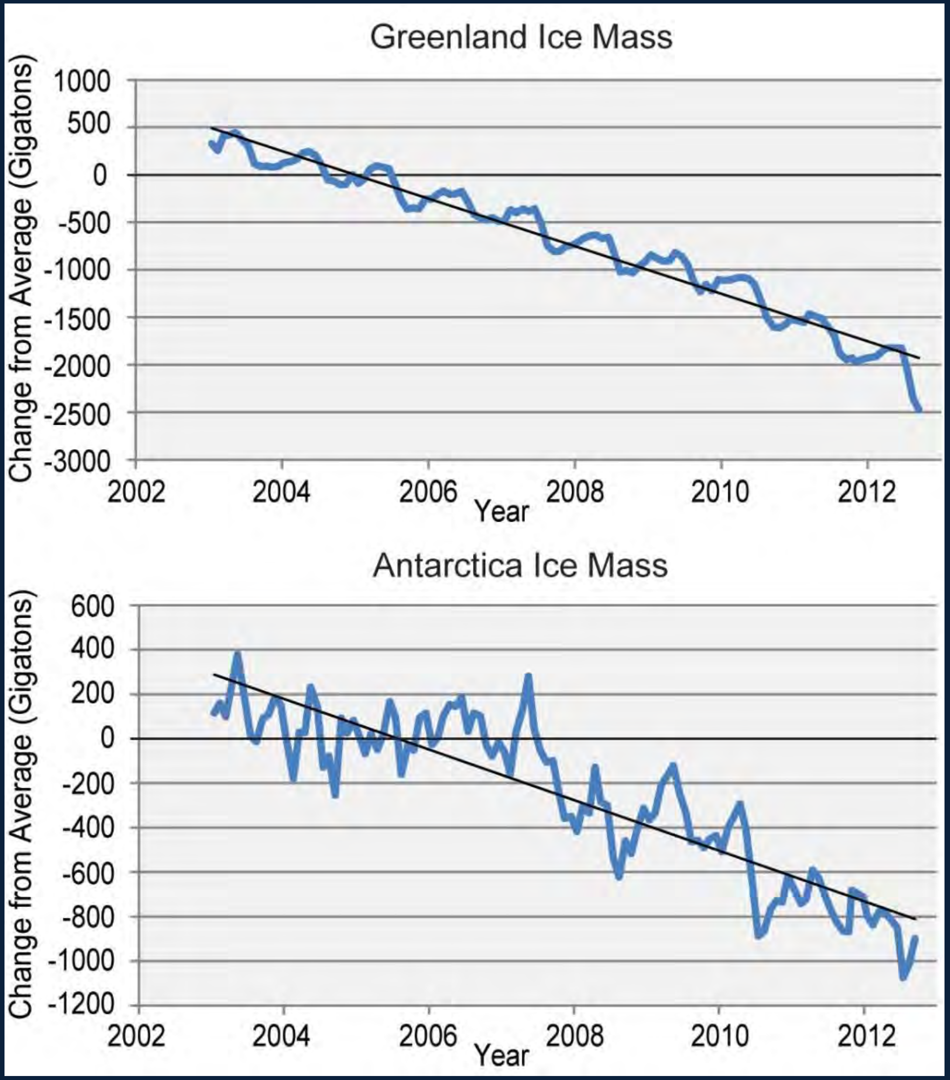
National Academy of Sciences, agencies, public review, responses to all comments

Ice Loss from the Two Polar Ice Sheets

The 2000 Assessment

unknown

The 2014 Assessment



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globalchange.gov
U.S. Global Change Research Program

Muir Glacier Decline

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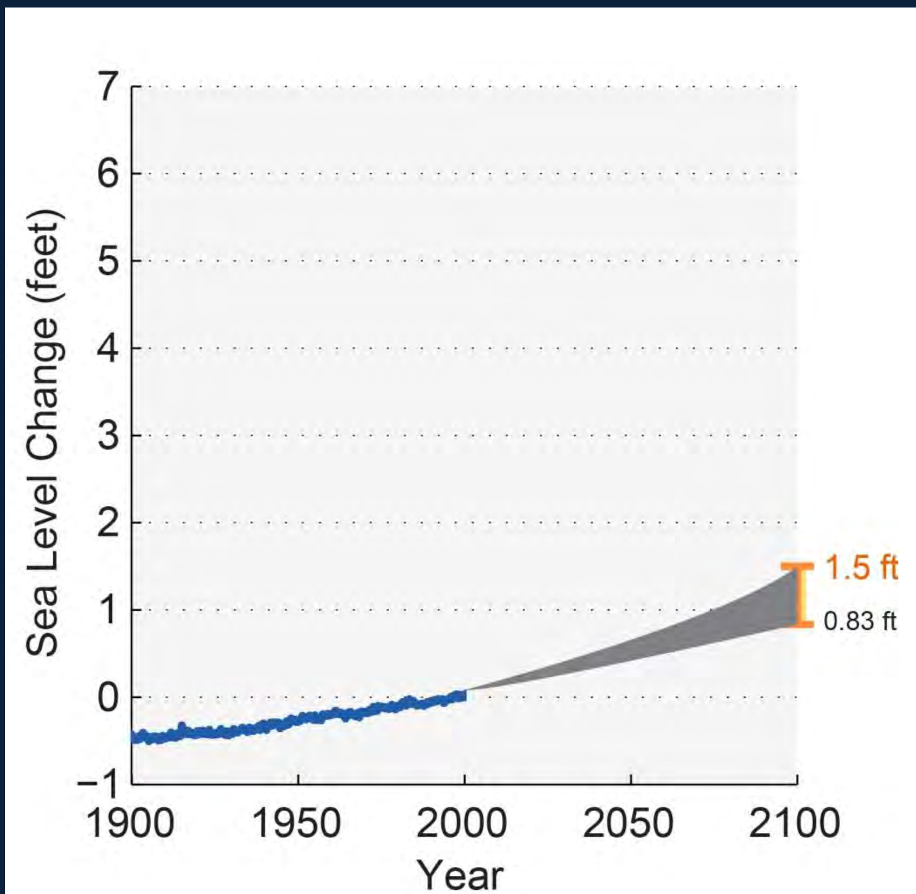
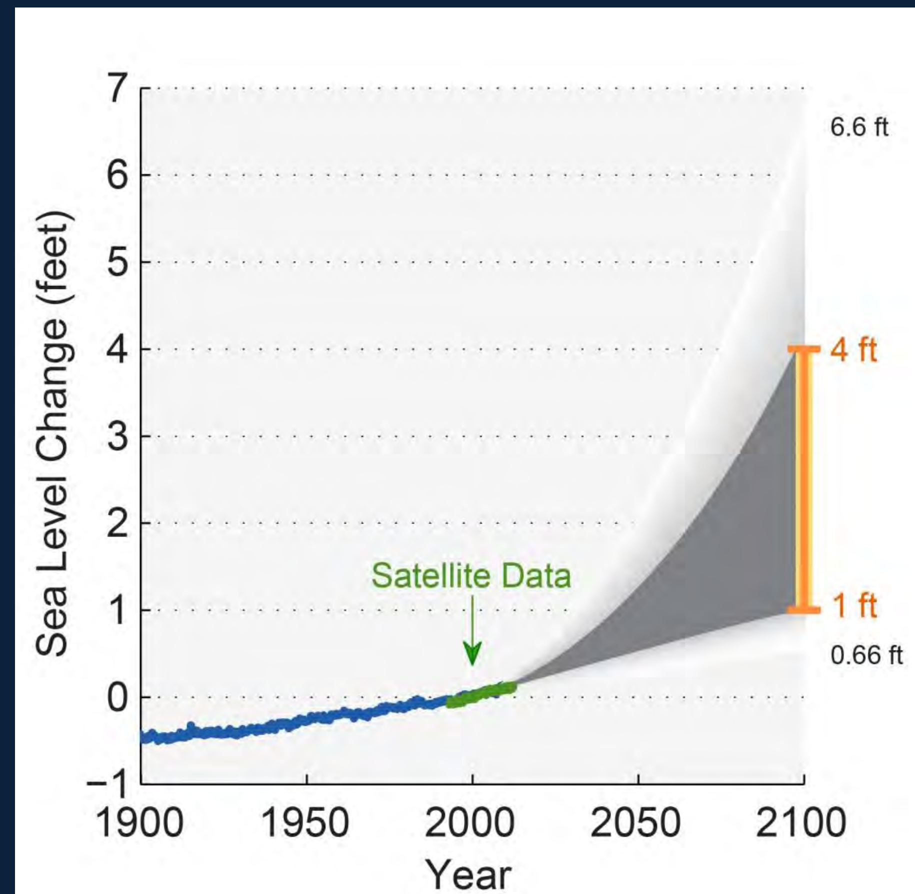
Observed and Projected

Global Sea Level Rise

The 2000 Assessment



The 2014 Assessment



Goals of the NCA

- A **sustained process** for informing an **integrated research program**
- A scientific foundation for decision support, including **scenarios and other tools at multiple scales**
- **Evaluation** of the implications of alternative **adaptation and mitigation options**
- **Community building** within regions and sectors that can lead to enhanced resilience

globalchange.gov
U.S. Global Change Research Program

Outcomes of the NCA

- **Ongoing, relevant, highly credible analysis** of scientific understanding of climate change impacts, risk, and vulnerability
- Enhanced timely **access to Assessment-related data** from multiple sources useful for decision making
- **National indicators** of change and the capacity to respond
- **Risk framing**

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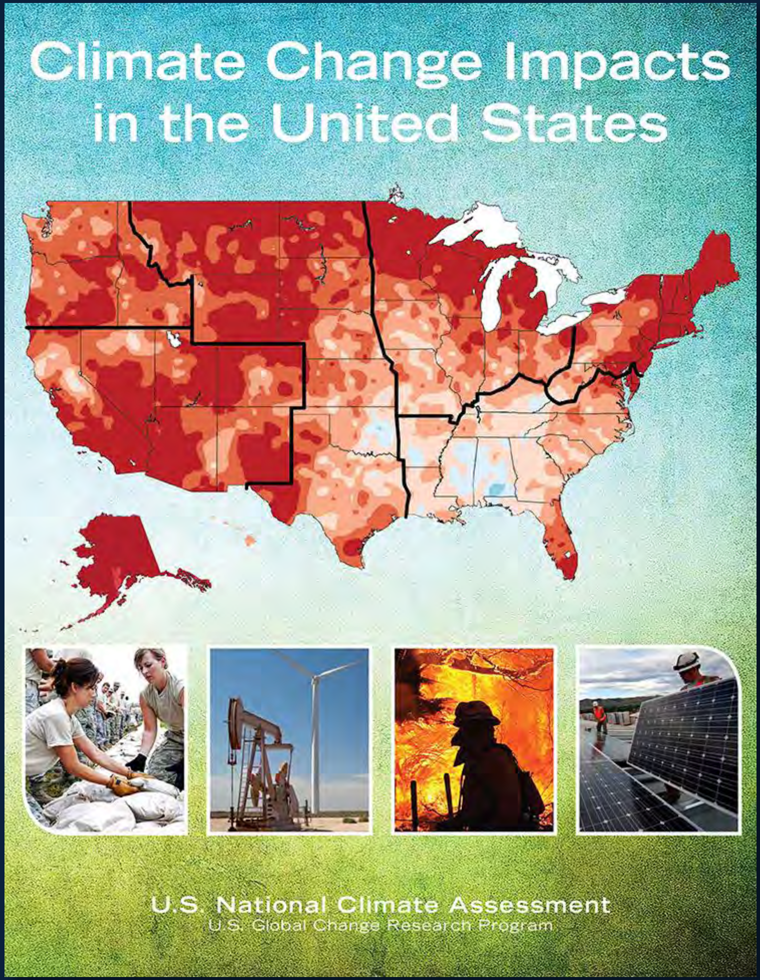
Where does the data come from?

- **Observations**: a description of historical climate trends
  - Temperature and precipitation
  - Examples include: Cooperative Observer Network (COOP), Global Historical Climatology Network (GHCN)
- **Climate projections**: simulated future climate conditions based on different emissions scenarios
  - Metrics such as number of hot days, number of warm nights, number of heavy precipitation days
  - Examples include: Coupled Model Intercomparison Project (CMIP3/CMIP5)

Outline for Third NCA Report

- Climate Change and the American People
- Overview and Report Findings
- Our Changing Climate
- Sectors & Sectoral Cross-
- cuts
- Regions & Biogeographical Cross-cuts
- Responses
- Appendices



Sectors

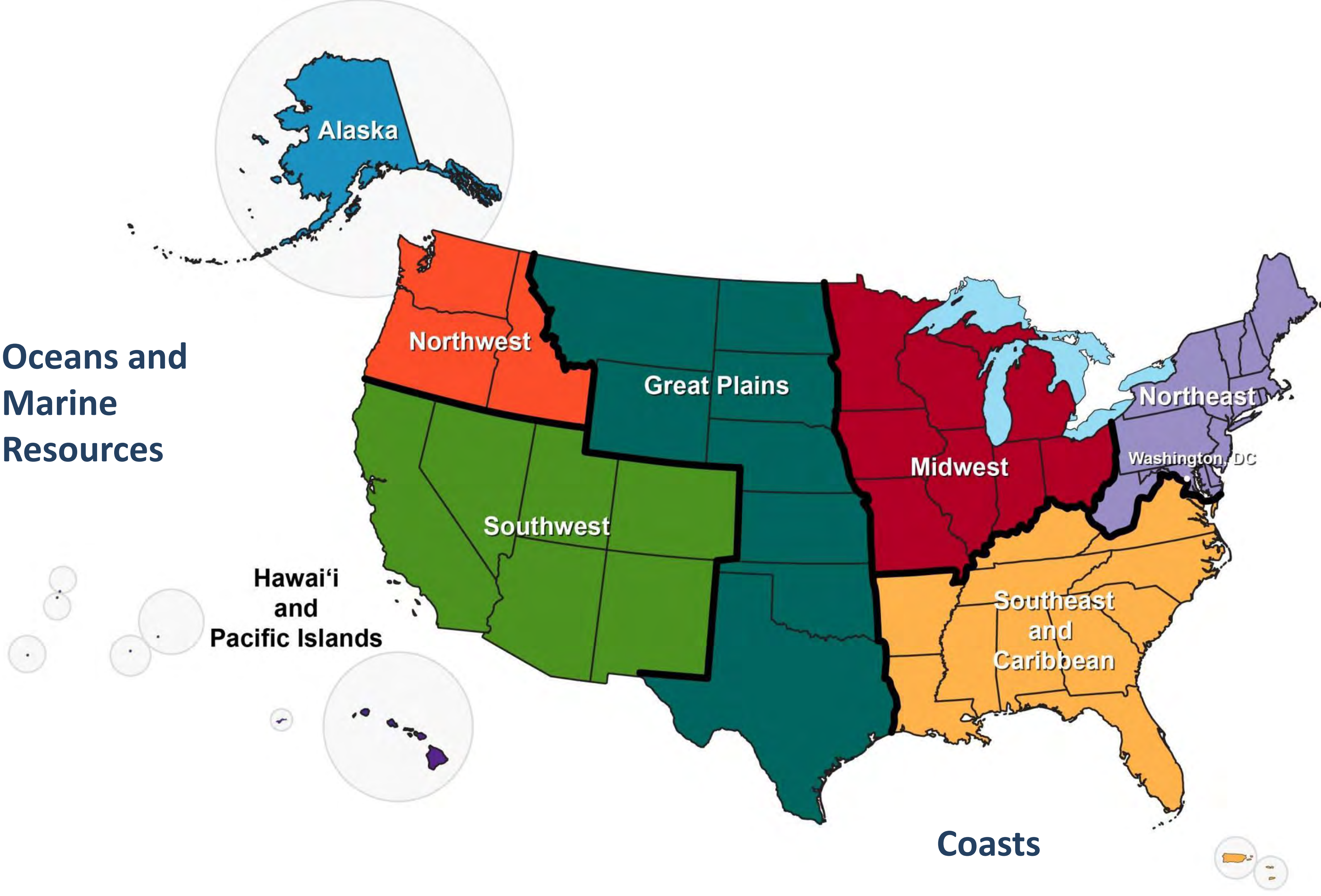
- Water Resources
- Energy Supply and Use
- Transportation
- Agriculture
- Forests
- Ecosystems and Biodiversity
- Human Health

Sectoral Cross-Cuts

- Water, Energy, and Land Use
- Urban Systems, Infrastructure, and Vulnerability
- Impacts of Climate Change on Tribal, Indigenous, and Native Lands and Resources
- Land Use and Land Cover Change
- Rural Communities, Agriculture, and Development
- Biogeochemical Cycles

Regions & Biogeographical Cross-Cuts

Oceans and Marine Resources



Coasts

Responses

- Decision Support
- Mitigation
- Adaptation
- Research Needs
- Sustained Assessment

Appendices

- Process
- Information Quality
- Climate Science Supplement
- Frequently Asked Questions
- Scenarios and Models
- Future Assessment Topics

Climate change, once considered an issue for a distant future, has moved firmly into the present

A Sampling of results from the NCA3 Report

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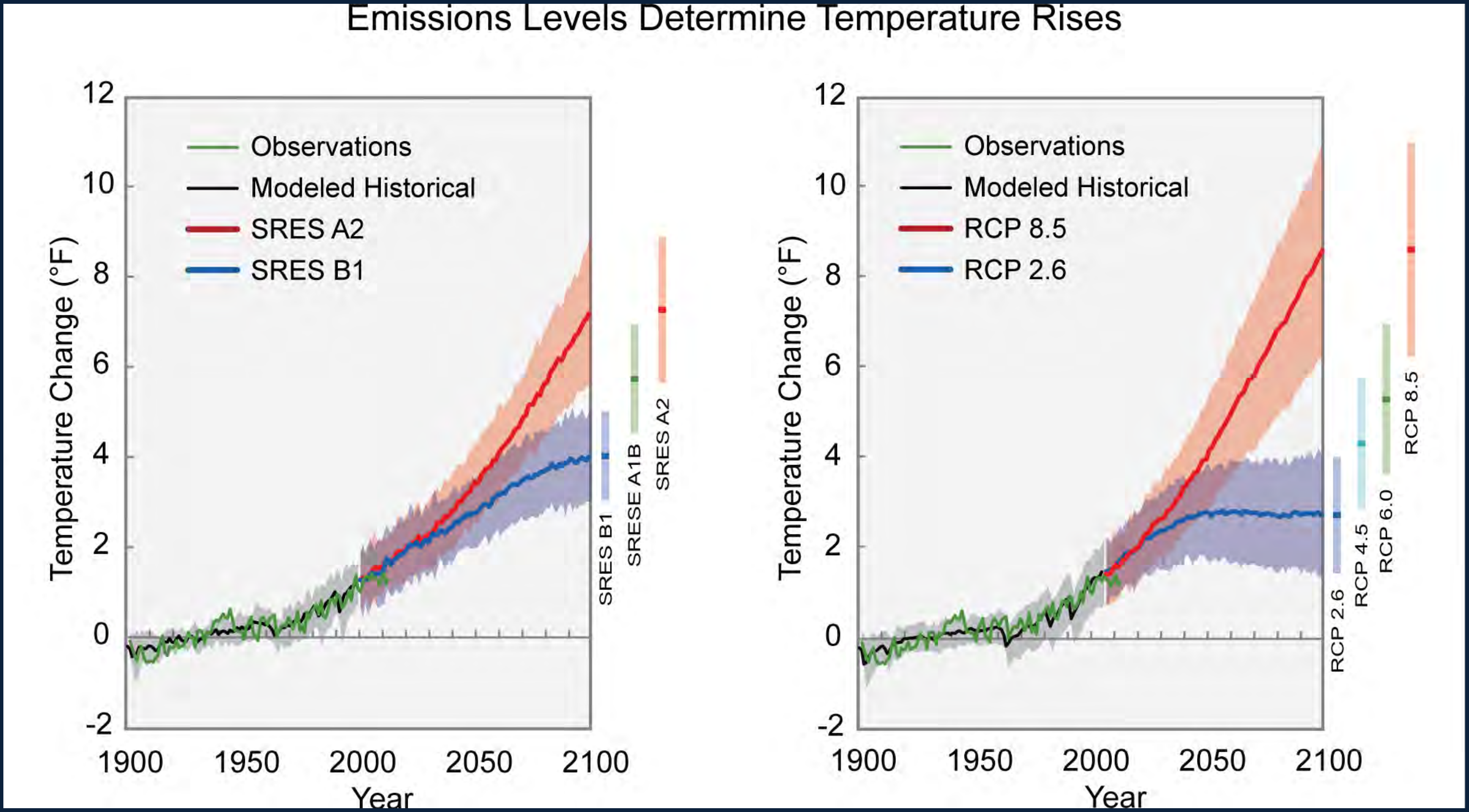
U.S. Global Change Research Program

Scenarios

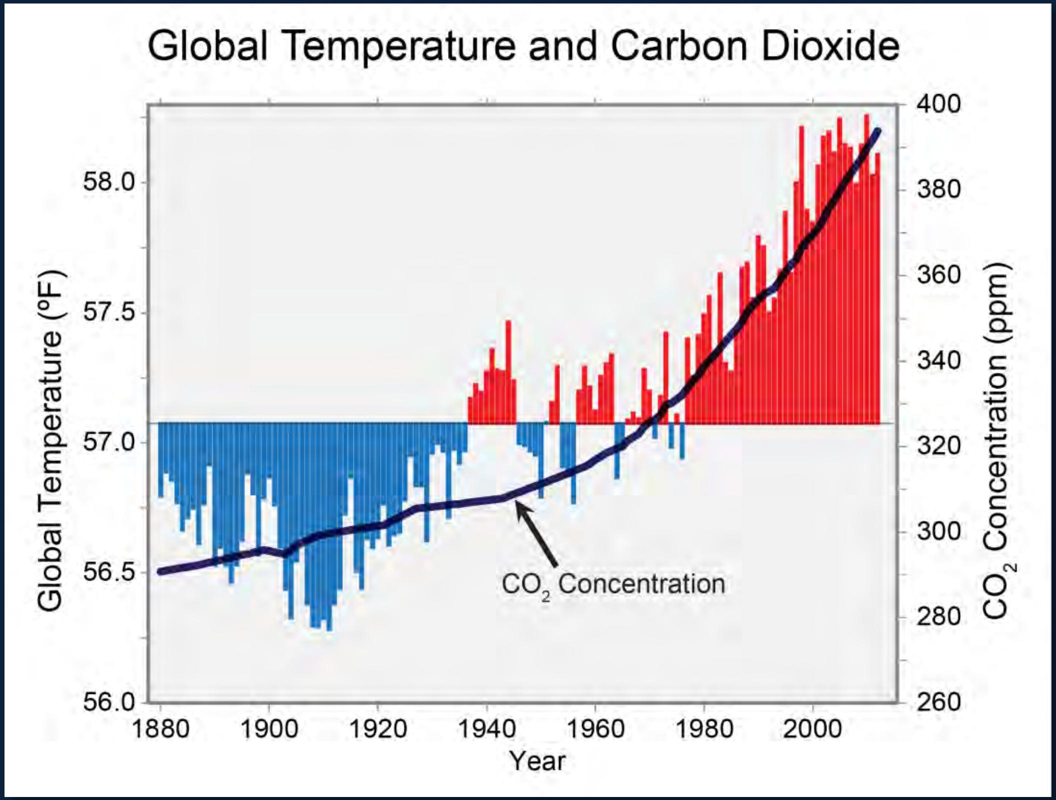


Emissions Levels Determine Temperature Rises
Temperature Change (°F)
Year
Observations
Modeled Historical
SRES A2
SRES B1
SRES B1
SRESE A1B
SRES A2
RCP 8.5
RCP 2.6
RCP 2.6
RCP 4.5
RCP 6.0
RCP 8.5
12
10
8
6
4
2
0
-2
1900
1950
2000
2050
2100

Report Finding 1

Global climate is changing and this is apparent across the US in a wide range of observations.

The global warming of the past 50 years is primarily due to human activities, predominantly the burning of fossil fuels.



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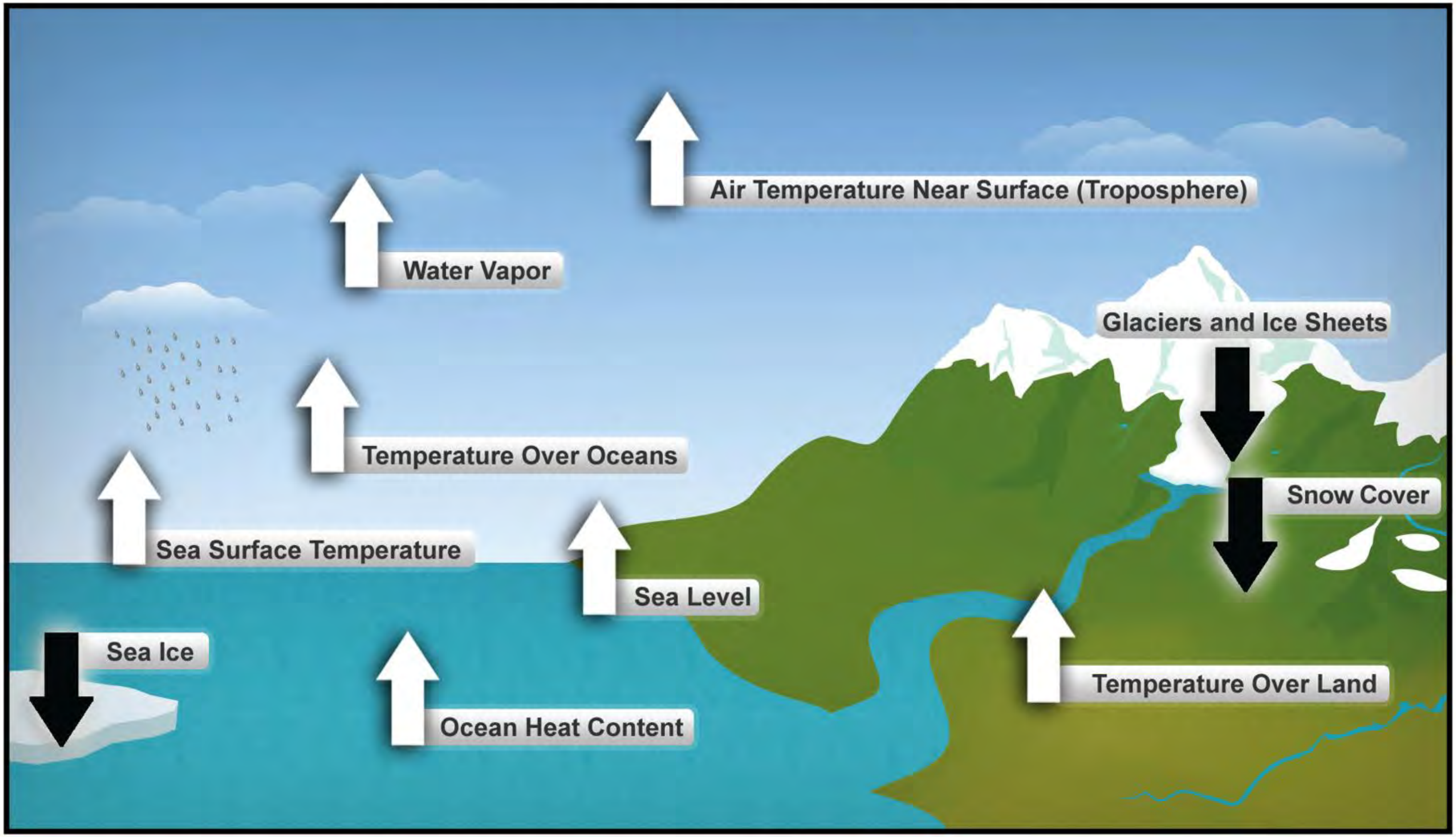
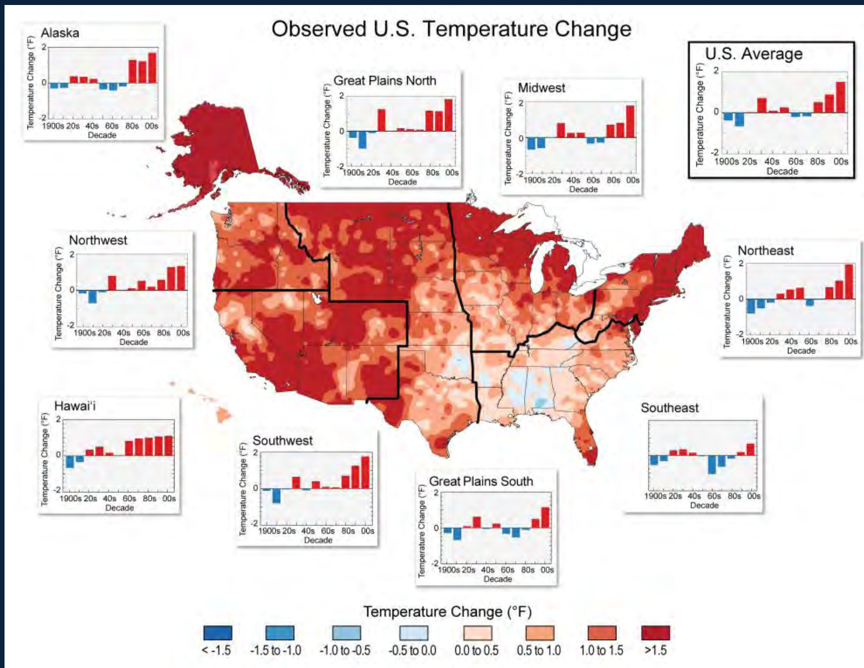
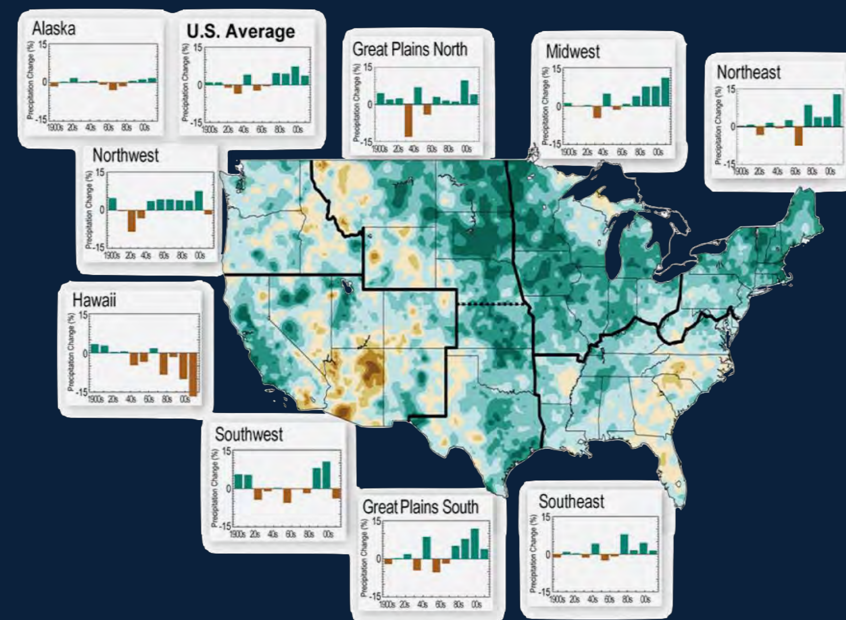
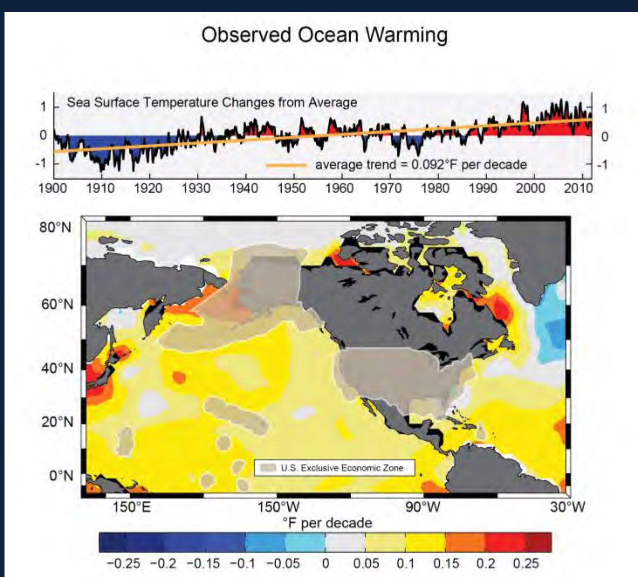
Ten Indicators of a Warming World

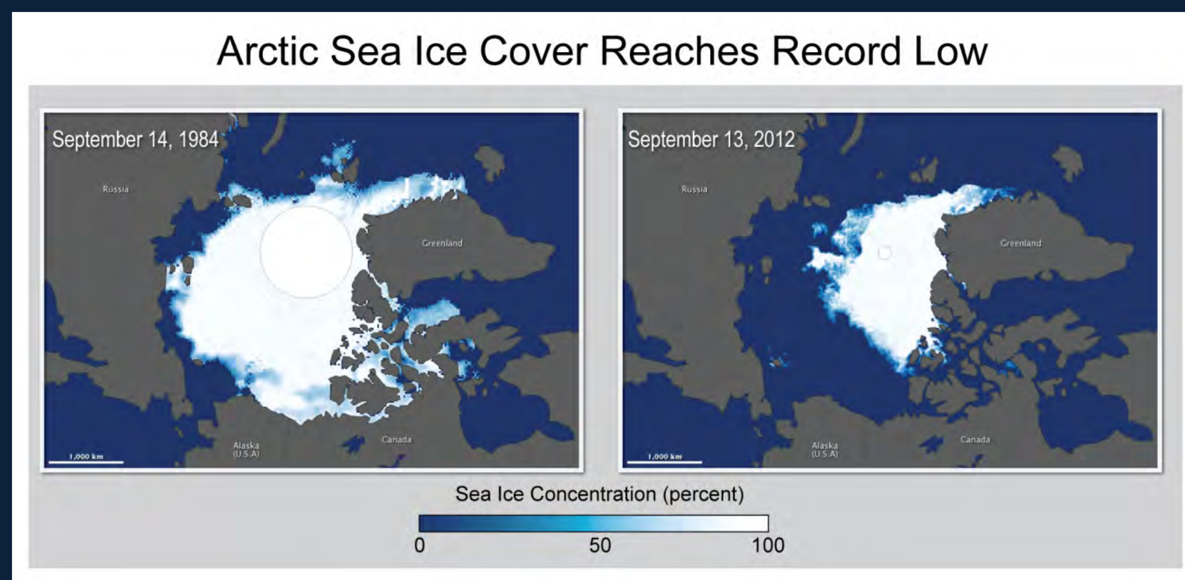


Our Changing Climate



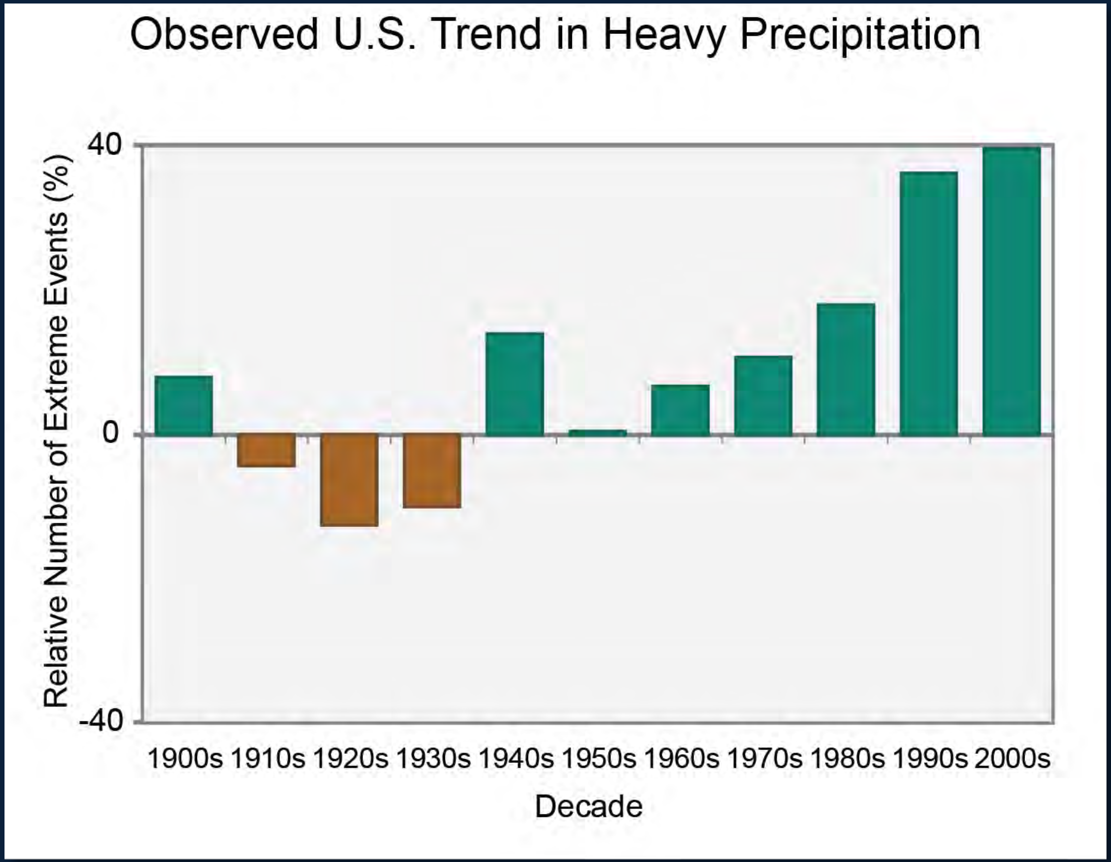




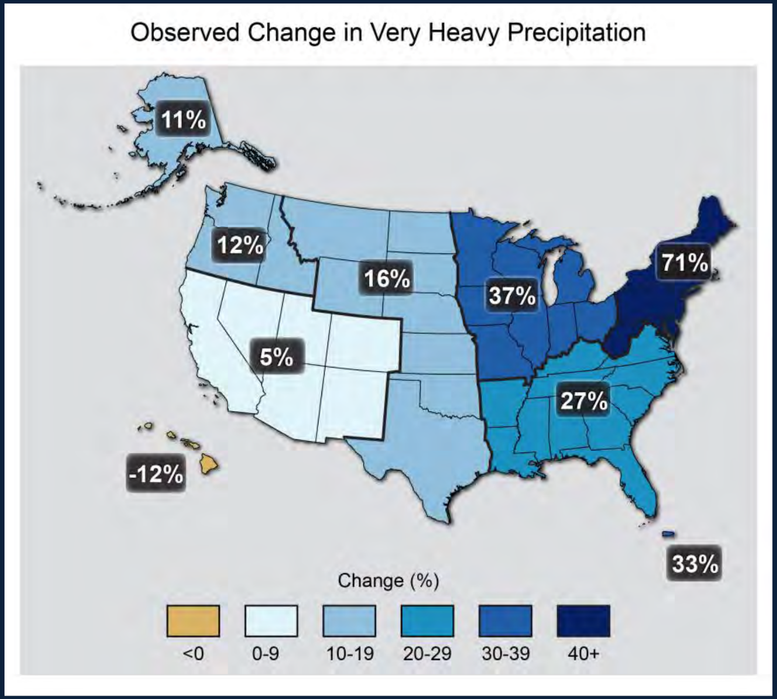


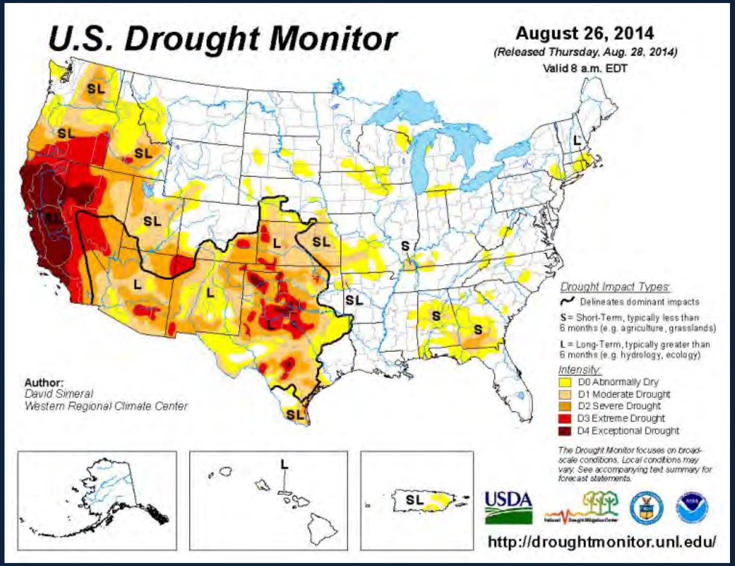
Report Finding 2

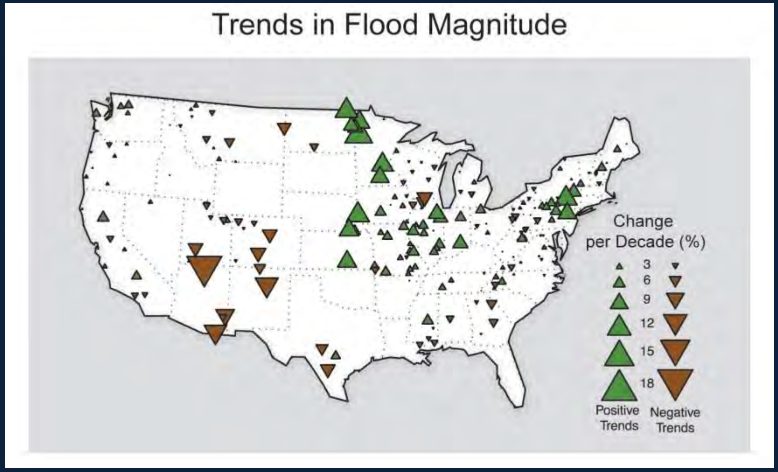
Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities.

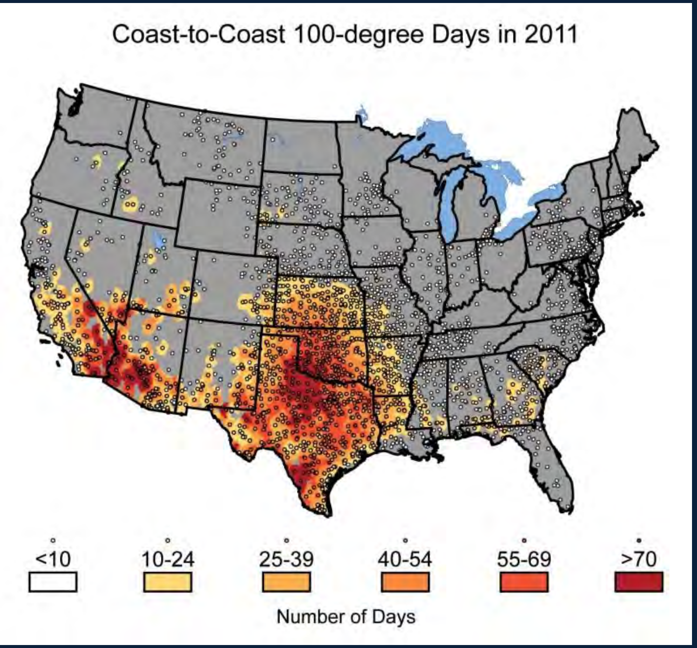


Extreme Weather



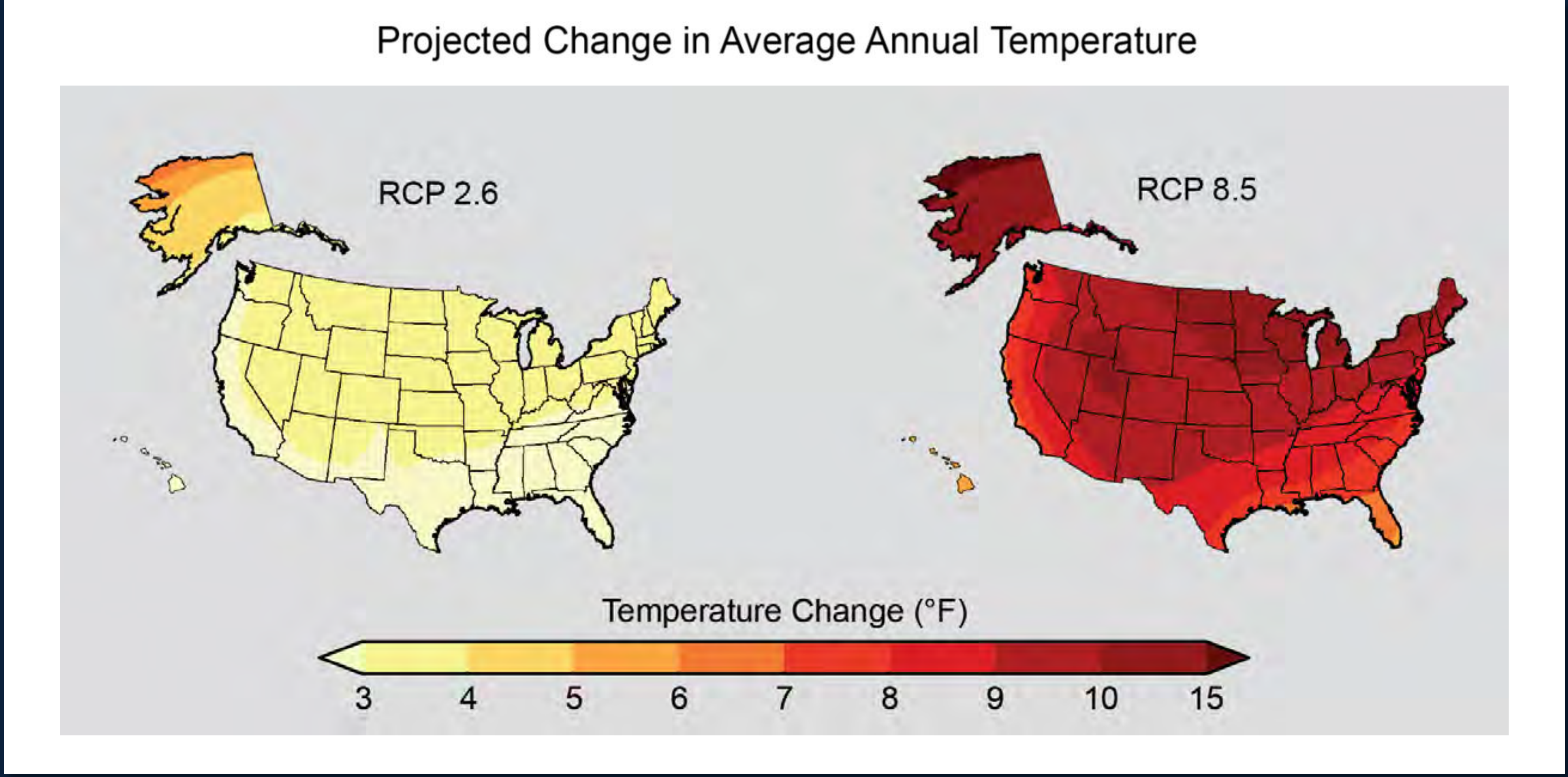




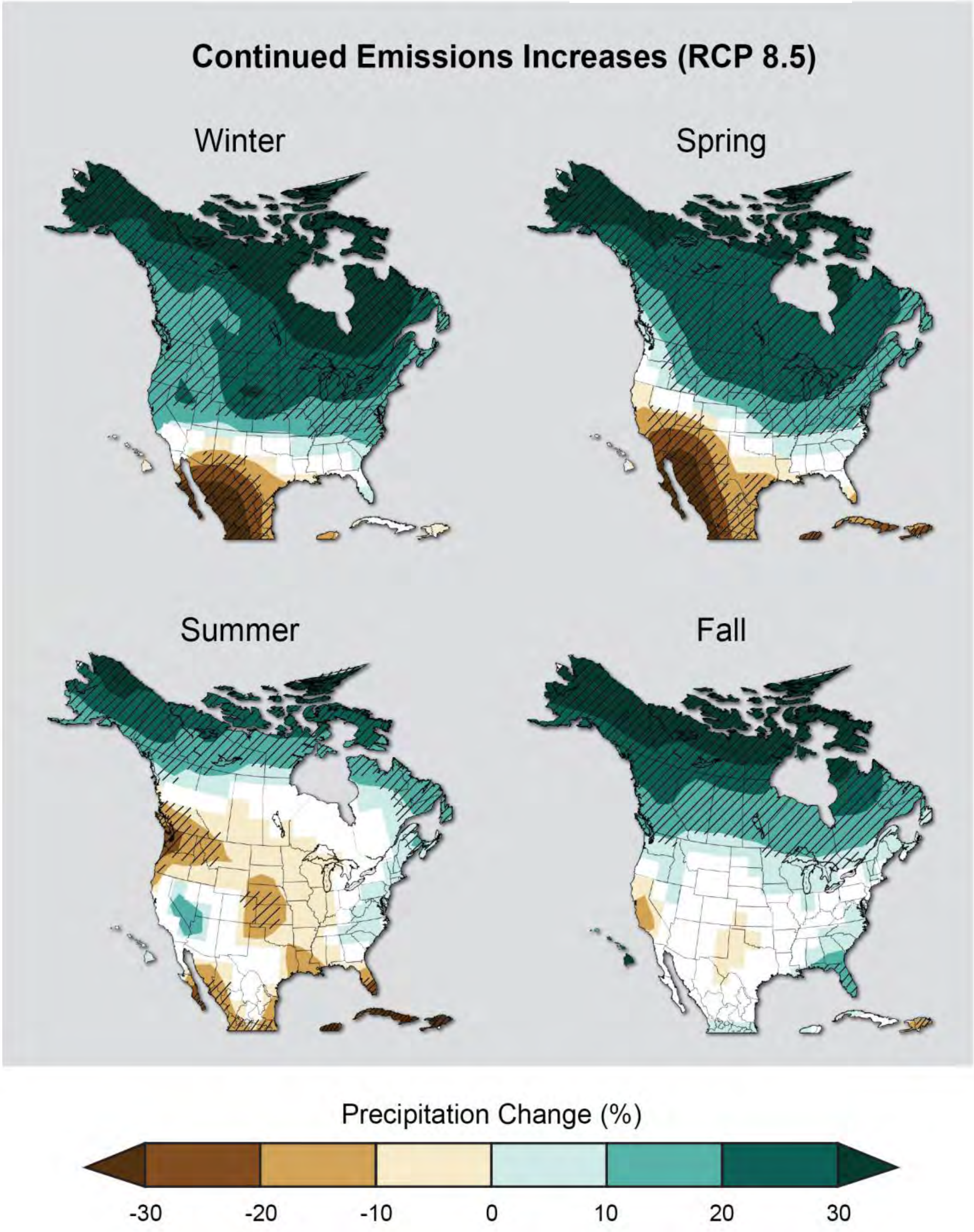


Report Finding 3

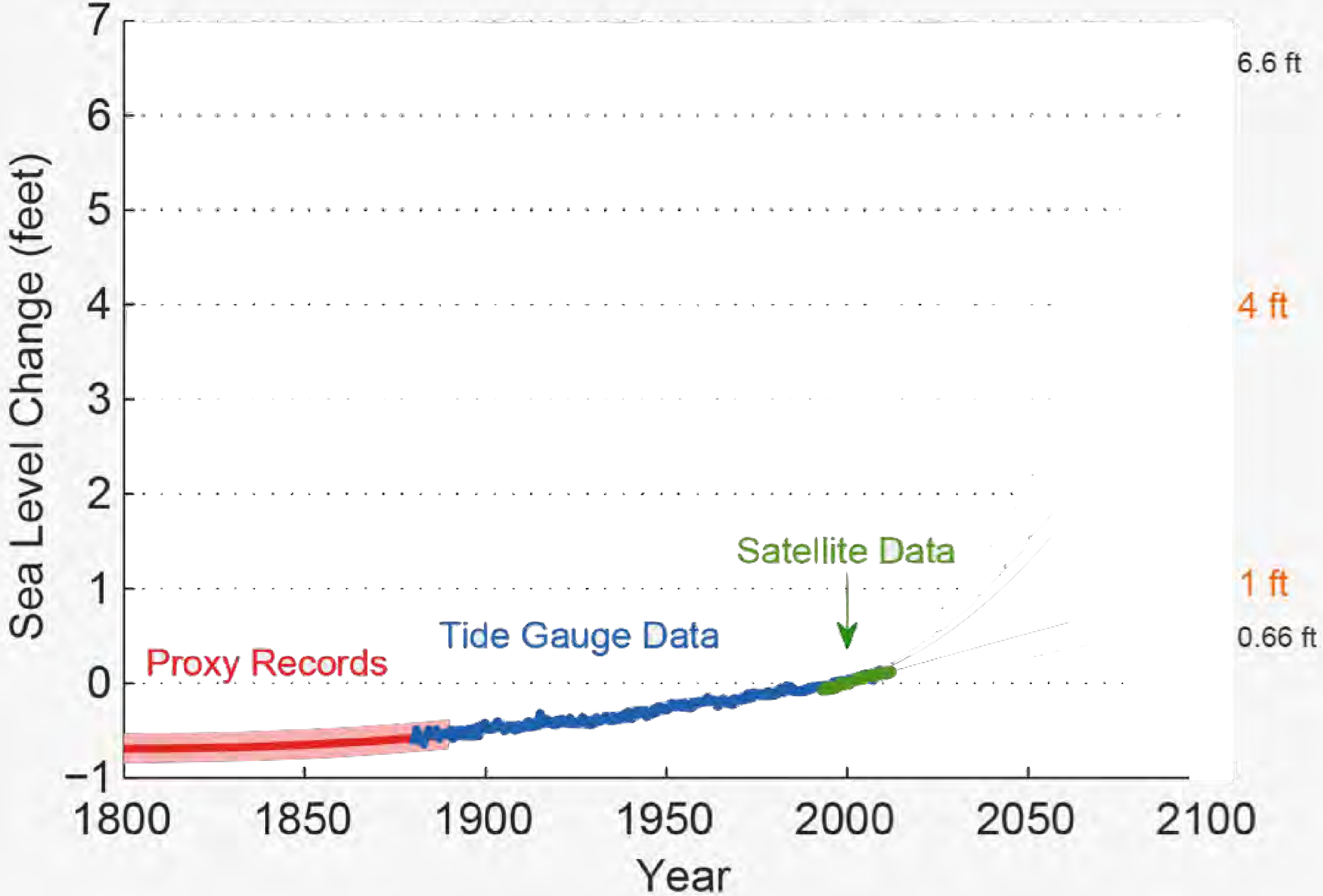
Human-induced climate change is projected to continue, and it will accelerate significantly if emissions of heat-trapping gases continue to increase.



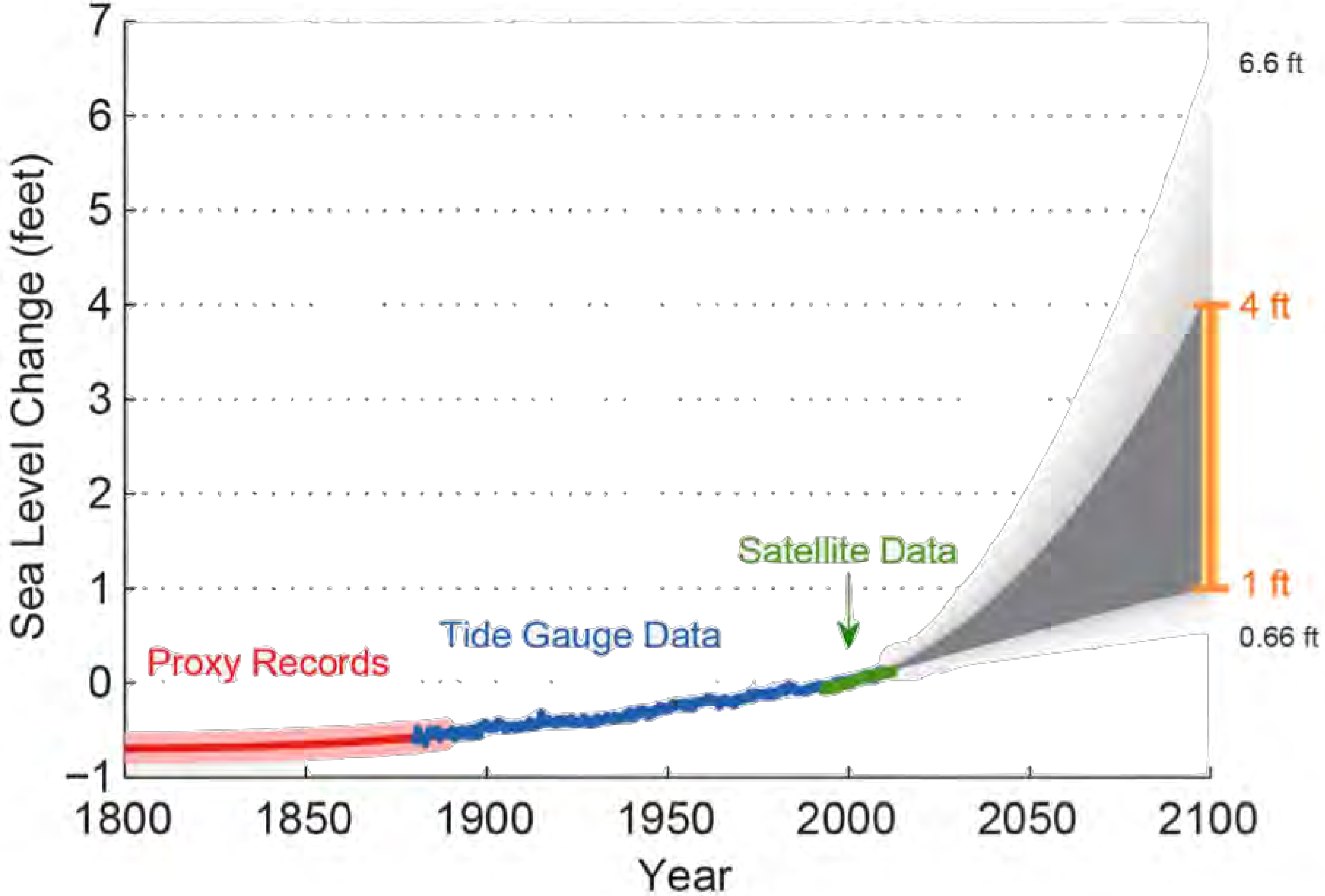
Projected Change in Precipitation

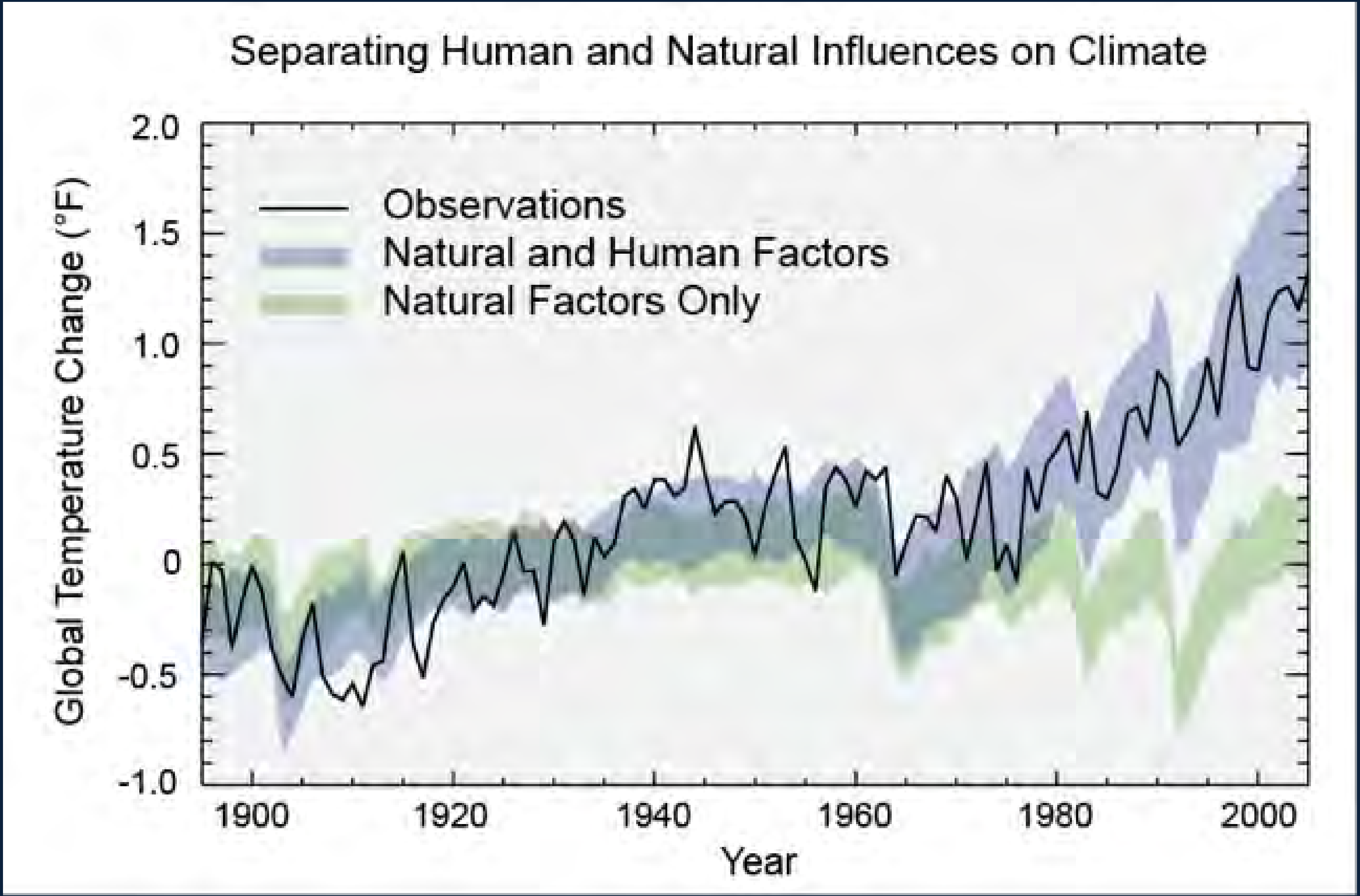


PAST CHANGES IN GLOBAL SEA LEVEL



PROJECTED CHANGES IN GLOBAL SEA LEVEL

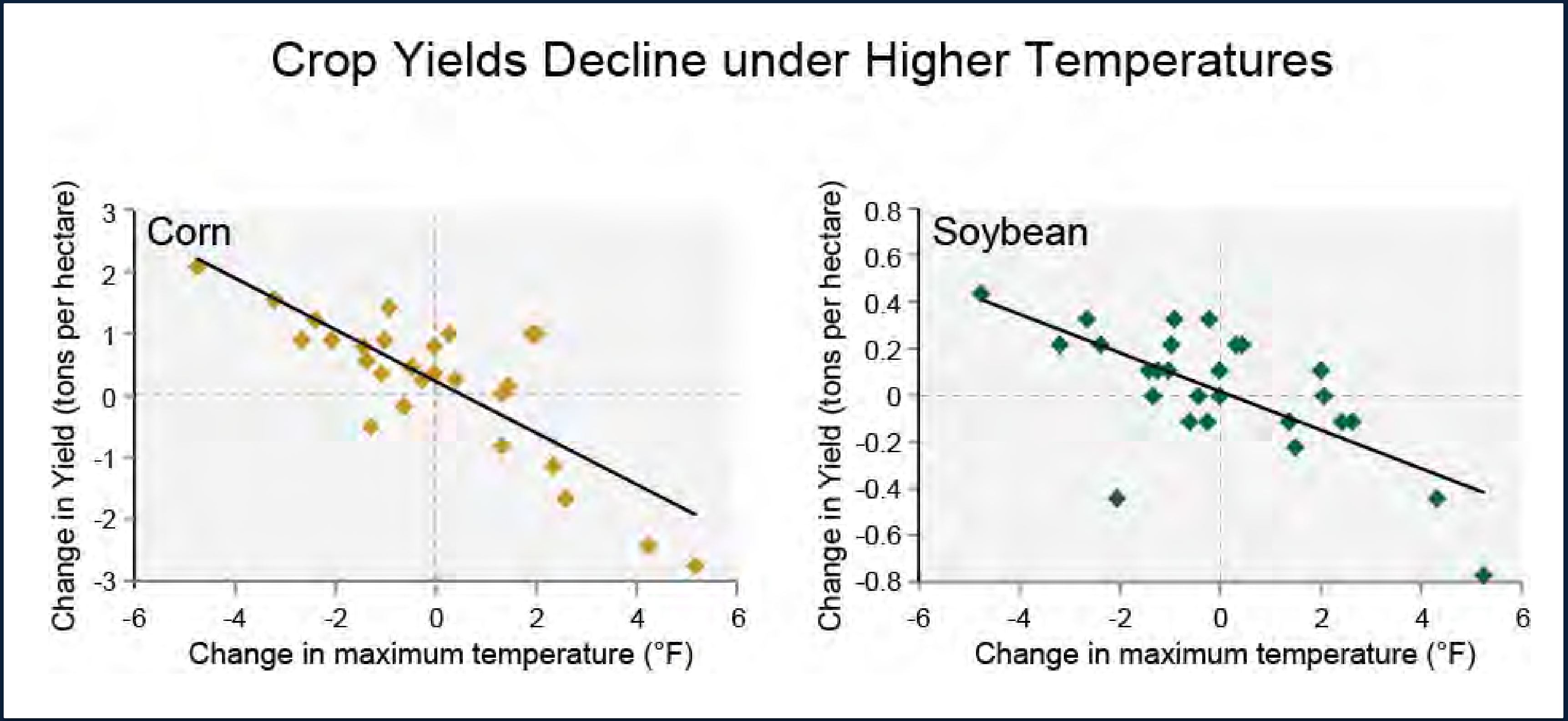




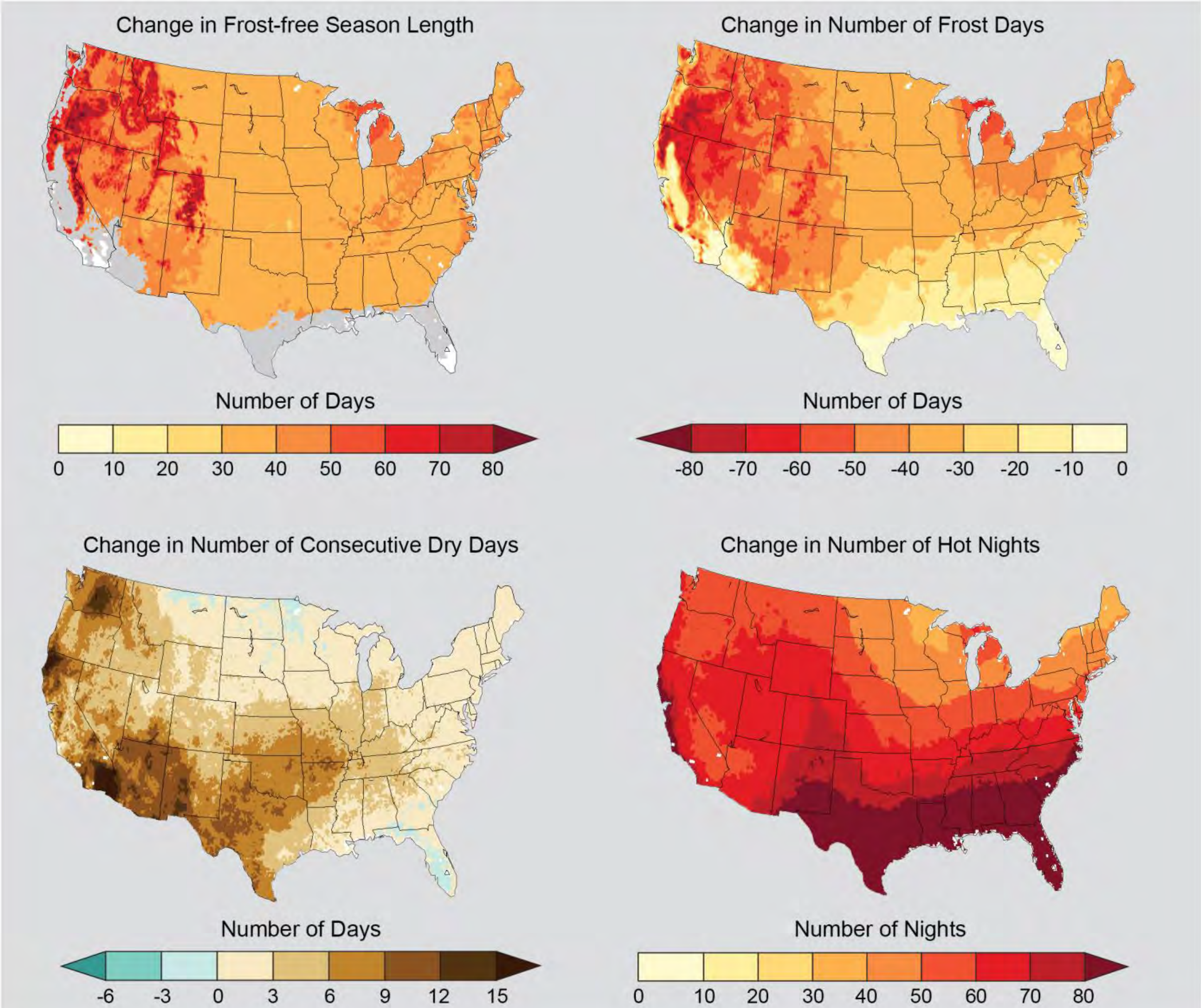
Separating Human and Natural Influences on Climate
Observations
Natural and Human Factors
Natural Factors Only
Global Temperature Change (°F)
2.0
1.5
1.0
0.5
0
-0.5
-1.0
1900
1920
1940
1960
1980
2000
Year

Report Finding 8

Climate disruptions to agriculture have been increasing and are projected to become more severe over this century.

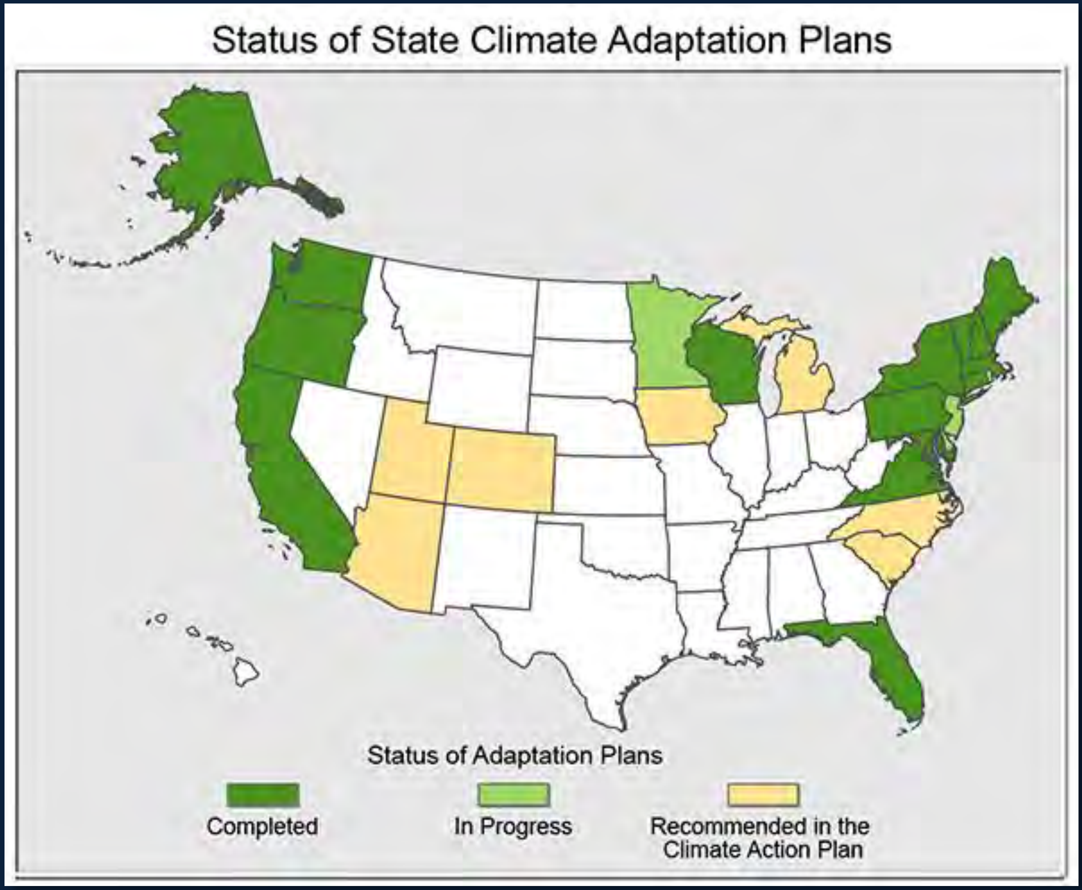


Projected Changes in Key Climate Variables Affecting Agricultural Productivity

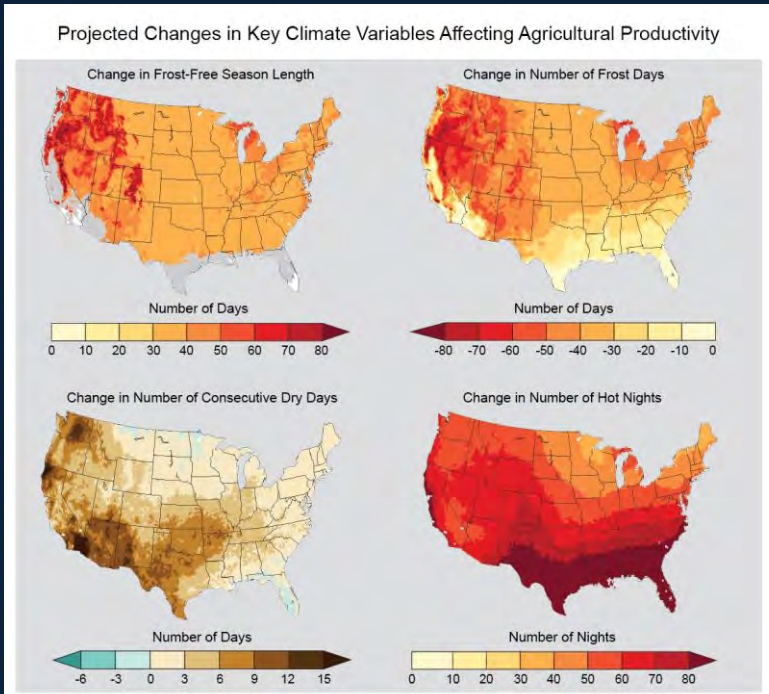


Report Finding 12

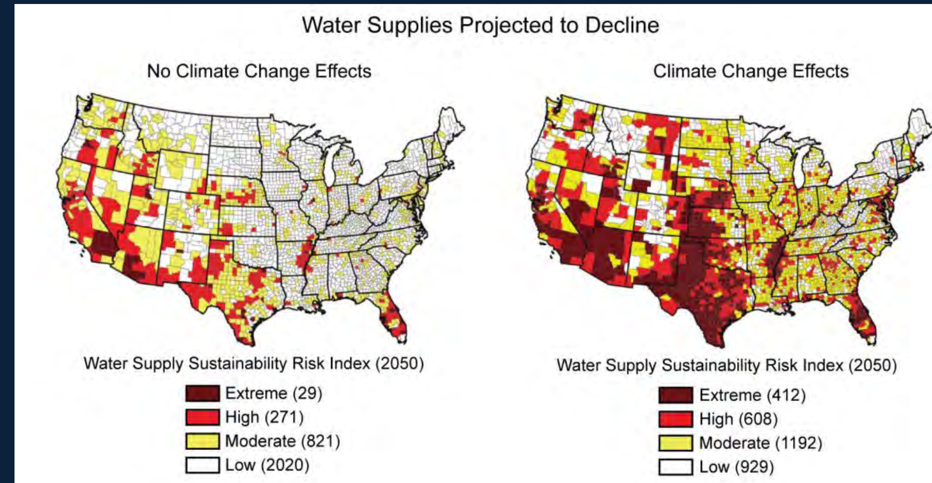
Planning for adaptation and mitigation is becoming more widespread but current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.



Widespread Impacts

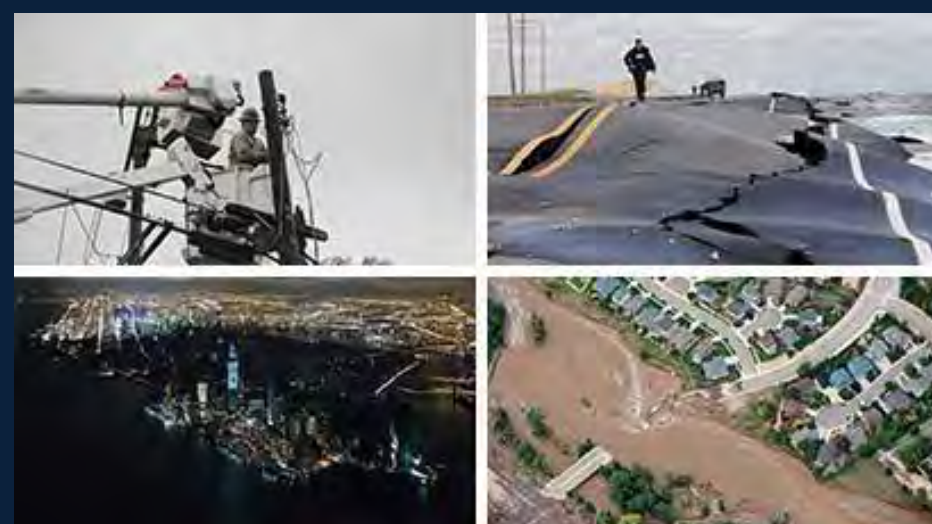


Agriculture

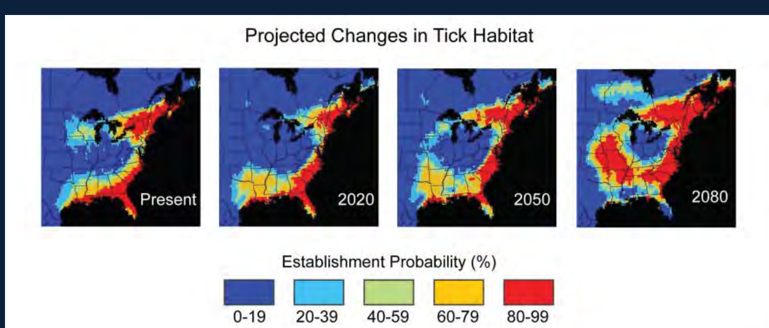


Water Supply

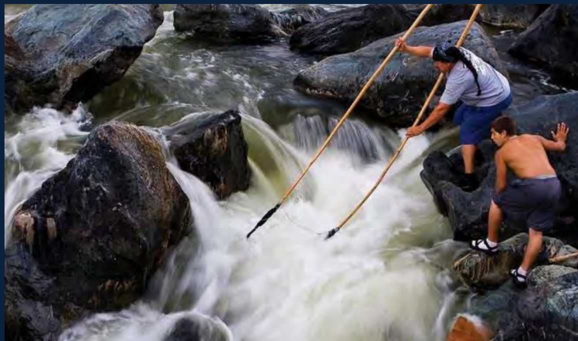
Infrastructure



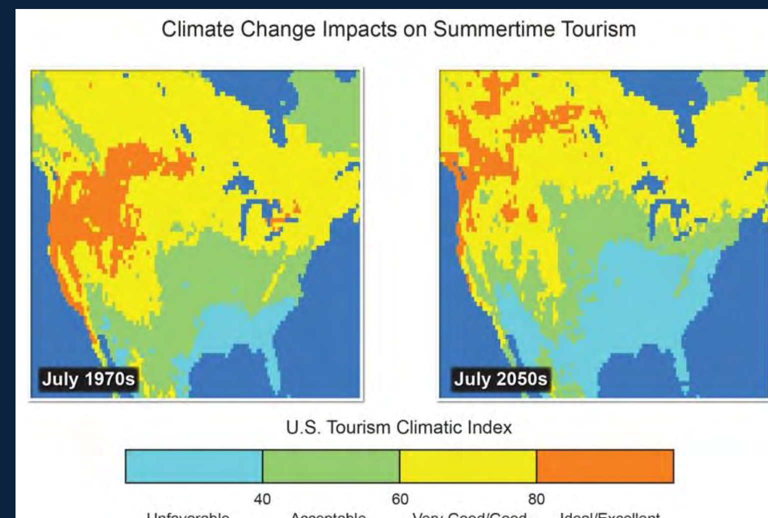
Human Health



Widespread Impacts



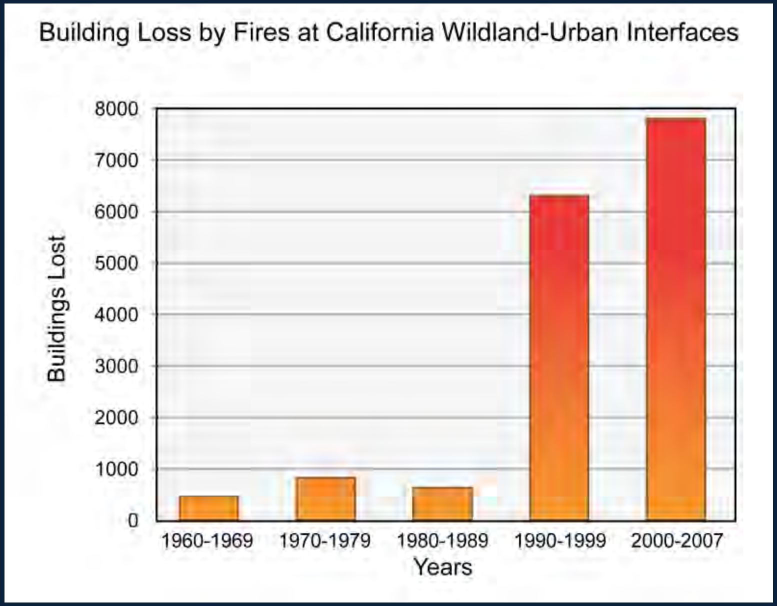

Indigenous Peoples



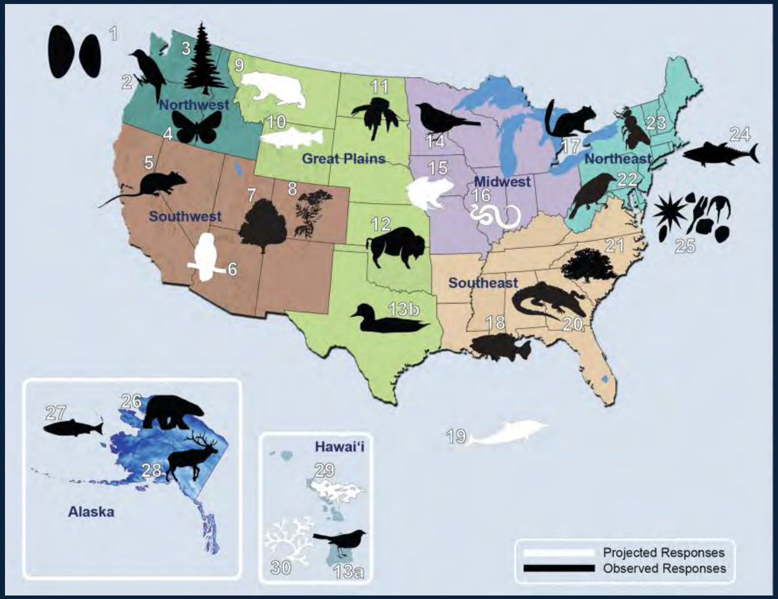
Urban Areas

Rural Communities

Widespread Impacts

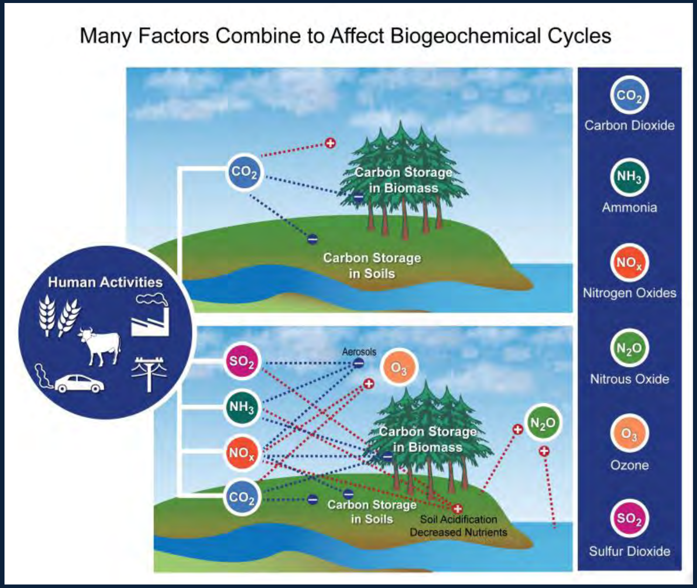


Forests

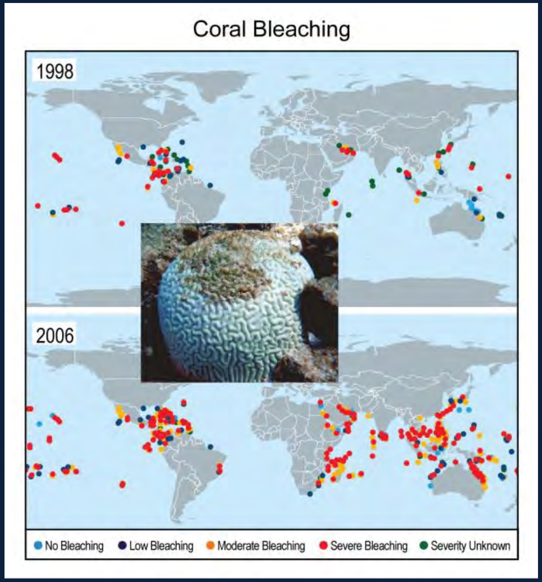


Ecosystems

Oceans



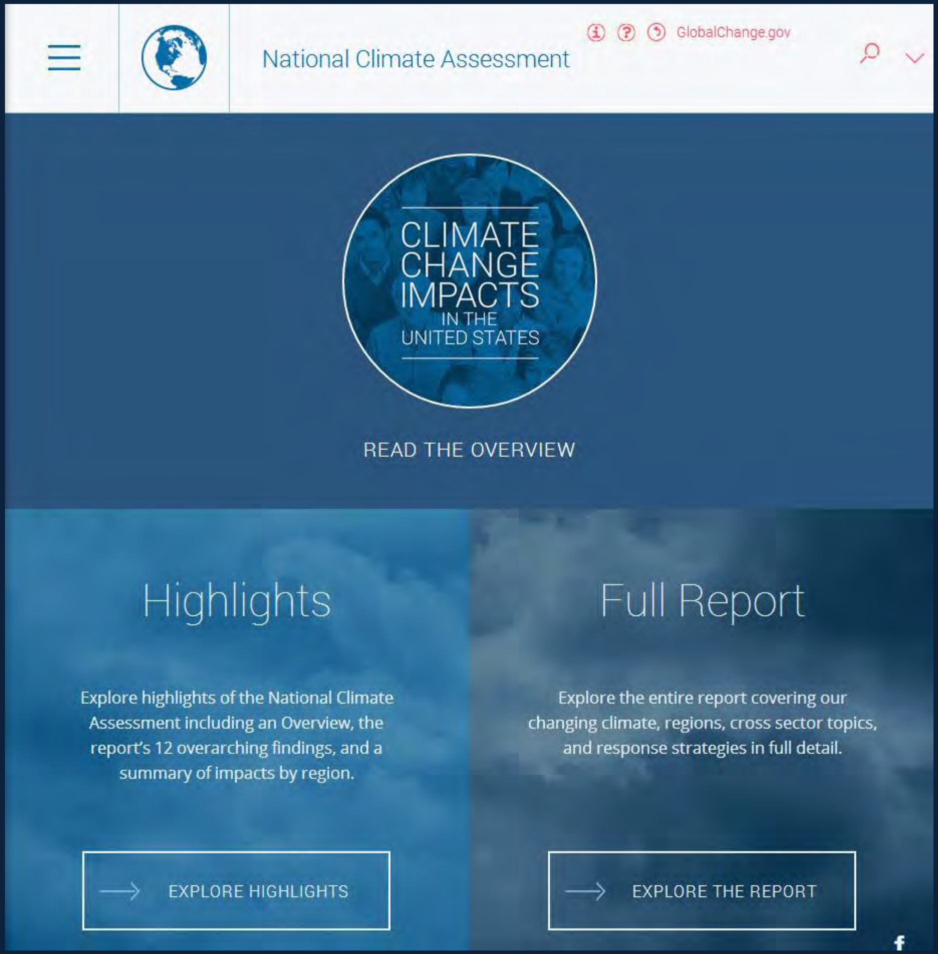
Biogeochemical Cycles



Global climate is projected to continue to change over this century and beyond, but there is still time to act to limit the amount of change and the extent of damaging impacts

Interactive Tools

(these graphics are hyperlinked)

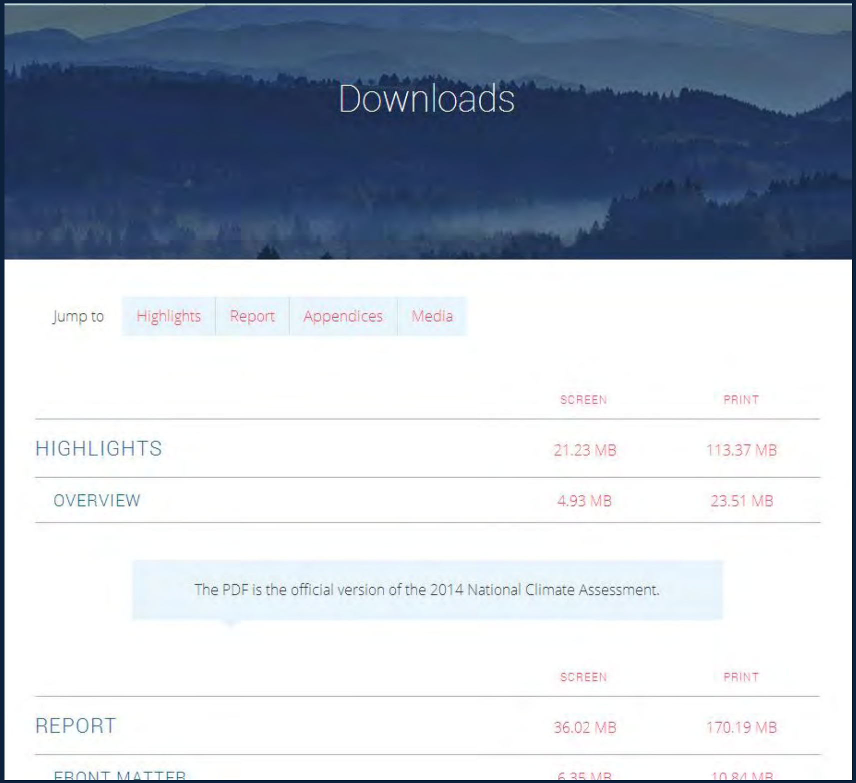


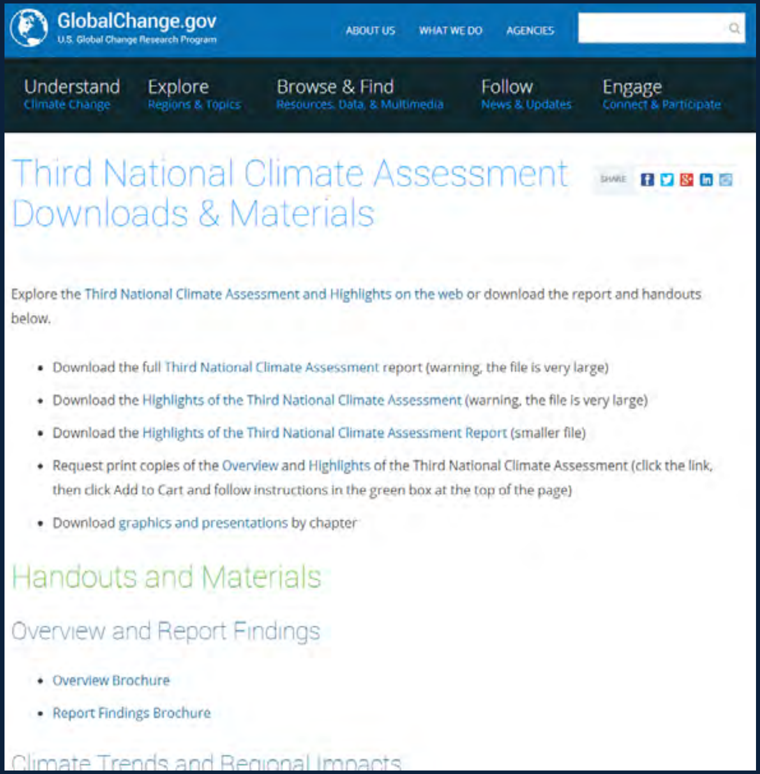
Interactive Tools

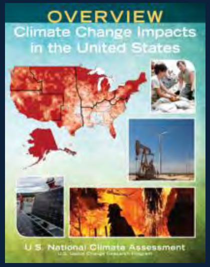
(these graphics are hyperlinked)

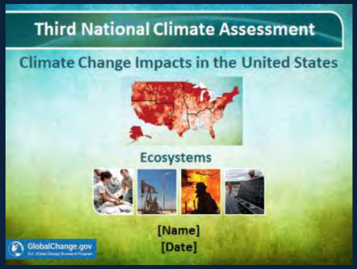
Downloadable Resources

(main graphics are hyperlinked)



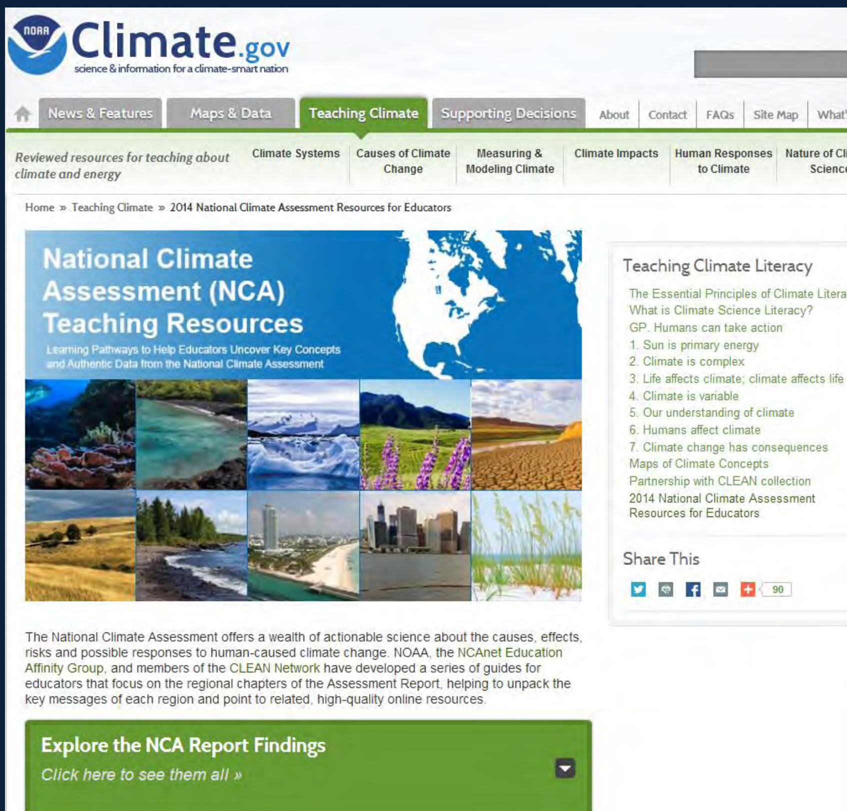






Teaching Resources

(these graphics are hyperlinked)



- Ten regional support pages
- Resources by chapter key message
  - Guiding questions
  - Key figures
  - Other resources
  - Lesson plans
  - Videos & visualizations
- General resources

Keep Exploring!

http://nca2014.globalchange.gov

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Laura Stevens
Laura.stevens@cicsnc.org

Impact of Climate Change on Bees: Pollination in Action

Region: Eastern Forests and Woodlands

Grade Level(s): 5-8

Time Required: 1 class period

Focus Question(s):
- What is the bee's role in the forest ecosystem?
- How will plant-pollinator interactions respond to climate change?
- What will happen to the ecosystem when pesticides are used to control the spread of insects?

Learning Objectives:
- Students will develop an understanding of the pollination process and the relationship between pollinator and flowering plant.
- Students will model a scenario depicting the impact of climate change on pollination.

Materials:
- Carpenters' Straight-line Chalk, (powdered colored chalk for a straight-line tool.) Available in orange, red, blue and other colors.
- A few hundred Q-tips or cotton applicators.
- Spray bottle with water
- ABC Brainstorming Worksheet (See attached)

Background and Resources(Optional):
- Lindsey, Rebecca. 2007. Buzzing About Climate Change. NASA's Earth Observatory. http://earthobservatory.nasa.gov/Features/Bees/bees.php

Procedures/Instructional Strategies:

1. Review the concept of pollination with students. Explain that pollination is the process of moving pollen from one plant to another. It is through this process that plant reproduction happens. Briefly discuss the importance of plant reproduction to all living things.

2. Review the ways in which bees and butterflies pollinate plants as they get food for themselves. Bees, while sipping nectar from flowers, get pollen stuck on various parts of their bodies. This pollen then rubs off on certain parts of the next flower that they fly to. Bees are the most important pollinators in nature.

3. Take the class outside to an open area where they can run safely. Separate the students into groups of orange trees, apple trees and bees. Give the "trees" colored chalk to hold. The orange trees hold the orange chalk, the apple trees hold red chalk. Explain to the students that their chalk represents the tree's flowers.

4. Keep the supply of Q-tips a distance away at the "hive".

5. The bees take the clean Q-tips to the “trees’ flowers” to collect chalk and return the stained Q-tips to a basket near the hive. (Note: the chalk will not stain clothing)

6. When they deposit the stained Q-tip they take another clean one to find another tree.

7. Have the students rotate and change roles so that everyone gets a turn in each. Continue until all have had a turn and you have collected a considerable number of pollinated Q-tips at the hive.

8. Now create a new scenario and provide the background. The earth is getting warmer and this has caused the bees to come out of dormancy before the tree flowers are blooming. Take away most of the “tree flowers” (chalk) from the trees. Have farmers spray pesticides. (Have a student with spray bottle go around and spray, if it touches a bee the bee dies and end of game.)

9. Run the game again with these obstacles to pollination.

10. Have students discuss the game and their results.

11. Have students create an ABC Brainstorming Worksheet (See attached) on the topic of pollination. Tell students that the purpose of ABC Brainstorming is to think about what they already know and generate a list of ideas that might be connected to the topic of Pollination. Ask: What is pollination? What does it involve? As they brainstorm, ideas should be placed on the handout according to the letter of the alphabet with which they begin. Student volunteers can type the ideas onto the form. More than one idea can be placed into a letter category. An example of what a portion of the form might look like is included below. If students are having trouble getting started, fill in a few of the boxes with ideas of your own. Think out loud to show students how you come up with ideas for the form. For example: “When I think of pollination I’m reminded of bees and butterflies. I know that animals like birds can also help to pollinate flowers. Some pollinators are attracted to colorful flowers…etc.” Not all letters need to be used.

ABCs of Pollination (Example)

A (possible answers include: animal	N (night time blooms
B (bee, butterfly, birds, bats	O (organic, orange
C (color of flower, climate,	P (Pollen, pesticides
…..	……

Extensions:

- Have students read “A Scientist With a Real Bee in Her Bonnet”. Have students write new scenarios based on what they have just read and their activity. http://www.livescience.com/14886-marla-spivak-bee-health-bts.html

- Have the students write about anything the activity has inspired. Open their imagination by attributing human characteristics to the trees and bees. How does the world look to a bee that zooms around? What does a bee think when it is all the way inside a big flower? Do the trees want to be visited? What happens to the blossom after a bee has visited?

- Probe for questions and inquiry.

Outcome/Assessment (Optional):

- Have students create a food or community web based on the activity.
- Have students create a Pollination ABC Worksheet (See attached).

National Science Education Standards Addressed:

Life Science:

- Reproduction is a characteristic of all living systems; because no individual organism lives forever, reproduction is essential to the continuation of every species. Some organisms reproduce asexually. Other organisms reproduce sexually.
- The number of organisms an ecosystem can support depends on the resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition. Given adequate biotic and abiotic resources and no disease or predators, populations (including humans) increase at rapid rates. Lack of resources and other factors, such as predation and climate, limit the growth of populations in specific niches in the ecosystem.

ABC Brainstorming
Topic: Pollination Ecology

A	N
B	O
C	P
D	Q
E	R
F	S
G	T
H	U
I	V
J	W
K	X
L	Y
M	Z

NASA Wavelength – Cassie Soeffing

Yellowstone National Park as a Hotbed for Inquiry - Dr. Shelley Olds

Taking the pulse of Yellowstone's "breathing" volcano: Problem-Based Learning in America's first national park

Denise Thompson. Revised by Nancy West and Shelley Olds.

Yellowstone National Park has an aura of magic. When it's mentioned, people's faces light up. Who doesn't treasure a memory of Yellowstone or dream of going there? In this activity you experience its sublime geology, flora, and fauna virtually as you solve a problem: you will use layers of earth science and cultural data to place a research station within the park, somewhere where it will be safe from volcanism, seismicity, and crustal deformation.

Objectives

With classmates, you will:

- identify a good spot to build a scientific research station in Yellowstone National Park;
- interpret historical and real-time scientific data about volcanic activity in the park;
- analyze the data to detect regions of high and low risk for volcanic hazards;
- define criteria for determining when the research station must be evacuated; and
- communicate your findings.

Problem:

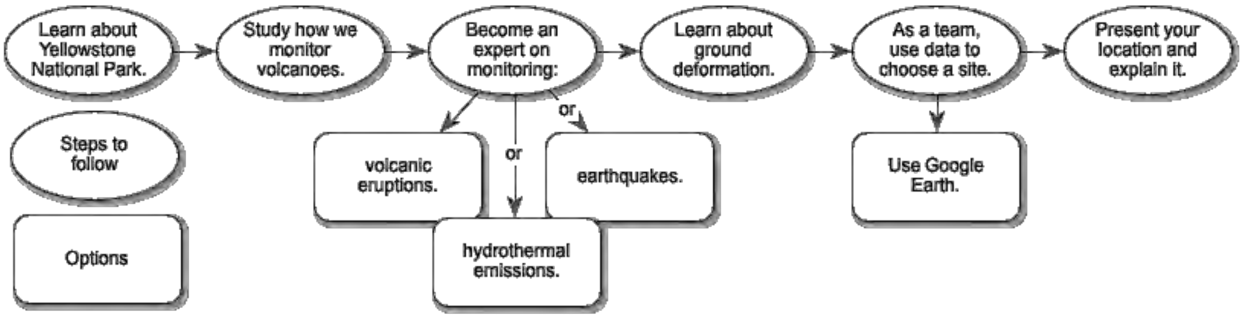
Congratulations! You are a private consultant, and you have just been awarded a $250,000 contract. A research group has preliminary approval to create a research station within Yellowstone National Park. The station is for scientists to live and work as they do research on geological features, flora and fauna, and weather and climate. They will stay at the station for as long as several months. Therefore, the station—or camp--will have

- bedrooms or bunkrooms for about 20 people;
- two laboratories, one for geologists and one for biologists to prepare and examine specimens;
- a kitchen;
- a dining room;
- a living room big enough for all 20 people to relax at the end of the day's work;
- covered porches;
- and a garage to store snowmobiles.

Figure 1. University of Colorado--Boulder Mountain Research Station. Photographer and date unknown.

Because the park is already in recreation heaven, there will be no need to build recreational facilities like a movie theater. The station needs to be located near an existing road but not visible from the main roads. Assume that the station will cover five to ten acres. How big is ten acres? An acre is about the size of a football field without the end zones. On the map at the end of these instructions, 10 acres would be a square about 0.2 mm on a side. If you made a dot with the sharpest pencil you could find, that dot would be larger than the field station's area.

Quick Overview of How You Will Tackle the Problem



First, you will decide where the camp should be. Plan for it to exist for at least a century, without disturbing animals or altering the astounding geological features that draw visitors.

To do this, you will learn about Yellowstone National Park and its geological setting—in volcanic calderas. All of you will learn about how we monitor volcanoes, using the 1980 eruption of Mount St. Helens as an example. Then you'll become an expert about volcanic eruptions, hydrothermal activity (and gas emissions), or earthquakes. Finally, all of you will learn about how the ground deforms.

With that knowledge, an expert from each group -- volcanoes, hydrothermal activity, and earthquakes—will join to form a team of three people who combine their expertise to locate the site for the camp. You will use Google Earth or paper maps to analyze your data to find the perfect site.

You will propose a location and explain why it is the best site within the park.

Also, you will develop guidelines to establish when the risk of an eruption is too high for scientists to stay at the camp. They must evacuate—according to your guidelines, or your "Safety Protocol."

Figure 2. "First" Picture of Old Faithful Eruption. William Henry Jackson, 1872.

Introduction

In your team of three, or as a whole class, review the presentation, "The Science of Prediction: Monitoring Volcanic Activity." This presentation shows you how scientists monitor volcanoes. You will see the kinds of measurements scientists made before Mount St. Helens erupted and are making now at volcano observatories in the United States. Yellowstone National Park hosts the Yellowstone Volcano Observatory.

Learning about the Yellowstone Supervolcano

Individually, you will become knowledgeable about Yellowstone's volcanic history or its earthquakes ("seismicity") or hydrothermal activity and volcanic gases. Each of the topics has a presentation.

Get together with classmates who are learning the same topic.

If you're using paper maps and transparencies, you'll want to record important information by hand. (The information might be where the big earthquakes occurred, for instance.) If you'll be using Google Earth to analyze your data, then pay attention to the slides about Google Earth.

Materials

1. Google Earth and instructions *or*
2. A map of Yellowstone NP (see last page of this handout: **Yellowstone National Park Base Map**); colored pencils or transparency pens; and transparency sheets
3. Graph paper or Excel/spreadsheet program
4. "Monitoring Yellowstone's Volcanic Activity" presentation on a computer or a printout.
5. Yellowstone GPS data set (Excel file or print version in the slides)
6. (optional) Real-time data (access to Internet or print copies)

Procedure

1. Based on your teacher's instructions, open your presentation,

Taking the Pulse of Yellowstone's "Breathing" Caldera—Eruptive History; or
Taking the Pulse of Yellowstone's "Breathing" Caldera—Seismic Activity; or
Taking the Pulse of Yellowstone's "Breathing" Caldera—Hydrothermal Activity.

These presentations describe the current and historical monitoring data at Yellowstone NP. Some slides will ask you to follow links to websites.

2. If you're using paper maps, as you follow along with the presentation, use the Yellowstone National Park Base Map on the last page of this document to record your data. You will need to make a key for your map like those you see on several of the slides. Consider making a draft copy of the map and then dress it up for a final clean copy. Also, discuss the relevant questions in the Analysis section with everyone who is learning the same thing.

3. Now return to your team and learn about GPS and ground deformation. You'll do this by working through another presentation,

"Taking the Pulse of Yellowstone's 'Breathing' Caldera—Ground Deformation."

You will graph the deformation data from four GPS locations. Draw the GPS locations and ID labels on your map.

You might also be graphing data from the "Deformation data--optional" data set, a larger set provided by your teacher. And, you might be exploring ground deformation data with Google Earth.

Data

Your data will be your labeled maps or Google Earth files and your graphs.

Analysis

Now you get to assemble what you've learned and decide where you propose building a research station. Refer to your maps or use Google Earth to look at the data as you think about and discuss with your teammates each of the following questions.

Volcanic eruption data

How often does the Yellowstone hot spot create a new caldera?

What types of volcanic eruptions are associated with Yellowstone?

How are these volcanic eruptions dangerous?

Where are the areas most prone to hazardous eruptions?

In your professional opinion, is there an immediate (next 100 years or so) danger related to volcanic eruptions at Yellowstone?

Hydrothermal activity data

In what way is hydrothermal activity dangerous?

Where would hydrothermal activity keep you from building a research station?

In your professional opinion, is there an immediate (next 100 years or so) danger related to hydrothermal activity at Yellowstone?

Figure 3. Castle Geyser, Upper Geyser Basin. Thomas Moran, undated.

Volcanic gases data

What gases are monitored at Yellowstone?

In what way are these gases dangerous?

Where are the areas that are most dangerous?

In your professional opinion, is there an immediate (next 100 years or so) danger related to release of volcanic gases at Yellowstone

Earthquake activity data

How are earthquakes dangerous?

How many modern day large (greater than magnitude 5) earthquakes have occurred at Yellowstone?

What is the most common magnitude of earthquakes recorded at Yellowstone?

Does the pattern of earthquakes at Yellowstone suggest movement of magma? (Remember the pattern at Mount St Helens.

Where would earthquakes most likely affect a research station?

In your professional opinion, is there an immediate (next 100 years or so) danger related to earthquakes at Yellowstone?

Ground deformation data

In what way could ground deformation be dangerous?

What patterns do you observe in the data?

Why might leveling data be different from GPS data? (Think about how and when each is measured.)

Does uplift or subsidence affect some areas more than others? Would this affect where you might put your research station?

In your professional opinion, is there an immediate (next 100 years or so) danger related to ground deformation at Yellowstone?

Conclusions

Read the problem on the first page again. Now, use either your paper maps or Google Earth, and what you've discussed in your group, to agree as a group upon the best place to build a five to ten acre research station.

Prepare Your Recommendations

How you do this depends on what your teacher assigns. For instance, you might make an oral presentation or write a paper or glossy brochure, or some combination of those. No matter what your assigned format is, you will want to:

Figure 4. Tourists Wading in Great Fountain. Artist unknown, 1908.

1. Restate the problem—remind the research group of what they are paying you to do.
2. Summarize your data—they don't have expertise or time. That's why they hired you. Explain to them what data you collected and what it means.
3. Make your recommendations—be specific as to where you think it is appropriate for research station to be.
4. Support your recommendations—explain why the spot you recommend is the best spot. Use specific details from your data. You should also describe any further data collection that you recommend.
5. Make your case in a conclusion by emphasizing the important points.
6. Persuade your classmates that yours is the best site for the research station.

Create guidelines for evacuation: Also, if you've been asked to do this, draft guidelines that will be used to decide if and when scientists (and tourists nearby) must be evacuated in order to keep them safe. How many guidelines and what kind of data you use is up to you. Consider saying something like, "If an earthquake swarm occurs and lasts for x months, then…." Or, if geysers in a geyser basin begin erupting unusually, then...." Or, "If heat values seen on LandSat images exceed x, then…." (The last refers to data visible on Google Earth.)

Image Sources

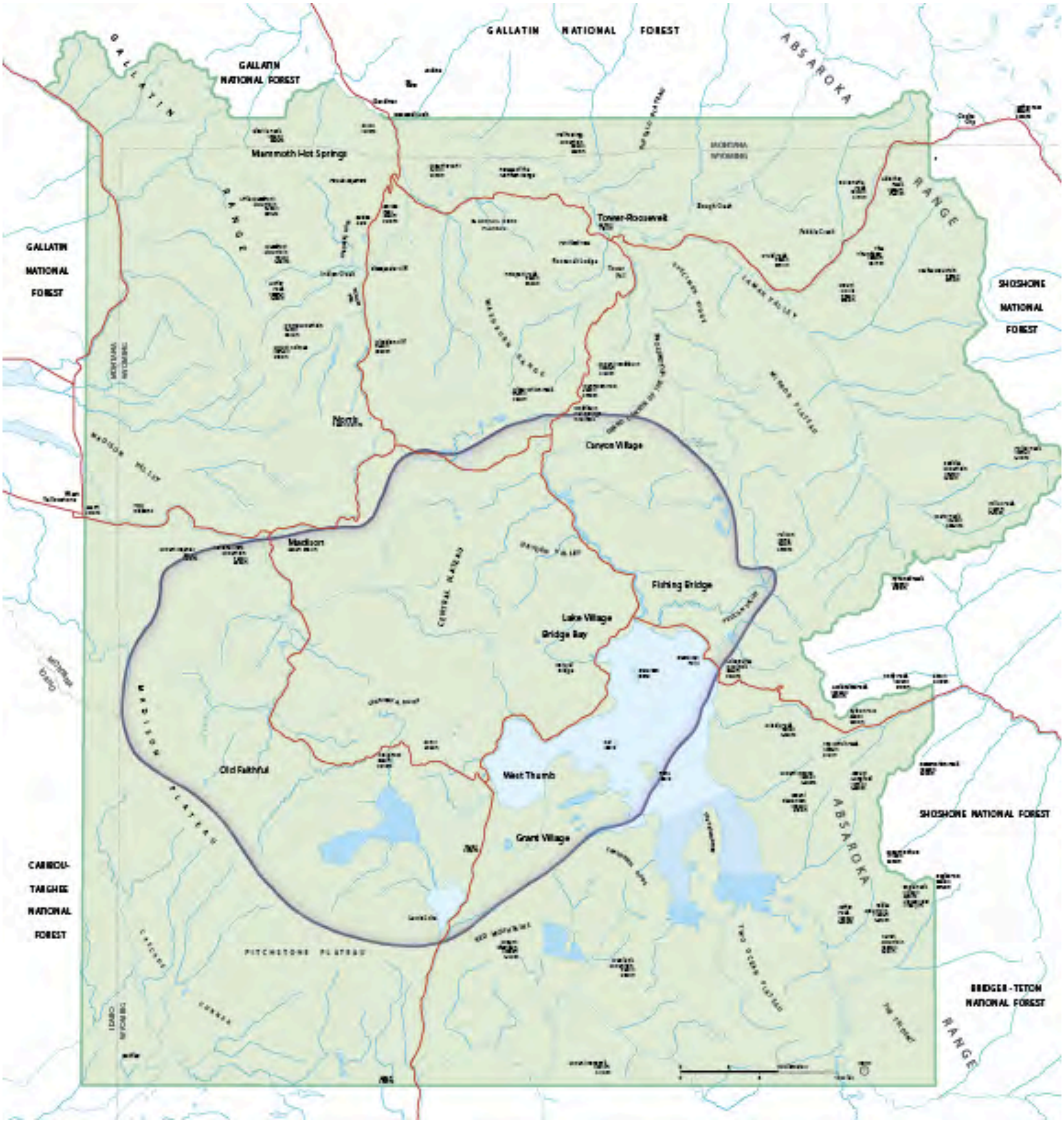
Figure 1. University of Colorado Mountain Research Station' Wildrose Dining Hall. Photo. Photographer unknown. Date unknown. http://www.colorado.edu/mrs/setting-facilities Retrieved 26 March 2012.

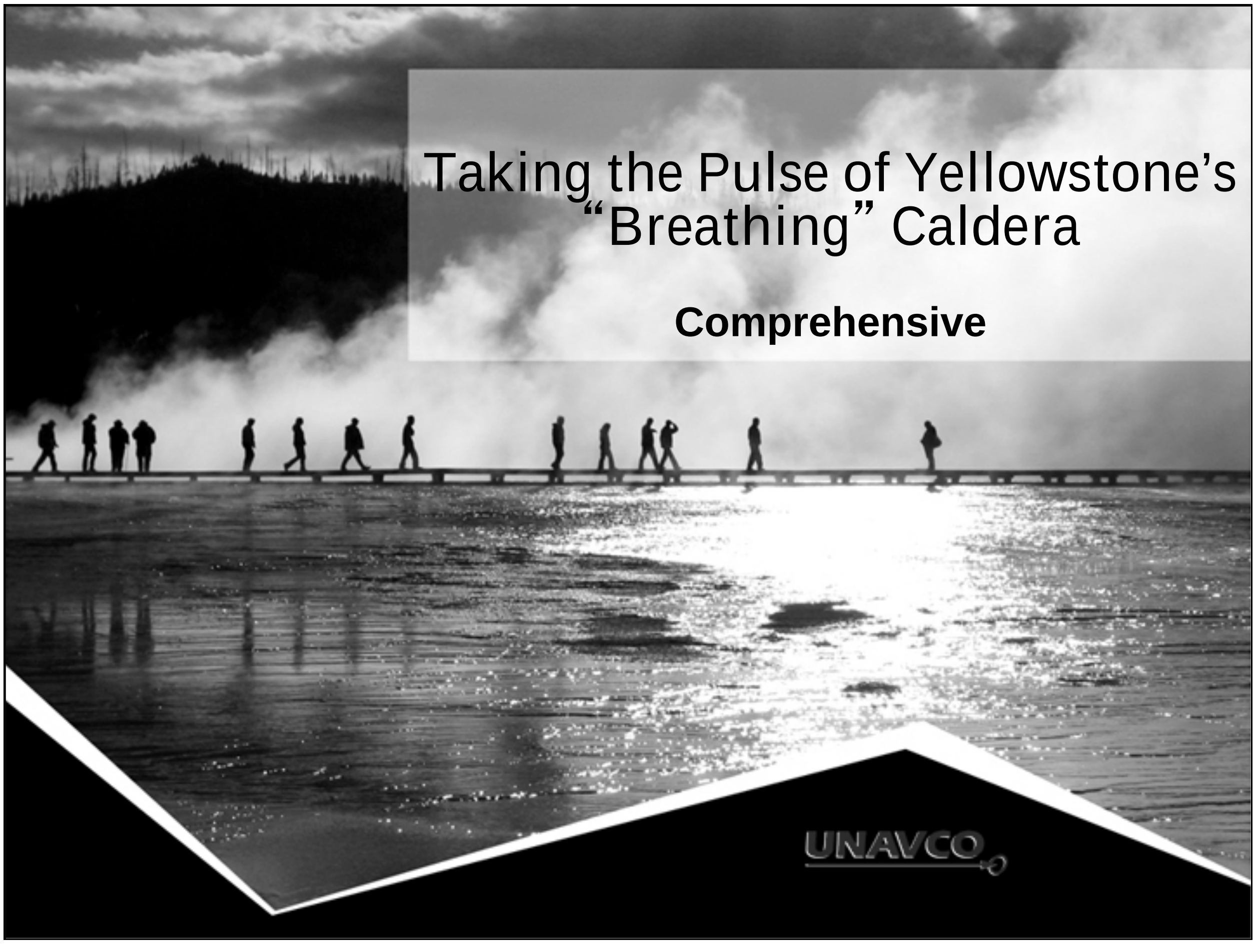
Figure 2. William Henry Jackson. "First" Picture of Old Faithful Eruption. Photograph. 1872. Yellowstone Digital Slide File k# 64,176. http://www.nps.gov/features/yell/slidefile/history/jacksonphotos/Page-2.htm Retrieved 24 March 2012.

Figure 3. Moran, Thomas. Castle Geyser, Upper Geyser Basin. Watercolor. No Date. Yellowstone Digital Slide File. http://www.nps.gov/features/yell/slidefile/history/moranandotherart/Page-1.htm Retrieved 24 March 2012.

Figure 4. Artist unknown. Tourists Wading in Great Fountain. Photograph. 1908. Yellowstone Digital Slide File. http://www.nps.gov/features/yell/slidefile/history/1872_1918/visitoractivities/Page.htm Retrieved 25 March 2012.

Yellowstone National Park Base Map





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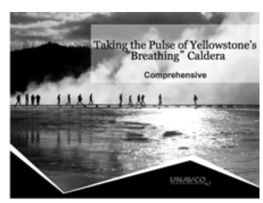
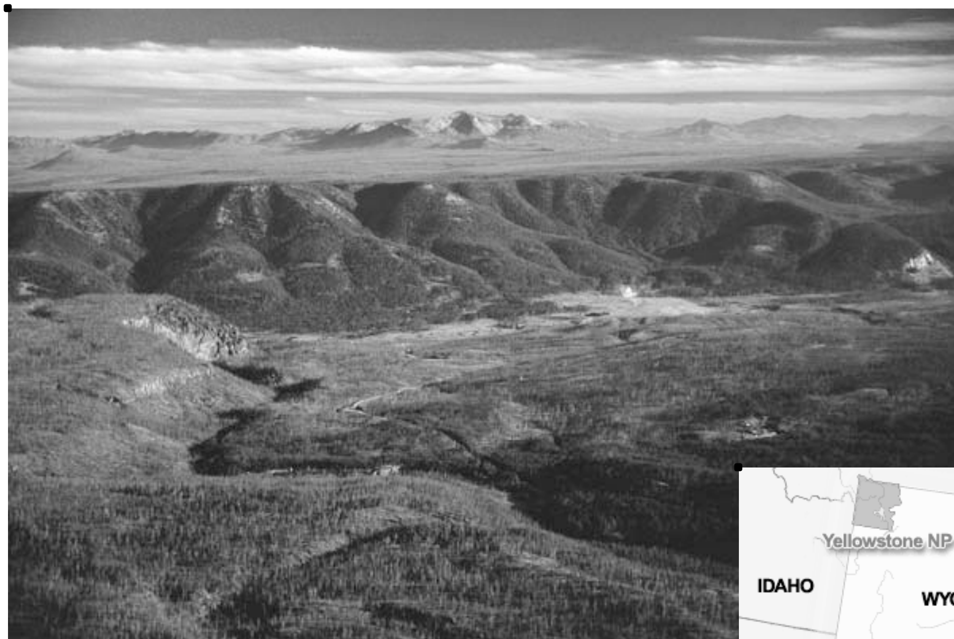
Notes for slide 1



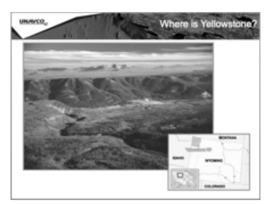
This presentation focuses on volcanoes and their side-effects in the Yellowstone region. First, you will view a seven minute video about volcanoes and hydrothermal features. To watch it, click anywhere on this slide. Then, you'll examine a few maps to see where Yellowstone National Park is and its significant features—geological as well as practical ones like roads and villages. Finally, you'll learn more about the history of eruptions in Yellowstone while your teammates learn more about earthquakes and hydrothermal systems.

The link to the video takes you to the American Museum of Natural History's Science Bulletin: "Monitoring the Fire Below." https://www.youtube.com/watch?v=rFe-VSf-TQ8 Retrieved 5 November 2014. (Search for "monitoring fire below youtube.")

Where is Yellowstone?



Notes for slide 3



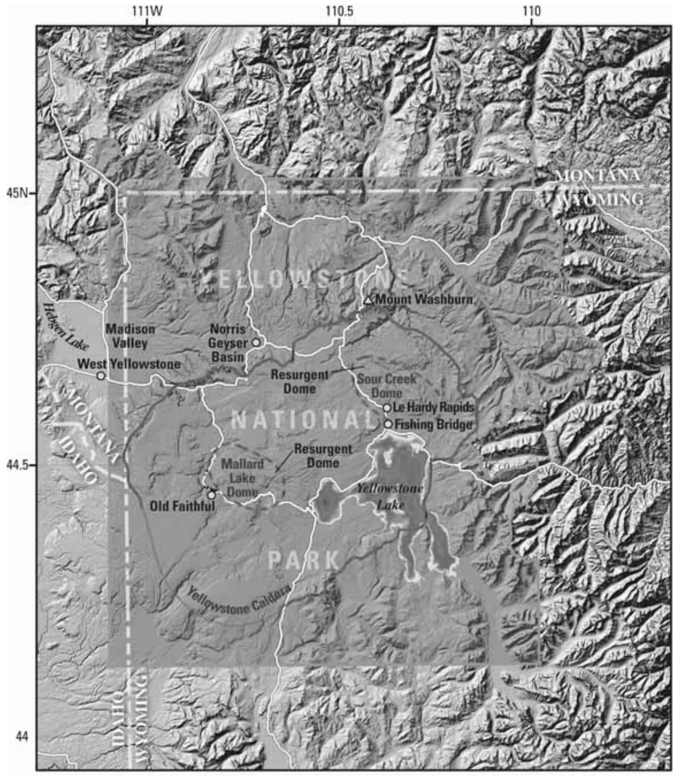
Yellowstone lies partially in three states -- Montana, Idaho and Wyoming.

Much of Yellowstone is a large crater (a “caldera”) that is surrounded by cliffs. The cliffs are topped by lava flows. This picture was taken from the top of a lava flow. The green bluffs below the mountains are the rim of the caldera. In the foreground are two lava flows.

Photo by Bob Smith, University of Utah. Accessed from National Science Foundation: Discovery. “Yellowstone Rising.” http://www.nsf.gov/discoveries/disc_images.jsp?cntn_id=110651&org=NSF Retrieved 27 December 2011.

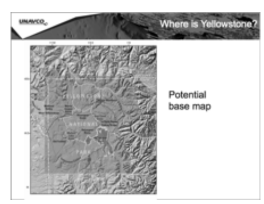
Map from National Park Service: “Yellowstone Location Map.” http://www.nps.gov/features/yell/interactivemap/yelllocationmap.htm Retrieved 27 December 2011.

What is Yellowstone?



Exploring the landscape

Notes for slide 5



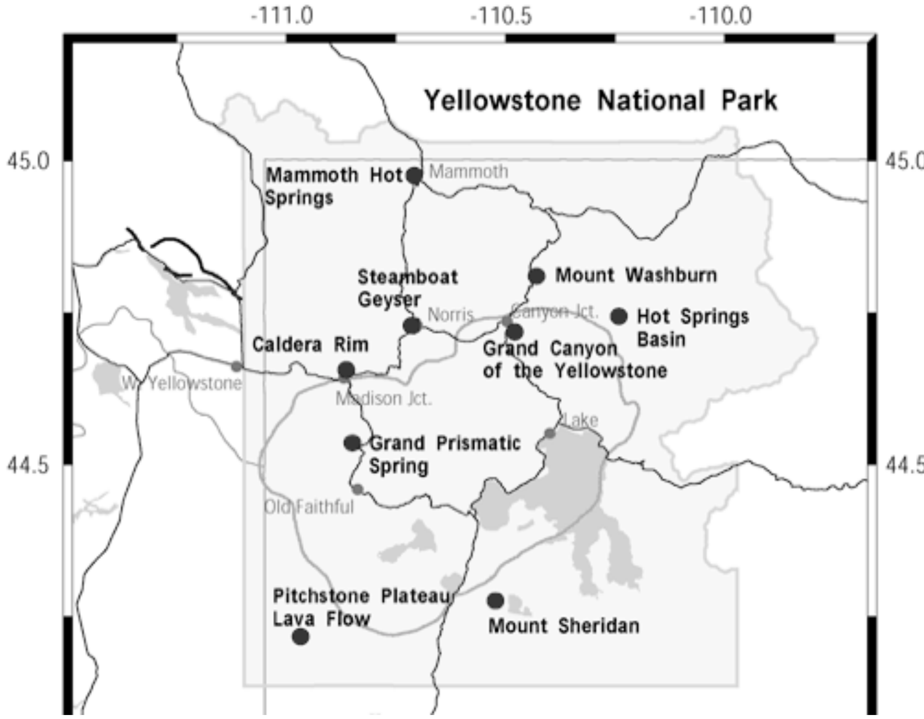
This image shows that the region is mountainous, but there is more subdued topography within most of the national park. The Yellowstone caldera, 640,000 years old, appears as a red-orange line. Where the line is thinner, geologists can only infer the caldera boundary. Volcanic material has filled the caldera and smoothed out the topography. Two later episodes of volcanism pushed up domes within the caldera: the Mallard Lake Dome and Sour Creek Dome.

The squiggly white lines are paved roads.

If you are doing this assignment with a paper map and transparent overlays instead of Google Earth, this map or the one on the next slide could serve as your base map. Your team of three experts will need to decide which map you will use. If you are using paper maps, you have a copy of the two maps in your instructions.

Image from USGS Fact Sheet 100-03. 2004. "Tracking Changes in Yellowstone's Restless Volcanic System." http://pubs.usgs.gov/fs/fs100-03/index.html#yellowstone_fig2 Retrieved 27 December 2011.

What is Yellowstone?



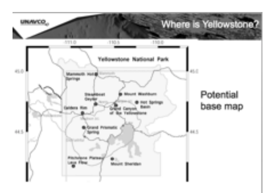
Exploring the landscape

Notes for slide 7

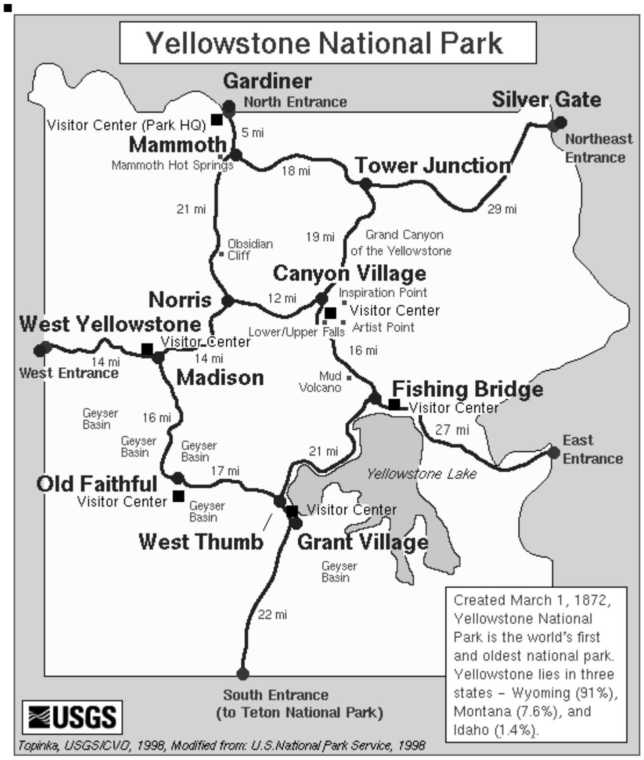
This map of Yellowstone shows roads as red lines and the location of the most recent caldera as a gold line. The park is the green area.

Red dots are links to photos and information about the park from the Yellowstone – Teton Epicenter's "Location Map." By clicking anywhere on the slide, you will open the webpage with live links on the red dots. http://www.yellowstonegis.utah.edu/maps/index.html. (Search for "yellowstone gis epicenter" and choose the maps link.

Image from Yellowstone – Teton Epicenter: "Location Map." http://www.yellowstonegis.utah.edu/maps/index.html Retrieved 28 December 2011.

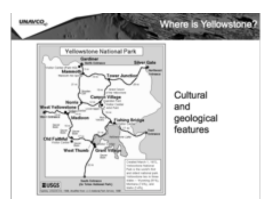


What is Yellowstone?



Cultural and geological features

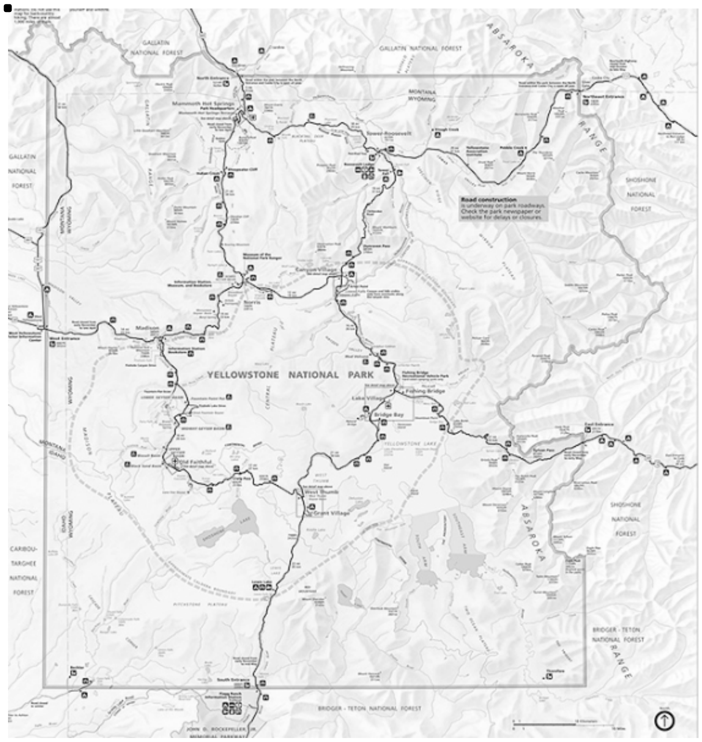
Notes for slide 9



This general map shows where some of the geological and cultural or tourist attractions are. These are where many visitors stop to look at sights, buy supplies, or stay the night. The next map shows more detail.

Map from USGS Cascade Volcano Observatory. http://vulcan.wr.usgs.gov/Imgs/Gif/Yellowstone/Maps/map_yellowstone.gif Retrieved 28 December 2011.

What is Yellowstone?



Cultural and geological features

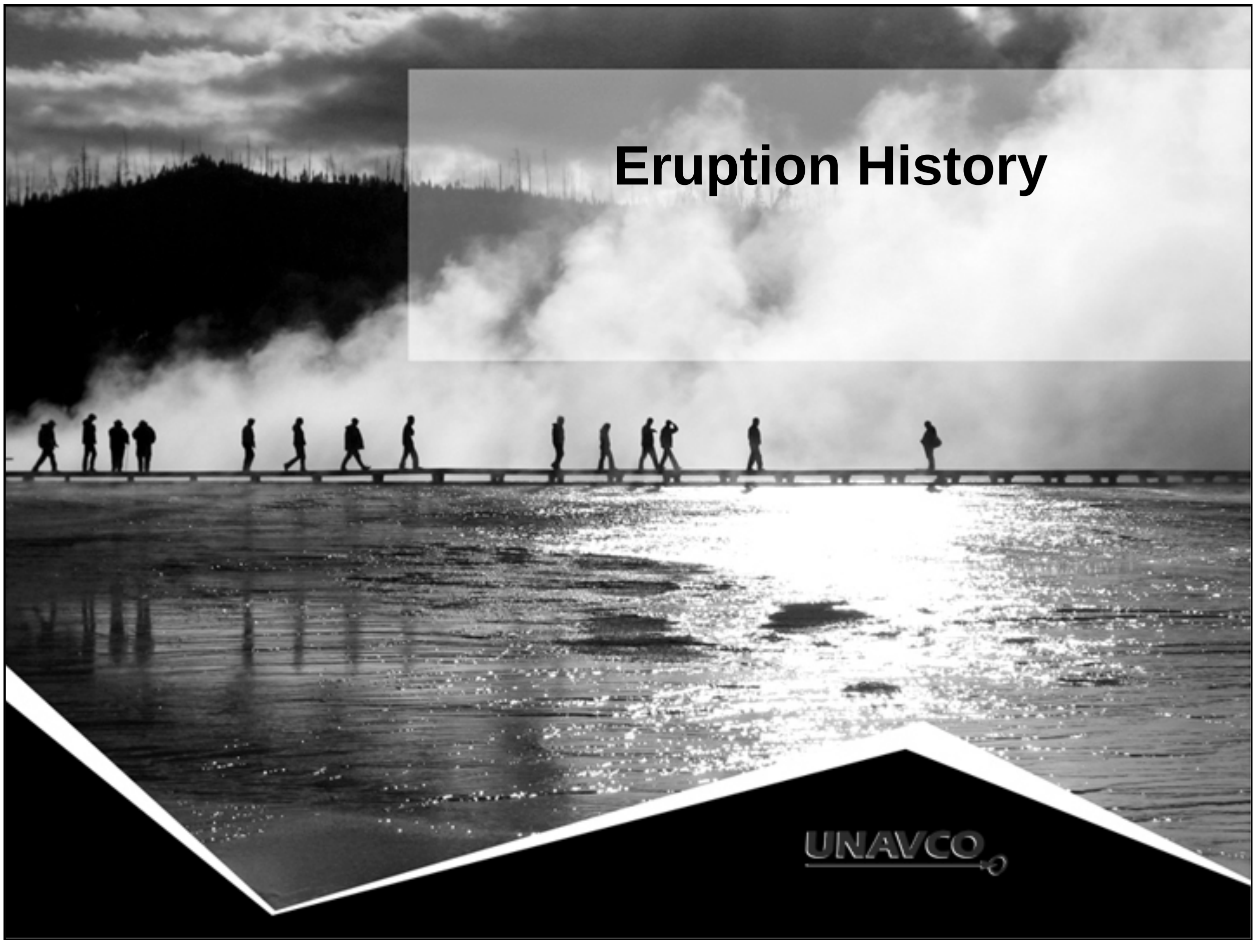
Notes for slide 11

This map shows details that you might want to refer to when learning your part of the geology. It is part of the map/brochure that the National Park Service gives visitors as they enter the park. You can view this map better by clicking anywhere on the map and then being patient….there's a lot of data to open. http://www.nps.gov/hfc/carto/PDF/YELLmap1.pdf (Search for "Yellowstone detail yellmap1.")

The base map that you will draw on is a simplified version of this map.

Image from National Park Service: Park Map Viewer. http://www.nps.gov/pwr/customcf/apps/maps/showmap.cfm?alphacode=yell&parkname=yellowstone%20national%20park Retrieved 28 December 2011.

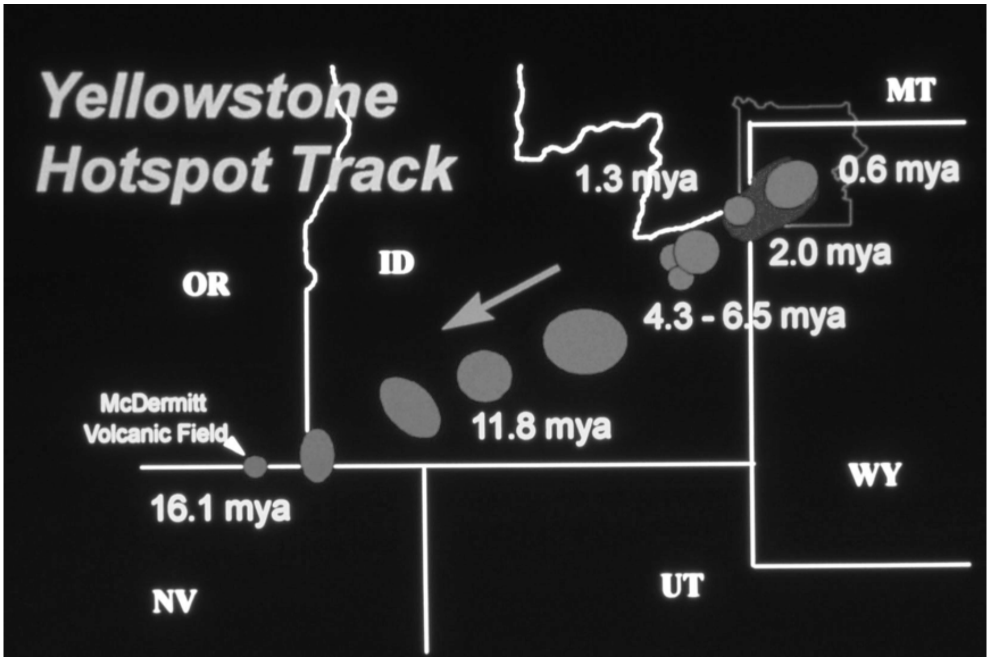
Eruption History



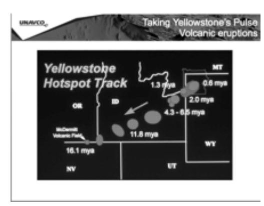
Use the Yellowstone National Park Base Map to record your data.

You will need to make a key for your map like those you see on several of the slides.

Taking Yellowstone's Pulse
Volcanic eruptions



Notes for slide 15



Yellowstone is one of the largest and most active calderas in the world. Eruptions in Yellowstone started about 2.3 million years ago. But, they follow a string of eruptions in the region that has left a path of calderas. Click on this slide and then on "Interactive: A Hotspot Trail" on the webpage to explore an animation of volcanism moving across the region over time.

The center of volcanism has moved because the North American plate is moving over a "hotspot" in the mantle that produces magma by melting rocks in the crust. The light blue arrow shows the direction that the North American plate is moving compared to the (almost) stationary hot spot.

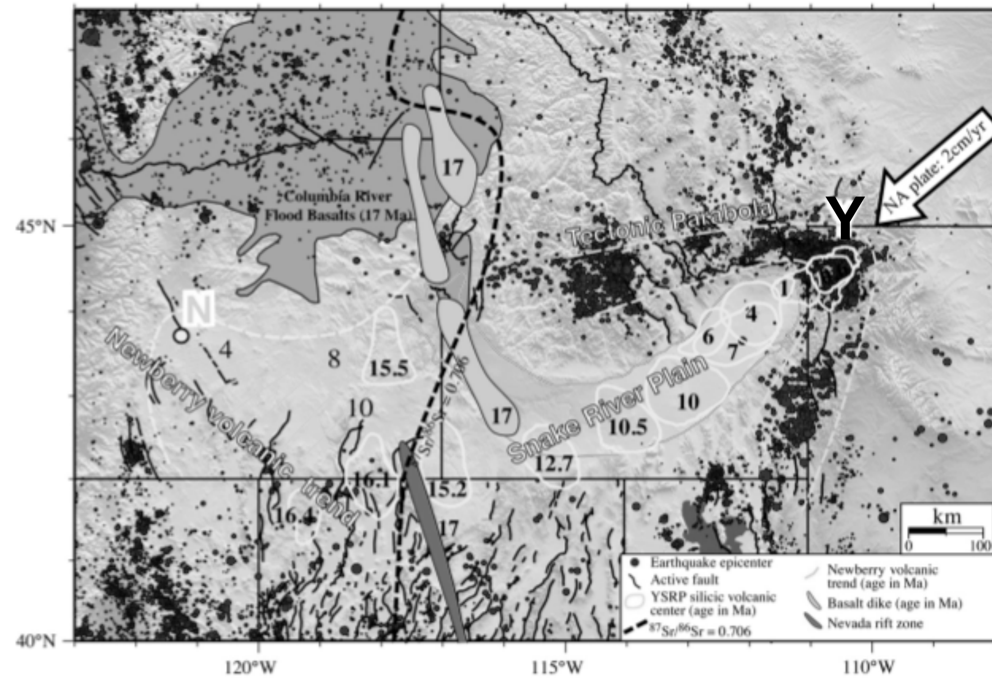
"Mya" stand for "million years ago." That is when the hotspot was active there. For instance, the McDermitt Volcanic Field had volcanoes erupting 16.1 million years ago.

Between the caldera-forming events (three in Yellowstone), other lava eruptions and hydrothermal eruptions occurred. The topography of the older craters is quite flat because of millions of years of erosion and burial by other volcanic events such as the Snake River Plain flood basalts.

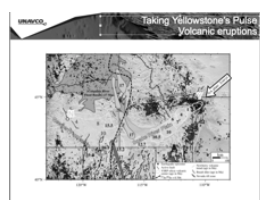
http://www.amnh.org/explore/science-bulletins/earth/documentaries/yellowstone-monitoring-the-fire-below/interactive-a-hotspot-trail (Search for "amnh hotspot trail.")

Image from Yellowstone's Photo Collection. "Yellowstone Hot Spot Track." http://www.nps.gov/features/yell/slidefile/graphics/diagrams/Images/15899.jpg Retrieved 12 November 2014.

Taking Yellowstone's Pulse
Volcanic eruptions



Notes for slide 17



Look for the large yellow and white Y by the big white and black arrow. That is where the Yellowstone hot spot currently lies deep under the surface.

The rest of the map *is* certainly complicated but it shows the science behind the animation you explored in the previous slide. The black numbers show the ages of volcanic rocks west of Yellowstone in millions of years. 15.5, for instance, stands for rocks that are 15.5 million years old.

The red dots show where earthquakes were first felt on Earth's surface (the "epicenters.") Look at the legend to see what the other symbols represent.

This figure compiles the work of many geologists and is published in a scientific research journal. It's this kind of article, and the research that goes into it, that allowed the American Museum of Natural History to build the animation you explored on the previous slide.

Figure from Smith, R.B.; Jordan, M.; Steinberger, B.; Puskas, C.M.; Farrell, J.; Waite, G.P.; Husen. S.; Chan, W-L; and O'Connell, R.. 2009. "Geodynamics of the Yellowstone hotspot and mantle plume: Seismic and GPS imaging, kinematics, and mantle flow." Journal of Volcanology and Geothermal Research. v. 188. pp 26–56. Retrieved 29 December 2011.

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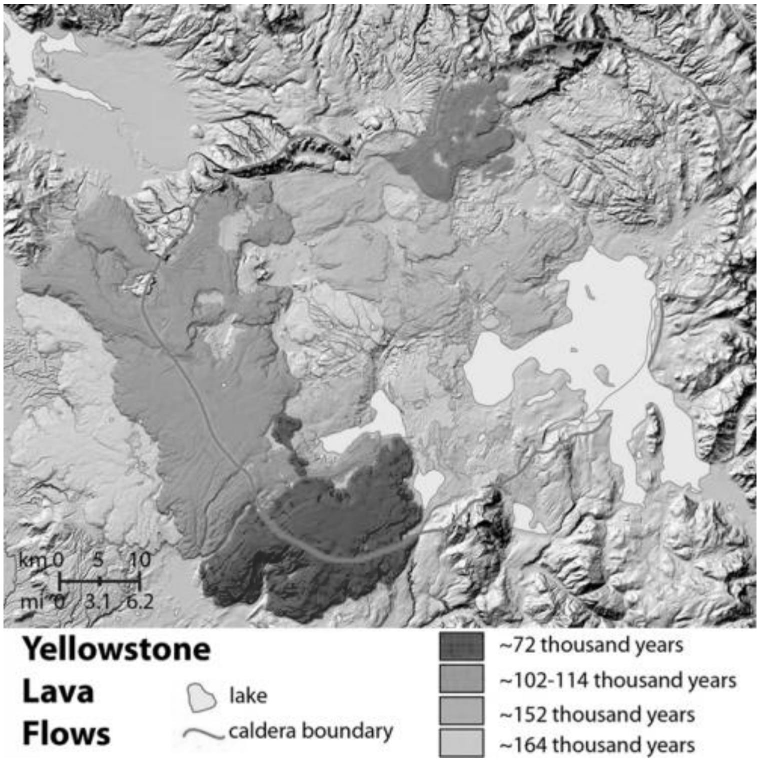
Taking Yellowstone's Pulse
Lava flows



Volcanic rocks erupted after caldera collapsed

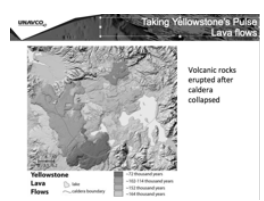
UNAVCO

Notes for slide 19

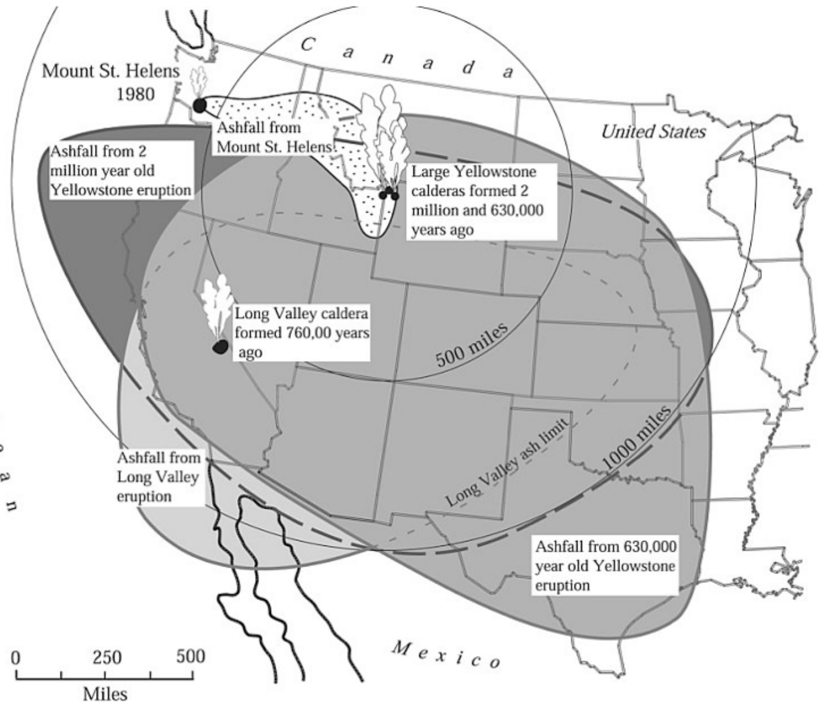
There have been about 80 lava flows since the most recent caldera formed 640,000 years ago. This map uses color to show different ages of the rocks, both inside and outside the caldera.

Clicking on the map links to The American Museum of Natural History's Science Bulletin. Select the "Different magmas - Different volcano" interactive link on this page to investigate the relationship between the different kinds of lava and volcanoes. http://www.amnh.org/explore/science-bulletins/earth/documentaries/yellowstone-monitoring-the-fire-below/interactive-different-magmas-different-volcanoes (Search for "amnh different magmas.")

Image from USGS Volcano Hazards Program: Yellowstone Volcano Observatory. Yellowstone maps. http://volcanoes.usgs.gov/volcanoes/yellowstone/yellowstone_gallery_14.html Retrieved 6 November 2014.

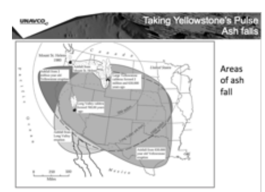


Taking Yellowstone's Pulse
Ash falls



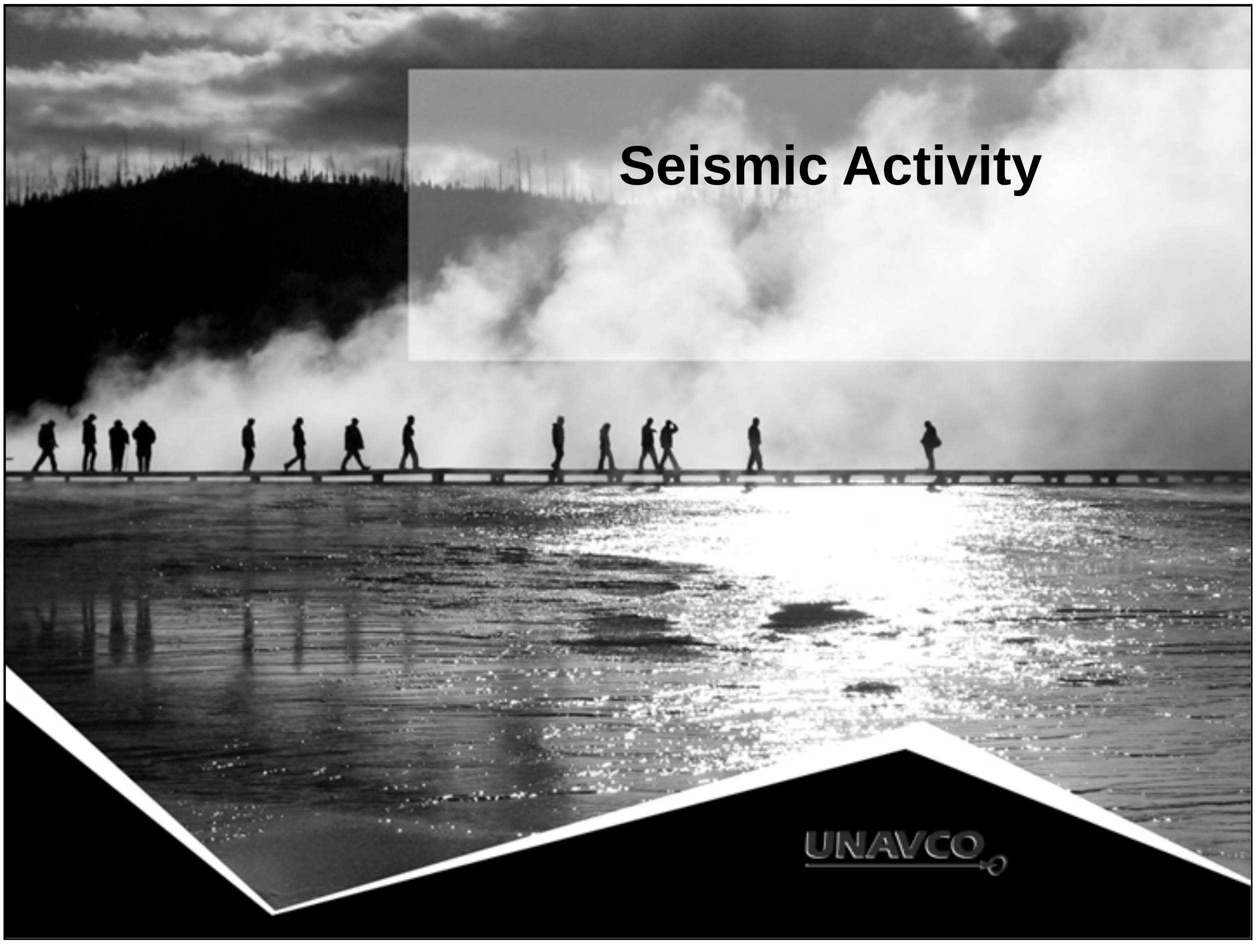
Areas of ash fall

Notes for slide 21



The collapse of calderas is cataclysmic. Rocks and lava explode upward and outward as the caldera collapses, and the debris covers huge regions. This map shows how far volcanic ash went during the 2,100,000 and 630,000 year-old eruptions that led to calderas in Yellowstone.

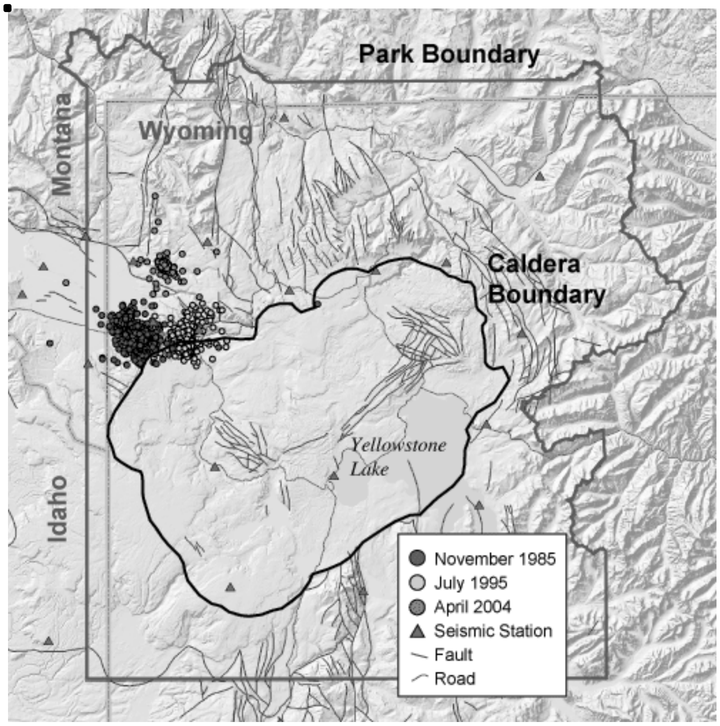
Figure from Smith, R.B. and Seigel, L.J. 2000. Windows into the Earth, The Geologic Story of Yellowstone and Grand Teton National Park. Oxford University Press. Accessed from the Yellowstone Volcano Observatory. http://volcanoes.usgs.gov/yvo/images/2000-rbs-3.2volcanicashcover_large.jpg Retrieved 30 December 2011.



UNAVCO

Use the Yellowstone National Park Base Map to record your data.

You will need to make a key for your map like those you see on several of the slides.

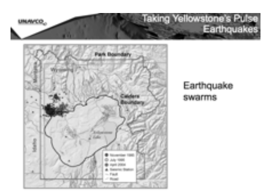


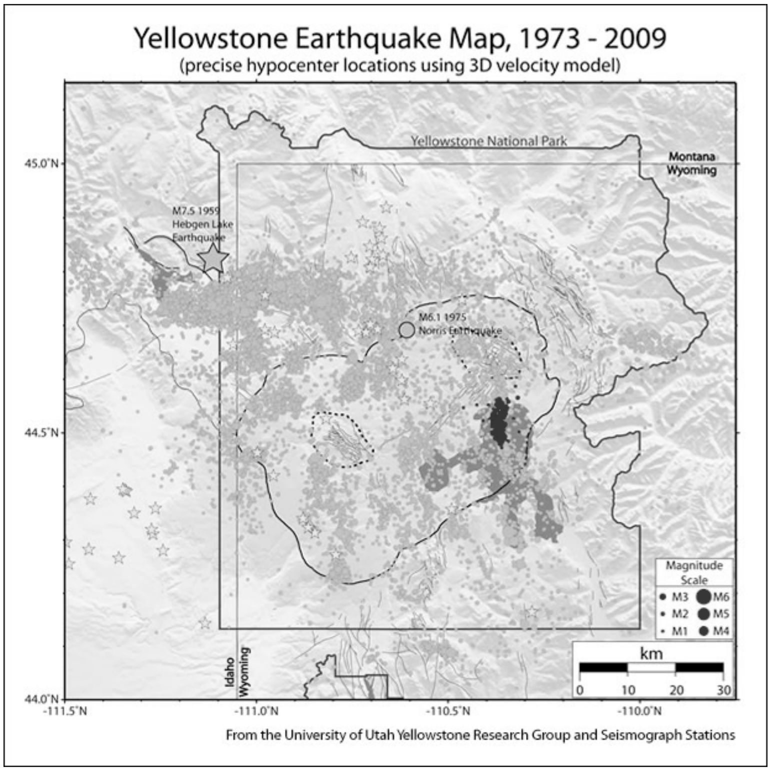
Earthquake swarms

Earthquake swarms from 1985 to 2004 are shown on this map. Colored dots stand for different periods of time, as shown in the key. The black line marks the caldera boundary.

Map from Yellowstone Volcano Observatory: Yellowstone Earthquake Swarms.

http://volcanoes.usgs.gov/yvo/publications/2004/apr04swarm.php Retrieved 30 December 2011.





36 years of earthquakes

This map shows the locations of earthquake epicenters. In the 36 years of records shown here, there have been only 2 major earthquakes:

1959 7.5 Hebgen Lake earthquake, marked with a grey star; and
1975 6.5 Norris Geyser Basin, marked with a large grey circle.

Red circles mark earthquakes that occurred in a swarm in 2008. Small grey circles mark other earthquakes. Yellow stars are volcanic vents.

Map from Yellowstone Volcano Observatory: More Yellowstone Lake Earthquake Swarm Images.
http://volcanoes.usgs.gov/yvo/publications/2009/moreswarm.php
Retrieved 30 December 2011.

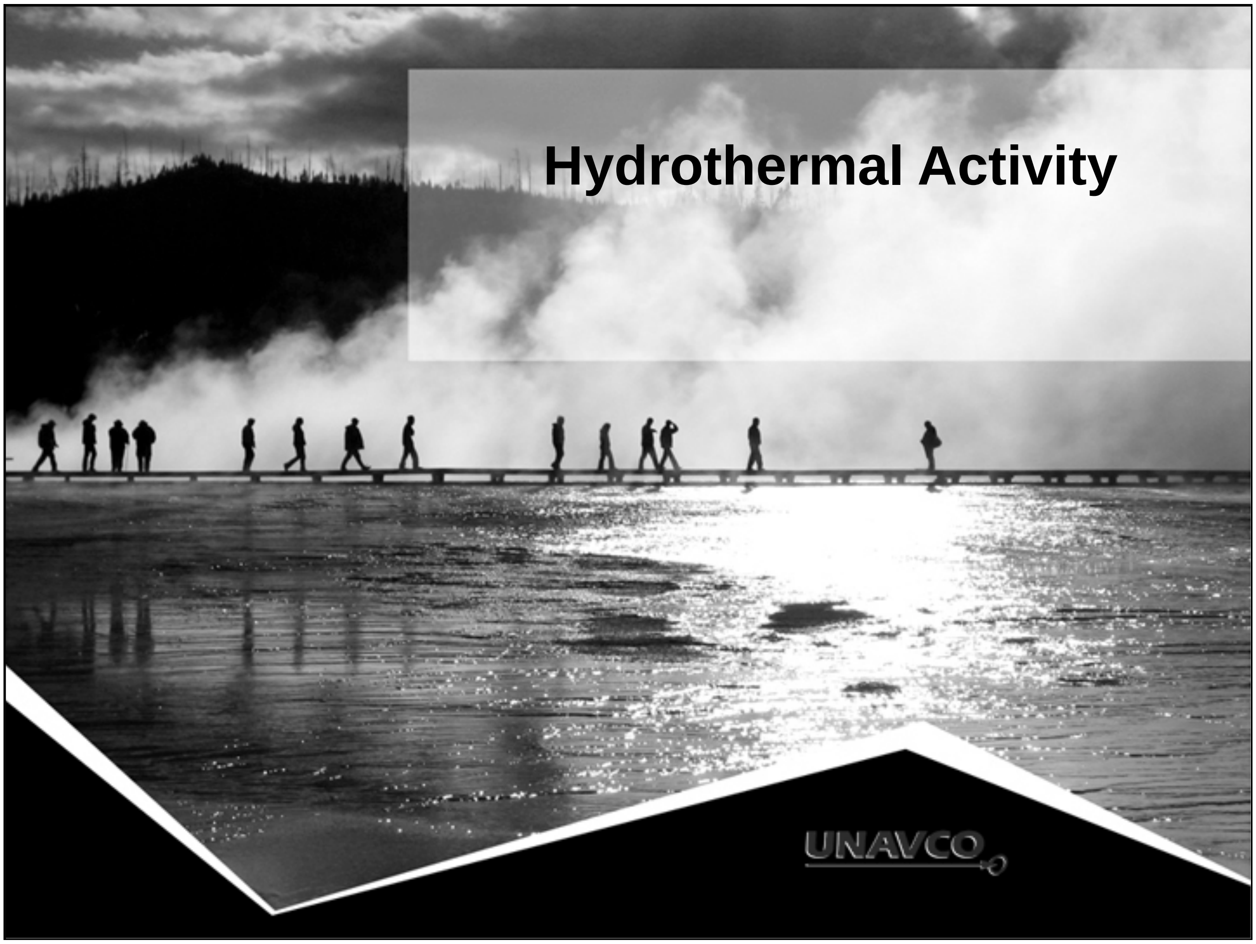
Other resources:

Data

- Recent earthquake activity (7 day)
  http://www.seis.utah.edu/req2webdir/recenteqs/Maps/Yellowstone.html (Search for "recent earthquakes yellowstone.")
- Live seismograms
  http://quake.utah.edu/helicorder/yell_webi.htm (Search for "earthquake helicorder yellowstone.")

Use these links to update your maps with the most recent earthquake information.


Taking Yellowstone's Pulse
Student resources
Other resources:
Data
Recent earthquake activity (7 day)
Live seismograms

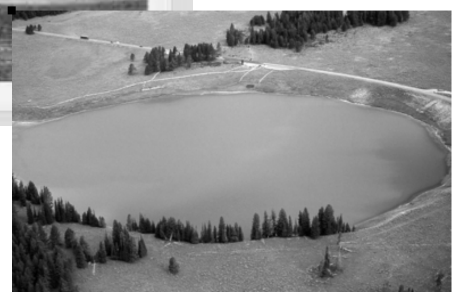


Use the Yellowstone National Park Base Map to record your data.

You will need to make a key for your map like those you see on several of the slides.

UNAVCO

Taking Yellowstone's Pulse
Hydrothermal explosions



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Notes for slide 33

The left-hand image is an old postcard of a hydrothermal explosion at Excelsior geyser in 1888. In the 1880's to 1890's Excelsior Geyser, in Midway Geyser Basin, had a series of explosions. (Note that the date on the postcard is wrong.) Unlike volcanic eruptions, hydrothermal explosions are from pressurized water exploding out of the ground—not lava.

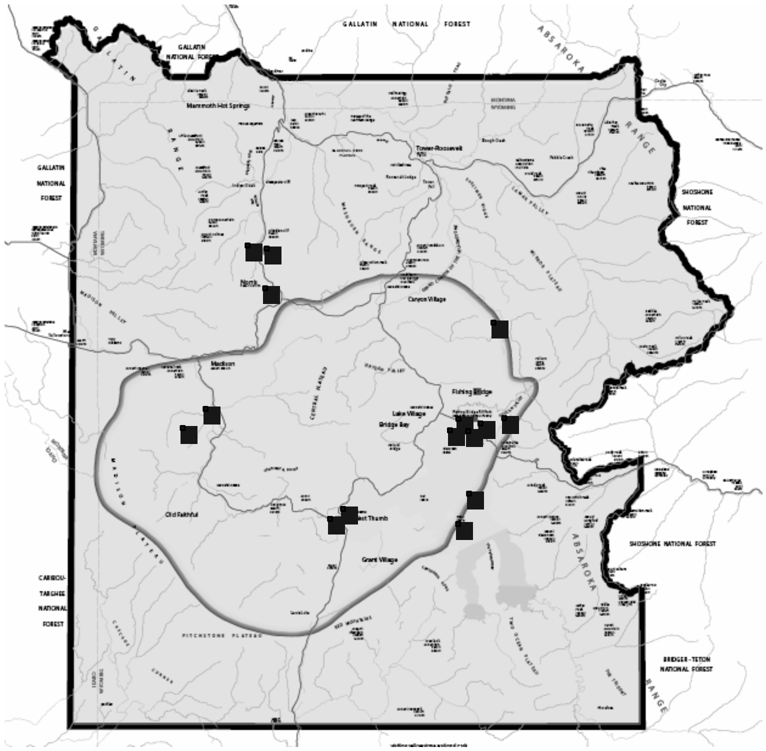
The right-hand picture is of Indian Pond, which is a crater made by a hydrothermal explosion in Yellowstone. The crater has since filled with water.

The largest hydrothermal-explosion crater in the world is located on the northern edge of Yellowstone Lake. There are more than a dozen large hydrothermal-explosion craters between Norris Geyser Basin and Mammoth Hot Springs. And, as recently as 1989, Porkchop Geyser exploded. You can learn much more by clicking on the postcard. http://yellowstone.net/geology/steam-explosion/ Retrieved 17 November 2014. (Search for "porkchop steam explosion.")

Postcard from Haynes, KF.J. 1888. Accessed from U.S. Geological Survey Fact Sheet 2005-3024. 2005. "Steam Explosions, Earthquakes, and Volcanic Eruptions—What's in Yellowstone's Future?" http://pubs.usgs.gov/fs/2005/3024/ Retrieved 31 December 2011.

Photo from Peaco, J. 2001. National Park Service: Yellowstone Digital Slide File: Thermal Explosions: 17244. http://www.nps.gov/features/yell/slidefile/thermalfeatures/thermalexplosions/Page.htm Retrieved 30 December 2011.

Taking Yellowstone's Pulse
Hydrothermal explosions

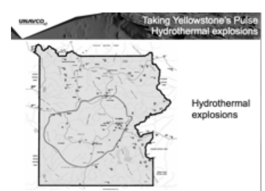


Hydrothermal explosions

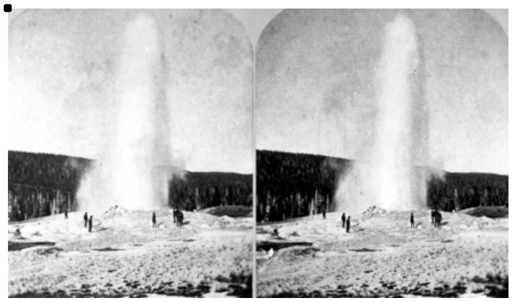
Notes for slide 35

Look for the dark blue squares that mark where scientists find evidence for hydrothermal explosions. (Red lines are roads; the grey oval is the caldera.)

Data from USGS Fact Sheet 2005-3024. 2005. "Steam Explosions, Earthquakes, and Volcanic Eruptions—What's in Yellowstone's Future?" http://pubs.usgs.gov/fs/2005/3024/ Retrieved 30 December 2011.



Old Faithful



Notes for slide 37

Old Faithful is probably the most famous geyser in the world, gathering an international audience even in winter to watch it erupt next to the Old Faithful Inn. The photos on the left were taken in 1872 by the famous photographer William Henry Jackson. He worked for the "Hayden Survey," the first official survey of Yellowstone, led by Ferdinand V. Hayden. Jackson and the painter Thomas Moran produced images that were essential for bringing the marvels of Yellowstone into the public eye—and into Congress's eye. The pair of images are slightly offset from each other so that viewers could see Old Faithful in 3D using a stereopticon.

When you click on the 1872 photos, you will be taken to a streaming webcam of Old Faithful. This can take a minute or more to load. http://www.nps.gov/features/yell/webcam/oldFaithfulStreaming.html Retrieved 16 November 2014. (Search for "old faithful geyser webcam.")

When you click on the modern color photograph, you will be taken to a webcam at Old Faithful and several other sites in Yellowstone. (Be patient) http://volcanoes.usgs.gov/volcanoes/yellowstone/yellowstone_multimedia_10.html Retrieved 7 November 2014. (Search for "YVO webcam.")

Left-hand image from Jackson, W.H. 1872. US Geological Society Photographic Library. ID. Jackson, W.H. 1572. http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Jackson,%20W.H.%201572 Retrieved 31 December 2011.

Right-hand image from National Park Service: Yellowstone Digital Slide File. Upper Geyser Basin: 05205. 1964. http://www.nps.gov/features/yell/slidefile/thermalfeatures/geysers/upper/Page-6.htm Retrieved 31 December 2011.

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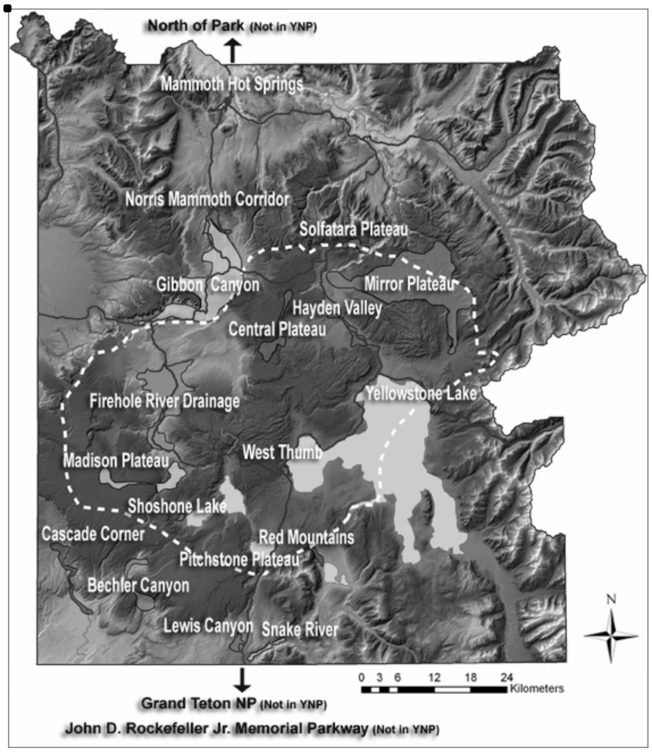
Taking Yellowstone's Pulse
Hydrothermal activity



Regions of geysers, volcanic vents, and mudpots

UNAVCO

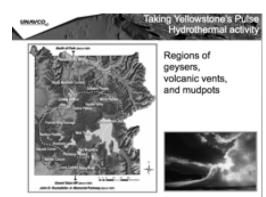
Notes for slide 39

Yellowstone has over 10,000 water and hydrothermal features. Hydrothermal regions are labeled on this map in white letters. Clicking on the map links to a website that details the geysers and fumaroles and mudpots known to researchers at Montana State University and the National Park Service. Click on a balloon to zoom into a thermal region. By continuing to zoom, you can learn about individual features. http://www.rcn.montana.edu/Default.aspx Retrieved 7 November 2014. (Search for "rcn montana yellowstone.")

The photo is of Great Fountain Geyser, in the Lower Geyser Basin.

Left-hand image from the Research Coordination Network: YNP Thermal Features. http://www.rcn.montana.edu/resources/features/features.aspx?nav=11&map=81 Retrieved 31 December 2011.

Right-hand image from Schmidt, H. 1977. Yellowstone Digital Slide file: Midway & Lower Geyser Basins: 06675. http://www.nps.gov/features/yell/slidefile/thermalfeatures/geysers/midwaylower/Page-3.htm Retrieved 31 December 2011.



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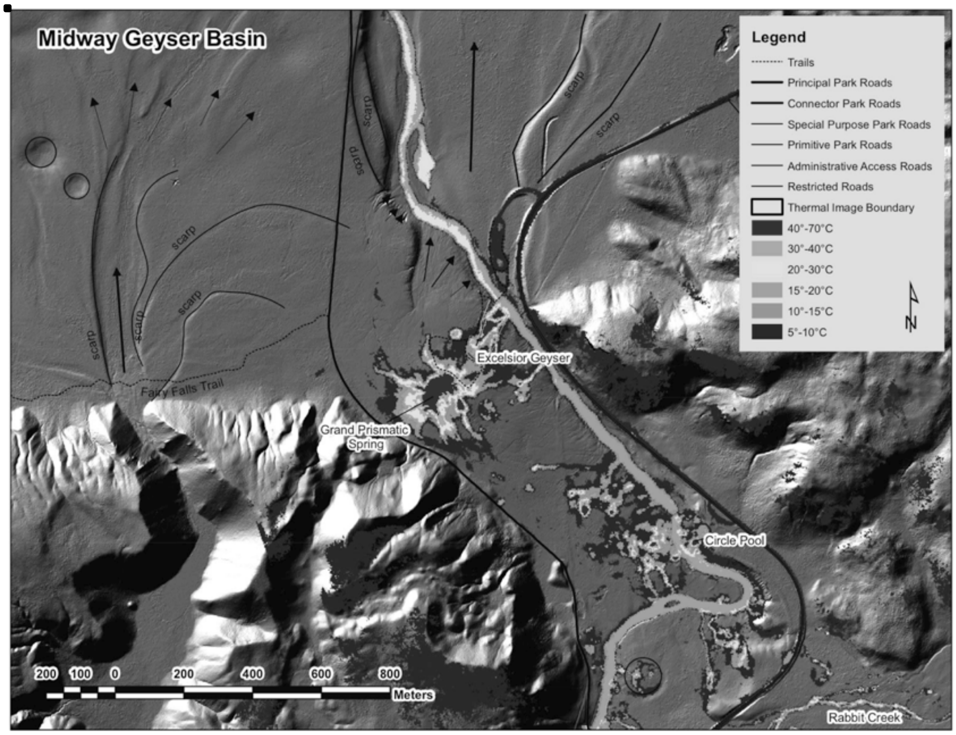
Taking Yellowstone's Pulse
Hydrothermal activity

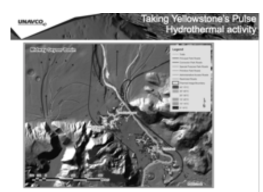


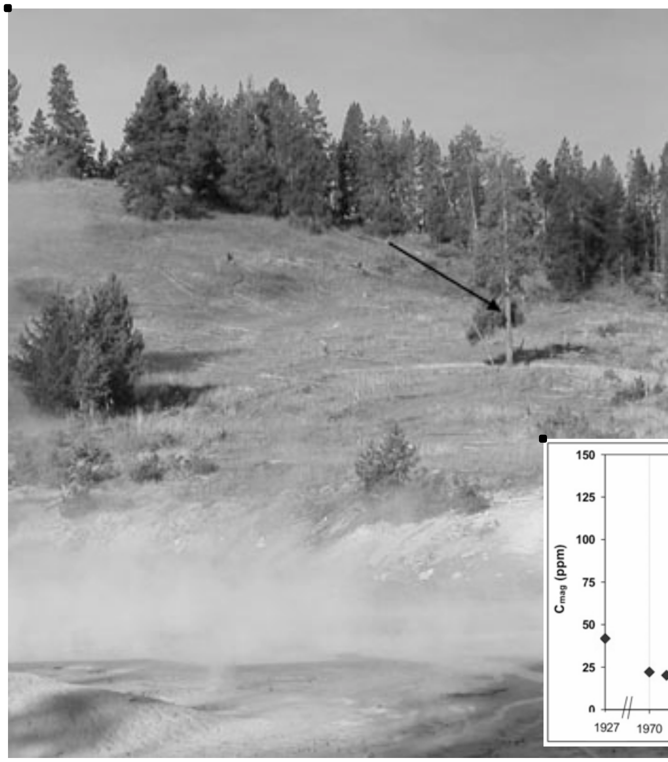
UNAVCO

Notes for slide 41

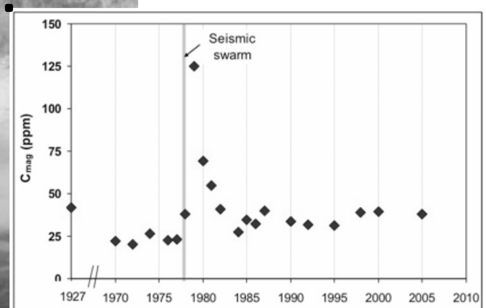
We can also now view hydrothermal features with infrared cameras on airplanes. The technology is called Forward Looking InfraRed (FLIR) and is suited perfectly for Yellowstone and other volcanic areas.

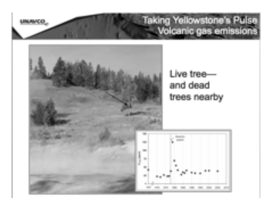
Image from Jaworowski, C.; Heasler, H.P.; Neale, C.M.U.; and Sivarajan, S. 2010. "Using Thermal Infrared Imagery and LiDAR in Yellowstone Geyser Basins," Yellowstone Science, v. 18, no. 1, pp. 8-19. Accessed from from Yellowstone Volcano Observatory: "New technologies help characterize hydrothermal activity at Yellowstone." http://volcanoes.usgs.gov/yvo/publications/2010/jaworowski.php Retrieved 31 December 2011.





Live tree—and dead trees nearby



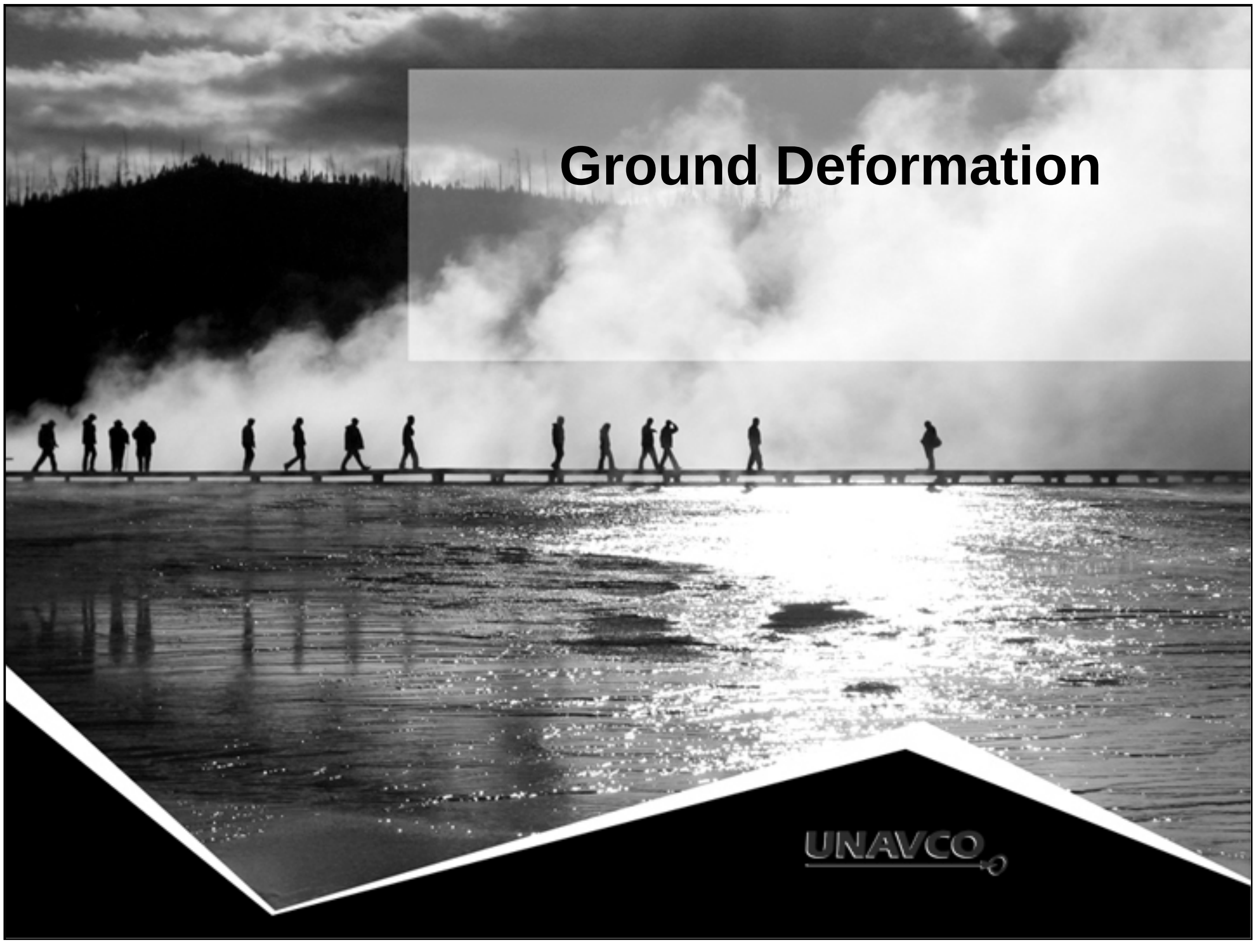


Volcanic gases can be unsafe to sample. However scientists can use other sign that the ground has emitted volcanic gas. The arrow in the photo points to a tree at Cooking Hillside, just north of Yellowstone Lake. Scientists sampled a core of its wood to measure its carbon content. The graph shows the results of the measurements. The spike in 1978 is associated with a swarm of earthquakes. Click on the graph to learn more. http://volcanoes.usgs.gov/volcanoes/yellowstone/yellowstone_monitoring_85.html (Search for "yvo gassy link.")

The dead trees around the live one were killed by heat. Other tidbits are that:

- 1897. Eight bears were found dead near "Death Gulch" (southeast of the park boundary) from carbon dioxide (CO_2) or hydrogen sulfide (H_2S) poisoning. These gases are heavier than air and tend to stay near the ground especially on windless cold nights.
- 2003. Several new vents that release volcanic gases were found in Norris Geyser Basin. These are called "fumaroles."
- 2004. Five bison were found dead in the Norris Geyser Basin, probably from CO_2 or H_2S poisoning.
- Only one human has died due to gases in Yellowstone.
- CO_2 is released in small amounts from virtually all of Yellowstone's hydrothermal features.

Images from Evans, W.C.; Bergfeld, D; McGeehin, J.P.; King, J.C.; and Heasler, H. 2010. "Tree-ring ^{14}C links seismic swarm to CO_2 spike at Yellowstone, USA," Geology v.38, p. 1075-1078. Accessed from Yellowstone Volcano Observatory: "New Study Reveals Gassy Link to Past Earthquake Swarm." http://volcanoes.usgs.gov/yvo/publications/2011/11cookinghillside.php Retrieved 31 December 2011.



UNAVCO

Use the Yellowstone National Park Base Map to record your data.

You will need to make a key for your map like those you see on several of the slides.

UNAVCO

Taking Yellowstone's Pulse
Ground deformation

Measuring deformation in ancient times

UNAVCO

Notes for slide 47

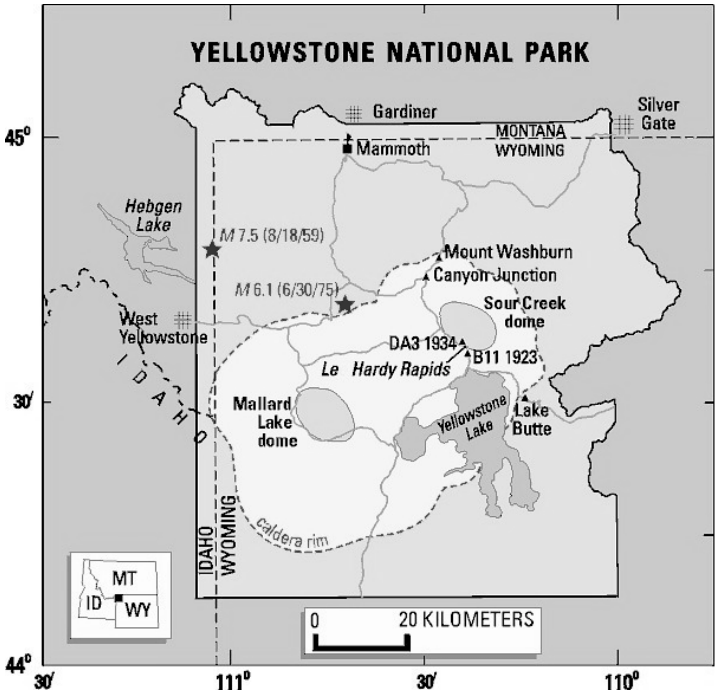
At Yellowstone, scientists began monitoring changes in ground level in 1923 using old-fashioned surveying equipment like that seen in the photos. This was decades before GPS was invented. They continued surveying this way until 1996. They had to survey every year, a time consuming task, but in gorgeous surroundings.

Scientists measured distance and elevation between points on "leveling lines." The photos show scientists surveying leveling lines in 1905 and 1981. The black and white photo is of scientists on Mount Whitney, California, at 14,500 feet elevation. The color one is of geologists working in the crater of Mount St. Helens on 6 November 1981.

Right-hand image from Department of Agriculture, Experiment Stations, Berkeley. 1905. US Geological Society Photographic Library. "ID. Topography A 240." http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Topography%20A%202402 Retrieved 2 January 2012.

Left-hand photo from Topinka, L. 1981. USGS. U.S. Geological Survey Earthquake Information Bulletin, v. 16, no.2, p. 77. March-April 1984. Accessed from US Geological Society Photographic Library. "ID. CVO-F. 87ct." http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20CVO-F.%20%2087ct Retrieved 2 January 2012.

Taking Yellowstone's Pulse
Ground deformation



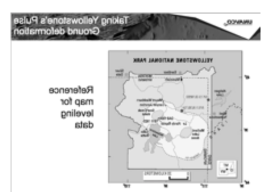
Reference map for leveling data

Notes for slide 49

On your paper map, draw a line between Lake Butte and Mount Washburn. This will be like a leveling line. We have surveyed ("leveling") data from Lake Butte, Mount Washburn, and from many other stations in between, including at the Le Hardy Rapids and where B11 1923 is. located Mark those four points on your map.

Where is this line compared to the caldera? Discuss this as a group.

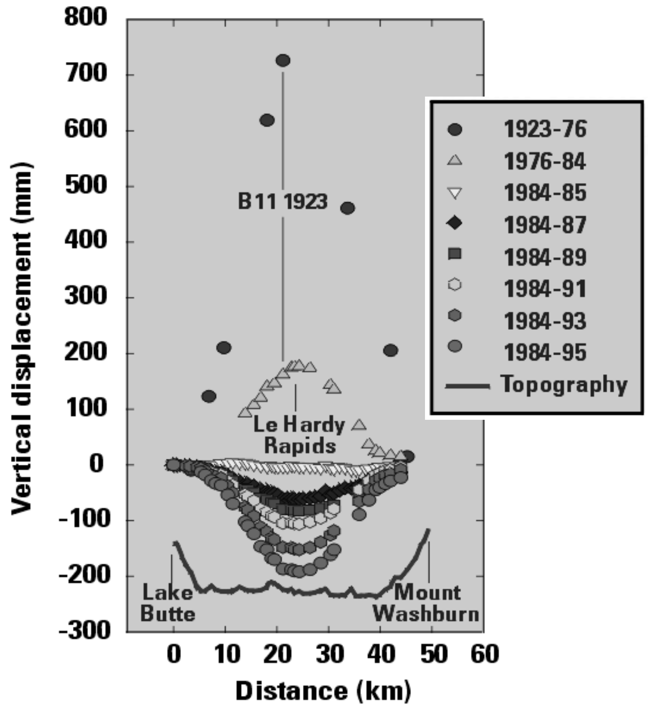
Map from Yellowstone Volcano Observatory: Map of Yellowstone Caldera and Leveling Benchmarks. http://volcanoes.usgs.gov/yvo/LvlMap.html Retrieved 30 December 2011.



UNAVCO

Taking Yellowstone's Pulse
Ground deformation

1923 - 1976



Leveling data from Lake Butte to Mount Washburn, 1923 - 1995

UNAVCO

Notes for slide 51

This graph shows how the elevation has changed along your leveling line from 1923 to 1995. Benchmark locations were measured repeatedly using surveying methods like those shown in the photos.

You might find it useful to look at one benchmark location, such as Le Hardy Rapids, closely. You could extend the short blue vertical line above the "H" to follow the symbols through time to see what happened to the ground at Le Hardy Rapids. The benchmarks can go either up or down through time.

The data on the graph are in the same order as the legend.

As a group, discuss these questions—and, if your teacher asks you to, write down your responses.

1. What does the horizontal axis show? The vertical axis?
2. What do positive numbers on the vertical axis mean? What about negative ones?
3. When was the area rising? When was it falling?
4. Which benchmarks moved the most – near the center or at the edges of the leveling line.

This data is for only the portion of Yellowstone along your leveling line from Lake Butte to Mount Washburn. That's about 50 km—30 miles. Other parts of the park might have behaved very differently from 1923 to 1995.

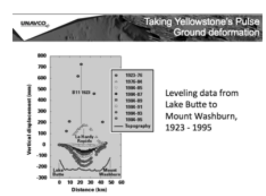
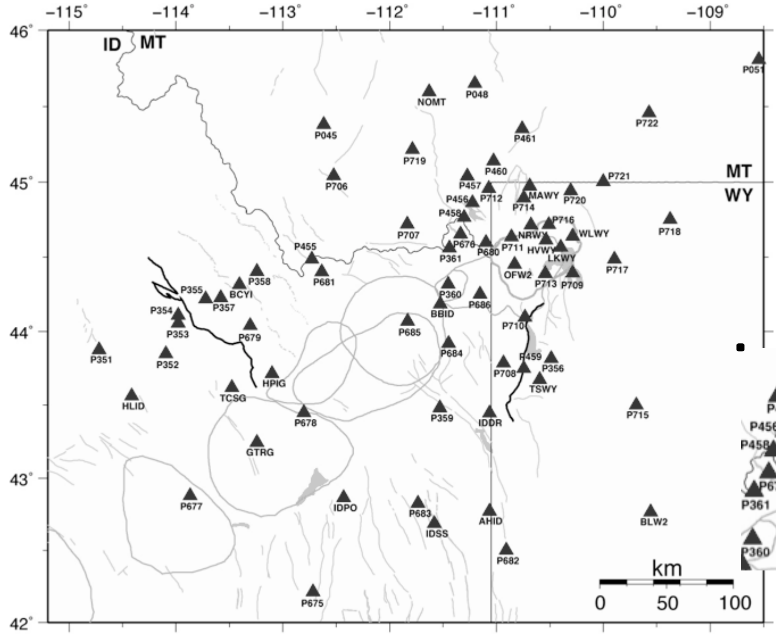
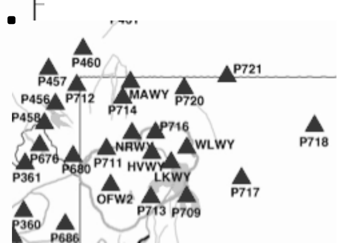


Image from Dzurisin, D., Savage, J.C., and Fournier, R.O., 1990, "Recent crustal subsidence at Yellowstone Caldera, Wyoming." Bulletin of Volcanology, v. 52, p. 247-270. Accessed from Yellowstone Volcano Observatory. http://volcanoes.usgs.gov/yvo/LvlData1923-1995.html Retrieved 2 January 2012.

Taking Yellowstone's Pulse
Ground deformation

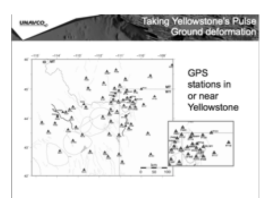


GPS stations in or near Yellowstone



Notes for slide 53

We also use ground stations that work in concert with satellites in a Global Positioning System, or GPS. Each of the stations on this map records data repeatedly every day. The stations are set into the ground ten meters, in concrete. They measure the position of the station very precisely. If the ground moves only a few millimeters in a year, the station can detect the change in position.



When you click on the large, regional, map, you will link to an interactive website that feeds you GPS data for the stations shown. The smaller map zooms in closer to Yellowstone. http://www.uusatrg.utah.edu/ts_ysrp.html (Search for "utah permanent gps network.")

The golden loops mark calderas.

Maps from Yellowstone-Snake-River-Plain GPS Network http://www.uusatrg.utah.edu/ts_ysrp.html Retrieved 2 January 2012.

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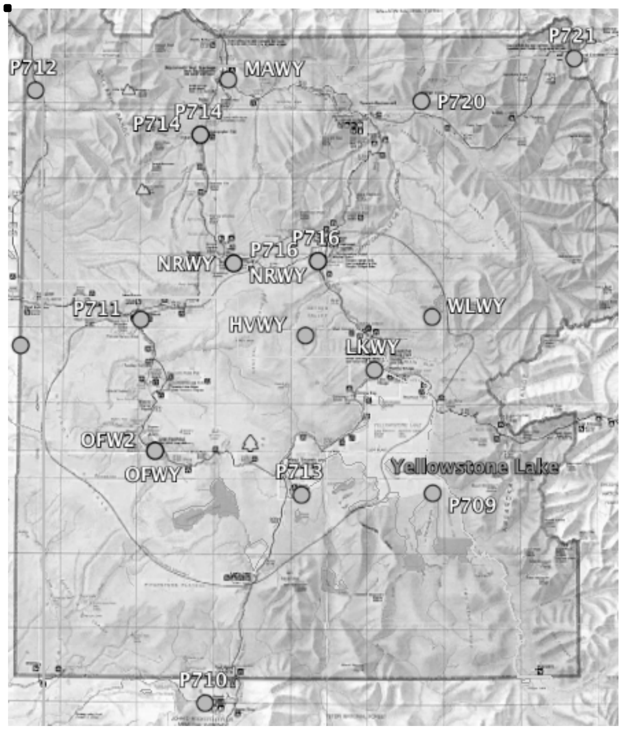
Taking Yellowstone's Pulse
Ground deformation



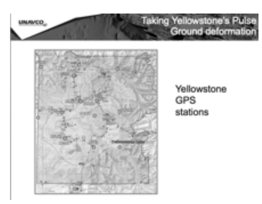
Yellowstone
GPS
stations

UNAVCO

Notes for slide 55

You will now work with GPS data near your leveling line. Four GPS stations lie near the line you drew on your paper map. They are P716, HVWY, LKWY, and P709. Draw their locations and ID labels on your map.

The data you need to graph is on the next slide.

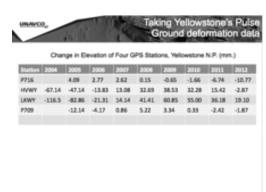


Taking Yellowstone's Pulse
Ground deformation data

Change in Elevation of Four GPS Stations, Yellowstone N.P. (mm.)

Station	2004	2005	2006	2007	2008	2009	2010	2011	2012
P716		4.09	2.77	2.62	0.15	-0.65	-1.66	-6.74	-10.77
HVWY	-67.14	-47.14	-13.83	13.08	32.69	38.53	32.28	15.42	-2.87
LKWY	-116.5	-82.86	-21.31	14.14	41.41	60.85	55.00	36.18	19.10
P709		-12.14	-4.17	0.86	5.22	3.34	0.33	-2.42	-1.87

Notes for slide 57



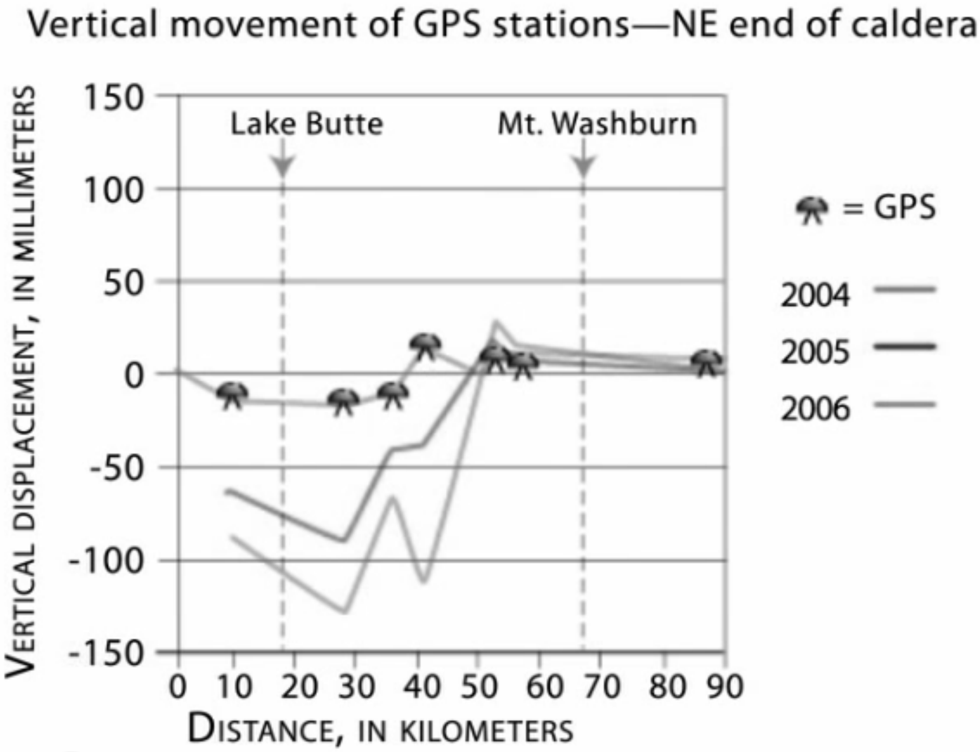
Here is data that shows how much four GPS stations have moved up or down from 2004 to 2012. Positive numbers mean that that spot has risen. Negative values means that it has sunk. For instance, station P716 rose 4.09 millimeters in a year in 2005. These numbers are averaged from measurements taken daily for a year.

You will graph these stations' elevation over time, much like the leveling data was graphed in slide 9.
Make a line graph using the **station names on the X-axis** and the **change in elevation on the Y-axis**. You will want to find the range in the data for the four locations in order to set up the graph. *The X-axis will NOT be to scale like the leveling data was. If you would like to use the same scale, you can use a map of the park and measure the distance each station is from Lake Butte.*

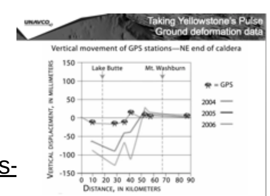
Use a different color or symbol for each year's data or make a separate graph for each year. If you use different colors, make a key, and put the colors in a sequence like the rainbow or "ROY G. BIV."

Discuss the following questions:
1. Do you see the same trend in the GPS data as was in the leveling data?
2. Can you assume this trend is true for all of Yellowstone?
3. Why might the GPS data be different from the leveling data?

Taking Yellowstone's Pulse
Ground deformation data



Notes for slide 59



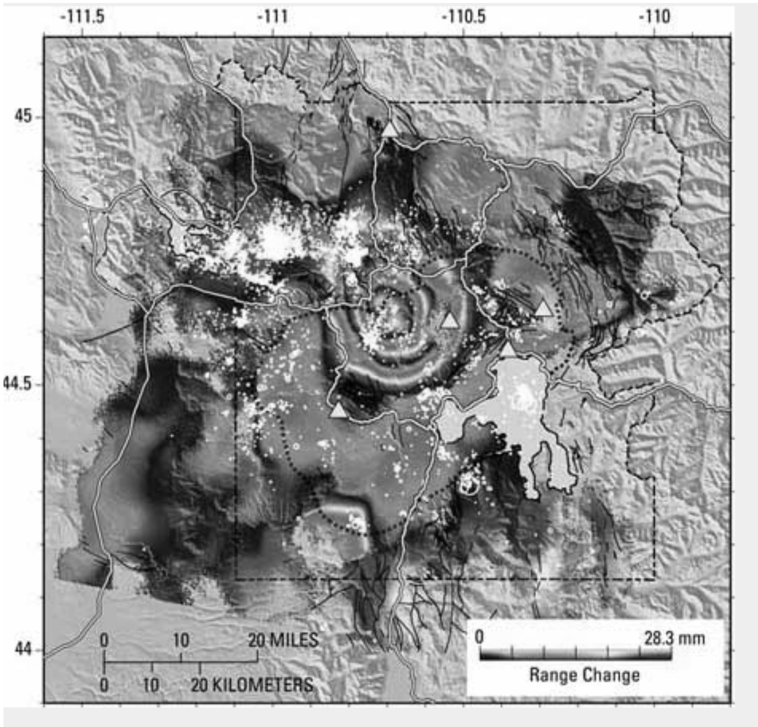
If you click on this graph, you can view an animation of the data that shows stations rising and falling.

Animation by Jenda Johnson for UNAVCO, 2013.

http://www.unavco.org//education/resources/educational-resources/lesson/gps-yellowstone/module-materials/yellowstone-gps-2004-2011.mov (Search on YouTube for "UNAVCO research P8.")

UNAVCO

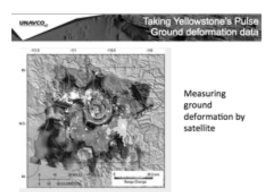
Taking Yellowstone's Pulse
Ground deformation data



Measuring ground deformation by satellite

UNAVCO

Notes for slide 61



Scientists can also collect data about how the ground has deformed using a satellite-based instrument called Interferometric Synthetic Aperture Radar (InSAR). Computers compare two radar images of the area taken at different times and show changes in elevation with the colors you see. Each repetition of a color (say, from a yellow band to another yellow band) represents 28 mm of uplift. This image shows changes between 1996 and 2000. How much uplift was there?

Other features: white dots are earthquake epicenters. Yellow triangles are GPS stations. Yellow lines are roads.

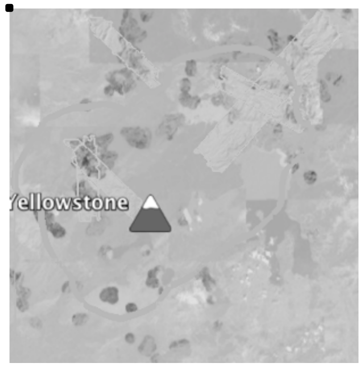
Click on the image to link to a brief article about ground deformation in Yellowstone. http://volcanoes.usgs.gov/yvo/publications/2007/upsanddowns.php (Search for "yvo ups downs.")

Compare and contrast leveling, InSAR, and GPS data for this area.

Use what you have learned about the changes in elevation at Yellowstone as you decide on a suitable site for a research station in Yellowstone.

Image from "Monitoring YNP's Heartbeat," Old Faithful Virtual Visitor Center, National Park Service. http://mms.nps.gov/yell/ofvec/exhibits/science/heartbeat/index.htm Retrieved 20 November 2014.

Geologic features in Google Earth



If your team will be using Google Earth (GE) to compare where the interesting features in the park are, you might want to become familiar with your data on GE now. These two images were made with GE. The lefthand one shows all of the park, with an overlay of the National Park Service map, the caldera in gold, and turquoise outlined areas of high-tech satellite-based topography (LiDAR).

The righthand image is zoomed in closer. You can see where it's from by the northwest-southeast trending LiDAR region. This image does not have the official park map showing. It just has the base map, the caldera, LiDAR, and hot areas in orange shades. The heat was measured from NASA's Landsat satellites from 1985 to 2007. With GE, you can see the changes over time. You'll be able to add layers and remove them easily in GE.

There is a separate set of instructions which guide you through using Google Earth. Also, we have prepared some files that are ready for you to open in GE. (You can also make your own files from a spreadsheet by following our instructions.) The next slide has links to these files.

Taking Yellowstone's Pulse Data

Links to data files:

- The National Park Service map as an overlay
- Satellite images of the ground (LiDAR)
- Yellowstone's caldera
- Yellowstone's hot areas
- Yellowstone's 200 most recent earthquakes (as of January 2012)
- Yellowstone's 200 largest earthquakes
- Earthquakes from the last week

Taking Yellowstone's Pulse Google Earth Instructions

Links to instructions:

- Instructions for using Google Earth
- Instructions for converting an Excel spreadsheet into a file for Google Earth

Information

- EARTH: "Tracking Yellowstone's Activity"

  http://www.earthmagazine.org/article/tracking-yellowstones-activity
  (Search for "tracking yellowstone's activity.")

- "Steam Explosions, Earthquakes, and Volcanic Eruptions—What's in Yellowstone's Future?"

  http://pubs.usgs.gov/fs/2005/3024/fs2005-3024.pdf (Search for "pdf usgs explosion yellowstone.")

- "Tracking Changes in Yellowstone's Restless Volcanic System"

  http://pubs.usgs.gov/fs/fs100-03/ (Search for "tracking changes yellowstone.")

Other Resources

Data

- Map linking to data for individual hydrothermal features.

  http://www.rcn.montana.edu/Default.aspx (Search for "rcn montana yellowstone.")

Information

- Learn about hydrothermal systems and how they work.

  http://www.nps.gov/yell/naturescience/geothermal.htm (Search for "nps how hydrothermal systems work.")
- Learn about geysers and other hydrothermal features of Yellowstone.

  http://yellowstone.net/geysers/ (Search for "yellowstone net geysers.")
- Learn more about geysers from the Geyser Observation and Study Assoc.

  http://www.geyserstudy.org/ (Search for "geyser observation.")
- Learn more measuring volcanic gas emissions.

  http://volcanoes.usgs.gov/activity/methods/gas/index.php (Search for "usgs monitoring volcanic gases.")

Other Resources:

Information

- Learn about the 2008 earthquake swarm at Yellowstone lake
  http://volcanoes.usgs.gov/yvo/publications/2009/09swarm.php (Search for "usgs 2009 swarm.")
- Learn about the 2010 earthquake swarm at Madison Plateau
  http://volcanoes.usgs.gov/yvo/publications/2010/10swarm.php (Search for "2010 swarm madison.")
- Learn about Yellowstone's earthquakes and volcanoes (Geology chapter).
  http://www.nps.gov/yell/planyourvisit/resourceandissues.htm (Search for "nps yellowstone resources.")
- Learn from National Geographic about the Yellowstone supervolcano and earthquakes.
  http://ngm.nationalgeographic.com/2009/08/yellowstone/achenbach-text (Search for "achenbach yellowstone.")

- American Museum of Natural History (n.d.) Science Bulletins: "Yellowstone: Monitoring the Fire Below, "Signs of Restlessness." http://www.amnh.org/explore/science-bulletins/earth/documentaries/yellowstone-monitoring-the-fire-below/article-signs-of-restlessness (Search for "amnh signs restlessness.")
- Christensen, R. et. al.2007. USGS: Open-file Report 2007-1071. "Preliminary Assessment of Volcanic and Hydrothermal Hazards in Yellowstone National Park and Vicinity." http://pubs.usgs.gov/of/2007/1071/ (Search for "preliminary volcanic hydrothermal hazards yellowstone.")
- Dzurisin, D.; Savage, J.C.; and Fournier, R.O. 1990. "Recent crustal subsidence at Yellowstone Caldera, Wyoming." Bulletin of Volcanology, v. 52, p. 247-270. accessed from Yellowstone Volcano Observatory," Leveling Data Across Yellowstone Caldera." http://pubs.er.usgs.gov/publication/70016303 (Search for "recent subsidence at yellowstone.")
- Puckas, C.; Smith, R; Meertens, C.; and Chang, W-L. 2007. "Crustal deformation of the Yellowstone-Snake River Plain volcano-tectonic system: Campaign and continuous GPS observations, 1987-2004." Journal of Geophysical Research, v. 112. http://volcanoes.usgs.gov/yvo/2007/PuskasJGR.pdf (Search for "Puskas deformation yellowstone-snake river.")
- UNAVCO: Johnson, J. 2013. "Vertical Movement of GPS Stations—NE End of Caldera. http://www.unavco.org//education/resources/educational-resources/lesson/gps-yellowstone/module-materials/yellowstone-gps-2004-2011.mov Retrieved 20 November 2014. (Search on YouTube for "UNAVCO research P8.")
- USGS. 2007. Yellowstone Volcano Observatory. "Recent Ups and Downs of the Yellowstone Caldera—2007 article" http://volcanoes.usgs.gov/yvo/publications/2007/upsanddowns.php (Search for "yvo ups downs.")
- USGS. 2010. Yellowstone Volcano Observatory. "Volcano Monitoring at Yellowstone National Park" http://volcanoes.usgs.gov/yvo/activity/monitoring/index.php (Search for "YVO monitoring.")
- USGS. 2008. Yellowstone Volcano Observatory. "Recent ups and downs of Yellowstone Caldera." http://volcanoes.usgs.gov/yvo/publications/2007/upsanddowns.php (Search for "ups downs yellowstone.")
- USGS. 2005. U.S. Geological Survey Fact Sheet 2005-3024: "Steam Explosions, Earthquakes, and Volcanic Eruptions--What's in Yellowstone's Future?" http://pubs.usgs.gov/fs/2005/3024/ (Search for "usgs steam explosions yellowstone.")
- USGS. 2004. U.S. Geological Survey Fact Sheet 100-03: "Tracking Changes in Yellowstone's Restless Volcanic System." http://pubs.usgs.gov/fs/fs100-03/ (Search for "tracking changes yellowstone.")

Changing Planet: Earth and Life Through Time – Dr. Mark Neilsen, HHMI

AT A GLANCE FILM GUIDE

DESCRIPTION

The disappearance of the dinosaurs at the end of the Cretaceous period posed one of the great mysteries of Earth's natural history. Scientists from multiple disciplines, including geology, physics, biology, chemistry, and paleontology, helped form the shocking hypothesis that the mass extinction was caused by an asteroid impact.

KEY CONCEPTS

- Earth's 4.6-billion-year geological and biological history is deduced from the analysis of fossils, rocks, and chemical signatures found in sediments worldwide. The layered evidence reveals a pattern of change varying in tempo.
- Geological sediments reveal that Earth's environment generally changes gradually and that conditions are relatively stable over many millions of years. However, some sediment layers show evidence of rapid, even catastrophic, change.
- Catastrophes have played an important role in evolutionary history. The mass extinctions that have occurred in the past 550 million years are examples of catastrophic change.
- During mass extinctions, a large proportion of species, living in different habitats and around the world, abruptly go extinct, opening up new opportunities for survivors.
- Careful observations lead scientists to ask questions that can be answered by gathering evidence. A good scientific question leads to additional observations and questions, and ultimately to a hypothesis that can be tested.
- Not all hypotheses can be tested in a controlled laboratory experiment. For example, the study of deep Earth history, aspects of ecology, and astronomy, require gathering multiple lines of evidence to understand events that occurred in the past.
- Although the totality of evidence is important, certain pieces of evidence are more critical than others to confirming a hypothesis.
- Some of the most interesting problems require the combined efforts of experts from many scientific disciplines to find a solution.
- Scientists share information with other scientists in their communities, striving to reach consensus. Overturning long-established models and ways of thinking to arrive at a new consensus is appropriately difficult.

CURRICULUM AND TEXTBOOK CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	MS-PS3.C, MS-LS2.C, MS-LS4.A, MS-LS4.C, MS-ESS1.C, MS-ESS2.A, HS-LS2.B, HS-LS2.C, HS-LS4.C, HS-LS4.D,HS-ESS1.C, HS-ESS2.A, HS-ESS2.E, HS-PS1.C,
AP Biology (2012-13)	4.B.4, 1.C.1, SP5
IB Biology (2009)	5.1, 5.4.8, D.2.7, D.2.9, D.1.3, G.2.6, G.2.7
APES: Themes and Topics (2013)	**Themes**: 1, 3; **Topics**: I.A; VII.C

Textbook	Chapter Sections
Miller & Levine, *Biology* (2010)	1.1-1.3, 19.1, 19.2
Reese *et al. Campbell Biology* (9th Ed. 2011)	1.3-1.4, 25.4
Pearson Earth Science (2011 Ed.)	1.5, 13.3, 22.3
Cunningham, *Environmental Science* A Global Concern 11e	2.1 - 2.3, 4.1, 4.4, 14.1, 15.3, 15.5, 16.2
Friedland and Relyea, *Environmental Science* for AP 2012	Ch.1 (p. 15), Ch. 4 (pp99 – 108), Ch. 5, Ch. 8 (pp. 208 – 209) Ch. 15 (pp410 – 415),

SUGGESTED AUDIENCE

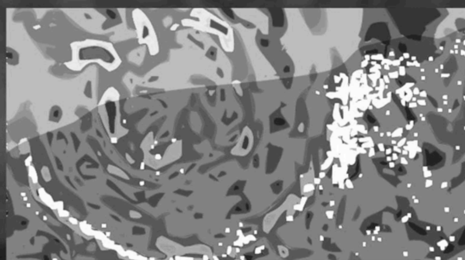
This film is intended to engage *all* students in *all* science classes. The story of this mass extinction is an unbeatable introduction to the process of science for novice students. For students with a more advanced understanding of science, including content knowledge in biology and geology, the film is a memorable example of the excitement of scientific discovery.

KEY REFERENCES

Alvarez, L.W., Alvarez, W., Asaro, F., Michel, H.V. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science* 208: 1095-1108.

Smit, J., Hertogen, J. 1980. An extraterrestrial event at the Cretaceous-Tertiary boundary. *Nature* 285: 198-200.

FINDING THE CRATER



THE DAY
THE MESOZOIC DIED
BioInteractive.org

The asteroid impact left behind different types of evidence

- Drs. Alvarez, Smit, and colleagues proposed that a 10-km asteroid struck Earth 66 million years ago.
- The impact would have left behind a massive crater and a lot of other physical evidence.

THE DAY
THE MESOZOIC DIED
BioInteractive.org

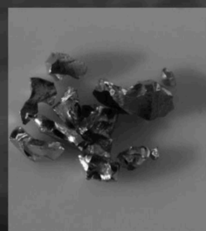
The evidence is found in 66-million-year-old rock layers

Signs of the impact can be found at the boundary between the Cretaceous and Tertiary periods (the K-T boundary)—the time of the asteroid impact.

THE DAY
THE MESOZOIC DIED
BioInteractive.org

The K-T boundary is rich in iridium

- Iridium is an element rare in Earth's crust but relatively abundant in asteroids and comets.
- The K-T asteroid was vaporized on impact; fine particles of iridium traveled high into the atmosphere and were then distributed all over Earth.



THE DAY THE MESOZOIC DIED

BioInteractive.org

Deposits at the K-T boundary hold other clues

Many K-T event deposits worldwide contain pieces of melted or crushed rocks that were blasted from the impact site, which are called **ejecta**.

THE DAY THE MESOZOIC DIED

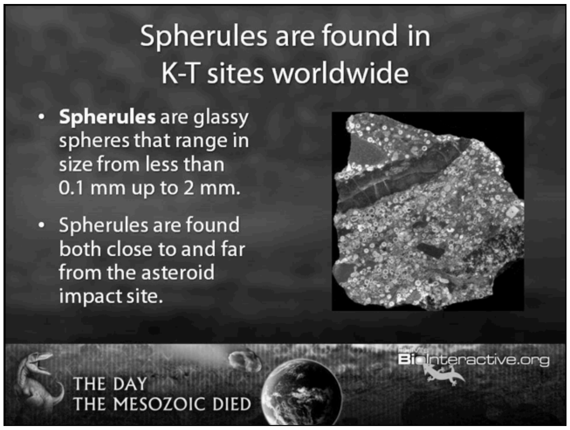
BioInteractive.org

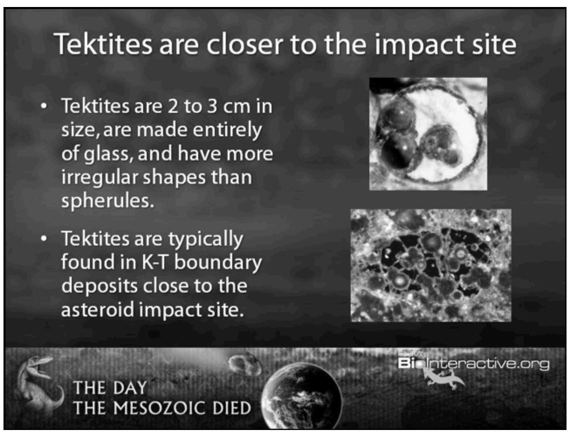
Ejecta include spherules and tektites

- When the asteroid struck, some of the rock in Earth's surrounding crust melted as it was ejected from the impact site.
- As these melted rock particles fell back to Earth and cooled, they formed glass-like objects called **spherules** and **tektites**.

THE DAY THE MESOZOIC DIED

BioInteractive.org


Spherules are found in K-T sites worldwide
• Spherules are glassy spheres that range in size from less than 0.1 mm up to 2 mm.
• Spherules are found both close to and far from the asteroid impact site.
THE DAY THE MESOZOIC DIED
BioInteractive.org


Tektites are closer to the impact site
• Tektites are 2 to 3 cm in size, are made entirely of glass, and have more irregular shapes than spherules.
• Tektites are typically found in K-T boundary deposits close to the asteroid impact site.
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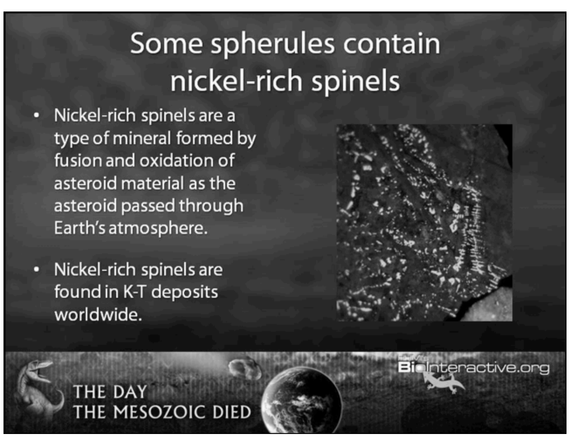
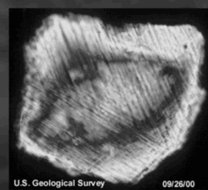
BioInteractive.org


Some spherules contain nickel-rich spinels
• Nickel-rich spinels are a type of mineral formed by fusion and oxidation of asteroid material as the asteroid passed through Earth's atmosphere.
• Nickel-rich spinels are found in K-T deposits worldwide.
THE DAY THE MESOZOIC DIED
BioInteractive.org

Ejecta debris also includes shocked quartz

The extremely high pressure of an asteroid impact caused quartz grains at the impact site to shatter and fracture internally as they were blasted into the air.



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The size of shocked quartz grains reveals distance from impact site

- Shocked quartz grains bigger than 0.5 mm are abundant in K-T deposits closer to the impact.
- Smaller grains (less than 100 microns in size) are found at other locations, and they are not as abundant.

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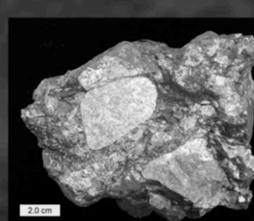
Broken-up rock is found close to the impact site

- K-T event deposits very close to the impact site may contain large chunks of broken-up rock, called **breccia.**
- Breccia represents Earth crust that was crushed by the asteroid impact.



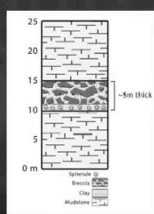
THE DAY THE MESOZOIC DIED
BioInteractive.org

Tsunami deposits are also found close to the impact

- Some K-T event deposits also contain large rocks and boulders mixed with the ejecta.
- The rocks were carried there by giant waves generated by the force of the impact.

Deposit thickness varies depending on distance from the impact

In general, K-T boundary locations closer to the impact site have thicker deposits than sites further away.



Evaluating the evidence

K-T event deposits are found at sites all over the world—at varying distances from the crater. Sites can be classified as:

Close:
- Deposit thickness greater than 10 cm.
- May contain breccia.
- May contain spherules, tektites, large and small shocked quartz grains, Ni-rich spinels, and iridium.

Intermediate:
- Deposit thickness 1 to 10 cm.
- Does not contain breccia.
- May contain spherules, tektites, large and small shocked quartz grains, Ni-rich spinels, and iridium.

Distant:
- Deposit thickness less than 1 cm.
- Does not contain breccia.
- May contain spherules, small shocked quartz grains, Ni-rich spinels, and iridium.

Today's activity…

- Today you will evaluate K-T event deposits at 10 different K-T sites.
- You will map each site and determine whether it is close to, an intermediate distance from, or distant from the impact site.
- You will then propose the general location for the impact crater.
- Write down the iridium concentration for each site, if available.

THE DAY THE MESOZOIC DIED

BioInteractive.org

Credits

Developed by: Scott Wahlstrom, Wachusett Regional School District; Laura Bonetta, HHMI; Mark Nielsen, HHMI

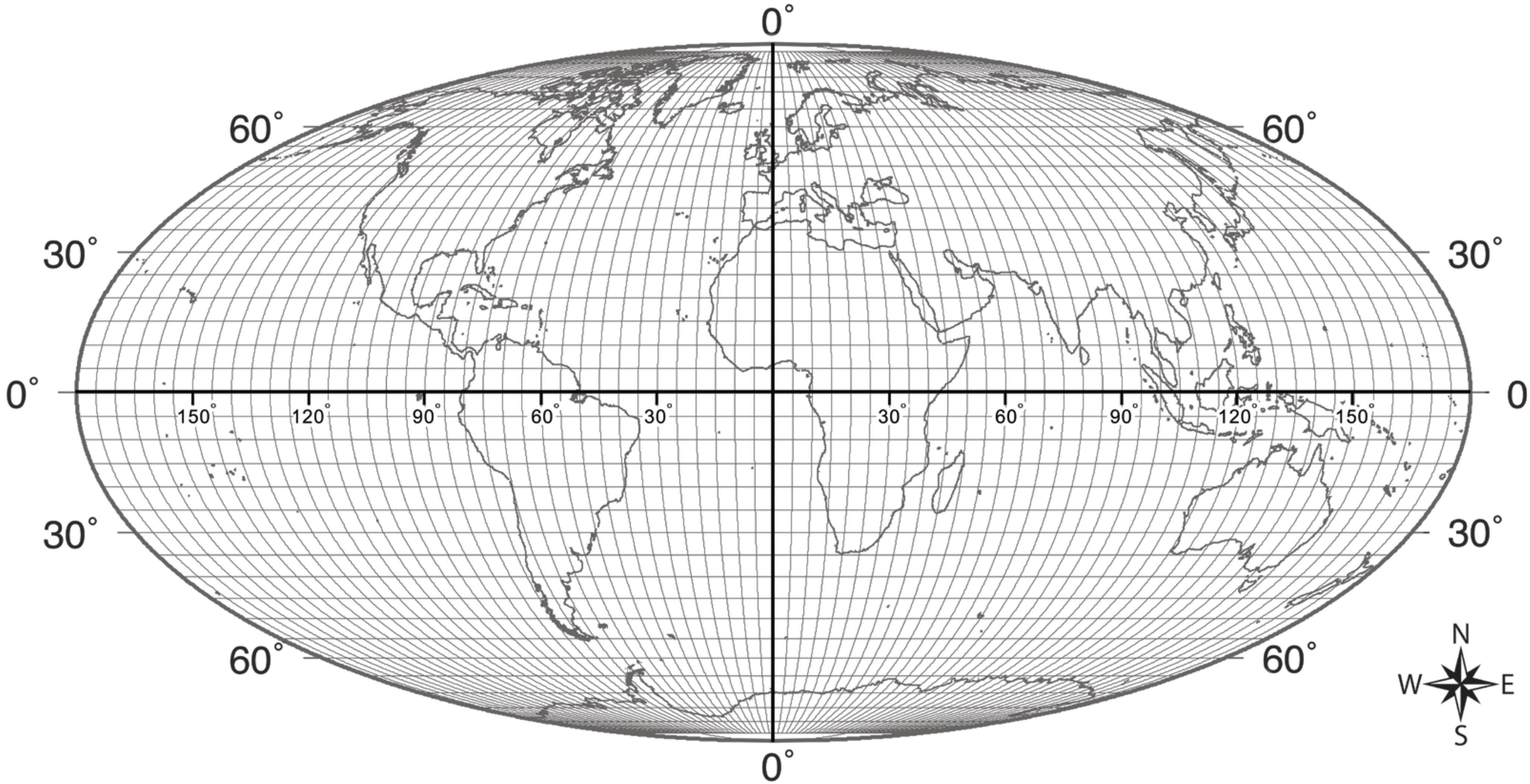
Scientific review by: Jan Smit, VU University Amsterdam; Philippe Claeys, VUB Brussels; Peter Schulte, Erlangen-Nürnberg University

References: Schulte, P., *et al*. (2010)" The Chicxulub Asteroid Impact and Mass Extinction at the Cretaceous-Paleogene Boundary." *Science* 327:1214-1218.

Photos: Photos courtesy of Philippe Claeys, VUB Brussels; Jan Smit, VU University Amsterdam; Frank Kyte, University of California, Los Angeles; Bruce Simonson, Oberlin College; United States Geological Survey (USGS); image of iridium courtesy of image-of-elements.com/iridium.php.

THE DAY THE MESOZOIC DIED

BioInteractive.org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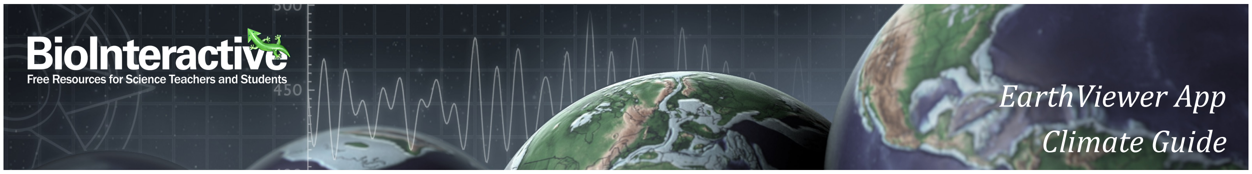


Exploring Earth's Climate with EarthViewer

Tips for using the App:

- Spin the Earth with your finger to get a 360-degree view of the world
- Zoom in or out by pinching or spreading your fingers on the screen
- Use the silver slider to view the changing Earth through geologic time
- To switch between the three timelines, use the pinch or spread gesture
- Select "CHARTS" to explore data on climate, atmospheric composition, and biodiversity
- Select "VIEW" to display different types of information such as fossils, impact events, cities, geologic events, and biological events
- Select "IN DEPTH" to learn more about select Earth system topics

1. Over the last 540 million years, icecaps covered at least one of the Earth's poles during three intervals.
   a. When were those intervals? ____________________
   ____
   ____
   b. Use the CHART button to find an approximate temperature range for the three intervals. ____________________
2. Pinch on the timeline to view all of Earth history.
   a. What did the planet look like when global temperatures were less than 5 °C?
   (hint: average global temperatures can be found using the CHART feature.)
   ____
   b. Tap "VIEW" and select "Geologic Events", tap on the flag that opens on the timeline at 2200 million years ago.
      i. What are these events called? ____________________
      ii. How do they start? ____________________
      iii. How do they end? ____________________
3. Use a spread gesture on the timeline until you see only the last 100 years.
   a. What do the colors on the globe represent?
   ____
   b. What was the average global temperature for the period 1951-1980? ________
   c. Based on the temperature chart, how much has the Earth warmed in the last 100 years? ____________________

d. Tap each of the variables on the top chart and describe the trend in relation to temperature.

example: *% Oxygen* in the atmosphere has remained constant as the temperature has increased.

Carbon dioxide ____

Day Length ____

Luminosity ____

Biodiversity ____

4. Based on the average global temperature and the trend over the last 100 years, how many years will it take until we are outside of the range you identified in Q1b?

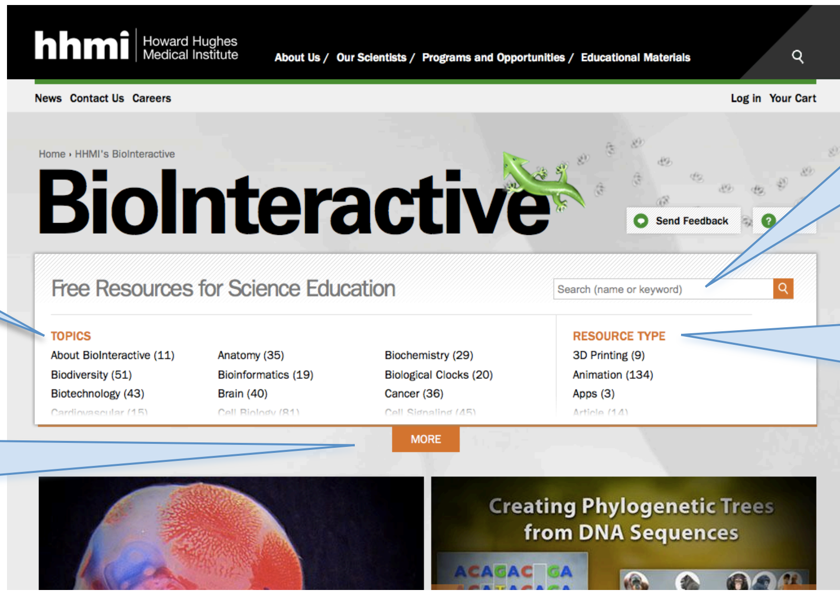
____

Access Science Education Resources on HHMI's BioInteractive

Visit www.BioInteractive.org:

Topics
Select lists of resources grouped according to science topic, such as DNA or evolution.

More
Expand the menu to reveal additional topics and resource types.

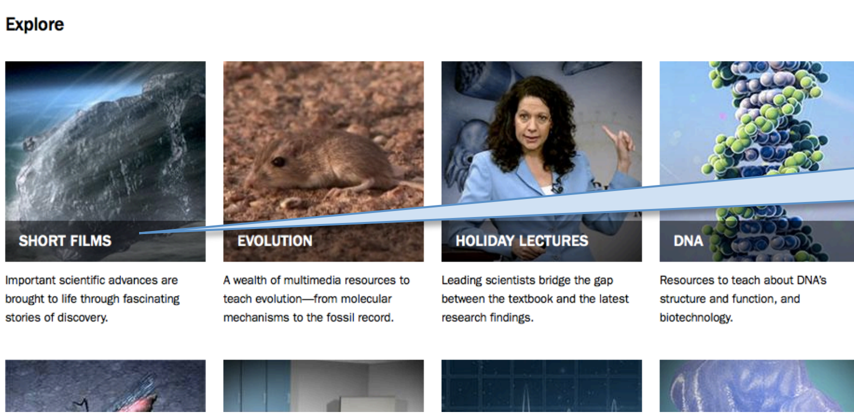


Search
Search BioInteractive's extensive database of science education materials using key words like "lactase" or "origin of humans."

Resource Type
Select lists of resources grouped according to medium, such as apps, animations, and short films.

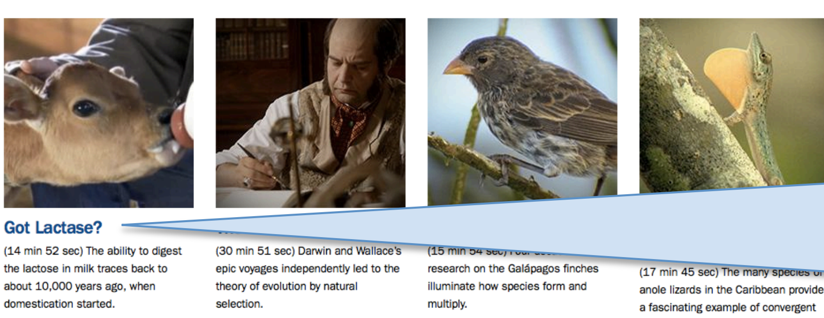
Scroll down the page to the EXPLORE section and select SHORT FILMS:

Explore
Find collections of resources grouped by topic, type, or curriculum unit.



Collections
Clicking on an item will take you to that collection.

Browse the collection and select your film of choice:



Short Film
Each short film is 10 to 30 min long and designed for classroom use. Each film is accompanied by film guides that list **key concepts**, **curriculum connections (AP, IB, NGSS)**, suggested times for **pausing the film and reviewing content**, discussion questions, additional background materials and references, a list of related content, and a **student quiz**.

Watch the short film in your choice of format:

Stream
The film can be streamed directly from the BioInteractive website.

Summary

Follow human geneticist Spencer Wells, Director of the Genographic Project of the National Geographic Society, as he tracks down the genetic changes associated with the ability to digest lactose as adults, tracing the origin of the trait to less than 10,000 years ago, a time when some human populations started domesticating animals.

Play Short Film (Duration: 14 min 52 sec)

Download this item

- HD (M4V) 572 MB
- HD (WMV) 461 MB
- SD (M4V) 185 MB
- SD (WMV) 118 MB
- Transcript (PDF) 331 KB

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Download
All short films can be downloaded in SD and HD formats. The download section also includes a PDF of the film transcript.

YouTube
The film can also be watched on the BioInteractive YouTube channel. Subscribe to the channel to be notified about new videos and animations.

YouTube Watch this video on our YouTube channel!

Human babies drink milk; it's the food especially provided for them by their mothers. Various cultures have also added the milk of other mammals to their diet and adults think nothing of downing a glass of cows' milk. But worldwide, only a third of adults can actually digest lactose, the sugar in milk. In this short film we follow human geneticist Spencer Wells, Director of the Genographic Project of the National Geographic Society, as he tracks down the genetic changes associated with the ability to digest lactose as adults, tracing the origin of the trait to less than 10,000 years ago, a time when some human populations started domesticating animals, including goats, sheep, and cows. Combining genetics, chemistry, and anthropology, this story provides a compelling example of the co-evolution of human genes and human culture.

> *"Did you ever wonder why some adults can drink milk and eat ice cream without any problems, while others get stomach aches and produce a lot of gas? Well, the Howard Hughes Medical Institute has just released a short video that answers that question [...]* Got Lactase? The

Related Materials

CLICK & LEARN
Regulation of the Lactase Gene

CLICK & LEARN
Recent Adaptations in Humans

Related Materials
Find other films, interactives, and activities that relate to this short film.

Scroll down the page to see supporting materials:

Supporting Materials (6)

Film Guides: Got Lactase? The Co-evolution of Genes and Culture

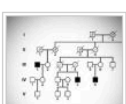
FILM GUIDES

The following classroom-ready resources complement Got Lactase? The Co-evolution of Genes and Culture, which tells the story of the evolution of the ability to digest lactose, a genetic trait that arose in humans within the last 10,000 years in some pastoralist cultures.

Lactose Intolerance: Fact or Fiction

CLASSROOM RESOURCE

Students evaluate and discuss several statements about lactose intolerance and evolution before and after watching the film.



Pedigrees and the Inheritance of Lactose Intolerance

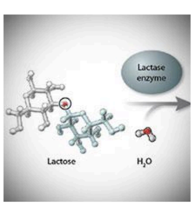
CLASSROOM RESOURCE

Students explore the genetic changes associated with lactose tolerance/intolerance and how the trait is inherited in families.

Supporting Materials
Each film is accompanied by several supporting resources, including film guides, lesson plans, hands-on activities, interactives, and more. All supporting materials provide key concepts, learning objectives, curriculum connections, and tips for classroom implementation.

All supplements are freely available for download:

Got Lactase? Blood Glucose Data Analysis



Summary

Students interpret the results of two different tests for lactase persistence.

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