Arctic Climate Connections

Using authentic Arctic research data to learn about climate

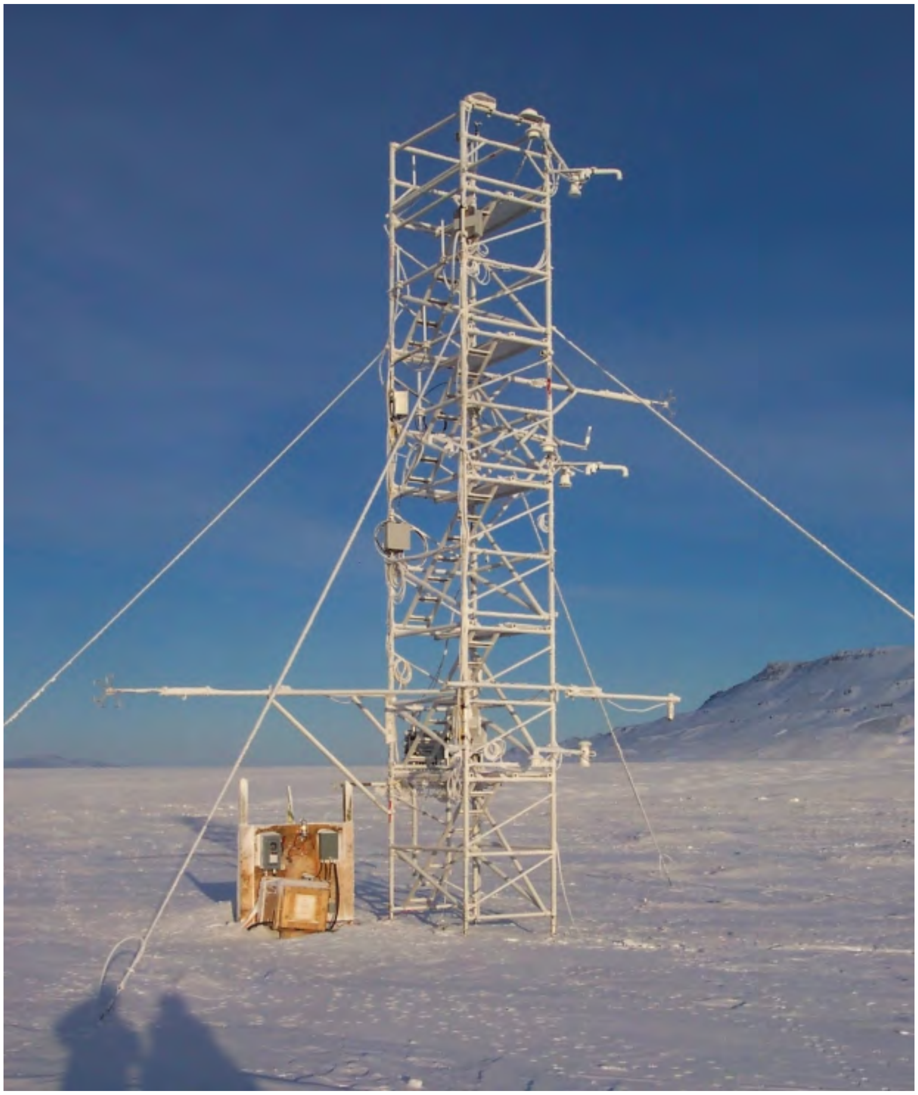

Photo by A. Grachev/O. Persson – Meteorological Tower in Eureka, Canada

ACC Curriculum prepared by Anne Gold and Karin Kirk.
Cooperative Institute for Research in Environmental Sciences (CIRES)
University of Colorado

Teacher Guide With Answer Key

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Acknowledgements and Funding

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Teaching Notes – Critical Literacy

Students can use this acknowledgements section to understand the provenance of this information and the intent of this work.

Optional pre-activity questions could include:

- Who constructed this material?
- Why should we believe what they have to say?
- Who funded this work?
- What is their intent in funding this type of work?
- What other work do the authors or funders do in the Arctic? Elsewhere?
- What expertise do the authors have in the topic of climate science?

For further information on this program please contact:

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Overview

Abstract of Curriculum:

This suite of activities is designed to engage learners in climate science through working with data from an ongoing Arctic research project. Educators can use the entire curriculum or select the components best suited to their audiences. Each activity contains multiple parts; educators can implement all or just parts of the activities. All activities include a teacher's guide along with possibilities for additional exploration, a teacher's guide with an answer key, a student guide, student worksheets and supporting data and image files.

Activity 1 introduces students to the Arctic and allows them to explore the geography of the Arctic using Google Earth. Students go on to learn about meteorological parameters that are measured by research teams and practice the measurements in hands-on activities.
In **Activity 2**, students work in a jigsaw format to examine data collected by CIRES researchers in the Arctic and draw connections to the weather and climate in their hometown.
Activity 3 puts students in the researcher position, and they work through real data using Excel. Students then explore the significance of albedo for global climates.

Driving Questions:

- What is the Arctic? What is the geographic extent of the Arctic?
- Why should we study the Arctic?
- How do scientists study Arctic weather and climate?
- How do scientists interpret and use their data?
- How are the findings from Arctic research related to global climate?
- How do feedback mechanisms operate, specifically the effect of albedo?

Grade Level

- This curriculum was primarily designed for a **high school audience – grades 9-12**
- Activities 1 and 2 can be adapted for **middle school** students with teacher support.
- Activity 3 and the extension activities from Activities 1-3 can be adapted for use at the **introductory college level**.

Organization of Curriculum

Activity 1 – Exploring the Arctic

Part A: What is the Arctic? *(time in classroom required: two 45-minute class periods)*

In this activity students brainstorm their knowledge about the Arctic and build a concept map of different aspects of the Arctic environment. Students try to define the Arctic and create a whole-class definition. Students further explore the Arctic environment by looking at vegetation and indigenous people.

Assessments: Concept Maps, Whole-Class concept map of Definition of Arctic, Worksheet questions

Part B: A Virtual Trip to the Arctic *(time in classroom required: two 45-minute class periods)*

Students take a virtual tour of the Arctic and Arctic research sites using *Google Earth*.

Assessments: Google Earth kmz files, worksheet questions, Thinking Further questions

Part C: Collecting Your Own Meteorological Data *(time in classroom required: two to three 45-minute class periods)*

Students conduct hands-on experiments measuring albedo, relative humidity, and soil temperature using simple classroom methods. In this jigsaw activity, they regroup and analyze the data in teams and discuss questions that have them think further. Then they research and identify scientific instruments at the Eureka Arctic meteorological tower.

Assessments: Data collection sheets, responses to discussion questions

Extension Activity I: Using ImageJ for Albedo Measurements *(time required: one 45-minute class period)*

Students use *ImageJ*, a free image processing software, to measure albedo digitally on images of their own choice.

Assessment: Estimated and measured albedo values

Activity 2 – Do you *Really* Want to Visit the Arctic?

Warm-up Activity *(time in classroom required: 20-30 minutes)*

The warm-up activity allows students to learn a little about the Arctic and the climate system and ask research questions like scientists do.

Assessment: Three research questions

Part A: Research Groups: Analysis of an Arctic Meteorological Dataset *(time in classroom required: one 45-minute class period*

Student groups examine and describe one of four guided datasets of the annual record of 2010 at Eureka Arctic meteorological tower for air temperature, wind speed, snow depth, and incoming solar radiation.

Assessment: Worksheet questions

Part B: Research Teams: Synthesis of Data to Determine Arctic Meteorological Dataset *(time in classroom required: 30 minutes)*

Students rearrange into *Research Teams* (each team will contain one member from each of the research groups). The research teams describe their parameter and then synthesize the data to determine the best time of year to visit the Arctic.

Assessment: Completed discussion questions

Part C: Individual Reflection *(time in classroom required: 20 minutes to one 45-minute class period, depending on the level of detail in comparing Eureka weather to hometown*

weather)

Students work individually to create a measureable definition for winter, taking into account what they learned about the Arctic climate, and then transfering this information to their hometown by finding weather and climate data for their hometown.

Assessment: Definition for winter, completed worksheet questions

Extension Activity: Infographics *(time in classroom required: one 45-minute class period)*

Students work in groups to create an infographic about the weather in Eureka, Canada. An infographic is a fun and creative way to organize and express data.

Assessment: Infographic

Activity 3 – Exploring Arctic Climate Data

Part A: Understanding Albedo *(time in classroom required: 30 minutes)*

Students practice calculating albedo as a simple ratio of incoming to outgoing short-wave radiation.

Assessment: Completed student guide

Part B: Analysis of Albedo, Snow Depth, and Temperature *(time required: two 45-minute class periods, possibly more depending on existing familiarity with Excel)*

Students dig into the Arctic data using Excel to unravel some causes and effects of the melting of the snowpack. Students develop concept sketches of albedo.

Assessments: Completed student guide, Excel graphs, concept sketch of albedo

Part C: Think Globally *(time in classroom required: 15 minutes)*

Students analyze glacier image pairs from a time series and think about the implications of albedo on the rate of glacial melt. Students then discuss global implications of their findings.

Assessment: Discussion questions

Extension Activity I: Greenland Albedo *(time in classroom required: one to two 45-minute class periods, depending on depth. Could also be assigned as homework.)*

Students use a variety of data sources to understand several causes of decreasing albedo in Greenland.

Assessment: Discussion questions

Extension Activity II: Dust on Snow *(time in classroom required: one 45-minute class period, depending on depth. Could also be assigned as homework.)*

Students learn about the relationship between dust storms, albedo, and water supplies in the Colorado River. Higher-order thinking questions address the challenges of establishing climate policy.

Assessment: Discussion questions

Materials Available for ACC Curriculum

- Teacher Guide with answer key (this document) [Word document]
- Teacher Guide without answer key [Word document]
- Student Guide [Word document]
- Student Worksheets [Word documents and PowerPoint slides]
- Companion Images [PowerPoint slides]

Activity 1:

- Background information – has to be printed double sided and then folded in half to make a little booklet [PowerPoint file, to be printed]
- Instructions for hands-on experiments [PowerPoint slides]
- Student guide [Word document]
- Student worksheet [Word document]

Activity 2:

- Guidelines for jigsaw/data description activity [PowerPoint slides]
- Graphs for jigsaw activity [Excel]
- Student guide [Word document]
- Student worksheet [Word document]

Activity 3:

- Instructor dataset and graphs [Excel]
- Student dataset [Excel]
- Paired glacier photographs [PowerPoint slides]
- Student guide [Word document]
- Student worksheet [Word document]

Arctic Climate Connections Resources

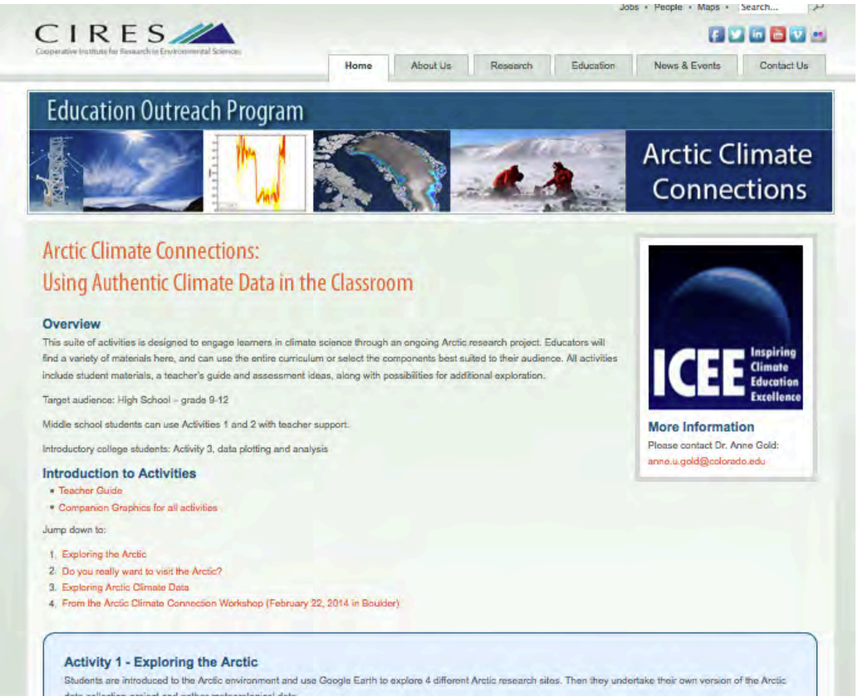
The Arctic climate connections curriculum consists of a classroom set of student materials and a teacher's guide for each lesson.

All materials are also available to use online or download from our website:

http://cires.colorado.edu/education/outreach/ICEE/arcticclimate/index.html

All materials and worksheets are available as downloadable Adobe PDF files as well as Microsoft Word, PowerPoint, and Excel files – allowing for edits of the original version.

The website also includes the recording of a presentation by Dr. Ola Persson that was held during a teacher professional development workshop around this curriculum



Arctic Climate Connections:
Using Authentic Climate Data in the Classroom

Overview

This suite of activities is designed to engage learners in climate science through an ongoing Arctic research project. Educators will find a variety of materials here, and can use the entire curriculum or select the components best suited to their audience. All activities include student materials, a teacher's guide and assessment ideas, along with possibilities for additional exploration.

Target audience: High School – grade 9-12

Middle school students can use Activities 1 and 2 with teacher support.

Introductory college students: Activity 3, data plotting and analysis

Introduction to Activities

- Teacher Guide
- Companion Graphics for all activities

Jump down to:

1. Exploring the Arctic
2. Do you really want to visit the Arctic?
3. Exploring Arctic Climate Data
4. From the Arctic Climate Connection Workshop (February 22, 2014 in Boulder)

More Information

Please contact Dr. Anne Gold:
anne.u.gold@colorado.edu

Activity 1 - Exploring the Arctic

Students are introduced to the Arctic environment and use Google Earth to explore 4 different Arctic research sites. Then they undertake their own version of the Arctic

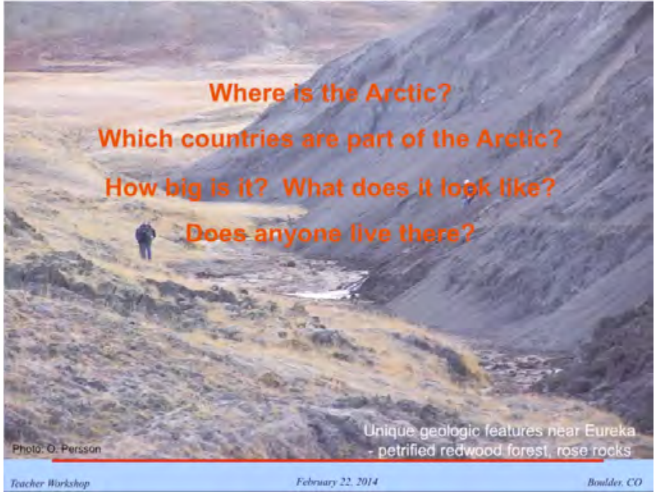
Presentation by Research Scientists

The ACC curriculum was presented by educators during a teacher professional development workshop. Dr. Ola Persson gave a presentation tailored to this curriculum. The presentation is recorded and can be viewed at the link below.

http://cires.colorado.edu/education/outreach/ICEE/arcticclimate/index.html#workshop

The talk was structured into four sections. See below the time stamps where to start the presentation for each of the sections:

Question 1: Timestamp 3:03 min –13:34 min



Where is the Arctic?

Which countries are part of the Arctic?

How big is it? What does it look like?

Does anyone live there?

Photo: O. Persson

Unique geologic features near Eureka
- petrified redwood forest, rose rocks

Teacher Workshop February 22, 2014 Boulder, CO

Question 2: Timestamp 13: 36 min – 30.48 min

Why are we doing climate research in the Arctic?

Why is the Arctic so important?

How does the Arctic climate affect the globe?

Photo: O. Persson

Teacher Workshop February 22, 2014 Boulder, CO

Question 3: Timestamp 30:48 min-1:00:00 min

What do scientists measure in the Arctic?

Where do scientists make measurements?

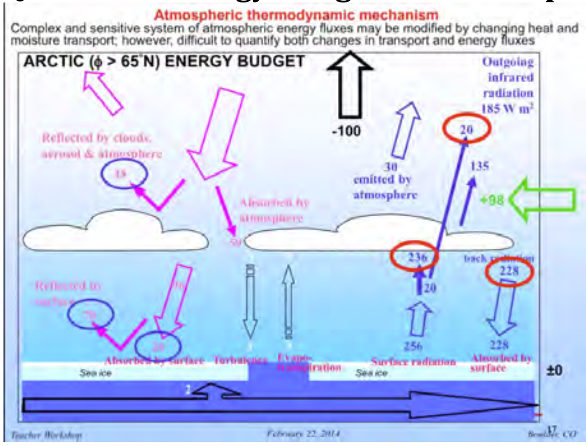
What instruments or tools do they use?

What are some of the challenges of Arctic research?

Eureka weather and research station, Ellesmere Island

Photo: O. Persson

Question – Energy Budget: Timestamp 48:51 min-52:13 min



Atmospheric thermodynamic mechanism

Complex and sensitive system of atmospheric energy fluxes may be modified by changing heat and moisture transport; however, difficult to quantify both changes in transport and energy fluxes

Question 4: Timestamp 1:00:00 min

What have we learned?

Arctic environment is changing rapidly
- sea ice is melting faster than expected
- the Arctic is warming twice as fast as the rest of the globe
- the permafrost is thawing, possibly releasing GHGs
- vegetation is moving northward
- wildlife is affected, esp. those dependent on sea ice (polar bear)
- indigenous lifestyles affected

The Arctic environment is a closely linked physical system with interdependent atmospheric, cryospheric, oceanographic, and terrestrial processes

Warming effect from clouds is underestimated by climate models, especially during winter

The changing Arctic will affect the rest of the world
- global weather and climate feedbacks
- commerce and transportation
- global resources (oil, mining)

Teacher Workshop February 22, 2014 Boulder, CO

Standard Alignment

Colorado Science Standards

Standard	Activity 1	Activity 2	Activity 3
1. Physical Science	Part B, C	Part A	Part A, B, C
2. Life Science	Part A		
3. Earth System Science	Part A, B, C	Part A	Part A, B, C

Next Generation Science Standards

Science and Engineering Practices	Activity 1	Activity 2	Activity 3
#1 Asking and Defining Problems	Part A	Warm Up	
#2 Developing and Using Models			
#3 Planning and Carrying Out Investigations	Part B, C		
#4 Analyzing and Interpreting Data	Part C	Part A, B	Part A, B, C
#5 Using Mathematics and Computational Thinking	Part C	Part A	Part A, B
#6 Constructing Explanations and Designing Solutions		Part B	Part B
#7 Engaging in Argument From Evidence	Part C	Part B, C	Part B, C; Extensions
#8 Obtaining, Evaluating, and Communicating Information	Part A	Part B, C; Extension	
CH11 Youth Discourses to Scientific Discourses	Part A	Warm Up; Part C; Extension	

Crosscutting Concepts:	Activity 1	Activity 2	Activity 3
#1 Patterns	Part A Part C	Part A	Part C
#2 Cause and Effect	Part A		Part B, C; Extension 1, 2
#3 Scale, Proportion, and Quantity	Part B		Part B, C
#4 Systems and System Models		Part B	Part B, C
#5 Energy and Matter: Flows Cycles & Conservation	Part B, C		Part B, C; Extensions
#6 Structure and Function			
# 7 Stability and Change		Part B	Part C

Disciplinary Core Ideas:	Activity 1	Activity 2	Activity 3
ESS1: Earth’s Place in the Universe	Part B		
ESS2: Earth’s Systems	Part A, B, C	Part A	Part A
ESS3: Earth and Human Activity	Part A	Part B	Part C; Extensions

Essential Principles of Climate Literacy

Climate Literacy Principle 1A. Sunlight reaching the Earth can heat the land, ocean, and atmosphere. Some of that sunlight is reflected back to space by the surface, clouds, or ice. Much of the sunlight that reaches Earth is absorbed and warms the planet.

Climate Literacy Principle 2F. The interconnectedness of Earth's systems means that a significant change in any one component of the climate system can influence the equilibrium of the entire Earth system. Positive feedback loops can amplify these effects and trigger abrupt changes in the climate system. These complex interactions may result in climate change that is more rapid and on a larger scale than projected by current climate models.

Climate Literacy Principle 4A. Climate is determined by the long-term pattern of temperature and precipitation averages and extremes at a location. Climate descriptions can refer to areas that are local, regional, or global in extent. Climate can be described for different time intervals, such as decades, years, seasons, months, or specific dates of the year.

Climate Literacy Principle 4B. Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals.

Climate Literacy Principle 5B. Environmental observations are the foundation for understanding the climate system. From the bottom of the ocean to the surface of the Sun, instruments on weather stations, buoys, satellites, and other platforms collect climate data. To learn about past climates, scientists use natural records, such as tree rings, ice cores, and sedimentary layers. Historical observations, such as native knowledge and personal journals also document past climate change.

Climate Literacy Principle 7B. Climate plays an important role in the global distribution of freshwater resources. Changing precipitation patterns and temperature conditions will alter the distribution and availability of freshwater resources, reducing reliable access to water for many people and their crops. Winter snowpack and mountain glaciers that provide water for human use are declining as a result of global warming.

Arctic Climate Connections Activity 1
Exploring the Arctic

Part A: What's the big deal about the Arctic anyway? Why are so many scientists studying the Arctic?

The Arctic consists of the large, ice-covered Arctic Ocean surrounding the North Pole and the adjacent land region. It is a unique place–a wide, empty, and spectacular landscape. Arctic species have to be well adapted to the extreme climatic conditions found in this region.

The Arctic is an important area for climate scientists who study global climate, as it is very sensitive to changes in climate. However, the Arctic is a difficult place to study. The main challenges to research in the region are extreme weather conditions, seasonal changes in light conditions (nighttime throughout winter and daylight throughout summer), and remoteness.

In this activity, you will explore the Arctic and research done in the region by examining different research sites.

CONCEPT MAPPING – WHAT IS THE ARCTIC?

Before visiting Arctic research sites, you should document your own understanding of the Arctic. To do this, construct a concept map titled, "What is the Arctic?". Consider the following questions when constructing this individual concept map:

- What do you know about the Arctic?
- What makes the Arctic so unique?
- What do you know about the environment, climate, plant cover, animals, human activity, habitability, natural resources, politics, history, populations, and other aspects that come to mind?

Teaching Tips for Part A:
In this activity, students brainstorm their knowledge about the Arctic and build concept maps of different aspects of the Arctic environment. Students try to define the Arctic and revisit the definition after completing a reading.

If your students have never created a concept map, you might want to give them a brief introduction on concept mapping —see next page for background and resources.

When creating the whole class concept map, you can highlight the facts that seem most widely known as well as unusual facts.

The "crumple and toss" or snowball fight activity is a fun break and allows for anonymous peer review.

The readings and explorations prepare students for the videos that are suggested. Guiding questions help students to focus while watching the videos.

Learning Goals:
After completing this activity students will be able to

- Define what the Arctic is.
- Describe the Arctic environment and life of indigenous people

Materials:

- Student Guide
- Student Worksheet
- White board for class concept map
- "Passport to the Arctic" - background readings
- Video streaming capacity
- Powerpoint with all relevant images

Background readings for teachers:
Arctic Report Card (http://www.arctic.noaa.gov/reportcard/) - Updated annually with latest research on changes in the Arctic
NSIDC Arctic Primer (http://nsidc.org/cryosphere/arctic-meteorology/index.html) - Excellent website by a trusted source
NOAA Arctic FAQ Page (http://www.arctic.noaa.gov/faq.html) - Frequently asked questions

Assessment:

- Concept maps (individual, group, and whole-class concept map)
- Definition of Arctic including revisiting of definitions

In groups, create a group **concept map** to show how the different aspects of the Arctic relate to each other based on the individual concept maps of each group member.

Create a **whole-class concept map** by combining the small group concept maps into one.

DEFINITION OF THE ARCTIC:

Using a blank piece of paper, write down a possible definition for the Arctic in your own words.

Crumple up the paper with the definition and toss it to someone else. Everyone tosses the papers until definitions are well mixed, and each student has one definition (that is not his/her own).

Compile all definitions on a shared class sheet. Come to a class consensus about the best definition for the Arctic.

Teaching Tips – Concept Mapping

A concept map is a graphical representation to organize knowledge and show connections between different concepts. They are organized in hierarchical nodes that are linked together with directional lines and are arranged from general to specific.

Suggested background readings about concept mapping:

- http://cmap.ihmc.us/Publications/ResearchPapers/TheoryCmaps/TheoryUnderlyingConceptMaps.htm
- http://www.appliedconceptmapping.info/
- http://www.ifets.info/journals/14_3/3.pdf
- http://serc.carleton.edu/NAGTWorkshops/assess/conceptmaps.html
- http://serc.carleton.edu/introgeo/assessment/conceptmaps.html

Now, read through the background materials “Passport to the Arctic”.

Revisit the definitions on the shared class sheet and the definition in front of you.

- What are the four possible definitions of Arctic? Arctic Circle, Polar Treeline, Average Summer Temperatures, Political Boundaries
- Which of the four possible definitions of Arctic are listed on the class sheet?
- Which of the four definitions in the background reading is the closest to the definition you have in front of you?

EXPLORING VEGETATION IN THE ARCTIC

Reading: Landscapes and Vegetation in the Arctic

When thinking about the Arctic, images of snow and ice usually come to mind for many people. However, the Arctic is covered with vegetation and is home to many animals and people. Read the following background materials on “Landscapes and Vegetation in the Arctic” by the Russian Geographical Society: http://arctic.ru/geography-population/landscapes-vegetation

Guiding questions for the reading “Landscapes and Vegetation in the Arctic”:

- In which of the four Arctic landscapes are trees found? Taiga, Tundra, forest-tundra transition
- What is permafrost? Where does permafrost occur? Permanently frozen ground that remains at or below 0° C. It occurs under tundra and in polar desert.

- Why do we care about Arctic vegetation? Arctic is a sensitive ecosystem where many plants are dependent on stable environmental conditions or otherwise lose their habitat. A changing climate affects the vegetation in the Arctic.

Extension: Exploration of Arctic Environmental Atlas

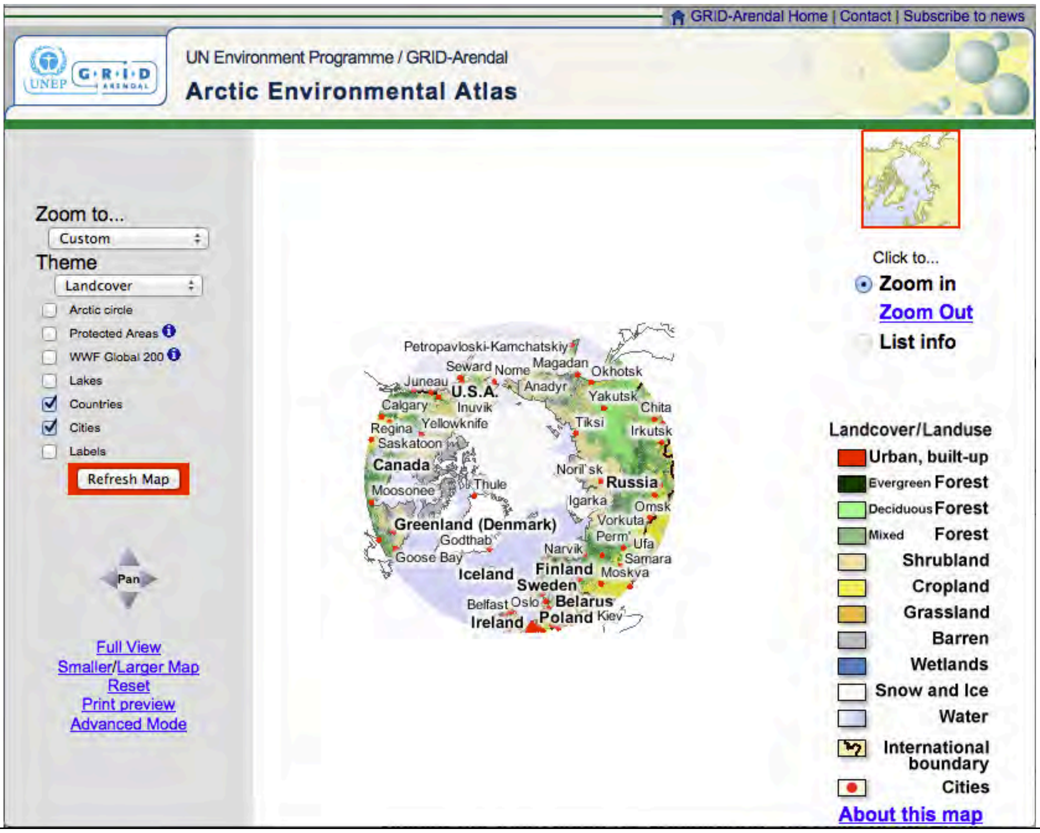
Students can explore the "Arctic Environmental Atlas" by the UN Environmental Program here: http://maps.grida.no/arctic/

Guiding questions for exploring the "Arctic Environmental Atlas":

- In which country/region does forest cover reach furthest north? Central Russia
- In general, do deciduous or evergreen forests extend further north? In most locations, deciduous trees extent further north. However, in Scandinavia, the evergreen trees extend as far as or further north than the deciduous trees.

Additional information for using the "Arctic Environmental Atlas":

- On the left menu bar click "Countries" and "Cities" to make orientation easier.
- Click on the map to zoom in and click on the blue hyperlink "Zoom Out" in upper right hand corner to zoom out.
- For further exploration, you can choose in the upper left hand corner to zoom into defined geographic areas or replace the displayed information by choosing a different theme.



Zoom to... Custom
Theme Landcover
☐ Arctic circle
☐ Protected Areas
☐ WWF Global 200
☐ Lakes
☑ Countries
☑ Cities
☐ Labels

Click to...
● Zoom in
○ Zoom Out
○ List info

Visualization: Greening of the Arctic
View the following visualization about vegetation in the Arctic.

Greening of the Arctic (3:34 minutes)
by American Museum of Natural History
http://www.amnh.org/explore/science-bulletins/%28watch%29/bio/visualizations/greening-of-the-arctic

Science Bulletins

Greening of the Arctic

November 2013

In the Arctic, where air temperatures
rising at about twice the global rate,
scientists are seeing major shifts in p
life. Trees and shrubs are expanding
pushing northward, while the low-to-
the-ground tundra plants to their nor
shrinking in range. In this visualizatio
watch these changes and the influen
they are forecasted to have on the c
system.

Dataset Information
Google+ Hangout
For Science on a Sphere
Related Links

Download the Video: HD

Guiding questions about the visualization, "Greening of the Arctic":

- How does the Arctic vegetation respond to a changing climate? Arctic will become greener; vegetation zones will extend further north.
- Based on the visualization, how do scientists study vegetation in the Arctic? Models and observations
- Explain what is meant by a positive feedback loop with respect to climate change and vegetation in the Arctic. Does this mean the feedback is beneficial? A positive feedback loop is reinforcing an effect; a negative feedback loop is dampening an effect. Positive and negative do not correspond to being either beneficial or harmful. An example of a positive feedback loop is albedo and climate change. An example of a negative feedback loop is (more difficult to find) pushing a rock uphill.

EXPLORATION OF ARCTIC'S INDIGENOUS POPULATION:

Read a short article about the "Population of the Arctic" from the Russian Geographical Society:
http://arctic.ru/geography-population/population

Take a look at the map below that shows the population distribution in the Arctic by country.
http://www.grida.no/graphicslib/detail/population-distribution-in-the-circumpolar-arctic-by-country-including-indigenous-population_1282

Guiding questions:

- What percentage of the Arctic population is comprised of indigenous people in Canada, Greenland and Russia, respectively? Canada ~ 50%, Greenland ~ 80%, Russia ~ 10% (Numbers will vary since the percentage has to be guessed based on the graphic.)
- How did people in the Arctic originally adapt to live in the extreme Arctic environment? Nomadic or semi-nomadic lifestyle

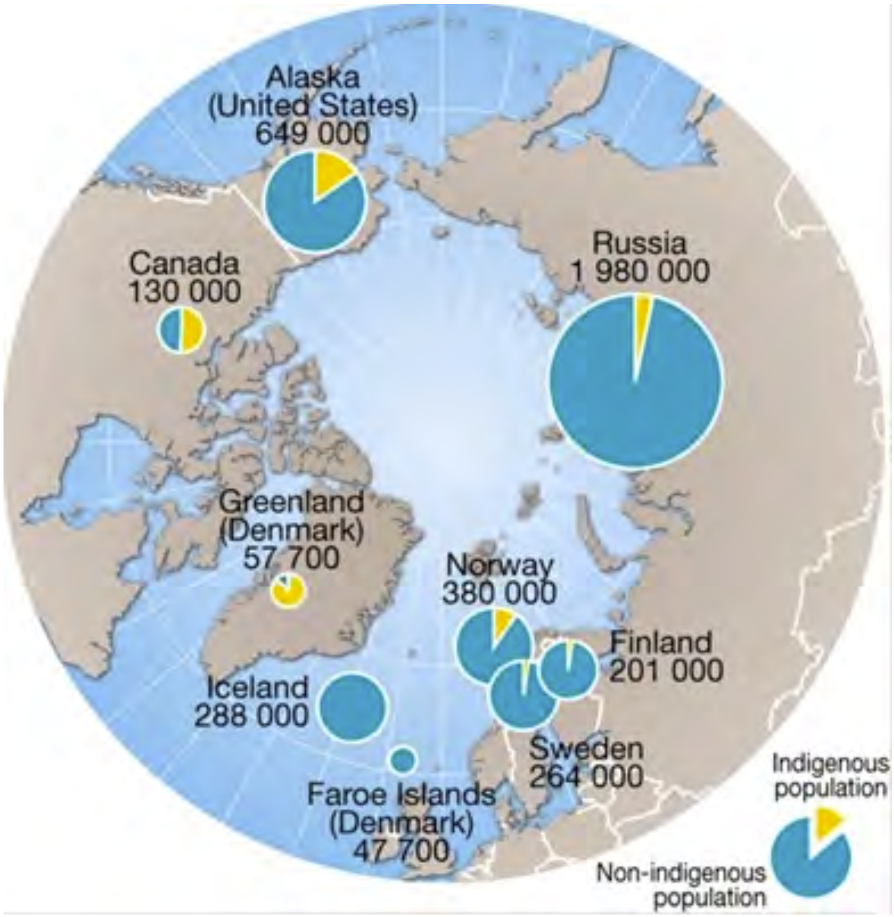
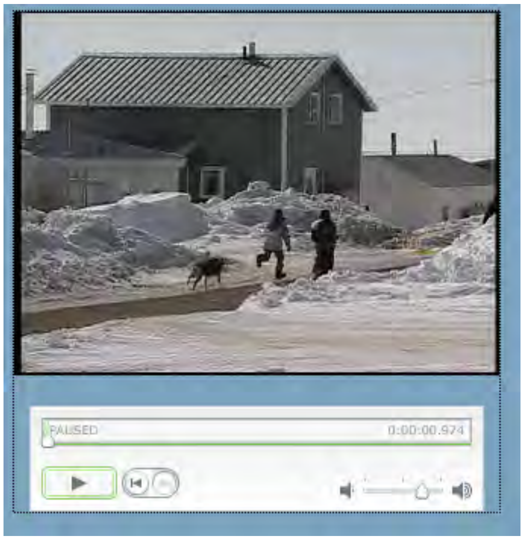


***Image source: U**NEP: Population distribution in the circumpolar Arctic, by country (including indigenous population)*

Extension – Documentary of Arctic People and Climate Change:

Watch the following documentary about the Inuits in Sachs Harbor, Canada
Eyewitness of Changes in the Arctic's Climate (5:33 min)
from Smithsonian Institution / National Museum of Natural History:
http://forces.si.edu/arctic/video/eyewitness.html



Guiding questions:

- What effects of climate change are being reported by Inuit people of Sachs Harbor?
- How are scientists working together with these Sachs Harbor citizens?

Part B: A Virtual Trip to the Arctic

The Arctic is politically shared by many nations. The Arctic is sparsely populated and home to many indigenous people. Research is often conducted as international research efforts. One large international research organization that coordinates atmospheric research efforts working in the Arctic is the International Arctic Systems for Observing the Atmosphere (IASOA). They coordinate research conducted in atmospheric observatories around the Arctic.

The following data analysis activities (Arctic Climate Connections Activities 2 and 3) are based on data collected at one of the IASOA observatories. This research was conducted by scientists from the National Oceanic and Atmospheric Administration (NOAA) and University of Colorado's Cooperative Institute for Research in Environmental Sciences (CIRES). This next exploration takes you on a virtual tour of different Arctic research sites using Google Earth.

Exploration of Arctic Research Sites:
Visit the International Arctic Systems for Observing the Atmosphere (IASOA) website at http://www.esrl.noaa.gov/psd/iasoa/, and click on "Observatories". Click through different stations and look at their webcams or images. Then visit the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) website at http://eloka-arctic.org/about/

Guiding questions:

- Who participates in the IASOA? International agencies, academic institutes and individuals
- What role do Arctic people play in Arctic research efforts? Observations of Arctic people are important to understanding changes in the environment. They live in the Arctic year round and are very knowledgeable about and sensitive to changes in the Arctic environment

Teaching Tips for Part B:
Students take a virtual tour of the Arctic and Arctic research sites using Google Earth.
The short tutorial introduces students to all features necessary to complete the activity.
The PowerPoint file includes screenshots of step-by-step description of answers.

Learning Goals:
Students will be able to

- Describe geographic extent of the Arctic.
- Describe differences between mid-latitudes and the Arctic latitudes.
- Locate Arctic research stations using Google Earth.
- Rationalize why people study the Arctic.

Materials:

- Student Guide
- Student Worksheet
- Computers with Google Earth installed and internet connectivity
- Powerpoint file with relevant images and step-by-step description of answers

Background readings for teachers:

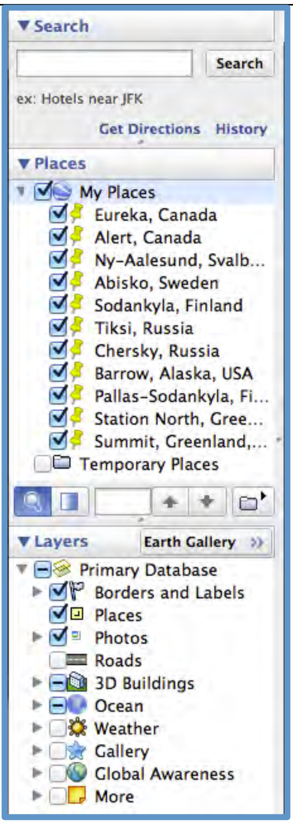
- Google Earth tutorials https://support.google.com/earth/answer/176576?hl=en
- Google Earth user's guide https://docs.google.com/file/d/0BzmdpKjx5MyDZjc5NzM5ZTUtNGIwMy00MDg1LWE3NWQtYzZhZWU1ODFkZDQz/edit?hl=en_US
- How to teach with Google Earth http://serc.carleton.edu/sp/library/google_earth/how.html

Preparation:
Go to http://www.google.com/earth/index.html. Download the latest version of Google Earth using the blue "Download Google Earth" button in the upper right hand corner.
Follow the instructions and prompts to install the software onto your computer.

Assessment:

- Google Earth kmz files
- Worksheet questions
- "Thinking Deeper" questions

Brief Google Earth Tutorial



Layers and Featured Content

Note the panels on the left side of the screen (**Search**, **Places**, **Layers**). You can search Google Earth in the **Search** panel, just as you would search any other online mapping software. The **Places** panel is where you can store your own files and folders, and where you can save downloads. Finally, the **Layers** panel allows you to turn on and off other features, such as borders, roads, pictures, and many more. All these layers can be turned on and off by clicking the box to the right of each layer. The little arrow that points to the right shows that there are additional sub-layers available. Clicking this arrow unfolds the additional layers.

Navigation

In the upper right corner of your screen there is a control panel that only appears when you move your cursor over the window. It has three parts:

- The upper control lets you look around (as if you were turning your head) and it indicates where north is relative to your view.
- The middle control panel lets you move around from one place to another.
- The bottom panel is used to zoom in and out. If you zoom in enough, Google Earth automatically tilts your view up toward the horizon, and you can use the top panel to change the direction.

Saving Your Work:

Click on the **Add** menu at the top of the Google Earth window and add a folder. Name this folder with your last name. Once added, you will see the folder in your **Places** panel. Be sure that the folder is inside the **My Places** folder and NOT inside the **Temporary** folder – simply drag and drop to rearrange the folders.

Trouble Shooting:

If Google Earth is not working properly try to close the program and restart it.

START GOOGLE EARTH EXPLORATION CLOSE TO HOME

1) Launch Google Earth on your computer and "fly" to your school by typing the name of the school (and possibly the street address) in the **Search** box at the top. You will see an overview of the neighborhood of the school. You can zoom in further to look at the school buildings, sports facilities, and parking lots. Once you zoom in enough, Google Earth will change to Street View and you can look at the school in 3D. Can you recognize any landforms like ponds, parks, rivers, streams, lakes, hills,

and valleys?

2) Add a "placemark" at your school by clicking on the yellow pin icon at the top of the screen. A pin shows up on the Google Earth image, and you can move the pin while it has a yellow border until it sits right at your front door. Please name the placemark by typing the name you choose in the New Placemark window that appears. If you want to edit your placemark, right click and choose **Get Info**.

3) Use the navigation tools to navigate around your hometown. Make sure to note what vegetation you can see in the images – can you see trees, grass, and shrubs? Describe the vegetation that you can identify. Answers will vary but likely include trees, bushes, shrubs, grass.

LET'S VISIT THE ARCTIC

Later in this module, you will use meteorological data that was collected by a research team from Boulder, CO–Andrey Grachev and Ola Persson—who study Arctic weather and climate. They are part of a pan-Arctic IASOA research network that has weather stations located across the Arctic. Using Google Earth, you can "visit" a few of the sites where they collect their data.

1) The first site you will visit is **Eureka** in Canada. Type in your Google Earth search box, "Eureka, Canada." Add a placemark that you name, "Eureka".
Now zoom out to see where the placemark (=Eureka) is located relative to your hometown and where in Canada.

2) Explore the settlement. Make a simple hand-sketch on a separate piece of paper that shows the layout of the settlement.

- What type of vegetation do you see around Eureka, Canada? Barren ground; no visible vegetation, but greenish color in some locations
- Describe the physical setting (mountains, rivers, ocean) of Eureka, Canada using cardinal directions (N, S, E, W)? Located at mouth of river, along ocean, low mountains to north
- What does the infrastructure of Eureka, Canada look like (roads, buildings)? Dirt roads, large industrial size buildings, airport to east of settlement

More information about Eureka, Canada

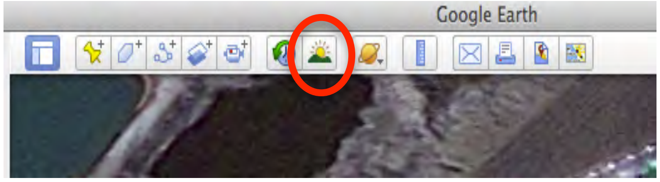
In the following activities students will be working with data collected in Eureka. Eureka is located on Ellesmere Island in Nunavut, the northernmost of Canada's three territories (Nunavut, Northwest Territories, and Yukon).
The Eureka weather station was established in 1947 and has been manned continuously since then. At 80N, Eureka is well north of the treeline where the main biome is tundra. Arctic mammals such as the polar bear, arctic fox, caribou, muskox, narwhale, and walrus frequent Ellesmere Island and its surrounding waters. Geological features in the area include glaciers, low mountains, and the ocean.

Additional materials about Eureka:

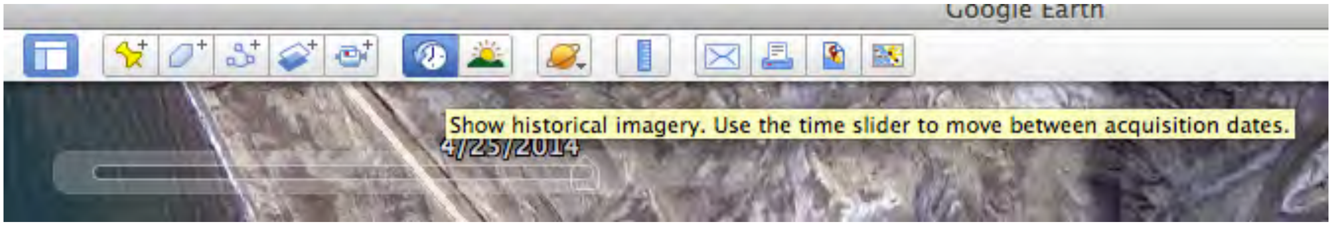
http://www.uphere.ca/node/140
http://www.youtube.com/watch?v=UAVUZsNvbtw

3) What is the elevation above sea level of Eureka, Canada? Approximately 10 ft/3 m above sea level (hint – zoom into ground level or street view by dragging the orange person to a place in Eureka,

Canada (see left) – then Google Earth zooms into ground-level view (see right pic). You can read the elevation in the lower right hand corner.



4) Click on the icon with the sun in the top bar above the image. You will see the amount of daylight in Eureka at the current time. Move the slider to find out when it gets light in Eureka today. You can also play a time slider animation that shows the amount of daylight throughout the year by clicking the “Show historical images” icon that has a globe with a left pointing arrow. That will open the time slider. By clicking on the wrench icon you can choose the time and day but can also just use the time slider function. When does it get light in Eureka today and when does it get dark? Answers will vary depending on the date that the activity is completed – in the winter months it will be darker than in the mid-latitudes, and in the summer months it will stay light longer than in the mid-latitudes.



5) Go to http://www.esrl.noaa.gov/psd/iasoa/stations/eureka, then read more details about Eureka’s observatories. Next, look at some images from the settlement by scrolling down the page to “site map”. Click on the image and find the location of the flux tower on the photograph (marked in green). Now go back to Google Earth. Look for the location of the flux tower that you just saw on the IASOA website in Google Earth. You will measure the distance from the NOAA observation tower to the ocean.

- Select the ruler icon in the menu bar above the image.
- Choose a sensible unit of measurement.
- Click the starting point of the measurement (tower).
- Click the end point of the measurement (ocean).

Approximately, how far is the flux tower away from the ocean (make sure to include the unit you used for the measurement)? Results will vary slightly depending which exact points students choose but approximately 400 m.

6) Now visit the research station **Barrow, Alaska** using Google Earth. The research station is located exactly at 71.325 N 156.625 W outside the town of Barrow. Copy or type the geographic coordinates in the Search field to find the exact location of the station. Set a placemark where the station is and choose an appropriate name for your placemark.

7) Measure the distance (in a straight line) from the station to the airport in the town of Barrow (following the instructions about distance measurements under question 5). Results will vary slightly depending which exact points students choose but approximately 1.8 km. (See detailed instructions on ppt for question 5.)

8) Click on the sun icon at the top of the screen to see whether it is light or dark in Barrow (same process as for question 4). Then go to the website from IASOA about the Barrow station: http://www.esrl.noaa.gov/psd/iasoa/stations/barrow and look at the webcam.
Does the webcam show the same light/darkness as you see in Google Earth? No, the amount of daylight is likely different as visible in Google Earth and in the webcam. The webcam does not update instantaneously – check the timestamp for the webcam.
If not, please explain and explore if there is a way to replicate the webcam light conditions. You can reconstruct the same amount of daylight by moving the slider in Google Earth back to the time the webcam was last updated.

9) Now visit **Ny Ålesund,** Svalbard in Norway and set a placemark. You can see little image icons around the town. Click on some of the pictures and see what Ny Ålesund looks like. What does the vegetation in Ny Ålesund look like based on the pictures? The ground in Ny Ålesund is barren except for only small shrubs and grasses.

10) Now visit **Tiksi** in Russia, another IASOA station. Explore the town using Google Earth and visit the IASOA website: http://www.esrl.noaa.gov/psd/iasoa/stations/tiksi. Set a "placemark".

11) Determine the distance from each of the four stations (see your placemarks) to the Arctic Circle (66° 33′ 44″N or 66.5622°N). Use the ruler and determine the distance between each station and the Arctic Circle–make sure to use a sensible unit: Find the location with the same longitude as each site on the Arctic Circle by replacing the latitude of the geographic coordinate of each site with66.5622°N in the search box at the top, keeping the latitude the same as the research site. Zoom out so that the research site placemark and the location south of the research site on the Arctic Circle is visible. Measure distance as shown before.

Eureka – Arctic Circle: about 1495 km or 928 miles
Ny Ålesund – Arctic Circle: about 1500 km or 932 miles
Tiksi – Arctic Circle: about 570 km or 354 miles
Barrow – Arctic Circle: about 527 km or 327 miles

12) Save your work: Right-click on the folder that includes the four placemarks that you have created. Choose **Email** and follow the instructions for sending an email. The program will automatically create a .kmz file (zipped version of the .kml file for each placemark) of all your placemarks. Send the .kmz file to your teacher and your school email or save it to a flashdrive for data transfer.

Thinking Deeper:

In these activities you have defined what the Arctic is and explored sites across the Arctic. What effect does the tilt of the Earth's axis have on the Arctic? Earth's axis is tilted at an angle of about 23.5°. The tilt remains in the same direction as the Earth spins around the Sun. This causes the seasons in the mid and high latitudes. The tilt therefore also causes the extremes of the seasons--polar night and polar day at the poles. Because of this tilt, sunlight doesn't reach the North Pole in the winter (polar night), and in the summer the North Pole receives continuous daylight (polar day).

Now imagine Earth's axis wasn't tilted. What would the effect be on the Arctic in terms of temperatures, daylight, and vegetation? The Arctic (just like any other place on Earth) would not have seasons. The poles would be perpendicular to the sun throughout the entire year. Each location would have equal day and night lengths with the sun angle at noon being about the same everyday. However, at the poles, the sun would always be at the horizon for 24 hours per day. This distribution of daylight is like that found at the equator. The temperature and precipitation pattern would be similar to today's, with temperatures getting colder the further pole-wards one goes. The poles would have much more uniform temperatures year round with a constant low sun angle. Temperatures in the Arctic as well as the entire Northern Hemisphere would be slightly warmer in the northern hemispheric summer (as we know it now) and colder in the winter due to the annual variation in the Earth-Sun distance.

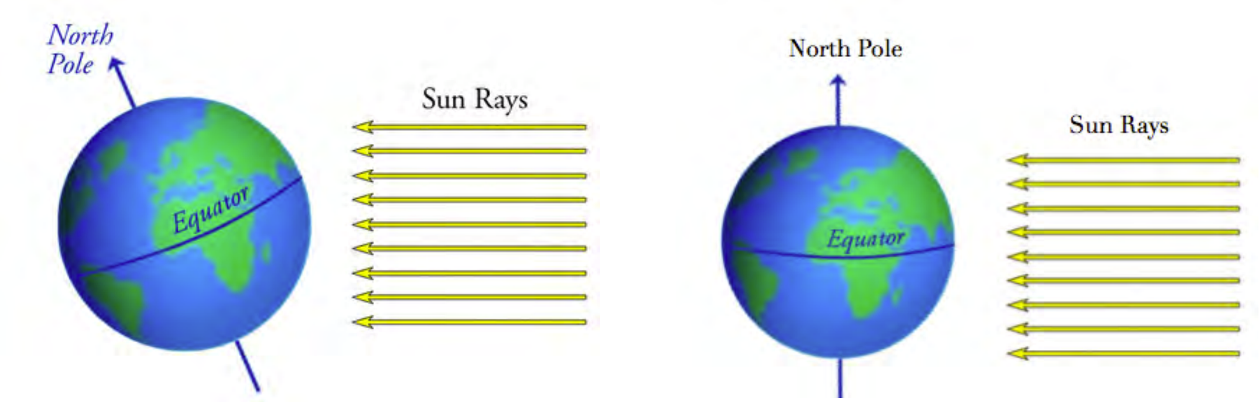


Image: Earth with an axial tilt of about 23.5deg (left) and without a tilt (right). Modified from Illustrative Mathematics

Going back to the four definitions of the Arctic we have provided and the four corresponding maps, can you identify any locations that are being considered part of the Arctic based on one (or more) of the four definitions but not considered part of the Arctic by one of the other definitions? Explain.

	Arctic Circle	**Average summer temperature**	**Polar treeline**	**Political boundaries**
Arctic Circle – Average	--	Area over ocean goes much further south than over land due to lower heat capacity of land vs. water.	Over land, the treeline goes further north than the Arctic circle. The larger the land mass, the further north treeline extends due to lower heat capacity of land vs. water.	Political boundaries are not dependent on any physical properties.
Average summer temperature	Area over ocean goes much further south than over land due to lower heat capacity of land vs. water.	--	The geographic distribution between the two is similar because of the lower heat capacity of land vs. water. Treeline can only be observed over land.	Political boundaries are not dependent on any physical properties.
Polar treeline	Over land, the treeline goes further north than the Arctic circle. The larger the land mass, the further north treeline extends due to lower heat capacity of land vs. water.	The geographic distribution between the two is similar because of the lower heat capacity of land vs. water. Treeline can only be observed over land.	--	Political boundaries are not dependent on any physical properties.
Political boundaries	Political boundaries are not dependent on any physical properties.	Political boundaries are not dependent on any physical properties.	Political boundaries are not dependent on any physical properties.	--

Part C — Collecting Your Own Meteorological Data

Teaching Tips for Part C:
Students conduct hands-on experiments measuring albedo, relative humidity, and soil temperature using simple techniques. In the jigsaw activity, students analyze the collected data in teams and discuss the provided questions. Then students research and identify scientific instruments at the Eureka Arctic meteorological tower.

The hands-on experiments have to be done in groups of no more than four students because the report-out will be done in a jigsaw format. Assign a role to each student to increase accountability, e.g., 1) set up, 2) note taker, 3) measurements, 4) results.

An excellent reference on teaching with the jigsaw method can be found at:
http://serc.carleton.edu/sp/library/jigsaws/index.html

The last part of the activity (Eureka flux tower) encourages students to think about how scientists know what they know. This can also be completed as a homework assignment.

Learning Goals:
Students will be able to

- Describe and measure albedo, relative humidity, and soil temperature.
- Evaluate collected data.
- Name instruments that are used for meteorological observations.

Materials:

- Student Guide
- Student Worksheet
- *Albedo Materials:*
  - 1-3 light meters ($15, for example here: http://www.amazon.com/dp/B000JWUT6O/ref=pe_385040_30332190_TE_M3T1_ST1_dp_1)
- *Relative Humidity Materials:*
  - 2-4 red bulb glass thermometers
  - wet cloth
  - cardboard squares, rubber bands
- *Soil Temperature Materials:*
  - 2-4 soil thermometers
  - nail or spike, hammer for pilot hole

Preparation:

- Set up stations outside for three activities

Assessments:

- Data collection sheets
- Responses to discussion questions

Research scientists like Dr. Andrey Grachev and Dr. Ola Persson measure many climate and weather parameters at research sites across the Arctic. They use automated measurement stations to get continuous data. This means that the measurements are controlled by computers and conducted automatically without the need of a person to be present. Having scientific personnel at each research site around the year would be too expensive and difficult to maintain. Having continuous measurements of Arctic meteorological data allows calibration of climate models and the study of meteorological conditions across the Arctic.

Collect your own data

Before you start analyzing data that was collected by researchers in the Arctic you will get some experience with collecting data yourself. In this activity you will gather the same type of data that scientists collect, only using simpler instruments. In groups of two to four students you will be conducting measurements and recording your data on your data collection worksheets just like scientists do in the field. Make sure that you sketch the experimental set up; note the date, collectors, general conditions, and any other observations and metadata that you might have at the site. This will allow revisiting the data collection conditions. You will rotate through all three stations (albedo, relative humidity, soil temperature).

Data Collection I: Albedo (modified from EarthLabs)

Background:
Albedo is a measure of reflectivity. It is the ratio of the incoming solar radiation (or shortwave radiation) reflected by a surface to the total incoming solar radiation. Albedo can either be expressed in a ratio (dimensionless number) or as a percentage. The

higher the value, the more energy is reflected back to the source. Complete reflection is 1 or 100%, and complete absorption is 0. Surfaces that have a low albedo such as rocks or water are dark colored and will absorb more incoming solar radiation. High albedo surfaces are light, such as snow, ice, or sand, and reflect most of the incoming solar radiation back into the atmosphere.
Incoming solar radiation is measured in Watt/m^2, and the instrument that is used for the measurement is called a **pyranometer**.


Pyranometer (above) Source: NOAA

Lightmeter (above) Source: Amazon

Since pyranometers are very expensive, the following experiment will be done with lightmeters. Lightmeters provide a measure of the light intensity (measured in the unit, **lux**), a good approximation of solar radiation.

Procedure:
At this station you will measure the albedo of different surfaces such as grass, sand, dirt, asphalt, snow, or concrete. At each site, you will measure light intensity of your light source and different surfaces with a lightmeter and calculate the albedo for each material.

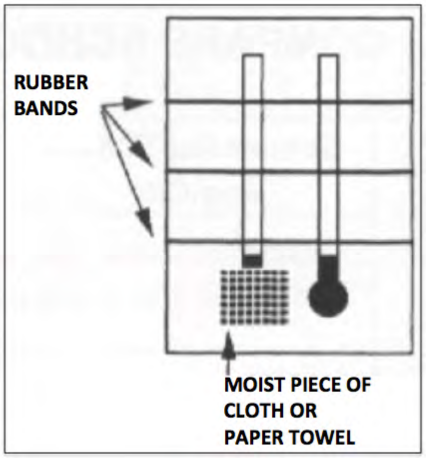
1) Point the lightmeter directly to the incoming light source (sun or lamp). Avoid measurements if a shadow covers the lightmeter.
2) Record the incoming illuminance on your data sheet.
3) Point the lightmeter directly at the surface that you want to measure.
4) Record the reflected illuminance on your data sheet.
5) Calculate the albedo for the surface by determining the ratio of the outgoing illuminance over the incoming illuminance.
6) Conduct measurements for other surface types. Ensure that you measure the incoming versus reflected illuminance in a short time period.

Data Collection II: Relative Humidity (modified from Science Giants – Earth and Space):

Background:
Relative humidity measures the amount of water vapor that is currently in the air *compared to* how much water vapor the air can hold at that temperature. Relative humidity can be defined as:

Relative humidity % = (Moisture in the air now / Maximum possible moisture air can hold at the current temperature) x 100

The amount of water vapor air can hold is dependent on the air temperature. Warm air can hold more moisture than cold air, so the relative humidity of air is higher on a warm, cloudy day than on a clear, cold day. Relative humidity is stated as a percent. If the relative humidity is 50%, this means that the air contains half of the water vapor that it can hold at that temperature.



Procedure:
At this station you will create a sling hygrometer to measure relative humidity.

1) Lay two thermometers side by side on a piece of cardboard. Use rubber bands to hold them in place (see image).

2) Wrap the bulb of one thermometer with a moistened piece of cloth or paper towel (=wet bulb thermometer) and keep it moist.

3) Read and record the temperature of the dry bulb and the wet bulb. The dry bulb thermometer simply measures the air temperature.

4) Carefully fan the cardboard with the two thermometers in the air for about 30 seconds or until the wet bulb temperature stops falling and remains constant.

5) Record the temperatures for both thermometers on the worksheet and calculate the difference between the temperatures [dry bulb temperature – wet bulb temperature].

6) On the Relative Humidity chart find the dry bulb temperature that you measured on the y-axis and the difference between the two measured temperatures on the x-axis. The relative humidity is given as a percentage where the corresponding rows meet.

Data Collection III: Soil Temperature (modified from GLOBE Soil Temperature Protocol):

Background:
Soils are a mixture of weathered bedrock or other local rock material (“parent material”) and organic matter. The temperature of soil fluctuates over the day and over the year and is affected mainly by variations in air temperature and solar radiation. The water content of the soil plays an important role in the temperature exchange between air and soil temperature since higher water content in the soil increases the thermal conductivity of the soil. A temperature gradient exists if the air and soil temperature are different, and heat will be transferred to reduce the temperature gradient. Soil

surface temperatures are usually closer to the air temperature, while deeper soil layers are usually delayed in displaying any changes in air temperature. Thus, soil temperature varies with depth below ground. The degree of shading by plants and trees, as well as a snow cover, affects the temperature profile in the ground due to insolation properties (insolation = **in**coming **sol**ar radi**ation**).

The Plan:
At this station you measure soil temperature by placing the thermometer in the ground at different depths and carefully measuring the temperature. Air temperature measurements will also be conducted at this station.

1. Choose two different sampling sites that appear to have different soil properties (sandy versus clay or different vegetation cover) for each student group conducting a measurement. Note the density of soil and the vegetation cover

2. Measure the air temperature about 30 cm (one foot) above the ground using a thermometer or temperature probe. Make sure not to measure in direct sunlight since that will cause an erroneously high measurement. Record the temperature.

3. Make two pilot holes at each site that have the approximate diameter of your thermometers (by using for example a thick nail and a hammer or a hand-drill). The pilot holes should be about 5 cm (2 inches) deep. Try to disturb the soil as little as possible when pulling out the nail or drill. Twisting as you pull out may help. If the soil cracks or bulges, choose another site and drill new holes.

4. Measure 5 cm (2 inches) from the temperature sensor (not the tip–the sensor is often located about 2 cm above the tip) and mark the two thermometers (this will be the depth to which the thermometers are being inserted in the ground).

5. Gently push the thermometers into the soil down to the mark that you made on the thermometer shaft. Put on safety equipment such as gloves and goggles if working with glass thermometers. Be careful to not break the glass of the thermometer when pushing it in the soil to avoid injuries to your hands. You are measuring the soil temperature at 5 cm depth. Wait 2 minutes. Record the temperature for each thermometer on the worksheet as the 5 cm reading. Remove the thermometers from the holes.

6. Now deepen both holes to 10 cm (4 inches) using the thick nail or spike. Measure 10 cm (4 inches) from the temperature sensor and mark the thermometer shaft.

7. Insert the thermometer in the same hole and gently push it down until the mark on the thermometer shaft is level with the surface, indicating that the temperature sensor is 10 cm below the surface. Wait 2 minutes and record the temperature.

8. Calculate the average of the two measurements for 5 cm depth and 10 cm depth below ground.

9. Compare the measurements from different sites.

How hot is it today? Air temperature is not the only factor that we need to consider when talking about the perceived heat of a day; we also have to take into account the relative humidity. A 100°F day in Montgomery, Alabama feels much hotter than in Tucson, Arizona because of the higher relative humidity in Alabama. The human body cannot as effectively cool itself due to the high humidity, causing heat related issues such as heat stroke. This effect is measured in the so-called Heat Index. You can calculate the Heat Index by using the NOAA Heat Index Calculator http://www.wpc.ncep.noaa.gov/html/heatindex.shtml.

Thinking Deeper

For the debrief, student research groups reorganize into three “expert teams”: one for Albedo, one for Relative Humidity, and one for Soil Temperature. Each student research team sends at least one student with the group measurements to one of the three expert teams with their team’s corresponding data (i.e. albedo expert team representative brings albedo data only).

Albedo Expert Team

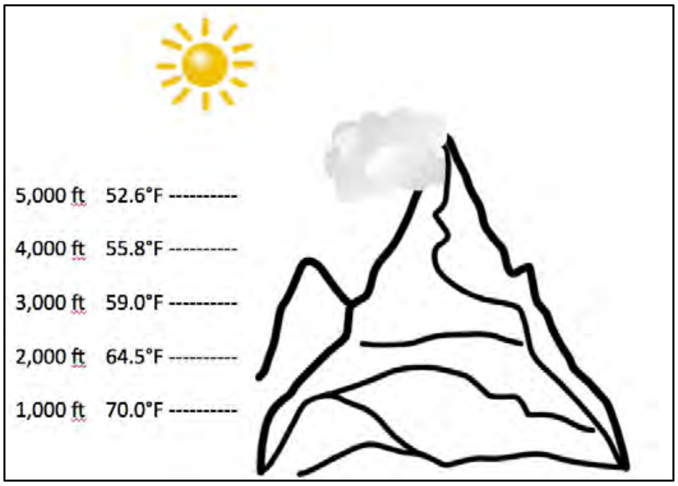
Compare the albedo measurements from the different student research groups by looking at variation of data among the different groups, identifying possible outliers and discussing reasons, emerging patterns, or relationships. Please discuss the following guiding questions:

- Which surface had the highest albedo? Which surface had the lowest albedo? Lighter surfaces like snow or sand will have a higher albedo than darker surfaces.
- Which surfaces in the Arctic would have the highest albedo, assuming the sun hits the surface at the same angle: open ocean or sea ice? Explain why. Sea ice because the light surface of sea ice reflects a lot of the incoming solar radiation; water absorbs a lot of the incoming solar radiation.
- Thinking globally:
  - What is the effect of a large volcanic eruption that reaches the stratosphere (like Mount Pinatubo on the Philippines in 1991) on the albedo in the Arctic? Dust that reaches the stratosphere increases the albedo of the atmosphere, reflecting a larger than usual percentage of incoming solar radiation and therefore reduces the global temperature. A small global cooling of about 0.5°F was recorded for the Mt. Pinatubo eruption in 1991 (see e.g., http://www.giss.nasa.gov/research/briefs/hansen_02/).
  - What is the effect of a dust storm on the albedo of ice sheets? Explain why. Dust on ice reduces the surface albedo of ice, increases the absorption of incoming solar radiation at the surface, and therefore causes increased melting at the surface.

Relative Humidity Expert Team

Compare the relative humidity measurements from the different student research groups by looking at variation of data among the different groups, identifying possible outliers, and discussing reasons, emerging patterns, or relationships. Please discuss the following guiding questions:

- What were the average and the range of relative humidity determined by the groups? What were the average and the range of air temperature measured by all groups? Results will vary
- Think globally:
    - Think about the effect that changing air pressure has on relative humidity. Does the relative humidity of an air parcel change if it moves upslope? The relative humidity drops if an air parcel is lifted (but only if the temperature stays the same). The relative humidity is a function of air temperature and pressure. The same amount of water vapor in an air parcel is equivalent to a certain relative humidity at a given temperature and pressure. If the temperature decreases, the relative humidity of the same air parcel and the same amount of water vapor increases. If the absolute pressure of the system decreases (like in a lifted air parcel) the relative humidity increases. Because air that rises upslope cools and experiences a decrease in air pressure, the effects are opposing.
    - Which side of a mountain chain receives higher precipitation–the windward facing or the leeward facing side? Why? The windward facing side brings a certain amount of humidity. When the air gets forced uphill it cools, and the relative humidity drops. Depending on the height of the mountain, and therefore the amount of cooling, the air exceeds 100% relative humidity, and it rains. The air on the leeward facing side of the mountain will therefore contain less total water vapor because some of it was lost as rain. It will therefore be less likely for water vapor to condense and for precipitation to occur.



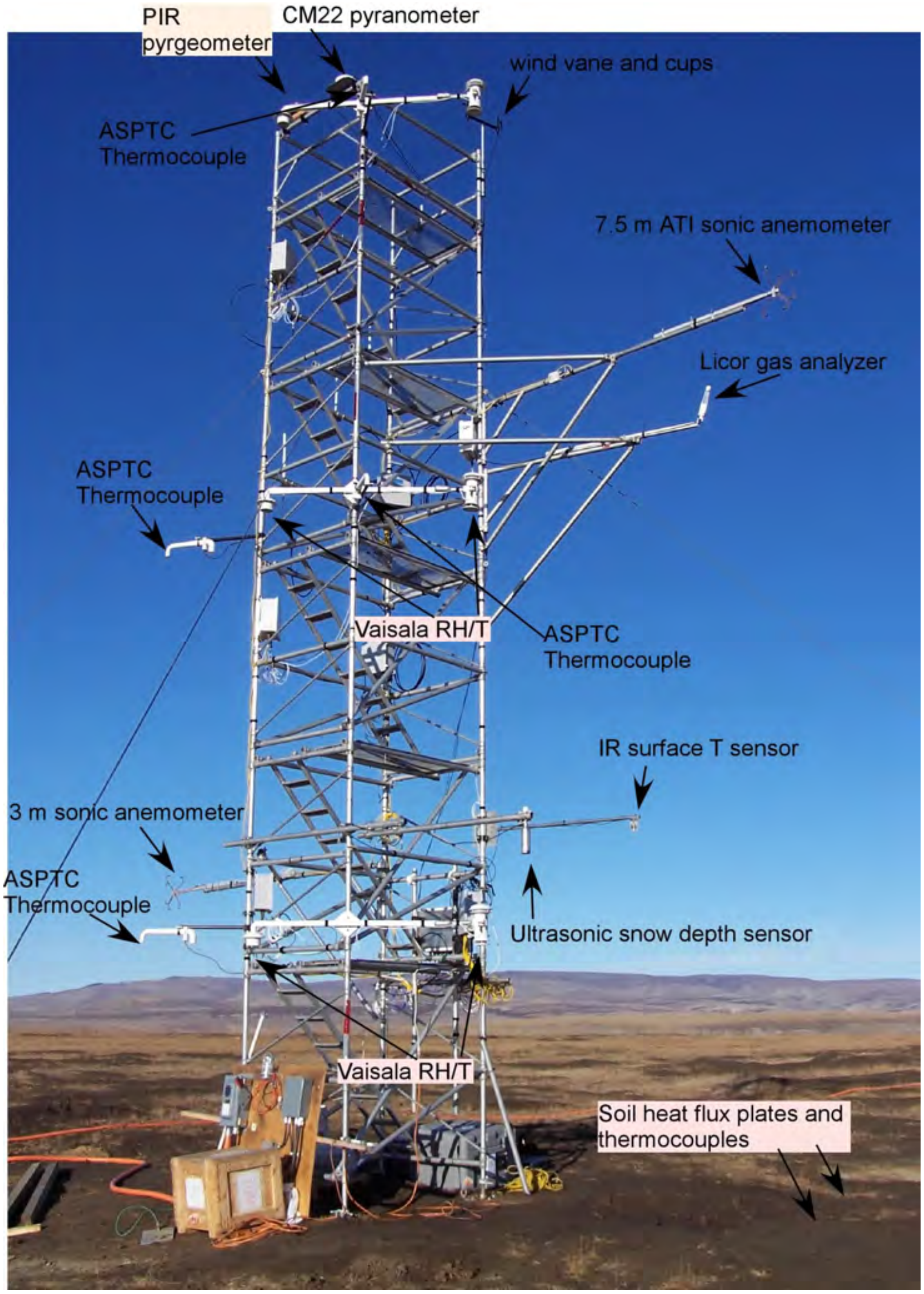
Soil Temperature Expert Team

Compare the soil temperature measurements from the different student research groups by looking at variation of data among the different groups, identifying possible outliers, and discussing reasons, emerging patterns, or relationships. Please discuss the following guiding questions:

- At which sampling location did you find the largest difference between air and soil temperatures? Results will vary.
- Can you explain why the difference was largest? Air temperature changes more quickly than soil temperature.
- Which soils would you expect to warm faster with warming air temperatures? Why?
    - Wet soils or dry soils? Dry soils because the heat capacity is lower. Wet soils will retain heat that they absorb better–the effect will be more long-lasting but slower.
    - Snow covered soils or barren soils? Barren soils because they are not insulated by a snow pack.
    - Light soils or dark soils? If the sun is shining on the soils, the dark soil will warm faster because its albedo is lower.
- Thinking globally: Increasing soil temperature in the Arctic raises important concerns with climate scientists as well as the local population in the Arctic. Can you brainstorm why? Effects on local populations: In places where permafrost is present, all infrastructure is very sensitive to thawing of the permafrost; foundations of houses, bridges, roads, and railways will be unstable once permafrost thaws. Effects scientists worry about: Thawing permafrost releases greenhouse gases like methane into the atmosphere, causing global warming.

Scientific Data Collection: Eureka Tower

How do scientists conduct measurements? The National Oceanic and Atmospheric Administration (NOAA) and Environment Canada constructed together a 10.5 m tower, called a flux tower that holds multiple meteorological instruments that record hourly data year round. This tower is located just outside of Eureka, Nunavut, Canada (you visited the site with Google Earth earlier).



In the previous activity you conducted measurements of basic meteorological parameters like albedo, soil temperature, and relative humidity. The instruments that you used were simplified versions of the instruments that the scientists use. Research instruments conduct measurements with high precision so that scientists can trust their results.

The meteorological data that you will be using in the following Activities 2 and 3 (Arctic Climate Connections Activities 2 and 3) was collected at the Eureka flux tower in 2010. In order for you to understand how the data was derived, please look in detail at the photograph of the flux tower. Using internet-based research, find out what each of the instruments measure and complete the matrix below.

Thinking Deeper:

- What is precision? Precision of a measurement can also be referred to as reproducibility. It measures to which degree measurements with the same instrument produce the same result.
- How is precision different from accuracy? Use the meteorological measurements as an example when explaining the concept. Precision describes reproducibility. Accuracy describes the quality of the measurement–does it measure what the instrument is supposed to measure. A thermometer might repeatedly produce the same temperature, but the calibration of the measurement might be off, so the accuracy of the measurement is not high while the precision is.

	What does the instrument measure?	**Unit that parameters are measured in**	**Height above/below ground**	**Instrument Direction** (facing upward, facing downward, no direction)
Soil heat flux plates and thermocouples	Soil temperature gradients are measured with thermocouples (two different conductors measure electricity between the two).	Degree Celsius	Soil temperature measured at 2 cm, 5 cm, 10 cm, 20 cm, 25 cm, 30 cm, 45 cm, 70 cm, 95 cm, 120 cm depth below ground	Down
Vaisala RH/T	Relative Humidity and Temperature–Both relative humidity and air temperature are measured with the same device at the Eureka Flux Tower	Temperature - Degree Celsius, Relative humidity - percentage	The temperature of the air in Eureka is measured at 2 m, 6 m, 10 m height above ground on the Flux Tower	Horizontal

	What does the instrument measure?	**Unit that parameters are measured in**	**Height above/below ground**	**Instrument Direction** (facing upward, facing downward, no direction)
ASPTC thermocouple	Air temperature	Degree Celsius	Top, middle, and bottom of tower	Horizontal
PIR pyrgeometer	Both incoming and outgoing longwave radiation are measured with precision infrared radiometers.	W/m2	Top of tower – 10 m.	Up and down
CM22 pyranometer	Both incoming and outgoing short wave or solar radiation are measured with a pyranometer. Pyranometers measure the downward or upward (i.e., reflected) solar irradiance through a horizontal surface.	W/m2	Top of tower – 10 m.	Up and down
Wind vane and cups	Wind direction and speed - The cup anemometer used at the Eureka flux tower consists of three cups. The air flow past the cups in any horizontal direction turn the shaft in a manner that is proportional to the wind speed. Therefore, counting the turns of the shaft over a set time period produces the average wind speed.	Meters per second	At top of tower – 10 m	Horizontal
7.5 m ATI sonic anemometer	The wind speed is measured using an anemometer.	Meters per second	At top of tower – 10 m	Horizontal
Ultrasonic snow depth sensor	The snow depth at Eureka is measured using an acoustic sensor. The sensor measures the distance from the sensor to the top of the ground or the snow pack and can thus determine the depth of the snow column.	Millimeters	Base of tower	Down

Thinking Deeper:

You have spent time conducting meteorological measurements yourself and explored how scientists measure the same data.

- What is the difference between weather and climate? Weather characterizes the condition of the atmosphere over a short period of time (hours/days); climate characterizes the state of the atmosphere over relatively long periods of time (average 30 years).
- What are these instruments measuring: weather or climate? Weather–a long record of data provides information about climate

Extension Activity: Using Image-Processing Software *ImageJ* to Measure Albedo

Teaching Tips for Extension Activity

Students use ImageJ, a free image-processing program, to measure albedo digitally.

ImageJ is a free imaging software package developed by the National Institutes of Health. It is easy to use and allows displaying, editing, analyzing, processing, saving, and printing of images (such as .tif, .gif, .jpg, and other image formats).

Free download is here (website is very basic): http://rsbweb.nih.gov/ij/download.html
More information here: http://rsbweb.nih.gov/ij/docs/index.html or http://en.wikipedia.org/wiki/ImageJ

See https://sites.google.com/site/albedoproject/home/analyzing-the-data/using-imagej-for-albedo-analysis
for instructions for how to conduct the activity. Have students either find images online (e.g., of glaciers surrounded by mountains) and use them in the albedo analysis. Have students estimate the albedo before they measure to establish quantitative reasoning skills.

Arctic Climate Connections Activity 2
Do you really want to visit the Arctic?

Your Mission:

You have been accepted into CIRES's Arctic intern program to work with scientists, Dr. Andrey Grachev and Dr. Ola Persson on their research project in the Canadian Arctic.

Warm-up Activity:

Before scientists undertake new research, they do a lot of reading to learn from what has already been studied, to come up with questions that need to be answered, and to understand methods that have been used to answer similar questions.

So before you dive into your Arctic research, take a moment to read up on Arctic climate and how it is related to the climate worldwide. The data you will be working with is from 2010, so take a look at the State of the Climate report from that year: http://www1.ncdc.noaa.gov/pub/data/cmb/bams-sotc/2010/bams-sotc-2010-brochure-lo-rez.pdf

Write down 3 questions about the Arctic that you might like to know the answers to. For example, do you want to know about the environment, the landscape, the people, or the weather? Try to phrase your questions so they are specific.

Analyzing Weather Data

Your team is planning to visit EUREKA on Ellesmere Island in Nunavut, Canada. You need to plan the visit during a time when the conditions will allow your team to be there in relative safety and comfort. You have year-round weather data to use to help you make your decision. Because there is so much data to analyze, your research team will break into smaller groups to examine parts of the data.

Meteorological data collection instruments have been

Teaching Tips for Activity 2

This is a jigsaw activity and is primarily designed for students to become familiar with the Arctic weather data, reading and interpreting graphs before moving on to Activity 3.

The warm-up activity is optional, but it allows students to learn a little about the Arctic and the climate system. Students are prompted to ask questions like scientists do before they start analyzing data. This section may be assigned as homework before engaging in this activity. High-resolution versions of the brochure, supporting slides, and reports from other years can be found at: http://www.ncdc.noaa.gov/bams-state-of-the-climate/

An excellent reference on teaching with the jigsaw method can be found at: http://serc.carleton.edu/sp/library/jigsaws/index.html

Learning Goals

Students will be able to:

- Read and interpret Arctic data graphs.
- Articulate seasonal weather patterns in Arctic datasets.
- Synthesize data from four different datasets to determine the optimal time to visit the Arctic.
- Create a measureable definition for "winter."
- Compare Arctic weather to weather in their hometowns.

Activity Format

This activity is designed for 16 students. For more or fewer students, you can alter the number of groups or the number of students in each group. For a class size around 32 students, you can run two parallel sets of groups.

Materials:

- Student guide
- Student worksheet
- Jigsaw worksheet (Each student only needs the one for their assigned Research Group)
- PowerPoint with data graphs (Print so that each student has a graph and data tips for their Research Group assignment.)

Assessment:

- Completed worksheets
- Extension activity or homework assignment: Infographic about weather in Eureka

set up at this research station. To understand what this data means, each group will examine one dataset, and then compare your findings with the other groups. In the meantime, you will also learn about the data and how it is measured and you will discover what the weather conditions are like in this special environment of the Arctic.

THE PLAN

- For Part A, start in *Research Groups* where your group will work together to examine one weather parameter that was measured at Eureka Station.
    - Research Group A – Air Temperature
    - Research Group B – Wind Speed
    - Research Group C – Snow Depth
    - Research Group D – Incoming Solar Radiation

- Next, for Part B, one member from each Research Group will join a *Research Team*.

- Each Research Team has a particular research focus and will need to plan their visit to the Arctic accordingly. Teams will have to combine the needs of their research focus, along with the weather conditions at Eureka to come up with the ideal time to visit.
    - Research Team 1 – Testing a fat-tired bicycle for travel across a snowy surface for field research
    - Research Team 2 – Collecting seeds from Arctic wildflowers
    - Research Team 3 – Astronomy research and photographing the night sky
    - Research Team 4 – Annual visit to maintain the meteorological instruments on the tower

Teaching Tips for Part A.
Guided by questions, student groups examine and describe one of four datasets of the annual record of 2010 at Eureka for air temperature, wind speed, snow depth, and incoming solar radiation.

Arrange students into *Research Groups*.
- Research Group A – Air Temperature
- Research Group B – Wind Speed
- Research Group C – Snow Depth
- Research Group D – Incoming Solar Radiation

Students work together in their Research Groups to answer the questions in Part I. Each student completes their own worksheet for the parameter their group is studying.

- Research Teams will contain one member of each Research Group. Thus each person is an “expert” in the particular parameter that they learned about with their Research Group. Each expert will present a summary of the data they examined. Then, the whole team will consider all of the data to reach a conclusion about when to visit Eureka at a time that makes sense for the purposes of their Research Team.

  Research Team 1 – One member of Research Group A, one member of Research Group B, one member of Research Group C, and one member of Research Group D.

  Research Team 2 – One member of Research Group A, one member of Research Group B, one member of Research Group C, and one member of Research Group D.

Research Team 3 – One member of Research Group A, one member of Research Group B, one member of Research Group C, and one member of Research Group D.

Research Team 4 – One member of Research Group A, one member of Research Group B, one member of Research Group C, and one member of Research Group D.

Part A – Research Groups

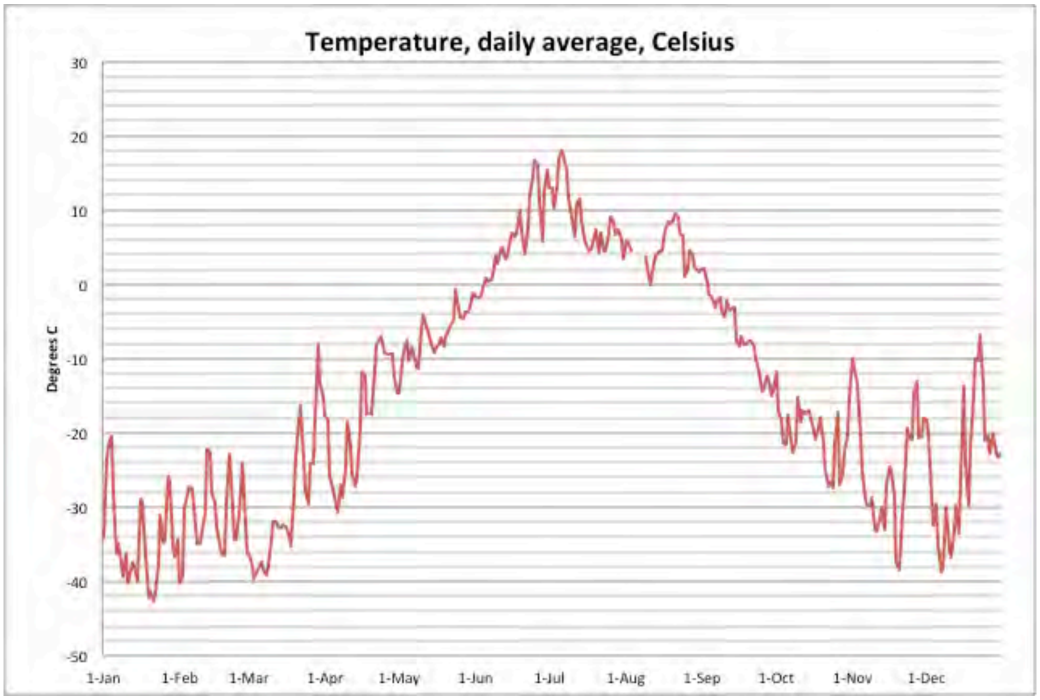
Work in groups of 4 to analyze the data as outlined below.

Research Group A – Air Temperature
Research Group B – Wind Speed
Research Group C – Snow depth
Research Group D – Incoming Short-wave Radiation

Use the graph, 'about the data' and 'analysis tips' to learn about the parameter that is assigned to your research group. (Your teacher will give these materials to each research group.)

Answer the questions on the worksheet for your Research Group only.

Research Group A – Air Temperature



About the data:

Air temperature varies throughout the day in response to direct solar heating and from day to day as weather systems move around the globe. Average air temperature also changes with the seasons. Scientists want to know both the extremes of temperature and the average temperature for some periods ranging from 24 hours to a month, a year, or longer.

The Eureka project measured air temperature at 2, 6, and 10 meters from the ground surface. This data is from 2 meters above the ground surface. This graph shows data collected in 2010.

Analysis tip:

This data is the ***average daily temperature*** from readings taken every minute and then averaged together to give one reading for the day. This means that the high temperature for the day was warmer than this value, and the low temperature was colder than this value.

There was a period from August 4-8 when data was not collected. This is shown as a gap in the line on the graph.

Examine the graph of **air temperature**.

1. What does the x-axis show? Date

2. What does the y-axis show? What are the units? Temperature in degrees C

3. Draw a vertical line on the graph at the following dates:

First day of spring
First day of summer
First day of autumn
First day of winter

4. What is the warmest daily average temperature for the year? When did that occur?

Warmest daily average temperature was 18° Celsius on July 6, 2010.

5. Temperatures are shown in degrees Celsius. Convert your high temperature reading to Fahrenheit so that you can better relate to what the temperature was.

The formula for conversion °C to °F is: Multiply °C by 9, then divide by 5, then add 32

64° F

6. What is the coldest daily average temperature for the year? When did that occur?

Coldest daily average temperature was -42.6° Celsius on January 21, 2010

7. Convert your low temperature reading to Fahrenheit.

-45° F (keep in mind that -40° C = -40° F)

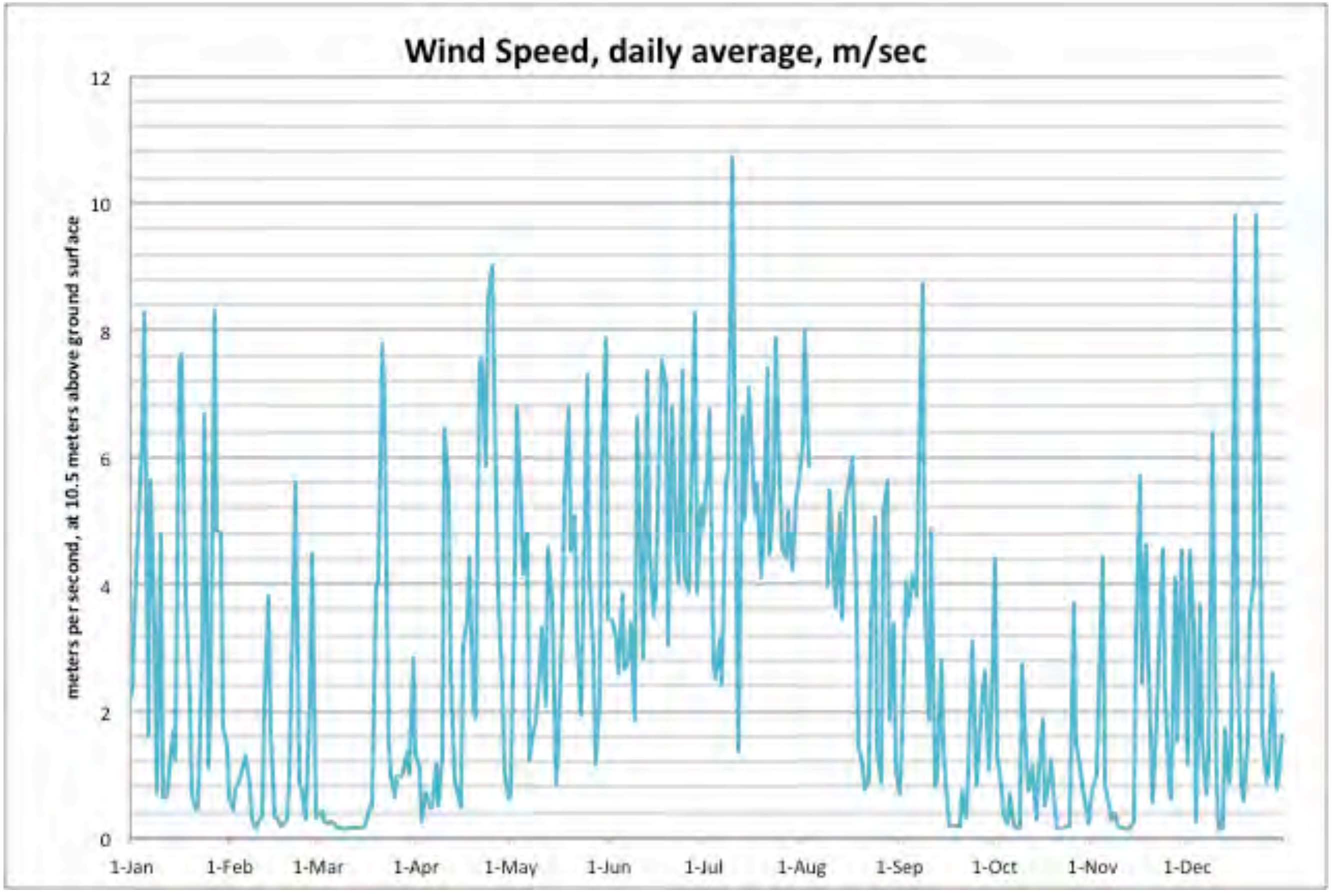
8. How do these compare to the temperatures in your own hometown during similar times of the year?

Answers will depend on where you live.

9. During which parts of the year would you consider the temperatures to be habitable?

Habitable is an inexact term, and this is intentional so that students can consider what they think habitable means. Expected answers would be the times of year where it is above freezing or above zero, but it depends on the hardiness of your students.

Research Group B – Wind Speed



About the data:

Winds are a result of uneven heating of Earth's atmosphere. Winds can accompany weather fronts and storms, or they can be steady throughout a number of days.

The Eureka project measured wind speed at a height of 10.5 meters above the ground surface. Wind direction was also measured but is not included here, just to keep things simple. This graph is for data collected in 2010.

Analysis tip:

This data is the ***average daily wind speed*** from readings taken every minute and then averaged together to give one reading for the day. This means that the highest wind speed for the day was greater than this value, and the lowest wind speed was lower than this value.

There was a period from August 4-8 when data was not collected. This is shown as a gap in the line on the graph.

Examine the graph for **wind speed.**

1. What does the x-axis show? Date

2. What does the y-axis show? What are the units? Wind speed in meters/sec

3. Draw a vertical line on the graph at the following dates:

First day of spring
First day of summer
First day of autumn
First day of winter

4. What was the maximum daily average wind speed during the year? When did that occur?

11 m/sec on July 10, 2010.

5. Convert the maximum wind speed from meters per second to miles per hour, so that the units are easier to relate to.

You'll need to know that there are 1609 meters/mile

11 m/sec = 24.6 miles/hour

11 m/sec / 1609 meters/mile = 0.0068 miles/sec

0.0068 miles/sec x 60 sec/min x 60 min/hr = 24.6 miles/hr

6. When were there periods of generally low wind speeds?

Early March is the quietest stretch of calm wind.
There were also days of quiet winds from mid-September through mid-November.

7. Can you see any pattern to when the winds were the strongest and when they are quieter?

In general the winds were higher in the summer and winter, and quieter in spring and fall.

Research Group C – Snow depth

About the data:

Snowfall and snow depth may vary significantly over distances less than 10 km. In order to understand the local, regional, and global weather patterns, scientists must know how much precipitation falls at many different locations around the world. Topography, winds, and other local effects can create large differences in snow depth. This graph is for data collected in 2010.

Analysis tip:

This data is the ***average daily snow depth*** from readings taken every minute and then averaged together to give one reading for the day.

There were periods from July 10-13 and August 4-8 when data was not collected. These are shown as gaps in the line on the graph.

This dataset has an error in it, which is a normal part of scientific data collection. During the summer months, you can see that the snow depth never goes all the way down to zero. This is partly because of the way the instrument detects snow (by sending sound waves from the tower down to the ground and measuring the response time) and partly because the instrument experienced “drift” where the instrument loses accuracy over time. The instrument was re-calibrated in August. Corrections for these kinds of calibration drifts are often necessary, and this is a good example of real-world decisions scientists have to make when looking at data.

There is a spike of snow depth in late July. To confirm if this is real, other factors need to be considered. In Activity 3, you will look at albedo along with snow depth. But to keep things simple for now, we can safely say that there are no other indications that it snowed in July. Given all of that, question 6 on the worksheet asks you to estimate the snow-free season in Eureka in 2010.

1. What does the x-axis show? Date

2. What does the y-axis show? What are the units? Snow depth in mm

3. Draw a vertical line on the graph at the following dates:

First day of spring
First day of summer
First day of autumn
First day of winter

4. When was the greatest snow depth during the year? How deep was the snow?

319 mm on May 13, 2010.

5. Convert the value from millimeters to feet and inches so that you can better relate to the depth of the snow.

1 foot = 305 mm

Snow depth was a little over a foot, 1.04 feet.

6. Note that the snow depth never reads zero, but instead the data “wiggles” around between 15-30 mm of snow. Upon analyzing the data and re-calibrating the instrument, the scientists working on this project realize that these are erroneous readings from the instrument. (See the data analysis tips for more details.)

Given that, what is your **best estimate** of when the snow-free season was in Eureka?

For Teachers: Further notes about snow depth

The inconsistencies in the summer snow depth data are an important part of the scientific process. Sometimes, data does not seem to make sense. Scientists need to work to understand if there is an unexpected process at work, if the instruments are malfunctioning, or what other cause might underlie the unexpected data.

The curriculum development team asked the scientific research team about the irregularities in the summer snow depth. Their answer is below.

The snow depth measurement at Eureka is made by a Campbell Scientific SR50 Ultrasonic range finder. It uses the speed of sound to measure the distance between the sensor and the surface, be it soil or snow. Because the speed of sound is partly dependent on temperature, this measurement is corrected for temperature. The accuracy of the Campbell Scientific Sonic Snow Depth Gauge is +/- 1 cm or 0.4% of the reading. Hence, little "wiggles" in the data that fall within this range may not be related to any physical event.

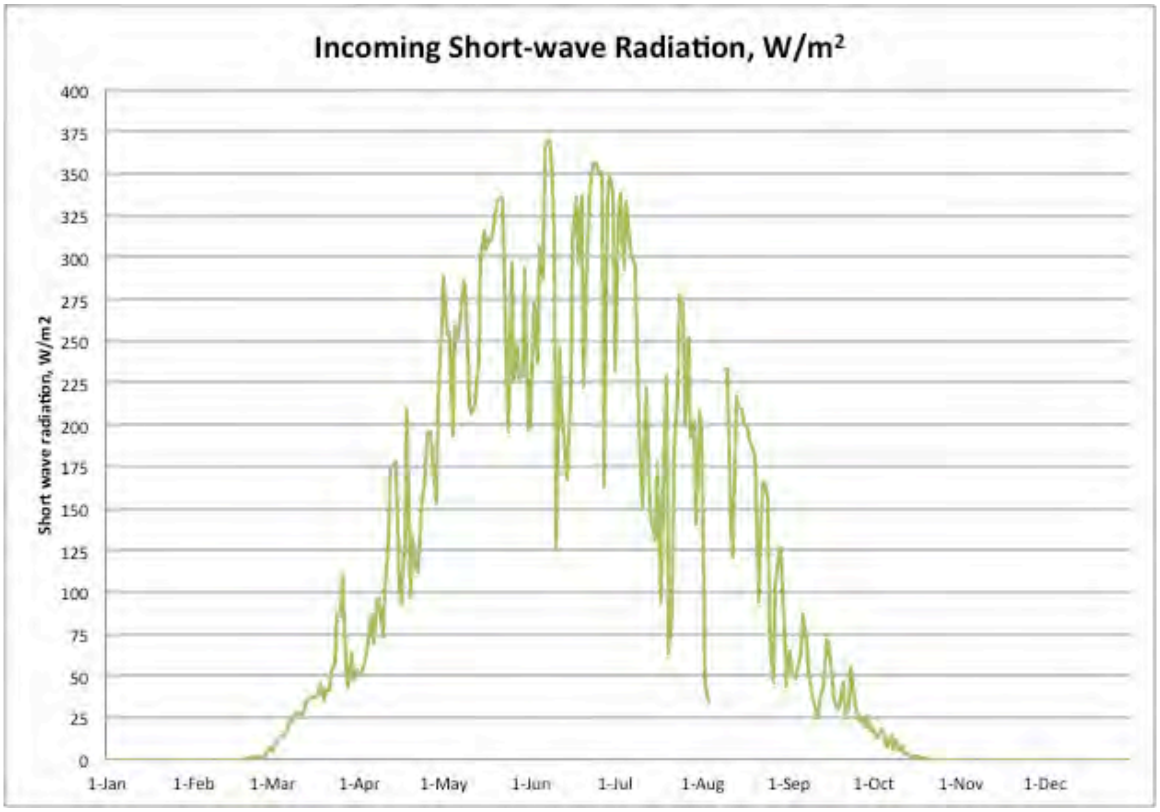
In converting the electrical signal to distance, there are a couple of calibration coefficients, which are typically set in the factory and also adjusted when the instrument is serviced. Unfortunately, we have noticed that the calibrations for this instrument tend to drift with time, and most likely the servicing and latest calibration adjustment was done the previous summer (typically August). Hence, by the following summer, the calibration has often drifted. There are very few melt-offs as measured by this instrument that go exactly to zero. Some are slightly positive by a few cms, such as this case, and some are negative. Corrections for these kinds of calibrations drifts are often necessary, and this is a good example of real-world decisions scientists have to make when looking at the data.

To correct for this problem, we would need some independent information. I would look at the albedo measurements and identify the hour that the albedo reaches a value typical of soil (wet soil) of about 0.10. I would also verify what the "snow depth" measurement was the previous autumn just before the albedo increased above a dry-soil value (about 0.15) (the first snowfall will rapidly increase the albedo to 0.50 or higher depending on the amount). This autumn snow depth should have been zero. Our best estimate for the snow depth measurement through the winter is then obtained by linearly interpolating in time the drift of the instrument between the previous autumn and the summer onset, and subtract this value from the actual measurements. Your graph suggests that it would be a correction of no more than about 2 cm.

Furthermore, students may find it surprising that the snow depth is so small. The scientists responded to this question as well.

Eureka's location in a u-shaped valley seems to reduce the precipitation there. Clouds are often seen to have a thin spot or even be broken over Eureka while the surrounding mountains are heavily enveloped, suggesting downward motion and hence less cloud and precipitation production. The Arctic bush pilots (at least the one I flew with) refer to Eureka as the "Garden spot of the North", *because they can generally depend on being able to land there while weather makes it impossible at other locations. I have done a comparison of conditions at Eureka and Alert, which are both on Ellesmere Island and about 500 km apart, and there is typically much more snow at Alert (2-3X). Snow typically disappears earlier at Eureka and summer temperatures are a bit warmer.*

Also, note, however, that many locations in the Arctic are deserts. The amount of precipitation is quite small. That is because at these cold temperatures, the absolute humidity is quite small (the saturation water vapor pressure -- given by the Clausius-Clapyron equation-- increases exponentially with temperature, so is very low at very cold temperatures). For instance, over the sea ice away from any effects of topography, snow depths are believed to be ~ 30 cm at the end of winter (e.g., SHEBA).



Hence, the value at Eureka is not atypical for Arctic regions away from topography (though the year you chose to look at seems to have more snow at Eureka than most years -- some have only ~ 10 cm). The values at Alert show the effect of topography on producing more lifting and more precipitation.

Research Group D – Incoming shortwave radiation

About the Data:

Energy from the Sun reaches Earth as visible light and ultraviolet radiation. These electromagnetic waves have a short wavelength. Some of this inbound energy is reflected or absorbed by the atmosphere and some makes it all the way to Earth's surface. The amount of incoming solar energy varies by:

> Season - Due to the tilt of Earth's axis, more solar energy falls on parts of the Earth that are tilted toward the Sun (this is the definition of summer).
>
> Latitude - More solar energy reaches tropical latitudes compared to the poles.
>
> Weather - Clouds tend to reflect the incoming radiation so that less of it reaches the ground.
>
> Time of day - Solar radiation only hits parts of the Earth that are facing the Sun. Thus, there is no incoming shortwave radiation at night, while that part of the Earth is facing away from the Sun.

Once shortwave radiation hits the surface of the Earth, some of it bounces off, and some of it gets absorbed by the surface of Earth, which warms the surface. Energy in the form of longwave radiation is then re-emitted from the warmed surface. The Earth then radiates much of this longwave radiation back out to space. (Incidentally, the ability of the atmosphere to capture and retain some of this longwave radiation is called the *Greenhouse Effect*.)

Analysis tip:

This data is the ***average daily incoming shortwave radiation*** from readings taken every minute and then averaged together to give one reading for the day. This means that the highest incoming solar energy for the day was greater than this value, and the lowest incoming solar energy was lower than this value. This graph is for data collected in 2010.

There was a period from August 4-8 when data was not collected. This is shown as a gap in the line on the graph.

Examine the graph of **incoming shortwave radiation**. Note that the value for each day is an average throughout the day, with readings taken every hour and then averaged.

1. What does the x-axis show? Date

2. What does the y-axis show? What are the units? Short-wave radiation in watts per square meter

3. Draw a vertical line on the graph at the following dates:

    First day of spring
    First day of summer
    First day of autumn
    First day of winter

4. What does downward short-wave radiation mean anyway? What is meant by the units of watts per square meter? Explain these concepts in your own words.

Downward short-wave radiation is the amount of energy from the Sun that falls on the surface of the Earth. The unit of watts per square meter is a way of expressing energy that is distributed over an area. In other words, the value tells us how many watts of energy are received per square meter of land area.

5. What was the greatest amount of incoming radiation?

370 W/m^2

6. On what date did the maximum incoming radiation occur?

Jun 7, 2010

7. Why is there zero incoming radiation for a large part of the year?

It is dark in the Arctic in the winter.

Part B – Research Teams

Recombine the teams so that each Research Team has one member of each of the four Research Groups. Your newly-formed team assembles experts from each aspect of the Eureka weather conditions. Each team member will contribute information they learned in Part A of this activity to assist in the decision about when to visit Eureka.

Each team has a particular reason they are visiting the Arctic, so they need to combine the purpose of the visit with the conditions at Eureka during different times of the year.

- Research Team 1 – Testing a fat-tired bicycle for travel across a snowy surface for field research
- Research Team 2 – Collecting seeds from Arctic wildflowers
- Research Team 3 – Astronomy research and photographing the night sky
- Research Team 4 – Annual visit to maintain the meteorological instruments on the tower

Step 1 – The team should first consider the purpose of their trip. What are they studying? What time of year would work best for this purpose?

Purpose of trip:

Conditions needed to engage in the research mission:

Teaching Tips for Part B.

To facilitate discussion, the graphs from each Research Group can be printed on transparency film so they can be overlaid and all the data can be seen at once.

Students rearrange into *Research Teams*.
Each team will contain one member from each of the groups, so that there is a representative from each of the datasets the groups studied. Each Research Team has an assigned research focus – thus they need to consider the conditions in Eureka with that focus in mind.

Research Team 1: contains one member of Research Group A, one member of Research Group B, one member of Research Group C, and one member of Research Group D.
Research Team 2: contains one member of Research Group A, one member of Research Group B, one member of Research Group C, and one member of Research Group D, etc.

Once the groups have formed, each member of the *Research Team* gets a few minutes to describe the parameter they studied. All students write a summary of each of the datasets on their worksheet.

The *Research Team* then goes on to synthesize all of the data and then reach a conclusion about the overall best time to visit the Arctic. For most students, they will conclude that the optimal time to visit is when it is warmest, least windy, with sunlight rather than darkness, and a shallow or absent snowpack. But some groups may have a different idea of what constitutes the best time for a visit. The point of the activity is to have students engage in the data and use several datasets to reach a conclusion, and it is far less important that students reach a certain conclusion. Some latitude should be allowed, so long as their answer is well-supported by the data.

Research Team 1 – Testing a fat-tired bicycle for travel across a snowy surface for field research.
Would need to visit during a time when there is both snow and daylight. March, April, May or September could work.

Research Team 2 – Collecting seeds from Arctic wildflowers
The only time wildflowers could bloom is when there is no snow on the ground, so that would be late June through late August.

Research Team 3 – Astronomy research and photographing the night sky
Would need to visit when there is at least some darkness. It never gets dark in the summer, so that would be a poor choice.
Research Team 4 – Annual visit to maintain the meteorological instruments on the tower
Would want to visit during a time of year when there is daylight and tolerable conditions for working on the tower. For example, if the tower was ice-covered, it would be difficult to work on it.

Step 2 – In turn, each team member will describe the highs and lows for the parameter they examined. They will also describe when the best time of year would be to visit Eureka based on their particular variable **and** the research purpose. Everyone should write down the summary for each weather parameter on their own worksheet.

Best time of year to visit and why

Air temperature:

Wind speed:

Snow depth:

Incoming radiation:

Step 2 – After every team member has presented their data summary, the whole group should decide on a time of year that makes the most sense to plan for an Arctic visit. This answer should take into consideration both the research mission of the trip and the meteorological conditions necessary to engage in the research mission.

Best overall time of year to visit Eureka for your Research Team and why:

How does the Eureka weather compare to the weather in your hometown?

(A good place to look is the NOAA Climate Data Online http://www.ncdc.noaa.gov/cdo-web/datasets or for mountain regions of the Western US, you can find data (including snowfall and snow depth) here: http://www.wcc.nrcs.usda.gov/snow/)

Would you, personally, want to take a trip to the Arctic? Why or why not? What time of year would you want to go?

Part C – Individual Reflection

Aside from the usual calendar-based definition, how would you define “winter“? Scientists need to come up with measureable ways of defining what they are looking for (otherwise, how do you know if you’ve found it?). So, create a concrete definition for “winter” that is measureable using the all of the datasets that you have seen today.

Using your definition and the available data for 2010, how long was winter in this location in the Arctic?

Using the same definition, how long is winter in your hometown?

Data about your hometown is available from many sites. A good place to look is the NOAA Climate Data Online http://www.ncdc.noaa.gov/cdo-web/datasets or for mountain regions of the Western US, you can find data (including snowfall and snow depth) here: http://www.wcc.nrcs.usda.gov/snow/

Teaching Tips for Part C.

After working in groups for the first two sections of this activity, students work individually to create a measureable definition for winter. Obviously, the calendar definition of winter is measureable, but here students should be able to reflect on just how long “winter” is in the Arctic, and how much more severe it is compared to most locations in the US. The key is that their definition has to be something that is concrete.

Some possible, measurable definitions for winter:

- The length of time snow is on the ground
- The period during which the sun does not shine
- The period when the daily average temperature is below freezing (0°Celsius)
- The period when the daily average temperature is below 0° Fahrenheit (-18° Celsius)

Students are then asked to apply their definition of winter to their own hometown. Ideally this would be data-driven, and educators can have some local datasets available for comparison.

Some good places to look for climate data are:

NOAA Climate Data Online
http://www.ncdc.noaa.gov/cdo-web/datasets

Natural Resource Conservation Service
http://www.wcc.nrcs.usda.gov/snow/
Data for the mountain regions of the Western US. This data includes snowfall and snow depth.

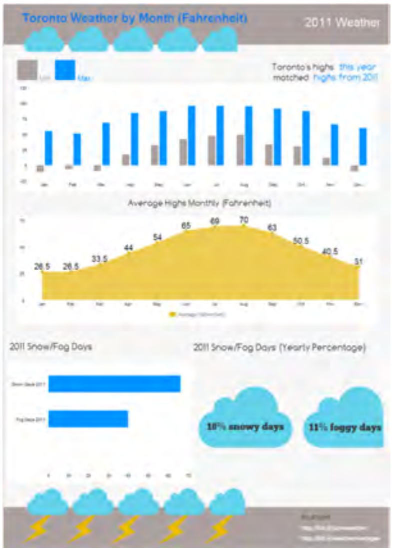
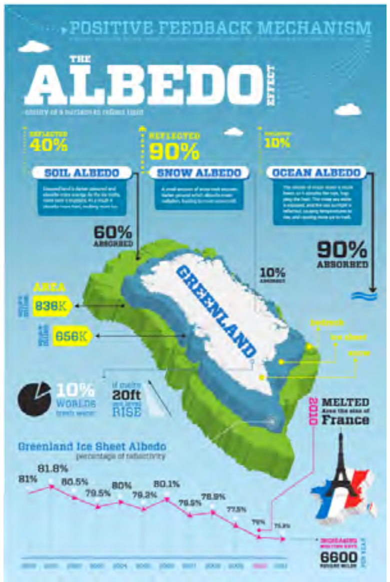
Extension Activity - Create an Infographic

Students work in groups to create an infographic as a means to communicate the weather in Eureka. An infographic is a fun and creative way to organize and express data, but this method also helps develop the ability to synthesize several different types of data in one place. Three examples of infographics are shown below, and many more can be found via web searches.

Teaching Tips for Extension Activity
Here are some starting points. Tools for creating infographics:

- Google Public Data Explorer www.google.com/publicdata
- Piktochart: piktochart.com
- Infogr.am infogr.am
- Gapminder www.gapminder.org

A rubric for evaluating infographics was developed by Loyola University New Orleans and can be found at http://sites.tufts.edu/tischinstruction/files/2010/11/Rubric-for-Assessing-Information-Literacy-in-Infographics.pdf. This file is also available from the Arctic Climate Curriculum website.

Toronto Weather from Venngage.com https://venngage.com/blog/index.php/its-getting-hot-in-toronto-infographic/ 	**British Weather** from Creation Media UK http://www.loveinfographics.com/categories/marketing-infographics/the-great-british-weather-infographic 	**Greenland Albedo** from Visual.ly This example summarizes albedo data from Greenland and is very relevant to Lesson Three. http://visual.ly/albedo-effect 

Arctic Climate Connections Activity 3
Exploring Arctic Climate Data

Part A. Understanding Albedo

Albedo is the ratio of incoming solar radiation that is reflected back into space. Albedo is expressed as a value from 0 to 1, with 1 meaning that 100% of the incoming solar radiation is bounced off the surface, and 0 meaning that all of the incoming radiation is absorbed by the surface of the Earth.

Note that albedo can be expressed either as a ratio or as a percentage. While reading about albedo, you are likely to find values expressed either way, for example, 30% or 0.30.

A surface that reflects most of the radiation it receives has *high albedo.*

1. Give an example of a surface that has high albedo.
Answers could be mirrors, water, ice, glass, etc.

2. Explain your reasoning. Why do you think this surface has high albedo?
Answers will vary.

A surface that absorbs most of the radiation it receives has *low albedo*.

3. Give an example of a surface that has low albedo. Answers could be dirt, leaves, pavement, rooftops, dark-colored surfaces, etc.

4. Why do you think this is true?

Teaching Tips for Part A.

Students practice calculating albedo as a simple ratio of incoming to outgoing short-wave radiation.

A nice reference about albedo is here: http://www.eoearth.org/view/article/149954/
Note that albedo can be expressed either as a ratio or as a percentage. While reading about albedo, you are likely to find values expressed either way, e.g., 30% or 0.30.

Learning goals
Students will be able to:
- List surfaces that have high and low albedo and explain why.
- Calculate albedo from incoming/outgoing radiation data.
- Use known values for albedo to see if their calculated values make sense.

Materials:
- Student guide
- Students graphs for albedo, snow depth and temperature (Excel file)

Assessment:
- Completed student worksheet
- Creation of springtime graphs of albedo, snow depth, and temperature

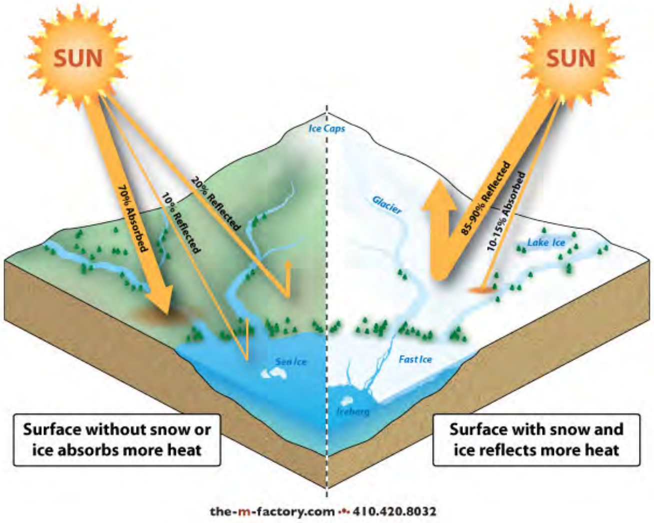


Image courtesy of the Smithsonian Institution.

The mathematical definition of albedo is the ratio of incoming to outgoing shortwave radiation.

incoming shortwave radiation (w/m^2) ÷ outgoing shortwave radiation (w/m^2) = albedo (unitless)

Incoming shortwave radiation is energy that is coming from the Sun. It is expressed in units of watts per square meter. In other words, the value tells us how many watts of energy are received per square meter of land area.

5. On the graph of incoming short-wave radiation, why is the value zero in November – February?
It's dark! This is the Arctic after all!

Calculate some practice albedo values. Use the graphs of incoming shortwave radiation and outgoing shortwave radiation to calculate albedo.

On May 1	**On July 1**
Incoming (downward) = 288 (w/m^2)	Incoming (downward) = 232 (w/m^2)
Outgoing (upward) = 206 (w/m^2)	Outgoing (upward) = 50 (w/m^2)
Albedo = 206/288 = 0.72 or 72%	Albedo = 50/232 = 0.22 or 22%

6. Confirm your answers with the data on the albedo graph. Do they agree?
Yes, they should agree.
(Note - The student graphs of albedo, temperature, and snow depth are in an Excel file for teachers to print out.)

Compare your calculated albedo values with known averages for the following surfaces:

Asphalt 0.05 - 0.10
Forest 0.05 - 0.20
Tundra 0.18 - 0.25
Open ocean 0.06
Sea ice 0.50 - 0.70
Snow 0.40 - 0.95 (Fresh snow is up to .95 reflective, meaning it reflects back 95% of the incoming sunlight. Very dirty snow is in the 0.4 range. Recent work in Greenland found ice with albedo as low as 0.3.)
Earth and atmosphere average 0.30

7. Explain your two values with respect to these average values. Do they make sense?

Part B. Analysis of Albedo, Snow Depth and Temperature

Teaching Tips for Part B.
Students dig into the Arctic data to unravel some causes and effects related to the melting of the snowpack.

Learning Goals
Students will be able to:

- Create graphs in Excel.
- Use the graphs to examine the reasons for the melting of the snowpack.
- Explain how warming temperatures triggers melting.
- Explain the way in which albedo acts as a feedback mechanism for warming and melting.

Students make their own Excel plots and examine the data for temperature, snow depth, and albedo. The following are the takeaway points:

- Decrease in snow depth is initiated by warming temperatures.
- It may be confusing that the snow is melting even though the graph shows the temperature below freezing. But this is because the temperature is the *daily average*; thus, it can still be above freezing for part of the day even when the average is below freezing. Snow depth can also decrease from sublimation, which can occur even when the temperatures are below freezing.
- The rapid drop off in snow depth begins when the daily average temperature goes above freezing. At that point, it never cools down to below freezing at night, so the snowpack thins quickly.
- At the same time, albedo rapidly decreases as the snow surface thins and becomes dirty and patchy. This is an example of a *positive feedback cycle*, also known as a *self-reinforcing cycle*.
- The terms *positive feedback* and *negative feedback* can be confusing because they have other meanings that are more familiar to students. Is positive feedback a good thing? In terms of climate change, positive feedback mechanisms are often not a good thing because they amplify warming. Thus, the term *self-reinforcing cycle*, or *self-reinforcing feedback* might be easier to understand.
- As snow and ice melts worldwide, the decreased albedo causes an increase in the absorption of radiation and accelerated warming. This is linked to global climate change.

Excel Notes

- General step-by-step instructions for Excel are included here, but there are several different versions of Excel so these instructions and screen shots may vary from your version.
- Ideally, plotting in Excel is a part of the overall exercise and not a major roadblock to understanding the concepts. You can tailor the difficulty of the activity to fit your students, the time available, and their prior experience with Excel.
- The teacher file has all the graphs needed.
- The student file only has the annual graphs and the annual dataset. It does not contain the springtime data and the springtime graphs because creating those graphs is part of the activity.
- Some helpful Excel tutorials are:
  - http://www.wikihow.com/Create-a-Graph-inExcel
  - http://spreadsheets.about.com/od/excelcharts/ss/line_graph.htm
- Google Sheets is a free alternative to Excel, if your school system does not have Excel installed on student computers. Learn more about Google Sheets via this URL https://support.google.com/drive/answer/140784?hl=en&ref_topic=20322

Materials:

- Student guide
- Student worksheet
- Student version of datasets

- Teacher version of datasets and pre-made graphs
- PowerPoint slides of paired glacier images

Assessment:

- Completed student guide and Excel graphs
- Concept sketch and essay (this can be assigned as homework at the completion of the activity)

Teaching Note – Irregularities in Albedo Data

You'll see in the Excel data that there are a few places where the value for albedo is over 100%. This occurs mostly in the winter when there is little or no incoming solar radiation. During the dark times of the year the values for incoming and outgoing radiation are essentially zero, but the instruments don't read exactly zero; instead they give small values that are slightly above or below zero. To prevent confusion, albedo values are not calculated when the incoming radiation is less than 1 w/m^2. Even with this correction applied, there are still some dates that have albedo ratios over 100%, which is also due to the low level of incoming solar radiation. During the times of the year when the sun is stronger, the albedo ratios are as expected.

Students will only be working with albedo data from May and June, and all of this data works well for analysis. So, this should not present any issues for the class, but it is helpful to understand why some of the values are anomalous.

Next, work with three datasets from the Eureka weather station.

- Temperature
- Snow depth
- Albedo

8. Of these three graphs, where do you see a strong *correlation*? In other words, find a point where the data on one graph seems to be similar, or strongly related to data on another graph.
(answer: snow depth and albedo in early June)

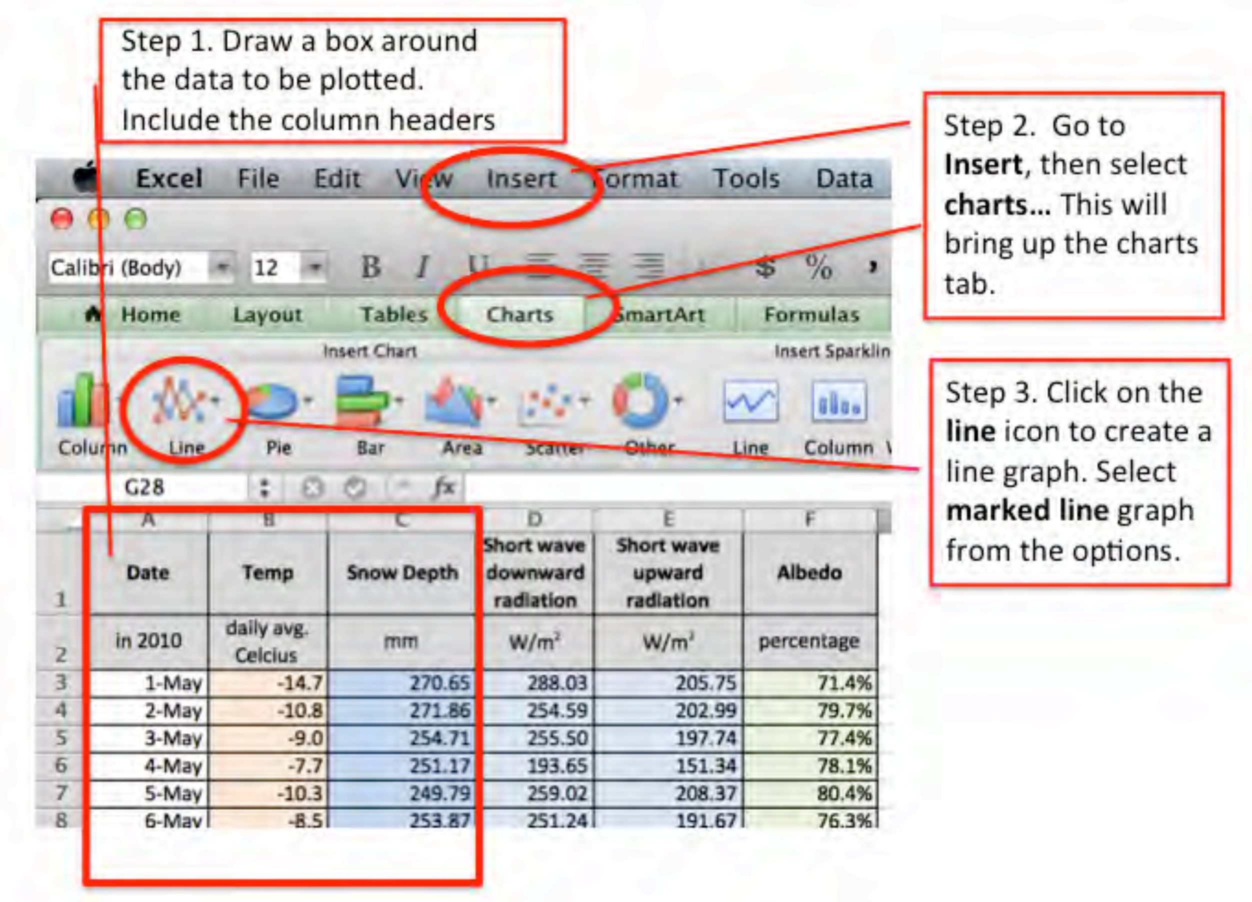
Let's explore that correlation more closely. To do that, we'll want to zoom in on what's going on during the time when the snowpack is melting.

- Go to the Excel file. Save the file under your name by clicking *File > Save as…* and then adding your last name to the file name (such as Eureka_Smith.xlsx)
- Click on the tab called 'student datasets'. (The first tab contains all the same data, but remains there in case you make a mistake while working with the data.)
- That tab contains data for the entire year, but we only want to look at the spring and early summer, from May 1 through July 1.
- So you'll want to delete the rows that are before and after spring and summer.
- Keep the column headings, but delete rows from January 1 through April 30.
    - Highlight the rows, then right-click, then select 'delete.'

- Repeat this for July 2 – December 31
- Now you should just have data for May 1 through July 1.

Next, create a marked line graph that plots temperature and snow depth over time.

- Starting with cell A1, drag the mouse to draw a box around columns A, B, and C, then drag your box down to surround all of the data. (It should go from A1 to C64.)
- In the uppermost menu, click on **insert** and select **chart…**
- This brings up the 'charts' tab. (Note – this may vary depending on your version of Excel.)
- From the types of charts, select **line** and then from the types of line graphs, select **marked line graph**.



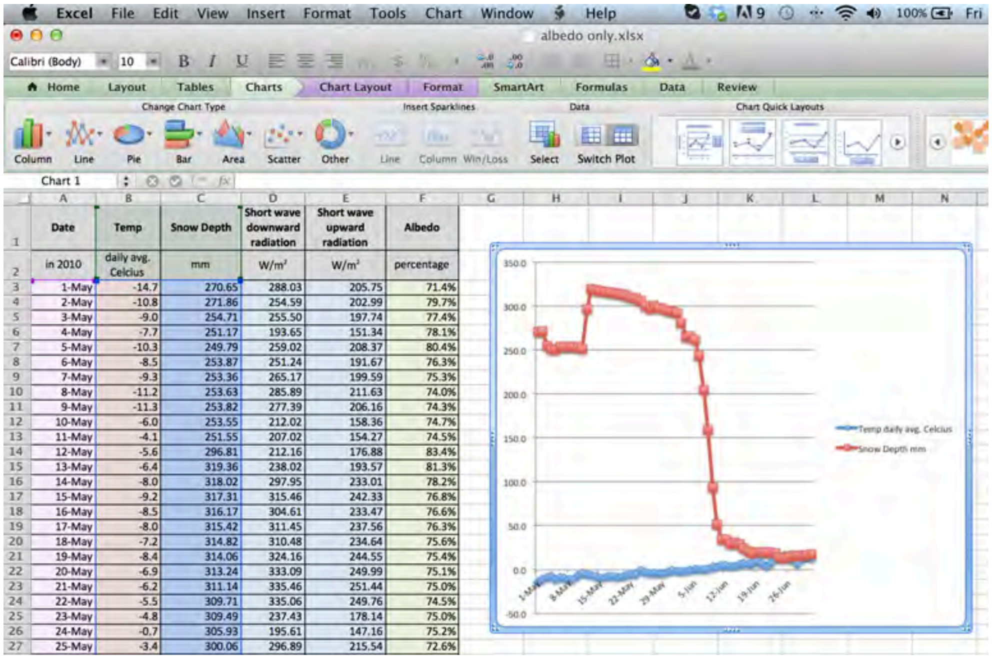
Step 1. Draw a box around the data to be plotted. Include the column headers

Step 2. Go to **Insert**, then select **charts…** This will bring up the charts tab.

Step 3. Click on the **line** icon to create a line graph. Select **marked line** graph from the options.

	A	B	C	D	E	F
1	**Date**	**Temp**	**Snow Depth**	**Short wave downward radiation**	**Short wave upward radiation**	**Albedo**
2	in 2010	daily avg. Celcius	mm	W/m²	W/m²	percentage
3	1-May	-14.7	270.65	288.03	205.75	71.4%
4	2-May	-10.8	271.86	254.59	202.99	79.7%
5	3-May	-9.0	254.71	255.50	197.74	77.4%
6	4-May	-7.7	251.17	193.65	151.34	78.1%
7	5-May	-10.3	249.79	259.02	208.37	80.4%
8	6-May	-8.5	253.87	251.24	191.67	76.3%

A chart will appear somewhere on your screen. Drag it to a location where it does not overlap the data, and then click and drag the corners to make it larger and more legible.

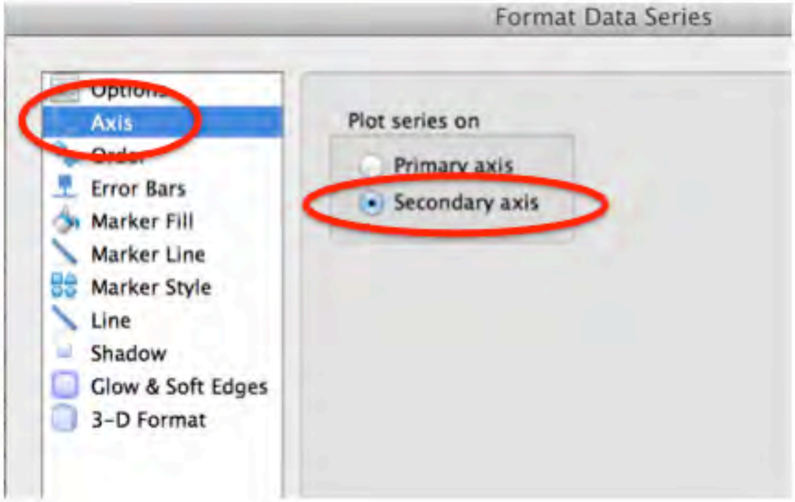


Date	Temp	Snow Depth	Short wave downward radiation	Short wave upward radiation	Albedo
in 2010	daily avg. Celcius	mm	W/m²	W/m²	percentage
1-May	-14.7	270.65	288.03	205.75	71.4%
2-May	-10.8	271.86	254.59	202.99	79.7%
3-May	-9.0	254.71	255.50	197.74	77.4%
4-May	-7.7	251.17	193.65	151.34	78.1%
5-May	-10.3	249.79	259.02	208.37	80.4%
6-May	-8.5	253.87	251.24	191.67	76.3%
7-May	-9.3	253.36	265.17	199.59	75.3%
8-May	-11.2	253.63	285.89	211.63	74.0%
9-May	-11.3	253.82	277.39	206.16	74.3%
10-May	-6.0	253.55	212.02	158.36	74.7%
11-May	-4.1	251.55	207.02	154.27	74.5%
12-May	-5.6	296.81	212.16	176.88	83.4%
13-May	-6.4	319.36	238.02	193.57	81.3%
14-May	-8.0	318.02	297.95	233.01	78.2%
15-May	-9.2	317.31	315.46	242.33	76.8%
16-May	-8.5	316.17	304.61	233.47	76.6%
17-May	-8.0	315.42	311.45	237.56	76.3%
18-May	-7.2	314.82	310.48	234.64	75.6%
19-May	-8.4	314.06	324.16	244.55	75.4%
20-May	-6.9	313.24	333.09	249.99	75.1%
21-May	-6.2	311.14	335.46	251.44	75.0%
22-May	-5.5	309.71	335.06	249.76	74.5%
23-May	-4.8	309.49	237.43	178.14	75.0%
24-May	-0.7	305.93	195.61	147.16	75.2%
25-May	-3.4	300.06	296.89	215.54	72.6%

You are plotting two variables (snow depth and albedo) vs time. So there will be two y-axes, one for snow depth and one for albedo. Put snow depth on the y-axis on the left side. Put temperature on the y-axis on the right side ("secondary axis").

To do that:

- Click the line on the graph that shows temperature.
- On the **Format** menu, click **Selected Data Series**.
- On the **Axis** tab, click **Secondary axis**.

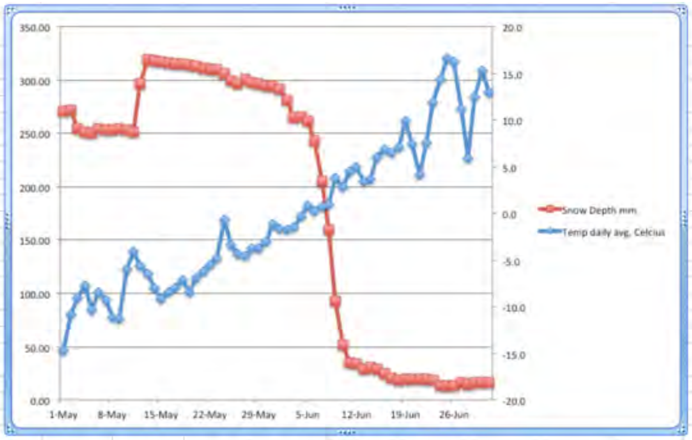


Plot series on

○ Primary axis

● Secondary axis

Your graph should now look something like this:



Following the same steps as above, create another graph that plots snow depth and albedo on the same graph.

- Note – One way to make this plot is to draw a box around Columns A, B, C, and D (even though you don't want Column B). Then create a marked line graph. On the graph, click on the line that represents that column and delete that data series.

- Put snow depth on the y-axis on the left side. Put albedo on the y-axis on the right side.

Looking at snow depth vs. albedo:

9. What are some reasons that albedo could vary while there is snow covering the ground?

The brightness and freshness of the snow varies. Freshly fallen snow has albedo of up to 95%. Dirty snow can have albedo as low as 40%.

10. Can you come up with an explanation for the sharp increase in albedo on May 12?

Fresh snow fell – you can see that on the snow depth graph.

Looking at snow depth, temperature, and albedo:

11. What causes the initial drop in snow depth?

Warming temperatures. Even though the daily average remains below freezing, the warm parts of the day are above freezing.

12. On what date does the snow depth begin to rapidly decrease?

Around June 5

13. What happens to the temperature around that same time?

The daily average temp goes above freezing, meaning it does not drop below freezing, even at night.

14. What other effects can you see in the data that are closely linked with melting?

Albedo decreases, hand-in-hand with the decrease in snow depth.

15. How does that, in turn, affect snow depth?

Albedo rapidly decreases as the snow surface thins and becomes dirty and patchy. Decreasing albedo allows more sunlight to be absorbed by the surface, thus warming the surface and causing more melting of the snow, which further amplifies the melting. This is an example of a *positive feedback cycle*, also known as a *self-reinforcing cycle*.

Concept sketch and essay

Graphics are powerful tools for explaining complex concepts. How would you summarize albedo graphically? Sketch, label, and describe what albedo is. Identify the key features you decide to include. Explain the processes that happen. Indicate how the features and processes are related. Use clear, complete sentences and leaders.

Then, write a short essay (2 - 4 paragraphs) that leads the reader through the concept of albedo and the related processes and features you used in your concept sketch. Use complete sentences and proper writing mechanics.

Teacher's Notes - Assessment using concept sketch and essay

Students can use a **concept sketch** to organize the ideas presented in this activity.

A concept sketch is a simplified sketch illustrating the main aspects of a concept, annotated with concise but complete labels that (1) identify the features, (2) depict the processes that are occurring, and (3) characterize the relationships among features and processes.

- A concept sketch is more than a labeled diagram. It includes full-sentence captions explaining important processes and relationships, rather than merely labeling parts.
- In concept sketches, concept captions are connected to particular parts of the sketch with what are called leaders, which are short straight or curved line segments. Arrows should be reserved for places in the concept sketch where movement occurs.

This activity allows students to work through several related concepts and diagram the relationships between them. Some suggested concepts that can be used in a concept sketch are:

> Temperature, incoming solar radiation, reflected radiation, absorbed radiation, albedo, low albedo, high albedo, snow depth, snowfall, fall, winter, spring, summer, freezing, melting, self-reinforcing feedback, climate change.

The assessment is more challenging if teachers do not provide these suggested terms. So to increase the difficulty, ask the students to determine what the essential concepts are.

The accompanying essay should echo each of the concepts and relationships in the sketch. The essay allows students to further strengthen their thoughts and helps to build a bridge between the visual aspects of the concept sketch with the verbal approach of essay writing.

Part C: Think Globally

Let's think about how the concept of albedo is related to global climate on a larger scale. Examine the paired images below that show changes in snow and ice cover over time.
How has the albedo of this area changed over time? In turn, how does that affect further melting? What are the implications for global climate change?

Okpilak Glacier, Alaska

June 1907

Image credit:
Leffingwell, Ernest. 1907. Okpilak Glacier: From the Glacier Photograph Collection. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

August 2004

Image credit:
Nolan, Matt. 2004. Okpilak Glacier: From the Glacier Photograph Collection. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

Extension Activities: I) Greenland Albedo, II) Dust on Snow

Teacher's Notes: Supplemental references and extension activities

The topic of albedo can be further explored and linked to global climate change in several regions. In the suggested activities below, students consider the albedo in two case studies: Greenland and the Colorado River Basin.

Demonstrations of the effects of dirty snow can be set up in the classroom by sprinkling dirt on snow and comparing how it melts to a sample of clean snow. This can be demonstrated outside in the wintertime, or indoors using shaved ice and light bulbs as a heat source.

Extension Activity I - Greenland Albedo
Greenland is home to some of the largest expanses of snow and ice on Earth. The combined effects of shrinking ice mass, longer melt season, and accumulations of dust on the ice are causing decreased albedo on Greenland. Thus, warming and melting are accelerated even further. As scientists examine the mechanics of a changing climate, feedback effects such as this one play an important role because the initial warming is accelerated. This is even more significant in Arctic and Antarctic systems, which contain most of the Earth's ice cover.

A case study about albedo and climate change in Greenland can be found in NOAA's Arctic Report Card for 2013.
http://www.arctic.noaa.gov/reportcard/greenland_ice_sheet.html
Figure 56 shows the ice mass shrinking.
Figure 57 illustrates the decreasing albedo overall, but increased in 2013. An explanation of 2013 is here:
http://www.meltfactor.org/blog/?p=1099

http://www.youtube.com/watch?v=qOauOAwbn6c This video is based on the same data in the references above, showing the decrease of albedo in Greenland from April through July.
Possible question for students:

- Figure 56 shows the ice mass in Greenland shrinking. What are some factors that are causing this? How does that affect the albedo of Greenland?

Greenland – an albedo feedback laboratory: http://www.meltfactor.org/blog/?p=1032
This resource introduces the idea of particulate matter and soot on snow causing a decrease in albedo. Note how dark the ice surface can become, which lowers albedo and contributes to melting.
Possible questions for students:

- What is the albedo value for very dirty ice? What makes the ice so dark?
- Using the figure from Dark Snow near the end of the page, explain how fossil fuel burning contributes to melting snow and ice. Can you describe the concept of feedback?
- In your personal experience, have you seen dirty snow? What caused it? What have you noticed about how clean vs. dirty snow melts?

http://nsidc.org/greenland-today/2013/06/springtime-melt-in-greenland-late-start-rapid-spread/
This report from the National Snow and Ice Data Center illustrates the many effects of spring melt in Greenland. Of particular interest is Figure 6, which compares Greenland albedo in 2000 and 2012. Note that in the maps of albedo, the areas of highest albedo are red shades. Red colors feel like they ought to represent warming but in this case they represent more reflective surfaces, thus fresher snow and ice.

Possible questions for students:

- List the factors that contribute to the decreasing albedo of Greenland (there are several).
- What changes can you observe between the 2000 and 2012 images?

Extension Activity II: Dust on snow

http://snowstudies.org/news/news_PNAS_Pub.html and http://snowstudies.org/CODOS/index.html

The Colorado Center for Snow and Avalanche Studies has been actively engaged in research about many aspects of snow, with implications far beyond Colorado. A recent study uncovered the relationship between dust storms, albedo, and water supplies in the Colorado River. Students investigate these issues and find answers to the following questions. Note that the first four questions engage only lower-order thinking skills, while the last two call for higher-order thinking. Encourage your students to focus on the last two questions.

- What is causing dust on the snowpack?
- What are the effects of the dust? (There are several.)
- How does this affect fresh water supplies in the Colorado River?
- What are some possible solutions to alleviate the dust on the snow?
- This case study points out how the causes of a climate problem can be disconnected from the effects. In this case, they are separated in both space and time, and can even seem unrelated. Can you think of other concerns in the climate system where the cause for a problem is far away from the time or location where the impacts are felt?
- Given your answer to the question above, what does that mean in terms of creating new laws, policies, or agreements? How can those who feel no impacts from their actions be expected to support rules that force them to change their actions? How does this relate to climate policy in general?