Arctic Climate Connections Activity 3 Exploring Arctic Climate Data

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

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.

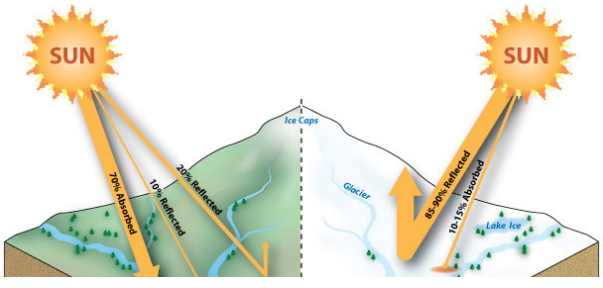
Note that albedo can be expressed either as a ratio or as a percentage. While reading about albedo, you are likely to find values expressed either way, for example, 30% or 0.30.

A surface that reflects most of the radiation it receives has *high albedo*.
1. Give an example of a surface that has high albedo.

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

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

3. Give an example of a surface that has low albedo.



3. Give an example of a surface that has low albedo.

4. Why do you think this is true?

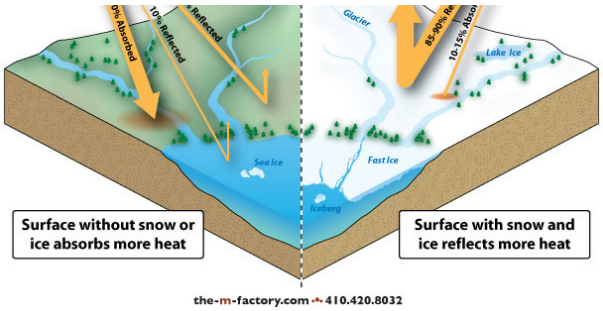


Image courtesy of the Smithsonian Institution.

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

outgoing shortwave radiation (w/m^2) ÷ incoming 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?

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) =	Incoming (downward) =
Outgoing (upward) =	Outgoing (upward) =
Albedo =	Albedo =

6. Confirm your answers with the data on the albedo graph. Do they agree?

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.

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- 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.

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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

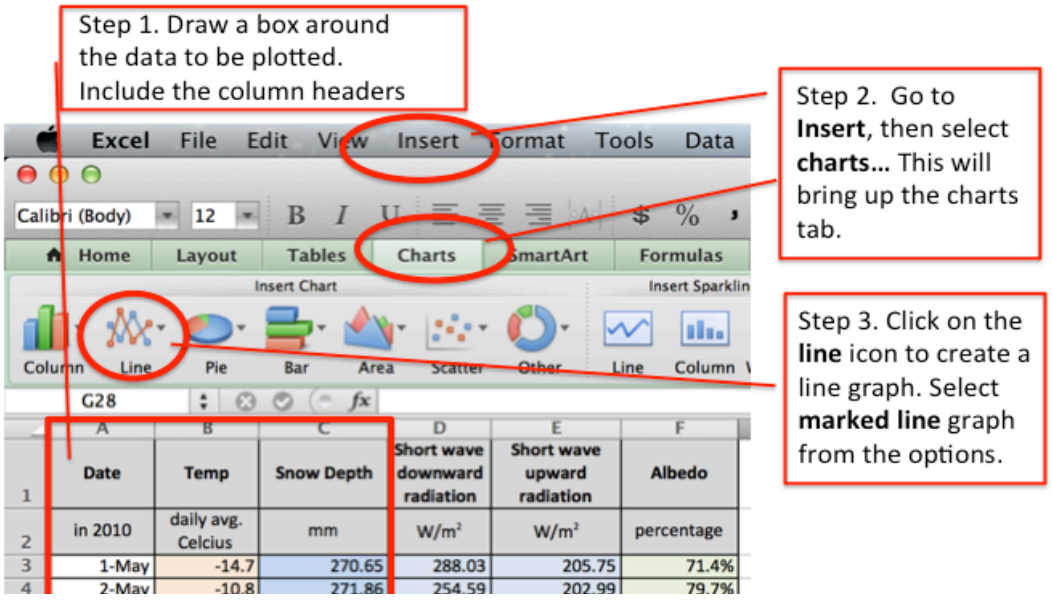
8. Of these three graphs, where do you see a strong *correlation*? In other words, find a point where the data on one graph seems to be similar, or strongly related to data on another graph.

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.

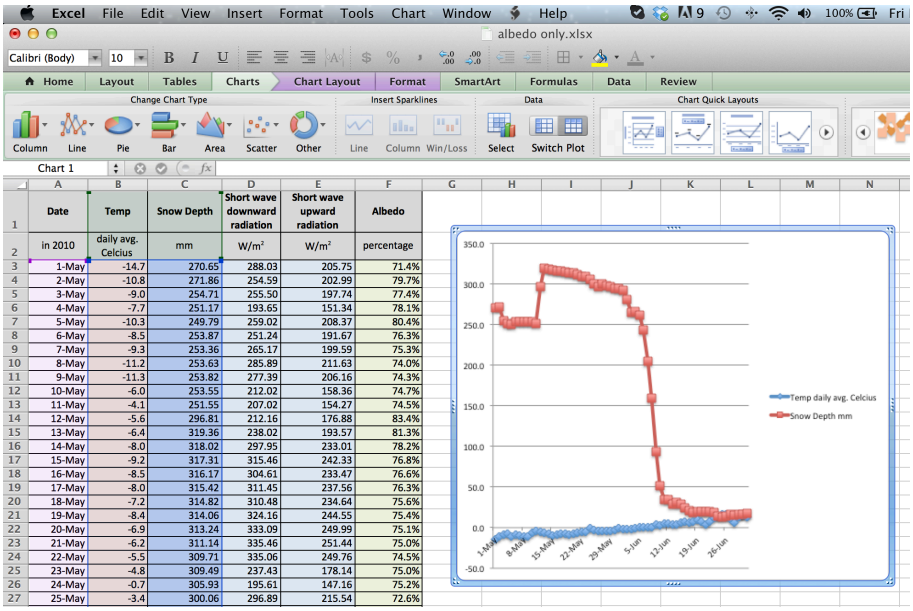
Next, create a marked line graph that plots temperature and snow depth over time.

- 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**.



	in 2010	daily avg. Celcius	mm	radiation W/m²	radiation 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%

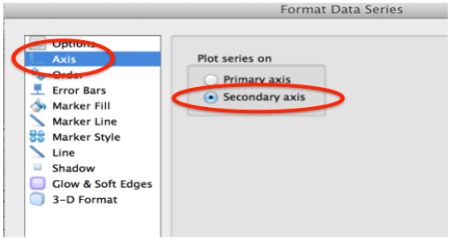
A chart will appear somewhere on your screen. Drag it to a location where it does not overlap the data, and then click and drag the corners to make it larger and more legible.



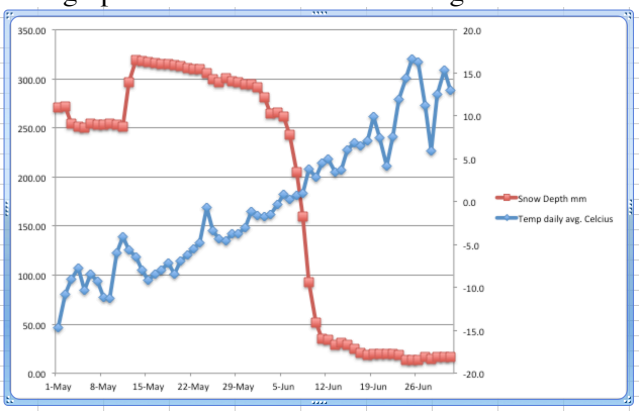
	Date	Temp	Snow Depth	Short wave downward radiation	Short wave upward radiation	Albedo
2	in 2010	daily avg. Celcius	mm	W/m²	W/m²	percentage
3	1-May	-14.7	270.65	288.03	205.75	71.4%
4	2-May	-10.8	271.86	254.59	202.99	79.7%
5	3-May	-9.0	254.71	255.50	197.74	77.4%
6	4-May	-7.7	251.17	193.65	151.34	78.1%
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%
9	7-May	-9.3	253.36	265.17	199.59	75.3%
10	8-May	-11.2	253.63	285.89	211.63	74.0%
11	9-May	-11.3	253.82	277.39	206.16	74.3%
12	10-May	-6.0	253.55	212.02	158.36	74.7%
13	11-May	-4.1	251.55	207.02	154.27	74.5%
14	12-May	-5.6	296.81	212.16	176.88	83.4%
15	13-May	-6.4	319.36	238.02	193.57	81.3%
16	14-May	-8.0	318.02	297.95	233.01	78.2%
17	15-May	-9.2	317.31	315.46	242.33	76.8%
18	16-May	-8.5	316.17	304.61	233.47	76.6%
19	17-May	-8.0	315.42	311.45	237.56	76.3%
20	18-May	-7.2	314.82	310.48	234.64	75.6%
21	19-May	-8.4	314.06	324.16	244.55	75.4%
22	20-May	-6.9	313.24	333.09	249.99	75.1%
23	21-May	-6.2	311.14	335.46	251.44	75.0%
24	22-May	-5.5	309.71	335.06	249.76	74.5%
25	23-May	-4.8	309.49	237.43	178.14	75.0%
26	24-May	-0.7	305.93	195.61	147.16	75.2%
27	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**.



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?

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

Looking at snow depth, temperature, and albedo:

11. What causes the initial drop in snow depth?

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

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

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

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

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.

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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:

August 2004

Image credit:

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 snowpack and why is it important?

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?