# Black Ice-A Slippery Arctic Road

In this lesson students investigate the effects of black carbon on arctic warming and are introduced to a mechanism of arctic warming that is not directly dependent on greenhouse gases in the atmosphere. Black carbon is the particulate form of carbon that results from burning carbon based fuels and biomass. We often refer to this type of carbon as soot. As fuels are burned the black carbon rises into the atmosphere and can circulate around the globe in atmospheric currents; this lesson will focus on black carbon deposition on Arctic snow and ice. The presence of black carbon on the surface of ice and snow can change the way these surfaces reflect and absorb solar radiation. As black carbon increases on the surface of snow and ice, more solar radiation is absorbed thereby increasing the surface temperature of the ice which in turn increases melt rate. This lesson requires that students understand the concepts of absorption and reflection of light energy and can also be used to introduce the concept of albedo.

This lesson is designed to be used with either the Earth/Environmental (EES) curriculum or the Chemistry curriculum. It may also be used as an enrichment activity in Physics or Physical Science during a unit on energy. The main topic addressed in EES is arctic warming and ice melt in response to black carbon deposition which falls within the Global Climate Change unit. In Chemistry, this lesson addresses phase changes, heating curves, and phase diagrams within the States of Matter and Phase Change Unit. Depending on the needs of the class, the activity can be completed as a structured lab or a student driven inquiry activity.

The lesson begins with an activity that introduces students to the concept of thermal energy and how light and dark surfaces reflect and absorb radiant energy differently. To help quantify the relationship between carbon and ice melt, the wet-lab activity has students create ice samples both with and without black carbon and then compare how they respond to radiant energy while considering implications for the Arctic.

## Key Search Words

Absorption and reflection of light radiation, albedo, Arctic, Black Carbon, hands-on lab activity, NASA

## Learning Outcomes

Upon completion of this activity, students will be able to:

- Generate diagrams depicting light reflecting off white and dark surfaces.
- Explain how the presence of black carbon alters the albedo of snow and ice.
- Describe the relationship between black carbon and ice melt

## Curriculum Alignment

**2010 North Carolina Essential Standards High School Science**

***Earth/Environmental Science***

| | |
|---|---|
| EEn.2.6.2 | Explain changes in global climate due to natural processes. |
| EEn.2.6.3 | Analyze the impacts that human activities have on global climate change (such as burning hydrocarbons, greenhouse effect, and deforestation). |

***Chemistry***

| | |
|---|---|
| Chm.2.1.1 | Explain the energetic nature of phase changes. |
| Chm.2.1.2 | Explain heating and cooling curves (heat of fusion, heat of vaporization, heat, melting point, and boiling point). |
| Chm.2.1.3 | Interpret the data presented in phase diagrams. |

**Climate Literacy Framework**

| | |
|---|---|
| Principle 2A | Climate is regulated by complex interactions |
| Principle 5 | Understanding of the climate system is improved through observations, theoretical studies, and modeling. |
| Principle 6 | Human activities are impacting the climate system |

## Classroom Time Required

| | |
|---|---|
| Student Engagement Activity | 30 minutes (can be done as homework or in class) |
| Preparation of Ice Samples | 5-10 minutes plus overnight freezing |
| Student Wet-lab Investigation | 20-30 minutes |
| Class Discussion | 10-15 minutes depending on level of discussion |

## Student Engagement Activity

### Materials Needed

- Computer with Internet access
- LCD Projector

- *Black Carbon*-NOAA Video (2:38 minutes)
  http://oceantoday.noaa.gov/blackcarbon/

- *Black and White: Soot on Ice*
  http://www.nasa.gov/vision/earth/environment/arctic_soot.html

- *Black Carbon*
  http://www.biologicaldiversity.org/programs/climate_law_institute/global_warming_what_how_why/black_carbon/index.html

### Procedure

1. Show the class a photo of a snow/ice scene with black carbon deposition apparent. Ask the class if they know what is causing the black coloration on the ice. One such photo can be found at: http://earthobservatory.nasa.gov/Features/Aerosols/images/mt_ruapehu_ash_snow.jpg

2. Next, show the NOAA video titled *Black Carbon* (2:38 minutes) to the class. This is an excellent video describing what black carbon is and how it effects the melting of Arctic ice.

3. You may also want to show students this NASA video illustrating the dispersal of dust (red), sea salt (blue), sulphate (white) and black and organic carbon (green) around the world by winds.

4. As a follow-up, either in class or as a homework assignment, ask students to read the following articles about black carbon:

   *Black and White: Soot on Ice*
   This article is a description of what black carbon is and how NASA is researching the effects of black carbon on the Arctic ice. This is a good website for background information.

   *Black Carbon*
   This is a short article summarizing the problem of black carbon and some possible solutions.

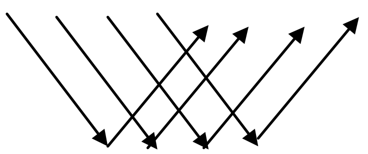
5. In student pairs, small groups, or as a whole class, discuss these articles, checking for critical vocabulary understanding. Students should be able to state the following: sources of black carbon emissions; the regions of the globe that are responsible for significant black carbon emissions; how black carbon travels to the Arctic; and, solutions to reduce global black carbon emissions.

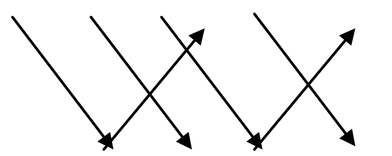
6. Next, introduce the concept of **albedo**. The term albedo refers to the ratio of reflected light relative to the amount of incident light hitting the surface. Albedo values range from 0 (no reflection) to 1 (100% reflection). The Earth has an albedo that represents the combined albedo of different surfaces like forests, deserts, oceans, and even clouds. Invite students to predict albedo for different surfaces like snow, water, forest, or desert and then share actual values with them. Finally, ask students to predict how the presence of black carbon will alter the albedo of clean snow and ice.

7. Tell students they will conduct a wet-lab activity to investigate how the presence of black carbon will alter the albedo of snow and ice.

## Assessment

- Use the white board to assess student understanding of albedo, reflection, and absorption.
- Ask students to whiteboard a high albedo (ice) and low albedo (black carbon on ice) situation.
    - *Possible Student Diagrams*





**Ice** **Ice and Black Carbon**

Source: NASA/USGS, NASA Goddard Space Flight Center Scientific Visualization Studio, and NSIDC

- Ask students to summarize their findings in writing or by constructing and labeling a diagram or concept map.

## Pre-Lab Activity or Alternative to the Wet-lab Activity

*This activity could proceed the wet-lab or be conducted as an alternate to the wet-lab activity.*

## Materials Needed

One of each of the following if completed as a demonstration or 1 set per group of students:

- One sheet each of non-glossy, matte, or flat white and black paper (construction paper works well)
- Infrared thermometer
- Overhead light or natural outdoor light
- Light sensor or light meter

## Procedure

1. Set both pieces of paper next to each other so they are receiving the same amount of incident light from overhead.
2. Ask students to use the infrared thermometer to measure the surface temperature of both pieces of paper and then use the light meter to measure the amount of light being reflected by each surface.
3. Let each paper be exposed to the light source for 5-10 minutes and then take the surface temperature and light reflectivity readings again.
4. Next, direct students to calculate the differences in surface temperature before and after being exposed to light. Compare the surface temperatures and reflectivity of each color of paper.

## Assessment

Discuss or have students write answers to the following questions:

- Based on the articles you read, what might the two colors of paper represent?
  *White = ice, black = carbon soot*
- If conducted indoors, what does the light source represent? *Radiation from the sun*
- Why did we take temperatures before and after exposure to overhead light?
  *To determine how the light radiation impacted surface temperature.*
- What conclusions can you draw from your observations? *Black paper reflects less light and gets warmer, white paper reflects more light and has a lower surface temperature than black*
- How do you think black carbon will affect the melting of the ice sheets? Why? *Black absorbs more energy which should increase the temperature of the ice causing it to melt at a faster rate.*

**Black Carbon Formation (*Optional Demonstration*):**

There is a quite simple and dramatic demonstration that might be useful to show how black carbon (aka "soot") is formed from incomplete combustion. Hold a clean glass microscope slide over a lit candle or Bunsen burner to demonstrate the formation of soot (*Note: soot contains particles other than black carbon*).

- **Materials needed**: glass slide, flame from candle or Bunsen burner, tweezers for holding slide

## Student Wet-lab Investigation

### Materials Needed

For each student group:

- 2 large weigh boats, applesauce cups or other small plastic cups
- 2, 250 mL graduated cylinders
- Water
- Access to freezer
- 2 ring stands and clamps
- 2 light sensors (e.g. Vernier probeware)
- ruler or meter stick
- 2 pieces of white cardstock
- charcoal, ground into a fine powder or purchased as carbon powder
- popsicle sticks for obtaining and spreading the carbon powder onto ice
- Data collection interface that utilizes probeware (e.g., computer with Vernier's Logger Pro software )
- *Student Data Collection Worksheet*, provided

#### Preparation of Ice Samples

For each group, add 200 ml of water to two large weigh boats or other small plastic containers; **be sure to leave space for expansion of water and freeze for at least 24 hours.**

#### Student Preparation for Data Collection Activity

Students need to be familiar with the data collection interface (e.g Vernier's Logger pro or Lab Quest 2 or PASCO's PASPORT, etc.) they will use for this experiment. If they have not previously used the data collection interface that they will be using in this activity, the instructor should take time to explain the appropriate use of the data collection interface/device. This activity utilized Vernier's Logger Pro software but any data collection interface that can connect with light sensor probeware will be sufficient.

The instructor should also explain what the light sensor is measuring (reflectivity) and can make a connection between the work of the light sensors they will be using and satellite instruments that measure light being reflected by Earth and its atmosphere. Tell students they will be using the data collection interface to acquire **mean values** for reflectivity between two different ice samples. The User manual for the light sensor can be a useful guide for the instructor or the curious student.

#### Experimental Set-Up

Experimental set-up can be done ahead of time by teacher or by student groups; a short video describing the set-up can be viewed at: http://vimeo.com/51450474.

1. Place two ring stands side by side on an open lab table. (Avoid shadows/reflections from other objects because it could interfere with the light readings). Adjust so that each ring stand base receives equal lighting from above; as long as each ice sample will be receiving similar levels of incident light, the recorded surface reflectivity will be strongly related to albedo.
2. Use ring clamps to tightly secure the light sensors vertically over the base of the ring stand, position each light sensor so that the light-sensing end will be located approximately 12 or 13 cm above the top of the ice sample (once the ice samples are placed on the base of the ring stand).

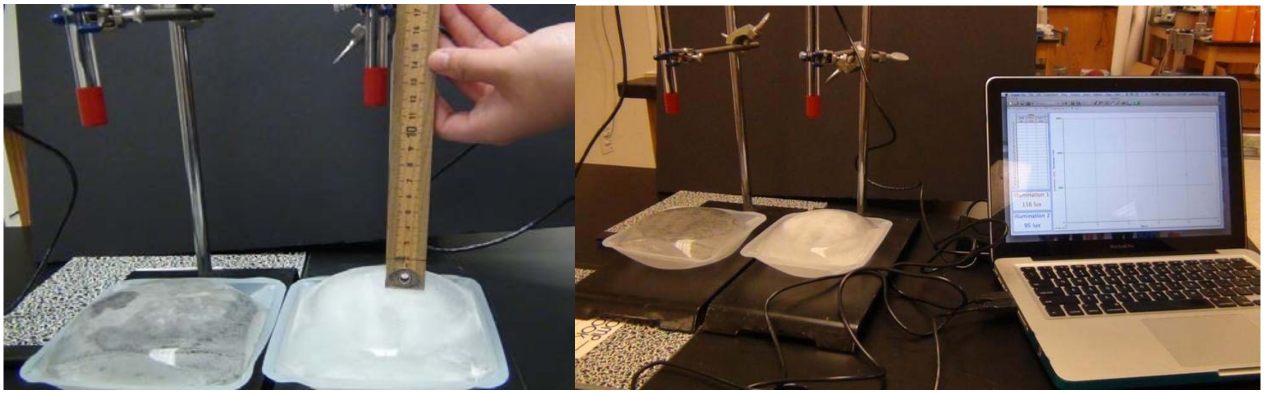


**Figure 1**. Experimental Set-Up. *Photos by Chelyn Lee and Katherine Whang, NCSSM.*

3. Connect the light sensor USBs to the computer and open LoggerPro. Take note of which sensor is indicated as "1" and "2" on LoggerPro.
4. Calibrate light sensors.
5. Place white cardstock over the base of the two ring stands such that white is beneath both light sensors.
6. Take the initial sensor readings for the white card stock. Both sensors should be reading the same value within standard error.

## Student Investigation

1. Remove ice samples from the freezer. Record the time on your data collection worksheet.
2. Obtain carbon powder from your teacher. This powder will simulate black carbon deposition. Using a popsicle stick or spoon, scoop carbon powder onto the surface of one ice sample and spread to create an opaque layer of black carbon over the ice. Your teacher may provide you with additional instructions for creating your black carbon layer as groups may be asked to investigate different amounts of black carbon.

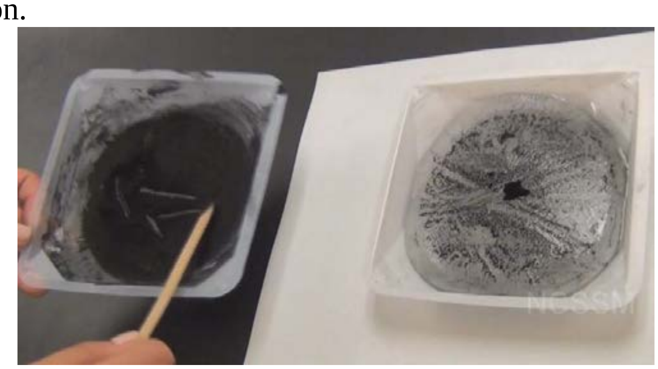
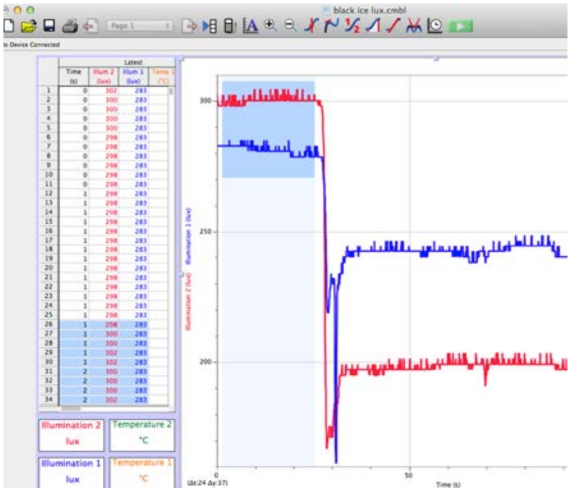
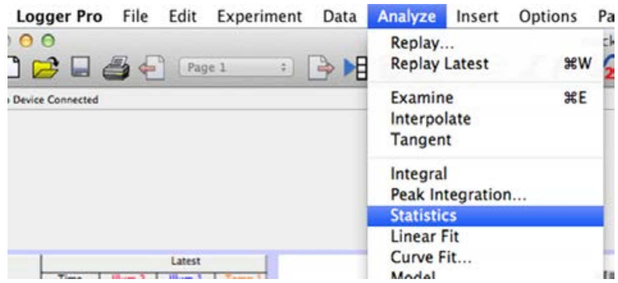


**Figure 2.** Adding black carbon to the ice sample. *Screen shot from video by Chelyn Lee and Katherine Whang, NCSSM.*

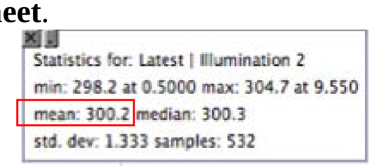
3. Set data collection time for 2 minutes by adjusting data collection time with the  button at the top of the program.
4. Start data collection by clicking the  button. **At this point, nothing should be beneath the light sensors except for the white cardstock.**
5. After approximately 30 seconds, place the clean ice sample under sensor 1 and the black ice sample under sensor 2. The sensors should continue to collect data until two minutes has elapsed.
6. Once data collection is finished, click and drag the mouse over the first 30 seconds of data for both samples (see figure on left below). On the graph, this first segment should be highlighted in blue.
7. Click ‘Analyze’ at the top menu bar and click ‘Statistics’ (see figure on right below).
8. When a box pops up asking which columns to display statistics for, select both illumination 1 and 2 and click “OK.”.



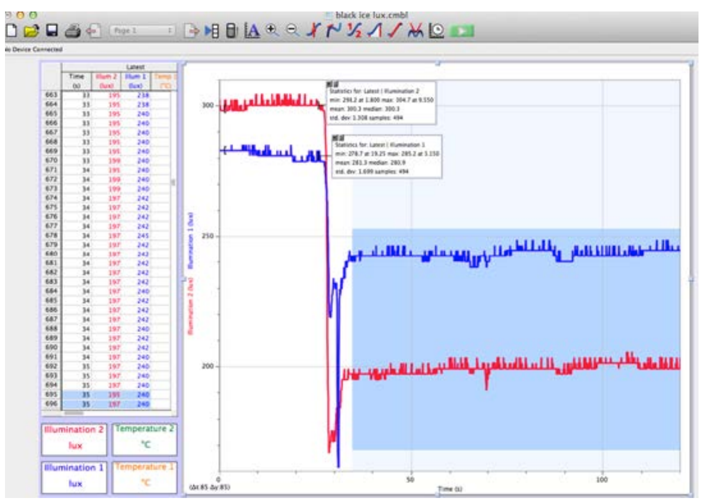



Student Investigation, continued

9. A statistics box for each light sensor should pop up on the graph by the blue highlighted area. The data point of interest is the mean illumination (lux). **Record the Mean for each sensor where appropriate on your data collection worksheet**.




10. Repeat steps 6 and 7 for the second segment on the graph where the sensors are reading a mostly constant value (see blue box in the figure below).



11. Record the Mean illumination (lux) for each sensor in the appropriate location in your data collection worksheet.
12. Next, calculate the change in lux for each light sensor and record on your data collection worksheet.
13. When all data are collected, record time when experimentation is complete.
14. Pour the melt water that has formed within each weigh boat into separate graduated cylinders; record the volume of melt water (ml) that resulted from each ice sample.

15. Answer the questions on the front and back of your data collection worksheet and be prepared to discuss results with the class.

## Wet-Lab Variations & Extensions

1. **How does the amount of black carbon covering (thin versus thick layer) impact your results?** Student groups could cover their ice samples with different amounts of back carbon and compare results.
2. One consequence of black carbon deposition (cryoconite) on glaciers is the formation of Cryoconite holes. These are water filled holes caused by increased melting around black carbon or sediment. One could conduct the same experiment above but instead of creating a uniform layer of black carbon on the ice sample you could place black carbon in discrete spots and observe how the ice sample melts over time. **Do the areas with the black carbon melt faster than the surrounding clean areas?**
3. **How do the masses of the ice samples compare?** In addition to comparing the volume of melt water between the two samples, ice samples could be weighed at the beginning and end of the experiment and their change in mass calculated.
4. **How might other impurities, like dust, affect snowmelt and water resources?** Students can predict how impurities like dust impact snowmelt and conduct the wet-lab using different types/colors of dust (e.g. fine sand). Then have students read the NASA Earth Observatory article, Dusting the Virtues of Snow and explain in their own words how impurities on snow/ice impact water resources.

***Chemistry Extensions***

5. Glaciers are constantly in a cycle of melting and refreezing, so over time, the black carbon particles that initially sat on top of the ice become dispersed throughout the ice. Instead of placing a layer of carbon powder over the ice sample, **how would your results differ if the black carbon was placed into water prior to freezing?** Will the difference in reflected light between the clean vs. dirty ice be more or less pronounced? How does the composition of the sample affect the amount of melt water produced? Students could create their own black ice samples prior to freezing by mixing black carbon powder into their water sample. All groups should be sure to use the same volume (200ml) of water for adequate comparison of results. *Note: While this is an appropriate line of student inquiry, due to the nature of black carbon, its hydrophobic properties,high surface area and tendency to coagulate, acquiring a black ice sample with a uniform distribution of black carbon is not feasible and will yield inconsistent experimental results but will allow for a discussion of experimental results and the chemical nature of black carbon.*
6. **How can we distinguish whether the increased rate of melting is because of the dark color of the black carbon particles rather than the very presence of the particles at all?** To control for the possible colligative property effects of having a solute present, what type of particle would act as an appropriate control? Students could design an experiment to test how the presence of salt impacts the melting of the ice samples.

### Conclusion

1. Invite students to share their results, comparing the reflectivity of clean ice and ice containing differing amounts of black carbon (if applicable).
2. Discuss or have students write answers to one or more of the following questions:
   - How did the reflectivity compare between samples? Which surface had the greater albedo (higher reflectivity)? What are the implications of this in the Arctic?
   - How did the rate of melt water formation from clean ice compare to black ice? Were your results expected? Why or why not?

- Using the principles of thermodynamics, explain why there are differences between clean ice and black ice.
- What observations did you make about samples of black ice containing differing amounts of carbon?
- How are temperatures of glaciers affected by black carbon? Based on the IR photos you observed, which ice sample had a higher surface temperature? Why?
- [*Chemistry extension*] Colligative properties are properties of solutions that depend on the ratio of solute particles to solvent molecules. For example, salt is often used to lower the freezing point of water. In this investigation, we placed black carbon particles on ice. **How can we distinguish whether the increased rate of melting is because of the dark color of the particles rather than the very presence of the particles at all?** To control for the possible colligative property effects of having a solute present, what type of particle would act as an appropriate control?
    - ***Note about common student misconception**:* Chemistry students may incorrectly try to explain their experimental results using the concept of colligative properties and thus should be redirected to think about what conditions are necessary to form a true solution. Colligative properties apply only to true solutions or homogeneous mixtures. When students add black carbon to ice or liquid water during this activity, a true solution or homogeneous mixture, is not achieved. The chemical nature of black carbon, its hydrophobic properties, high surface area and tendency to coagulate does not allow for solvation in water.
- [*NASA extension*] Invite your students to learn more about the various NASA missions to assess Arctic variability and change. Divide the class into small groups and have each group learn about one NASA mission whose data is helping scientists to understand how the Arctic is responding to global change (such as increased aerosols). Missions of interest include: CALIPSO, ICESat 1 and 2, Aqua, GRACE and Operation Ice Bridge.

## Differentiation

**Students with Special Needs**

- Perform experiment as a demonstration.
- Omit experiment and provide students with a data set to analyze.
- Place students in mixed ability partners or small groups for activity completion.
- Give students additional time to set-up and complete the experiment.

**Low-technology Option**

- Should light sensing probeware technology not be available to conduct this lab as written, the lab could be conducted as written and under ambient classroom lighting conditions! Students can compare rates of melting; students would determine the mass (in grams) of each ice sample at time = 0 minutes and again at 10 minutes, 20 or 30 minutes. The change in mass (g) and total melt water volume (ml) for each ice sample would be compared and experimental results could be discussed in relation to reflectivity and albedo of each ice sample (making a connection to the pre-lab activity). See attached *student data collection sheet*.

## Assessment

- Ask students to draw and explain a diagram representing how sunlight reflects off of black ice and clean ice.
- Ask students to complete a formal lab write-up or white board the lab. If white boarding, compare the results for each group. Discuss similarities and differences among the samples.

## Critical Vocabulary

*Definitions for the terms below were obtained from*

**Albedo:** a unitless quantity that indicates how well a surface reflects solar energy. Surface albedo varies between 0 (black) and 1 (white) (National Snow and Ice Data Center).

**Black carbon:** also known as soot, is a type of dark particulate matter produced by the incomplete combustion of fossil fuels, wood, and other biofuels. Black carbon, along with other particles, can come from motor vehicles, residential stoves, forest fires, and certain industrial processes (NASA).

**Cryoconite holes:** water-filled depressions on the surface of glaciers that contain deposits of dark organic material "cryoconite" (SpringerReference).

**Particulate matter:** also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (US EPA).

## Contributing Authors

*This lesson was developed by* ***DeeDee Whitaker****, science teacher at Southwest Guilford High School, in High Point, NC, and the wet-lab activity was refined and written by* ***Katherine Whang****, a student at the North Carolina School of Science and Math (NCSSM). This lesson was reviewed and edited by* ***Dana Haine****, MS, K-12 Science Education Manager for UNC-Chapel Hill's Institute for the Environment and Program Director for the NC Climate Fellows Program, a teacher professional development program made possible with support from NASA's Innovations in Climate Education (NICE) project.*

## Acknowledgements

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## Supplemental Resources

Has the Arctic Gotten Sootier Over the Last Century?
*This is an update of NASA data on black carbon in the arctic. The post date is May 2011.*
http://blogs.nasa.gov/cm/blog/whatonearth/posts/post_1305321008880.html

Why Cutting Black Carbon Emissions May Save Arctic Sea Ice
*A brief discussion of the effects of black carbon on the ice and its relationship to carbon dioxide output.*
http://blogs.nasa.gov/cm/blog/whatonearth/posts/post_1292991500275.html

Black Carbon Deposits on Himalayan Ice Threaten Earth's "Third Pole"
*This is a 2009 research article that examines the effect of black carbon on the glaciers in Tibet. Changes in temperature and amount of glacial melt are discussed. Researchers indicate the source of carbon is coal fired power plants.*
http://www.nasa.gov/topics/earth/features/carbon-pole.html

Arctic Sea Ice Continues Decline, Hits 2nd-Lowest Level
*This October 2011 article reviews the extent of arctic sea ice using satellite imagery. The site also includes an embedded video of a scientist explaining the results.*
http://www.nasa.gov/topics/earth/features/2011-ice-min.html

Is Antarctica Melting?
*This is a 2003 research article that examines the data on the amount of ice melt in Antarctica. It discusses the topography of Antarctica underneath the ice sheet and how the ice sheet actually crumbles.*
http://www.nasa.gov/topics/earth/features/20100108_Is_Antarctica_Melting.html

Arctic: NOAA UAV's Sniff for Black Carbon
*This 2011 article describes how NOAA scientists will investigate soot in the arctic using data gathered by aircraft, ships and on land. The study focused on aerosol size, number, light absorption and chemical composition.*
http://www.global-adventures.us/2011/04/22/arctic-noaa-uav-black-carbon/

Aerosols May Drive a Significant Portion of Arctic Warming (July 2009)
http://www.nasa.gov/topics/earth/features/warming_aerosols_prt.htm

This is a news report of findings on the effects of black carbon on arctic ice.
http://news.stanford.edu/news/2010/july/soot-emissions-ice-072810.html

Black Carbon: The Dark Horse of Climate Change Drivers
*This article describes policies connected with global climate change, including those to address black carbon emissions.*
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3080958/

Sampling Black Carbon Over Arctic Sea-Ice and Open Leads
*This is a You Tube video that documents how scientists sample in the arctic.*
www.youtube.com/watch?v=kTx4Rf6abu8

Variability of black carbon deposition to the East Antarctic Plateau, AD 1800–2000
*This is the abstract and link to the pdf for this scientific article on the effects of black carbon.*
http://www.atmos-chem-phys-discuss.net/11/31091/2011/acpd-11-31091-2011.html

Icelights: Your Burning Questions About Ice & Climate
*This article highlights the importance of the arctic oscillation and its relationship to weather and sea ice. It includes archived data and articles back to January 2011.*
http://nsidc.org/icelights/2011/02/23/is-dirty-air-adding-to-climate-change-2/

The Cryosphere Today
*This is a web site that houses the current, daily pictures of sea ice extent. Different regions can be selected for comparison. Archived data is also available.*
http://arctic.atmos.uiuc.edu/cryosphere/

US EPA, Black Carbon
*This website contains background information and a link to US EPA's Report to Congress on Black Carbon, 2012*
http://www.epa.gov/blackcarbon/

An Unrecognizable Arctic
*This article from NASA summarizes the change happening in the Arctic.(July 2013)*
http://climate.nasa.gov/news/958

2013 Wintertime Arctic Sea Ice Maximum Fifth Lowest on Record
http://www.nasa.gov/topics/earth/features/arctic-seaicemax-2013.html

Dusting the Virtues of Snow
*This is a NASA Earth Observatory article that describes the research taking place to understand impact of impurities on snow melt and water resources (Aug 2013)*
http://earthobservatory.nasa.gov/Features/DirtySnow/?src=eoa-features

The Arctic shifts to a new normal (October 2013)
http://scitation.aip.org/content/aip/magazine/physicstoday/article/66/10/10.1063/PT.3.2147

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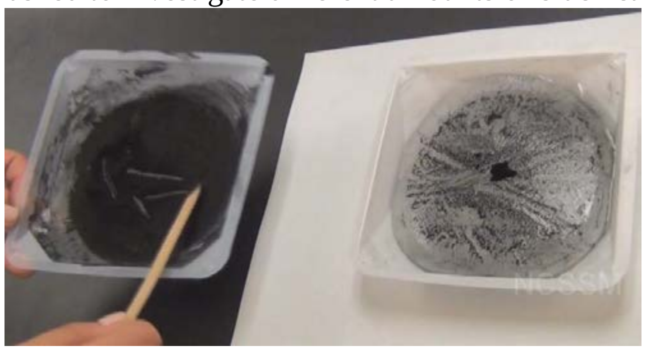


**Figure 1.** Adding black carbon to the ice sample.
*Screen shot from video by Chelyn Lee and Katherine Whang, NCSSM.*

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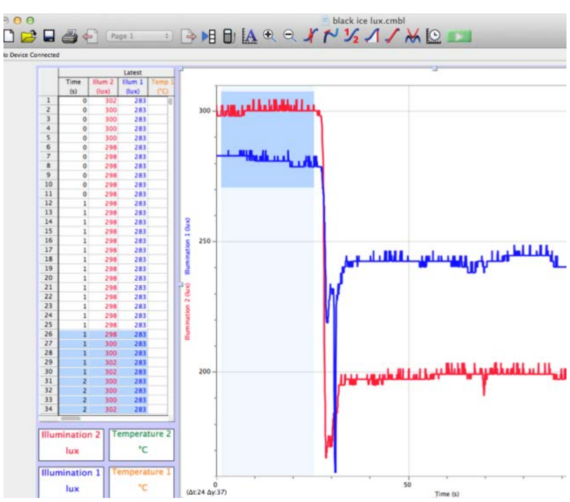


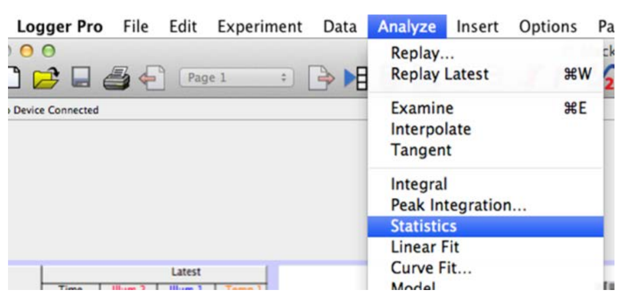

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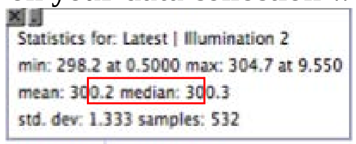
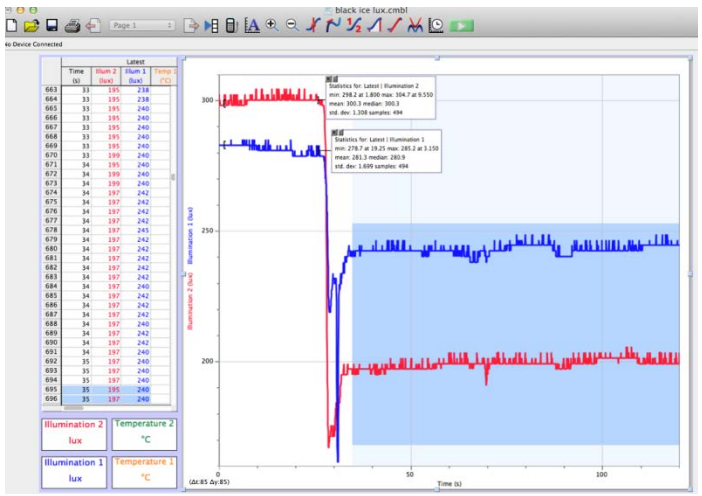
9. A statistics box for each light sensor should pop up on the graph by the blue highlighted area. The data point of interest is the mean illumination (lux). **Record the Mean for each sensor where appropriate on your data collection worksheet**.




10. Repeat steps 6 and 7 for the second segment on the graph where the sensors are reading a mostly constant value (see blue box in the figure below).




11. Record the Mean illumination (lux) for each sensor in the appropriate location in your data collection worksheet.
12. Next, calculate the change in lux for each light sensor and record on your data collection worksheet.
13. When all data are collected, record time when experimentation is complete.
14. Pour the melt water that has formed within each weigh boat into separate graduated cylinders; record the volume of melt water (ml) that resulted from each ice sample.
15. Answer the questions on the front and back of your data collection worksheet and be prepared to discuss results with the class.

**Student Data Collection Worksheet** **Name: ________________________**

| | |
|---|---|
| Time Ice was Removed From Freezer | |
| Time at Completion of Experiment | |
| Elapsed Time of Experiment (in minutes) | |

| | Mean Illumination (lux) from **Clean Ice** Sample (Light Sensor 1) | Mean Illumination (lux) from **Black Ice** Sample (Light Sensor 2) |
|---|---|---|
| White Cardstock | | |
| Ice Sample | | |
| Change in Lux | | |

| | | |
|---|---|---|
| Volume (ml) of Melt Water | Clean Ice | Black Ice |
| | | |

**Analysis of Results:**

1. Why was it important for you to measure the amount of light being reflected by the white cardstock first?

2. How does the amount of light reflected off the clean ice differ from that off the black ice? By how many luxes do the two differ?

3. In this case, the light in your classroom represented light energy coming from the sun. Did both ice samples receive the same amount of energy? Did both ice blocks reflect the same amount of energy? What accounts for any observed differences?

4. If you observed a difference in the amount of light reflected by each sample, what other features of your ice samples might also be impacted?

5. Based on your experimental results, describe how black carbon deposition will affect the melting of Arctic snow/ice.

### Impact of Black Carbon on Surface Temperature

As radiation from the sun reaches the Earth, the Earth heats up and emits infrared radiation back to space. This radiation is not visible but can be felt as heat (surface temperature). An Infrared camera was used to detect the amount of infrared radiation (IR) being emitted by clean and black ice samples IR is closely associated with surface temperature. The left hand side of each image below was untreated (clean ice) while the right hand side had black carbon spread on the surface. Variations in the IR image on the black carbon surface correspond to ridges and valleys that formed due to carbon distribution over the ice surface.

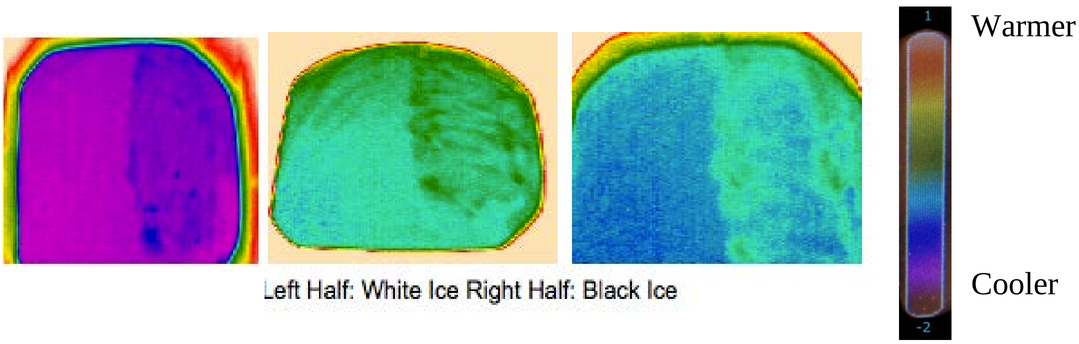



**Figure 1. Infrared Images of clean (left side) and black (right side) ice; photo credit: Katherine Whang, NCSSM.**

6. Using the IR color scale on the right as a guide, what do the images above reveal about surface temperature of clean and black ice?

### Impact of Black Carbon on Glaciers

One consequence of black carbon deposition (cryoconite) on glaciers is the formation of Cryoconite holes. These are water filled holes caused by increased melting around black carbon or sediment.

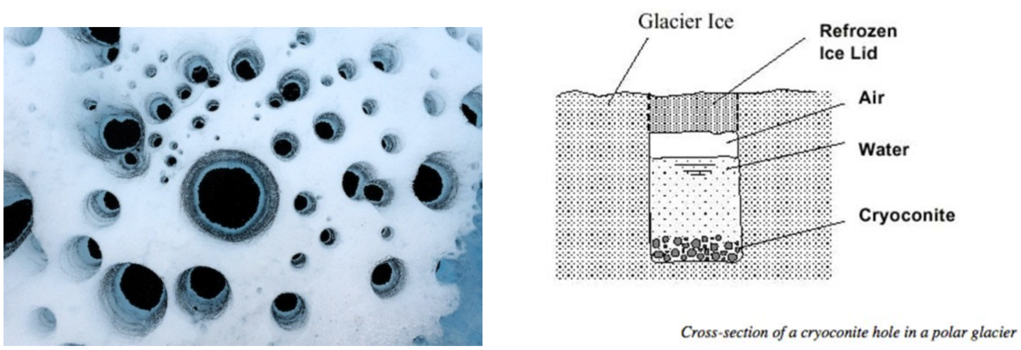



**Figure 2. (Left) Cryoconites in glacier; photo credit James Balog, http://www.wired.com/wiredscience/2012/09/balog-glacier-photographs/?pid=4764**
**(Right) Cryoconite cross-section; photo credit Jonathan Ebnet, Portland State University http://www.glaciers.pdx.edu/Thesis/J_Ebnet/Subsurface_Energy_Balance.html**

7. In your own words and using the knowledge obtained from this investigation, describe how cryoconite comes to be at the bottom of these holes and predict the impact of these holes on glaciers.

**Student Data Collection Worksheet** **Name:** ***Answer key***

| | |
|---|---|
| Time Ice was Removed From Freezer | |
| Time at Completion of Experiment | |
| Elapsed Time of Experiment (in minutes) | |

| | Mean Illumination (lux) from **Clean Ice** Sample (Light Sensor 1) | Mean Illumination (lux) from **Black Ice** Sample (Light Sensor 2) |
|---|---|---|
| White Cardstock | *281.3* | *300.2* |
| Ice Sample | *242.9* | *199.3* |
| Change in Lux | *38.4* | *100.9* |

| Volume (ml) of Melt Water | Clean Ice | Black Ice |
|---|---|---|
| | *53.2ml* | *60.4 ml* |

**Analysis of Results:**

1. Why was it important for you to measure the amount of light being reflected by the white cardstock first? *To ensure that both sensors are receiving the same amount of incident light enabling for a comparison of experimental results. Both sensors should read the same value within standard error.*

2. How does the amount of light reflected off the clean ice differ from that off the black ice? By how many luxes do the two differ? *The amount of light reflected off of the clean ice is expected to be greater than the black ice since the black ice absorbs more light energy.*

3. In this case, the light in your classroom represented light energy coming from the sun. Did both ice samples receive the same amount of energy? Did both ice blocks reflect the same amount of energy? What accounts for any observed differences? *Ideally, the ice samples should receive the same of amount of incident light so that experimental results can be compared. Any observed differences in reflection of light off the sample would then be due to differences in the nature of the ice surfaces.*

4. If you observed a difference in the amount of light reflected by each sample, what other features of your ice samples might also be impacted? *The less light reflected, the more light absorbed by the sample and this would be evident by an increase in surface temperature and an increased in the rate of melt water formation.*

5. Based on your experimental results, describe how black carbon deposition will affect the melting of Arctic snow/ice. *Black absorbs more energy which should increase the surface temperature of the ice causing it to melt at a faster rate*.

## Impact of Black Carbon on Surface Temperature

As radiation from the sun reaches the Earth, the Earth heats up and emits infrared radiation back to space.  This radiation is not visible but can be felt as heat (surface temperature). An Infrared camera was used to detect the amount of infrared radiation (IR) being emitted by clean and black ice samples IR is closely associated with surface temperature.  The left hand side of each image below was untreated (clean ice) while the right hand side had black carbon spread on the surface. Variations in the IR image on the black carbon surface correspond to ridges and valleys that formed due to carbon distribution over the ice surface.

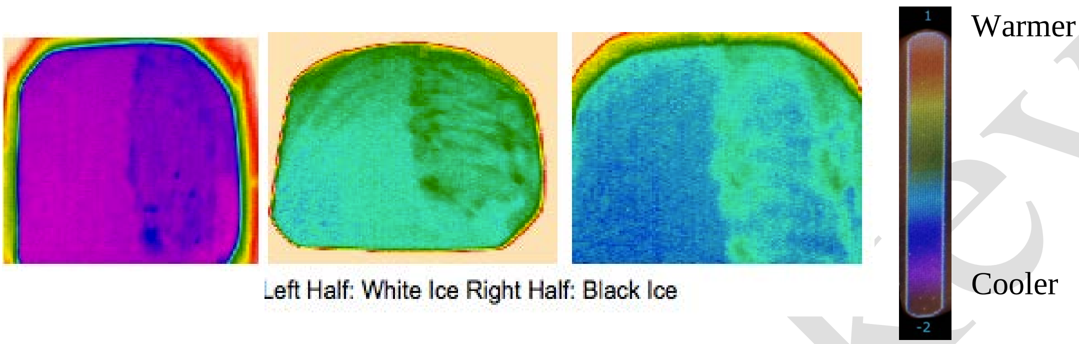



**Figure 1. Infrared Images of clean (left side) and black (right side) ice; photo credit: Katherine Whang, NCSSM.**

6. Using the IR color scale on the right as a guide, what do the images above reveal about surface temperature of clean and black ice?  *Ice containing black carbon has a higher surface temperature (emits more IR) when compared to clean ice.*

## Impact of Black Carbon on Glaciers

One consequence of black carbon deposition (cryoconite) on glaciers is the formation of Cryoconite holes. These are water filled holes caused by increased melting around black carbon or sediment.

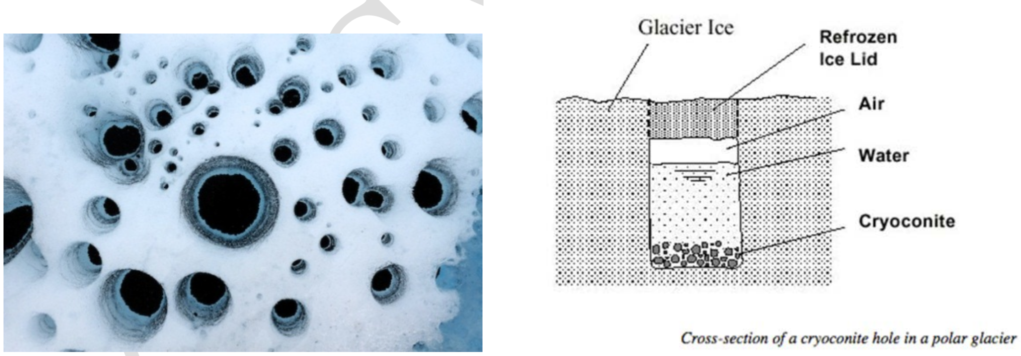



**Figure 2.  (Left)  Cryoconites in glacier; photo credit James Balog, http://www.wired.com/wiredscience/2012/09/balog-glacier-photographs/?pid=4764 (Right) Cryoconite cross-section; photo credit Jonathan Ebnet, Portland State University http://www.glaciers.pdx.edu/Thesis/J_Ebnet/Subsurface_Energy_Balance.html**

7. In your own words and using the knowledge obtained from this investigation, describe how cryoconite comes to be at the bottom of these holes and predict the impact of these holes on glaciers.  *Black carbon or sediment will absorb more light energy and cause the surrounding ice to melt. As this ice melts, black carbon sinks to the bottom of the melt water which can refreeze resulting in a cryoconite hole.*