

## **SUPPLEMENTARY MATERIAL: SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

**Grade Level:** 7-12

**Lesson Overview:** Students will learn how *albedo* (surface reflectivity) affects climate in the Arctic and in regions with seasonal snow cover. Students will graph and analyze a time series of albedo and snow density using data that they have collected with the Community, Collaborative, Rain, Hail, Albedo, and Snow (CoCoRAHS-Albedo) Network Measuring Kit or using data collected by another classroom participating in the CoCoRAHS-Albedo Network available for download at <http://www.cocorahs-albedo.org>.

A PowerPoint that accompanies the lesson plan is available for download at <http://www.cocorahs-albedo.org/lesson-plans/>.

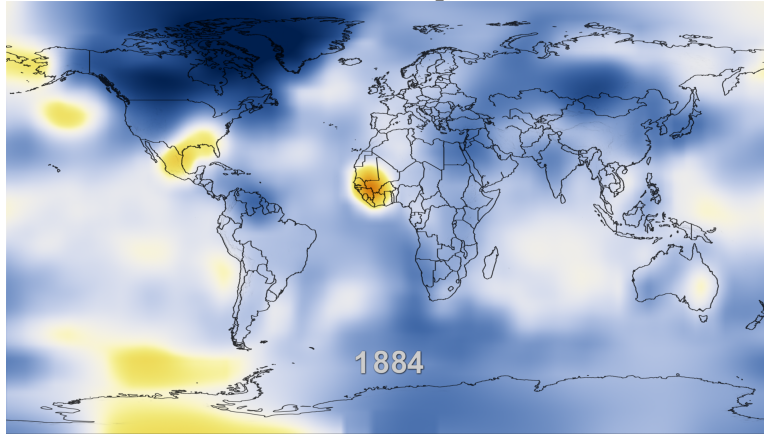
### **Lesson Goals:**

- Learn the definition of *albedo*
- Discover how changes in surface albedo affect climate in the Arctic and in regions with seasonal snow cover
- Calculate albedo over snow and pavement.
- Calculate the density of snow by applying the formula for density, volume of a cylinder, and relate density of snow to the density of water.
- Convert albedo and snow density into percentages
- Analyze snow density and albedo as a time series throughout the course of the winter snow sampling season
- Identify patterns in time series analysis and investigate relationships using x-y scatterplots.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

1. Start the lesson by showing the students two NASA Scientific Visualization Studio videos:

**VIDEO 1: Global Surface Temperature, 1884-2012**



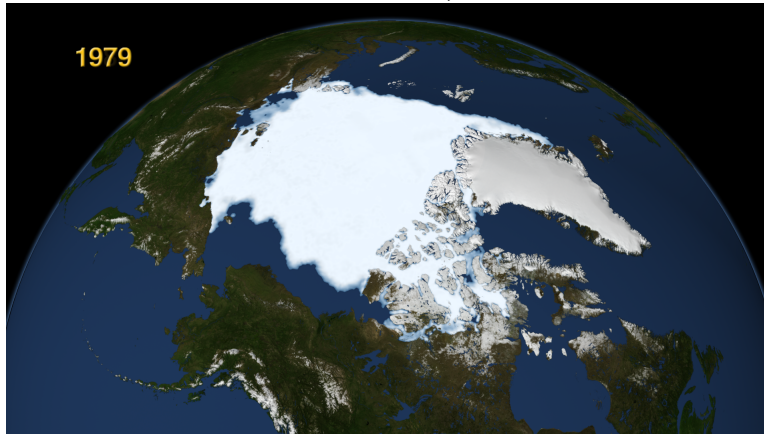
Copy and past link into browser (you may need to View → zoom out)  
[http://svs.gsfc.nasa.gov/vis/a000000/a004000/a004030/2012\\_GISSTEMP\\_update\\_withdates.mp4](http://svs.gsfc.nasa.gov/vis/a000000/a004000/a004030/2012_GISSTEMP_update_withdates.mp4)

It will be helpful to narrate the movie as it plays for the class. Here are some key features you can point out as it plays:

- Areas in blue show temperatures lower than long-term average.
- Areas in red show temperatures warmer than long-term average
- In the 1930's, the US lights up in orange. This is the 1930's **dust bowl** that caused widespread drought conditions in the mid-west.
- In the 1960's, much of the US and world is blue. Scientists believe pollution from coal and fossil fuel emissions contributed to the cooler temperatures by emitting tiny atmospheric particles, or aerosols, that blocked the sun's energy.
- From the 1970's onward, a distinct warming pattern emerges. Ask the students where most of the warming is taking place.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

**VIDEO 2: Arctic Sea Ice Extent, 1979-2012**



[http://svs.gsfc.nasa.gov/vis/a000000/a003800/a003893/sealceArea\\_2011\\_Wdate.mp4](http://svs.gsfc.nasa.gov/vis/a000000/a003800/a003893/sealceArea_2011_Wdate.mp4)

As with the first video, it will be helpful to narrate the movie as it plays. Here are some key features you can point in the sea ice video out as it plays:

- Areas in white show the extent of sea ice in *September*. This is the minimum area covered by sea ice throughout the year. The bright sea ice reflects most of the sun's energy.
  - Areas in dark blue are open ocean. The dark ocean absorbs most of the sun's energy.
  - Throughout the 1980's and 1990's, the "Northwest Passage" remains choked with sea ice. Ship travel was generally not possible.
  - In 2007, satellites reveal for the first time that the "Northwest Passage" was passable.
  - In 2012, Arctic Sea Ice reached a new record low extent, breaking the previous low sea ice extent record set in 2007.
2. After showing the students the two videos, ask the students if they think warmer Arctic temperatures in the first video and the decline in sea ice from the second video might be related. [They should come up with an answer about how the sea ice reflects the sun's energy and how the dark ocean absorbs the sun's energy, making it warmer].

If they are having a difficult time coming up with an answer relating to how sea ice reflects the sun's energy, ask them what color t-shirt they would wear on a hot summer day. Most students will chose white. Now it is time to introduce *albedo*.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

3. Introduce the term *albedo* to the students. **Albedo** is a measure of reflectivity. It is the ratio of reflected solar energy to incoming solar energy:

$$\text{Albedo} = \frac{\text{Reflected Solar Energy (in Watts/meter}^2\text{)}}{\text{Incoming Solar Energy (Watts/m}^2\text{)}}$$

... Point out the units solar energy. Ask them where they have heard the term watts used before (usually they mention light bulbs).

.... Note the units of the numerator and the denominator cancel each other out. This means that albedo is a *unitless* quantity. It ranges from **0.0** (no solar energy is reflected, all energy is absorbed) to **1.0** (all solar energy is reflected, none is absorbed).

Have the students perform a simple calculation of albedo over the following surfaces. Assume that the incoming solar radiation for the day is 200 W/m<sup>2</sup>:

**Snow:** 150 W/m<sup>2</sup> reflected (albedo<sub>snow</sub> =  $\frac{150 \text{ W/m}^2}{200 \text{ W/m}^2} = 0.75$ )

**Pavement:** 10 W/m<sup>2</sup> reflected (albedo<sub>pavement</sub> =  $\frac{10 \text{ W/m}^2}{200 \text{ W/m}^2} = 0.05$ )

Based on our above calculations of albedo for snow and pavement, ask the students which surface would they expect to be warmer (Answer: pavement). If your classroom has infrared temperature guns (~\$45 from the hardware store) and there is snow outside, you can take the students outside to measure the temperature of different surfaces.

4. Albedo of snow can change over time as the snow pack melts, compacts, and gets covered with dust, dirt, and debris. We are interested in learning how albedo changes with snow *density*. Ask the students if anyone knows the formula for density:

$$\text{Density} = \frac{\text{Mass (kg)}}{\text{Volume (m}^3\text{)}}$$

Let's start with how we measure the numerator, **Mass**.

We measure the mass of a snow pack by inserting an empty cylinder vertically into the snowpack, capping the ends of the cylinder to trap the snow inside, and weighing the total in kilograms (kg). To get the mass of *just* the snow, we subtract the weight of the empty snow tube and caps (also called the *tare weight*) from the total weight.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

$$\text{Snow Mass (kg)} = \text{Total (tube + caps + snow)} - \text{Tare (tube + caps)}$$

Next we calculate the denominator, or **Volume**. This requires the formula for the volume of a cylinder. We will use our snow depth as the height of the cylinder.

$$\text{Volume Cylinder (m}^3\text{)} = \pi * r^2 * \text{height}$$

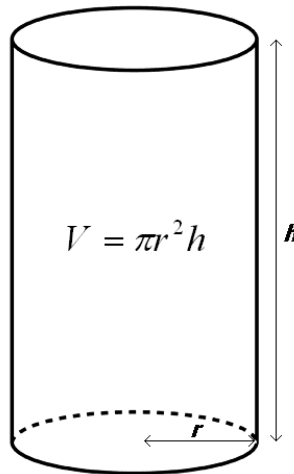


Figure 1. Calculating the volume of a cylinder, or snow tube.

It can be challenging to measure the radius ( $r$ ) of a cylinder because we don't know where the exact center of the tube is. Instead, we can measure the *diameter* ( $d$ ) of the tube and divide by two to get the radius.

$$r = d / 2$$

We can now substitute the above formula for radius in our volume formula:

$$\text{Volume Cylinder (m}^3\text{)} = \pi * (d/2)^2 * h$$

Note that the units of snow *density* are in  $\text{kg/m}^3$ .

In the northeastern US, fresh snow typically has a snow density of  $100 \text{ kg/m}^3$ . Over time, as the snowpack compacts and melts, the density typically increases to  $250\text{-}350 \text{ kg/m}^3$ . Ask the students what the density of water is (Answer:  $1000 \text{ kg/m}^3$ ).

We can use the density of water to convert the density in  $\text{kg/m}^3$  to a percentage (%):

$$\text{Snow Density (\%)} = \frac{\text{Density of Snow (kg/m}^3\text{)}}{\text{Density of Water (kg/m}^3\text{)}} * 100$$

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

... Note how the units (kg/m<sup>3</sup>) cancel out in the numerator in denominator, leaving us with a percentage.

Now calculate the density (%) for fresh snow and old snow:

$$\text{Fresh snow density (\%)} = \frac{100 \text{ kg/m}^3}{1000 \text{ kg/m}^3} * 100 = 10\%$$

$$\text{Old snow density (\%)} = \frac{350 \text{ kg/m}^3}{1000 \text{ kg/m}^3} * 100 = 35\%$$

**Plot a Time Series of Snow Albedo and Snow Density:**

Instruct the students on how to plot a *time series* of snow albedo and snow density from the beginning of the snow sampling season through the end of the sampling season.

In order to help visualize our time series, it will be helpful to have our variables of interest (albedo and snow density) in the same units, in this case we'll plot them both as percentage (%). For albedo, we multiply by 100 to convert it to a percentage. For snow density (%), we first divide the snow density in kg/m<sup>3</sup> by the density of water in kg/m<sup>3</sup>, then multiply by 100. We plot albedo and snow density on the y-axis (vertical) and time on the x-axis (horizontal).

If your classroom is an active contributor to the CoCoRAHS Albedo project, the students can plot the time series throughout the snow sampling season on a large piece of poster paper in the classroom. Alternatively, you use data downloaded from the <http://www.cocorahs-albedo.org> website to plot in Microsoft Excel (detailed plotting instructions below).

In the example below, we downloaded data from Nov-25-2012 through March-19-2014 collected at station NH-CS-7 from the CoCoRAHS-Albedo website using the download tool:

[http://cocorahs-albedo.org/pages/request\\_data/](http://cocorahs-albedo.org/pages/request_data/)

## SUPPLEMENTARY MATERIAL: SNOW, ALBEDO, AND CLIMATE LESSON PLAN

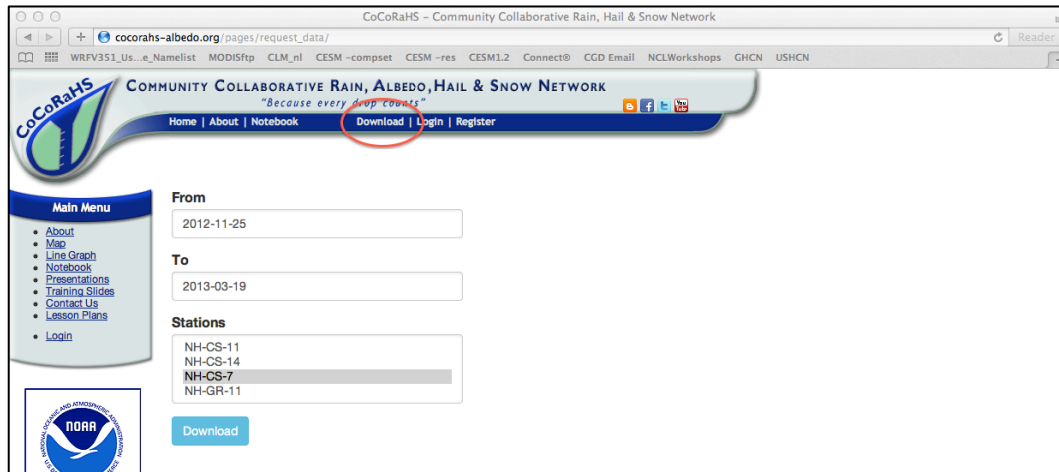


Figure 2. The download page at [www.cocorahs-albedo.org](http://www.cocorahs-albedo.org). The example uses 2012-11-25 through 2013-03-19 for NH-CS-7.

When you download the data, it will arrive as a comma-separated values (.csv) file. Open this file in Microsoft Excel and immediately 'Save As' an Excel file (.xlsx).

### Excel Instructions for plotting a time series of albedo and snow density:

1. Inspect the Excel spreadsheet you downloaded. What is the start date? What is the end date? How many days have '0' for snow depth?
2. Find the 'Albedo\_avg' (column X) and the 'SnowDensity\_kgm3' (column Z) columns. We want convert albedo and snow density to percentages. To do this, right-click on column Y and select 'Insert'. A new column will be added to the right of 'Albedo\_Avg'. Label the top of this column 'Albedo\_%'. In the top empty cell (Y2), enter the following formula:

$$= X2*100$$

3. To fill the remaining empty cells with the same formula, hover over the lower right corner of cell Y2 until you see a black + sign. Double-click and the remaining cells will be filled with the same formula. Some boxes will have '#VALUE'. These are days when no data was collected and deleted so that the cell is empty.
4. Repeat the same steps to convert SnowDensity\_kgm3 to percentage. Insert a new column to the right of SnowDensity\_km3. Label the column 'SnowDensity\_%'. Enter the following formula into your new column:

Recall that the formula for converting snow density in kg/m<sup>3</sup> to % is

$$\% = (\text{Snow Density kg/m}^3 / 1000 \text{ kg/m}^3) * 100$$

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

As such, your formula in the new empty column should be:

$$= (AA2/1000)*100$$

5. You now have albedo and snow density in the same units (%) and are ready to plot the time series.
6. Select the three columns called 'Date', 'Albedo\_%' and 'SnowDensity\_%' (use the CTRL key to select multiple columns).
7. Insert → Chart → Line
8. Inspect your time series chart. Note that '0' values for both albedo\_% and SnowDensity\_% are being plotted. We do not want these values plotted so the easiest way to remove them is to simply delete the contents of the cells that contain '0' or '#VALUE' for both columns.
9. Ask the students to use the patterns over time to create a hypothesis predicting what happens to albedo when snow density changes. For example, between 27-Dec-2012 and 06-Jan-2013 we see that albedo decreases over time. What happens to snow density during this period? Have them write their hypothesis down.

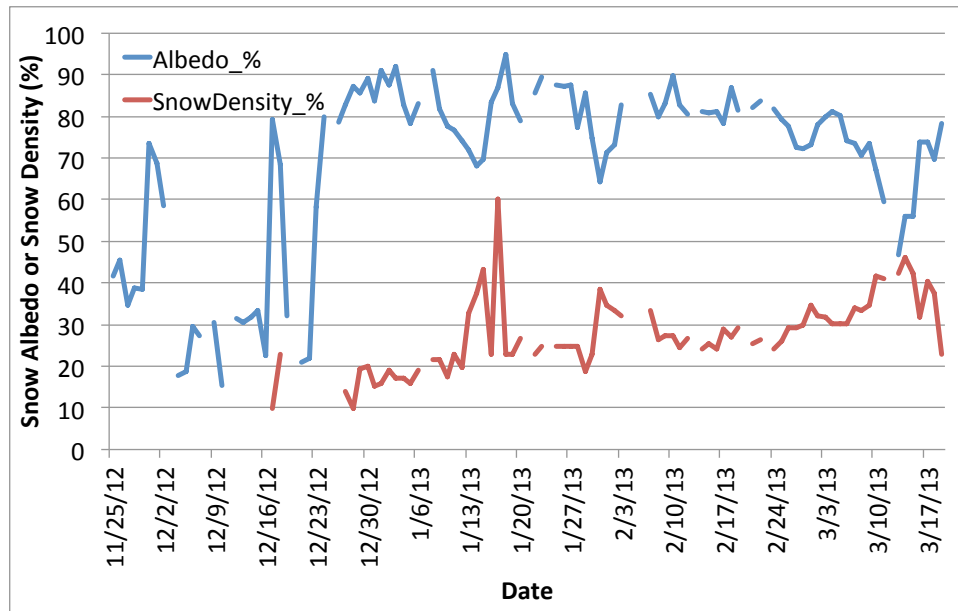


Figure 1. Time series plot of snow albedo (blue) and density (red) data from volunteer observer station NH-CS-7.

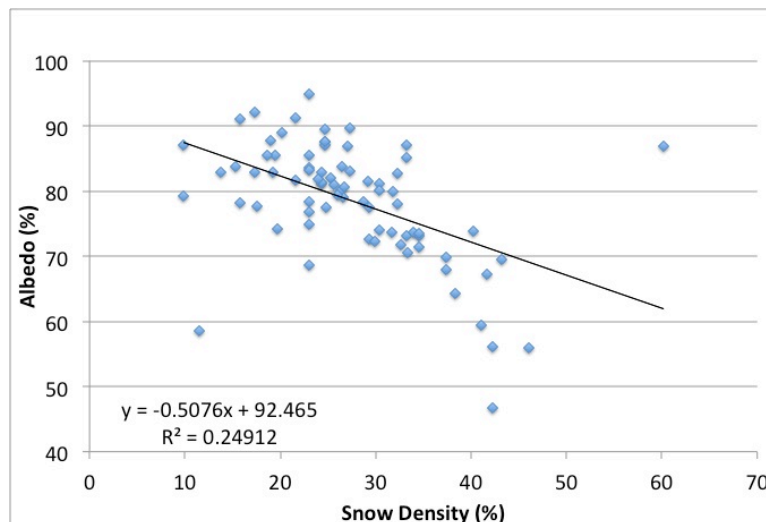
**Plot an x-y scatterplot of albedo vs. snow depth:**

1. Select the two columns called 'Albedo %' and 'Snow Density %'.
2. Insert → Chart → XY Scatter



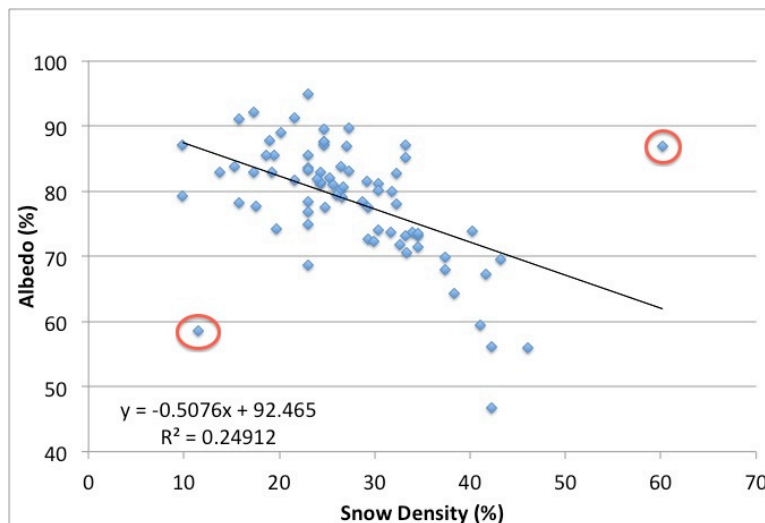
**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

3. Make sure that albedo is on the y-axis and snow density is on the x-axis. If they are not, right click on the chart area and click 'Select Data'. Switch the X values and the Y values.
4. What happens to albedo as snow density increases? Does this relationship match the hypothesis you formulated from the time series plot?
5. Add a trendline to check your answer. Right click on the data series in the graph. Select 'Add Trendline'. Under Type, select 'Linear'. Under 'Options', check the boxes that say 'Display equation on chart' and 'Display R-squared value on chart'.
6. The equation of the line takes the form:  $y = mx + b$ . Here,  $y$  is the albedo value,  $m$  is the slope (or change in albedo per unit change in snow density),  $x$  is snow density, and  $b$  is the y-intercept. What is the slope of line (include units in your answer)?
7. Is the slope of the line negative or positive? A negative slope indicates an inverse relationship (e.g., as snow density increases, albedo decreases). A positive slope would indicate a direct relationship (e.g., as snow density increases, albedo increases). Which relationship does the graph show?
8. The  $r^2$  value is indicative of how strong the relationship is between albedo and snow density. An  $r^2$  of 1.0 indicates a perfect relationship or correlation. An  $r^2$  of 0.0 indicates no relationship or correlation between albedo and snow density. What is the  $r^2$  of the albedo and snow density relationship? Why might the  $r^2$  value be low?

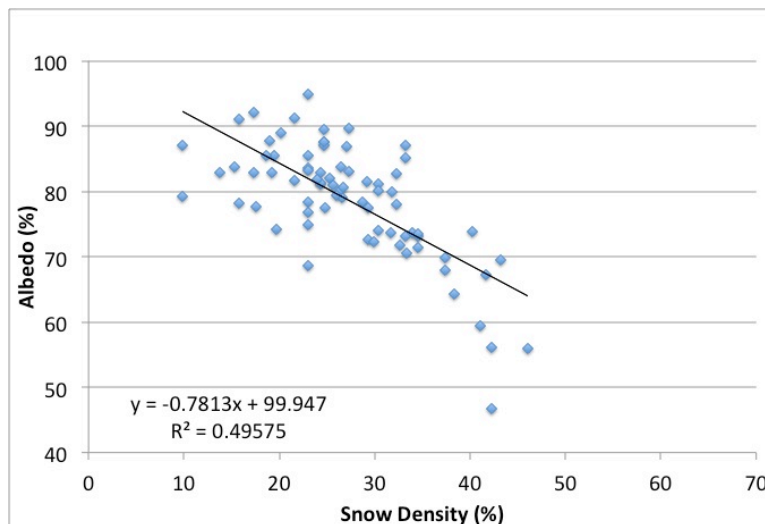


9. Two of the data points are located very far away from the rest of the group. These two points might be considered *outliers*.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**



10. Remove the outliers by deleting these values from the columns in the spreadsheet, leaving the cells empty. What happens to the slope of the line? What happens to the  $r^2$ ?



There are several reasons why we might see a relationship between snow density and albedo. Brainstorm some ideas in groups. These ideas could include:

- As the snowpack melts and compacts, snow density increases. Dirt and debris become concentrated in the snow, lowering the albedo.
- As the snowpack ages, the snow grains grow larger, absorbing more of the sun's incoming energy (lower albedo) instead of reflecting it

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE LESSON PLAN**

11. Ask the students to brainstorm other variables that might be contributing to the changes in snow albedo, in addition to snow density. Does the CoCoRAHS dataset include any of these additional variables? If so, plot them and see what the relationship is. If not, have them describe how they might collect data to investigate whether the relationship exists.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE STUDENT WORKSHEET**

**Albedo = Outgoing/Incoming**

1. Calculate the albedo of the following surfaces. Assume that incoming solar radiation is  $200 \text{ W/m}^2$ .

Snow Outgoing =  $150 \text{ W/m}^2$

Pavement Outgoing =  $10 \text{ W/m}^2$

Snow Albedo = \_\_\_\_\_

Pavement Albedo = \_\_\_\_\_

2. What are the units of albedo?
3. Based on your albedo calculations above, which surface would you expect to be warmer?

**Density = mass/volume**

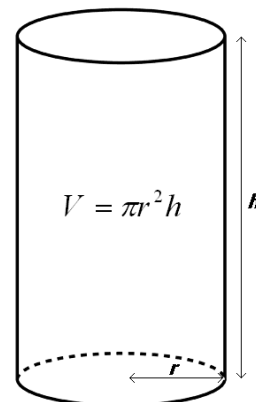
4. Calculate the mass of snow collected inside a snow tube that weighs  $0.547 \text{ kg}$  when empty. The total mass of the empty tube and snow is  $0.687 \text{ kg}$ .

Mass of Snow = \_\_\_\_\_

5. Calculate the volume the snow occupies in the snow tube, assuming snow depth ( $h$ ) was  $28 \text{ cm}$  and the diameter of the tube is  $4.5 \text{ cm}$ . Remember to include units in your answer.

Volume of cylinder =  $\pi * r^2 * h$

Volume of snow in Tube = \_\_\_\_\_



6. Using the equation for density, calculate the density of the snow based on your answers for mass and volume above. Remember to include units in your answer.

Density = \_\_\_\_\_

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE STUDENT WORKSHEET**

7. Convert your snow density into a percentage of liquid water.

$$\text{Snow Density (\%)} = \frac{\text{Density of Snow (kg/m}^3\text{)}}{\text{Density of Water (kg/m}^3\text{)}} * 100$$

$$\text{Snow Density (\%)} = \underline{\hspace{2cm}}$$

**Time Series Plot**

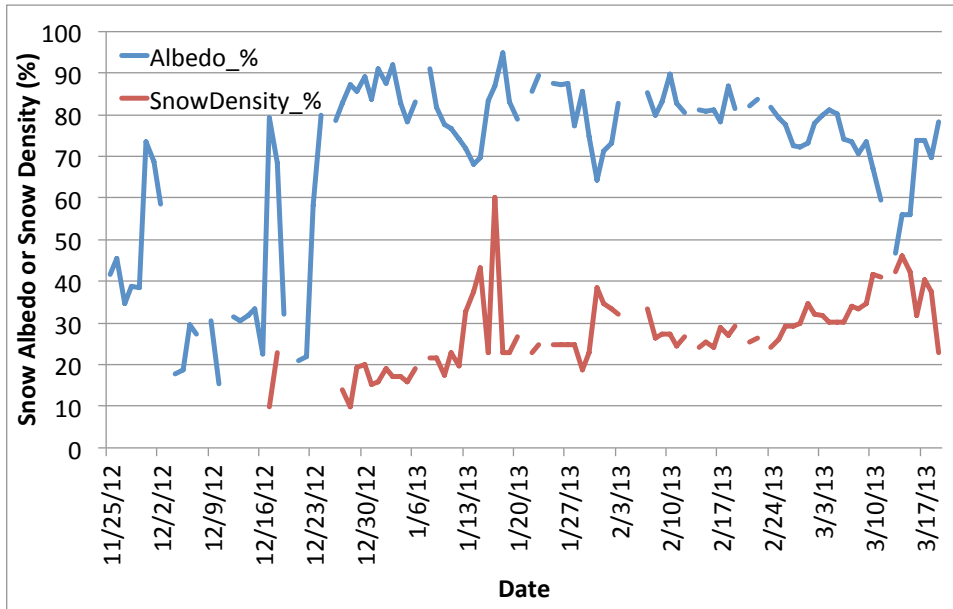


Figure 1. Time series plot of snow albedo (blue) and density (red) data from volunteer observer station NH-CS-7.

8. Over what time range does the time series provide data?

Date start = \_\_\_\_\_

Date end = \_\_\_\_\_

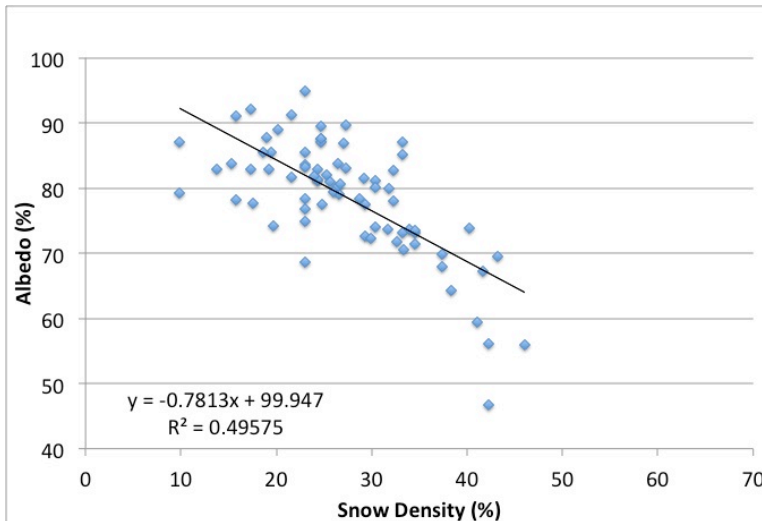
9. Describe the pattern you see between albedo and snow density. What happens to albedo when snow density increases? What happens to albedo when snow density decreases? Write down a hypothesis describing how snow albedo responds to snow density.

**SUPPLEMENTARY MATERIAL:  
SNOW, ALBEDO, AND CLIMATE STUDENT WORKSHEET**

**XY Scatter plot**

In an xy scatterplot, the independent variable is plotted on the x-axis (horizontal) and the dependent variable is plotted on the y-axis (vertical). The dependent variable (y) changes in response to the independent variable (x).

Use the xy scatterplot below to answer the questions and test your hypothesis from the time series plot section.



10. Which variable is the *independent* (x) variable?

11. Which variable is the *dependent* (y) variable?

12. Note the equation of the *trendline*,  $y = mx + b$ .

What is the *slope* (m) of the line? \_\_\_\_\_ (remember units)

Is the slope of the line negative or positive and what does it indicate?

Does the direction (positive or negative) slope of the line match your hypothesis from question #9? Why or why not?

13. The  $R^2$  value indicates how strong the relationship is between your independent and dependent variable (0.0 = no relationship, 1.0 = perfect relationship).

What is the  $r^2$  value between snow density and albedo? \_\_\_\_\_

What other factors, in addition to snow density, might affect albedo in winter?

**SUPPLEMENTARY MATERIAL**  
**CoCoRAHS Step-By-Step Snow Data Collection**

Instructions for classrooms participating in the Community Collaborative Rain, Hail, Albedo, and Snow (CoCoRAHS) Network. More info: <http://www.cocorahs-albedo.org>

- 1) Assign one person to be “data cop”. This person is responsible for recording data into the field notebook.
- 2) Record the date, time, and cloud cover. Cloud cover can be one of four options:
  - ACLR - all clear (0% cloud cover)
  - CLR – clear (1% to 30% cloud cover)
  - PCL – partly cloudy (30% to 60% cloud cover)
  - OVC – overcast (>60% cloud cover)
- 3) Collect incoming and outgoing solar radiation
  - Point the leveling boom toward the sun with the Apogee MP-200 optic pointing upwards at the sky
  - Level the boom by centering the bubble in the black circle. Record the value on the screen as Incoming 1.
  - Rotate the boom so the optic is now pointing at the ground. Level and record the value as Outgoing 1.
  - Repeat the incoming and outgoing for a total of three paired measurements.
- 4) Collect surface temperature (°F) over the area where you just measured solar radiation. Point the IR gun vertically about three inches (3”) above the snow surface (or bare ground if no snow) and record the value.
- 5) Collect snow depth by inserting the metal snow tube vertically into the snowpack where you measured radiation and temperature. Record the snow depth to the nearest 0.5 inch.
- 6) Collect the snow in the tube by scraping away the snow with the spatula and carefully inserting the spatula underneath the base of the tube. Cap the tube at both ends and weigh using the digital scale. Record the weight of the snow, tube, and caps in pounds.
- 7) Note the following in your field notebook:
  - Is it snowing? Yes or No.
  - Did it snow in the last 24 hrs? Yes or No. If Yes, how much?
  - Was there any melt in the last 24 hours? Yes or No.
- 8) Record any other observation notes in the line below the data you just entered. Include notes on patchy snow, grass showing, bare ground, cloud types or shapes, and snow pack characteristics (ex: grainy, slushy, heavy, light & fluffy, etc).