ALISON
Alaska Lake Ice and Snow Observatory Network

SNOW

Using a familiar material to explore the natural world.

Prepared by:

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An Introduction to Snow Studies

After completing this module, you will be knowledgeable about snow, snowflakes, and ice. You will have all the information and tools you need to create your own activities and lesson plans.

You will be able to show your students how to:

- Use weather data to predict the shapes of snowflakes (grades 3-8)
- Design experiments to study snow (all grades)
- Investigate ice freeze-up and break-up of a stream, river, lake or pond (grades 5-8) (Globe protocol)
- Measure snow temperature, mass and depth (various grades)
- Calculate snow volume and density (grades 5-12)
- Calculate the rate of heat flow from the ground through the snow to the atmosphere or from the water through the river/lake ice and snow into the atmosphere (grades 5-12)
- Use mathematics within science (all grades)
- Create and use mathematical calculations in an excel spreadsheet (grades 5-12)

All teaches are encouraged to become members of *Teachers' Domain*. It's easy and it's free. Becoming a member gives you access to an extensive library of free digital media resources and lesson plans produced by public television, designed for classroom use and professional development.

Dr. Delena Norris-Tull, a science educator, and *Ms. Kim Morris* and *Dr. Martin Jeffries*, two snow and ice scientists, designed these web pages for teachers. A number of *science teachers* have provided inspiration and developed activities. Martin first started working with teachers through the Teachers Experiencing the Arctic and Antarctica (TEA) project, taking a teacher with him to conduct research in Antarctica. Martin, Delena, and Kim, and middle school science teacher Ron Reihl started collaborating with teachers in Alaska in 2000. The Alaska Lake Ice and Snow Observatory Network (ALISON) project was the outgrowth of that collaboration. Quickly, teachers from other states became interested in research on ice and snow. To date, teachers from Alaska, Connecticut, Montana and Oregon have been involved in the ALISON project.

So now, let's get *started*........

At a Glance: What You Will Find in this Snow Module

In this snow module, you will learn about and find materials on:

- *Snowflakes*
- *Snowflake Shapes*
- *Snowflake Symmetry* (and other symmetries)
- *Snow Metamorphism* (changes through Time)
- *The Earth's Systems*
- *The Meaning of the Earth's Systems Names*
- *The Earth's Energy Budget*
- *Variations in Solar Energy Reaching the Earth's Surface*
- *Absorption and Reflection of Energy*
- *Albedo*
- *Energy, Temperature and Heat*
- *SI Units and Nomenclature*
- *Specific Heat and Heat Storage*
- *States of Matter*
- *Phase Changes and Latent Heat* (for H_2O)
- *The Water Cycle*: Phase Change and Energy Transfer Through the Hydrosphere
- *Thermal Conductivity and Insulation*
- *Factors that Affect a Snow Cover's Thermal Conductivity*
- *Determining the Density of a Snow Cover*
- *Calculating the Thermal Conductivity of a Snow Cover*
- *Determining the Temperature Gradient of a Snow Cover*
- *Determining the Conductive Heat Flux through a Snow Cover*
- *Freeze-up and Break-up on River, Streams, Lakes and Ponds*
- *The Role of ice, Snow and Water in Regulating Climate*
- *The Impact of Global Climate Change on the Cryosphere*

    - *Snow*
    - *River and Lake Ice*
    - *Glaciers*
    - *Sea Ice*

In many of these sections, you will find questions called "Check Your Thinking". You can download all of the *Check Your Thinking* questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards. The answers to all of the questions can be found in *Appendix 1*.

Please note that:

- There is a complete list of the *learning activities and suggested extensions* embedded in the Snow Module.
- There is a *glossary of terms* used throughout the Snow Module.
- There is a list of some *snow resources*.
- There is a list of *acronyms* used in the Snow Module.

Snowflakes

Snowflakes are familiar to just about everyone (Figure 1). The properties of snow provide an excellent gateway to many science and math topics.

Figure 1: Real snowflakes clinging to a car window. Phoney flakes lack the characteristic six-fold, hexagonal symmetry. Photograph: M Scott Moon/AP.

A snowflake is made up almost exclusively of ice. A dry snow cover is comprised of ice (snowflakes) and air; a wet snow cover also includes liquid water and water vapor.

❄ ***Activity 1:***

Learn about snowflake formation and much more by going to Teachers' Domain interactive primer Snowflake Physics, which is adapted from SnowCrystals.com (requires Adobe Flash Player to view).

❄ ***Resources:***

For the basic facts about snow crystals read through A Snow Crystal Primer by K. G. Libbrecht, a physics professor at the California Institute of Technology. For more detailed scientific information about snowflakes, view or download the paper The physics of snow crystals (pdf) by Dr. Libbrecht.

Snowflake Shapes

New Snow

As you learned in the Snowflake Primer, the shape (morphology) of snowflakes is dependent on climatic conditions, in particular, air temperature and humidity (Figure 2).

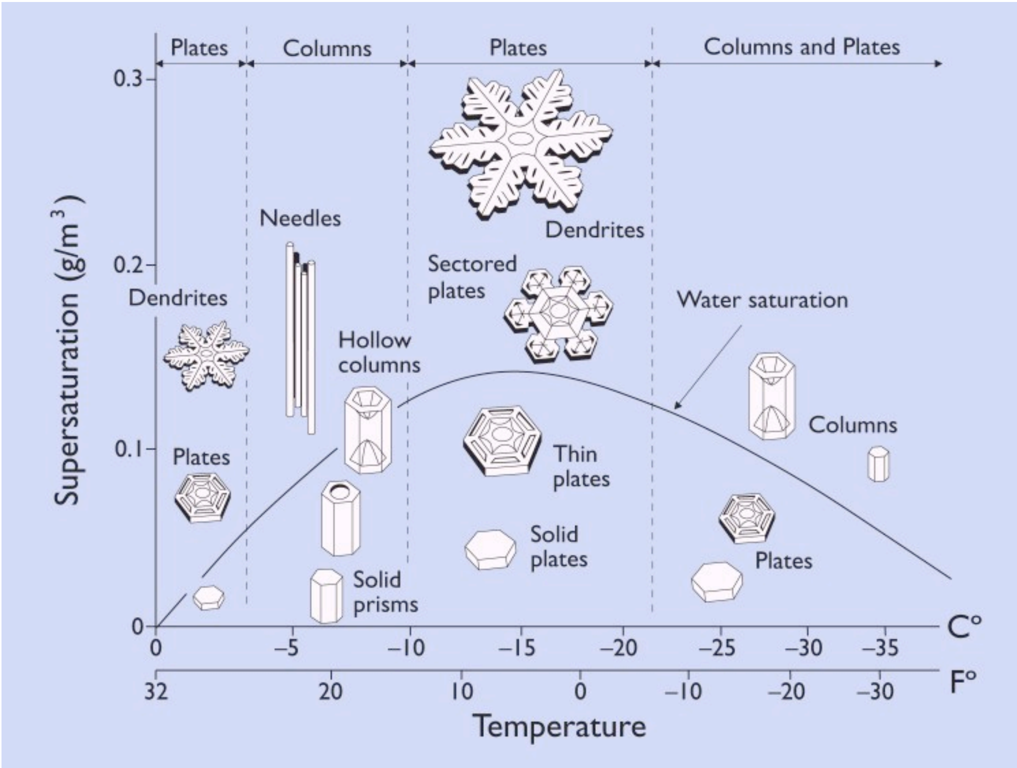


Figure 2: A diagram illustrating the relationship between air temperature and humidity (or supersaturation) and the shapes of snow crystals. (K. G. Libbrecht)

Activity 2:

Familiarize your students with snowflake shapes and the conditions that produce them. Have them predict the shape of snowflakes by collecting air temperature and humidity data whenever it snows and using the snow morphology diagram. Have them examine freshly fallen snow crystals using a hand-lens to verify their predictions. Conversely, they can look at the shapes of the snowflakes and determine what air temperature and humidity conditions they formed under. Download two different versions of the Snowflake Morphology graph (pdf) to assist with this task.

Also check out Extension Activities 1, and 2.

Activity 3:

Observe and document the snowflakes in your schoolyard. Refer to Snowflake Watching, How to Photograph Snowflakes and Preserving Snow Crystals to learn to look at, photograph and preserve snowflakes.

Snowflake Symmetry (and other symmetries)

Snowflakes provide wonderful examples of symmetry. In mathematics, *symmetry* is defined as an attribute of a shape or relation; exact reflection of form on opposite sides of a dividing line or plane. It is useful to engage students in examining symmetry.

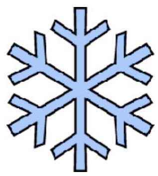
There are two basic types of symmetry:

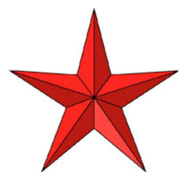
- **Rotational symmetry** (also known as Radial symmetry)
- **Reflection symmetry** (also known as Bilateral, or Mirror symmetry)

In **rotational symmetry**, you can cut the image in half in more than one direction, and the two halves will appear as mirror images of each other. The object has more than one line of symmetry. For example, a triangle can be cut along three different axes. A circle can be cut along an infinite number of axes.

Check Your Thinking:

The two images below are examples of rotational symmetry.
How many lines of symmetry are possible in each?





You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

In **reflection symmetry**, you can cut the image in half in only one plane. In other words, there is only one direction in which you can draw a line that will result in two halves that are mirror images of each other. There is only one line of symmetry. For example, for the two pictures below, there is only one way you can fold each one that will result in the two halves being equal.

Check Your Thinking:

The two images below are examples of reflection symmetry.
Can you identify the line of symmetry in each?

Are snowflakes an example of reflection symmetry?

Activity 4:

Download Snowflake Shapes & Activities (pdf) for a variety of activities you can do with your students related to snowflake shapes and symmetry.

Also check out Extension Activities 3, 4, 5 and 6.

Snow Metamorphism (changes through time)

The shapes of the new snowflakes change after they have been on the ground for a while. Figure 3 provides information on the types of changes you can expect to see as snow crystals accumulate on the ground over time.

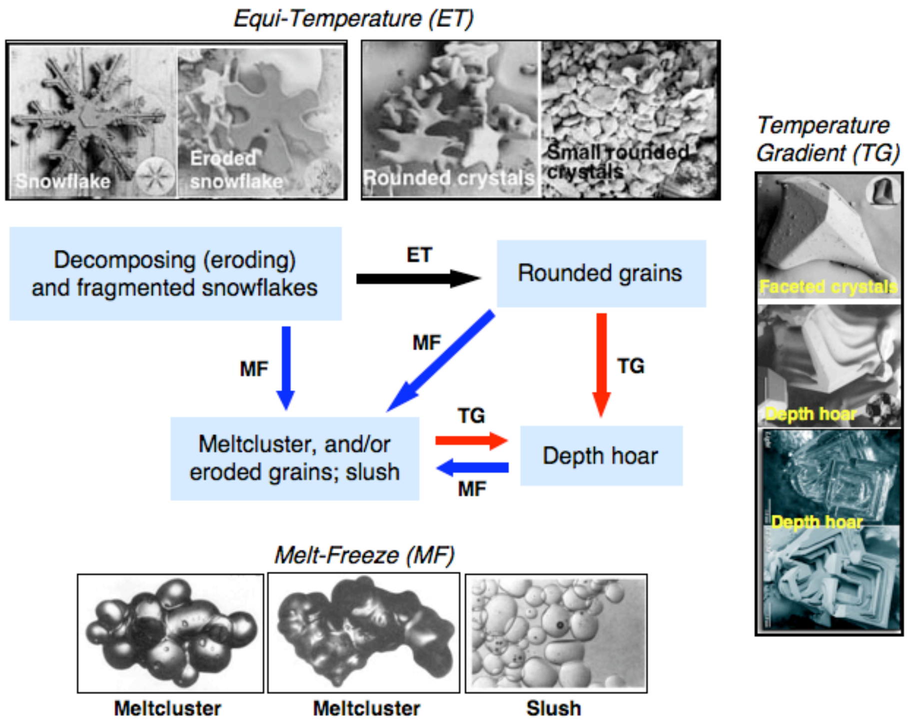


Figure 3: Temperature regimes and the resulting snow crystal configuration. (Kim Morris)

Equi-temperature metamorphism refers to the changes that occur to snow crystals over time in a snowpack, when the temperature at the surface of the snow and the temperature at the base of the snow are virtually the same. This generally occurs when air temperatures remain close to 0°C for an extended period of time. A snow cover that is the same temperature all the way through is called isothermal.

Temperature-gradient metamorphism refers to the changes that occur to snow crystals over time in a snowpack, when the temperature at the surface of the snow is significantly colder than the temperature at the base of the snow for a period of time. This is most apparent when air temperatures are between 0 and -40°C. Due to the insulating properties of snow, the base of a deep layer of snow will remain higher than the air temperature in these conditions.

❄ *Activity 5:*

Download Snow Crystals in a Snow Pit (pdf) and identify the snow grain types in your snowpit layers. If you have an established snow cover (>10 cm), dig a snow pit, so that students can compare the shape of snow crystals in layers of snow from the bottom to the top. Dig these pits at different sites and compare the number of layers in the snow and the kinds of snow crystals found in each layer.

The Earth's Systems

Snow is one component of the one of the Earth's systems. A system is a group of interacting, interrelated, or interdependent components forming a complex whole. It is helpful to think of the Earth as being composed of various large, intricate systems that interact with each other in a manner that keeps things in balance (and, as a result, makes it possible for humans and other organisms to survive on the Earth). This is often referred to as Earth System Science.

Check Your Thinking:

Can you name the main large Earth systems?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

For Your Information: Foreign (Ancient) Words in Science

This is where it is handy to know a little bit of Latin or Greek.

By the way, several research studies have shown that high school science textbooks typically include more unfamiliar (foreign) words than do high school foreign language textbooks. Is that crazy, or what!

When students learn, for example, the Spanish word for house (casa), they are learning a new name for a concept that they already understand. But in science, the unfamiliar words (such as photosynthesis*) typically represent unfamiliar, abstract concepts. Most science textbooks overwhelm students with too much non-essential terminology. As a teacher, it's important to know that K-12 students do not need to memorize or understand all the terminology found in typical science textbooks. The Content Standards established as part of the National Science Education Standards help teachers get a handle on what the most essential concepts are. A very useful book to assist you in this regard is Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993 & 2009),* which is available *online. Take a look at the section The Physical Setting for many concepts that relate to snow study.*

However, you can help your students understand what they read in science textbooks if you assist them to memorize some of the Latin and Greek roots that are commonly used as parts of English words. These root words are used a lot in science. Memorizing root words will make it much easier for students to figure out the meanings of long scientific terms (such as photosynthesis, from the Greek words "photo" meaning "light" and "synthesis" meaning "putting together" or "composition") when they encounter them in text. This reduces the amount of new information they have to learn as they read science text. In fact, many scientific terms are composed of several root words, making it possible for students to guess the meanings of many terms with a high degree of accuracy.

The Meaning of the Earth's Systems Names

We have identified some of the major Earth systems: atmosphere, lithosphere, biosphere, hydrosphere and cryosphere. Now, let's break down the terminology to define these terms. Here we go!

Check Your Thinking:

What does "sphere" mean?

Check Your Thinking:

*What do **atmo**-, **litho**-, **bio**-, **hydro**- and **cryo**- mean?*

Check Your Thinking:

What is the atmosphere made up of?

Check Your Thinking:

What is the lithosphere made up of?

Check Your Thinking:

What is the biosphere made up of?

Check Your Thinking:

What is the hydrosphere made up of?

Check Your Thinking:

What is the cryosphere made up of?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Note that these definitions are NOT necessarily mutually exclusive. Water vapor in the air could be considered part of the hydrosphere, as could glaciers (frozen water). Figure 4 summarizes the five main Earth systems.

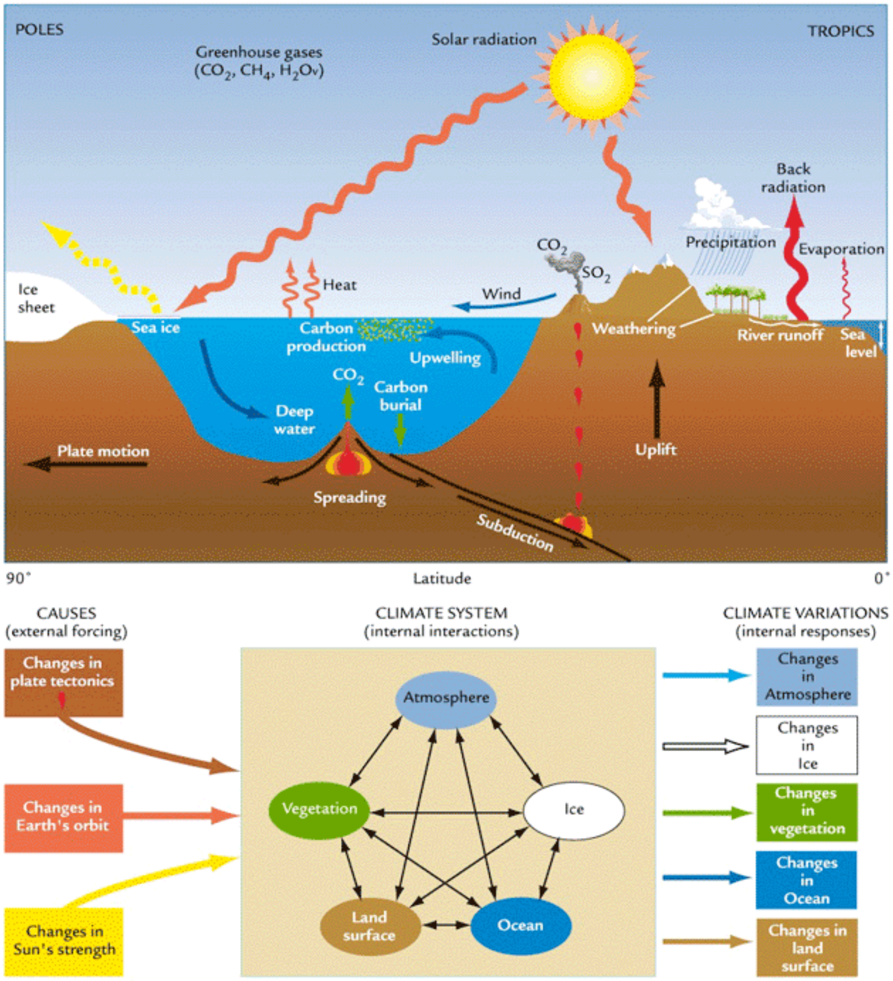


Figure 4: The five main Earth systems (Atmosphere, vegetation (part of Biosphere); land surface (part of Lithosphere); ocean (part of Hydrosphere) and ice (part of Cryosphere)), their location on the planet's surface (top) and some their relationship to change (bottom). (NOAA)

Activity 6:

Download Greek & Latin Root Words for Science (pdf) for a list of root words from Latin and Greek that will help students understand the meaning of the Earth system names and would be useful for them to memorize.

Resources:

Find out more about the five main Earth systems: Atmosphere, Lithosphere, Biosphere, Hydrosphere, and Cryosphere.

For more information on the sources of water on the Earth, refer to the USGS Water Science for Schools website.

For lots of great information on other things that go on in the atmosphere (ozone layer, greenhouse effect, etc.) take a look at Project Learn: Cycles of the Earth and Atmosphere.

The Earth's Energy Budget

> ***Check Your Thinking:***
>
> *What do we mean by the Earth's energy budget?*

> ***Check Your Thinking:***
>
> *Where does the energy that enters the Earth's energy budget come from?*

> ***Check Your Thinking:***
>
> *Where does the energy that leaves the Earth's energy budget come from?*

> ***Check Your Thinking:***
>
> *Where is energy stored in the Earth's energy budget?*

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

The Earth can be considered as a physical system with an energy budget that includes all gains of incoming energy and all losses of outgoing energy. The planet is approximately in equilibrium, so the sum of the gains is approximately equal to the sum of the losses.

Earth's systems constantly move energy around in *cycles* (e.g., *water cycle*, *rock cycle*, *life cycles*). The balance of this movement of energy within the Earth's systems is crucial in maintaining life and in regulating the climate of the Earth.

Figures 5 and Table 1 summarize the Earth's energy budget. Notice that:

- The Sun is the sole source of incoming energy (~342 W m^{-2}). This shortwave energy ranges from the Ultraviolet (UV 0.001-0.4µm) through the visible range (light 0.4-0.7µm) to the Infrared (IR 0.7-100µm). **Note that the wavelength of light is measured in nanometers (µm)**.
- Some of this energy is immediately reflected back into space by particles/molecules in the atmosphere and clouds and never reaches the Earth's surface.
- Some of this energy is absorbed by the atmosphere and clouds and never reaches the Earth's surface.
- Some Earth surfaces reflect incoming energy back into space.
- The Earth (land and oceans) absorbs solar energy.
- The Earth radiates energy as longwave thermal radiation.
- The atmosphere and clouds absorb some of the energy radiated from the Earth.
- The atmosphere and clouds radiate energy back into space.

As can be seen in Table 1, the incoming energy (100%) is equal to the reflected and radiated into space values (30% + 70%) and the amount of energy absorbed by the Earth's surface (land and oceans) is equal to the amount radiated from the Earth's surface (51%). However, the atmosphere and clouds present a more complicated scenario. They absorb energy from the Sun and the Earth and receive energy from the Earth through conduction and latent heat.

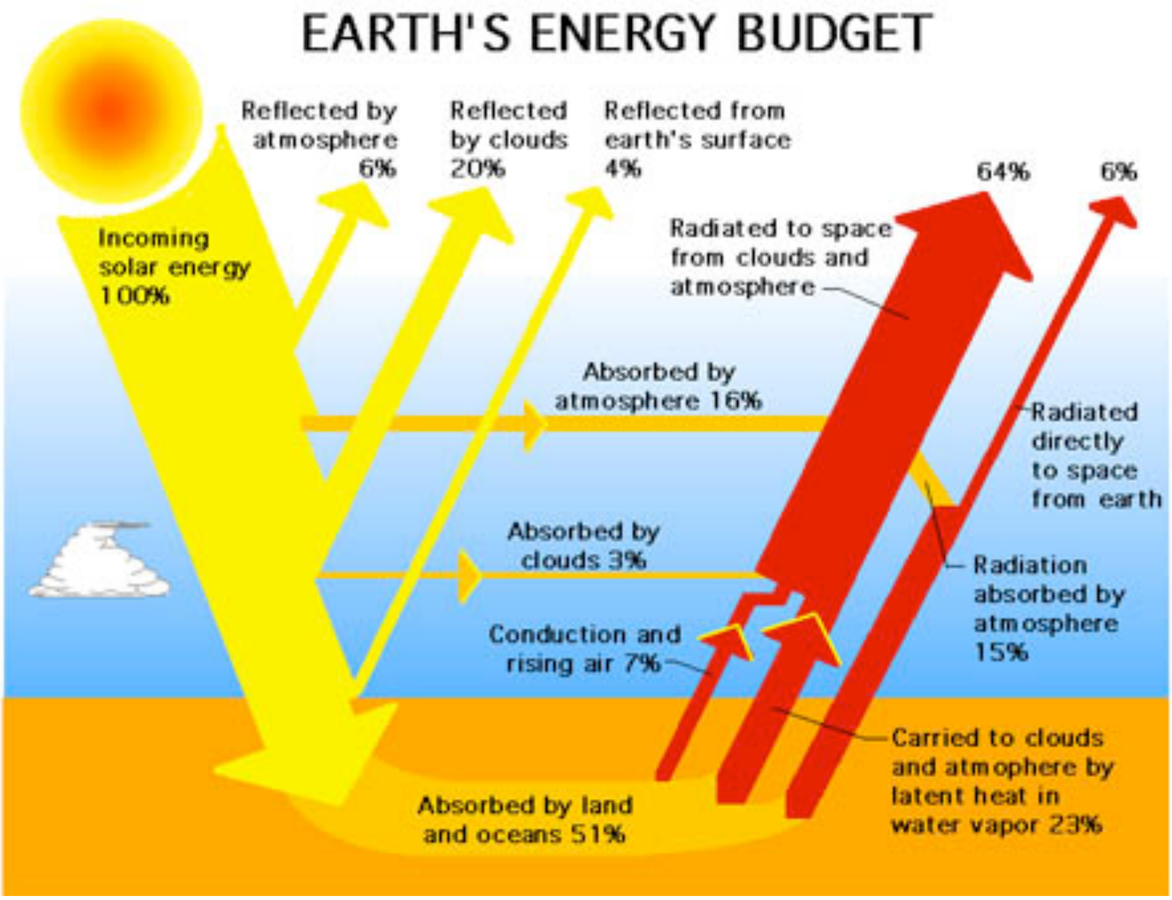


Figure 5: Net energy transfer. The role of greenhouse gases and the exchange that occurs between the Earth's surface and the atmosphere or any other exchanges are not shown. (Wikipedia)

Table 1. A Summary of the Earth's energy balance as seen in Figure 5. Note that the numbers are color coordinated to show their relationship; for example, the 51% (Earth and Oceans) in the Absorbed column is the same 51% (Total) from the Radiated from the Earth column.

	Incoming	*Reflected*	*Absorbed*	*Radiated from the Earth*	*Radiated to Space*
	Solar 100%	Atmosphere 6% Clouds 20% Earth and Ocean 4%	Atmosphere 16% Clouds 3% Earth and Oceans 51%	Conduction 7% Latent Heat 23% Radiated 21% (15% absorbed by atmosphere)	Clouds and Atmosphere 64% Directly from Earth's surface 6%
TOTAL:	**100**%	**30**%	**70**%	**51**%	**70**%

It is worth noting that the "The Earth emits more heat than it absorbs from the sun, and part of the reason for this excess heat is the decay of radioactive elements in the Earth. There are other sources of heat in the Earth, including thermal energy left over from when the Earth first formed, thermal energy from the large collision that formed the moon, and thermal energy remaining from the formation of the Earth's core. However, these other sources of thermal energy are not as long-lasting as that from radioactive decay of natural elements in the Earth" (*Karam, 2003*). See the Wikipedia article on the *geothermal gradient* for an explanation of heat sources and heat flow within the Earth. This kind of energy is not included in our discussion of the Earth's energy budget but is important to understand when calculating the heat flux from the ground.

❄ *Activity 7:*

Download The Energy Budget of the Earth (pdf). Make two columns and label them "Net gain" and "Net loss". What is the value of these two columns? Are they equal?

❄ *Resources:*

For a more detailed explanation of Earth's energy budget, refer to the NASA Earth Observatory web page on Climate & Earth's Energy Budget and Columbia University lecture notes on Solar Radiation and the Earth's Energy Balance.

For details on the role of the atmosphere in reflecting sunlight, see Atmospheric Effects on Incoming Solar Radiation from PhysicalGeography.net.

Variations in Solar Energy Reaching the Earth's Surface

Check Your Thinking:

What factors influence the amount of solar energy reaching the Earth's surface?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

The *solar constant* is the amount of incoming *insolation* per unit area on a plane perpendicular to the sun's rays at a distance of one astronomical unit (AU) (the distance between the Sun and the Earth). It equals approximately 1.366 kW m^2.

Many people believe that the seasons are caused by the Earth's distance from the sun, i.e., winter occurs when the Earth is farthest from the Sun. However, contrary to popular belief, in the northern hemisphere, the Earth is actually closer to the Sun in the winter than in the summer.

The reason for the seasons (and the annual variability of solar energy) is the angle (tilt) of the Earth on its axis in relationship to the Earth's elliptical path around the Sun (Figure 6).

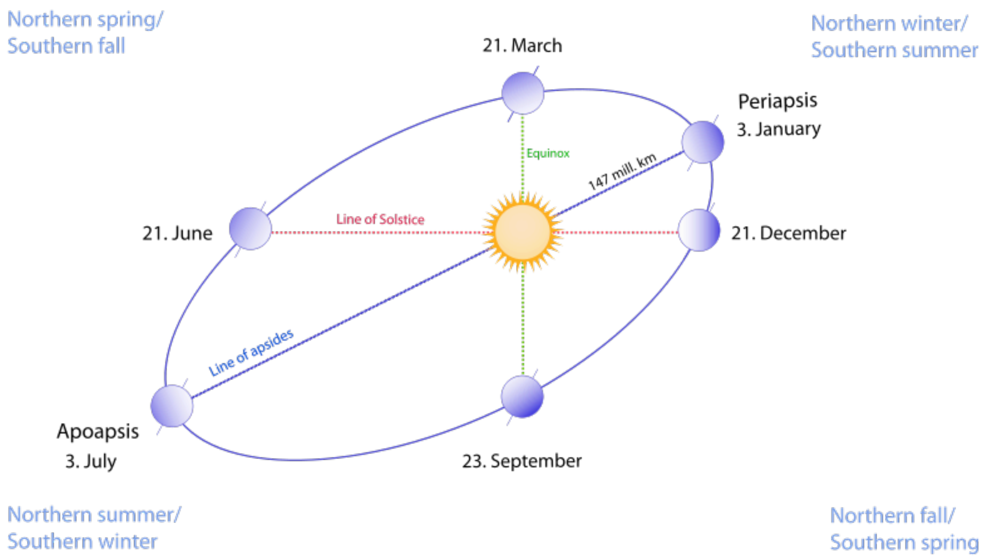
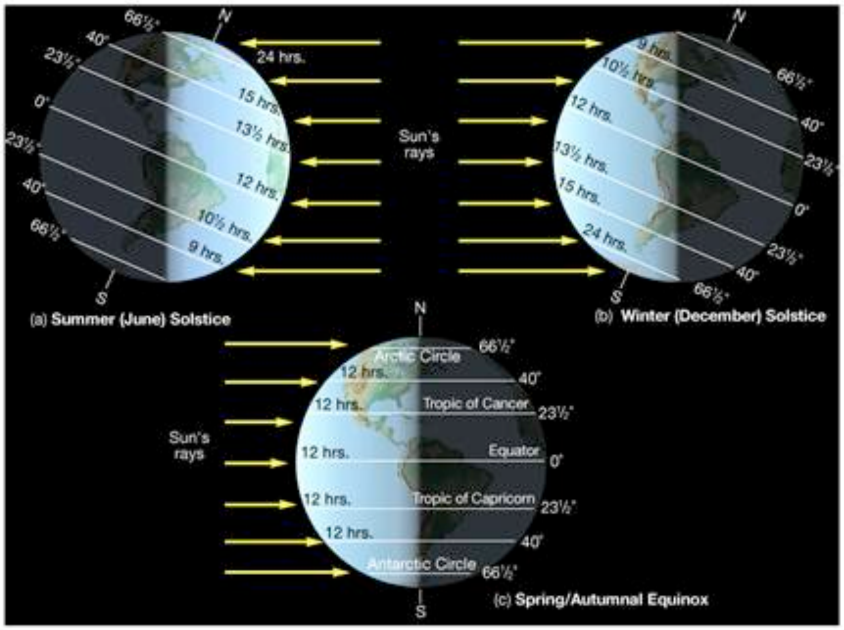
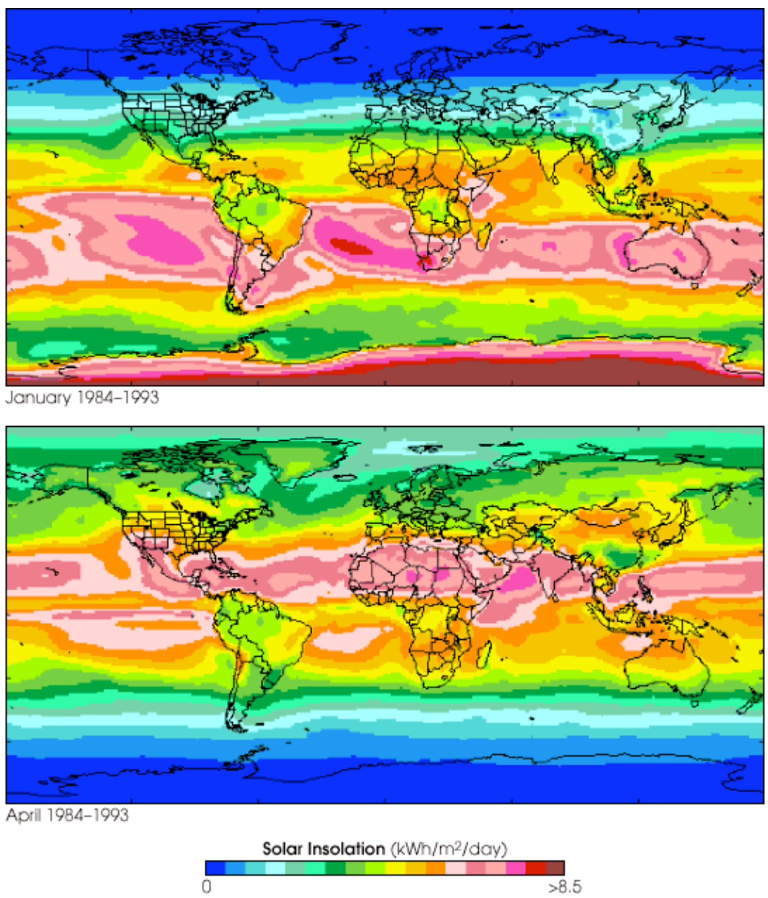


Figure 6: The position of the Earth relative to the Sun during the course of one year. (Wikipedia)

The Earth-Sun relationship results in significant differences in the angle of incidence of the Sun's rays from summer to winter (Figure 7). The Earth's axis always points in the same direction, but because the Earth moves in its orbit, the axis leans toward the Sun in summer and away from the Sun in winter. As a consequence, the average solar insolation changes with latitude during the year (Figure 8).



[Figure 7:](#) *An illustration of the changes to the incidence angle of the suns rays on Earth at significant points during the Earth's journey around the Sun. (Nick Strobel)*



[*Figure 8*](#)*: The average solar insolation for the years 1984-1993 for the month of January (top) and April (bottom). (NASA.)*

Activity 8:

Download Exploring Solar Energy Variation on Earth: Time and Seasons (pdf) to learn about the daily and annual variations of solar insolation.

Activity 9:

Download Exploring Solar Energy Variation on Earth: Changes in the Length of Day, Solar Angle and Solar Insolation Through the Year (pdf) to learn about the variations in the duration and intensity of solar insolation on the Earth's surface.

Activity 10:

Download Sun Angles (pdf) to learn how to measure the angle of the sun to the horizon.

Resources:

For more information about the Earth in space and its relationship to the Sun refer to the Earth-Sun Geometry.

Absorption and Reflection of Energy

Now, let's think about absorption and reflection in relationship to Earth's systems and energy budget. The components of Earth's systems (air, water, land, ice, and living things) reflect and absorb solar radiation in ways that moderate the global energy budget.

Reflection: Change in wave direction after it strikes a reflective surface, causing the angle the wave makes with the reflective surface in relation to a normal line to the surface to equal the angle the reflected wave makes with the same normal line.

Absorption: The taking up and storing of energy, such as *radiation*, light, or sound, without it being reflected or transmitted. During absorption, the energy may change from one form into another. When radiation strikes the electrons in an atom, the electrons move to a higher orbit or state of excitement by absorption of the radiation's energy.

❄ ***Check Your Thinking:***

*Which colors **reflect** the most sunlight?*

❄ ***Check Your Thinking:***

*Which colors **absorb** the most sunlight?*

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

❄ ***Activity 11:***

Perform a simple experiment to illustrate the impact that color has on absorption and reflection of energy. Place different colors of the same materials in the sun or under a light to see which materials get hotter than others. For example, you can place construction paper of different colors in the sun, then measure the temperature of their surfaces (be careful to shade the thermometer when doing this), or simply feel them with your hand. Certain colors reflect sunlight (solar radiation) more than do others, and certain colors absorb sunlight and convert it into heat (infrared radiation) more than do others.

Albedo

Albedo is the ratio of reflected to incident solar radiation on a surface or object. Its value depends on the frequency of radiation considered: unqualified, it usually refers to some appropriate average across the spectrum of visible light. In general, the albedo depends on the direction and directional distribution of incoming radiation. *Albus* is Latin for *white*, which you will recognize from the English word *albino*.

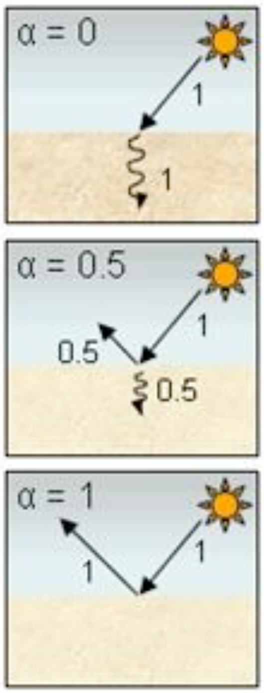


Figure 9: Three examples of albedo. (NSIDC)

Albedo is a measure of reflectivity of a surface or body. It is the ratio of electromagnetic radiation (EM radiation) reflected to the amount incident upon it. The fraction, usually expressed as a percentage from 0% to 100% (or as a dimensionless value between 0 and 1), is an important concept in climatology and astronomy.

A **perfect absorber** does not reflect any of the sunlight that strikes it. It looks black and has an albedo of 0 (Figure 9 – top). When an object absorbs most of the light that hits it, it looks dark and has a low albedo.

A **perfect reflector** reflects all the sunlight that strikes it. It looks white and has an albedo of 1 (Figure 9 – bottom). Objects that reflect most of the light that hit them appear bright and have a high albedo.

Check Your Thinking:

What parts of the Earth's systems can reflect solar radiation back into space?

Check Your Thinking:

Of the following materials on the surface of the Earth, which will ***reflect*** *the most solar radiation back into space?*

- *Vegetation (such as, grass and trees)*
- *Bare ground*
- *Water*
- *Ice*
- *Snow*

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

The Earth as a whole has a global average albedo of roughly 0.3 to 0.4.

The gases in the atmosphere, clouds (water vapor), and particles suspended in the atmosphere combine to reflect about 26% of the incoming solar radiation.

Table 2 summarizes the average albedo values for a number of common surfaces on the planet. Notice that water has a relatively low albedo (0.06). This means that it absorbs a very large percentage of the incoming solar radiation. This is important because roughly 71% of the surface of the Earth is covered with water.

Table 2. Albedo (Reflectivity) Values for Common Earth Surfaces. *(Dobos, 2006.)*

Surface	*Albedo*	*Surface*	*Albedo*
Blackbody	0.0	*Mean albedo of the Earth*	**0.36±0.06**
Forest	0.05-0.2	Granite	0.3-0.35
Water (small zenith angle)	0.03-0.1	Glacier ice	0.3-0.4
Water (large zenith angle)	0.1-1.0	Light colored soil surfaces	0.4-0.5
Grassland and cropland	0.1-0.25	Dry salt cover	0.5
Dark colored soil surface	0.1-0.2	Tops of clouds	0.6-0.9
Dry sandy soil	0.25-0.45	Fresh, deep snow	0.9
Dry clay soil	0.15-0.35	Absolute white surface	1.0
Sand	0.2-0.4		

Figure 10 summarizes the distribution of average albedo values around the world. *Can you see any relationship between the average albedos in Table 2 and this map?*

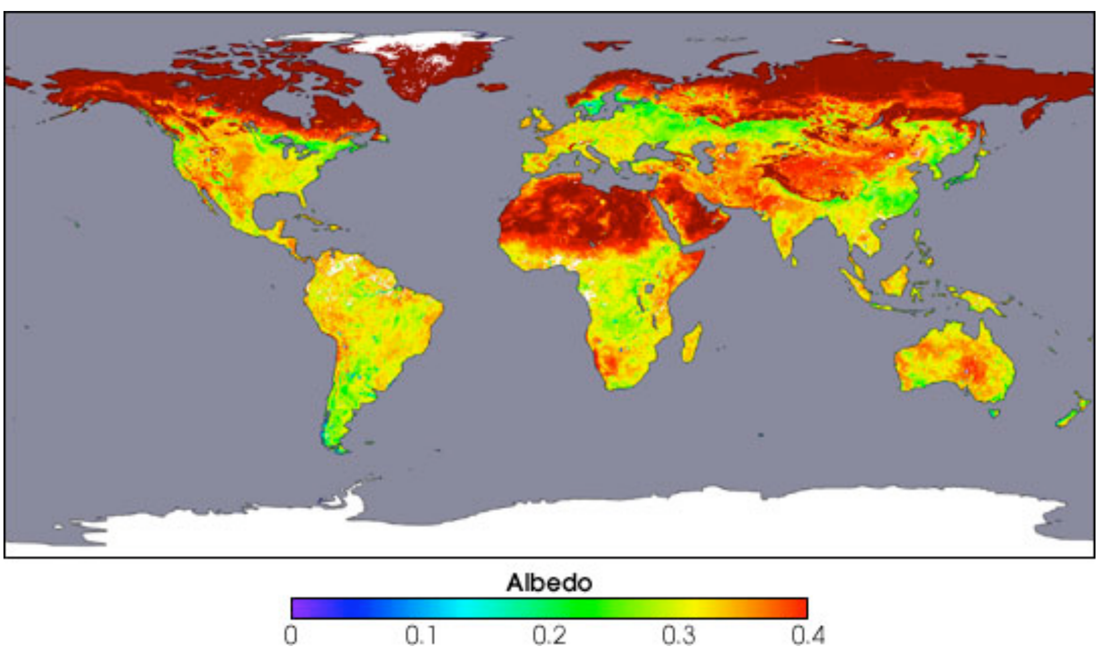


Figure 10: The annual global distribution of albedo as measured by NASA's Terra satellite. (NASA)

Activity 12:

Visit Earth's Albedo from Meteorology: Understanding the Atmosphere for a simulation that shows variations in albedo at different locations and in different months, Note that the darker colors represent areas with low albedo (low reflectivity, high absorption), light colors represent areas with high albedo (high reflectivity) In that simulation, can you answer the accompanying questions?

Activity 13:

Look at “My NASA Data” lesson Variables Affecting Earth’s Albedo. This lesson plan allows students to use real NASA data to understand what factors influence the Earth’s albedo.

Check out Extension Activity 7.

Resources:

To see some nice photos of various arctic surfaces and their albedos, go to Albedos of snow, ice and tundra.

Energy, Temperature and Heat

Check Your Thinking:

What is energy? What kinds of energy can you name?

Check Your Thinking:

What does temperature measure?

Check Your Thinking:

What are the three ways that heat can be transferred? Describe each one.

Check Your Thinking:

How is energy transferred throughout the Earth's atmosphere?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Energy is defined as the ability or capacity to do work on some form of matter (the amount of work one system is doing on another). There are several forms of energy:

- **Potential** energy is the energy that a body possesses as a consequence of its position in a gravitational field (e.g., water behind a dam).
- **Kinetic** energy is the energy that a body possesses as a consequence of its motion (e.g., wind blowing across a wind generator). It is dependent upon an object's mass and velocity (e.g., moving water versus moving air). The kinetic energy of a point mass m is given by:

  Kinetic Energy = 0.5 mv^2 m = mass

  v = the speed of the body.

- **Internal** energy is the total energy (potential and kinetic) stored in molecules. It is the energy associated with the random, disordered motion of molecules; it refers to the invisible microscopic energy on the atomic and molecular scale.
- **Heat** (or thermal) energy is kinetic energy due to motion of atoms and molecules. It is energy that is in the process of being transferred from one object to another because of their temperature difference.
- **Radiant** energy is the energy that propagates through space or through material media in the form of electromagnetic radiation.

Heat (thermal energy) moves from a high temperature region to a low temperature region. This is called heat transfer. **Heat transfer** refers to the movement of heat from one object to another. The **First Law of Thermodynamics** states that energy lost during one process must equal the energy gained during another, i.e., all energy is conserved.

Heat is transferred in three different ways (Figure 11):

Conduction is the most significant means of heat transfer in a solid. It is the spontaneous transfer of thermal energy through matter. An object transfers heat energy to another object when they are in direct contact.

Convection is usually the dominant form of heat transfer in liquids and gases. It is the internal movement of currents within fluids (i.e. liquids and gases). It cannot occur in solids because the atoms are not able to flow freely.

Radiation is the only form of heat transfer that can occur in the absence of any form of medium and as such is the only means of heat transfer through a vacuum. Thermal radiation is electromagnetic radiation emitted from the surface of an object, which is due to the object's temperature.

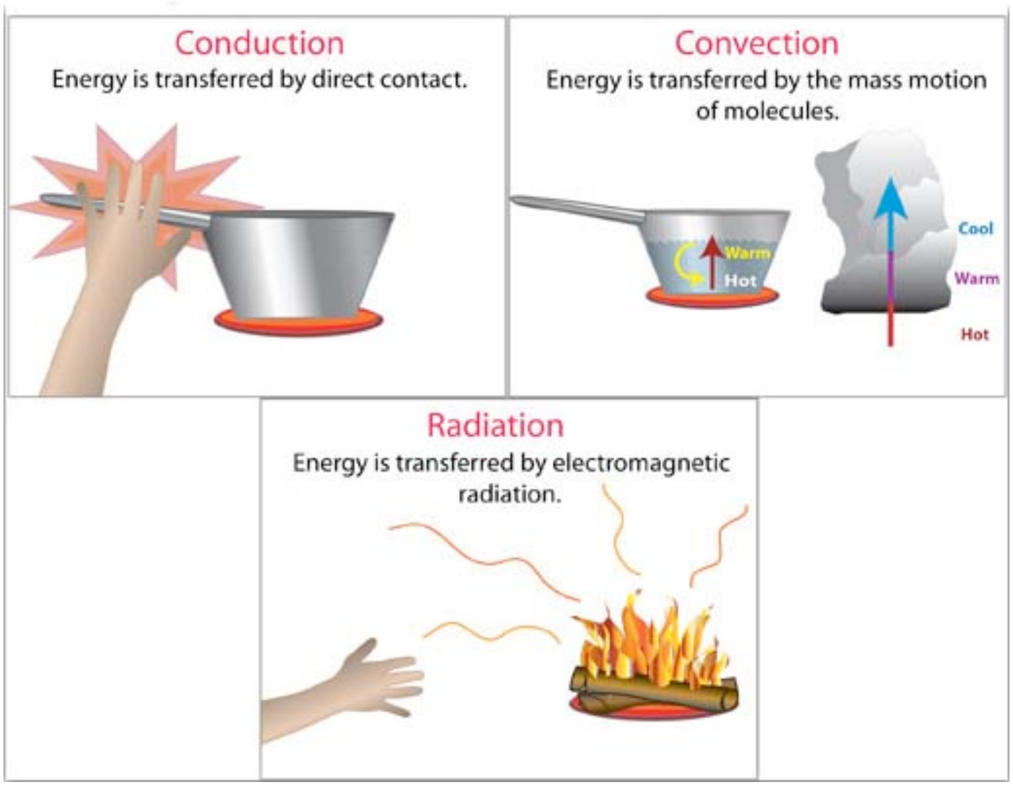


Figure 11: This diagram illustrates the three forms of energy transfer. (Earthstorm, U of Oklahoma)

For Your Information:

A Few Words About SI Units and Nomenclature

In science we use the International System (SI) units. Here is a summary of the things you need to know in order to understand heat, heat flow and snow properties (NIST).

SI Measurements

Measurement	*Name*	*Symbol*
Length	meter	m
Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K

Derived SI Units

Measurement	*Name*	*Symbol*	*Expression in SI*
Area	square meter	m^2	m^2
Volume	cubic meter	m^3	m^3
Speed/velocity	meters per second	m/s	$m\ s^{-1}$
Mass density	kilograms per cubic meter	kg/m^3	$kg\ m^{-3}$
Force	newton	N	$m\ kg\ s^{-2}$
Energy, work, quantity of heat	joule	J	$m^2\ kg\ s^{-2}$
Celsius temperature	degrees Celsius	°C	K
Heat flux density, irradiance	watt per square meter	W/m^2	$W\ m^{-2}$
Heat capacity	joule per kelvin	J/K $J\ K^{-1}$	$m^2\ kg\ s^{-2}\ K^{-1}$
Specific energy	joule per kilogram	J/kg $J\ kg^{-1}$	$m^2\ s^{-2}$
Specific heat capacity	joule per kilogram kelvin	J/(kg K) $J\ kg^{-1}\ K^{-1}$	$m^2\ s^{-2}\ K^{-1}$
Thermal conductivity	watt per meter kelvin	W/(m K) $W\ m^{-1}\ K^{-1}$	$kg\ s^{-3}\ K^{-1}$

A space or half-high dot is used to signify the multiplication of units. A solidus (*i.e.,* slash), horizontal line, or negative exponent is used to signify the division of units.

Newton: the unit of force required to accelerate a mass of 1 kilogram 1 meter per second

Joule: energy expended in applying a force of one newton through a distance of one meter.

Watt: a unit of power equal to 1 joule per second.

Note that joule per kilogram kelvin (or watt per meter kelvin) means a change to produce a change of 1 degree Kelvin.

Specific Heat and Heat Storage

> ### ***Check Your Thinking:***
>
> *What happens to the temperature of a lake over the course of the spring and summer? Why does this happen?*

> ### ***Check Your Thinking:***
>
> *What happens to the temperature of the same lake in the fall and winter? Why does this happen?*

> ### ***Check Your Thinking:***
>
> *Why does ice float on water?*

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Recall that:

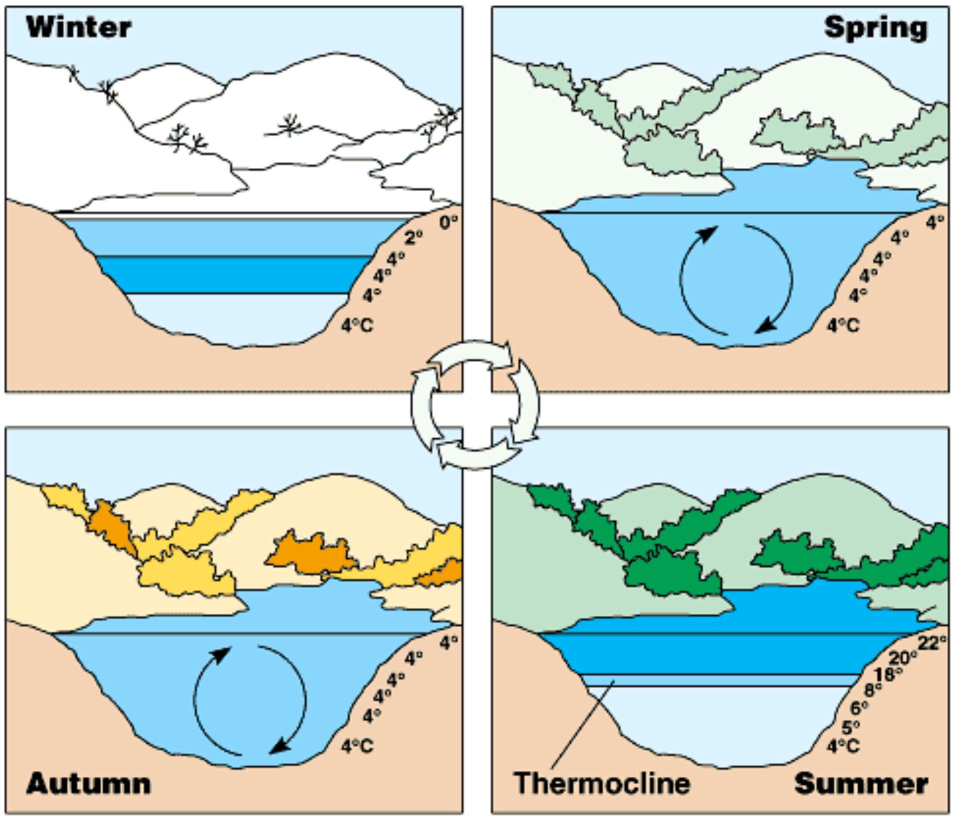
- Heat (or thermal) energy is kinetic energy due to motion of atoms and molecules. It is energy that is in the process of being transferred from one object to another because of their temperature difference.
- The amount of solar energy reaching a specific location of the surface of the Earth changes throughout the year (seasons). Note that, at the equator, the amount of solar energy is constant throughout the year.

Heat moves into and out of bodies of water on a daily and seasonal basis. In the summer, the temperature of a lake will increase because energy is being transferred from the overlying atmosphere to the water due to the temperature difference (although this is not a constant process – night time air temperatures can dip below the water temperature and temporarily reverse the energy transfer). The opposite occurs in the fall and winter when the air temperature is lower than the water temperature.

Because water reaches its maximum density at T = 4°C, water with a temperature (T < 4°C < T) is less dense than (T = 4°C); this allows for overturning in the water column when a cold body of water is warmed at the surface and for stratification of the water column after overturning is complete. This process is summarized in Figure 12:

- In late spring, once the ice is gone, the upper layer of water warms to 4°C, the temperature of maximum density for water. This layer "sinks" to the bottom of the lake. The "new" upper layer warms to 4°C and sinks. This is repeated until the entire water column is at 4°C (isothermal).
- In the summer, the upper layer of water continues to warm (>4°C) and it "floats" on top of the denser (4°C) water. The water column becomes stratified, with warmer, low density water at the top and cool (4°C), high density water on the bottom. Energy is transferred from the upper warm layer to the cool lower layer.

- In the fall, the upper layer of water cools to 4°C and sinks to the bottom of the lake. This process continues until the entire water column is at 4°C. The upper layer continues to cool and ice forms once the surface of the water reaches 0°C, the freezing point of fresh water.
- In winter, the ice grows thicker as long as the air temperature is less than or equal to 0°C and heat is conducted upwards through the snow and ice into the atmosphere. As the ice grows, the upper layer of the water cools and the entire water column becomes stratified, with the cool, low density layer sitting on the lower layer of water that is at the temperature of maximum density (4°C).
- In early spring, once the air temperature rises above 0°C, first the snow on the ice warms to 0°C and melts away, then the ice absorbs solar radiation, warms to 0°C and melts. The ice cover shrinks as it melts around the edges and also at the top and bottom.



[Figure 12](): The water-air energy cycle and temperature-induced water stratification. (Kent Simmons, University of Winnipeg)

A *thermocline*, a depth at which the temperature of the water changes significantly, may develop in deeper lakes (as well as oceans) as a consequence of this water cooling and warming.

There is an obvious lag between the temperatures of a lake and the dominant air temperatures. This is because the specific heat of air and water are very different. *Specific heat* is the amount of heat per unit mass required to raise the temperature by 1°C. It can be expressed by the equation:

$$Q = c\, m\, \Delta T$$

Q = heat added, m = mass,
c = specific heat, ΔT = change in temperature

The specific heat of water is *1 calorie/gram °C = 4.186 joule/gram °C* (or approximately *4190 joules/kilogram °C*) which is higher than any other common substance including air (Table 3).

This means it takes a higher energy input to warm up a body of water than many substances and a higher energy loss to cool it (Figure13). As a result, water plays a very important role in temperature regulation at the Earth's surface.

Table 3. Specific heat capacity of some selected materials. (Wikipedia)

Material	*Specific Heat cρ (J/kg °C)*	*Material*	*Specific Heat cρ (J/kg °C)*
Air (-50°C)	**1534**	Glass (pyrex)	753
Air (0°C)	**1293**	Granite	790
Air (20°C)	**1205**	Gypsum	1090
Asphalt	920	Marble	880
Brick	840	Sand	835
Concrete	880	Soil	800
Glass (silica)	840	Wood	1700 (1200 – 2300)
		Water	***4190***

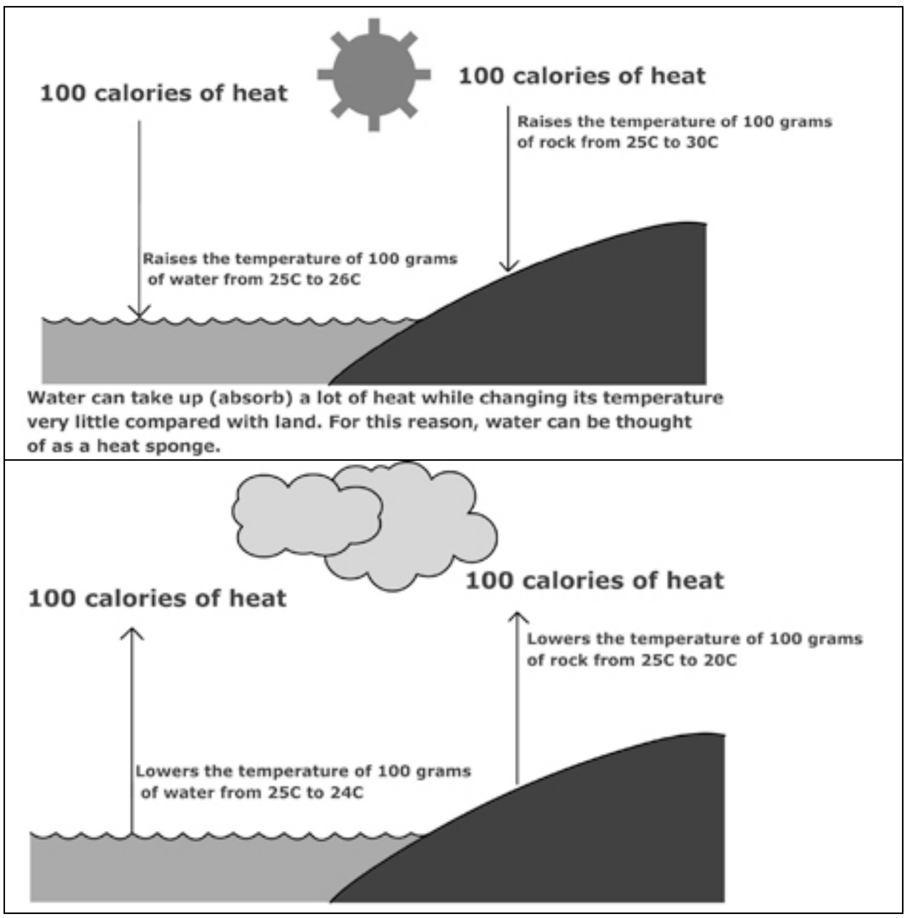


Figure 13: The amount of energy required to increase the temperature of water 1°C is about 5 times higher than the amount of energy required to increase rock by the same amount. This means that water heats up and looses heat at a much slower rate than rock (land), making water a heat sink in the summer (and during the day) and a heat source during the winter (and at night). (Texas A&M University)

The relationship does not apply if a *phase change* is encountered, because the heat added or removed during a phase change does not change the temperature. (See Latent Heat of Freezing and Fusion.)

Thermal energy can be stored in a material as sensible heat (the heat that is related to a change in temperature) by raising its temperature. The heat storage can be calculated as:

$$\mathbf{q = V\,\rho\,c_p\,\Delta T = m\,c_p\,\Delta T}$$

q = sensible heat stored in the material (J)
V = volume of substance (m^3)
ρ = density of substance (kg/m^3)
m = mass of substance (kg)
c_p = specific heat capacity of the substance (J/kg °C)
ΔT = temperature change (°C)

Table 4 summarizes the data necessary to calculate the sensible heat stored in some common materials.

Table 4. Specific Heat and Heat Storage of Common Materials. (Engineering Toolbox)

Material	*Temperature Range (°C)*	*Density ρ (kg/m^3)*	*Specific Heat c_p (J/kg °C)*	*Energy Density (kJ/m^3 °C)*
Aluminum	Max. 660*	2700	920	2484
Cast iron	Max. 1150*	7200	540	3889
Granite		2400	790	1896
Water	0-100	1000	4190	4190

* *melting point*

Heat stored in a 2 m^3 cube of granite which is heated from 20°C to 40°C (ΔT = 20°C) is calculated as follows:

$$\mathbf{q = V\,\rho\,c_p\,\Delta T = m\,c_p\,\Delta T}$$

$$q = (2\ m^3)\ (2400\ kg/m^3)\ (790\ J/kg°C)\ (20°C) = 75840\ kJ = 21\ kWh$$

(recall 1 kJ = 0.000278 kilowatt hours)

❄ *Activity 14*:

Download the Heat Flow in Snow and Ice – Change in temperature and mass activity (pdf) for a simulation of what occurs on a lake that is covered with ice and snow. Perform the activity with your students to help them understand that snow and ice slow down the loss of both heat and mass from bodies of water in winter.

States of Matter

Check Your Thinking:

What are the three main states of matter on Earth?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Matter exists in three states on planet Earth: solid, liquid and gas. (Plasmas are only found in the coronae and cores of stars.) The state of matter is determined by the strength of the bonds between the atoms that makes up matter. The change from one state of matter to another is called a phase transition or phase change. For example, ice (solid water) converts (melts) into liquid water as energy is added. Continue adding energy and the water boils to steam (gaseous water).

As can seen seen in Figure 14, *frozen water* molecules (solid - ice) arrange themselves in a particular highly organized rigid geometric pattern that causes the mass of water to expand and to decrease in density. This pattern is necessary to ensure the strongest degree of hydrogen bonding in a uniform, extended crystal lattice.

In the *liquid phase*, water molecules arrange themselves into small groups in which hydrogen-bonds are continually forming, breaking apart, and re-forming. The more crowded and jumbled arrangement in liquid water can be sustained only by the greater amount of thermal energy available above the freezing point (0°C). The fact that these arrangements are small allows liquid water to move and flow.

Water molecules in the form of a gas are highly charged with energy. This high-energy state causes the molecules to be always moving reducing the likelihood of bonds between individual molecules from forming.

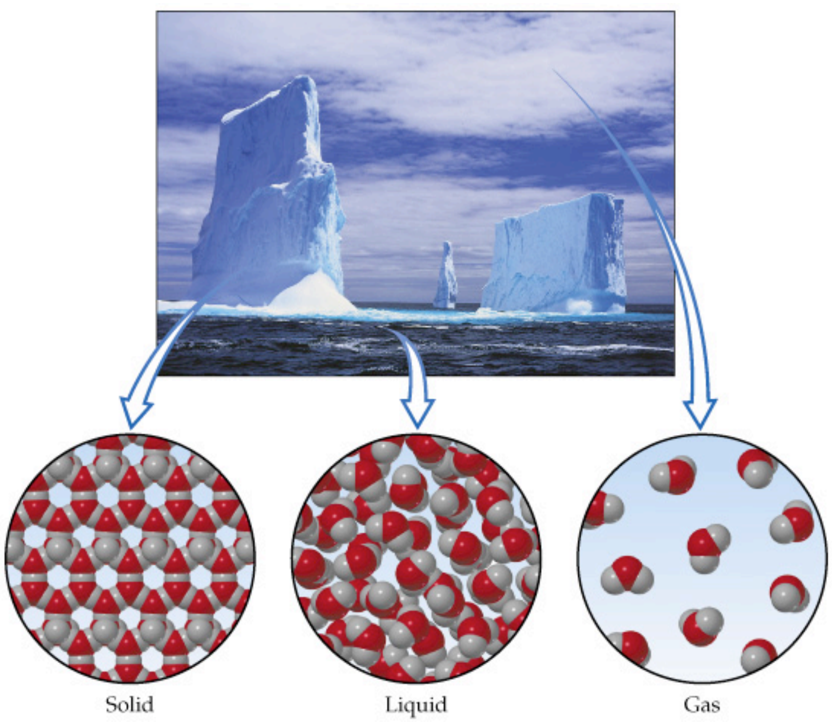


Figure 14: A representation of the three states of matter of water (solid/ice, liquid water, and gas/water vapor). (Prenhall.com)

Phase Changes

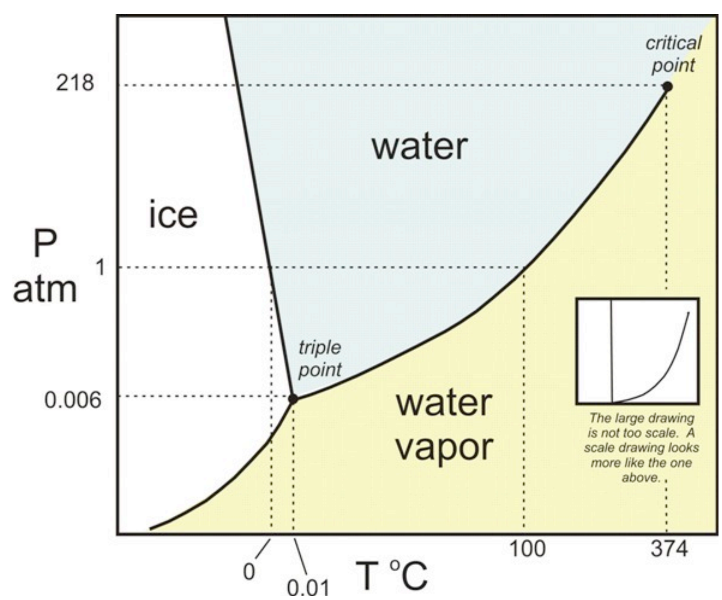
> ***Check Your Thinking:***
>
> *What causes changes in the state of matter on Earth?*

> ***Check Your Thinking:***
>
> *Name the main state-of-matter transitions. Which require energy input and which release energy?*

You can download all of the [Check Your Thinking]() questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

A phase change is a change from one state to another without a change in chemical composition. These phase changes are induced by changes in temperature and/or pressure (Figure 15). These transitions are:

- Solid-to-liquid transition - *melting*
- Liquid-to-solid transition - *freezing*
- Liquid-to-gas transition - *evaporation*
- Gas-to-liquid transition - *condensation*
- Solid-to-gas transition - *sublimation*
- Gas-to-solid transition - *deposition*



[Figure 15](): This graph illustrates the phase changes of water, as they occur based on temperature (T°C) and/or pressure (P_{atm}). (The Science Education Resource Center at Carleton College)

Phase Changes and Latent Heat (for H_2O)

Latent heat is the energy required to change a substance from one state to another at constant temperature. When a substance changes from one state to another, latent heat is added or released in the process. (Figure 16):

- LIQUID to VAPOR: Latent heat is absorbed/taken from the environment (about 540 cal per gram). (Evaporation; boiling; vaporization)
- VAPOR to LIQUID: Latent heat is released to the environment. (Condensation)
- LIQUID to ICE: Latent heat is released to the environment (about 80 cal per gram). (Freezing)
- ICE to LIQUID: Latent heat is absorbed/taken from the environment. This is also known as the latent heat of fusion. (Melting)

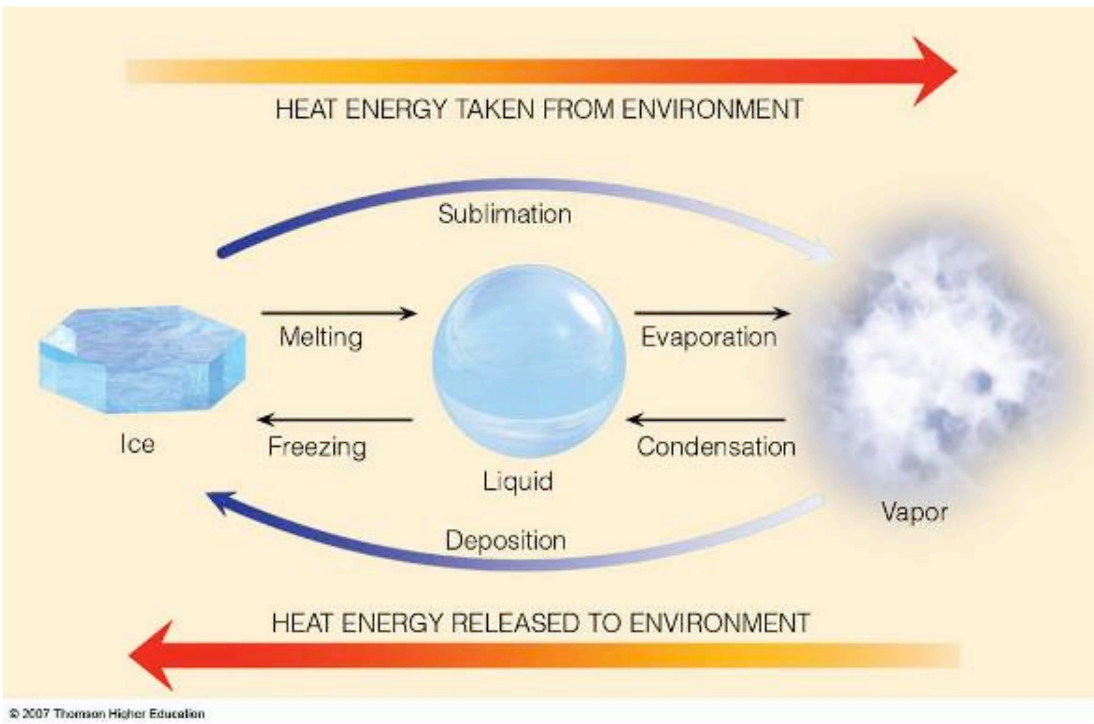


Figure 16: This diagram shows how heat is transferred as water changes states. (Thomson Higher Education, 2007)

The latent heat of freezing is the energy released from the water and added to the environment, in order for water to freeze into ice (Figure 17 – left). When heat is subtracted from liquid water, the individual water molecules will slow down. They eventually slow to the point at which the hydrogen bonds do not allow the liquid to rotate anymore. Ice now develops.

The latent heat of fusion (melting) is the energy that is taken from the environment and added to the ice to melt it into water (Figure 17 – right). This energy is used to break the ice lattice bonds and allows the ice to go from a lower energetic state to a higher energetic state (water).

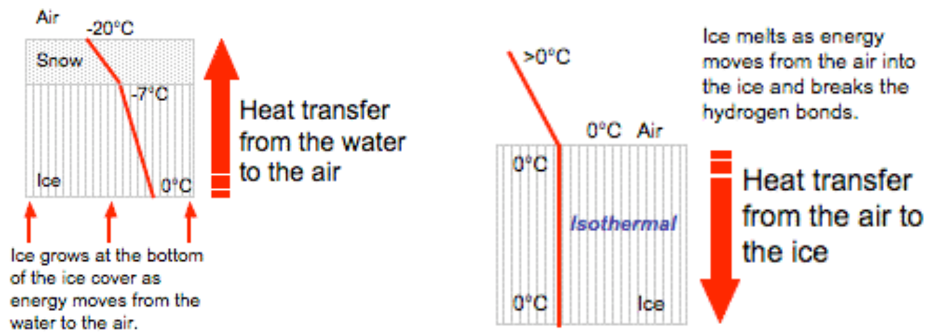


Figure 17: *These diagrams illustrate the latent heats of freezing (left) and fusion (right). (Kim Morris)*

When water undergoes a phase change (a change from solid, liquid or gas to another phase) the temperature of the matter stays the same until the phase change is complete (Figure 18). Energy is being used to either weaken the hydrogen bonds between water molecules or energy is being taken away from the water, which tightens the hydrogen bonds. When ice melts, energy is being taken from the environment and absorbed into the ice to loosen the hydrogen bonds. The temperature of the melting ice stays the same (0°C) until all the ice is melted. All hydrogen bonds must be broken from the solid state before energy can be used to increase the water's temperature.

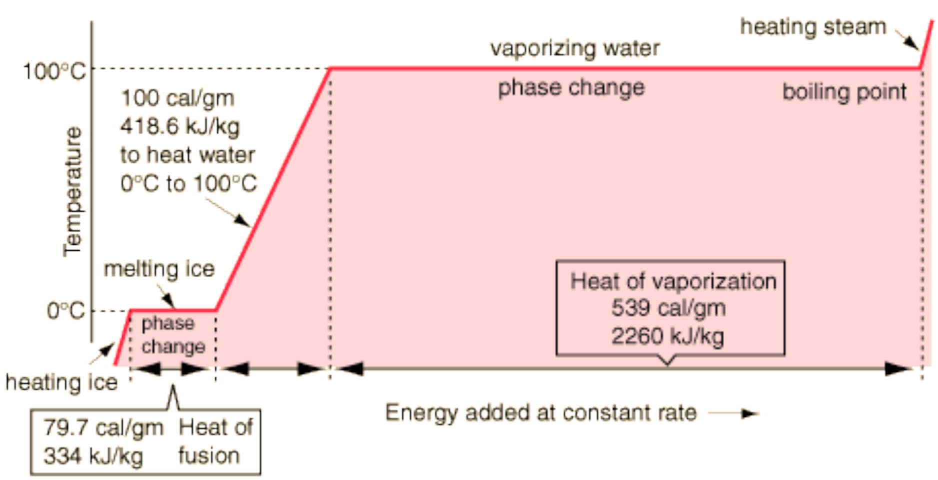


Figure 18: This diagram shows that, during a phase change, all of the added energy is used to break molecule bonds. This means that until all the bonds are broken, the matter (ice, water, gas) does not heat up. That is what creates the flat portions of the graph. (R. Nave)

❄ *Activity 15*:

Download Measuring the Temperature of Water, Snow and Ice (pdf) for a variety of activities for students of various ages for measuring the temperature of snow and water.

The Water Cycle: Phase Change and Energy Transfer Through the Hydrosphere

Check Your Thinking:

What are the states of matter found in the water cycle? Give examples of each.

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

The water cycle also known as the hydrologic cycle or H_2O cycle, describes the continuous movement of water on, above and below the surface of the Earth. As the water changes phases, energy is transferred (refer back to the previous sections). The water cycle is summarized in Figure 19.

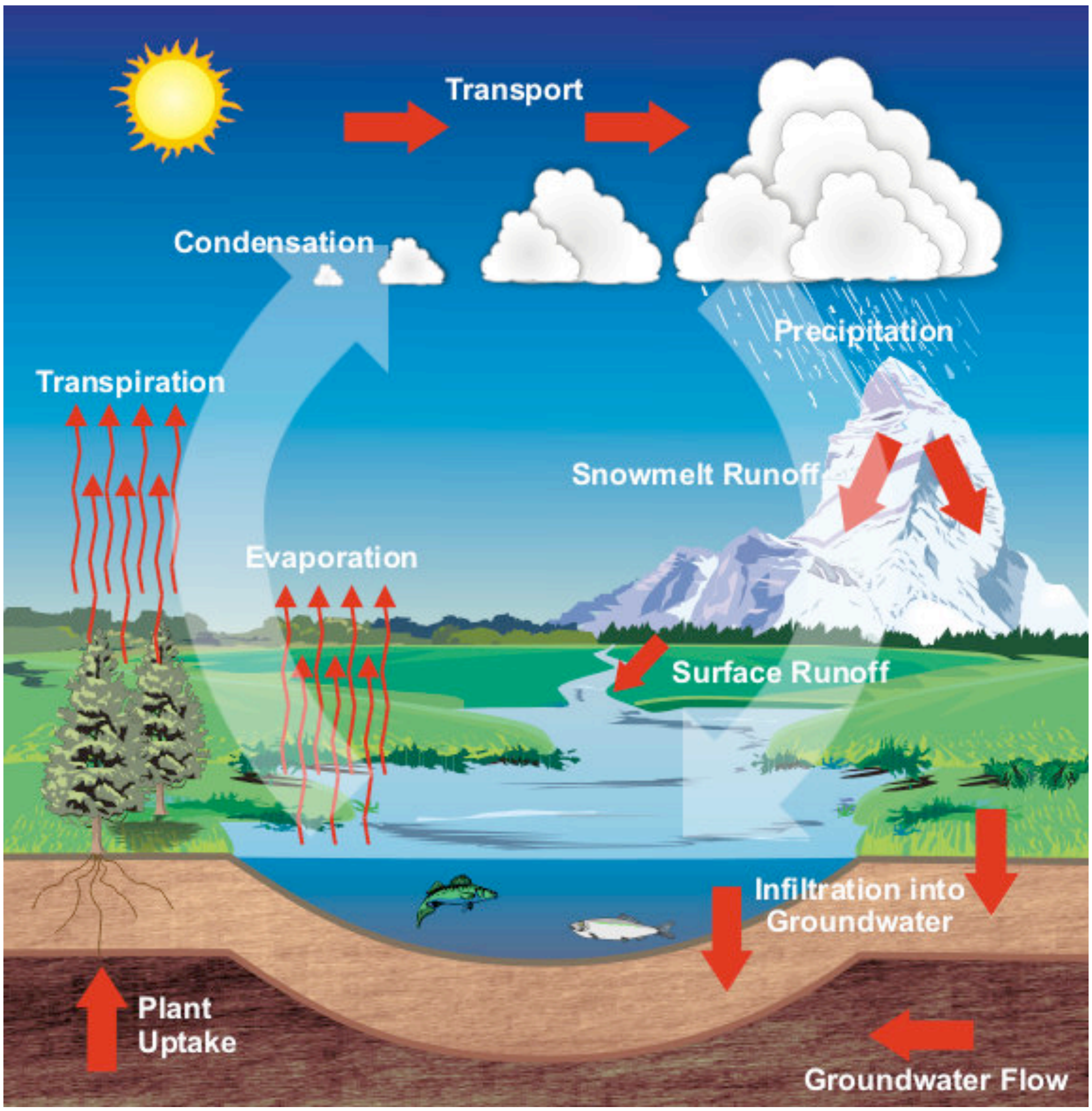


Figure 19: A diagram of the water cycle. (K.R. Roussy, University of Illinois at Urbana-Champaign)

***Activity 16*:**

Visit Meteorology » Earth's Atmosphere, Energy Budget and Energy Cycle from the Satellite Applications for Geoscience Education website for an interactive exercise in identifying energy transfer for some phase changes of water in the hydrologic cycle. Click on "3. Earth's Energy Cycle" and follow the instructions to complete the exercise.

***Activity 17*:**

Go to the National Weather Service for several learning lessons about specific elements of the hydrological cycle.

Thermal Conductivity and Insulation

Check Your Thinking:

What do we mean by thermal conductivity?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Heat conduction is the flow of internal energy from a region of higher temperature to one of lower temperature (temperature gradient) by the random interaction of the adjacent particles (atoms, molecules, ions, electrons, etc.) in the intervening space.

Factors affecting the heat transfer by conduction are:
- temperature difference between the two sites,
- length or distance between the two sites,
- cross-sectional area, and
- type of material.

As a consequence, thermal conductivity is the rate of thermal conduction through material per unit area (cross section), per unit thickness (length), per unit temperature difference. The SI units are W m K (watt per meter Kelvin). Please note that the heat conduction (thermal conductivity) refers to the **rate** (amount of energy per second per meter) at which heat is transferred, not just the **amount** of heat transferred.

Some thermal conductivity values are listed in Table 5. It includes values for the air and water, at various pressures and temperatures, and common materials used for clothing, construction and cooking.

Table 5. The Thermal Conductivity Values (k) for Selected Materials (~300°K except where noted). (The Physics Hypertextbook)

Material	*k ($W\,m^{-1}\,K^{-1}$)*	*Material*	*k ($W\,m^{-1}\,K^{-1}$)*
Vacuum	0.0	Asphalt	0.15-0.52
		Brick	0.18
Air, sea level	0.025	Concrete	0.05-0.15
Air, 10,000m	0.02	Fiberglass	0.035
		Glass	1.1-1.2
Water, vapor (273°K)	0.16	Granite	2.2
Water, vapor (373°K)	0.025	Marble	1.75
Water, liquid (273°K)	0.561	Paper	0.04-0.09
Water, liquid (373°K)	0.679	Particle board (gypsum)	0.15
Water, ice (223°K)	2.8	Plywood	0.11
Water, ice (273°K)	2.2	Polyurethane foam	0.02-0.03
Snow (<273°K)	0.16	Sand	0.27
		Straw	0.05
Cotton	0.04	Wood	0.09-0.14
Feathers	0.034		
Felt	0.06	Aluminum	237.0
Polyester	0.05	Copper	401.0
Wool	0.03-0.04	Steel, stainless (273°K)	14.0
		Teflon	0.25

(recall that 0°C = 273.15°K)

Insulation is the ability of a material to *resist* heat flow. In effect, it is the opposite of thermal conductivity. For construction materials, insulation is quantified as the R-value: the higher the value the more effective the material is as an insulator. The R-value can be calculated by:

$$\mathbf{R = \Delta T/Q_A}$$

ΔT is the change in temperature
Q_A is the heat flow per unit area

In SI units, an R value of one is equivalent to *0.17611 square meter kelvins per watt* ($m^2\ K\ W^{-1}$).

Factors That Affect A Snow Cover's Thermal Conductivity

> ***Check Your Thinking:***
>
> *Is snow an effective insulator?*

> ***Check Your Thinking:***
>
> *What type of snow do you think would be the best insulator:*
> - *Wet, heavy snow;*
> - *Dry, well-packed snow; or*
> - *New, fluffy snow?*

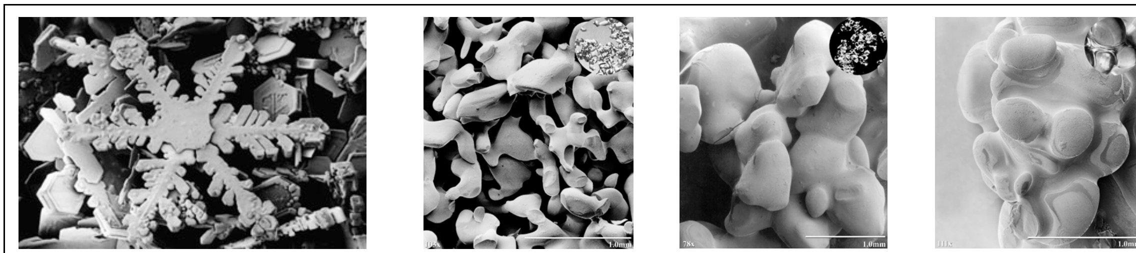
You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Recall that:

- A dry snow cover is comprised of ice (snowflakes), air and water vapor; a wet snow cover also includes liquid water.
- These components have different thermal conductivities:
  - Air at sea level is 0.025 $W\,m^{-1}\,K^{-1}$
  - Water vapor at 273°K (-0.15°C) is 0.16 $W\,m^{-1}\,K^{-1}$
  - Liquid water at 273°K (-0.15°C) is 0.561 $W\,m^{-1}\,K^{-1}$
  - Ice at 273°K (-0.15°C) is 2.2 $W\,m^{-1}\,K^{-1}$
- The higher the thermal conductivity of a material, the lower insulation value, i.e., it transfers heat at a higher rate.

According to the data in Table 5, the thermal conductivity of snow (<273°K) is 0.16 $W\,m^{-1}\,K^{-1}$. However, depending on the temperature, condition and age of the snow cover, the relative percent contribution of each component will change (refer to *Snow Metamorphism* and Figure 20):

- New, fluffy snow contains lots of air and no water. This is because the snow crystals still have their "arms" which create spaces between them.
- A dry well-packed snow cover has lots of ice and little air. The snow crystals have become rounded and are packed more closely together leaving little space for air.
- A wet heavy snow cover will contain water and water vapor.



New snowflakes – note the large spaces surrounding each crystal. *Closely packed rounded snow grains.* *Melting snowpack with little free water apparent.* *Surface layer of a melting snowpack with free water.*

Figure 20. Low Temperature Scanning Electron Microscope images of snow grains in various conditions and ages. Note the amount of space around each kind of snow grain. (USDA)

One way to integrate these elements and estimate the thermal conductivity of the snow cover is to determine the snow's **density**.

Determining the Density of a Snow Cover

> ### ***Check Your Thinking:***
>
> *What do you need to measure in order to determine the density of snow (or anything else)?*

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Density is defined as the mass per volume.

$$\textbf{Density } (\rho) = \frac{\textbf{mass}}{\textbf{volume}}$$

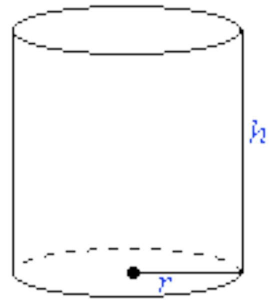
ρ can be expressed in g cm^3 or kg m^3.

In the field, you would have to measure the snow depth (cm) and obtain a snow sample of known volume. The materials you need include: a metal tube of known diameter; a spatula; a meter stick (or smaller ruler for a thin snow cover); a re-sealable sampling bag (i.e., a Ziploc bag); and a permanent marker. The images in Figure 21 show teachers and students making measurements and taking the samples needed to calculate the snow's density. The snow sample is weighed in the classroom to determine its mass (g).

Figure 21: Students and teachers collecting snow samples along a sampling transect. (ALISON)

Remember that:

Volume of snow in a cylinder = $\pi r^2 h$



π is 3.14159265

r is the radius of the cylinder (recall that the radius is 1/2 of the diameter of a circle)

h is the depth of the snow

Some conversions that you might need are:

- 1 inch = 2.54 centimeters
- 1 ounce = 28.3495231 grams

For Your Information: Students' Understanding of Density

Studying the density of snow is something that teachers can do with upper elementary age students. Students have a lot of trouble understanding density because they confuse density with mass (sometimes incorrectly referred to as weight). For example, if you ask a child what causes something to sink, they will usually say an object sinks because it is heavy. In order to understand density, students need a lot of practice with measuring density and examining the properties of objects in relationship to density.

Activity 18:

Download Buoyancy and Density: Middle School Unit Plan (pdf) for a series of activities to help students understand density and buoyancy. The basic sinking and floating activities can be carried out with very young children. Typically, the mathematical calculations for density can be introduced between fourth and eighth grade. Students need to apply the concept of density over and over again in order to understand the difference between weight and density. Just calculating the mathematical formula for density does not help students understand density. Having them measure the densities of real objects will help them understand the meaning behind the mathematics.

Activity 19:

Download the two activities (Snow, Volume, Temperature and Density (pdf) and The Science of Snow (pdf)) to engage students in collecting snow temperature data and data to calculate the density of snow. Download the Snow Field Data Sheet (pdf) and use it to record your field data. The data sheet can be used to gather data on snow along a 100 meter transect, with sampling sites at every 5 or every 10 meters. Or you can gather data at several different locations (record descriptions of each location).

Calculating the Thermal Conductivity of a Snow Cover

As we have seen, snow density is an important characteristic in determining the effectiveness of snow as an insulator. Dense snow, snow that is compacted or wet, loses much of its insulation value because it loses a lot of its trapped air. Scientists study the density of snow to help them understand how rapidly heat can move from the ice surface or the ground into the atmosphere.

Figure 22 shows the relationship between snow density and snow thermal conductivity. As the density of snow increases, the rate at which heat is transferred through the snow (snow thermal conductivity) also increases. In other words, dense snow is a poor insulator: heat is transferred rapidly. Fluffy snow is a good insulator: heat is transferred slowly.

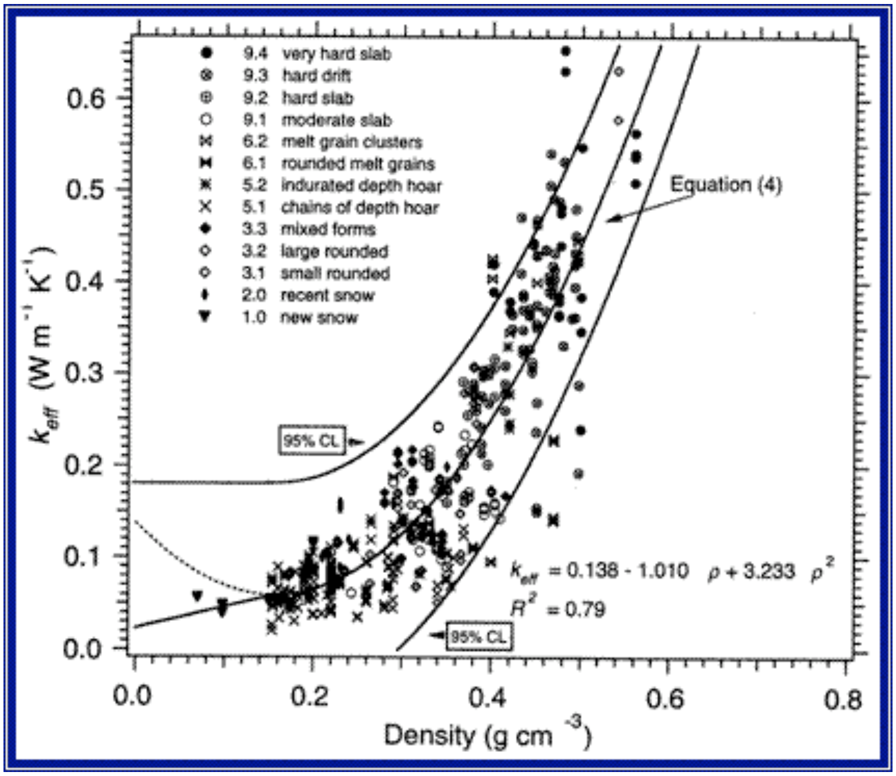


Figure 22: The relationship between snow density and snow thermal conductivity. As the density of snow increases, the rate at which heat can move through the snow (snow thermal conductivity) also increases. (CRREL)

As seen from Figure 22, the snow thermal conductivity (k_{eff}) can be calculated by one of these two equations:

$\mathbf{0.023 + 0.234\,\rho = k_{eff}}$	Snow density is $\rho < 0.156$ g cm^3
$\mathbf{0.138 - 1.01\rho + 3.2332\,\rho^2 = k_{eff}}$	Snow density is $0.156 < \rho < 0.6$ g cm^3

k_{eff} is expressed in W m^{-1} K^{-1}.

Determining the Temperature Gradient of a Snow Cover

> ***Check Your Thinking:***
>
> *Which way does heat flow through a snow cover?*

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Recall that **heat** (or thermal) energy is kinetic energy due to motion of atoms and molecules. It is energy that is in the process of being transferred from one object to another because of their temperature difference.

In order to determine if heat is entering or leaving the snow cover, we have to measure the temperature of the top of the snow and the bottom of the snow (or the top of the surface the snow is resting on).

> ***Check Your Thinking:***
>
> *Under what conditions would the temperature at the bottom of the snow be higher than at the snow surface?*

> ***Check Your Thinking:***
>
> *Under what conditions would the temperature at the bottom of the snow be lower than the air temperature?*

Remember that snow is an insulator. In relatively deep snow, the longer the surface remains covered with snow, and the colder the air temperatures are, the larger the differences between the surface of the snow and the base of the snow. In this case, heat will transfer from the bottom of the snow to the top of the snow and out to the atmosphere. However, if a warm air mass suddenly comes into the area, the air temperature could be warmer than the bottom of the snow cover and heat will be transferred into the snow cover from the atmosphere.

Once the snow surface and bottom temperatures, and the distance between them (snow depth), have been measured, the temperature gradient in the snow can be calculated. A *temperature gradient* is a physical quantity that describes in which direction, and at what rate, the temperature changes at a particular location. The temperature gradient is expressed in units of degrees (on a particular temperature scale) per unit length. The SI unit is Kelvin per meter (K/m or K m^{-1}). In a snow cover, this is expressed as:

Snow temperature gradient (T_{grad}) = ($T_s - T_b$)/Z_s

T_s = Snow surface temp. (K)
T_b = Snow bottom temp. (K)
Z_s = Snow depth in meters

Determining the Conductive Heat Flux through a Snow Cover

Conductive heat flux (also called heat flow) dominates the energy balance of the ice and snow and is the major source of heat transfer from the water through floating ice and snow to the atmosphere in winter. Consequently, in addition to determining the rate of growth and ice thickness, it plays a role in weather and climate.

The following facts help us understand heat flow between the atmosphere and bodies of water:

- Water stores a tremendous amount of heat.
- Latent heat of freezing is released when ice forms.
- As ice forms, the latent heat is conducted away from the water-ice interface to the atmosphere. In other words, heat moves from the water, through the ice, through the snow, into the air.
- Heat conduction and ice growth are possible because of negative temperature gradients in the snow and ice.
- Snow density is one of the factors that determine how quickly heat can be transferred through the snow cover.
- The rate at which the latent heat is conducted from the water to the atmosphere (heat flux), and thus the rate of ice growth and the thickness of the ice on bodies of water, is a function of: (a) snow depth, temperature and density; (b) ice thickness, temperature and density.
- To determined the conductive heat flow through the combined thickness of ice and snow we only need to measure the depth, density and temperature of the snow (top and bottom).

Figure 23 summarizes the measured and calculated variables that are required to determine the heat flow (flux) through a particular snow cover at a given point.

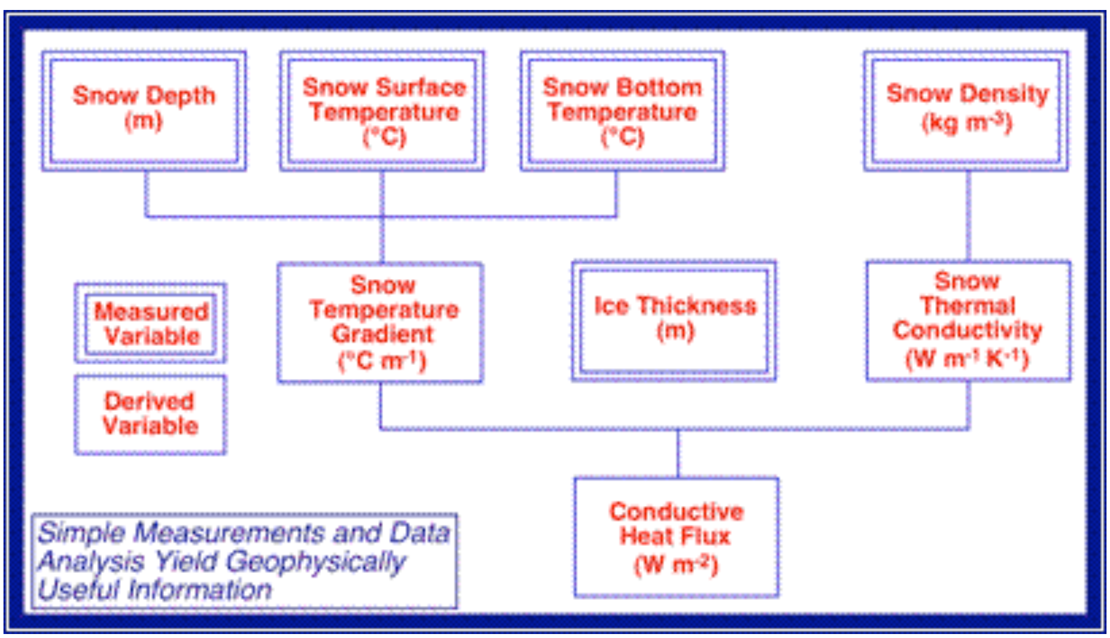


Figure 23: Snow variables necessary to determine the conductive heat flux through the snow cover. The double-lined boxes are measurements and the single-lined boxes are variables calculated from the measured values. (ALISON)

Students in grades 3-12 can collect the data on snow and temperature needed for these calculations. Middle school and high school students can carry out the calculations needed to determine the conductive heat flow.

The conductive heat flux through the snow cover can be calculated by:

$$\textbf{Conductive heat flux } (F_a) = (T_{grad}) \times (k_{eff})$$

F_a is expressed in W m^{-2}.

While many scientists focus their research on heat flux using bodies of water, heat is also stored in the ground. It is interesting to compare data collected on snow-covered ground with data from the surface of an ice and snow-covered lake or pond. You can also compare data from different types of ground surfaces (sidewalks, grass, forested area, bare ground under a building, areas with compacted snow, etc.). Snow density and ground temperatures tend to vary significantly between different surfaces. The snow must have remained on the ground for a period of time, and the air temperature must remain fairly cold for a period of time, for the data to be meaningful.

❄ ***Activity 20*:**

Download Conductive Heat Flow (ppt) It contains instructions for calculating heat flux. It also includes several "Thought Experiments", designed to give you practice in thinking about the relationships between snow depth, snow density, and temperatures. See if you can answer the thought experiments. Try calculating heat flux using the examples in the Powerpoint file.

❄ ***Activity 21*:**

Download one of the two calculators (Excel file): one for snow data taken on frozen lakes, the other for snow data taken on the ground to complete the exercises in Conductive Heat Flow (ppt) and/or in

- *Snow Calculator for Ice (xls)*
- *Snow Calculator for the Ground (xls)*

Be sure to use the "Save As" command to save the calculator as a separate Excel spreadsheet before you start to use it, to reduce the risk of deleting the calculation commands embedded in the spreadsheet. To view the calculation commands, just put the cursor on any of the fields.

❄ ***Activity 22*:**

Teach students to create their own calculator for automating any type of calculations they need. Download Creating an Excel Calculator (pdf) for instructions.

❄ ***Activity 23*:**

Download the Arctic Climate Modeling Program's Matter and Energy activities "Introduction to Energy Transfer", "The Science of Snow", "Lake Ice and Energy Transfer" and "Lake Ice and Conductive Heat Flow" and use them as a review for the previous sections relating to the snow variables necessary for calculating the heat flux through a snow cover. These activities were developed in collaboration with ALISON scientists.

Freeze-up and Break-up on Rivers, Streams, Lakes and Ponds

Everyone who has lived in the northern U.S. has observed the phenomena known as freeze-up and break-up on local rivers, streams, lakes and ponds. While the overall pattern of the freeze-up and break-up of a water body may be similar from year to year, the timing and precise evolution of events differs on an annual basis.

The freeze-up date, break-up date and ice cover duration define the seasonality of an ice cover. Freeze-up (FrzUp) defines the period between initial ice formation and the establishment of a complete ice cover. The FrzUp date is the day that the lake or river is completely ice covered (100%). Break-up (BrkUp) defines the period between the onset of snowmelt and the complete disappearance of the ice. The BrkUp date is the day when the lake or river is completely ice-free (0%). Taken together, the FrzUp date and BrkUp date denote the endpoints of the ice cover duration. This annual scenario is described by a ***single freeze-up/break-up cycle***.

In many places around the world, winter air temperatures oscillate between below freezing (<0°C) and above freezing (>0°C). As a consequence, river ice and lake ice can alternate between active growth and melting throughout the entire winter. This annual scenario is described by ***multiple freeze-up/break-up cycles.***

What causes a river or lake to freeze-up in the fall? What causes a river or lake to melt out (break-up) in the spring? Have the dates of freeze-up and break-up changed in your area over the past few decades? You could have your students ask a long-time resident of the area whether they have noticed a change in the dates for freeze-up and break-up.

❄ ***Activity 24***:

Observe and document the freeze-up and break-up of a local body of water. Download The Ice Seasonality Investigation (pdf), a protocol developed for the GLOBE Project (including data sheets) that enables students to study freeze-up and break-up locally. You can also download the River Ice Glossary and Lake Ice Glossary (pdf). The GLOBE Ice Seasonality Protocol was developed by Kim Morris and Martin Jeffries.

❄ ***For Your Information: The GLOBE Program***

Global Learning and Observations to Benefit the Environment (GLOBE) Program is a worldwide hands-on, primary and secondary school-based science and education program. GLOBE's vision promotes and supports students, teachers and scientists to collaborate on inquiry-based investigations of the environment and the Earth system working in close partnership with NASA and NSF Earth System Science Projects (ESSPs) in study and research about the dynamics of Earth's environment. A Teacher's Guide to a number of GLOBE protocols and activities designed to help students explore their environment is available online.

The Role of Ice, Snow and Water in Regulating Climate

The atmosphere, water, snow, and ice work together to help keep the global temperature within a range that will support life. More importantly, these factors keep temperatures fairly constant from year to year, thus preventing abrupt changes in local climates. Abrupt changes in local climate (which can cause events such as severe, prolonged drought) cause shifts in what food crops can grow, and what vegetation is available for food for animals. Abrupt changes in local climate can cause food shortages and force human populations to adapt to new conditions or migrate to new locations with more favorable conditions.

Check Your Thinking:

Name the properties of ice, snow and water that help to regulate the global climate.

Check Your Thinking:

What impact does the high albedo of snow and ice have on the Earth's energy budget?

Check Your Thinking:

What impact does water's high specific heat capacity have on the Earth's energy budget?

Check Your Thinking:

How does the snow's insulating characteristics affect local and regional energy budgets?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Figure 24 shows the mean (average) extent of snow cover and sea ice cover in February and August during the period 1996-2006 in the Northern Hemisphere. On the Northern Hemisphere continents, snow covers a maximum mean area of 45.2 million km2, typically in January. The minimum snow-cover extent usually occurs in August and covers a mean area of 1.9 million km2, most of which is snow on the Greenland ice sheet and on mountain glaciers. As a result, snow cover is the surface characteristic responsible for the largest annual and inter-annual differences in surface reflectivity (albedo) in the Northern Hemisphere. This has a direct affect on the amount of solar energy that is available for the Earth to absorb.

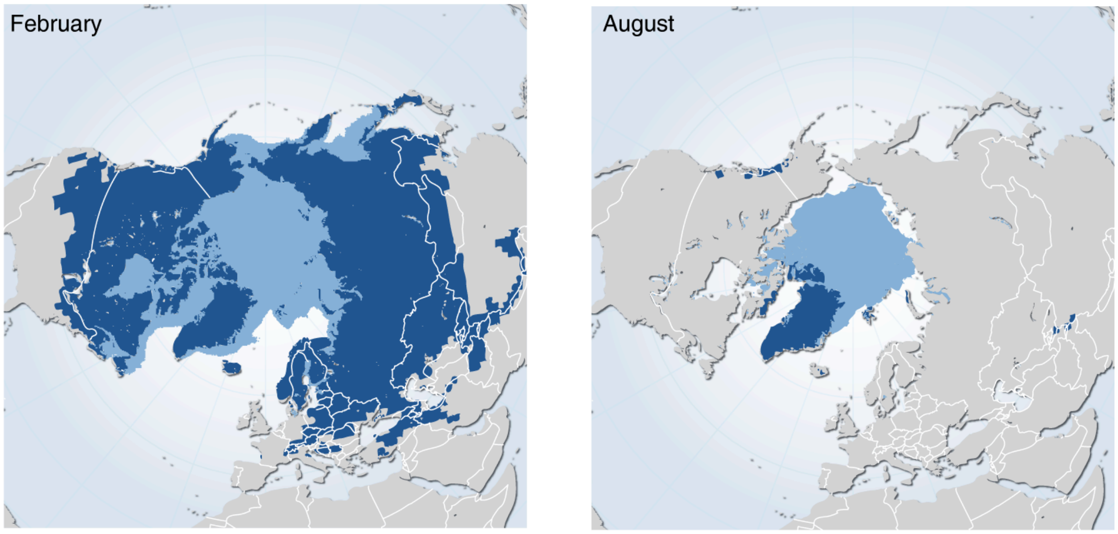


Figure 24: Mean snow-cover extent in the Northern Hemisphere 1966-2006. Snow occurs predominantly on the northern continents, on the sea ice of the Arctic Ocean and on Antarctica (not shown). The dark bue represents snow on the land and the light blue represents sea ice on the Arctic Ocean and adjacent water bodies. (UNEP)

As noted in the section on *Heat Capacity and Heat Storage*, large bodies of water (oceans and lakes) can store very large amounts of heat. Heat moves into and out of bodies of water on a daily and seasonal basis. There is a time lag between the warming and cooling of the air temperature and the warming and cooling of a water body because of their different heat capacities. As a consequence, areas adjacent to a large water body are cooler in early to mid-summer because energy is being "used" to warm the water; they are warmer in the winter, when the water body becomes a source of heat for the area.

Snow and ice impede the movement of energy between the atmosphere and a water body (or the ground). The density of the snow and the thickness of the ice are two factors that determine how effective these materials are as insulators. In addition to its insulating effects, ice is also important because it effectively holds in water (mass). In other words, because ice forms a cap on the liquid water, it prevents evaporation of water from the seas and lakes. If you prevent or slow down evaporation of water (matter or mass), you also slow down the rate of heat-loss, because the water (mass) is holding a lot of heat.

The Impact of Global Climate Change on the Cryosphere

Check Your Thinking:

What do you think would happen to the distribution, duration and thickness of snow and ice covers on the Earth if the global temperature increases slightly?

Check Your Thinking:

If there were less snow and ice on the planet, what do you think would happen to the average temperature of the Earth? Why?

You can download all of the Check Your Thinking questions (and answers) and print or photocopy them (double-sided) onto heavy paper to create a set of "flash" cards.

Increases in annual average air temperatures have been documented over most of the Earth (Figure 25). Warming is greater over land than over oceans, and the largest gains in temperatures for the planet are over the North American Arctic, north central Siberia, and on the Antarctic Peninsula. These recent increases in temperature are confirmed by changes in other features: the decline in extent and thickness of sea ice and glaciers; increasing ground temperatures and loss of permafrost; vegetation changes, including increase in shrub on the tundra; marine and terrestrial ecosystems chnages, including migration of lower latitude speices to highter latitudes.

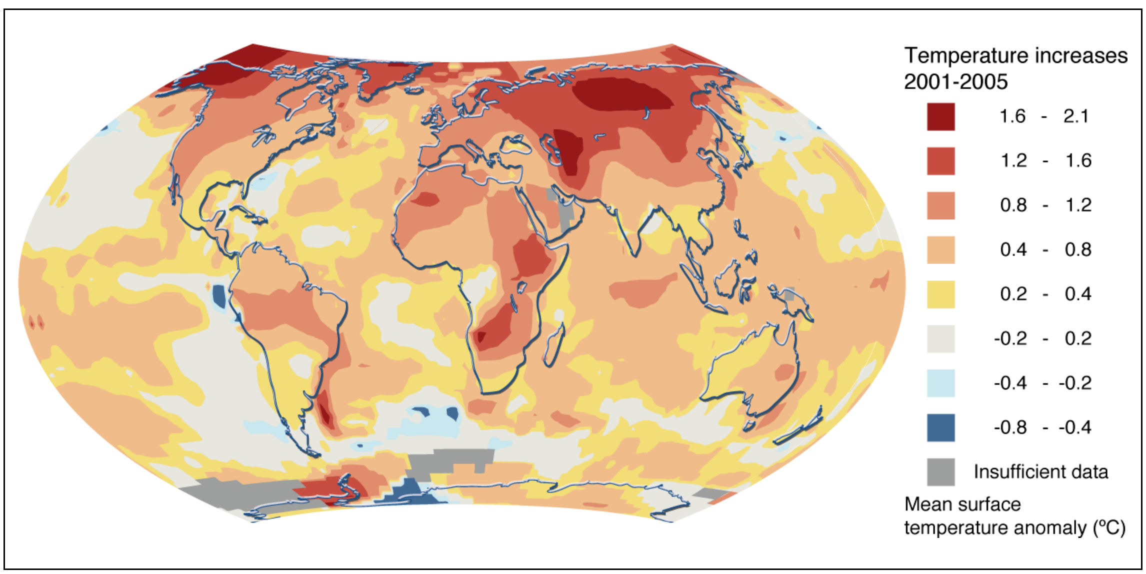


Figure 25: Increases in annual temperatures for a recent five-year period, relative to 1951-1980. (UNEP)

Activity 25:

Download How to Make a Climograph from Your Local Weather Data (pdf), Comparing Current Monthly Averages to Climate (pdf) and How Does Climate Change Over Time? (pdf). Use them to determine how the air temperatures have changing in your area over time. These activities have been developed for the GLOBE Project (including data sheets and a river and lake ice glossary). They enable students to explore their local weather and climate.

The *UN Environmental Programme Global Outlook for Ice and Snow* is a "state of the art" summary of scientific research that provides the perspectives of many scientists to help us seek answers to the following questions:

- Why are ice and snow important to us?
- Why are ice and snow changing globally?
- Where do scientists get evidence that the climate is changing?
- How can the impact of global temperature increases be determined?
- How do changes in snow and ice affect the rest of the environment?
- Why does it matter that glaciers and polar ice caps are melting?

By looking at patterns of change, scientists can examine the extent to which global climate change has already impacted the amount of snow and ice on the Earth. By comparing data from a wide variety of sources, scientists piece together the intricate balance between different Earth systems. Here are a few of the impacts that can occur (or, in some cases, already are occurring):

- Rising sea level change shorelines.
- Diminished summer sea ice cover is already opening up new shipping routes, which require new international agreements.
- Reduction of sea ice increases the water temperature, which increases the melting of ice, which increases the water temperature, and so on, in a positive feedback loop.
- Increased temperatures change the dynamics of agriculture worldwide, resulting in extended droughts that can reduce agricultural production in some areas of the world, and increased rainfall in other parts of the world, requiring shifts in what is grown in all parts of the world.

Ice and snow are important components of the Earth's climate system and are particularly sensitive to global warming. Over the last few decades, the amount of ice and snow, especially in the Northern Hemisphere, has decreased substantially. Changes in volumes and extents of ice and snow have both global and local impacts on climate, ecosystems and human well-being. The following examples of changes in the cryosphere come from the UNEP report, except where indicated.

Positive Feedback Loop

Warming leads to a decrease in ice/snow cover (extent and duration) which in turn leads to a decrease in albedo over the ocean/land, the result of which is further warming and further decreases in the ice cover. Figure 26 shows an example of a positive feedback loop involving sea ice; snow cover or lake ice can be substituted for the sea ice.

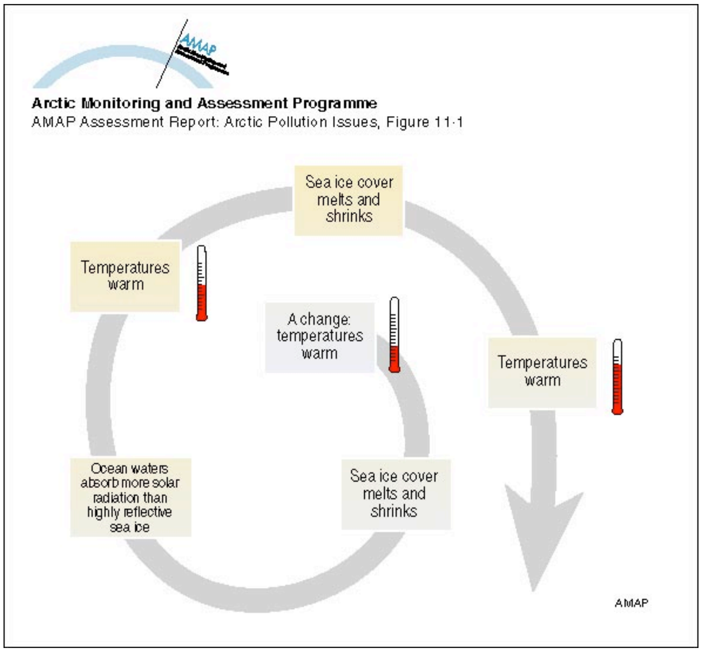


Figure 26: An example of a positive feedback loop. (AMAP)

Snow

Observations of snow-covered area for the Northern Hemisphere show a significant development in the late 20th century, with a reduction of the area covered by snow in the spring (March-April) from some 38 million km^2 in the 1930s to today's 35 million km^2 (Figure 27). Snow is important because it reflects incoming sunlight. The linear trend shows a decrease in snow-covered area of 2.7 ± 1.5 × 106 km^2 or 7.5 ± 3.5 %. The shaded fields in the figure represents the 5 to 95% range of the data.

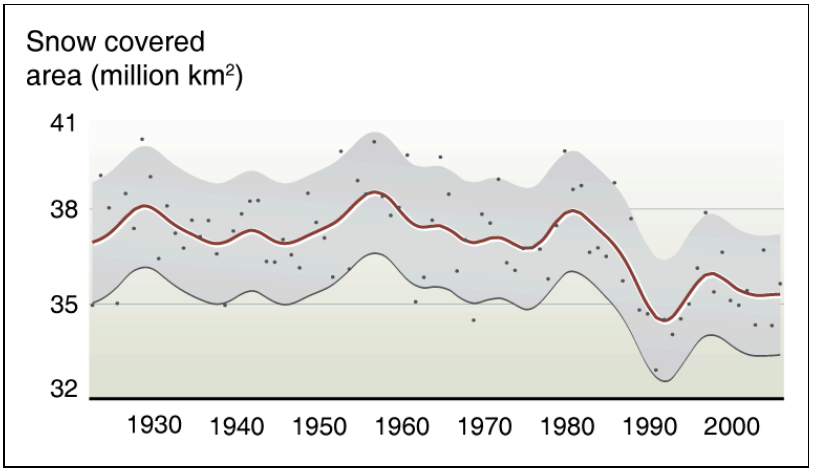


Figure 27: Trends in snow-covered area for the Northern Hemisphere 1922-2005. (UNEP)

Examination of regional trends in spring snow-cover duration from 1969–2003 using NOAA snow-cover data shows the western United States to be among the regions with the strongest decreases (Figure 28). This supports results from studies based on measurements on the ground. Springtime snow cover shows a decline particularly in the Pacific Northwest region of the western United States, where snow water equivalent, a common snow cover measurement equivalent to the depth of water which would result from snow melt, has drastically decreased. This decrease is attributed to an increase in temperature; observations of temperatures in the western United States already show warmer winters. Changes, presented in this figure, exceeding ~ ±1 represent significant local changes at the 95% level. Greenland was excluded from the analysis.

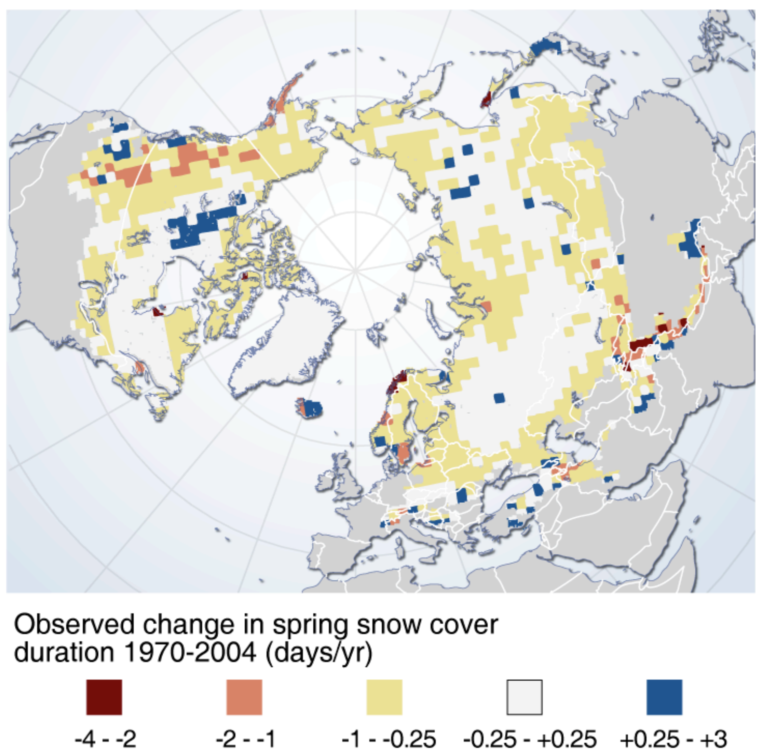


Figure 28: Trends in spring snow cover duration for the Northern Hemisphere, 1970-2004. (UNEP)

River and Lake Ice

River and lake ice, with their smaller areas and volumes, react relatively quickly to climate effects, influencing ecosystems and human activities on a local scale. Therefore, they are good indicators of climate change.

Globally, scientists have documented changes in the dates that bodies of water freeze over in the winter and thaw out in the spring. Rising air temperatures are affecting river and lake ice. This is mainly seen as earlier spring break-up and, to a lesser extent, later autumn freeze-up. The trend to longer ice-free periods is projected to continue.

The main study on the changes in Northern Hemisphere lake and river ice was done by [Magnuson and 13 others](#) (2000). Their findings are summarized in Figure 29. Limited by the availability of detailed observations, most historical evaluations of changes in freshwater ice have focused on relatively simple characteristics, such as the timing of autumn freeze up and spring break up, and maximum ice-cover thickness. Based on 27 long-term (about 150-year) records from around the Northern Hemisphere, Magnuson and others discovered that freeze up has been delayed by approximately six days per hundred years and break up advanced by a similar rate, resulting in an almost two-week per century reduction in the ice-covered season. Numerous other regional and continental studies have been conducted using the more spatially-detailed sets of observations available for the latter half of the 20th-century. Results reveal strong contrasts in freeze-up and break-up timing between decades and between regions largely paralleling trends in major atmospheric patterns that have produced regional climatic warming or cooling.

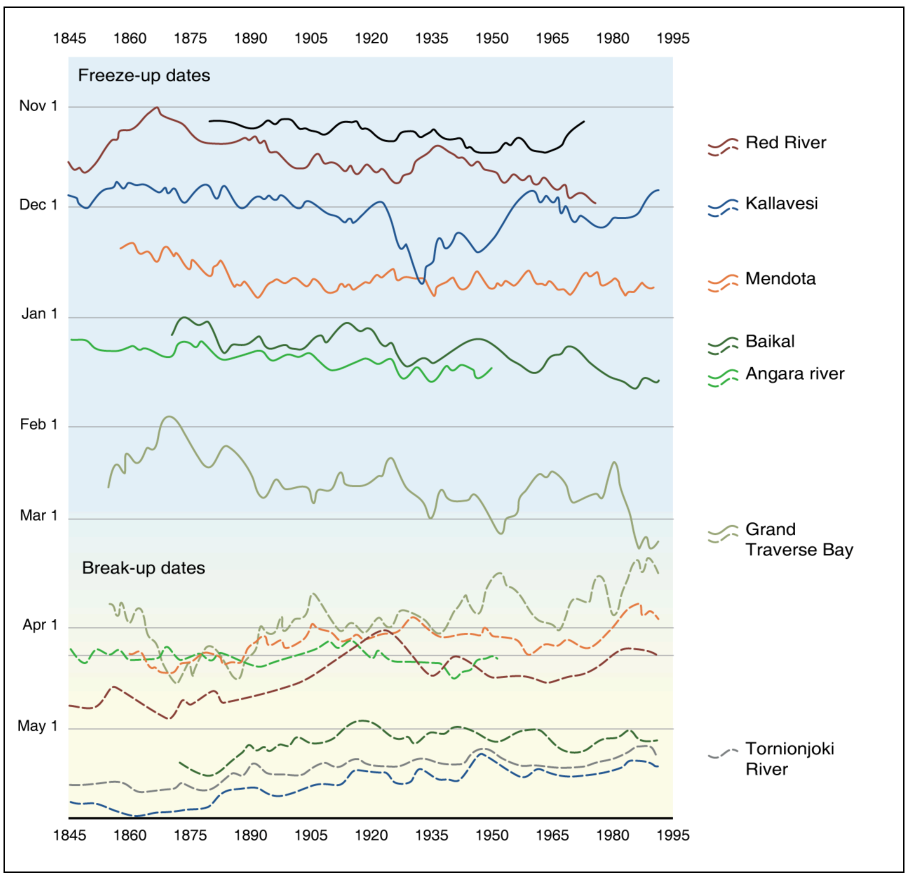


Figure 29: Time series of freeze-up and break-up dates from selected Northern Hemisphere lakes and rivers, 1846–1995. Note the downward trend of the freeze-up section, indicating later freeze-up, and the upward trend in the break-up section, indicating earlier break-up. (UNEP)

In Canada, recent evidence indicates a shortening of the freshwater-ice season over much of the country with the reduction being mainly attributable to earlier break ups (Figure 30). These trends match those in surface air temperature during the last 50 years. For example, similar spatial and temporal patterns have been found between trends (1966 to 1995) in autumn and spring 0°C isotherms (lines on a map showing location of 0°C air temperatures) and lake freeze-up and break-up dates, with generally significant trends toward earlier springs and earlier break-up dates over most of western Canada and little change in the onset of cooler temperatures and in freeze-up dates over the majority of the country in autumn.

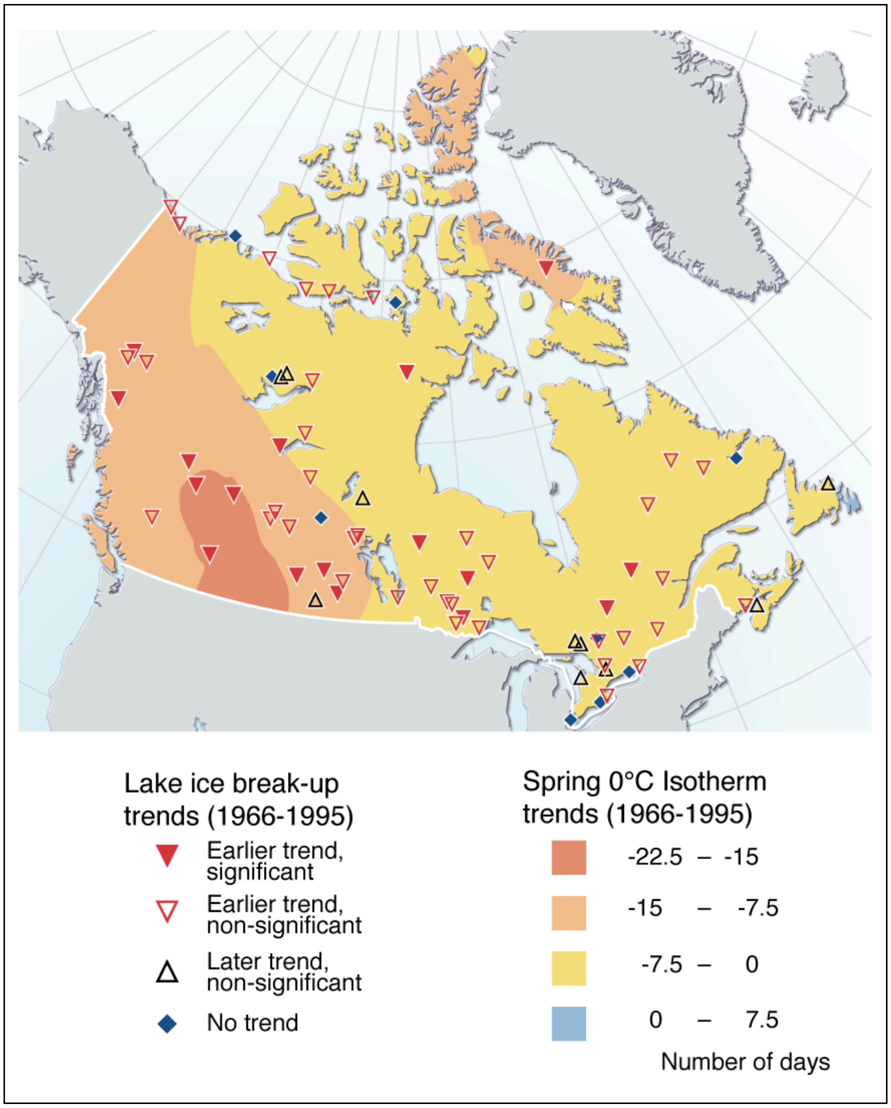


Figure 30: Trends in spring temperatures and ice break-up dates in Canada. (UNEP)

Activity 26:
List the changes that are already occurring or could occur in your area, due to later freeze-up and earlier break-up of local water bodies. How have they affected your daily life? How might they affect your life in the future?

Glaciers

The mass balance of a glacier is the difference between the accumulation of snow and ice (usually high up on the glacier) and ablation or melting/sublimation (usually at lower elevation on the glacier) (Figure 31). If the mass balance is positive, the glacier is growing and, probably, advancing. If the mass balance is negative the glacier is shrinking or retreating.

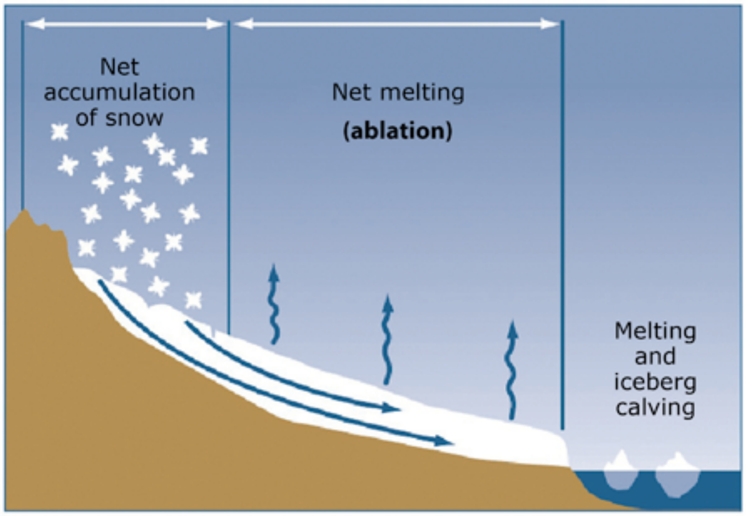


Figure 31: Elements of the mass balance of a glacier. (USGS)

Figure 32 shows the cumulative specific mass balance curves for the mean of all glaciers in the world and 30 'reference' glaciers with (almost) continuous series since 1976. It clearly shows a decrease in the mass balance over the period of data acquisition.

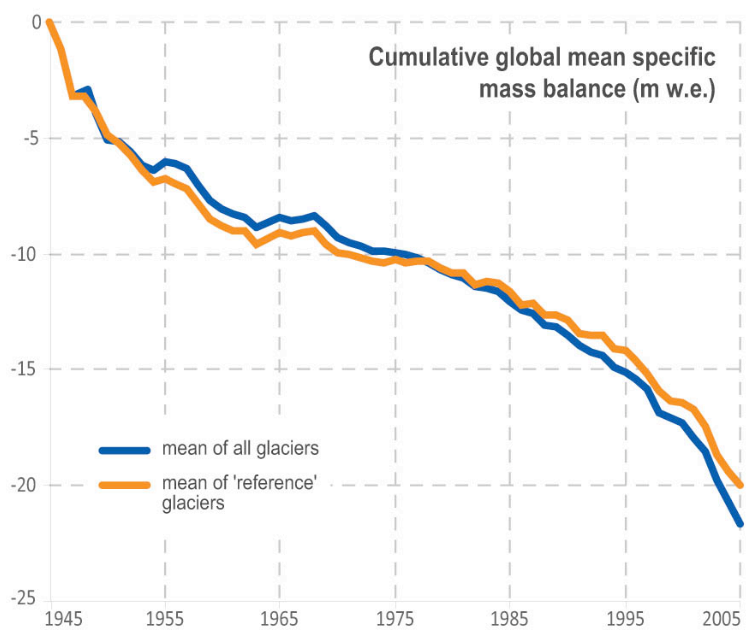


Figure 32: The mass balance of the world's glaciers. (UNEP)

The retreat of Grinnell Glacier in Glacier National Park is documented in Figure 33. This glacier has retreated from a total extent of ~2.3 square kilometers circa 1850 to ~1.1 square kilometers in 1993, and is now distributed in two major and five minor segments. Like other glaciers in Glacier National Park, it is predicted that Grinnell Glacier will disappear by 2030 under current projections for the rate and extent of global warming.

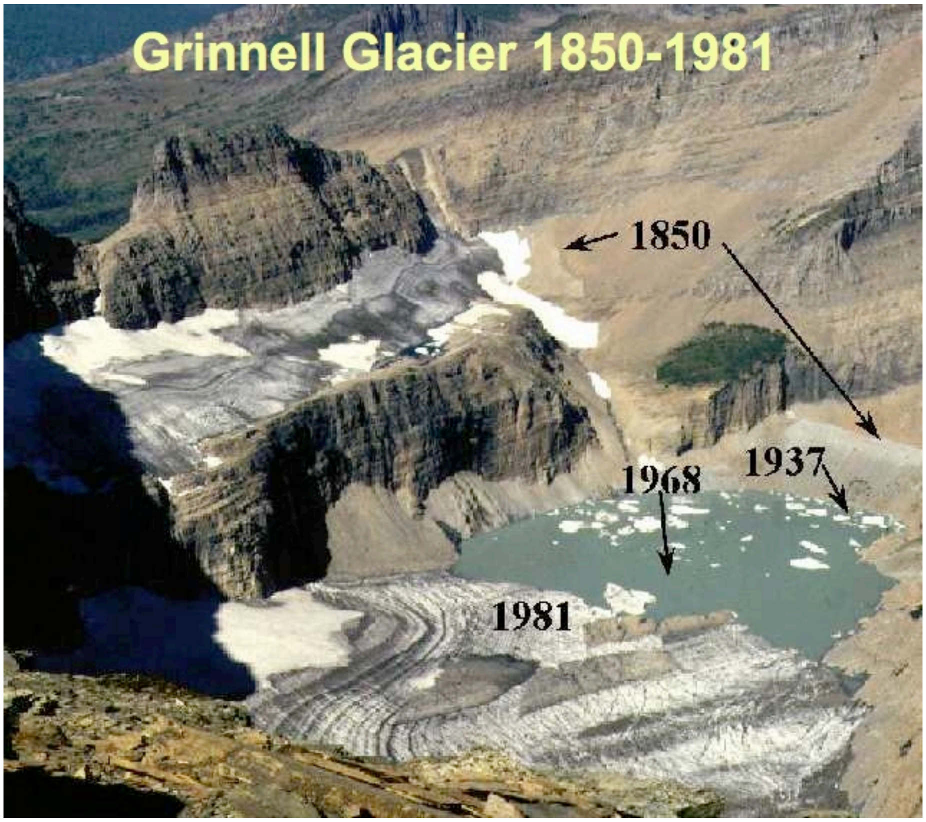


Figure 33: A 1981 aerial photograph of Grinnell Glacier in Glacier National Park. The decrease in the ice extent since 1850 is indicated by the dates. (USGS)

❄ ***Activity 27***:

Go to Teachers' Domain Documenting Glacial Change to see a collection of images that demonstrate the changing positions of glaciers in the past 100 years or so. What are the consequences of these glacier changes to the local environment and the global energy budget?

Sea Ice

Sea ice covers the Arctic Ocean, and surrounds Antarctic during their respective winter months. While there is little change in the maximum and minimum extent of the Antarctic sea ice cover, there has been a significant decrease in the extent of Arctic sea ice since satellite observations began in the 1970s (Figure 34). The graph shows a dramatic and reocrd loss of sea ice in summer 2007 and a significant, near-record loss of ice in summers 2008 and 2010.

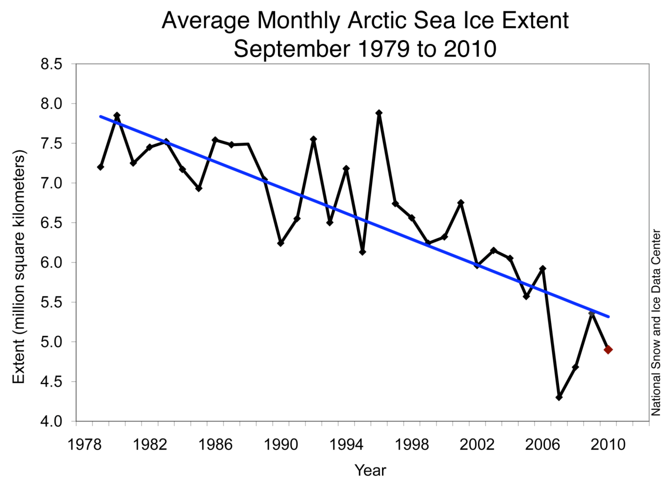


Figure 34: Changes in the average monthly Arctic sea ice extent in September (1979-2010). The blue trend line blue indicates the overall reduction of the sea ice extent during this period. (NSIDC)

Scientists often use ice age data as a way to infer ice thickness—one of the most important factors influencing end-of-summer ice extent. It is assumed that the older the ice is, the thicker it is. In fact, multiyear ice (that is, sea ice that survives two or more summer melt seasons) can be several meters thick.

A proportionally large amount of multiyear ice can help more ice to survive the summer melt season. Although thickness plays an important role in ice melt summer ice conditions will also depend strongly on weather patterns through the melt season.

Figure 35 shows a decrease in old ice in the Arctic between the mean conditions of 1981-2000 and the data acquired in 2009.

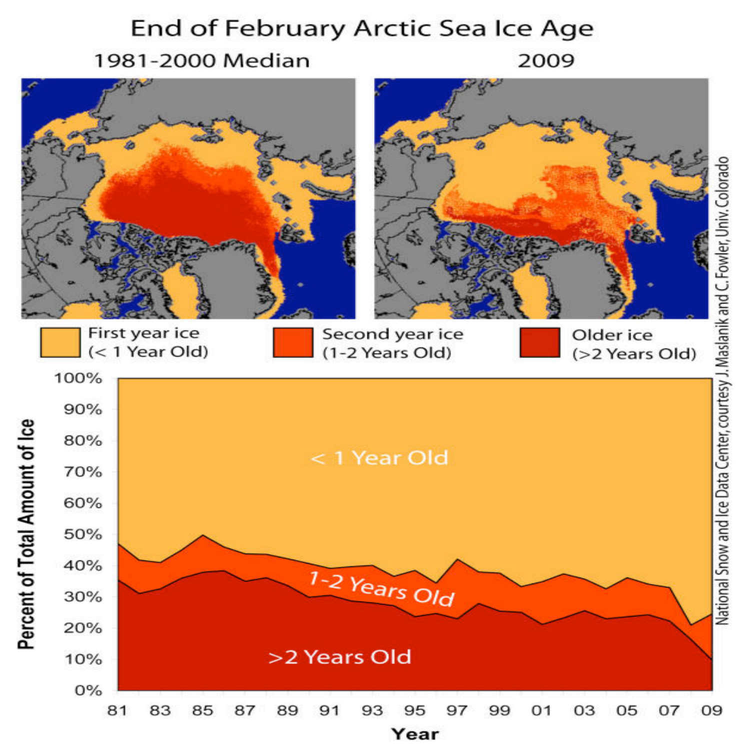


Figure 35: Changes in the areal extent of several age and inferred thickness categories of sea ice in the Arctic. (Chuck Fowler and Jim Maslanik, U of Colorado/NSIDC)

Activity 28:

Go to Teacher's Domain Arctic Sea Ice Satellite Observations and learn how the sea ice in the Arctic has changed. Data from the years 1982 and 2007 are compared in this interactive activity.

Resources:

For more information about snow conditions see the Rutgers University Global Snow Lab (gsl). This site offers snow data in visible satellite charts, graphs and tables.

For more information and images of what is often called the ***ice albedo feedback loop*** *see Ice Albedo - Global View from the Goddard Space Flight Center. This cycle (or feedback loop), once started, can continue to exacerbate itself, unless something happens to reverse or mitigate the cycle.*

For more information on albedo, see Earth's Albedo in Decline from the NASA Earth Observatory. You can also download Earth's Albedo and Global Warming, a module from TeachersDomain.org that includes some simulations.

About the Authors of this Snow Module

Scientists from a variety of types of disciplines study snow and ice and its relationship to climate. Studies of conductive heat flow through snow and ice provide data relevant to global climate change and has been the focus of the Alaska Lake Ice and Snow Observatory Network (ALISON). The scientists involved in the development of this snow study module are Dr. Delena Norris-Tull, Ms. Kim Morris, and Dr. Martin Jeffries.

Delena Norris-Tull *is a Science Educator, formerly with the University of Alaska Fairbanks. Delena is now a professor at the University of Montana Western, teaching both education and science courses. She is also a botanist who has written two field guides to wild plants of Texas, under the name Delena Tull.*

Delena Norris-Tull

Kim Morris *is Research Scientist at Geophysical Institute, University of Alaska Fairbank. She has conducted research on snow and sea ice in the Arctic and Antarctic and snow and lake ice in Alaska. She currently manages the ALISON project and is writing science curriculum for K-12 schools through the GLOBE Seasons and Biomes Project.*

Kim Morris

Martin Jeffries *is a Research Scientist at the Geophysical Institute, University of Alaska Fairbanks. He has studied sea ice in the Arctic and Antarctic, ice shelves and icebergs in the Canadian High Arctic and lake ice in Alaska. He was Project Director for the Arctic Observing Network at National Science Foundation from 2006-2010.*

Jeffries and Morris have written several papers about ALISON and ALISON data:

Jeffries, M. O., K. Morris and C. R. Duguay. 2005. Lake ice growth and decay in central Alaska: observations and computer simulations compared. Annals of Glaciology, 40*, 113-118.*

Jeffries, M. O. and K. Morris. 2006. Instantaneous daytime conductive heat flow through snow on lake ice in Alaska. Hydrological Processes*, 803-815.*

Jeffries, M.O., Gallego, P., DeBlauw, D., Morris, K., Norris-Tull, D. (Dec 2006). Lake ice and snow study in Denali National Park and Preserve promotes elementary school science education. Alaska Park Science, 5 *(2), 18-23.*

Martin Jeffries

These three individual have worked together since 2000, helping teachers understand the science of snow and its relationship to climate. Along with now-retired middle school science teacher, Ron Reihl, they developed the Alaska Lake Ice and Snow Observatory Network (ALISON), a project that engages K-12 teachers and their students in studying ice and snow on lakes and ponds throughout Alaska.

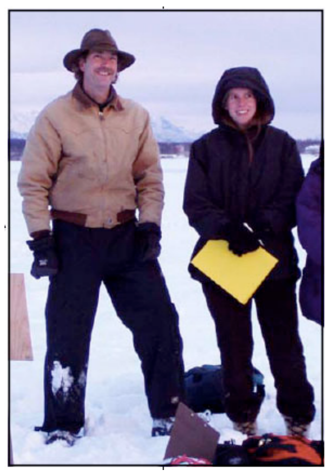
Teachers Involved in Developing & Testing ALISON Measurements

Ron Reihl *Marge Porter & M. Jeffries*

Ron Reihl *is a cofounder of the ALISON program and was a Physical Science teacher at Tanana Middle School (retired - 2005). He taught Physical Science for more than 23 years and was always looking for new ways to focus the natural curiosity and energy of middle level students on science. In winter 2001-02 a school district grant allowed him to collaborate with science teachers from two other middle schools on snow and ice activities they wanted to conduct with their students. Each teacher was able to take students to field study sites to make snow temperature measurements using remote sensing technology (CBLs and digital thermometers) and snow density measurement using sampling tubes and electronic balances.*

Marge Porter *is a high school biology and environmental science teacher from Connecticut. She taught at Woodstock Academy for 23 years until 2002, when she moved to Somers High School. In addition to participating in the Poker Flat study and working with Fairbanks teachers, Marge has used Antarctic sea ice data in the classroom, encouraged her students to communicate by e-mail with Martin when he has been in the Antarctic pack ice aboard the research vessel Nathaniel B. Palmer, and taken her students out into the school grounds to measure snow depth and temperature, determine snow density and calculate the conductive heat flow through the snow. In February 2005, 2006, 2007 and 2008 Marge brought some of her students to Fairbanks during spring break.*

Shannon Graham *taught middle and high school science at the Washington School for the Deaf, Vancouver, WA. Shannon participated in the Poker Flat study under the auspices of Teachers Experiencing the Arctic and Antarctic (TEA). She spent two weeks in Fairbanks in January 2002 and returned in March and April for her research experience when she visited Poker Flat Research Range 3-4 times per week to measure snow depth, temperatures and density, and ice thickness at four ponds. Shannon was responsible for the computer entry and analysis of her data, and she shared the results and her research experience with her students via her daily journal at the TEA Web site and by video-conference.*



Marc Swanson *(Seward Elementary School -retired) and* ***Cheryl Williams*** *(previously at Wasilla High School, now at Palmer High School) have prepared two guidebooks for ALISON teachers and others interested in the ALISON program. The Educator's Guide to ALISON Measurements provides a brief background of the ALISON project and describes in detail how to select an ALISON site, make ALISON measurements and other important aspects of running and ALISON site. The ALISON Guide to Heat and Energy Activities in the Classroom provides descriptions of classroom activities related to heat and energy. These include: joules vs calories; heat capacity; thermal conductivity; the rate of heat transfer; latent heat and more.*

Resources:

Abbott, C., & Swanson, M. (April/May 2006). A rewarding partnership: Critical components of a successful scientist-student partnership. The Science Teacher*. National Science Teachers Association, Washington, D.C.*

Acronyms Used in this Snow Module

ALISON – Alaska Lake Ice and Snow Observatory Network

AMAP – Arctic Monitoring and Assessment Programme

CRREL – U.S. Army Cold Regions Research and Engineering Laboratory

GLOBE - Global Learning and Observations to Benefit the Environment Project

NASA – National Aeronautics and Space Administration

NIST – National Institute of Standards and Technology

NOAA – National Oceanic and Atmospheric Administration

NSIDC – National Snow and Ice Data Center

UNEP – United Nations Environmental Programme

USDA – United States Department of Agriculture

USGS – United States Geological Survey

Learning Activities and Supplementary Extensions

There are many opportunities to extend and expand the information described in this module. All the activities found in the snow module, plus some additional ones, are listed below.

Activity 1:
Learn about snowflake formation and much more by going to Teacher's Domain interactive primer *Snowflake Physics,* which is adapted from *SnowCrystals.com* (requires *Adobe Flash Player* to view).

Activity 2:
Familiarize your students with snowflake shapes and the conditions that produce them. Download two different versions of the *Snowflake Morphology* graph (pdf) to assist with this task.

Extension 1:
Snowflake Morphology Activity: Have students read the information that explains The Snow Morphology Diagram from the *SnowCrystals.com Snowflake Primer*. On the diagram, "Supersaturation" refers to humidity. Low supersaturation values indicate low humidity. Have students obtain data (air temperature, humidity, and shapes of snowflakes) each time it snows throughout the winter. Have them use this data to create a graph similar to the Morphology Diagram. Have the students see if their weather data enables them to predict the shapes/types of snowflakes. Get the Snow Morphology Diagram *here*.

Extension 2:
Snow Crystal Lesson: Look at Teacher's Domain *Why Do Snowflakes Come in So Many Shapes and Sizes? Lesson Plan*. In this in-depth lesson, students build an apparatus that creates conditions similar to a winter cloud and produce their own snow crystals indoors. By watching the snow crystals grow, they learn about the molecular forces that shape ice crystals, and gain a deeper understanding of the states of matter. By exploring media resources, including microphotographs of real snowflakes, students also learn about molecular forces, the particulate nature of matter, and condensation.

Activity 3:
Observe and document the snowflakes in your schoolyard. Refer to *Snowflake Watching*, *How to Photograph Snowflakes* and *Preserving Snow Crystals* to learn to look at, photograph and preserve snowflakes.

Activity 4:
Download *Snowflake Shapes & Activities* (pdf) for a variety of activities you can do with your students related to snowflake shapes and symmetry.

Extension 3:
Symmetry Tutorial: An online children's video tutorial on symmetry can be viewed at *LINKS Learning*.

Extension 4:
Symmetry Activity: Have students examine a number of objects in the classroom, both two-dimensional and three-dimensional, to determine how many lines or planes of symmetry can be found in each.

Extension 5:
Symmetry Activity: Take the students on a field trip in the schoolyard to look for patterns in other objects in nature. Have them draw simple pictures of objects they find in nature, and use those drawings to help examine the symmetry of the objects. Help the students begin to understand that the angle at which they make their drawing affects the presence of symmetry. Painters often alter the angle of three-dimensional symmetrical objects to make them appear asymmetrical in two-dimensional drawings, to add interest to the paintings.

Extension 6:

Snowflake Symmetry Activity: Have students examine the symmetry of snowflakes by viewing photographs. *The Bentley Snow Crystal Collection of the Buffalo Museum of Science*, available online, is an excellent place to begin. You can find more online photos at the *SnowCrystals.com Snow Crystal Photo Gallery*. The students should be able to figure out that, while most snowflakes have rotational symmetry, they do not all have the same number of lines of symmetry. Also, snowflakes sometimes have reflection symmetry (only 1 line of symmetry). And sometimes snowflakes are asymmetrical. Bentley's photographs include information about the weather conditions for each snowflake. Have the students study the weather conditions for various snowflakes to determine if weather conditions affect the number of lines of symmetry of snowflakes. Some answers can be found online at the *SnowCrystals.com Guide to Snowflakes.*

Activity 5:

Download *Snow Crystals in a Snow Pit* (pdf) and identify the snow grain types in your snowpit layers.

Activity 6:

Download *Greek & Latin Root Words for Science* (pdf) for a list of root words from Latin and Greek that will help students understand the meaning of the Earth system names.

Activity 7:

Download *The Energy Budget of the Earth* (pdf). Make two columns and label them "Net gain" and "Net loss". What is the value of these two columns? Are they equal?

Activity 8:

Download *Exploring Solar Energy Variation on Earth: Time and Seasons* (doc) to learn about the daily and annual variations of solar insolation.

Activity 9:

Download *Exploring Solar Energy Variation on Earth: Changes in the Length of Day, Solar Angle and Solar Insolation Through the Year* (pdf) to learn about the variations in the duration and intensity of solar insolation on the Earth's surface.

Activity 10:

Download *Sun Angles* (pdf) to learn how to measure the angle of the sun to the horizon.

Activity 11:

Perform a simple experiment to illustrate the impact that color has on absorption and reflection of energy. Place different colors of the same materials in the sun or under a light to see which materials get hotter than others.

Activity 12:

Visit *Earth's Albedo from Meteorology: Understanding the Atmosphere* for a simulation that shows variations in albedo at different locations and in different months. Can you answer the accompanying questions?

Activity 13:

Look at "My NASA Data" lesson *Variables Affecting Earth's Albedo*. This lesson plan allows students to use real NASA data to understand what factors influence the Earth's albedo.

Extension 7:

Albedo Lesson: Look at Teachers' Domain *Earth's Albedo and Global Warming*. This interactive activity adapted from NASA and the USGS data illustrates the concept of albedo.

Activity 14:

Download the *Heat Flow in Snow and Ice – Change in temperature and mass activity* (pdf) for a simulation of what occurs on a lake that is covered with ice and snow.

Activity 15:

Download *Measuring the Temperature of Water, Snow and Ice* (pdf) for a variety of activities for students of various ages for measuring the temperature of snow and water.

Activity 16:
Visit *Meteorology » Earth's Atmosphere, Energy Budget and Energy Cycle* from the Satellite Applications for Geoscience Education website for an interactive exercise in identifying energy transfer for some phase changes of water in the hydrologic cycle.

Activity 17:
Go to the *National Weather Service* for several learning lessons about specific elements of the hydrological cycle.

Activity 18:
Download *Buoyancy and Density: Middle School Unit Plan* (pdf) for a series of activities to help students understand density and buoyancy.

Activity 19:
Download the two activities (*Snow, Volume, Temperature and Density* (pdf) and *The Science of Snow* (pdf)) to engage students in collecting snow temperature data and data to calculate the density of snow

Activity 20:
Download *Conductive Heat Flow* (ppt). It contains instructions for calculating heat flux.

Activity 21:
Download one of the two calculators (Excel file): one for *snow data taken on frozen lakes*, the other for *snow data taken on the ground* to complete the exercises in *Conductive Heat Flow* (ppt).

Activity 22:

Teach students to create their own calculator for automating any type of calculations they need. Download *Creating an Excel Calculator* (pdf) for instructions.

Activity 23:

Download the Arctic Climate Modeling Program's *Matter and Energy* activities "Introduction to Energy Transfer", "The Science of Snow", "Lake Ice and Energy Transfer" and "Lake Ice and Conductive Heat Flow" and use them as a review for the previous sections relating to the snow variables necessary for calculating the heat flux through a snow cover.

Activity 24:
Observe and document the freeze-up and break-up of a local body of water. Download The Ice Seasonality Investigation (pdf), a protocol developed for the GLOBE Project (including data sheets) that enables students to study freeze-up and break-up locally. You can also download the River Ice Glossary and Lake Ice Glossary (pdf). The GLOBE Ice Seasonality Protocol was developed by Kim Morris and Martin Jeffries.

Activity 25:
Download *How to Make a Climograph from Your Local Weather Data* (doc), *Comparing Current Monthly Averages to Climate* (doc) and *How to Does Climate Change Over Time?* (doc). Use them to determine how the air temperatures have changed in your area over time.

Activity 26:
List the changes that are already occurring or could occur in your area, due to later freeze-up and earlier break-up of local water bodies. How have or will they effected your daily life?

Activity 27:
Go to Teachers' Domain *Documenting Glacial Change* to see a collection of images that demonstrate the changing positions of glaciers in the past 100 years or so.

Activity 28:
Go to Teachers' Domain *Arctic Sea Ice Satellite Observations* and learn how the sea ice in the Arctic has changed. Data from the years 1982 and 2007 are compared in this interactive activity.

Snow Studies Glossary

Ablation: The combined processes (such as sublimation, fusion or melting, evaporation) which remove snow or ice from the surface of a glacier or from a snow-field. Also used to express the quantity lost by these processes. It is also the reduction of the water equivalent of a snow cover by melting, evaporation, wind and avalanches. (*http://nsidc.org/arcticmet/glossary/ablation.html*).

Absorption*:* The taking up and storing of energy, such as radiation, light, or sound, without it being reflected or transmitted. During absorption, the energy may change from one form into another. When radiation strikes the electrons in an atom, the electrons move to a higher orbit or state of excitement by absorption of the radiation's energy (*http://www.thefreedictionary.com/absorption*).

Albedo: The albedo of an object is the extent to which it diffusely reflects light from light sources such as the Sun. It is therefore a more specific form of the term reflectivity. Albedo is defined as the ratio of diffusely reflected to incident electromagnetic radiation. It is a unitless measure indicative of a surface's or body's diffuse reflectivity. The range of possible values is from 0 (dark) to 1 (bright) (*http://en.wikipedia.org/wiki/Albedo*).

Atmosphere: The gaseous mass or envelope surrounding a celestial body, especially the one surrounding the earth, and retained by the celestial body's gravitational field (*http://www.thefreedictionary.com/atmosphere*).

Biosphere: The *biosphere* is the global sum of all ecosystems. It can also be called the zone of life on Earth. From the broadest biophysiological point of view, the biosphere is the global ecological system integrating all living beings and their relationships, including their interaction with the elements of the lithosphere, hydrosphere, and atmosphere. The biosphere is postulated to have evolved, beginning through a process of biogenesis or biopoesis, at least some 3.5 billion years ago (*http://en.wikipedia.org/wiki/Biosphere*).

Condensation: It is the process by which water vapor in the air is changed into liquid water (*http://ga.water.usgs.gov/edu/watercyclecondensation.html*).

Conduction: The process by which energy is transferred by the direct contact of molecules, not by the movement of the material (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Convection: The process by which energyis transferred by the mass motion of groups of molecules resulting in the transport and mixing of properties (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Cryosphere: The cryosphere includes those places on the Earth's surface that are covered with ice and snow or where the ground is frozen. Glaciers and permafrost are part of the cryosphere. For more information, refer to the National Snow and Ice Data Center at *http://nsidc.org/cryosphere*.

Density: The density of a material is defined as its mass per unit volume (*http://en.wikipedia.org/wiki/Density)*.

Earth's Energy Budget: The Earth can be considered as a physical system with an energy budget that includes all gains of incoming energy and all losses of outgoing energy. The planet is approximately in equilibrium, so the sum of the gains is approximately equal to the sum of the losses (*http://en.wikipedia.org/wiki/Earth%27s_energy_budget*).

Energy: It is the ability or capacity to do work on some form of matter (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Equi-temperature Metamorphism: The changes that occur to snow crystals over time in deep snow packs when the temperature at the surface of the snow and the temperature at the base of the snow are virtually the same. This generally occurs when air temperatures remain close to 0°C for an extended period of time.

Evaporation: It is the process by which water changes from a liquid to a gas (vapor) (*http://ga.water.usgs.gov/edu/watercycleevaporation.html*).

Feedback Loop: A circular series of relationships that can enhance or buffer changes that occur in a system. Positive feedback loops enhance or amplify changes; this tends to move a system away from its equilibrium state and make it more unstable. Negative feedbacks tend to dampen or buffer changes; this tends to hold a system to some equilibrium state making it more stable. (*http://serc.carleton.edu/introgeo/models/loops.html*).

First Law of Thermodynamics: It states that the energy lost during one process must equal the energy gained during another, i.e., no net loss of energy (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Freezing: It is the process by which a liquid becomes a solid when enough energy is removed (http://en.wikipedia.org/wiki/Freezing).

Geothermal Gradient: It is the rate of change of temperature with depth in the Earth. It is affected by the thermal conductivity of the rock in which it is being measured (*http://www.enotes.com/earth-science/geothermal-gradient*).

Heat (Thermal) Energy: It is the kinetic energy due to the motion of atoms and molecules. It is the energy that is in the process of being transferred from one object to another because of a temperature difference (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Heat Conduction: It is the flow of internal energy from a region of higher temperature to one of lower temperature by the interaction of the adjacent particles (atoms, molecules, ions, etc) in the intervening space. It is affected by: (1) temperature difference, (2) length, (3) cross-sectional area and (4) material (*http://physics.info/conduction/*).

Hydrosphere: All the components of water present on the Earth, including bodies of water, water vapor, ice, etc. (*http://www.dmh.gov.mm/glossary.cfm#H*).

Ice-Albedo Feedback Loop: Ice-albedo feedback (or snow-albedo feedback) is a positive feedback climate process where a change in the area of snow-covered land, ice caps, glaciers or sea ice alters the albedo. This change in albedo acts to reinforce the initial alteration in ice area. Cooling tends to increase ice cover and hence the albedo, reducing the amount of solar energy absorbed and leading to more cooling. Conversely, warming tends to decrease ice cover and hence the albedo, increasing the amount of solar energy absorbed, leading to more warming. The effect also applies on the small scale to snow-covered surfaces. A small amount of snow melt exposes darker ground which absorbs more radiation, leading to more snowmelt. (*http://en.wikipedia.org/wiki/Ice-albedo_feedback*).

Infiltration: The portion of water that falls as rain and snow and eventually moves into the subsurface soil and rock. The rate of infiltration is affected by the intensity and duration of the precipitation episodes, the soil characteristics and saturation level, land cover, slope of the land and evapo-transpiration (*http://ga.water.usgs.gov/edu/watercycleinfiltration.html)*.

Infrared Radiation: Infrared **(**IR**)** radiation is electromagnetic radiation with a wavelength between 0.7 and 300 micrometres, which equates to a frequency range between approximately 1 and 430 THz. Its wavelength is longer (and the frequency lower) than that of visible light, but the wavelength is shorter (and the frequency higher) than that of terahertz radiation microwaves. Bright sunlight provides an irradiance of about 1 kilowatt per square meter at sea level. Of this energy, 527 watts is infrared light, 445 watts is visible light, and 32 watts is ultraviolet light (http://en.wikipedia.org/wiki/Infrared).

Insolation: The measure of solar radiation received on a given surface at a given time (http://en.wikipedia.org/wiki/Insolation).

Insulator: An object, such as a blanket, a fur coat or snow cover, that tends to slow down the rate at which heat is transferred from one object to another as the material "resists" heat flow (http://www.alcwin.org/Chemical_Terms_Description-624-T.htm).

Internal Energy: It is the total energy (potential and kinetic) stored in molecules (http://earthstorm.mesonet.org/materials/ref_heattrans.php).

International System (SI): The modern metric system of measurement (Systeme Internationale) (http://physics.nist.gov/cuu/Units/index.html).

Joule (J): The work required to continuously produce 1 watt of power per second (http://en.wikipedia.org/wiki/Joule).

Kelvin (K): It is a unit of increment of temperature and is the base SI unit of temperature. 0 K is referred to as absolute zero and denotes the absences of all thermal energy (http://en.wikipedia.org/wiki/Kelvin).

Kilogram (kg): A basic measure of mass. 1 kilogram = 1000 grams = approximately 2.2 pounds (http://wordnetweb.princeton.edu/perl/webwn?s=kilogram).

Kinetic Energy: It is the energy that a body possesses as a consequence of its motion. It is dependent on the object's mass and velocity (http://earthstorm.mesonet.org/materials/ref_heattrans.php).

Lake Ice: Ice that forms on the surface of a lake (pond) as a consequence of water freezing. There are two kinds of lake ice: (1) congelation ice (black ice) that forms as a consequence of the conduction of heat from the underlying water to the atmosphere and (2) snow ice (white ice) that forms through the flooding and refreezing of a snow cover on the lake ice (http://www.gi.alaska.edu/alison/ALISON_Science_Lake.html).

Latent Heat: It is the heat energy required to change a substance from one state to another (http://earthstorm.mesonet.org/materials/ref_heattrans.php).

Lithosphere: The solid part of a celestial body (as the earth); *specifically*: the outer part of the solid earth composed of rock essentially like that exposed at the surface, consisting of the crust and outermost layer of the mantle, and usually considered to be about 60 miles (100 kilometers) in thickness (http://www.merriam-webster.com/dictionary/lithosphere).

Mass Balance: On a glacier, the difference between the accumulation and ablation (melting and sublimation). When the mass balance is positive the glacier is growing (expanding/advancing); when it is negative the glacier is decreasing in volume (retreating and/or thinning) (http://en.wikipedia.org/wiki/Glacier_mass_balance).

Matter: It is anything that has mass and occupies a volume (http://en.wikipedia.org/wiki/Matter).

Melting: It is a phase change from solid to liquid due to an increase in internal energy (http://en.wikipedia.org/wiki/Melting).

Metamorphism: In snow, it is the change in the structure and texture of snow grains, which result from variations in temperature, migration of liquid water and water vapor, and pressure within the snow cover (*http://www.gi.alaska.edu/alison/ALISON_Science_Snowmeta.html*).

Meter (m): It is a unit of length. Originally intended to be one ten-millionth of the distance from the Earth's equator to the North Pole. Since 1983, it is defined as the distance travelled by light in vacuum in $^{1}/_{299,792,458}$ of a second (*http://en.wikipedia.org/wiki/Meter*).

Newton (N): The unit of force required to accelerate a mass of 1 kilogram, 1 meter per second per second (*http://www.answers.com/topic/newton*).

Potential Energy: It is the energy which a body possesses as a consequence of its position in a gravitational field (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Precipitation: It is water released from clouds in the form of rain, freezing rain, sleet, snow or hail (*http://ga.water.usgs.gov/edu/watercycleprecipitation.html*).

Radiant Energy: It is the energy that propagates through space or through material media in the form of electromagnetic radiation (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Radiation: The energy transferred by electromagnetic radiation. It is the only form of heat transfer that can occur in the absence of any form of medium and as such is the only means of heat transfer through a vacuum including outer space (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

Reflection: Change in wave direction after it strikes a reflective surface, causing the angle the wave makes with the reflective surface in relation to a line normal to the surface to equal the angle the reflected wave makes with the same normal line (*http://en.wikipedia.org/wiki/Wave*).

Reflection Symmetry: In reflection symmetry, you can cut the image in half in only one plane. In other words, there is only one direction in which you can draw a line that will result in two halves that are mirror images of each other. There is only one line of symmetry.

Rotational Symmetry: In rotational symmetry, you can cut the image in half in more than one direction, and the two halves will appear as mirror images of each other. The object has more than one line of symmetry. For example, a triangle can be cut along three different axes. A circle can be cut along an infinite number of axes.

Sea Ice: It is a thin, fragile, solid layer that forms in the Polar Oceans. It forms a boundary between the relatively warm ocean and the cooler atmosphere (*http://southport.jpl.nasa.gov/polar/iceinfo.html*). There are many different kinds of sea ice (*http://www.gi.alaska.edu/~eicken/he_teach/GEOS615icenom/form/types.html*).

Second (s): It is the base SI unit of time. Since 1967, the second has been defined to be the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom (*http://en.wikipedia.org/wiki/Second*).

Sensible Heat: It is the energy that is related to a change in temperature. Latent heat is its opposite as it is the heat that is consumed/released by a phase change that DOES NOT change the temperature of the material (*http://en.wikipedia.org/wiki/Sensible_heat*).

Snow: A snowflake is a crystal made up of ice (*http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.htm*). Once snow falls to the ground, it begins a process of change. Pressure, temperature and moisture change the form of the snowflake's crystals and the texture (*http://www.nasa.gov/audience/foreducators/son/winter/snow_ice/F_Snow_and_Ice.html*).

Snow Thermal Conductivity: The ability of snow to serve as an insulator is described mathematically in terms of the amount of heat that can be transferred through the snow.

Solar Constant: It is the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays of the Sun at a distance of one astronomical unit. Its mean value is 1367.7 W m^{-2} (*http://en.wikipedia.org/wiki/Solar_constant#Solar_constant*).

Solar Radiation: All the electromagnetic radiation and subatomic particles radiated from the Sun, especially that part that reaches the Earth (*http://en.wiktionary.org/wiki/solar_radiation*).

Specific Heat: It is the amount of heat needed to raise the temperature of 1 gram of a substance 1 degree Celsius (*http://earthstorm.mesonet.org/materials/ref_heattrans.php*).

States of Matter: On Earth, these are gases, liquids and solids. The microscopic particles that make up the material in each of these states exhibit distinct behaviors (*http://www.chem.purdue.edu/gchelp/atoms/states.html*).

Sublimation: It is the phase change from solid to gas with no intermediate liquid stage (*http://ga.water.usgs.gov/edu/watercyclesublimation.html*).

Surface Runoff: Precipitation that does not infiltrate into the ground and therefore flows (downslope) over the land surface (*http://ga.water.usgs.gov/edu/watercyclerunoff.html*).

Symmetry: Exact correspondence on either side of a dividing line, plane, center or axis. (*http://en.wiktionary.org/wiki/symmetry*).

System: A group of interacting, interrelated, or interdependent elements forming a complex whole (*http://www.thefreedictionary.com/system*).

Temperature: It is the measure of the average kinetic energy of the particles in a substance. In practical terms, temperature is a measure of heat (*http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/temper.html#c1*).

Temperature Gradient: It is a physical quantity that describes in which direction and at what rate the temperature changes the most rapidly around a particular location. The temperature gradient is a dimensional quantity expressed in units of degrees (on a particular temperature scale) per unit length. The SI unit is kelvin per meter (K/m) (*http://en.wikipedia.org/wiki/Temperature_gradient*).

Temperature Gradient Metamorphism: The changes that occur to snow crystals over time in a deep snow pack, when the temperature at the surface of the snow is significantly colder than the temperature at the base of the snow for a period of time. This is most apparent when air temperatures are between 0 and -40°C. Due to the insulating properties of snow, the base of a deep layer of snow will remain higher than the air temperature in these conditions.

Thermal Conductivity: A measure of the ability of a material to transfer heat. Given two surfaces on either side of the material with a temperature difference between them, the thermal conductivity is the heat energy transferred per unit time and per unit surface area, divided by the temperature difference. It is expressed in watts per Kelvin (*http://www.thefreedictionary.com/thermal+conductivity*).

Thermocline: A distinct layer in a large body of water, such as an ocean or lake, in which temperature changes more rapidly with depth than it does in the layers above or below. Thermoclines may be a permanent feature of the body of water in which they occur, or they may form temporarily in response to phenomena such as the solar heating of surface water during the day. Factors that affect the depth and thickness of a thermocline include seasonal weather variations, latitude and longitude, and local environmental conditions (*http://www.thefreedictionary.com/thermocline*).

Transect: (1) A line on the ground along which observations are made or data are collected at fixed intervals. (2) A line across a region selected to show spatial relationships of landforms, vegetation, or other features. (*Definition adapted from: Armantrout, N. B. compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.)*

Transpiration: The release of water from plant leaves. Transpiration rates depend on weather conditions such as air temperature, humidity, sunlight availability and intensity, precipitation, and wind as well as soil type and saturation and land slope (*http://ga.water.usgs.gov/edu/watercycleevapotranspiration.html*).

Watt (W): It is a unit of power equal to 1 joule per second (*http://wordnetweb.princeton.edu/perl/webwn?s=watt*).

Some Snow Studies Web Resources

Alaska Lake Ice and Snow Observatory Network (ALISON) for information on snow, lake ice, heat fluxes and setting up your own lake ice observation site.

Albedos of snow, ice and tundra page from arcticice.org: Photos of a variety of different landscapes and corresponding albedos.

Atmospheric Effects on Incoming Solar Radiation from PhysicalGeography.net: Details on the role of the atmosphere in reflecting sunlight.

Arctic Climate Modeling Program: The research-based Arctic Climate Modeling Program (ACMP) is funded by NSF ITEST. Curriculum based resources were designed with input from 21 scientists from the University of Alaska Fairbanks Geophysical Institute. Resources include K-12 inquiry-based classroom lessons, a student network for observing arctic weather, digital lectures, and an interactive multimedia learning system (on DVD).

The Bentley Snow Crystal Collection of the Buffalo Museum of Science: Available online, this is a comprehensive collection of photos of snowflakes and snow crystals. Wilson A. Bentley, nick-named “Snowflake Bentley,” spent his life taking photographs of snowflakes.

Earth’s Albedo and Global Warming at TeachersDomain.org: From TeachersDomain.org, this interactive activity adapted from NASA and the U.S. Geological Survey illustrates the concept of albedo—the measure of how much solar radiation is reflected from Earth's surface.

Earth's Albedo from Meteorology: Understanding the Atmosphere: Includes a simulation that shows variations in albedo at different locations and in different months.

Earth's Albedo in Decline from the NASA Earth Observatory: Graphic and discussion of changes to the Earth's albedo.

Geophysical Aspects of Sea-Ice Nomenclatures: For supplemental information on types of sea ice.

The GLOBE Program: GLOBE (Global Learning and Observations to Benefit the Environment) is a worldwide hands-on, primary and secondary school-based science and education program. GLOBE's vision promotes and supports students, teachers and scientists to collaborate on inquiry-based investigations of the environment and the Earth system working in close partnership with NASA and NSF Earth System Science Projects (ESSPs) in study and research about the dynamics of Earth's environment.

Ice Albedo - Global View from the Goddard Space Flight Center: This is a conceptual animation showing how polar ice reflects light from the sun.

Illustrated Lessons: Line Symmetry from LINKS Learning: This video tutorial illustrates basic symmetry concepts.

Historical Trends in Lake and River Ice Cover in the Northern Hemisphere. (2000). J.J. Magnuson and 13 others. *Science*, Volume 289, 1743-1746.

Los Angeles Pierce College Weather Station: Detailed information on the physics of water, the Earth's water cycle, and the role of water in the Earth's energy budget.

Measuring the Temperature of Water, Snow and Ice (pdf): A variety of activities for students of various ages for measuring the temperature of snow and water. You can also view Measuring the Temperature of Water in the Content Map at the left.

NASA Earth Observatory - Climate & Earth's Energy Budget: Detailed information on the Earth's energy budget, its relationship to climate change, and much more.

NASA Earth Observatory - Global Albedo: Satellite imagery and information from NASA related to global albedo.

National Snow and Ice Data Center Education Center: Earth is home to snow and ice in many different forms. The frozen realms of the cryosphere influence life all over our planet. Here in the NSIDC Education Center, you will find a range of information about Earth's snow and ice, from comprehensive "All About" sections to quick facts on popular snow and ice topics.

Project Learn: Cycles of the Earth and Atmosphere: The goal of *LEARN* is to increase middle school science teacher knowledge of and interest in the atmospheric sciences. The site has lots of great information on many atmospheric factors (ozone layer, greenhouse effect, etc).

A Snow Crystal Primer by Kenneth G. Libbrecht from CalTech: A great introduction to the basic facts about snowflakes and snow crystals. The parent site, *SnowCrystals.com*, contains additional information and activities on snowflakes, including a *Snow Crystal Photo Gallery*.

Snowflake Physics at TeachersDomain.org: In this interactive activity adapted from SnowCrystals.com, learn about snowflake formation. Explore the molecular structure of ice and learn how the typical six-sided shape of snowflakes is due to the arrangement of water molecules in a hexagonal crystal lattice. Discover how snowflakes form and how different conditions affect their growth and morphology. Includes a background essay and questions for discussion, as well as a downloadable version of the activity.

Teachers' Domain: This is an online library of more than 1,000 free media resources featuring material from NOVA, Frontline, Design Squad, American Experience, and others. Teachers' Domain resources include video and audio segments, Flash interactive content, images, documents, lesson plans for teachers, and student-oriented activities. Teachers' Domain strives to strengthen teacher knowledge by providing innovative teaching methods that incorporate technology in the classroom and inspire students to learn.

UN Environmental Programme Global Outlook for Ice and Snow: Ice, snow and climate change are closely linked. The Global Outlook for Ice and Snow investigates those linkages. It also presents information on the trends in ice and snow, the outlook for this century and beyond and the consequences to ecosystems and human well-being of these changes. It covers all parts of the cryosphere (the world of ice): snow, land ice, sea ice, river and lake ice, and frozen ground. The "Global Outlook for Ice and Snow" report was written by more than 70 scientists from around the world.

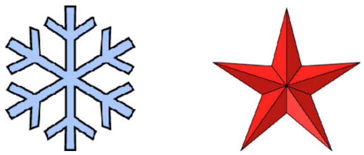
USGS Water Science for Schools: Information about the distribution of water on Earth.

Why Do Snowflakes Come in So Many Shapes and Sizes? Lesson Plan at teachersdomain.org: In this in-depth lesson, students build an apparatus that creates conditions similar to a winter cloud and produce their own snow crystals indoors. By watching the snow crystals grow, they learn about the molecular forces that shape ice crystals, and gain a deeper understanding of the states of matter. By exploring media resources, including microphotographs of real snowflakes, students also learn about molecular forces, the particulate nature of matter, and condensation.

APPENDIX 1

Check Your Thinking:

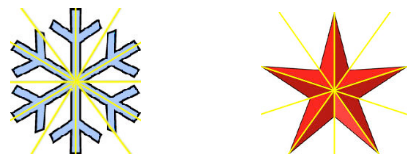
The two images below are examples of rotational symmetry. How many lines of symmetry are possible in each?



1.

Answer:

Six lines of symmetry are possible for the snowflake and five lines of symmetry are possible for the red star.



1.

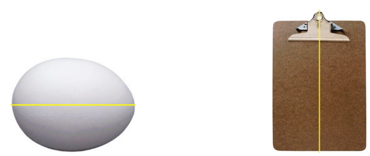
Check Your Thinking:

The two images below are examples of reflection symmetry. Can you identify the line of symmetry in each?

2

Answer:

The line of symmetry runs through the middle of the egg in the horizontal and in the vertical for the clipboard.



2.

Check Your Thinking:

Can you name the main large Earth systems?

3.

Answer:

Atmosphere, lithosphere, biosphere, hydrosphere and cryosphere.

3.

Check Your Thinking:

What does "sphere" mean?

4.

Answer:

Any round body, from Latin = sphaera = globe; Greek = sphaira = ball. In this case, we use sphere to refer to systems, *such as the water system (hydrosphere).*

4

Check Your Thinking: *What do **atmo-**, **litho-**, **bio-**, **hydro-** and **cryo-** mean?* 5.	**Answer:** *Atmo:= air; Greek = atmós = vapor, smoke. Litho: Greek = líthos = stone. Bio: Greek = bios = life. Hydro: Greek = hýdōr = water. Cryo: Greek = kryos = cold.* 5.
Check Your Thinking: *What is the atmosphere made up of?* 6.	**Answer:** *The gases that surround the Earth. These include: Nitrogen (78%), Oxygen (21%), Argon (0.9%), Carbon Dioxide (0.04%), and very small amounts of other gases including water vapor (roughly 1% globally, with great local variation).* 6.
Check Your Thinking: *What is the lithosphere made up of?* 7.	**Answer:** *All the rocks and soil in the Earth's crust and upper mantle, approximately 100 km thick. (The layer of the Earth in which soil forming processes take place is sometimes called the pedosphere.)* 7.
Check Your Thinking: *What is the biosphere made up of?* 8.	**Answer:** *All the organisms on the Earth; from bacteria to moles in the soil, lichens to sequoia trees and mice to elephants on the land, insects to birds in the sky, and phytoplankton to whales in the ocean.* 8.

Check Your Thinking: *What is the hydrosphere made up of?* 9.	**Answer:** *All the water on the Earth and in the atmosphere.* 9.
Check Your Thinking: *What is the cryosphere made up of?* 10.	**Answer:** *All of the ice, snow and frozen ground (permafrost). This includes glaciers, seasonally frozen lakes and rivers and sea ice.* 10.
Check Your Thinking: *What do we mean by the Earth's energy budget?* 11.	**Answer:** *An energy budget refers to the approximate balance between energy flowing into the Earth and its systems, and energy flowing out of the Earth and its systems.* 11.
Check Your Thinking: *Where does the energy that enters the Earth's energy budget come from?* 12.	**Answer:** *Energy comes from the Sun, in the form of solar radiation, or radiant energy.* 12.

Check Your Thinking:

Where does the energy that leaves the Earth's energy budget come from?

13.

Answer:

- *Solar radiation (shortwave sunlight) reflected by the Earth's atmosphere and clouds*
- *Solar radiation that hits the Earth's surface and is reflected directly back into space*
- *Solar radiation that has been absorbed by the Earth and re-radiated as long-wave radiation.*
- *Energy that is radiated by the Earth, absorbed by the atmosphere and clouds and then radiated by them.*

13.

Check Your Thinking:

Where is energy stored in the Earth's energy budget?

14.

Answer:

- *In the water of oceans, lakes, rivers*
- *In the ground*
- *In the atmosphere (such as, in clouds and water vapor)*

14.

Check Your Thinking:

What factors influence the amount of solar energy reaching the Earth's surface?

15.

Answer:

- *Duration of daytime and Season (tilt of the Earth)*
- *Latitude*
- *Cloud cover*
- *Angle of incidence of the Sun's rays*

15.

Check Your Thinking:

*Which colors **reflect** the most sunlight?*

16.

Answer:

*Light colors **reflect** the most sunlight. White is the best reflector. Light-colored materials will be cooler when exposed to sunlight.*

16.

Check Your Thinking: *Which colors **absorb** the most sunlight?* 17.	***Answer:*** *Dark colored materials **absorb** more light, and convert it into heat. Dark-colored materials will be warmer when exposed to sunlight.* 17.
Check Your Thinking: *What parts of the Earth's systems can reflect solar radiation back into space?* 18.	***Answer:*** *Almost all surfaces reflect some solar radiation.* 18.
Check Your Thinking: *Of the following materials on the surface of the Earth, which will **reflect** the most solar radiation back into space?* • *Vegetation (grass and trees)* • *Bare ground* • *Water* • *Ice* • *Snow* 19.	***Answer:*** *All reflect some sunlight, but snow and bare white ice are the best reflectors. The random nature of the matrix of ice crystals within snow causes snow to be an excellent reflector of sunlight. In fact, snow reflects light so effectively that skiers often get sunburnt from the sunlight reflected off the snow.* 19.
Check Your Thinking: *What is energy? What kinds of energy can you name?* 20.	***Answer:*** *Energy is the ability or capacity to do work. There are five kinds:* • *Potential* • *Kinetic* • *Internal* • *Heat* • *Radiant* 20.

Check Your Thinking: *What does temperature measure?* 21.	**Answer:** *Temperature measures the average kinetic energy of the particles in a substance (matter). Temperature is a measure of heat energy.* 21.
Check Your Thinking: *What are the three ways that heat can be transferred? Describe each one.* 22.	**Answer:** ***RADIATION**: energy is transferred by electromagnetic radiation. Energy is emitted from the surface of the object due to its temperature.* ***CONDUCTION:** energy is transferred by direct contact, usually in solids.* ***CONVECTION**: energy is transferred by the mass motion of molecules, usually in liquids and gases.* 22.
Check Your Thinking: *How is energy transferred throughout the Earth's atmosphere?* 23.	**Answer:** ***Radiation** from the Sun, the Earth's surface, the atmosphere and clouds;* ***Reflected** from the atmosphere, clouds and the Earth's surface:* ***Convection** moves energy up (warm air rises) and down (cold air descends);* ***Conduction** moves a small amount of energy near the Earth's surface (air is a poor conductor).* 23.
Check Your Thinking: *What happens to the temperature of a lake over the course of the spring and summer? Why does this happen?* 24.	**Answer:** *The temperature of the water rises over the course of the summer as energy is transferred to the lake from the warmer overlying air. In the summer, the days are longer and the sun is higher in the sky than in winter. This means that there is more intense solar radiation for longer periods of time available to warm the Earth's surface.* 24.

Check Your Thinking: *What happens to the temperature of the same lake in the fall and winter? Why does this happen?* 25.	**Answer:** *The temperature of the lake decreases over the course of the winter, until (in some cases) the surface of the lake freezes. This happens because energy is transferred from the lake water to the colder overlying air. The air temperature is colder because of the reduced amounts of solar energy. The tilt of the Earth causes the angle of the sun's rays to be less direct (acute angles), so less solar radiation is reaching the Earth's surface.* 25.
Check Your Thinking: *Why does ice float on water?* 26.	**Answer:** *Almost all substances of Earth have their maximum density in their solid phase. One of the few exceptions is water. It has a higher density (1000 kg m^3 at 4°C, the temperature of maximum density) in its liquid phase than in its natural solid state (ice, 830-917 kg m^3). As a consequence, ice floats on water.* 26.
Check Your Thinking: *What are the three main states of matter on Earth?* 27.	**Answer:** • *Gas* • *Solid* • *Liquid* 27.
Check Your Thinking: *What causes changes in the state of matter on Earth?* 28.	**Answer:** *Either energy is added to matter or removed from matter.* 28.

Check Your Thinking: *Name the main state-of-matter transitions. Which transitions require energy input and which release energy?* 29.	**_Answer:_** • *Solid-to-liquid* – melting; **requires energy** • *Liquid-to-solid* – freezing; **releases energy** • *Liquid-to-gas* – evaporation; **requires** • *Gas-to-liquid* – condensation; **releases** • *Solid-to-gas* – sublimation; **requires** • *Gas-to-solid* – deposition; **releases** 29.
Check Your Thinking: *What are the states of matter found in the water cycle? Give examples of each.* 30.	**_Answer:_** • *Solid - ice (snow, river and lake ice, sea ice, glaciers and ice sheets)* • *Liquid - water (lakes, rivers, oceans, rain, groundwater)* • *Gas - clouds and water vapor* 30.
Check Your Thinking: *What do we mean by thermal conductivity?* 31.	**_Answer:_** *Thermal conductivity is the rate of heat conduction through material per unit area (cross section), per unit thickness (length), per unit temperature difference. The SI units are W m^{-1} K^{-1} (watt per meter Kelvin).* 31.
Check Your Thinking: *Is snow an effective insulator?* 32.	**_Answer:_** *That depends – dry, new snow is a good insulator because it contains a lot of air by volume. Wet or hard-packed snow is not as good an insulator because it contains less air.* 32.

Check Your Thinking: *What type of snow do you think would be the best insulator:* • *Wet, heavy snow;* • *Dry, well-packed snow; or* • *New, fluffy snow?* 33.	***Answer:*** *New, fluffy snow would be the best insulator because it contains the most air, and air has a very low thermal conductivity (it does not transfer heat well).* 33.
Check Your Thinking: *What do you need to measure in order to determine the density of snow (or anything else)?* 34.	***Answer:*** *The volume of the material and its mass.* 34.
Check Your Thinking: *Which way does heat flow through a snow cover?* 35.	***Answer:*** *It depends:* *If the air temperature is higher than the snow surface temperature then heat will flow into the snow.* *If the snow surface temperature is higher than the air temperature then heat will flow out of the snow to the atmosphere.* 35.
Check Your Thinking: *Under what conditions would the temperature at the bottom of the snow be higher than at the snow surface?* 36.	***Answer:*** *The snow cover is warmed from below by heat that is transferred from the ground (or water under a lake or river ice cover) and warmed or cooled at its surface by the air above it.* *If air temperatures have been cold for some time, the snow surface may have cooled to a temperature below that of the snow base.* 36.

Check Your Thinking: *Under what conditions would the temperature at the bottom of the snow be lower than the air temperature?* 37.	**Answer:** *The snow cover is warmed from below by heat that is transferred from the ground (or water under a lake or river ice cover) and warmed or cooled at its surface by the air above it.* *If air temperatures have been warm for some time, the snow surface may have warmed to a temperature above that of the snow base.* 37.
Check Your Thinking: *Name the properties of ice, snow and water that help to regulate the global climate.* 38.	**Answer:** *Albedo (snow and ice)* *Good Insulator (new/low density snow)* *High specific heat (water)* 38.
Check Your Thinking: *What impact does the high albedo of snow and ice have on the Earth's energy budget?* 39.	**Answer:** *Snow and ice reflect solar energy back into space and keeps the surface of the Earth cool. They also impede the flow of heat from the ground or water into the atmosphere.* 39.
Check Your Thinking: *What impact does water's high specific heat capacity have on the Earth's energy budget?* 40.	**Answer:** *The high specific heat capacity of water means that in summer it cools the surrounding area as heat is used to warm the water. In winter the water warms the surrounding area as heat is released from it.* 40.

Check Your Thinking: *How does the snow's insulating characteristics affect local and regional energy budgets?* 41.	***Answer:*** *When the snow is new or of low density and the overlying air temperatures are lower than the snow, it slows the transfer of heat from the ground or water to the atmosphere and maintains cooler air temperatures.* 41.
Check Your Thinking: *What do you think would happen to the distribution, duration and thickness of snow and ice covers on the Earth if the global temperature increases slightly?* 42.	***Answer:*** *Snow and ice covers may be distributed differently over the Earth's surface. In some places they would not be as deep/thick and they would not last as long as they do now; in other places the reverse may be true.* 42.
Check Your Thinking: *If there were less snow and ice on the planet, what do you think would happen to the average temperature of the Earth? Why?* 43.	***Answer:*** *The average air temperature would increase because of loss of snow and ice will lead to an increase in the Earth's average surface albedo leading to greater heat absorption and higher temperatures.* 43.