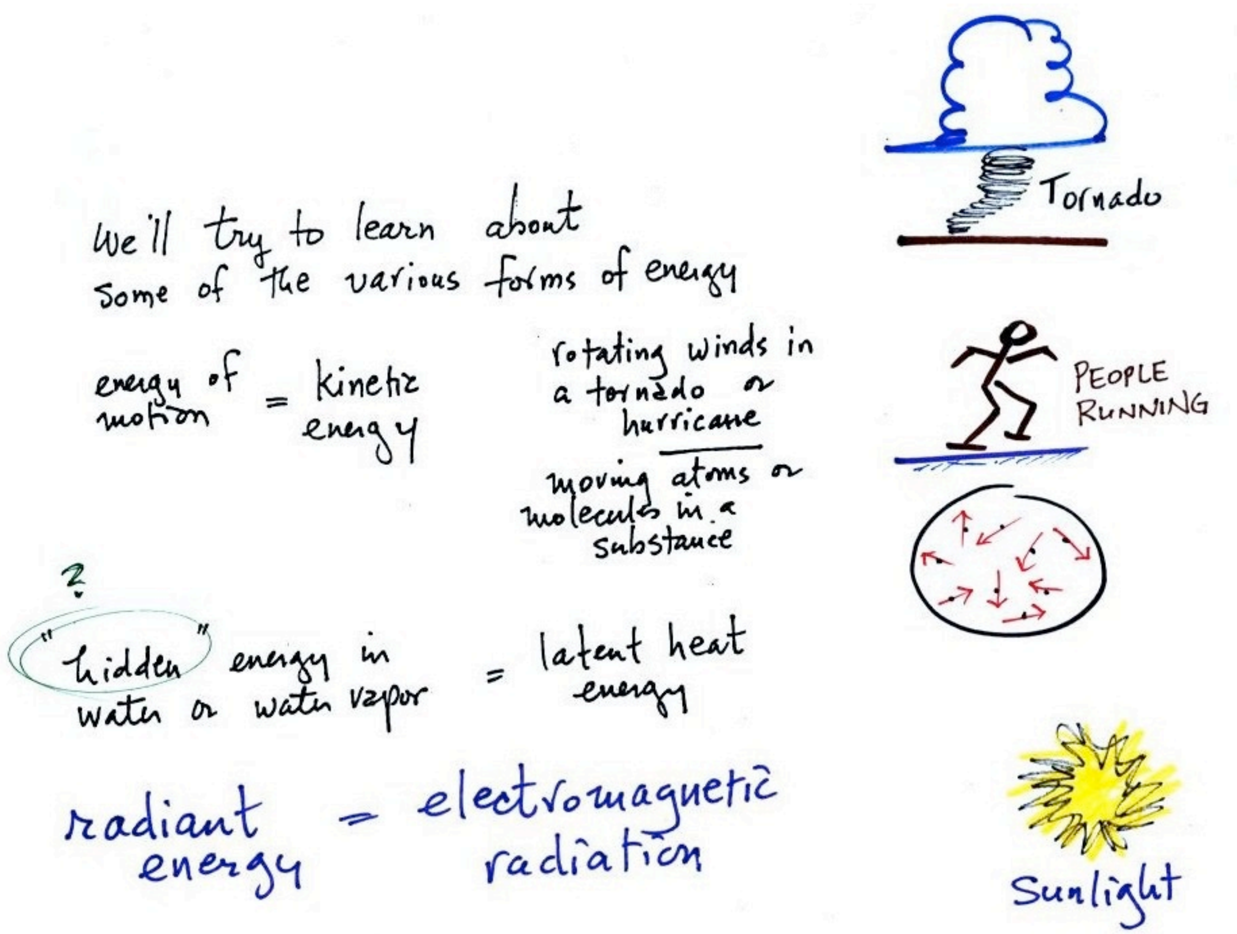
Module 4 - Lecture 10

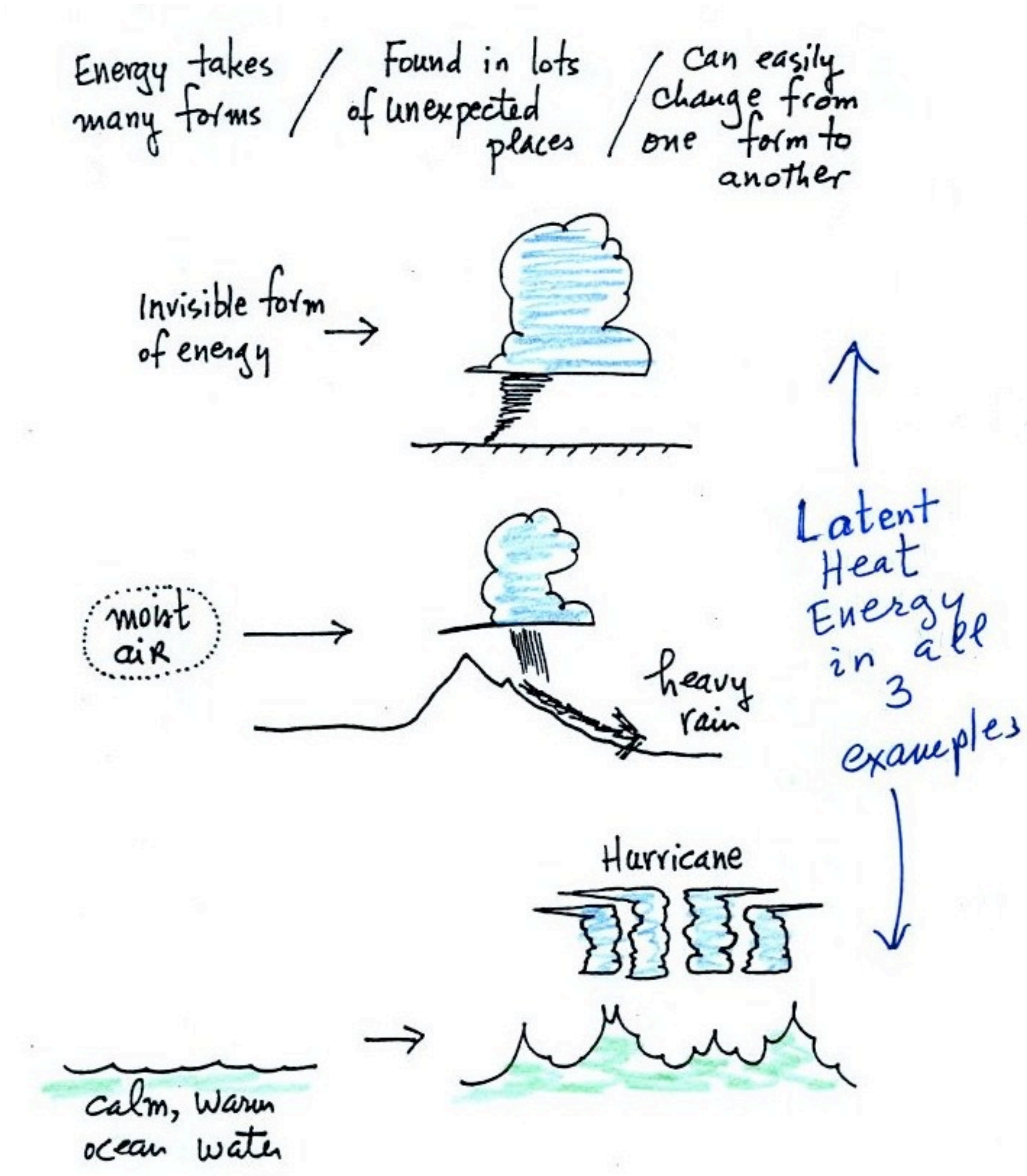
This lecture will discuss three different forms of energy: kinetic energy, latent energy and radiant energy. They are illustrated in the figure below.



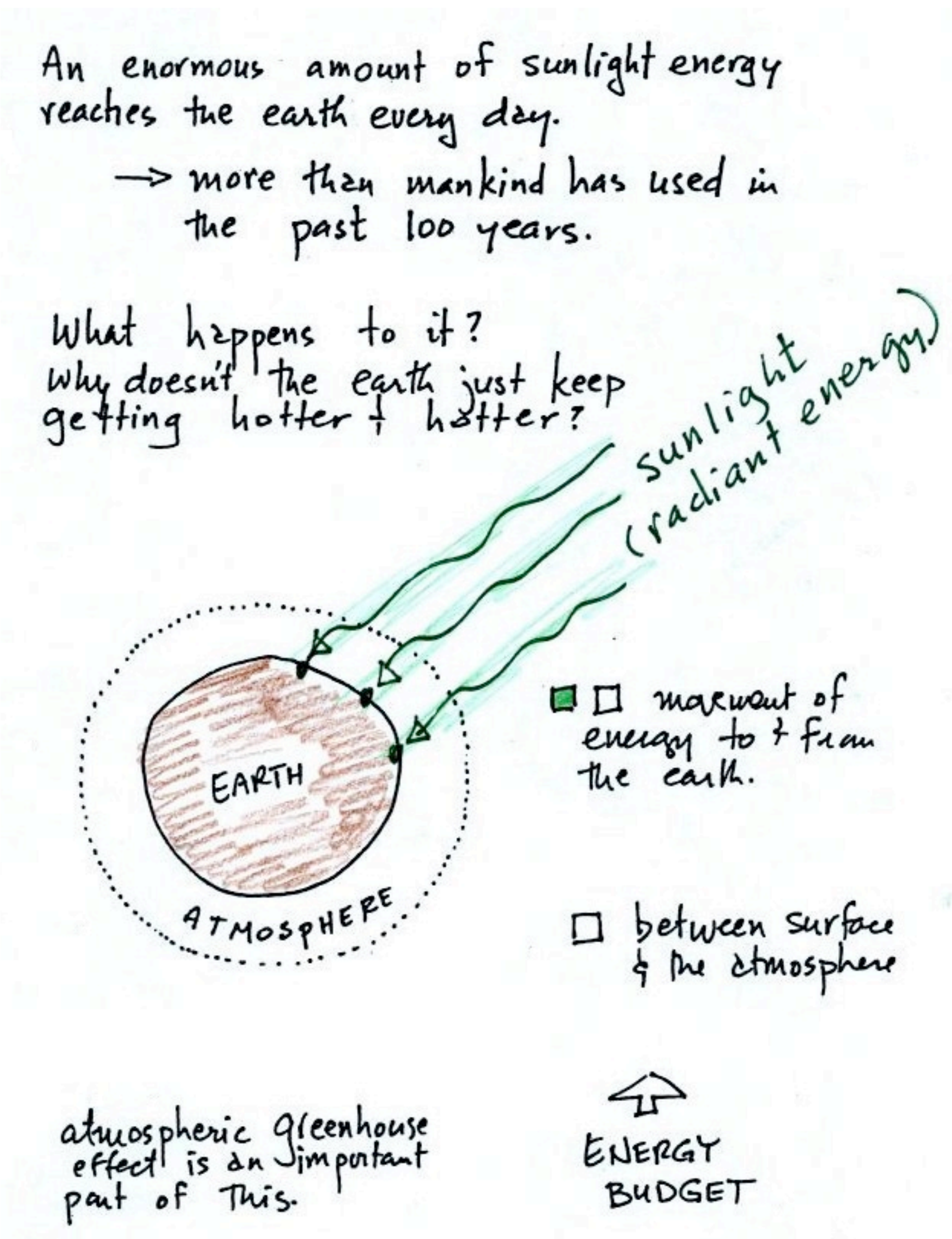
Kinetic energy is the energy of motion. Kinetic energy is generated by molecules moving around in the atmosphere and is a function of temperature. We will not worry about the math here. What you need to know is that molecules at a higher temperature move faster than molecules at a lower temperature.

Latent heat energy refers to energy that is hidden in water and water vapor. The energy is released when water vapor condenses into a liquid or liquid water freezes. In clouds, water phase changes release an enormous amount of energy into the atmosphere. You can imagine the work that it takes to carry a gallon of water, which weighs 8 pounds, from Tucson to the top of Mt. Lemmon. To accomplish the same goal the atmosphere must first evaporate the water, which requires about 100 times the energy that you would use to carry 8 pounds of water to the summit of Mt. Lemmon. And the atmosphere contains much more than a single gallon of water.

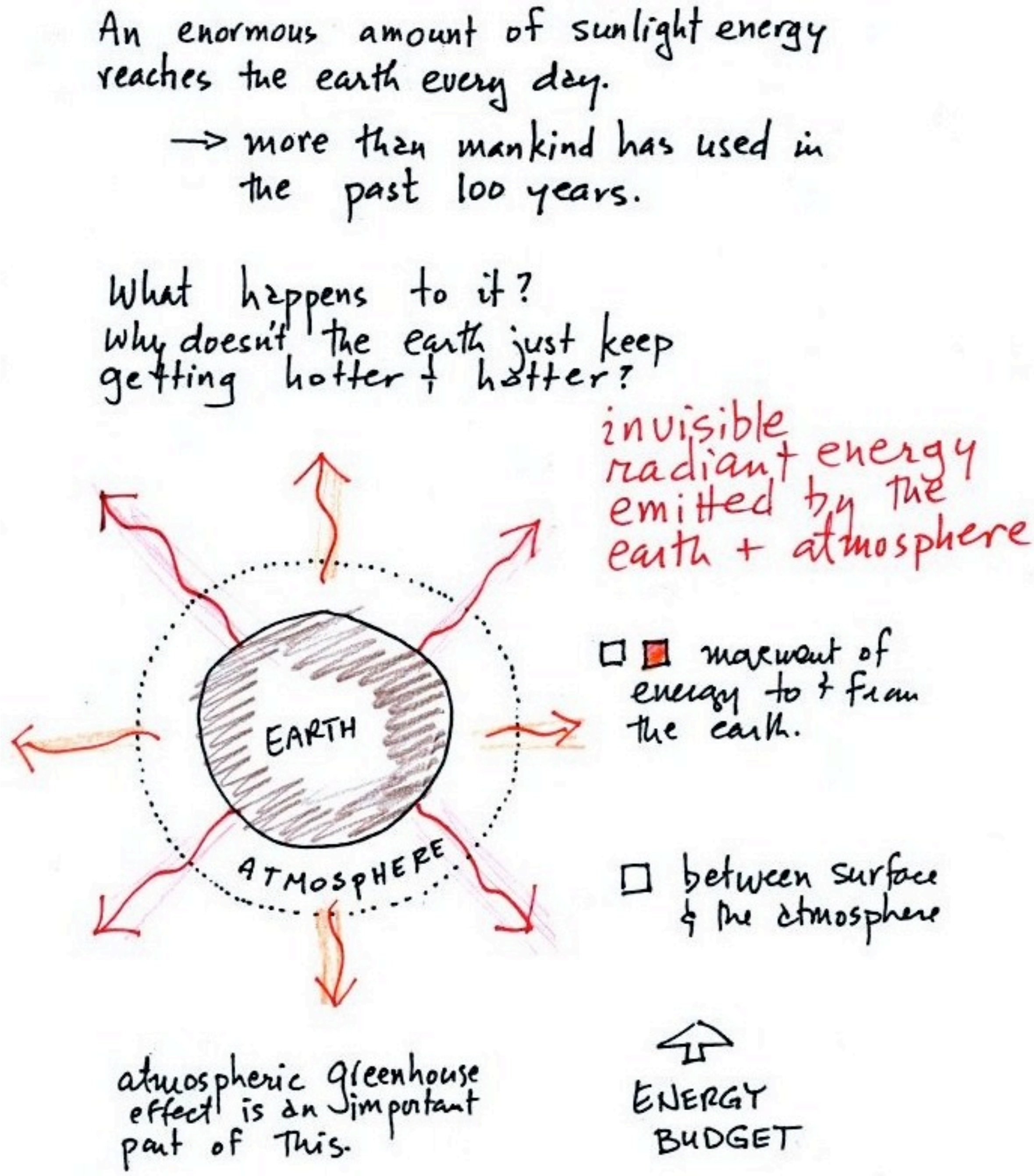
The picture below illustrates how latent heat is released into the atmosphere.



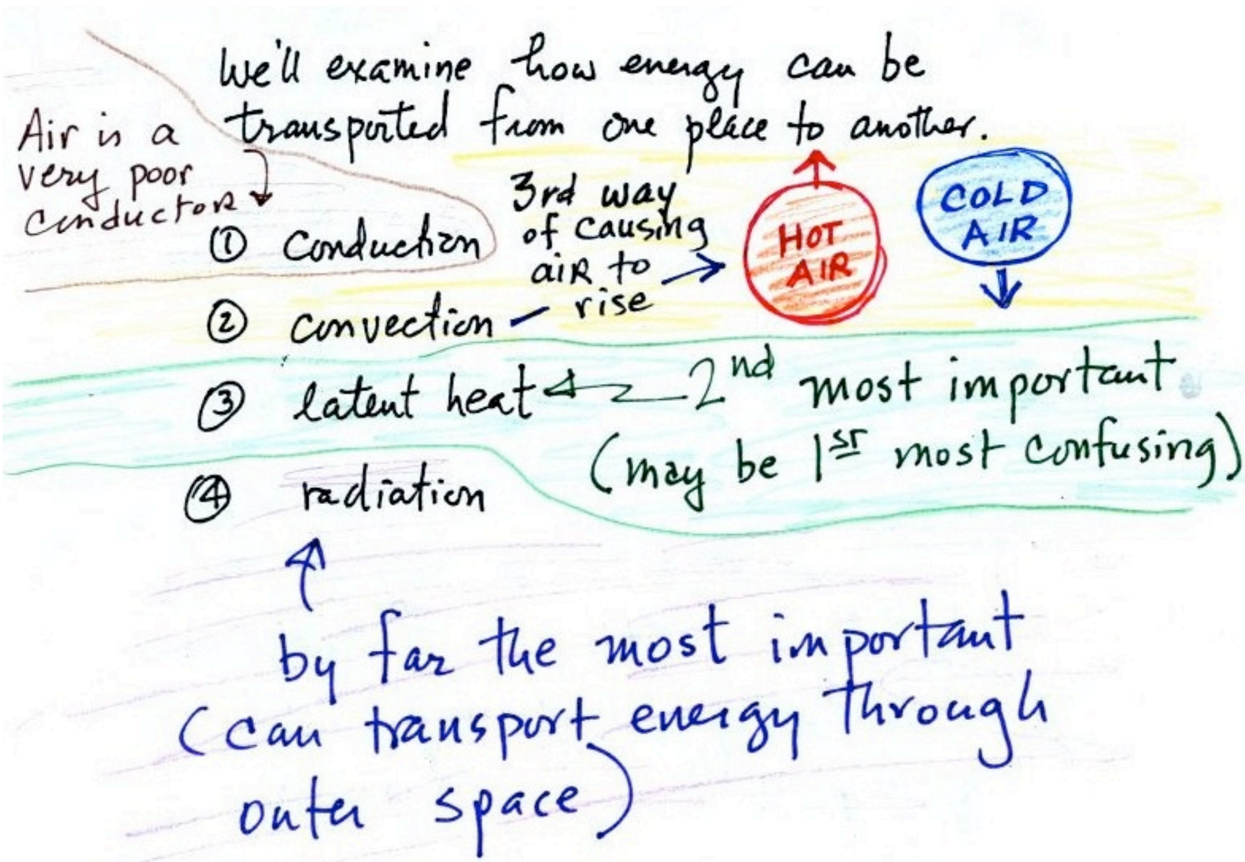
Radiant energy is essential to all life on Earth. The most familiar form of radiant energy is solar energy. Through photosynthesis, plants convert solar energy to chemical energy into food which animals and people consume for energy.



What prevents the huge amount of solar radiation that the earth receives from overheating the earth? The answer is that the earth also sends energy back into space in the form of infrared energy (the red arrows in the figure below). A balance between incoming and outgoing energy is achieved and the earth's annual average temperature remains constant. Infrared light is invisible to the human eye. Sunlight also contains a small amount of infrared energy.



There are four processes by which energy is transported in the atmosphere: conduction, convection, latent heat and radiant energy.



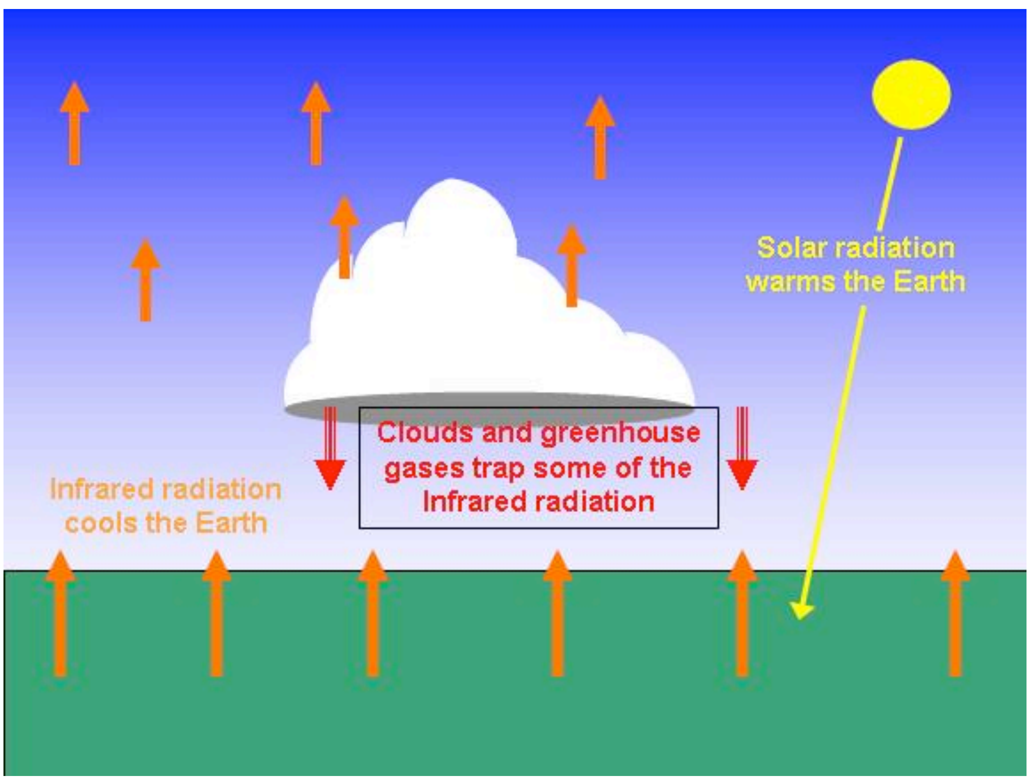
By far the most important energy transport mechanism is ***electromagnetic radiation***, the only process that can transport energy through empty space. The sun provides the energy that sustains life on earth and the earth radiates infrared energy back into space. Electromagnetic radiation is responsible for about 80% of the energy transported between the ground and atmosphere.

L***atent heat*** is the second most important energy transport process. Energy is transported when water vapor or liquid water, which contain hidden latent heat energy, move from the warm tropics to the colder, polar regions.

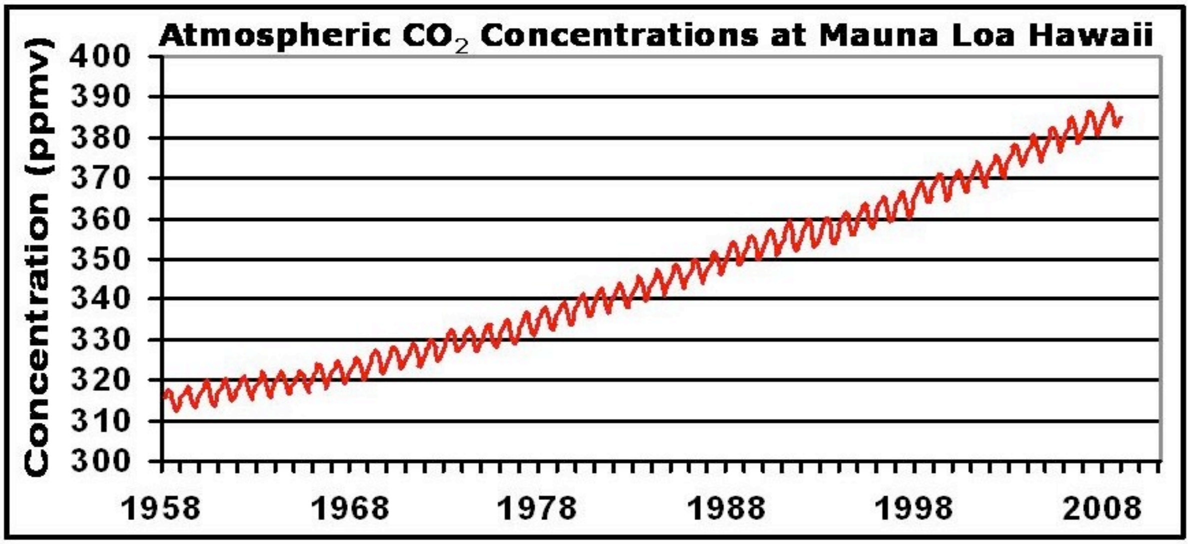
Convection is the turbulent mixing that occurs when you boil water. Convection also occurs in air because air is also a fluid, even though it is invisible. The turbulence you experience while flying is an example of convection. Rising parcels of warm air and sinking parcels of cold air are another example of convection. A very important example of convection is the ocean currents such as the Gulf Stream, which transport energy from the warm tropics to colder Polar Regions. Note that convection is one of four ways of causing rising air motions in the atmosphere (convergence, fronts, and topographic lifting are the others).

Conduction is the transfer of thermal energy due to a temperature gradient. Heat spontaneously flows from a region of higher temperature to a region of lower temperature until thermal equilibrium is reached. When you heat a pan of water on the stove, heat is conducted through the pan to the liquid. Pans are made of metal because metals are good at conducting heat. By contrast, the atmosphere is such a poor conductor of heat that it is considered an insulator rather than a conductor.

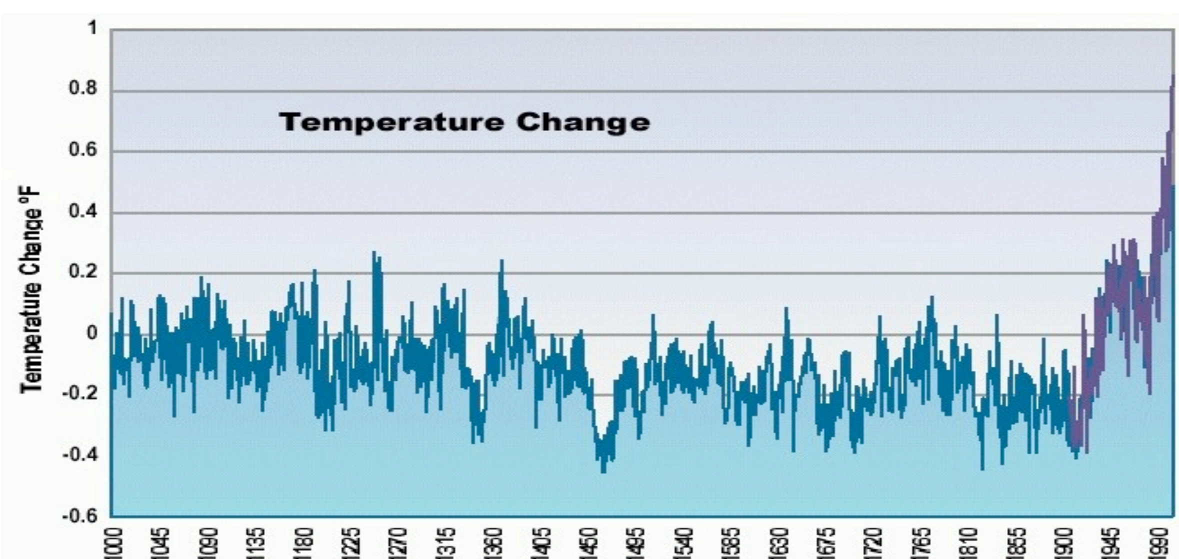
Now we will discuss the ***greenhouse effect***. When the surface of the earth is warmed by sunlight, it emits infrared radiation. Certain gases in the atmosphere absorb much of this infrared energy and warm the atmosphere by radiating the infrared energy back to the surface. This process is called the greenhouse effect, which is vital to life on earth. Without the greenhouse effect, the entire earth would be covered with a sheet of ice because the planet would have an annual average surface temperature of about 0^o F. Instead the global annual average temperature is about 60^o F. The greenhouse effect is illustrated in the picture below, which was obtained from WeatherQuestions.com.



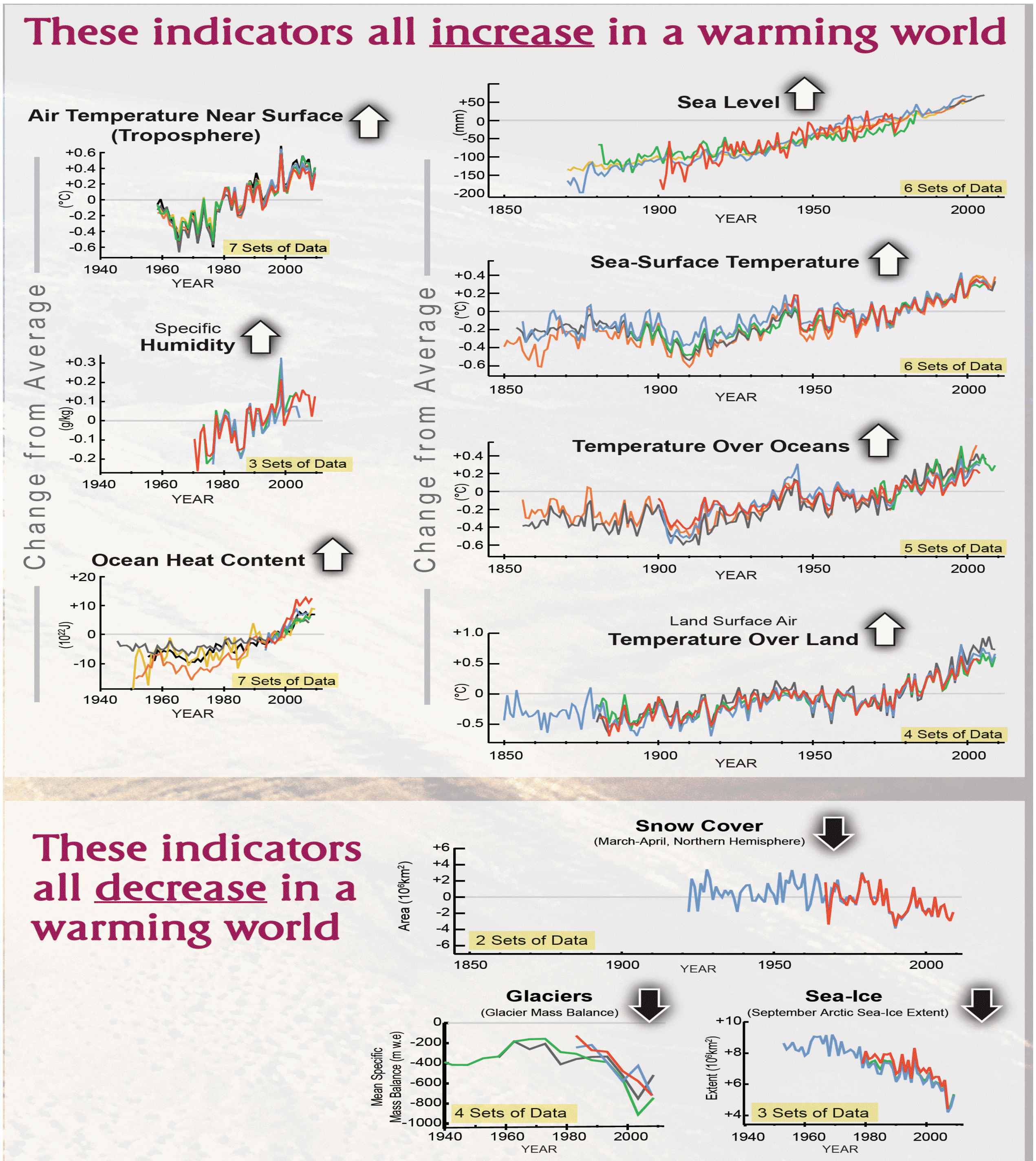
Carbon dioxide, water vapor, ozone and methane are the most important greenhouse gases. Carbon dioxide is released into the atmosphere when fossil fuels such as gasoline, diesel and coal are burned. Scientists are concerned because the concentration of carbon dioxide has increased, as illustrated by these measurements made in Hawaii. (This graph was obtained from the Carbon Dioxide Information Analysis Center.)



Scientists are now fairly certain that the increased levels of carbon dioxide are causing increased temperatures on earth. Here is the famous hockey stick graph which shows that the earth is warmer now than in the past 1000 years. The UA's own Malcolm Hughes, a professor in the Tree Ring Laboratory, was one of the creators of this graph. Detractors (some of them hired by the energy industry) argue that it was actually warmer during the Medieval Warm Period (700-1300 AD) and that certain sets of tree ring data should have been either excluded or included in the analysis. (This graph was taken from the Global Warming and the Climate web site.)



The increase in average global temperature is not large, but it may already be having some effects on climate indicators, as shown in the figure below (from Wikipedia). More research is needed on how these climate changes will affect human health and welfare. There is some evidence that the ranges of insect vectors that transmit human and livestock diseases may expand and some areas of the world may experience drought.



Fossil fuel energy is absolutely essential for society, yet burning fossil fuels generates carbon dioxide which causes climate change. Balancing the world's the need for energy with the need to reduce carbon dioxide emissions is going to require wisdom from policy makers and more research into alternate fuels which do not generate carbon dioxide. Here at UA, scientists are conducting research into improving the efficiency of solar energy.

In this section, we introduce an equation that shows the relationships between temperature, energy and mass. When you add energy to an object, the object will usually warm up (conversely when you take energy from an object the object will cool). It is relatively easy to come up with an equation that allows you to figure out what the temperature change will be. Do not worry, the math is not difficult.

Adding energy to (or removing energy from) an object will <u>usually</u> cause the object's temperature **to increase (decrease).**

what is the relationship between energy added or removed, ΔE, and temperature change, ΔT?

$$\Delta T = \frac{\Delta E}{\text{mass} \times \text{specific heat}}$$

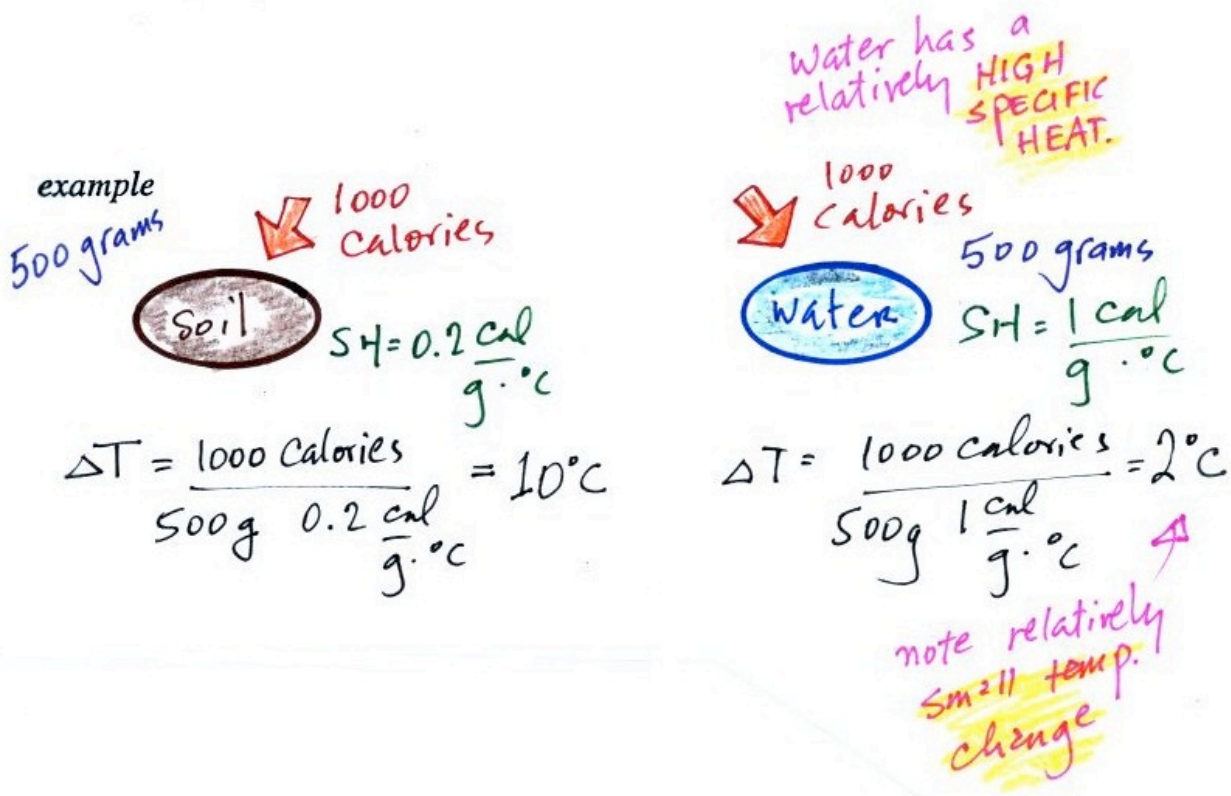
heats up more, reaches a boil more quickly.

specific heat aka thermal capacity thermal mass

equal amounts of energy added to each

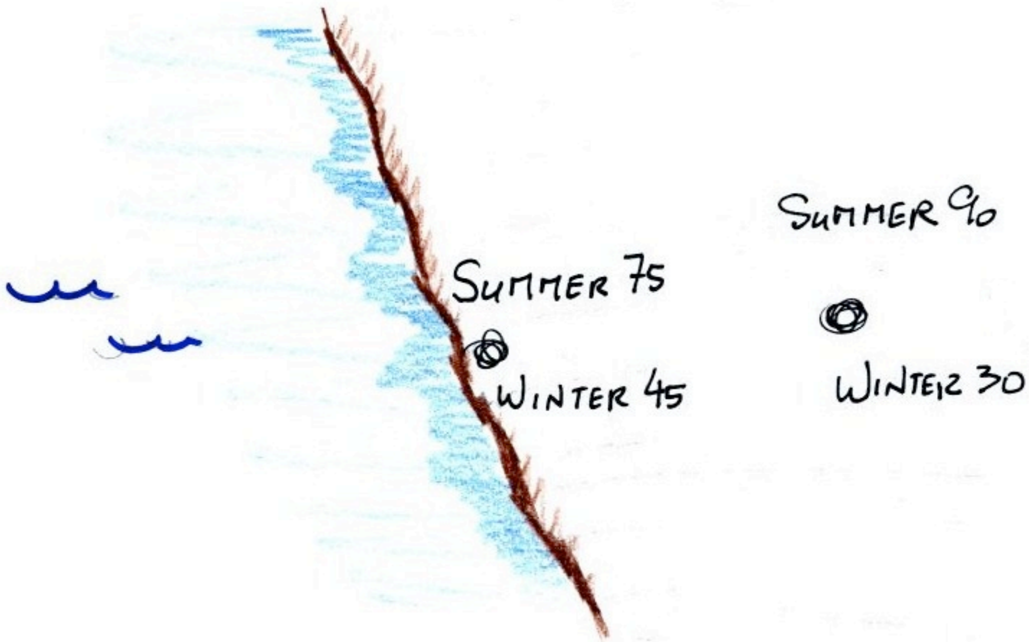
The temperature increase depends upon the mass of the object and the ability of the object to absorb heat (specific heat). When you add equal amounts of energy to a large pan of water and a small pan of water, the small pan will heat up more quickly because it has less mass. If you boil wine and wine in pans of equal size, the wine will boil first because it has a lower specific heat. That is, it can absorb less heat before increasing in temperature.

Water has a high specific heat, which means that a lot of energy is needed to raise the temperature of water. Soil has a lower specific heat, which means that less energy is needed to raise the temperature of soil. In the figure below, equal amounts of energy (1000 calories, note that calories are units of energy) are added to equal masses (500 grams) of water and soil. We use water and soil in the example below. Because water has a higher specific heat than soil, it only warms up 2° C as compared to 10° C for the soil.



The different warming rates of soil and water have important effects on regional climate. Oceans moderate the climate. Coastal cities which are near a large body of water will be cooler in the summer and warmer during the winter compared to a city that is surrounded by land. A good example is San Francisco which has monthly average temperatures that vary only 13 degrees. To a lesser extent, the same effect can be observed in cities along the Great Lakes. Chicago still has wide variations in temperature, but the variations are smaller in downtown Chicago because of its proximity to Lake Michigan.

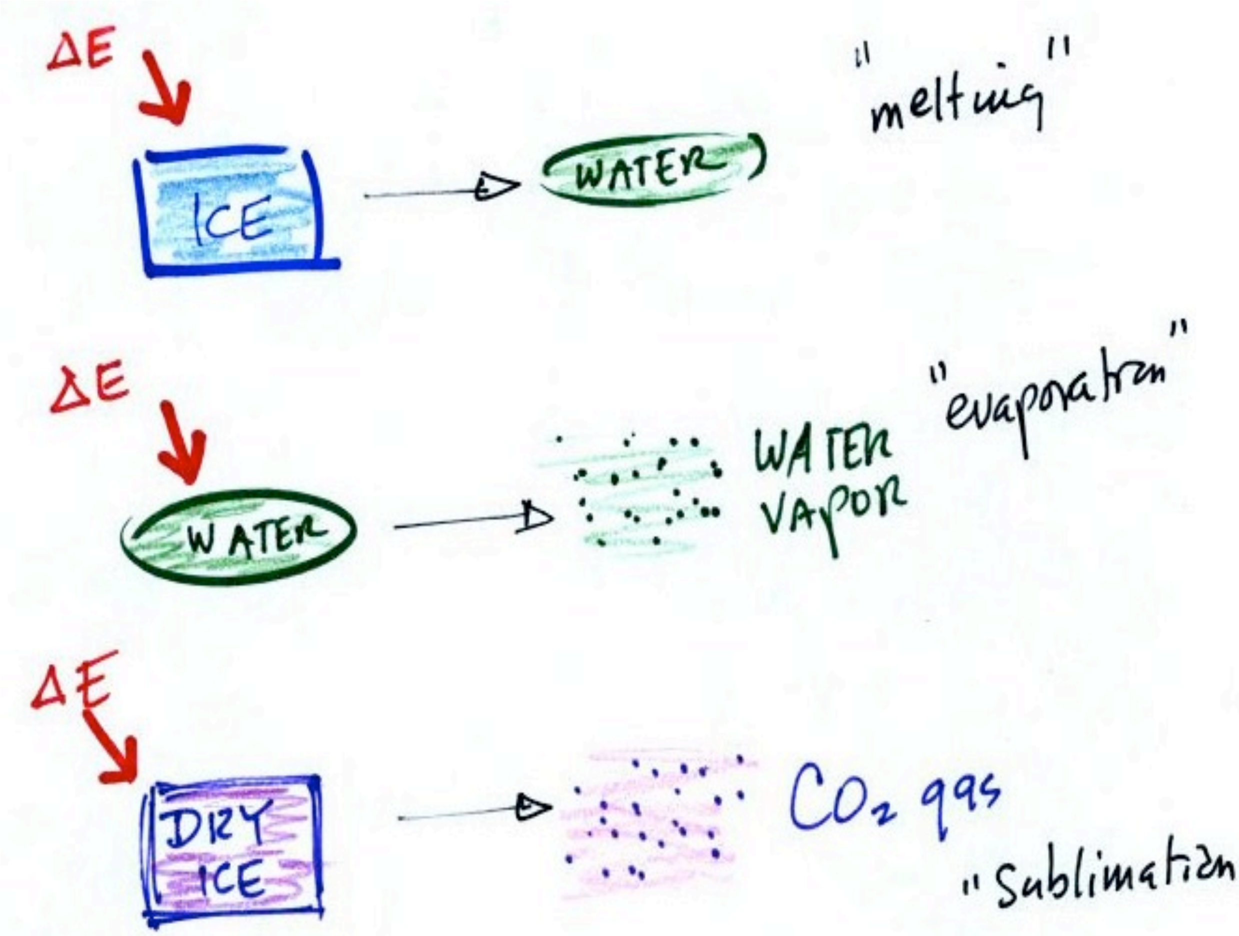
The yearly high and low monthly average temperatures are shown at two locations below. The city on the coast has a 30° F annual range of temperature (range is the difference between the summer and winter temperatures). The city further inland (assumed to be at the same latitude and altitude) has an annual range of 60°F. Note that both cities have the same 60°F annual average temperature.



Here is another situation where you can take advantage of water's high specific heat to moderate climate on a very small scale. Many people in the Tucson area plants tomatoes in February so that the plants can mature and produce fruit before it starts to get too hot in May. In February and March, it can still get cold enough at night to kill the tomatoes, so you must provide some kind of frost protection.

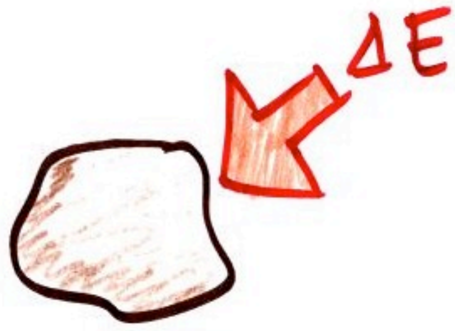
One way of accomplishing this is to put a "wall of water" around each plant. The tepee like arrangement is made up of several cylinders about 2 inches in diameter filled with water. The high specific heat of the water means the water and the plants inside the tepee will not cool nearly as much as the soil and the outside air.

Adding energy to an object will usually cause it to become warmer. But there is another possibility. The object could change phase (change from solid to liquid or gas). Adding energy to ice might cause the ice to first melt and then evaporate.

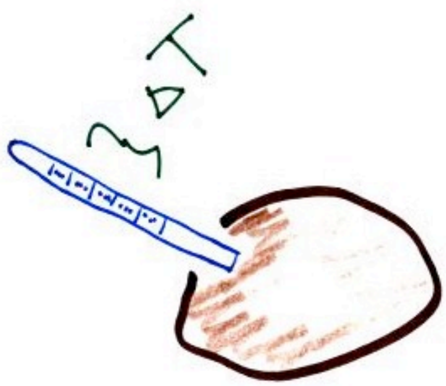


$$\Delta E = \text{mass} \times \begin{pmatrix} \text{Latent} \\ \text{Heat} \end{pmatrix}$$

The equation at the bottom of the figure above allows you to calculate how much energy is required to melt ice or evaporate water or sublimate dry ice. You multiply the mass by the latent heat, a variable that depends on the particular material that is changing phase.



$$\Delta T = \frac{\Delta E}{\text{mass} \times \text{specific heat}}$$



$$\Delta E = \text{mass} \times \text{specific heat} \times \Delta T$$

The following experiment is given in the classroom version of this class. We determined the amount of energy gained or lost by an object by measuring its temperature change. The object of the experiment was to measure the latent heat of vaporization of liquid nitrogen, or the energy needed to evaporate one gram of liquid nitrogen.

(a) Water at room temperature was poured into a Styrofoam cup. The total weight of the cup and water was 104.4 g. The cup itself weighed 3.4 g, so the water weighed 101.0 g.

(b) The water temperature was 21.0 ^{0}C (room temperature).

(c) 40.0 g of liquid nitrogen was poured into the cup of water. Energy is required to turn liquid nitrogen into nitrogen gas, which was supplied by the water. This flow of energy is shown in the middle figure below. We assumed that the Styrofoam insulated the water from the atmosphere, so that there was no energy flowing between the water in the cup and the surrounding air.

(d) After the liquid nitrogen had evaporated the water temperature was 20.0 ^{0}C, a 1.0 ^{0}Cdecrease.

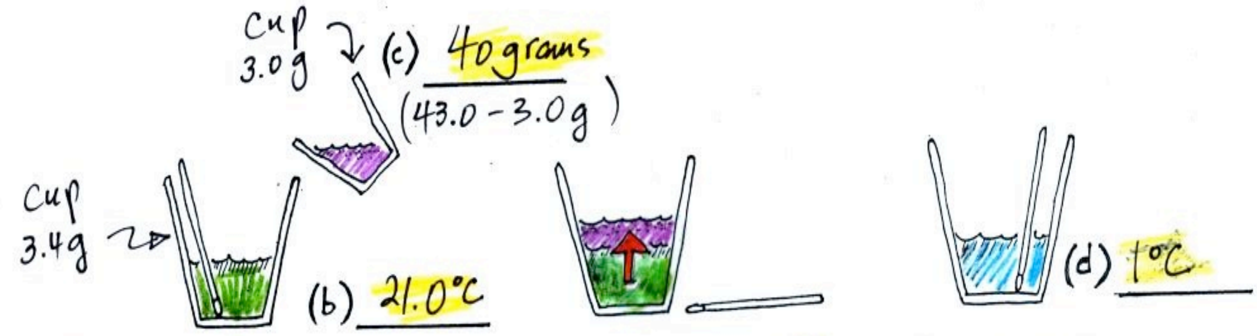
We knew how much water we started with, its temperature drop, and the specific heat of water. We can calculate how much energy was removed from the water to evaporate the liquid nitrogen.

$$101.0 \text{ g x } 20 \text{ C x } 1 \text{ cal/g C} = 2020 \text{ calories}$$

We then divide that number by the amount of liquid nitrogen that was evaporated.

$$2020 \text{ calories} / 40 \text{ grams} = 50.5 \text{ calories per gram}$$

A trustworthy student in the class informed us that the known value was 48 cal/g, so our measurement was pretty close.



(a) 101.0 grams (104.4g - 3.4g)

$\Delta T = 21.0°C - 1.0°C$
$= 20°C$

Energy lost by warm water = Energy used to evaporate liquid nitrogen

$$M_{water} \times \Delta T \times SH = M_{N_2} \times LH$$

$$101.0g \times 20°C \times 1 \frac{cal}{g \cdot °C} = 40g \times LH$$

$$50.5 \frac{cal}{g} = LH$$ ← measured value

Known value $= 48 \frac{cal}{g}$