The Study

The Arctic has Gas

Angela Bedard-Haughn, Maxime Paré

Learning Objectives

- Describe the role of soil in greenhouse gas emissions
- Understand the effects of plant residue and soil moisture content on greenhouse gas emissions from soil
- Understand positive feedbacks with respect to climate change in the Arctic
- Understand negative feedbacks with respect to climate change in the Arctic
- Understand the five factors to soil-formation
- Describe the effect of "topography" as a factor to soil-formation

The Story Behind the Study

Changing Climate and Greenhouse Gases

One of the great environmental challenges we face in the 21st century is **climate change**. There is now substantial scientific evidence that on average, our climate is warming. This is not an unusual phenomenon in itself - there is historical evidence of naturally-occurring variations in climate including the last ice age and the Hypsithermal (a warm period 9000-5000 y.b.p). We know from the historical record that these naturally-occurring variations have dramatically altered global precipitation and temperature patterns, changing the hydrologic cycle, raising and lowering sea levels, and changing the patterns of warm ocean currents.

Do you want to know more about how climate has changed over millennia and resulted in both warm periods and cold periods? Check out:

US EPA
http://www.epa.gov/climatechange/science/pastcc.html

NASA's Earth Observatory
http://earthobservatory.nasa.gov/Features/Paleoclimatology/paleoclimatology_intro.php

What makes the current climate change unique in our history is the rate and the evidence that it is caused in large part by the activities of one species: humans. Since the Industrial Revolution (about 250 y.b.p), our emissions of "**greenhouse gases**" have increased dramatically due primarily to the increase in burning of **fossil fuels** but also to changes in land use over this period. Greenhouse gases, like the glass of a greenhouse, act to trap or retain some of the sun's heat in the upper atmosphere. Greenhouse gases - especially water vapor - are an important part of what makes our planet habitable. But with our rapid growth in greenhouse gases, too much heat is being trapped, and earth is warming quickly.

Do you want a primer on Climate Change 101? The Government of Canada's web resource provides background information:

Government of Canada

http://www.climatechange.gc.ca/default.asp?lang=En&n=65CD73F4-0

Sandy's Notes – The Arctic has Gas

In some parts of the world, the effects of climate change to date have been pretty minor. Where we hear of the most dramatic change, however, is in the polar regions: the Arctic and Antarctic. According to all of our current data and to global climate change models, the polar regions are warming rapidly. Evidence that we have seen reported in the popular media includes rapid melting of massive ice shelves and polar bears going hungry waiting for the open water to freeze up so they can hunt.

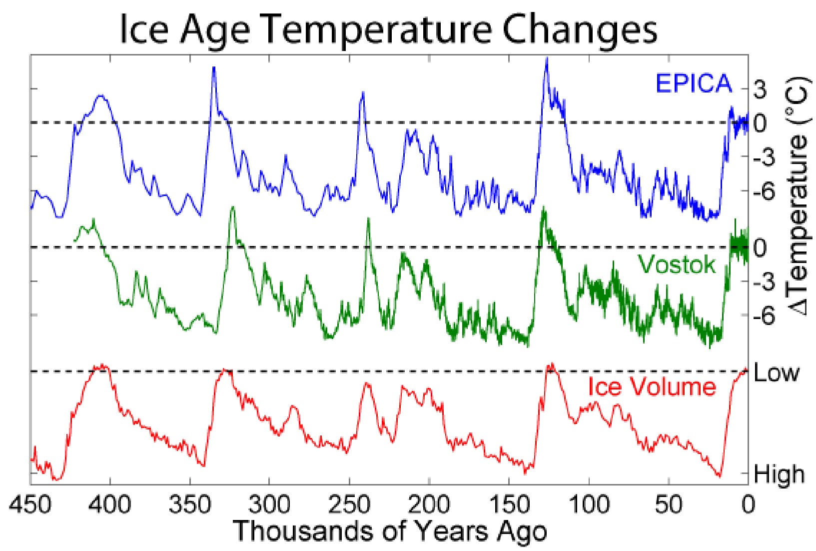
Learn more about the nitrogen cycle:

UBC - Nitrogen Cycling

http://www.landfood.ubc.ca/soil200/nutrient_cycle/fullscreen_n.htm

Historical Temperature Changes

Changes to global climate have occurred throughout geologic history. These changes have led to environments that are dramatically different from today, including ice ages and extreme warm periods. Explore historical changes in climate history at NOAA [http://www.ncdc.noaa.gov/paleo/ctl/clisci10k.html#]

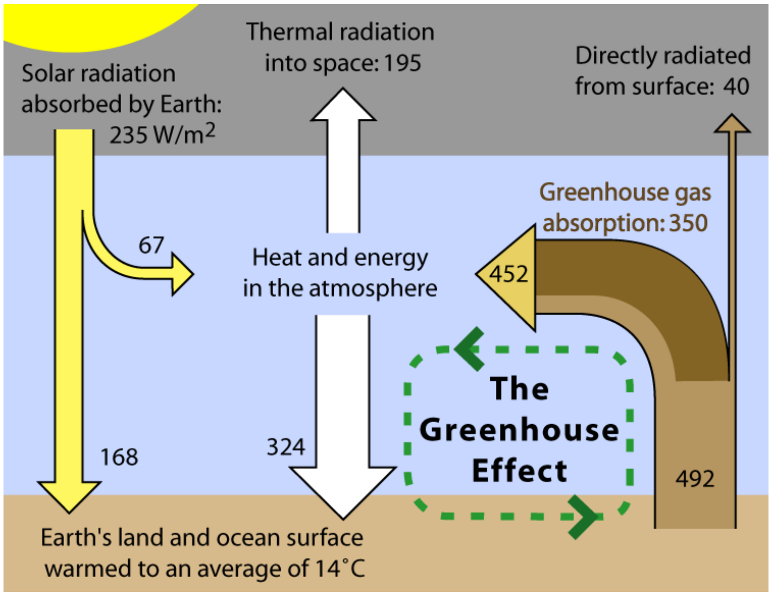


Wikimedia Commons; image created by Robert A. Rohde / Global Warming Art

The Greenhouse Effect

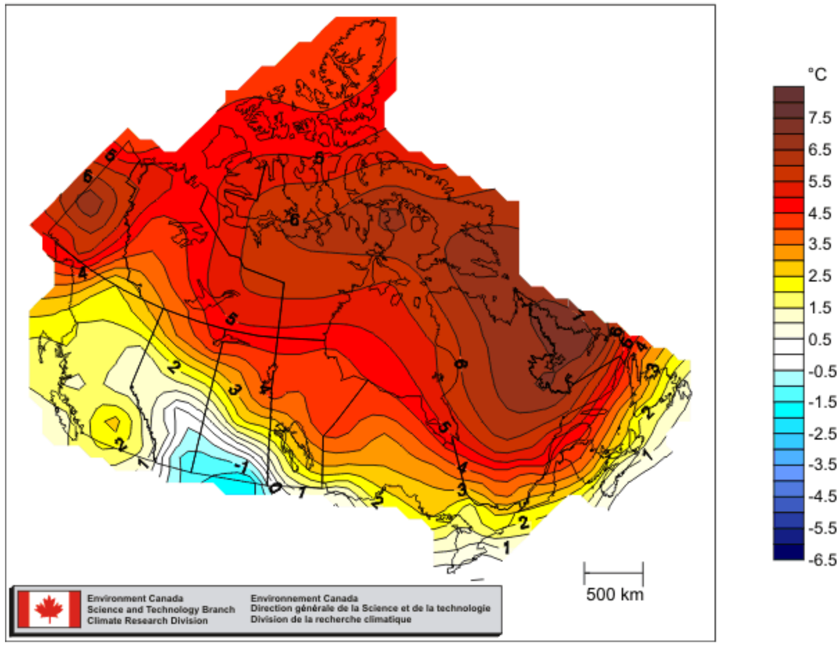
Greenhouse gases, like the glass of a greenhouse, act to trap some of the sun's heat in the upper atmosphere. This image shows how energy flows between space, the atmosphere, and the Earth's surface, leading to the greenhouse effect.

Image by Robert A. Rohde, Global Warming Art Project.



http://commons.wikimedia.org/wiki/File:Greenhouse_Effect.pn

<table>
<tr><td></td><td>g</td></tr>
<tr><td>Changing Climate

The impacts of climate change vary across the world. In Canada, northern regions have experienced greater warming than southern regions. This image shows the difference between winter temperatures in 2009-10 from 1948-2009 normals. To learn more visit Environment Canada site at www.ec.gc.ca/adsc-cmda/default.asp?lang=En&n=4A21B114-1</td><td>
</td></tr>
</table>

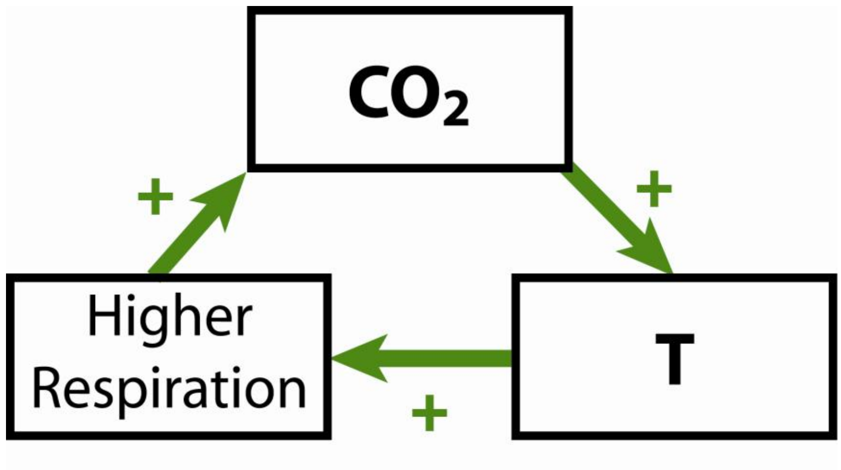
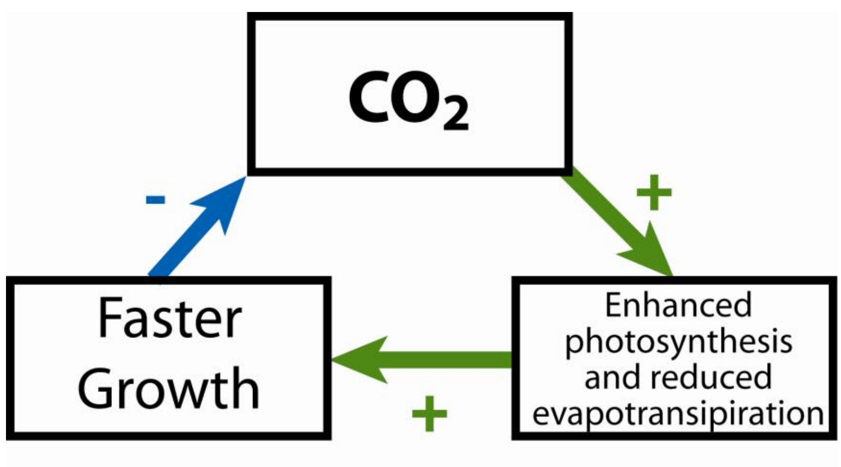
Soil and Greenhouse Gas Production

So what does this have to do with soils? Well, *soils can serve as an important* **source** *and* **sink** *for greenhouse gases, especially carbon dioxide, methane, and nitrous oxide*. In other words, soil can both produce and store greenhouse gases. In soil, carbon dioxide is produced when microorganisms decompose plant residues and other organic matter. Methane is also produced by decomposition, but under wet or **anaerobic** conditions. Nitrous oxide is produced primarily by **denitrification**, commonly under wet conditions. These soil microbial processes are all important natural processes that produce nutrients for plants and contribute to ecosystem stability. However, if their equilibrium is disrupted by a rapid change in climate, the rate of emissions could change rapidly.

There are many models that try to guess the future, or project what will happen to climate over time. These are called projections. Some projections for the Arctic suggest the climate will be much warmer than today; others suggest that climate will be much warmer and also much wetter than today.

We can imagine two scenarios. In the first scenario, a rapidly warming climate increases the activity of microorganisms in Arctic soils, increasing greenhouse gas emissions from the soil (i.e. the soil would become a major ***"source"*** of greenhouse gases, producing more than it stores), and creating a ***positive feedback***. More greenhouse gas emissions leads to more warming, and the cycle becomes more intense.

In the second scenario, a more wet and warm climate would allow microorganisms to produce more nutrients for plant uptake. Under these improved nutrient and climate conditions, vegetation cover could increase on the Arctic tundra, which would allow for more vegetative uptake of carbon dioxide through photosynthesis and more carbon storage in soil organic matter. The soil acts as a *"**sink**"*, which could perhaps slow further warming - ***a negative feedback***.

Positive Feedback Ecosystems may respond to changes in climate in different ways. In one scenario, known as the temperature-respiration feedback, when temperature rises, respiration increases, adding CO_2 to the atmosphere. Additions of CO_2 enhance warming, creating a positive feedback loop. Image by Lesley Dampier, UBC	
Negative Feedback In a second possible scenario, known as the CO_2-growth feedback, plants may increase photosynthesis as exposed to higher CO_2 environments and reduce evapotranspiration. This leads to faster plant growth which takes up more CO_2 and decreases the overall effect. This is an example of a negative feedback. Image by Lesley Dampier, UBC	

We can see that the interactions between soil and climate change are very complex! But not all soils behave the same way so we are faced with another challenge: how will *different kinds* of soils respond to changes in climate? Soils form as a result of five factors: ***parent material*** (the sediments or rock that soils develop on/in), ***climate*** (temperature and precipitation), ***topography*** (the "shape" of the landscape which affects how and where water moves), ***organisms*** (the plants, animals, and microorganisms), and ***time*** (how old the soils are). Differences in these soil forming factors will lead to different types of soil.

If we picture a hill, the type of soil at the top of the hill will be quite different from the soil at the bottom of the hill, reflecting the interactions among these factors at each location. Upper-slope soils tend to be drier, with thinner vegetation cover. Lower-slope soils will be wetter, and may have more organic matter. This topographic pattern gives rise to groups of soils along a slope, which we call a catena (after the Latin term for "chain", because the soils are related to each other like links in a chain) or a toposequence.

Research Summary

The International Polar Year was a major scientific research program focused on studying the Arctic and Antarctic (2007-2009). Scientists from around the world traveled to both ends of the earth in an effort to quantify the rapid changes occurring in the terrestrial (land) and marine (ocean) environments. As part of this initiative, Dr. Angela Bedard-Haughn and her Ph.D. student, Maxime Paré, traveled to sites from the High Arctic to the Sub-Arctic to look at what was happening in the soils. In particular, they were interested in understanding the type of organic matter present in the soil and examining whether the type of organic matter found in the soil affects: 1) the kind of greenhouse gases that are emitted; 2) the total amount of greenhouse gas emissions; and 3) the rate of nitrogen cycling (Figure 3). The sites were located at Truelove Lowland on Devon Island, Nunavut, Daring Lake, Northwest Territories, and Churchill, Manitoba. At each site, they selected one or more **toposequence**, where the upper-slope soils were thin, relatively dry soils with minimal organic matter and the lower-slope soils were wet and often had thick layers of organic matter or peat at the surface.

Along each toposequence, they established a series of **transects** (a transect is a line with points along it where samples are collected). At each sampling point, they measured greenhouse gas emissions coming from the soil and nitrogen mineralization (the amount of inorganic nitrogen produced). They also collected soil samples to determine a range of organic matter characteristics. These analyses were used to tell them whether the organic matter varied in terms of how labile (easily decomposed) or recalcitrant (very resistant to further decomposition) it was, and whether this property could be used to predict how much inorganic nitrogen would be available in the soil and/or how much greenhouse gases would be produced. The results showed that the lower-slope soils had both the greatest amount of organic matter and the most labile organic matter. In addition, the soils from the southern-most sites (Churchill and Daring Lake) tended to have more labile organic matter than the High Arctic site (Truelove), suggesting that these soils will be most vulnerable to future changes in climate.

Research Locations Researchers sampled soil across an ecosystem gradient in the Canadian Arctic. Sites ranged from the Sub-arctic (Churchill, MB) through the Low Arctic (Daring Lake, NT) to the High Arctic archipelago (Truelove, NU). Image Maxime Paré, University of Saskatchewan.	
Measuring GHG in the field Greenhouse gases were measured in the field using automatic chambers. The chambers would close for five minutes, and a gas analyzer attached to the unit took about 3 samples per minute. Photo by Maxime Paré, University of Saskatchewan	

Measuring GHG in the field

The measurements collected by the gas analyser are then used to determine the flux rate. This is the concentration of gas measured coming out of a unit area of soil over a specified period of time.

Photo by Angela Bedard-Haughn, University of Saskatchewan

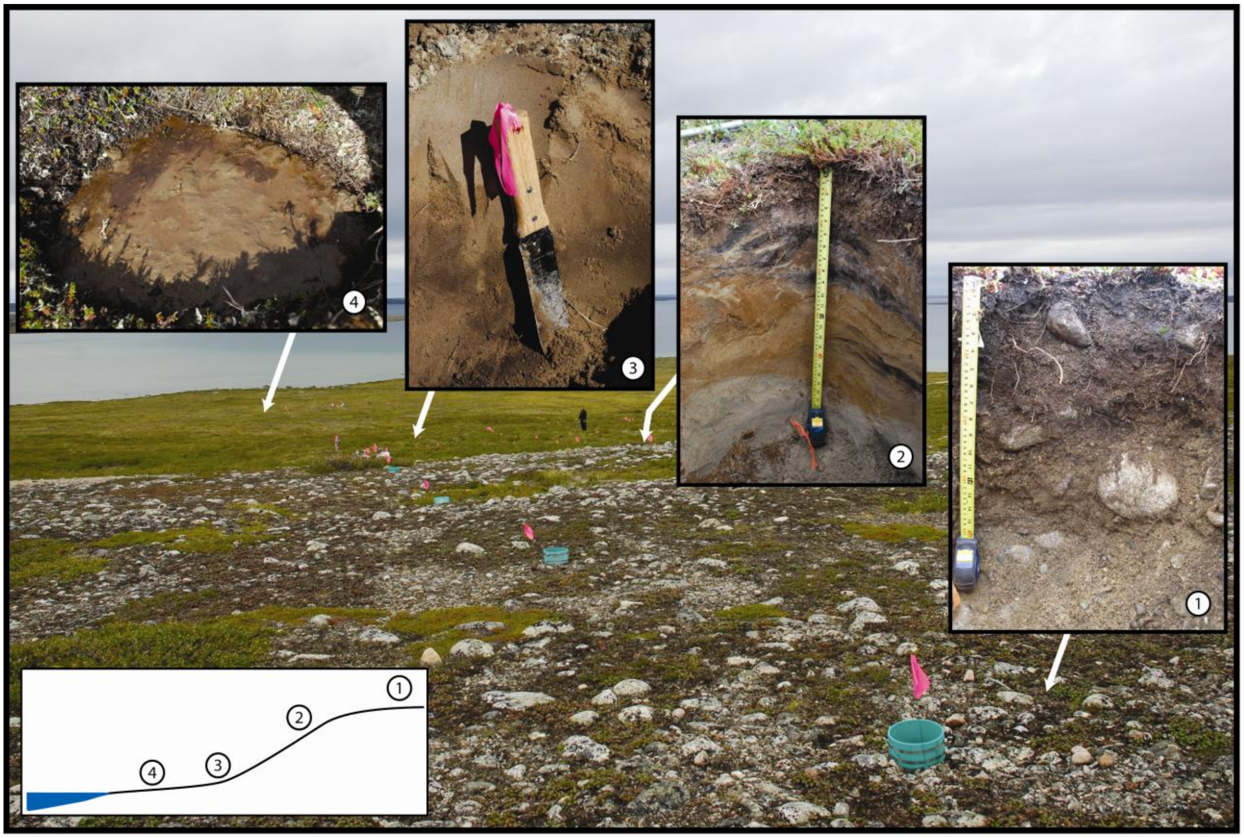
Nitrogen Mineralization

Mineralization is the production of plant-available ammonium (NH_4^+) from organic nitrogen. This was measured by adding a specific isotope (in this case, NH_4^+ enriched with ^{15}N) to a soil core collected from the field. The changing ratio of enriched to unenriched nitrogen was used to calculate the amount of naturally-occurring mineralization.
Photo by Angela Bedard-Haughn, University of Saskatchewan

Nitrogen Mineralization

Chemical extractions were done in temporary laboratory set up at the research sites. The extracts were frozen until they could be analyzed back in Saskatoon.

Photo by Maxime Paré, University of Saskatchewan



A **toposequence** is a sequence of related soils that differ, one from the other, primarily because of topography as a soil-formation factor. This image shows an example of a toposequence near Daring Lake, NWT.

(1) At the **top of the hill**, in this case an esker, the soil is drier and well-drained. This is an Orthic Dystric Brunisol.

(2) On the **backslope**, the soil is very unstable due to the steepness of the slope. The dark stripes here are actually topsoil from further upslope that has migrated downslope due to slope instability. This is a Brunisolic Static Cryosol.

(3) At the **bottom of the hill**, there is dark material mixed into the profile again, but in this case, it is due to cryoturbation, the mixing of soil by freeze-thaw action. The organic-matter rich soil from the surface is mixed deeper into the profile. This is a Brunisolic Turbic Cryosol (Turbic refers to the evidence of cryoturbation).

(4) The **flat base of the hill** has the highest moisture content as water drains from up slope. This is a mud boil.

Photographs by Angela Bedard-Haughn

Definitions

Anaerobic: The absence of molecular oxygen.

Climate change: long-term shift in climate measured by changes in temperature, precipitation, winds, and other indicators. Climate change can involve both changes in average conditions and changes in variability, including, for example, changes in extreme conditions.

Denitrification: Reduction of nitrogen oxides to molecular nitrogen or nitrogen oxides with a lower oxidation state by bacterial activity.

Fossil Fuels: Fuels such as coal, oil, and gas that have been formed from the organic remains of prehistoric plants and animals

Greenhouse Gas: An atmospheric gas that absorbs and emits radiation. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Negative feedback: A process in which the effects of a disturbance on or a change to a system results in a reduced impact of the disturbance. If the overall feedback of the system is negative, then the system will tend to be stable.

Positive feedback: A process in which the effects of a disturbance on or a change to a system include an increase in the magnitude of the perturbation. . If the overall feedback of the system is positive, then the system will tend to be unstable.

Toposequence: A sequence of soils of about the same age, derived from similar parent material, and occurring undersimilar climatic conditions, but having different characteristics due to variation in relief and in drainage.

Transect: A path (or a line) along which one records and counts occurrences of the phenomena of study.

Student Activities

1) Exploring Paleoclimate and Climate Change

There are several interesting resources for learning about the earth's past climate and atmospheric carbon dioxide.

- **US EPA** – Explains possible causes of climate change through history
  http://www.epa.gov/climatechange/science/pastcc.html
- **NASA's Earth Observatory** – Provides an interesting history of climate exploration
  http://earthobservatory.nasa.gov/Features/Paleoclimatology/paleoclimatology_intro.php
- **Carbon Tracker** – This YouTube video shows changes in carbon through time.
  http://www.youtube.com/watch?v=H2mZyCblxS4&feature=player_embedded
- **Government of Canada** – A Climate Change 101 primer.
  http://www.climatechange.gc.ca/default.asp?lang=En&n=65CD73F4-0]
- **NOAA** – http://www.ncdc.noaa.gov/paleo/ctl/clisci10k.html#

2) Measure soil organic matter content

Soil organic matter content greatly impacts many other soil properties, including water holding capacity and thermal (temperature) properties. It also has a significant impact on the

- **Wildlands School** – http://www.youtube.com/watch?v=XmprDMqu4zc
  A video that leads students through determining soil water and soil organic matter content

3) Determine soil water content

Soil water content is an important parameter that is routinely determined by soil scientists. Other parameters, such as organic matter content, will impact the soil's ability to hold water.

- **Colorado State Extension** – http://www.ext.colostate.edu/drought/soilmoist.html
  Simple oven-dry method for measuring water content
- **Wildlands School** – http://www.youtube.com/watch?v=XmprDMqu4zc
  A video that leads students through determining soil water and soil organic matter content

4) Soil Respiration Experiments

Although we can't see it, we can measure soil respiration. These two links provide instructions for running your own soil respiration experiment:

- **Radford University**
  http://www.google.ca/url?sa=t&rct=j&q=soil%20respiration%20experiment&source=web&cd=5&ved=0CEYQFjAE&url=http%3A%2F%2Fwww.radford.edu%2F~biol-web%2FSoil%2520Respiration%2520Lab%2520B.doc&ei=gXPqTtD-HsPu0gH2y93kCQ&usg=AFQjCNHkfv3ILyg2l5tMJN0-Znf1UqY5zw&sig2=k9ebMK8gY3Ar77-h_JCmjA
- **Teaching Issues and Experiments in Ecology**
  http://www.esa.org/tiee/vol/v6/experiment/soil_respiration/description.html
- **UBC – Virtual Soil Lab Modules**
  http://soilweb.landfood.ubc.ca/labmodules/respiration

5) Exploring the Arctic

Arctic: A friend acting strangely is an excellent resource developed by the Smithsonian. The site contains background information on the arctic and relevant climate-related issues. There are several activities designed specifically for educators to incorporate into the classroom.

- **Smithsonian -** http://forces.si.edu/arctic/05_00_00.html

This video explains how methane trapped inside permafrost can enter the atmosphere during melting. It is a dramatic video that illustrates the presence of methane! Students will enjoy!

- **YouTube -** http://www.youtube.com/watch?v=vSLHvZnbYwc