SWAC MODULE: COLD REGIONS

PERMAFROST

Part I: Background - Permafrost & climate

Over the past few years, much of the information reaching the general public about the environmental impacts associated with climate change has revolved around what are called "Cold Regions," and the profound morphological change that shifts in climate can bring about in these areas over time. We see images of ice masses breaking off into the oceans, global sea level rises flooding beaches, and stranded polar bears on ice pads being forced out of their homes. All of the attention that Cold Regions receives is for good reason: to understand the concept of climate, it is essential to have a working knowledge of the types of processes in Cold Regions, and how these processes both respond to, and drive Earth's climate.

"***Cold Region***" is a relatively general term that can be broken up into two sub-categories: areas of permafrost and areas of glacial ice cover.

Permafrost is defined as earth material that has been continuously frozen for at least two years. It generally occurs in extreme latitudes where yearly temperatures (generally areas with a Mean Annual Air Temperature (MAAT) of less than 32˚ F) permit continuous freezing, although permafrost is not limited to these places. Permafrost also frequently occurs in high altitude areas, such as major mountain ranges (Alps, Andes, Himalaya, etc.), where temperatures permit. Permafrost can also form underneath oceans, and is called "*subsea permafrost*."

Water found frozen in the spaces between sediment is known as "*pore ice,*" and can be found in a range of volumes from microscopic to massive. The presence of ground ice keeps the ground around it frozen so long as it remains frozen, although permafrost can exist in regions without ice, so long as the material is below freezing.

In the year 2000, it was estimated that about 24% of the Northern Hemisphere's land surface was covered with permanent permafrost, with some additional 60% being seasonally frozen (NSIDC). Figure 1 shows this distribution of Earth's permafrost in the Northern Hemisphere.

Types of Permafrost

1. *Continuous:* Forms in areas with a MAAT of less than 24ºF, independent of aspect and topographical influences.

2. *Discontinuous:* Forms in areas with a MAAT of less than 28ºF, but more than 24ºF. As the air temperature alone is not enough to cause permafrost formation, this type requires some form of topographical shading, usually mountains with north aspects.

3. *Sporadic:* Forms in areas with a MAAT of less than 32ºF, but more than 28F. Sporadic Permafrost forms as pockets of ice within peat and under existing ice. This sort of permafrost may also occur in high altitude mountain environments.

4. *Isolated Patches:* Forms in areas that provide temperatures cold enough for ice production. These patches are often found in higher altitudes that exhibit variability in MAAT, but ultimately support ice retention in certain areas.

Permafrost as an Indicator of Climate

Since permafrost is so fundamentally dependent upon temperature, it is known as a "cryogenic indicator" of climate. Several quantifiable attributes allow scientists to study how permafrost is reacting to climate:

1. *Extent*: The two-dimensional area of the Earth covered by permafrost. This measurement allows scientists to study how permafrost coverage changes over time, and allows them to spatially visualize which regions of the Earth are able to support permafrost and which aren't.

2. *Depth*: The vertical depth of permafrost. This measurement allows scientists to establish a rough volume (by combining extent with depth), and illustrates how a specific ground type reacts to temperature.

3. *Ground Thermal Regime*: The changes in temperature with depth. The ground thermal regime allows scientists to study how the sun's energy is absorbed by a given cross section of permafrost. These changes in ground temperature can yield clues about how a region's permafrost may be changing.

Equally important to measured data, the broader analysis of geomorphologic changes in cold regions allows scientists to assess how permafrost may be changing. The geomorphologic changes can be broken up into several subcategories:

1. *Hydrologic*:

    a. *Thermokarst*: The thawing of ice within permafrost into water causes subsidence and saturation of underlying material known as *"thermokarst."* Marshy areas filled with many small lakes and river systems characterize this dynamic landscape. This type of landscape is found in the Arctic, as well as on a smaller scale in Alpine Environments.

    b. *Surface Hydrology Change*: In the warmer summer months, Arctic lakes are refilled with the water that is perennially frozen during the winter. These lakes form above the permafrost, which retains the water like the impermeable bottom of a swimming pool. When permafrost thaws, the permafrost interface that permits the retention of water moves lower into the ground. In many cases, this subsidence causes the water to simply be absorbed into the soil, causing the morphological disappearance of the lake.

    c. *Turbidity*: The collapse of river and lake banks from subsidence due to permafrost thaw deposits clay and silt sediments in water bodies. This sediment can stay suspended in the water for long periods of time, creating the water to appear "cloudy."

2. *Ecological*:

    a. *Vegetation Change*: Organic material "locked" in permafrost is oftentimes rich in nutrients in bacteria, which are present but inactive due to freezing temperatures. When permafrost thaws, these nutrients and bacteria are released into the Active Layer. Moisture once frozen in permafrost is also released, creating new soil conditions rich in nutrients and moisture. Vegetation that was once unable to survive in the colder environment moves in to take advantage of the more hospitable conditions, and profound ecological changes can take place. These newer plant species tend to photosynthesize at higher levels, giving them a different spectral signature from the older vegetation.

b. *Eutrophication*: The same nutrients that help change the vegetation in the landscape can also change the organisms in water bodies. In Arctic lakes, the release of nutrients from thawing contributes to algae blooms and other bacterial activates that populate the water and render it no longer pure.

3. *Geologic/Topographic*:

    a. *Patterned Ground*: In areas that experience freezing and thawing, the resulting heave forces the sorting of material into geometric shapes based on their size.

    b. *Ground subsidence*: Because the volume of water in the frozen state is larger than in the liquid, when permafrost thaws there is often a subsidence of the ground surface. This subsidence can damage human infrastructure (oil pipelines, highways, towns, etc.) in Arctic regions.

    c. *Rock Glaciers*: In alpine environments, permafrost may exist in the form of large masses of ice, rock, and unconsolidated material called "*rock glaciers.*" Like traditional glaciers, they are dynamic landforms that tend to "flow" downhill. Studying the morphological response of rock glaciers to climate is relatively simple and effective thanks to the wealth of satellite and aerial images that have been taken over the past 60 years.

    d. *Landslides*: In alpine areas, permafrost often serves as a kind of "glue" that binds unsorted grounds materials together on slopes. When permafrost thaws, this glue no longer binds the materials together, and massive landslides can occur.

Permafrost as a Driver of Climate

Aside from being an important indicator of Climate, it also may play a pivotal role in regulation. Permafrost is what is called a "*Carbon Sink*," or a structure that is able to store carbon dioxide gas for periods of time. The carbon being stored in permafrost generally comes from the slow decomposition of organic material locked in the layers of frozen soil. Although this process takes place very slowly, some permafrost in the Arctic is over 10,000 years old – ample time to have accumulated approximately 14% of Earth's carbon. When increases in temperature occur, permafrost begins to thaw, allowing quick-working bacteria and fungi to start breaking down thawed organic material, releasing it into the atmosphere as carbon dioxide and methane. This process serves to further exacerbate global warming by providing yet another positive feedback loop to the global warming system. (*see illustration*)

Future Prospectives on Permafrost and Climate

Data collected from borehole sites throughout the Arctic and Antarctic all seem to indicate warming trends in permafrost temperature over the past 30 years (Table 1). Although for many of these sites, permanent loss of permafrost would require hundreds, if not thousands of years, the effects of polar warming has been clearly recorded in both the reduced spatial extent of frozen material, and the changes in ground temperatures that show higher temperatures in the layers near the surface.

The exact impacts of carbon dioxide release from Arctic permafrost are extremely difficult to predict, and there are several models currently being developed to address how these releases will affect the atmosphere. What the models do not differ on however, is the fact that thawing permafrost releases measurable amounts of greenhouse gases into the atmosphere, and will respond positively to continued air temperature rises.

Permafrost thaw has already started to impact the lives of millions of people, directly or indirectly. In towns in northern Canada and Russia, municipal infrastructure such as roads, pipelines, buildings, etc. has been damaged by the subsidence of land affected by thaw. In the Alps, landslides and rockfalls have cost millions of dollars in damages to public infrastructure, and have imperiled everyday life in those areas. Perhaps the most frightening impact of permafrost thaw has been, and will likely continue to be, the addition of more greenhouse gases into the atmosphere as sequestered materials are released from centuries of ice storage. It is an impact that we will all feel, independent of proximity to cold regions, and one whose inner workings can only be fully understood by studying the frozen earth.

Permafrost & climate resources:

Natural Resources Canada:	http://gsc.nrcan.gc.ca/permafrost/regional_e.php
NASA Earth Observatory:	http://earthobservatory.nasa.gov/IOTD/view.php?id=5713
National Snow and Ice Data Center:	http://nsidc.org/frozenground/index.html