SWAC MODULE: COLD REGIONS
PERMAFROST

Part II: Remote Sensing of Permafrost

1. Visual Interpretation

Because of the responsive nature of permafrost, the first and most important indicators of changes in climate are the geomorphologic variations in landscape features over time. As mentioned earlier, warming of climate causes the gradual thawing of soils, which affects the landscape's morphologic configuration over time. For example, one of the most well documented cases of such land surface change is the disappearance of lakes throughout the northern latitudes of the Northern Hemisphere. The landscapes of Northern Canada and Russia have historically been dotted with thousands, if not millions, of small lakes. Although these lakes contain water in liquid form, the soils that retain the water are frozen in permafrost. Gradually warming temperatures have been causing this frozen ground to thaw, making the lakes unable to support water. The end result is that the water from the lake eventually soaks into the now unfrozen ground, with, the ultimate disappearance of the lake. Other surficial morphologic changes can also occur, including the localized rise of lake levels from runoff, the creation of new hydrologic features such as stream, bogs, ponds, and other larger scale land surface systems.

2. Spectral Analysis using false colour infrared composites

Another important technique in detecting permafrost change involves examining ecological changes in an area over time. As we learned earlier, areas of continental permafrost have an *Active Layer* of unfrozen soils above them that is able to support vegetation growth. This ability to support plant life is highly dependent on permafrost for two main reasons:

1. The cold temperatures of permafrost introduce a temperature gradient into the ground that may or may not be suitable for some plants.
2. Permafrost controls soil water content by allowing or blocking water drainage through the soil. It also can add or remove moisture from the soil depending on temperature conditions.

In areas where temperatures are sufficiently cold to maintain permafrost, plant growth conditions are often very limited. For this reason, plant species that are more "hardy" than others are able to survive. The plants tend to grow at slower rates, and require less moisture and nutrients to maintain growth over time. When permafrost thaws, photosynthetic activity increases as nutrients once locked in the ice begin to be released. This increase in photosynthesis can lead to two important changes in the land surface:

1. Standing water bodies (ponds, slow flowing streams, lakes, etc.) often undergo a process called *eutrophication*, where the concentrations of chemical nutrients in the water increases, leading to an increase in *primary productivity* (algae, bacteria, other small photosynthetic organisms).

2. Existing plants conditioned to life in the colder, drier pre-thaw environment are often replaced by newer species that are better suited to the more nutrient and moisture rich conditions created by permafrost thaw. These new species carry out higher rates of photosynthesis than their predecessors, and thus are biologically distinguishable. In some cases, plants that had been living in cold temperatures simply begin to photosynthesize at higher rates, experiencing higher growth rates. In either case, the landscape responds to permafrost change with changes in its ecology.

By looking at two images of a single place over time, we are able to make comparisons and draw conclusions about what may be happening in that region. As we learned in the SWAC land surface interpretation module, images viewed from space-borne sensors can yield important information about the land surface when properly interpreted. We also established that each of these sensors records data at different *wavelengths* or *bands*. One band of particular importance to the sensing of vegetation is the *Infrared Band* (wavelengths of 0.76μ - 500μ depending on sensor).

In the infrared range, pure water appears black, as it does not reflect infrared radiation. Just simply looking at the "color" of water from one scene to another can give the interpreter a sense of what sorts of changes the scene may have undergone from one year to another. In arctic environments, when turbidity is noted from one image to another, it is a good indicator that something has happened to the lake system, probably related to sediment being introduced into the lake system. The introduction of this sediment can stem from a river draining into a basin, or the erosion of the walls of given basin by subsidence. In either case, the resulting turbidity is a direct result of permafrost thaw.

Green vegetation, noted for its high reflectivity in the infrared band, appears as various shades of red (in the false colour composite), depending on factors such as species type and health. Generally speaking, coniferous vegetation appears as darker shades of red since they photosynthesize at lower levels. Deciduous vegetation tends to appear as a brighter red, due to the higher reflectivity in the IR band. Image analysts often look at the spectral signatures of features in an image to classify vegetation type, as different plants each have their own unique signature.

Vegetation stress (from human or environmental factors) will usually turn a feature a darker shade of red, mauve or even render it a light blue, denoting more serious stress. Conversely, vegetation whose stress has been alleviated will usually become brighter, as the health of the plant improves over time.

3. Photogrammetry (making measurements from imagery)

Another way of quantifying permafrost's reactions to climate is to measure how the shape of frozen ground changes over time. There are several key landforms to look for when trying to determine whether any change in permafrost structure has occurred. They include:

1. *Landslides*

2. *Rock Glaciers*

3. *Changes in water bodies*

Going to these sites to take physical measurements would be quite expensive and oftentimes dangerous. To cope with this problem, scientists in the 19^{th} century developed a technique called “photogrammetry” to make measuring easier, faster, and safer. The idea is relatively simple: take a photograph with a known scale, and make physical measurements on the photograph itself to find the distances between objects, their sizes, areal extent etc..