High Resolution, Surface and Subsurface, Survey of a Non-sorted Circle System

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Abstract

The non-sorted circle pattered ground features are abundant in the Arctic tundra. These features show large variability in active layer depth in summer and heave in winter. There is a lot of research devoted to measuring active layer depth, yet little is know about small scale variability of the active layer in patterned ground systems. Active layer is sometimes used an indicator of a warming climate which is not correct. The active layer depth varies from year to year as it freezes and thaws. It also expands and shrinks as it accumulates ice and looses ice. We have conducted two surveys starting in spring of 2007 and summer of 2007. The surveys where taken from the Biocomplexity research site near Franklin Bluffs, North Slope Alaska. We where able to reference the surveys points to a deep well located near the site that is used for deep permafrost temperature sampling. The well is 60 meters deep and therefore permanently anchored in the permafrost. The surface elevation is recorded in a 25cm dense grid over an area of 10 by 10 meters. The plot contains approximately 20 non-sorted circles. The average surface elevation in winter was 85 cm below the reference point and in the summer it was 97 cm below the reference point. This means that there was a 12 cm surface elevation difference. This difference can not be explained by the by the expansion of water to ice alone. It is our assumption that no water could have enter the domain from outside. We therefore need to find other reasons to explain the difference we suggest: drying of the soil during freezing (segregated ice lenses), shrinkage of the soil due to drying in summer and water movement to freezing mineral soil from organic deposits. The water freezes outside the pore structure in ice lenses that can be seen in winter samples. Long term observation of this grid will reveal more detailed information on the behavior of ice accumulation in the active layer. Current active layer development shows a decreasing trend with long term observations near our site in contrast to the annual average soil temperatures. Reasons for a decreasing trend may include a lack of a warming trend in summer temperatures, changes in thermal conditions, and greening of the Arctic which may lead to increased transpiration rates and absorption of incoming shortwave radiation.

Keywords: Non-sorted circles, Active layer, Permafrost, Survey, Snow, Soil.

Introduction

During the annual cycle arctic soils form an active layer in the summer that refreezes during the fall and winter. The process is scale depended and can be viewed as one dimensional on a landscape scale (Brown et al. 2000, Hinkel and Nelson 2003). The Circumpolar Active Layer Monitoring (CALM) sites are treated as a landscape scale measurement, where it takes many measurements to determine the average active layer depth for a region. On a smaller scale it is however a three dimensional process. Small heterogeneities are observed at a typical plot scale of a 100m^2. Differences in active layer depth are caused by soil and soil surface properties. Micro climate at the soil surface generated by vegetation and micro relief has a strong effect on the soil surface energy balance. Soil climate below the soil surface depends on: the micro climate above the soil, soil properties, wetness, and permafrost conditions below the active layer. The soil climate drives thawing and freezing processes that cause the soil surface to move up and down within the season and between annual cycles. This aspect of movement of the soil surface is not monitored in the CALM sites and it is therefore not possible to monitor the loss and gain of ground ice within and between the annual cycles. This loss or gain of ground ice has only a limited effect on the active layer depth, due to the limited amount of soil present in the ice rich upper permafrost layer, also called the intermediate layer (Shur and Jorgenson 2007).

The annual soil surface movement is driven by frost heave or frost action, where the strongest movement is expected in frost susceptible soils, such as silts found in any places in the arctic tundra. During freezing these soils accumulate ice in the form of lenses that form perpendicular to the temperature gradient (Kokelj and Burn 2005, Kokelj et al. 2007). This is also called secondary frost heave (Miller 1980). This process drives an expansion of the soil which exceeds the difference in density between water and ice. For secondary frost heave to take place water needs to flow to the freezing front, driven by cryostatic suction, to make this expansion possible (Daanen et al. 2007). The source of this water is still not resolved in the literature. Many models require an unlimited water supply to be able to generate the amount of frost heave observed. In a laboratory setup it was found that even without adding water to a frost susceptible soil during one dimensional freezing it was possible to generate heave beyond the expansion of water alone (Daanen, unpublished data).

The inter-annual soil movement is caused by segregated ice at the bottom of the active layer, or intermediate layer (Shur and Jorgenson 2007). Slow refreezing in the fall generally causes larger ice lenses compared to the upper active layer, where freezing is faster. Formation and loss of this ice depends on many of the same energy balance processes as mentioned above but in addition it depends on variations in hydrological conditions between years (Kokelj and Burn 2005).

Soil surface movement is generally hard to detect due to a lack of a proper reference point in the tundra. Romanovsky (Walker et al. 2004) and Washburn (Washburn 1997) have used permafrost anchors as a reference point to measure the difference between frost heave in non-sorted circles (n-circles) and vegetated tundra. This method is good when the anchors are deep enough to prevent them from heaving out of the ground on a longer time span. Satellite observations through interferometry would be an option when data is available during a small window in the fall before freezing and spring after snowmelt, but before the soil thaws. Differences between seasons may be too small to detect. Global Positioning System (GPS) equipment could be used to identify the movement of the soil surface; however accuracy of the equipment is a concern.

The non-sorted circle system is defined as interacting areas of vegetated and semi barren surfaces. The system can be as small as a single n-circle with its surrounding vegetation, which can be anywhere from 10 cm to 10 meters.

Methods

For this study we used a deep borehole casing as a reference point to survey our site with a total station, at a resolution of 25 cm. The borehole is 60 meters deep (with at least 59 meters anchored in permafrost) located near Franklin Bluffs along the Dalton Highway Alaska. The site was part of a biocomplexity study 'Biocomplexity associated with biogeochemical cycles in arctic frost-boil ecosystems', which ended in 2006 (Walker et al. 2004). The site can be described as 'mesic' or 'zonal' and therefore a good representation of the regions in terms of vegetation and soil climate conditions (Walker et al. 2004). The silty clay loam soils at the site are frost susceptible and generate a lot of ice lenses during freezing (Figure 1).

Figure 1 Ice lens formation in silty clay loam.

These soils are capable of forming and sustaining n-circles (Daanen et al. 2007). These n-circles provide a heterogeneous soil and soil surface that causes a large spatial variability in the active layer depth and frost heave level (Kade et al. 2006, Walker et al. 2004). Due to the scale of the n-circles we choose to survey our plot with a resolution of 25 cm to capture the smaller nuances of relief between the n-circles and the surrounding tundra.

The first survey was done in the April of 2007, well before the onset of snowmelt. The second survey was done in August of 2007 near the point of maximum thaw depth. In addition to the soil surface survey we also measured the snow depth in winter and the thaw depth in the summer.

Results

The spatial distribution of surface elevation in winter and summer is shown in Figure 2 and 3 respectively.

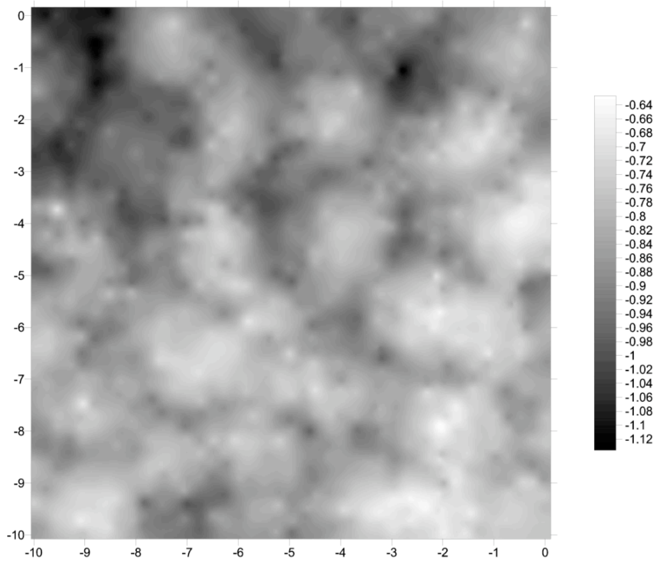

Figure 2 Elevation of the grid in winter relative to the fixed well casing, April 26 2007.

The winter results show a clear distribution of n-circles in the lighter areas where the surface is raised above the inter circle areas. Compared with Figure 3 the n-circles are more visible due to increased frost heave in the circles. From Figure 3 the elevations still show the n-circles, which implies that the elevation gain during freezing is not all lost during the summer thaw. Also visible from both illustrations is the slope from upper left to lower right or North West to South East.

We found that there was on average a 12 cm elevation difference between the summer and winter conditions. The scales on Figures 2 and 3 have an offset; for the lowest point 8 cm and the highest point 18 cm relative to the well casing.

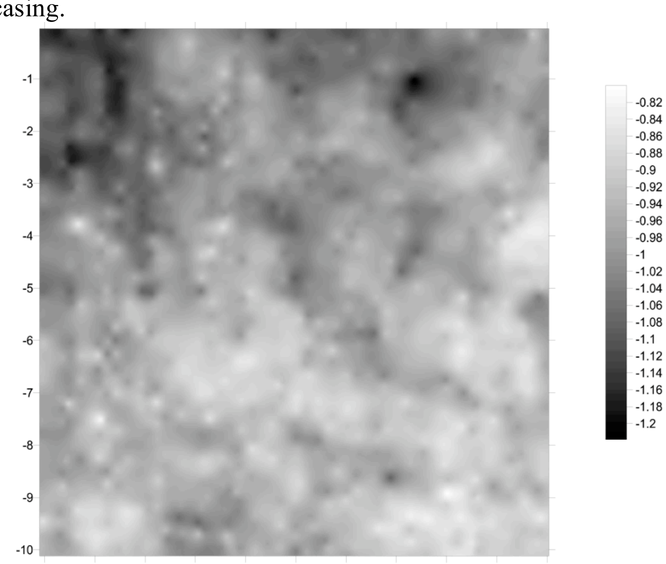

Figure 3 Elevation of the grid in summer August 27 2007, relative to the fixed well casing.

The elevation difference for each observation point between the two data sets is given in Figure 4. Areas with the greatest difference are shown in the lighter shades. The n-circles are also here distinctly visible as areas with the greatest amount of annual frost heave.

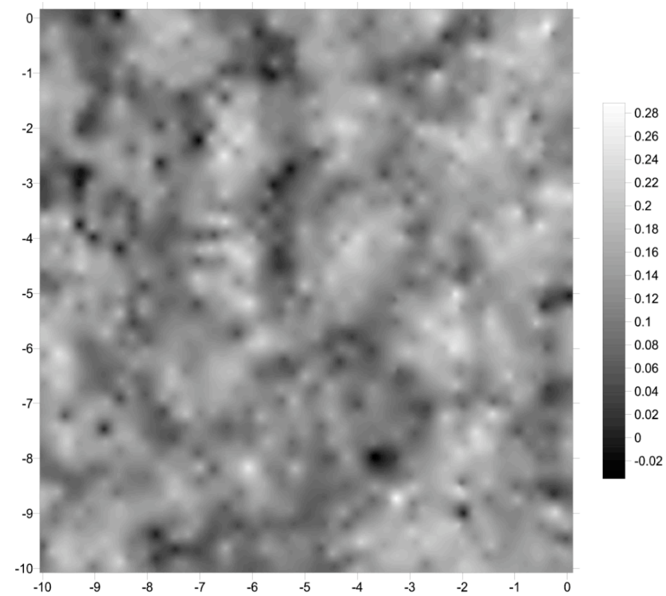

Figure 3 Elevation differences between summer and winter for the Franklin Bluffs site.

The permafrost table elevation map is given in Figure 4.

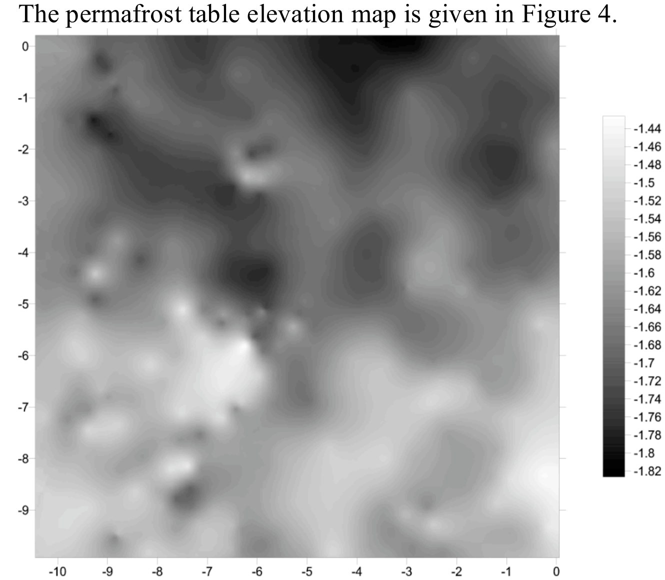

Figure 5 Permafrost table elevation for the site relative to the well casing on August 28 2007.

The active layer depth is the difference between the surface elevation in summer and the permafrost table. A map of this depth is given in Figure 6. The average depth measured in the grid was 65.9 cm with a standard deviation of 7.8 cm. This depth is on track with active layer depths measured over a long period for the area as part of the long term permafrost observation network (Figure 7). Figure 7 also shows the trends in air and soil temperature over the past 20 years near Franklin Bluffs, AK. Over that period following the trend lines the annual average air temperature increased by 1.334 degrees, the soil at 0.07 m increased by

1.774 degrees, the soil at 0.7 m increased 2.34 degrees and the active layer depth decreased 0.036 m.

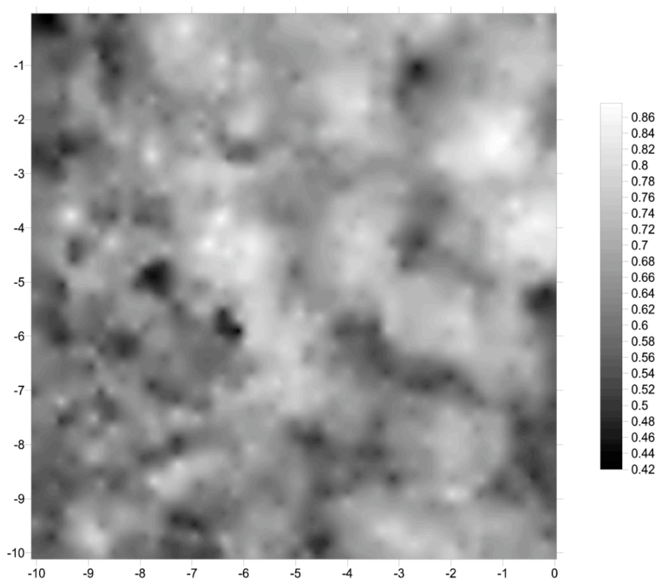

Figure 6 Active layer depth generated from the difference between the surface elevation and the Permafrost table elevation.

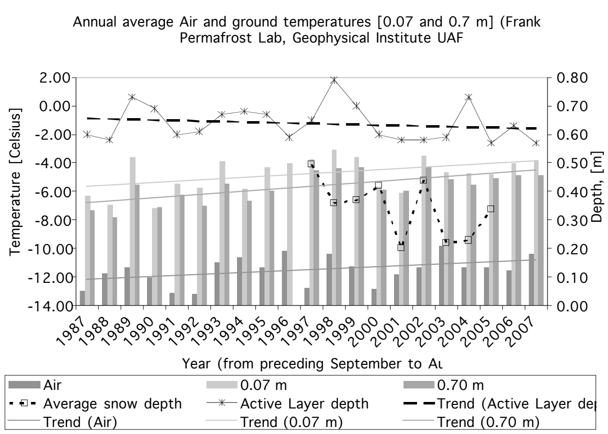

Figure 7 long term trends in active layer depth, air temperature, soil temperature (0.0 and 0.7 m), and snow depth near Franklin Bluffs, AK, from 1987-2007.

The active layer depth at the Franklin Fluffs site is measured by the permafrost laboratory at the Geophysical institute as part of the long term permafrost observation network. These measurements are taken in a larger 100 by 100 meter grid surrounding the deep permafrost temperature well. The average thaw depth measured for long term observations for Franklin Bluffs was 57.1 cm for august 28 2007. The standard deviation for the larger grid was 10.4 cm.

Daily air and soil temperature data associate with a more recent period is given in Figure 8. Soil moisture data from the same period is given in Figure 9.

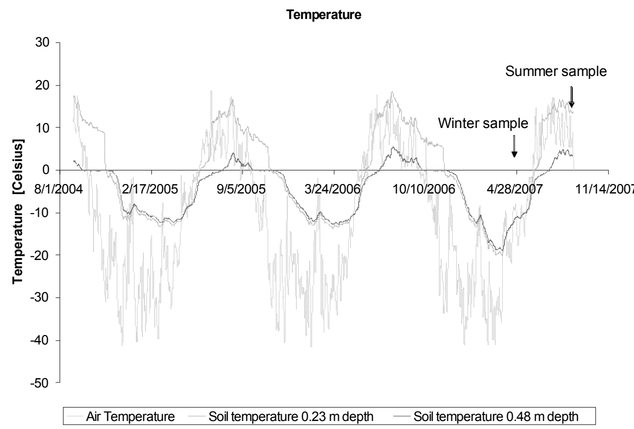

Figure 8 Air and soil temperature neat the surveyed grid.

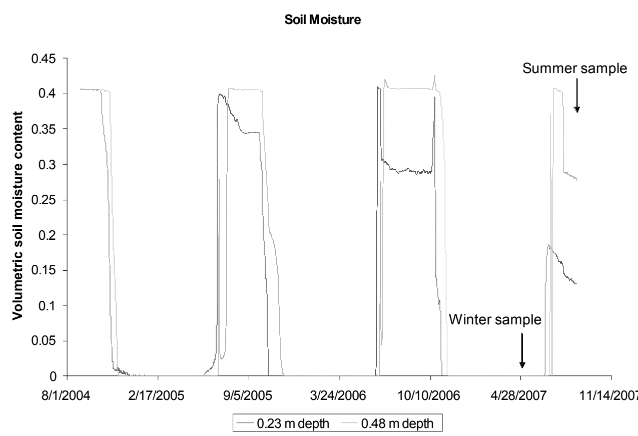

Figure 9 Soil moisture near the surveyed grid.

Discussion

The observed movement of the soil surface resulted in an average 12 cm of annual heave. The error in this measurement is approximately 3 cm due to operation during hard climate conditions. These 12 cm can not be explained by expansion due to phase change alone, because there is a limited amount of water in the active layer. The mineral soils have approximately 40 % moisture by volume that would only result in 3 cm of heave during refreezing of the active layer, which is also observed in annual soil surface movement in Canada (Mackay and Burn 2002). There are no other large water reservoirs in the area that are close enough to make a difference to the amount of heave. There is some additional water contained inside the soil profile, like water stored in small surface depressions and thick organic layers. It was observed during our spring measurements that there was no ice in the depressions where there is normally water in summer. Part of this water could have been absorbed by the freezing mineral soil, which is cooling more rapidly them the organic soils in between the n-circles (Daanen et al. 2007). Additional heave can be attributed to drying of the soil as it freezes. Air would replace water in the pore spaces and increase the volume of the soil column. Evidence was found that larger cracks within the active layer are ice free (Romanovsky pres. Com.). A last reason for the low elevation of the soil surface could be attributed to the dry soil conditions during the summer survey see Figure 9. There are clay minerals in the soil profile that may have the potential to shrink as the soil dries.

The active layer depths within the surveyed grid and larger long term grid are different. This may be caused by the location of the grid in the landscape. The grid is better drained due to small relief close to the grid compared to the larger grid sampled. The draining of water would result in less ice buildup in the active layer and therefore less energy required for thawing the profile. Historically data from the gird shows a similar trend with a few centimeters deeper active layer depths in the biocomplexity grid.

The active layer depth over time shows a slight decreasing trend even though the soil temperature shows a trend toward warmer conditions (Figure 7). There are many reasons to explain the trend. The summer air temperature did not increase. Average annual temperatures from the more recent period do not show a major trend toward warming conditions. The winter of 2006/2007 was colder than normal due to less snow compared with normal conditions, these data are not in the graph due to malfunction of the probe. The colder soils take longer to warm up and thaw. The dry conditions over the summer months had a reducing effect on the thermal conductivity of the organic layer. Another reason for a limited active layer depth could be loss of segregated ice near the bottom of the active layer. The potential loss of segregated ground ice is what we will measure during future surveys when we compare different years. The last reason is related to long term observations of 'greening' in the Arctic (Jia et al. 2003). Increased vegetation or Leaf Area Index (LAI) may be responsible for increased insulation (boundary layer), shading or transpiration at the site during the summer which leads to shallower thaw depths, even though the average annual temperatures have increased. Cooler conditions due to increased evapotranspiration have been observed on Banks Island where a constant wind made soils of south west facing slopes cooler in summer (French 2007). In our situation an increase in LAI leads to increased radiation adsorption which causes increased transpiration rates.

Conclusions

A high resolution elevation survey of a non-sorted circle ecosystem near Franklin Bluffs Alaska shows substantial soil surface movement. The average elevation difference between summer and winter sampling is 12 cm. This heave can not be explained with expansion of water due to phase change. Other explanations for the large difference are additional water from organic material froze as ice lenses in the mineral soil, ice lens formation in conjunction with soil drying, and soil shrinkage due to dry conditions in summer.

The long term active layer observations do not show a clear trend with average air and soil temperatures in our records. Some reasons suggested here are that the summer is not warming enough to affect the active layer and the increased greening of the Arctic may lead to increased transpiration by the vegetation. More data is needed to identify a set of reasons that can fully explain the variability and behavior of the active layer system.

Acknowledgments

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