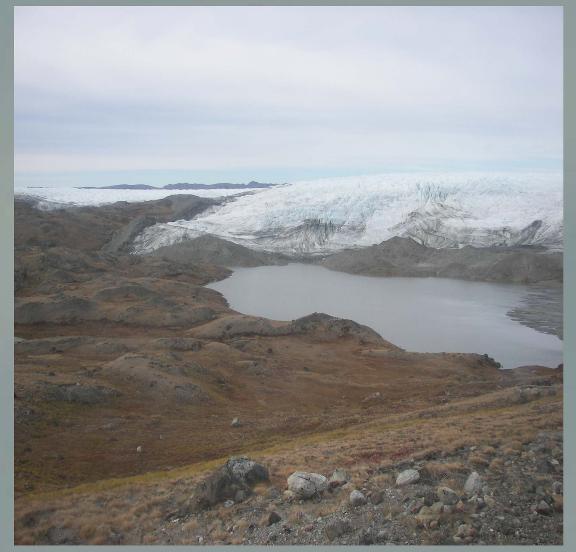
Greenland Permafrost Temperature Simulations

Ronald P. Daanen[1], Vladimir E. Romanovsky[1], Sergey Marchenko[1], Martin Stendel[2], Jens H. Christensen[2], Thomas Ingeman-Nielsen[3], Niels Fogged[3]

1) Geophysical Institute , Permafrost Laboratory, University of Alaska Fairbanks, Fairbanks, Alaska, USA;
2) Danish Meteorological Institutes, Copenhagen, Denmark;
3) Technical University of Denmark, Copenhagen, Denmark.

Ronald Paul Daanen



Abstract

Permafrost is a crucial component in landscape formation and functioning. The presence of permafrost is reflected in geomorphology, hydrology, ecology, but often much less in human made infrastructure and the climate modeling community. Predictions of permafrost stability over the next 75 years will add to the understanding of landscape changes, and will determine the need for infrastructure improvements. Very little research has been done to integrate long term climate predictions and high resolution permafrost temperature predictions for future climate. The goal of this research is to utilize high resolution climate simulations to estimate the consequences of rising air temperatures on the permafrost. Our research domain is the non-glaciated land mass of Greenland, where we have climate simulations at a 25 kilometer grid from 1950 till 2080 simulated by HIRHAM 4.0 The Permafrost model GIPL2.1 is used to asses current and future permafrost conditions. In general we found that some areas will be losing ground ice over the next 75 years, while some areas will lose all permafrost. A reduction or removal of the organic mater has a very clear warming effect on the permafrost temperatures. Decreasing snow density (thermal conductivity) also has a warming effect on the permafrost. It was also found that more detailed information is needed for better local predictions of permafrost conditions.

Introduction

For this study we used the GIPL 2.1 model. This model was developed by the Geophysical Institute Permafrost Laboratory. The version 2.1 is a numerical solution of the nonlinear heat conduction equation for a multi processor environment. Input to the GIPL 2.1 model consists of monthly air temperature and snow data from HIRHAM 4.0. The climate simulation was performed by the Danish Meteorological Institute. An overview of the data is given below in the center of the poster. Soils where classified according to the UNESCO soil map of the world. Data for other soil properties were estimated based on the soil classification and location. A deep thermal gradient of 2 degrees per 100m and an initial temperature of 20 degrees Celsius were used at a depth of 1000m. Initial temperatures were set at the surface equal to the first air temperature reading, at 20 meters the annual average temperature of the first 10 years of air temperature data. At 10 meters we defined an initial temperature which is an average of the surface temperature and the 20m temperature. All depths between these points were linearly interpreted between two known points. In total there are 175 vertical nodes with a higher density of nodes near the surface. We applied a spinup period of 100 years, which is the monthly temperature over the first ten years repeated.

Results

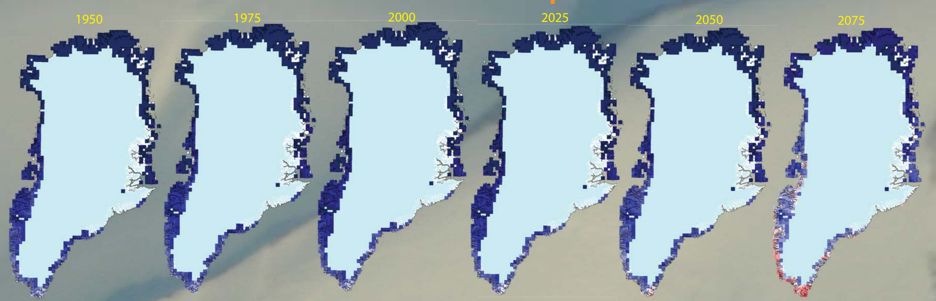
Bedrock outcrop area is abundant over large areas of Greenland (see pictures upper left). We focus our permafrost simulation on these areas and the sedimentary areas between. The result of the simulations are presented in the figures below left and right, they show a 10 year average temperature. A clear warming trend is predicted for the period beyond 2050. Increased soil temperatures also affect the active layer depth shown in the bottom row of images. The graphs in the center illustrate the temporal dimension in a higher resolution for Illulisat using regular sediment and salty sediment. The bedrock simulation is given in the bottom graph.

Discussion

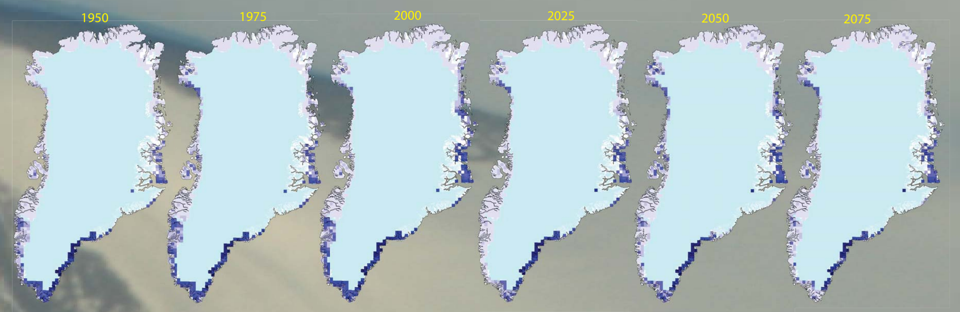
The warmest simulation scenario is the bedrock scenario and this can be seen on the bottom left of this poster which reflects bedrock temperatures. The sediment simulation is given on the bottom right of the poster and shows cooler conditions. The sediment simulation has an organic layer as the upper part of the domain, this layer is lacking in the bedrock simulation. Sediment is located in the poorly drained areas and is expected to be ice rich. This ground ice is at risk of being degraded due to climate warming and could impact construction or stability of infrastructure. Our modeling shows that the whole simulation domain warms slowly. Active layer depth is determined based on liquid water content above 10%. Deepening of the active layer is predicted for bedrock as well as sediment conditions. The simulation does not include massive ice like ice wedges or ice lenses, which can degrade slower or faster based on the location with respect to the local hydrological features, but rather saturated pore ice conditions for sediments. Salt affects the thermal regime dramatically through sifting of the phase change temperature.

http://qrc2.ess.washington.edu/PUBLIC/Ron/Thule/2005_Kangerlussuaq_Lakes/pages/_MG_1205.html

HIRHAM 4.0 air temperature



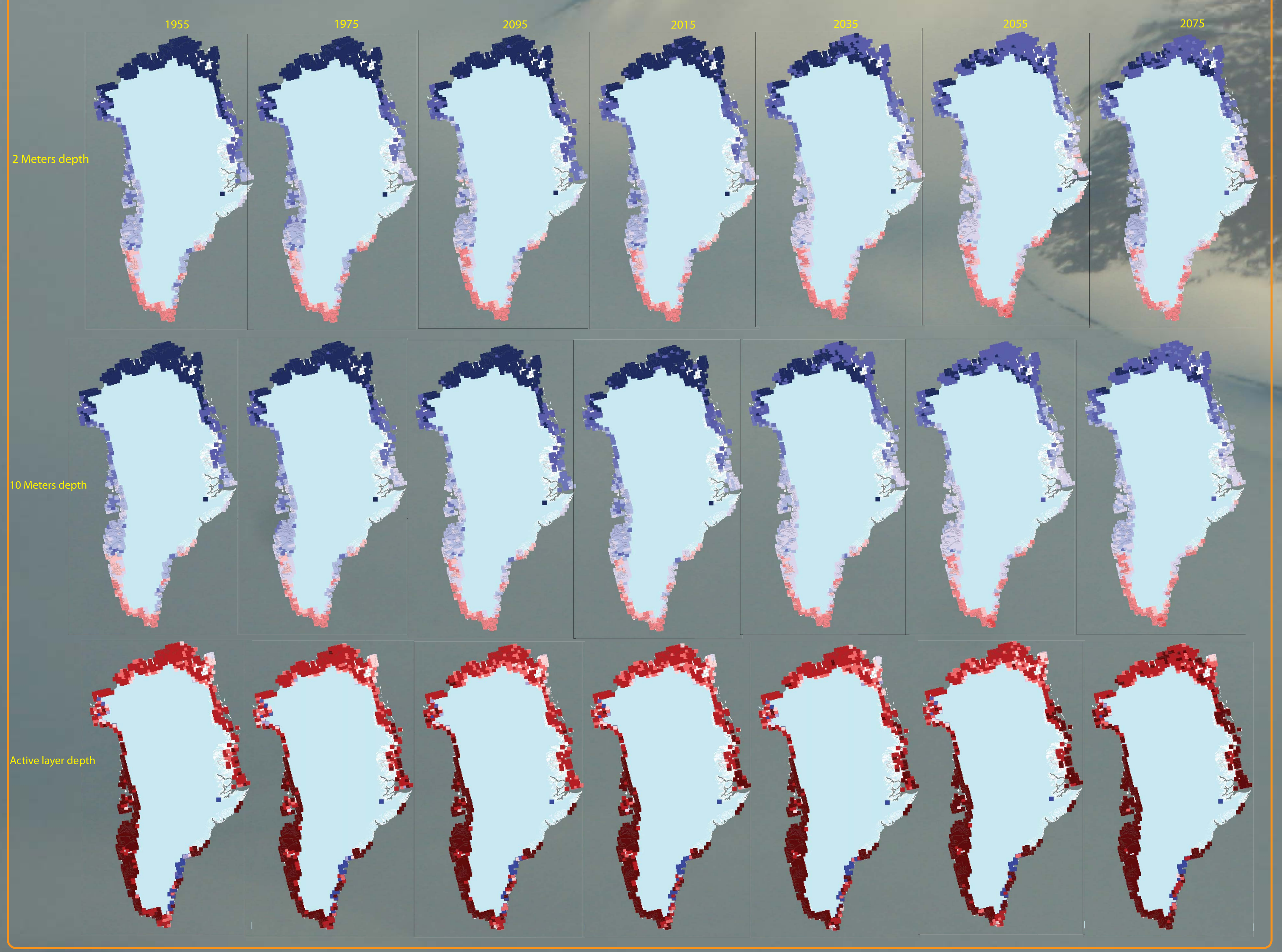
HIRHAM 4.0 snow depth



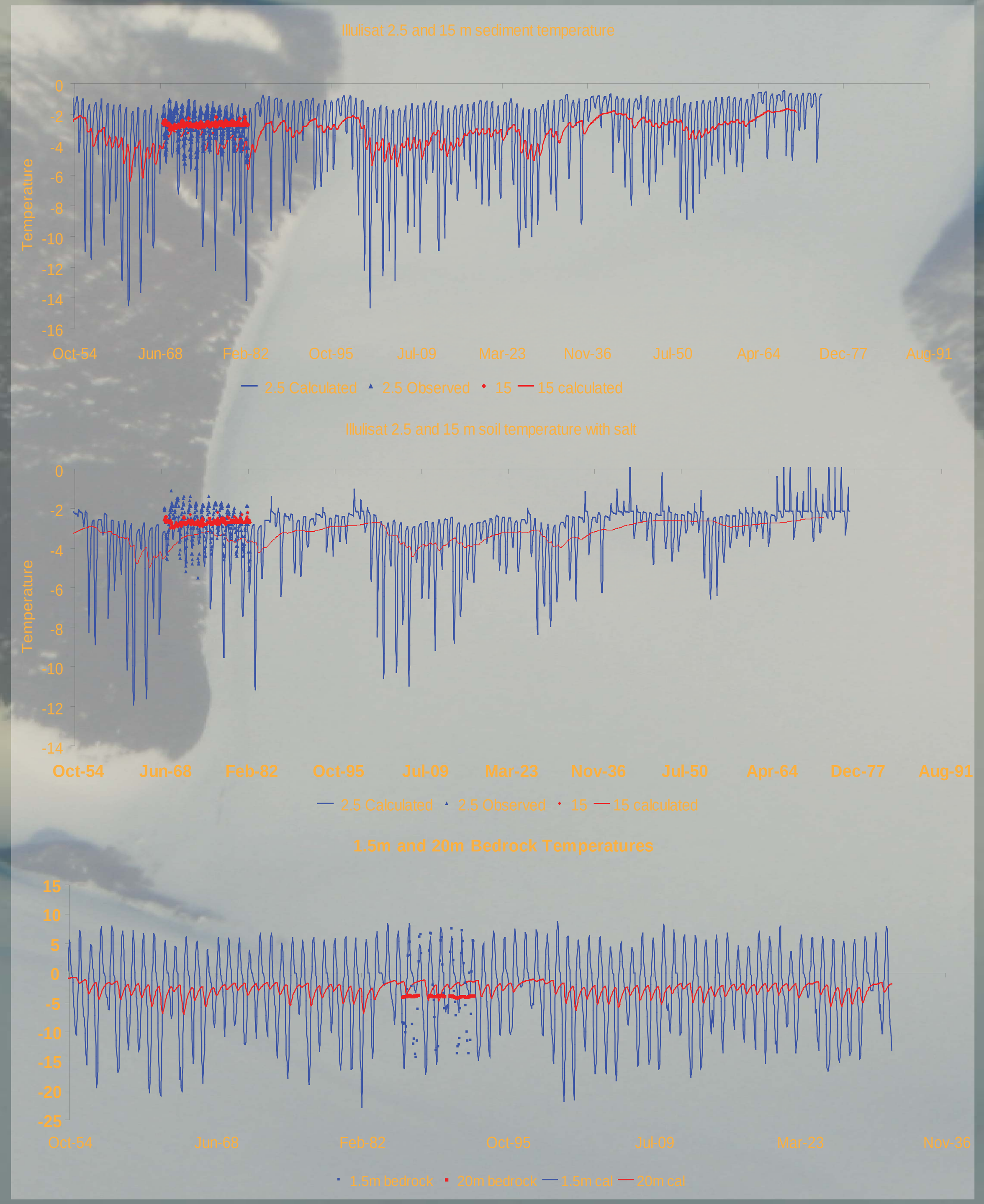
Conclusions

Permafrost temperatures strongly depend on air temperature and the amount of snow predicted by the climate model. In complex landscapes like Greenland down scaling of those variables to a permafrost relevant scale is crucial to ensure correct permafrost temperature predictions. Ultimately we are interested in the engineering aspect of infrastructure in Greenland, which would need better knowledge of organic layer distribution and snow distribution as well as snow density estimations. The current study does however indicate that Greenland permafrost is relatively stable for the next 50 years. After that degradation of ice rich permafrost is projected to occur. Smaller scale degradation may happen sooner depending on the smaller scale conditions.

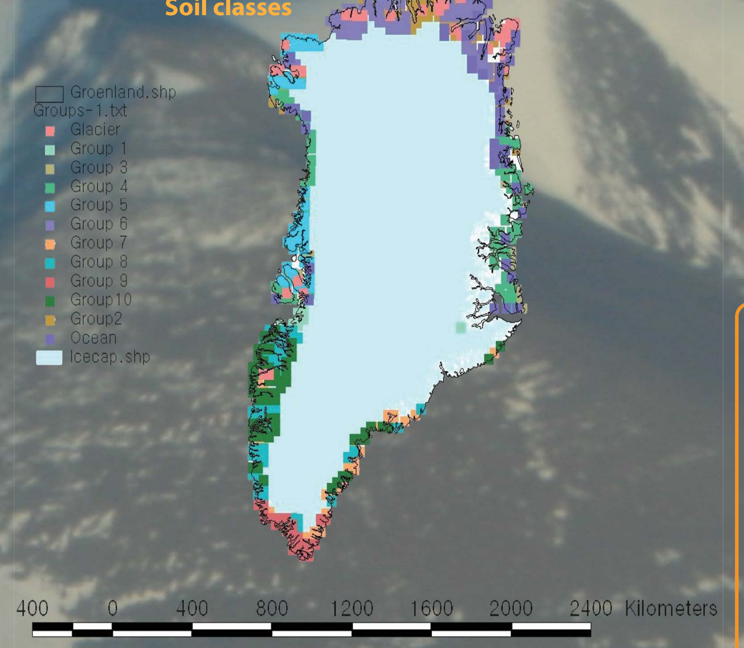
Bedrock Outcrop ground temperatures and active layer depth



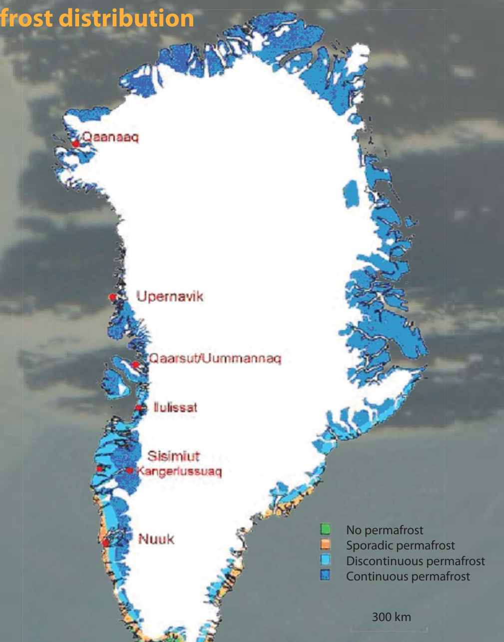
Illulisat 2.5 and 15 m sediment temperature



Soil classes



Permafrost distribution



Humlum & Christensen 2000

Temperature legend
Temperature, °C
- < -12
- -12 - -8
- -8 - -5
- -5 - -2.5
- -2.5 - -0.5
- -0.5 - 0
- 0 - 0.5
- 0.5 - 2.5
- > 2.5
- Ice

Active layer legend
Depth, m
- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2 - 3
- > 3
- Ice

Snow depth legend
SWE
- 0 – 0.15
- 0.15 – 0.25
- 0.25 – 0.3
- 0.3 – 0.4
- 0.4 – 0.5
- 0.5 – 0.75
- 0.75 – 1
- 1 – 1.5
- 1.5 – 2
- 2 – 3
- > 3
- Icecap.shp

Acknowledgements

Funding for this study was provided by the National Science Foundation under grant no: ARC-0612533. We would also like to thank ASIAQ for there field support and the Arctic Regions Supercomputing Center for computational support.

Sediments with organic layer ground temperatures and active layer depth