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Thematic:
Impact of climate change on Arctic environments

Arctic river streamflow records:

A potential indicator to predict permafrost dynamics at a regional scale

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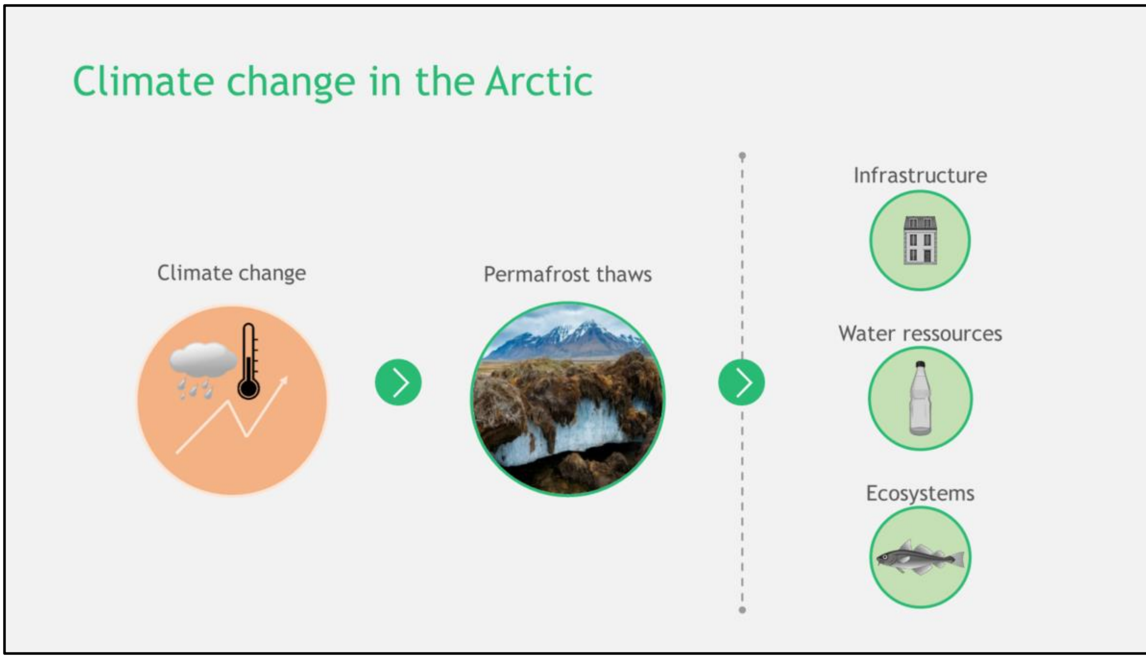
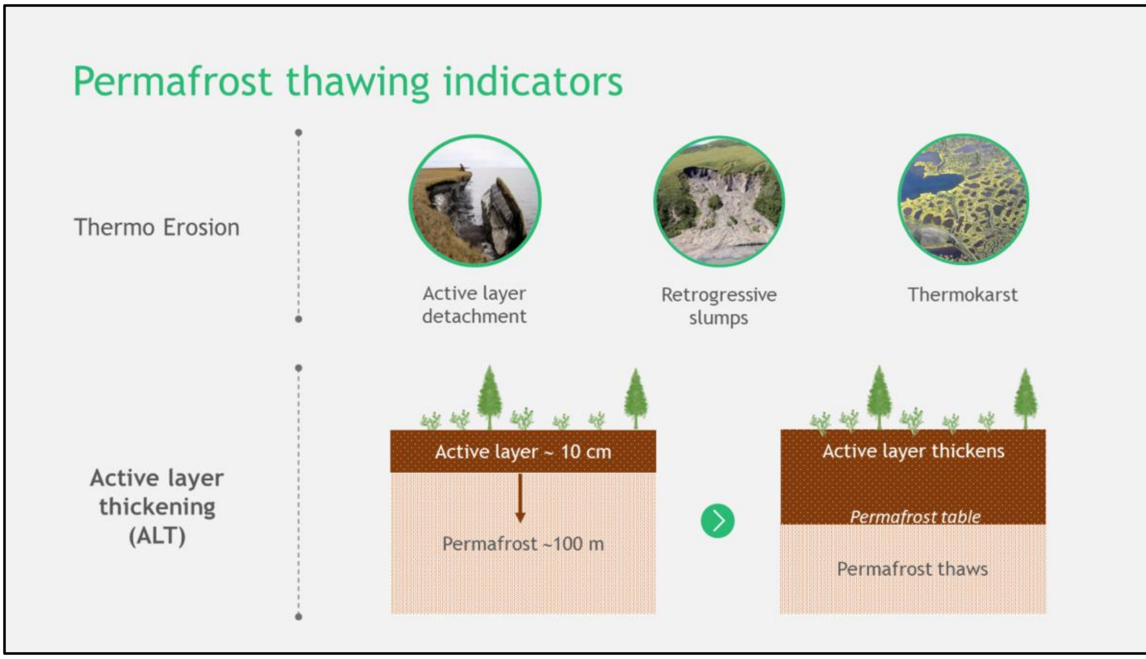


At a global scale, air temperature has increased by approx. 1°C over the last 10 years and this warming has been three times higher in the Arctic. As a result, permafrost is thawing. Permafrost, which refers to soil/rock below 0°C over 2 consecutive years, is estimated to underlie 20 percent of the world's land surface and its depth can vary from meters to 1.5 km in Siberia. In cold regions, ground stability, water cycle and local habitats are heavily dependant on permafrost sustainability. Thus, it is crucial to be able to assess permafrost-thawing-rate.

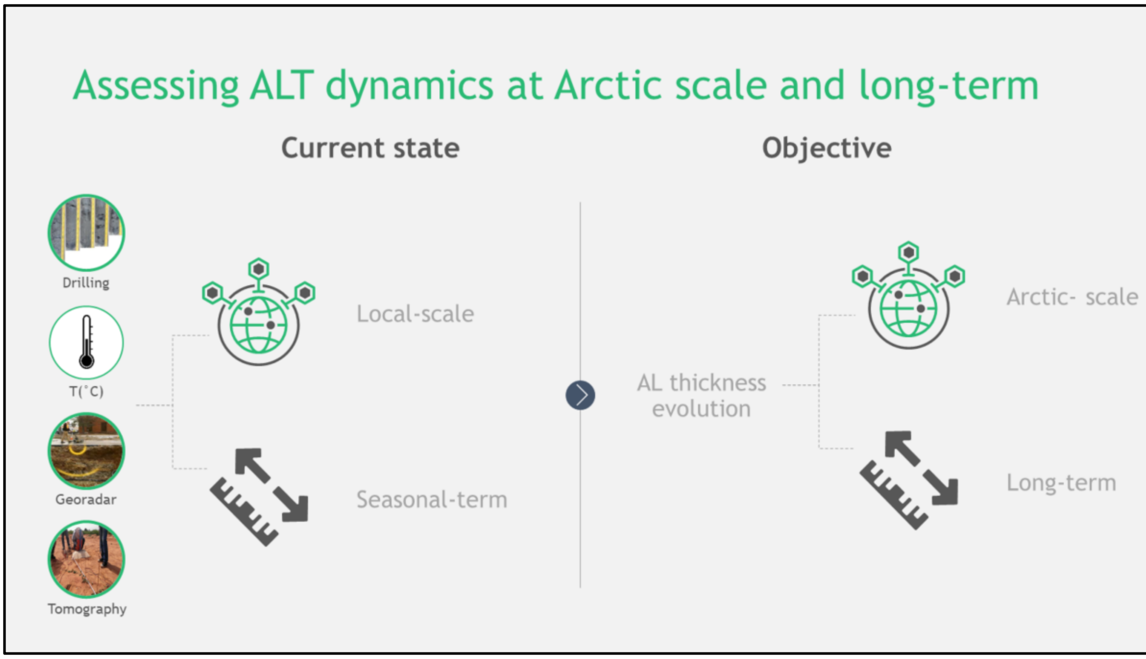


There are two main indicators of permafrost thawing process: the thermo-erosion and the active layer thickening (ALT).

The first is related to strong precipitation and/or air temperature increase that disturb the ground stability and create thaw subsidence processes such as active layer detachment, retrogressive slumps and thermokarst.

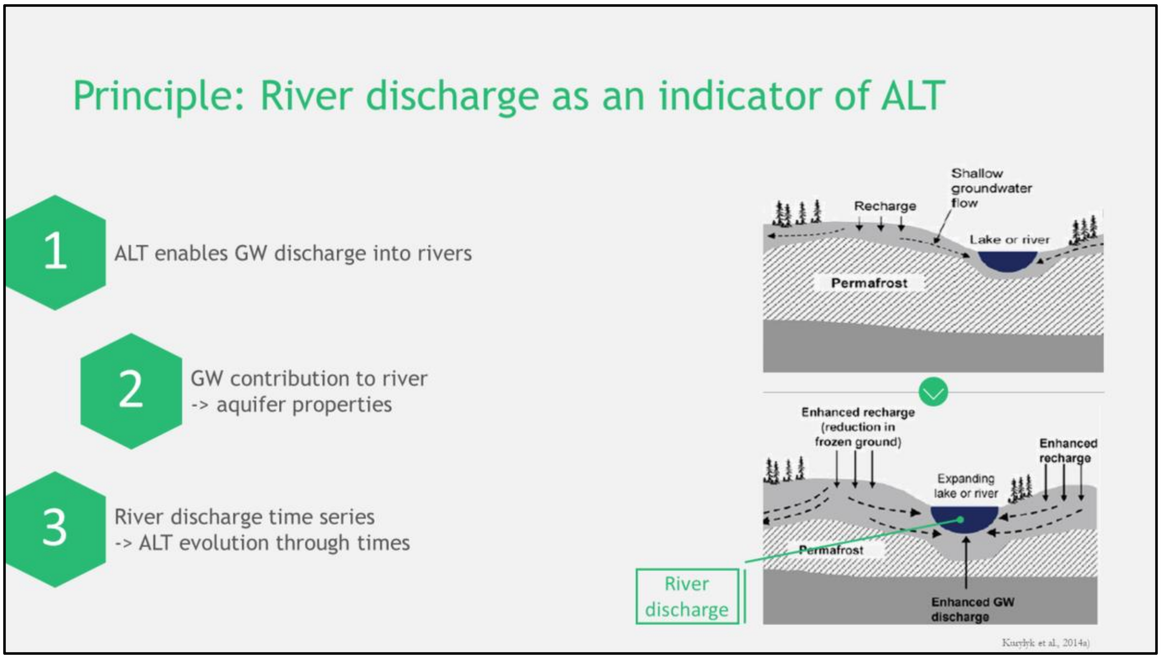
The second is related to the soil-layer above permafrost table that freezes and thaws seasonally. Through years, if winter is not long/cold enough to penetrate the active layer to its base, the permafrost table goes deeper. Thus, with increasing air temperature, the active layer thickens leading to thinner permafrost.

We based our study on the active layer thickening indicator (ALT) to assess permafrost-thawing-rate.



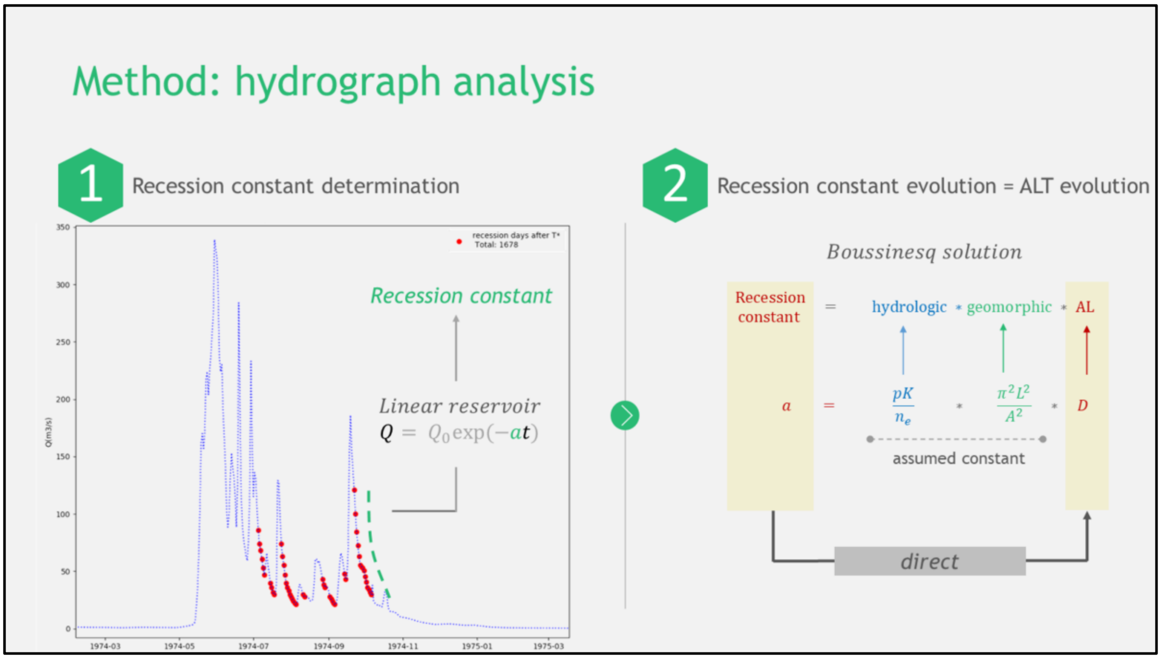
The study of the active layer (AL) dynamics is well-documented. However, most of the AL analysis are local in space (drilling, geo-radar, tomography) and because of Arctic landscapes' heterogeneity, these results are difficult to up-scale. Moreover, due to a lack of long-term time series data, most of the studies focus on seasonal dynamics of the active layer thickness (freeze/thaw process). Fewer observe the thickening process of the AL over years, i.e. related to climate change.

The objective of the project is to assess AL thickness evolution over large period of time and at the Arctic-scale to represent the impact of climate change on permafrost.



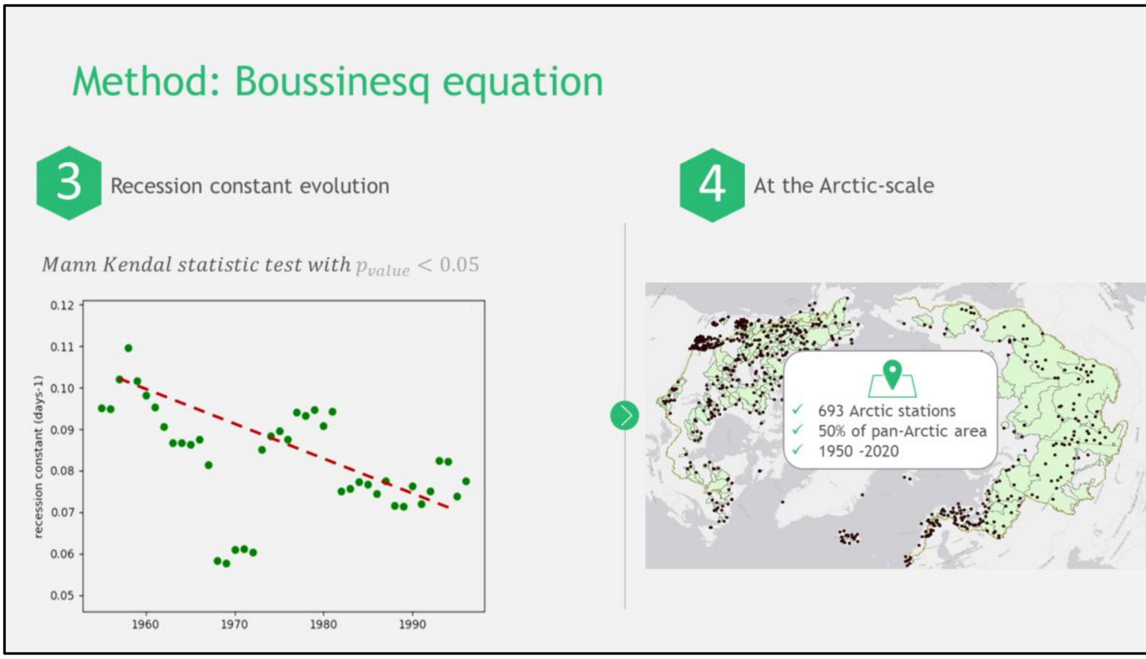
The method used to calculate ALT rate is based on the following principle: River streamflow analysis can reflect the AL dynamics

- While thickening, the active layer enables recharge of the ground and enhances ground/river connection
- The ground water (GW) contribution to river streamflow provides information about the aquifer properties (i.e. the AL) it flows through



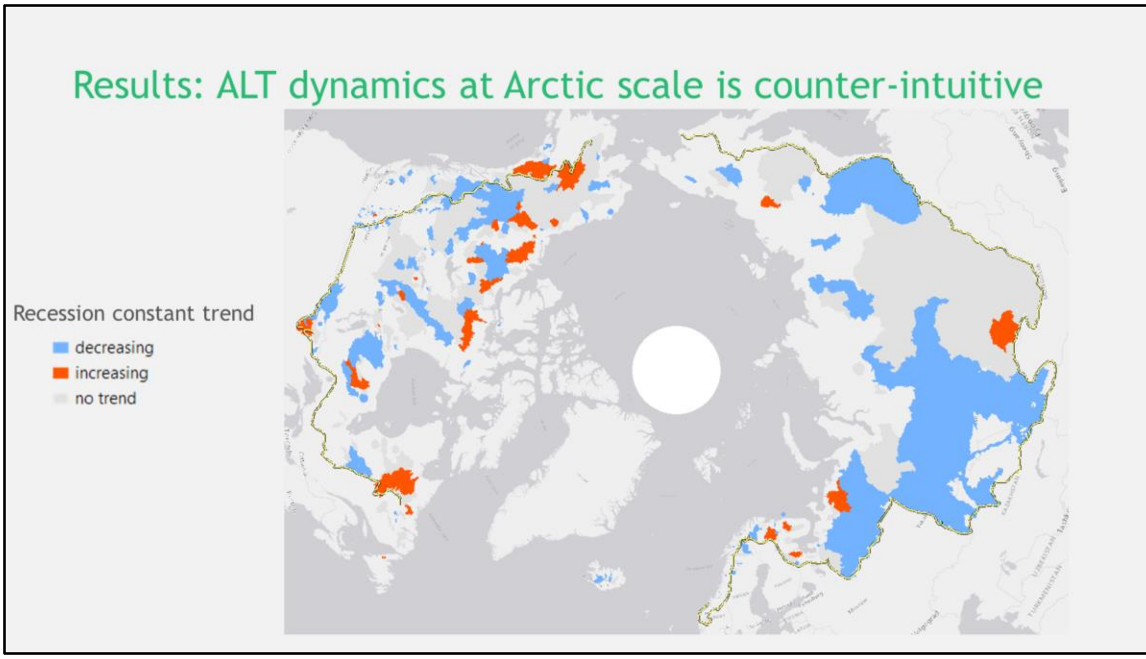
The method used to assess ALT rate is the hydrograph analysis of Arctic river discharge.

1. An hydrograph is the graph of river discharge evolution through times. We analyse the periods of decline of the river discharge, so-called “recession period”. During recession period, there is no forcing due to rainfall or snowmelts and river discharge results solely from GW storage. Assuming that the aquifer responds as a linear reservoir, GW flow rate follows an exponential decay function. Determining the rate of this decay implies determining the recession constant (RC) of the hydrograph.
2. If we assume constant hydrologic and geomorphic parameters, the RC (*a* coefficient in Boussinesq solution) can be related to the depth of the aquifer. As a result, from RC evolution, we can infer ALT dynamics.

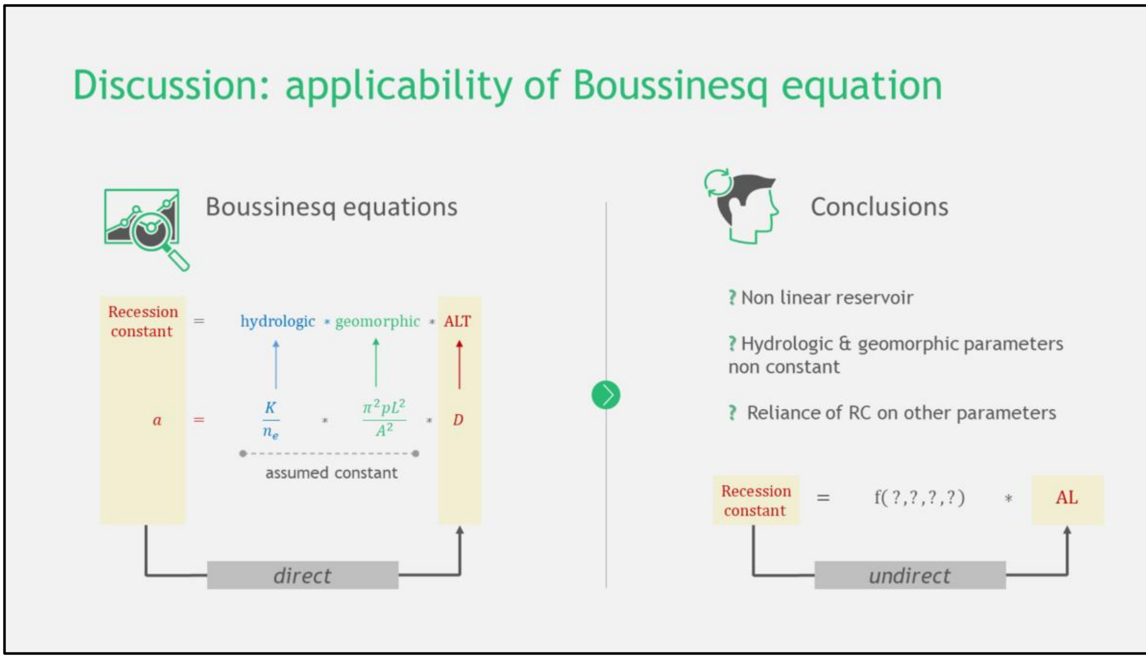


3. We represent the evolution of RC over time. With Mann Kendal statistic test, we infer RC trend. The trend is significant if p value < 0.05

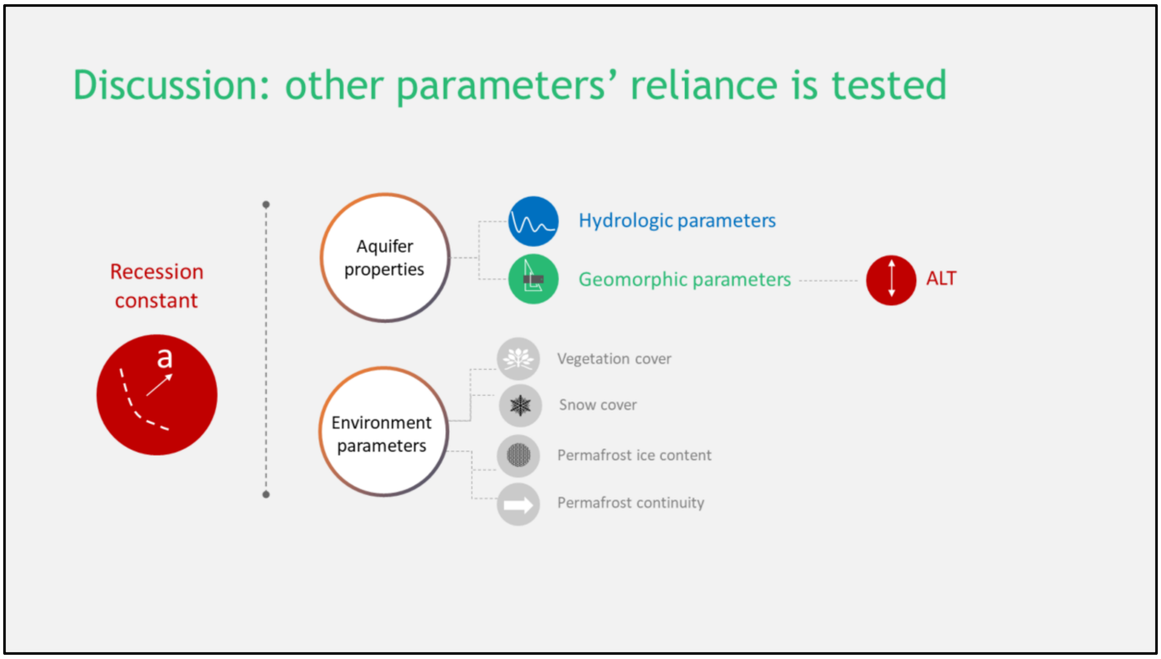
4. This hydrograph analysis method is processed for 693 Arctic stations that drain 50 % of the whole pan-Arctic area and cover 1950-2020 time period



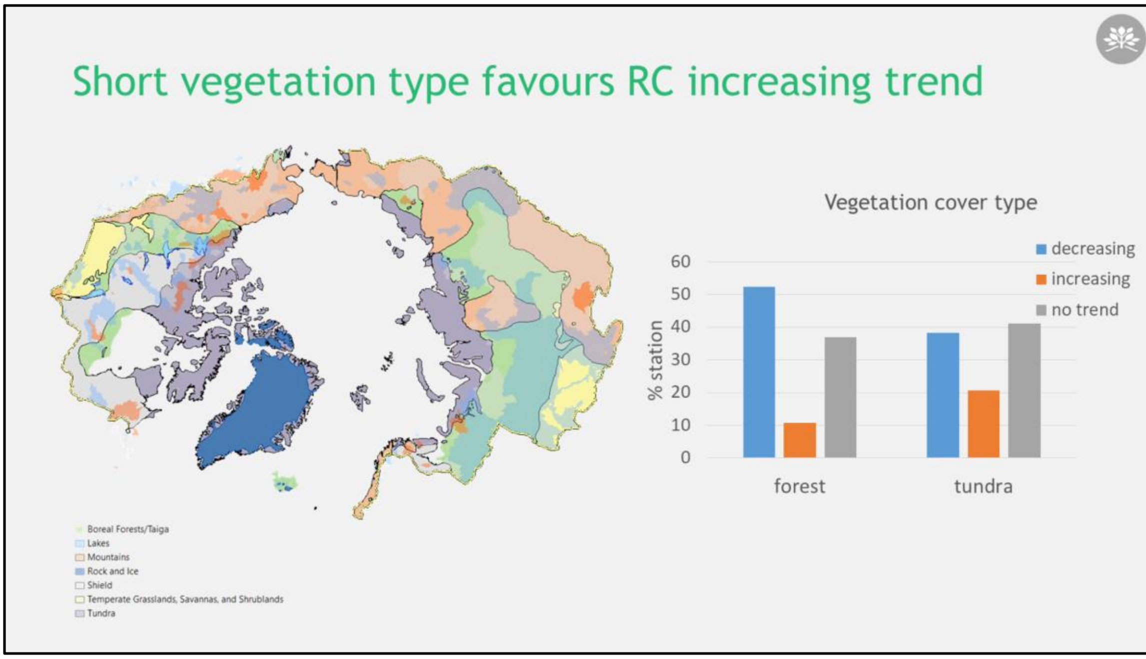
Most of the analysed catchments reflect either no trend or a decreasing trend in RC. If the RC were directly proportional to ALT (as assumed with Boussinesq equation), our results would suggest that, in most of Arctic catchments, the AL shrinks instead of thickening with time. This observation is counter-intuitive because, with climate change, we expect a majority of AL thickening trends.



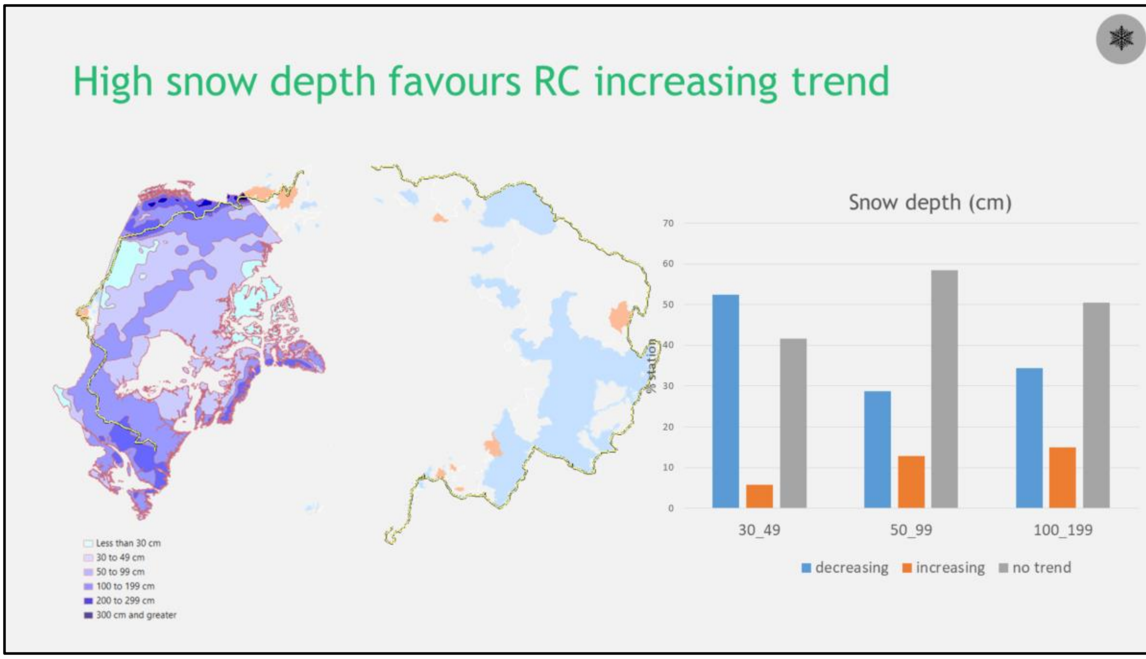
The counter-intuitive results leads to two options: either the Boussinesq solution is not applicable to our case-study, either other parameters than the AL thickness impact RC evolution with time.



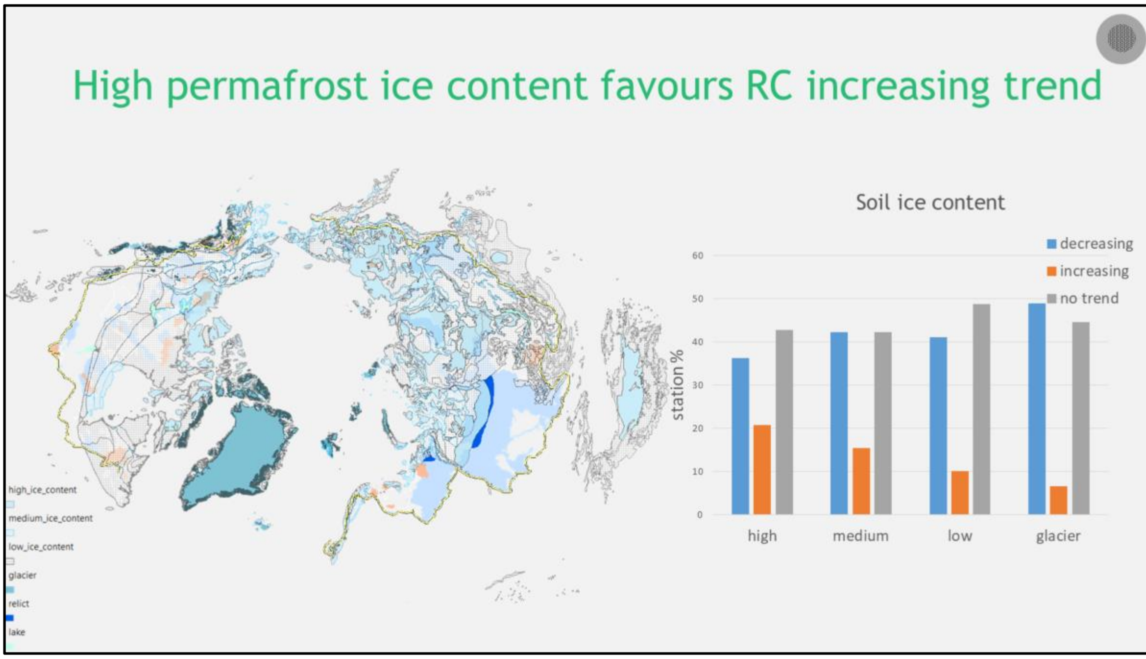
We test the reliance of RC on other parameters than aquifer properties, such as environment parameters: vegetation cover type, snow cover, permafrost ice content and permafrost permeability. These environment parameters are known to have crucial impact on permafrost state.



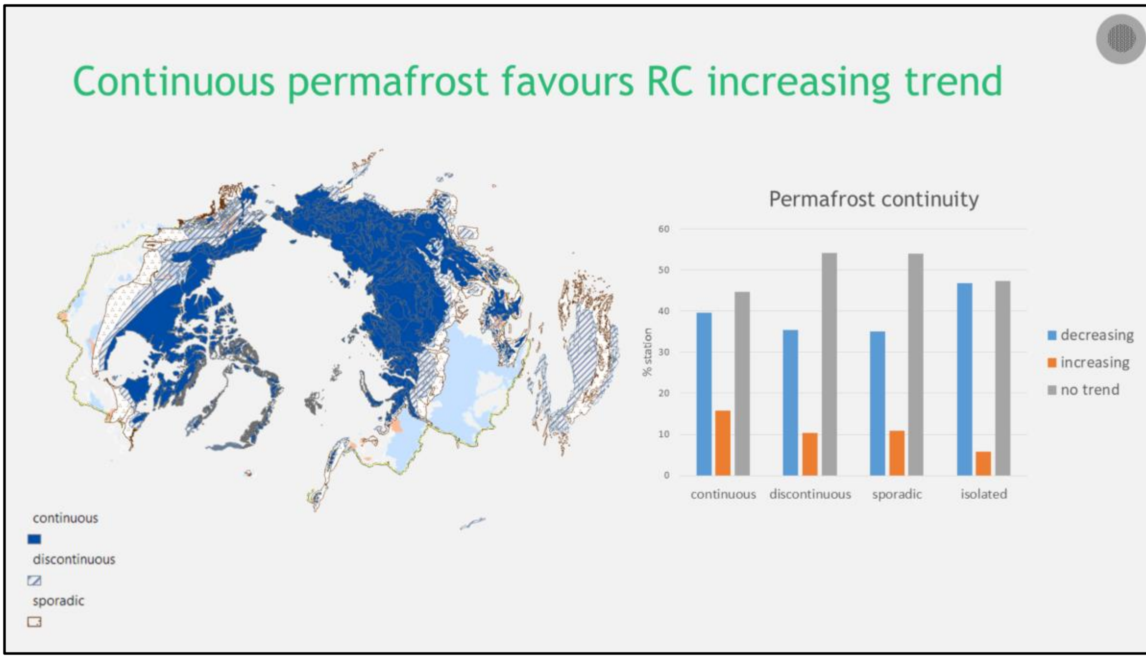
The shortness of the vegetation cover enhances increasing trend in RC



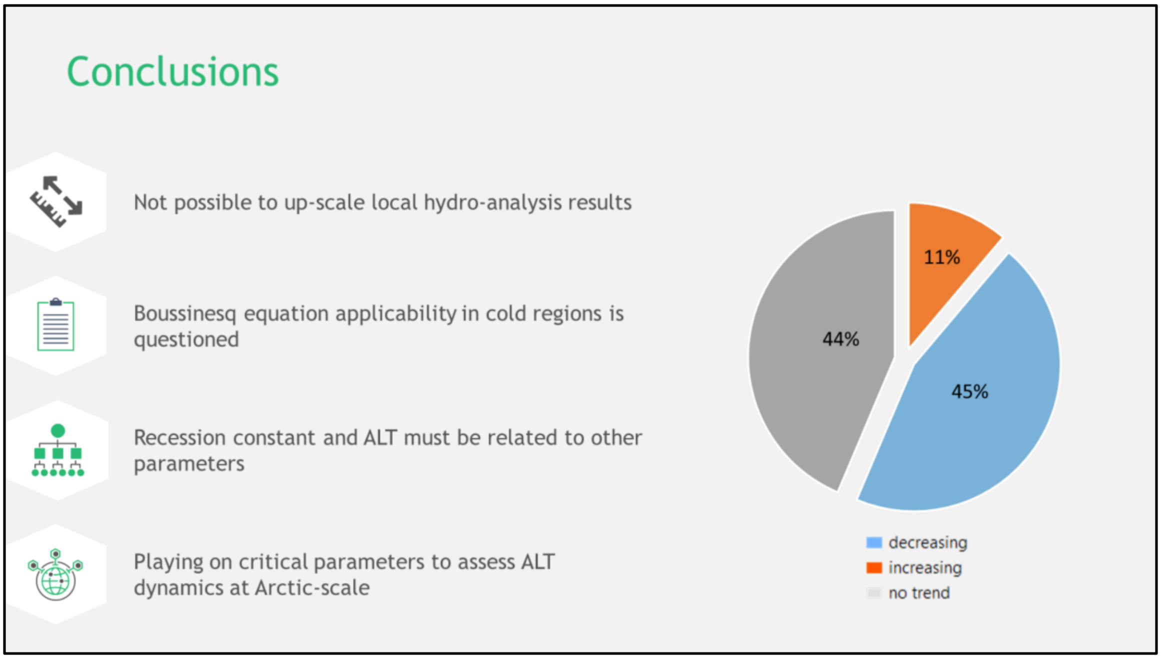
The height of the snow depth enhances increasing trend in RC



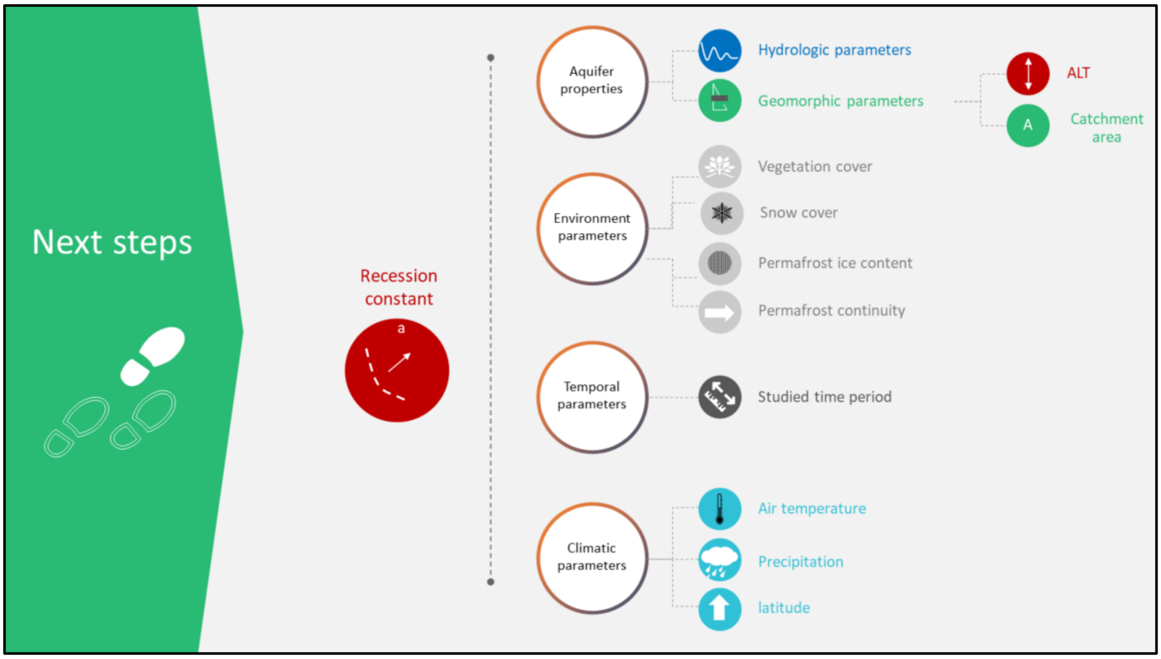
The level of permafrost ice content enhances increasing trend in RC



The continuity of the permafrost distribution enhances increasing trend in RC



45% of the analysed catchments reflect a decreasing trend in RC in the Arctic. These counter-intuitive results suggest to discuss Boussinesq solution applicability to cold regions. To do so, other parameters that could interfere in the relationship between ALT and RC have been tested.



Next steps of the project are to test other parameters such as climatic parameters (air temperature, precipitation, latitude), temporal parameters (studied time period) and geomorphic parameters (catchment area) that could play a role on RC constant evolution.