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Discussions

Interactive comment on "New insights into the environmental drivers of the circumpolar ground thermal regime" *by* Olli Karjalainen et al.

Anonymous Referee #2

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General Comments

This paper uses ground temperature and active layer data acquired from various sources to determine their relationships with various climate and other parameters to gain insights into the environmental drivers of the circumpolar ground thermal regime. While the analysis of this rather large data set is interesting (although others e.g. Peng et al. 2018 have made use of similar data sets) some of the insights regarding the various relationships are not necessarily new and have been reported elsewhere. In addition, some of the conclusions would appear to be at odds with those of other studies, which may be partly an issue of scale. A number of comments are offered below. These concerns should be addressed before the manuscript is considered for publication.

Some of the relationships considered in this paper particularly those concerning air temperature and soil conditions have been well summarized in key equations such as the Stefan equation and the TTOP equation and their variants (see for eg. Brown et al. 2000; Harland and Nixon, 1978; Hinkel and Nelson, 2003; Nelson and Outcalt 1993; Romanovsky and Osterkamp, 1995; Risborough and Smith 1998; Smith and Riseborough 2002). There have also been a number of studies over the last decade, including those at local to continental scales, that have considered permafrost-climate relations (i.e. consideration of ground temperature and active layer thickness) and role of various local factors (e.g. Romanovsky et al. 2010, 2017; Smith et al. 2009, 2010, 2012; Burn and Kokelj 2009; Palmer et al. 2012; Throop et al. 2012; Morse et al. 2012 etc).

The broad scale of the analysis and lack of site specific data likely obscures some of the important relationships between MAGT and various local factors such as vegetation, snow cover and terrain conditions (including properties of the earth materials). Studies over 40 years ago showed the relevance of these factors and their influence on the ground thermal regime and also the occurrence of permafrost, i.e. whether MAGT is above or below 0°C (e.g. Brown 1965, 1973; Nicholson and Granberg 1973; Thie 1974). The importance of substrate conditions (thermal properties, moisture content) is described in the thermal offset component in the TTOP model. The thermal offset which, under equilibrium conditions, is due to a difference between frozen and unfrozen thermal conductivity, can result in subsurface temperatures being below 0°C, and therefor the existence of permafrost, even though the ground surface temperature is above 0°C (see Romanovsky and Osterkamp, 1995; Risborough and Smith 1998; Smith and Riseborough 2002). This effect along with latent heat effects can result in the persistence of permafrost under warm climate conditions (e.g. Romanovsky et al. 2010; James et al. 2013).

This paper largely considers spatial variation in ALT and MAGT rather than temporal variations and the authors should be careful in making conclusions regarding future changes in these variables in response to a changing climate. Also, a number of papers (such as Romanovsky et al. 2010, 2017; Smith et al. 2010 and others mentioned above) have considered the temporal variation in the ground thermal regime in the permafrost region and the factors affecting the response to a changing climate. In particular, these other studies have made conclusions regarding the importance of the initial ground thermal regime (i.e. how close MAGT is to 0°C and the importance of latent heat effects), the effect of snow cover, vegetation and substrate or soil conditions.

A large part of the paper appears to focus on the permafrost regions. However, the MAGT data utilized extends well beyond the permafrost regions and the cryospheric aspect (such as the seasonal frost depth) is not really considered in these more southerly regions and might be negligible in some areas. Given this is a journal focussed on the cryosphere and there appears to be a significant focus in the MS on permafrost, it is not clear why these additional sites were included in the analysis.

Specific Comments

Line 25-26 – One could argue that it is the presence of ground ice that influences the geomorphological processes and the impact of changing permafrost conditions.

Line 29 – Snow cover or snow depth is as (or perhaps more) important as precipitation with respect to the ground thermal regime.

Line 37-38 – One could argue it is the moisture content and drainage that are the important factors.

Line 39-41 – Romanovsky et al. (2010) is probably a better reference to use here for the role of latent heat in determining the response of the ground thermal regime to changes in air temperature.

Line 46-47 – As mentioned above, there have been circumpolar and continental analyses of the environmental drivers.

Line 52-54 – This observation wasn't unknown prior to Peng et al (2018) and as men-

tioned above, these relationships and the relevance of the "edaphic factors" are describe in variants of the Stefan Equation (e.g Harlan and Nixon, 1978; Nelson et al. 2000). Also, in an investigation of air temperature – ALT relationships across a range of ecoclimate zones, Smith et al. (2009) showed that the relationship varied according to vegetation and soil conditions (i.e. the edaphic factors).

Line 67 – Was ALT only obtained through mechanical probing or were some values acquired through analysis of shallow ground temperature records. In the results section you give a maximum value of ALT of >7 m and it is unlikely that this was determined through mechanical probing. Some of the reports used for sources of ALT data may report ALT determined by methods other than probing (including thaw tubes and ground temperature measurements). Note also that probing does not necessarily capture the maximum thaw depth.

Line 68 – The depth of ZAA can be much greater than 15 m and will depend on thermal properties of the subsurface materials. ZAA depth can be greater than 20 m for example in bedrock (see for eg. Romanovsky et al. 2010; Smith et al. 2010; Throop et al. 2012).

Line 60-83 – It is unclear whether the analysis utilizes a mean value for the entire 2010-2014 period for ground temperature, ALT, air temperature etc.

Line 95-98 – Snow depth can be highly variable in northern environments depending on exposure to wind and vegetation. This is a site specific factor and its influence is probably not adequately considered by only utilizing precipitation records.

Line 104-106 – What is the resolution?

Line 151-152 – This relationship was not unknown and has been shown by others (a couple of examples Brown, 1967, Throop et al. 2012 and GSC Open File 3954 available through GEOSCAN).

Line 153-154 – As shown in Smith et al. (2009), there is a more direct relationship between TDD and ALT for tundra sites compared to vegetated sites or organic terrain.

Line 161-169 – Aren't these factors inter-related?

Line 180-187 – I would disagree that this finding about the effects of TDD and FDD is all that significant. Cold conditions are a requirement for permafrost so FDDair will have a higher value in permafrost environments compared to non permafrost environments. This is described by the Frost Index model of Nelson and Outcalt (1983).

Line 181 – Do you really mean there is a negative energy balance or do you mean FDD>TDD which is not the same thing (a negative energy balance would mean there is cooling over time).

Line 188-190 – See earlier comment regarding relationship between TDD and ALT and its variability with vegetation etc.

Line 189-193 – High Arctic sites do not necessarily have decimeter thaw depths. Greater thaw depths can be found in bedrock so the material type is important. Also, if thaw depths are largely obtained by probing there may be some bias in the data set as the method is limited by soil type (difficult or impossible in granular material and bedrock) and the depth of probing. As mentioned in previous comments, site specific factors are an important influence on ALT and its relationship with TDD and this is likely masked in your analysis.

Line 200-209 – The results presented don't really allow attribution of the effect of precipitation to advection over latent heat. Drainage will be an important factor.

Line 210-217 – As mentioned above, the amount of snow on the ground (snow depth) is probably the more important factor and is highly variable. Other studies have utilized winter n-factors to account for this effect in investigations of climate-ground temperature relationships. (see for example Morse et al. 2012; Palmer et al. 2012; Throop et al. 2012 as well as those cited in the MS).

Line 218-225 – A general northward decrease in MAGT which is associated with de-

creasing solar radiation and air temperature has been reported elsewhere (e.g Brown 1967, Smith et al. 2010; Romanovsky et al. 2010). As others have pointed out (see various papers already cited) the relationship is modulated by local factors. The incoming solar radiation that reaches the ground surface, and therefore influences the ground surface temperature and the deeper thermal regime, is probably the more important variable and probably not well captured in your data set.

Line 223-224 – Other studies (see those cited earlier) conclude that vegetation and soil properties are an important influence on the response of MAGT to changes in climate and therefore predictions of future conditions. Also, soil properties are an important influence on the thermal offset (which is not mentioned in this MS) which can be an important factor determining whether permafrost exists or not under warmer conditions (See previous comments).

271-272 – This has been concluded in other studies as mentioned in earlier comments.

Line 273-275 – See earlier comments regarding importance of substrate conditions (soil or rock properties) in influencing the response of the ground thermal regime (and future permafrost conditions) to changes in climate.

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