Responses to Reviewer's Comments and Suggestions
(Responses are shown in blue.)

Review comments on ESSD-2021-83

Youhua Ran et al. present a relevant raster data collection of permafrost-related ground quantities, these are the GCOS Essential Climate Variables, ECVs: mean annual ground temperature MAGT at zero annual amplitude (ZAA), and active layer thickness (ALT) representative for a thermal state of permafrost for the time window from 2010 to 2016. In addition, the authors also derived permafrost probability and what is the novelty: aridity-index related permafrost regions.
Despite the high value of providing these mapped permafrost related quantities and the very interesting novel approach integrating the aridity, the manuscript still lacks clarity and accuracy in describing products and methods and the published permafrost map products are not consistent.
The training data set as it is described in this manuscript using a large data collection of MAGT at ZAA lacks transparency and is not publicly available. The major revision requirements are better product descriptions and higher transparency on the training data collection on MAGT in ZAA as most important issue.
Response: Thank you. We have carefully revised the paper to provide better product descriptions and higher transparency regarding the collection of the training data.

These are the main points of concern that should be solved by providing more details and discussion on MAGT in ZAA:
i) The depth of ZAA is stongly changing throughout the Northern hemisphere: e.g. at higher latitudes minimum and maximum air temperature span a much large temperature range than at mid latitudes. In case of this large temperature range the ZAA depth is only reached at deeper ground depths of 10 to 15 m. This is in contrast to ZAA at more shallower depths in discontinuous permafrost and mid latitude regions. This means the depth of MAGT varies considerably in this map product, please add this to discussion, Is it possible to add the depth of ZAA as an additional metadata raster in the product? Please expand on this in the discussion chapter. This is also relevant for comparison with other products because mapped regional, circumarctic, global MAGT products and simulations in other communities refer to MAGT in specific depths always.
Response: Yes, the depth of MAGT varies for this MAGT product. Your idea to add the depth of ZAA as an additional raster is a good one. However, the exact depth of ZAA is not available for specific boreholes. To increase transparency, a more detailed description of the MAGT measurement data has been added in section 2.1. Furthermore, a paragraph discussing the variation of ZAA depth has been added.

ii) As the authors state the MAGT at ZAA training data is based on the most comprehensive field data collection by Alto et al. 2018. However, this higher level data collection derived from various sources is not publicly available. Alto et al. 2018 describe in their comprehensive manuscript in detail the methods and the sources of the data. The authors describe how for extracting MAGT at ZAA or close to ZAA they manually calculated these data from ground temperature depth profiles from the different data providers (GTN-P data base, Roshydromet, national PIs). However, in context of this MAGT at ZAA map product there are open questions: for example Roshydromet

temperature depth profiles have a standardized maximum depth of 3.20 m. What value exactly represents MAGT at ZAA in regions with considerably deeper ZAA depths then 3 meters? Please show transparency on this issue and discuss. Please also provide the detail on how you averaged the different temporal resolutions (e.g., hourly, daily etc measurements) of the ground temperature input data sets.

Response: Thank you. We have provided a more detailed description of the MAGT measurement data in section 2.1. A citation, i.e., Karjalainen et al., 2019, has been added to improve the transparency regarding the MAGT data.

Regarding your question, "What value exactly represents MAGT at ZAA in regions with considerably deeper ZAA depths then 3 meters?", we do not know the exact MAGT at ZAA in regions where we only have values to a depth of 3.20 m (and where the actual ZAA depth (DZAA) is greater). However, in light of the discussion in Karjalainen et al (2019), we assume that the MAGT at 3.20 m based on a year-round time series is representative of the MAGT at the ZAA.

Regarding the averaging ground temperature values, in the case of the RosHydromet data, it is true that the measurements were not necessarily from the DZAA, and we averaged the temperature time series at 3.20 m depth to compute MAGT. In this study, we ensured that we included only those time series that covered entire years, that is, all 12 months or 365 days (although in some cases, several days were missing; however, this was considered unlikely to greatly affect the annual averages). All provided temperature values were used in these computations apart from those values flagged unreliable by the data providers.

These techniques apply to all of the used time series input data. When the ground temperatures at the DZAA were in question (and intraannual variability was thus minimal), some interannual temperature trends were usually visible (oftentimes increasing), and all available full years (or months, days or hours) from the 2000-2014 period were used to compute MAGT.

iii) The majority of the MAGT sites of this data collection are not within permafrost zones (continuous, discontinuous, isolated) and do not represent ‘permafrost’ temperatures. Please show the share of ‘permafrost’ vs non permafrost MAGT at ZAA training data and could you add an estimate of different accuracies in deriving ‘permafrost’ vs non permafrost MAGT, at least the authors should make readers aware of this issue and discuss it.

Response: This is a good point. We have added “The accuracy of the predicted MAGT in permafrost regions, with field measurements in permafrost sites (MAGT $\leqslant 0$ ℃) used as reference, was significantly higher (RMSE=1.06 ℃, bias=-0.22 ℃) than that in nonpermafrost regions (RMSE=1.56 ℃, bias=0.88 ℃” to the revised manuscript.

iv) The MAGT at ZAA data collection in Alto et al. 2018 refers to the time span 2000 – 2014. The presented state of permafrost in the raster layer is from 2010 to 2016. Eventually the authors have explained the temporal representativeness of the training data set related to the time span from 2010 to 2016 in their manuscript. If the authors did they should describe it more clearly, if not the authors should add this information.

Response: The collection of the MAGT at ZAA data in this study corresponds to the time span

2000-2016. The presented thermal state of permafrost in the raster layer corresponds to the period from 2000 to 2016.

This referee comments do not implement that the produced raster sets are not valid – they are of value and should be used in several communities - but the accuracy of these products stated in this manuscript is unrealistic already by the nature and the noise of the MAGT at ZAA input data.
Response: Yes, permafrost is more of a climate product; it is also a product of ecosystems in some cases. According to the change characteristics of permafrost and the current level of prediction accuracy, the data released in this study represent the thermal state of permafrost at the Northern Hemisphere scale for the period 2000-2016.

In summary, an additional raster or other form of meta data information on the depth of MAGT is required for a good usage of the mapped permafrost products in other, also permafrost-not experienced communities: discussions and details on i) to iv) should be provided in the manuscript.
The other input data should be described more clearly, stating data sources, exact product names, native spatial resolution, temporal resolution and time stamps of the products, e.g. also in the form of a table.
Response: This is a good idea. Table 1 summarizes the environmental and climate variable datasets used in this study to predict MAGT and ALT.

Table 1: Environmental and climate variable datasets used in this study to predict MAGT (mean annual ground temperature) and ALT (active layer thickness). MODIS, Moderate Resolution Imaging Spectroradiometer; LST, land surface temperature; AVHRR, Advanced Very High Resolution Radiometer; GLASS, Global Land Surface Satellite).

Variable	Data source	Spatial resolution	Temporal resolution and time span
Freezing degree-days, ℃-days	MODIS LST	1 km	Daily, 2000-2016
Thawing degree-days, ℃-days	MODIS LST	1 km	Daily, 2000-2016
Snow cover duration, days	MODIS, AVHRR	0.05 °	Half-month, 2000-2016
Leaf area index	GLASS	1 km	Eight-day, 2000-2016
Precipitation, mm	WorldClim v2.1	1 km	1970–2000 but adjusted to 2000–2016
Solar radiation, kJ m^{-2} day^{-1}	WorldClim v2.1	1 km	1970–2000 but adjusted to 2000–2016
Soil organic content, g kg^{-1}	SoilGrids250	250 m	-
Soil bulk density, kg m^{-3}	SoilGrids250	250 m	-
Coarse fragment content, vol %	SoilGrids250	250 m	-

Examples are the source of the lake data set is unclear, its native spatial resolution, also the sentence ‘small lakes were filtered out by majority statistical processes’ remains unclear. Still

other large surface water bodies, such as the large Arctic rivers are not excluded. This data treatment does not seem to be consistent. Please discuss. When showing the permafrost extent of the Northern hemisphere, could the authors add also the values including the lake area for a comparison with other permafrost map products that have lake areas included?

The inspection of the published map products Ran et al. 2021 https://data.tpdc.ac.cn/en/data/5093d9ff-a5fc-4f10-a53f-c01e7b781368/ shows that large lakes are not excluded, e.g. the area of the deep Lake Baikal in Siberia contains MAGT at ZAA values in spatial patterns related to the bathymetry of Lake Baikal. The authors need to correct their product masking surface waters and upload a new version.

It would be user-friendly to convert the GIS no data value of – 9999 into a more user-friendly no data value, e.g. NaN.

Response: Thank you. We have clarified the description of the lake data used in this study. The extent of lakes was sourced from the global lakes and wetlands database, level 1 (Lehner and Döll, 2004), which comprises large lakes (area ≥ 50 km^2) and large reservoirs (storage capacity ≥ 0.5 km^3). All of the results have been updated in the revised manuscript, and new data products have been uploaded.