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Permafrost temperature and active-layer thickness of Yakutia with 0.5 degree spatial resolution for model evaluation

C. Beer[1,2], A. N. Fedorov[3,4], and Y. Torgovkin[3]

[1]Max Planck Institute for Biogeochemistry, Jena, Germany
[2]Department of Applied Environmental Science (ITM) and the Bert Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden
[3]Melnikov Permafrost Institute SB RAS, Yakutsk, Russia
[4]International Center BEST, North-Eastern Federal University, Yakutsk, Russia

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Correspondence to: C. Beer (christian.beer@itm.su.se)

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Abstract

Based on the map of landscapes and permafrost conditions in Yakutia (Merzlotno-landshaftnaya karta Yakutskoi0 ASSR, Gosgeodeziya SSSR, 1991), rasterized maps of permafrost temperature and active-layer thickness of Yakutia, East Siberia were derived. The mean and standard deviation at 0.5 degree grid cell size are estimated by assigning a probability density function at 0.001 degree spatial resolution. The gridded datasets can be accessed at the PANGAEA repository (doi:10.1594/PANGAEA.808240). Spatial pattern of both variables are dominated by a climatic gradient from north to south, and by mountains and the soil type distribution. Uncertainties are highest in mountains and in the isolated permafrost zone in the south. The maps are best suited as a benchmark for land surface models which include a permafrost module.

1 Introduction

Physical and biogeochemical processes in permafrost underlain landscapes in high latitudes are important components of the Earth system. This importance has let to recent advancements of heat conduction and phase change representations in land surface schemes of Earth system models (e.g. Lawrence and Slater, 2005; Koven et al., 2009). These models calculate the physical and biogeochemical state of the ecosystem for large grid cells (approximate 0.5 to 3.75 degree spatial resolution) by using soil texture and land cover information as well as climate data from the atmospheric component of the Earth system model or from observation-based datasets, such as reanalysis products. For instance, these 1-D models simulate a mean soil temperature profile as a result of air temperature forcing on top of the soil, snow and organic layer insulation, and soil moisture, organic matter and soil texture type impacts on thermal diffusivity. These models are to be used to project future ecosystem states under global

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change including the effects of thawing permafrost on vegetation functions and carbon dioxide and methane production from carbon-rich permafrost soils.

In global models, big assumptions are made about initialization of state variables, such as soil temperature, and about parameter values, such as snow thermal parameters. Therefore, the validation of the simulation of recent permafrost state variables, such as permafrost temperature or active-layer thickness is an important step before projecting future conditions. For doing so, comparisons to databases of point measurements, such as GTN-P (Romanovsky et al., 2010) or CALM (Brown et al., 2000) are powerful tools (e.g. Oelke et al., 2003; Beer et al., 2007; Lawrence et al., 2008). However, for such point-wise comparisons the models should be run using site-level soil texture type information and site-level meteorological observations, which is an enormous effort for a large set of sites, such as represented by CALM. In addition, the comparison of a large-scale temperature value representing a mean for an 0.5 degree grid cell with a single measurement inside that grid cell is highly unreliable since local conditions and processes, such as the horizonthal water flow are usually not represented by a site-level run of a global model. Therefore, the assignment of typical ranges of permafrost temperature and active-layer thickness (ALT) for certain landscape characteristics is a first useful generalization of the observations. It also allows a detailed mapping of such ranges from which one can scale to large grid cells representing e.g. 0.5 degrees times 0.5 degrees.

One important map in this context is the map of landscapes and permafrost conditions in Yakutia (Merzlotno-landshaftnaya karta Yakutskoi0 ASSR, Gosgeodeziya SSSR, 1991) (Fedorov et al., 1989, 1991). It represents permafrost landscape conditions with a scale of 1 : 2500000 as an average during 1960–1987. The map covers Yakutia which is a huge area within the Siberian permafrost zone. Therefore, the information about permafrost state variables stored in this map is a useful for the initialization of land surface and ecosystem models or can be used for a validation of model results. This information from East Siberia is also complementary to the high density of data points in Alaska in CALM and GTN-P databases. In this paper, we use the

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information stored in this map to scale permafrost and subsoil temperature, and ALT to 0.5 degree spatial resolution for subsequent comparisons to model results.

2 Methods

Several features of the map of landscapes and permafrost conditions in Yakutia (Fedorov et al., 1989, 1991) (Merzlotno-landshaftnaya karta Yakutskoi0 ASSR, Gosgeodeziya SSSR, 1991) were digitized and the respective GIS vector data reprojected to a plain latitude/longitude grid. For mapping permafrost temperature and active-layer thickness (ALT), layers 4 and 5 are useful. These layers represent the soil type and permafrost type information which are displayed in hachures and in color in the original map. The respective polygons were rasterized with 0.001 degree spatial resolution. Visual comparison with the vector data has proven an accurate and full representation of all polygons using such high resolution.

Then, the two types of information on soil type and permafrost type were combined for assigning permafrost temperature and ALT according to the map legend at the full 0.001 degree spatial resolution. The legend usually indicates a common range and a most frequent range of temperature and ALT for combinations of soil type and permafrost type. We calculate the mean value using the two indicators for the most frequent range of values and also interpret this range as the standard deviation. Then, we approximate a normal distribution by 100 random values representing the probability density function with that mean and standard deviation. In some cases, the values for the total possible range of values from the map legend do not exactly follow a normal distribution. Then, all of the randomly selected 100 data points along the density function which are out of the reported possible range are discarded. In summary, this step gives 100 values for each of the 0.001-degree pixels of the original map representing a normal distribution of permafrost temperature, and another 100 values for representing the ALT distribution.

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For scaling to 0.5 degree grid cell size, all 100-element vectors of the 0.001-degree pixels belonging to one 0.5-degree pixel are combined to one unique vector. This latter big vector is used for estimating the mean and standard deviation of either permafrost temperature or ALT.

In some cases, there is reported only one range for permafrost temperature or ALT instead of two ranges. To be most conservative, we use their difference for the standard deviation but at the same time cut the distribution at these values. This approach ensures a high uncertainty of the values in these landscapes but also avoid the contribution of unrealistic values to the calculation of the overall mean and standard deviation for the 0.5-degree pixel.

In the case of discontinuous permafrost or isolated permafrost landscapes, the legend indicates the permafrost temperature range in concert with the subsoil temperature range for the non-permafrost areas. In this case, two temperature distributions were approximated, for permafrost and non-permafrost areas. Assuming 75 % permafrost cover and 25 % permafrost cover for discontinuous and isolated permafrost landscapes, respectively, the two temperature or ALT distributions hold either 75 or 25 data points. Then, all the individual vectors belonging to the 0.5-degree grid cell which represent the normal distribution of temperature or ALT are combined again to one unique vector, as described above.

With the scaling methods described in this section we make sure to produce a subsoil temperature map and a ALT map that are most comparable with global modelling results.

3 Results and discussion

Figure 1a shows subsoil temperature (permafrost temperature in continuous permafrost zone and mainly permafrost temperature in discontinuous permafrost zone) with 0.5 degree spatial resolution. These values represent the mean for each grid cell during 1960–1987. Values range between –11 and –0.3 °C from north to south.

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Only some isolated permafrost areas in the south show slight positive subsoil temperatures. However, there are also clear longitudinal differences reflecting different climate regimes in mountains versus lowlands, in particular east of the river Lena. Figure 1b shows that with a standard deviation of more than 3 °C the uncertainties in these mountains is also highest.

The huge range of subsoil temperature reflects the different climatic conditions and landscape types of Yakutia which were also the basis for defining the region as a IGBP transect (McGuire et al., 2002). These environmental conditions are also the reason for specific ecosystem types from tundra in the north to larch-dominated taiga in the south. Therefore, the region is useful for a validation of a global model (Sazonova et al., 2004).

Active-layer thickness spatial patterns follow temperature patterns (Fig. 2a). Maximum thaw depth in summer can be very shallow north of 70° N (0.3–0.6 m) but also quite deep south of 65° N and west of 136° E (1.5–2.7 m). Between 65° N and 70° N or west of 136° E, ALT usually varies between 0.6 and 1.4 m. Uncertainty of ALT increases with ALT and is highest (up to 1 m) in the south (Fig. 2b). The ALT map is unique in terms of spatial extend and ALT range and therefore very useful for a comparison with global or regional models.

ALT in discontinuous and isolated permafrost zones are still not completely comparable to modeling results since the mapped data represents the ALT of the permafrost areas within the landscape while the global model usually simulates one mean soil temperature profile from which ALT is further derived. Therefore, the comparison of subsoil temperature should have higher priority in discontinuous and isolated permafrost zones.

Uncertainty, expressed as standard deviation, increases to the south because of the occurrence of discontinuous and isolated permafrost landscapes. The uncertainty information is most important for a comparison with global model results because it is an indicator for the spatial variability within the 0.5-degree pixel.

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4 Summary

This paper presents a map of permafrost temperature and a map of active-layer thickness of Yakutia, East Siberia at 0.5 degree grid cell size. A detailed scaling from 0.001 degree raster images to 0.5 degree maps using probability density approximations allows a spatial mean and standard deviation that are most useful for a comparison with results from land surface models which represent heat conduction and phase change. The gridded datasets can be accessed at the PANGAEA repository (doi:10.1594/PANGAEA.808240). In general, there is a strong north-south gradient of both subsoil temperature and active-layer thickness. However, mountains and soil types distributions lead to also more detailed longitudinal pattern. Uncertainties are highest in mountains and in the isolated permafrost zone in the south.

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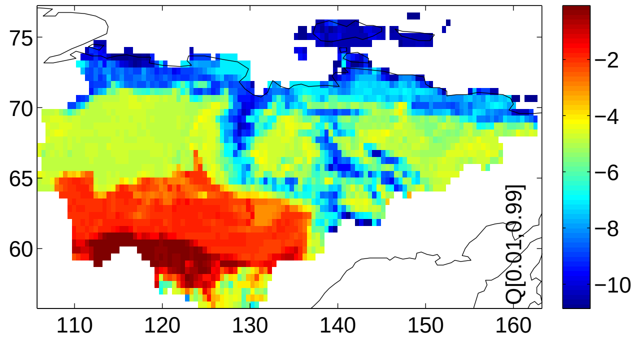
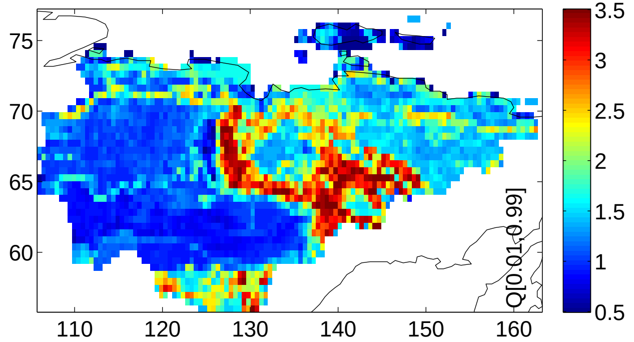


(a) Mean of subsoil temperature



(b) Standard deviation of subsoil temperature

Fig. 1. Subsoil temperature. Shown are (0.01,0.99)-quantile ranges of mean and standard deviation from several soil and permafrost types within a 0.5 degree grid cell.

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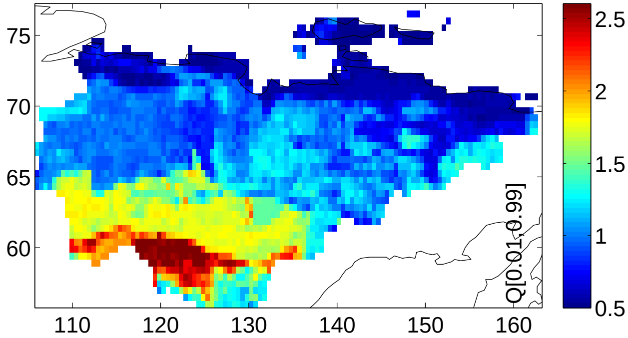
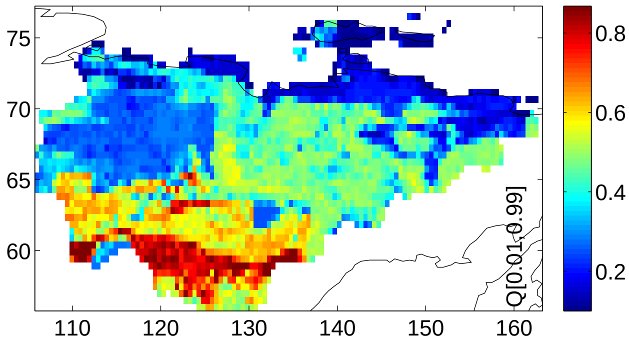


(a) Mean of active-leayer thickness



(b) Standard deviation of active-leayer thickness

Fig. 2. Active-layer thickness. Shown are (0.01,0.99)-quantile ranges of mean and standard deviation from several soil and permafrost types within a 0.5 degree grid cell.

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