PeRL: A Circum-Arctic Permafrost Region Pond and Lake Database
Metadata on waterbody maps and permafrost landscape maps

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1. Introduction

This metadata information is an excerpt of the paper by Muster et al. (2016) which describes the compilation of the Permafrost Region Pond and Lake Database (PeRL). Ponds and lakes are abundant in Arctic permafrost lowlands. They play an important role in Arctic wetland ecosystems by regulating carbon and water fluxes and providing freshwater habitats. However, ponds, i.e., waterbodies surface areas smaller than 1.0E+04 m², have not been inventoried globally. PeRL presents the results of a circum-arctic effort to map ponds and alkes from modern (2002-2013) high-resolution aerial and satellite imagery with a resolution of 5 m or less that resolves waterbodies down to a surface area of 1.0E+02 m². The database also includes historical imagery from 1948 to 1965 with a resolution of 6 m or smaller. PeRL includes 69 circum-arctic maps covering a wide range of environmental conditions from tundra to boreal regions and from continuous to discontinuous permafrost zones which present a baseline for high-resolution pond and lake change detection. Waterbody maps are linked to regional permafrost landscape maps which provide information on permafrost extent, ground ice volume, geology and lithology. Regional permafrost landscape units in Arctic lowlands (<300 m) are used to extrapolate waterbody distribution statistics from the site to the landscape scale. PeRL presents pond and lake estimates for a total area of 1.4E+06 km² across the Arctic, some 18 % of the Arctic lowland land surface area. PeRL waterbodies with sizes of 1 km² down to 100 m² contributed up to 21 % to the total water fraction. Waterbody density ranged from 1.0 km^{-2} to 94 km^{-2}. Ponds are the dominant waterbody type in all landscapes with 45 % to 99 % of the total waterbody number.

2. Metadata on waterbody maps

2.1. Individual water body maps

Files include 69 individual waterbody maps as ESRI shape-files in the North Pole Lambert Azimuthal Equal-Area projection (NPLAEA) projection. Each map is identified by a map ID which consists of a site identifier (three letter abbreviation of the site name), followed by a running three-digit number and the acquisition date of the base imagery (YYYY-MM-DD). Each shape-file also contains the attributes “AREA” and “PERIMETER” which are reported in square meters. More information about image processing and classification for each waterbody map can be found in Muster et al. (2016).

2.2. Study area boundaries

Each map has a polygon associated with it that describes the study area, i.e. the total land area of the waterbody map. All study areas are stored in the ESRI shape-file *PeRL_study_areas.* Waterbody maps and study area polygons and can be identified via the map ID. Attributes of study areas are described in Table 1. Detailed information on the source of each attribute is reported in Muster et al. (2016).

Table 1: Attributes of ESRI shape-file *PeRL_study_area.*

Field name	**Description**
country	country
Map_ID	ID of individual waterbody map
site	site name
MAAT	mean annual air temperature [°C]
TP	mean annual total precipitation [mm]
PE_DEPTH	Permafrost depth [m]
lat	latitude coordinate of polygon centroid in decimal degrees (WGS84)
long	longitude coordinate of polygon centroid in decimal degrees (WGS84)
AREA	area of polygon in square metres
AREA_SQKM	area of polygon in square kilometres

3. Metadata on Regional maps of pond and lake distributions

Regional maps of permafrost landscapes (PL) were used to extrapolate waterbody maps of PeRL for lowlands with elevations less than 300 m. We define PLs as a unique combination of climate, geology, lithology, permafrost extent and ground ice volume. Vector maps of these landscape properties are available on the regional level: the Alaskan Map of Permafrost Characteristics (AK2008) (Jorgensen et al., 2008), the National Ecological Framework for Canada (NEF) (Marshall et al., 1999), and the Land Resources of Russia (LRR) (Stolbovoi and McCallum, 2002). Despite differences in mapping approaches and terminology, the databases report similar landscape characteristics at a similar scale. All PL maps were clipped in ArcGIS v10.4 with a lowland mask including only areas with elevations of 300 m or lower. The lowland mask was derived for the whole Arctic using the digital elevation model GTOPO30 (USGS). Vector files of permafrost landscapes are available for Alaska, Canada and Russia. Processing of each map is described in detail in the sections 3.1, 3.2 and 3.3.

3.1. Alaskan permafrost landscape maps

The permafrost map of Alaska reports surfical geology, MAAT, primary soil texture, permafrost extent, ground ice volume, and primary thermokarst landforms. A rule-based model was used to incorporate MAAT and surficial geology. Permafrost characteristics were assigned to each surficial deposit under varying temperatures using terrain-permafrost relationships and expert knowledge. (Jorgensen et al., 2008)

Table 2: Attributes of ESRI shape-file *alaska_perma_land.*

Field name	**Description**	**Source**
ECOZONE	ecozone	AK2008
GEN_GEOL	generalized geology	AK2008
LITHOLOGY	texture	AK2008
GROUND_ICE	ground ice content [vol %]	AK2008
PF_EXTENT	permafrost extent	AK2008
PERMA_LAND	combined label of PF_EXTENT / GROUND_ICE/GEN_GEOL/LITHOLOGY	PeRL
ECOZID	ecozone ID	PeRL
PERMID	ID for each polygon in the vector file. The first digit stands for the region (1 – Alaska, 2 – Canada, 3 – Russia), digits 2 – 6 identify the single polygon, and the last three digits identify the ecozone.	PeRL
AREA	area of polygon in square meters	PeRL
PERIMETER	perimeter of polygon in square meters	PeRL

3.2. Canadian permafrost landscape maps

PL of Canada are described in the National Ecological Framework (NEF). The NEF distinguishes four levels of generalization nested within each other. Ecozones represent the largest and most generalized units followed by ecoprovinces, ecoregions, and ecodistricts. Ecodistricts were delineated based mainly on differences in parent material, topography, landform and soil development derived from the Soil Landscapes of Canada (Soil Landscapes of Canada Working Group, 2010) at a map scale of 1:3,000,000 to 1:1,000,000 (Ecological Stratification Working Group, 1995, Marshall, 1999). Ecoregions and ecoprovinces, on the other hand, are generalized based mainly on climate, physiography, and vegetation. Ecodistricts were therefore chosen as most appropriate to delineate

PLs. NEF reports the areal fraction of the underlying soil landscape units and their attributes nested within each ecodistrict. The dominant fraction (>50%) of surficial geology, lithology, permafrost extent and ground ice volume was chosen to describe each ecodistrict. Ecodistricts with the same PL characteristic within the same ecozone were then merged to PL units.

Table 3: Attributes of ESRI shape-file *canada_perma_land.*

field name	**description**	**source**
ECOZONE	ecozone	NEF
ECOREGION	ecoregion	NEF
ECODISTRIC	ecodistrict	NEF
GEN_GEOL	dominant fraction of generalized (surficial) geology	NEF
LITHOLOGY	dominant fraction of texture	NEF
GROUND_ICE	dominant fraction of ground ice content in vol%	NEF
PF_EXTENT	dominant fraction of permafrost extent	NEF
PERMA_LAND	combined label of PF_EXTENT / GROUND_ICE/GEN_GEOL/LITHOLOGY	PeRL
ECOZID	ecozone ID	PeRL
PERMID	ID for each polygon in the vector file. The first digit stands for the region (1 – Alaska, 2 – Canada, 3 – Russia), digits 2 – 6 identify the single polygon, and the last three digits identify the ecozone.	PeRL
AREA	area of polygon in square meters	PeRL
PERIMETER	perimeter of polygon in square meters	PeRL

3.3. Russian permafrost landscape characterization

Russian maps about permafrost extent, ground ice content, generalized geology and lithology was retrieved from Land Resources Russia (LRR) as individual vector maps.

- Web source: http://webarchive.iiasa.ac.at/Research/FOR/russia_cd/site.htm
- Download data: http://webarchive.iiasa.ac.at/Research/FOR/russia_cd/download.htm

The individual maps were combined to delineate Russian PL units similar to the Canadian and Alaskan databases. Russian ecozones were mapped using the global-scale map by Olson et al. (2001) which conforms to the Alaskan and Canadian ecozones. The geometric union of ecozone, ground ice content, and permafrost extent was calculated in ArcGIS v10.4 via the tool “intersect”.

Each unique combination of these three variables was assigned the dominant fraction of geology and lithology type.

Table 4: Attributes of ESRI shape-file *russia_perma_land.* Attribute names in square brackets report the original attribute name of the source file.

field name	description	source
ECOZONE	Metadata: http://maps.tnc.org/files/metadata/TNC_Lands.xml	Olson et al., 2001 Downloaded at http://maps.tnc.org/gis_data.html#TerrEcos
GEN_GEOL	Surficial geology [PARROCK]	LRR, Stolbovoi et al. (2002c)
LITHOLOGY	Texture [TEXTURE]	LRR, Stolbovoi et al. (2002c)
GROUND_ICE	ground ice content in vol% [MIN_MAX]	LRR
PF_EXTENT	permafrost extent [EXTENT_OF_]	LRR
PERMA_LAND	combined label of PF_EXTENT / GROUND_ICE/GEN_GEOL/LITHOLOGY	LRR
ECOZID	ecozone ID	PeRL
PERMID	ID for each polygon in the vector file. The first digit stands for the region (1 – Alaska, 2 – Canada, 3 – Russia), digits 2 – 6 identify the single polygon, and the last three digits identify the ecozone.	PeRL
AREA	area of polygon in square meters	PeRL
PERIMETER	perimeter of polygon in square meters	PeRL

4. PeRL permafrost landscapes

The individual regional PL maps were merged in ArcGIS to produce a unified vector file and map representation (*PeRL_perma_land.shp*). Landscape attributes that were retained from the original regional maps were ecozone, permafrost extent, ground ice volume, surficial geology, and lithology (Table 6). Waterbody distribution statistics were joined with the permafrost landscape map (Section 5.1 and Table 6).

4.1. Extrapolation of waterbody statistics to permafrost landscapes

Waterbody maps were spatially linked with their associated PL. Maps within the same PL were combined whereas maps spanning two or more PLs were divided by selecting all waterbodies that intersected with the respective PL. Generally, waterbody statistics were extrapolated for study areas with single or combined total mapped areas of 1.0E+02 km² or larger. Maps in the Canadian High Arctic were smaller than 1.0E+02 km² but represent typical wetlands in that region and were therefore included in the extrapolation. Several maps within one permafrost landscape were combined and average statistics were calculated across all maps in that PL unit. Extrapolated values were assigned two confidence classes: high (1) and low (2) confidence. PLs were assigned a high confidence if a map was present in the PL of that ecozone. The same PL but in located in a different ecozone was assigned the same waterbody statistics but with a low confidence. In sufficiently large study areas, 10x10 km subsets were for which average statistics and their relative error were calculated and reported. The same was done if four or more individual maps in a PL were combined. Due to differences in the methodology of mapping and extrapolating permafrost characteristics, the extrapolation was limited to each region.

Table 5: Attributes of ESRI shape-file *perma_land.*

Field name	**Description**
PERMA_LAND	permafrost landscape: [permafrost extent]/[ground ice volume]/[surficial geology]/[texture]
AREA	area of polygon in square meters
PERIMETER	perimeter of polygon in square meters
Map_ID	ID of waterbody map used for extrapolation
confidence	1: high confidence, 2: low confidence
frac	areal fraction of waterbodies (1.0E+02 m² to 1E+06m² in surface area) in %
frac_re	relative error of areal fraction of waterbodies (1.0E+02 m² to smaller than 1E+06m² in surface area) in %
dens	density: number of waterbodies (1.0E+02 m² to 1E+06m² in surface area) per square kilometre
dens_re	relative error of density of waterbodies (1.0E+02 m² to 1E+06m² in surface area) in %
frac_ponds	areal fraction of waterbodies (1.0E+02 m² to smaller than 1E+04m² in surface area) in %
frac_po_re	relative error of areal fraction of waterbodies (1.0E+02 m² to smaller than 1E+04m² in surface area) in %
dens_ponds	ponds density: number of ponds (1.0E+02 m² to 1E+04m² in surface area) per square kilometre
dens_po_re	relative error of pond density (1.0E+02 m² to smaller than 1E+04m² in surface area) in %

5. Uncertainty of circum-arctic map

Uncertainties regarding the upscaling of waterbody distributions arise from (i) the combination of different waterbody maps, (ii) the accuracy of the underlying regional permafrost maps, and (iii) the level of generalization inherent in the permafrost landscape units.

PeRL is a static database that presents late summer inundation conditions only. The effect of image acquisition in relation to rainfall may impact the waterbodies at the site level. However, the effect is hard to quantify as other factors such as spectral properties and resolution also impact classifications of different times at the same site. Average size distributions over large regions probably reduce the importance of seasonal variability as site level variability within the thaw period is being traded for the large spatial coverage of waterbodies across permafrost landscapes.

Permafrost landscapes present a unified circum-arctic categorization to upscale waterbody distributions. Due to the uncertainty and scale of the regional PL maps, however, it cannot be expected that non-overlapping waterbody maps within the same permafrost landscape have the same size distribution. The regional PL data sources are themselves extrapolated products where finite point sources of information have been used to describe larger spatial domains. No error or uncertainty measure, however, was reported for the regional maps. In addition, the variables used to describe permafrost landscapes present the dominant classes within the landscape unit. Thus, certain waterbody maps may represent landscape subtypes that are not represented by the reported average characteristic. For example, two permafrost landscapes have been classified in the Lena Delta in Northern Siberia. The Southern and Eastern part of the delta is characterized by continuous permafrost with ground ice volumes larger than 40%, alluvial-limnetic deposits and organic substrate. Local studies differentiate this region further based on geomorphological differences and ground ice content. The yedoma ice complex in the southern part features much higher ground ice content of up to 80% and higher elevations than the eastern part which is however not resolved in the Russian PL map. These sub-regional landscape variations are also reflected in the waterbody size distributions which are significantly different for the southern and eastern part of the delta. In the averaged statistics this is indicated by a high relative error of 11 % and 28 % for areal fraction of waterbodies and ponds, respectively, and about 50 % for density estimates. In this case, the PL unit in that area does not adequately reflect the known distribution of ground ice and geomorphology and demonstrates the need to further improve PL maps in the future.

6. References

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