Lake and mire isolation data set for the estimation of post-glacial land uplift in Fennoscandia

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Abstract. Postglacial land uplift is a complex process related to the continental ice retreat that took place about 10,000 years ago and thus started the viscoelastic response of the Earth's crust to rebound back to it's equilibrium state. To empirically model the land uplift process based on past behavior of shoreline displacement, data points of known spatial location, elevation and dating are needed. Such data can be obtained by studying the isolation of lakes and mires from the sea. Archaeological data on human settlements (i.e., human remains, fireplaces etc.) are also very useful as the settlements were indeed situated on dry land and were often located close to the coast. This information can be used to validate and update the postglacial land uplift model. In this paper, a collection of data underlying empirical land uplift modeling in Fennoscandia is presented. The data set is available at https://doi.pangaea.de/10.1594/PANGAEA.905352 (Pohjola et al., 2019).

1 Introduction

Holocene land uplift has been known to people living along the shores of the northern Baltic Sea for centuries. Land uplift is a consequence of the Weichselian stadial and the massive ice layer that covered the Northern Europe from the British Isles to the proximity of Ural mountains in Russia. Heavy ice load pressed the Earth's crust down during the Weichselian period and when the ice started to melt at the beginning of the post-Weichselian or the Holocene period, the crust began to rebound to it's equilibrium state. During the Holocene land uplift, the area of the current Baltic Sea experienced several lake and sea phases before finally settling to the present form of the Baltic Sea. More detailed review of the history of the Baltic Sea and the changes in the sea level can be found in (Tikkanen and Oksanen, 2002; Björck, 1995), (Punning, 1987) and (Ojala et al., 2013).

The timing of the ice retreat phases is also important in land uplift modeling. The estimated time of withdrawal of the edge of the ice sheet from a certain location marks the phase when subsidence turned into land uplift at that particular location. Several studies are available considering the timing of ice retreat (Hughes et al., 2016; Stroeven et al., 2016).

In empirical land uplift modeling, the most important source of information is that describing the shoreline displacement. Nowadays land uplift can be monitored using precise GPS station networks and gravimetric measurements from satellites described, for example, in (Lidberg et al., 2010; Müller et al., 2012; Poutanen et al., 2010; Timmen et al., 2004). Unfortunately, the GPS-based time series are relatively brief compared to other, less accurate data. The historical land uplift rate in Fennoscandia has been studied using information on lake isolation from the sea. In (Eronen et al., 2001; Cato, 1992) the isola-

tion of several lakes was examined using sediment samples taken from the bottom of the lakes. The samples were dated using the ^{14}C radiocarbon dating method and the age and depth of the layer where saltwater algae changed into freshwater algae were determined. The resulting shoreline displacement curves show that the land uplift rate has not been steady and there have also been local variations in the uplift. The same technique has been used with the ponds and mires by dating the first organic

5 layer in top of the inorganic clay layer. This method cannot be directly compared to the dating of lakes, because ponds and mires are usually missing the algae samples. On the other hand, the bottom organic layer may have formed very rapidly in the ponds and mires after the continental ice retreat.

Archaeological findings are useful in cases where the sea level can be checked against the location and age of human settlements. In Fennoscandia it can be safely assumed that people during the Holocene lived on dry land and, therefore, the

10 location and elevation of these settlements sets an upper bound for the sea level at the time the settlements are dated to.

In this paper we present a data set underlying our efforts in developing empirical land uplift models (Pohjola et al., 2014). The data set consists of lake isolation data, data on the oldest dated layers of peat bogs as well as relevant archaeological findings. In the next chapters we describe the data and the data cleaning procedure and present the data collectors and the owners of the data repositories.

15 ## 2 The data sets

2.1 Data description

The data set presented in this paper is a collection of 1918 data points and it can be divided into two subsets: lake/mire isolation data (669 data points) and archaeological data (1249 data points). Lake/mire isolation data are represented by black circles and archaeological data by red circles in Figure 1. Each data point has a spatial location, elevation and timing information that is

20 preferably obtained using the ^{14}C dating and calibration. In most cases, the uncertainties in the ^{14}C dating are also taken into account, but the user of this data set must be aware of the uncertainties in spatial coordinates and elevation values (explained in more detail in the 'Data Handling' section). In the following sections, the sources of the two data subsets are presented. An example of the data from both data sets can be seen in Figure 2.

2.2 Lake and mire isolation data set

25 The lake/mire isolation data forms the main data set used in the modeling. The basic idea behind these type of data is the determination of the freshwater/saltwater ecosystem boundary from a core drilled sample from a lake or mire bottom sediment. The layer where the marine or brackish water algae change to fresh-water algae is determined in laboratory analysis. These kinds of samples have been collected especially in the area of Finland and Sweden. In Finland the main data contributors have been Matti Eronen and Gunnar Glückert (Eronen et al., 2001). Arto Vuorela collected additional data points and included the

30 data set of Matti Eronen and Gunnar Glückert into his own data set, published in (Vuorela et al., 2009). (Mäkilä et al., 2013) is a collection of mire and bog evolution and isolation datings in Finland. The collection of data points presented in this paper
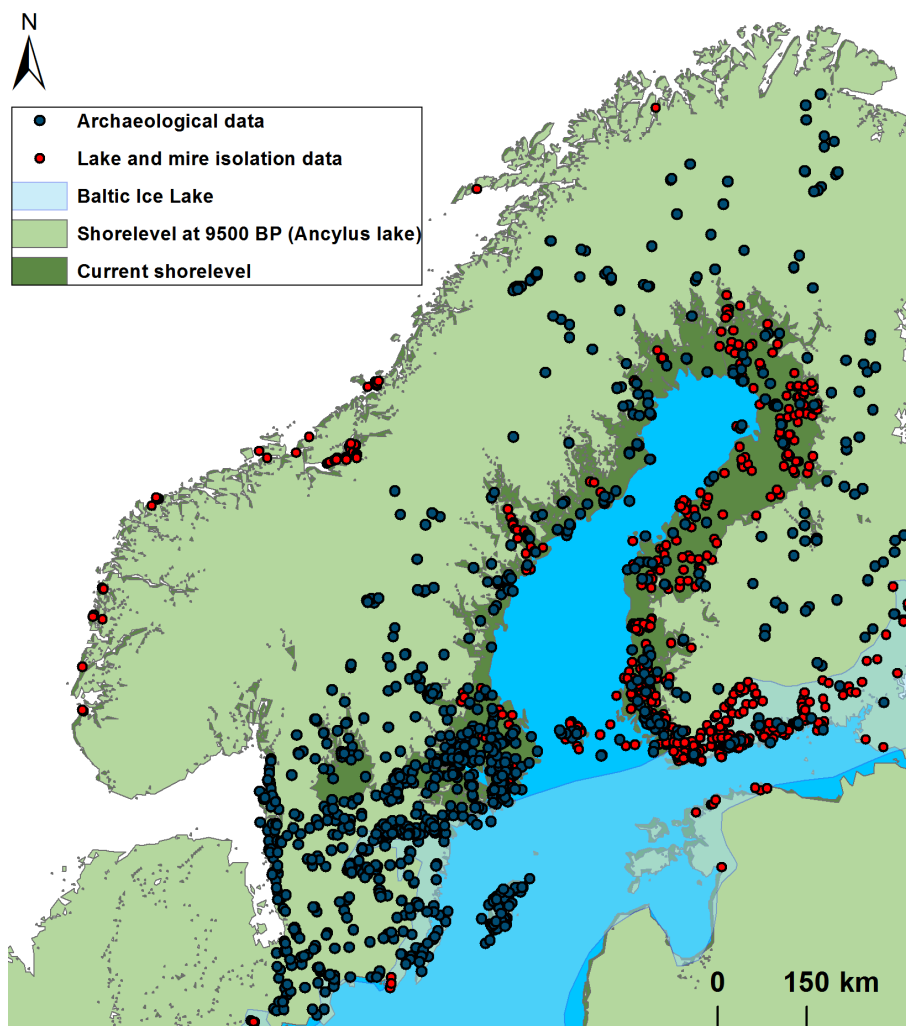
Figure 1. Spatial location of source data points. Maximum extent of the Ancylus lake phase is indicated in dark green color and the Baltic Ice Lake area is marked in mild blue color. *Data points: (Pohjola et al., 2019). Background map: Esri. Historical shorelines: Geological Survey of Finland.*

is sampled selectively from these sources and complemented with data points gathered from other scientific sources. Bog and mire data sets are based on core drillings and in some cases the layers of different datings are close to one another in the core. In some rare cases the datings do not fully correspond to the depth of the dated sample along the core for some unknown reasons. In these cases the oldest sample was considered even if it is not the deepest one near the clay sediment in the drilling core. Some

5   Norwegian shoreline points experienced several oscillatory rebound and retreat phases. The same issue can be seen in Finland and Sweden, where the same spatial location may have shore markings of the Baltic Ice Lake, the Litorina Sea and possibly
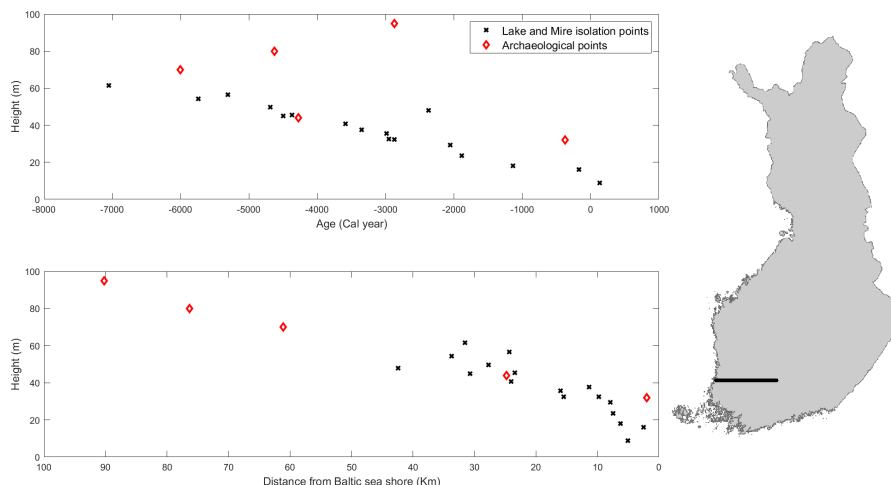
Figure 2. A sample of the data set containing data points along the line from (61° 0' 0,0", 21° 6' 0,0") to (61° 0' 0,0", 24° 0' 0,0") in WGS84 coordinate system. The distribution of the data points in the height – age and height – distance domains is presented in the upper and lower panel, respectively. Black circles denote the lake/mire isolation data and red circles the archaeological data. *Background map: Esri.*

the Ancylus Lake. Fortunately, in most cases the elevation is different and this allows to use all the available elevation/dating information of the point in question.

2.3 Archaeological data set

There are plenty of archaeological data available, but our main focus is to acquire samples that have an existing ^{14}C dating. For example, if there were coal remains from different time periods in dwelling site fireplaces, the oldest dated sample was included in the data set. The oldest sample is also an evidence of the site in question being above the water level at that time. However, there are issues of which the user of this data set must be aware. For example in Kolmhaara, Eura in southern Satakunta, Finland, the radiocarbon dated burial remains seem to be younger than expected from the radiocarbon datings. Kolmhaara is a famous place, because it contains human remains (graves, fireplaces etc.) from a time period of thousands of years. The site has been located near the Baltic Sea shoreline. However, when using shoreline modeling, these burials appear to be several meters below the sea level at the time the remains are dated to. Either the shoreline displacement model is incorrect or the 'Marine reservoir effect' (Dettman et al., 2015; Philippsen, 2013; Reimer and Reimer, 2006) has had an influence on the samples.

Main sources of the archaeological findings are the Finnish Heritage Agency archives (http://www.kyppi.fi) and the Swedish National Heritage Board archives (http://www.raa.se). [14]CARHU database consists of the radiocarbon data collected by Helsinki University (Junno et al., 2015). More detailed references are included in the data sets.

3   Data handling and organization

Various different coordinate systems were used in the original data sets. The data were reprojected to the WGS84 coordinate system and the elevation is presented as meters above the sea level corresponding to the average sea level datum. Some of the archaeological point locations were described verbally like *"half a kilometer west from the main building..."* and some of the site locations were drawn manually illustrating the significant landmarks in the area. All these data points were checked using the National Land Survey of Finland (NLS) maps as some of the archaeological sites are included in the NLS base maps. If they were not included in the base maps, the best estimates, based on the verbal clues and possible hand drawings, were determined using the NLS maps. In some cases the elevation information was also checked from the NLS base maps or NLS digital elevation maps and refined if possible. In the cases where elevation was known, it was possible to check the location using elevation information. The maximum error in the spatial location of the data points can be estimated to be about 100 meters, however, as a single data point usually represents a larger area of several kilometers' radius when estimating the land uplift behavior, the exact location of the data points is not critical. As an example, a part of this data set was used in the study by Pohjola et al. (2018).

The vertical error in the lake/mire isolation and archaeological data sets is assumed to be ±0.5 m. Defining the altitude is sometimes very challenging, especially in villages situated at hill slopes. In these cases the lowest altitude is used and it is assumed that the lowest point of the village has existed during the oldest period. This is somewhat questionable, because the village might have expanded during the centuries around the oldest settlement. As said before, the archaeological data set is used only for validation purposes when modeling land uplift.

In all cases concerning both the archaeological and the lake/mire isolation data, latitude (WGS84), longitude (WGS84), altitude (meters above sea level), ^{14}C age (calibrated years BP), ^{14}C error (years), the name of the place, the reference (^{14}C) Laboratory Identification, if available), URL of the database (if available) and possible additional information are provided. The reference field will contain the ^{14}C Laboratory report or a link to a database. In some cases the samples are collected as a side product of other work and in these cases the laboratory number is the link to digital site report (in Finnish) or some commonly referred article, where the finding is mentioned.

The calibration for the ^{14}C radiocarbon dated data points was done using the Oxcal program containing Oxford radiocarbon acceleration unit calibration curve (IntCal 13) (Bronk Ramsey, 2009). An example of the calibration curve is presented in Figure 3.

4   Conclusions

This data set is intended to be used for modeling the postglacial land uplift in Fennoscandia between 12,500 and 0 years BP. The collected set in this paper covers the area of Finland and Sweden reasonably well, but the data set is still too sparse in certain areas (see Figure 1). Also, the work for searching additional data is currently going on and other data sets such as the lake tilting data set presented in (Påsse, 1996) is worth studying.
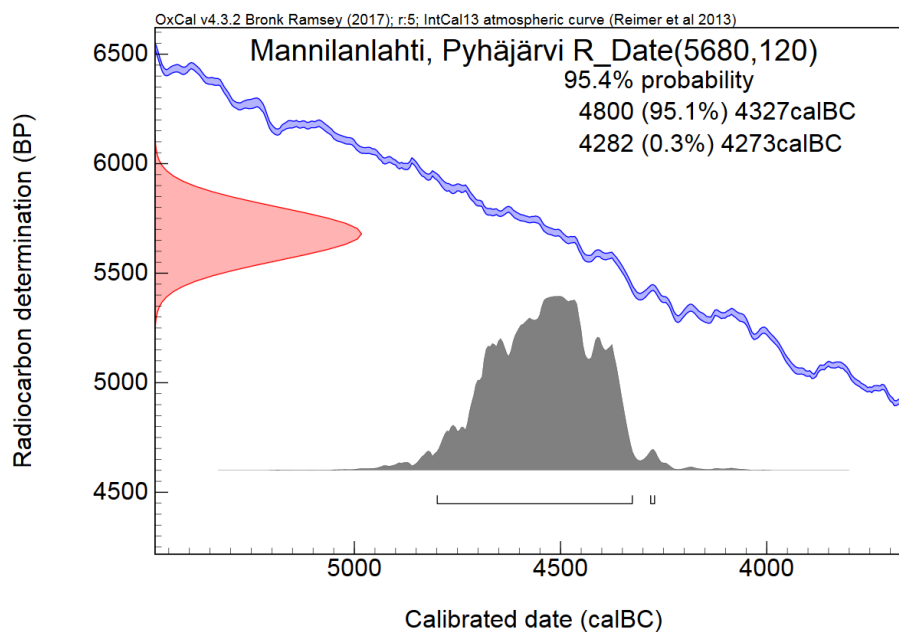
Figure 3. The calibration curve and the error distribution from OxCal program (Bronk Ramsey, 2009).

5   Data availability

Both datasets are available at https://doi.pangaea.de/10.1594/PANGAEA.905352 (Pohjola et al., 2019).

Author contributions. J.P. and J.T. performed the data collection and handling. The manuscript was written by J.P., J.T. and T.L. in collaboration.

5   *Competing interests.* The authors declare that they have no conflict of interest.

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