Tree-ring reconstruction of the level of endorheic lakes in the south of West Siberia

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Abstract. The paper presents the dendrochronological method applied in reconstructing the changes in the water level of endorheic lakes from arid areas (on the example of two large endorheic lakes Kulundinskoye and Chany). Chronologies of annual ring width of Scots pine (Pinus sylvestris L.), growing in the pine belt forests in the south of West Siberia, were used as indicators of climate change. To obtain the longest reconstructions, we used the length chronologies. For analysis, specimens of living trees and old wooden houses in the Altai Krai villages (adjacent to pine-belt forests) were used. Due to the dendrohydrological analysis, we have determined the relationship between the lake level and the radial pine growth. We have revealed a one-two-year lag in the response of hydrological objects to climate fluctuations. Correlation between the tree-ring chronologies and the average annual water level of Lake Kulundinskoye occurred more often due to proximity of both geosystems, i.e. the lake and pine-belt forests. At the same time, there was the best correlation for Lake Chany and the dry-steppe chronology Uglovskoye 42 LL. In the course of investigations, we have extended the series for lakes Chany and Kulundinskoye up to 1584 and 1763, respectively. Spectral analysis of the series of the water level in both lakes allowed us to identify common cycles (i.e. 25-26, 40-46 and 80-100-year ones). For Lake Kulundinskoye, the 8 and 11-year cycles turned out to be the most significant. The analysis of secular cycles of hydrological series enabled to specify the trends in water-level changes of the studied lakes in the future.

1. Introduction

A water level of endorheic lakes, which depends on moistening of the territory, is among the indicators of regional climate change [1-4]. To understand the dynamics of level regime variability in endorheic lakes, the analysis of long hydrological series is required. The main source of such data is the in-situ observations implemented at gauging stations. However, their duration often hampers the identification of long-term (e.g. secular, etc.) cyclical fluctuations. Due to the common limiting factor (i.e. territory moistening), dendrochronological data may contribute to solving this problem. In arid regions, the increase in precipitation amount favors the radial growth of trees and the increase in the water level of a lake. On the contrary, the increase in summer temperature leads to a decrease in the annual ring width and the water level due to intensive water evaporation from the reservoir surface. Thus, being climate-related, the relationships between these features do certainly exist.

A large body of dendrohydrological research carried out in different regions [5-10] is evidence of the method reliability, therefore, and it can be recommended for applying under insufficient moistening conditions when a climatic signal in geosystems is more pronounced.
2. Models and methods

In this paper presents the dendrohydrological analysis of the dynamics of the radial growth (annual ring width) of Scots pine (Pinus sylvestris L.) from the pine-belt forests in the forest-steppe and steppe (arid and dry) areas of Altai Krai. The island nature of pine-belt forests, growing outside the Scots pine dense area, makes the trees sensitive indicators, which are used for the reconstruction of past climatic conditions of the vegetation period and climate-driven processes, e.g. dynamics of parameters of hydrological objects.

In the south of West Siberia, the area of internal drainage with a large number of lakes was formed. For instance, these are the largest lakes Kulundinskoye (Altai Krai) and Chany (Novosibirsk Oblast), whose water level, along with the 30 tree-ring width (TRW) chronologies for the pine-belt forests [11], have become the basis of our studies. The chronologies were obtained through the generally accepted method [12]. The extended chronologies were used to reconstruct the dynamics of hydrological indicators. For this purpose, the specimens of living trees from the pine-belt forests, as well as wood from historic wooden houses in the Altai villages, were collected.

Salty Lake Kulundinskoye is located almost in the center of the Kulunda lowland, in the west of Altai Krai (in the steppe zone). The total area of the lake is approximately 728 km²; its average depth – 3.2 m. A series of field observations for 1934-1969 (except for 1959-1960) implemented at the gauging station Belgrad is available. Lake Chany is situated in the Baraba plain, specifically in its forest-steppe zone. The reservoir consists of several independent limnosystems (stretches). The size of the water area is currently 1500 km². The depth ranges from 1.4-1.9 m; in the southeast of brackish Lake Yarkul it reaches 4.8-8.5 m [13]. The 1934-2008 observation period (data from the gauging station Kvashnino) was analyzed. To ensure the accurate comparison of the results for both lakes during the correlation analysis, we selected the period between 1934 and 1969.

For establishing relationships in the functioning of different-scale geosystems, the asynchronous response to external factors should be properly taken into account. Standardized tree-ring series ARSTAN (which, unlike residual chronologies, preserve long-term cycles) were used to provide the maximum similarity in hydrological/biological objects response to climate changes. It is worth noting that lake level fluctuations are slower in comparison with tree growth dynamics. Along with the recorded increase in the average correlation, dendrohydrological relationships are traced over the next two years (the delay in climate response of the lake level) (table 1). During the third year, the relationships grow weak. Their maximum is typically observed with a one-two year delay relative to changes in the TRW (absolute maximum occurs in one year). Compared to Lake Chany, for the water level of Lake Kulundinskoye, significant correlations with chronologies prevailed, and the average correlation was higher. This can be explained by the territorial proximity of two geosystems (Lake Kulundinskoye and the adjacent pine-belt forest). In both cases, there are no traces of spatial coherence with some TRW chronologies.

| Table 1. A generalized description of the dendrohydrological relationship of chronologies of pine belt forests and water level series for lakes Chany and Kulundinskoye (1934-1969). |
|---------------------------------------------------------------|
| The shift of hydrological series relative to TRW chronologies | Lake Kulundinskoye | Lake Chany |
|---------------------------------------------------------------|
| coefficient of average correlation of water level with all chronologies; the maximum correlation between water level and TRW is given in parentheses |
| Synchronous | 0.20 (0.56 with Uglovskoye 42_LL) | 0.06 (0.67 with Uglovskoye42_LL) |
| A year ago | 0.33 (0.67 with Mamontovo_Buk) | 0.16 (0.79 with Uglovskoye 42_LL) |
| 2 years ago | 0.36 (0.66 with Mamontovo _Buk) | 0.20 (0.77 with Uglovskoye 42_LL) |

For Lake Chany, the best correlation was obtained for the dry-steppe chronology Uglovskoye 42_LL (with a one-year shift in hydrological series). This TRW chronology, which was built with living pine trees from the southern part of the Barnaul belt forest (1997-1844), was extended using
historic wood sampled from three old wooden houses in the Laptev Log village (Altai Krai) adjacent to the model site of the pine-belt forest. The total chronology length of 415 years was extended (up to 1584). The standard deviation of the extended generalized chronology was 0.3, which is indicative of its climatic sensitivity.

For Lake Kulundinskoye, TRW chronology Mamontovo_Buk showed the best correlation (also with a one-year shift in hydrological series). The chronology was built with living trees that grow in the middle part of the Kasmal belt forest (1852-2002) as well as logs from the house that was built in the early 20th century in the Bukanskoye village adjacent to the sampling site. It allowed us to extend the series up to the year 1762.

The regression equation for the water level of Lake Kulundinskoye and TRW chronology Mamontovo for the 1934-1969 period is as follows:

\[ x = 110.72 \times y + 114.02, \]

where \( x \) is the average annual water level of the lake, \( y \) – the index of the annual increment. The correlation coefficient is 0.67, the coefficient of determination is 0.44.

The regression equation for the water level of Lake Chany and TRW chronology Uglovskoye 42_LL was derived for the same period (note: the data available up to 2008 provide visual verification of the developed model) and has the following form:

\[ x = 141.2 \times y + 161.33, \]

where \( x \) is the average annual water level of the lake, \( y \) – the index of the annual increment. The correlation coefficient is 0.79, the determination one is 0.63.

The reconstructed series for the years 1934-2003 generally coincide with field observations. However, in the 1970s, a discrepancy between the reconstructed and the natural series was recorded, and the total correlation for both series in 1934-2003 was 0.37 despite their great visual similarity. In 1971-1972, the dams separating the Yudinsky stretch from the main part of the lake were constructed [14]. Perhaps this hydrotechnical intervention influenced the synchronism in the variability of two natural objects.

3. Results and discussion

During the studies, we have reconstructed a series of the water level for lakes Chany and Kulundinskoye up to the years 1584 and 1762, respectively. The reconstructed series have a pronounced cyclicism of water level fluctuations. For a series of Lake Kulundinskoye, the 8 and 11-year cycles are the most significant. The 17-, 26.5-, 40-, and 80-year cycles are also essential. The 8- and 11-year cycles occur in dynamics, whereas an 80-year cycle stands out when smoothing the 30-year moving average (Figure 1). At present, the 80-year cycle descends, though in the mid-20s and early 30s of the 21st century it is expected to be ascending.

![Figure 1. Reconstructed and actual series of the average annual water level of Lake Kulundinskoye](image)
The reconstructed series for Lake Chany also show cycles of different duration (figure 2). The 12-, 21-26-, 32-37-, 41-46-, 52-, and 100-year cycles (specifically the 103-year cycle) in water level fluctuations prevail. The reconstructed series covers the period of the Little Ice Age, during which there were positive and negative fluctuations in the water level of the lake. The specificity of the processing data method (standardization of raw tree-ring chronologies) is that it results in removing long-term fluctuations from a series. For this reason, only secular and intra-secular cycles are present in the reconstructed hydrological series.

Figure 2. Reconstructed and actual series of the average annual water level in Lake Chany

To obtain more reliable results, it is necessary to extend the indication basis (TRW chronologies) into the past and increase the replication of individual series. Nowadays, proper efforts are underway.

4. Conclusion
This dendrohydrological study suggests the reconstructed changes in water level fluctuations of large closed-basin lakes in West Siberia (i.e. lakes Chany and Kulundinskoye until the late 16th century and mid-18th century, respectively). The reconstructed series show cyclicity (11-, 25-26, 40-46, and 80-100-year cycles) similar to that of natural-climatic rhythms driven by solar activity. Overall, the dendrochronological method application is quite promising for studying arid and poorly moistened areas. Moreover, the formation of the TRW base for the forest-steppe and steppe zones could ensure reconstructing the climatic and climate-related processes. Extension of chronologies using historic wood is of considerable importance in providing the longer reconstruction of hydrological events of the past.

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