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Modelling air temperature in catchments of Čertovo and Plešné lakes in the Bohemian Forest back to 1781

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Abstract

We revised a ten-year old reconstruction of air temperature (2 m above ground) at Čertovo Lake using hourly measurements at four stations situated at elevations of 1057–1334 m in the catchments of Čertovo and Plešné lakes during 2004–2012. The new model is elevation-dependent and provides daily and monthly mean air temperatures back to 1961 and 1781, respectively, using daily data from the Churáňov meteorological station (Bohemian Forest) and monthly data from the Hohenpeissenberg meteorological station (Germany). Modelled daily mean air temperatures varied between –25.1 and 25.3°C during 1961–2012, with an average of 4.7°C and mean absolute error of 0.6°C for a reference plot at Čertovo Lake (elevation of 1057 m). Monthly mean air temperatures were predicted with mean absolute error of 0.4°C and varied between –12.9°C and 17.5°C in the 1781–2012 period, with long-term averages between –4.5°C in January and 12.9°C in July. Annual mean air temperatures varied between 2.3°C (in 1829) and 6.0°C (in 2011), with the 1781–2012 average of 4.1°C. Long-term trend in annual mean air temperature exhibited significant variations with three distinct periods: (i) temperature fluctuation along the 1781–2012 average between 1781 and 1830, (ii) colder period during 1831–1940, and (iii) increasing temperature since the early 1960s, with the most rapid increase (0.039 $°C.yr^{-1}$; $p < 0.01$) between 1981 and 2012. Monthly mean air temperature lapse rates varied within 0.0052–0.0073 $°C.m^{-1}$ with an annual average of 0.0061 $°C.m^{-1}$. Transposition of the modelled trends from the reference plot to other healthy forest plots in vicinity of Čertovo and Plešné lakes using these monthly lapse rates resulted in daily, monthly, and annual mean errors varying between –0.42 and 0.87°C. The predictive ability of the model decreased for the Plešné Lake plots after 2004 due to forest dieback caused by bark beetle infestation. Air temperature continuously increased at these plots with increasing number of dead and broken trees, with mean values by ~0.6°C higher in 2010–2012 than in 2002–2004.

Key words: climate, long-term trend, bark beetle, forest dieback, lapse rate, modelling

Introduction

Numerous ecological and dendrochronological studies require precise historical records of climatic variables, especially air temperature (e.g., Psenner & Schmidt 1992, Sommaruga-Wögrath & al. 1997, Šantrůčková et al. 2007). Long-term climatic records (longer than a few decades) are, however, usually missing for remote mountain areas and must be reconstructed using intensive several-year measurements at the site of interest and long-term records at some neighbouring climatic station (e.g., Augustí-Panareda et al. 2000, Augustí-Panareda & Thompson 2002). Similar situation has occurred in the Bohemian Forest. Daily mean air temperatures have been measured at the meteorological station Churáňov since 1953, but no long-term air temperature records are available for forested areas in this region.

Table 1. Locations of air temperature measurements in the Bohemian Forest (abbreviations: PL, Plešné Lake; CT, Čertovo Lake; L, low elevation; H, high elevation; In, inlet; O, outlet).

Parameter	Unit	CT and CN catchments					PL catchment	
		CT-O[1)]	CT-L[2)]	CT-H	CT-In	CN-In	PL-L	PL-H
Latitude, N (WGS-84)	Degree	49.1649	49.1627	49.1696	49.1667	49.1761	48.7752	48.7767
Longitude, E (WGS-84)	Degree	13.2030	13.1993	13.1858	13.1959	13.1822	13.8680	13.8547
Elevation	m	1003	1057	1330	1032	1020	1122	1334
Beginning of measurement	Month/Year	12/1997	12/2003	12/2003	12/2003	12/2003	04/2002	04/2002
End of measurement	Month/Year	12/2012	12/2012	12/2012	09/2006	09/2006	12/2012	12/2012
Healthy/broken trees in 2000[3)]	%	99/<1	97/<1	93/<1	99/<1	n.d.[4)]	94/<1	93/<1
Healthy/broken trees in 2005[3)]	%	99/<1	94/2	84/5	96/4	n.d.[4)]	68/3	52/4
Healthy/broken trees in 2011[3)]	%	99/1	90/6	70/23	93/7	n.d.[4)]	0/69	6/46

[1)] CT-O is situated at the CT outlet and represents the original reference plot used in model by Kettle et al. (2003).
[2)] CT-L is used as a new reference plot in this study.
[3)] Percent proportion of healthy and broken trees at the study plots (1 ha circle with thermometer in its centre; for more details on changes in tree numbers during 2000–2011, see Kopáček et al. 2013).
[4)] n.d., not determined using aerial photographs, but healthy forest in the surrounding of the CN-In plot remained unchanged during the study.

Kettle et al. (2003) have reconstructed air temperature trends for forests surrounding Čertovo Lake (CT), using an intensive 3-year measurement at the lake and long-term records from meteorological stations Churáňov (daily measurements at 7, 14, and 21 hour back to 1961) and Hohenpeissenberg in Germany (monthly means back to 1781). Their reconstruction was based on temperature measured at the lake outlet, using an automatic weather station (CT-O, Table 1), primarily constructed for monitoring of water discharge and water temperature. The station was situated in a small valley near the outlet at elevation of 1003 m. A subsequent more detailed measurements of air temperature in the CT catchment, however, showed that the CT-O station was not representative for the area and the measured air temperature was systematically lower there than at other sites of similar elevation (Turek, unpubl. data). It means that the original model by Kettle et al. (2003) underestimates the reconstructed values for the CT catchment. Moreover, an absence of lapse rate in the original model disables transposing of the modelled trends to other elevations.

The aim of this study is (i) to revise the original air temperature reconstruction for the CT catchment by Kettle et al. (2003) using new 8-year-long intensive measurements at four stations situated at different elevations in the catchments of CT and Plešné Lake (PL) and (ii) to provide (using a lapse rate and temperature measurements at the southeast and northwest slopes) a more general model, enabling transposition of the modelled values to other plots in the Bohemian Forest.

Materials and methods

Data sources

Air temperature was measured in mature Norway spruce forests in the catchments of Čertovo and Plešné lakes on the hillsides of Jezerní Hora Mt. and Plechý Mt., respectively, using registration thermometers TBI32–20+50 and U23-001 (Onset Computers, USA) with an accuracy of ±0.4 and ±0.2°C, respectively. Prior to use, the thermometers were kept several days at 4°C and at laboratory temperature of ~20°C and only the thermometers that met accuracy range of ±0.2°C at both temperatures were used. It means that the maximum systematic difference between individual thermometers was ≤0.4°C. The thermometers were situated in solar radiation shields (diameter of 10 cm, height of 15 cm) fixed on northern sides of wooden poles 2 m above ground in the middle of experimental plots used for throughfall sampling (Fig. 1). These plots are situated at low (L, 1057 and 1122 m) and high (H, 1330 and 1334 m) elevation of each catchment (Table 1). To estimate an effect of slope orientation, we operated two additional thermometers on the southeast and northwest slope of Jezerní Hora Mt. These thermometers were fixed in solar radiation shields 2 m above ground on northern sides of trees (10 cm off the trunk) in vicinity of major inlets to Čertovo (CT-In) and Černé (CN-In) lakes at similar elevations of 1032 and 1020 m, respectively (Fig. 1, Table 1). The measurement lasted from April 2002 to December 2012 at the PL-L and PL-H plots, from December 2003 to December 2012 at the CT-L and CT-H plots, and between December 2003 and September 2006 at the CT-In and CN-In plots. Air temperature ($T_{CT\text{-}L}$, $T_{CT\text{-}H}$, $T_{PL\text{-}L}$, $T_{PL\text{-}H}$, $T_{CT\text{-}In}$, and $T_{CN\text{-}In}$) was recorded in 60-minute intervals and the respective daily and monthly means were calculated as arithmetic means of all 24 hourly records and daily means.

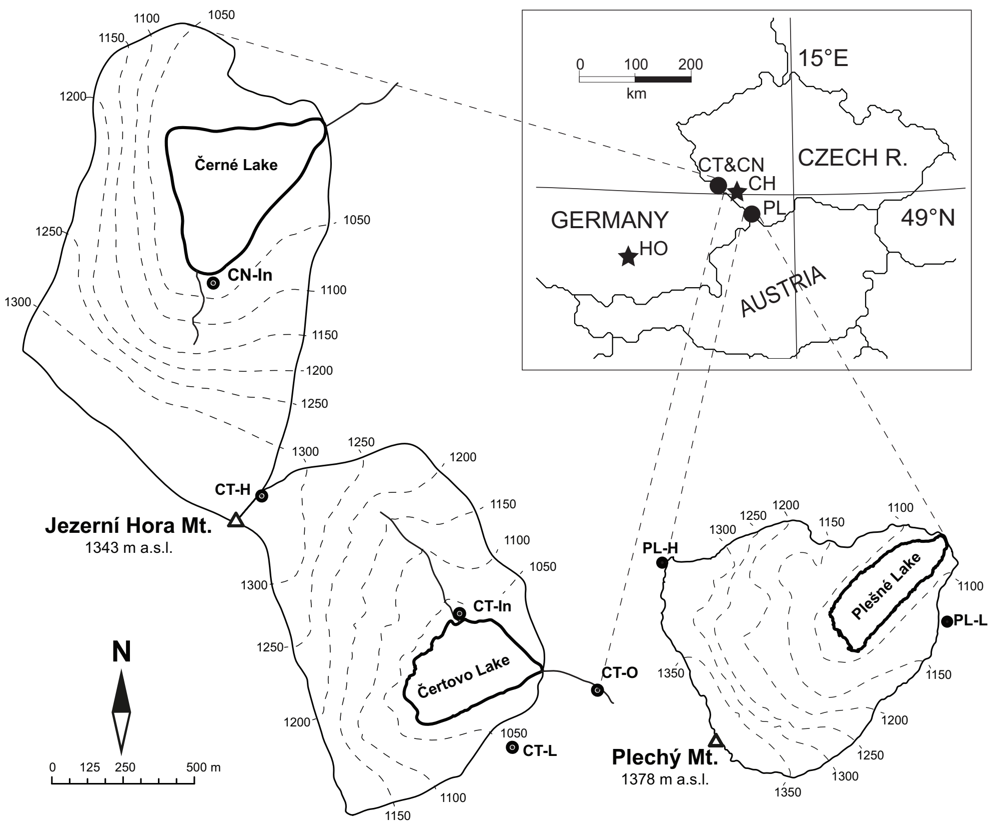

Fig. 1. Location of meteorological stations Churáňov (CH) and Hohenpeissenberg (HO), catchments of Plešné (PL), Čertovo (CT) and Černé (CN) lakes (top left map), and detail maps showing locations of thermometers. For other abbreviations and details on position, available records, and forest status of the CT, CN and PL plots see Table 1. Plots CT-O and CT-L were used as reference plots in the original (Kettle et al. 2003) and present study, respectively.

Recording of air temperature continued at CT-O plot (a reference site for the original temperature reconstruction by Kettle et al., 2003) using an automatic weather station (MS4016-G; Fiedler-Mágr, České Budějovice), situated ~150 m downstream of the lake outflow at elevation of 1003 m and at height of 1.5 m above ground. The data were recorded in 15-minute intervals from November 1997 to December 2012, and the respective daily and monthly means were calculated as arithmetic means of all 96 daily records and daily means.

Long-term air temperature data are from the meteorological station Churáňov (Czech Hydrometeorological Institute), situated in the central part of the Bohemian Forest (49.07° N, 13.61° E, 1118 m a.s.l.; ca. 40 km southeast of CT and 30 km northwest of PL). The data were recorded daily at 7, 14, and 21 hour ($T_{CH\text{-}7h}$, $T_{CH\text{-}14h}$, and $T_{CH\text{-}21h}$) from 1 January 1961 to 31 December 2012.

Long-term reference air temperature records are from the Hohenpeissenberg station (Deutscher Wettersdienst, Germany) situated in Bavaria (47.80° N, 11.01° E, 977 m a.s.l.; ca. 220 km southwest of CT and PL). The homogenised data come from HISTALP project (Auer et al. 2007) for 1781–2010 and from Global Historical Climatology Network, version 3 (Lawrimore et al. 2011) for 2011–2012, and were downloaded via the web page of www.zamg.ac.at/histalp/ and www.ncdc.noaa.gov/ghcnm/, respectively. The data consist of monthly means and have been demonstrated to be robust and free of interference due to urbanisation or changes in instrumentation or position (Schönwiese 1987).

Linear regression analysis was used to estimate significances of temporal trends in temperature records. All abbreviations used in this study are summarized and explained in Table 2.

Changes in forest health during measurements

Changes in the areal densities of healthy and broken trees in the PL and CT catchments during the study were quantified using colour aerial photographs (scales of 1 : 5000–7000), prepared by Argus Geo System Ltd. (Hradec Králové), Geodis Ltd. (Brno), and Georeal Ltd. (Plzeň) in 2000, 2005, and 2011.

The PL forest has been damaged by a bark beetle (*Ips typographus*) outbreak since the summers of 2004 (northwest part with the PL-H plot) and 2006 (the rest of the catchment, including the PL-L plot), and most of trees died within 2–3 years of the infestation. The trees lost needles during the first several months after the outbreak. Then, they have been continuously losing twigs, bark, and branches until the end of this study. Dead trees were continuously broken by winds, and 69% and 46% of the original trees were already broken at PL-L and PL-H, respectively, in 2011 (Table 1). The CT forest was almost intact in 2000–2005 and was affected by windstorms in 2007 and 2008 that damaged 6% and 23% of the original trees at the CT-L and CT-H plots, respectively (Table 1). Negligible changes in forest health and density occurred at plots CT-In and CN-In during the study in 2003–2006 and at CT-O during 2000–2011. For more details on changes in tree numbers at individual plots during 2000–2011 see Kopáček et al. (2013).

Because the CT-L plot (among all new plots) exhibited the lowest changes in forest health and density during the study, we used this plot as a new reference site for the new model. Moreover, the CT-L plot is situated close to the CT-O plot, for which the original model by Kettle et al. (2003) was calculated, and enabled thus the best records for comparison of both models.

Modelling mean air temperature at the reference plot CT-L during 1961–2012

A relationship between the measured daily mean air temperatures at the reference plot CT-L

Table 2. List of abbreviations and air temperature symbols.

Abbreviation	Meaning
CT, PL, CN	Čertovo, Plešné, and Černé lakes, respectively
L, H	low and high elevation plots, respectively
In, O	inlet and outlet plots, respectively
$T_{CT\text{-}O}$	temperature measured at automatic weather station at the CT outlet, 15-minute readings (old reference site)
$T_{CT\text{-}L}$, $T_{CT\text{-}H}$, $T_{CT\text{-}In}$, $T_{CT\text{-}In}$, $T_{PL\text{-}L}$, $T_{PL\text{-}H}$	temperature measured at CT-L, CT-H, CT-In, CN-In, PL-L and PL-H plots (see Table 1), 1-hour readings (CT-L plot is new reference site)
$T_{CT\text{-}L\text{-}d}$, $T_{CT\text{-}H\text{-}d}$, $T_{PL\text{-}L\text{-}d}$, $T_{PL\text{-}H\text{-}d}$	daily mean temperature at CT-L, CT-H, PL-L and PL-H plots; arithmetic mean of hourly data
$T_{CT\text{-}L\text{-}m}$	monthly mean temperature at CT-L plot; arithmetic mean of daily data
$T_{CH\text{-}7h}$, $T_{CH\text{-}14h}$, $T_{CH\text{-}21h}$	temperature measured at the Churáňov station at 7, 14, and 21 hour
$T_{HO\text{-}m}$	monthly mean temperature at Hohenpeissenberg 1781–2010: www.zamg.ac.at/histalp/ (homogenised) 2011–2012: www.ncdc.noaa.gov/ghcnm/
$T_{CT\text{-}L\text{-}d}*$	modelled daily mean temperature at CT-L from $T_{CH\text{-}7h}$, $T_{CH\text{-}14h}$, and $T_{CH\text{-}21h}$ (equation 1)
$T_{CT\text{-}L\text{-}m}*$	modelled monthly mean temperatures at CT-L; arithmetic mean of $T_{CT\text{-}L\text{-}d}*$ during 1961–2012, and modelled from $T_{HO\text{-}m}$ (equation 2) during 1781–2012
$T_{CT\text{-}L\text{-}a}*$	modelled annual mean temperature at CT-L; calculated from $T_{CT\text{-}L\text{-}m}*$
T_E*	modelled (daily or monthly) mean air temperature at elevation *E* (equation 4)
LR_m	monthly lapse rate (°C.m^{-1}); average for the CT and PL catchments (Table 3)
ME	mean error; ME = mean of residuals (differences) between modelled and observed data
MAE	mean absolute error; MAE = mean of absolute values of (modelled – observed) data

($T_{CT\text{-}L\text{-}d}$) and air temperature at the Churáňov station was evaluated as follows: The $T_{CT\text{-}L\text{-}d}$ and $T_{CH\text{-}7h}$, $T_{CH\text{-}14h}$, and $T_{CH\text{-}21h}$ data were divided into months. Then, the best fit between the measured $T_{CT\text{-}L\text{-}d}$ data and the Churáňov data (equation 1) was obtained for each month by multiple linear regression.

$$T_{CT\text{-}L\text{-}d} = a + b\,T_{CH\text{-}7h} + c\,T_{CH\text{-}14h} + d\,T_{CH\text{-}21h} \qquad (1)$$

The parameters *a*, *b*, *c*, and *d* were obtained for individual months (Table 3) and were then used to model daily mean air temperatures at the CT-L plot ($T_{CT\text{-}L\text{-}d}*$) from the Churáňov data.

The monthly models were cross validated by removing one month at a time (e.g., January 2004) and building the model with the remaining months (e.g., January 2005–2012). Then we used the model to predict the temperatures in the omitted month. This technique allows the predictive accuracy of the models to be tested (Kettle et al. 2003). The mean absolute

Table 3. Parameters used in air temperature modelling: (i) parameters *a*, *b*, *c*, and *d* of equation (1) used for modelling daily mean air temperature at the reference (CT-L) plot from the Churáňov data, (ii) parameters *e* and *f* of equation (2) used for modelling monthly mean air temperature at the reference plot from the Hohenpeissenberg data, and (iii) monthly lapse rates (LR_m, °C.km^{-1}) used in equation (4) for transposition of the daily and monthly mean temperature data from the reference plot to other Bohemian Forest sites.

Month	*a*	*b*	*c*	*d*	*e*	*f*	LR_m
January	–0.27	0.44	0.18	0.26	–2.75	0.83	5.65
February	–0.13	0.43	0.22	0.25	–2.74	0.82	5.78
March	–0.10	0.38	0.26	0.26	–2.47	0.81	6.44
April	0.10	0.41	0.23	0.28	–1.38	0.82	7.17
May	0.55	0.42	0.21	0.33	–0.17	0.86	7.31
June	0.70	0.39	0.20	0.37	0.92	0.81	6.45
July	0.69	0.44	0.21	0.30	–1.15	0.95	6.29
August	1.20	0.43	0.20	0.28	1.41	0.77	6.13
September	0.88	0.42	0.24	0.29	–0.72	0.88	6.00
October	0.48	0.46	0.30	0.19	–1.17	0.86	5.22
November	0.32	0.52	0.22	0.23	–1.77	0.84	5.40
December	–0.20	0.52	0.20	0.18	–2.66	0.80	5.52

errors (MAE) of the cross validations were averaged over all the months, indicating a predictive error of 0.62°C for daily temperatures at CT-L, with the best predictions in August (0.53°C) and the worst in November (0.75°C). When no data were omitted for validation, the final set of monthly models resulted in MAE of 0.60°C for the daily mean air temperature at the reference CT-L plot. This set of monthly models (Table 3) was then used to reconstruct $T_{CT\text{-}L\text{-}d}$* values back to 1 January 1961.

Modelling monthly and annual mean air temperature at the reference plot CT-L from Hohenpeissenberg

We reconstructed monthly air temperatures at CT-L ($T_{CT\text{-}L\text{-}m}$*) back to January 1781 using monthly mean data from Hohenpeissenberg as follows: First, we calculated monthly mean temperatures at CT-L ($T_{CT\text{-}L\text{-}m}$) as averages of $T_{CT\text{-}L\text{-}d}$* values for the 1961–2012 period. Then, we divided the $T_{CT\text{-}L\text{-}m}$ data, as well as monthly mean air temperatures from Hohenpeissenberg ($T_{HO\text{-}m}$) into individual months, and finally computed the best linear regression models (equation 2) between $T_{CT\text{-}L\text{-}m}$ and $T_{HO\text{-}m}$ for each month.

$$T_{CT\text{-}L\text{-}m} = e + f\,T_{HO\text{-}m} \qquad (2)$$

The parameters *e* and *f* obtained for individual months during 1961–2012 are given in Table 3. The average MAE of this monthly model was 0.40°C, with the best predictions in August (0.33°C) and the worst in October (0.46°C).

Annual mean temperatures at CT-L ($T_{CT\text{-}L\text{-}a}$*) were calculated for calendar years (January through December) using the $T_{CT\text{-}L\text{-}m}$* values (modelled from the Hohenpeissenberg and Churáňov data for the 1781–2012 and 1961–2012 periods, respectively) according to equation (3):

$$T_{CT\text{-}L\text{-}a}{}^{*} = (\sum_{1}^{12} D_m \,.\, T_{CT\text{-}L\text{-}m}{}^{*}) \,/ \sum_{1}^{12} D_m \qquad (3)$$

where D_m is number of days in a month *m*.

Table 4. Distribution of daily mean air temperatures ($T_{CT\text{-}L\text{-}d}$*) at the reference plot (CT-L) near Čertovo Lake modelled from Churáňov data (1 January 1961 to 31 December 2012). AVG, arithmetic mean; SD, standard deviation; 25% and 75%, quartiles.

	All data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AVG	4.71	–3.8	–3.4	–0.8	3.4	8.7	11.9	13.3	13.1	10.0	5.7	0.7	–2.9
SD	7.58	4.3	4.5	4.3	4.4	4.2	4.1	3.8	3.5	3.7	4.2	4.4	4.2
Minimum	–20.9	–20.9	–18.4	–16.3	–8.2	–4.5	0.3	3.5	4.8	0.3	–7.6	–11.6	–18.0
25%	–1.14	–6.5	–6.4	–3.6	0.0	5.8	8.8	10.4	10.6	7.2	2.4	–2.4	–5.5
Median	4.84	–3.3	–2.9	–0.7	3.2	8.6	11.7	13.3	13.1	9.9	5.9	0.7	–2.6
75%	10.8	–0.7	–0.1	2.2	6.3	11.7	15.0	16.1	15.7	12.7	8.8	3.8	0.2
Maximum	25.3	7.9	7.6	11.2	18.8	21.6	23.8	25.3	23.8	22.0	16.2	14.3	7.7

Lapse rate and the model transposition from the reference plot to other elevations

Lapse rate (*LR*, °C.m^{-1}) in air temperature was calculated for both the CT and PL catchments, using daily data during 2004–2012. The differences between $T_{CT\text{-}H\text{-}d}$ and $T_{CT\text{-}L\text{-}d}$ values and $T_{PL\text{-}H\text{-}d}$ and $T_{PL\text{-}L\text{-}d}$ values were divided by the respective differences in the plot elevations (273 and 212 m), and then, monthly mean lapse rates were calculated from all available data for individual months. Monthly mean lapse rates differed only slightly between the catchments (<±0.002 °C.m^{-1}). Consequently, we used average monthly laps rates (LR_m, calculated from all data observed in the CT and PL catchments; Table 3) to transpose the modelled data from the reference CT-L plot into other Bohemian Forest sites using equation (4):

$$T_E^* = T_{CT\text{-}L}^* - LR_m \,.\, (E - 1057) \tag{4}$$

where T_E* is modelled (daily or monthly) mean air temperature at elevation *E* (m), $T_{CT\text{-}L}$* is the modelled (daily or monthly) air temperature at the reference plot CT-L, LR_m is the respective monthly average lapse rate (Table 3), and coefficient of 1057 represents elevation (m) of the CT-L plot.

Results and discussion

Modelled air temperature at the reference plot CT-L

The modelled daily mean air temperatures at the reference plot reconstructed from the Churáňov data varied between –25.1 and 25.3°C during 1961–2012, with an average of 4.7°C (Table 4). The difference between the maximum and minimum $T_{CT\text{-}L\text{-}d}$* values in the individual months varied within 24–29°C (with the exception for July to September; 19–22°C), showing similar variation in daily air temperatures for most months throughout the year. The predictive accuracy of the new model (equation 1; monthly parameters *a*, *b*, *c*, and *d* summarized in Table 3) was better than that of the original model by Kettle et al. (2003), with MAE values (provided by cross validation) of 0.62 vs. 0.81°C. The modelled daily mean air temperatures explained 99% (p <0.001) of the observed variability in daily temperatures measured at the reference plot, with the minimum and maximum residuals ($\Delta T = T_{CT\text{-}L\text{-}d}^* - T_{CT\text{-}L\text{-}d}$) varying between –6.1°C (30 January 2011) and 5.0°C (2 February 2011) and with the mean residual value of –0.02°C during 2004–2012 (Fig. 2). The model overestimated the observed data especially during winter months, due to an existence of inverse air temperature stratification that resulted in higher temperatures at the Churáňov station (as well as at the CT-H plot), situated at higher elevation than the CT-L plot (1118 versus 1057 m). A typical example of this effect occurred during 1–3 February 2011, when daily mean air temperature was by 2.7–6.9°C higher at the CT-H than at the CT-L plot (Fig. 3). In contrast, the model based on Churáňov data underestimated air temperature at the reference plot during clear frosty days (e.g., on 30 January 2011), when temperature decreased more in the open area covered with snow than in forest and was by ~5°C lower at the Churáňov station than at both forest CT-L and CT-H plots (Fig. 3). This effect is probably associated with high albedo of snowcover around the Churáňov station, while darker forest canopy reflects less solar radiation, and accumulates more heat.

The modelled monthly mean air temperatures at CT-L (based on the Hohenpeissenberg data) varied between –12.9°C (February 1956) and 17.7°C (July 2006), with long-term averages varying between –4.5°C in January and 12.9°C in July during 1781–2012 (Table 5). The difference between the maximum and minimum values in the individual months was lowest in summer (7.6–8.7°C on average in June to August) and highest in winter (11.8–14.4°C on average in December to February). The predictive accuracy of the new model (equation 2; monthly parameters *e* and *f* summarized in Table 3) was better than that of the original model by Kettle et al. (2003), with MAE values of 0.40 vs. 0.49°C. Mean error (ME) between the modelled and observed monthly mean air temperature at the reference plot ($\Delta T = T_{CT\text{-}L\text{-}m}^* - T_{CT\text{-}L\text{-}m}$) varied between –0.94°C (April 2007) and 0.68°C (September 2011), with an average of –0.05°C during 2004–2012 (Fig. 2B, Table 6). MAE between the modelled and observed monthly mean air temperature varied between 0.32 and 1.52°C at the reference plot during 2004–2012 (Fig. 2B).

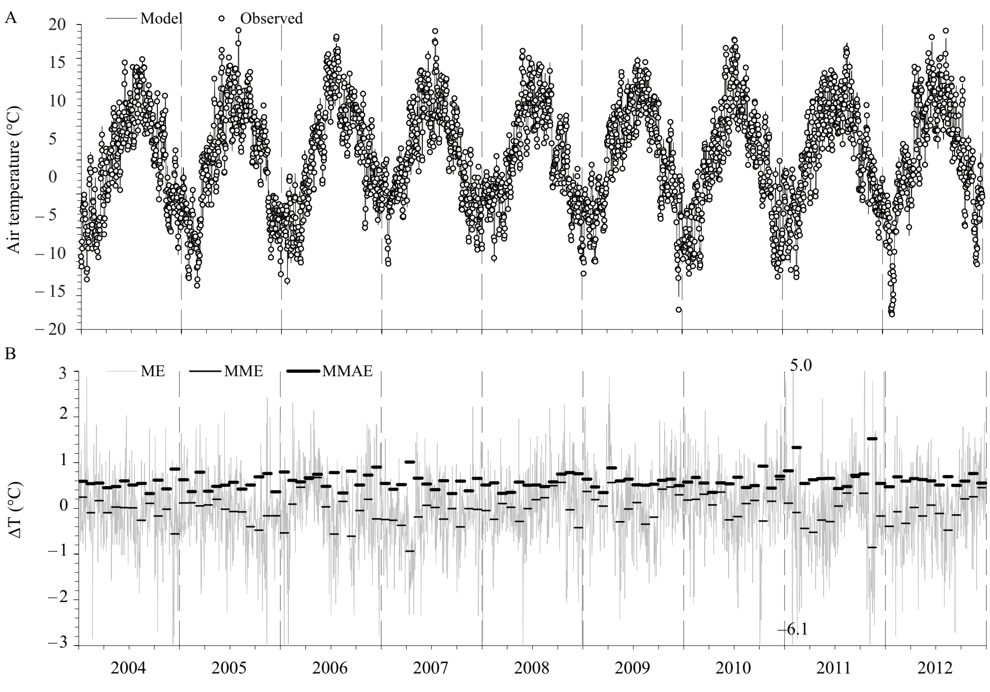

Fig. 2. A: Observed ($T_{CT\text{-}L\text{-}d}$) and modelled ($T_{CT\text{-}L\text{-}d}$*) daily mean air temperatures at the reference plot CT-L during 2004–2012. B: Daily residuals between the modelled and observed data ($\Delta T = T_{CT\text{-}L\text{-}d}^* - T_{CT\text{-}L\text{-}d}$), their monthly averages (MME, monthly mean error) and monthly averages of their absolute values (MMAE, monthly mean absolute error). Maximum and minimum daily residuals are indicated by numbers in panel B.

The better predictive accuracy of the new models than the original ones for both daily and monthly means resulted from almost 3-times more values available for development of the new regression models.

The modelled annual mean air temperatures at CT-L varied between 2.3°C (in 1829) and 6.0°C (in 2011), with the 1781–2012 average of 4.1°C (Table 5; Appendix 1). The long-term trend in $T_{CT\text{-}L\text{-}a}$* exhibited significant variations (Fig. 4). Between 1781 and 1830, the $T_{CT\text{-}L\text{-}a}$* values fluctuated along their long-term averages in periods lasting roughly a decade, being lower than the long-term average in the 1780s and 1810s and higher in the 1790s and 1800s. The 1831–1940 period was relatively cold, with all 10-year averages below the long-term average (Fig. 4), and with the coldest decade over the study period in the 1880s (10-year average of 3.7°C). In the 1940s, there was a significant peak in the $T_{CT\text{-}L\text{-}a}$* values (10-year average of 4.6°C), which was followed by a steep temperature decline in the middle 1950s. Since the early 1960s, the $T_{CT\text{-}L\text{-}a}$* values have an increasing trend, and the 10-year averages reached their maximum of 5.2°C in the 2000s.

Annual mean air temperatures increased significantly (p <0.001) by 0.028 °C.yr^{-1} between 1960 and 2012. Trend analysis of monthly mean data showed that $T_{CT\text{-}L\text{-}m}$* values exhibited significantly increasing trends in April through August, with the steepest trends in May (0.056 °C.yr^{-1}; p <0.001) and August (0.042 °C.yr^{-1}; p <0.001). Similar trends for other months were not significant at the 0.05% level during 1961–2012, but steep increases (~0.03 °C.yr^{-1}; p <0.1) occurred also in November and December. The steepest increase in annual air temperatures has occurred since 1981 (0.039 °C.yr^{-1}; p <0.01), when only four $T_{CT\text{-}L\text{-}a}$* values decreased below the long-term average value of 4.1°C during 1781–2012 (Fig. 4). On a monthly basis, significant trends occurred in April through June and in November during 1981–2012, with the steepest trends in April (0.102 °C.yr^{-1}; p <0.01). Consequently, the present increase in annual air temperatures in the Bohemian Forest is predominantly associated

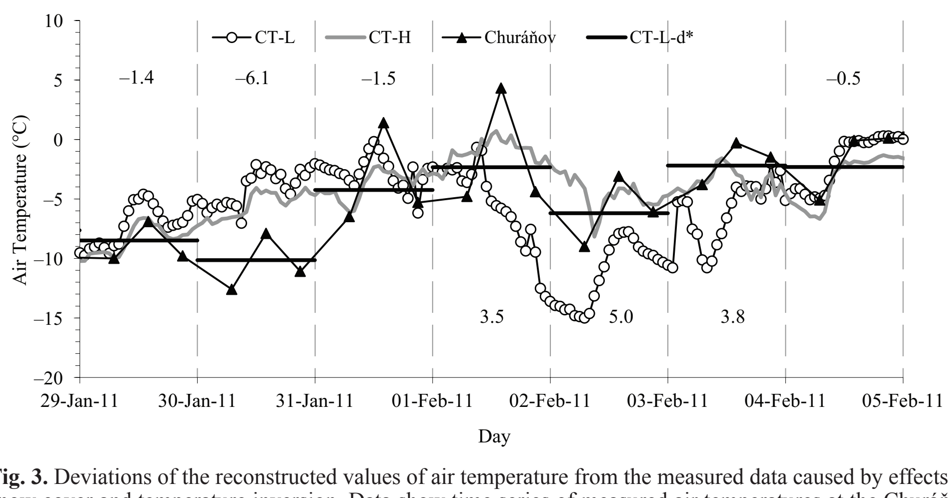

Fig. 3. Deviations of the reconstructed values of air temperature from the measured data caused by effects of snow cover and temperature inversion. Data show time series of measured air temperatures at the Churáňov meteorological station (1118 m a.s.l.) and two forest plots in the catchment of Čertovo Lake (CT-L, the reference plot, 1057 m a.s.l.; and CT-H plot, 1330 m a.s.l.) in winter 2011. Abbreviation CT-L-d* represents daily mean air temperature modelled for the CT-L plot using equation (1) and data from the Churáňov station. Numbers indicate differences between the modelled and observed daily mean temperatures ($T_{CT\text{-}L\text{-}d}$* – $T_{CT\text{-}L\text{-}d}$). The effect of higher albedo at the Churáňov station resulted in underestimating air temperature at the CT-L plot on 30 January 2011, while the temperature inversion resulted in overestimating the modelled temperature at the lower elevation CT-L plot during 1–3 February 2011.

Table 5. Distribution of annual ($T_{CT\text{-}L\text{-}a}$*) and monthly ($T_{CT\text{-}L\text{-}m}$*) mean air temperatures at the reference plot (CT-L) near Čertovo Lake during 1781–2012 modelled from Hohenpeissenberg (1781—2012) data. AVG, arithmetic mean; SD, standard deviation; 25% and 75%, quartiles.

	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AVG	4.13	–4.5	–3.8	–1.5	2.9	8.2	11.2	12.9	12.6	9.5	5.1	0.0	–3.5
SD	0.72	2.2	2.3	1.9	1.7	1.7	1.3	1.6	1.2	1.5	1.8	1.7	2.1
Minimum	2.31	–10.0	–12.9	–7.1	–2.0	4.0	7.8	9.3	9.7	3.9	–0.4	–5.1	–11.1
25%	3.60	–6.0	–5.2	–2.8	1.7	7.0	10.4	11.8	11.8	8.5	4.1	–1.1	–4.7
Median	4.15	–4.3	–3.6	–1.4	2.8	8.3	11.2	12.8	12.5	9.6	5.1	0.0	–3.5
75%	4.63	–2.8	–2.1	–0.2	4.1	9.5	12.0	13.9	13.3	10.5	6.2	1.3	–2.0
Maximum	5.99	2.1	1.4	2.6	8.2	12.8	16.6	17.7	17.3	13.6	9.8	4.4	0.7

with the increasing trends in spring–summer and November–December, while no trends were observed for September–October. The 1981–2012 average seasonal trend in monthly mean air temperatures was, however, 0.4–1.1°C higher than the 1781–2012 average trend for each month (Fig. 5).

The steep increase in air temperature during the last three decades concurred with the general warming trend in central Europe (Brázdil et al. 1996, Dubrovský et al. 2005), despite relatively high variability in $T_{CT\text{-}L\text{-}a}$* varying between 3.6 and 6.0°C during this period (Fig. 4). Even higher variability in the $T_{CT\text{-}L\text{-}a}$* values occurred two hundred years ago, when annual mean air temperature varied between 2.7 and 5.0°C during 1785–1794 and between 2.3 and 5.1°C during 1829–1834 (Fig. 4). However, unlike the temperature variability in 1785–1794 and 1829–1834, which appeared as oscillations around the long-term average, the recent data have oscillated mostly above the long-term average since 1981.

A number of historical and recent declines in annual mean air temperatures can be associated with cooling effect of dust and sulphur aerosols released into the atmosphere by vol-

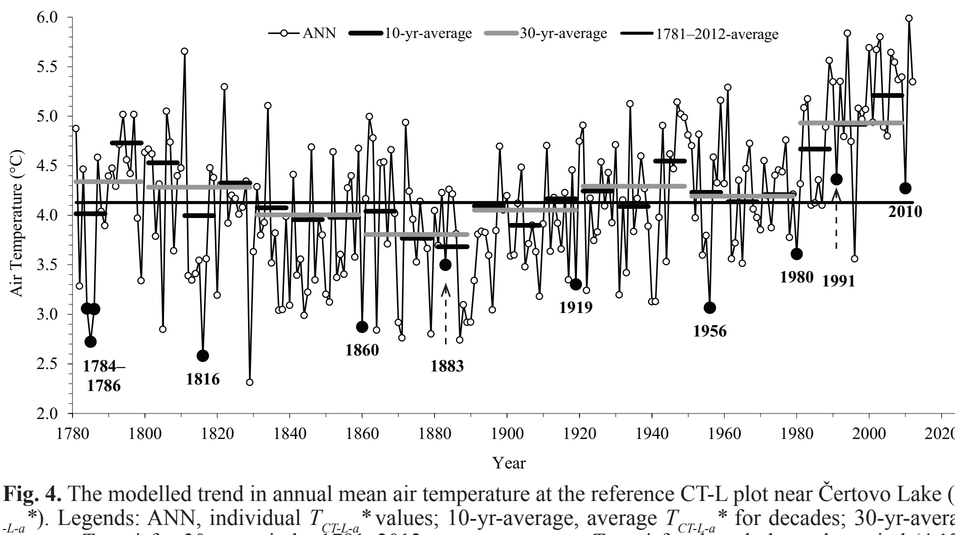

Fig. 4. The modelled trend in annual mean air temperature at the reference CT-L plot near Čertovo Lake ($T_{CT\text{-}L\text{-}a}$*). Legends: ANN, individual $T_{CT\text{-}L\text{-}a}$* values; 10-yr-average, average $T_{CT\text{-}L\text{-}a}$* for decades; 30-yr-average, average $T_{CT\text{-}L\text{-}a}$* for 30-yr periods; 1781–2012-average, average $T_{CT\text{-}L\text{-}a}$* for the whole study period (4.1°C). Large black points indicate years with climate affected by the volcanic eruptions. Date of eruption: Laki and Grímsvötn (1783–1785), Tambora (April 1815), Katla (May 1860, October 1918), Krakatau (August 1883), Bezymianny (March 1956), St. Helens (May 1980), Pinatubo (June 1991), and Eyjafjallajökull (May 2010).

canic eruptions (e.g. DEVINE et al. 1984, SHINDELL et al. 2004). A significant continental scale effect of volcanic activity on cooling surface air temperature has been recognized over central Europe (FISCHER et al. 2007) and is evident also from the $T_{CT\text{-}L\text{-}a}$* data (Fig. 4). Cold years 1784–1786 followed eruptions of Laki and Grímsvötn volcanoes in Iceland during 1783–1785, and extremely cold summer of 1816 resulted from Tambora eruption in April 1815. Also some of other cold years (Fig. 4) can be associated with large eruptions like those of Krakatau (1883), Bezymianny (1956), St. Helens (1980), and Pinatubo (1991) (DEVINE et al. 1984, SHINDELL et al. 2004, FISCHER et al. 2007), and probably also those of Katla (1860, 1918) and Eyjafjallajökull (2010) in Iceland.

Model transposition from the reference plot CT-L to other Bohemian Forest plots

Monthly mean air temperature lapse rates varied within 0.0052–0.0073 °C.m^{-1} with an annual average of 0.0061 °C.m^{-1} (Table 3). We used these lapse rates and equation (4) to calculate daily, monthly, and annual mean air temperatures for all plots in this study and compared the modelled and observed results. Among all plots, the ME and MAE of the modelled values were highest for the CT-O plot (Table 6), which was used as the reference plot in the original model (KETTLE et al. 2003). Daily, monthly, and annual ME were 0.78–0.87°C for the CT-O plot, indicating that this plot was colder than the new reference plot. The original model thus systematically underestimated air temperature for the CT forest. The CT-O thermometer is situated in a small narrow valley, which is probably filled with cold air more frequently or for longer periods than other relatively flat plots used in this study.

The daily, monthly, and annual mean errors and mean absolute errors varied in relatively narrow ranges between –0.21 and 0.16°C (ME) and within 0.06–0.71°C (MAE) for other CT and CN plots (CT-L, CT-In, and CN-In; Table 6). A surprising result was that similar ME and MAE values occurred for the CT-In and CN-In plots, despite their opposite orientation on the slopes of Jezerní Hora Mt. (Fig. 1). The low errors for most of the CT and CN plots

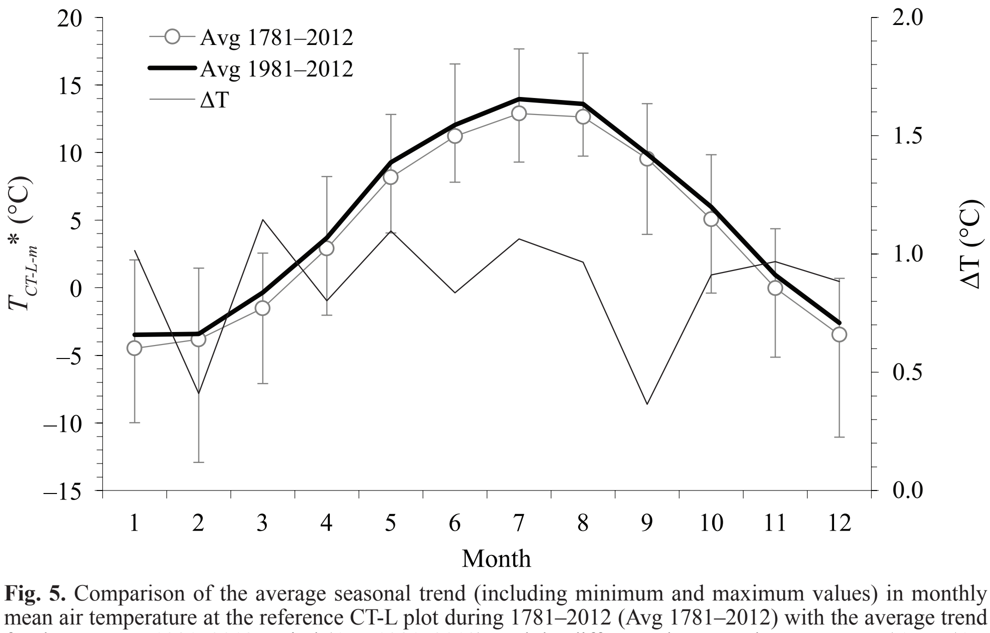

Fig. 5. Comparison of the average seasonal trend (including minimum and maximum values) in monthly mean air temperature at the reference CT-L plot during 1781–2012 (Avg 1781–2012) with the average trend for the warmest 1981–2012 period (Avg 1981–2012), and the difference between these averages (*ΔT = (Avg 1981–2012) – (Avg 1781–2012)*).

Table 6. Daily, monthly, and annual mean error and mean absolute error of the modelled data for individual plots.

Plot	Period	Mean error[1)]			Mean absolute error		
		Daily	Monthly	Annual	Daily	Monthly	Annual
CT-L	2004–2012	–0.02	–0.07	–0.11	0.6	0.4	0.1
CT-H	2004–2012	–0.19	–0.21	–0.19	0.7	0.4	0.2
CT-O	2004–2012	0.87	0.82	0.76	1.1	0.9	0.8
CT-In	2004–2006	0.04	0.12	0.06	0.6	0.5	0.1
CN-In	2004–2006	0.09	0.16	0.09	0.6	0.5	0.1
PL-L (All data)	2002–2012	–0.62	–0.65	–0.61	0.8	0.7	0.7
PL-L (BBBI)[2)]	2002–2006	–0.42	–0.36	–0.23	0.7	0.5	0.4
PL-L (ABBI)[2)]	2007–2012	–0.70	–0.89	–0.92	0.9	0.9	0.9
PL-H (All data)	2002–2012	–0.50	–0.53	–0.51	0.8	0.7	0.6
PL-H (BBBI)	2002–2004	–0.29	–0.21	–0.04	0.8	0.5	0.2
PL-H (ABBI)	2005–2012	–0.58	–0.64	–0.68	0.9	0.7	0.7

[1)] Mean of (modelled – observed) data; negative values indicate that the model underestimates observed data.
[2)] BBBI and ABBI are means before and after bark beetle infestation, respectively.

indicate that the model can be successfully used for the study area and elevations >1000 m on daily basis back to 1961, and on monthly and annual basis back to 1781. The systematic model error for the CT-O plot, however, suggests that model transposition to local terrain depressions and places with limited air exchange may overestimate the actual temperatures.

Model transposition to the PL catchment underestimated the observed data at both PL-L and PL-H plots throughout 2002–2012 (Table 6). Daily, monthly, as well as annual ME values were relatively small and stable, and varied between –0.42 and –0.04°C at both PL plots before bark beetle infestation (Table 6). After bark beetle infestation, the model uncertainty increased and trends in residuals between the modelled and observed data decreased continually (and significantly; p <0.001) at the PL-L (Fig. 6A) and PL-H (Fig. 6B) plots, while remained stable at the CT-H plot (with less damaged forest; Table 1) throughout the study (Fig. 6C). The forest dieback in the PL catchment resulted in a continuous increase in air temperature, and the daily, monthly, and annual ME varied between –0.92 and –0.58°C at the PL plots after the bark beetle infestation (Table 6). A difference between monthly mean errors calculated for the 2010–2012 and 2002–2004 periods showed that monthly mean air temperature increased at both PL plots by ~0.6°C on average after the forest dieback. This temperature increase is related to 2 m height above ground and does not represent temperature increase on the soil surface, which is undoubtedly significantly higher. For example, Hais & Kučera (2008) have reported increases in the surface area temperature by 3.5 and 5.2°C in the naturally decayed and clear-cut spruce forest, respectively, compared to healthy mature stands. Because the forest damage still continues at both PL plots as the dead trees are continuously broken by wind, we can expect a further increase in air temperature at the PL plots.

Conclusions

We revised the original reconstruction (Kettle et al. 2003) of daily, monthly, and annual mean air temperatures (2 m above ground) at forest stands surrounding CT Lake. Our model was derived for a new reference plot (more representative for mature Norway spruce forest in the study area) near CT Lake using daily data from the Churáňov station and monthly data from the Hohenpeissenberg station. The model provided good fit with data observed at the reference plot on daily (Fig. 2A), as well as monthly (Fig. 2B) basis. Model transposition from the reference plot to other Bohemian Forest plots provided relatively low mean errors of –0.42 to 0.09°C for daily data, –0.36 to 0.16°C for monthly data, and –0.23 to 0.09°C for annual data (Table 6). There were, however, two exceptions from this generally good fit: (1) Systematically lower air temperatures (by 0.76–0.87°C) than the modelled data were observed at plot CT-O, situated in a terrain depression. (2) A systematic increase in air temperatures compared to the modelled data has occurred at the PL plots since bark beetle infestation and the resulting forest dieback (Fig. 6A,B).

The model can be used for reconstructing day-to-day variability in mean air temperature back to 1961 and long-term trends in monthly and annual mean air temperature back to 1781

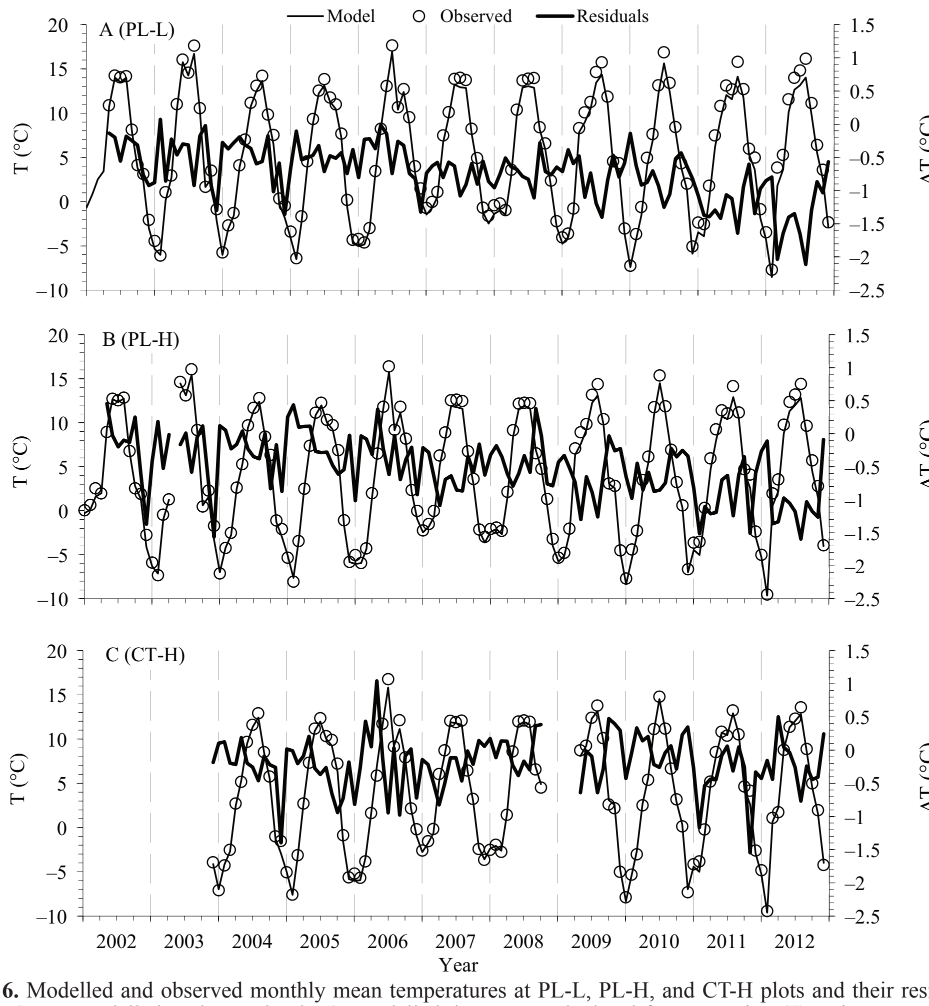

Fig. 6. Modelled and observed monthly mean temperatures at PL-L, PL-H, and CT-H plots and their residuals (*ΔT = modelled – observed values*). Modelled data were calculated from equation (4), using $T_{CT\text{-}L\text{-}m}$* data from Appendix 2.

for ecological and dendrochronological studies in the mature forest stands at elevations >1000 m in the Bohemian Forest. A caution is, however, necessary for reconstructing absolute temperature values for plots situated in local depressions or affected by forest dieback, which requires calibration of the modelled data using the actual measurements of air temperature at the plot of interest. Similar calibration might be also necessary for the model transposition for plots located in south-oriented parts of the mountain range in the Bavarian Forest.

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Appendix 1. Mean annual ($T_{CT\text{-}L\text{-}a}$*) and monthly ($T_{CT\text{-}L\text{-}m}$*) air temperatures (°C) at the reference plot (CT-L) near Čertovo Lake, modelled from the Hohenpeissenberg data (1781–2012). Similar results based on the Churáňov data are for the 1961–2012 period given in Appendix 2.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1781	4.87	–4.2	–3.2	–0.3	5.7	9.9	12.1	13.1	14.1	10.3	2.6	–0.5	–1.7
1782	3.28	–3.5	–6.9	–2.2	1.7	7.4	13.2	14.8	12.3	8.7	1.9	–4.2	–4.5
1783	4.46	–2.1	–2.1	–2.6	3.7	8.7	11.0	13.9	12.3	9.8	5.9	–0.8	–4.6
1784	3.06	–7.1	–6.0	–2.1	0.3	10.3	11.1	12.9	11.7	11.8	0.8	–0.8	–6.4
1785	2.72	–3.8	–7.7	–7.1	–0.4	7.1	9.9	11.0	11.4	11.6	4.0	0.1	–4.2
1786	3.05	–3.6	–4.8	–2.6	4.4	7.1	11.7	9.7	10.7	7.5	1.8	–2.3	–3.5
1787	4.58	–5.6	–1.7	0.4	1.7	5.5	11.9	12.2	13.7	9.8	6.7	–0.3	0.5
1788	4.04	–4.2	–0.6	–0.4	3.1	9.3	12.4	15.2	12.0	11.1	3.6	–2.0	–11.1
1789	3.89	–3.5	–2.7	–5.0	3.8	10.6	9.3	12.5	12.3	8.9	4.4	–1.5	–2.9
1790	4.40	–3.5	–2.2	–1.4	1.4	9.6	12.1	11.5	13.4	8.9	6.1	0.2	–3.9
1791	4.47	–2.3	–4.4	–1.1	5.6	7.7	11.0	12.6	14.0	9.0	4.9	–0.9	–3.0
1792	4.29	–3.7	–4.6	0.3	4.7	7.1	11.6	13.2	13.5	7.9	5.7	–0.3	–4.2
1793	4.72	–5.2	–2.2	–0.8	1.7	7.0	10.4	15.5	14.6	8.9	7.3	1.3	–2.3
1794	5.02	–4.3	–0.4	2.1	6.6	8.6	11.9	16.0	12.1	7.6	4.2	0.8	–5.4
1795	4.56	–8.9	–3.2	–1.4	5.7	8.7	11.9	10.2	13.4	11.4	9.2	–2.1	–0.7
1796	4.42	2.1	–3.6	–3.8	1.9	8.4	11.1	13.2	12.5	11.8	5.5	–1.4	–5.0
1797	5.02	–4.2	–2.0	–2.9	4.5	10.8	9.7	14.9	14.0	10.3	4.9	1.9	–2.1
1798	3.97	–5.1	–3.6	–1.7	3.7	8.9	11.6	12.6	13.0	10.5	5.0	–0.9	–6.9
1799	3.34	–6.0	–2.1	–2.1	1.4	7.1	9.7	11.7	13.5	9.4	4.5	0.1	–7.4
1800	4.63	–2.7	–4.2	–3.9	8.2	10.1	9.2	13.0	13.7	9.9	3.8	0.3	–2.4
1801	4.67	–2.8	–3.6	–0.2	3.6	9.7	9.5	12.2	11.9	10.9	6.7	1.3	–3.9
1802	4.62	–6.7	–4.1	–1.2	3.6	8.0	12.9	12.4	15.6	9.8	8.2	–0.1	–3.6
1803	3.79	–6.1	–6.6	–1.8	5.7	5.9	10.4	14.0	13.4	7.4	4.9	0.2	–2.7
1804	4.31	–1.0	–5.0	–2.1	2.6	9.5	11.7	12.6	12.6	10.6	5.6	–0.8	–4.9
1805	2.85	–5.5	–3.6	–2.6	1.3	6.7	10.3	11.5	11.4	9.9	2.4	–3.3	–4.7
1806	5.05	–2.6	–1.9	–1.4	0.3	10.6	11.5	13.2	12.7	9.8	4.9	2.2	0.6
1807	4.74	–6.0	–2.4	–4.8	1.9	9.7	11.5	16.4	16.4	8.5	7.4	1.6	–4.0
1808	3.64	–5.4	–5.7	–5.5	1.1	10.6	11.3	14.9	14.1	10.5	3.8	0.6	–6.8
1809	4.40	–3.4	0.0	–0.7	–0.1	9.0	11.4	13.9	12.0	9.8	4.2	–1.2	–2.6
1810	4.48	–5.7	–5.9	0.5	2.4	8.6	10.6	13.4	12.8	12.5	4.5	1.6	–2.3
1811	5.65	–7.7	–3.1	0.5	4.4	12.0	14.6	15.3	13.2	10.3	9.2	1.5	–3.1
1812	3.39	–6.5	–2.7	–1.5	–0.1	9.5	11.8	12.0	12.4	9.0	7.1	–1.9	–8.7
1813	3.34	–7.2	–1.9	–2.6	4.0	8.9	9.5	10.7	10.7	7.9	4.6	–1.8	–2.9
1814	3.41	–5.8	–8.9	–2.8	4.8	6.5	9.7	13.8	12.2	7.2	4.1	1.3	–1.9
1815	3.54	–9.0	–1.2	0.8	3.7	9.3	10.5	10.5	11.6	9.2	5.1	–2.9	–5.3
1816	2.58	–5.7	–6.0	–3.2	2.4	6.1	9.1	10.5	10.9	8.2	5.2	–2.2	–4.6
1817	3.56	–2.2	–2.7	–3.4	–2.0	7.7	12.5	11.1	11.7	11.3	1.0	1.3	–4.0
1818	4.48	–2.8	–2.7	–1.4	5.1	7.5	12.0	12.8	11.1	9.4	4.9	1.6	–4.3
1819	4.38	–3.5	–3.2	–0.9	4.4	9.2	11.1	13.0	12.2	10.2	4.5	–0.8	–4.1
1820	3.19	–7.3	–2.9	–3.2	4.5	8.9	8.8	11.5	14.3	7.1	3.7	–1.9	–5.3
1821	4.31	–3.1	–4.5	–1.1	4.8	6.5	8.3	10.3	12.8	9.7	4.6	3.4	–0.6

Appendix 1. Continued.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1822	5.30	–4.5	–1.6	2.5	4.1	10.4	15.1	13.4	12.0	9.0	7.5	2.5	–7.2
1823	3.92	–5.9	–2.7	–2.0	1.7	9.5	9.8	10.9	13.1	10.3	5.0	–0.3	–2.8
1824	4.20	–5.7	–1.8	–3.0	1.1	7.2	10.0	13.2	12.1	10.7	5.1	1.7	–0.4
1825	4.17	–5.4	–4.9	–3.6	4.6	8.2	10.1	12.1	12.2	9.8	4.4	1.7	0.4
1826	4.01	–8.5	–1.3	–0.5	2.3	5.7	10.3	13.4	14.8	11.0	6.1	–2.1	–3.4
1827	4.08	–7.0	–6.5	–0.8	4.0	9.9	11.3	14.3	11.2	9.9	6.2	–3.7	–0.7
1828	4.34	–1.8	–4.0	–1.4	3.0	8.6	11.2	12.6	11.0	9.4	3.7	1.3	–1.8
1829	2.31	–7.5	–6.3	–1.9	3.2	7.5	9.3	12.6	10.7	7.9	3.1	–2.8	–8.7
1830	3.63	–9.6	–5.8	0.1	4.9	9.0	10.6	13.2	12.2	7.0	4.0	1.3	–4.2
1831	4.29	–5.3	–2.4	–0.7	4.9	7.7	9.8	12.4	12.3	7.8	9.0	–1.1	–3.5
1832	3.80	–3.4	–3.2	–1.3	3.2	6.6	9.7	11.9	13.6	8.9	4.5	–0.8	–4.3
1833	3.92	–5.8	–0.9	–1.8	1.0	11.4	12.3	9.6	9.7	7.6	5.3	–0.2	–1.3
1834	5.10	–0.9	–3.2	–2.0	1.0	11.0	12.9	15.3	13.3	12.5	4.9	0.2	–4.3
1835	3.52	–3.2	–3.2	–2.7	1.5	8.2	11.0	14.5	11.9	9.7	2.8	–3.4	–5.4
1836	3.82	–5.2	–4.6	2.0	1.7	5.4	11.5	13.2	12.8	8.0	5.5	–1.0	–3.7
1837	3.04	–4.3	–3.7	–4.7	0.7	5.0	11.9	10.9	14.4	6.9	3.9	–1.9	–3.1
1838	3.05	–7.6	–5.0	–2.0	–0.1	8.2	10.4	11.7	11.1	9.8	4.0	0.8	–5.1
1839	3.99	–6.5	–3.6	–3.4	–0.4	6.6	13.3	13.6	10.7	9.9	6.4	2.6	–1.7
1840	3.09	–2.8	–5.0	–5.6	3.9	7.4	10.7	10.2	12.2	8.6	2.2	1.6	–6.3
1841	4.41	–5.9	–3.9	1.0	3.5	11.6	9.3	10.5	11.8	10.5	6.1	0.2	–2.4
1842	3.39	–8.8	–3.4	–1.4	1.7	7.8	11.8	11.9	14.0	8.3	1.2	–2.3	–0.6
1843	3.56	–4.3	–0.8	–2.1	2.4	6.0	8.1	10.2	12.2	8.4	4.6	0.1	–2.3
1844	2.99	–7.1	–5.7	–3.1	4.0	6.2	11.7	10.2	9.7	9.7	5.1	0.6	–5.5
1845	3.22	–2.9	–9.4	–5.0	3.1	4.6	11.5	12.6	10.3	9.1	5.2	1.8	–3.2
1846	4.69	–2.8	–1.9	0.1	3.0	8.8	13.2	14.1	13.3	10.3	5.6	–0.3	–7.5
1847	3.35	–3.3	–6.4	–2.6	–0.2	10.9	8.3	12.8	12.3	6.8	4.7	0.2	–4.3
1848	3.98	–10.0	–1.6	–0.9	4.4	8.1	11.9	12.4	12.3	8.7	5.5	–1.9	–1.5
1849	3.80	–3.7	–2.7	–3.3	1.5	8.5	12.4	12.8	11.3	9.2	5.6	–1.0	–5.5
1850	3.20	–8.1	–1.6	–3.8	2.6	6.5	11.3	11.9	12.5	7.3	2.1	0.6	–3.1
1851	3.12	–2.7	–4.4	–2.8	3.8	4.6	11.5	11.3	12.3	6.1	5.8	–5.1	–3.5
1852	4.64	–1.8	–4.6	–4.0	0.8	8.5	11.6	14.1	12.7	8.8	4.2	4.4	0.7
1853	3.37	–1.3	–6.8	–5.1	0.6	7.1	10.7	14.0	13.2	9.1	6.4	–1.0	–7.1
1854	3.60	–4.4	–6.8	–2.3	3.5	8.6	10.2	13.0	11.8	9.4	5.9	–2.6	–3.9
1855	3.40	–7.9	–4.5	–2.3	1.5	7.3	11.2	12.6	13.6	9.5	7.9	–1.9	–6.6
1856	4.28	–1.7	–1.9	–2.7	4.9	6.9	12.6	11.1	14.2	8.3	6.7	–4.2	–3.2
1857	4.40	–6.5	–6.0	–2.6	2.2	8.5	11.3	14.7	13.3	11.1	7.3	0.7	–2.0
1858	3.58	–6.7	–6.3	–2.8	3.9	6.3	14.3	11.5	11.4	11.7	5.7	–2.8	–3.9
1859	4.67	–4.8	–3.3	0.5	3.3	7.7	11.7	17.0	14.6	9.5	6.6	–0.8	–6.3
1860	2.87	–2.3	–8.0	–3.9	1.7	8.5	11.0	9.6	11.8	8.9	4.0	–3.1	–4.2
1861	4.17	–7.0	–0.8	–1.4	1.2	7.0	11.9	12.4	14.3	9.2	6.7	0.6	–4.5
1862	5.00	–5.0	–4.5	2.1	5.2	10.2	10.2	13.5	12.1	10.4	7.2	0.4	–2.6
1863	4.78	–1.8	–3.3	–1.6	3.5	9.2	10.9	11.8	14.5	8.9	7.3	0.5	–3.1

Appendix 1. Continued.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1864	2.84	–7.2	–4.4	–0.9	0.8	7.5	10.4	11.6	11.2	9.0	3.4	–1.5	–5.9
1865	4.53	–3.8	–7.5	–5.8	6.7	11.4	10.2	15.0	12.0	11.8	5.9	1.3	–3.6
1866	4.54	–1.4	–2.1	–2.2	4.1	5.4	12.5	12.0	11.7	10.8	4.9	–0.6	–1.1
1867	3.71	–5.1	–1.3	–2.2	2.9	8.4	11.0	11.4	13.5	10.5	3.9	–2.1	–6.5
1868	4.66	–6.9	–2.7	–3.2	2.1	12.8	12.2	12.7	13.1	12.3	4.9	–2.1	0.4
1869	4.02	–6.1	0.5	–3.9	4.5	9.6	8.5	14.8	11.3	11.1	2.4	–0.8	–3.8
1870	2.92	–5.9	–6.3	–4.4	2.0	9.6	11.1	14.6	10.6	7.6	4.2	–0.6	–8.2
1871	2.76	–8.3	–2.6	–0.9	2.4	5.7	8.2	13.3	12.8	11.3	2.4	–3.9	–7.5
1872	4.94	–3.1	–2.2	–0.4	3.5	7.7	10.6	13.3	11.5	10.5	6.4	1.8	–0.6
1873	4.24	–2.0	–4.8	0.3	1.9	5.0	11.0	14.6	13.7	8.4	6.1	–0.3	–3.6
1874	3.96	–3.2	–4.4	–2.4	4.0	4.6	11.7	15.4	11.0	11.5	6.9	–2.1	–6.0
1875	3.53	–2.7	–7.8	–3.9	2.8	9.7	12.0	11.8	13.9	9.8	3.0	–1.5	–5.5
1876	4.14	–5.1	–2.8	–1.5	3.2	4.1	11.0	13.3	13.3	8.3	7.2	–1.0	–0.6
1877	3.78	–1.8	–3.0	–3.1	1.6	5.2	13.5	11.8	13.7	6.8	3.2	1.3	–4.3
1878	3.66	–6.0	–2.7	–3.0	3.0	8.9	10.9	11.6	12.5	9.4	5.6	–1.3	–5.3
1879	2.80	–5.1	–3.9	–2.2	1.7	4.5	11.6	10.3	14.0	10.0	3.2	–3.2	–7.5
1880	4.05	–7.3	–5.0	0.2	3.5	6.3	10.2	14.1	11.8	10.2	4.9	0.3	–0.8
1881	3.69	–7.7	–2.6	–1.2	1.2	7.0	10.9	15.4	13.3	8.3	1.0	1.3	–2.9
1882	4.23	–2.3	–3.2	1.0	2.6	8.2	9.9	12.3	10.9	8.3	6.0	0.0	–3.5
1883	3.50	–4.1	–2.7	–6.0	1.7	8.3	11.0	12.2	12.4	9.4	4.1	0.3	–5.0
1884	4.26	–2.3	–2.0	0.0	2.0	9.2	8.3	14.1	13.2	9.8	3.3	–1.4	–3.5
1885	4.21	–5.5	–0.5	–2.5	4.7	6.3	12.8	13.5	12.3	9.8	3.7	0.2	–4.5
1886	3.81	–5.8	–7.1	–3.6	4.3	8.5	9.7	13.2	12.5	11.4	6.0	0.2	–4.2
1887	2.74	–6.3	–6.4	–3.6	2.5	5.2	11.7	14.8	12.1	8.3	0.6	–0.6	–5.9
1888	3.10	–6.3	–5.9	–3.4	0.9	8.6	11.8	10.3	11.4	9.1	2.3	–0.3	–1.5
1889	2.92	–6.7	–7.7	–4.3	1.7	10.3	12.5	11.8	11.5	7.0	4.5	0.1	–6.3
1890	2.92	–1.8	–7.7	–1.5	2.2	9.1	9.7	10.9	12.3	8.4	2.9	–1.9	–8.5
1891	3.34	–8.7	–5.2	–2.1	0.4	8.4	11.2	11.5	11.3	10.1	6.4	–1.0	–2.8
1892	3.81	–5.4	–3.3	–3.8	3.0	7.9	11.1	11.9	14.5	10.4	4.2	1.0	–5.9
1893	3.84	–9.8	–3.0	–1.0	5.3	7.3	11.4	12.7	13.2	9.3	6.5	–1.9	–4.4
1894	3.82	–5.2	–4.1	–1.2	5.3	7.0	10.2	13.4	12.2	7.6	4.5	0.8	–5.1
1895	3.59	–8.5	–10.9	–2.9	3.7	7.2	11.1	13.8	12.6	13.0	4.2	2.2	–3.3
1896	3.04	–6.2	–4.9	0.4	0.4	5.6	11.4	12.7	10.2	8.7	4.3	–2.6	–3.8
1897	3.85	–5.2	–1.8	–0.1	2.4	5.5	12.2	11.9	12.1	7.8	3.7	0.3	–3.1
1898	4.70	–0.7	–4.6	–2.1	3.2	7.3	10.5	10.8	14.3	10.8	6.5	2.1	–2.3
1899	4.05	–2.3	–1.6	–1.3	2.2	6.5	10.4	12.0	12.9	8.5	5.5	1.4	–5.9
1900	4.20	–3.9	–2.0	–4.7	1.6	6.0	11.5	13.9	11.7	11.1	5.1	1.0	–1.1
1901	3.59	–5.1	–8.0	–2.6	2.9	8.4	11.6	13.4	12.0	10.1	4.7	–2.3	–3.0
1902	3.60	–2.8	–4.5	–1.6	4.3	4.0	10.0	13.1	12.2	8.9	3.7	–0.6	–4.1
1903	4.12	–4.3	–1.5	0.5	–0.2	8.3	10.3	11.6	12.4	9.9	6.3	–0.3	–4.0
1904	4.48	–3.7	–3.9	–1.3	4.4	8.8	11.8	15.7	13.1	7.2	4.5	–0.8	–2.5
1905	3.48	–6.2	–4.5	–0.8	1.7	6.5	11.9	15.2	12.3	9.6	–0.4	–0.3	–3.8

Appendix 1. Continued.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1906	3.71	–3.9	–5.2	–2.9	2.6	7.7	9.5	12.6	12.8	7.9	7.1	1.8	–6.2
1907	3.90	–5.7	–6.8	–3.2	0.8	9.5	10.9	10.6	13.1	10.1	7.4	1.2	–2.0
1908	3.63	–4.2	–4.6	–2.6	0.6	9.5	12.7	12.2	11.0	8.1	5.4	–1.4	–3.5
1909	3.18	–6.2	–7.3	–2.5	3.9	6.6	9.7	10.3	12.2	8.7	6.5	–2.3	–2.4
1910	3.91	–3.8	–2.9	–1.1	2.1	6.9	11.3	10.7	12.0	7.2	5.8	–0.8	–0.9
1911	4.70	–6.1	–4.0	–0.8	2.1	7.7	10.4	15.4	14.7	10.5	5.5	1.3	–1.1
1912	3.63	–3.8	–0.4	0.7	1.5	8.3	11.2	12.0	10.0	3.9	3.1	–2.5	–0.7
1913	4.18	–3.2	–4.0	1.1	2.6	7.5	9.8	9.3	11.1	8.5	7.3	2.5	–3.0
1914	3.92	–7.8	–0.1	–0.9	4.9	6.0	9.7	11.3	12.9	8.3	4.2	–0.6	–0.9
1915	3.66	–4.9	–3.2	–3.0	2.1	9.4	12.7	11.9	11.0	7.2	2.0	–2.1	0.5
1916	4.23	–1.3	–3.2	–0.3	3.0	8.9	8.8	11.5	11.8	7.6	5.0	0.7	–2.1
1917	3.35	–7.4	–6.4	–3.5	–0.3	11.1	13.2	12.5	12.2	11.7	2.9	0.1	–6.4
1918	4.46	–2.1	–2.6	–0.4	3.8	9.2	8.7	12.2	11.8	9.9	3.4	–0.1	–0.8
1919	3.30	–3.8	–4.3	–1.5	0.2	6.5	10.9	9.4	13.1	11.5	1.5	–1.7	–2.6
1920	4.75	–1.4	–1.0	1.2	3.9	10.0	10.2	12.7	11.0	9.2	3.8	0.2	–3.1
1921	4.91	–0.8	–4.1	0.9	1.8	9.3	10.3	15.3	13.0	10.3	7.9	–2.0	–3.6
1922	3.24	–5.7	–4.6	–0.8	1.2	9.4	11.7	11.5	12.3	6.8	1.6	–2.4	–2.7
1923	4.17	–5.0	–2.6	–0.8	2.5	8.4	7.8	14.8	13.0	9.7	7.2	0.0	–5.5
1924	3.75	–4.7	–7.3	–2.3	2.3	9.2	10.6	12.4	10.0	9.8	5.5	0.4	–1.5
1925	3.83	–1.8	–1.7	–4.6	3.1	8.3	11.0	12.5	12.0	6.8	5.3	–2.1	–3.4
1926	4.54	–4.2	0.7	–1.6	4.6	6.5	8.9	11.3	12.2	11.4	5.2	3.6	–4.2
1927	4.09	–3.7	–3.9	0.0	2.5	8.1	11.4	12.6	12.1	9.5	4.3	0.6	–4.8
1928	4.43	–2.6	–2.8	–1.3	3.2	5.4	11.2	15.9	13.1	8.8	5.5	1.5	–5.0
1929	3.92	–7.7	–9.9	–1.3	0.3	8.3	11.2	13.8	13.0	12.0	6.0	1.8	–1.3
1930	4.71	–0.3	–5.2	–0.3	3.5	7.1	13.9	11.6	12.0	9.8	4.9	2.5	–3.3
1931	3.20	–4.8	–5.9	–4.5	1.3	10.3	13.0	12.1	11.1	5.1	3.7	1.4	–5.1
1932	4.15	–2.4	–8.6	–3.4	2.0	7.6	10.4	12.5	14.4	12.0	4.5	1.0	–0.7
1933	3.42	–6.1	–4.8	–0.1	2.5	6.0	8.9	13.6	13.1	10.0	5.4	–0.5	–7.5
1934	5.12	–3.8	–4.1	–1.1	5.6	9.5	11.4	14.1	12.0	11.5	5.0	0.2	0.6
1935	3.84	–7.0	–4.0	–2.6	1.7	6.4	13.1	13.8	12.3	10.1	4.3	1.7	–4.2
1936	4.17	–0.8	–3.3	0.7	2.5	7.7	10.8	11.9	12.0	9.0	1.2	0.1	–1.9
1937	4.60	–2.3	–2.2	–1.7	2.6	10.1	12.0	13.0	12.5	9.3	6.3	–0.2	–4.7
1938	4.27	–3.7	–3.9	2.1	–0.6	6.5	12.6	12.3	12.3	10.4	5.2	2.4	–4.9
1939	3.89	–2.0	–2.0	–4.1	4.4	5.1	11.4	12.2	12.7	8.4	3.1	2.3	–5.0
1940	3.13	–8.8	–3.6	–1.7	3.5	7.6	10.9	11.6	10.8	9.4	4.5	1.3	–7.9
1941	3.13	–6.7	–3.3	–0.8	0.9	4.6	11.8	13.0	11.2	8.4	3.2	–1.0	–4.3
1942	3.98	–9.1	–8.0	–0.4	2.8	8.3	10.9	12.2	13.0	12.0	8.5	–2.3	–1.1
1943	4.90	–3.5	–1.8	1.4	4.1	8.3	9.7	13.2	14.3	10.4	7.1	–1.5	–3.5
1944	3.53	–2.3	–6.6	–5.1	3.8	7.2	9.9	12.1	15.0	8.8	4.0	–0.3	–4.4
1945	4.62	–8.3	–1.2	0.1	3.6	9.8	12.9	13.9	12.2	10.0	5.8	–0.8	–3.0
1946	4.47	–4.7	–3.0	–0.3	5.7	9.4	10.6	13.8	12.3	10.8	3.6	0.3	–5.4
1947	5.14	–7.5	–5.9	0.0	5.6	10.2	12.9	14.8	14.5	13.4	5.4	1.6	–3.9

Appendix 1. Continued.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1948	5.02	–0.6	–4.1	1.7	4.4	9.5	10.5	10.3	12.1	9.8	5.7	2.3	–1.7
1949	4.99	–2.8	–2.5	–3.0	5.5	7.1	10.2	13.8	12.8	12.6	7.5	–0.3	–1.5
1950	4.81	–4.7	–1.2	0.0	1.7	10.2	14.0	15.0	13.2	9.1	4.6	0.8	–5.2
1951	4.70	–2.7	–2.8	–2.4	2.6	7.6	11.0	13.2	13.0	10.6	4.2	2.6	–1.0
1952	3.97	–4.7	–5.8	–1.3	5.0	7.7	12.1	15.6	14.0	6.4	4.1	–1.4	–4.7
1953	4.82	–6.3	–5.1	0.4	4.2	8.7	10.6	13.4	12.7	10.5	6.5	1.7	–0.1
1954	3.60	–8.1	–6.3	0.4	0.8	7.0	11.5	10.3	11.8	9.8	6.0	1.5	–2.1
1955	3.79	–3.2	–5.0	–3.4	2.3	7.2	11.1	12.2	12.1	9.0	3.9	–0.2	–1.1
1956	3.07	–3.5	–12.9	–1.3	1.7	8.6	8.9	12.9	11.4	11.1	4.2	–2.6	–2.4
1957	4.59	–3.4	–0.6	2.6	2.6	5.2	12.3	13.0	11.3	8.6	5.8	0.2	–2.9
1958	4.33	–4.1	–1.5	–4.7	0.6	10.8	10.8	13.4	13.6	11.1	4.4	–0.8	–2.1
1959	5.16	–4.2	–1.6	1.8	4.6	8.3	11.5	14.5	12.2	10.4	5.5	0.2	–1.6
1960	4.32	–4.3	–2.7	0.0	2.8	8.9	11.9	10.8	12.3	8.5	5.5	2.0	–4.0
1961	5.29	–4.2	0.0	1.0	6.0	6.1	12.0	11.7	12.7	13.6	6.9	0.7	–3.1
1962	3.56	–3.2	–5.4	–4.3	3.8	6.2	10.5	12.2	13.9	9.6	5.8	–1.0	–5.8
1963	3.72	–9.6	–7.5	–1.3	4.1	7.4	11.5	14.0	12.0	10.1	5.1	3.6	–5.4
1964	4.35	–5.0	–3.0	–3.2	4.3	9.5	12.5	14.9	12.3	10.1	2.8	0.3	–3.5
1965	3.51	–3.2	–7.8	–1.7	1.7	6.6	12.0	11.4	11.7	8.7	5.3	–1.1	–2.3
1966	4.47	–6.2	1.1	–2.5	4.9	8.3	12.3	11.1	11.2	10.6	7.7	–1.5	–3.5
1967	4.72	–4.0	–2.3	–0.4	1.9	8.4	10.7	15.0	12.9	9.8	8.2	1.1	–5.1
1968	4.06	–5.9	–3.0	–0.9	4.5	7.7	11.5	11.9	11.4	9.0	7.2	0.5	–5.2
1969	3.97	–2.8	–5.5	–2.2	2.6	9.9	9.6	13.6	11.6	10.4	6.9	0.9	–7.8
1970	3.85	–3.5	–5.1	–3.6	0.8	6.5	12.6	12.4	12.8	10.1	4.9	2.5	–4.7
1971	4.55	–2.5	–5.0	–4.3	5.2	9.5	9.9	14.5	13.8	8.3	6.1	–0.7	–1.0
1972	4.20	–4.3	–0.6	1.4	2.0	7.4	10.5	12.4	12.1	6.8	3.1	0.8	–1.5
1973	3.87	–4.7	–5.3	–2.2	0.1	9.3	11.6	12.1	14.1	10.7	3.6	–0.1	–3.5
1974	4.40	–0.6	–2.0	1.3	2.9	7.0	9.8	12.1	13.5	9.2	0.1	0.4	–1.4
1975	4.46	–0.8	–2.5	–1.6	2.1	8.5	9.8	13.1	12.9	12.0	4.1	–0.7	–4.0
1976	4.44	–3.8	–2.6	–2.5	2.6	9.1	13.3	14.5	11.0	8.7	6.9	0.0	–4.3
1977	4.76	–3.2	–1.2	2.0	1.1	7.8	11.5	12.9	11.7	8.0	7.1	0.3	–1.5
1978	3.78	–4.1	–5.0	–0.6	2.3	6.6	10.7	11.5	11.3	8.7	4.6	0.6	–2.0
1979	4.21	–6.7	–3.6	–0.2	1.1	8.7	11.9	11.9	11.7	9.6	6.7	–0.6	–0.6
1980	3.61	–5.7	–1.6	–0.9	0.3	6.1	10.2	10.6	13.4	10.7	4.6	–0.6	–4.1
1981	4.32	–5.9	–5.4	2.1	4.1	8.3	11.7	12.1	13.1	10.0	5.0	0.3	–4.3
1982	5.08	–2.9	–3.9	–1.1	1.4	8.9	12.5	14.7	12.6	12.1	5.5	2.7	–2.2
1983	5.17	–0.9	–6.2	–0.2	4.4	7.6	12.1	17.6	13.2	10.1	5.8	–0.2	–2.0
1984	4.10	–3.3	–5.9	–2.8	1.8	6.5	10.7	12.8	12.6	8.3	6.6	3.9	–2.3
1985	4.12	–8.1	–5.1	–2.2	3.0	9.0	10.0	14.4	13.0	11.2	5.5	–2.2	0.3
1986	4.36	–4.2	–9.5	–1.2	2.1	10.5	11.5	12.8	12.9	9.4	6.6	2.4	–2.2
1987	4.10	–8.6	–2.9	–4.7	4.6	5.5	10.6	13.3	12.5	12.6	6.7	0.8	–1.2
1988	4.89	–0.3	–3.5	–2.7	4.0	9.8	11.0	13.7	13.3	9.5	7.0	–0.8	–2.7
1989	5.56	–1.7	–0.2	2.6	2.8	9.5	10.6	13.7	13.1	9.6	7.1	–0.1	–0.7

Appendix 1. Continued.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	5.35	–1.3	1.4	2.0	1.7	10.2	11.0	13.2	14.1	8.4	7.4	–0.3	–4.0
1991	4.36	–3.9	–5.0	1.6	2.1	5.1	10.6	14.8	14.2	11.7	4.7	0.3	–4.4
1992	5.35	–3.1	–2.0	–0.2	3.0	10.6	11.9	14.4	16.1	10.2	3.2	2.3	–2.6
1993	4.79	–0.9	–4.2	–1.3	5.3	10.6	12.1	12.1	13.0	9.1	4.9	–2.5	–1.2
1994	5.84	–2.3	–2.7	2.5	2.4	8.9	12.7	16.8	14.5	9.6	5.3	3.4	–1.7
1995	4.74	–4.4	–0.3	–2.1	3.6	8.8	9.9	16.0	12.7	7.9	8.5	–0.1	–4.1
1996	3.56	–5.2	–6.7	–3.6	3.0	9.1	12.0	12.6	12.6	7.1	6.0	1.7	–6.3
1997	5.08	–3.6	–0.5	1.2	1.7	9.3	11.3	12.1	14.5	11.0	4.2	1.3	–1.8
1998	4.97	–2.3	0.0	–1.0	3.9	9.7	13.0	13.3	13.8	8.9	5.1	–2.6	–2.5
1999	5.07	–1.1	–5.4	0.4	3.5	10.3	11.0	14.1	13.3	12.1	5.5	–1.4	–2.7
2000	5.69	–4.4	–1.2	–0.4	5.4	10.7	13.6	11.1	14.7	10.4	6.2	2.1	0.0
2001	4.94	–2.8	–2.1	1.0	2.1	11.1	10.9	14.3	14.5	6.9	9.8	–1.8	–5.6
2002	5.67	–2.1	–0.1	1.4	3.2	9.5	14.4	13.6	13.3	8.0	5.4	2.8	–1.7
2003	5.80	–4.7	–5.9	1.4	3.8	10.8	16.6	15.2	17.3	10.3	2.5	3.1	–1.6
2004	4.89	–4.5	–2.6	–0.9	4.4	7.6	11.8	13.4	14.0	10.4	7.6	–0.4	–2.3
2005	4.80	–3.5	–5.9	–0.6	4.4	9.5	13.4	13.8	11.7	10.9	7.9	0.2	–4.9
2006	5.64	–4.7	–4.8	–2.7	3.6	9.2	13.1	17.7	10.7	12.9	8.9	3.6	–0.5
2007	5.54	–0.9	–0.4	0.4	7.8	10.2	13.2	13.6	12.9	8.3	4.7	–0.9	–2.7
2008	5.37	–0.7	–0.5	–1.2	3.0	10.8	13.1	13.6	13.5	8.3	6.1	1.3	–3.0
2009	5.39	–5.0	–4.1	–1.7	6.9	10.8	11.4	14.3	15.0	11.0	5.1	3.9	–3.4
2010	4.27	–6.6	–3.7	–0.9	4.4	7.1	12.5	15.7	12.7	8.7	4.7	0.8	–4.7
2011	5.99	–3.6	–2.2	0.9	7.0	10.5	12.2	11.8	14.8	12.0	5.8	3.8	–1.5
2012	5.35	–3.4	–7.9	2.5	4.0	10.5	13.2	13.8	14.8	10.2	5.9	2.5	–2.5

Appendix 2. Mean annual (T_{CT-L-a}*) and monthly (T_{CT-L-m}*) air temperatures (°C) at the reference plot (CT-L) near Čertovo Lake, modelled from the Churáňov data (1961–2012).

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961	5.40	–3.9	–0.1	1.3	6.9	6.3	12.6	11.2	12.2	13.8	7.1	1.1	–3.9
1962	3.37	–3.2	–5.4	–4.5	4.3	5.4	10.0	11.5	13.2	9.3	5.9	–0.9	–5.6
1963	3.73	–10.5	–7.8	–1.3	4.0	7.7	12.2	14.2	12.2	10.7	4.8	3.6	–5.6
1964	4.34	–4.3	–3.6	–3.9	4.4	9.0	13.6	14.3	11.9	10.1	3.3	0.3	–3.1
1965	3.47	–3.0	–7.6	–1.7	1.6	6.1	11.7	11.3	11.5	9.6	5.9	–2.2	–2.4
1966	4.58	–7.0	1.2	–2.1	5.0	8.8	12.6	11.7	11.4	9.9	8.3	–1.2	–3.5
1967	4.83	–4.2	–2.3	0.1	1.9	8.5	11.0	14.8	12.4	10.0	8.4	1.3	–4.6
1968	4.15	–6.0	–2.9	–0.7	4.5	7.4	11.9	12.1	11.7	9.2	6.7	1.0	–5.2
1969	4.19	–2.6	–5.6	–3.3	2.4	10.2	10.6	14.3	11.7	10.5	7.7	1.0	–7.3
1970	3.85	–4.3	–5.2	–3.3	0.8	6.0	12.7	12.4	12.8	10.1	4.8	2.7	–3.9
1971	4.64	–2.6	–4.2	–3.7	4.4	9.7	9.9	14.2	14.6	8.0	5.6	–0.5	–0.5
1972	4.32	–5.4	–0.2	1.2	2.1	7.3	11.5	13.6	12.1	6.9	3.1	0.6	–0.9
1973	4.22	–3.0	–4.1	–1.0	0.3	8.7	11.9	12.6	14.4	11.2	3.9	–1.1	–3.8
1974	4.63	–0.8	–1.0	1.9	3.1	7.0	9.7	11.2	14.0	10.0	0.5	0.5	–0.8
1975	4.99	–0.5	–2.3	–0.5	2.3	8.5	10.3	13.7	13.7	13.1	5.0	–0.9	–3.3
1976	4.41	–4.2	–2.6	–3.8	2.7	9.0	13.2	14.8	11.1	8.9	7.4	0.7	–4.4
1977	4.94	–2.8	–1.3	2.2	1.2	8.0	12.0	12.6	12.3	7.8	8.0	0.2	–1.6
1978	3.84	–3.9	–4.7	0.1	2.0	6.4	10.5	11.4	10.8	8.2	5.4	1.7	–2.6
1979	4.11	–6.9	–4.4	0.0	1.2	8.9	13.6	10.7	11.7	9.7	5.6	–0.6	–0.7
1980	3.26	–5.6	–1.9	–1.5	0.5	5.5	10.2	10.5	12.7	10.3	4.3	–1.5	–4.5
1981	4.16	–6.1	–4.9	2.2	3.2	8.9	11.9	12.0	12.5	10.7	4.5	–0.3	–5.1
1982	5.13	–3.5	–4.5	–0.6	0.5	8.8	12.5	14.3	13.0	13.0	6.1	2.8	–1.6
1983	5.16	–1.4	–6.0	–0.3	4.6	8.2	12.2	16.9	13.4	10.4	5.4	0.2	–2.4
1984	3.88	–4.2	–5.4	–2.8	1.8	6.7	10.0	11.7	12.6	8.3	7.1	2.6	–2.1
1985	3.70	–8.1	–6.8	–1.5	2.4	9.2	8.9	13.5	12.7	10.4	5.8	–3.2	0.2
1986	4.29	–5.1	–10.3	–1.6	3.8	10.8	11.4	12.8	12.8	9.1	6.4	2.5	–2.2
1987	3.78	–8.1	–2.7	–5.8	3.9	6.0	10.5	13.3	11.5	11.9	5.8	0.8	–2.0
1988	4.70	–0.7	–3.2	–2.9	3.5	9.6	11.1	13.6	13.0	9.3	7.0	–1.6	–2.6
1989	5.60	–0.6	0.0	2.1	3.5	8.9	10.5	13.2	12.7	10.4	6.7	–0.2	–0.6
1990	5.23	–1.6	1.4	2.2	1.9	9.8	11.3	12.4	14.2	7.5	7.4	0.0	–4.3
1991	4.26	–2.9	–5.9	2.1	2.0	4.5	10.0	14.6	13.9	11.3	3.9	0.4	–3.5
1992	5.37	–2.7	–1.6	–0.6	2.3	9.9	12.5	14.8	16.8	10.4	2.9	1.3	–1.7
1993	4.71	–1.7	–2.7	–1.8	5.1	10.8	11.6	11.8	12.9	9.4	4.8	–2.6	–1.8
1994	5.68	–2.1	–3.7	1.4	3.1	8.5	12.4	17.3	14.1	10.3	4.2	3.2	–1.2
1995	4.71	–4.7	–0.4	–2.1	3.5	8.7	10.2	16.1	13.2	8.4	8.7	–0.8	–4.7
1996	3.63	–4.8	–5.4	–4.3	4.0	8.8	12.7	11.6	12.7	6.4	5.8	1.2	–5.4
1997	4.99	–3.3	–0.9	1.0	0.8	9.0	12.0	12.5	14.7	11.0	3.6	0.7	–1.6
1998	5.01	–1.8	0.4	–1.3	4.8	9.9	12.9	12.7	13.5	9.4	5.1	–2.8	–3.1
1999	5.25	–1.2	–5.1	0.8	4.1	9.8	11.5	14.5	13.3	13.0	5.3	–0.9	–3.0
2000	5.99	–4.4	–1.6	–0.6	6.3	11.1	14.0	11.0	14.7	10.3	8.0	2.9	–0.1
2001	4.99	–3.2	–1.7	0.6	2.4	11.0	10.5	14.1	14.6	7.5	9.7	–1.1	–5.3
2002	5.78	–2.6	0.0	1.1	3.0	11.4	14.6	14.0	14.5	8.4	4.3	2.8	–2.5

Appendix 2. Continued.

Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	5.69	–4.8	–5.5	0.8	3.3	11.2	16.3	14.8	17.2	10.9	2.1	3.0	–1.7
2004	4.79	–5.5	–2.6	–1.0	4.5	7.3	11.4	13.0	14.2	10.2	7.0	0.2	–1.4
2005	4.69	–3.6	–6.0	–1.6	4.6	9.5	12.8	13.7	11.8	11.0	7.7	–0.1	–4.3
2006	5.83	–4.5	–4.3	–2.6	3.7	8.9	13.5	17.5	10.9	12.9	9.2	3.6	0.6
2007	5.68	–1.0	–0.2	1.1	7.3	10.2	13.8	13.5	13.4	8.1	4.5	–0.8	–2.0
2008	5.58	–0.9	–0.5	–0.9	3.6	10.3	13.5	13.6	13.4	8.6	6.3	2.1	–2.4
2009	5.56	–4.3	–3.5	–0.8	8.4	9.6	11.1	14.0	14.9	11.5	4.5	4.0	–3.2
2010	4.34	–6.9	–3.8	–1.0	4.7	7.5	12.8	16.2	12.9	8.4	4.4	1.8	–5.4
2011	6.01	–3.0	–3.4	.0	6.8	10.0	12.6	12.1	14.7	12.3	5.8	4.1	–1.4
2012	5.38	–3.8	–8.0	2.4	4.3	10.8	13.2	13.7	14.6	10.3	6.0	3.0	–2.4