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Modelling air temperature at Čertovo Lake back to 1781

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Abstract
At Čertovo (CT) Lake in Bohemia mean daily and monthly air temperatures were reconstructed back to 1961 and 1781 respectively, using daily data from Churáňov (Bohemian Forest) and monthly data from Hohenpeissenberg (Germany). Daily air temperatures varied between –17.7°C and 23.2°C in the 1961–2001 period, with an average of 3.8°C. Average daily error for the mean daily air temperature at CT Lake was 0.7°C. Mean monthly air temperatures were predicted with mean absolute error of 0.5°C and varied between –12.0°C and 16.2°C in the 1781–2001 period with long-term averages between –5.3 °C in January and 12.3°C in July–August. Mean annual air temperatures varied between 2.1°C (in 1829) and 5.1°C (in 2000), with the 1781–2001 average of 3.4°C. Long-term trend in mean annual air temperature exhibited significant variations with 3 distinct periods: (i) temperature fluctuation along the 1781–2001 average between 1781 and 1830, (ii) colder period from 1830 to 1940, and (iii) increasing temperature since the 1960s, with the most rapid increase between 1980 and 2001. This increase was predominantly associated with the increasing trend in mean winter and summer temperatures, particularly May, August, and December temperatures.

Key words: Climate, long-term trend, Bohemian Forest, temperature

Introduction

Mineralisation and desorption of sulphur accumulated in soils, and temperature or chemically driven changes in the ability of some terrestrial ecosystems to retain nitrogen have become the most important processes affecting soil and water quality in mountain areas recovering from atmospheric acidification (e.g., Gundersen et al. 1998a,b; Monteith et al. 2000; Kopáček et al. 2001, Prechtel et al. 2001). The prediction of future impacts of various scenarios of acid emissions or climatic changes on these processes requires process-based whole ecosystem studies on the present, as well as the historical status of ionic fluxes, nutrient cycling, vegetation, and climate variations (Johnson & Lindberg 1992, Psenner & Schmidt 1992).

Surface water chemistry has been responding quickly to decreased chemical inputs in the central European mountain areas of the Bohemian Forest and the Tatra Mountains (Evans et al. 2001, Prechtel et al. 2001). Although long-term trends in chemical inputs into these mountain regions can be reasonably reconstructed from their emission trends (Kopáček et al. 2001, 2002), long-term climatic records (longer than a few decades) are usually missing in these areas. However, some climatic data (particularly temperature) can 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). Such long-term temperature data are of great scientific interest and can explain a large portion of the observed variability in the chemistry of mountain lakes (e.g., PSENNER & SCHMIDT 1992, SOMMARUGA-WÖGRATH et al. 1997).

An important question, dealing with the historical and future water composition in the Bohemian Forest (BF), is the extent to which inter-annual air temperature variations and possible global change may affect the N cycling and the future NO_3^- export from soils (VESELÝ et al. 2003). Year-to-year changes in tree growth are tightly linked to year-to-year changes in air temperature (ZHOU et al. 2001). An increase of 1.3–1.5°C over the last 17 years such as that shown in the annual mean air temperature in the Czech Republic (VESELÝ et al. 2003) can prolong the growing season by ~3 weeks (ZHOU et al. 2001) and consequently, increase N assimilation and reduce the NO_3^- leaching. In addition to trends in annual mean air temperature, seasonal variations in climatic parameters (and consequently, in soil temperature and moisture) play an important role in nitrogen dynamics (e.g., GUNDERSEN et al. 1998). For example, although not yet fully explained it has been observed that cold winters, as well as dry and warm summers are followed by extremely high NO_3^- leaching (MONTEITH et al. 2000, HARRIMAN et al. 2001). The above examples suggest that knowledge of long-term temperature trends could significantly help to explain the observed historical changes in water and sediment chemistry, as well as in tree ring increments and composition. Therefore, since available climatic data measured in the BF span only the last four decades we were prompted to model a longer temperature trend for this mountain area as a background for further studies dealing with soil N dynamic or forestry in the region.

The aim of this study was to reconstruct air temperature variations in the area of Čertovo Lake over the last 220 years: (i) monthly mean temperatures back to 1781 and (ii) daily mean temperatures back to 1961.

METHODS

Study site and data sources

Čertovo (CT) Lake is situated in the western part of the BF at 13°12' E and 49°10' N, at altitude of 1030 m above sea level (a.s.l.). The lake has an area of 10.5 ha and volume of 1.85×10^6 m^3. The lake is surrounded by the steep, east-oriented, forested (Norway spruce) slopes of the Jezerní Hora massive (maximum elevation of 1343 m a.s.l.).

Air temperature at CT Lake (T_{AWS}) was measured using an automatic weather station (MS16; J. Fiedler, České Budějovice), situated ~150 m downstream of the lake outflow at altitude ~1020 m a.s.l. in the forest 1.5 m above ground. The data were recorded in 15-minute intervals from 17 November 1997 to 31 December 2001 with the exception of missing data from 18 November to 27 December 1998 and from 13 January to 4 February 1999. Long-term air temperature data in the BF come from Churáňov station (Czech Hydrometeorological Institute), situated in the central part of the mountain area ~50 km east of CT Lake at 13°37' E, 49°04' N, and 1122 m a.s.l. The data were recorded daily at 7, 14, and 21 h (T_{CH-7h}, T_{CH-14h}, and T_{CH-21h}) from 1 January 1961 to 31 December 2001.

The reference historical temperature records come from Hohenpeissenberg station in Germany (via the web page of Global Historical Climatology Network: http://cdiac.esd.ornl.gov/ghcn/ghcn.html), situated at 11.02° E, 47.8° N, and 977 m a.s.l. The data consist of monthly means (T_{HO-m}) from January 1781 to October 1990, with the exception of some missing data over the period 1971–1980. When investigating long term climatic trends it is important to avoid warming signals generated by increasing urbanisation. Thus, in this work we use air

Table 1. List of abbreviations and temperature symbols.

Abbreviation	Meaning
BF	The Bohemian Forest
CT Lake	Čertovo Lake
T_{AWS}	Air temperature at automatic weather station at CT Lake, 15-minute readings.
T_{CT-d}	Daily mean air temperature at CT Lake: arithmetical mean of all T_{AWS} per day.
T_{CH-7h}, T_{CH-14h}, T_{CH-21h}	Air temperature measured at Churáňov station at 7, 14, and 21 hour, respectively.
T_{HO-m}	Monthly mean air temperature at Hohenpeissenberg station
$T_{CT-CH-d}$	Daily mean air temperatures at CT Lake reconstructed from the Churáňov data (equation 1).
$T_{CT-CH-m}$	Monthly mean air temperatures at CT Lake: arithmetical mean of $T_{CT-CH-d}$.
$T_{CT-HO-m}$	Monthly mean air temperatures at CT Lake reconstructed from the Hohenpeissenberg data (equation 2).
T_{DJF}, T_{MAM}, T_{JJA}, T_{SON}	Seasonal mean air temperatures at CT Lake (December of previous year to February; March to May; June to August; September to November); arithmetical means of $T_{CT-HO-m}$ (before 1961) and $T_{CT-CH-m}$ (after 1961).
T_{CT-a}	Annual mean air temperatures at CT Lake: arithmetical mean of $T_{CT-HO-m}$ (before1961) and $T_{CT-CH-d}$ (after 1961).
T_{MAY}, T_{AUG}, T_{DEC}	Monthly mean air temperatures at CT Lake in May, August and December: $T_{CT-HO-m}$ (before1961) and $T_{CT-CH-m}$ (after 1961).

temperature data from the rural station at Hohenpeissenberg rather than those from the nearer station at Klementinum in Prague. The data from Hohenpeissenberg have been demonstrated to be robust and free of interference due to urbanisation or changes in instrumentation or position (SCHÖNWIESE 1987).

All temperature data throughout the text are in °C. All abbreviations used in this paper are explained in Table 1.

Modelling mean daily air temperature at Čertovo Lake in the 1961–2001 period

Mean daily air temperatures at CT Lake were reconstructed from the Churáňov data as follows. First, average daily air temperatures at CT Lake (T_{CT-d}) were obtained as an arithmetic mean of the 15-minute interval T_{AWS} data. Second, the T_{CT-d} data for the 1999–2001 period were divided into months and a separate equation (1) was derived for each month to achieve best fit with the Churáňov data:

$$T_{CT-d} = a + bT_{CH-7h} + cT_{CH-14h} + dT_{CH-21h} \quad (1)$$

The parameters *a*, *b*, *c*, and *d* are summarised in Table 2 for individual months. With the exception of d, these parameters display an annual periodicity such that the influence of the each parameter changes according to the time of year.

The monthly models are cross validated by removing one month at a time (e.g., January 1998), building the model with the remaining months (e.g., January 1999–2001), then using the model to predict the temperatures in the omitted month. This technique allows the predic-

Table 2. Constants *a*, *b*, *c*, and *d* of equation (1) used for modelling daily mean air temperature at Čertovo Lake from the Churáňov data.

Month	*a*	*b*	*c*	*d*
January	−0.92	0.57	−0.11	0.27
February	−0.58	0.40	−0.06	0.39
March	−0.53	0.38	−0.03	0.27
April	−0.47	0.27	0.11	0.26
May	0.73	0.38	0.19	0.27
June	1.22	0.43	0.11	0.32
July	1.82	0.39	0.14	0.30
August	1.57	0.43	0.16	0.28
September	0.99	0.46	0.17	0.29
October	1.08	0.49	0.16	0.19
November	−0.15	0.48	0.12	0.23
December	−0.44	0.52	0.03	0.29

tive accuracy of the models to be tested. The mean absolute errors of the cross validations (CVMAE) are averaged over all the months, indicating a predictive error of 0.81 °C for daily temperatures at CT Lake, with the best predictions in September (CVMAE = 0.56°C) and the worst in April (CVMAE = 1.45°C). As with all linear regression models the predictions will tend to underestimate extreme events and will not reproduce very localised effects.

To find the best models all the data are used (no data omitted for validation). The final models give an average daily error of 0.72°C for the mean daily air temperature at CT Lake. Fig. 1 shows an example of the model fit. This model was used to reconstruct CT mean daily air temperatures ($T_{CT(CH)\text{-}d}$) back to 1 January 1961.

Modelling mean monthly air temperature at Čertovo Lake from Hohenpeissenberg

To reconstruct the monthly air temperatures at CT Lake back to 1781 it is necessary to construct a linear regression model between CT Lake air temperatures and those at Hohenpeissenberg. To do this the reconstructed mean daily air temperatures at CT Lake were converted to monthly means ($T_{CT(CH)\text{-}m}$) and a linear regression model was found between these and the mean monthly air temperatures at Hohenpeissenberg station. There is a period of missing data from Hohenpeissenberg over 1971–1980 so the model is built over the periods 1961–1971 and 1980–1990. Because of the relatively small amount of data available (236 points), only one model was developed with no splitting into seasonal or monthly components.

The best fit between $T_{CT(CH)\text{-}m}$ and $T_{HO\text{-}m}$ was achieved with equation 2:

$$T_{CT(CH)\text{-}m} = -0.71 + 0.64\,T_{HO\text{-}m} - 1.48\sin\theta - 3.11\cos\theta \tag{2}$$

where θ (radians) is given by:

$$\theta = \frac{2\pi J}{365.25} \tag{3}$$

in which J is Julian day since 1 January 1960, and θ is the Julian day scaled so that one year is equivalent to 2π radians. The last 2 terms in equation (2) simply describe an annual cycle using the sum of scaled sine and cosine curves. This model has a mean fit error of 0.49°C each month. The coefficient of determination, R^2, is 0.84, which is calculated after the annual cy-

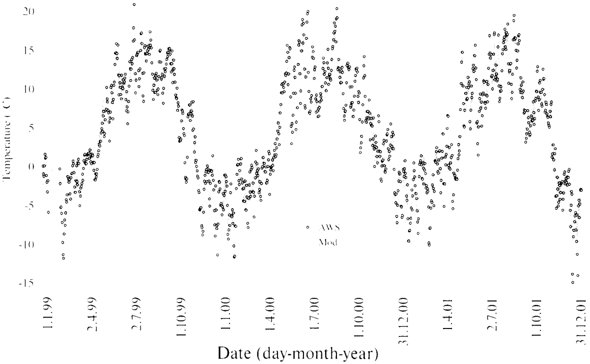

Fig. 1. Mean daily air temperature at Čertovo Lake. Dots are observed data at the automatic weather station at the lake; lines are modelled from Churáňov records.

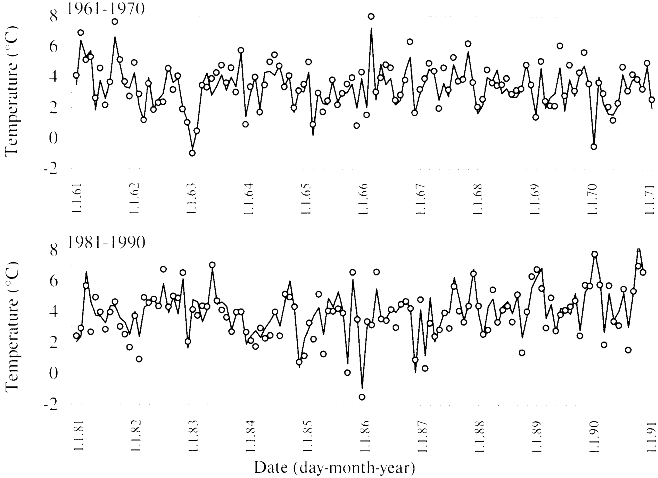

Fig. 2. Mean monthly temperatures at Čertovo Lake with the annual cycles removed. Circles are modelled from Churáňov records, lines are modelled from Hohenpeissenberg.

cles are removed from the data so that the real skill of the fit can be judged. The annual cycles are removed by fitting sin (θ) and cos (θ) curves to the temperature data using a linear regression model; e.g., an expression in the same form as the right hand side of equation (2) without the T_{HO-m} term, would describe the annual cycle of $T_{CT-CH-m}$. Fig. 2 shows the model fit between the reconstructions from Hohenpeissenberg and Churáňov ($T_{CT-HO-m}$ and $T_{CT-CH-m}$ respectively) with the annual cycle removed. By removing the annual cycle the excellent model fit between these data is clearly demonstrated. This model is also cross validated by removing one year of data at a time, building the model on the remaining years then predicting the data in the omitted year. The average CVMAE is 0.49°C. Thus we can predict the monthly mean temperature at CT Lake to within 0.5°C. Given its good predictive capability this model was then used to reconstruct the CT mean monthly air temperatures ($T_{CT-HO-m}$) back to January 1781 using the appropriate value for J (note that J is negative for dates prior to 1 January 1960).

A complete data set of the modelled mean monthly air temperatures is given in Appendix 1. These data were used to calculate mean seasonal air temperatures (T_{DJF}, December of previous year to February; T_{MAM}, March to May; T_{JJA}, June to August; and T_{SON}, September to November) as arithmetic means of $T_{CT-HO-m}$ and $T_{CT-CH-m}$ values before and after 1961, respectively.

Results and Discussion

Mean daily air temperature at Čertovo Lake in the 1961–2001 period

The $T_{CT-CH-d}$ values varied between –17.7 and 23.2°C in the 1961–2001 period, with an average of 3.78°C (Table 3). The difference between the maximum and minimum values in the individual months was relatively stable (~20°C) which suggests comparable variation in daily air temperatures throughout the year.

As the model for daily air temperatures is built on a relatively short time span (~4 years), reconstructions back to 1961 may not be accurate if there is some change in the relationship between these two sites over time. This could possibly occur if there is a change in large-scale circulation patterns. Northwest European winter climate is regulated by large-scale atmospheric circulation, characterised by the NAO index (the North Atlantic Oscillation; Rodwell et al. 1999). The NAO is the difference between the surface pressure at Azore Islands and Iceland (Hurrell 1995). The model is built on data from a period when the NAO index is generally in its high phase (1997/8: +0.80; 1998/9: +0.98; 1999/2000: +1.85; 2000/1: –0.50). However, in winter 2000/1 where the index is slightly negative the cross validation errors are no larger than for the other winters, indicating that the NAO is not an obvious source of error.

Mean monthly air temperature at Čertovo Lake in the 1781–2001 period

In the 1781–2001 period, mean monthly air temperatures at CT Lake varied between –12.0°C (February 1956) and 16.2°C (July 1994), with average values between –5.3°C and 12.3°C in January and July–August, respectively (Table 4). The difference between the maximum and minimum values in the individual months is inversely related to the average temperature, being lowest during summer months (6.2–6.4°C in June to August) and highest in winter (9.7–11.8°C in December to February). This pattern is due to a higher variability in winter than summer data during the study period. This variability was further tested as the difference between seasonal air temperatures and their 1781–2001 averages (Fig. 3). These differences ranged between –3.2 and 3.0°C for T_{DJF} and between –1.8 and 2.4°C for T_{JJA}. While the T_{MAM} and T_{SON} values had relatively uniform distribution throughout the study period (except in-

Table 3. Distribution of mean daily air temperatures at Čerovo Lake reconstructed from Churáňov data (1 January 1961 to 31 December 2001). AVG, arithmetical average; SD, standard deviation; 25% and 75%, quartiles.

	All data	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
AVG	3.8	−4.6	−4.0	−1.9	1.3	7.7	10.6	12.5	12.5	9.3	5.2	−0.4	−3.4
SD	7.2	3.6	3.5	2.8	2.9	3.7	3.6	3.3	3.3	3.4	3.6	3.7	3.9
Minimum	−17.7	−17.7	−15.7	−13.5	−6.0	3.6	0.9	4.2	4.8	1.1	−6.4	10.5	−17.2
25%	−2.0	−6.5	−6.4	−3.7	−0.9	5.1	7.9	10.0	10.2	6.7	2.4	−2.8	−5.8
Median	3.4	−4.0	−3.5	−1.7	1.0	7.6	10.4	12.5	12.5	9.1	5.4	−0.4	−3.2
75%	9.8	−2.1	−1.4	0.1	3.3	10.3	13.2	14.9	14.9	11.9	8.0	2.1	−0.6
Maximum	23.2	3.7	4.3	5.9	9.5	18.2	20.4	23.2	22.8	20.4	14.3	10.4	6.7

Table 4. Distribution of mean annual and monthly air temperatures at Čerovo Lake reconstructed from Hohenpeissenberg and Churáňov data (1781 to 2001). AVG, arithmetical average; SD, standard deviation; 25% and 75%, quartiles.

	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
AVG	3.39	−5.3	−4.6	−2.2	1.9	6.9	10.2	12.3	12.0	9.1	4.6	−0.5	−3.8
SD	0.55	1.8	1.9	1.5	1.3	1.4	1.1	1.1	1.0	1.2	1.4	1.4	1.7
Minimum	2.11	−9.8	−12.0	−6.8	−1.6	3.7	7.4	9.9	9.7	5.0	0.7	−4.2	−10.0
25%	2.99	−6.6	−5.7	−3.3	1.0	5.9	9.5	11.4	11.4	8.3	3.8	−1.5	−5.0
Median	3.40	−5.1	−4.4	−2.1	1.8	7.0	10.2	12.2	11.9	9.1	4.7	−0.4	3.8
75%	3.80	−3.9	−3.3	−1.2	2.8	7.9	10.9	13.0	12.6	9.7	5.4	0.4	−2.6
Maximum	5.08	−0.1	−0.2	1.0	6.5	10.2	13.6	16.2	16.1	13.0	8.6	3.0	−0.3

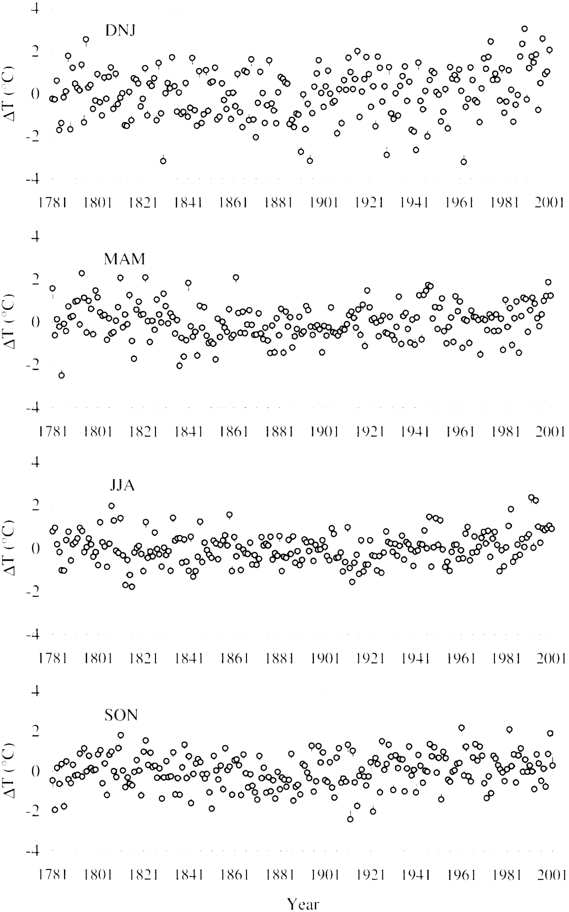

Fig. 3. The differences between mean seasonal air temperatures and their 1781–2001 averages. DJF, December to February; MAM, March to May; JJA, June to August; SON, September to November. The 1781–2001 averages of T_{DJF}, T_{MAM}, T_{JJA}, and T_{SON} were –4.6, 2.2, 11.5, and 4.4°C, respectively.

creasing T_{MAM} values in the 1981–2001 period), winter and summer temperatures exhibited the following trends. The T_{DJF} values were mostly lower than the 1781–2001 average in the 1810s, 1880s and 1890s and higher between 1971 and 2001. The cold summer periods were in the 1810s and 1900–1930, while warmer summers were typical for the last four decades, when most T_{JJA} values were higher than their long-term average (Fig. 3).

Reconstructed trend in mean annual air temperature at Čertovo Lake

Mean annual air temperatures ($T_{CT\text{-}a}$) were calculated as arithmetic averages from the $T_{CT(HO)\text{-}m}$ and $T_{CT(CH)\text{-}d}$ data before and after 1961, respectively. In the 1781–2001 period, the $T_{CT\text{-}a}$ values varied between 2.1°C (in 1829) and 5.1°C (in 2000), with the average of 3.4°C (Appendix 1, Table 4).

The long-term trend in $T_{CT\text{-}a}$ exhibited significant variations. These are demonstrated in Fig. 4 by 10-year averages (calculated for each decade), a 5-year running average, and a 5-order polynomial trend line. Between 1781 and 1831, the $T_{CT\text{-}a}$ values fluctuated along their long-term averages in periods lasting roughly a decade, being lower than the long-term average in 1780s and 1810s and higher in the 1790s and 1800s. The 1830–1940 period was relatively cold with all 10-year averages below the long-term average (Fig. 4) and with the coldest decade

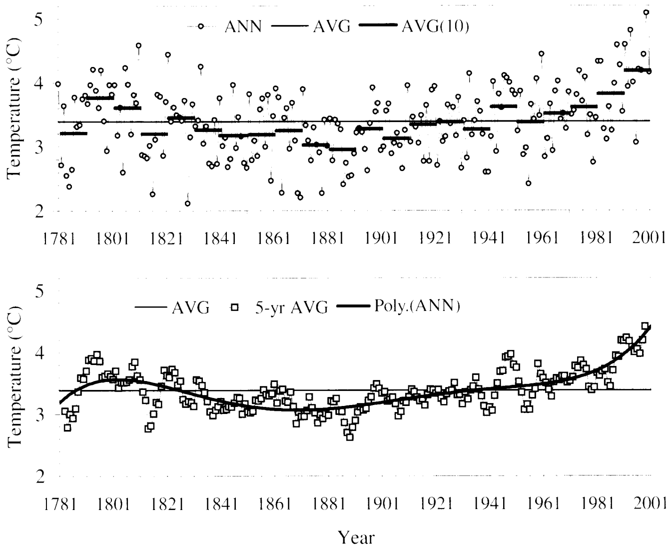

Fig. 4. The reconstructed trend in mean annual air temperature at Čertovo Lake ($T_{CT\text{-}a}$). ANN: individual $T_{CT\text{-}a}$ values; AVG: average $T_{CT\text{-}a}$ for the 1781–2001 period; AVG(10): average $T_{CT\text{-}a}$ for decades; Poly.(ANN): 5-order polynomical trend line calculated for $T_{CT\text{-}a}$ ($r = 0.48$); 5-yr AVG: five-year running average of $T_{CT\text{-}a}$.

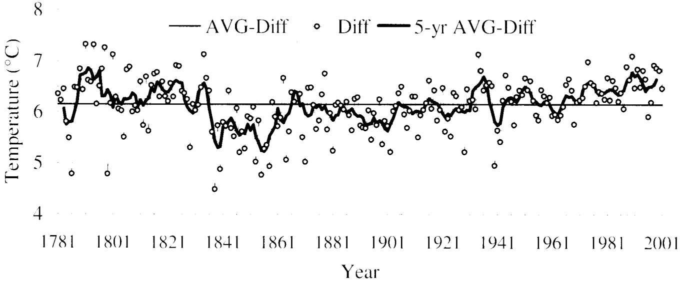

Fig. 5. The difference between mean annual air temperature at Klementinum in Prague (data of Czech Hydrometeorological Institute) and the reconstructed mean annual air temperature at Čertovo Lake. AVG-Diff: average difference (6.2°C) for the 1781–2001 period; Diff: annual difference; 5-yr AVG-Diff: five-year running average of annual differences.

over the study period in the 1880s (3.0°C). In the 1940s there is a significant peak in the $T_{CT\text{-}a}$ values (see the 5-year running average in lower part of Fig. 4), which was followed by a steep temperature decline in the middle 1950s. Since the early 1960s, the $T_{CT\text{-}a}$ values have an increasing trend, with rapidly increasing 10-year averages toward the maximum in the 1990s (4.2°C).

Mean annual air temperatures increased by 0.02 °C yr^{-1} between 1961 and 2001. This pattern was associated with increasing T_{DNJ}, T_{MAM} and T_{JJA}, while mean autumn air temperatures did not exhibit any trend (Fig. 3, Table 5). Trend analysis of mean monthly data showed that only mean May, August and December air temperatures (T_{MAY}, T_{AUG} and T_{DEC}) exhibited increasing trends over the 1961–2001 period (Table 5). Consequently, the trends in mean seasonal temperatures are predominantly associated with the increasing trends in these three months.

The trend exhibited the steepest increase in the last two decades (0.05 °C yr^{-1}), with the minimum and maximum value of 2.8°C and 5.1°C in 1980 and 2000, respectively (Fig. 4). All significant trends in the 1980–2001 period were approximately twice as large as those in the 1961–2001 period (Table 5). This substantially higher temperature increase during the last two decades concurs with the warming trend in central Europe (Brázdil et al. 1996). However, even more rapid change in the $T_{CT\text{-}a}$ values occurred two hundred years ago, when mean annual air temperature increased from 2.4 to 4.2°C between 1785 and 1794 (Fig. 4). This suggests that even the current temperature increase could be associated with a natural temperature variation. However, unlike the temperature increase in 1785–1794, which appears as an oscillation around the long-term average, the recent increase in temperature begins at a temperature already higher than the long-term average.

The steepest increase in mean seasonal air temperatures over the last four decades occurred in winter (Table 5). The winter NAO index and air temperature are strongly correlated such that mild winters are associated with high NAO indices and cold winters with low NAO indices (Rodwell et al. 1999, Jones et al. 2001). Veselý et al. (2003) have shown that mean monthly air temperatures at Churáňov and six other Czech meteorological stations correlated with the NAO between October and March, with the best fit in the December to February period. Thus the recent increase in T_{DNJ} values in the BF may be associated with the increasing winter NAO indices and related to the global surface warming (Jones et al. 2001).

Table 5. Parameters of linear regression ($Y = aX + b$) between time (X, years Anno Domini) and air temperature at Čertovo Lake in the 1961–2001 and 1980–2001 periods. For explanation of temperature symbols see Table 1. Correlation coefficient of linear regression, r. Significance level: $P<0.05$ (*), $P<0.01$ (**), $P<0.001$ (***).

	1961–2001			1980–2001		
Y	a	b	r	a	b	r
T_{CT-a}	0.021	–37	0.46**	0.048	–91	0.50*
T_{DH}	0.039	–82	0.38*	0.076	–154	0.40
T_{MAM}	0.028	–54	0.43**	0.070	–136	0.51*
T_{JJA}	0.024	–35	0.38*	0.055	–97	0.43*
T_{SON}	–0.004	13	0.06	–0.003	11	0.02
T_{MAY}	0.054	–99	0.45**	0.114	–218	0.47*
T_{MG}	0.048	–83	0.51***	0.080	–147	0.50*
T_{DEC}	0.038	–79	0.27	–0.013	21	0.05

The reconstructed T_{CT-a} values were compared also with mean annual air temperature at Klementinum in Prague (data of the Czech Hydrometeorological Institute). The differences between the Klementinum and T_{CT-a} values varied between 4.5 and 7.5°C with the 1781–2001 average of 6.2°C (Fig. 5). Compared to the Klementinum trend, the T_{CT-a} data seemed to be less varied. Relatively large differences occurred during the (i) 1790–1835 period, when the difference between the Klementinum and T_{CT-a} values was on average 0.25°C higher than the long term average and (ii) 1835–1865 period, when the difference was on average 0.54°C lower than the long term average. The trends were reasonably comparable between the 1860s and 1960s with the mean of 6.1±0.4°C (± standard deviation). Since the 1960s the Klementinum trend has increased more steeply than T_{CT-a} trend probably because of warming caused by increased urbanisation in Prague. The similarity between the trends in air temperature at Prague and CT Lake suggests that our reconstructed mean annual air temperatures at CT Lake are reliable between 1860 and 2001.

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Appendix 1. Mean annual ($T_{ChHO,a}$ and $T_{ChCH,a}$) and mean monthly ($T_{ChHO,m}$ and $T_{ChCH,m}$) air temperatures at Čertovo Lake (°C), modelled from the Hohenpeissenberg (1781–1960) and Churáňov (1961–2001) records. For abbreviations see Table 1.

Part (1 of 6)

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1781	3.98	−5.2	−4.5	−1.4	4.3	8.3	11.1	12.5	13.3	9.6	2.9	−0.7	−2.4
1782	2.71	−4.6	−7.5	−2.9	1.1	6.5	11.9	13.6	11.8	8.5	2.4	−3.6	−4.7
1783	3.63	−3.5	−3.7	−3.2	2.7	7.4	10.2	13.0	11.8	9.3	5.3	−1.0	−4.7
1784	2.55	−7.4	−6.8	−2.8	0.1	8.7	10.3	12.3	11.3	10.7	1.5	−1.0	−6.2
1785	2.38	−3.6	−8.0	−6.8	−0.5	6.3	9.3	11.1	11.0	10.6	3.9	−0.3	−4.4
1786	2.64	−4.1	−5.8	−3.3	3.3	6.3	10.8	10.2	10.4	7.6	2.3	−2.1	−3.8
1787	3.77	−6.2	−3.4	−0.9	1.1	5.0	10.9	11.8	12.9	9.3	6.0	−0.6	−0.7
1788	3.31	−5.2	−2.5	−1.5	2.3	7.9	11.4	13.9	11.5	10.2	3.6	−1.9	−10.0
1789	3.34	−4.6	−4.2	−5.1	3.5	8.9	8.9	12.1	11.8	8.6	4.2	−1.5	−2.4
1790	3.74	−4.4	−3.3	−1.9	1.1	8.1	11.1	11.3	12.6	8.5	5.5	0.1	−3.9
1791	3.80	−3.4	−5.0	−1.7	4.4	6.6	10.2	12.1	13.1	8.6	4.7	−0.8	−3.2
1792	3.67	−4.6	−5.2	−0.5	3.7	6.3	10.7	12.5	12.7	7.8	5.2	−0.4	−4.2
1793	3.96	−5.7	−3.3	−1.4	1.4	6.2	9.7	14.0	13.6	8.5	6.4	0.9	−2.7
1794	4.21	−5.0	−1.9	0.9	5.2	7.4	10.9	14.4	11.5	7.6	4.2	0.5	−5.1
1795	3.88	−8.6	−4.1	−1.9	4.5	7.4	10.9	10.4	12.6	10.4	7.9	−1.7	−1.3
1796	3.60	−0.1	−4.7	−3.7	1.6	7.3	10.3	12.5	11.8	10.7	3.7	−1.3	−4.8
1797	4.19	−4.9	−3.2	−3.0	3.6	9.0	9.2	13.6	13.1	9.6	4.6	1.3	−2.5
1798	3.39	−5.6	−4.4	−2.2	2.9	7.6	10.7	12.1	12.2	9.8	4.7	−0.9	−6.4
1799	2.93	−6.3	−3.2	−2.5	1.1	6.2	9.2	11.4	12.7	8.9	4.4	−0.1	−6.7
1800	3.96	−3.1	−4.9	−3.9	6.5	8.4	8.7	12.3	12.9	9.3	3.9	0.2	−2.7
1801	3.81	−3.8	−4.5	−1.0	2.8	8.2	9.0	11.8	11.3	9.4	5.4	0.9	−3.9
1802	3.96	−6.9	−4.2	−1.8	2.8	6.9	11.7	11.9	14.4	9.3	7.2	−0.2	−3.7
1803	3.17	−6.4	−6.8	−2.3	4.4	5.3	9.7	13.0	12.6	7.5	3.8	0.1	−2.9
1804	3.61	−1.8	−6.8	−2.5	2.0	8.0	10.7	12.1	11.9	9.9	5.2	−0.8	−4.7
1805	2.59	−5.3	−4.5	−2.9	1.0	5.9	9.6	11.3	11.0	9.4	2.8	−2.6	−4.6
1806	4.23	−3.7	−3.1	−1.9	0.2	8.8	10.6	12.5	12.1	9.3	4.7	1.6	−0.3
1807	3.97	−6.3	−3.5	−4.7	1.5	8.1	10.6	14.6	15.2	8.3	6.6	1.2	−4.0
1808	3.19	−5.8	−6.1	−5.2	1.5	8.8	10.4	14.3	13.6	9.7	3.2	0.3	−6.4
1809	3.81	−3.0	−1.5	−1.4	−0.1	8.2	10.3	12.7	11.2	9.2	4.1	−1.1	−3.0
1810	3.68	−6.0	−6.2	−0.4	1.9	7.2	9.6	12.3	11.9	11.2	4.4	1.1	−2.7
1811	4.58	−7.7	−4.0	−0.4	3.5	9.7	12.8	13.6	12.2	9.6	8.0	1.0	−3.3
1812	2.87	−6.7	−3.6	−2.0	−0.1	7.8	10.6	11.4	11.5	8.6	6.3	−1.6	−7.9
1813	2.85	−7.3	−3.0	−2.9	3.2	7.4	8.8	10.5	10.1	7.8	4.5	−1.5	−3.2
1814	2.82	−6.2	−8.9	−3.0	3.7	5.6	8.9	12.6	11.4	7.3	4.1	0.8	−2.4
1815	3.01	−8.6	−2.5	−0.2	2.9	7.7	9.5	10.4	10.8	8.8	4.9	−2.4	−5.1
1816	2.26	−6.1	−6.3	−3.3	1.9	5.3	8.5	10.4	10.2	8.0	4.9	−1.9	−4.6
1817	3.11	−3.3	−3.6	−3.5	−1.6	6.5	11.2	11.3	11.4	10.5	1.7	0.9	−4.1
1818	3.81	−3.9	−3.8	−2.1	3.9	6.5	11.2	12.5	10.9	9.1	4.7	1.1	−4.3
1819	3.78	−3.8	−4.3	−1.8	3.4	7.8	10.4	12.6	11.8	9.7	4.4	−0.8	−4.1

Appendix 1. Part (2 of 6)

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1820	2.85	-7.4	-4.0	-3.5	3.5	7.6	8.6	11.6	13.5	7.4	3.7	-1.7	-5.1
1821	3.70	-4.1	-5.2	-1.9	3.7	5.8	8.2	10.8	12.3	9.3	4.4	2.4	-1.3
1822	4.44	-5.9	-3.0	1.0	3.1	8.7	13.6	12.8	11.7	8.8	6.6	2.4	-6.6
1823	3.39	-6.3	-3.9	-2.6	1.3	8.0	9.4	11.2	12.6	9.8	4.7	-0.4	-3.1
1824	3.61	-6.1	-3.1	-3.4	0.8	6.4	9.6	12.7	11.7	10.1	4.8	1.1	-1.2
1825	3.49	-5.9	-5.6	-3.9	3.5	7.1	9.6	11.9	11.8	9.4	4.3	0.2	-0.5
1826	3.48	-8.3	-2.7	-1.4	1.7	5.2	9.8	12.9	14.0	10.3	5.5	-1.7	-3.5
1827	3.42	-7.1	-6.8	-1.6	3.0	8.3	9.9	13.5	11.0	9.5	5.7	-2.9	-1.4
1828	3.73	-3.1	-4.8	-2.1	2.3	7.4	10.5	12.4	10.8	9.1	3.8	0.8	-2.3
1829	2.14	-7.5	-6.7	-2.5	2.4	6.5	9.1	12.3	10.6	8.0	3.3	-2.2	-7.8
1830	3.16	-9.1	-6.3	-0.9	3.8	7.7	10.1	12.7	11.8	7.4	4.0	0.9	-4.2
1831	3.68	-5.8	-3.6	-1.6	3.7	6.6	9.4	12.2	12.0	8.0	7.7	-0.9	-3.6
1832	3.33	-4.4	-4.3	-2.1	2.5	5.9	9.3	11.8	13.0	8.7	4.4	-0.7	-4.2
1833	3.43	-6.2	-2.5	-2.4	0.7	9.5	11.4	10.3	9.8	7.8	4.9	-0.3	-1.9
1834	4.27	-2.4	-4.3	-2.6	0.7	9.2	11.9	14.1	12.7	11.4	4.7	0.0	-4.2
1835	3.07	-4.2	-4.2	-3.2	1.1	7.0	10.4	13.6	11.6	9.3	3.1	-2.7	-5.1
1836	3.34	-5.8	-5.4	0.6	1.2	5.0	10.8	12.7	12.3	8.1	5.1	-0.9	-3.8
1837	2.76	-5.1	-4.6	-4.7	0.5	4.7	11.0	11.2	13.7	7.3	3.9	-1.5	-3.3
1838	2.71	-7.6	-5.7	-2.6	-0.1	7.0	9.9	11.7	10.9	9.4	4.0	0.5	-4.9
1839	3.43	-6.7	-4.6	-3.7	-0.4	5.9	12.2	13.0	10.6	9.5	5.8	1.9	-2.2
1840	2.75	-4.4	-5.7	-5.4	3.0	6.5	10.2	10.7	11.8	8.5	2.6	1.1	-5.9
1841	3.77	-6.3	-4.8	-0.2	2.6	9.6	9.0	10.9	11.5	10.0	5.5	0.1	-2.8
1842	3.03	-8.5	-4.4	-2.1	1.3	6.8	11.0	11.8	13.3	8.4	2.0	-1.8	-1.3
1843	3.16	-5.1	-2.4	-2.7	1.8	5.4	8.1	10.7	11.8	8.5	4.5	0.0	-2.7
1844	2.70	-7.2	-6.2	-3.5	3.0	5.6	10.9	10.7	9.8	9.3	4.8	0.3	-5.2
1845	2.83	-4.0	-9.1	-4.9	2.4	4.4	10.8	12.3	10.2	8.9	4.9	1.3	-3.4
1846	3.98	-3.9	-3.2	-0.9	2.2	7.5	12.1	13.4	12.7	9.8	5.2	-0.4	-6.8
1847	3.00	-4.3	-6.8	-3.0	-0.3	9.1	8.2	12.5	12.0	7.2	4.5	1.1	-4.2
1848	3.48	-9.4	-3.0	-1.7	3.4	7.0	11.1	12.2	11.9	8.6	5.1	-1.5	-2.0
1849	3.18	-4.6	-3.8	-3.5	1.0	7.1	11.2	12.2	10.9	8.8	5.1	-1.0	-5.3
1850	2.77	-8.0	-2.9	-3.9	1.9	5.6	10.3	11.6	11.8	7.4	2.5	0.2	-3.3
1851	2.69	-3.8	-5.0	-3.1	2.8	4.2	10.4	11.2	11.6	6.5	5.2	-4.1	-3.6
1852	3.83	-3.1	-5.2	-4.0	0.5	7.1	10.5	13.1	11.9	8.5	4.0	3.1	-0.3
1853	2.81	-2.8	-6.9	-4.9	0.3	6.0	9.8	13.0	12.4	8.8	5.6	-1.0	-6.5
1854	3.11	-3.8	-7.0	-2.7	2.6	7.1	9.4	12.3	11.3	9.0	5.3	-2.2	-4.0
1855	2.87	-7.8	-5.2	-2.7	1.0	6.1	10.2	12.1	12.7	9.0	6.8	-1.7	-6.1
1856	3.60	-3.0	-3.1	-3.0	3.7	5.9	11.3	11.1	13.2	8.2	5.9	-3.5	-3.5
1857	3.76	-6.7	-4.4	-2.9	1.6	7.1	10.3	13.5	12.5	10.2	6.3	0.3	-2.5
1858	3.01	-6.9	-6.5	-3.1	2.9	5.4	12.6	11.3	10.9	10.6	5.2	-2.4	-4.0
1859	3.82	-5.4	-4.2	-0.5	2.4	6.4	10.6	15.0	13.6	9.0	5.8	-0.9	-5.9
1860	2.49	-3.5	-7.9	-4.0	1.2	7.1	10.1	10.0	11.2	8.5	3.8	-2.6	-4.2
1861	3.49	-7.1	-2.2	-2.0	0.8	5.9	10.8	12.0	13.3	8.8	5.9	0.2	-4.5

Appendix 1. Part (3 of 6)

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1862	3.92	−5.8	−5.2	0.7	3.8	8.3	9.4	12.6	11.4	9.5	5.9	−0.3	−3.3
1863	3.78	−3.3	−4.3	−2.2	2.5	7.5	9.9	11.4	13.4	8.4	6.0	−0.2	−3.6
1864	2.30	−7.5	−5.2	−1.6	0.4	6.2	9.5	11.3	10.7	8.4	3.1	−1.8	−6.0
1865	3.47	−4.9	−7.6	−6.2	5.0	9.2	9.4	13.6	11.3	10.5	4.9	0.4	−4.1
1866	3.61	−3.0	−3.4	−2.7	3.0	4.7	11.2	11.6	11.1	9.8	4.3	−1.1	−2.0
1867	2.98	−5.8	−2.8	−2.7	2.0	6.9	9.9	11.2	12.6	9.5	3.5	−2.2	−6.4
1868	3.70	−7.2	−3.8	−3.5	1.4	10.2	10.9	12.1	12.3	10.9	4.2	−2.3	−0.9
1869	3.11	−6.6	−1.4	−5.0	3.3	7.8	8.0	13.5	10.7	10.0	2.3	−1.2	−4.2
1870	2.30	−6.5	−6.6	−4.4	1.3	7.8	10.1	13.4	10.2	7.4	3.7	−1.1	−7.7
1871	2.23	−8.3	−3.8	−1.7	1.6	4.9	7.8	12.5	12.0	10.2	2.4	−3.6	−7.2
1872	3.91	−4.3	−3.5	−1.2	2.5	6.4	9.7	12.5	10.9	9.6	5.3	0.7	−1.7
1873	3.35	−3.5	−5.5	−0.7	1.3	4.4	10.0	13.4	12.7	8.0	5.1	−0.9	−4.1
1874	3.11	−4.4	−5.2	−2.8	2.9	4.1	10.5	13.9	10.5	10.3	5.7	−2.2	−6.0
1875	2.80	−4.0	−7.9	−4.1	2.0	7.9	10.8	11.4	12.9	9.0	2.8	−1.8	−5.6
1876	3.30	−5.8	−4.0	−2.1	2.3	3.7	10.0	12.5	12.4	7.9	5.9	−1.5	−1.7
1877	3.02	−3.3	−4.1	−3.4	1.0	4.6	11.9	11.4	12.7	6.8	2.9	0.4	−4.7
1878	2.91	−6.6	−3.9	−3.4	2.1	7.3	9.9	11.3	11.7	8.7	4.7	−1.6	−5.5
1879	2.27	−5.8	−4.8	−2.7	1.1	3.9	10.4	10.4	13.0	9.2	2.9	−3.1	−7.3
1880	3.41	−7.6	−3.1	−0.8	2.5	5.3	9.3	13.0	11.1	9.3	4.2	−0.4	−1.9
1881	3.01	−7.9	−3.8	−1.9	0.7	5.8	9.9	13.9	12.4	7.9	1.2	1.3	−3.6
1882	3.44	−3.7	−4.2	−0.1	1.8	6.7	9.1	11.8	10.4	7.9	5.0	−0.7	−2.8
1883	2.78	−5.1	−3.8	−5.7	1.1	6.8	9.9	11.7	11.7	8.7	3.6	−0.4	−5.2
1884	3.42	−3.7	−3.3	−0.9	1.4	7.5	7.8	13.0	12.3	9.6	3.0	−1.8	−4.0
1885	3.35	−6.2	−2.1	−2.9	3.5	5.3	11.4	12.6	11.6	9.0	3.3	−0.5	−4.8
1886	3.27	−6.1	−7.1	−3.4	3.3	7.2	9.0	12.7	12.0	10.7	5.4	−0.2	−4.3
1887	2.41	−6.6	−6.6	−3.6	1.9	4.7	10.6	13.7	11.7	8.3	1.3	−0.8	−5.7
1888	2.74	−6.6	−6.2	−3.3	0.6	7.3	10.7	10.7	11.1	8.8	2.6	−0.6	−2.1
1889	2.53	−6.8	−7.6	−4.1	1.2	8.5	11.2	11.7	11.2	7.2	4.2	−0.3	−6.0
1890	2.55	−3.1	−7.6	−1.9	1.6	7.6	9.1	11.1	11.9	8.3	3.1	−1.7	−7.8
1891	2.88	−8.5	−5.7	−2.4	0.2	7.1	10.3	11.5	11.0	9.6	5.7	−1.0	−3.2
1892	3.22	−6.6	−4.1	−3.7	2.2	6.8	10.2	11.8	13.7	9.7	4.0	0.3	−5.6
1893	3.28	−9.3	−3.9	−1.5	4.1	6.2	10.4	12.3	12.6	9.0	5.7	−1.8	−4.5
1894	3.22	−5.9	−4.8	−1.6	3.9	6.0	9.5	12.8	11.8	7.8	4.2	0.2	−5.0
1895	2.96	−8.3	−9.9	−3.1	2.7	6.2	10.2	13.2	12.1	11.7	4.0	1.3	−4.6
1896	2.63	−6.6	−5.4	−0.5	0.2	5.0	10.3	12.3	10.1	8.5	4.1	−2.6	−4.0
1897	3.36	−5.8	−3.0	−0.8	1.7	4.9	11.2	11.9	11.9	8.0	3.7	0.0	−3.4
1898	3.92	−2.2	−5.2	−2.5	2.4	6.2	9.6	11.0	13.6	10.1	5.7	1.2	−2.8
1899	3.54	−3.5	−2.7	−1.8	1.6	5.7	9.8	11.8	12.7	8.5	5.1	0.8	−5.7
1900	3.67	−4.9	−3.1	−4.4	1.2	5.5	10.8	13.3	11.6	10.5	5.0	0.5	−1.9
1901	2.94	−5.8	−8.0	−3.0	2.0	7.0	10.6	12.6	11.6	9.5	4.4	−2.2	−3.5
1902	2.99	−4.0	−5.3	−2.2	3.1	3.7	9.3	12.4	11.7	8.6	3.8	−0.9	−4.3
1903	3.55	−4.0	−2.2	−0.5	−0.5	6.9	9.5	11.4	11.9	9.4	5.7	−0.6	−4.3

Appendix 1. Part (4 of 6)

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1904	3.67	−4.7	−4.7	−1.9	3.2	7.3	10.7	14.1	12.5	7.4	4.3	−1.0	−3.1
1905	2.89	−6.7	−5.3	−1.5	1.1	5.5	10.8	13.9	11.8	9.1	0.7	−0.6	−4.1
1906	3.05	−4.9	−5.8	−3.2	1.7	6.5	8.9	12.1	12.2	7.9	6.3	1.0	−6.0
1907	3.20	−6.4	−7.0	−3.5	0.4	7.8	10.0	10.8	12.5	9.6	6.5	0.5	−2.7
1908	3.01	−5.1	−5.3	−2.9	0.2	7.9	11.4	11.8	10.7	8.0	4.9	−1.5	−3.9
1909	2.66	−6.7	−7.4	−2.9	2.8	5.7	9.1	10.5	11.7	8.5	5.8	−2.2	−3.0
1910	3.25	−4.9	−4.0	−1.8	1.4	5.8	10.3	10.8	11.5	7.4	5.3	−1.1	−1.8
1911	3.95	−6.6	−4.9	−1.6	1.4	6.5	9.6	14.0	13.8	10.5	5.1	1.5	−1.9
1912	3.07	−4.9	−2.0	−0.4	0.9	7.0	10.2	11.7	9.8	5.0	3.3	−2.4	−1.5
1913	3.46	−4.4	−4.8	0.0	1.7	6.3	9.1	9.9	10.8	8.4	6.4	1.5	−3.4
1914	3.30	−8.0	−1.8	−1.7	3.6	5.2	9.0	11.2	12.3	8.2	4.1	−0.9	−1.8
1915	3.05	−5.7	−4.2	−3.3	1.3	7.7	11.4	11.5	10.7	7.4	2.5	−2.0	−0.7
1916	3.48	−2.9	−4.2	−1.1	2.1	7.3	8.3	11.3	11.3	7.7	4.7	0.1	−2.8
1917	2.76	−7.6	−6.7	−3.7	−0.5	8.9	11.8	12.1	11.7	10.7	3.1	−0.4	−6.2
1918	3.64	−3.5	−3.7	−1.3	2.7	7.6	8.1	11.8	11.4	9.4	3.5	−0.5	−1.7
1919	2.77	−4.9	−5.1	−2.1	−0.2	5.5	9.9	9.9	12.5	10.6	2.1	−1.7	−3.1
1920	3.88	−3.0	−2.5	0.0	2.8	8.2	9.3	12.2	10.7	8.9	3.8	−0.3	−3.5
1921	3.93	−2.6	−4.9	−0.2	1.2	7.7	9.4	13.9	12.3	9.7	6.8	−2.0	−4.0
1922	2.71	−6.4	−5.3	−1.5	0.6	7.7	10.5	11.3	11.8	7.2	2.1	−2.2	−3.3
1923	3.39	−5.8	−3.7	−1.6	1.7	7.0	7.4	13.6	12.4	9.2	6.3	−0.4	−5.5
1924	3.08	−5.5	−7.4	−2.7	1.6	7.6	9.7	11.9	9.8	9.3	5.1	−0.1	−2.3
1925	3.15	−3.3	−3.0	−4.6	2.2	6.9	9.9	11.9	11.6	7.1	4.8	−2.0	−3.8
1926	3.65	−5.2	−1.1	−2.2	3.3	5.6	8.2	11.2	11.7	10.5	4.8	2.4	−5.4
1927	3.35	−4.8	−4.7	−1.0	1.7	6.7	10.2	12.1	11.6	9.1	4.2	0.1	−4.9
1928	3.61	−3.9	−3.9	−2.0	2.3	4.8	10.1	14.3	12.5	8.6	5.1	0.7	−5.1
1929	3.16	−7.9	−9.4	−2.0	−0.1	6.9	10.1	12.8	12.4	10.9	5.3	0.9	−2.1
1930	3.76	−2.2	−5.8	−1.2	2.4	6.0	12.2	11.4	11.5	9.3	4.6	1.5	−4.7
1931	2.66	−5.6	−6.3	−4.4	0.8	8.4	11.5	11.7	10.8	5.9	3.8	0.7	−5.2
1932	3.40	−3.8	−8.4	−3.6	1.3	6.4	9.5	12.1	13.6	10.9	4.3	0.3	−1.7
1933	2.81	−6.6	−5.4	−1.0	1.7	5.2	8.3	12.7	12.5	9.5	5.0	−0.8	−7.1
1934	4.14	−4.9	−4.9	−1.8	4.1	7.8	10.2	13.1	11.5	10.6	4.7	−0.3	−0.5
1935	3.18	−7.3	−4.8	−3.0	1.1	5.4	11.6	13.0	11.7	9.9	4.2	0.9	−4.4
1936	3.40	−2.6	−4.3	−0.7	1.7	6.4	9.8	11.6	11.6	8.7	1.8	−0.4	−2.6
1937	3.70	−3.8	−3.5	−2.2	1.7	8.3	10.9	12.5	11.9	8.9	5.5	−0.8	−5.1
1938	3.55	−4.9	−4.8	0.7	−0.7	5.6	11.3	11.9	11.8	9.7	4.7	2.6	−5.2
1939	3.19	−3.6	−3.3	−4.3	3.4	4.5	10.4	11.9	12.1	8.3	3.1	1.2	−5.4
1940	2.60	−8.9	−4.7	−2.2	2.7	6.4	10.0	11.5	10.6	8.9	4.1	0.3	−7.6
1941	2.59	−7.2	−4.4	−1.5	0.7	4.2	10.7	12.5	10.9	8.2	3.2	−1.4	−4.7
1942	3.15	−9.1	−8.0	−1.2	1.5	6.9	10.0	11.8	12.4	10.9	7.1	−2.3	−2.2
1943	4.01	−4.1	−3.1	0.2	3.1	7.0	9.1	12.6	13.5	9.7	6.1	−1.8	−4.0
1944	2.92	−3.8	−6.9	−5.0	2.9	6.2	9.2	11.8	14.0	8.6	3.7	−0.8	−4.8
1945	3.82	−8.5	−2.7	−0.8	2.8	8.4	12.2	13.0	11.7	9.4	5.1	−1.2	−3.6

Appendix 1. Part (5 of 6)

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1946	3.60	−5.6	−4.1	−1.2	4.4	7.7	9.7	13.0	11.8	10.0	3.5	−0.4	−5.6
1947	4.11	−7.8	−6.4	−0.8	4.3	8.3	11.6	13.7	13.6	11.9	4.8	0.6	−4.4
1948	4.07	−2.5	−5.0	0.5	3.3	7.8	9.7	10.7	11.6	9.3	5.0	1.2	−2.6
1949	4.00	−4.2	−3.7	−3.3	4.3	6.0	9.5	13.0	12.2	11.3	6.4	−0.9	−2.5
1950	3.87	−5.7	−2.7	−1.0	1.3	8.3	12.4	13.8	12.5	8.8	4.2	0.0	−5.4
1951	3.80	−4.1	−4.0	−2.8	2.0	6.4	10.0	12.6	12.3	9.9	4.0	1.4	−2.0
1952	3.24	−5.6	−6.3	−1.9	3.9	6.6	11.0	14.2	13.2	6.8	3.8	−1.7	−5.0
1953	3.86	−6.9	−5.8	−0.6	3.2	7.3	9.8	12.5	12.0	9.7	5.7	0.8	−1.3
1954	2.87	−8.3	−6.8	−0.8	0.3	5.7	10.2	10.5	11.2	9.2	5.3	0.7	−2.9
1955	2.98	−4.5	−5.8	−3.8	1.5	5.9	10.0	11.7	11.0	8.7	3.8	−0.6	−2.1
1956	2.42	−4.7	−12.0	−2.1	1.0	7.0	8.3	12.2	10.9	10.2	3.9	−2.5	−3.1
1957	3.65	−4.6	−2.3	1.0	1.7	4.4	10.9	12.3	10.9	8.4	5.1	−0.4	−3.5
1958	3.42	−5.1	−3.0	−4.8	0.1	8.5	9.7	12.5	12.7	10.2	4.2	−1.1	−2.9
1959	4.06	−5.3	−3.1	0.3	3.2	6.7	10.2	13.2	11.6	9.7	4.9	−0.3	−2.5
1960	3.48	−5.4	−4.0	−1.1	1.9	7.2	10.6	10.8	11.7	8.4	4.9	1.1	−4.4
1961	4.44	−4.7	−1.3	−0.4	4.0	5.9	11.5	10.9	11.8	13.0	6.3	0.3	−4.3
1962	2.84	−3.8	−5.3	−4.4	2.2	5.0	9.2	11.1	12.8	8.6	5.3	−1.4	−5.9
1963	3.12	−9.8	−7.7	−2.1	1.9	7.1	11.2	13.5	11.9	10.1	4.3	2.5	−6.0
1964	3.66	−5.4	−4.2	−3.8	2.2	8.3	12.4	13.5	11.5	9.5	3.2	−0.3	−3.5
1965	2.93	−3.8	−7.3	−2.5	0.4	5.7	10.7	10.9	11.1	9.0	5.2	−2.5	−2.7
1966	3.86	−7.2	−0.2	−2.5	2.6	8.0	11.5	11.3	11.1	9.3	7.6	−1.6	−3.8
1967	4.02	−4.8	−3.3	−1.2	0.6	7.8	10.1	14.1	12.0	9.4	7.5	0.4	−4.9
1968	3.42	−6.1	−3.7	−1.8	2.2	6.8	10.9	11.7	11.4	8.7	6.0	0.2	−5.6
1969	3.52	−3.7	−5.7	−3.3	0.8	9.3	9.8	13.6	11.4	9.8	6.9	0.3	−7.5
1970	3.28	−5.1	−5.2	−3.4	−0.1	5.6	11.6	11.9	12.4	9.4	4.5	1.7	−4.4
1971	3.85	−4.1	−4.6	−4.0	2.2	8.8	9.2	13.5	14.1	7.5	4.9	−1.0	−1.0
1972	3.49	−6.0	−1.8	−0.6	0.7	6.7	10.5	13.0	11.7	6.5	2.9	−0.2	−1.8
1973	3.56	−4.0	−4.4	−2.1	−0.5	8.0	11.0	12.1	13.9	10.4	3.6	−1.6	−4.2
1974	3.80	−2.3	−2.1	−0.1	1.3	6.4	9.0	10.8	13.5	9.3	0.8	−0.2	−1.2
1975	4.18	−1.7	−3.5	−1.5	0.8	7.8	9.5	13.1	13.3	12.3	4.6	−1.4	−3.7
1976	3.71	−4.5	−3.7	−4.0	1.1	8.2	12.0	14.0	10.7	8.3	6.7	0.1	−4.9
1977	4.08	−3.8	−2.3	0.1	0.1	7.4	11.0	12.1	11.9	7.3	7.2	−0.4	−2.2
1978	3.18	−4.4	−5.2	−1.2	0.6	5.9	9.7	11.1	10.5	7.7	5.0	0.8	−3.0
1979	3.49	−7.0	−4.8	−1.2	0.1	8.1	12.5	10.4	11.4	9.0	5.1	−1.1	−1.2
1980	2.75	−6.0	−2.9	−2.2	−0.3	5.1	9.4	10.3	12.3	9.6	4.0	−1.9	−4.8
1981	3.44	−6.4	−5.3	0.2	1.3	8.2	10.9	11.6	12.1	10.1	4.2	−0.8	−5.3
1982	4.33	−4.4	−5.2	−1.8	−0.4	8.1	11.5	13.6	12.6	12.2	5.6	1.7	−2.1
1983	4.32	−2.2	−6.1	−1.4	2.4	7.6	11.2	15.8	12.9	9.6	4.9	−0.6	−3.0
1984	3.27	−4.7	−5.5	−3.4	0.5	6.2	9.2	11.2	12.2	7.8	6.3	1.6	−2.7
1985	3.11	−8.0	−7.0	−2.2	0.9	8.4	8.2	12.8	12.2	9.6	5.1	−3.3	−0.4
1986	3.61	−5.2	−9.7	−2.2	1.8	9.8	10.4	12.2	12.4	8.4	5.7	1.4	−2.7
1987	3.25	−7.8	−3.4	−5.2	1.9	5.6	9.7	12.7	11.2	11.2	5.4	0.1	−2.5

Appendix 1. Part (6 of 6)

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1988	3.98	−2.2	−3.8	−2.9	1.6	8.7	10.3	12.9	12.6	8.8	6.3	−2.0	−3.0
1989	4.58	−2.4	−1.4	0.1	1.7	8.2	9.7	12.6	12.3	9.8	6.0	−0.9	−1.2
1990	4.27	−3.0	−0.4	0.3	0.6	9.0	10.3	11.9	13.7	7.0	6.6	−0.6	−4.6
1991	3.54	−3.6	−6.3	0.2	0.6	4.3	9.1	13.9	13.4	10.6	3.6	−0.2	−3.9
1992	4.59	−3.6	−2.6	−1.6	0.8	9.0	11.5	14.0	16.1	9.8	2.9	0.5	−2.3
1993	3.93	−2.6	−3.7	−2.6	2.7	9.9	10.7	11.4	12.5	8.8	4.5	−2.9	−2.1
1994	4.81	−2.8	−4.4	−0.1	1.4	7.8	11.3	16.2	13.6	9.7	3.9	2.1	−1.7
1995	4.00	−5.1	−1.3	−2.7	1.8	8.0	9.5	15.2	12.8	7.9	7.8	−1.3	−4.9
1996	3.06	−5.4	−5.8	−4.1	2.0	8.0	11.7	11.2	12.3	6.0	5.3	0.4	−5.8
1997	4.20	−4.6	−2.0	−0.4	−0.2	8.3	11.0	12.1	14.2	10.3	3.3	0.0	−2.0
1998	4.18	−2.9	−1.1	−2.0	2.5	9.0	11.7	12.2	13.1	8.9	4.9	−2.9	−3.5
1999	4.43	−2.4	−5.1	−0.7	2.0	8.9	10.6	13.8	12.9	12.3	4.9	−1.4	−3.3
2000	5.08	−5.0	−2.4	−1.4	3.5	10.1	12.8	10.7	14.2	9.7	7.4	1.9	−0.9
2001	4.16	−4.0	−2.7	−0.6	0.8	10.0	9.7	13.4	14.1	7.1	8.6	−1.6	−5.6