Variability of North-Atlantic-European Circulation Patterns Since 1780 and Corresponding Variations in Central European Climate

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Abstract. Time series of Central European temperature and precipitation show marked decadal scale variations during the period 1780 to 1995. On the basis of monthly mean SLP grids reconstructed back to 1780 by Jones *et al.* (1999) basic North-Atlantic European circulation patterns have been derived by means of T-mode principal component analyses. Decadal scale variability of the large scale atmospheric circulation since 1780 is described in terms of indices representing variations in both relative importance and internal characteristics (within-type changes) of the T-mode circulation patterns. The results show that variations of temperature and precipitation in Central Europe may only partly be attributed to changes in relative importance of North-Atlantic-European circulation patterns. Large parts of the observed climatic variability are due to within-type variability of the circulation patterns.

27.1 Introduction

In view of possible future global and regional scale climatic change it is of primary importance to increase knowledge about climatic variability during historical times in order to place recent and possible future variations of climate and atmospheric circulation into a long-term context of natural variability of the climate system. As most projections of future regional climate change are obtained by deriving changes in regional or local climate parameters from projected large-scale atmospheric circulation changes by means of different downscaling methods, it is also necessary to investigate the low-frequency variability of relationships between the large-scale atmospheric circulation and climate on a regional scale. Due to the restricted availability of observed pressure data, however, objective circulation analyses so far have mainly been confined to the last 100 years or even shorter periods (e. g. Barnston and Livezey, 1987; Jacobeit, 1993; Klaus, 1997; Mächel *et al.*, 1998; Kapala *et al.*, 1998). A reconstructed gridded monthly mean SLP data set for the North-Atlantic-European region back to 1780 was first provided by Jones *et al.* (1987), and was substantially improved by Jones *et al.* (1999) due to enhanced station pressure data for the earlier periods.

Based upon these gridded data several analyses concerning decadal to century scale circulation variability since the year 1780 have been performed. Schmutz and Wanner (1998) applied a correlation based classification to the former version of the SLP data. Jacobeit *et al.* (1998) gave an overview of various statistical analyses of circulation variability performed within the European research project ADVICE (Annual to Decadal Variability in Climate in Europe). Beck (2000) compared, by means of several synoptic analyses, an historical period (1780 to 1860) with the 20th century in particular with respect to frequency and within-type changes of objectively determined circulation patterns. Jacobeit *et al.* (2001b) investigated circulation changes in Europe since 1780 based on a seasonal NAO index, monthly Großwettertypes and PCA derived circulation patterns, and Jacobeit *et al.* (2001a) analysed the long-term variability of relationships between the NAO and Central European temperatures.

The present study refers to circulation pattern variability in the North-Atlantic-European region since 1780 and its importance for Central European climate variability. In this context frequency changes as well as internal modifications of PCA-derived North-Atlantic-European circulation patterns are investigated with special regard to their relevance for decadal-scale variations in Central European temperature and precipitation. Analyses presented in this paper will focus on January and July representing high winter and summer conditions, respectively.

27.2 Data

The following data sets were used in this study: monthly mean gridded SLP data for the North-Atlantic European Region and Central European monthly temperature and precipitation time series covering the period from 1780 to 1995. Gridded monthly mean SLP data for the North-Atlantic-European region have been reconstructed back to 1780 by Jones *et al.* (1999). These reconstructions have been produced on the basis of homogenised long-term pressure time series by means of EOF/multiple regression models on a 5° latitude by 10° longitude grid covering the region from 35 to 70°N and from 30°W to 40°E. The station network comprises between 10 stations, with continuous pressure time series starting in 1780, and 51 stations since the middle of the 19th century. The EOF-regression models for deriving gridded SLP data were calibrated over the period 1936 to 1995 and verified for the period 1881 to 1935. Best model results (in terms of explained variance) were obtained for the central gridpoints and during the periods with the most extensive station network. Explained variance decreases towards the periphery of the grid and with the decreasing number of stations during earlier periods. In general, better results were obtained during winter than for the summer months (Jones *et al.* 1999). In spite of these minor restrictions the SLP data provides an appropriate basis for studies concerning the variability of the atmospheric circulation during periods that are not covered by commonly available SLP data sets.

Central-European time series of monthly temperature and precipitation have been determined on the basis of 26 temperature and 39 precipitation time series (see Fig. 27.1). All these series have been tested for homogeneity by applying several statistical tests, including the Alexandersson (1986) test, to the annual time series. Significant inhomogeneities have been homogenised on the basis of the monthly series. For a more detailed description of the testing methods and the homogenisation procedure see Beck (2000). According to Jones and Hulme (1996) missing values within the individual station series have been interpolated by using normalised anomaly fields calibrated onto one common 30-year reference period. Finally, Central-European time series have been calculated as spatial averages of the corresponding station time series.

27.3 Methods

Analyses of the atmospheric circulation are based on monthly large-scale circulation patterns determined by applying varimax rotated T-mode PCAs to the reconstructed gridded SLP data separately for January and July. Parameters describing temporal variations of these circulation patterns during the period 1780 to 1995 are derived for moving 31-year periods with time steps of one year, focussing on different aspects of variability:

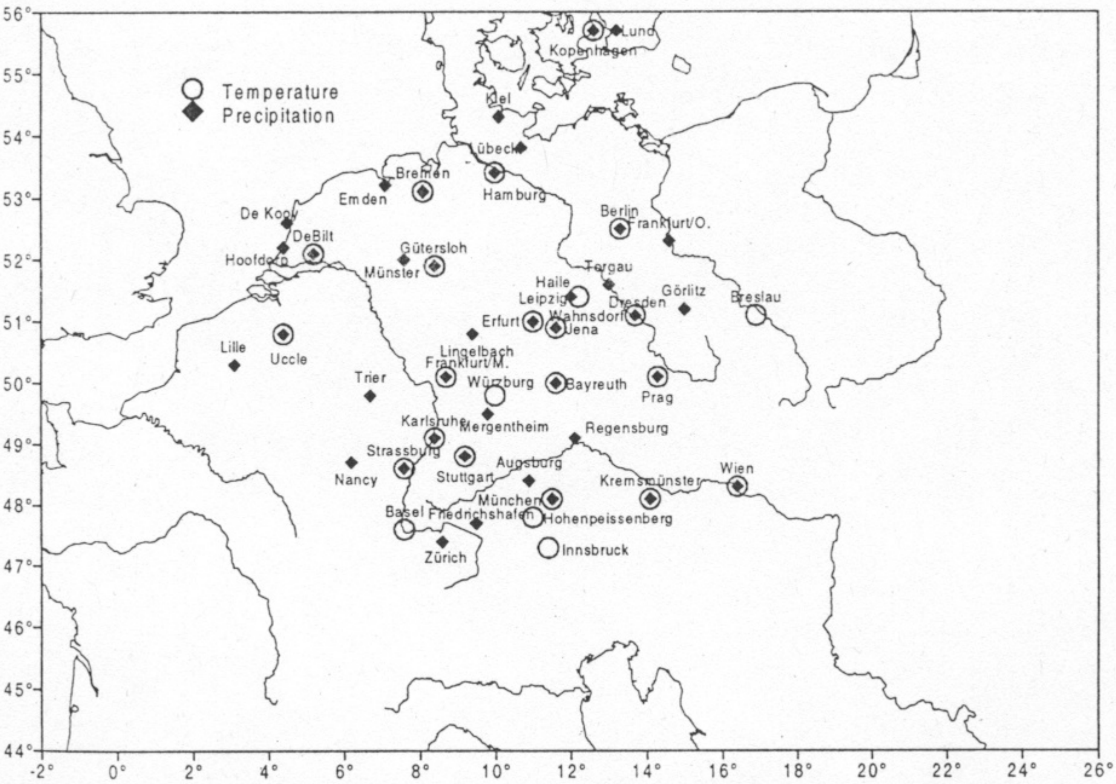

Fig. 27.1. Spatial distribution of Central European temperature and precipitation time series used for the determination of Central European index series of temperature and precipitation since 1780.

- Sums of leading time coefficients for these moving time windows have been calculated for each circulation pattern as an indicator of variations in its relative importance.
- For each circulation pattern two contrasting subtype composites have been determined with respect to variations of position and extension of major pressure systems. Time series of root-mean-square values between these subtypes and moving 31-year composites for the corresponding circulation pattern (calculated as weighted means of those monthly SLP fields with their highest loading on the corresponding PC) are able to reveal variations in spatial pattern configuration.
- To determine within-pattern intensity variations pressure gradients between pattern-dependent centres of action have been calculated.
- Temperature and precipitation indices related to the corresponding circulation patterns (i.e. referring to those months with leading time coefficients for a particular pattern, respectively) have been derived in order to ascertain indications of within-type climate variability.

In accordance with the temporal representation of circulation indices the overall Central European temperature and precipitation time series since 1780 have also been transferred to moving averages referring to 31-year time periods and time steps of one year.

27.4 Results

Fig. 27.2 and 27.3 show the circulation patterns (represented by normalised SLP fields of those months with maximum loadings on the corresponding PC) resulting from the January and July PC analyses. Five and four PCs have been retained for January and July explaining about 99 % and 97 % of total variance, respectively. Circulation patterns for January are the following:

- A typical wintertime westerly circulation developed between a subtropical high reaching towards the western Mediterranean and low pressure in subpolar regions (Pattern 1).
- An extended Russian high and a well developed low pressure system over the central North Atlantic (Pattern 2).
- A distinct low pressure system centred over the North Sea extending over large parts of Europe (Pattern 3).
- A NAO reversal due to high pressure located near the Icelandic region (Pattern 4).
- A high pressure cell centred over the British Isles and a cut-off low over the Mediterranean area (Pattern 5).

Circulation in July is characterised by the following patterns:

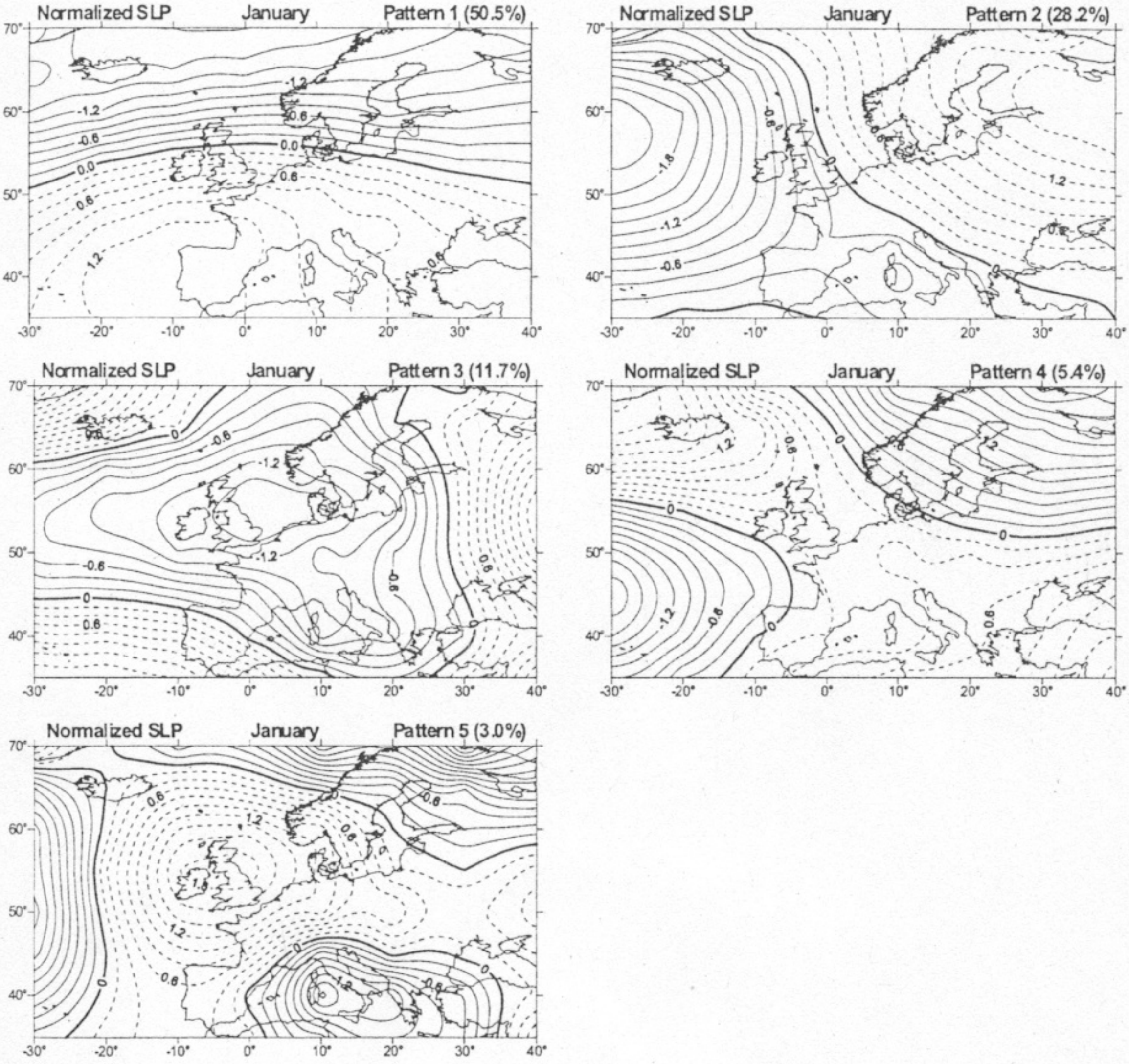

Fig. 27.2. Normalised SLP patterns for January derived from T-mode PCA of monthly mean SLP fields of the period 1780 to 1995 (percentages give the explained variances, respectively).

- A well developed westerly flow between a zonal high pressure ridge in the south and low pressure in subpolar regions (Pattern 1).
- A widespread low pressure system with its centre over southern Scandinavia and an Azores high in a southwesterly position (Pattern 2).
- A diagonal high pressure ridge extending from north of the Azores towards Scandinavia influencing large parts of Western and Central Europe (Pattern 3).
- A high pressure ridge connecting two anticyclonic centres in the Azores region and over southern Scandinavia (Pattern 4).

The main question we want to address in this paper is the following: how far have the low-frequency variations of climate in Central Europe since 1780 been reflected by variations of the relative importance of large-scale circulation patterns described above and to what extent these climate variations have been due to internal changes of the circulation patterns?

Temporal variations of temperature and precipitation for January and July since 1780 are given in Fig. 27.4. The time series of both temperature and precipitation show marked decadal-scale variations: In January a cold and dry period is indicated at the beginning of the 19th century before both temperature and precipitation started to increase. Still during the warming period precipitation started to decrease during the second half of the 19th century before the well-known climate variations throughout the 20th century occurred. In July the earliest period was warm and dry indicating, together with the cold and dry january months, a more continental climate than later in Central Europe. Around the turn of the 19th to the 20th centuries a cool and wet period occurred in high summer, and during the second half of the 20th century there is a distinct decrease in July precipitation.

Looking at selected indices for circulation patterns, Figs. 27.5 to 27.8 only show the moving sums of leading time coefficients and the climate indices related to the corresponding circulation patterns, we may see those variations concomitant with the above-mentioned climate variations. Thus, the recent decrease in July precipitation is reflected in the opposite development of the relative importance of patterns 2 and 3 (decreasing for the cyclonic pattern 2, increasing for the Atlantic ridge pattern 3), but also in the declining precipitation index for the westerly pattern 1 (i.e. rainfall due to this pattern decreased significantly during the recent

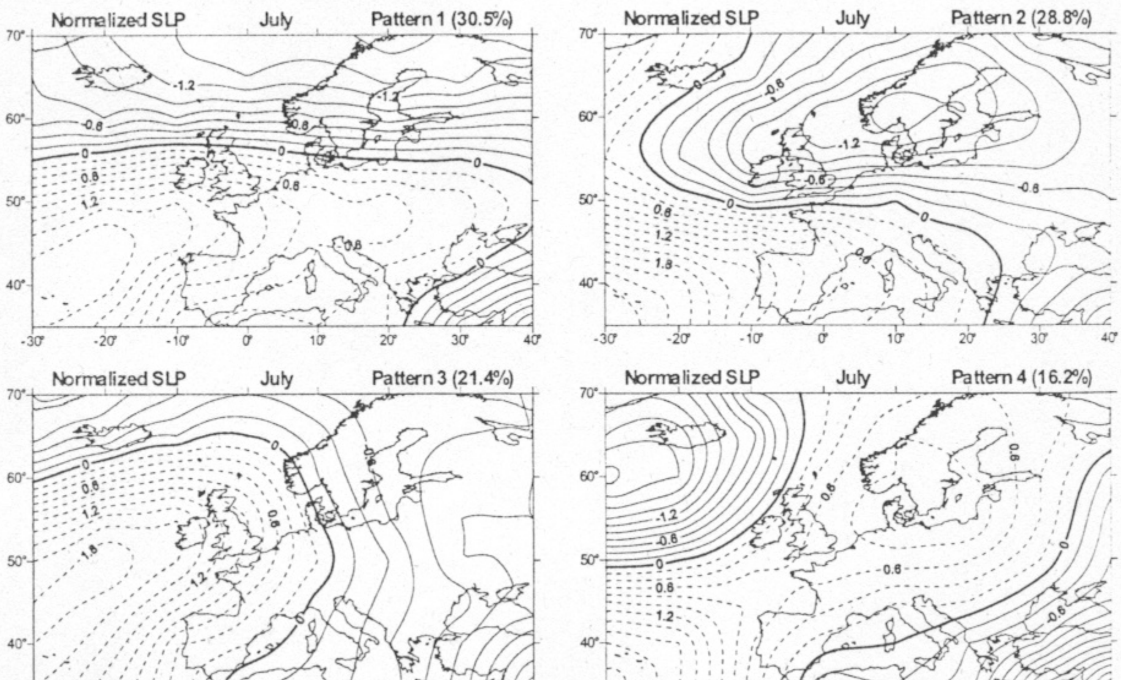

Fig. 27.3. Normalised SLP patterns for July derived from T-mode PCA of monthly mean SLP fields of the period 1780 to 1995 (percentages give the explained variances, respectively).

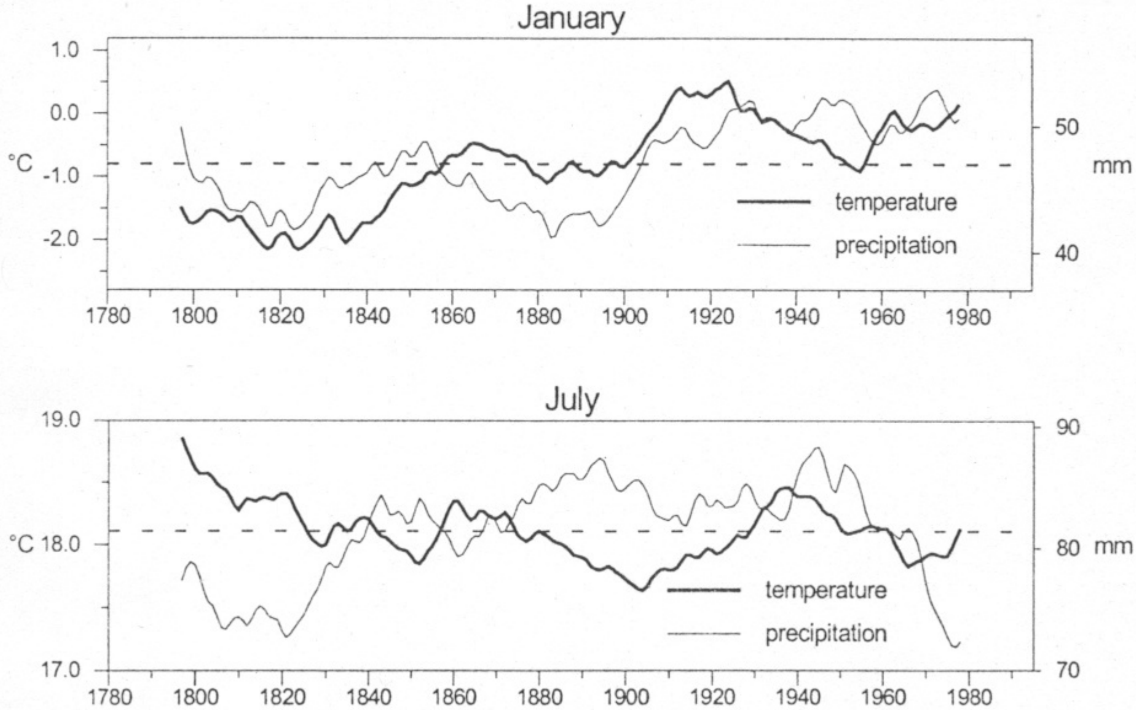

Fig. 27.4. Central European temperature and precipitation indices for January (top) and July (bottom): Moving averages of 31-year time windows with time steps of one year. Dashed lines indicate the long-term mean values, respectively.

decades). The cool and wet July period around the turn of the 19th century, however, seems to be caused quite differently: most correspondences exist with the climate indices for pattern 3, indicating that during this period the anticyclonic influence of the Atlantic ridge did not extend as far towards Central Europe than afterwards. The warm and dry July period at the beginning of the time series is marked by corresponding deviations in the climate indices of all high summer circulation patterns thus pointing to different boundary conditions during this earliest period.

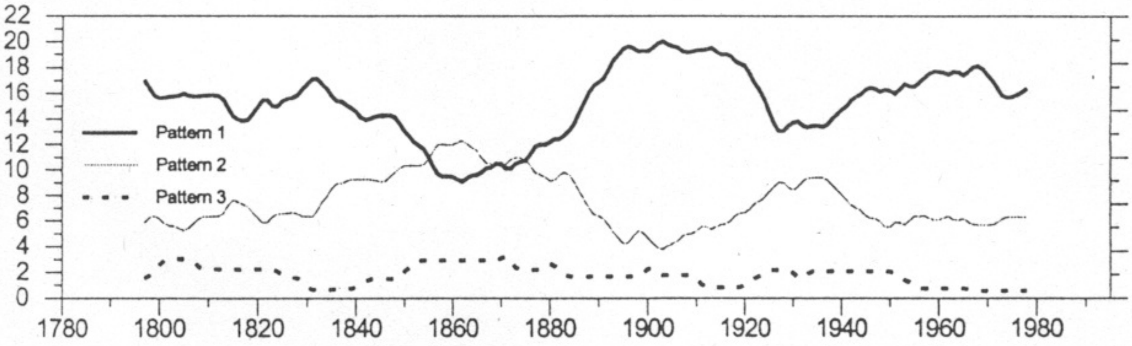

Fig. 27.5. 31-year moving sums of leading time coefficients of PCA derived circulation patterns for January (no time series are plotted for patterns 4 and 5 having only insufficient numbers of months with the highest time coefficient among all extracted patterns).

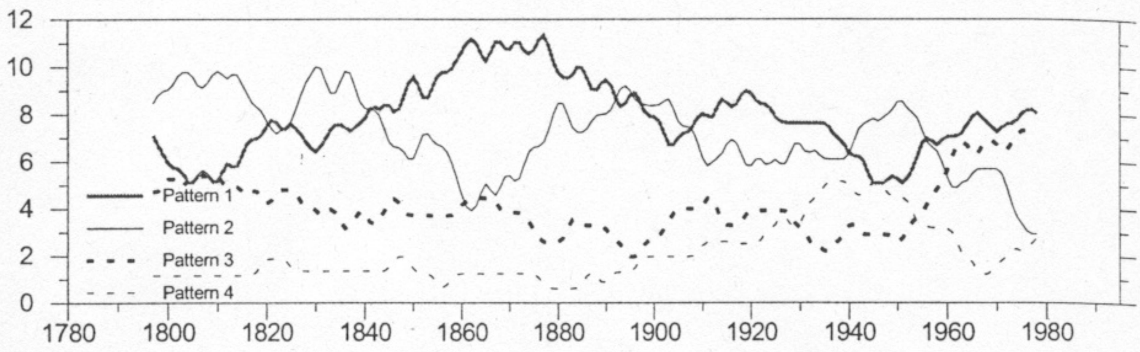

Fig. 27.6. 31-year moving sums of leading time coefficients of PCA derived circulation patterns for July.

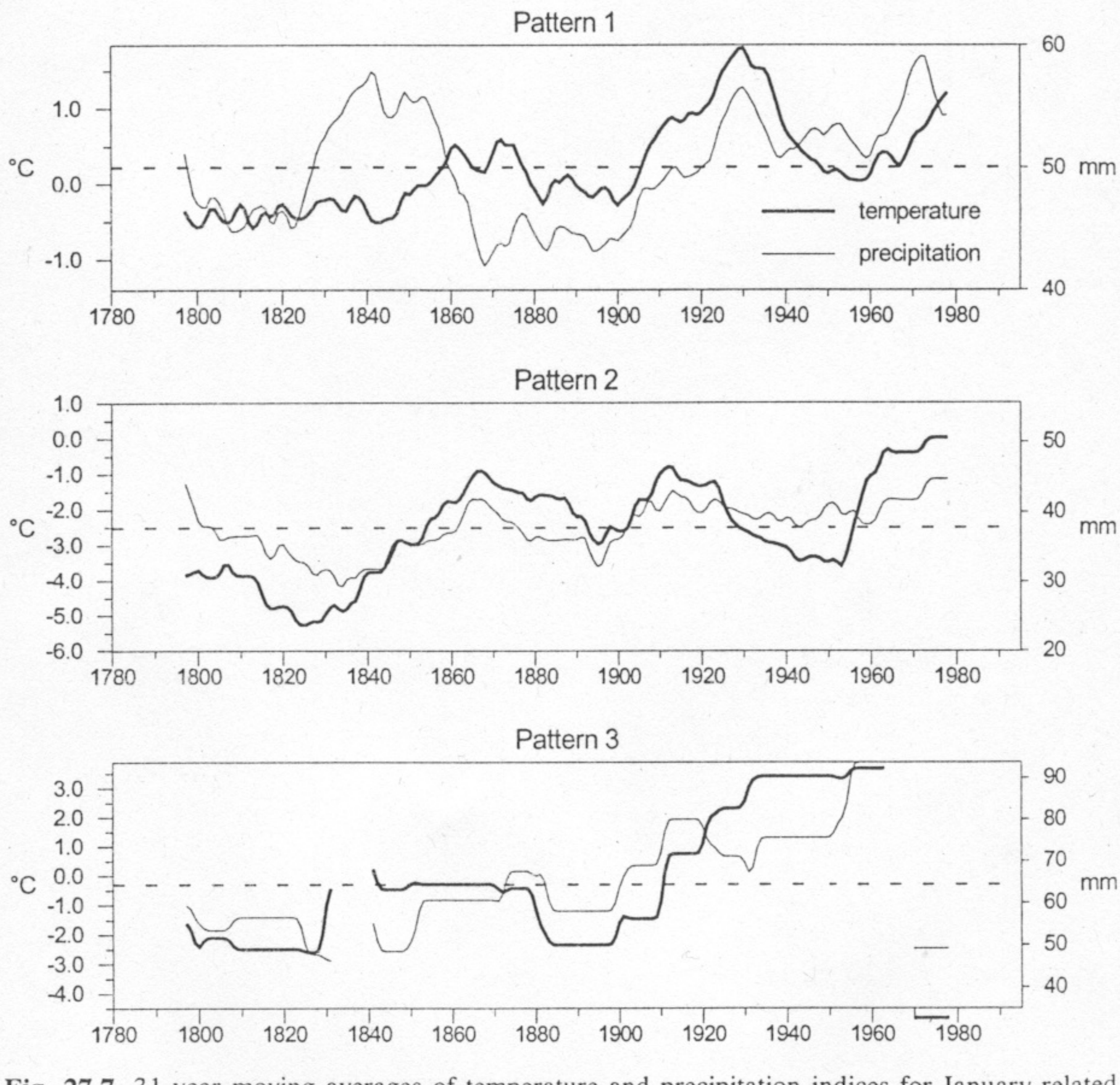

Fig. 27.7. 31-year moving averages of temperature and precipitation indices for January related to corresponding circulation patterns (no time series are plotted for patterns 4 and 5 having only insufficient numbers of months with the highest time coefficient among all extracted patterns). Dashed lines indicate the long-term mean values, respectively.

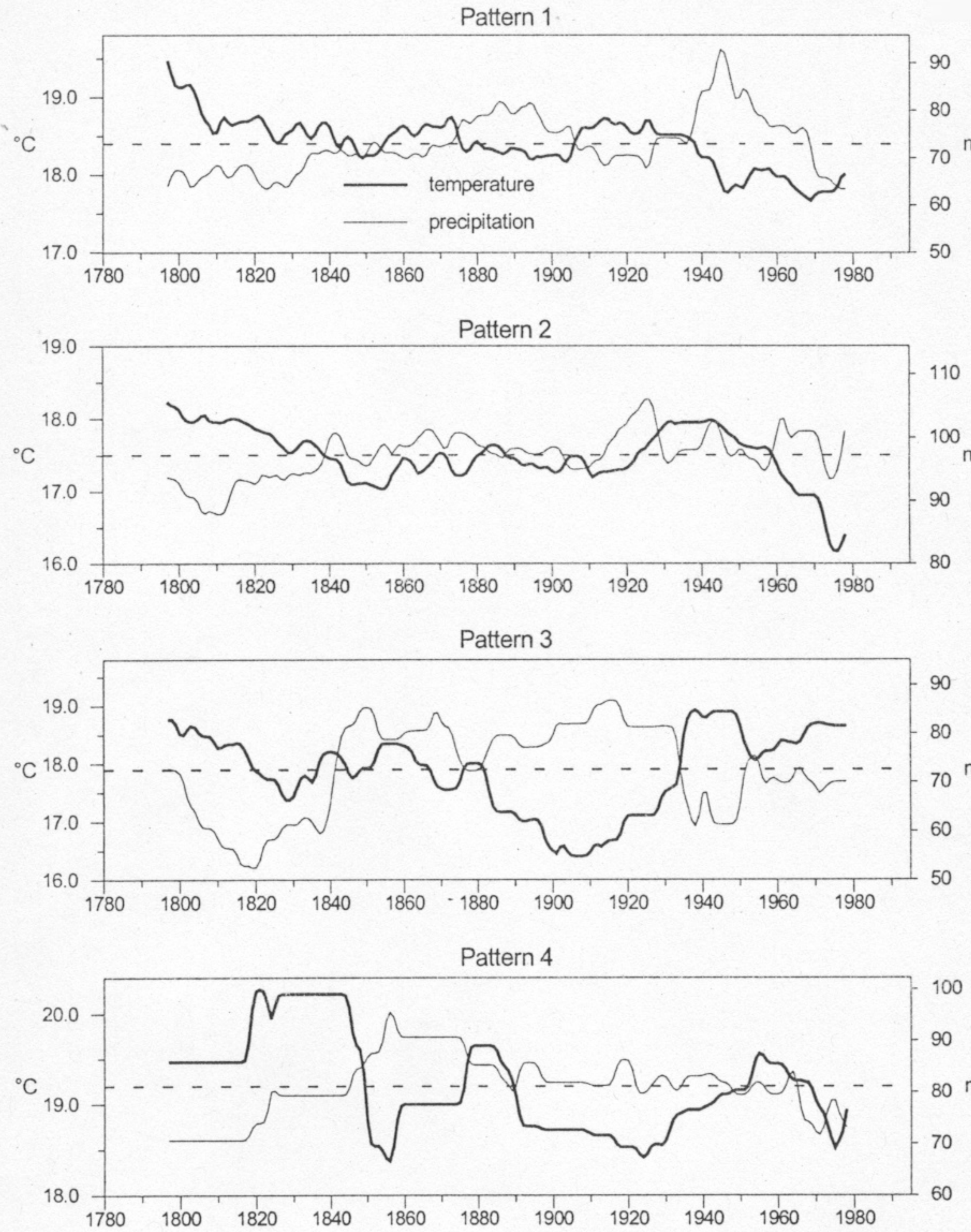

Fig. 27.8. 31-year moving averages of temperature and precipitation indices for July related to corresponding circulation patterns. Dashed lines indicate the long-term mean values, respectively.

In January, there is a distinctly inverse relationship between the relative importance of the westerly pattern 1 and the Russian high pattern 2, but again, the climate of particular periods is highly influenced by within-type changes of these patterns themselves: thus, the early cold and dry period is marked by corresponding climate deviations for all circulation patterns, and the general warming between 1830 and 1860 - concomitant with decreasing importance of the westerly pattern and increasing importance of the Russian high pattern - can only be understood by considering the significant warming of the latter pattern around this period (dynamic reasons will be mentioned in the conclusions). Furthermore, decreasing precipitation in Central Europe after the mid-19th century is clearly reflected in the declining precipitation values for the westerly pattern pointing to shifts from cyclonic to anticyclonic subtypes for this pattern during this period. Opposite developments are evident for the early decades of the 20th century.

27.5 Conclusions

Results have shown that variations of temperature and precipitation in Central Europe may only partly be attributed to changes in the relative importance of North-Atlantic-European circulation patterns. Large parts of the observed climatic variability are due to within-type variability of the circulation patterns themselves. One reason for these variations in within-type climate characteristics are changes in internal pattern configuration concerning variations of pressure gradients or variations of position and extension of the major pressure systems. Time series of these parameters (not shown here) for instance indicate that rising within-type temperatures of January circulation pattern 1 during the period 1830 to 1860 are linked with a strengthening of the meridional pressure gradient over the North Atlantic. During the same period a subtype of January circulation pattern 2 with an expanded North Atlantic low pressure system and a reduced extension of the Russian high is dominating implying southwesterly flow over Central Europe thus leading to warmer conditions than earlier.

Further investigations concerning the relationship between large-scale atmospheric circulation and Central European climate will focus on the determination of parameters that will allow the quantitative comparison of within-type variability and changes in relative importance of particular circulation patterns with regard to their relevance for decadal-scale climatic variations.

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