41. LINKS BETWEEN FLOOD EVENTS IN CENTRAL EUROPE SINCE AD 1500 AND THE LARGE-SCALE ATMOSPHERIC CIRCULATION

J. Jacobeit[1], *R. Glaser*[2], *J. Luterbacher*[3], *M. Nonnenmacher*[1] *& H. Wanner*[3]

(1) Institute of Geography, University of Würzburg, Germany; e-mail: jucundus.jacobeit@mail.uni-wuerzburg.de
(2) Institute of Geography, University of Heidelberg, Germany
(3) Institute of Geography, University of Berne, Switzerland and National Center of Competence in Research (NCCR) in Climate

ABSTRACT

Based on documentary sources incidence variations of Central European flood events have been reconstructed back to AD 1500. For the same period, combined atmospheric circulation modes have been derived from objectively reconstructed large-scale sea level pressure and 500 hPa geopotential height grids with monthly (since 1659) or seasonal resolution (pre-1659 period). Different indices describe the particular importance of these circulation modes as a dynamical background for the varying incidence of flood events. During winter time (DJF), the zonal circulation mode mostly achieves high quota of the flood events, but rather low index values in relation to mode-frequency. Particular periods of the Little Ice Age, however, reveal an increased flood importance of other circulation modes, especially concerning the meridional trough mode characterising cooling periods of distinctly enhanced flood frequency in Central Europe.

1 INTRODUCTION

Flood dynamics are partly influenced by river and catchment area characteristics (*Frei et al.*, 2000), but mainly controlled by climate variability on different time scales (*Shorthouse & Arnell*, 1999). In this context the primary importance of westerly flow types linked with the positive mode of the North Atlantic Oscillation (NAO) for Central European flood events in the cold season has been identified for the more recent past (*Caspary*, 1995). However, extreme events should be analysed for very long-term periods including different climatic conditions (*Knox*, 2000). The present study will focus on the last 500 years based on recently available data concerning both Central European flood events (*Glaser*, 2001) as well as reconstructed pressure grids for the North-Atlantic-European area (*Luterbacher et al.*, 2002).

The monthly to seasonal resolution of these atmospheric data does not allow, however, detailed case studies of synoptic disturbances implying anomalous river discharge. Investigations are rather directed towards flood hydroclimatology (*Hirschboeck*, 1988), i.e. hydrological extremes will be related to the large-scale atmospheric circulation whose different modes are constituting different conditions for the development of flood-prone weather systems; thus, variations in flood frequency on historical time scales are put into the context of long-term climate and circulation variability.

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2 DATA

Historical flood events known from documentary sources (e.g. *Brázdil et al.*, 1999) have been reconstructed back to AD 1500 for several catchment areas in Central Europe (*Glaser*, 2001). The four most reliable time series – from the river Main and from central parts of rivers Rhine, Elbe and Weser – have been integrated into one common flood series for Central Europe focussing on winter time (December to February) as the most important flood season in this central part of Central Europe. The documentary data extend until the end of the 18th century, subsequently gauge observations and discharge measurements allow to continue the historical flood series in terms of significantly above-average monthly maximum discharge (*Sturm et al.*, 2001). Figure 1 shows running flood frequencies for moving 31-year time windows clearly indicating long-term variations between increased and decreased flood incidence in Central Europe (the interruption of the integrated time series during the first half of the 19th century is due to some of the instrumental data not starting before AD 1850).

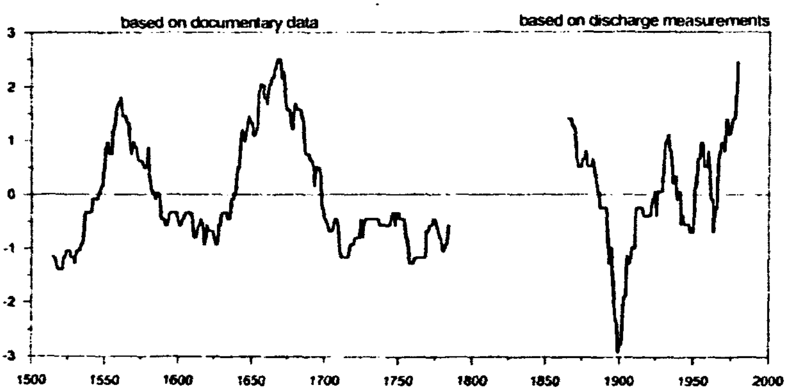

Figure 1. Normalized running 31-year flood frequencies in Central Europe for the winter (DJF) season since AD 1500 referring to four rivers (river Main and central parts of rivers Rhine, Weser, and Elbe).

Circulation analyses are based on gridded data for sea-level pressure (SLP) and 500 hPa geopotential heights (GPH), objectively reconstructed back to AD 1500 for the North-Atlantic-European area by *Luterbacher et al.* (2002) with seasonal resolution until AD 1658, monthly resolution afterwards. Atmospheric circulation modes have been derived according to *Jacobeit et al.* (2002) extended to a combined T-mode PCA of both atmospheric levels. The resulting modes are represented by combined GPH and SLP patterns (Figure 2) including i) a W to SW pattern (Z), ii) a meridional trough pattern (Tr), iii) a monopole pattern centered near the British Isles (T), and iv) a cellular pattern with Russian high and Mediterranean low pressure centres (C). The time coefficients of these two-level modes are subsequently used to establish links between the large-scale circulation and regional flood events.

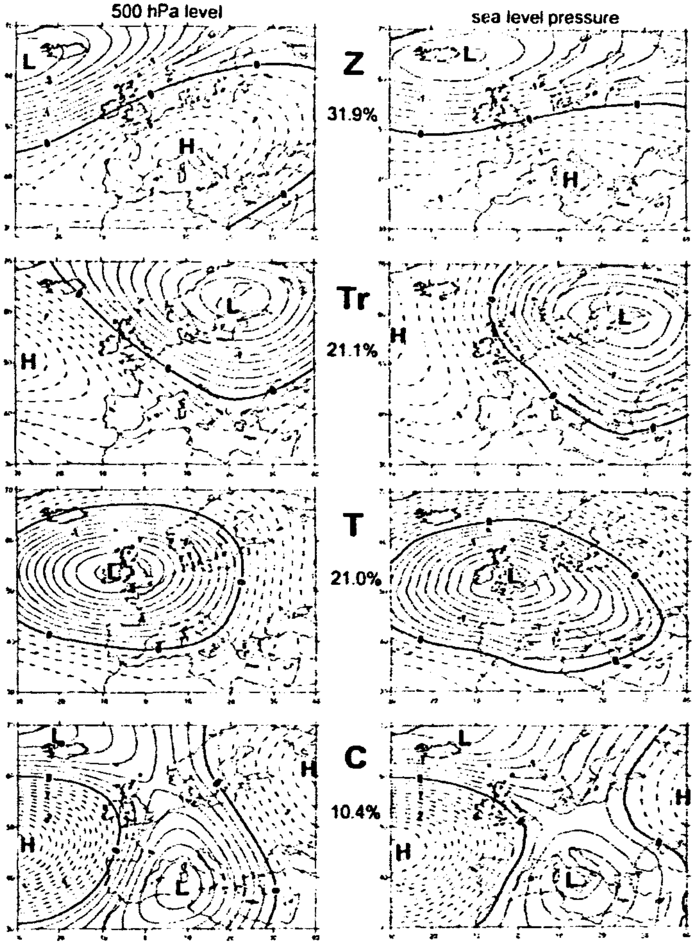

Figure 2. Combined principal modes of 500 hPa GPH and SLP for the winter (DJF) season 1500-1999 (abbreviations see text; percentages refer to variances accounted for by the corresponding modes).

3 METHODS

Quantifying the importance of different circulation modes as a dynamical background for the varying incidence of flood events is based on several indices (*Jacobeit et al.*, 2003), two of them will be applied in the present context:

a) Index Q(X) describes the flood quota of circulation mode X by relating the flood events occurring during dominance of mode X to the total amount of flood events. Mode X is dominating during a particular month when its time coefficient for this month is the greatest one among the time coefficients of all modes for this month (i.e. mode X has the leading time coefficient during this particular month). Instead of counting the number of flood events during dominance of mode X, its leading time coefficients for flooding months are summed up in the numerator of Q(X) implying a weighting factor depending on the degree of dominance of mode X. If several months of one particular winter season during the pre-1659 period are affected by flooding, the leading time coefficient – only available for the entire season – is counted several times. To consider variations in circulation-flood-relationships, calculations are generally based on moving 31-year time windows.

b) Index A(X) describes how frequently the dominant occurrence of a particular mode X is accompanied by flood events. For that the same numerator as in Q(X) is related to the overall incidence of mode X, the latter being assessed by summing up all leading time coefficients of mode X (i.e. for months both with and without flood events).

Both index time-series are standardised across all circulation modes thus indicating directly above- and below-average flood-importance of these modes in terms of the two different indices discussed before.

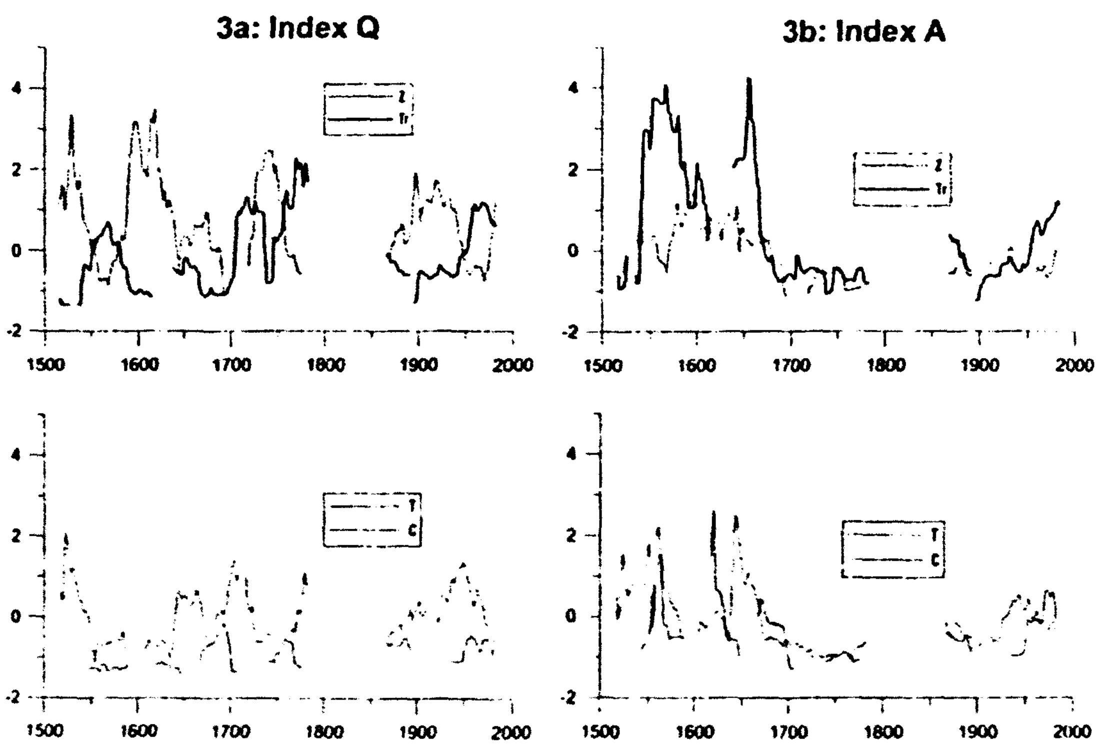

Figure 3. Normalized running 31-year Q and A Indices (see text) for the large-scale circulation modes of Figure 2 during the winter (DJF) season since AD 1500.

4 Results

Figure 3 shows Q and A time series for the last 500 years (except of the first half of the 19th century where no appropriate flooding data were available). Gaps within the individual time series occur if the corresponding circulation mode never dominates during this period. Index Q (Figure 3a) reveals that in most cases mode Z has the largest flood quota, but there are some particular periods with different conditions: during the second half of the 16th century – experiencing a prominent maximum in flood frequency (Figure 1) – the meridional mode Tr becomes more important in terms of index Q, and during the next flood frequency maximum around the mid-17th century mode T reaches similar flood quota as mode Z. Conditions during the 18th century are less important because of its persistingly low flood frequencies. During the last century modes T and Tr predominate in terms of index Q during the central period of meridional circulation before the well-known increases in zonal circulation and mode Z's flood quota during the last decades.

Completely different conditions appear with index A (Figure 3b): mode Z has lost its prominent position, instead there are several distinct peaks for other circulation modes, especially in association with the historical periods of increased flood frequency during parts of the 16th and 17th centuries. Between these peaks referring to mode Tr another peak associated with mode C appears during the first half of the 17th century (albeit with lower flood frequencies). This means that increased fractions of these modes implied dynamics resulting in Central European flood events whereas for mode Z such internal shifts remained secondary. Especially the occurrence of mode Tr was linked with an enhanced risk of flood incidence during particular periods of the Little Ice Age. Note that flood impacts of mode C - representing Russian high pressure influence towards Central Europe – are rather indirect referring to pre-flooding accumulation or storage of extensive snow and ice volumes.

5 CONCLUSIONS

Links between Central European flood events and the large-scale atmospheric circulation have been substantiated for the extended period since AD 1500 (winter season). The importance of westerly to southwesterly type zonal circulations known from the last century (e.g. *Caspary*, 1995) is reflected by mostly high flood quota (index Q) for the large-scale circulation mode Z. However, other modes may also get particular importance, not only with respect to flood quota, but especially in relation to their own mode-frequency (index A). Thus, around the mid-sixteenth century the meridional trough mode Tr gets primary importance in both indices implying much more frequent flooding dynamics in association with this mode. During this time in advance of a subsequent Little-Ice-Age-Type-Event cold period (*Wanner et al.*, 2000) the atmospheric circulation changed its preference from zonal to meridional modes implying progressive cooling and cyclonic disturbances with enhanced flood triggering linked to mode Tr. During the following cold period flood frequencies decreased at first, but the occurrence of Russian high influence (mode C) more frequently implied successive flooding (index A) due to increased ice accumulation. Around the mid-seventeenth century another re-enforcement of cyclonic activities (modes T and Tr) led to a second historical peak in flood frequency. The following decrease coincided with the so-called Late Maunder Minimum period which is known to have become progressively drier (*Wanner et al.*, 2000).

Thus, the assessment of flood dynamics at longer-term time scales going back to periods with changed climatic conditions as during the Little Ice Age, must not be restricted to zonal mode and NAO considerations, but has to take into account a much broader range of major atmospheric circulation modes. The present approach to combine SLP and GPH data within one common PCA decomposition is able to achieve consistent patterns at these levels for common circulation modes to be studied with respect to regional flooding incidence. On the other hand, the coupling of two levels prevents the study of further particularities that cannot be recorded by strictly related pairs of patterns. Thus, similar analyses will be performed on the basis of one-level modes for the large-scale atmospheric circulation (*Jacobeit et al.*, 2003).

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