CLIMATE FORCING OF PALEOFLOODS IN THE SWISS ALPS

Forzamiento climático de paleoinundaciones en los Alpes Suizos

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Abstract: A multidisciplinary approach provides data from natural and documentary archives, for the study of potential effects of climatic changes on alpine floods during historical times but also outside the known range of extreme events. For the reconstruction of climate and flood variability, interdecadal-resolution sedimentary delta records of the Bernese Alps were examined. Spectral analysis of the geochemical records and climate proxies ($\delta^{14}C$, $\delta^{18}O$, NAO) evidence similar periodicities of 60, 85, 105 and 200 yrs. Thus, the mechanisms of the flood processes are strongly influenced by the North Atlantic dynamics and solar activity. The proxies indicate that cooler climate pulses were an important external driving force of floods.

Key words: paleofloods, multi-proxy reconstruction, periodicities, solar and climatic forcing, Alps.

1. INTRODUCCIÓN

Mountain regions as the Alps cover sensitive and vulnerable ecosystems exposed to changes of atmospheric circulation, meteorological extreme events and land-use. Proxy data from sedimentary records can provide data for the study of potential effects of climatic changes on alpine floods outside the known range of extreme events reconstructed from documentary and instrumental data (Schulte et al., 2009). The research focuses on the densely populated Bernese Alps, which are a true "hot spot" of hydrological risk. For the reconstruction of climate variability and paleofloods, interdecadal-resolution sedimentary records from the Aare delta were examined.

2. REGIONAL SETTING

The upper Aare basin covers a total area of 596 km^2, 17% of the catchment area is covered by glaciers and the highest elevation reach 4274 m at the Finsteraarehorn. The Aare River flows into Lake Brienz (564 m asl) accumulating a 12 km-long and 1 km-wide delta that is limited by the slopes of the Lower Hasli valley. The flood plain morphology shows paleochannels, levees, crevasse splay and interdistributary basins, and rock avalanche deposits, debris cones, and alluvial fans are deposited at the valley margins. The Aare River gauge at Brienzwiler records a mean annual runoff of 35 $m^3\ s^{-1}$. The glacio-nival runoff regime coincides with summer precipitation maximums. According to historical documents 33 of 36 reported flood damage events (92%) occurred since 1480 during the extended summer period (JJAS).

3. METHODS

According to the geomorphological survey, historical maps, 2 m-spatial resolution digital terrain model and field work, meso-scale fluvial landforms were identified in the delta flood plain. A total of 12 cores were operated by percussion coring down to 10 m depth. The best sedimentary records, in terms of lithological-geochemical and temporal resolution, were retrieved from interdistributary basins and their lateral transition areas. In this paper we focus on two key cores: AA-2 at 1.5 km distance form the delta shore line and AA-5 at 4.5 km distance. Both age–depth models are based on 4 and 6 AMS radiocarbon datings of peat, wood and plant remains.

The chemical element composition of sedimentary archives was analyzed at 1 cm intervals by XRF-II core scanning techniques at the MARUM, University of Bremen. Total organic carbon (TOC) was performed by loss on ignition (LOI) at 550ºC. To explore the variability of the geochemical proxies, statistical treatment of the geochemical data sets – i.e. factor analysis (FA) – was computed with the STATISTICA 6 software. The generated time series were correlated with paleoclimate records ($\delta^{18}O$ GISP2, TSI and Alps summer temperatures). A segment of the geochemical record of core AA-2 were analysed by spectral analysis to determine the frequencies of the variability of these time series.

4. RESULTS AND DISCUSSION

The key cores show alluvial delta plain facies (delta top set beds) defined by shallow gravel channel beds, coarse and middle sand beds of levees, flood layers and crevasse splay deposits, silt and organic-rich alluvial and palustrine sediments and peat horizons. The lateral extension of the major units were traced by cross sections of 20 m-spaced shallow drillings.

4.1. Core AA-2 (2.6-1.6 kyr)

4.1.1. Sedimentary record

The 6 m-deep core AA-2 in the central area of the valley floor records during the last 2600 years 9 mayor aggradation pulses of upward thinning sequences, where the organic beds correspond to relatively stable conditions (minor or no flooding). Ca values are very low in core AA-2 and are related to Hornblende according to the X-ray diffraction analyses. The absence of carbonates in the fine-grained beds suggests a) efficient carbonate leaching (unless the lower gravel deposits) by acid water in peat wetland environments and b) the dominance of phyllosilicates as source of fine-grained materials (crystalline rocks of the Aare massive).

The scores of Factor 1 (Fig. 1), defined by the strong negative loadings of Al, K, Ti, Fe and Si and the positive loading of TOC, evidences minor aggradational pulses inside the overbank deposits, which are characterized by the progressive decline of the aluminium silicate content and increase in organic matter at the top of each pulse.

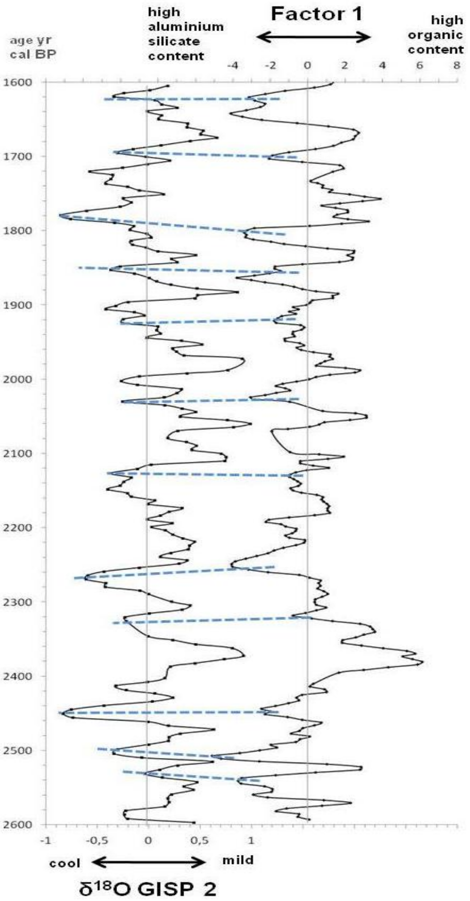

Fig. 1. Correlation between geochemical proxies (Factor 1 scores) of core AA-2 and $\delta^{18}O$ GISP2 record, Greenland. Time series are 3-data smoothed.

4.1.2. Correlation and periodicities

Figure 1 provide visual correlation from 2.6 to 1.6 kyr between the geochemical proxy of core AA-2 of the Hasli valley expressed by factor 1 and the $\delta^{18}O$ values of the GISP2 record of the Greenland Ice sheet (Reimer et al., 2004). Higher silicate content from aggradation phases correlates with cooler climate in Greenland whereas organic horizons (soil formation) correlate with milder climate pulses.

Because of the quasi-cyclic pattern of the Factor 1 (Fig. 1) possible correlation with the Greenland Ice record, spectral analyses were performed. The harmonic analysis (Fig. 2) was applied to detect periodicities in the time series in the presence of noise. According to the results the sedimentary record of core AA-2 show periodicities around 60, 80, 100 and 205 years for the period from 2.6 to 1.6 kyr which are very similar to the cycles obtained from the GISP2 record (69, 81, 105 and 208 yrs; Stuiver et al., 1997), the radiocarbon anomalies (81, 104 and 211 yrs; Reimer et al., 2004) and the North Atlantic Oscillation (65, 80 and 100 yrs).

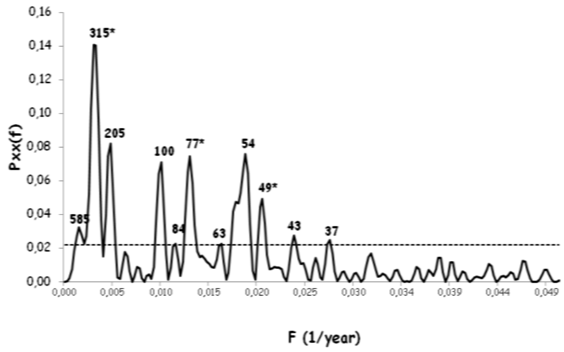

Fig. 2. Harmonic analysis for core AA-2. Dotted line represents critical level for the Siegel test and significant frequencies are shown in years. Peaks with asterisk represents false-alarm according to the red noise.

4.2. Core AA-5 (0.7 kyr-present)

4.2.1. Sedimentary record

The 10 m deep core AA-5 located at the southern valley margin reflects in general low energy deposition environments. Sand and silt beds are separated by 14 organic and peat horizons. Chronological model from 2.5 kyr to present was performed by 6 AMS radiocarbon ages. Below the depth of 218 cm carbonates are leached. To investigate the geochemical pattern excluding these major facies changes, the present paper examines the alluvial archive of the last 0.7 kyr (from 217 cm to the surface; Fig 3). TOC values of four organic beds range between 4 and 11 %. These periods of soil formation are interrupted by a total of 23 flood layers, divided into 3 intensity levels according to the macroscopic analysis of grain-size. Factor 1 which explains 44.6 % of the variability of the geochemical properties of the samples, is defined by the strong negative loading of the phyllosilicate components (Fe, Ti, K, Al), whereas Si and Ca indicate not significant loadings.

4.2.2. Paleoflood and climate proxies

Figure 3 shows the quasi cyclic variability of the scores of Factor 1 (values plotted reverse). Minima scores represents silty beds rich in phyllosilicates and organic matter, related to soil formation (in situ), soil erosion in the catchment, and deposition of fine grained material yield from areas with crystalline rock. Because of the distal location (southern valley margin) of the core site with regard to the mapped main Aare River paleochannels, smaller floods contributed to low sedimentation rates. According to figure 3 these reduced floods phases correlate to high Total Solar Irradiance (Steinhilber et al., 2009) and higher summer temperature reconstructed from oak ring width chronologies of central Europe (Büntgen et al., 2011).

Maximum scores of factor 1 were obtained in beds dominated by coarse grained flood layers (Fig. 3) which are defined by the highest Si/Ti and Ca/Ti ratios. Furthermore, correlation matrix shows negative coefficient R of -0.58 between Si and TOC. According to these relations, floods with high flow velocities deposited medium and coarse sand overbank layers of resistant siliciclastic grains (e.g. quartz), eroded from the hole catchment. The providence of coarse carbonate grains is related to the limestone areas of the lower catchment. The aggradation of these paleoflood deposits occurred during periods with cooler summer temperature and reduced solar irradiance (Fig. 3). However, the latest flood period from 1820 to 1880 cal yr BP apparently shows a time lag of 20 or 40 years with regard to the cool pulse indicated by the TSI and T_{JJA} curve. Thus the question arises, if the chronological control of the “high resolution” alluvial archive can provide precise flood chronology. There exist two arguments that support the validity of the paleoflood chronology (Schulte et al., in preparation):

1. With regard to the last 300 years, flood layers of Aare River have been successfully calibrated by historical documents (since 1480 AD) and instrumental data.
2. Comparison of Factor 1 with the annual temperature of Europe according to the multi proxy reconstruction of Luterbacher et al. (2002) shows very close correlation since 1500 AD (450 cal yr BP) and highlights the correspondence between the flood cluster (described by the negative Factor 1) and negative annual temperature anomalies during the 19th c.

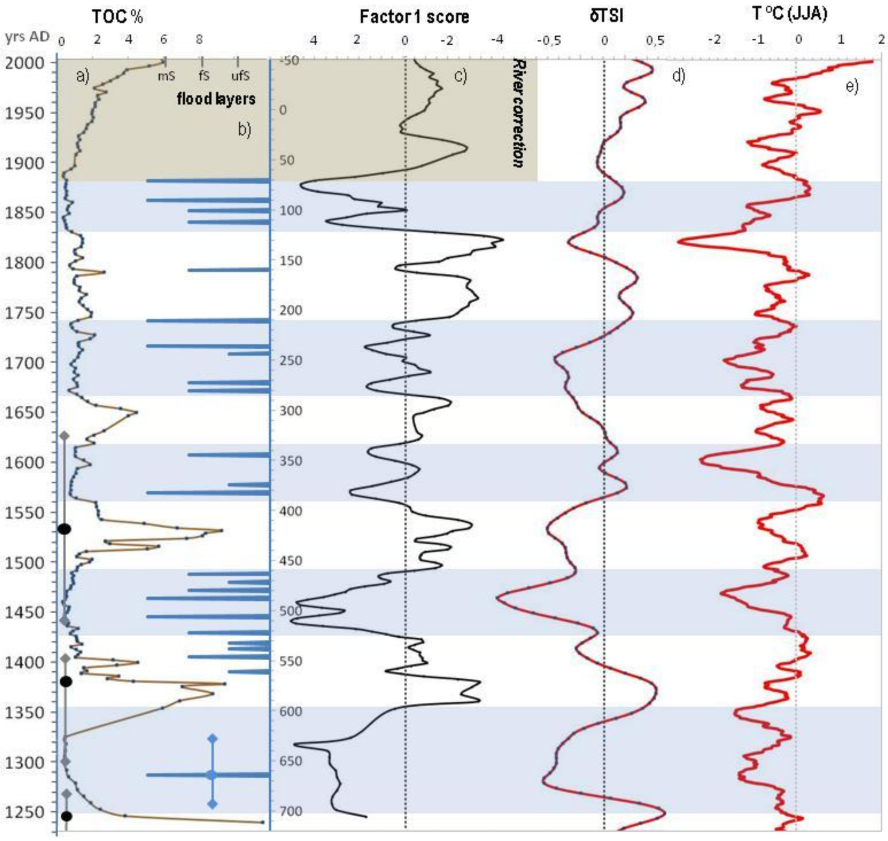

Fig. 3. Correlation between paleoclimate records and alluvial flood plain proxies of core AA-5, Lower Hasli Valley. Flood periods are shaded in blue color. a) Total carbon content (TOC); b) Flood layers. Intensity according to grain-size; c) Sample distribution according to scores of Factor 1 (3-data smoothed); d) Total Solar Irradiance (Steinhilber et al., 2009); e) Summer Temperature reconstructed from oak ring width chronologies of central Europe (Büntgen et al., 2006).

5. CONCLUDING REMARKS

The two high resolution alluvial flood plain sedimentary records provide evidences that with regard the time windows 2.6 to 1.6 kyr and 0.7 kyr to present, flood dynamics increased during cooler climate pulses.

The mechanisms of the aggradation processes are influenced by the North Atlantic dynamics as inferred from the similar periodicities of NAO and the fan delta proxies. However, paleoflood events are not only controlled by summer climatic conditions, but also by other seasonal, annual and pluri-annual phenomena such as snow cover and glacier dynamics, etc.

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