catchment areas. Its magnitude was probably comparable to one from the same area in July 1432, which was considered to be a "millennial flood".

For historical and recent floods, their social dimension is important. Consequences caused by historical floods can be divided into two groups (Wanner et al., 2002, see table 1): (i) short-term consequences (e.g. destruction of houses, streets and bridges, breakdown of water supply) (ii) medium-term consequences (e.g. shut down of industrial plants, soaked pastures, animal diseases).

Confronted with the harm caused by catastrophic floods, people are eager to get specific information and rapid support. Examples from Switzerland show that in addition to assistance from political authorities, media fund raising campaigns have been very successful. It becomes apparent that risk management, when consistently utilised by the political authorities, has strengthened the bonds of national unity.

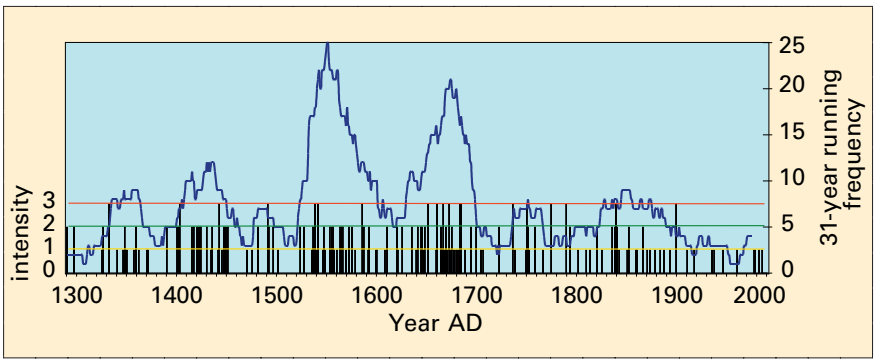

Fig. 2: Flood patterns of the river Pegnitz in Nuremberg (Germany) from 1300 to 2000. The altitude of the bars is proportional to the severity of the events (see Table 1). The curve displays 31-year running averages. Two distinct phases of high flood frequency stand out during the main phase of the Little Ice Age between 1550 and 1700.

Outlook

Historical climatology contributed significantly to the extension of our knowledge about historical floods in Europe for the pre-instrumental period. Flood frequency, seasonality, severity and impacts, as well as trends related to anthropogenic climate change, are all prime subjects for study by historical climatologists. Some historical events serve as analogues for recent floods and well documented recent events are important for understanding similar floods in the past. In these studies, variable anthropogenic effects in the catchment areas such as changes in land use, in riverbeds, in stream regulations and infrastructure (dams, reservoirs, etc.) should be taken into consideration. The value of historical flood evidence lies in its use for flood risk assessments and in helping to prepare flood-prone zones for maximum floods that are documented within the last centuries. These long-term records may reduce uncertainty in hydrological analyses and decrease losses of human lives and property.

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Reconstructions of Minimum Glacier Extensions in the Swiss Alps

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The advance and retreat of alpine glaciers indirectly reflects the natural variability of Holocene climate. Using different methods (analysis of historical sources, dating of trees and soil; Zumbühl and Holzhauser, 1988), we aim to reconstruct glacial fluctuations in order to verify Holocene climate variation.

In order to correctly interpret the current rapid glacier retreat in contrast to the previous maximum extent in 1850/60, it is important to know the Holocene minimum and maximum extent of alpine glaciers. The maximum advance of post- ice age alpine glaciers is well-documented by the high mark of moraines. In contrast, the glacial minimum, that is, the minimal glacial extent between two advances, is not well documented by moraines and is therefore difficult to determine.

The glacial minimum can be demonstrated and dated either by fossil soils and trees that surface at the melting ice edge (Holzhauser, 1984), or by the use of historical documents (Zumbühl, 1980). We provide two examples of how the glacial minimum during the Little Ice Age could be reconstructed using appropriate historical pictorial sources.

The Great Aletsch glacier in 1755

Due to a legal dispute between the Wallis townships of Ried-Mörel, Mörel und Bitsch on one side, and Naters und Rischinen on the other side, we know the extent of the Great Aletsch glacier in the middle of the 18th century. The parties concerned disputed the ownership of some grassland on the western slope of the Riederhorn mountain. An initial court hearing took place in 1684, and a second hearing took place 70 years later from 1754 to 1755. Three generations later, from 1855 to 1856, a third hearing took place.

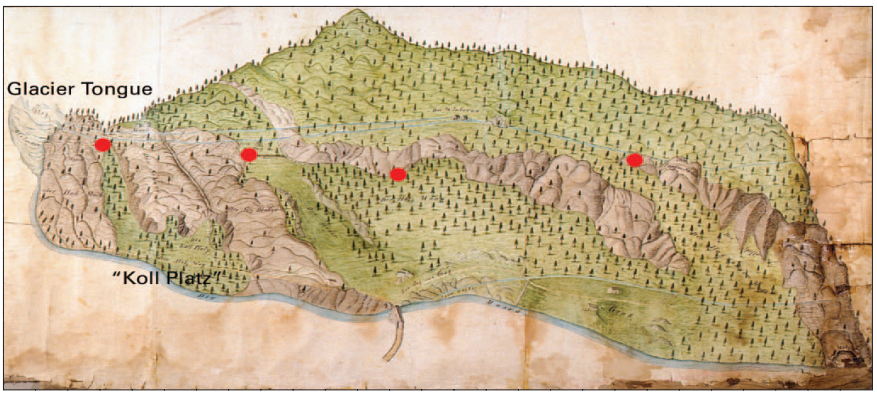

Fig. 1: The tongue of the Great Aletsch glacier in 1755 (middle left). This diagram, made in 1855/56, is a faithful reproduction of the original diagram from 1755. The year numbers mentioned in the text are circled in red (124 x 67 cm; Kantonsarchiv Sion, Plan divers, No. 42).

The complete records of this legal dispute have been kept in the town archives of Mörel and Naters (Holzhauser, 1984). In addition to written documents, it turns out that there is also a map from the Wallis cantonal archive in Sitten (Fig. 1), on which the western flank of the Riederhorn (clearly recognizable as the highest peak) is depicted. The Massa, the outflow of the Great Aletsch glacier, forms the lower border of the area portrayed. Fortunately, on the extreme left side of the picture, the ilustrator has depicted the tongue of the Great Aletsch glacier. The area is heavily forested, as evidenced by the numerous stylized trees even in the direct vicinity of the tongue of the glacier, on "Koll Platz." This observation is especially important for the interpretation of glacial history.

The connection between the map and the court records was not initially evident because the documents were archived in different locations. Also, the diagram was not dated. In order to assign a date to the glacier depicted, it was necessary to have a more exact age for the map. Analysis of the court records showed that first, the area referred to in the court records was identical with that pictured on the map, and second, the local names on the diagram (e.g. "Koll Platz") were also mentioned in the court records. Upon closer analysis of the map, four numbers corresponding to years could be recognized; these lay approximately in a straight line. From left to right, these are: 1756, 17 + 56, +1755 and 1756 (Fig. 1). The cross by the middle numbers led us to suspect that they could be boundary markers. This suspicion was confirmed through the analysis of written documents. In the court verdict from 1754/55, it was recorded that the boundaries must be carved into the rock. In the last court hearing from 1855/56, the year numbers were recorded on the diagram using the same notation as was used to carve them on the actual site. As to when the diagram originated, it must be the date of the last court hearing, namely 1855/56. However, this date is unsatisfactory, because in the middle of the 19th century, the glacier was demonstrably greater than pictured on the map. How can this paradox be resolved?

The solution was found, in another map in the town of Naters. This map is very similar to the one mentioned above, except that it consists of India ink on parchment, is not colored and does not include any year numbers. Apparently this parchment diagram dates from 1754/55, when it was submitted by the town of Naters to the court. It is the one often mentioned in the court records from 1855/56. The map pictured in Figure 1 is thus a later, faithful reproduction of the original parchment, and was used by the towns of Ried-Mörel, Mörel and Bitsch during the court hearing of 1855/56. Thus it is also clear why the extent of the glacier tongue in the reproduction corresponds not to that of the glacier in 1855/56, but rather to that of 1755. The topography is astonishingly well recorded. Therefore it is possible to relatively accurately estimate the extent of the glacier tongue in 1755. The Great Aletsch glacier at that time is of a magnitude comparable to that of 1890, and was thus 900 to 1000 meters shorter than during its last maximum extension during the Little Ice Age in 1859/60. During this time, the end of the glacier reached

Fig. 2: The Lower Grindelwald glacier in 1794, ending on the Schopffelsen. Oil painting by Josef Anton Koch (88,5 x 122,5 cm; Muzeum Narodowe we Wroclawiu, Wroclaw Polen).

"Koll Platz". As mentioned above, this area is forested on the diagram. This implies that the Great Aletsch glacier not reached this extension since long before the middle of the 18th century.

The Lower Grindelwald glacier between 1794 and 1826

During the Little Ice Age, the tongue of the Lower Grindelwald glacier often advanced into the valley, ending near the town of Grindelwald. Since the end of the 18th century, this glacier has thus been one of the most well-known and most frequently visited glaciers in the entire alpine region. This glacier is also exceptional in that it is represented in numerous (more than 360 pictorial sources before 1900) historical pictorial and written sources, some of which are of high quality. The abundance of sources for the last 300 years facilitates precise historical reconstructions, something that is not possible for most other alpine glaciers. The lower Grindelwald glacier remained in the area of the "Schopffelstterrassen" for a long time, approximately 600 m behind its greatest extent during the Little Ice Age (LIA) in 1600 and some 1250 m in front of its current tongue (see cover picture).

A LIA glacial minimum can be verified for the lower Grindelwald glacier, due to many high quality pictorial sources from the beginning of the 18th century. The minimum extension is depicted in a beautiful oil painting, painted by the classicist and realist Joseph Anton Koch (1768 – 1839) (Zumbühl, 1980: 191 K.38.3 and Fig. 2). Although the ice stream does not cover the entire canvas, and although the composition makes it look "small" and visually less attractive than the tail of the glacier in the valley floor, the illuminated ice stream is actually the focal point of the picture. Koch painted this work in Rome in 1823, based on a watercolored and gouached pencil drawn nature study completed 29 years earlier (in 1794). The eastern part of the glacier ends on the lower "Schopffelsband", a good 410 m behind the maximum extension of the last advance from 1778/79. The western tongue of the glacier has already

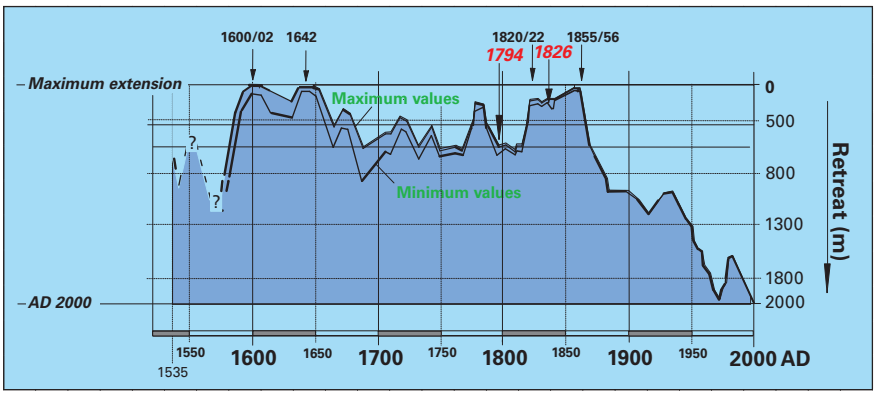

Fig. 3: Lower Grindelwald glacier: advance and retreat periods from AD 1535 - 2000 (after Zumbühl, 1983 and Pfister et al., 1994)

retreated enough to partly reveal the mountain-facing terrace of the upper "Schopffelsen", and therefore lies a further 300-350 m behind the eastern glacier front. Koch painted the topography of the boulders and the glacial edge so accurately that this information could be recorded in a map (Zumbühl, 1980).

By 1808, the Lower Grindelwald glacier had retreated. This is recognizable in a fine outline etching from J. J. Biedermann (Zumbühl, 1980:192 K.46). The glacial advance from 1814 to 1820/22, that led to the buildup of the glacial "tail" (a prominent ice feature that ends well ahead in the valley floor) is also well documented. In the older literature, it is reported that perhaps the glacier reached its greatest extent in the 19th century (Zumbühl, 1980: 43). Despite these written references, in spite of pedological and dendrochronological analyses, and in spite of an analysis of the moraines pictured in the foreground, it is not possible to make a definitive statement. On the other hand, Samuel Birmann of Basel (1793-1847) has numerous watercolors from 1826 (see cover picture) that strongly argue that the maximum LIA-extent was not reached at this time. This artist's drawings constitute the most exact topographical documents that have ever depicted the glacier; they are qualitatively absolutely equivalent to photographs (Zumbühl, 1997). On Birmann's watercolored pencil drawing of September 1826, taken from the Grindelwald parsonage, the advancing lower glacier, as well as the foreground with a clearly recognizable moraine system, is beautifully depicted (Zumbühl, 1980:193 K.60; see cover picture). The ice front at that time clearly already ended behind the moraine system, although the exact distance varied. In the middle of the foreground, moraines that were probably left by the 1820/22 glacial advance can be seen. On the west side (right in the cover picture) against the "Nellenbalmfelsen", the glacier advanced less and is here at least 250 m behind the moraine system of an older LIA-maximum (probably from 1600/02). The fact that there is wood between the ice front and the moraines conclusively eliminates the hypothesis that there was a historic maximum extension of the lower Grindelwald glacier in 1822 (Fig. 3).

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