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A 1600-year seasonally resolved record
of decadal-scale flood variability from the Austrian pre-Alps

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DR1, DR2, DR3, DR4 and DR5

DR1. INTRA-BASIN CORRELATION OF DETRITAL LAYERS COVERING THE LAST 100 YEARS

Investigating the spatial distribution of detrital layers within the lake basin based on detailed intra-basin correlation by using microscopic analyses allows tracing back the different types of detrital layers to their source regions. In turn, this provides information on sediment transport mechanisms and depositional processes.
Twelve short gravity cores (42-103 cm length) along two transects were obtained from Lake Mondsee **(Fig. DR1)**: a North-South transect across the southern lake basin (A-B) and a Northwest-Southeast transect from the northern to the southern part of the lake basin (C-D). Both transects meet at the location of the long piston core (Mo-05P3). Within the annually laminated lake sediments found in each of these gravity cores, nine detrital layers of facies type 1 and three of facies type 2 can be distinguished and used for correlation along the transects (Swierczynski et al., 2009). The two facies types exhibit distinctly different proximal-distal distribution patterns allowing to distinguish between two sediment transport pathways: (1) facies type 1 layers originate from the Griesler Ache River (C-D) and (2) facies type 2 layers originate from the Kienbach Creek (A-B) discharging into the lake from the south.

Transect A-B: All cores from the southern lake basin exhibit both types of detrital layers. However, only facies type 2 layers exhibit a clear pattern in thickness distribution. Close to the mouth of the Kienbach Creek (ca 400 m north), type 2 detrital layers are between 0.4 and 30 mm thick and contain coarse-grained (100-200 µm) clastic material and plant fragments (e.g. leaves). In cores further north including the master core (800 m north of the mouth of the Kienbach Creek), the correlating layers are thinner (0.2-6 mm) and consist of finer clastic material (50-100 µm), clearly indicating the Kienbach Creek as source region. This interpretation is confirmed by the predominantly dolomitic composition of these layers reflecting the Kienbach catchment geology.

In contrast, type 1 detrital layers are generally thinner and do not show a clear thickness pattern along the A-B transect. This points to a more distant source and excludes the Kienbach as source for these detrital layers. This is further supported by their mixed siliciclastic- dolomitic composition, which distinctly differs from the largely dolomitic type 2 detrital layers.

Transect C-D: Cores from the northern lake basin close to the delta of River Griesler Ache (ca 500 m east of the mouth of the river) are correlated with cores in the transition to the southern lake basin located ca 1.7 km and 2.4 km further southeast. In the near-delta cores 31 coarse-grained (100-200 µm) detrital layers (up to 8 mm thick) have been identified in the time interval A.D. 1940-2005. Only six of these layers correspond to layers in the more distal coring sites in the southern lake basin indicating the Griesler Ache as source. This is further supported by the mixed siliciclastic-dolomitic composition reflecting the mineralogy of the Griesler Ache catchment. In none of the near delta cores in the northern basin type 2 detrital layers occur. This excludes reworking of sediments from the Griesler Ache delta of the northern lake basin as triggering process for these layers.

DR2. COMPARISON OF DETRITAL LAYER OCCURRENCE WITH HISTORICAL FLOODS EVENTS

All independently dated type 1 detrital layers during the last 100 years correspond either to high-magnitude summer floods (A.D. 1936, 1954, 1959, 1997 and 2002) or snow melt events in spring (A.D. 1910, 1928 and 1994).
For some time intervals before instrumental monitoring, i.e. the 15th and 16th centuries, we can compare our detrital layer record with available historical flood data for the adjacent Traun River (Rohr, 2006; Rohr, 2007) **(Fig. DR2)**. Detailed reconstructions based on historical documents reveal that high magnitude summer floods occurred in two phases at the end of the 15th century (e.g. A.D. 1478, 1492, 1499 and 1501) and during the later 16th century (e.g. AD.. 1567, 1569 and 1572). The older interval coincides with the higher detrital layer frequency in episode FE1 (A.D. 1480-1520) suggesting intensified regional-scale flooding at the beginning of the LIA. The younger River Traun flood period likely correlates with the increase in detrital layer frequency commencing in the late 16th century. However, the increase in flood layers at that time appears not as strong in the sediment record and thus has not been classified as distinct flood episode. Unfortunately, there are no historical flood data available for the period after A.D. 1600 until the beginning of instrumental measurements.

DR3. HUMAN ACTIVITY AS RECORDED BY POLLEN DATA AND HISTORICAL CHRONICLE*S*

Human impact in the Lake Mondsee region is well reflected in a pollen profile **(Fig. DR3)** from the Moosalm peat bog located ca 5 km southeast of Lake Mondsee (Draxler, 1977). The Moosalm pollen record exhibits generally low non-arboreal pollen (NAP) not exceeding 5% until ca A.D. 1600 indicating that human impact in the Mondsee region remained low to moderate until that time. Nevertheless, in the period between 2800 cal. years B.P. (base of pollen zone IX) and A.D. 1600 four intervals of slightly increased NAP values appear. Since even in these intervals NAP values stayed below 5%, human impact in the catchment must be considered as low. The first two of these intervals are related to pre-Roman and Roman settlements between 500 B.C. and A.D. 200 (Kunze, 1986). These intervals are followed by a period of again very low NAP values corresponding to the migration period and the associated recovery of natural forests (*Fagus*, *Picea*) in the Lake Mondsee region (Draxler, 1977) and central Austria (Nicolussi et al., 2005). The third interval of slightly higher NAP values appears around A.D. 750 and coincides with peaks in herbs and the first appearance of cereals and *Rumex*. This interval corresponds to the time when the Mondsee monastery was built (A.D. 748). Despite the first appearance of cereals and *Rumex*, the abundance of tree pollen was still high indicating a still predominantly forested landscape. These data are in good agreement with historical chronicles, reporting that the monastery declared forest protection (Kunze, 1986). A low to moderate human impact on forests at that time is further confirmed by an unchanged composition of tree species in the pollen record. Therefore, we rule out human impact as a cause for the observed higher flood layer frequency between A.D. 700 and A.D. 750 (FE4). This is further corroborated by the earlier increase in flood layer frequency which commenced a few decades before the foundation of the monastery at A.D. 748. The fourth interval of increased NAP values at around A.D. 1300 coincides with a known phase of forest clearing in the Alpine realm (Brosch, 2000; Kaplan et al., 2009). However, since NAP still did not exceed 5% we assume that human impact remained low to moderate in the catchment of Lake Mondsee region during this period. Only around A.D. 1600 (pollen zone X in **Fig. DR3**) the Mondsee region experienced for the first time a pronounced increase in NAP exceeding 10%. Since that time increasing abundances of *Picea* pollen further indicate a principle change in forest management. The onset of an intense use of forests and the cultivation of *Picea* for salt production date during the late 16th century has also been reported also in historical chronicles (Kunze, 1986). Interestingly, the frequency of flood layers did not increase during times of most intense human impact on the vegetation in the catchment (all six flood episodes FE1 – FE6 occurred before A.D. 1600). This is a clear indication that human impact on flood layer generation and frequency in the Lake Mondsee sediment record is negligible.

DR4. THE HOLOCENE MAGNETIC SUSCEPTIBILITY RECORD

Magnetic susceptibility data for the entire Holocene measured at 1 mm resolution reveals generally low values and exhibits no significant variations and trends **(Fig. DR4)**. This indicates both, relatively low detrital matter deposition at the coring site and the absence of major fluctuations and trends in detrital matter flux during the Holocene. This is in contrast to other pre-Alpine lakes like, for example, Lake Bourget (Debret et al., 2010). A possible explanation for the specific behaviour of the Lake Mondsee record might be the comparably small size of the influent river Griesler Ache. In comparison with the Rhone River feeding Lake Bourget the Griesler Ache has a much smaller transport capacity for suspended detrital matter. The absence of a significant increase in the amount of detrital matter in the Lake Mondsee record even during times of human settlements in the catchment makes us confident that human induced erosion can be largely excluded as a major bias of detrital matter supply and that it is thus even more unlikely that human impact had an influence on the frequency of flood layer occurrence.

DR5. µXRF TI COUNTS VERSUS ANNUAL PRECIPITATION OF THE LAST 100 YEARS

In order to identify the relation between detrital input and precipitation, we correlated the µXRF Ti record with a 100-year instrumental precipitation data available from the climate station Kremsmünster, located ca 70 km NE of Lake Mondsee **(Fig. DR5.1)**. We consider this station as representative for the Lake Mondsee region based on the good correlation ($r=0.81$, $p<0.0001$) of precipitation data from Kremsmünster station with those from Thalgauberg station in the Lake Mondsee catchment for the period 1976-2003. The µXRF Ti data have been anchored to the varve time scale by aligning the rise in calcium counts measured together with titanium to the calcite sub-layer as observed in the thin sections. Since both the sediment slabs for µXRF scanning and thin sections have been prepared from the same sediment sample a precise link of the data is ensured **(Fig. DR5.2)**. Regular peaks in Ca counts reflect biochemical precipitation of calcite in the lake water column. Since the onset of calcite precipitation occurs in spring (April/May), we calculate the annual mean of Ti counts for each varve cycle starting with the rise in Ca counts. Given the 200-µm resolution of the element scans and the mean varve thickness of 2 mm the average number of µXRF data points per varve is about ten. The resulting annual averages of Ti counts are correlated with the annual precipitation data calculated from May to April of the following year **(Fig. DR 5.2)**. This division has been chosen to obtain best comparability of the climate and sediment-derived data. The Pearson's correlation coefficient of $r=0.34$ reveals a significant correlation at a 99% level between the annual mean of Ti counts and the annual precipitation sum suggesting a strong influence of rainfall on the average background detrital matter flux.

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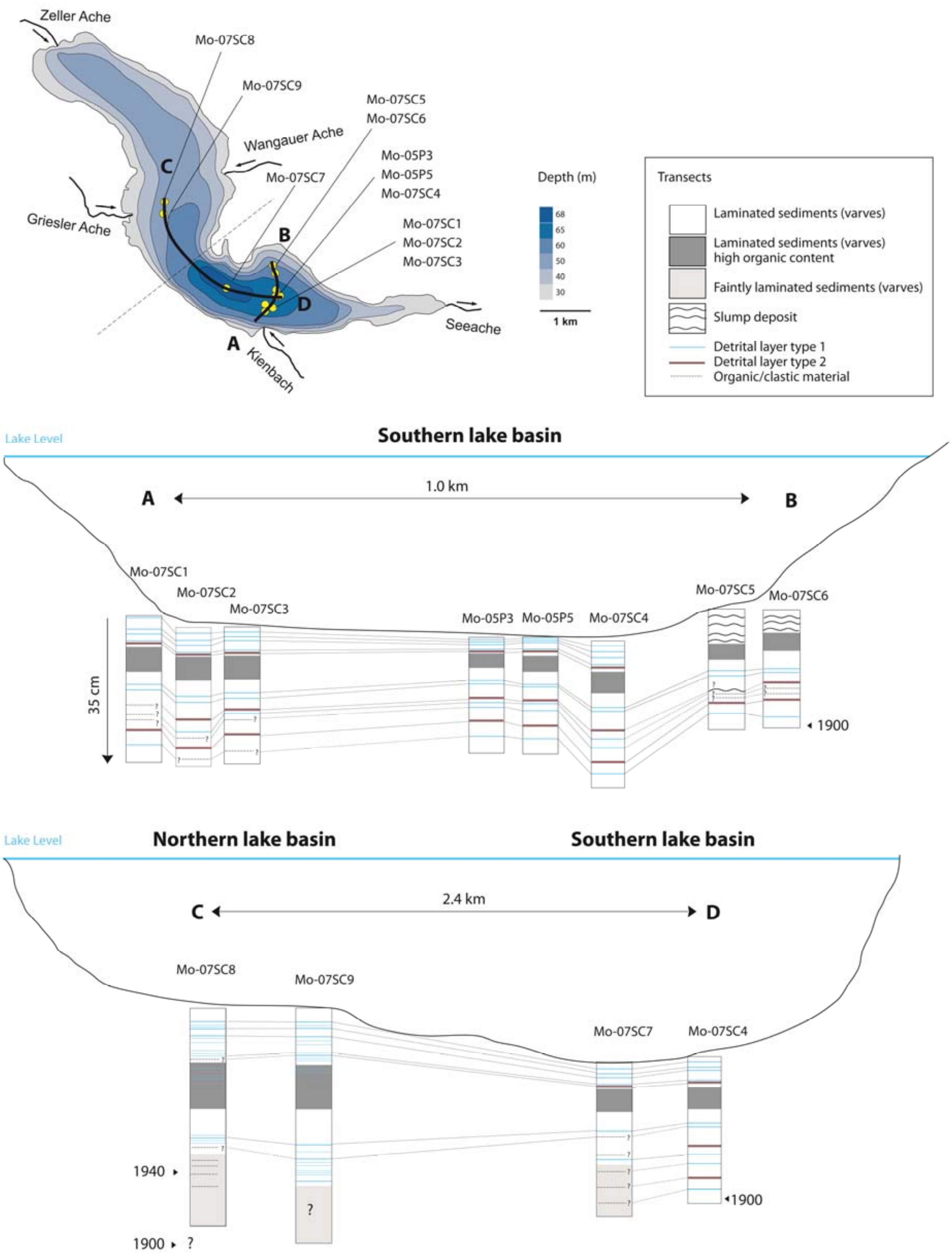

Fig. DR1. Intra-basin correlation of detrital layers along two transects across the southern (A-B) and from the northern to the southern lake basin (C-D) based on microscopic inspection of each core (modified after Swierczynski et al., 2009). Note: due to the higher sedimentation rate in the near-delta locations, cores Mo-07SC8 and Mo-07SC9 comprise shorter time interval spans.

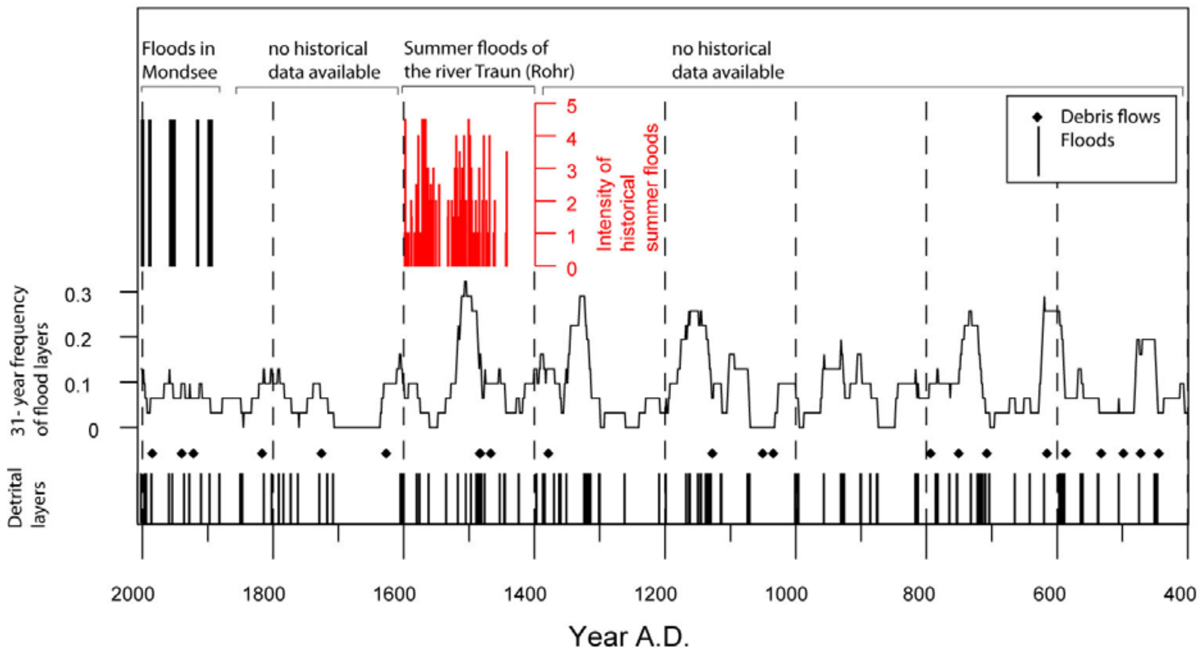

Fig. DR2. Comparison of detrital layers in the Lake Mondsee record (bars: flood layers, diamonds: debris flow layers, 31-year running mean frequency of detrital flood layers) with available information about historical floods in the Traun River during the 15th and 16th century and with lake level-highstands from Lake Mondsee indicating floods during the 20th century (Hydrographic Service from Upper Austria).

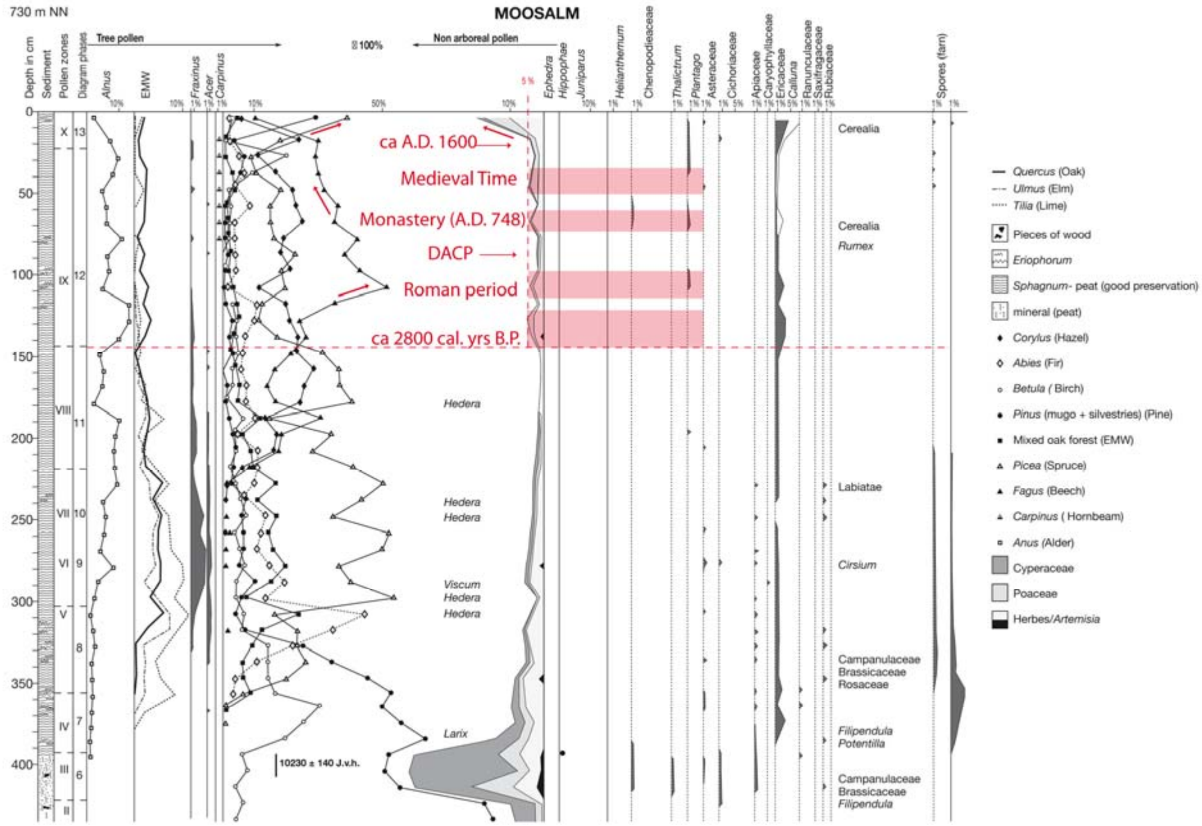

Fig. DR3. Pollen profile from the Moosalm peat bog (modified after Draxler, 1977), showing generally low values of non-arboreal pollen (< 5%) and indicator plants (e.g. *Plantago*) human for human impact until about A.D. 1600. The intervals of minor increases of human-induced vegetation changes from 2800 cal. years B.P. until A.D. 1600 are indicated by red rectangles. Low non-arboreal pollen contents prevail during the Dark Ages Cold Period (DACP).

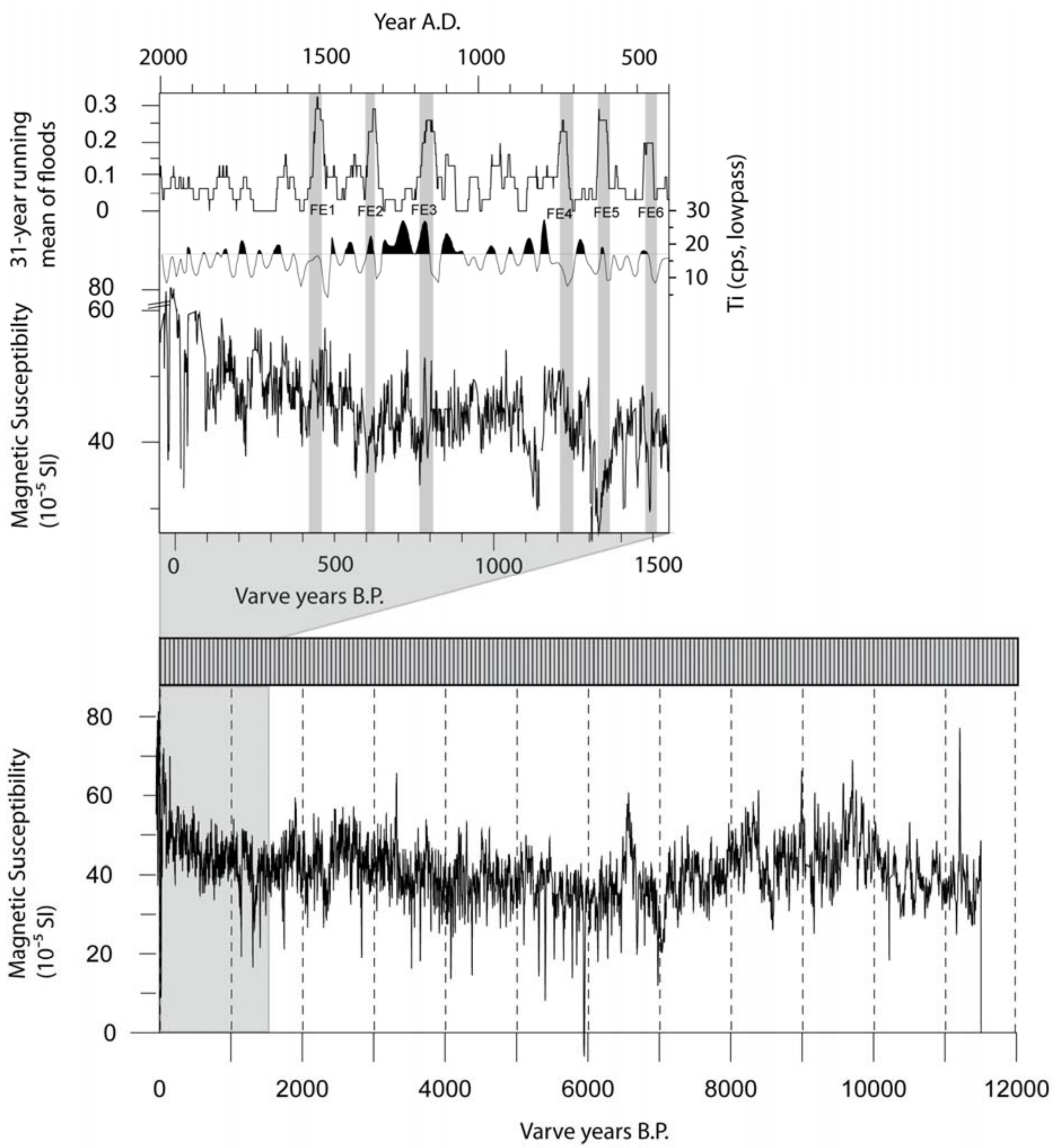

Fig. DR4. Magnetic susceptibility of the entire Holocene sediment record indicates generally low and rather constant contents of detrital material without any pronounced fluctuations. There is no correspondence to the described flood episodes FE1 - FE6 as indicated by grey bars in the upper graph (zoom-in).

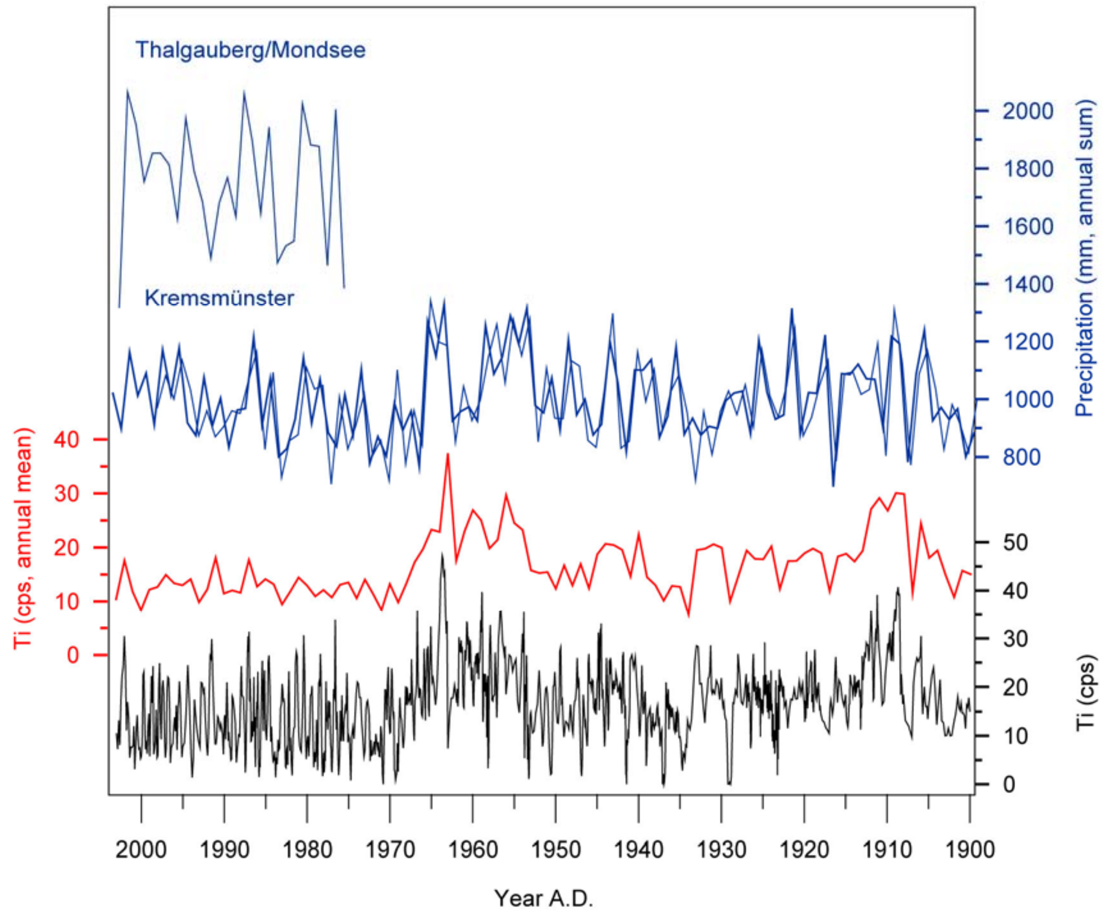

Fig. DR5.1. Comparison between the Lake Mondsee µXRF Ti record as a proxy for detrital material supply and annual precipitation data from the climate stations Kremsmünster and Thalgauberg (Mondsee). Thick blue line: annual precipitation May-April, thin blue line: annual precipitation January-December.

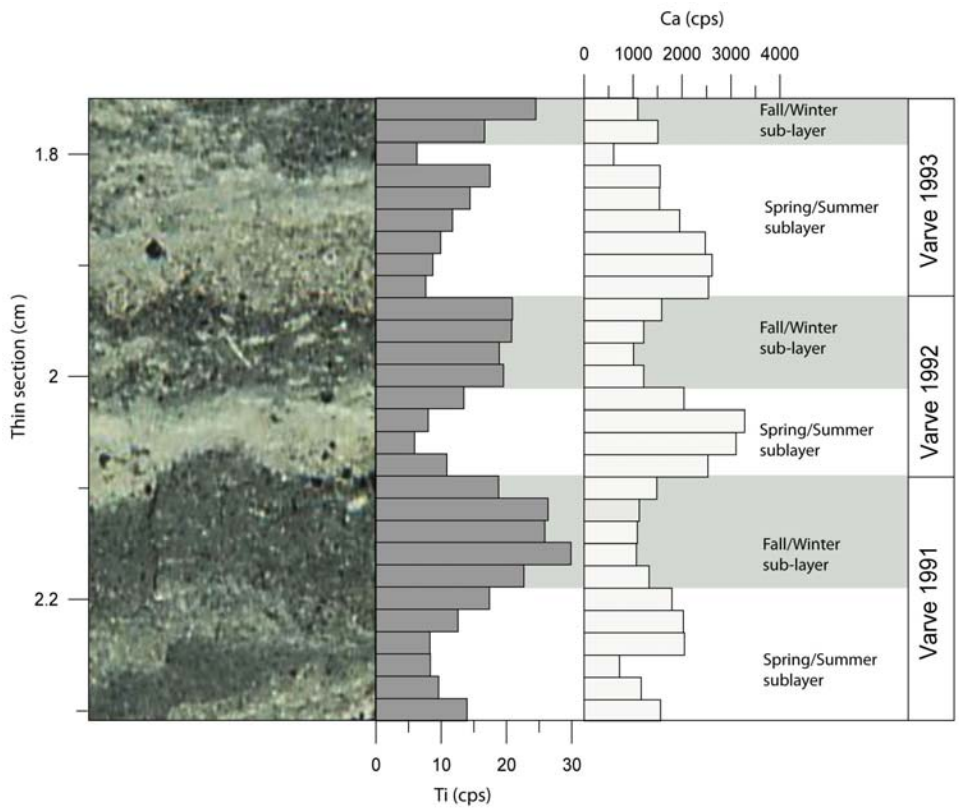

Fig. DR5.2. Anchoring of µXRF element counts at sub-seasonal resolution to the varve time scale demonstrated for varve years 1991, 1992, and 1993. Each varve cycle starts with an increase in Ca counts reflecting biochemical spring/summer calcite precipitation, whereas highest Ti counts occur in the fall/winter sub-layer. Mean annual Ti counts have been averaged over one varve cycle. Note: each bar represents an individual µXRF data point of a continuous line scan at 200 µm resolution.