Cross-community workshop on past flood variability
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Book of Summaries

Session I

Session I: What archives can be used to reconstruct past flood variability?

This session will review and introduce different types of flood archives, with focus on archive-specific advantages, challenges and limitations (e.g. length and temporal resolution of records, reliability of detection of flood events, calibration and reconstruction of flood magnitudes).

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Documentary flood records, so much more than just a flood magnitude

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The last decade has witnessed severe flooding across much of the globe, but have these floods really been exceptional? Instrumental river flow series rarely extend beyond 50 years, with short instrumental series presenting considerable challenges in determining flood risk from high-magnitude floods. Historical documentary records provide a valuable insight, not just into the quantitative elements of flood measurement (magnitude, discharge, level or extent), but also information on date/timing, damage, impacts, responses and the generating mechanisms, which are often unavailable from other sources used in palaeoflood reconstruction. This presentation explores how documentary information can be used in palaeoflood estimation, but also how the additional information available within documentary accounts can provided a fuller picture of extreme historic flood events which can be used in flood risk management.

Contribution of documentary archives to past flood variability. Limitations and opportunities in Western Mediterranean Basin

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Information about historical floods contained on documentary sources is already known and explored for research on climatic variability. Western Mediterranean Basin offer an excellent framework for this research with very large documentary collections well organized in historical archives.

Recent history of this activity can be show to know about results related to contributions in climatic variability. But this experience is also useful to analyze other aspects.

Methodological aspects: Documentary series are complex and tedious with a high time consumption. Data collection requires application of criteria and methods to have a correct efficiency. Definition of documentary series, periods, information to be extracted, management of information (databases, formats), are aspects under discussion.

Limitations: Basic problem to obtain information in documentary sources is time required for acces to information (manuscript and printed sources). Lenght and quality of documentary series is enoughly good to obtain long flood series for periods close to a millennium. But it requires time and funding programmes to cover this research effort.

Challenges: Flood variability is not only related to atmospheric processes. Documentary sources can contribute in study of these new "dimensions" of flood variability: Surface processes, providing details of overflow patterns for hydraullic reconstruction. Temporal patterns rainfall/flood and land use changes for hydrological reconstruction. And human factors affecting flood frequency and severity: urban growing, land use management, infrastructures, human activities on floodable areas, evaluation of impacts. Direct and permanent collaboration between thematic research groups from different disciplines is a basic requirement for future fruitful activities.

Experiences for spanish mediterranean basins obtained from PREDIFLOOD Project can be used as a framework to analyse and discuss about limitations and potentialities of documentary sources in this complex and transdisciplinar study on flood variability and interactions between natural and human factors.

Floods in Central Europe since AD1000
Data, methods and results in the context of modern risk analysis on the basis of the Collaborative Research Environment tambora.org

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There is a unique and rich culture of historical written documents on flood events in Central Europe since AD 1000. A short description is given about the specifications of such historical sources which usually cover a broad field of different hydrological, climatological and societal information of the flood events.

In a next step, the existing workflow is presented, which includes critical source analysis, derivation of indices and the classification of single flood events. The classification scheme presented takes into account the different temporal, spatial and societal dimensions.

Derived time series are presented covering the main climatic periods from the Medieval Warming over the Little Ice Age Climate into the Modern Warming. Some notes on the underlying climatological causes and their changes through time are given.

Examples are presented, in which major historical floods are brought into context with modern events to highlight the value of historical information for actual risk analysis and management. These findings summarize main results from a transnational French German research project on transnational flood risk management along the Rhine system.

A multi-secular database (AD 1300-2000) on the historical flood variability in the Lower Rhone Valley

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The HISTRHONE database (https://histrhone.cerege.fr) was built from a wide range of over a thousand different records distributed along seven centuries. A long historical and public recording prospection work was the basis of this project. The technical realisation was conducted at the SIGéo laboratory, Cerege, Technopole Petit Arbois in Aix-en-Provence (France).

For the poster, we will strive to develop three major aspects:

1. The wide range of research in documentary and historical sources survey: narrative sources available since the 14th century – technical sources, or similar, since the 17-18th centuries – Instrumental daily observations available since the end of the 18th c., or 1816, 1829 yr. according to the places of observation
2. The effort to make possible a cross-historical analysis of the data. From the four types of increase of the river flow (1009 events in total in the series), the three most severe flooding (517 events) can be subject to a safe statistical analysis since the 15th c.
3. The flood data analysis is related with a large quantity of metadata. The ices of river (174 episodes identified), the droughts and the rains (HISTRHONE include two complementary databases on the ice events and the drought episodes).

Such databases require comparisons with the other sites of flood studies and future prospects with the climate variability and forcing factors determining these evolutions.

BDHI: a French national database on historical floods

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In 2011, during the Preliminary Flood Risk Assessment (PFRA) of the European Floods Directive, a set of 176 flood events has been selected by the French Ministry of Environment (MEEM). A short description of the hydro meteorological conditions and the adverse consequences of each flood event have been included into regional technical reports in 2011. It was followed in 2014 by the publication of a book gathering all descriptive information with a set of maps and pictures illustrating the characteristics and the impacts of the flood events. In parallel, MEEM decided to launch a national database on historical floods (BDHI). After a preliminary work devoted to the definition of the database schema and its relative functionalities (2010-2011), a database prototype has been developed in 2012-2014 by a team composed of researchers in computer science and hydrology plus an independent consultant on historical research. Information from the 176 flood events has been integrated into the BDHI database and is officially on line since March 2015 (http://bdhi.fr/).

The BDHI database structure (figure 1) was designed to ensure a correct description of flood events as well as to provide access to original source documents. All flood information may be accessible by simplified or detailed queries, or by a spatio-temporal explorer. By the end of 2016, public will have a free access to the 176 flood events that have been selected during the PFRA 2011. The BDHI database is an efficient tool for data exchange, based on Internet and database features. Over the next years, the main challenges will be to implement a process for enlarging the contributions to the main stakeholders with flood knowledge, and to propose linkage between the various websites providing flood information to public.

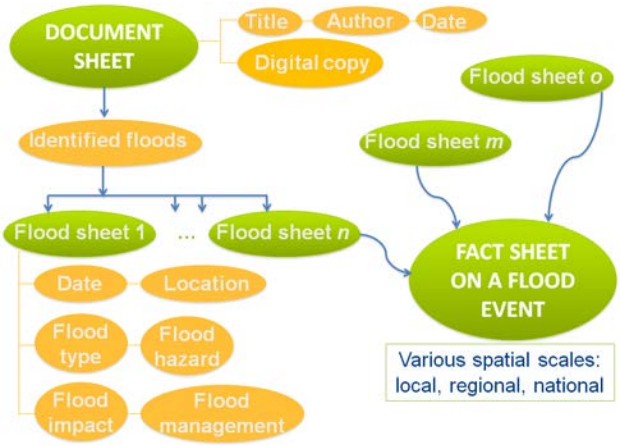

Table 1. Database structure of BDHI

Trees as flood sensors

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In many settings, trees growing on floodplains provide an important source of indirect evidence that may be used to infer the occurrence, extent, and magnitude of floods prior to direct observations. That evidence may take several forms, including external scars caused by abrasion or impact from floating debris, anatomical changes within the annual growth increment following prolonged stem or root inundation, or tilting or uprooting due to the hydraulic pressure of floodwaters. Likely the most useful characteristic of paleoflood studies based on floodplain trees is their relatively high temporal resolution and dating accuracy compared to most other methods. Dendrochronological methods can routinely date past floods to the year of their occurrence and, in rare cases, can estimate the timing of floods that occur during the growing season to within two weeks. This high degree of chronological control, which is surpassed only by that provided by direct observation or instrumentation, can be used to determine whether floods in separate watersheds were synchronous or offset by several years and test hypotheses that suppose linkages between extreme floods and specific forcing mechanisms. Furthermore, the wide geographic distribution of tree species with dateable rings combined with the broad suite of methods available to examine interconnections between floods and tree growth allow this style of paleoflood hydrology to be applied to many settings that are not suitable for techniques that depend on geological evidence. Future paleoflood research involving tree rings will need to strike a balance between improving our understanding of the biological and fluvial processes that link tree growth to past events, and providing answers to questions about flood dynamics and hazards that are needed to safeguard people and property from future floods.

Paleoflood reconstruction in the Indian Himalayas based on tree rings

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Floods are a common natural hazard in the Western Indian Himalayas. Given the assumption that ongoing and future climatic changes may impact on extreme precipitation and on the onset of monsoon patterns, the implementation of adaptation policies in this region is critically needed in order to improve local resilience against floods of Himalayan communities. However, its successful implementation is highly dependent on system knowledge and hence reliable baseline data of past disasters. Here, we demonstrate how tree rings can be used to obtain new knowledge on past flood incidents which should then have an impact on flood hazard assessments.

Paleoflood studies carried out in Himachal Pradesh (Indian Himalayas were using disturbed trees growing in floodplains to reconstruct the regional flood activity in this poorly gauged region. We focused on six different river reaches in four different catchments. Trees have been sampled using increment cores. The dating of flood incidents was based on the identification of disturbances in tree-ring records such as injuries and callus tissue. Stable river cross-sections were surveyed to estimate flood discharge as indicated by the height of scars. This information was then included as non-systematic data in a regional flood frequency framework by using Bayesian Markov Monte Carlo Chain algorithms. The impacts of the non-systematic record in flood quantiles were assessed at return period of 50 and 100 years.

Thirty-four unrecorded flood events at the study sites were defined since the early 20th century. We observe that 56% of the floods occurred simultaneously in more than two catchments, and that in 15% of the cases more than four catchments were affected. By contrast, 44% of the event years were restricted to one specific catchment, corroborating the assumption that large-scale atmospheric conditions and specific weather and/or geomorphic conditions may operate as triggers of floods in the Kullu district. The inclusion of peak discharge data related with these ungauged extreme flood events into the regional flood frequency evidenced that flood hazard was systematically underestimated. The new flood regional assessment is being used to determine flood risk at Himachal Pradesh and define key adaptation measurements to improve the resilience of local communities for the next decades.

Anatomical variability in tree-rings related to large-scale flooding

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Trees growing on flooded sites can record major flood events as inter-and intra-annual variability in size, shape and arrangement of vessels in the annual xylem growth increment. As part of an NSF-funded project to develop tree-ring records of past flooding, we have made collections of several oak species (e.g., Quercus lyrata, Q. macrocarpa) at four sites in the Mississippi River Basin. At each of these sites sampled trees exhibit notably anomalous anatomy of growth increments formed in years coinciding with major floods. We have used these "flood rings" to develop a regional chronology of potential flood events in the basin for the past several hundred years and compare this chronology with the instrumental and historical record of flooding as well as potential large-scale forcing mechanisms. We have also analyzed earlywood vessel width as a proxy for flooding and find that although this variable reflects only a fraction of the annual-growth increment it strongly reflects tree response to flooding at several sites so far examined and therefore warrants additional investigation as a potentially useful and easily developed proxy for flood impact on trees.

An evaluation of the Nepal Himalaya tree-ring network and its potential application to paleodischarge studies

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Climate in the Nepal Himalaya is changing at a rate that is greater than the global average.The brevity of climate records, however, poses a challenge to gauge the rate and causes of the recent variability. We synthesized tree-ring data across Nepal to help direct future research in paleoclimatology. The Nepalese network consists of 55 ring-width chronologies mostly developed from Abies spectabilis, Pinus roxburghii and Tsuga dumosa, and spans an elevational gradient of ~2800 m (3120 - 4100 m). A single national composite (median) chronology spanning 1158 years (AD 856 to 2013) was developed. The strength of the common signal shared between neighboring trees (RBAR) was 0.35, and we did not identify any consistent differences in signal quality between species, elevational positions, and regions. However, pine trees in central Nepal growing at elevations of approximately 3000 m have the greatest RBAR values, ranging up to 0.7. Although the median percentage of locally absent rings across the Nepal Himalaya network was only 0.12%, missing rings were more common from AD1817 to 1819 and during 1999. Again, the pine trees at lower
elevations had the highest percentage of missing rings. The Nepalese ring-width chronology showed remarkably reduced growth from 1809 to 1822, and that suppression was ubiquitous across all Nepal and observed in all major species. This sharp reduction in growth lasting over a decade might be due to the effects of the unknown AD 1809 eruption and the Tambora 1815 event. There is a clear trend towards increasing growth since the 1970s, becoming even more pronounced since 2000. The high elevation A. spectabilis exhibits the greatest increase in growth in the last decade.

Tree-ring records in Nepal have been used to examine tree-climate relations, reconstruct past temperatures, assess vegetation dynamics, and to date archaeological sites. But so far no attempt has been made to reconstruct river discharge. The pines growing in Nepal's dry river valleys might be sensitive to river flow, and the strong common signal observed for this species may suggest pines hold significant potential for dendrohydrological studies.

Speleothems as Records of Discrete Flood Events

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The use of speleothems as paleoflood archives is in its infancy but the method shows the potential to provide high-resolution paleoflood reconstructions (Dorale et al., 2005; Dasgupta et al., 2011; Frappier et al., 2014; Gonzalez-Lemos et al., 2015). In some cave systems, floodwaters periodically submerge stalagmites, disrupting their growth and coating their surfaces with sediment. When floodwaters recede and stalagmite growth resumes, some of the sediment on stalagmite caps may become entombed by subsequent carbonate deposition, thereby preserving a record of the flood event. Visual and/or geochemical identification of these layers, coupled with 234U-230Th dating of the speleothem carbonate, can therefore provide a continuous and high-resolution record of flood activity through time. For this method to be successful, several criteria must be met. First, the stalagmites must be suitable for high precision dating despite the introduction of detrital Th by flood sediment. Second, historical records of rainfall and in situ monitoring should be used to calibrate conditions required to initiate flooding. Third, replication of flood signals from multiple coeval stalagmites should be performed in order to assess biases in the respective records. The impacts of the geometry, location, and growth rate of each stalagmite should also be considered.

As an application of this technique, cave flooding events spanning the last two millennia were reconstructed from a suite of precisely-dated and fast-growing aragonite stalagmites from cave KNI-51 in the central Australian tropics (Denniston et al., 2015). This record has now been extended to 3600 yr BP using three additional stalagmites, each of which contains multi-decadal to centennial variations in flood frequency. One of these stalagmites is marked by a trend toward reduced average flood occurrence rates over time while another sample which partially overlaps in age contains nearly identical sub-centennial variations but does not trend toward lower values. The most likely explanation for this discrepancy involves the former having grown above average flood height, thereby restricting its ability to record more frequent, smaller events. Analysis of regional climatology suggests that tropical cyclones are responsible for the largest extreme rainfall events, and thus are interpreted here to represent the dominant origin of cave flooding.

References:

Dasgupta et al., 2011, EPSL, 300, 46.
Denniston et al., 2015, PNAS, 112, 4576.
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Tracking extreme precipitation events in speleothems: examples from the Alpine and Mediterranean regions

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Speleothems have gained increasing interest as paleoenvironmental archives as they can be dated accurately using U-series. The variegated proxies preserved in speleothems have commonly been used to reconstruct 1) hydrological changes; 2) paleotemperatures and 3) vegetation dynamics at seasonal to millennial time-scales. Here we focus on the record of extreme recharge events which can be identified from petrographic and geochemical changes.

Because semi-arid environments are particularly sensitive to small hydrological changes they represent ideal test sites for identifying extreme precipitation events. Preliminary results obtained from periglacial and Mediterranean regions are compared with available proxy-records. Whilst our data do not allow for resolving daily weather extremes they may provide useful chronological anchor points for decadal to centennial humid phases which may have led to increased frequency in flooding events.

Flood records from river sediments and the geomorphology of climate change impacts

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River sediments deposited during floods provide the most direct and unequivocal evidence of past extreme hydrological events in floodplain environments. Since the 1980s a growing range of depositional niches have been investigated most notably slack water sediments in canyon rivers, overbank sediments on floodplains and in palaeochannels, and boulder berms in upland catchments. These individually or collectively can be used to reconstruct event scale flood records over time periods ranging from centuries to millennia. This paper provides a critical review of the fluvial sedimentary archive of floods and highlights the importance of documenting river channel and floodplain erosion and sedimentation dynamics over the period of flood record. This equally and probably more critically, applies where documentary, epigraphic or archaeological evidence is used to reconstruct flood records in rural and especially urban locations. Currently most of these studies assume, usually without geomorphological investigation, that channel and floodplain dimensions and morphology have not changed over the period of flood record. This creates an unknown uncertainty that compromises flood series extension, particularly in floodplain environments with critical or high value infrastructure assets. In the light of current and predicted climate change impacts on river systems worldwide, it is important that geomorphologists provide information to flood managers and environmental regulators not only on the frequency and magnitude of extreme hydrological events but also the effects of major floods and changing flooding regimes on the river channel and floodplain morphodynamics.

A multi-dating approach applied to historical slackwater flood deposits of the Gardon River, SE France

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A multi-dating approach was carried out on slackwater flood deposits, preserved in valley side rock cave and terrace, of the Gardon River in Languedoc, Southeast France. Lead-210, caesium-137 and geochemical analysis of mining-contaminated slackwater flood sediments have been used to reconstruct the history of these flood deposits. These age controls were combined with the continuous record of Gardon flow since 1890 and the combined records were then used to assign ages to slackwater deposits. The stratigraphic records of terrace GE and cave GG were excellent examples to illustrate the effects of erosion/preservation in a context of a progressively self-censoring vertically accreting sequence. The sedimentary flood record of the terrace GE located at 10 m above the channel bed is complete for years post-1958 but incomplete before. During the 78-year period 1880-1958, 25 floods of a sufficient magnitude (> 1450 m3/s) have covered the terrace. Since 1958, however, the frequency of inundation of the deposits has been lower, there have only been 5 or 6 floods in 52 years large enough to exceed the necessary threshold discharge (> 1700 m3/s). The progressive increase of threshold discharge and the reduced frequency of inundation at the terrace could allow stabilisation of the vegetation cover and improved protection against erosion from subsequent large magnitude flood events. The sedimentary flood record seems complete for cave GG located at 15 m above the channel bed. Here, the low frequency of events would have enabled a high degree of stabilisation of the sedimentary flood record, rendering the deposits less susceptible to erosion.

Radiocarbon dating are used in this study and compared to the other dating techniques. Eighty percent of radiocarbon dates on charcoals were considerably older than those obtained by the other techniques in the terrace. On the other hand, radiocarbon dating on seeds provided better results. This discrepancy between radiocarbon dates on charcoal and seeds is explained by the nature of the dated material (permanent wood vs. annual production and resistance to degradation process). Finaly, we showed in this study that although the most common dating technique used in paleoflood hydrology is radiocarbon dating, usually on charcoal preserved within slackwater flood sediments, this method did not permit to define a coherent age model. Only the combined use of lead-210, caesium-137 and geochemical analysis of mining-contaminated sediments with the instrumental flood record can be applied to discriminate and date the recent slackwater deposits of the terrace GE and cave GG.

Late Holocene Paleoflood History of the Cauca River, Colombia (S.A)

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A set of Late Holocene (<3000 yr BP) fluvial terraces outcrop at 6°30-6°35 N/75° 48´W, and at 430 m asl in Colombia, South America. These terraces were formed in a narrow valley controlled by faults and low elevation hills of metamorphic rocks, and during a time when the river was naturally damned by tectonic forces. Stratigraphic, sedimentologic, geochemical and paleontologic (diatoms and organic matter) analyses were performed in seven different sections. 14C was use to date most sections. Terraces are composed by laminated silty clay, most common at the base of the successions, overlain a top unit composed of sand and silt beds that are massive, fining and coarsening up, interbedded with paleosols. Channels also occur. The basal unit was deposited on a distal floodplain where small ponds were frequently formed. The upper unit was deposited proximal to the channel and probably represent lateral sand bars. The change from the laminated basal unit to the upper inter-bedded sand/silt/paleosol indicates a change in the hydrological regime to stronger but less frequent river pulses. Most paleosols represent poorly developed entisols, however their thickness indicates development under undisturbed, quiet conditions. The seismic history of the area indicates that active seismicity occurred throughout the late Holocene, this is also evident in the soft sediment deformations observed in the studied sections. The river will soon be damned, few kilometres downstream of our studied area, as part of a large scale electrical project “Hydro-Ituango”. No estimations of paleofloods magnitude or frequency or paleoseismicity have been considered in this project. “paleo” studies have never been used in Colombia to assist in the development or management of any hydrological project. Since electrical dams most likely will increase in the future, we hope that our study can serve to create awareness about the advantages of knowing the long-term behaviour of rivers and their basins.

Paleosols and floods throughout the Holocene in the Southern Amazonia foreland Basin

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Alluvial plains are formed with sediments that rivers deposit on the adjacent floodbasin, mainly through crevasse splays and avulsions. Based on the floodplain sedimentation patterns of large rivers in the southern Amazonian foreland basin (SAFB), it has been suggested that alluvial plain sediment accumulation is primarily the result of river crevasse splays triggered by above normal precipitation events due to La Niña.

In the first part of my presentation, using Landsat images from 1984 to 2014, I analyse the behaviour of all the twelve tributaries of the Río Mamoré with a catchment in the Andes. I show that these are very active rivers and that the frequency of crevasses is not linked to ENSO activity. In the second part, I will look at the Holocene sedimentary archives built by these rivers. The mid- to late Holocene paleo-channels of these rivers are located tens of kms further away from the Andes than the modern depozone. Based on 27 radiocarbon ages from paleosols intercalated with fluvial sediments, I try to reconstruct the most important Holocene changes in the SAFB's floodplain dynamics.

I conclude that, on an annual to decade time scale, river sedimentation is controlled by intrabasinal processes, while the shifts in the depozone and the changes in river activity, which occur on a millennial scale, are controlled by climate and tectonics. Paleosols are valuable sedimentary archives that can help reconstruct alluvial plain dynamics on a millennial scale. We should define common protocols for paleosol sampling and analysis which can be used in different sedimentary basins across the world, allowing for meaningful comparison.

Extraordinary paleofloods response to Holocene climatic change over the East Asia monsoon zone: A case study from the upper Hanjiang River

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Slackwater palaeoflood deposits (SWDs) were identified in a bedrock gorge in the upper reaches of the Hanjiang River of central China. The Hanjiang River is the longest tributary of the Yangtze River, one of the most flood-prone rivers in China, and the main source of water for the South-to-North Water Transfer Project (SNWTP). A complete loess-soil profiles with Holocene palaeoflood SWD bedsets were found. Palaeoflood SWDs identified interbedded in the loess–soil sequence of late Holocene age within the cliff riverbanks were studied by field observations and laboratory analysis, including particle-size distribution and Optically Stimulated Luminescence (OSL) dating. Three extreme flood events documented by palaeoflood SWDs occurred in the Yanjiapeng reaches of the upper Hanjiang River. The discharge estimation associated with palaeoflood SWDs, indicates that the minimum flood peak discharges of these flood episodes range from 53,770 to 55,950 m3/s. The SWDs were OSL dated to between 3200–2800, 1800–1600 and 1000–900 a BP and these dates. These periods of increased flood magnitude coincide with contemporaneous global climatic events dated to 3100, 1800 and 900 a BP worldwide. These findings are of great significance in understanding the interactions between hydrological systems and climatic change in monsoonal zones.

Overbank flooding of the Mississippi River in the context of late Holocene climatic variability and land use change

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The Mississippi River valley is an economic artery of the United States that is heavily managed to provide flood control and maintain a navigable shipping channel. The river's current system of levees and spillway structures was devised nearly a century ago, and is based on a series of "hypo-floods" drawn from extreme rainfall events of the early 20th century. Yet, climate model simulations show that hydrological conditions for the next century are unlikely to resemble those of the past century, so the suitability of the current flood control system to withstand 21st century flooding is questionable. Here, we present initial results from a project that integrates new fluvio-lacustrine sedimentary records with climate model simulations to better understand the causes of extreme floods on the lower Mississippi River.

In our paleoflood records, flood events are characterized by turbidite facies identified using high-resolution laser particle-size analysis and elemental composition (XRF), and dated using radioisotopes (137Cs, 210Pb, 14C) and optically-stimulated luminescence (OSL) on quartz. Grain-size descriptors and elemental ratios of Zr/Fe and Fe/Rb are highly correlated, and are used alongside historical discharge records to develop a statistical model for reconstructing flood magnitude in prehistoric contexts. Geochemical analyses of sediments from the floodplains of major tributaries of the Mississippi are used to assess the systematics of 87Sr/86Sr, 143Nd/144Nd, 206Pb/204Pb, and 208Pb/204Pb across the basin, enabling identification of the synoptic patterns of individual paleo-flood events.

We investigate the dynamical drivers of past floods on the lower Mississippi using both reanalysis data and the last millennium simulation from CESM1 to find that increased likelihoods of extreme floods on the lower Mississippi River are associated with enhanced moisture flux over midcontinental North America that is controlled by the interaction of seasonally variable soil moisture over major tributaries with inter-annual (e.g., ENSO) and decadal (e.g., NAO, PDO) ocean-atmosphere variations. We also find preliminary evidence for increased frequencies of large floods following major human modifications to the Mississippi basin after the mid-19th century. The insights gained through integrated paleoflood data-model comparison will improve seasonal to decadal forecasts of flood risk for the largest river system in the United States.

Extending the palaeoflood record: assessing the reliability and viability of palaeoflood records

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Flood frequency during the Holocene is of particular interest to the scientific community as well as governments and flood risk agencies. Recent floods in the UK have caused widespread damage to property and risk to people's lives. It is necessary to establish if the recent floods are in fact unusual or if they are to be expected during the natural climate cycle. In order to achieve this geomorphological evidence from the fluvial environment can be used to gain a record of past flooding not covered by the instrumental record. Data may be collected from sediment cores or other flood deposits that have been radiocarbon dated using organic material. The methods of data collection have uncertainty associated with them because the context of the organic material is often unknown. There is also uncertainty associated with the methods used for accelerator mass spectrometry radiocarbon dating and the use of the calibration curve. In earlier palaeoflood studies, histograms with large bin sizes were used to look for patterns in uncalibrated dates. More recently, cumulative probability density functions are used to represent calibrated radiocarbon dates. However, this method has been criticised because peaks in the outputs may not necessarily reflect increases in the flood frequency but rather could reflect more samples at that time period. Also, uncertainty is not presented with this method. This study tests the different methods of data analysis and attempts to introduce a new Bayesian approach to create a reliable flood frequency and magnitude record.

Evidences of past-floods in Pleistocene Ratnapura, Sri Lanka

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Sri Lanka is located in the southern tip of the Asia and surrounded by the Indian Ocean. This island is size of 65,610 Km2 and nourished by South Asian Monsoon systems. Basically four Monsoon seasons supported throughout the year; North-East Monsoon, South-West Monsoon and two Inter-Monsoons. Due to geographical location other precipitations such as…..are being received. 103 river basins are located in the country including 17 large rivers. Also 22,000 internal water bodies has been identified from historical period.

Floods can be identified as a most common hazard of the country and a recent flood risk analysis shows 2003 was the most devastated flood occurred nearly 150 lives lost and generally 30 – 40 deaths recorded by other seasonal serious floods. Otherwise general floods taken few lives. Nearly 350,000 people affected by each of 2003 and 2011 floods and generally 100,000 – 200,000 people get affected by seasonal serious floods.

Palaeo-floods are a fresh research topic to the country even though many palaeo-research and archaeological outputs delivered. AMH of Mesolithic culture aged more than 40,000 years is a significant finding in Asian context. Pleistocene vertebrate fossils also highlighted in local context.

Multi-proxy analysis reconstruction of palaeo-environment and climate study has been concentrated from Pleistocene to Holocene and historical period in Sri Lanka. As a part of study evidences of palaeo-floods have been discovered from Ratnapura area. Ratnapura is very famous for gems and during gem mining evidences of Pleistocene proxy records have been identified. Recording of Pleistocene floods is one of them and it can be reconstructed to identify status of past monsoon system. Most significant observation is it can be projected to suggest extraordinary palaeo-floods occurred during Pleistocene period, which is leading to open wide range of research implementation.

Millennial–scale flood variability in the Iberian Peninsula from Lake Records: a review

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Changes in flood frequency and intensity have a strong impact on land degradation and soil erosion, key environmental problems in Mediterranean mountains. Floods also represent an increasingly significant hazard in populated areas. A review of well-dated Holocene lake records in Iberian mountains provides some long-term series of flood frequency at millennial and centennial scale. In Sanabria Lake (NW Iberian Peninsula) discrete silt layers intercalated in the organic-rich Holocene deposits reflect large flooding events of the Tera River ca 10.1, 8.4, 7.5, 6.2, 5.7-5.6, 4.6, 4.2, 3.7, 3.3, 3.1, 2.7, 2.5 and 2.0 cal ka BP and during the Little Ice Age (LIA) (ca. 1670 -1760 AD). In the Pyrenees, the Basa de la Mora sequence shows intensified run-off processes at the Holocene onset, rapid hydrological shifts from 9.8 to 8.1 cal ka BP, a decrease in sediment delivery during a high lake level phase (8.1 – 5.7 cal ka BP) and the end of the humid period at 5.7 cal ka BP. The varved Montcortés sequence shows a conspicuous period with reduced precipitation events between 1.5 and 1.2 ka BP while the largest hydroclimatic variability occurred during the Medieval Climatic Anomaly. This paleoflood record also shows stationary conditions during the LIA with two periods with increased rainfall frequency and intensity at the onset and termination of the LIA (AD 1347 - 1400 and AD 1844-1894). In the Lake Estanya sequence increased runoff occurred around 8.6, 6.2, 4.8, 1.2 cal ka BP and during the LIA. In the Iberian Range, increased sediment delivery has been identified during both more humid periods (e.g, LIA with stronger rainfall and higher flood frequency in possible association to solar forcing) and more arid periods (e.g., MCA, increased storminess, higher soil erodibility when vegetation cover was reduced in relation to human impact).

Holocene Iberian changes in intensity and timing of paleohydrological periods show similar regional centennial-millennial scale dynamics than western Mediterranean records, but point more to Atlantic versus Mediterranean controls than simple latitudinal boundaries. Values of quantified sediment delivery during floods are comparable with those from monitored Mediterranean mountain catchments.

Is deeper the better? The potential of deep coring in deep large perialpine lakes to get plurimillenial flood records

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I propose to explore the potential of large perialpine lakes to reconstruct past flood patterns over the whole Holocene period. In that aim, I'll review the available results around the Alps as well as from similar lake systems around the world. I will emphasize spatialization questions both in terms of catchment-scale and lake basin-scale representativeness of geological flood records. I'll also point the technical limitations and opportunities to get the necessary cores from such large, high sedimentation rates systems.

Patterns and controls of Holocene flood frequency across the Swiss Alps on the basis of 4700 lacustrine flood layers

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The frequency of large-scale heavy precipitation events in the European Alps is expected to undergo substantial changes with current climate change. Hence, knowledge about the past natural variability of floods caused by heavy precipitation constitutes important input for climate projections. We present a comprehensive Holocene (10,000 years) reconstruction of the flood frequency in the Central European Alps combining 15 lacustrine sediment records. These records provide an extensive catalog of flood deposits, which were generated by flood-induced underflows delivering terrestrial material to the lake floors. The multi-archive approach allows suppressing local weather patterns, such as thunderstorms, from the obtained climate signal. We found that flood frequency was higher during cool periods, coinciding with lows in solar activity. In addition, flood occurrence shows periodicities that are also observed in reconstructions of solar activity from 14C and 10Be records. As atmospheric mechanism, we propose an expansion/shrinking of the Hadley cell with increasing/decreasing air temperature, causing dry/wet conditions in Central Europe during phases of high/low solar activity. Furthermore, differences between the flood patterns from the Northern Alps and the Southern Alps indicate changes in North Atlantic circulation. Enhanced flood occurrence in the South compared to the North suggests a pronounced southward position of the Westerlies and/or blocking over the northern North Atlantic, hence resembling a negative NAO state (most distinct from 4.2 to 2.4 kyr BP and during the Little Ice Age). South-Alpine flood activity therefore provides a qualitative record of variations in a paleo-NAO pattern during the Holocene. Additionally, increased South Alpine flood activity contrasts to low precipitation in tropical Central America (Cariaco Basin) on the Holocene and centennial time scale. This observation is consistent with a Holocene southward migration of the Atlantic circulation system, and hence of the ITCZ, driven by decreasing summer insolation in the Northern hemisphere, as well as with shorter-term fluctuations probably driven by solar activity.

Diversity of the signature of floods within varves sediments of North America

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In this paper, we review four very different kind of floods recorded in varved sediments from North America, and comment on the potential links with the instrumental record. The first site is Lake Tuborg, Ellesmere Island in the Canadian high Arctic, which contains a record of the occurrence of past jokulhlaups, most probably the most powerful and catastrophic kind of floods. The second site is Mystic Lake, Massachusetts, USA, which contains a 1000-year long record of past Hurricane activity over New England. The third one is East Lake of Cape Bounty, Melville Island in the Canadian high Arctic that contains a 1750-year long record of summer rain events. The last one is Grand Lake, Labrador, Canada, that contains a 300-year long varved record; the varve structure, texture and geochemistry can be very nicely linked to a 50-year long instrumental record of water discharge.

The potential of fjord sediment geochemistry for high-resolution paleohydrological reconstructions

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Fjord sediments are increasingly used as high-resolution archives of past climate and environmental change. They are particularly suited for paleohydrological reconstructions because of their high accumulation rates (frequently > 1cm/yr), continuous deposition, and ability to record changes in river sediment input. As a result, fjord sediments are increasingly regarded as continuous and high-resolution recorders of hydrological variability, including floods, on par with tree-rings and varved lake sediments.

Fjords possess unique oceanographic characteristics. They are, for example, affected by large vertical salinity gradients, resulting in strong density stratification. As a result, sediment transport processes in fjords are relatively unique and clearly different from those observed in e.g., lakes. An accurate interpretation of fjord sediments in terms of past changes in hydrology therefore requires a comprehensive understanding of the variables that affect the composition of the sediment.

This presentation will discuss the processes that control the geochemical composition of modern sediments from the fjord-river systems of Chilean Patagonia, based on results obtained on river suspended sediments and on surface sediment samples collected along proximal-distal transects in selected fjords. Our results demonstrate that fjord sediment composition is primarily controlled by hydrodynamic mineralogical sorting, i.e., the intensity of river discharge. They suggest that concentrations in Fe, Ti and Zr are controlled by their association with heavy and/or coarse minerals, whereas Al is independent of hydrodynamic processes. Elemental ratios Fe/Al, Ti/Al and Zr/Al are therefore well suited to estimate changes in river discharge through time. These results have important implications for the interpretation of fjord sediment records in terms of hydrological variability. They show, for example, that the sensitivity of elemental ratios varies depending on distance from the river delta. While Fe/Al is linearly correlated with sediment input at distal sites, Zr/Al is best suited to reconstruct floods in proximal locations.

The last part of the presentation will focus on introducing ongoing collaborative efforts to (1) model the relations between river discharge and fjord sediment composition, and (2) apply these proxies to fjord sediment cores to reconstruct the occurrence of Glacial Lake Outburst Floods (GLOFs) in the vicinity of the Northern Patagonian Icefield.

Holocene floods in the inner Carpathian Region, Eastern Europe

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Rivers in the inner Carpathian region (Eastern Europe) are prone to large floods, induced by the peculiarities of the precipitation regime. Large rivers are subject to late spring through early summer floods, induced by precipitation maxima superimposed on melting of snow in the upper (mountainous) catchment areas, while small rivers are particularly subjected to convective storm-induced summer flash floods. As models suggest an increase in the frequency of extreme weather events on an overall warming trend, it is expected that spring floods will occur more frequently and summer floods could become both stronger and more frequent. In order to place the present-day and forecasted floods in a longer time-frame, we have initiated a study of floods on two catchments: a small one (P200 km2), subject of weather-induced flash floods, and a large one (10000 km2), with floods frequency and magnitude controlled by long term climatic changes. Sedimentological, morphological and chronological data from a small lake in Central Transylvania indicate high fluvial activity and flooding frequency at 10200, 4700, 2800, 1300 and 500 cal BP, possibly associated to increased moisture transport from the Mediterranean Sea (as seen in palaeoclimate reconstructions based on stable isotope analyses in nearby ice caves). In Northern Transylvanian, overbank floodplain sediments indicate an increase in the magnitude and frequency of flooding events after ca. 5000 cal BP, again correlated to increased amounts of precipitations and lowering winter temperatures, possibly associated to changes in moisture sources from the North Atlantic to the Mediterranean Sea. We tentatively suggest that an increase in snow accumulation in winter (resulting from low winter temperatures and increased transport of moisture from the Mediterranean Sea between November and January), correlated with an increase in early summer temperatures, could explain the higher frequency of flooding events in the late Holocene. Present-day climate data, as well as climatic models suggest that similar conditions are likely to become more frequent in the near future, thus triggering more frequent floods in the large basins in the region.

Mid to Late Holocene flood activity in Northern French Alps (Lake Savine)

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Over the last years our team developed a methodological approach based on high-resolution sedimentological and geochemical analysis of lake sediments to reconstruct past variability of flood frequency and intensity. Applied to 6 high-altitude lakes of the Western Alps, this aims to understand the response of flood activity to both Atlantic and Mediterranean climatic influences in mountain areas.

Our approach focused on four main challenges: (i) identify turbidites at the mm scale, ii) distinguish those induced by floods from those induced by other triggers, iii) provide chronologies with reduced uncertainties and iv) assess the potential impact of human activities on the recorded flood signal through different proxies (pollen, MNP, eDNA). Finally, the type of precipitation events (i.e. local convective or mesoscale advective events) triggering flood in the studied catchment was assessed for each flood record.

Here, we illustrate the developed methodological approach from a new lake sequence (Lake Savine) located at the French-Italian border that enables to reconstruct a 6kyr record of flood frequency and intensity. Weather reanalysis of historical floods recorded in the sediment sequence showed that the flood record represent past variability of both local thunderstorm and mesoscale events through “Lombarde-Type” events. The local human activity (i.e. grazing) was reconstructed through environmental DNA and shows that the erosion is mainly driven by the climate variability. Lake Savine flood chronicle presents high frequency and intensity events during cool periods, coinciding with low solar activity, as observed over the southern Alpine region; this interpretation is in good agreement with those observed for the last millennium from lake sediment. At 4kyr main paleohydrological transition observed in Mediterranean area seem to have an important influence in the Savine record, before 4kyr the flood frequency are in phase with flood frequency reconstructed in the northern Alps. This transition could illustrate a change between Atlantic to Mediterranean climatic influences on flood record in this part of the Alps.

Session II

Session II: How to develop a multi-archive approach?

This session will discuss approaches developed to overcome archive-specific limitations by combining multiple archives of the same type or different archive types — with the goal to strengthen the robustness of flood reconstructions. This theme also includes monitoring of modern processes and paleo-record calibration via instrumental data.

Authors	Title
Lothar Schulte	**The challenge of multidisciplinary reconstruction of paleofloods**
Gerardo Benito	Palaeoflood analysis from fluvial and lake records in Spain
Markus CZYMZIK	Calibrating detrital layers in varved lake sediments for quantified flood reconstruction
Tina SWIERCZYNSKI	Understanding floods and risks of the last 7000 years at Lake Mondsee
Richard CHIVERRELL	Quantifying magnitude and frequency of recent extreme floods (…)
Tobias SCHNEIDER	Ultra-high resolution flood history in lake sediments from SW Ecuador (…)

The challenge of multidisciplinary reconstruction of paleofloods

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In the context of global warming and related societal demand, the transfer of long flood series, which record also low-frequency extreme events, to public agencies is crucial for an accurate assessment of the most recent severe-catastrophic floods. However, the range of uncertainty and limitation of archives of different nature increase in general with age. In addition, catchment response can be strongly influenced by local physiographic parameters (differences in catchment lithology; altitudinal vegetation belts; topography; snow and glacier cover; periglacial and slope processes; intermediate sediment storage; catchment connectivity; base level changes, etc.), climatic conditions such as the unequal spatial distribution of precipitation caused by summer thunderstorms and advective rainfall events, and land-use changes (land-cover, mining, flood mitigation and management). Thus calibration of flood records by documentary, instrumental data, and different types of natural flood archives; spatial distribution of impacts and key changes of the geomorphologic and hydrological system; and analysis of atmospheric circulation modes are important in order to investigate (i) if paleoflood series are robust, (ii) catchment response occurs synchronously or asynchronously in basins with diverse features, size and location and (iii) which mechanisms and forcing (orbital, solar, climate, volcanic, land use, etc.) are involved in the control of flooding. To contribute to this discussion, the keynote explores the potential of different approaches performed in alpine and lowland basins.

Palaeoflood analysis from fluvial and lake records in Spain

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In Spain, palaeoflood studies from fluvial archives have been successfully applied in both large basins such as the Tagus, Llobregat and Segre rivers, and in small mountain basins of the Pyrenees. Paleohydrological studies in Iberian lacustrine sequences provide an excellent opportunity to reconstruct past hydrological balances during the Holocene. Nevertheless, only recently, palaeoflood records have been reconstructed from lake records in varved sequences (e.g. Moncortés Lake) and non-varved lakes (e.g. Taravilla and Sanabria lakes). In river channels, palaeoflood studies have been focussed on bedrock reaches based on palaeostage indicators , namely slackwater flood deposits accumulated at flow separation zones (eddy bars, flood benches). These palaeoflood investigations using palaeostage geological indicators can document the magnitudes of the largest floods over well-defined periods of time, and provide evidence of all other events below or above specified flow stages or thresholds. In the case of lake records, palaeoflood evidence is represented by detrital sediment inputs into the lake delivered by streams entering the lake. There is a need to calibrate these detrital layers with instrumental climate data to provide quantitative paleoflood reconstructions. Unfortunately this is often a complicated task due to uncertainties in the radiocarbon-based age models. Another limitation of lacustrine paleoflood sequences is that changes on land uses in the watersheds may affect the sediment delivery and runoff generation in the lake´s catchments. Although some attempts of comparison of fluvial and lake palaeoflood records have been performed at individual sites, there is a lack of studies dealing with regional analysis of palaeoflood multi-source chronologies. This presentation describes the theoretical difficulties related to the combined use of fluvial and lake palaeoflood chronologies, and it shows shared analytical methods for reconstructing flood chronologies and their temporal variability over the last millennia.

Calibrating detrital layers in varved lake sediments for quantified flood reconstruction

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Lately, three flood layer time-series from varved surface sediment cores from Lakes Mondsee (MO) and Ammersee (AS) and non-varved surface sediment cores from Lago Maggiore (LM) were calibrated against discharge records of the tributary rivers. This study evaluates similarities and differences in flood layer deposition in the three lakes and, thereby, the common potential for improved flood reconstruction. Calibrating the flood layer frequency time-series provided site-specific discharge thresholds of about 40 m3/s for MO, 125 m3/s for AS and 600 m3/s for LM above which the deposition of a detrital layer during a flood is very likely (MO: 92% coverage; AS: 71% coverage, LM: 78% coverage). Linear correlation between the detected discharge thresholds and mean and maximum discharges of the tributary rivers points to an influence of the river cross-sections on these values. Calibrating the flood layer thickness records against the magnitude of a triggering event revealed that (i) for about 20% of the flood layers (12.5 - 26.7%) the correlation between both variables is strong, (ii) for about 80% of the flood layers (73.3 - 87.5%) the correlation between both variables is weak or zero (r=0.04-0.41, rmean=0.24) and (iii) the thickest flood layer in each record is related to a disproportionate low magnitude flood (MO: 8.3 mm, 24.2 m3/s; AS: 47.1 mm, 103.1 m3/s; LM: 17.4 mm, 1100 m3/s). Air pressure anomaly composite maps for the MO, AS and LM flood layer frequency time-series provide physically consistent site-specific flood-prone atmospheric circulation patterns. Consequently, long flood layer time-series could provide information on past atmospheric circulation. This inter-lake comparison has shown that, although the processes of flood layer formation are partly site-specific, calibrating flood layer frequency and thickness data reveals common depositional mechanisms for all three sites. About 80% of the floods above a lake specific discharge threshold cause the deposition a flood layer, enabling decadal-scale flood frequency reconstruction. Only about 20% of the flood layer thicknesses are indicative of the magnitude of the triggering discharge event, inhibiting flood magnitude reconstruction.

Understanding floods and risks of the last 7000 years at Lake Mondsee

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Flood risk estimation is still based on the limited availability of flood damage data (i.e. a few decades in the best case), and therefore accounts large uncertainties in estimating the damage potential of low-probability high-impact flood events. Lake Mondsee sediments reveal a seasonally resolved 7000-year flood history recording highly variable flood frequencies through time. Interestingly, floods mainly occur during climate transitions to climate cooling, whereas flood remains lowest during warmest and coldest periods. Long flood series, such as sediment data provide useful information about flood occurrence on long time scales, which might help to improve the confidence for future predictions of flood risk in a warmer climate. However, bridging different types of data with different resolutions and uncertainties is a big challenge. The two-year project ‘FloodRisk-7000’ is motivated by the attempt to overcome methodological shortcomings by linking excellent sedimentological data and available socio-economical data sets. Upcoming challenges of the newly started project will be presented.

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Quantifying magnitude and frequency of recent extreme floods using lake sediment records from the UK

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Flooding in northwest England has been reconstructed from the coarse grained units preserved in lake sediment sequences at Bassenthwaite Lake, a record that includes the floods of December 2015 (Storm Desmond) and November 2009 and shows they were the most extreme in over 600 years. The inception and propagation of a lake sediment flood event horizon in the aftermath of the December 2015 storms in the UK will be explored as part of NERC Urgency Grant that focuses on the flood records in Bassenthwaite Lake, Brotherswater, Buttermere and Ullswater. We have installed traps and sediment monitoring on these lakes and will be examining how these new events develop into the sediment record.

For Bassenthwaite Lake linking our new sediment palaeoflood series to river discharges, the first assessment of flood frequency and magnitude based on lake sediments for the UK, shows that recent disastrous flooding in northern England was more extreme than revealed by standard hydrological approaches, making these events the rarest (Recurrence Interval >1:10000 years) ever recorded in the UK. Particle size characteristics of flood laminations, after correction for variations in the stability of catchment sediment sources, were correlated on a hydrodynamic basis with recorded river flows. The particle size flood record is underpinned by a robust chronology to CE1420 derived from Bayesian modelling (including modelled age uncertainties) of radionuclide (Pb210, Am241, and Cs137) dating and correlations to the rich history of metal (Pb, Zn, Ba and Cu) mining in the catchment accurately recorded in the sediment geochemistry. The sediment palaeoflood series reveals five flood rich periods (CE 1460-1500, 1580-1680, 1780-1820, 1850-1925, 1970-present), and these correspond with positive phases of reconstructed winter NAOI and other Atlantic circulation patterns. The hydro-climatology of the extreme events (top 1% of floods) in our series, show that 67% of floods have occurred in the 21st Century during a period of prolonged warmer northern Hemisphere temperatures and positive NAOI winter index. Climate model ensemble outputs for the Northern hemisphere forecast increased frequency and magnitude of positive NAOI, and warmer air temperatures; we infer from this that there will also be an increase in the frequency of extreme floods and flooding in general with concomitant impacts on communities and infrastructure.

Ultra-high resolution flood history in lake sediments from SW Ecuador of the past two thousand years: El Niño or not?

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The ENSO is a top priority in current climate change research. In particular, the event 2015/2016, which was one of the top three ENSO events since the beginning of the measurement period (www.climate.gov), showed the significance of this global ocean-atmosphere phenomenon.

Cajas National Park is a high altitude (ca. 3000-4300 m asl) Andean region in southwestern Ecuador characterized by hundreds of postglacial lakes. Rodbell et al. (1999) and Moy et al. (2002) related clastic layers in a sediment core from Lake Pallcacocha with El Niño events. They argued that these events, which increase convection over the Pacific Ocean, lead to enhanced precipitation on the western side of the Andes (based on precipitation data from the station Guayaquil at the shore of the Pacific Ocean). They hypothesized that heavy precipitation events intensify river discharge and enhance watershed erosion, creating flood-event layers in Lake Pallcacocha's sediments. However, Lake Pallcacocha lies on the eastern side of the highest Andean Ridge, and several authors (Bendix et al. (2011), Vuille (2013), among others) showed that ENSO impacts areas on the eastern side of the Andes differently: El Niño events weaken (wet) easterly winds and strengthen (dry) westerly wind flows, ultimately leading to less precipitation. In contrast, La Niña conditions intensify easterly winds (SASM; wet) and weaken the dry westerly wind flows, which leads to increased precipitation on the eastern side of the Andes and promotes event layers in the sediments of Lake Pallcacocha.

The present study is based on non-destructive (uXRF, hyperspectral imaging) and destructive lake sediment core analysis from three different lakes (Pallcacocha, Llaviucu, Fondococha), all containing clastic layers. Is the flood history (frequency) consistent in these three lakes for the past 2000 years? Can the newly available synoptic meteorological data and the new precipitation data from stations in the Cajas National Park be used to draw a conclusive picture about the atmospheric conditions producing flood layers? Do these layers really reflect variations in ENSO over the past two thousand years? And if so, which events (El Niño or La Niña) were causing these layers?

Our work also contributes to PAGES 2k South America.

Session III

Session III: How to proceed from paleo-flood data sets to statistical analysis, hydro-climate modelling and flood-hazard assessment?

This session should lead to a concept of how statistical and modeling approaches can be used to reconstruct flood patterns on different temporal (decades to millennia) and spatial scales (regional to continental) and how to identify the responsible climatic forcing. In addition, novel approaches regarding the handling of discontinuous time series, age uncertainties and non-calibrated data sets etc. are highly welcome.

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Statistical Flood Risk Analysis: From Paleo to Present

Manfred Mudelsee

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I will give an overview of statistical analysis of runoff data and flood risk. “Statistical analysis” means that the emphasis is on uncertainties in data, assumptions, and results. “Flood risk” means that the statistical estimation targets the extremes and the tails of the probability distribution. I will present tools how the uncertainties in data and assumptions can be taken into account by means of resampling techniques and sensitivity studies, and how they propagate into the uncertainty of the result. The keynote employs paleo and instrumental data to illustrate the methods.

The BINCOR R package: a computational software to estimate the correlation between two irregular paleoclimate time series

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This work presents a computational program named BINCOR (BINned CORrelation) to estimate the correlation between two unevenly spaced climate time series that are not necessarily sampled on identical time points. BINCOR is based on a novel estimation approach proposed by Mudelsee (2010) to estimate the binned correlation between two unevenly spaced climate time series taking into account the persistence contained in paleodata. We applied our procedure to obtain knowledge between unevenly spaced paleoflood" time series and diverse environmental variables.

Historical floods in Tabasco and Chiapas during sixteenth–twentieth centuries

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It is presented a chronology of historical floods during sixteenth–twentieth centuries in the Mexican states of Tabasco and Chiapas. There were 41 historical flooding events during 1528–1948, 16 of them were catastrophic flooding and 25 were extraordinary ones. There were periods of historical floods between 1651–1652, 1676–1677, 1679–1680, 1888–1889, 1927–1929, 1931–1933 and 1940–1944. During the instrumental period (1949–1999) there were only four extraordinary flood events in the Usumacinta River. Most of flood periods coincided with the warm phase of the Atlantic Multidecadal Oscillation (AMO). The flood period of 1940–1944 was as long as the most recent one (2007–2011). Wavelet analysis found flood periodicities of 2.5, 52 and 83 years, but only the last one was statistical significant and their occurrence was in phase with the AMO. Logistic regression showed that AMO index was the most correlated index with flood events. In fact, the odds ratio showed that floods were 1.90 times more likely to occur when AMO index was positive. This regression model predicted correctly 64.70 % of flood occurrences during twentieth century using its flood information only as validation data.

Hydrological Approach for Flood Reconstruction

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The contribution reflects the author's experience with using the documentary sources for estimation of flood peaks. In particular, the reconstruction of the 1714, 1784, 1846, 1862, and 1872 floods in the upper Elbe River catchment, and the augmentation of Prague records of estimated discharges during 1118–1825, resulted in three major recommendations or principles:

1. The flood reconstruction should be put into broader regional context: year by year, flood by flood, for major profiles selected (area of catchment >=2000km2).
2. The flood reconstruction should be based not only on flood indices but also on estimated peak discharges.
3. The time course of the flood should be analyzed in detail using e.g. reconstructed hygrograms, taking into account the approximate flood volume (if possible).

Accounting for the above principles would result in increased reliability of estimated flood peaks and filling the data gaps.

Reconstruction of peak water levels, peak discharges and long-term occurrence of extreme- as well as smaller pre-instrumental flood events of river Aare, Limmat, Reuss, Rhine and Saane in Switzerland.

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The methodology developed by Wetter et al. (2011) combines different documentary and instrumental sources, retaining relevant information for the reconstruction of extreme pre-instrumental flood events. These include hydrological measurements (gauges), historic river profiles (cross and longitudinal profiles), flood marks, historic city maps, documentary flood evidence (reports in chronicles and newspapers) as well as paintings and drawings. It has been shown that extreme river Rhine flood events of the pre-instrumental period can be reconstructed in terms of peak discharges for the last 750 years by applying this methodology to the site of Basel. Pfister & Wetter (2011) furthermore demonstrated that this methodology is also principally transferable to other locations and rivers. Institutional documentary evidence has not been systematically analysed in the context of historical hydrology in Switzerland so far. The term institutional documentary evidence generally outlines sources that were produced by governments or other (public) bodies including the church, hospitals, and the office of the bridge master. Institutional bodies were typically not directly interested in describing climate or hydrological events but they were obliged to document their activities, especially if they generated financial costs (bookkeeping), and in doing so they often indirectly recorded climatologic or hydrological events. The books of weekly expenditures of Basel ("Wochenausgabenbücher der Stadt Basel") were first analysed by Fouquet (1999). He found recurring records of wage expenditures for a squad of craftsmen that was called up onto the bridge with the task of preventing the bridge from being damaged by fishing out drifting logs from the flood waters. Fouquet systematically analysed the period from 1446-1542 and could prove a large number of pre-instrumental flood events of river Rhine, Birs, Birsig and Wiese in Basel. All in all the weekly led account books contained 54 Rhine flood events, whereas chroniclers and annalists only recorded seven floods during the same period. This is a ratio of almost eight to one. This large difference points to the significantly sharper "observation skills" of the account books towards smaller floods, which may be explained by the fact that bridges can be endangered by relatively small floods because of driftwood, whereas it is known that chroniclers or annalists were predominantly focussing on spectacular (extreme) flood events. We are now able to present first preliminary results of reconstructed peak water levels and peak discharges of pre instrumental river Aare-, Emme-, Limmat-, Reuss-, Rhine- and Saane floods. These first results clearly show the strengths as well as the limits of the data and method used, depending mainly on the river types. Of the above mentioned rivers only the floods of river Emme could not be reconstructed whereas the long-term development of peak water levels and peak discharges of the otherrivers clearly correlate with major local and supra-regional Swiss flood corrections over time. I am going to present the results for the above mentioned rivers and give a first insight on long-term recurring periods of smaller river Birs, Birsig, Rhine and Wiese flood events based on the analysis of the weekly led account books of the city of Basel.

Historical and palaeoflood records to assess flood risk and the impacts of climate change: an example from the Lower Rhine in the Netherlands

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Climate change is expected to significantly affect flooding regimes of river systems in the future. For Western Europe, flood risk assessments generally assume an increase in extreme events and flood risk, and as a result major investments are planned to reduce their impacts. However, flood risk assessments for the present day and the near future suffer from uncertainty, coming from short measurements series, limited precision of input data, arbitrary choices for particular statistical and modelling approaches and climatic non-stationarities. This study demonstrates how the use of historical and sedimentary information can extend data records, adds important information on extremes, and improves flood risk assessments. The collection of specific data on the occurrence and magnitude of extremes, and the natural variability of the floods, is shown to be of paramount importance to reduce uncertainty in our understanding of flooding regime changes in a changing climate. For the Lower Rhine (Netherlands and Germany) recurrence times and peak discharges of current protection levels correlate poorly with historical and sedimentary information and seem biased towards the recent multidecadal period of increased flood activity. Multi-decadal and centennial variability in flood activity is documented in more extended series of discharge data, historical information and sedimentary records, suggesting a strong correlation with Atlantic climate systems such as the North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) for at least the last six centuries. These climatic non-stationarities importantly influence flood activity and the outcomes of flood risk assessments based on short measurement series.

Paleoflood Hydrology in China, a Review

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In the U.S. paleoflood hydrology emerged from diverse studies in Quaternary geology and fluvial geomorphology. However, in China, this branch of hydrological science began with historical flood investigations during the 1950s and 1970s. This was necessitated because China did not have a sufficient network of long-term hydrometric stations to provide the data necessary to estimate engineering design floods of very high magnitude and very low recurrence probability. With a long history of civilization, China possesses an immense historical literature, old folk songs, and inscriptions carved in the stone together with flood marks, all of which can be used as evidence of extreme historical floods, thereby compensating for the lack of stream gauge data. However, because of incomplete and uncertain human documentation of historical floods, the resulting data can sometimes be unreliable, especially in the case of the earliest recordings. At the beginning of the 1980s, Chinese paleoflood research began to employ analytical techniques that were increasingly being applied internationally by other paleoflood researchers. In more recent years Chinese investigators fully embraced Slackwater-Deposit-Paleostage Indicator (SWD-PSI) methodologies, which derive their reliability and authority from well-preserved and complete natural evidence. Today considerable paleoflood hydrology research is being carried out for China's most important river basins, especially the Yangtze River Basin and Yellow River Basin, resulting in a large database on extreme floods. The most recent advances in Chinese paleoflood hydrology include the following: (1) the discovery of sedimentological criteria for paleoflood identification, combining international SWD identifying criteria with the results of investigations in China; (2) the use of OSL dating of paleoflood events, with checking by archaeological geochronology; (3) the application of computer flow models, such as HEC-RAS, to perform hydraulic calculations, replacing more simple hydraulic formulas; (4) the hydraulic analysis and paleoflood discharge estimation in the alluvium rivers. Today highly reliable paleoflood data are applied in Chinese hydrologic/hydraulic engineering for estimating risks posed by flooding to major dam projects, and to life and property related to the very dense human populations along river bottomlands. Of more general hydrological interest is the significance of paleoflood hydrological data for understanding the nature of very rare, high-magnitude flood events and the regional response of the hydrological system to global climatic change over long time scales.

Synoptic conditions, convective indexes and timescale during the major flash floods in NE Iberian Peninsula since 1871

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Floods are the most severe natural hazard in the western Mediterranean basin. They cause most of the damages and most of the victims. Some of the selected floods caused more than one hundred casualties each and a large quantity of damages in infrastructures.

In this work, using the PREDIFLOOD database (Barriendos et al., 2014), we analyze the atmospheric conditions that occurred during some of the most important floods occurred in the north-east of the Iberian Peninsula in the last centuries: 1874, 1875, 1894, 1897, 1898, 1901, 1907, 1913, 1919, 1932, 1937, 1940, 1962, 1963, 1977, 1994, 1996, and 2000.

By using NOAA 20th Century Reanalysis at 2.5ox2.5o horizontal resolution, we analyze the atmospheric synoptic situations during each flood and we study its frequency. We calculate the main convective indexes (LI, TT, CAPE, …), and we analyze its evolution during each flood. We also compare some of them with the rainfall duration or the specific peak flow for different areas of the region: coastal or Pyrenees and different seasons.

Finally, we analyze the evolution of the convective timescale proposed by Done et al. (2006) and modified by Molini et al. (2011). This index is obtained from the evolution of the convective available potential energy (CAPE) and is used to separate equilibrium and non-equilibrium convection. In the former, CAPE generated by large-scale processes is balanced by the consumption due to convection. In the second case, CAPE is created by large-scale processes over a long time and is rapidly consumed during outbreaks of convection. Both situations produced a totally different evolution of CAPE with low and approximately constant values in the first case and large and variable values in the second.

Anatomies of extreme Paraná River floods: Contributions of different time scales

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The present study provides the first complete examination of how different time scales contributed to generate the four largest observed floods of the Paraná River (1905, 1983, 1992 and 1998). This inspection is based on the results from a previous study where an empirical method was used to decompose a 1904–2010 Paraná flow record (monthly means) into several physically meaningful oscillations with distinctive time scales or periods (few months to decades), and a secular increasing trend. We show that all the oscillations largely contributed to the four extreme floods, except an 18-year cycle that did not contribute to the 1992 flood. Sporadic intense constructive interferences between interannual-to-interdecadal (3–85 years) cycles determined (i) the favorable conditions for extreme-flood occurrence, and (ii) notable differences among floods. Indeed, in 1983, the largest flood ever recorded resulted mainly from an exceptionally strong constructive interference between cycles of 3–5, 9, 18 and 31–85 years, which are related to El Niño events, the North Atlantic Oscillation, the South Atlantic Convergence Zone, and the Pacific Ocean, respectively. Contributions of the 31–85-year cycle to the two biggest floods (1983 and 1992) are larger than the contributions of the secular upward trend, suggesting the importance of this slow oscillation in flood formation processes. The implications of our results for understanding and predicting Paraná floods are discussed.

See more results and details in:

A. Antico, M. E. Torres, and H. F. Diaz. Contributions of different time scales to extreme Paraná floods. Clim. Dynam., doi: 10.1007/s00382-015-2804-x, 2015.

A. Antico, G. Schlotthauer, and M. E. Torres. Analysis of hydroclimatic variability and trends using a novel empirical mode decomposition: Application to the Paraná River Basin. J. Geophys. Res., 119:1218–1233, 2014.

Spatial and temporal flood variability in the Ebro basin since 1600 AD

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In this study, we analyse the greatest floods in the Ebro River basin since 1600 AD through the systematic (20th century) and reconstructed historical (previous) data. These great floods are the main events recorded in Zaragoza (approximately in the centre of the basin), in Tortosa (near the outlet of the basin), and in Lleida (near the outlet of the Ebro's most important Pyrenean tributary: the Segre River).

If only the floods exceeding the overbank flow at each location are considered, we can see a first period (1600-1850) with a relatively low frequency of floods, although the greatest event in the last millennium occurred within this period (that of 1787). In a second period (1850-1950), the flood frequency and their magnitude increase in Lleida (the Pyrenean Segre basin) and in Tortosa (near the outlet of the Ebro). In the third period (1950-2016), the reservoirs have a great role in moderating the peak flows across the basin.

Besides this temporal pattern, owing to the basin size and geomorphic characteristics, a spatial pattern appears: floods in Western Ebro Basin occurs mainly in winter due to Atlantic fronts whereas the floods in the Pyrenean tributaries of the Ebro in the eastern half of the basin are more typical of autumn and related to Mediterranean convective air masses.

Two floods are especially interesting: November 1617, that affected the Mediterranean catchments of the Iberian Peninsula and many Ebro headwaters' catchments in the Pyrenees, which, nonetheless, left the Ebro basin upstream Zaragoza unaffected. October 1787 was the flood with the highest reconstructed peak flows, especially in the Pyrenees and near the outfall.

In all the cases, the historical peak flows are far higher than the greatest in the systematic series. As a consequence, the flood frequency estimates may change dramatically depending on whether the calculations include historical data or not.

Patterns of extreme climate indices associated with observed and proxy Ammer river floods

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We investigate the relationship between the variability in the frequency of Ammer River floods (southern Germany) and temperature and precipitation extreme indices variability using observational and proxy data. We show that high frequency of observed Ammer River floods are accompanied by relatively high (low) extreme precipitation (Rx5day index) in the Western Europe (northeastern Europe) during summer. This pattern of extreme precipitation is possible forced by upper level potential vorticity anomalies. Strong increase in the frequency of warm days (TX90p index) and decrease in the frequency of cool nights (TN10p index) are detected over western and northeastern Europe during periods of high flood frequency. A reverse pattern of TN10p and TX90p is associated with high frequency of Ammer floods over central and Western Europe. Similar patterns of TX90p and TN10p indices are detected for River Ammer proxy floods. We argue that proxy records of River Ammer floods, which extend back for more than 5500 years, can be used to obtain information about the interannual to millennial scale variability of extreme phenomena during the past.

A method to evaluate the average holocene palaeoflood

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Nowadays, in reconstruction of historical floods it is the common use flow modelling based on 1D and 2D flow models. Many cases are conducted using 1D models like HEC-RAS because of its simplicity and well-tested set of assumptions. One of the problems presented is the variation, after centuries, of the flow geometry, which in many cases it does not fit with the position of the preserved limnimarks. This introduces mistakes in the reconstruction.

To diminish the effect of mistakes, and simultaneously, to extend the quantification up to Holocene palaeofloods, it is being developed a new method of discharges valuation based on the backwater effect produced in natural constrictions in the channel.

It is known that backwater effect produces an energetic rebound and increases water level upstream from a constriction by means of which it is possible to quantify discharges that passes through it. What is more relevant is the location of the end point upstream from the constriction. The end point is the place where the rise in water begins to cause damage. This is possible due to the fact that the energetic rebound produced by backwater effect changes, upstream the constriction, the drainage pattern of the river, passing to be meandering. This drainage pattern allows room in the channel for downstream flow and the backwater effect. Generally, it is difficult to stablish the position of the end point, specially for an average of formative palaeofloods. In special cases, as that one is presented, it is possible to calibrate the position of the end point in the upstream direction by means of a tributary affected also by this effect and which flows into the main river between the constriction and the end point.

The river Ter, NE of Iberia, has developed a high sinuosity pattern upstream from an important lithological constriction through which it leaves a strike valley. By the analysis of the first couple of meanders just upstream the constriction, duplicated on a tributary, it is possible to evaluate the average Holocene formative discharges. Besides, there is an historical flood limnimark (1941) near the location of the end point.

Climate drivers of high-summer floods in Switzerland (1800-2010)

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The study analyses the possible links between flood frequency in Switzerland and solar activity (exogenic forcing), volcanic eruptions, climate variability and the North Atlantic dynamics (endogenic forcings) over the period 1800-2010. The variability of floods in Switzerland has been determined from a July-August flood damage index (INU). The index considers severe and catastrophic floods from existing flood inventories, summarizing both the severity of these events and their spatial extent. Special attention will be focused also on the differences between flood dynamics at the northern and southern slopes of the Alps. The influence of solar forcing on flood frequencies is investigated applying a cross-spectral analysis to the sunspot record and INU. Finally, the analysis of the possible links between floods and North Atlantic dynamics is focused on the principal mode low-frequency atmospheric circulation for July-August period (EOF).

The INU index provides evidences that the 1830-1851, 1881-1927, 1977-1990 and 2005 to present flood clusters occur mostly in phase with paleoclimate proxies and North Atlantic dynamics. The cross-spectral analysis between solar variability and INU documents that the cycles detected in the coherency and phase spectra of 11 and 110 years are related to a high frequency of flooding and solar activity minima. The periodicities of so-called “100-year events” could be explained by centennial-scale solar cycles, which have also been identified in other flood records, including those in eastern France, Switzerland, Netherlands, the UK, Spain and California.

The analysis of EOF shows that the river catchments situated on the centre and southern flank of the Alps are affected by atmospherically unstable areas defined by the positive phase of mode, whereas those basins located in the northern slope of the Alps are predominantly affected by the negative phase of the mode. Furthermore, a change in the low-frequency atmospheric circulation mode related to the major floods occurred for the period 1800-2010: the EOF persists in negative phase during the last cool pulses of the Little Ice Age (1817-1851 and 1881-1927 flood clusters), whereas the positive phase of mode prevails during warmer climate of the last four decades (1977-1990 and 2005 to present flood clusters).