Editorial

Pluridisciplinary analysis and multi-archive reconstruction of paleofloods

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This Special Issue, which comprises 18 peer-reviewed papers, is the outcome of the Floods Working Group (FWG) session entitled "Multidisciplinary reconstruction of paleofloods" held at the PAGES OSM Conference (Past Climate Changes – Open Scientific Meeting) from 9-13 May 2017 in Zaragoza, Spain. Sixteen oral contributions and eighteen posters from most continents were presented and lively discussion ensued.

Research on Paleofloods is a fascinating topic with enormous societal relevance. Floods are one of the most serious natural hazards for societies, but they are worsened by factors such as population growth, unchecked development, and climate change (UNISDR, 2015). Building on the arguments of Vic Baker (2006), extreme events that occurred in past decades, centuries or millennia merit particular research interest because they shed new light on interactions with wider climate and environmental change.

Over the last decade, knowledge of long-term flood frequency and magnitude has been greatly improved by extracting data from different types of archive (Benito et al., 2015). Nevertheless, despite impressive advances in dating methods, proxies and statistical techniques as well as efforts to identify atmospheric drivers, we believe some fundamental questions remain unresolved. Floods introduce perturbations in catchments at different scales, palaeoflood archives span a wide range of geographical and environmental settings and "perfect" study sites rarely coincide, meaning paleoflood information is often fragmentary. Multi-proxy approaches have become standard in paleoenvironmental and paleoflood research but multi-archive studies in *sensu strictu* – those that integrate more than three different types of flood archives – are extremely rare, as shown by our meta-data analysis (Schulte, Schillereff and Santisteban, 2019) in this Special Issue. We believe there is an urgent need not only for the compilation of large data sets but also for their careful integration. Besides the impact of climate on flooding, we also have to consider the human imprint on fluvial landscapes (Schulte et al., 2015) and flood dynamics (Brisset et al., 2017). Another crucial issue is the inevitably that recent flood events are more likely to be recorded more accurately and in a higher number of archives than larger floods that occurred further back in time. Ensuring the effects of active flood risk mitigation do not distort flood reconstructions is another potential source of bias that could weaken our understanding of long-term flood dynamics. Spatial variability of flooding introduces another complexity, and different archives record flood information in different ways. For example, flood information can be obtained from high-altitude lakes, tree-rings and lichen colonization of river banks, gorge rock surfaces, and alluvial fan deposits at mid-altitudes, and from low-altitude floodplains, deltas (alluvial sediments, historical and archaeological evidence, pollen, etc.), and large low-altitude lakes and marine deposits (Wilhelm et al., 2019). Integrating multiple datasets will better reflect the diversity of landscapes that experience flooding and should provide a more comprehensive picture of flood occurrence but may introduce additional uncertainties.

Recognising the multitude of benefits as well as associated uncertainties of integrating many types of flood evidence is one of the key reasons that "multidisciplinary analysis and multi-archive reconstruction of paleofloods" define one of the three core activities

(WP2) of the Past Climate Changes (PAGES) Floods Working Group (FWG). This successful Working Group was founded in 2015 and has continued into a second phase (2019-2021). The FWG aims "to bring together all the scientific communities reconstructing past floods and those studying current and future floods to coordinate, synthesize and promote data and results on the natural variability of floods" (PAGES Floods Working Group, 2017).

We are very pleased to note that the 18 accepted papers showcase substantial progress in the analysis and interpretation of flood archives, important methodological advancements, including innovative approaches to integrate and model diverse archives and flood series, and a focus on remote regions with difficult access.

Our introductory review paper (Schulte, Schillereff and Santisteban 2019) systematically analysed the 17 paleoflood research papers and their meta-data in terms of i) geographical distribution; ii) methodologies applied; iii) types of archives; iii) numbers of flood series compiled and iv) spatial and temporal resolution of paleoflood data (Table 1 in therein paper). A qualitative comparison of the paleoflood reconstructions shows some consistent trends but also notable differences within and between regions.

An international cooperation enabled by the Flood Working Group network report on a pilot project (Schulte et al.), in which an innovative methodology was designed that integrates multi-archive datasets and builds a spatial-temporal (four-dimensional) paleoflood model for alpine catchments. Accurate series from natural and anthropogenic archives since 1400 CE were integrated into a synthetic flood master curve for the Bernese Alps. The most catastrophic flood events and the location and magnitude of all the compiled flood records were plotted, providing a richer perspective of the spatial pattern of flooding. This was compared to the pattern of atmospheric variability to facilitate an in-depth understanding of flood forcing in mountain catchments.

The two century-long dataset of regional glacial outburst floods (GLOF), presented by Zaginaev et al. for the Tien Shan (Central Asia), provides insights on spatial and altitudinal flood activity by reconstructing high discharge flash-floods from tree-ring analyses performed on six different torrential fans. At the southern edge of the Atacama Desert, Ortega et al. analyzed extreme ENSO-driven torrential rainfalls during the Late Holocene and their projection into the 21st century. The integration of marine paleoclimate proxies, historical data, and the future projection improves the understanding of how oceanic and climatic factors condition the variability of extreme rainfall events.

Four research papers in the Special Issue focus on fluvial depositional environments and landscape development. The contributions of Santisteban et al. and Fuller et al. are case studies from Central Spain and New Zealand, respectively, and demonstrate how high-resolution, continuous geochemical flood proxies can be inferred from alluvial sediments that span most of the Holocene. Santisteban et al. used several geochemical ratios as proxies for water competence, water level, and sediment discharge to reconstruct flood pulses. Similarly, Fuller et al. estimated the flood recurrence interval using normalized Zr/Rb measurements and a tight age-depth model in a volcanically-reset catchment. The studies of Agatova et al. and Lombardo et al. focus on large-scale flood areas in Asia and South America that are difficult to access. In south-western Amazonia, Lombardo et al. combined proxies including phytoliths and stable carbon isotopes from sedimentary flood archives and soils reconstruct Holocene land cover change and periods of low or modest flooding. Agatova et al. used geomorphological, geological and geoarchaeological data to reconstruct the presence of Late Pleistocene ice-dammed lakes and cataclysmic outburst floods in the Mongolian Inland Drainage Basin.

A different approach is adopted by the next four papers, which extract evidence f past floods from documentary archives. Barriendos et al. provide extensive centennial flood series for the Iberian Mediterranean coast. They consider the profound influence of social factors on historical flood data series and evaluate methods of integrating multi-source information such as population and flood protection measures. This human component also affects the 450-year reconstruction of historical discharges performed by Sánchez-García et al. from the driest region in Europe, semi-arid South-eastern Spain. They also investigated the synoptic atmospheric configurations of four catastrophic flood events to understand regional flood triggers. In the River Jing catchment, southern Chinese Loess Plateau, Yu et al. identified decadal solar activities as an important driver for floods and droughts. The extraordinary approach presented by Elleder et al. focused on a single event: multiple documentary sources and a precipitation-runoff model were used to explore the spatial imprint of the 1872 flash-flood in central Bohemia and model the river's runoff response.

The highest number of papers report on paleoflood reconstructions and flood frequency analysis using lake sediment records. Evin et al. developed a novel statistical approach that combines a classic series of paleoflood observations with paleodischarges for the Rhône River (Northwestern Alps, France) reconstructed from lake sediments (Lake Bourget) to better quantify uncertainties when estimating extreme quantiles from palaeoflood reconstructions. A statistical method is also presented by Albrecher et al. They applied a change-point analysis to sedimentary flood frequency data from six large alpine lakes. This enabled a comparison to be made with other flood records and possible links to be drawn between event frequencies and climatic conditions. Corella et al. present a new method for estimating seasonally-resolved flood erosion rates using varved lake sediments. Their use of high-precision, multi-proxy data also sheds light on the main environmental drivers controlling sediment yield in a mountainous Mediterranean watershed during the last three millennia. The respective roles of human and climate forcings on Holocene flood frequency were also investigated by Rapuc et al. in Lake Iseo. Similarly, Schillereff et al. showed that detailed sub-sampling and proxy analysis based on particle size data, coupled with careful evaluation against independent hydrological data and accounting for variations in external sediment supply potentially driven by anthropogenic landscape modification, is an appropriate methodology to extract paleoflood records from temperate lakes.

Finally, Peña and Schulte performed a paleoclimate simulation experiment of the atmospheric variability related to large summer floods in the Hasli-Aare (Swiss Alps) from the 1300 to 2010 CE to explore climatic forcing of floods. They propose the name of paleo-SNAO to define this decadal atmospheric variability related to summer floods in the alpine catchment.

We, the invited editors of the present Special Issue and authors of the review article, hope that the collection of papers presented in this Paleoflood Special Issue and at the PAGES Open Scientific Meeting 2017 contributes to the progress of paleoflood research and inspires interested readers to pursue new avenues of research on multidisciplinary analysis and multi-archive reconstruction of paleofloods. We are convinced that the study of past floods, from historical and natural archives, is challenging but offers unparalleled opportunities to document the frequency and magnitude of past floods, including rare, very large events, that occurred under a broad range of climate and/or environmental scenarios. The production of more robust paleoflood series will bring a range of scientific and societal benefits.

The paper collection presented in this Special Issue of Global and Planetary Change provides an excellent overview of the state-of-the-art in integrative multi-archive research of paleofloods. We would like to express our gratitude to the more than 101 authors and co-authors who shared enthusiastically their knowledge at the PAGES OSM conference session at Zaragoza and contributed with their studies and research projects to this Special Issue on Paleofloods. The OSM conference session and the related Special Issue were supported by the Past Climate Changes Project (PAGES) and Floods Working Group (FWG). Thanks to Juan A. Ballestero-Cánovas and Bruno Wilhelm co-leaders together with Lothar Schulte of the FWG. We would also like to express our gratitude to the other Editors-in-Chief Zhengtang Guo, Alan Haywood, Liviu Matenco and the Editorial Board of this Journal for accepting our SI proposal. Thanks to Sunoj Sankaran and Yanping Hou from Elsevier for patiently managing and monitoring the editing and production processes. We are also grateful to a large number of reviewers of the 18 research papers for their expertise and judgment. Without the help of all these experts the edition of this Special Issue would not have been possible.

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