doi.org/10.22498/pages.horiz.3.7

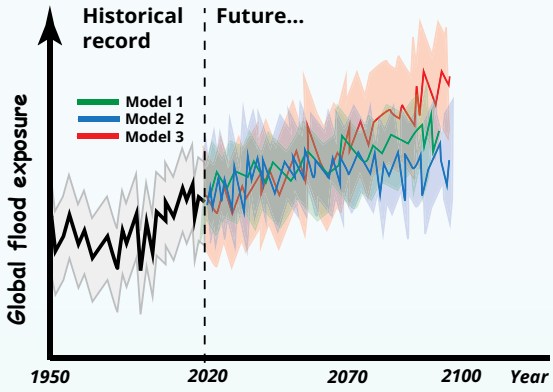
What do cave deposits tell us about past floods?

Miguel Bartolomé • Reyes Giménez
Guillermo Pérez-Villar • Marc Luetscher
Ana Moreno • Heather Stoll
Gerardo Benito • Art&Design by: Cooked Illustrations

Floods in a warm world

Addressing the consequences of current climate change represents one of the greatest challenges for our society. One fundamental and worrying outcome of global warming is the increase in frequency and intensity of river floods all over the world in relation to shifts in rainfall patterns [(1)]. A recent study reveals that the past three decades were the most flood-rich periods over the last 500 years in Europe [(2)].

Climate models show an intensification of extreme torrential events in the next decades as a result of climate change, which will affect social, ecological, and economic systems globally. However, there is still a high uncertainty with respect to projected changes at a regional scale since the trends are not yet robust.



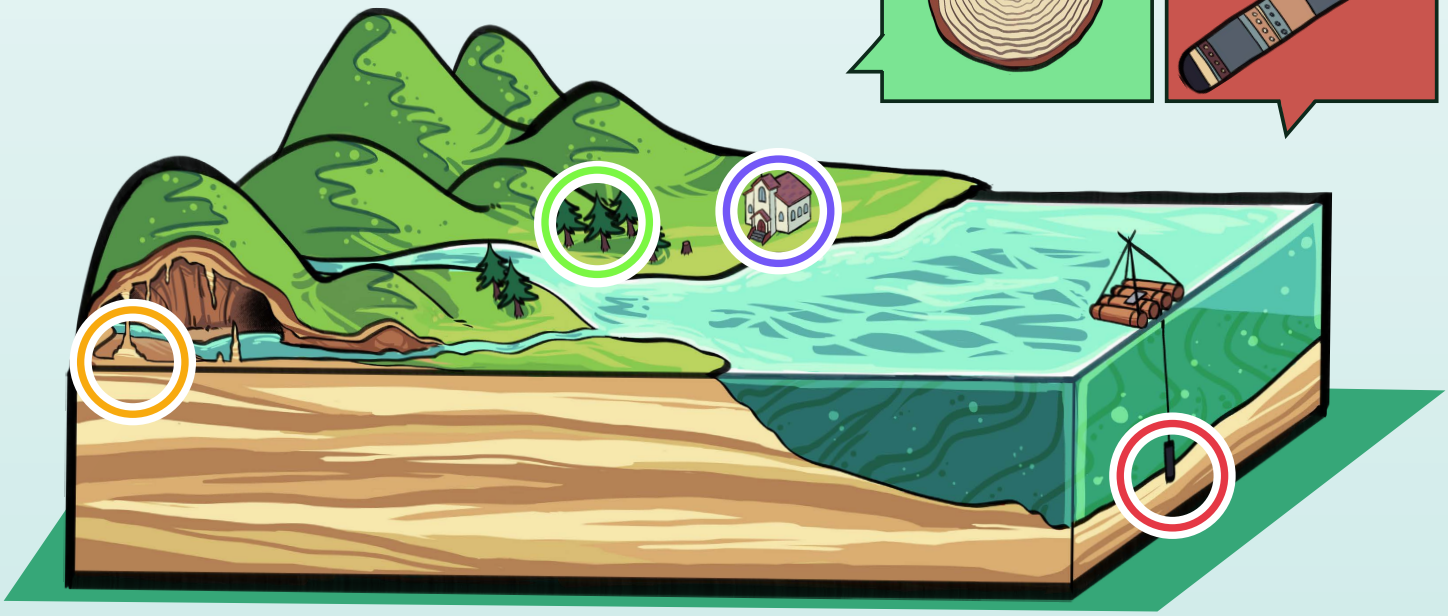
Historical record of global flood exposure and future flood trends using diferent climate models. Modified from reference [(3)]

Precipitation records, which are used to evaluate the return periods of floods, are too short or even absent in many regions. Moreover, most instrumental records are affected by land development, complicating the estimation of natural recurrence intervals of extreme floods.

Beyond the instrumental record...

Understanding the natural patterns of floods, in response to climate variability prior to the era of significant anthropogenic intervention in the climate system, is required. It is critical to extend records to understand the long-term flood variability at millennial to decadal scales to guide on future flood-risk adaptation.

Different paleoflood records such as riverine, lacustrine, marine, speleothem, botanical and historical documents can help us to understand the variability of past extreme events and improve future flood-risk assessments.



(1) IPCC (2021) Climate Change 2021: The Physical Science Basis.Cambridge University Press, 2391 pp
(2) Blöschl G et al. (2020) Nature 583: 560–566
(3) Hirabayashi Y et al. (2021) Sci Rep 11: 3740

Tracing the footprints of past floods

Rather than looking for clean caves to reconstruct past climate changes from stalagmites, the study of past floods using speleothems and detrital sequences require caves with some specific characteristics.

Caves with active rivers inside have intense and quick responses to rainfall events

Galleries with evidence of floods

Speleothems covered by sands / silts

Stalagmite with a thicker coat of sediments partially eroded by the impact of the dripping water.

Water-level marks in relation to floods

Visible **flood mark** along the cave after a flood event.

Sand and silt in elevated cave areas

Sand and silt deposited in higher cave passages, with respect to the cave streambed, inform about the karst water table during floods.

How are floods recorded?

Stalagmites & detrital deposits

During a flood event, sand and silt are transported through the **karst system.** The water can rise several meters from the streambed, flooding elevated areas of the cave. These sediments accumulate in protected areas from the main stream and/or blind cave passages, coating the surface of speleothems when the energy of the water decreases. The active precipitation of carbonate traps these detrital layers inside the speleothems.

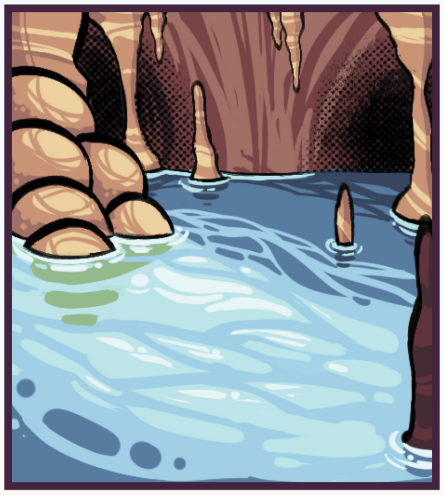
Speleothems and detrital sequences situated next to a water stream can record ordinary floods. In contrast, those located far from the river or in the upper cave levels may only record extraordinary floods.

1 year Flood

"Annual"

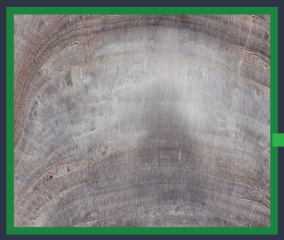
100 year flood

"Centennial"



1000 year Flood

"Millenial"



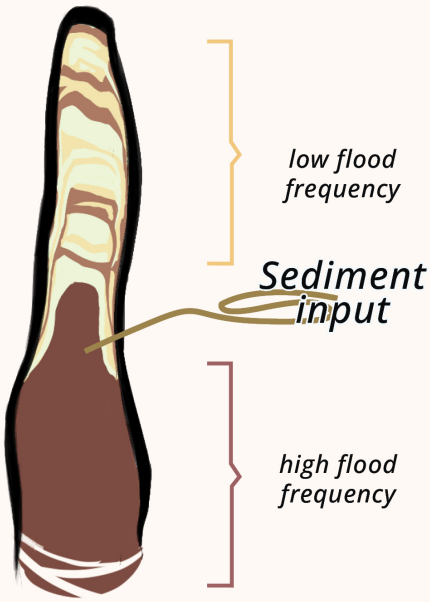
Flood events visible to the naked eye are recorded as detrital layers within the stalagmite.

1 *1000 year Flood*

2 *100 year flood*

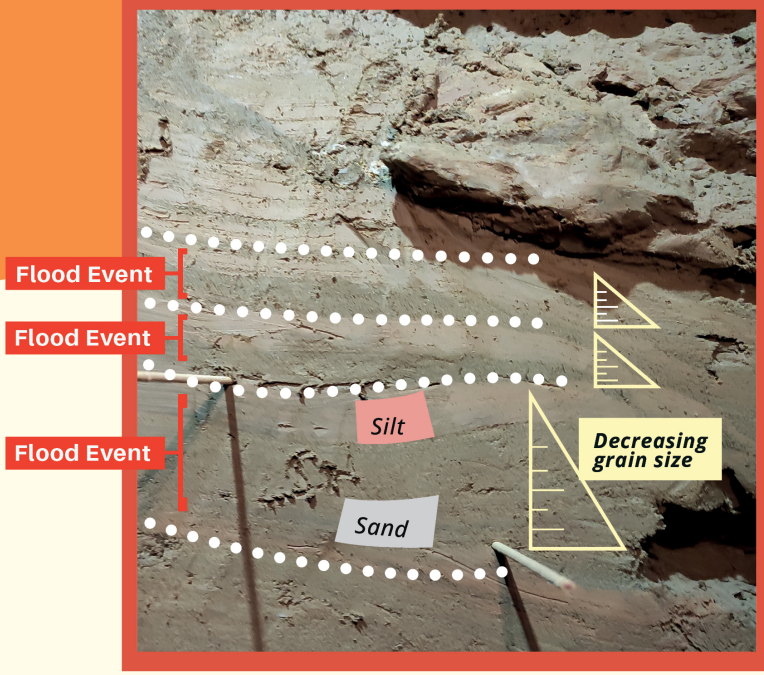
3 *1 year Flood*

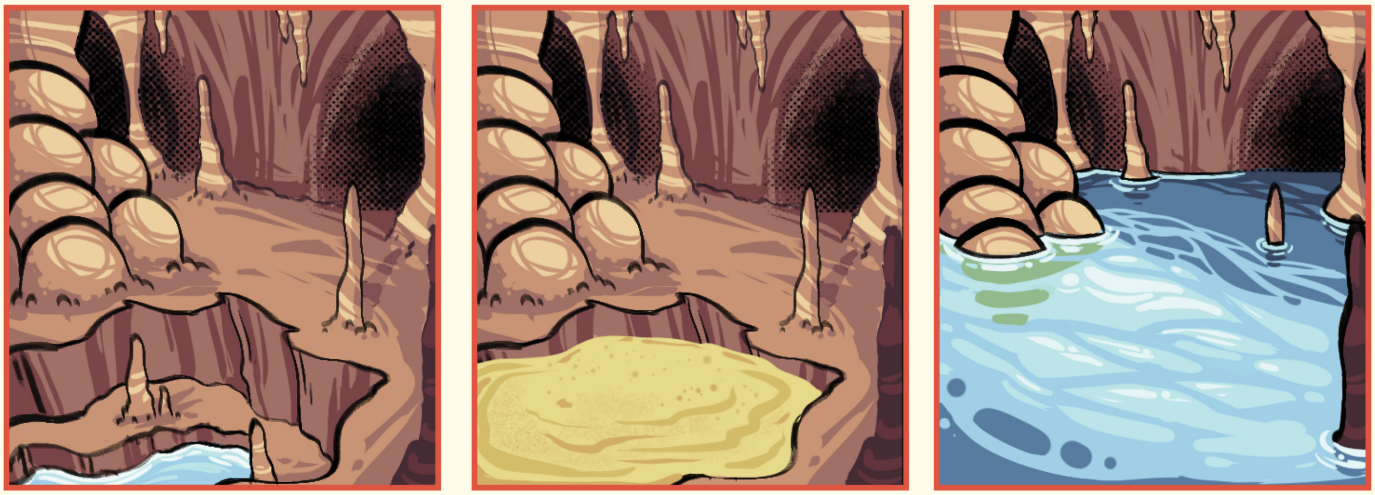
The U-Th dating of the cleanest carbonate areas of the stalagmites provides robust age models. The location of the speleothem with respect to the streambed plays an important role in studying past floods, given that a balance between clean areas and flood layers should be found. Very dirty speleothems cannot be dated by U-Th but possibly by 14^{C}.



The analysis of oxygen & carbon isotopes as well as trace elements in the carbonate inform about the climate conditions during the recorded flood periods.

The suspended sediment settles in low-energy basins, depositing the larger particles first followed by the silt and clay fractions. These sedimentary sequences accumulate for hundreds to thousands of years, forming distinguishable rythmites. These deposits are easily remobilised if they are not well protected from the main stream.





▲ *1 year Flood*

Sometimes an energetic flood can transport high amounts of sediment in suspension, which is suddenly deposited in a cave passage. In this situation, some passages can be completely blocked, generating an important change in the geometry of the gallery, affecting the water level during the next floods. This means that an ordinary flood (e.g. 1 year flood) can reach elevated areas (typically only affected by major floods) due to geomorphological changes caused by the sediment accumulation.

Dating detrital sequences

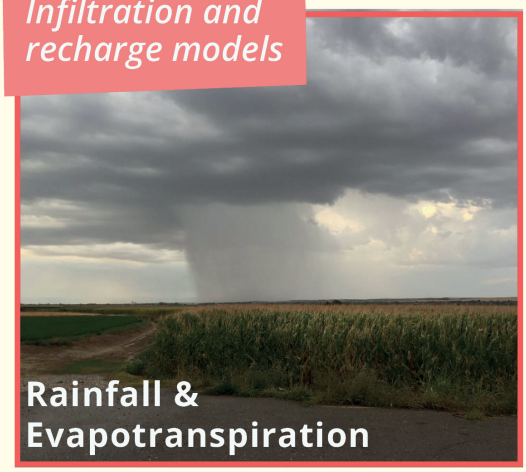
The chronology of clastic deposits can be determined by radiocarbon dating (^{14}C), which is applied to terrestrial plant macro-remains and charred organic matter found in sediments deposited during the flood. Alternatively, in the absence of organic matter, optically stimulated luminescence (OSL) dating can be used, provided the sandy layers are predominantly composed of quartz. This technique relies on the inherent ability of these minerals to accumulate environmental radiation after sedimentation.

Dating the detrital sequences is important not only for paleoflood reconstructions, but also to discern if coeval flood layers recorded in stalagmites correspond with extreme events or not.

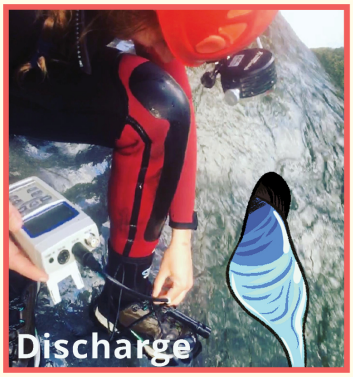
The research on caves affected by floods

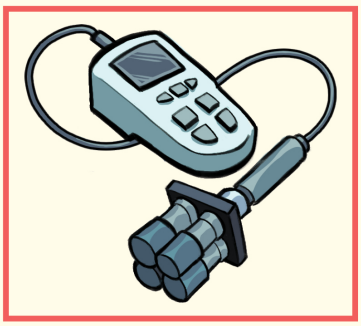
Karst systems have complex responses to rainfall, mostly based on hydrological thresholds and bypasses, and therefore show neither a linear nor gradual reaction. Although the floods in caves remain local and affect only marginally large populations, an abrupt increase in water levels inside the caves may threaten human lives, in particular when they are visited by tourists (e.g. show caves). As an example of a flood event in a cave, we all remember the rescue of children in Tham Luang cave in Thailand in 2018. Cave monitoring helps us to understand how the karst water table reacts to rainfall.

Infiltration and recharge models



Cave hydrological monitoring

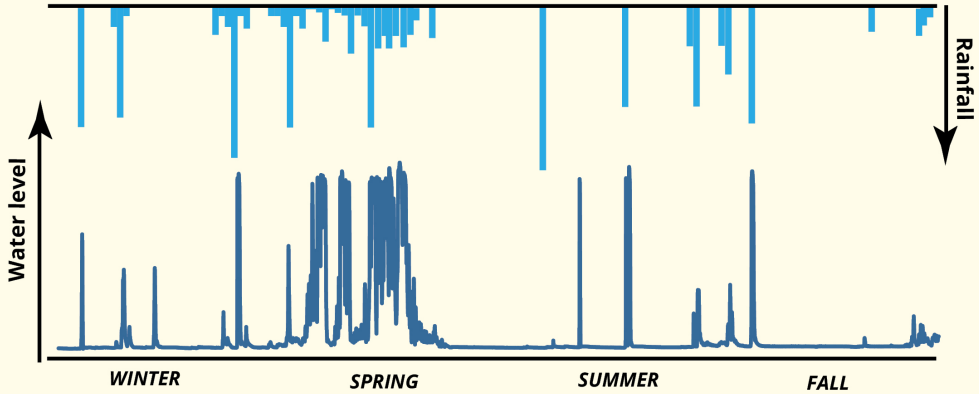




Quantification of paleofloods

Discerning the cave – flood magnitude is not straightforward since it may respond to different factors such as land use, changes in the sediment supply or changes in the cave geometry. For all these reasons, the cave hydraulic modeling, including the 3D structure of the conduits, as well as data from the water-level monitoring and discharge measurements, must be carried out to quantify flood magnitude recorded in the cave deposits.

The infiltration and hydraulic models, the water level monitoring, and water – flow gauging allow us to establish an empirical relationship between the amount of rainfall, the aquifer recharge and the water flow in cave passages, to quantify the floods recorded in the cave.



Changes in the water level in response to rainfall events during the year. Different responses are observed depending on the amount of rainfall and the water stored previously in the karst system.

Funding: Miguel Bartolomé is supported by the HORIZON TMA MSCA Postdoctoral Fellowships Global 2022 MODKARST project (nº 101107943) funded by the European Union.

Ratalpa's Nightmare