Flood variability in northern Spain during the last millennium recorded in lacustrine sedimentary archives

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Extreme floods in the Iberian Peninsula has devastating consequences in terms of casualties and economic losses.
Flood hazard — Need to understand the frequency variability of extreme hydrological events

INSTRUMENTAL RECORD -> Barely spans the last decades

Long-term proxy data series (natural archives)

Lakes sensitive to extreme hydrological events

Floods are recorded as discrete sedimentary layers

Archives of long-term flood variability in alpine environments

Wilhelm et al. (2019) WIREs.
**Goal:** Understand flood variability in the Iberian Península using lacustrine archives

A) Flood variability across an altitudinal transect in Southern Pyrenees

B) Flood variability across an E-W transect in Northern Spain
A) Flood variability across an altitudinal transect in Southern Pyrenees

- Lake Estaña (670 m a.s.l.)
- Lake Montcortès (1027 m a.s.l.)
- Lake Marboré (2612 m a.s.l.)

- Small watersheds (7-18 ha)
- Carbonated bedrock
- Similar water depths (24-30 m)
A) Flood variability across an altitudinal transect in Southern Pyrenees

Sub-alpine lakes

- Mid-montane areas
- Non connected with main fluvial systems
- Not affected by snowmelt and ice phenology
- Precipitation regime controlled by spring and autumn floods
  - 800-900 mm/yr in Lake Montcortès
  - 500-600 mm/yr in Lake Estanya
- Historical land-use and vegetation changes

Lake Montcortès (1027 m a.s.l.)

Lake Estanya (670 m a.s.l.)

- Small watersheds (7-18 ha)
- Carbonated bedrock
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A) Flood variability across an altitudinal transect in Southern Pyrenees

**Alpine lakes**

- **High-alpine environment**
- **Strongly affected by cold processes**
  - Permafrost
  - Snow-melt
  - Ice phenology
- **Precipitation regime controlled by summer and autumn floods**
  - 2000 mm/yr in Lake Marborè
- **Not affected by historical land-use and vegetation changes**

- **Small watersheds (7-18 ha)**
- **Carbonated bedrock**
- **Similar water depths (24-30 m)**
**Flood layers in the Pyrenean lakes**

- **Alpine lake (Marboré)**
  - Finning upward sequences
  - Coarser grain-size
  - Variable thicknesses (mm to cm)
  - Enriched in terrigenous elements (Zr, Ti, K, Si, Al… grouped in eigenvectors (PC1))

- **Sub-alpine lakes (Montcortès and Estaña)**

Lake Marboré (2612 m a.s.l.)
Lake Montcortès (1027 m a.s.l.)
Lake Estaña (670 m a.s.l.)
Lake Montcortès

Unique annually-laminated “varved” record in Southern Europe

Flood record with seasonal resolution for the last 2800 years
Biogenic varves


Depth (cm)

Autumn/winter
Flood events
Spring/summer

Detrital mud
Organic matter
Endogenic calcite

Calcite layer
Organic layer
Detrital layers and turbidites

Flood layers
Flood reconstruction during the Late Holocene

Medieval Climate Anomaly

Largest hydrometeorological variability during the MCA

Migration Period

Persistent hydrological deficit
300 years with only two storm events...

Visigoths invaded Iberia in the 6th century

Corella et al., 2016
Flood reconstruction during the Late Holocene

Good agreement between sub-alpine lakes in the Pre-Pyrenees

Medieval Climate Anomaly

Largest hydrometeorological variability during the MCA

Different flood signals in specific time-intervals that can be explained by….

- Spatial heterogeneity of local convective storms

- Different land use changes

Comparison of flood layers frequency with vegetation reconstructions to evaluate the influence of land use on run-off generation at decadal to centennial time-scales
Flood reconstruction during the Late Holocene

Comparison of flood-related sediment yield with land-use changes

Different flood signals in specific time-intervals that can be explained by:

- Spatial heterogeneity of local convective storms
- Different land use changes

Comparison of flood layers frequency with vegetation reconstructions to evaluate the influence of land use on run-off generation at decadal to centennial time-scales

Pre-Pyrenean sub-alpine lakes
Flood reconstruction during the Late Holocene

Extreme run-off events are strongly affected by land use changes in mid-montane areas

But… How was the flood and run-off variability in high-alpine environments?

Pre-Pyrenean sub-alpine lakes
Late Holocene flood variability in the Central Pyrenees

PC1
Lake Estanya

Pyrenean alpine lakes

Years with HR events > 90 mm (>80 mm)

LIA

MCA

Pre-Pyrenean sub-alpine lakes

Strong flood variability across the altitudinal gradient

Different forcings controlling run-off generation

- Ice phenology - Lake Marboré only records summer and early autumn floods
- Not influenced by land use and vegetation changes
- Direct run-off response to storminess frequency variability

Oliva et al., 2018

Morellón et al., 2010

Corella et al, 2016
Holocene flood variability in the Central Pyrenees

Complex relation between temperature and flood variability

- Higher flood frequency
  - 10-6 ka BP
  - 5.2-4.8 ka BP
  - 3.7-1.6 ka BP
  - 0.4-present ka BP

- Lower flood frequency
  - 11.7-10 ka BP
  - 6-5.2 ka BP
  - 4.8-3.8 ka BP
  - 1.6-0.4 ka BP

Relative good agreement between long-term flood variability in the Alps and the Pyrenees
To sum up...

- First lacustrine paleoflood reconstructions in the Pyrenees during the last 11,700 years

- Large spatio-temporal heterogeneity in flood frequency variability across an altitudinal transect in the Central Pyrenees

- Low-elevation (sub-alpine) records are strongly influenced by historical land-use changes

- High-elevation (alpine) record (Lake Marboré) shows summer and early autumn flood frequency evolution in the Pyrenees during the Holocene

  *In agreement with similar paleoflood reconstructions in Western Alps*
B) Flood variability across an E-W transect in Northern Spain

We have investigated flood variability during the last millennium in four different lake records.

All of them located in mid-montane regions (600-1000 m a.s.l.)
Lake Arreo

Climate

- Atlantic-Mediterranean
- 655 m a.s.l.
- 670mm/yr
- 12°C average
  - -20°C (July)
  - -5°C (February)

Vegetation

- Evergreen and deciduous oak forest
- Conifers
- Cultivated lands and pastures

Hydrology and Limnology

- Morphology:
  - Funnel-shaped
  - 24m depth
- Hydrology:
  - Groundwater inputs + Inlet
  - Evaporation outputs + Outlet
- Water chemistry:
  - Subsaline
  - Ca-(Mg)-(Na)-SO₄-HCO₃-(Cl)
- Limnology:
  - Mesothropic
  - Holomictic (tendence to meromixis)
2 flood layer types correlating with regional heavy rainfall extremes
Moderate flood-rich periods: 700-780, 850-1000, 1080-1150, 1250-1290 and 1590-1670 yrs CE

High flood-rich periods: 1720-1790, 1830-1870 and 1950-1990 yrs CE
Lake Sanabria

-Largest glacial lake in the Iberia Peninsula
-Second largest lake in Spain (348 ha)
-1005 m a.s.l.
-Hydrologically open (Tera river)
-Large watershed (127.3 km²)
Lake Sanabria: The Vega de Tera 1959 catastrophic flood

Largest flood recorded in a lake in the Iberian Peninsula

- Two orders of magnitude higher than any other flood layer recorded in Spain during the last millennium
Lake Sanabria: Extreme floods during the last millennium

1959 flood event

- Complex interplay between fluvial input and internal lake dynamics
- Increased in flooding events during the LIA
Different flood frequency and magnitude variability in Atlantic Vs Mediterranean sites during the last millennium

**MCA/LIA flood frequency variability**

- **Mediterranean** – flood-poor during the LIA
- **Atlantic** – flood-rich during the LIA
FLOODARC Project (2019-2021)

- Understanding long-term FLOOD pattern variability in Western Mediterranean using natural ARCHives
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