

INTERANNUAL TO MILLENNIAL SCALE VARIABILITY OF THE RIVER AMMER FLOODS AND ITS RELATIONSHIP WITH EXTREME CLIMATE AND SOLAR FORCING

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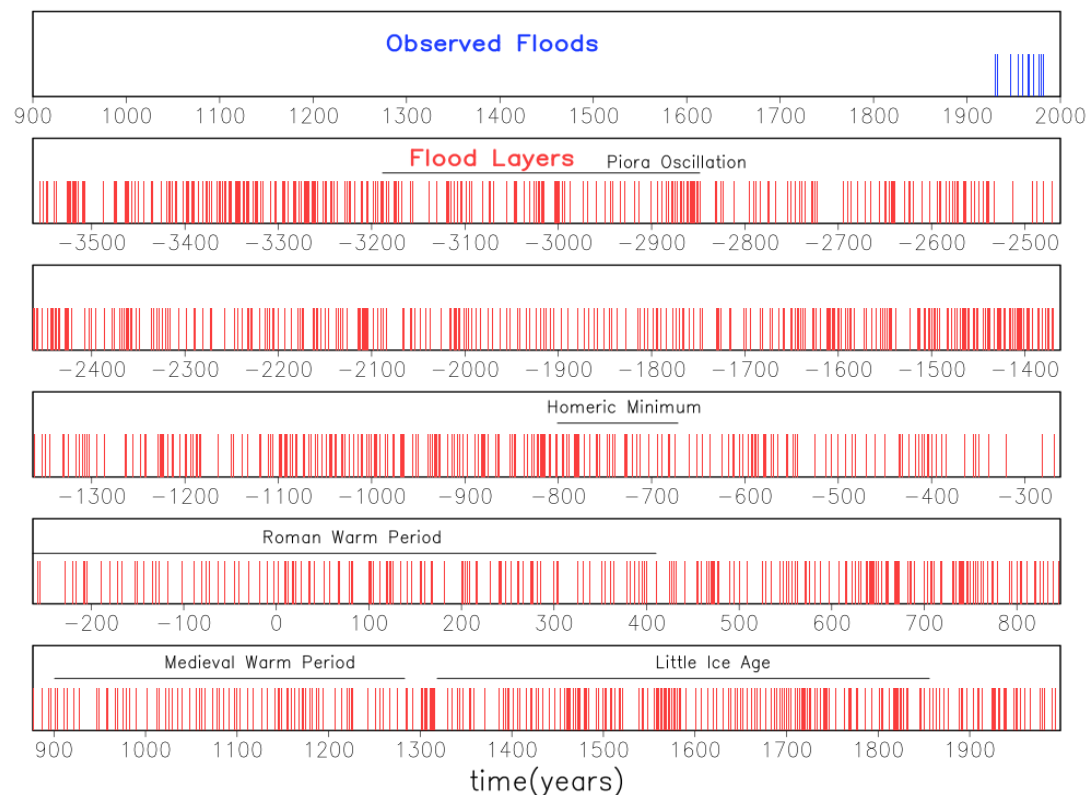
RIVER AMMER FLOOD FREQUENCY VARIABILITY DURING THE LAST ~5500 years

The River Ammer is located in the Bavarian Alpine Foreland (southern Germany). It is one of the main tributaries of the lake Ammer (48°00'N, 11°07'E). High water tables of the moorlands in the vicinity to the lake Ammer and low water-holding capacity of the Alpine soils favor the translation of precipitation extremes into floods by surface discharge. Late moraine, flysch and molasses formations in the Ammer catchment provides abundant, easy erodible detrital material for downstream transport into the lake during a flood. We analyze variability of observed (1926-1999) and proxy (3553 BC to 1999 AD) annual resolution river Ammer flood frequency.



Research questions

- What are the extreme weather and climate patterns associated with flood frequency variability?
- What is the dominant forcing on flood frequency variability at centennial to millennial time scales?



Observed flood year (blue bar)-at least one daily discharge >125m³/s; **Flood layer** (red bar)-distinct layer in the annual resolution lake sediment record

Figure source: Rimbu et al. 2020

A POTENTIAL VORTICITY PERSPECTIVE ON A DAILY FLOOD

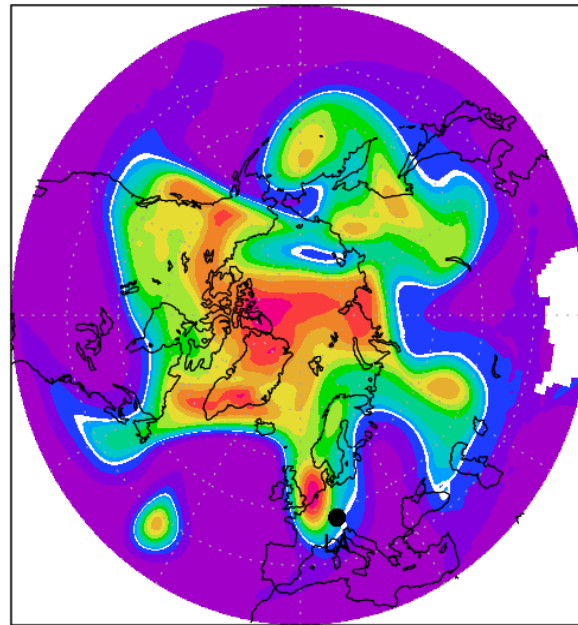
Positive upper level PV anomalies are associated with:

- unstable atmosphere
- strong WVT (atmospheric rivers)
- explosive cyclogenesis
- cut-off lows



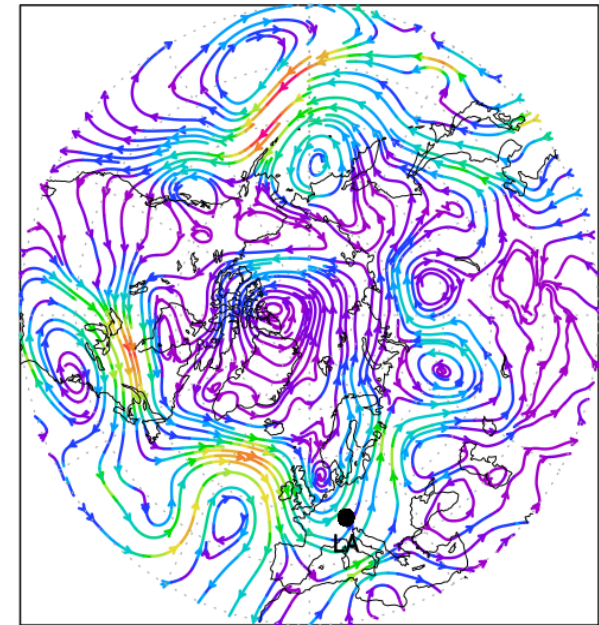
extreme weather

PV 330K 15.06.1979



0.7 2.4 4.7 7 PVU

WVT 15.09.1979



55 275 495 kg/(ms)

streamlines-WVT
color-WVT magnitude

PV 330 K-potential vorticity on 330K isentropic surface

PVU-potential vorticity unit

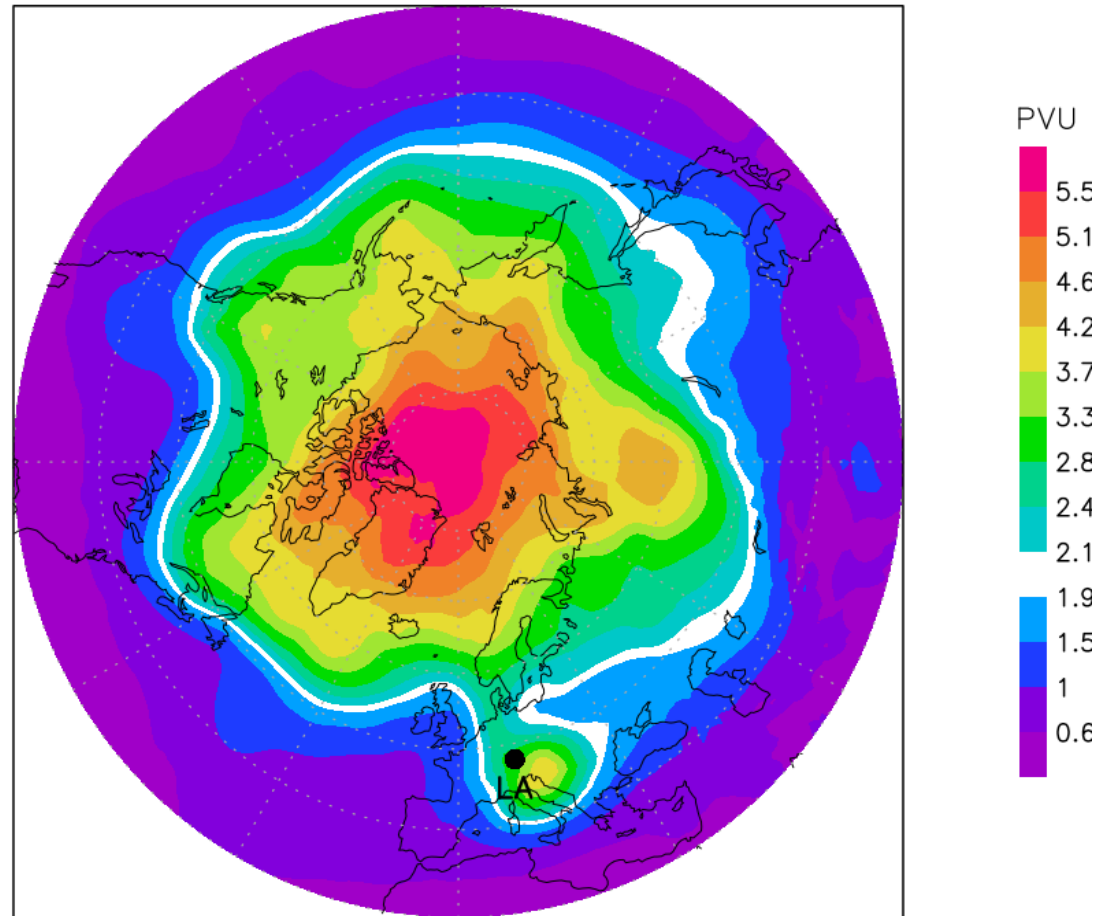
WVT-Vertically Integrated Water Vapor Transport

LA-Lake Ammer

DAILY FLOODS AND ROSSBY WAVE BREAKING

- High (>2 PVU) upper level potential vorticity in the flood region
- Wave-breaking over Europe
- Hemispheric wave-structure (wavenumber ~ 6)

PV 330K FLOOD DAYS

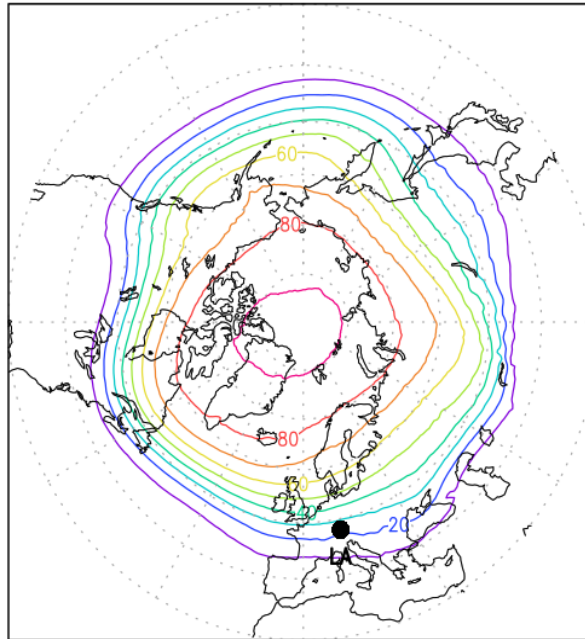


SEASONAL PATTERNS

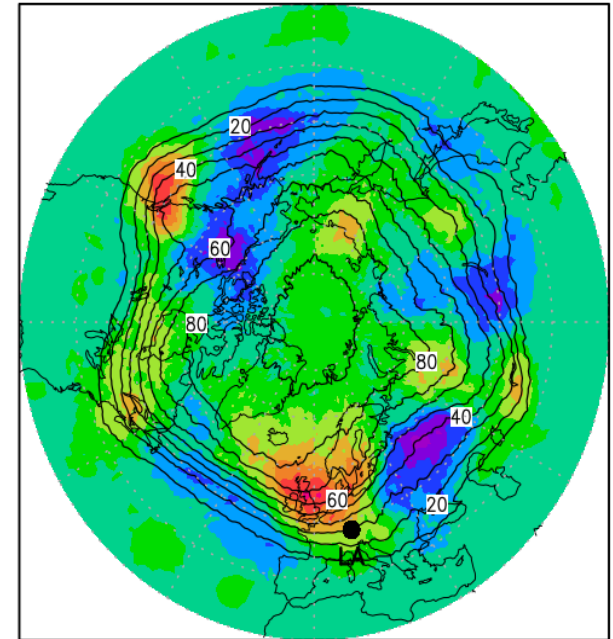
-More (less) high PV days over western Europe (Eastern Europe-western Russia) during flood years

-Northern Hemisphere pattern consistent with PV pattern associated with daily floods

PV INDEX CLIMATOLOGY



PV INDEX FLOOD YEARS



-12 0 12 days

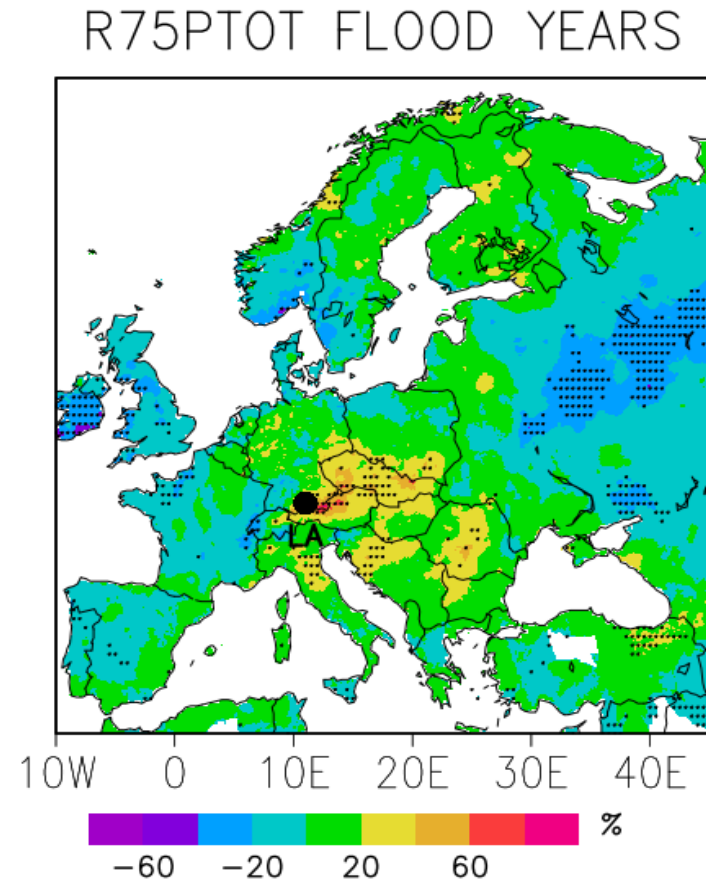
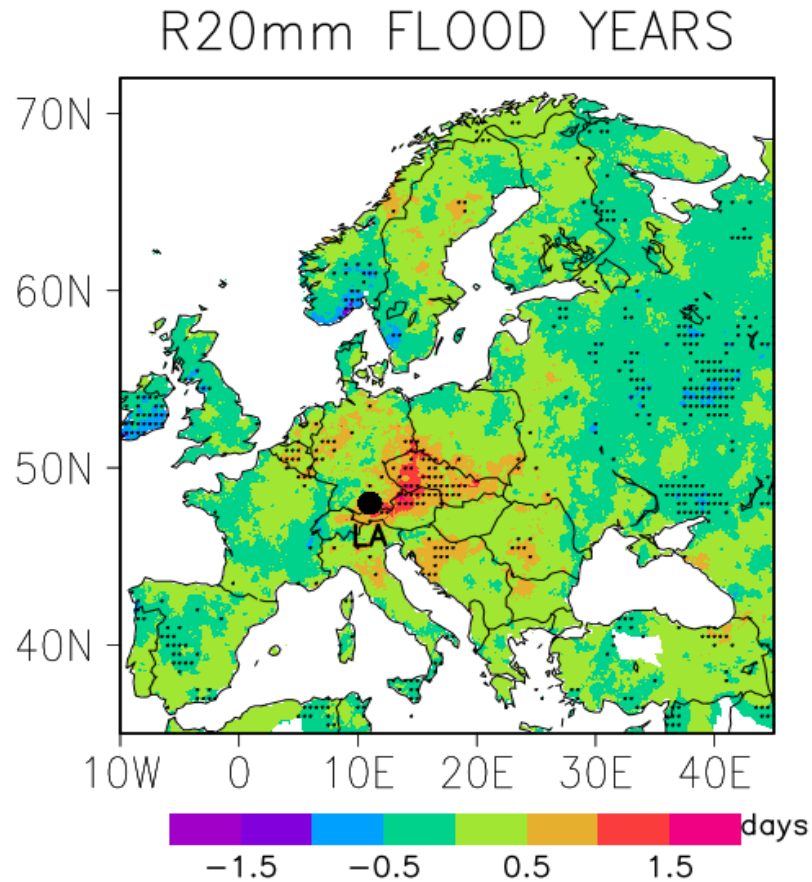
contour-absolute values
color-anomalies

PV INDEX-number of days in a summer with $PV > 2PVU$

Flood year-a year with at least one daily discharge higher than $125m^3/s$

Period of analysis: 1926-2015

LA-Lake Ammer



Large-scale extreme precipitation anomaly patterns associated with flood years

R20mm-very heavy rain days (number of days with total surface precipitation higher than 20mm)

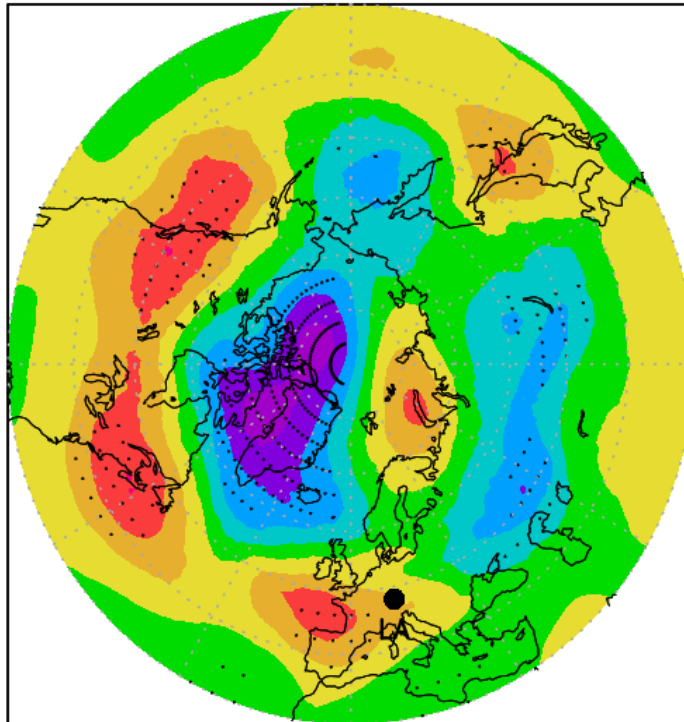
R75PTOT-percent of total precipitation due to daily precipitation higher than the 75th percentile

hatched-significance higher than 90% level

Period of analysis: 1950-2015

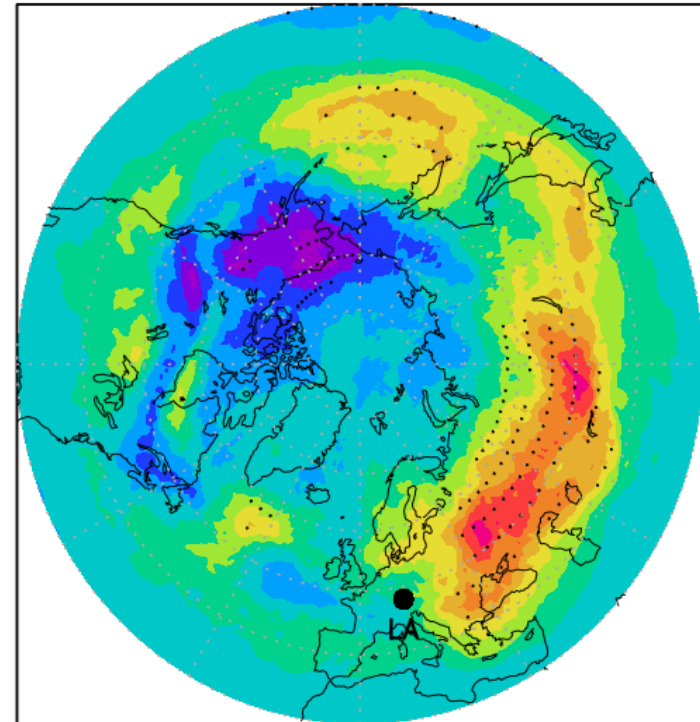
LA-Lake Ammer

PV INDEX LOW SOLAR



-8 -4 0 4 days

PV INDEX HIGH SOLAR



-3 1 5 days

- Large-scale PV anomaly patterns associated with solar forcing
- More frequent high PV events over western Europe for low solar forcing

PV INDEX-number of days in a summer with $PV > 2PVU$

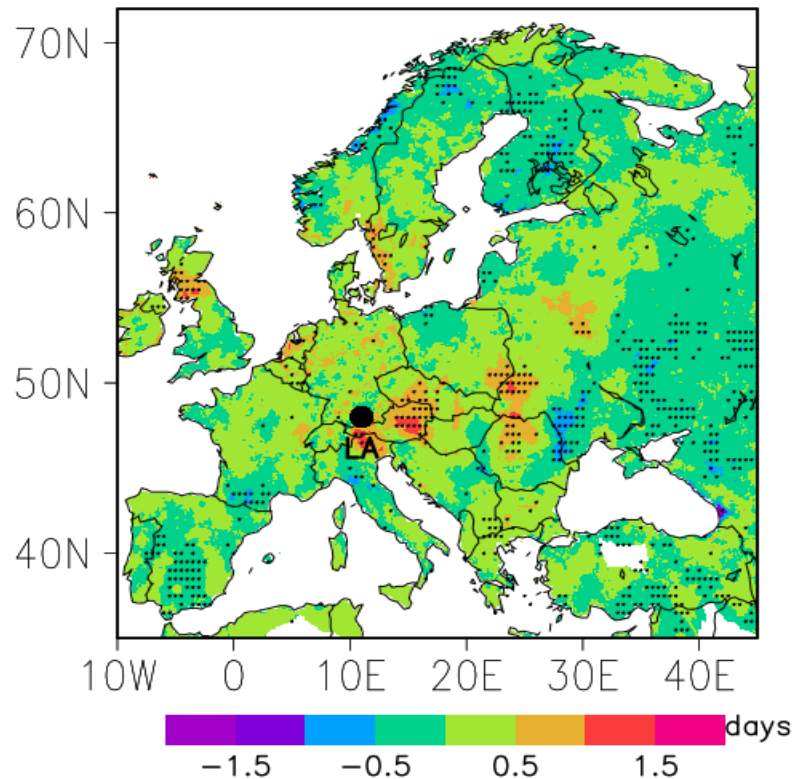
LOW (HIGH) SOLAR-open solar flux lower (higher) than minus one (one) standard deviation

Period of analysis: 1836-2015

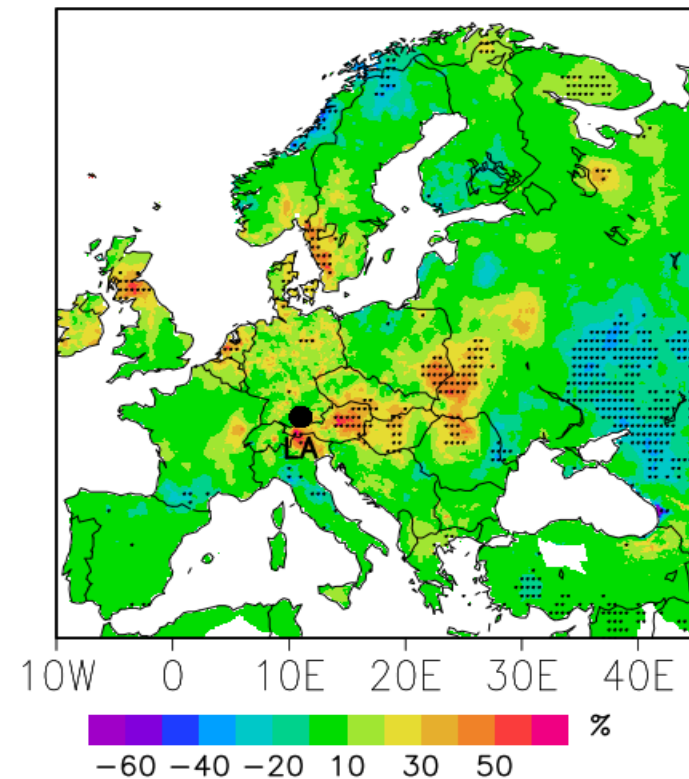
hatched-significance higher than 90% level

LA-Lake Ammer

R20mm LOW SOLAR



R75PTOT LOW SOLAR



Large-scale extreme precipitation anomaly patterns associated with low- solar forcing and flood years are similar

R20mm-very heavy rain days (number of days with total surface precipitation higher than 20mm)

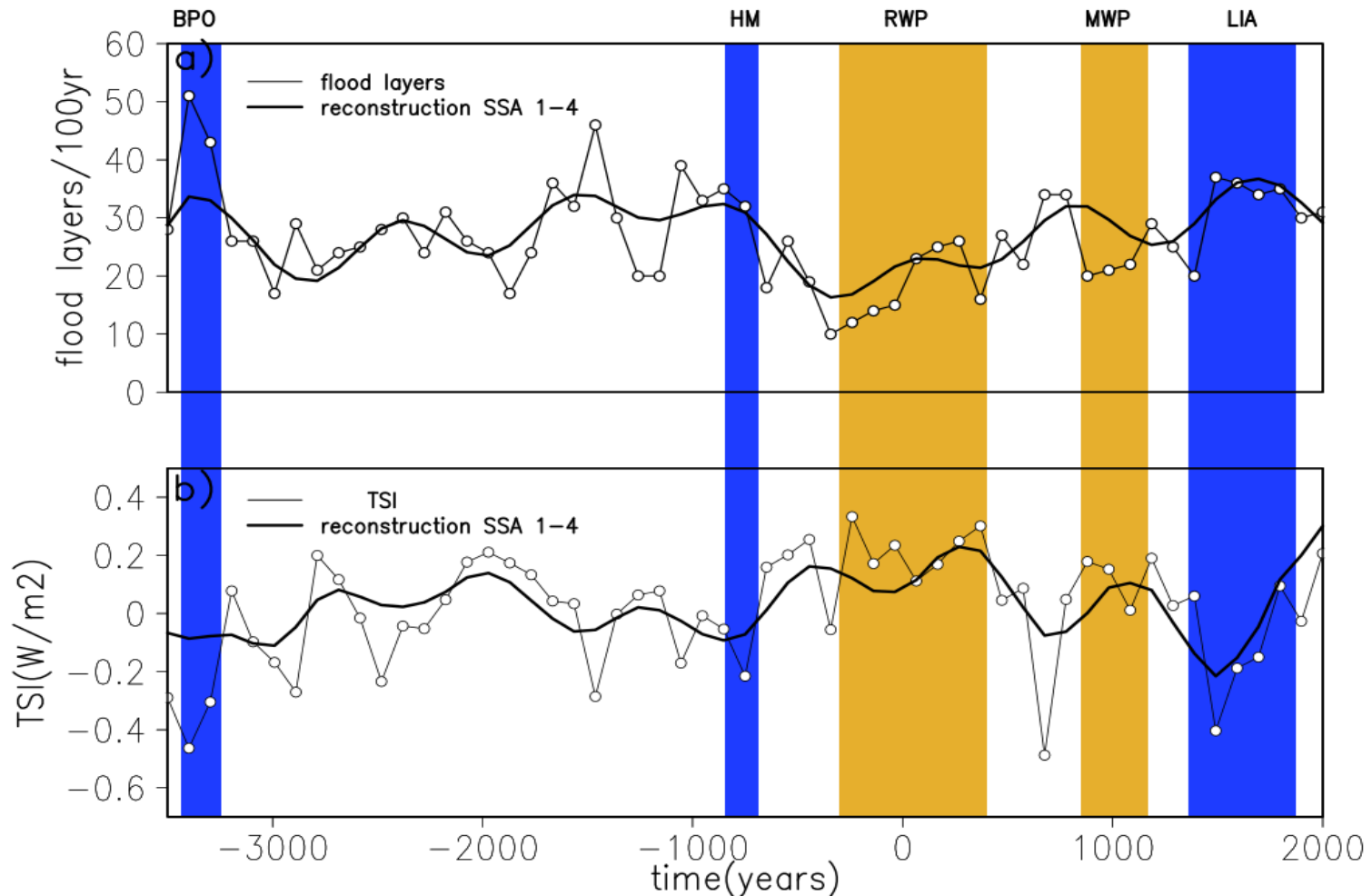
R75PTOT-percent of total precipitation due to daily precipitation higher than the 75th percentile

hatched-significance higher than 90% level

Period of analysis: 1950-2017

LA-Lake Ammer

MILLENNIAL SCALE CYCLES



More than 60% of the flood variability is described by the Eddy (~900 yr) and Bray(Hallstatt) (~2300yr) solar cycles

LIA-Little Ice Age ; **MWP**-Medieval Warm Period; **RWP**-Roman Warm Period ; **HM**-Homeric Solar Minimum; **BPO**-Before Piora Oscillation; **SSA**-Singular Spectrum Analysis; **TSI**-total solar irradiance

SUMMARY & CONCLUSIONS

- River Ammer floods are related to large-scale extreme climate anomaly patterns
- Blocking pattern over Eastern Europe-western Russia during low solar irradiance summers increases the probability of waves breaking over western Europe. This upper level forcing increases the probability of extreme weather including extreme precipitation and floods over western Europe
- The dominant forcing on flood frequency and the associated extreme climate patterns at centennial to millennial time scales is the solar irradiance
- Possible statistical predictability of flood frequency and precipitation extremes at centennial to millennial time scales

REFERENCES & DATA

References

- Rimbu, N. et al. (2016) Atmospheric circulation patterns associated with the variability of River Ammer floods: evidence from observed and proxy data. *Climate of the Past*, 12, 377–385. doi:10.5194/cp-12-377-2016.
- Rimbu, N. et al. (2020) Interannual to millennial scale variability of River Ammer floods and its relationship with solar forcing, (submitted to International Journal of Climatology).
- Czymzik, M. et al. (2013) Orbital and solar forcing of shifts in Mid- to Late Holocene flood intensity from varved sediments of pre-alpine Lake Ammersee (southern Germany). *Quaternary Science Review*, 61, 96-110. <https://doi.org/10.1016/j.quascirev.2012.11.010>.
- Czymzik, M. et al. (2016) Solar modulation of flood frequency in central Europe during spring and summer on inter-annual to multi-centennial time scales. *Climate of the Past*, 12, 799-805.

Data

- Flood layer record for the last 5500 years-<https://doi.pangaea.de/10.1594/PANGAEA.803368>
- Solar irradiance index (open solar flux)-https://climexp.knmi.nl/data/iosf_merged.dat
- Holocene total solar irradiance (TSI)
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/climate_forcing/solar_variability/steinhilber2009tsi.txt
- Extreme climate indices- https://surfobs.climate.copernicus.eu/dataaccess/access_eobs_indices.php
- Meteorological data- https://psl.noaa.gov/data/gridded/data.20thC_ReanV3.html