



Quantifying the effect of dams in reducing global flood exposure under climate change

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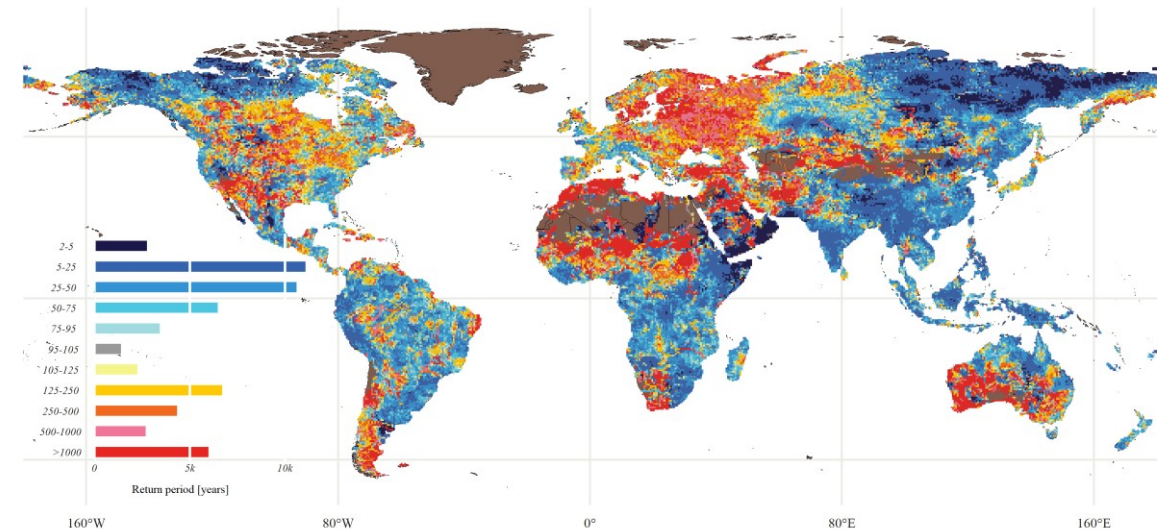


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Figure: Frequency of the historically 1 in a 100-year flood in the future.

Multi-model median return period (years) in 21C for discharge corresponding to the historical 100-year flood for RCP6.0 and considering dams.





- Global warming is expected to **increase flood risk**
 - Altering the **distribution, variability, and intensity** of precipitation events
- Global **estimates** of **populations exposed to river flooding** vary widely across studies
 - A **4–20-fold increase** by the end of the 21st century is commonly predicted
- To mitigate the destructive potential of floods an **estimated 2.8 million dams** have been constructed globally
 - Maximize water availability for human consumption
 - Total water impoundment capacity ranging from 7,000 to 10,000 km³
 - About half of the planet's major river systems are regulated by dams

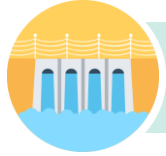
Understanding the role of dams in climate impact studies has become increasingly important



- Previous analyses of floods have **reconstructed historical flood patterns**
 - Considering climate change and/or socio-economic development factors
- Number of people exposed annually to the equivalent of a historical 100-year river flood was projected to triple (IPCC)
 - Comparing high and low emission scenarios
- Few studies have accounted for dams and/or flood protection at a national scale
 - Reported the **importance** of considering **dam**-induced changes in streamflow characteristics in flood-hazard modelling

Objective:

- Provide the first global assessment of the **role of dams in reducing future flood risk** under climate change
- Modelling framework quantifies how the frequency of historical 100-year return period floods varies in the future
 - Due to climate change and the consideration of dams



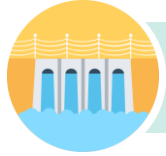
H08: **global hydrological** model

- Simulate the water cycle globally
- Daily, at a spatial resolution of 0.5° (longitude $\times$ latitude)
- Simulates both **natural** and **anthropogenic** water flow
 - Dam/reservoir, irrigation, water withdrawals...



CaMa-Flood: new generation of **global river routing** model

- Explicitly parameterizing sub grid-scale topography of a floodplain
- Can **realistically** simulate **floodplain inundation** dynamics
- Does **not currently consider dams and reservoirs**



Concept:

- Combined the **advantage** of using **H08** and **CaMa-Flood** in a modelling framework

- Conduct global simulation with the H08 model
 - Forcing data: ISIMIP2b
 - Dams are considered
- Conduct global simulation with the CaMa-Flood model
 - Forcing data: daily runoff from the previous simulation
 - In **grid cell containing dams**, the **discharge** produced by CaMa-Flood is **swapped** with that predicted by the H08 model

Caveat:

- Use same global river network

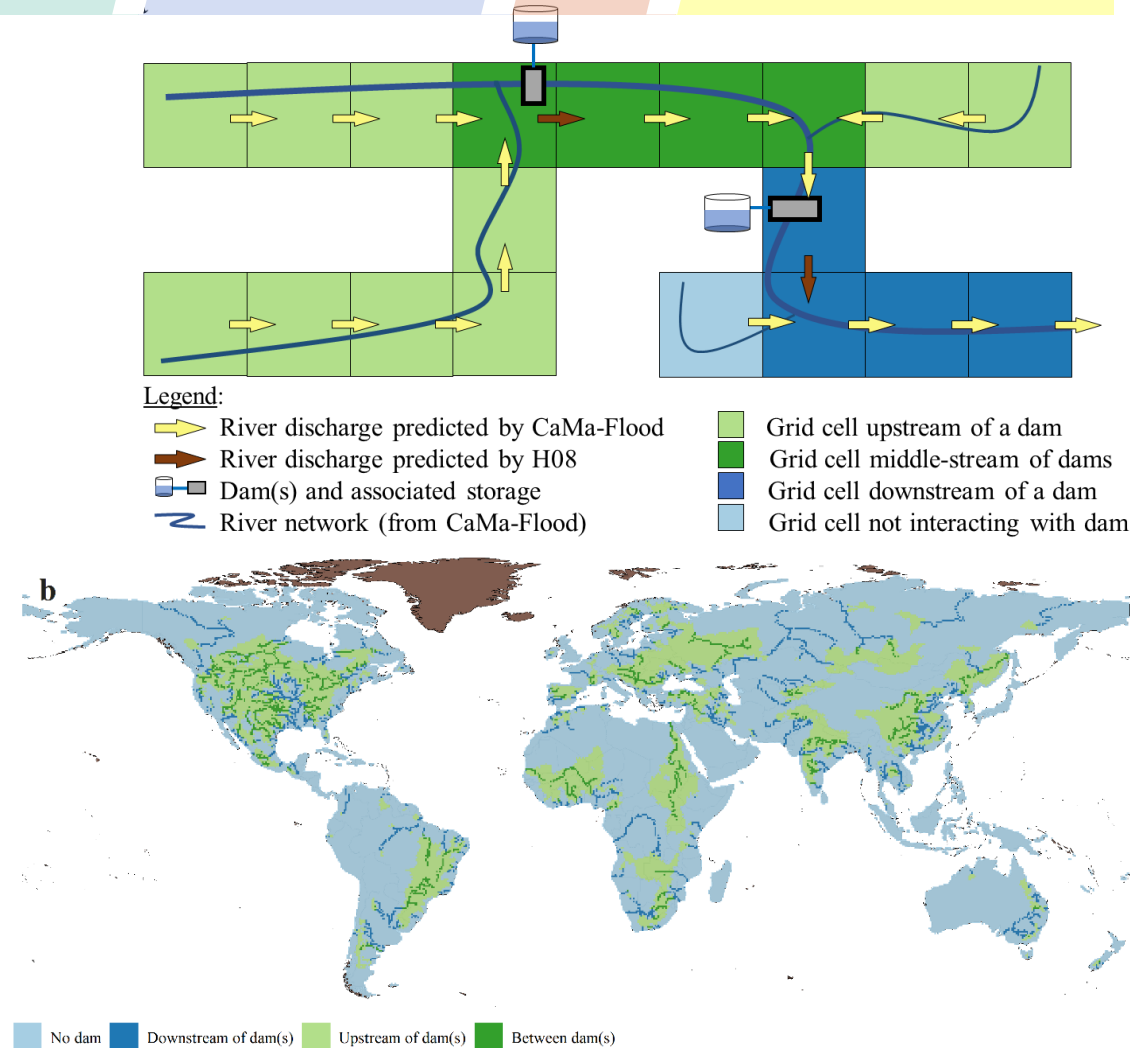
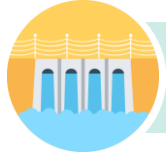


Fig. 1: Details of the coupling procedure between H08 and CaMa-Flood. **a**, Schematics of the coupled H08 and CaMa-Flood models for a hypothetical river. **b**, Global distribution of the position of grid cells relative to dams



Dams and reservoirs

- From the Global Reservoir and Dam (GRanD) Database (<http://www.gwsp.org/>)
 - Dams are georeferenced

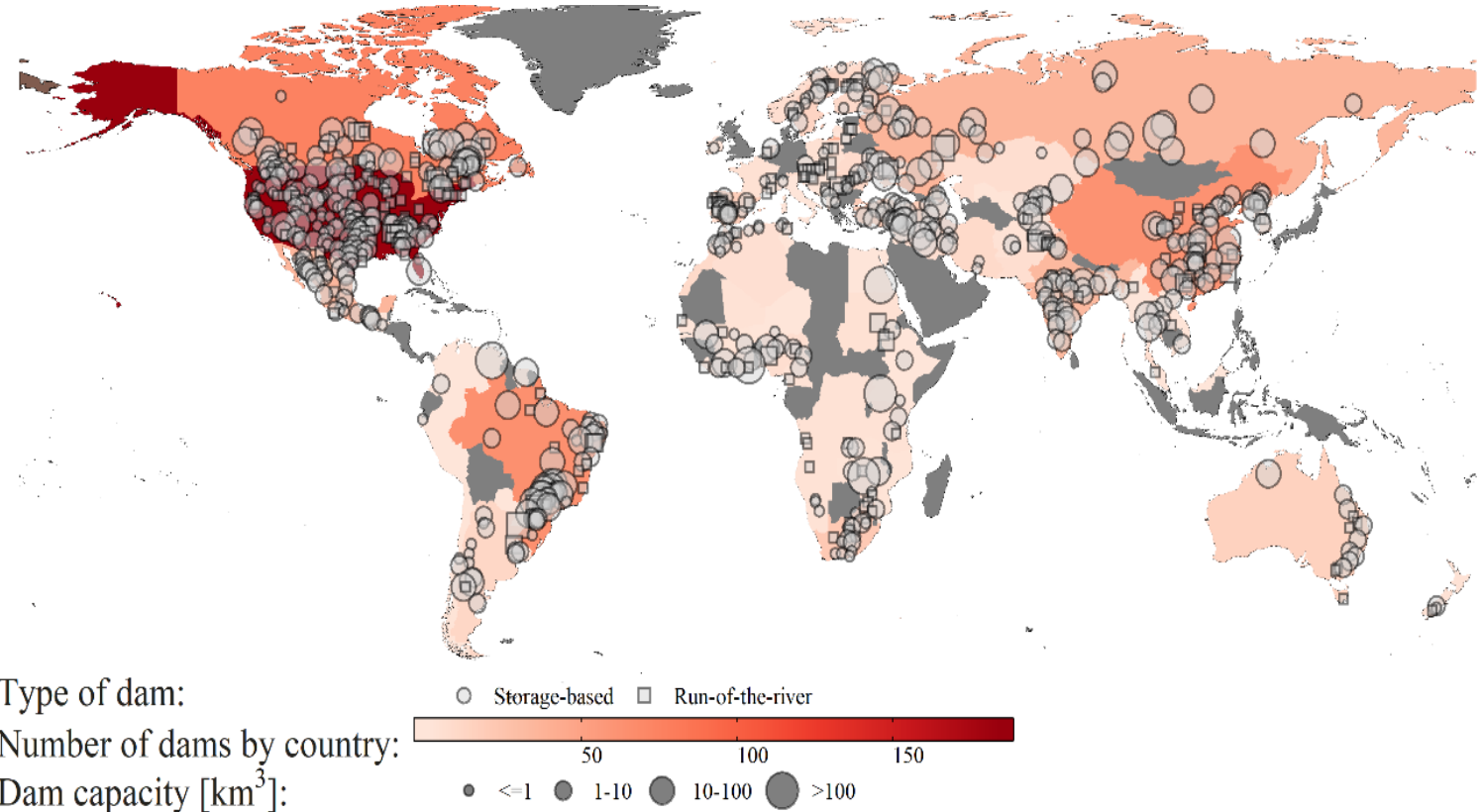
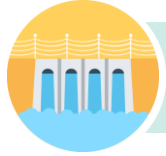


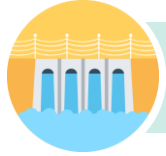
Fig. 2: Locations of the global dams included in this study.

Note: The run-of-the-river dams consisted of dams which storage divided by the annual mean inflow was inferior or equal to 0.05 year^{-1} . Storage-based dams simply consist of all other remaining dams.



ISIMIP2b

- The Inter-Sectoral Impact Model Intercomparison Project phase 2b
 - Used to consistently project the **impacts** of **climate change**
 - Across affected sectors and spatial scales
 - Facilitates **inter-model comparison** studies
 - Provides bias corrected input variables (hourly, 0.5 resolution)
- We used the four global circulation models (GCMs)
 - Two representative concentration scenarios: RCP2.6 and RCP6.0
 - Bias corrected
- Two **experimental simulations** are conducted:
 - Typical CaMa-Flood simulation → “no dam experiment”
 - CaMa-Flood coupled with H08 (see slides 5, 6) → “dam experiment”

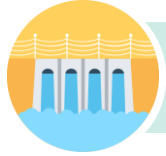


Analysis

- Focused on river **discharge** ($\text{m}^3 \text{s}^{-1}$) and grid **flooded fraction** (0–1)
 - The latter quantify the flooded surface (m^2) of a grid given the currently stored volume of water (m^3) in the floodplain
 - Computed using **sub-grid parameter** (elevation profile)

River discharge

- Investigate the **change** in **flooding** between an **historical period** and future period
- Fit annual maximum discharge to a **Gumbel distribution**
 - Annual maximum discharge corresponding to a 1 in a 100-year flood is first computed for an historical period
 - Investigate **the frequency** of the historically 1 in a 100-year flood in future scenarios
 - RCP2.6 and RCP6.0 given the “no dam experiment” and “dam experiment”



Flooded fraction

- Assessed where the **daily discharge exceeded** the historically 1 in a 100-year flood
 - Over 2070-2099
- For such locations, extract the **flooded fraction**
- We summarize these indices for **14 catchments**, using only grid-cell below dams
 - Annually
 - Sum of flood occurrence
 - Sum of flooded fraction
- Analyze how the data differ for the “no dam experiment” and “dam experiment”



- Downstream of dams, historically 1 in a 100-year **floods occurred less frequently** in the experiment considering dams than in the experiment with no dams
 - $66.6 \pm 4.2\%$ of grid-cells (RCP2.6)
 - $60.8 \pm 12.7\%$ of grid-cells (RCP6.0)
- Similar to other regional- and country-scale analyses
- Prominent reductions in future flood frequency were observed along **major sections of rivers containing multiple high-capacity dams**

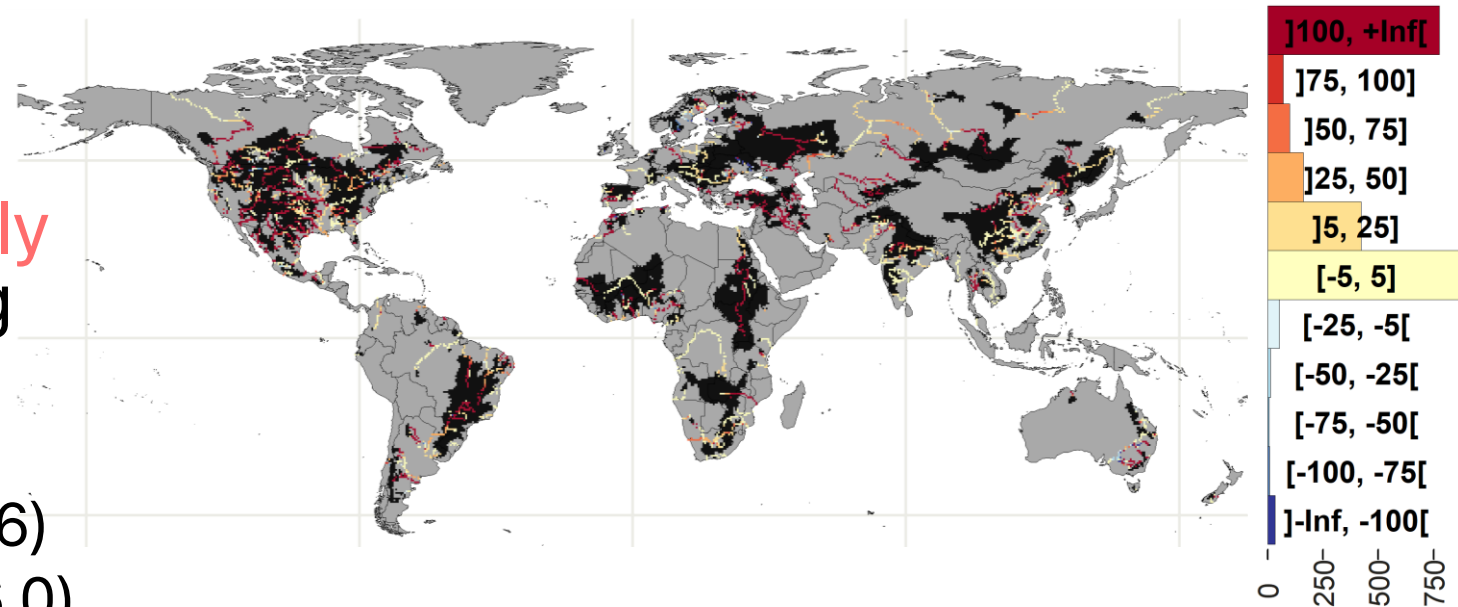
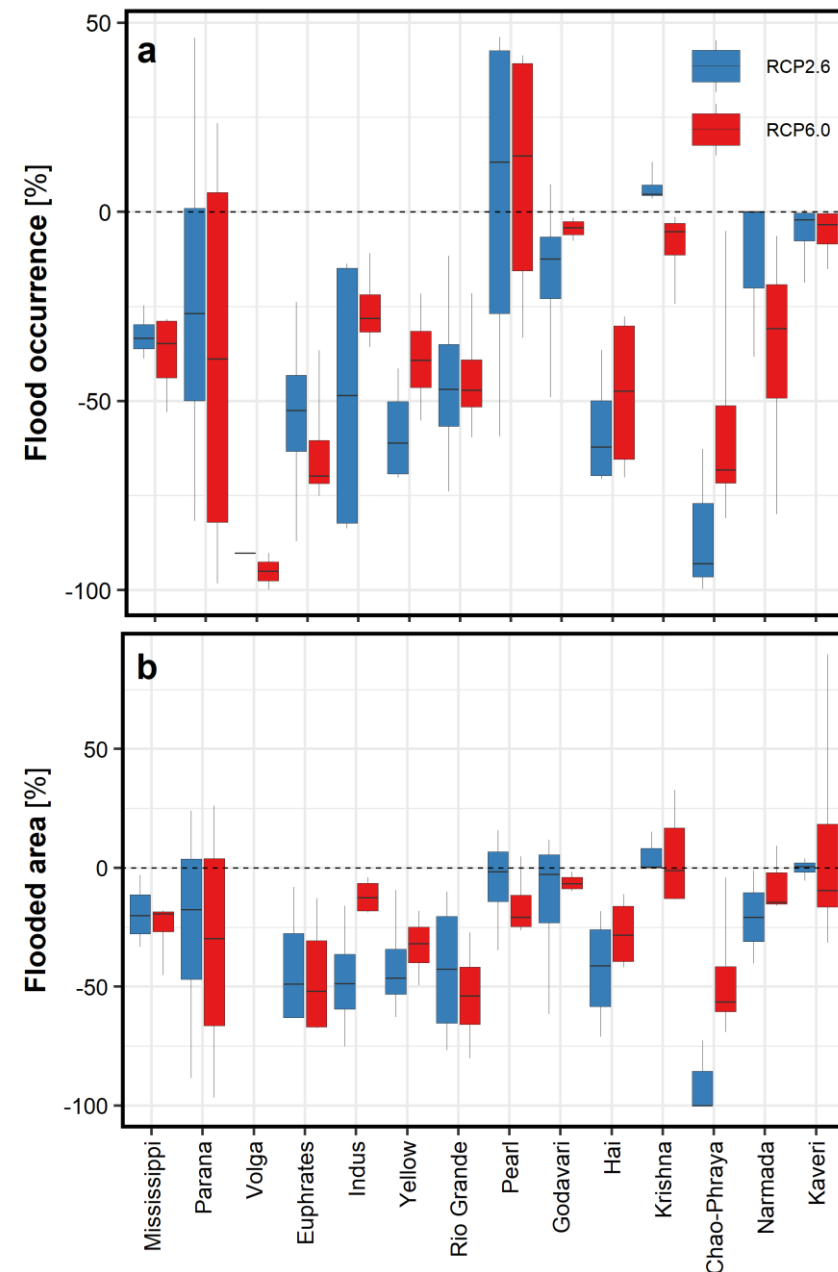


Fig. 3: Projected difference in multi-model median return period (years) in 21C for discharge corresponding to the historical 100-year flood between the experiment not considering dams minus the experiment considering dams.

The case for representative concentration pathway (RCP) 6.0 is shown



- Fig. 4: a) Occurrence of historical 100-year river floods and b) maximum flooded areas in the experiment considering dams relative to the experiment not considering dams
 - Over the 2070–2099 period for 14 catchments
- The historically 1 in a 100-year floods **occurred less frequently** in the experiment with dams
 - RCP2.6: decrease by 36.5% (26.6–49.1%)
 - RCP6.0: decrease by 35.5% (28.8–46.6%)
 - Across 14 catchments
- Similar result for **maximum flooded** area in the catchments (panel b)





- Risk of floods **increases in the future**
- Populations exposed to flooding below dams decreased:
 - RCP2.6: 16.3% (5.7–30.7%)
 - RCP6.0: 12.8% (4.2–27.5%)
 - Compared to the respective simulations not considering dams
 - Over 2006–2099
- Accounting for population growth, the implementation of **dams could further reduce populations exposed to flooding**
 - RCP2.6: 20.6–32.0% for RCP2.6 a
 - RCP6.0: 7.0–16.8% for RCP6.0
 - Lowest and highest values across five SSPs

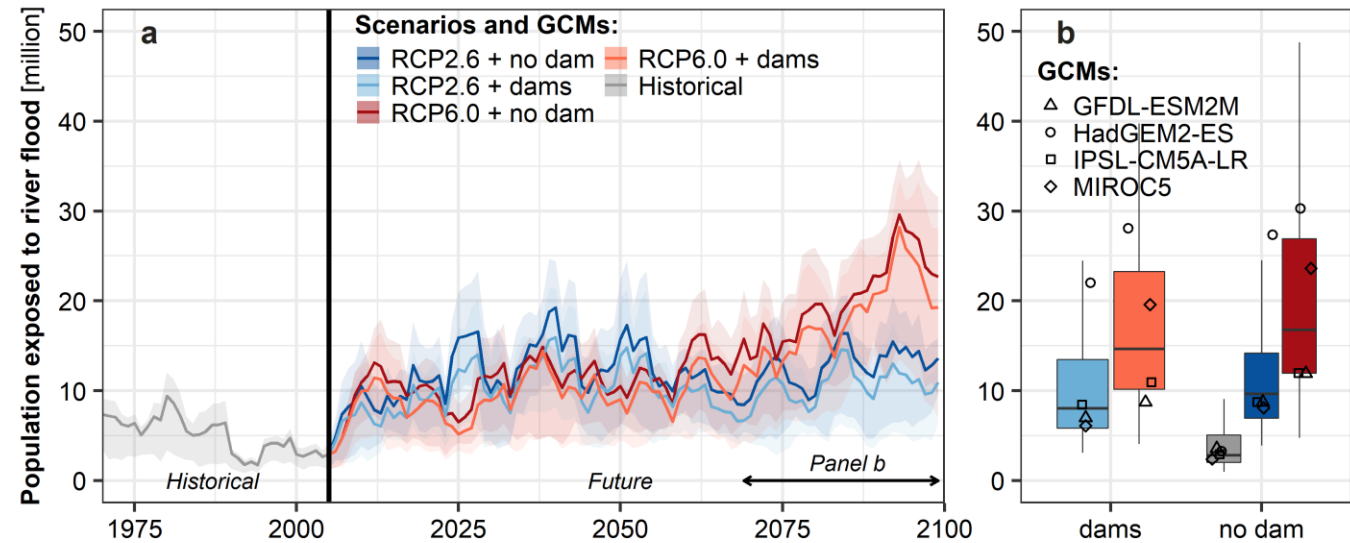


Fig. 5: Population exposure to the historical 100-year river flood (keeping population constant at 2010 level) downstream of dams.

a 5-year moving averages of the population living below dams exposed to the historical 100-year river flood for historical (grey line) and future simulations for 2 RCPs and experiments (color lines). The uncertainty range represent the spread among GCMs.

b The 95th and 5th range (whiskers), median (horizontal lines in each bar), and 1st and 3rd quartiles (height of box) and individual mean values among GCMs (markers) of the population exposed to the historical 100-year flood for grid-cells located below dams over the 2070–2099 period.