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GIRO Conference 2022

21–23 November, ACC Liverpool

#GiroConf22

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Where climate change and flood risk meets catastrophe modelling – A primer for actuaries

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FATHOM

Formed out of the University of Bristol Hydrology Research Group in 2013.

Co-founded by a team of world-leading flood scientists.

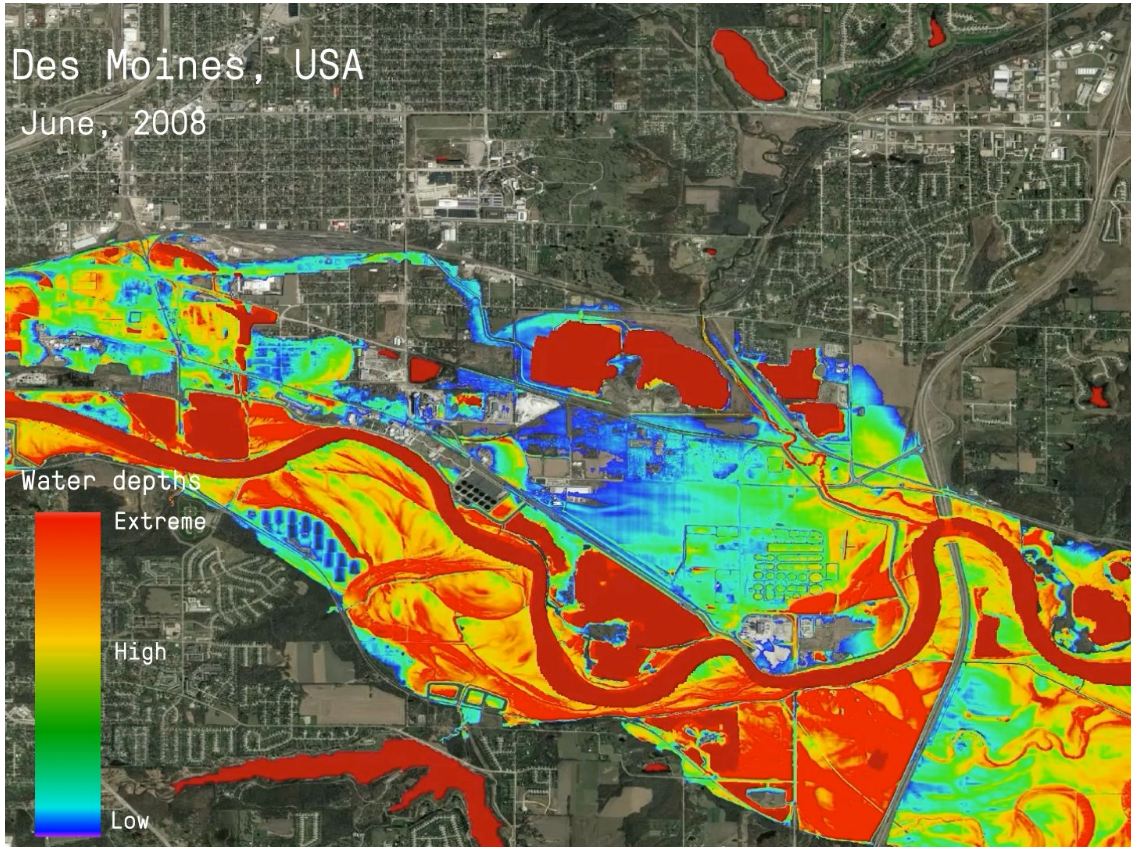
Aiming to provide comprehensive water risk intelligence for the entire planet.

Open methods and academic research are inviolable tenets of our foundation.*

***increasingly important as climate service providers with black box models emerge to meet the demands of newly climate-conscious businesses [Fiedler et al. (2021), *Business risk and the emergence of climate analytics*]**

Flood modelling: from local to global

- Computational flood models are nothing new
- Physics have been understood for centuries
- Very data-hungry!
- Very computationally expensive!



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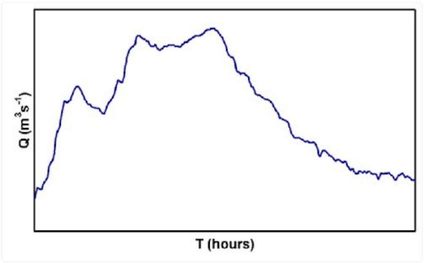
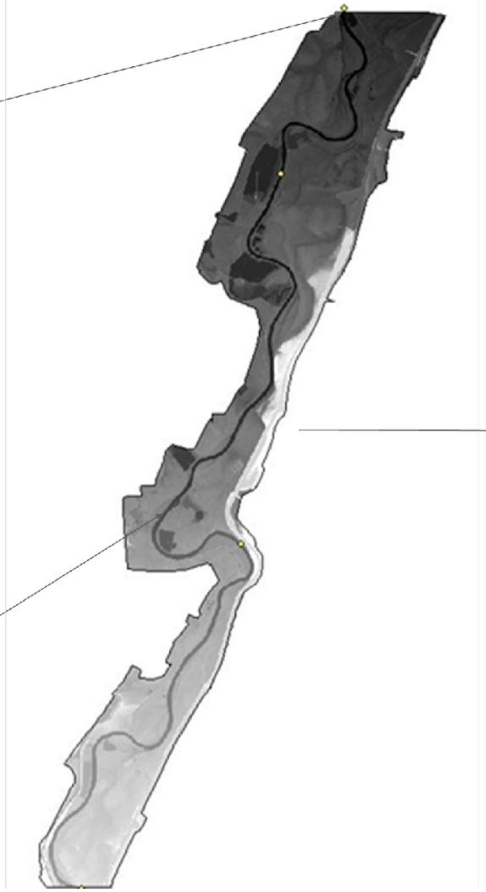
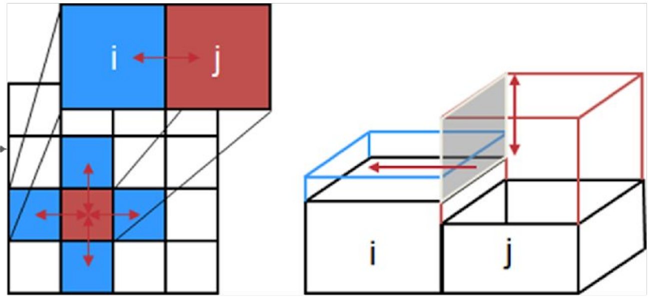
Flood models: the building blocks



Inflow hydrograph (QT)

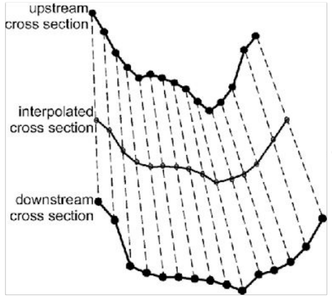
Eg: Gauging station records





Hydraulic engine

Eg: HEC-RAS



Channel bathymetry

Eg: Surveyed channels

Terrain data

Eg: LiDAR

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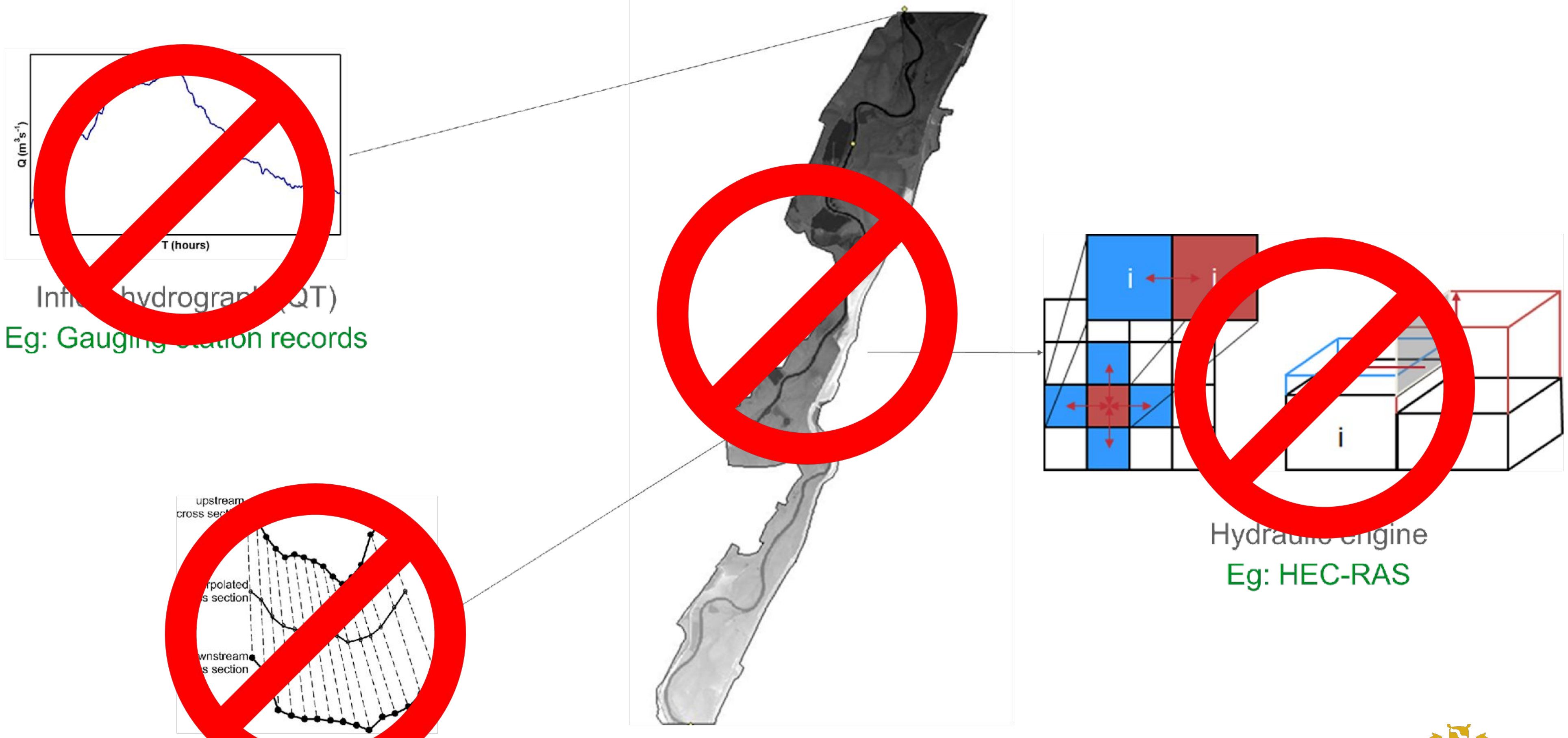
Flood models: the global outlook



Infl hydrograp (QT)
Eg: Gaug ation records

Char ymetry
Eg: Surveyed channels

Terrain data
Eg: LiDAR

Hydrau ngine
Eg: HEC-RAS

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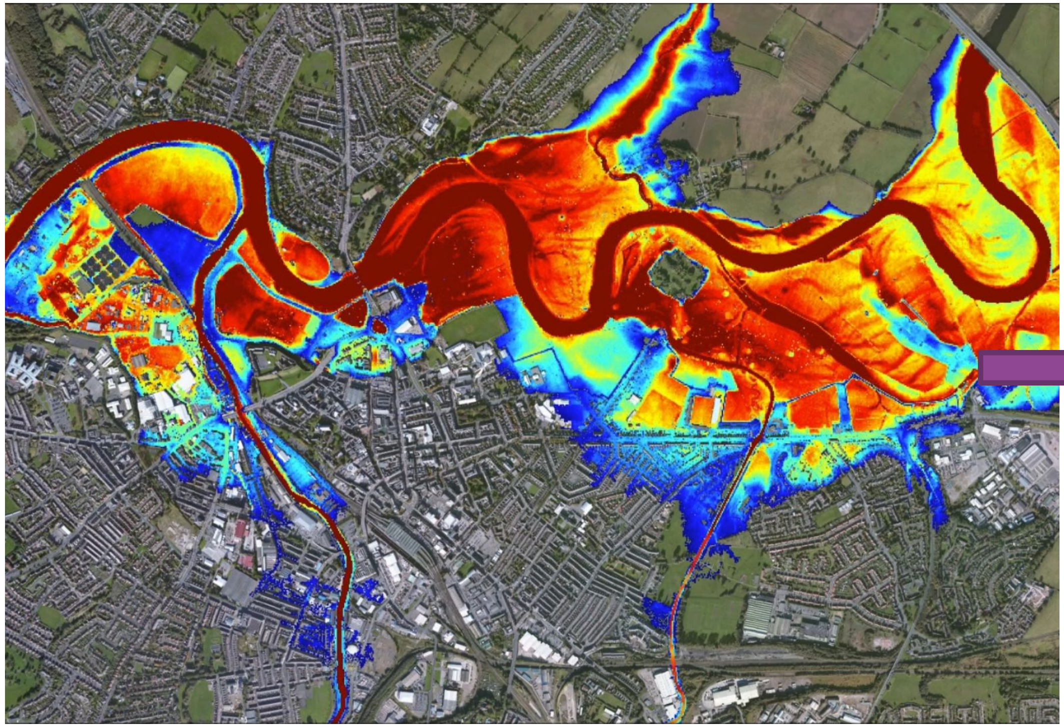
The problem

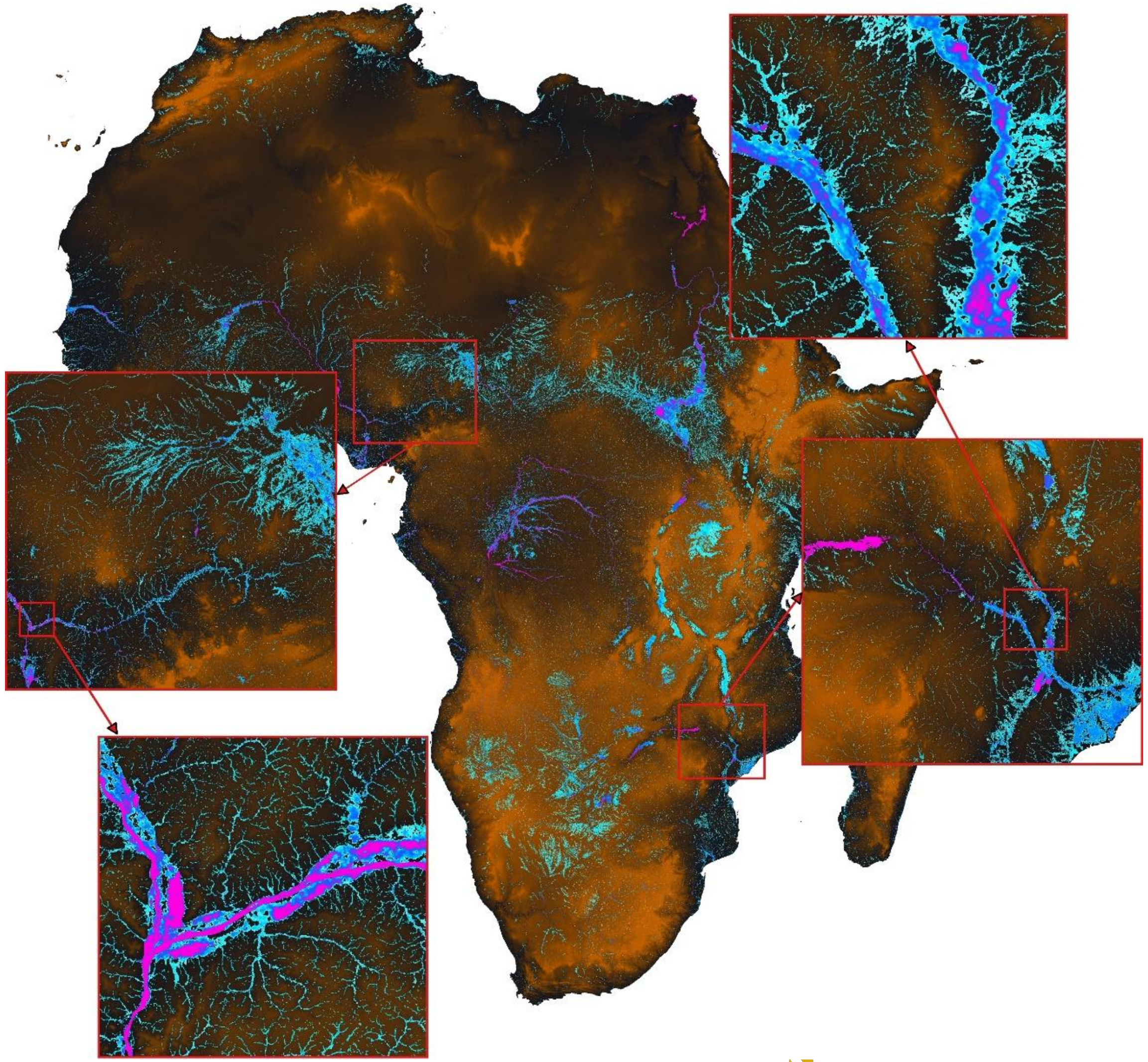


How do we move from small scale models…

… to models that cover entire countries, continents, and the globe?

Global modelling

- More / faster computers always helps!
- Parsimonious hydraulic model refined since 2000 [Bates et al. (2010), *J. Hydrol.*]
- New global terrain datasets [Hawker et al. (2022), *Environ. Res. Lett*.], supplemented with local data
- River locations [Yamazaki et al. (2019), *Water Resour. Res.*] and bathymetry estimation [Neal et al. (2021), *Water Resour. Res.*]
- Regionalisation techniques to predict frequency–mass relationships from hydrometric observations [Zhao et al. (2021), *Hydrol. Earth Syst. Sci.*]
- Automated model-building framework [Sampson et al. (2015), *Water Resour. Res.*]
- Stochastic models to characterise correlation between locations [Quinn et al. (2019), *Water Resour. Res.*].



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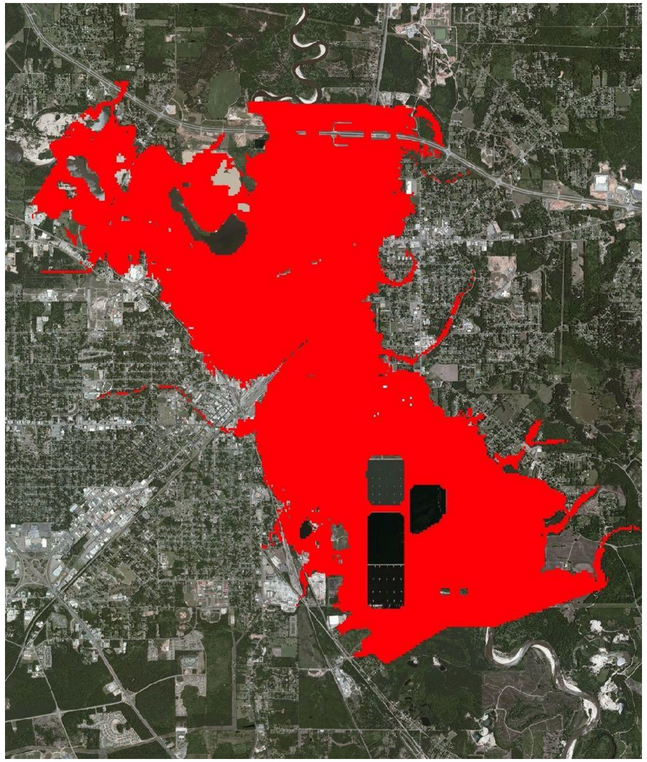
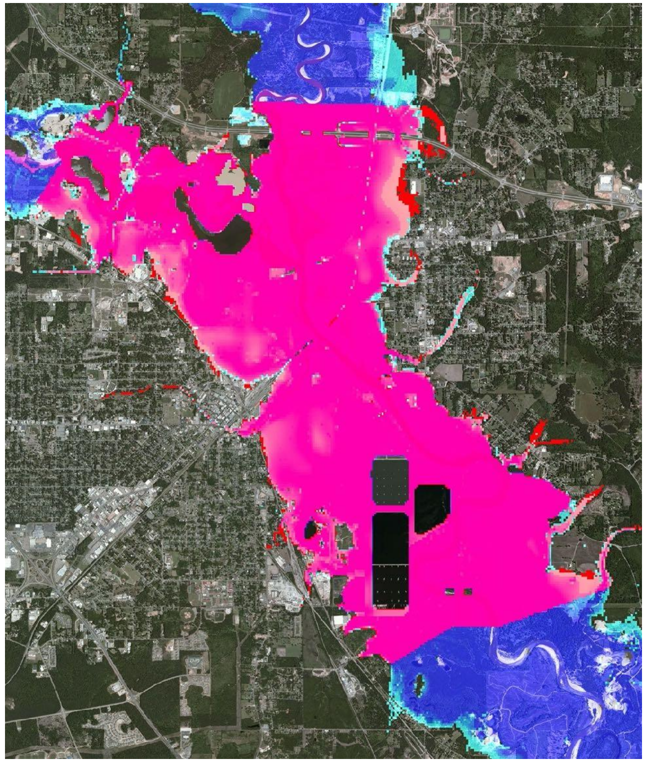
Validation

- Comparison to ~millions of local models and ~tens of observations in a series of papers, with particular focus on US, UK, Europe, & Japan
- Replicates local engineering models, where they exist



Engineering model



Global model

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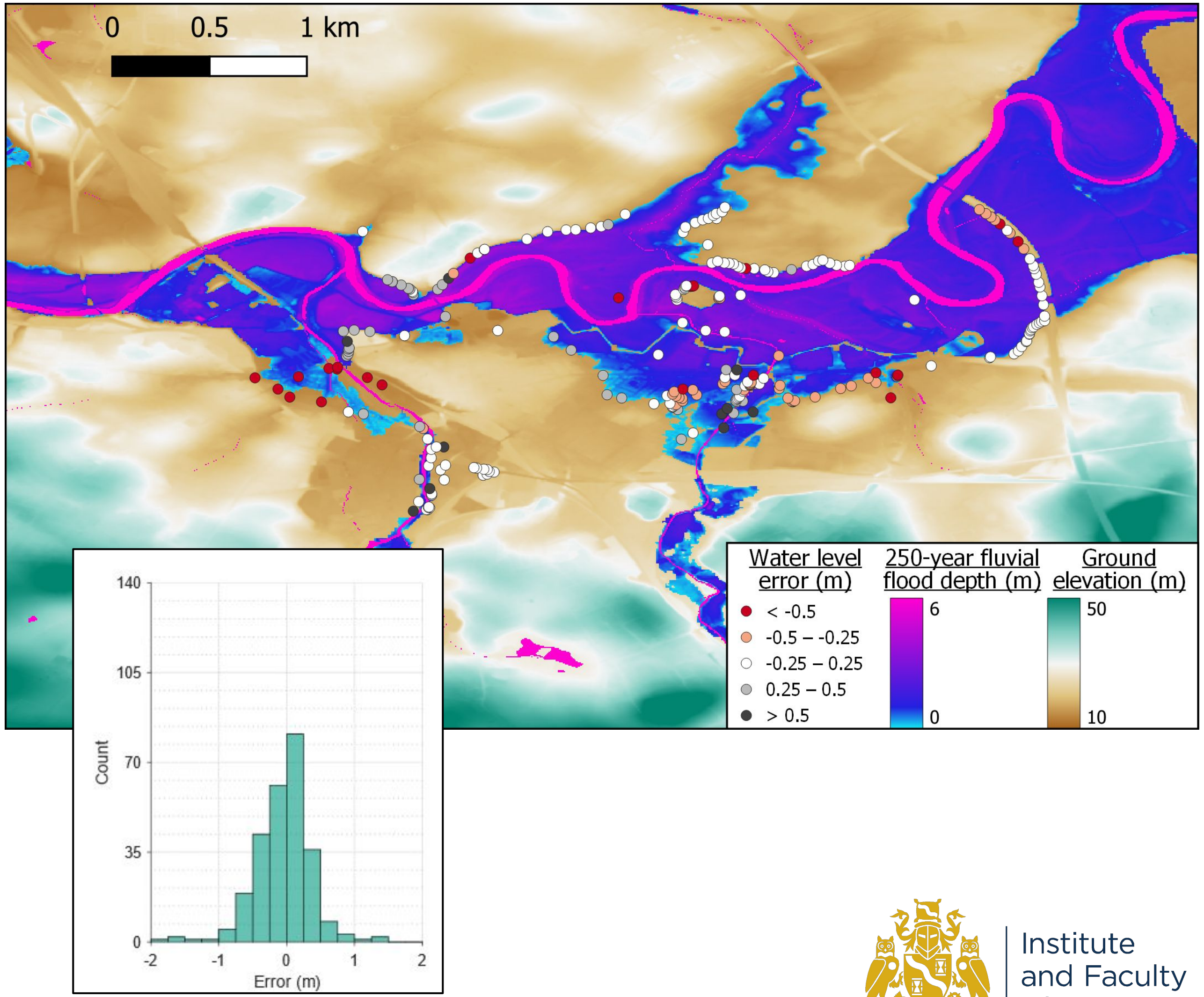
Validation

- Comparison to ~millions of local models and ~tens of observations in a series of papers, with particular focus on US, UK, Europe, & Japan
- Replicates local engineering models, where they exist
- Reproduces observations, within error



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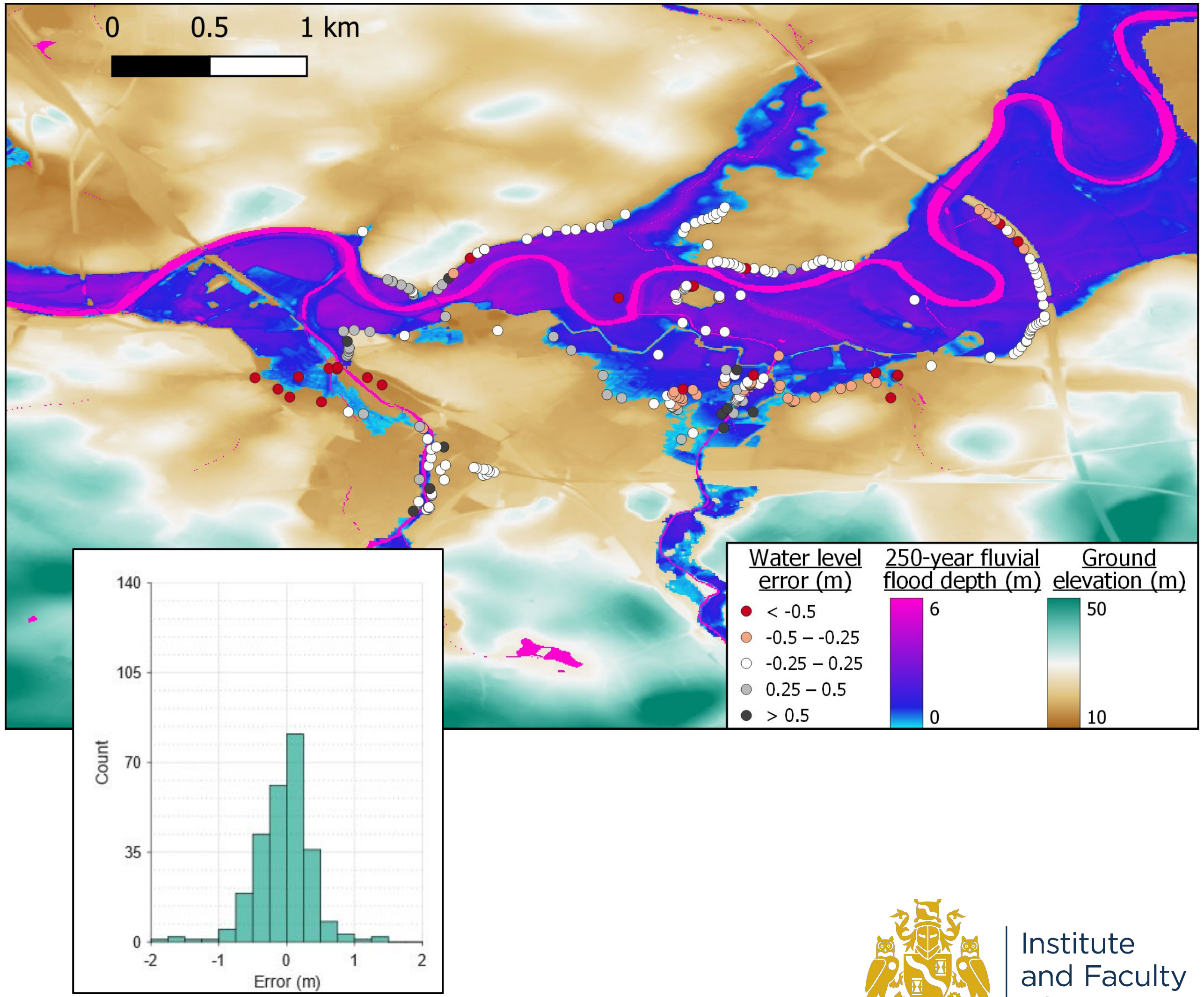
Validation

- [Wing et al. (2017), *Water Resour. Res.*]
- [Sampson et al. (2015), *Water Resour. Res.*]
- [Wing et al. (2019), *Water Resour. Res.*]
- [Wing et al. (2019), *J. Hydrol. X*]
- [Bates et al. (2021), *Water Resour. Res.*]
- [Wing et al. (2021), *Nat. Hazards Earth Syst. Sci.*]
- [Bates et al. (under review), *Nat. Hazards Earth Syst. Sci.*]
- [Choné et al. (2021), *Hydrol. Process.*]
- [Neal et al. (2021), *Water Resour. Res.*]



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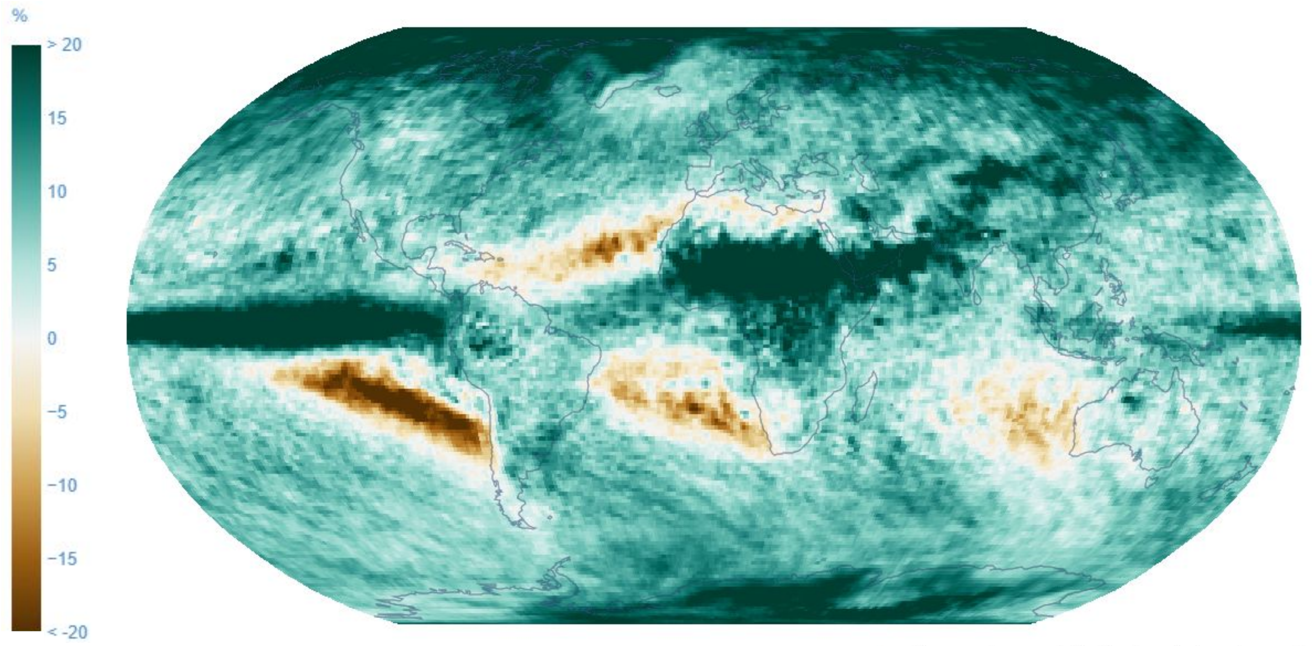
Climate change

- Conspicuously missing: *the nature of floods is changing because the climate is changing*
- Warming world = more rain
  - Pluvial floods probably increase
- More rain does not necessarily mean more floods
  - Fluvial floods mixed/uncertain
- Regardless of changes to storminess, coastal floods will increase due to sea-level rise



Maximum 1-day precipitation (RX1day) - Change (%)
Warming 2°C (SSP2-4.5) (rel. to 1961-1990)
CMIP6 - Annual (32 models)

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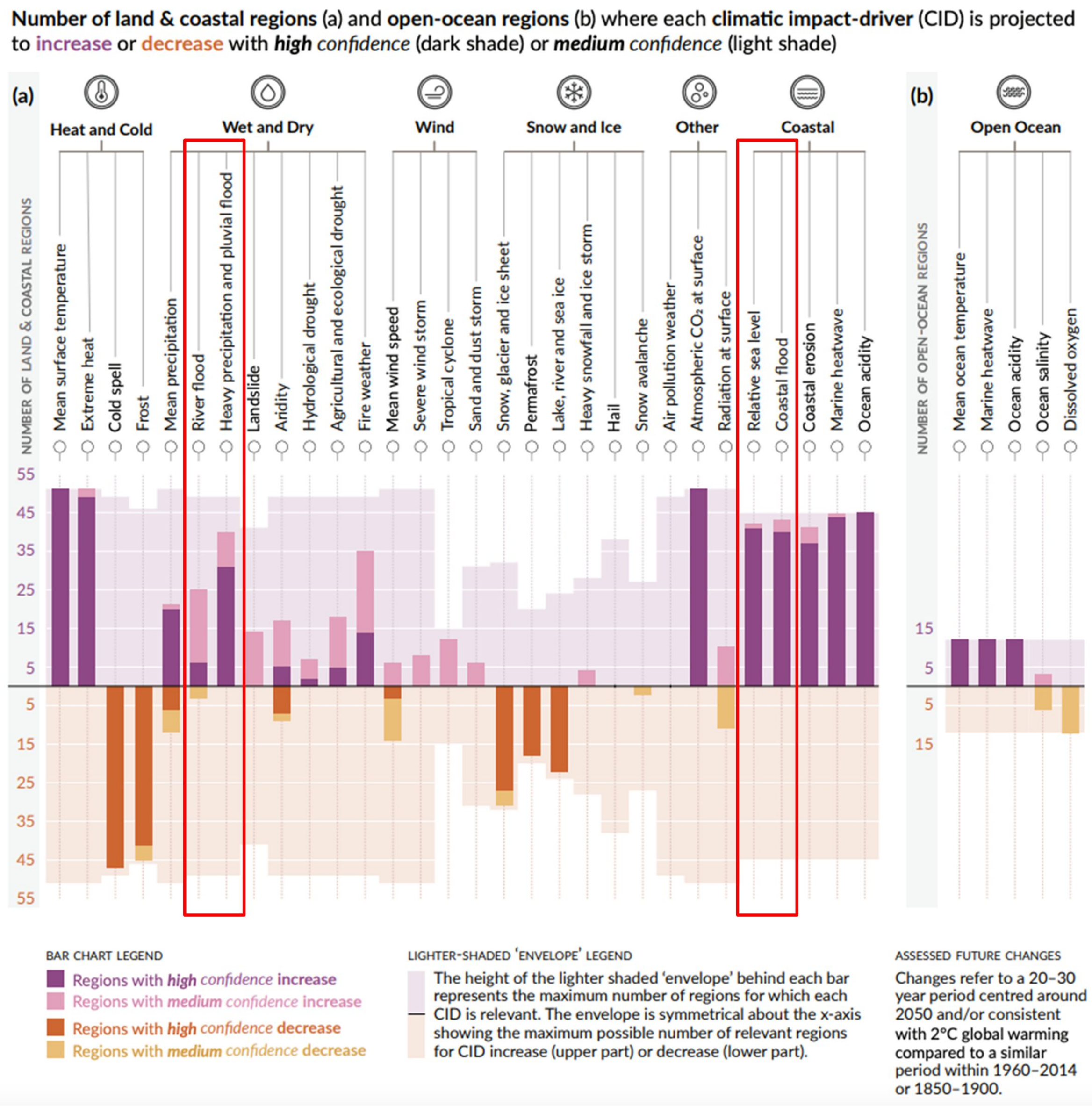
Climate change

- IPCC 6th Assessment Report

- River floods:
  - **Increase** ≈ 10%
  - Increase ≈ 40%
  - **Decrease** ≈ 0%
  - Decrease ≈ 5%
  - **Don't know** ≈ 45%



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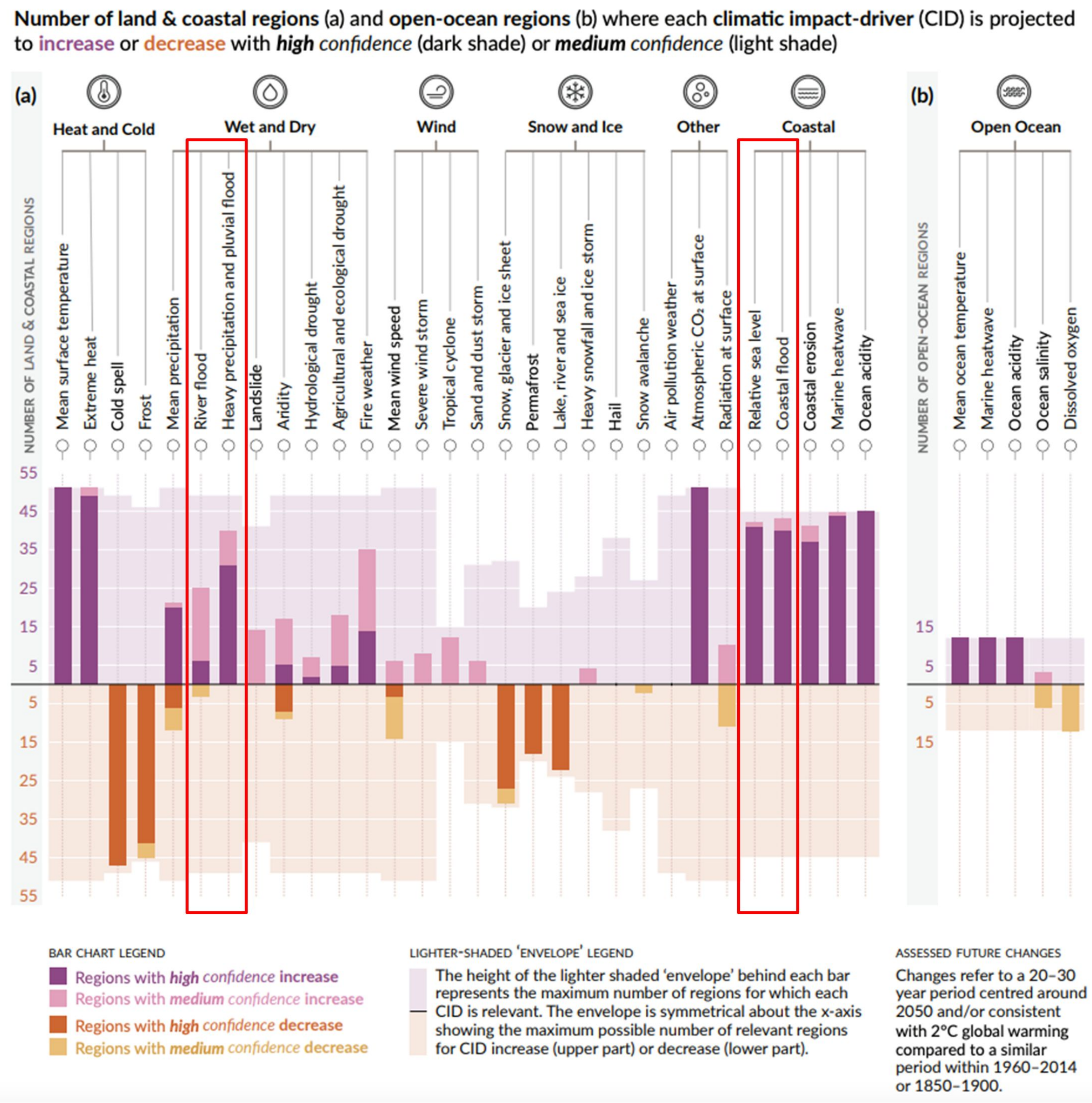
Climate change

- IPCC 6th Assessment Report

- Surface water floods:
  - **Increase** ≈ 60%
  - Increase ≈ 20%
  - **Decrease** ≈ 0%
  - Decrease ≈ 0%
  - **Don't know** ≈ 20%



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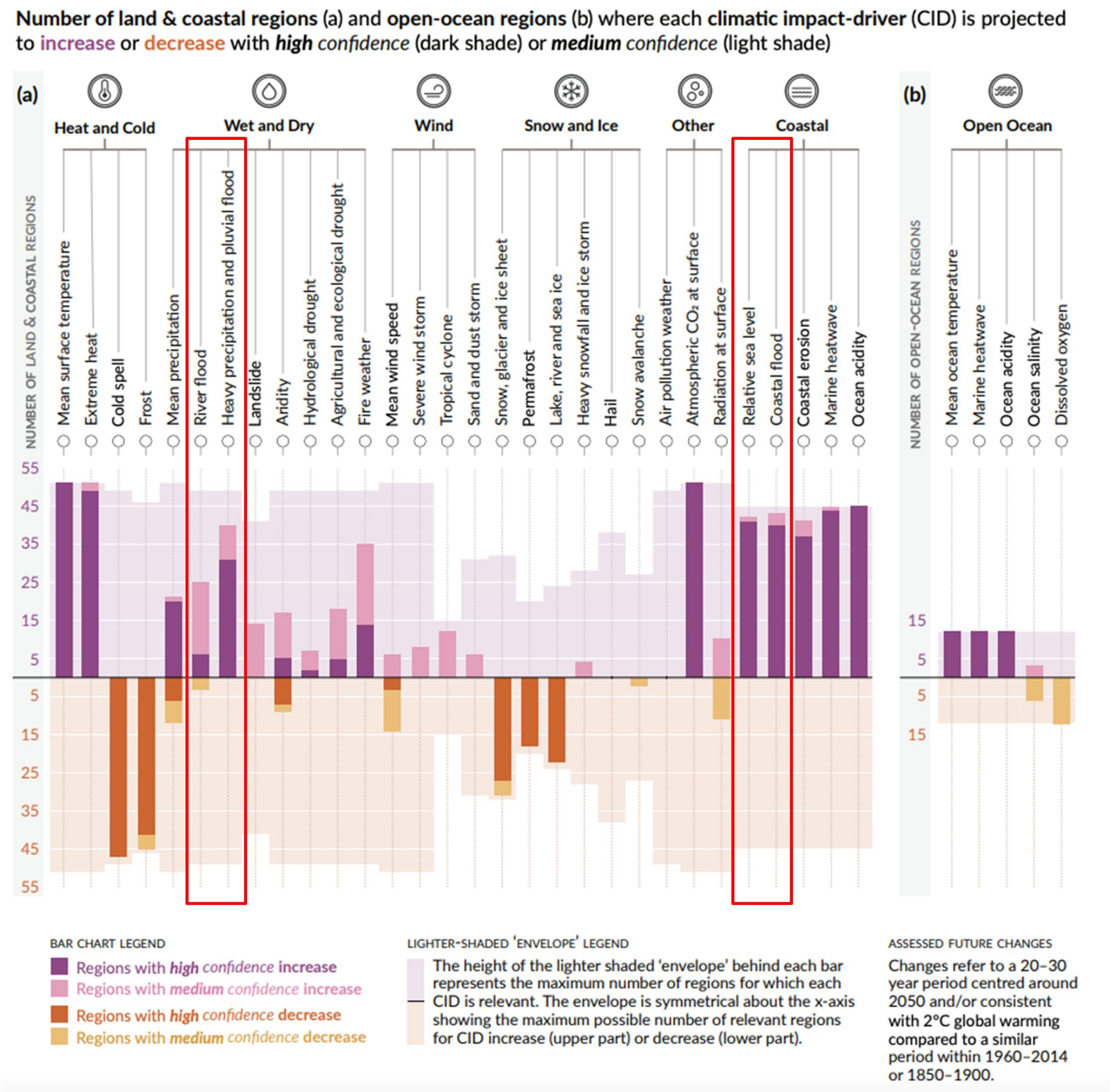
Climate change

- IPCC 6th Assessment Report

- Coastal floods:
  - **Increase** ≈ 90%
  - Increase ≈ 5%
  - **Decrease** ≈ 0%
  - Decrease ≈ 0%
  - **Don't know** ≈ 5%



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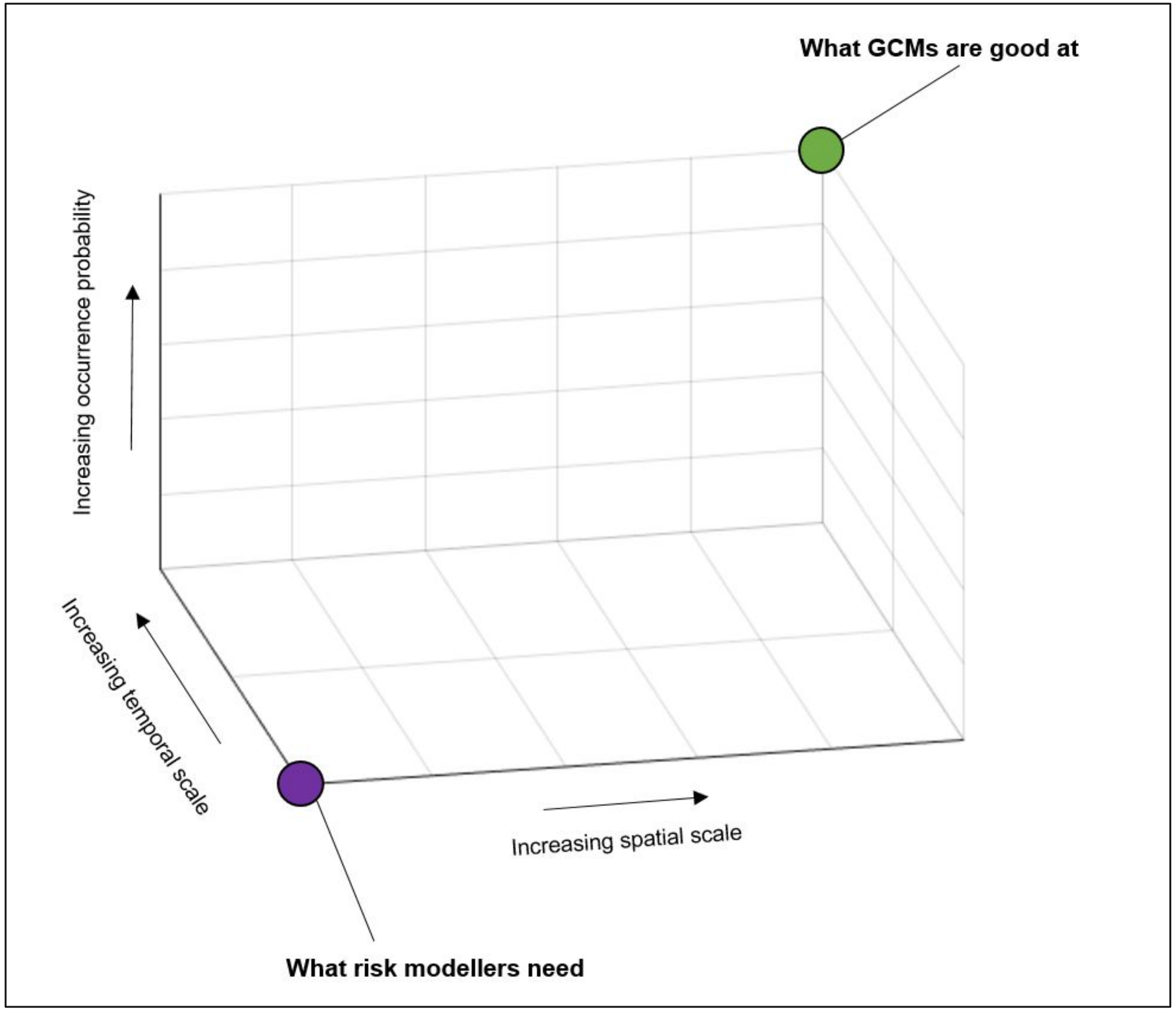
Climate vs. Catastrophe Models

Item	Catastrophe Models	Climate Models
Temporal relevance	~present-day	~end of century
Simulation length	~10,000 years	~100 years
Spatial resolution	~10s to ~100s of metres	~25 to ~100s of kilometres
Uncertainty	Compute time devoted to understand variability	Compute time devoted to parameter uncertainty
Strengths	Extremes / acute hazards Financial impact at individual locations	Slow / chronic hazards Physical variables reliable at >continental scales

Climate risk

- Climate models are not set-up to tell us ~anything about floods
- Simplification of a highly complex system
  - Limited relevance to the scale of risk modelling
- Application technique to bridge the gap
  - Regional models
  - Downscaling
  - Bias correction



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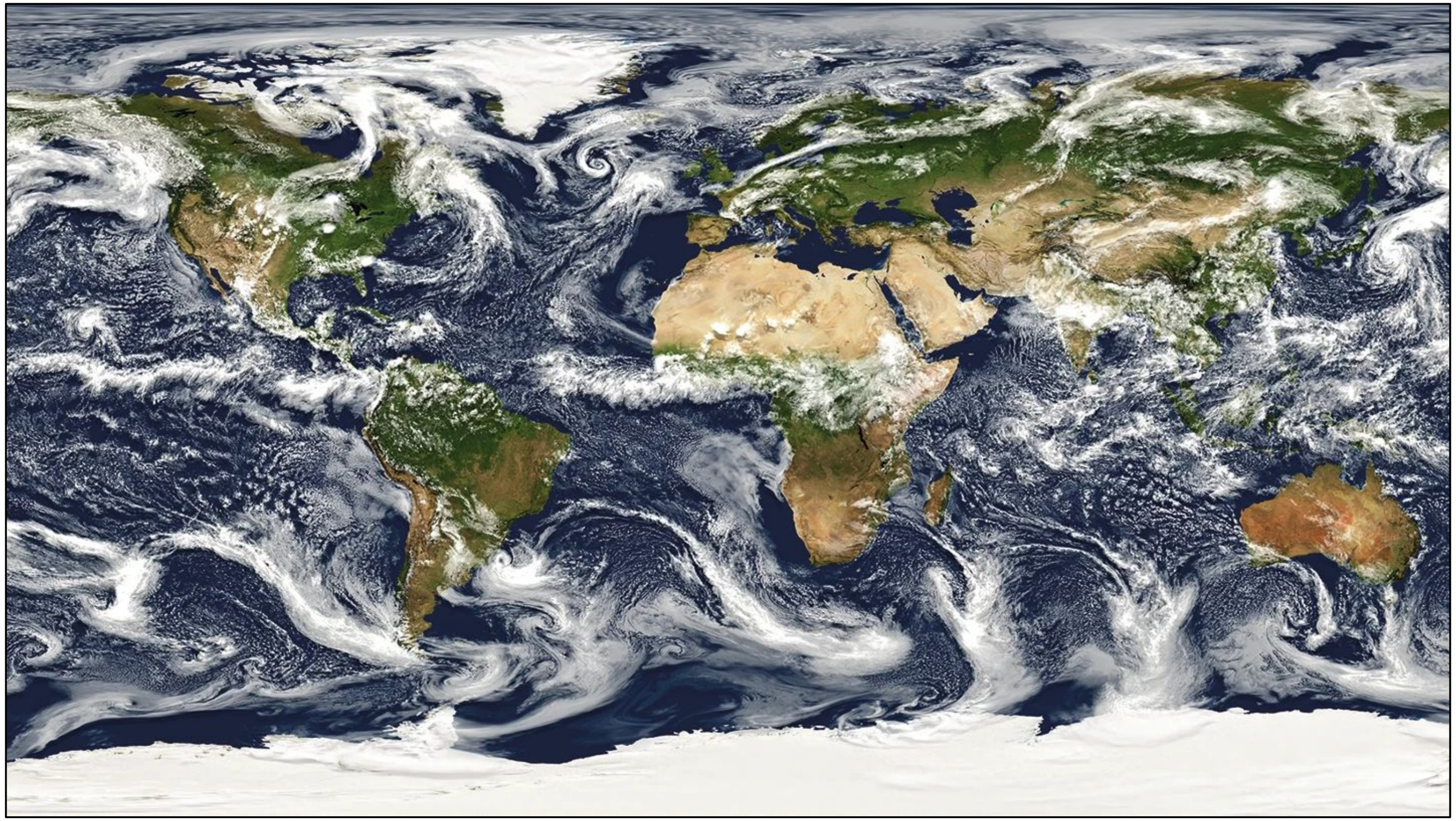
Climate change: the need for k-scale models

- [Slingo et al. (2022), Ambitious partnership needed for reliable climate prediction, *Nat. Clim. Change*.]

- Precipitation biases and inability to represent extremes are not solved by 'application techniques'
- $250M/yr to make accurate simulations a reality



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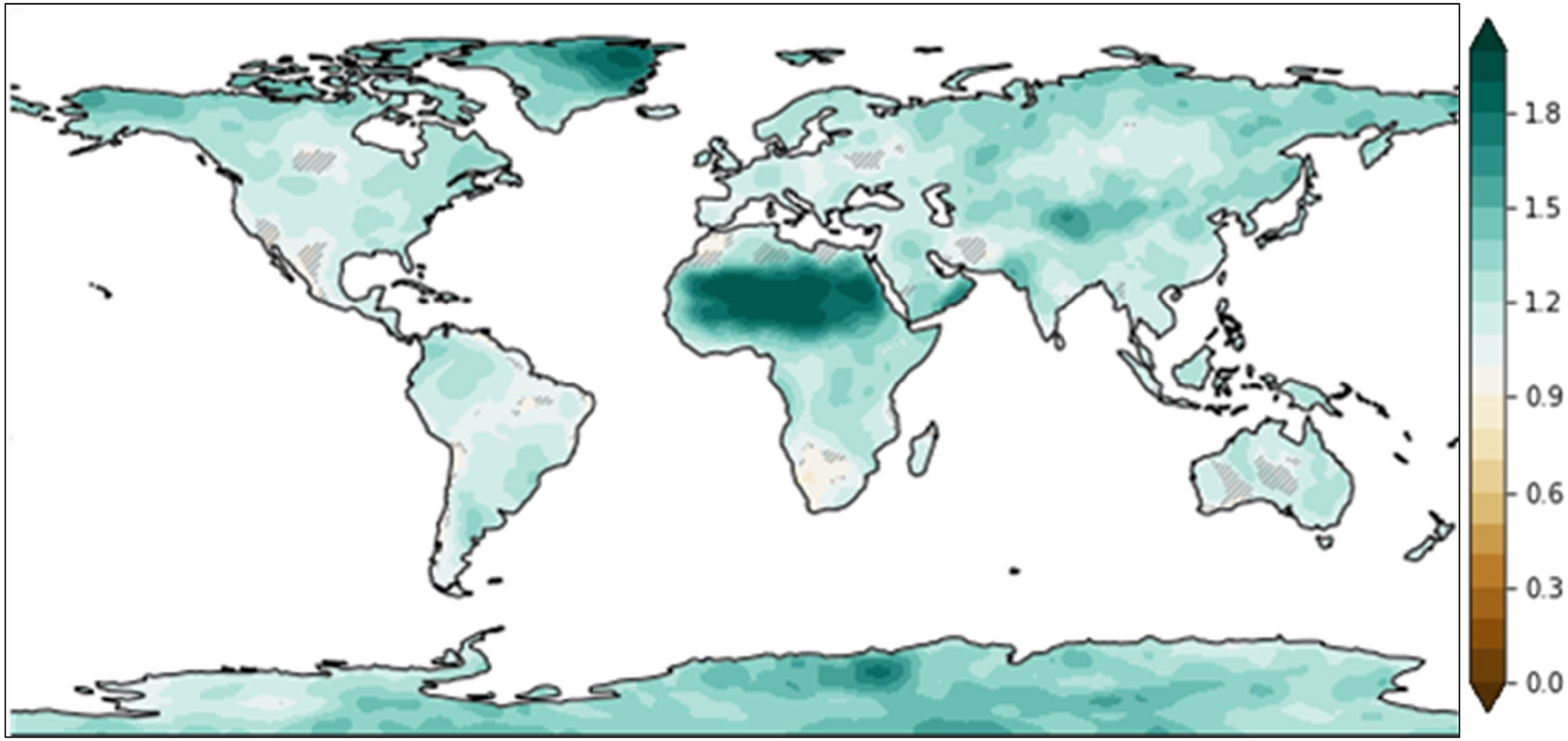
Climate change factors: pluvial

Change factors for precipitation (RX1day) | GWL = 4 °C | 4 GCMs (median)



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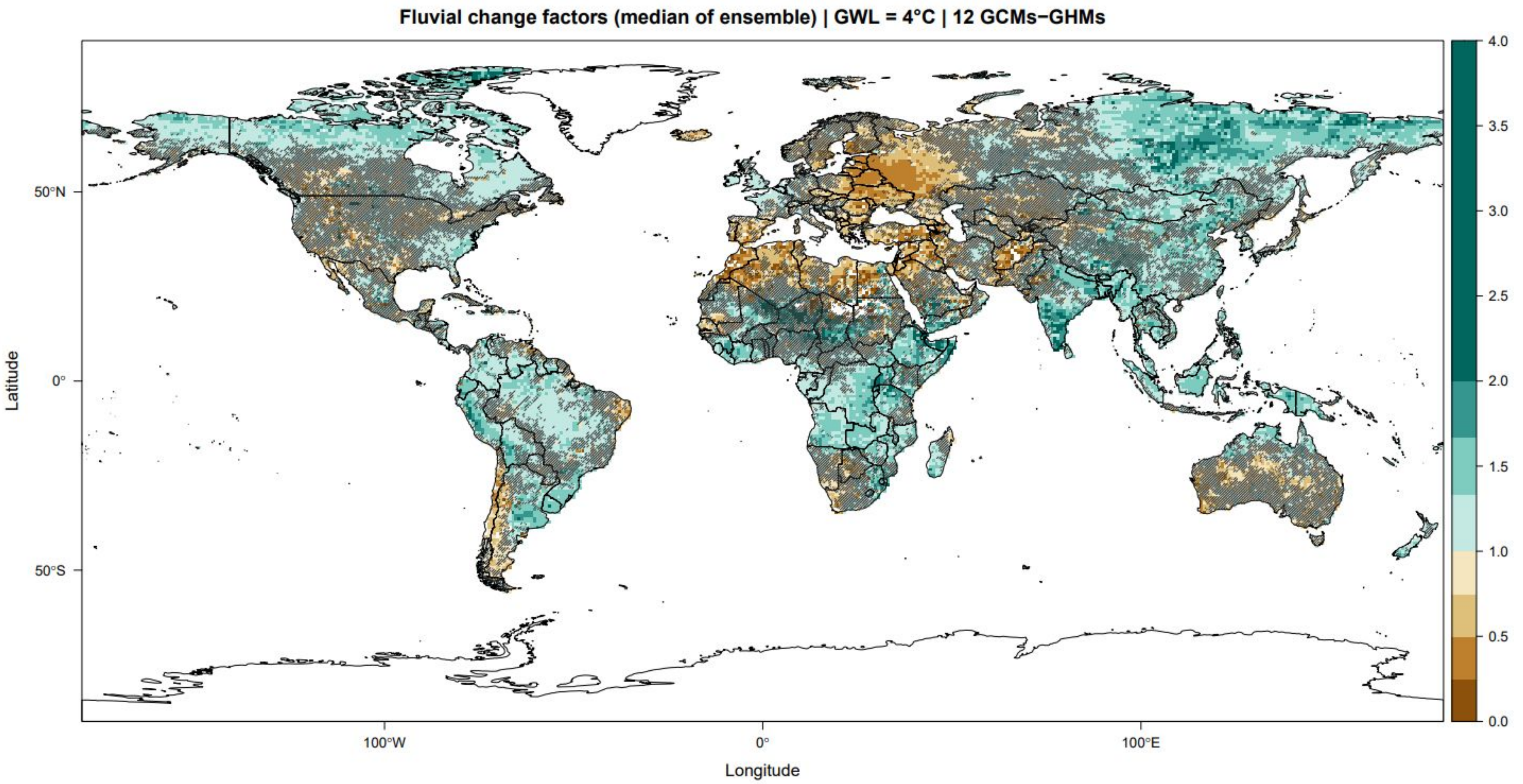
Climate change factors: fluvial



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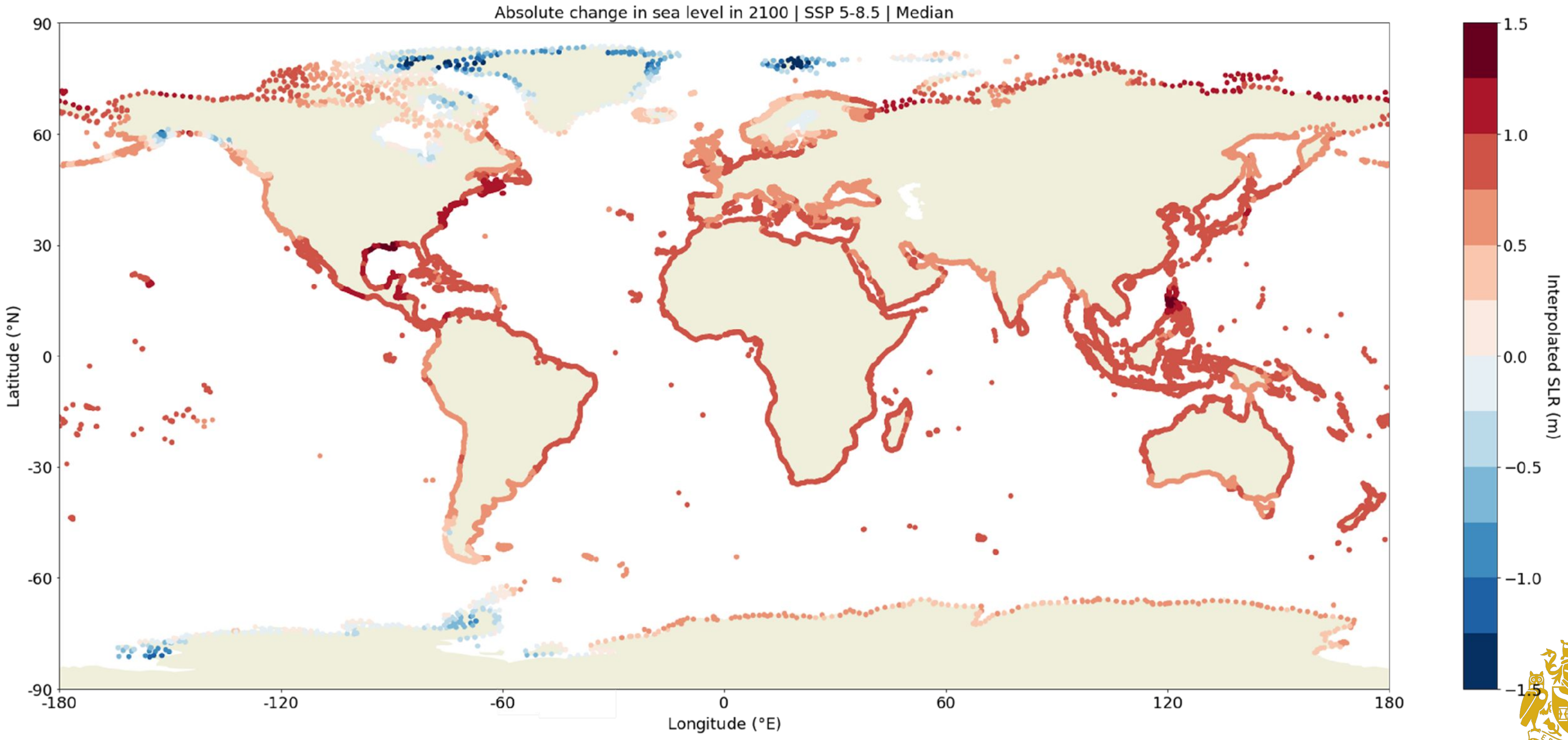
Climate change factors: coastal



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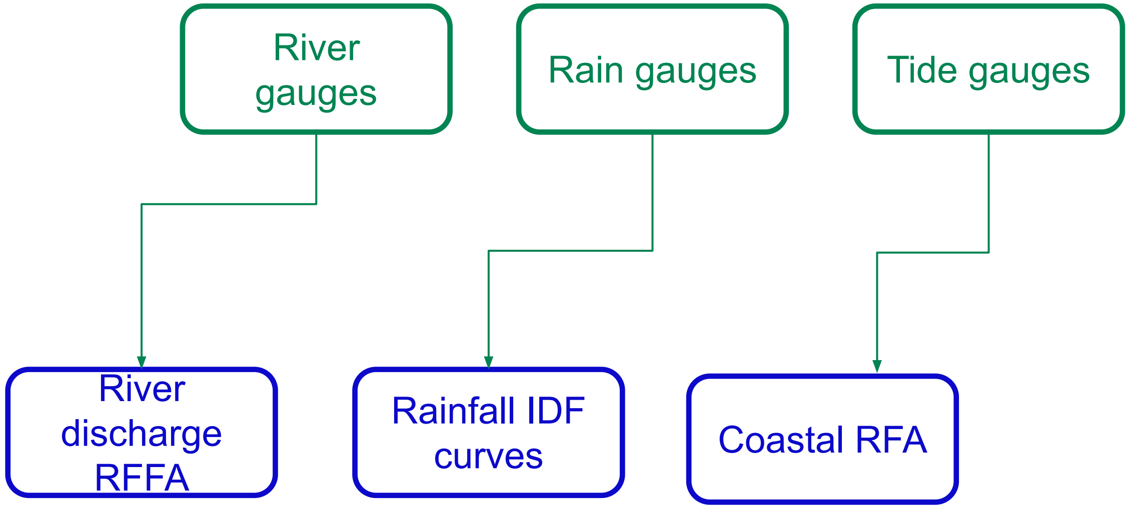

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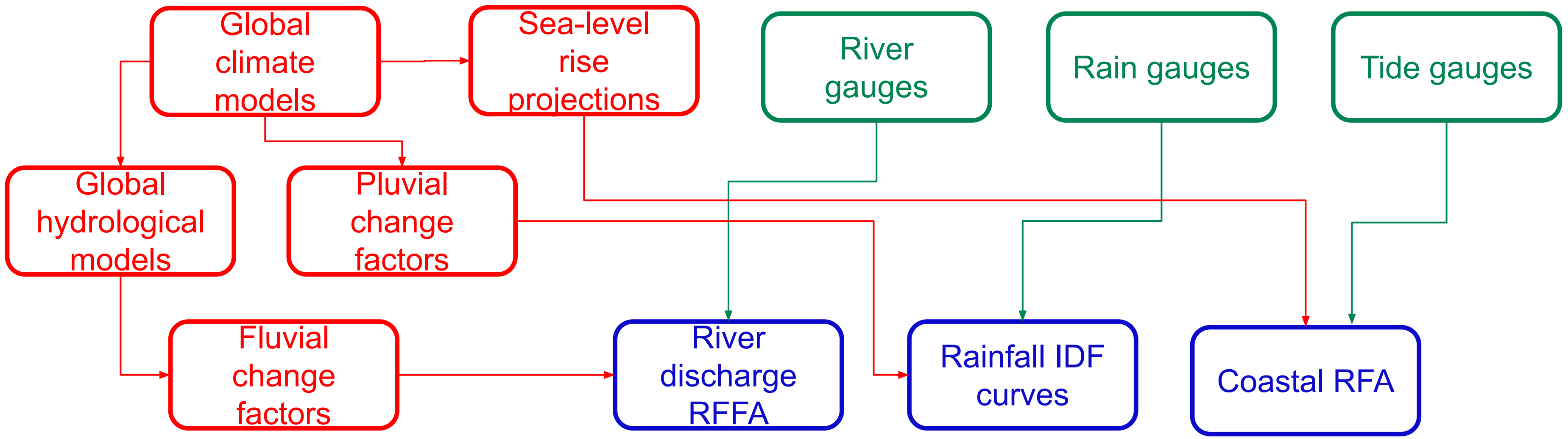
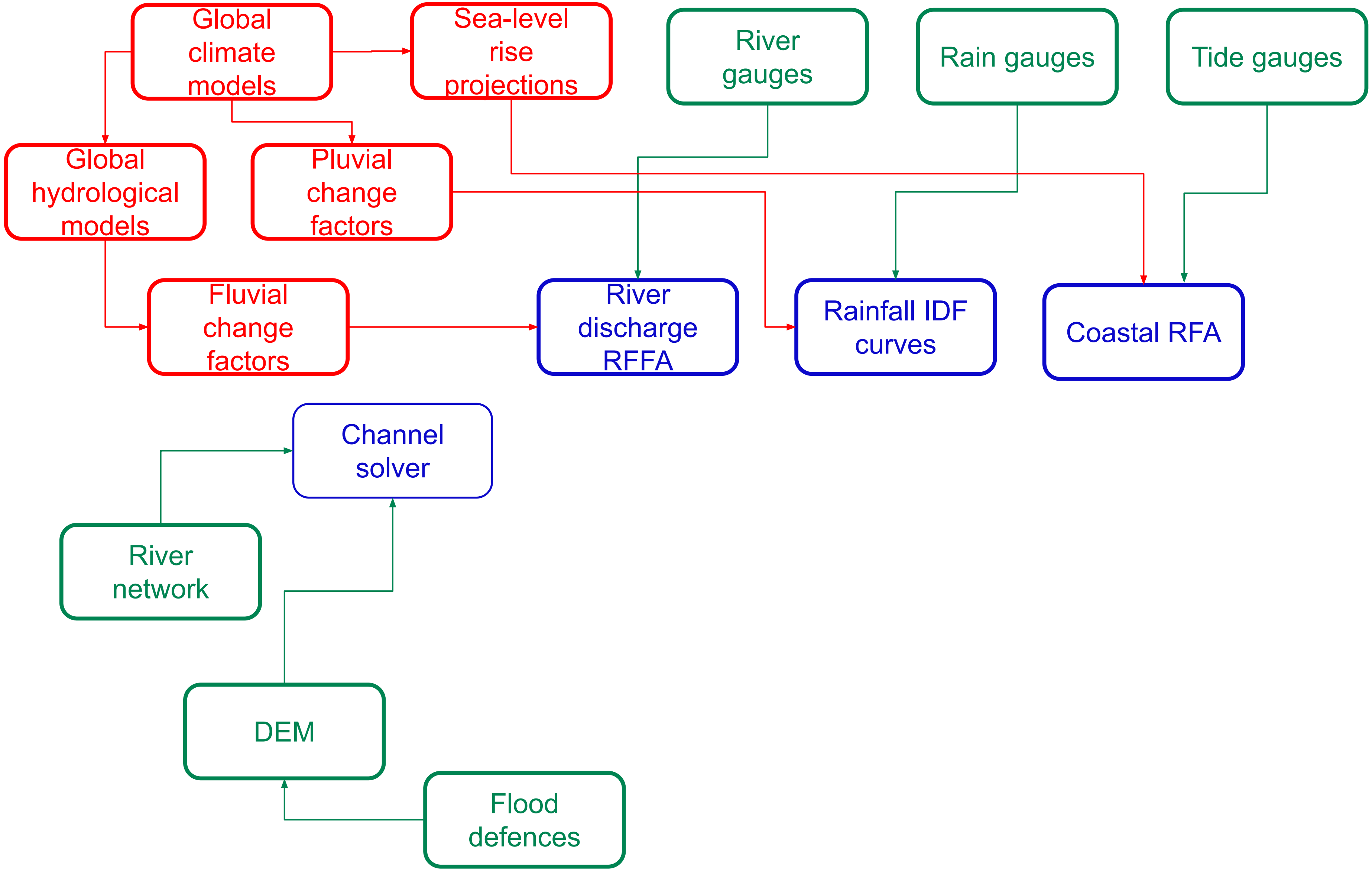

Global climate models
Sea-level rise projections
River gauges
Rain gauges
Tide gauges
Global hydrological models
Pluvial change factors
Fluvial change factors
River discharge RFFA
Rainfall IDF curves
Coastal RFA



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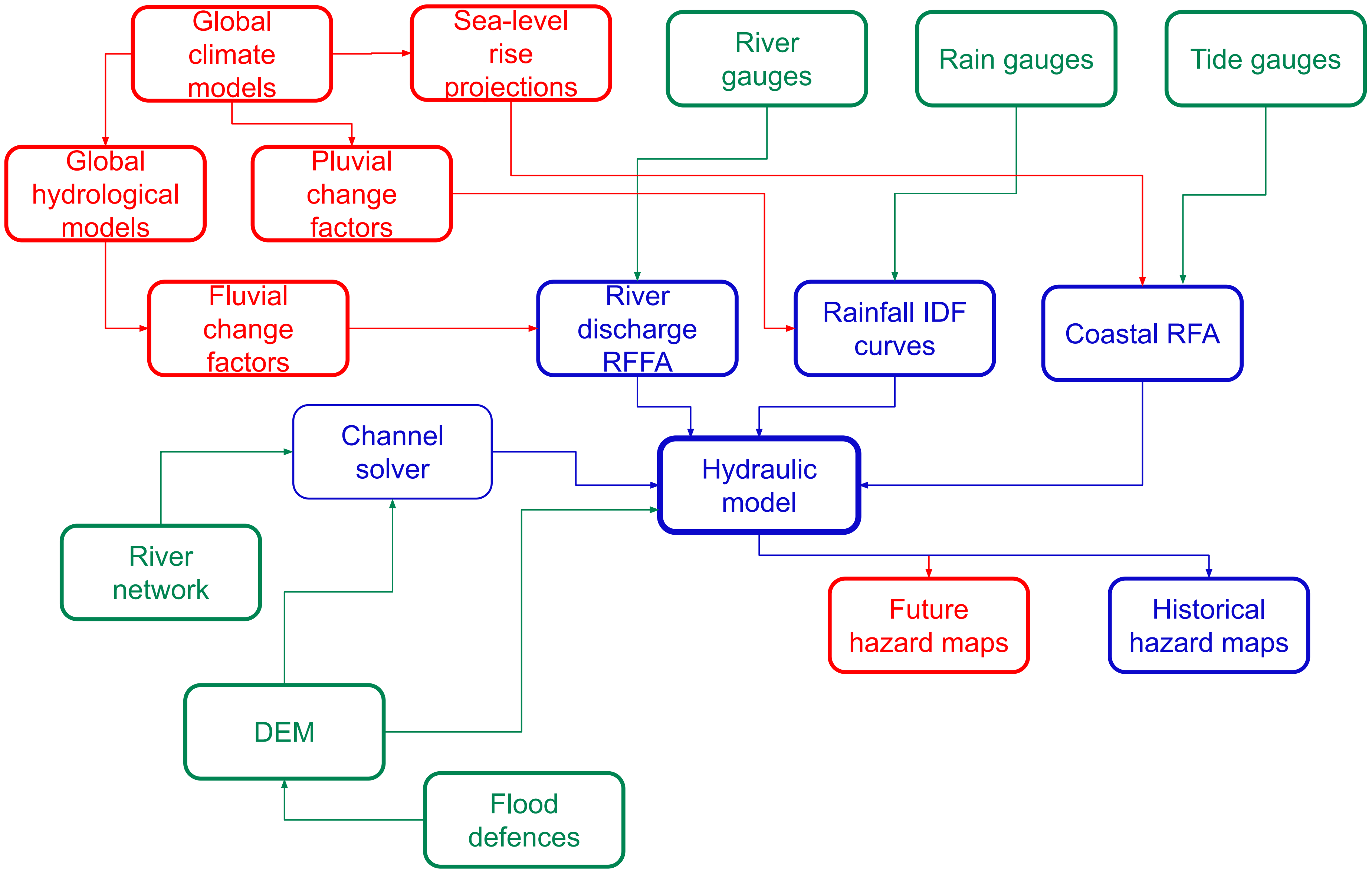

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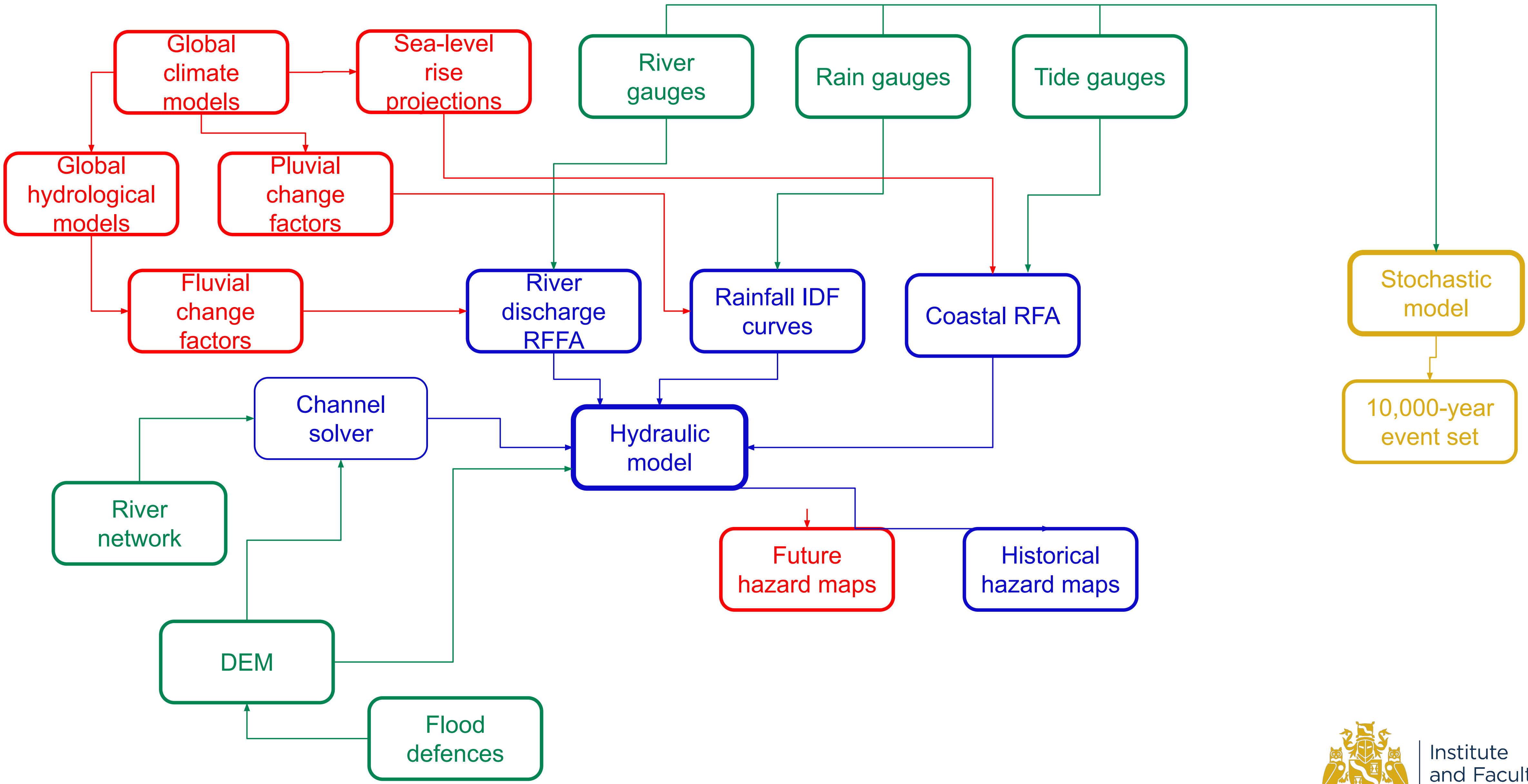
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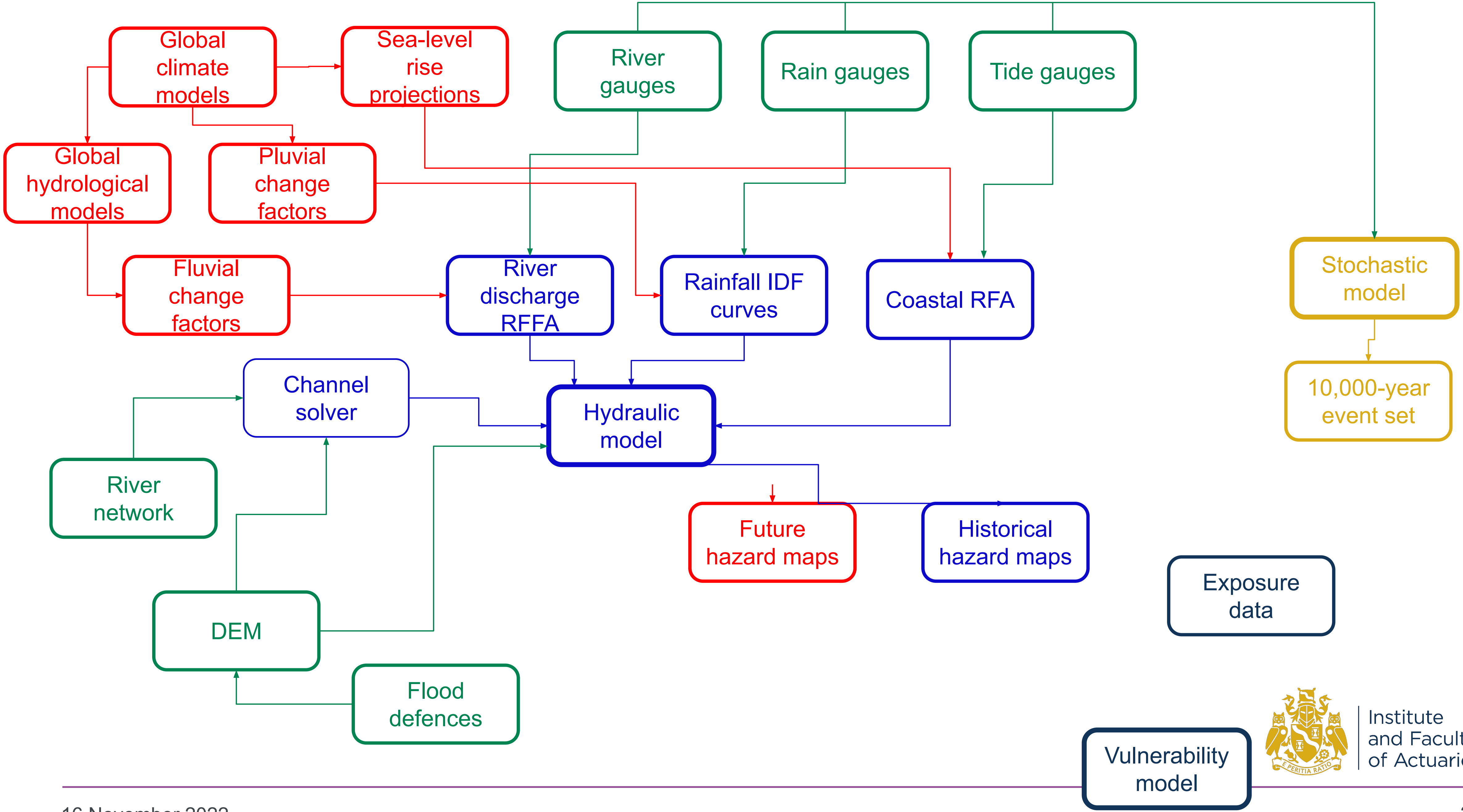
River discharge RFFA
Rainfall IDF curves
Coastal RFA
Stochastic model
10,000-year event set
Channel solver
Hydraulic model
River network
Future hazard maps
Historical hazard maps
DEM
Flood defences



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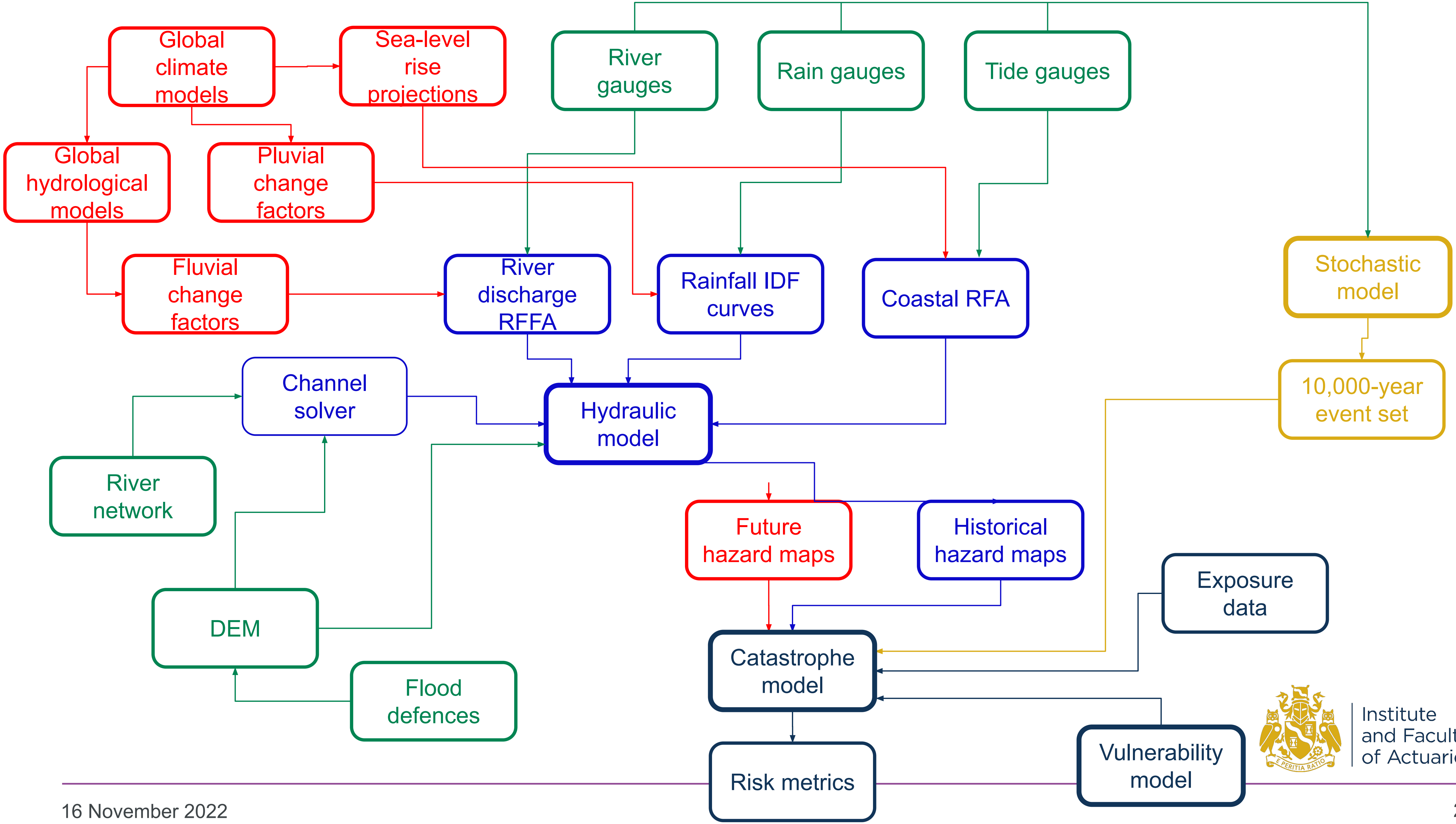

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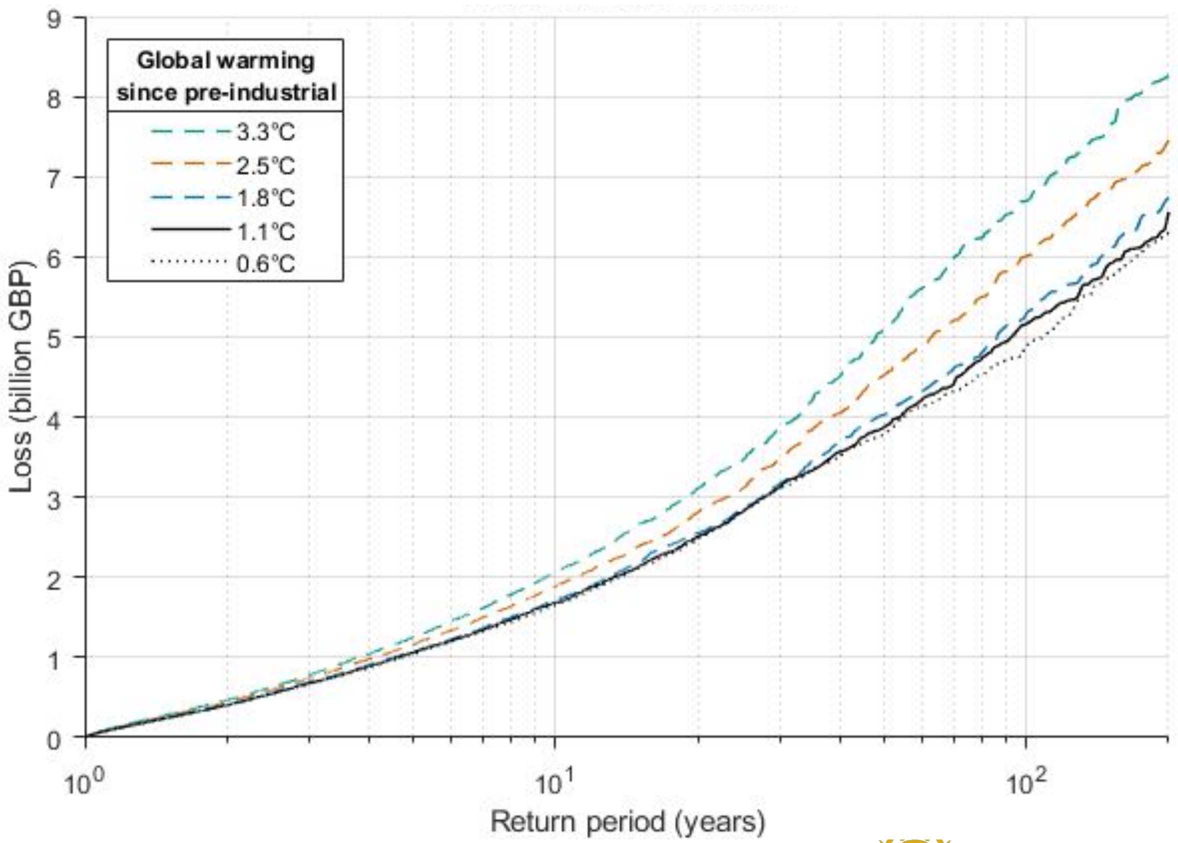
Climate risk in the UK

- AAL in 2.5°C world increases by 11% to £826M
- Present 100-year loss expected to happen every 68 years, or increase to £6000M



[Bates et al. (under review), *Nat. Hazards Earth Syst. Sci.*]

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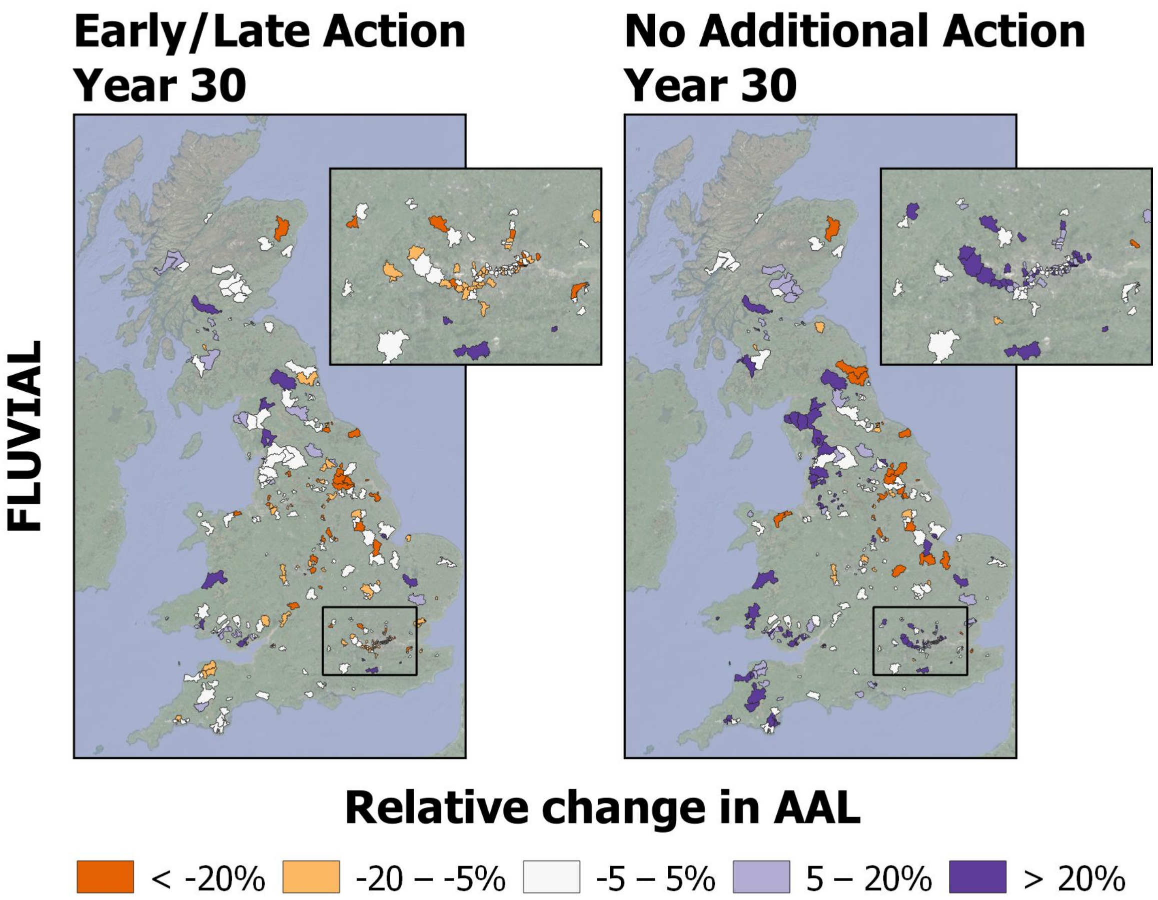
BoE PRA CBES

- Climate Biennial Exploratory Scenarios (CBES) stress test to “explore the vulnerability of current business models to future climate policy pathways”.
- 1.8°C and 3.3°C warming by 2050 shown
- Results from a Lloyd’s syndicate
  - Gross AAL at PC4 level
- **Fluvial**: mixed catchment response to changing climate



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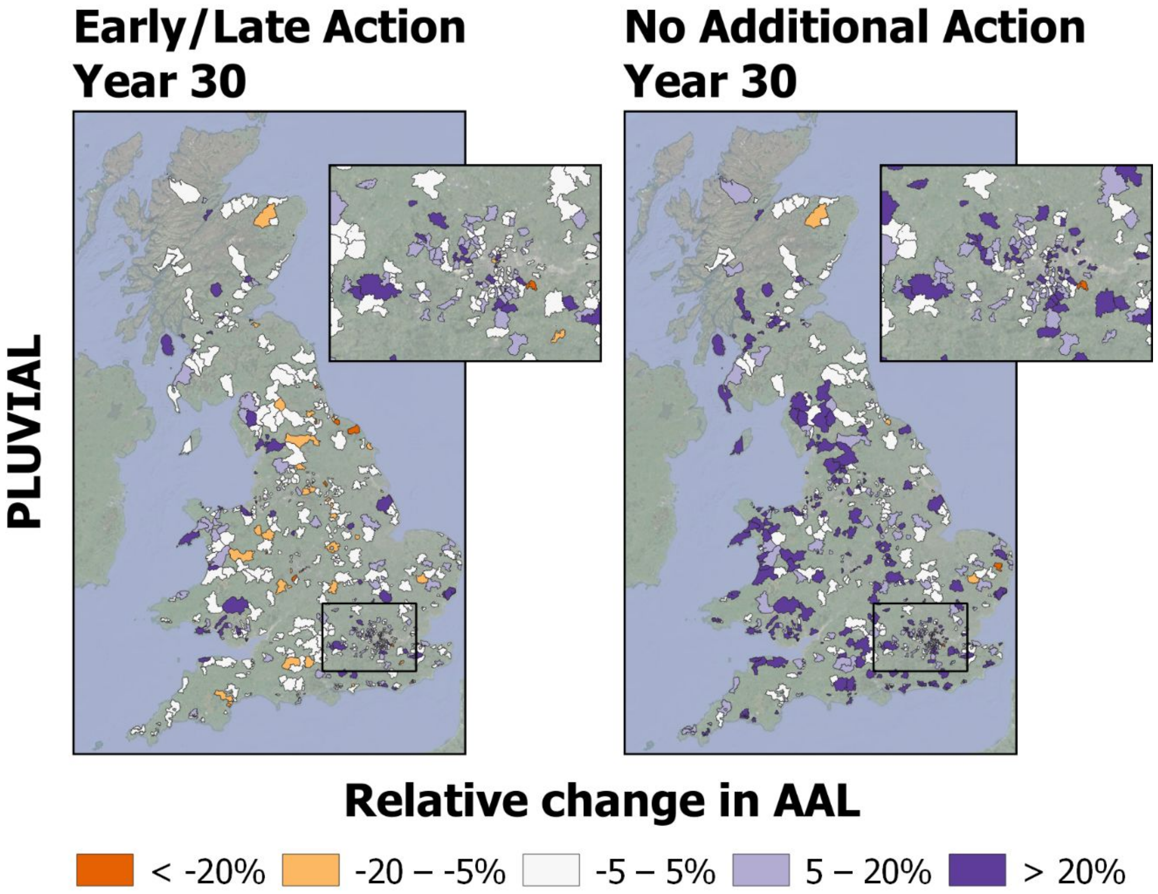
  - Gross AAL at PC4 level
- **Pluvial**: short-duration rainfall intensifying



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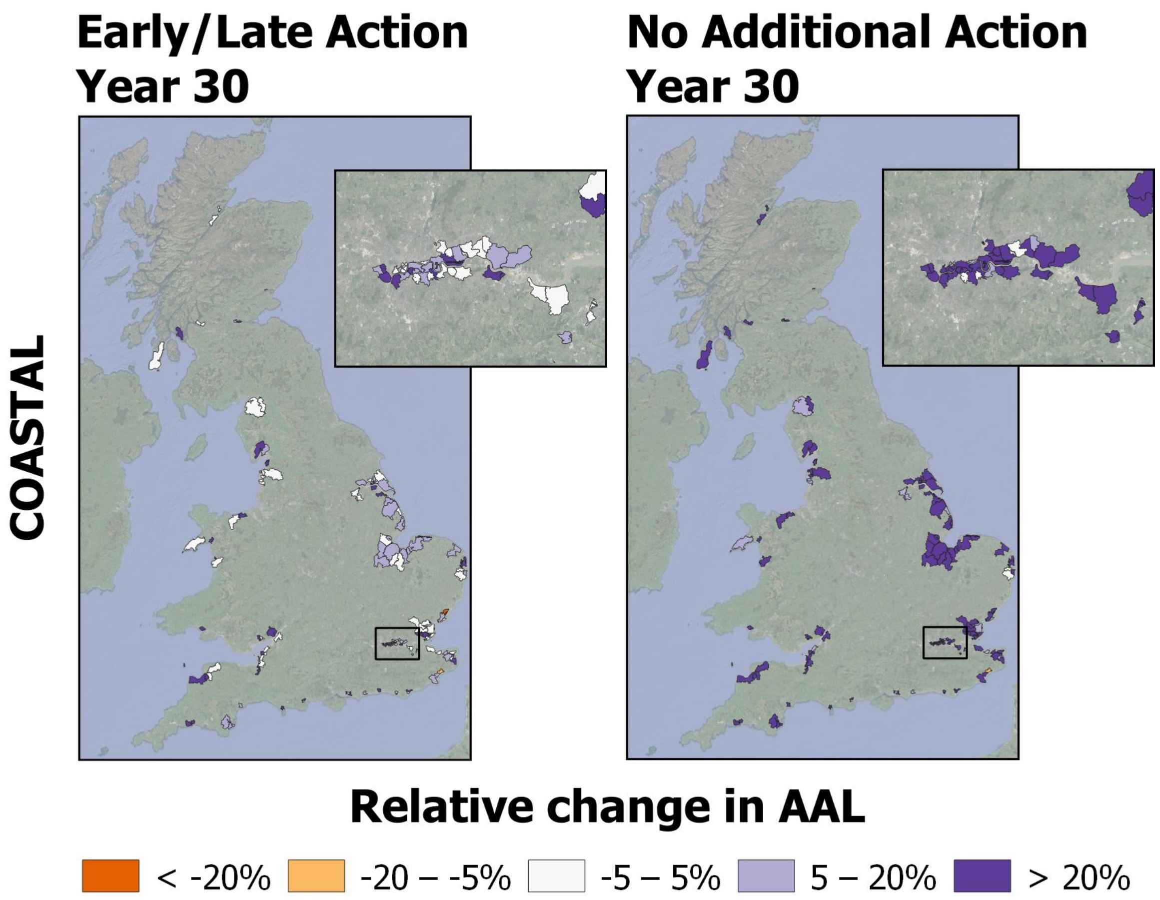
- Results from a Lloyd’s syndicate
  - Gross AAL at PC4 level
- **Coastal**: big increases due to sea-level rise



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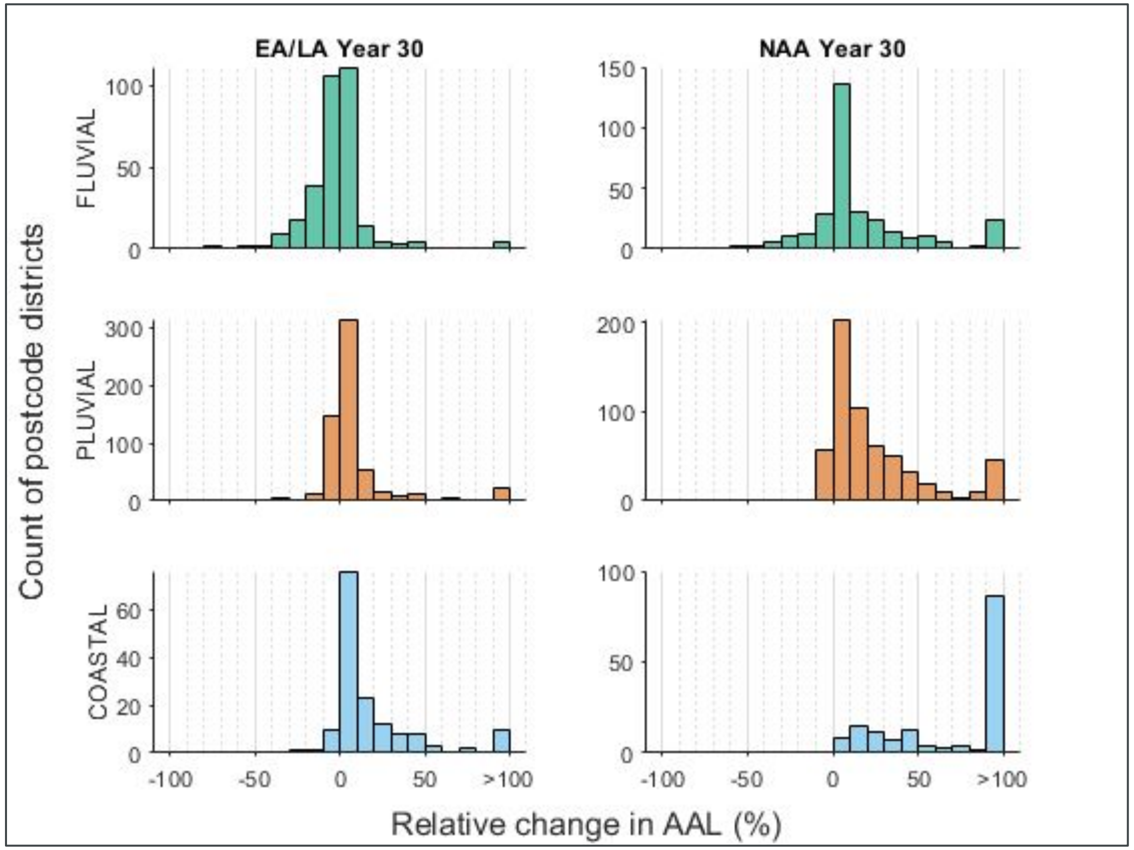
BoE PRA CBES

- Climate Biennial Exploratory Scenarios (CBES) stress test to “explore the vulnerability of current business models to future climate policy pathways”.
- 1.8°C and 3.3°C warming by 2050 shown
- Results from a Lloyd’s syndicate
  - Gross AAL at PC4 level
- Importance of sub-peril differentiation



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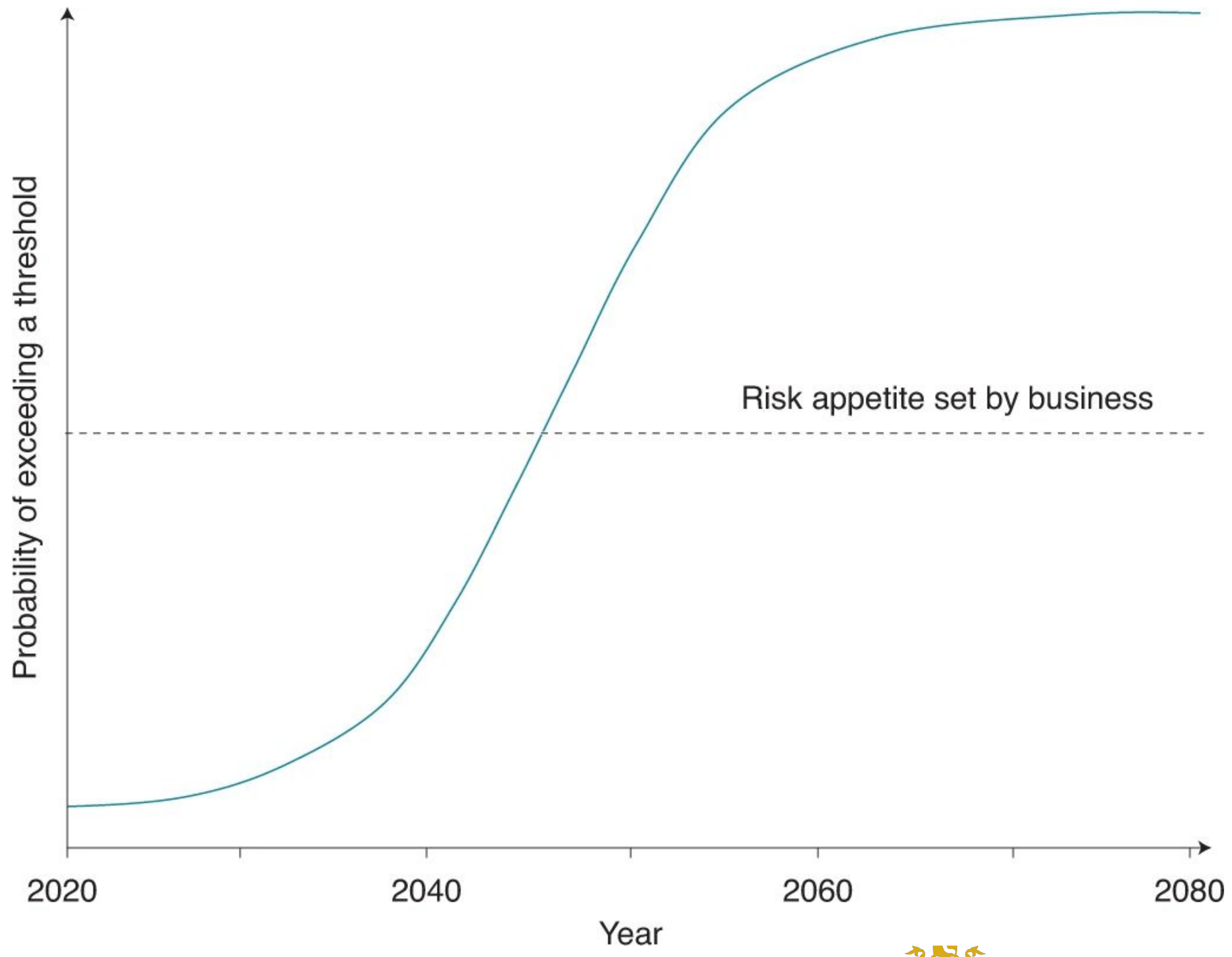
Normative scenarios

- Difficult to make business decisions based on exploratory scenarios
- Normative scenarios: define a business objective and calculate the probability of its failure over time
  - Profitability
  - Solvency
  - Growth
- Avoids "boiling frog syndrome"



[Rye et al. (2021), *Nat. Clim. Change*]

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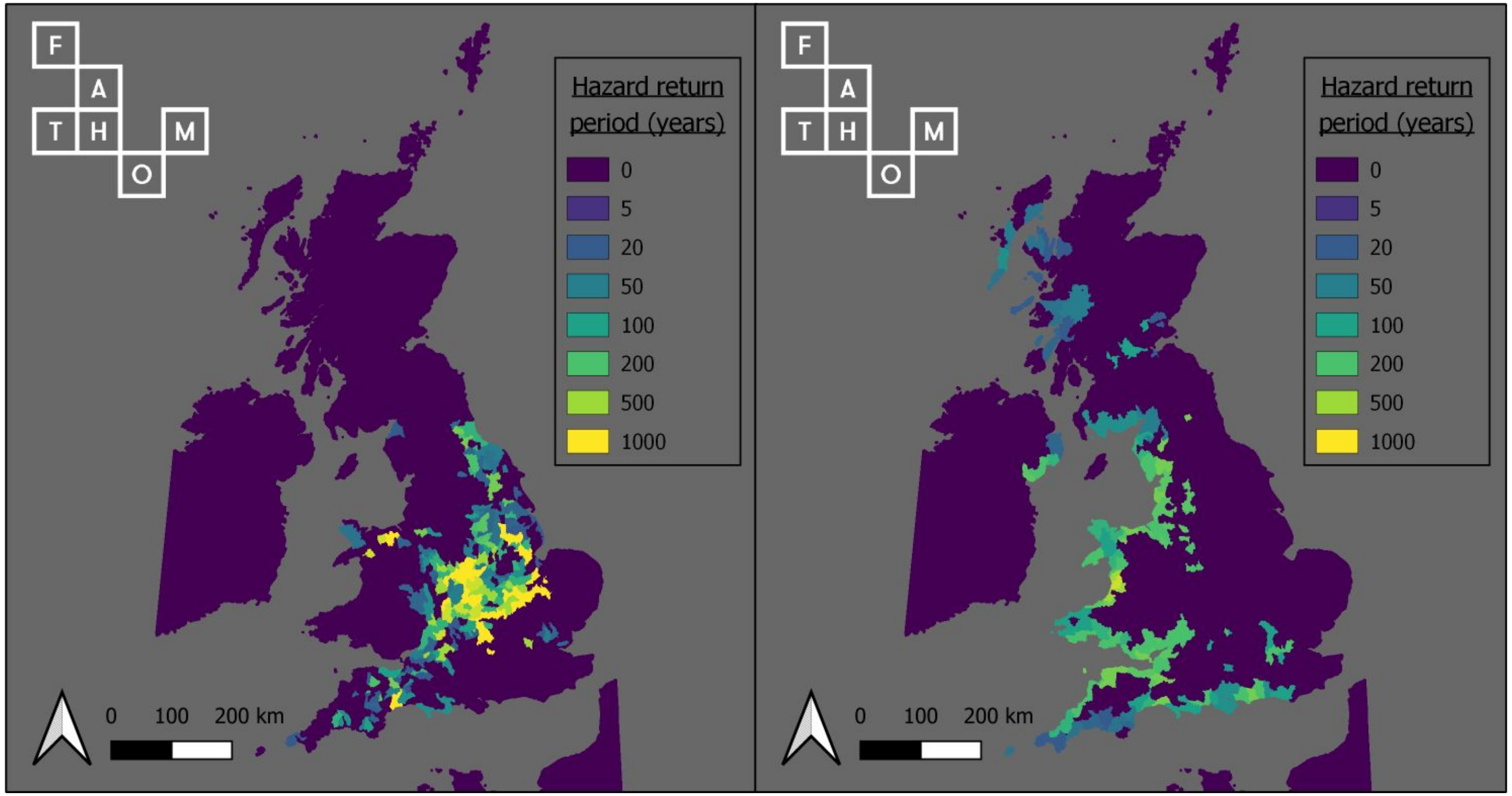
BoE PRA GIST

- Adapting the General Insurance Stress Test could be a good example
- Examine losses to a plausible but low-likelihood event
- Examine when insolvency frequency becomes unacceptable
- Plan capital holdings accordingly



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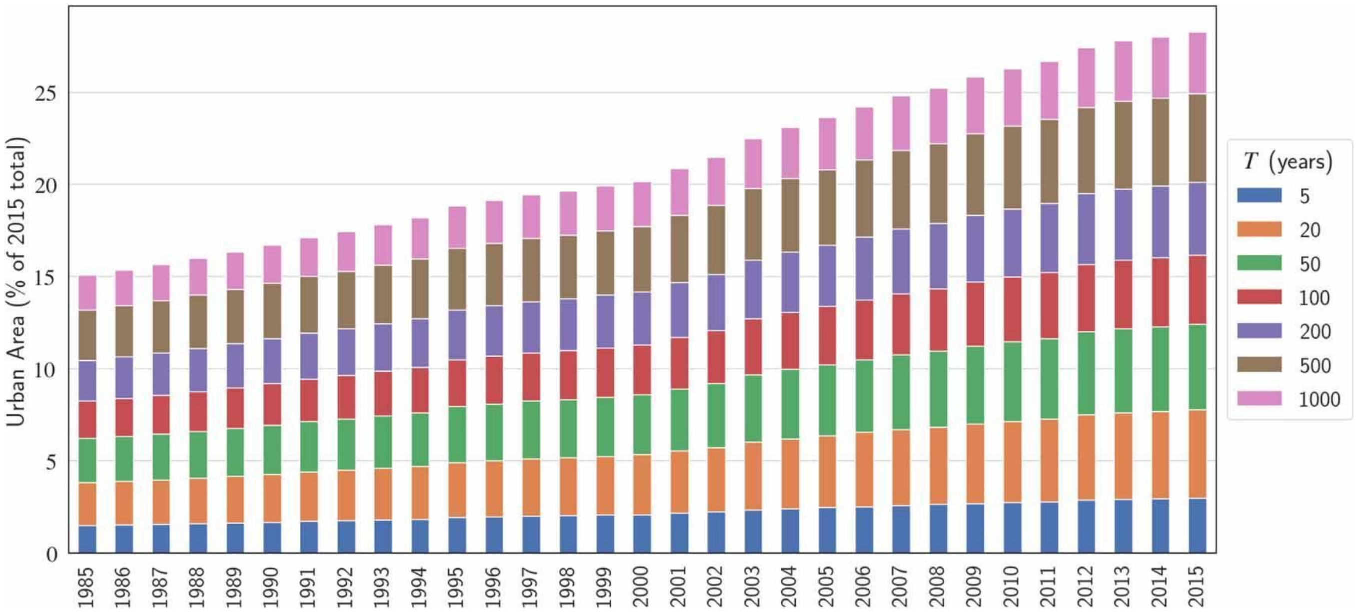
Global flood exposure

- From 1985–2015, the area of urbanised floodplains has **doubled**
- Higher-frequency flood zones have seen higher rates of development
- Urban encroachment is accelerating with time



[Andreadis et al. (2022), *Environ. Res. Lett.*]

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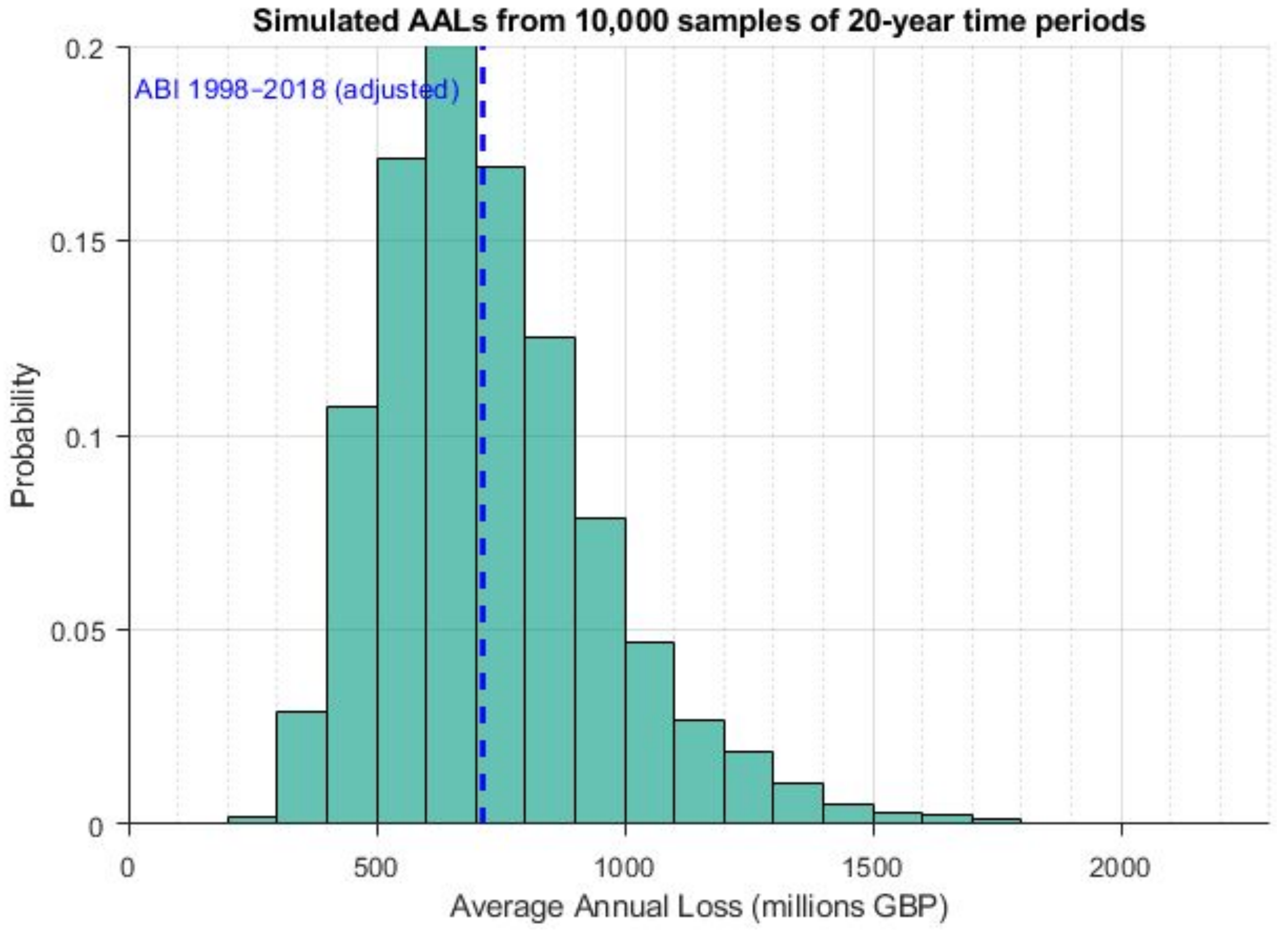
What do catastrophe models learn from history?

- Adjusted AAL observations from 20 years of ABI data
  - **£714M**

- Samples of 20 years of losses from the cat model:
  - Q_5 = **£424M**
  - Q_{95} = **£1163M**

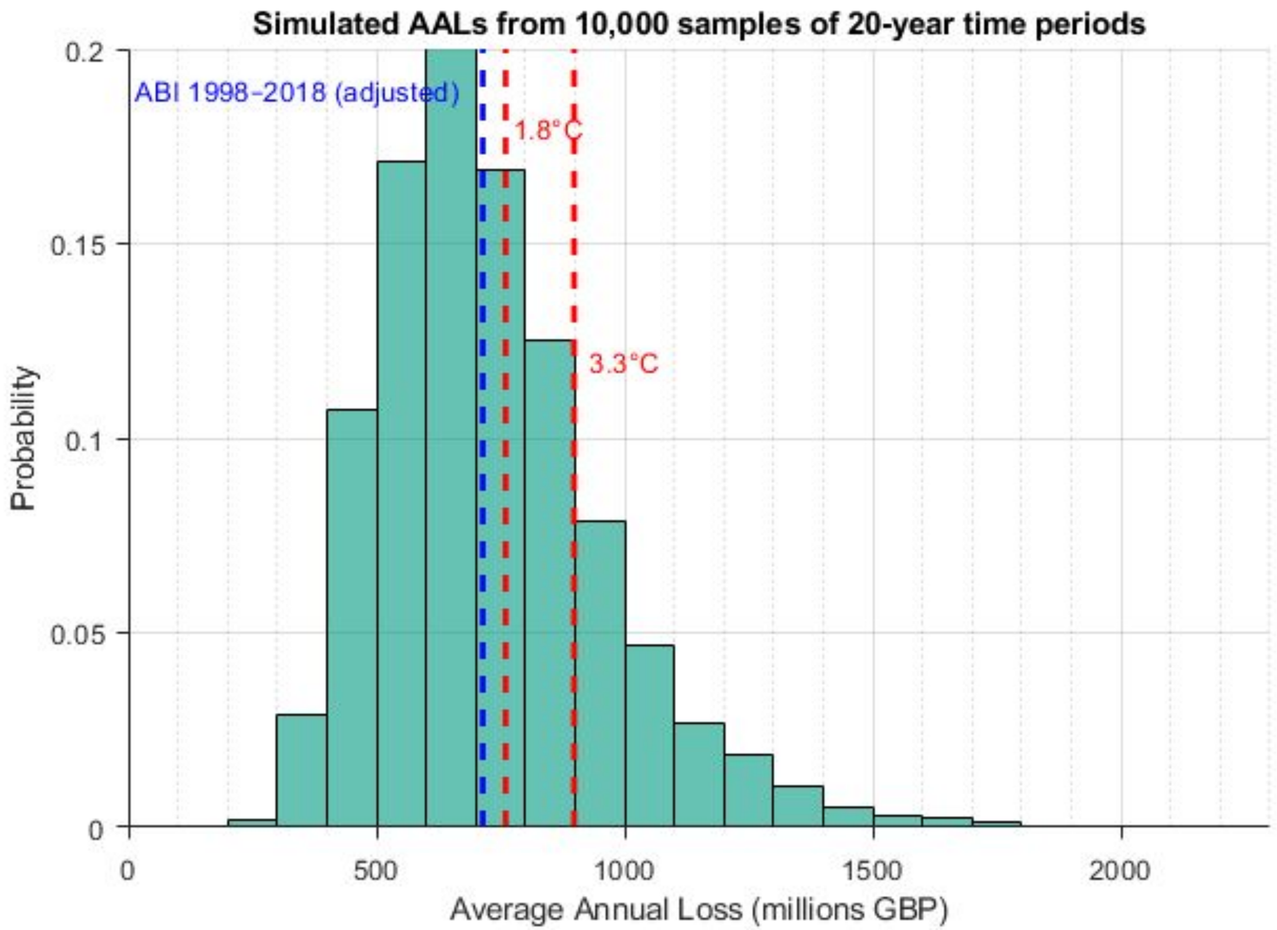
[Bates et al. (under review), *Nat. Hazards Earth Syst. Sci.*]



What do catastrophe models learn from history?

- Effect of climate change well within historical sampling error
  - 1.8°C = Q_{61}
  - 3.3 °C = Q_{80}

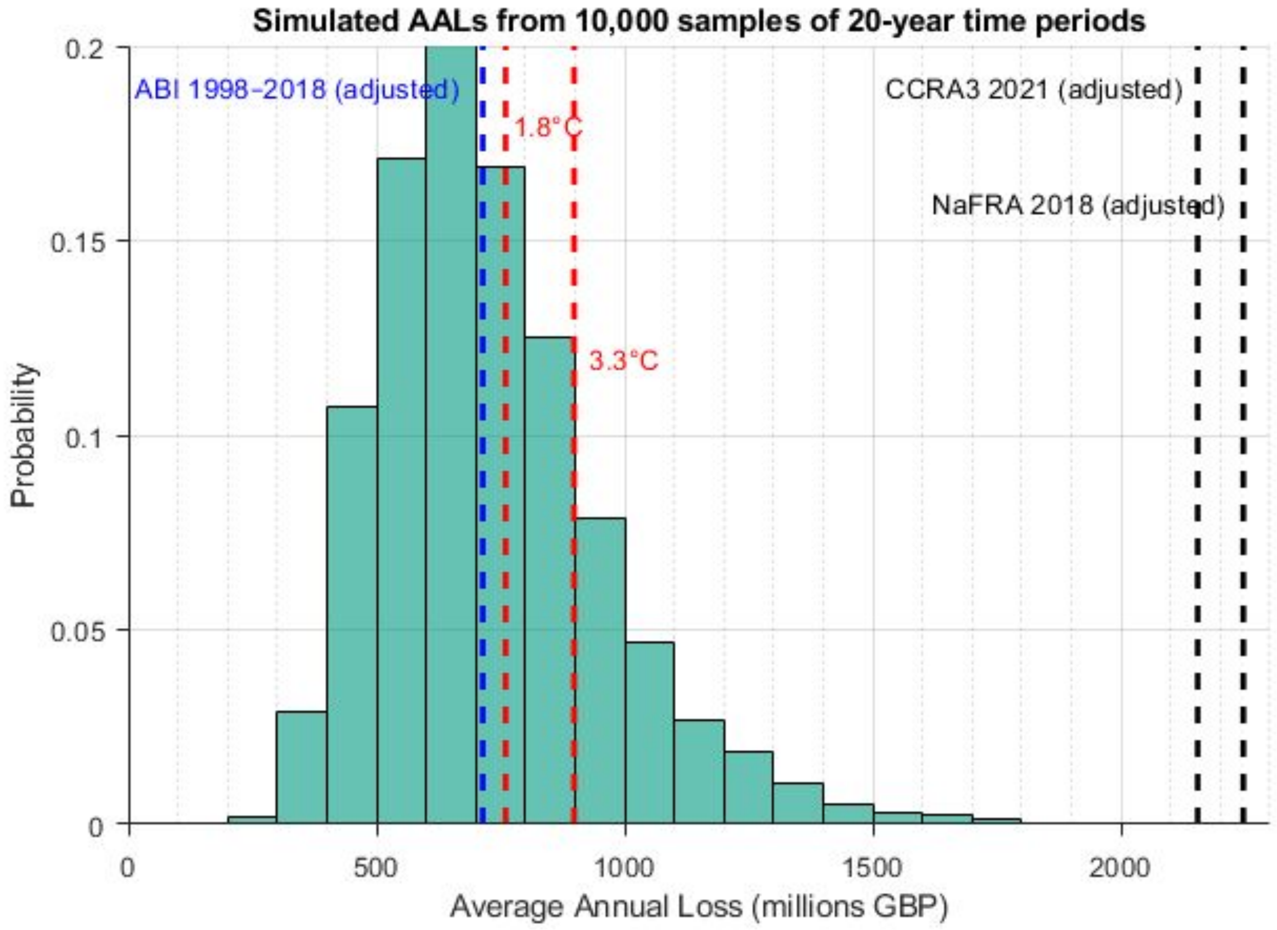
[Bates et al. (under review), *Nat. Hazards Earth Syst. Sci.*]



What do catastrophe models learn from history?

- Effect of climate change well within historical sampling error
  - 1.8°C = Q_{61}
  - 3.3 °C = Q_{80}

- UK government modelled AAL ≈ 15-year loss

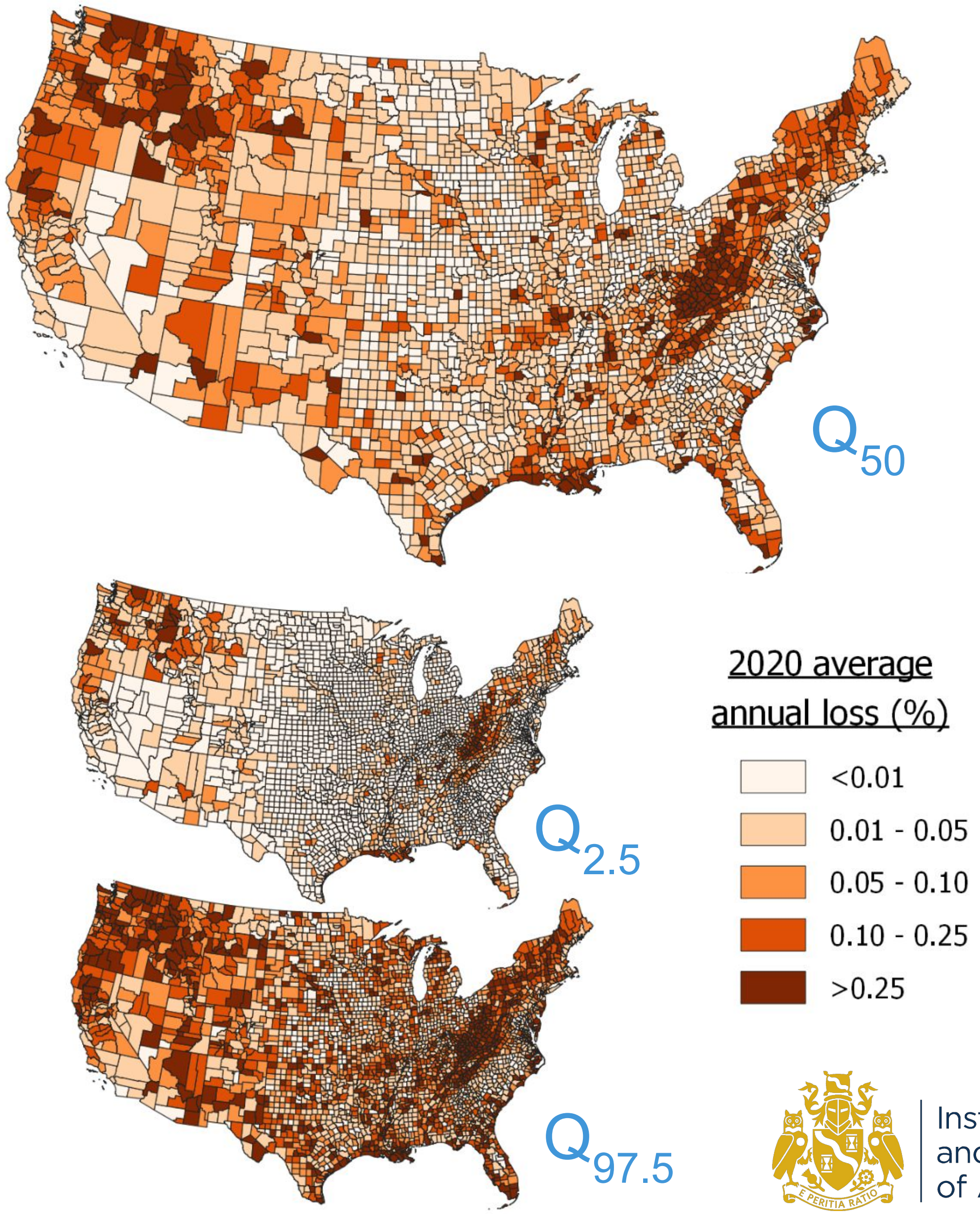


[Bates et al. (under review), *Nat. Hazards Earth Syst. Sci.*]

Secondary uncertainty

- Very expensive to quantify (properly)
- Effect at-scale depends on correlatio
  - They probably mostly cancel out (but we don't know!)
- Rough 95% range of US AALs at county level: **0.25–2.75x** the median
- Even larger uncertainties at location level

[Wing et al. (2022), *Nat. Clim. Change*]



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Climate change and catastrophe modelling

- Exposes the fallacy of over-calibrating cat models to history
  - Probably isn’t a good idea even in a stable climate
  - Sources of uncertainty squished together and (unphysically) adjusted so the model reproduces “expectations”
  - Violates the very reason why cat models were added to actuaries’ toolkit from the ‘90s
- Useful tool for examining cat model sensitivity
  - How do the answers change when adjusting the physical inputs to account for non-stationarity?
- Gets cat model consumers thinking more deeply about uncertainty
  - More than just primary uncertainty in the EP curve
  - And much more than just climate change
  - Capital currently absorbing *presumed* uncertainties due to the partial picture cat models currently paint
- Uncertainty isn’t necessarily a problem, but **bias** is
  - Unfortunately we’re uncertain about (some) bias

Outlook

- Climate-conditioned catastrophe models are valuable tools for understanding changing risk
- Must *not* be over-interpreted
- Can aid in obtaining and preserving business objectives
- Meet (& hopefully shape) regulatory requirements
- A great excuse to fold more uncertainties into the EP curve
- Climate-CAT models are advancing rapidly; ever improving our understanding of risk

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Questions

Comments

Expressions of individual views by members of the Institute and Faculty of Actuaries and its staff are encouraged.

The views expressed in this presentation are those of the presenter.

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Thank you

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