Compound flooding: Interactions of extreme river flows and sea levels

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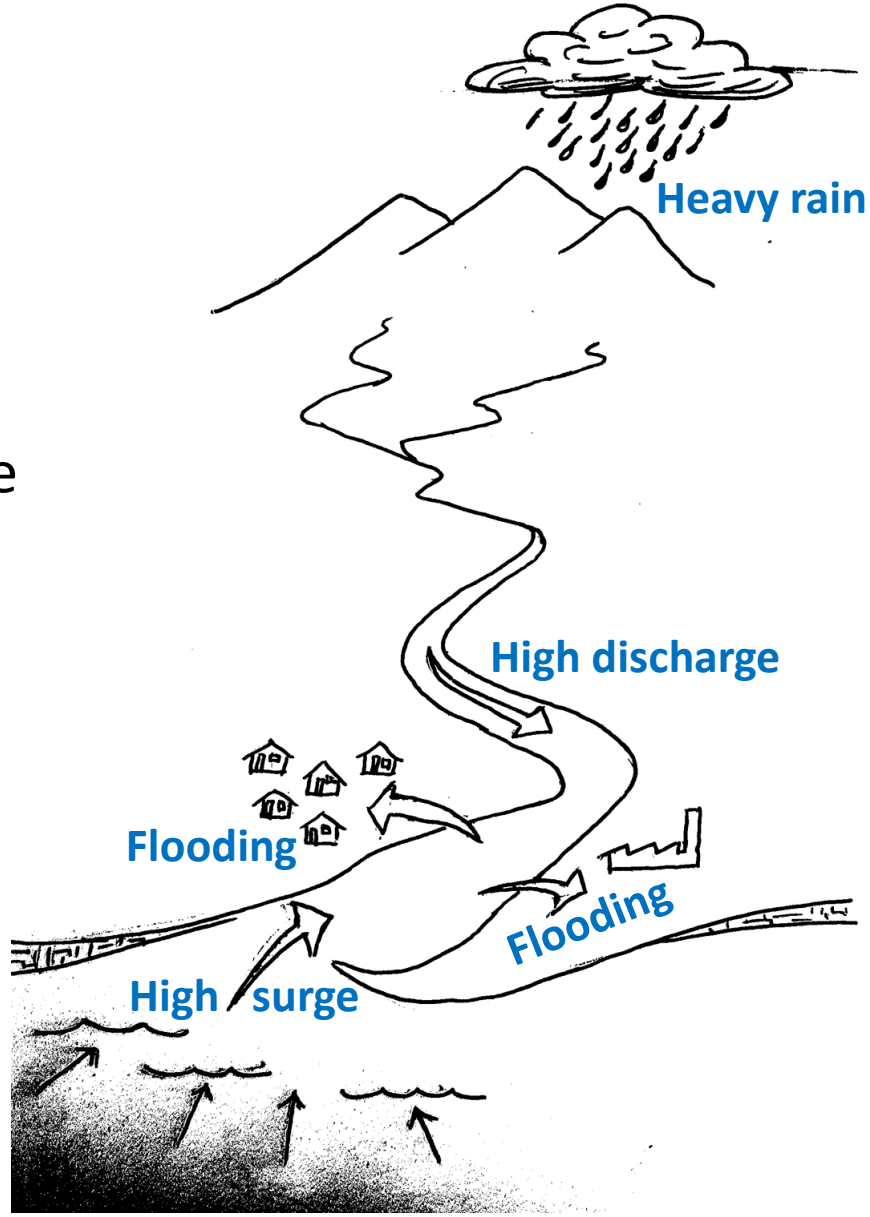
Compound flooding:

- Fluvial and storm-tide extremes can occur synchronously – resulting in **compound flooding hazards** in estuaries.
- Inter- and intra-estuary sensitivities and tipping-points to flooding occur due to the intensity, frequency and relative timings of these drivers, and the different types of catchment and estuary.
- Compound flooding may worsen in the future as these drivers change, combined with projected sea-level rise.
- These flooding sensitivities are poorly understood and inhibit effective flood risk assessments.



Contrasting systems…

- The sensitivity of different catchments and estuaries to compound flooding is unclear (size, shape, weather, geology…)

- We investigated two contrasting systems:
  - Humber (large/east-coast) and Dyfi (small/west-coast).

- ***Is there dependence between high fluvial and surge events?***

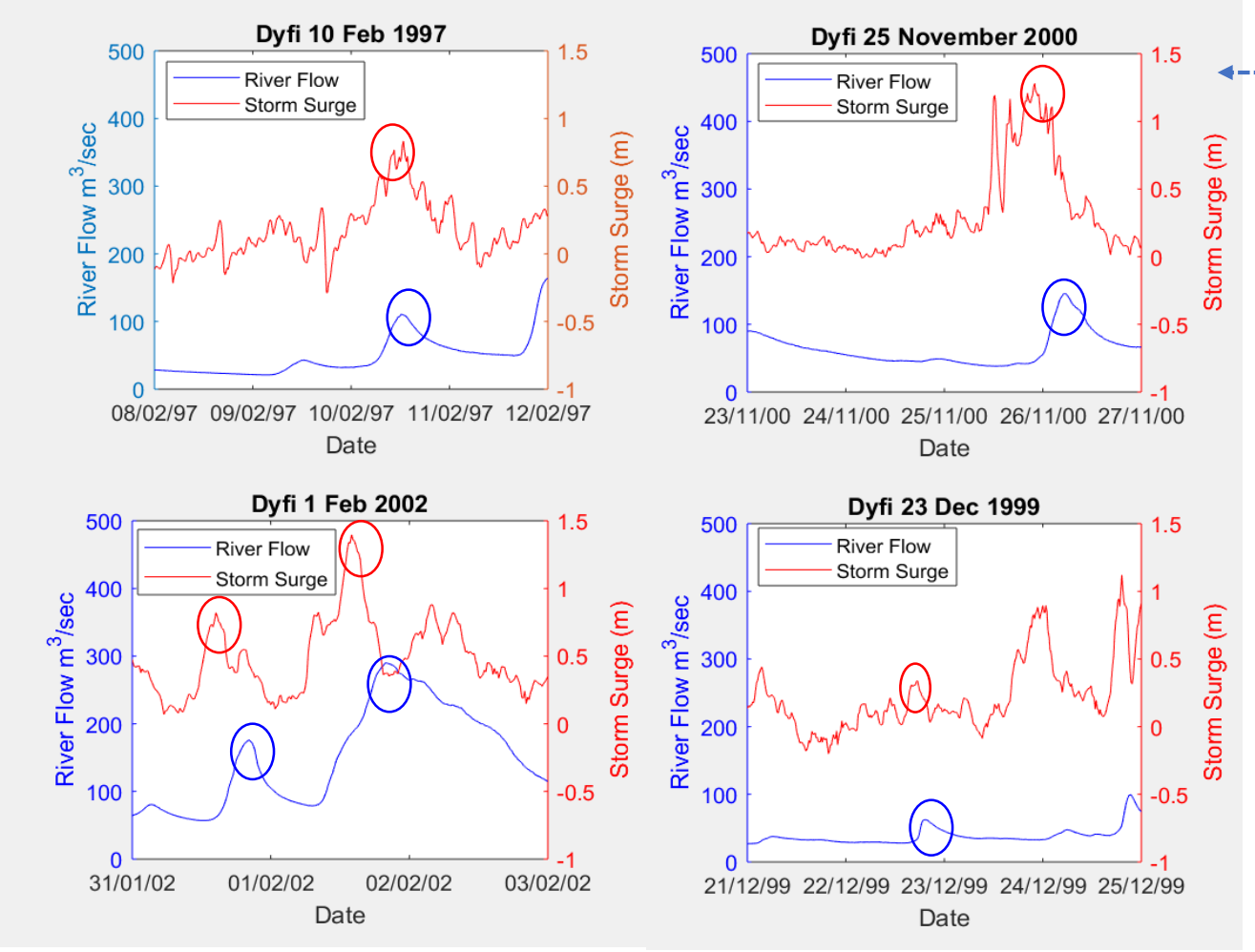
[Data: 35 years, 15-min fluvial flows and sea levels].

1980-2015

If yes, then compound flooding may occur…

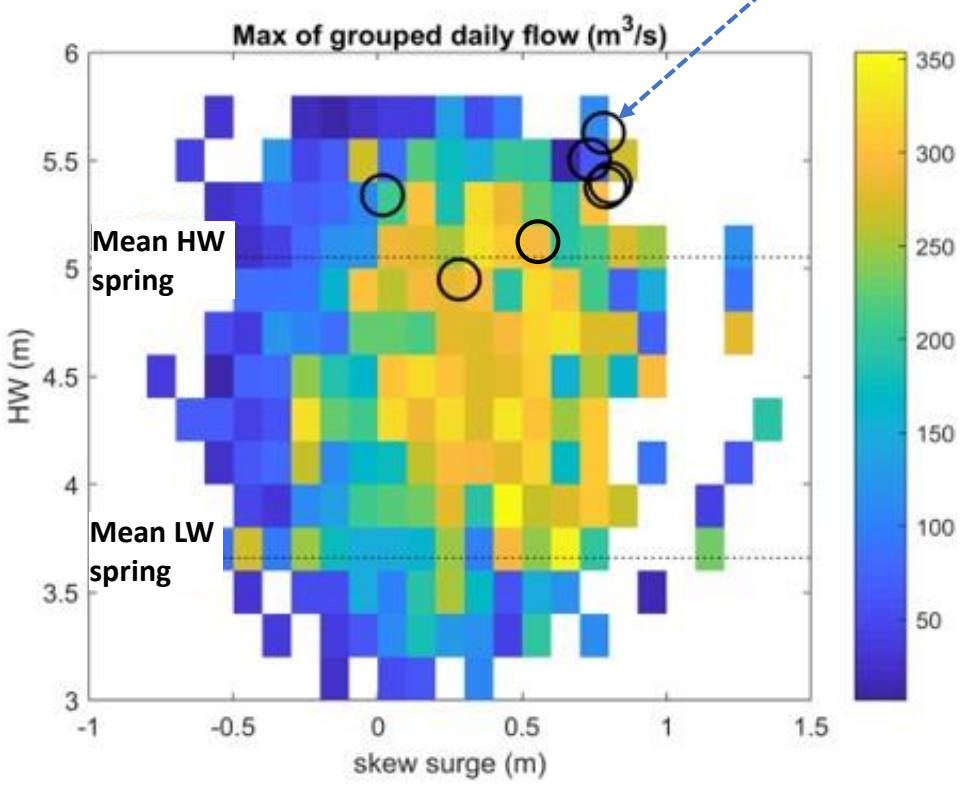
Dyfi (500 km²)

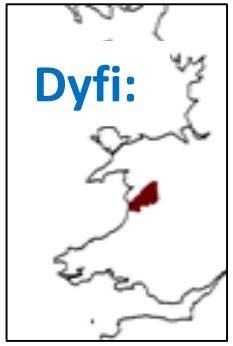
Humber (24,000 km²)



Flood events…

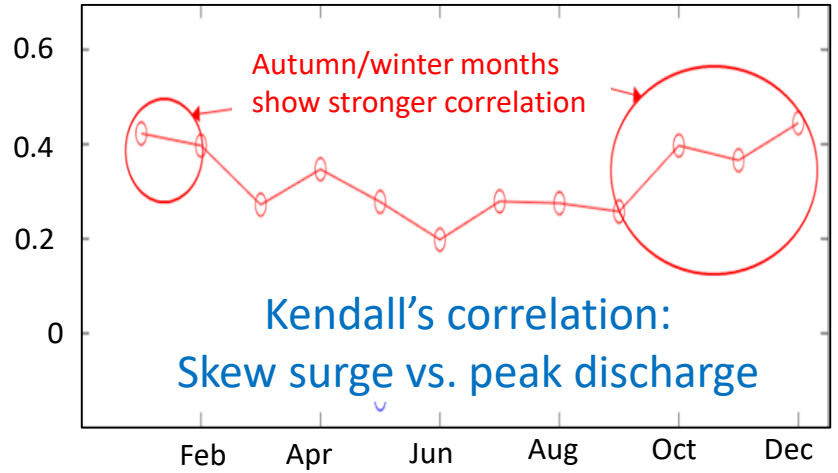
…happen at HW

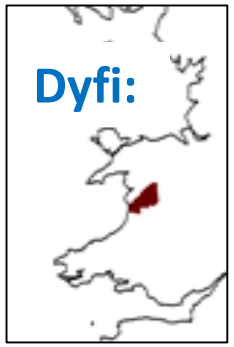




We show significant correlation between skew surge and peak fluvial flow.

Higher dependence during autumn/winter.

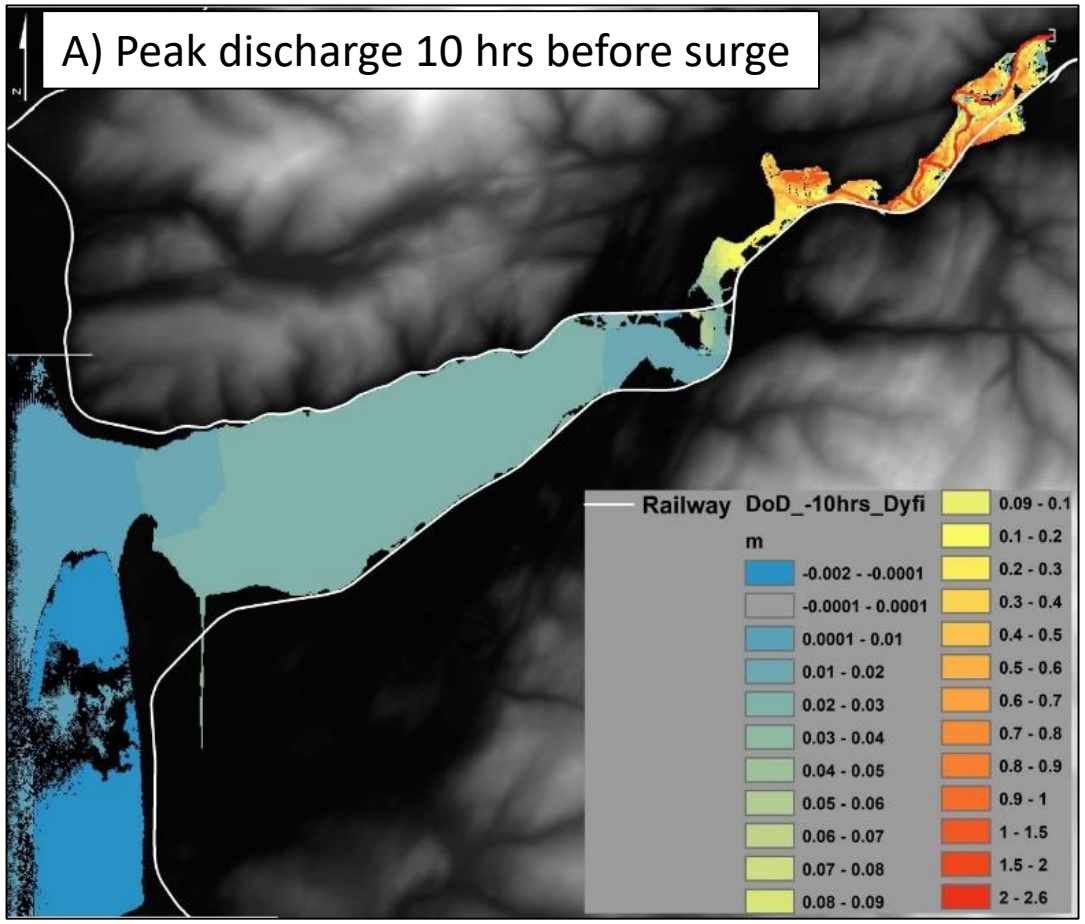


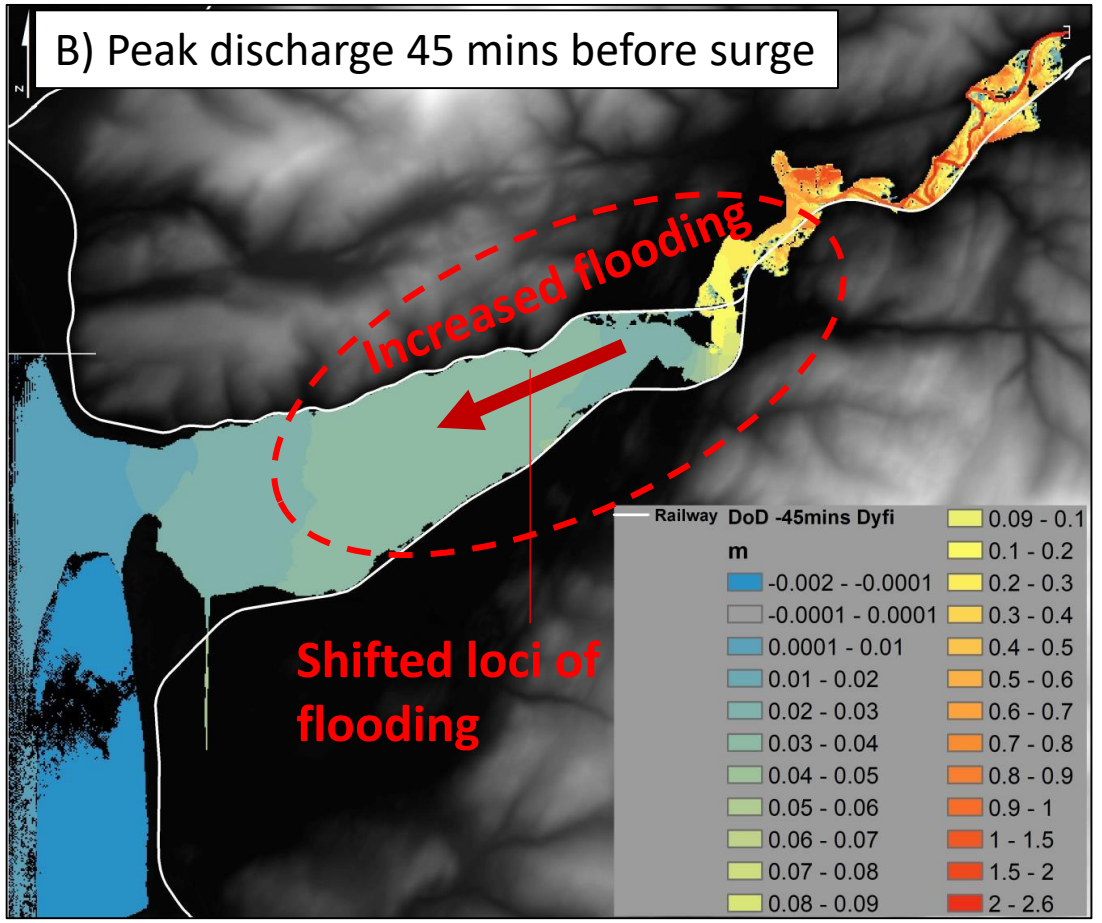


Fluvial–surge phasing is important

…makes a big difference to flooding, because Dyfi is a **fast response system** (small, steep catchment and small estuary).

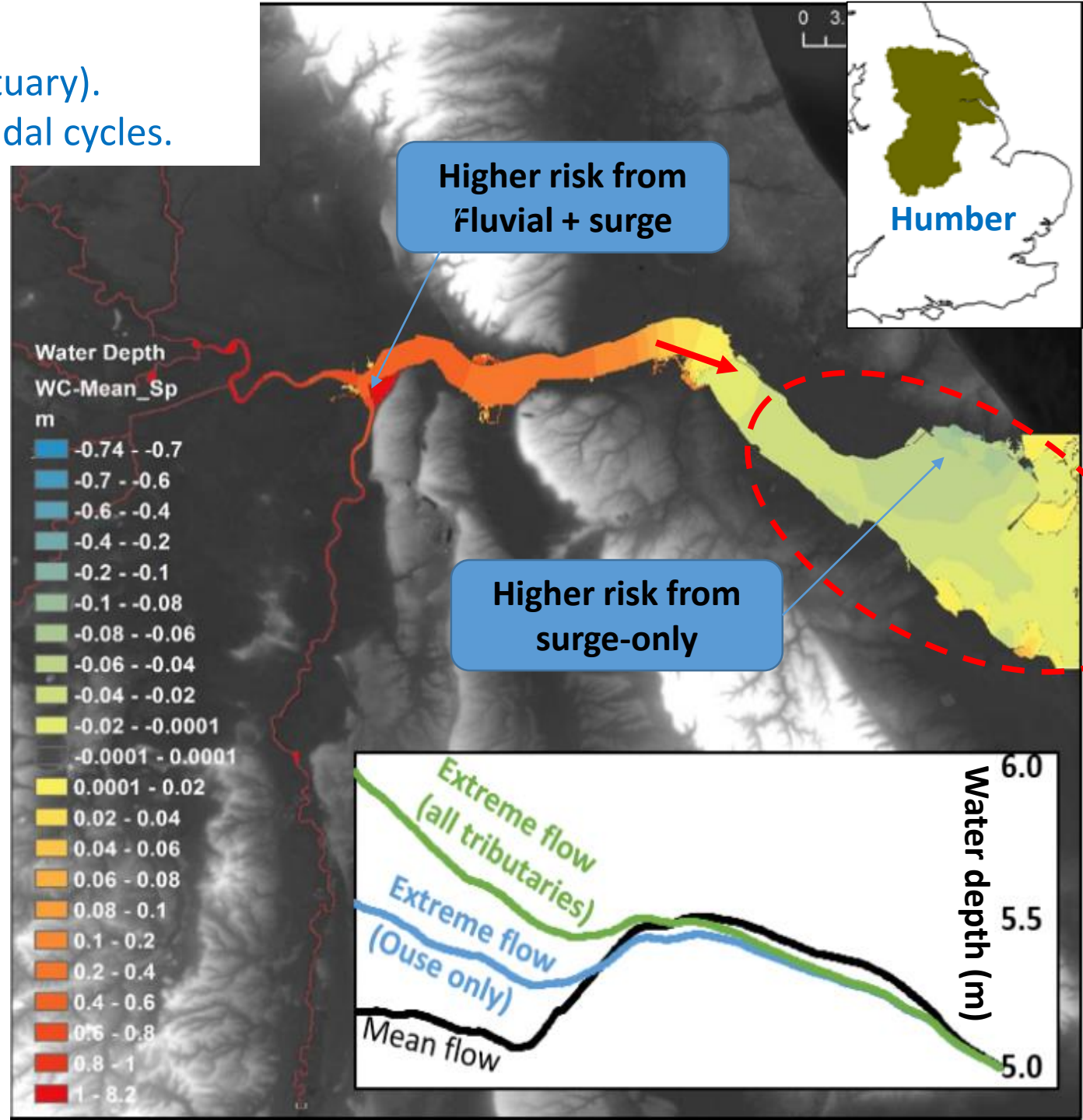
River floods are ‘flashy’ (last a few hours).





Humber: A **slow response system**
(large, gentle-slope catchment and large estuary).
River floods last >2 days, spanning several tidal cycles.

1. No dependence: skew surge vs. peak discharge.
2. Cross-correlation: correlation with 10hr lag.
3. Fluvial-surge phasing had little impact on flooding.
4. Intra-fluvial magnitudes (four tributaries covering different weather systems) is important (inset: worst flooding from all rivers in unison – affecting Hull and the Humber flood defence barrier).
5. Compound flooding actually **reduced** water levels in **outer estuary**, relative to surge-only events (high discharge prevents surge waters entering the estuary, and narrow estuary mouth causes a bottleneck effect for exiting fluvial flow).



Why do we get compound flooding in the Dyfi but not the Humber?

- Slow response catchments*:

Slow runoff times causes surge-river lag.

Slow catchment 'filters' flash storms into long-duration hydrographs.

- Fast response catchments #:

Quick runoff potentially causes surge-river correlation.

- UK west coast:

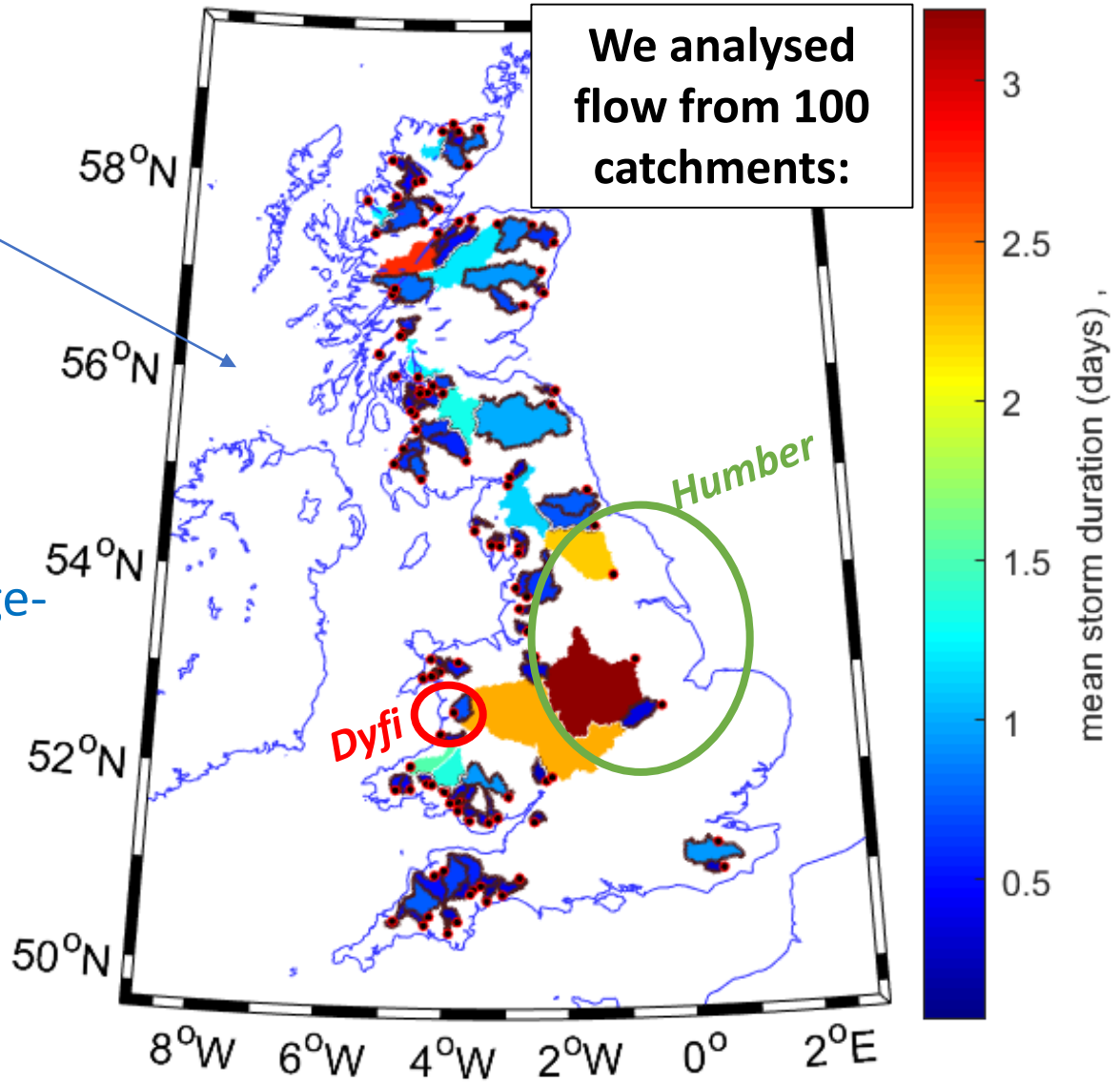
SW storm tracks bring surge and rain – so possible surge-river correlation.

- UK east coast:

SW storm tracks bring rain only, NE storm tracks bring surge only – so no surge-river correlation.

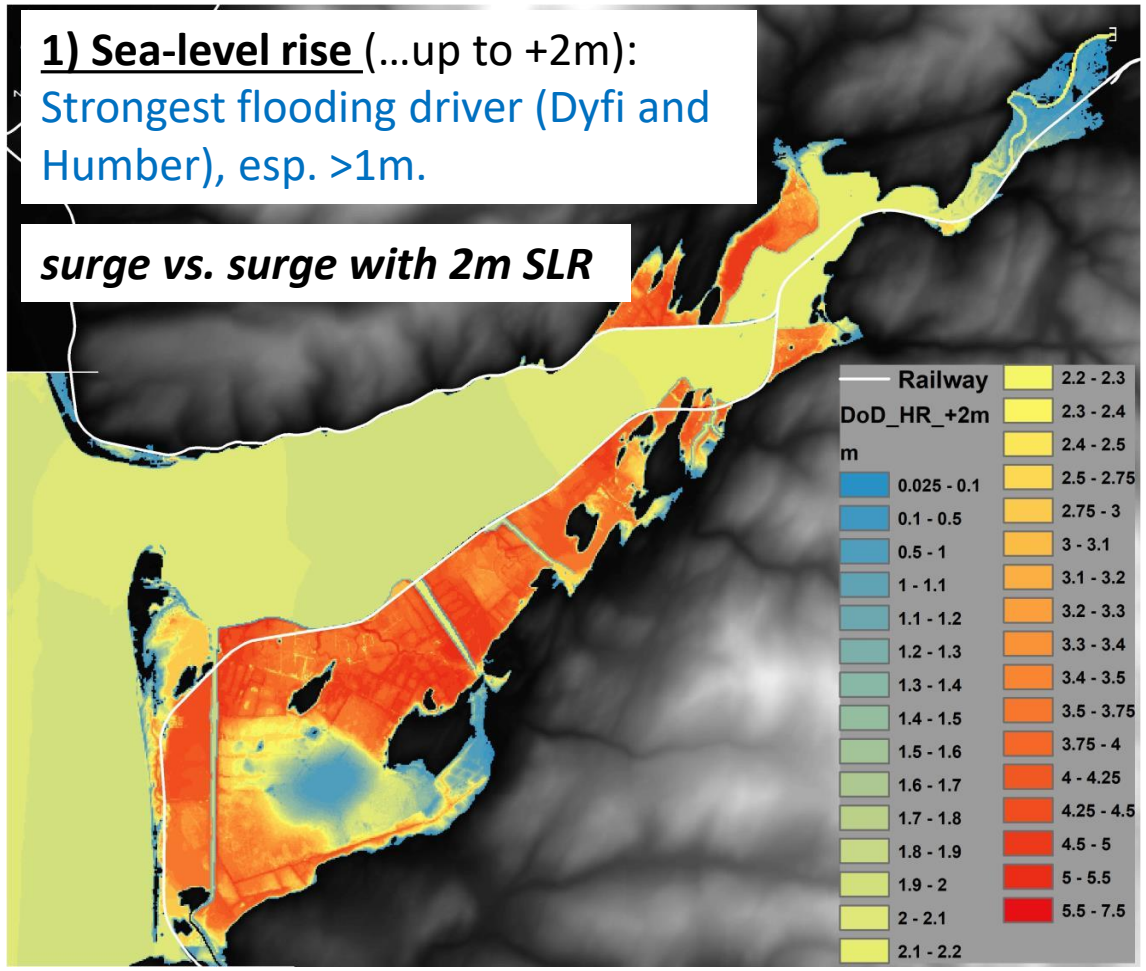
*e.g. *large/flatter catchments, groundwater flow*

#e.g. *small/steep/impermeable catchments*

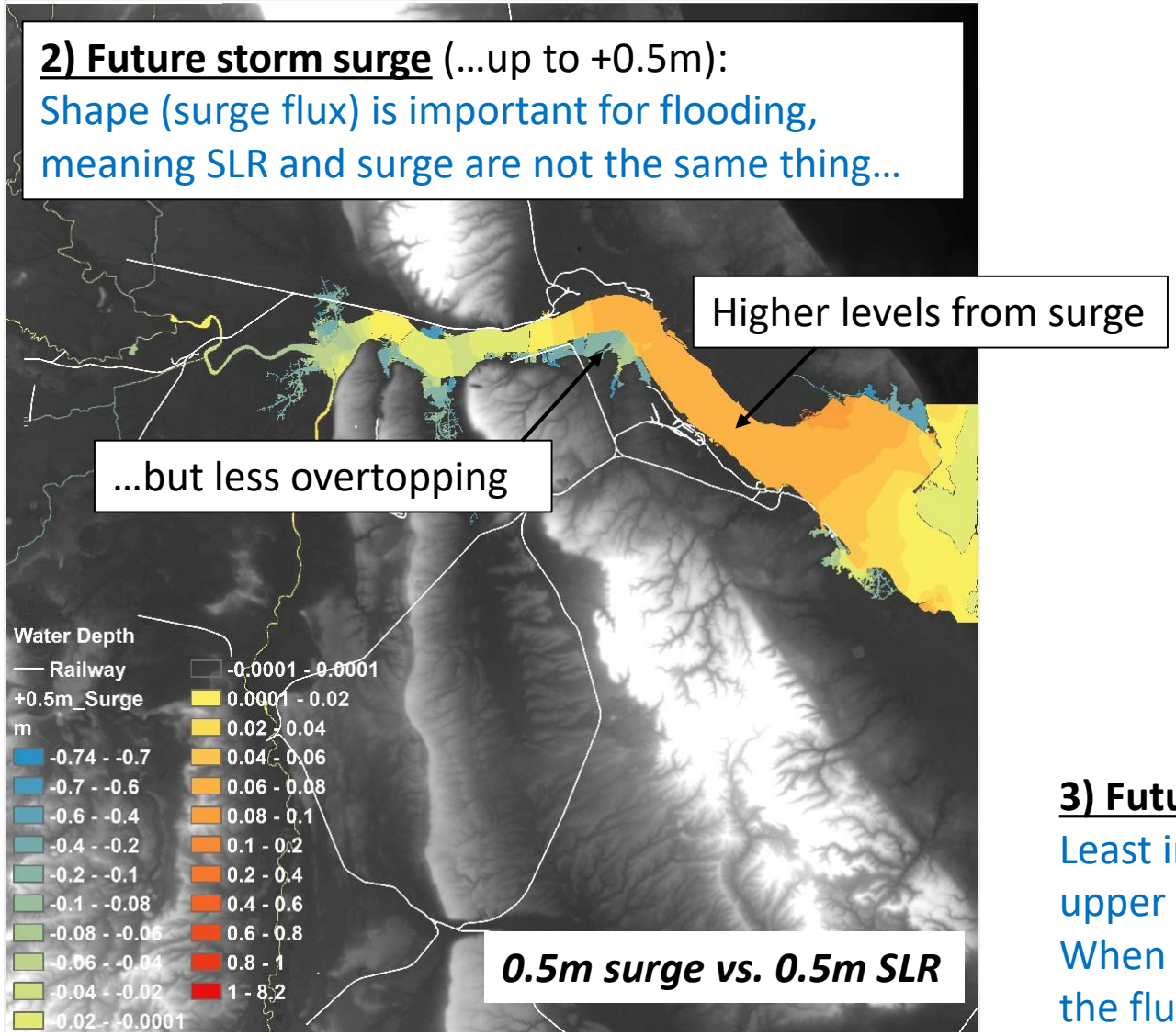


Climate change…

1) Sea-level rise (…up to +2m):
Strongest flooding driver (Dyfi and Humber), esp. >1m.



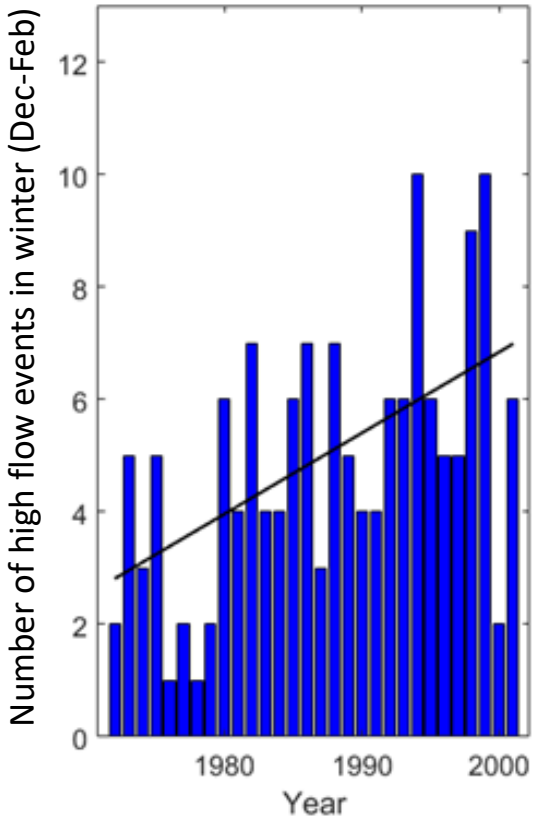
2) Future storm surge (…up to +0.5m):
Shape (surge flux) is important for flooding, meaning SLR and surge are not the same thing…

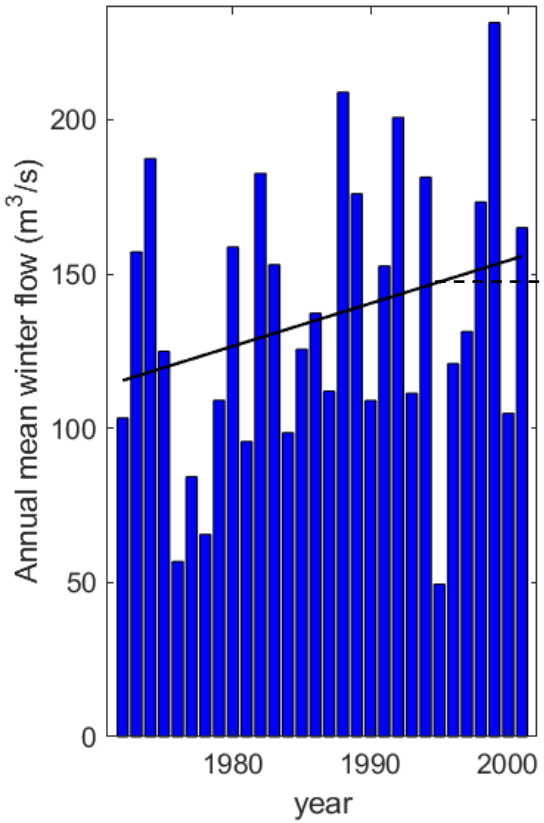


3) Future fluvial discharge (…up to +40%):
Least important flooding driver, because fluvial flooding confined to upper estuary. But more important in Dyfi than Humber.
When combined with SLR where sea defences already overtopped, the fluvial influences on flooding were wide-reaching.

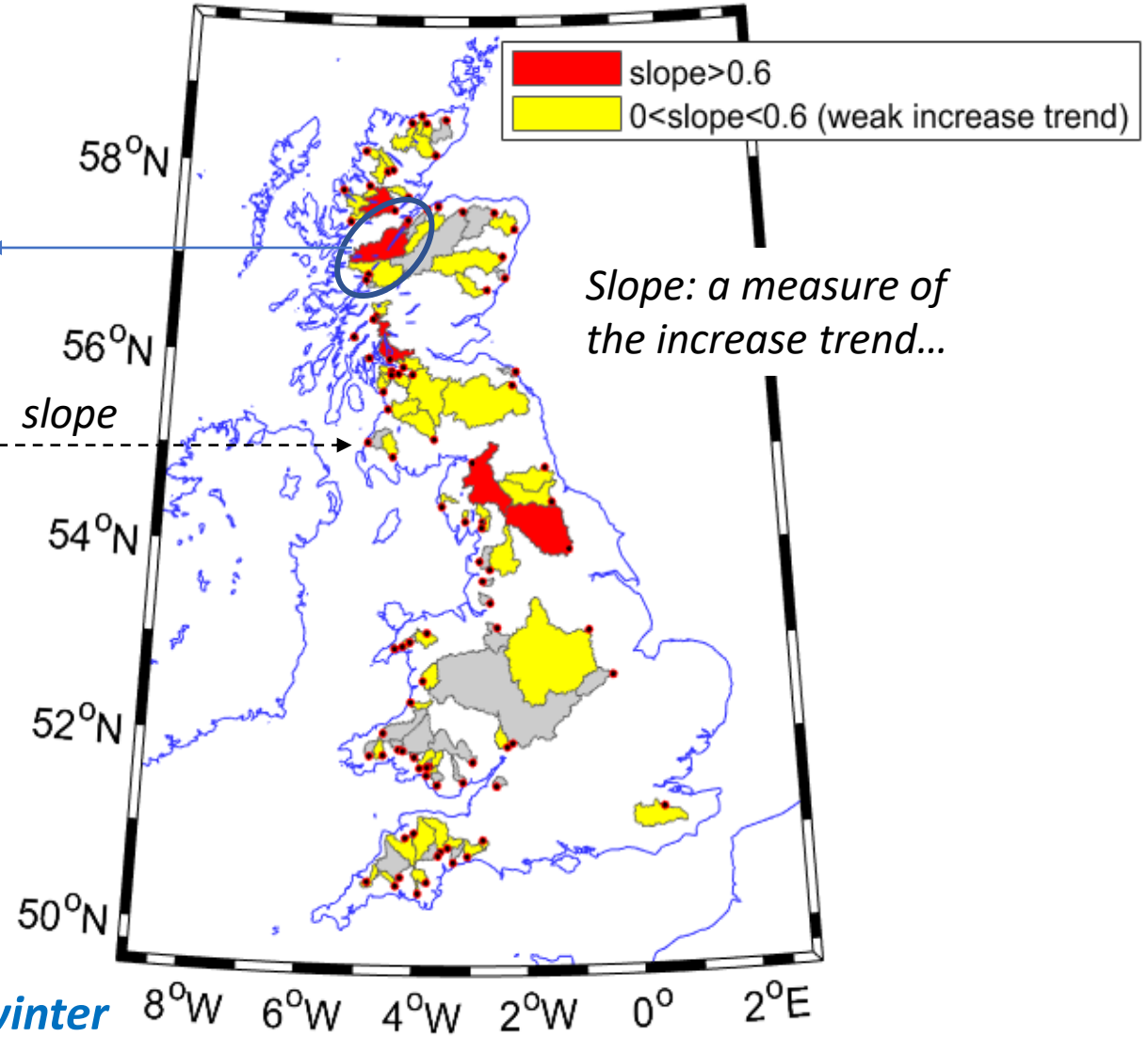
Is river behaviour changing?

River Ness, Scotland



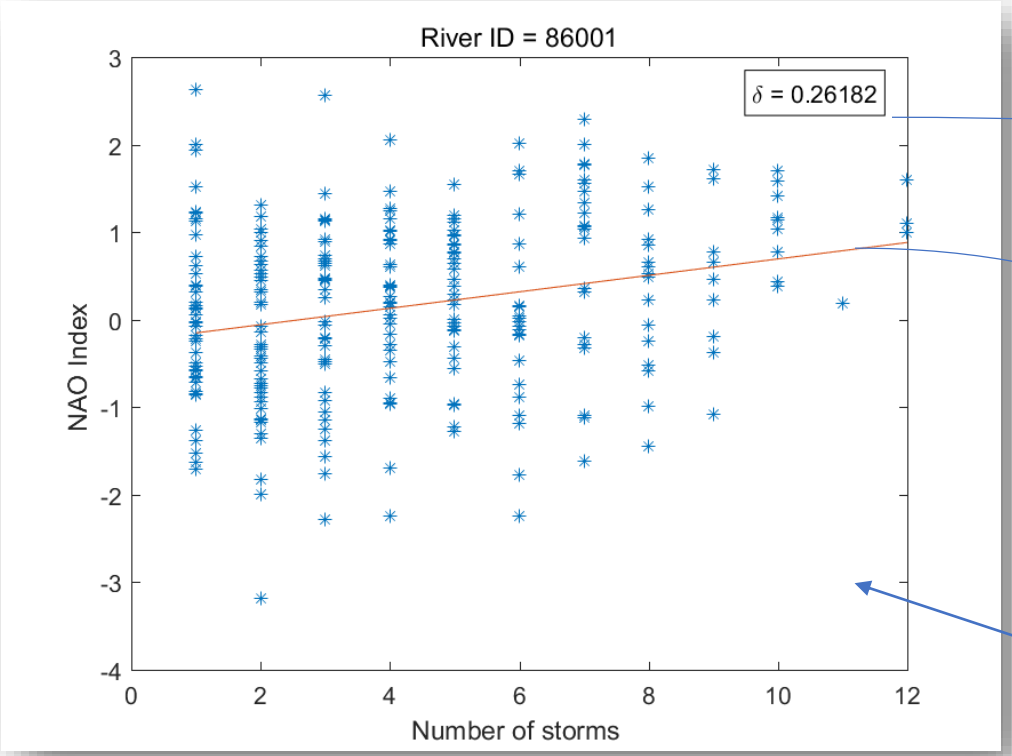


slope



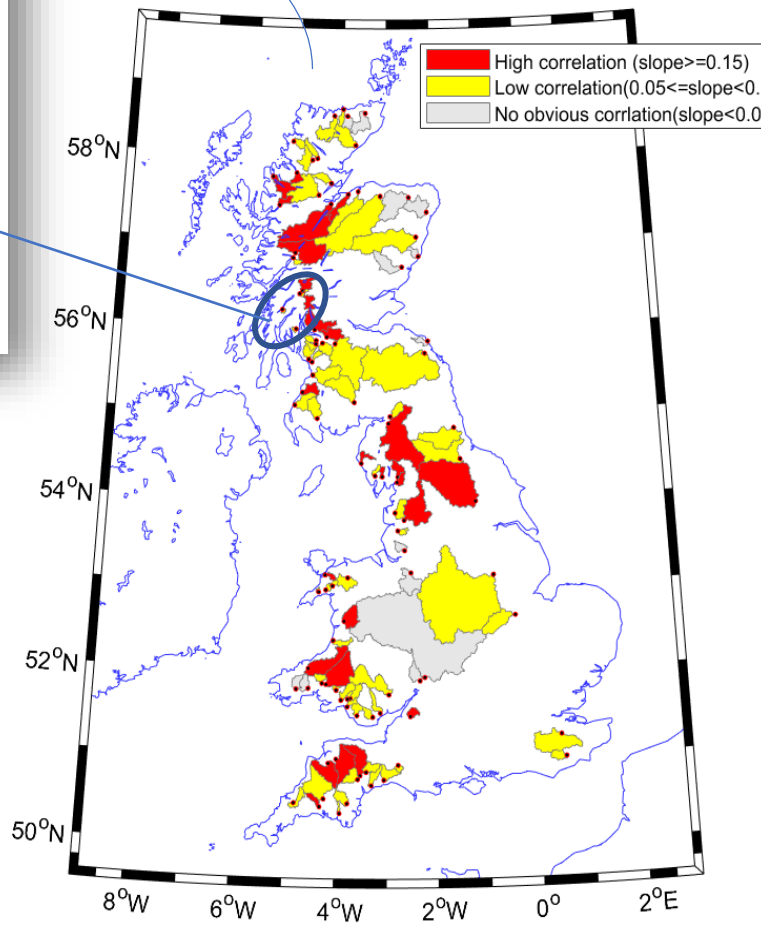
Slope: a measure of the increase trend…

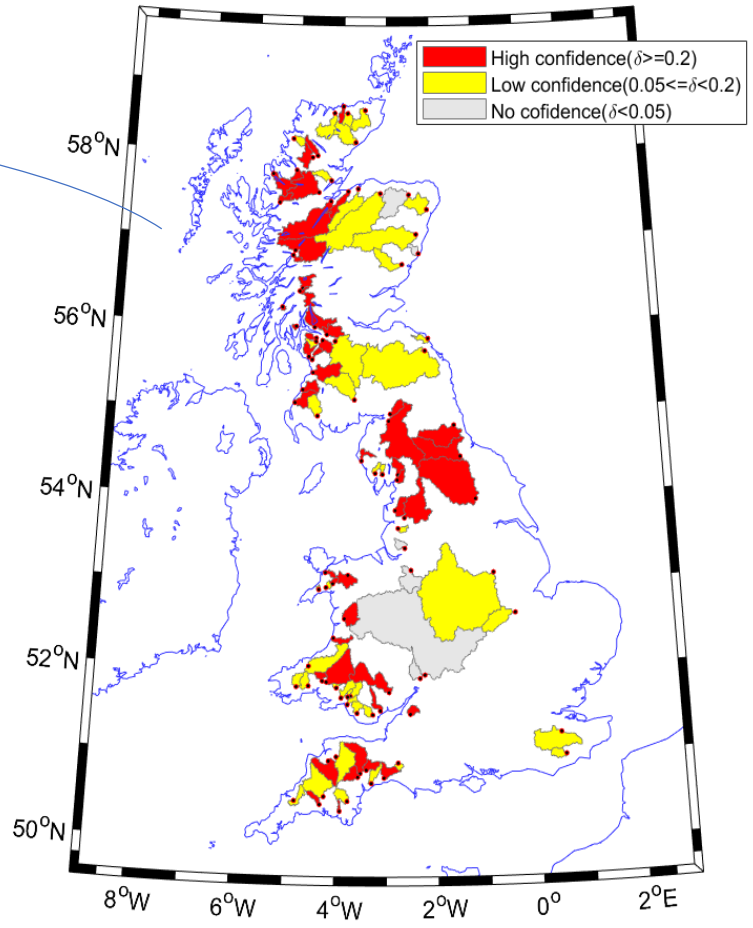
Some rivers are significantly increasing in winter storm magnitude and frequency…



confidence

slope





For some rivers, the winter storm frequency is significantly correlated with NAO…

NAO vs winter storm frequency:

- ***Red catchments: high correlation and high confidence***
- ***Yellow catchments: weak correlation and low confidence***
- ***Grey catchments: no trend.***

Hypotheses based on our proof-of-concept study:

- Small and west-coast systems are vulnerable to compound flooding (river + surge) hazards
- Projected changes in river/surge magnitudes, frequencies and relative timings will worsen combination and compound flooding hazards
- Projected sea-level rise is the biggest problem – causing substantial and widespread flooding across all estuaries
- Surges produce a different flooding hazard to sea-level rise (high flux vs slow rise) – hence, should be modelled differently
- Many river behaviours in the UK are changing – with more intense and more frequent winter high flow events that are linked to the North Atlantic Oscillation