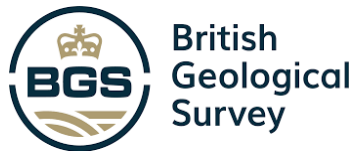
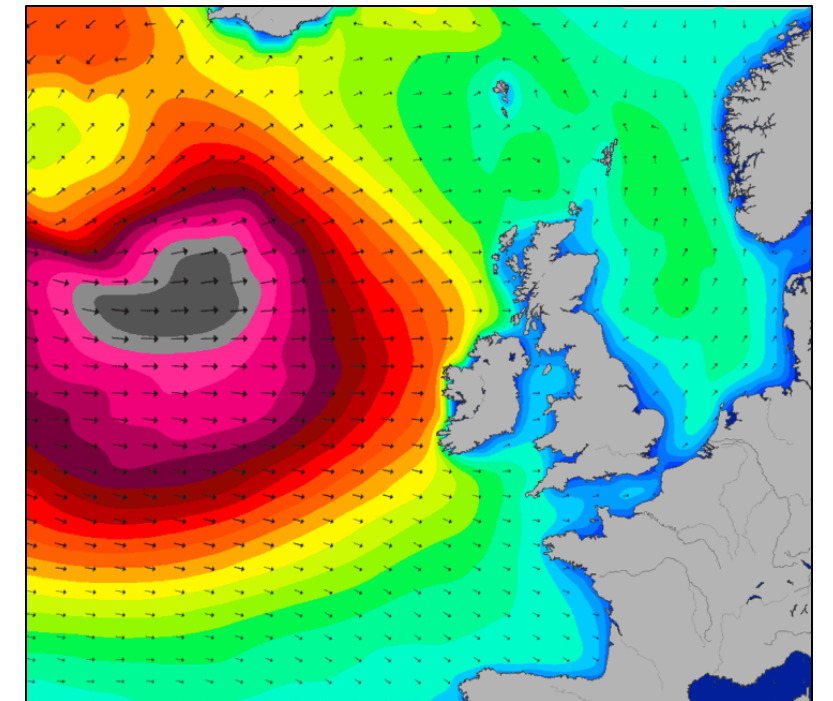
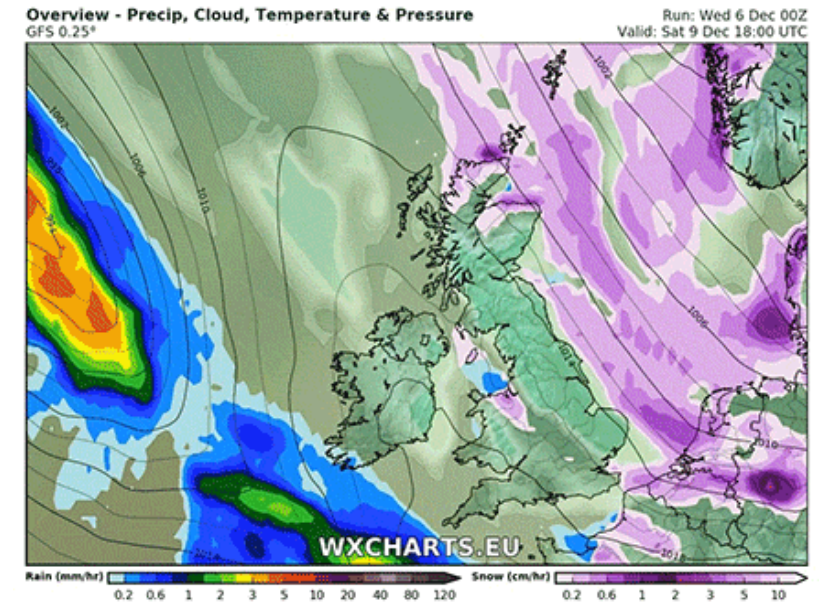


# SEARCH: Sensitivity of estuaries to climate hazards

Peter Robins, Charlotte Lyddon, Tom Coulthard, Andrew Barkwith,  
Matt Lewis, Greg Vasilopoulos, Chien Nguyen,  
Ankita Bhattacharya, Jonathan Tinker, Rachel Perks, Gemma Coxon



## Flooding globally:

3 million deaths, >\$1 trillion in economic losses.

## UK:

*Drivers* and *pathways* of flooding poorly understood.  
Historic flooding is undocumented.

*Impacts:* 1-in-6 properties (3 million) at risk.  
Annual damages >£540M.  
Human health and food security risks,  
mental health impacts poorly understood.

## Future risk:

*Drivers:* SLR, sea surface variability, river flows,  
rainfall, groundwater

*Pathways:* land use, water management, defenses,  
morphology

*Impacts:* resilience, perceptions, mitigation



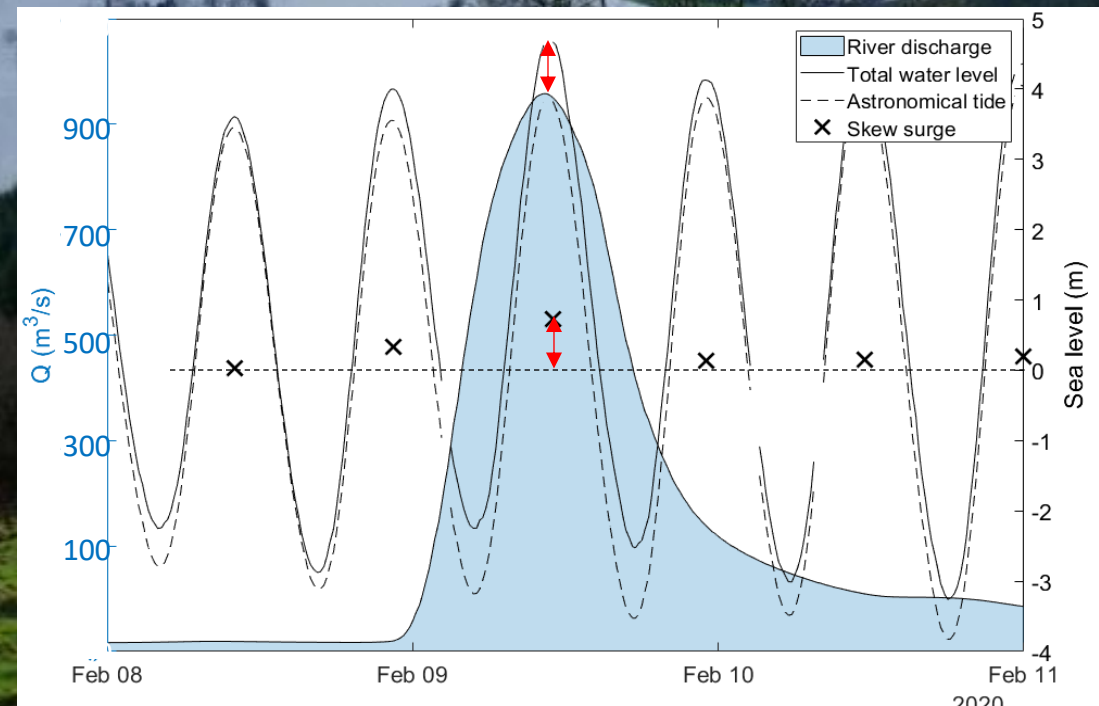
Conwy estuary, Storm Ciara

# Storm Ciara: Conwy estuary, February 2020 ...the perfect storm?

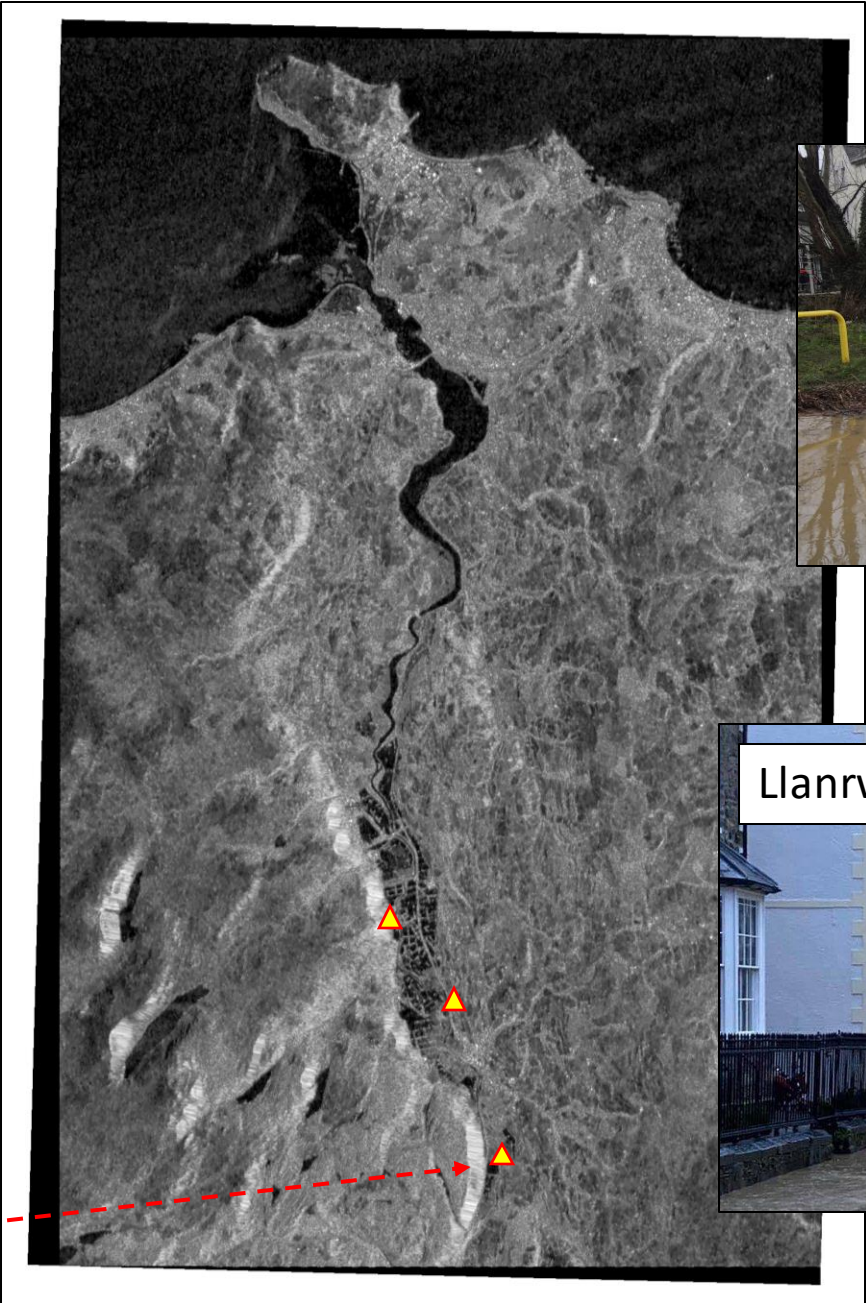
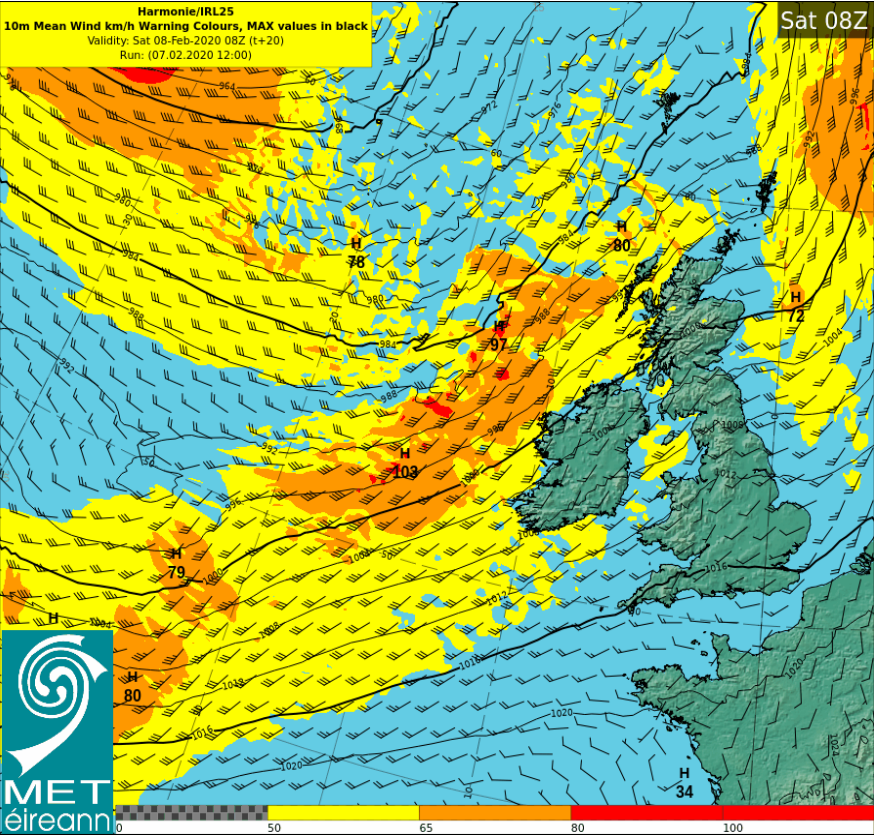
*“Two or more (extreme) events occurring simultaneously that lead to extreme impacts”*

- **Compound flooding in UK:**
  - South UK coasts (2013/14)
  - Cumbria (2015)
  - Conwy (2020)

[Svensson & Jones 2002, 2004, 2006; Hendry et al. 2018]



# Storm Ciara



154 properties flooded



**FLOOD WARNING**  
FLOODING IS EXPECTED. IMMEDIATE ACTION REQUIRED.

**FLOOD ALERT**  
FLOODING IS POSSIBLE. BE PREPARED.

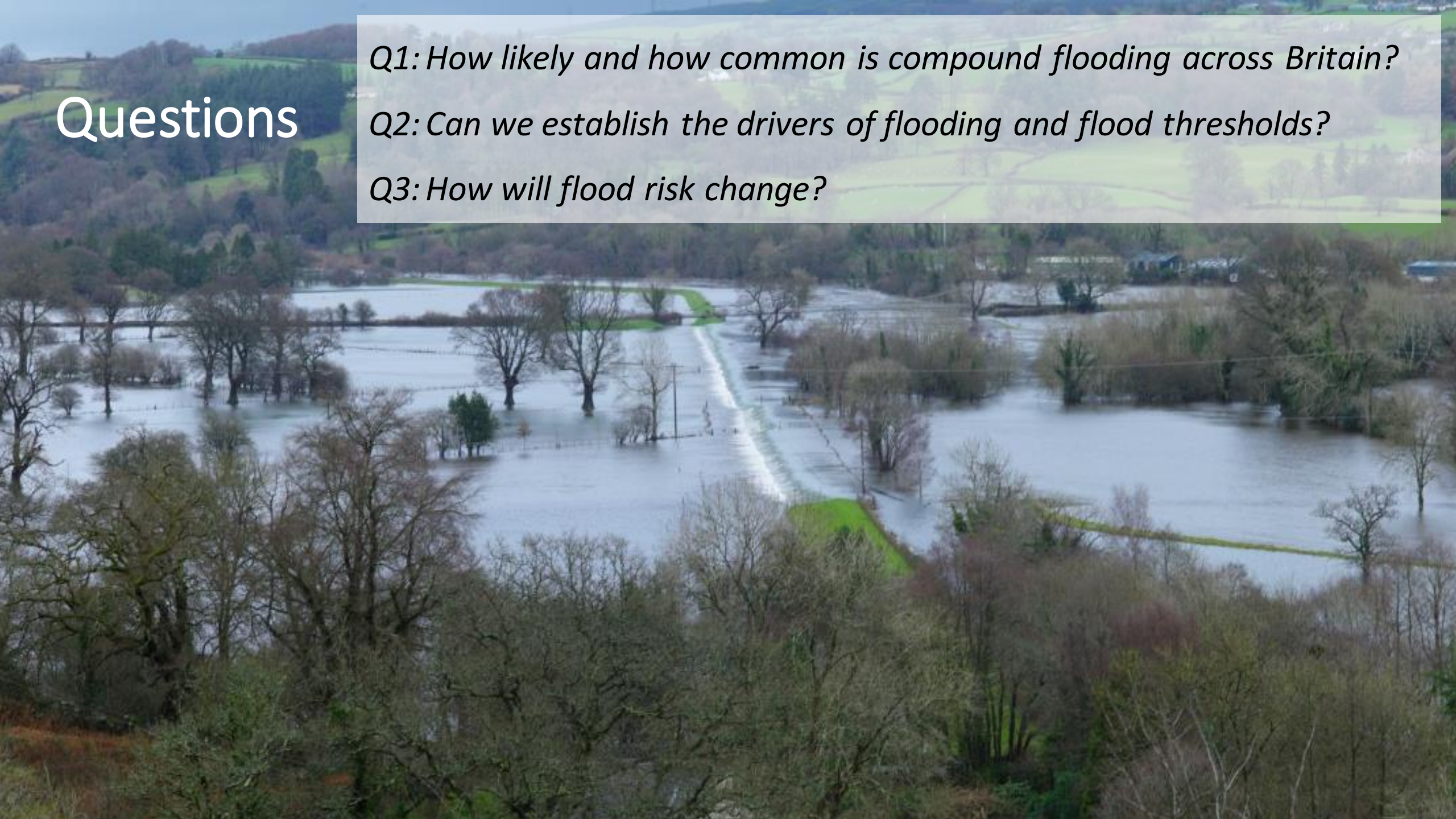
**SEVERE FLOOD WARNING**  
SEVERE FLOODING. DANGER TO LIFE.

# Questions

*Q1: How likely and how common is compound flooding across Britain?*

*Q2: Can we establish the drivers of flooding and flood thresholds?*

*Q3: How will flood risk change?*



# How likely and how common is compound flooding across Britain?

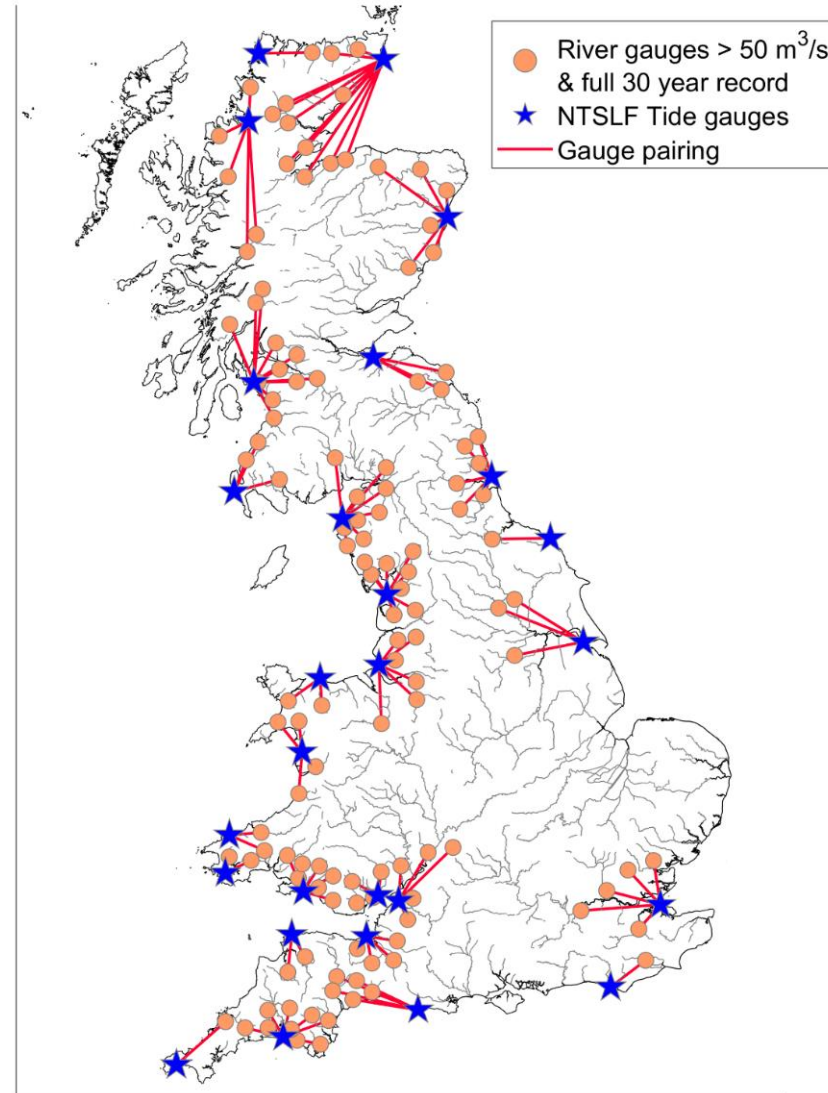
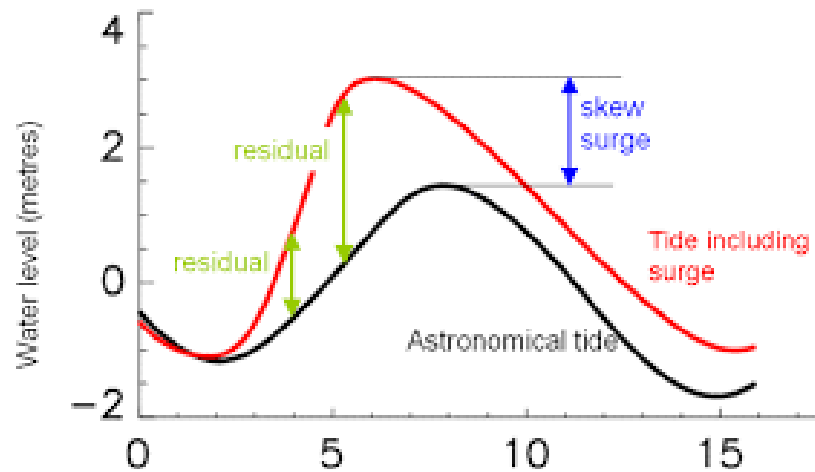
## 15-min river discharge data (126 gauges)

$$Q_{\max} > 50 \text{ m}^3/\text{s}$$

1984 – 2013 (30 yrs)

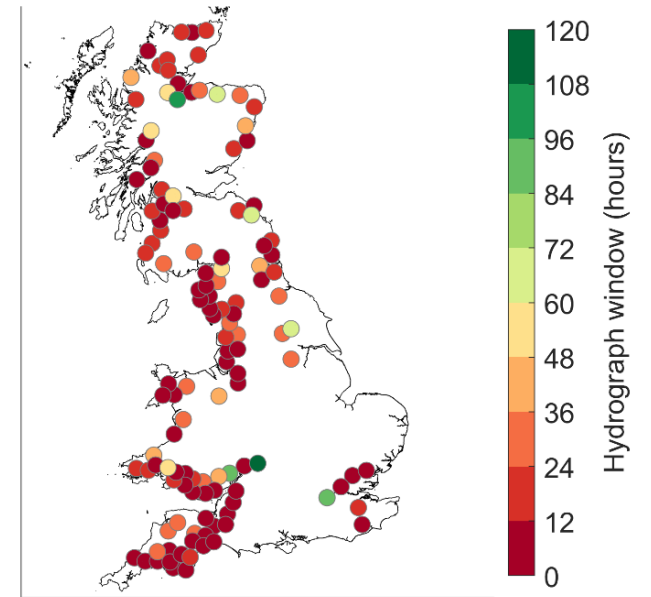
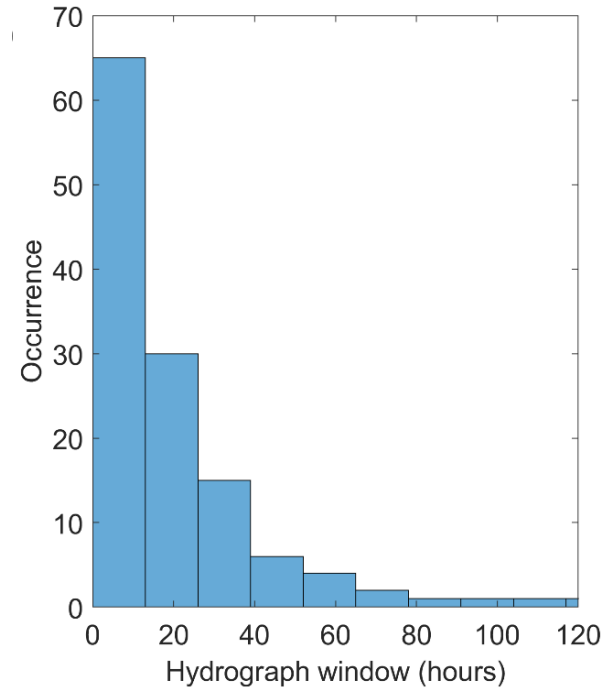
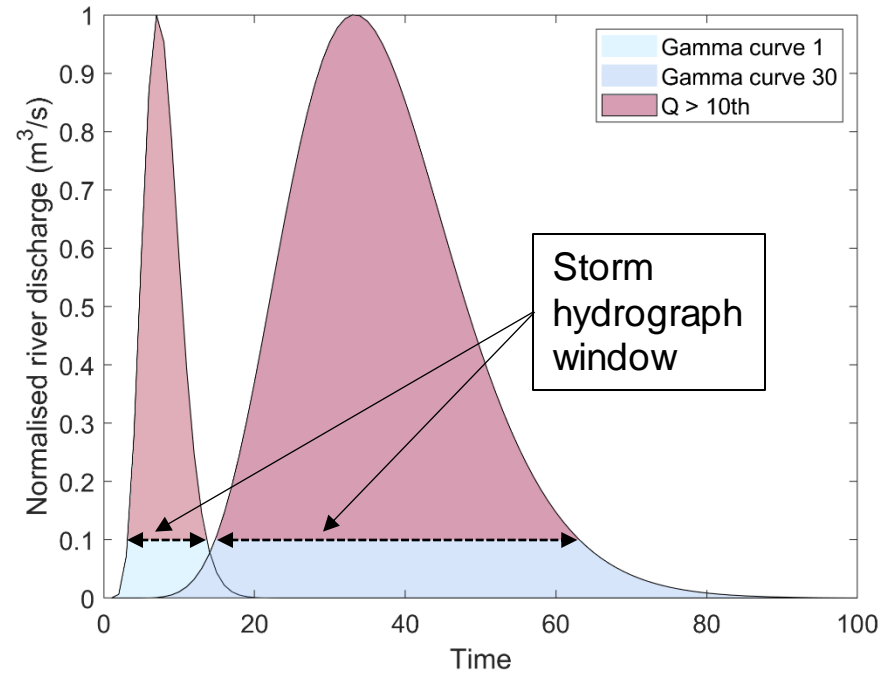
## 15-min sea level data (27 tide gauges)

1984 – 2013 (30 yrs)



# How likely and how common is compound flooding across Britain?

Why use 15-minute data rather than daily mean?

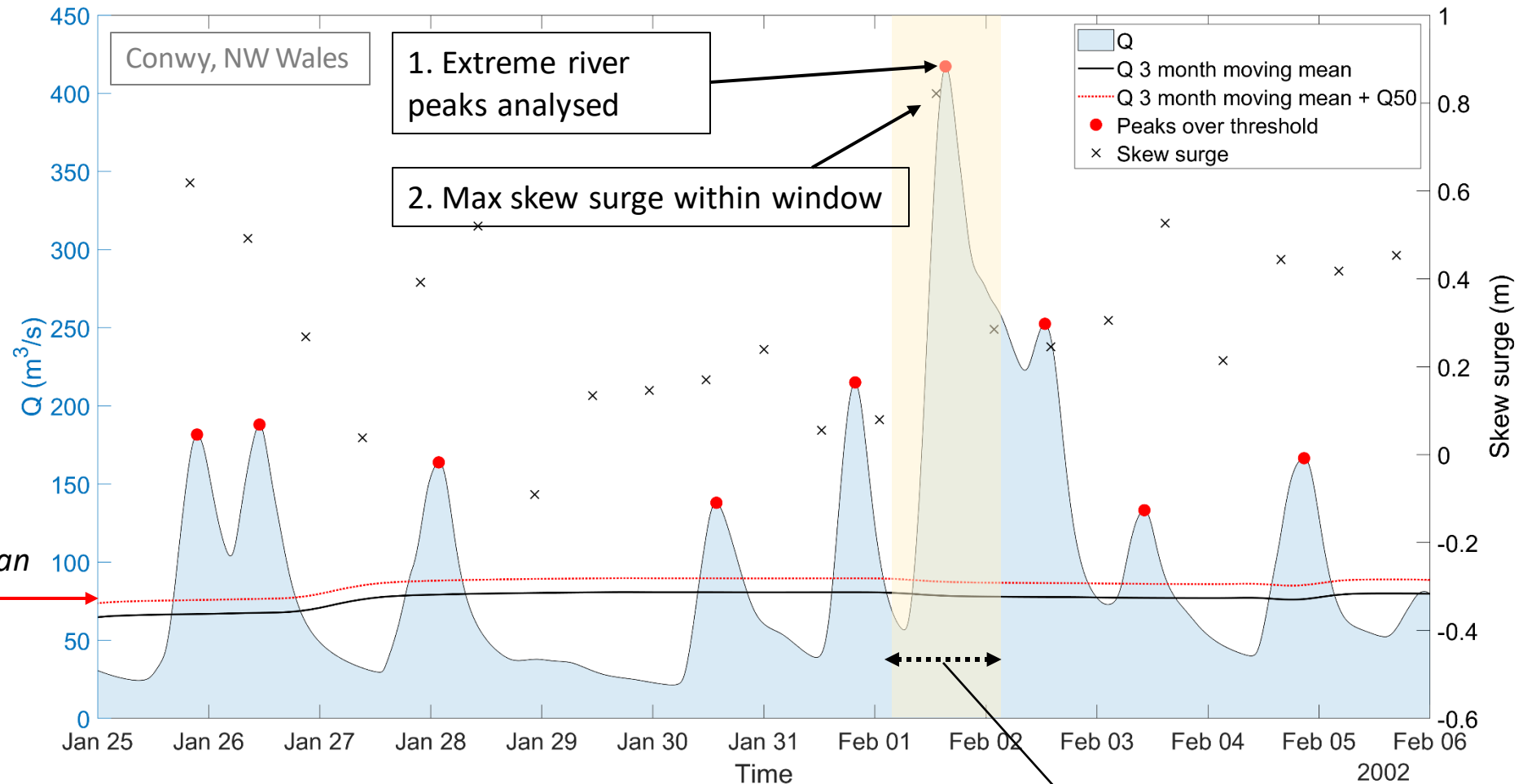


*The short windows (<24 hrs) at most sites indicated that for most catchments in Britain sub-daily data is needed to robustly assess the propensity for compound events.*

# How likely and how common is compound flooding across Britain?

Method: River ( $Q$ ) peaks over threshold + largest skew surge ( $S$ )

Kendall's rank correlation; events per season where  $Q$  and  $S > 95^{\text{th}}$  percentile

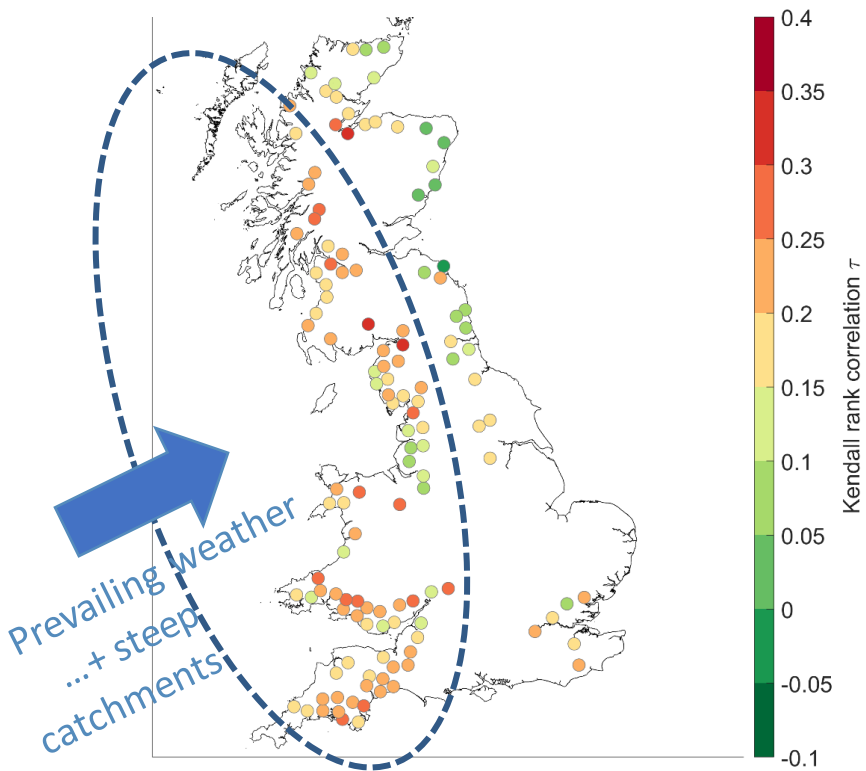


Storm hydrograph window duration (20.25 hrs)

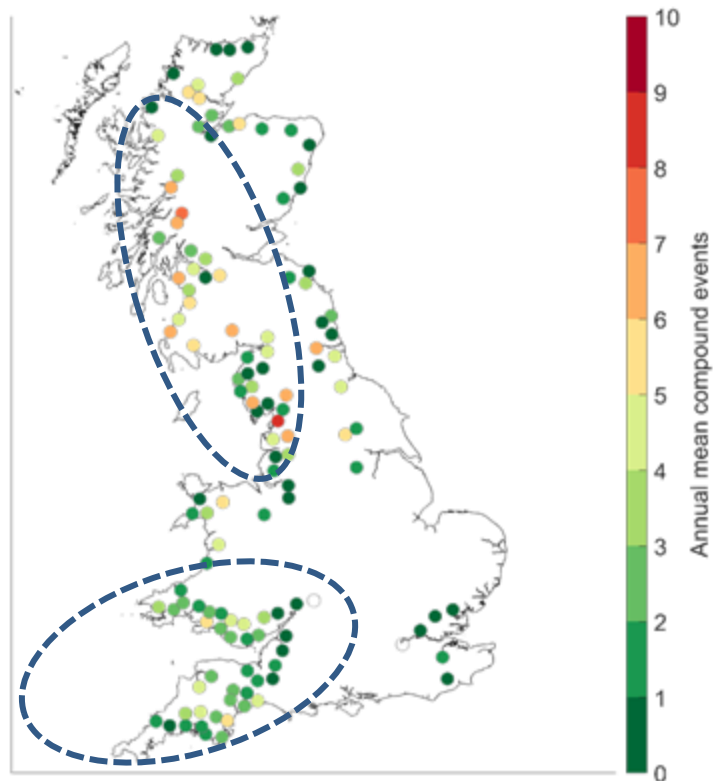


# How likely and how common is compound flooding across Britain?

Stronger correlations in **west** than **east**

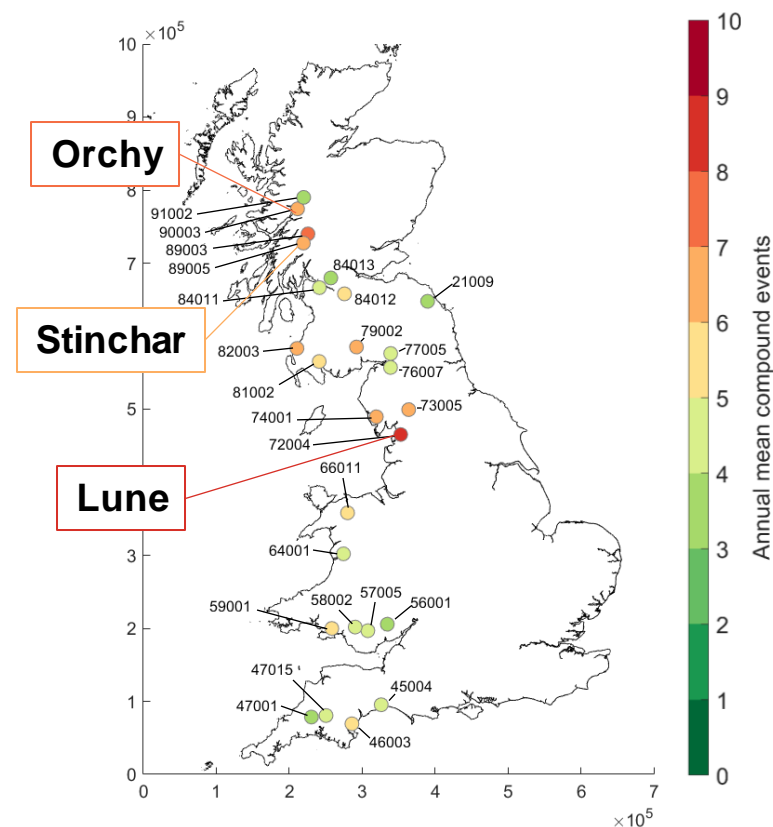


**NW:** High correlation and high occurrence



**SW:** high correlation but  
low occurrences

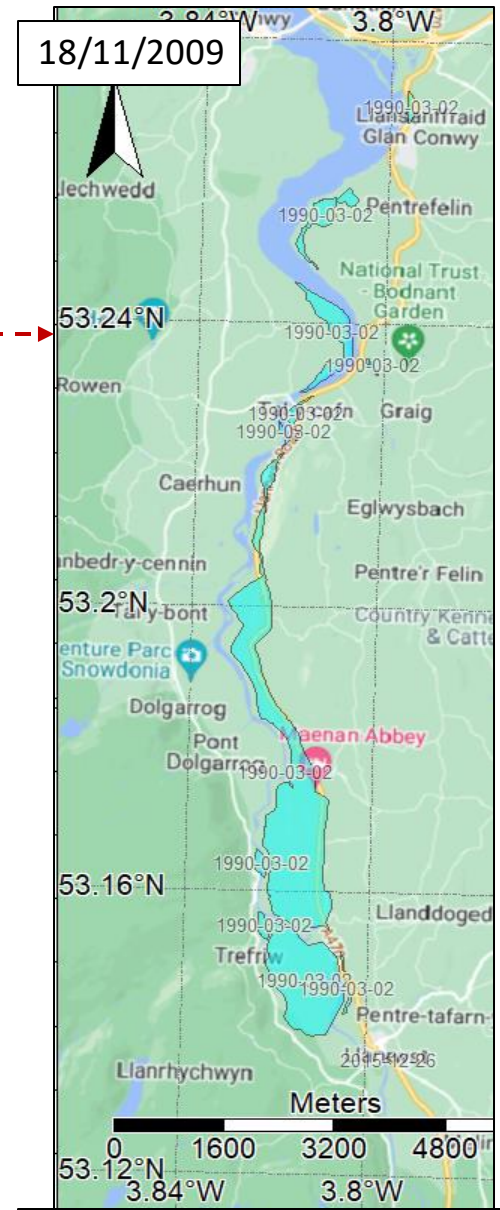
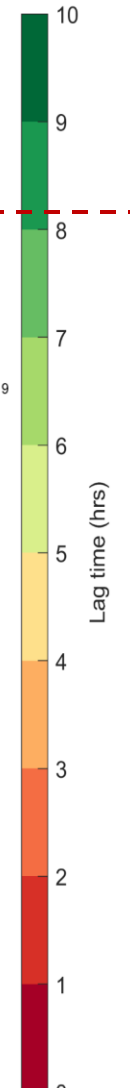
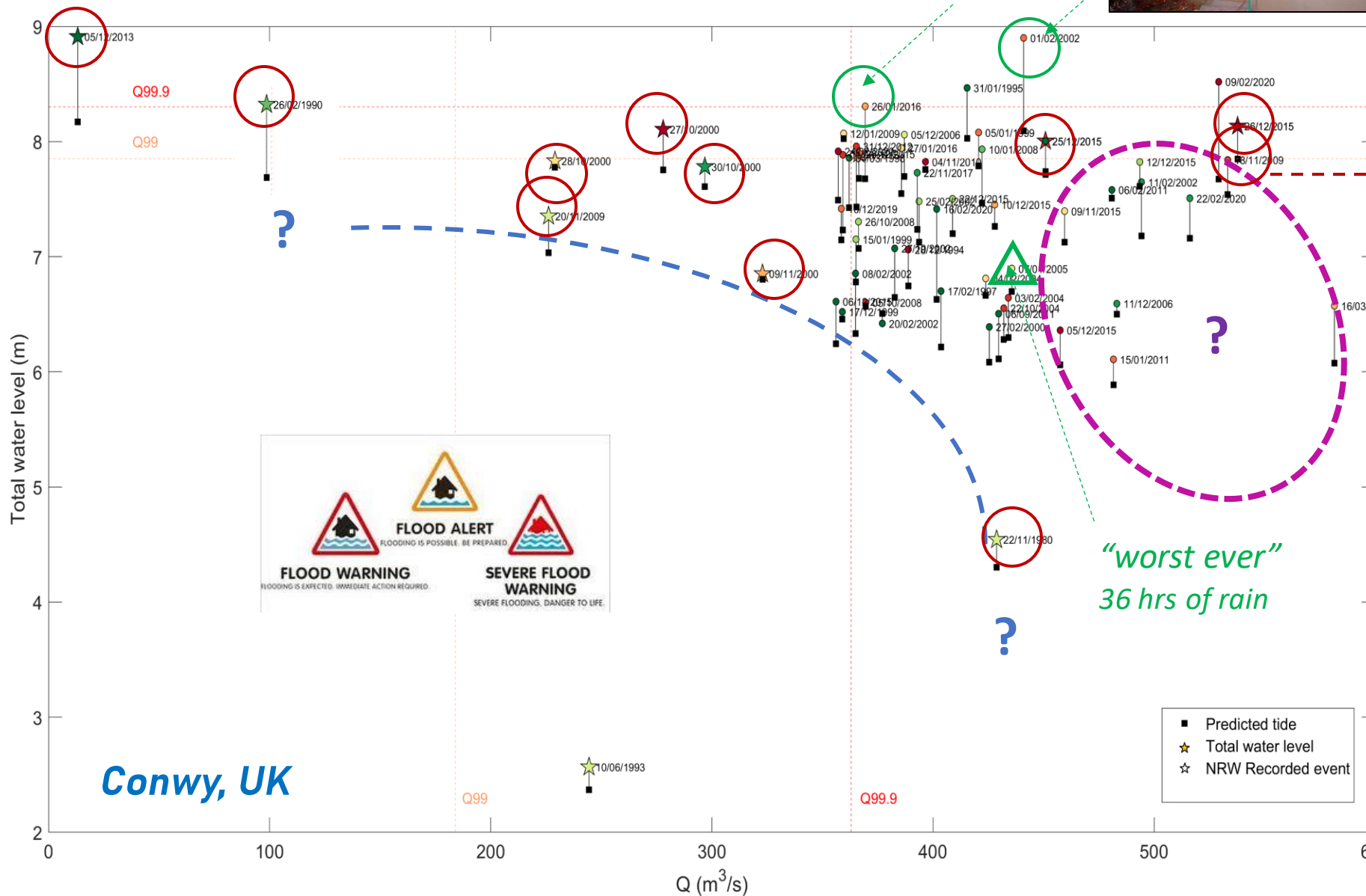
Most vulnerable (corr, no, overlap):



*Lyddon et al. 2022. Historic spatial patterns of compound flood events in UK estuaries. Reviewed in Estuaries & Coasts*

*Also: Harrison et al 2021; Robins et al 2021*

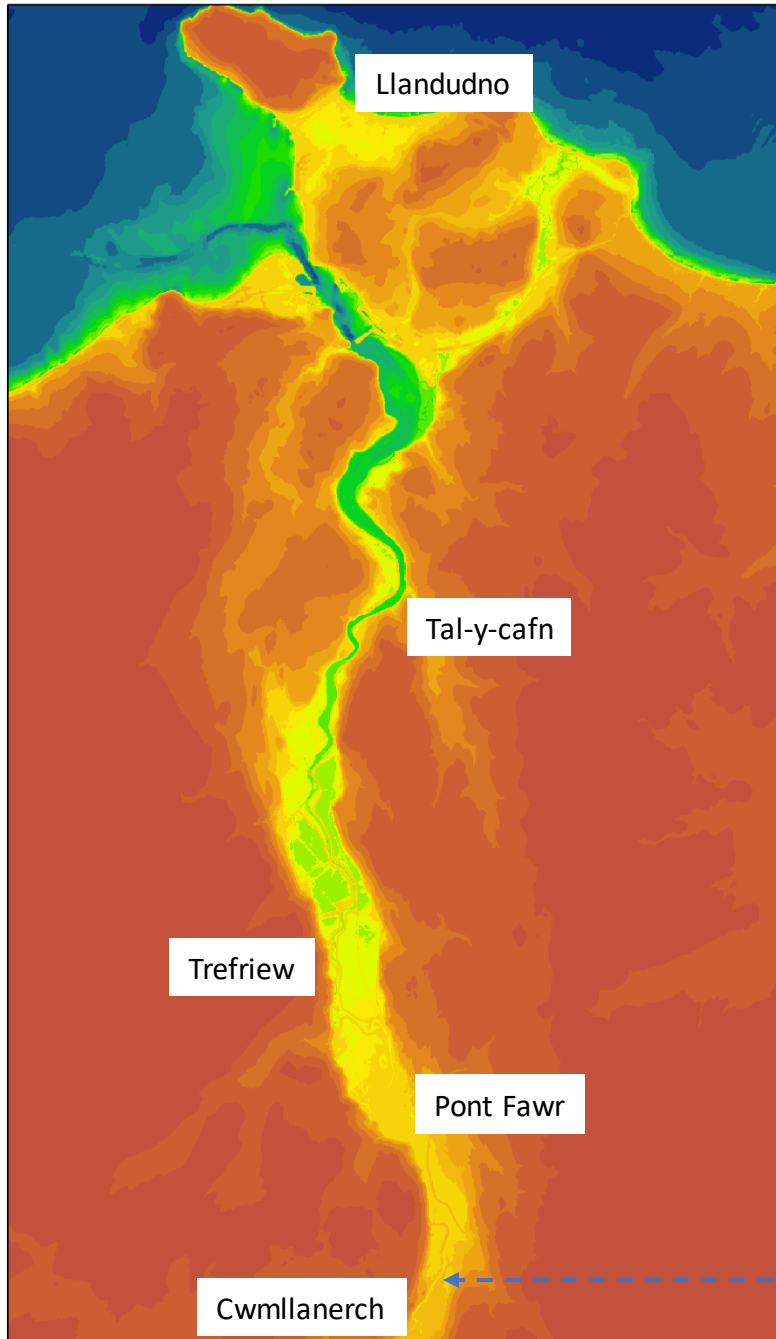
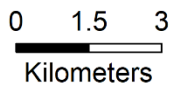
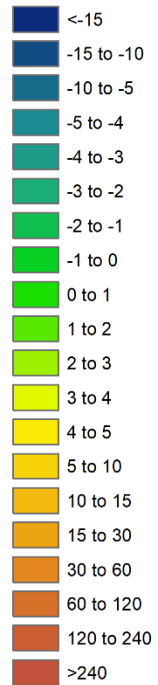
# Can we establish the drivers of flooding and flood thresholds?



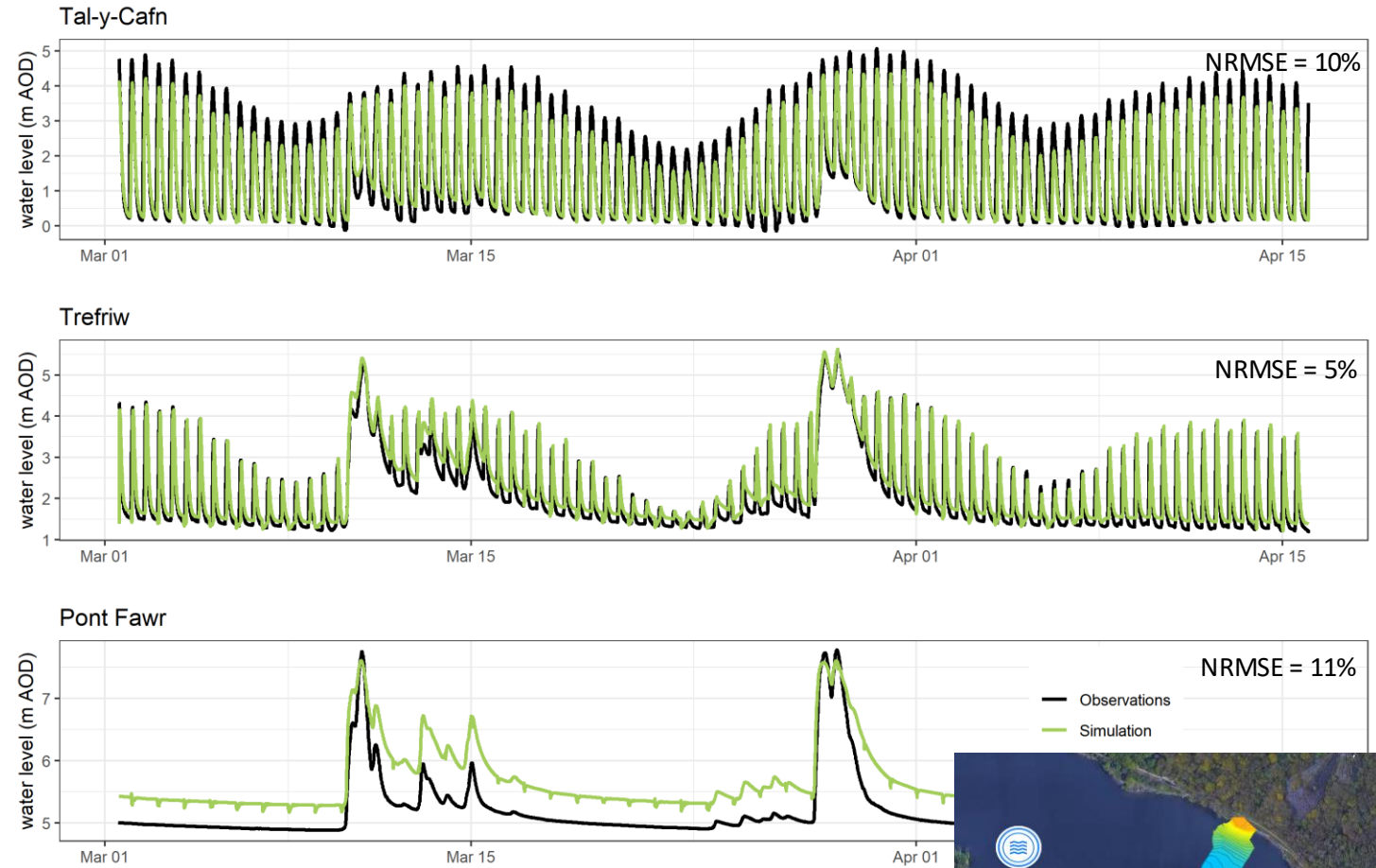
(NRW: <http://lle.gov.wales/>)



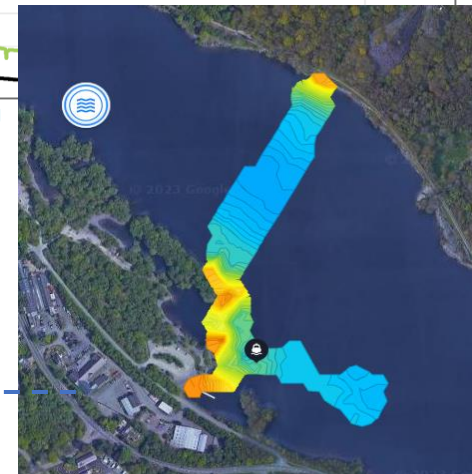
Elevation (m)



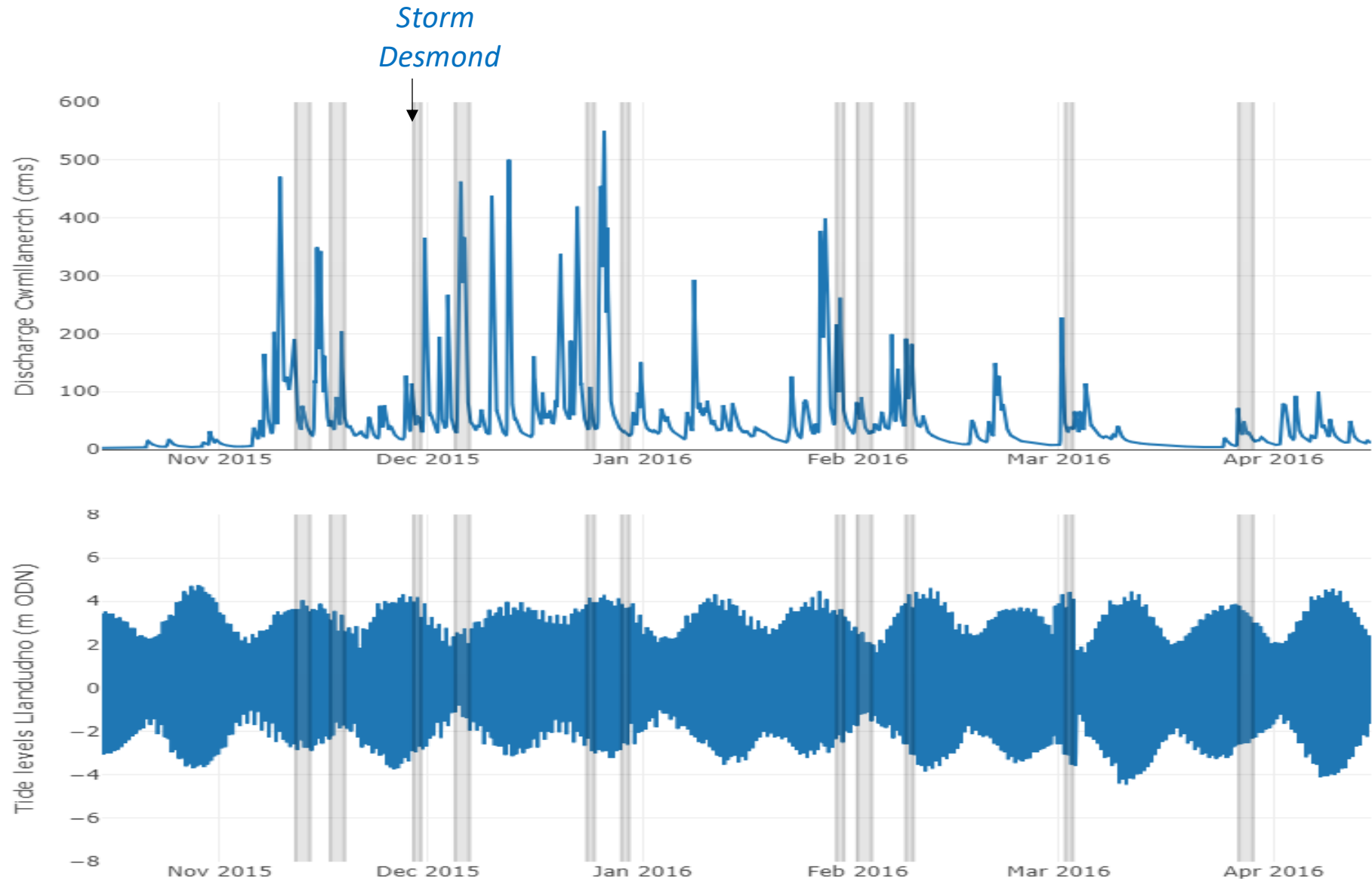
### Model calibration against 2021 observations



*NRW recently updated Q flow rating...*

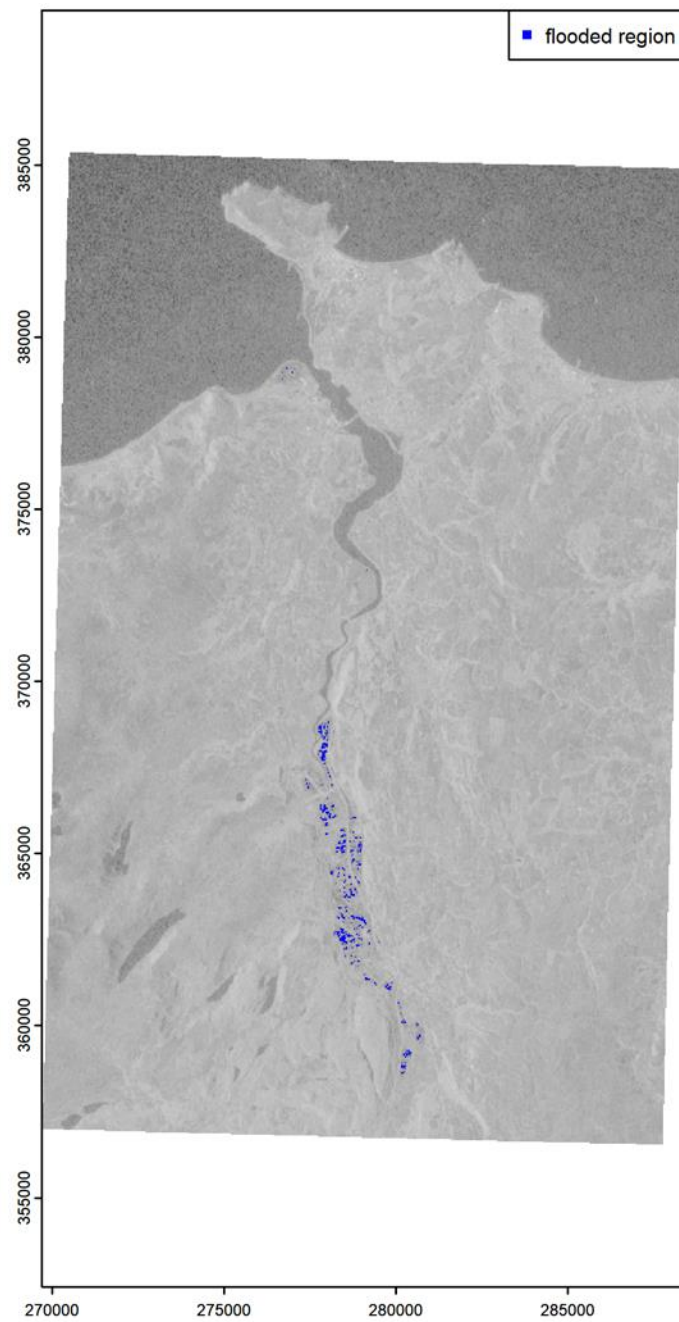


# Flood validation against 2015-2016 data

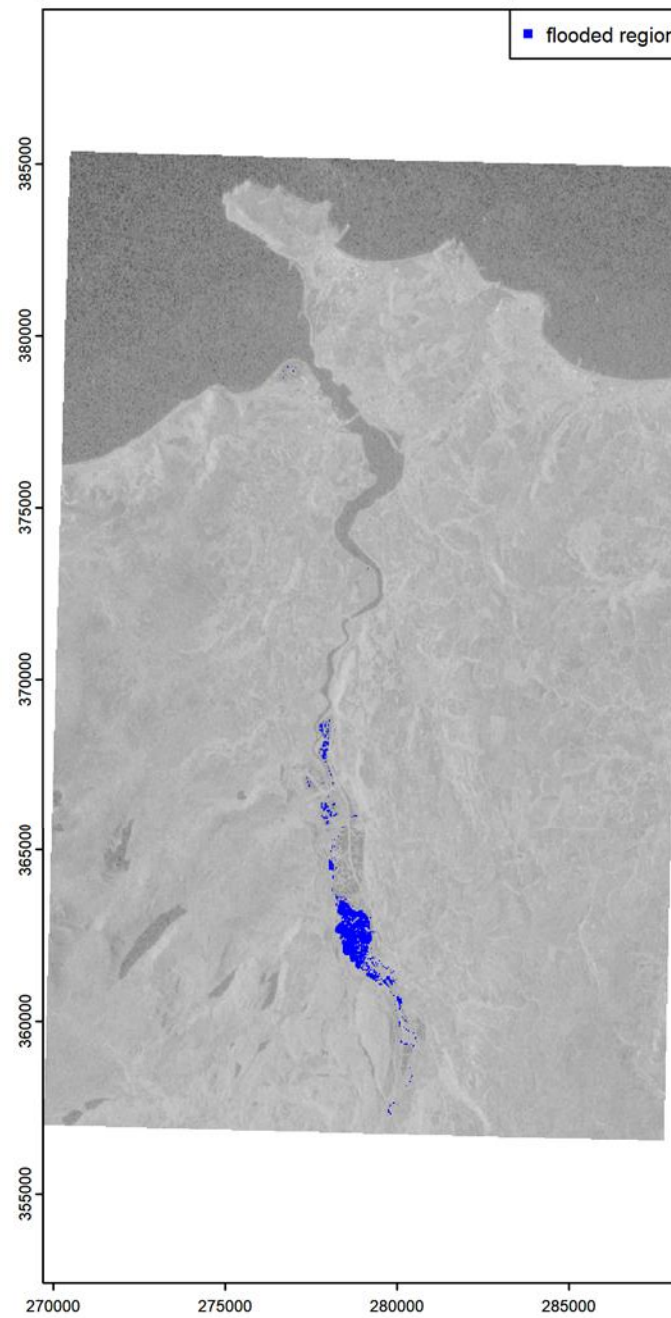


06/12/2015

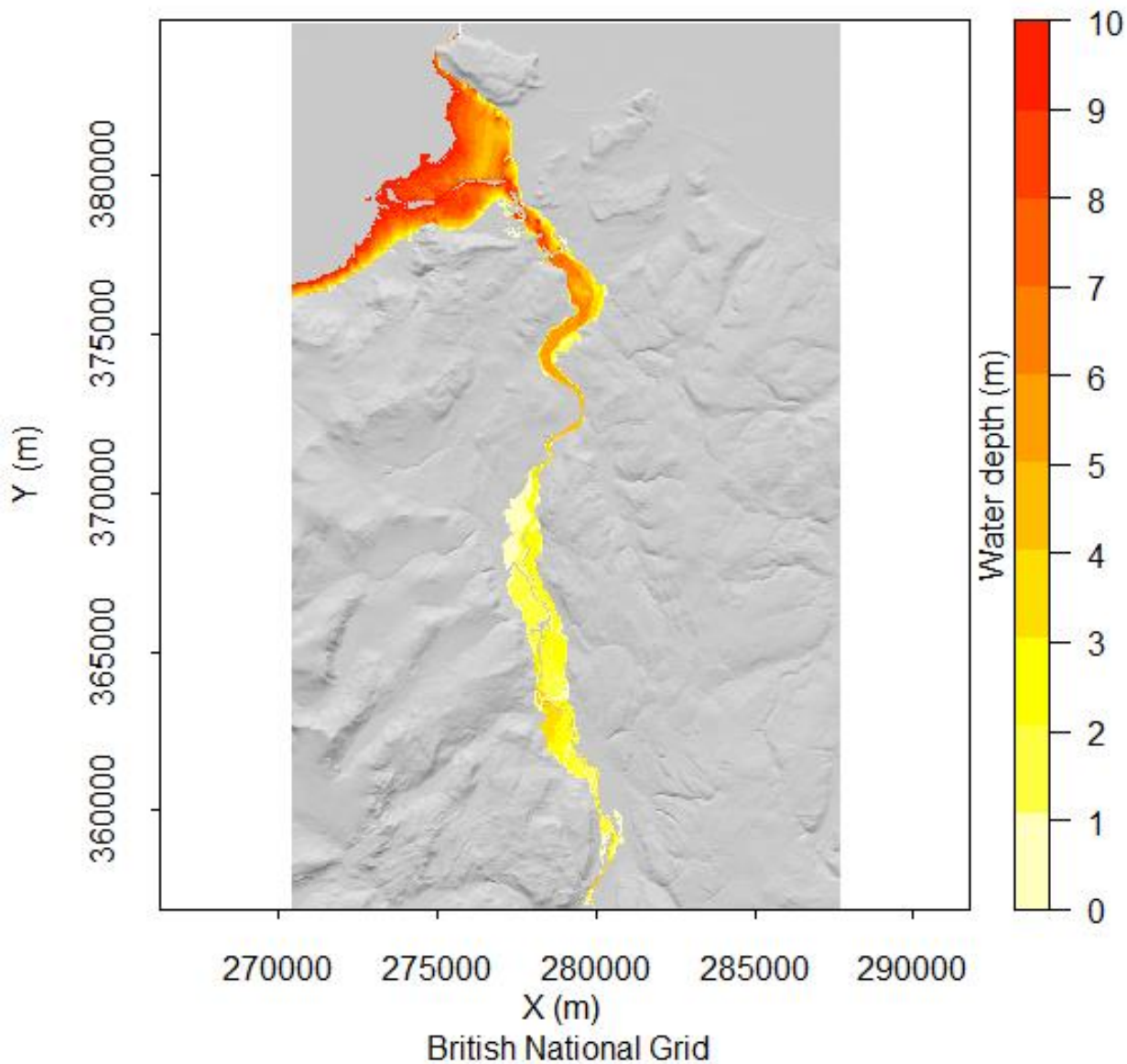
SAR-derived flooding



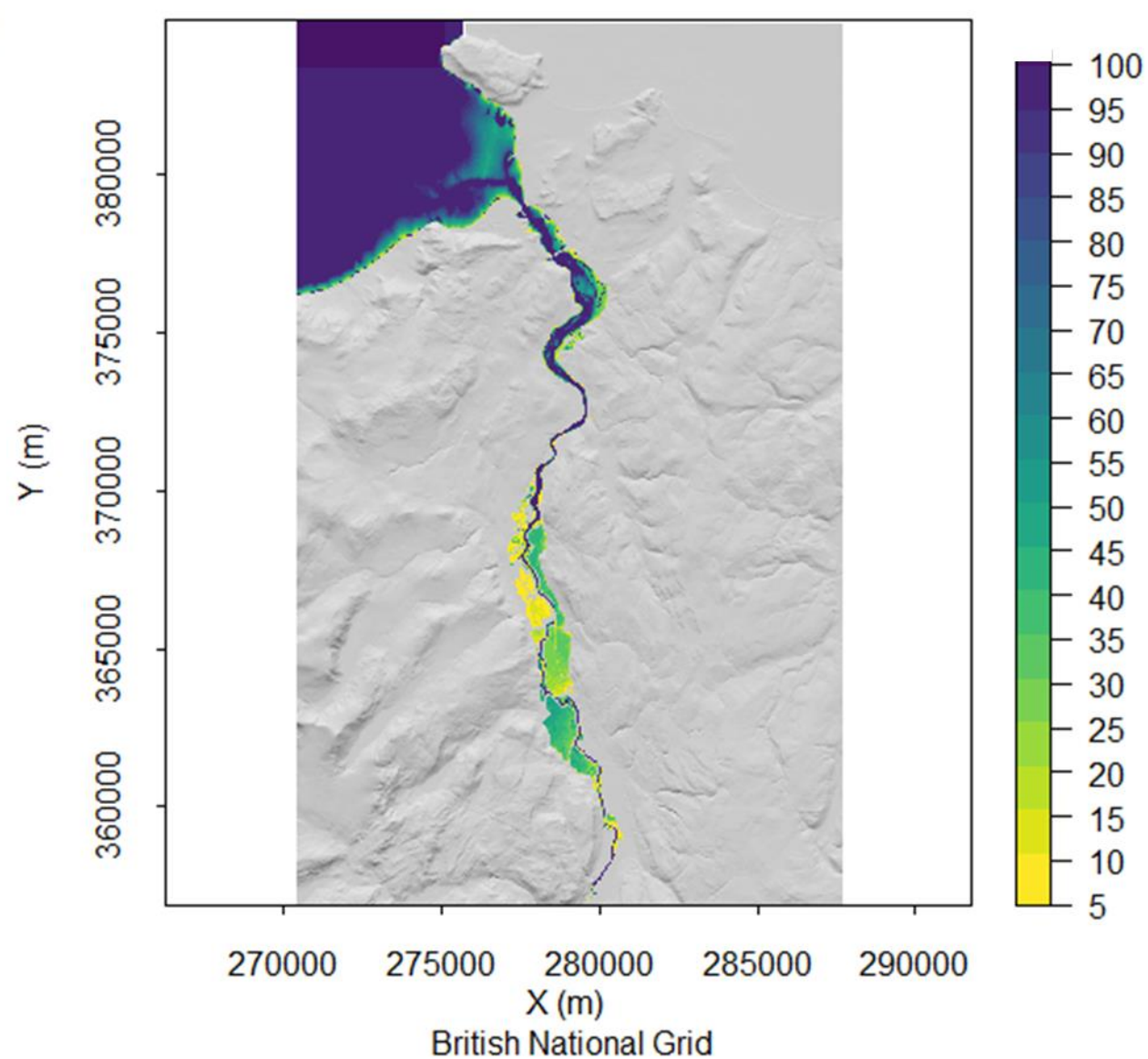
Model prediction



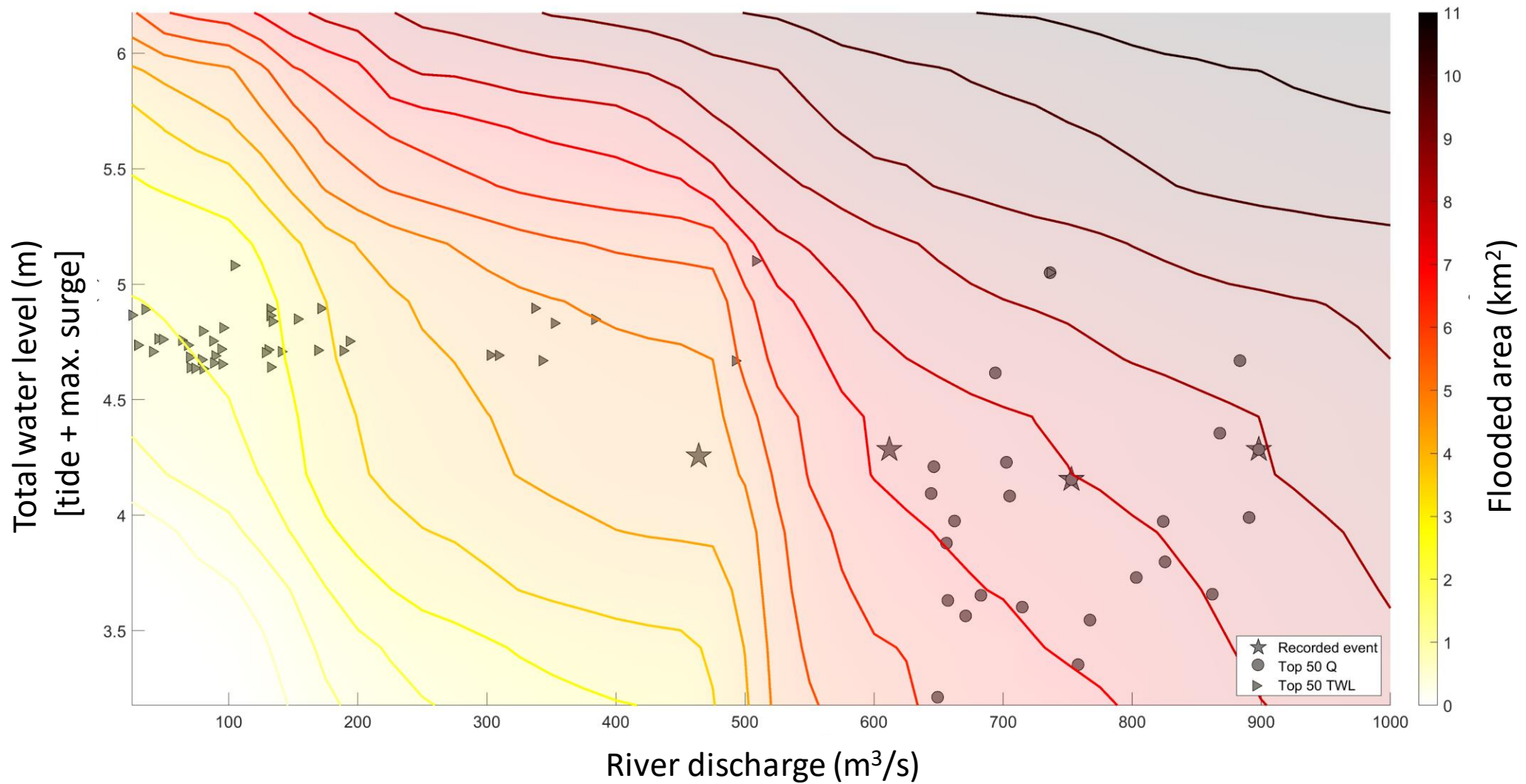
### Conwy - maximum water depths



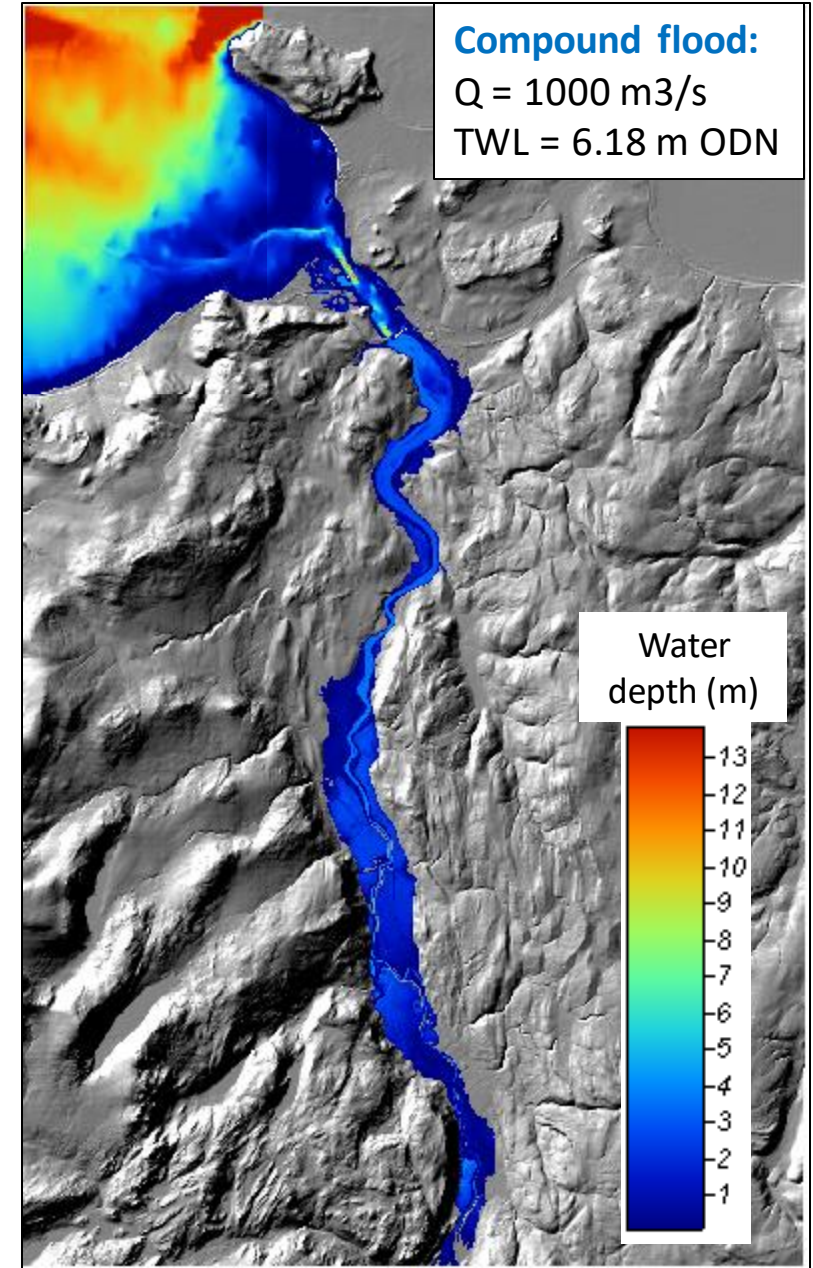
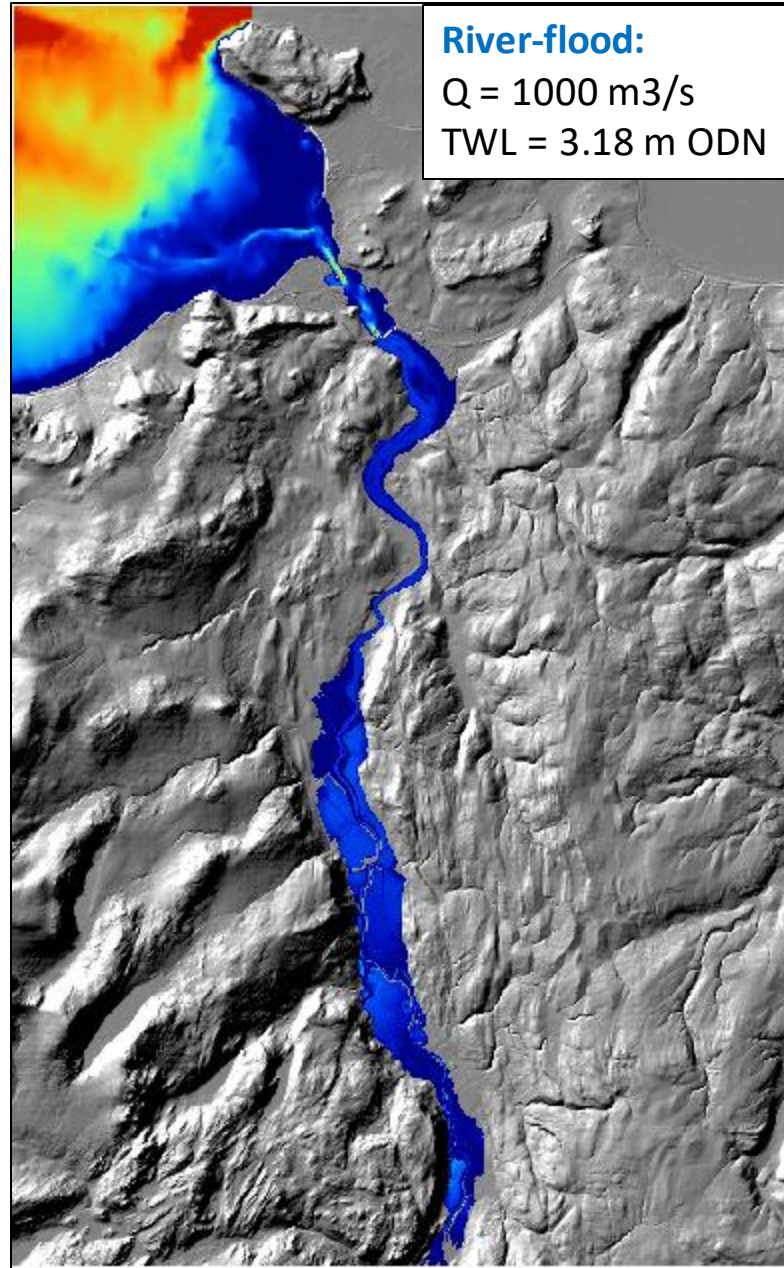
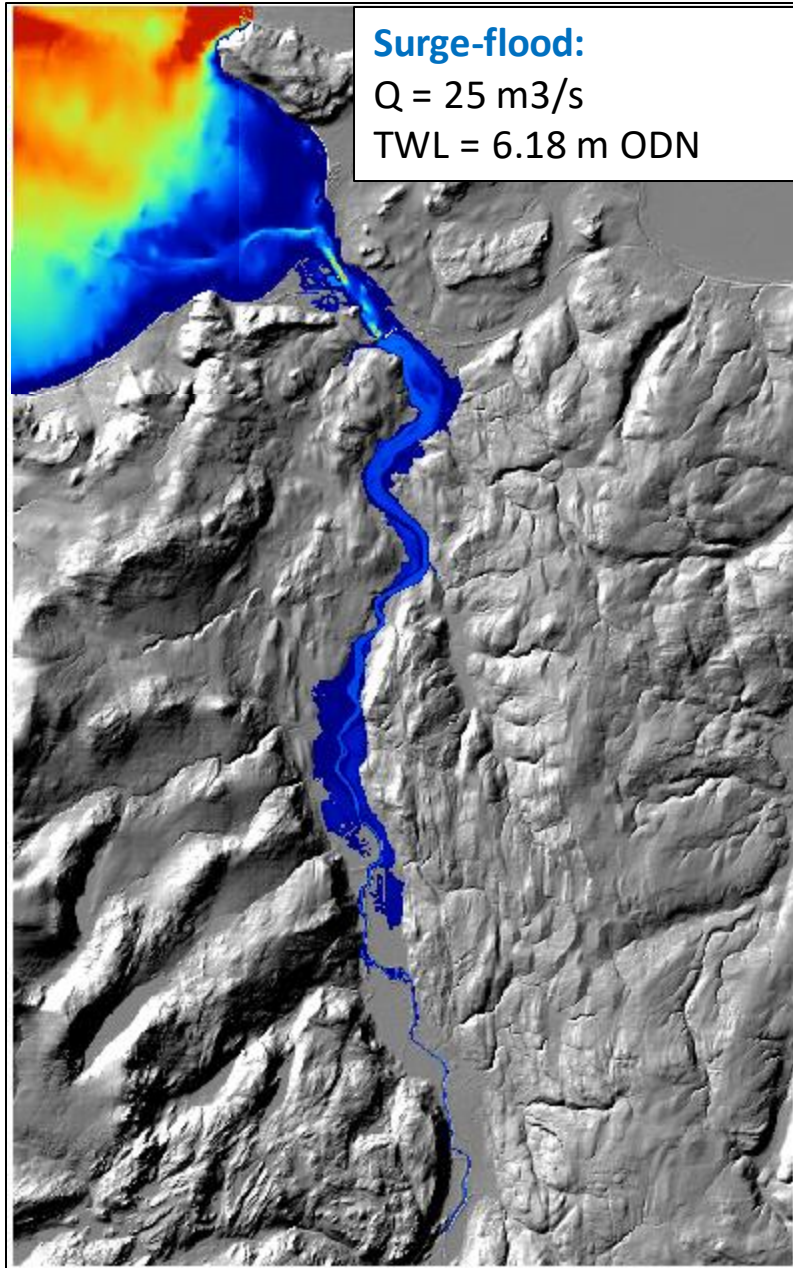
### Conwy - flood probability



# Can we establish the drivers of flooding and flood thresholds?



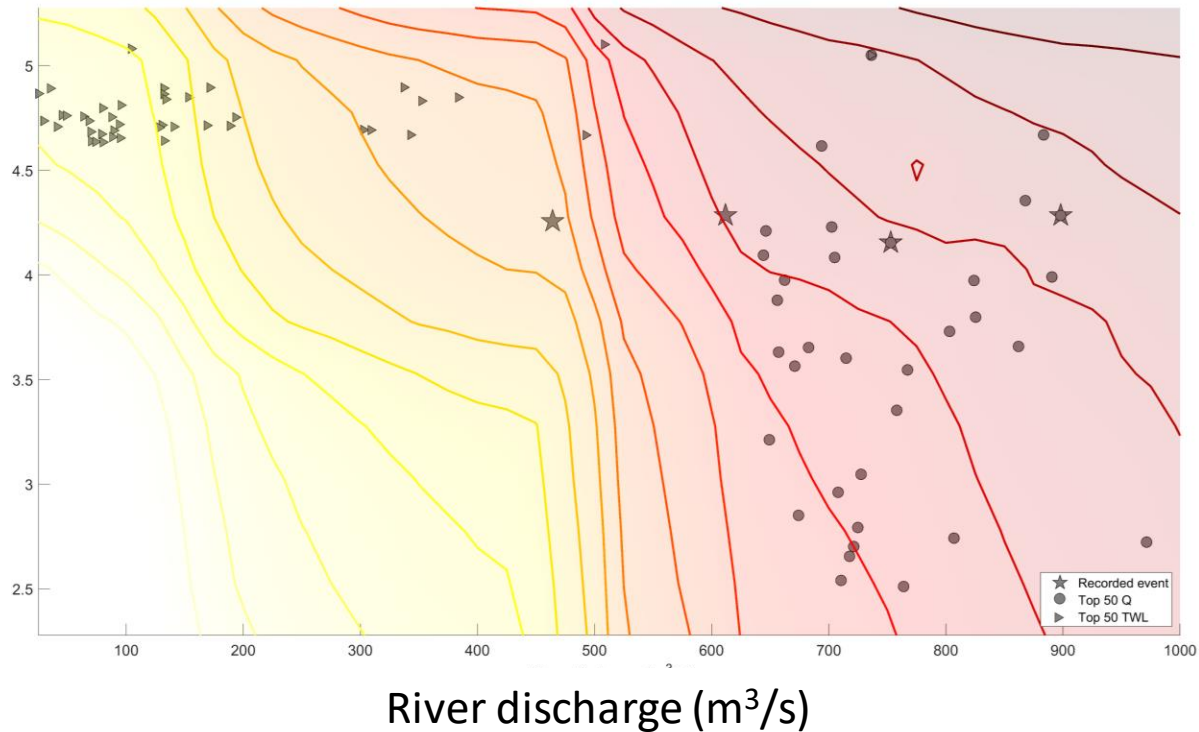
## Can we establish the drivers of flooding and flood thresholds?





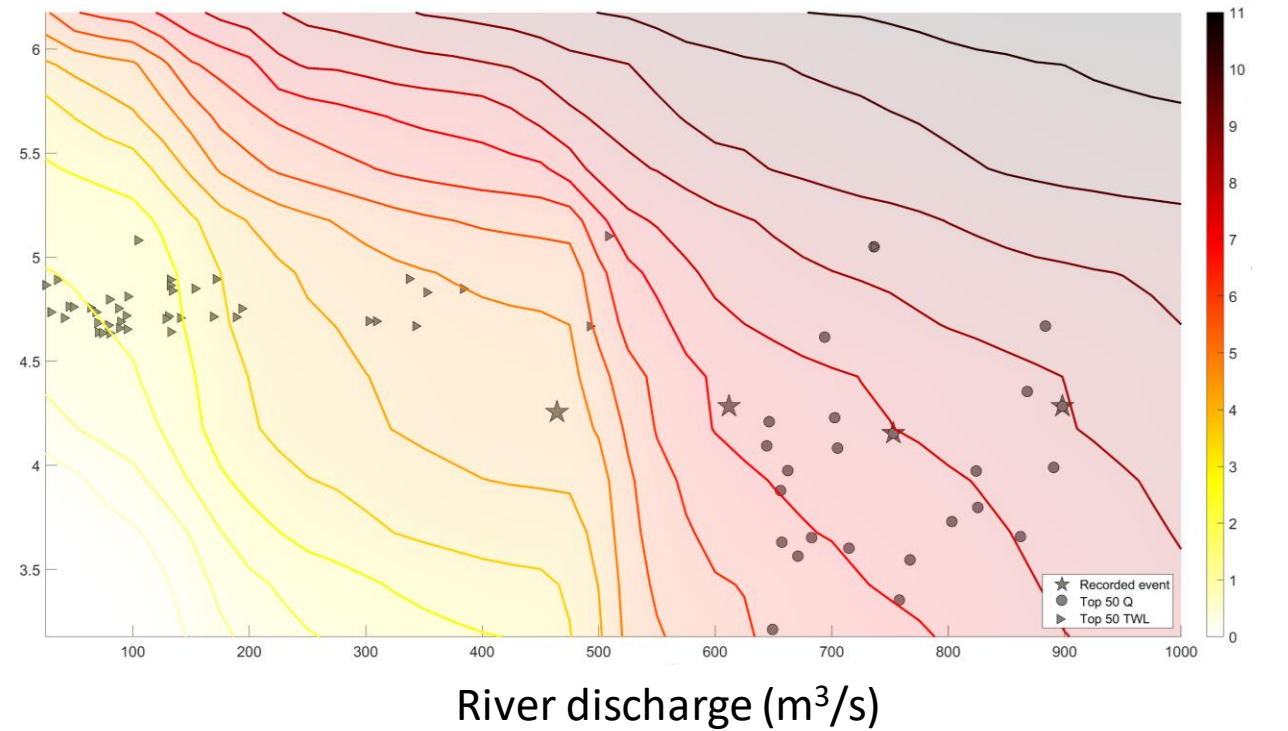
# Can we establish the drivers of flooding and flood thresholds?

Total water level (m) [tide + min. surge]



Total water level (m) [tide + max. surge]

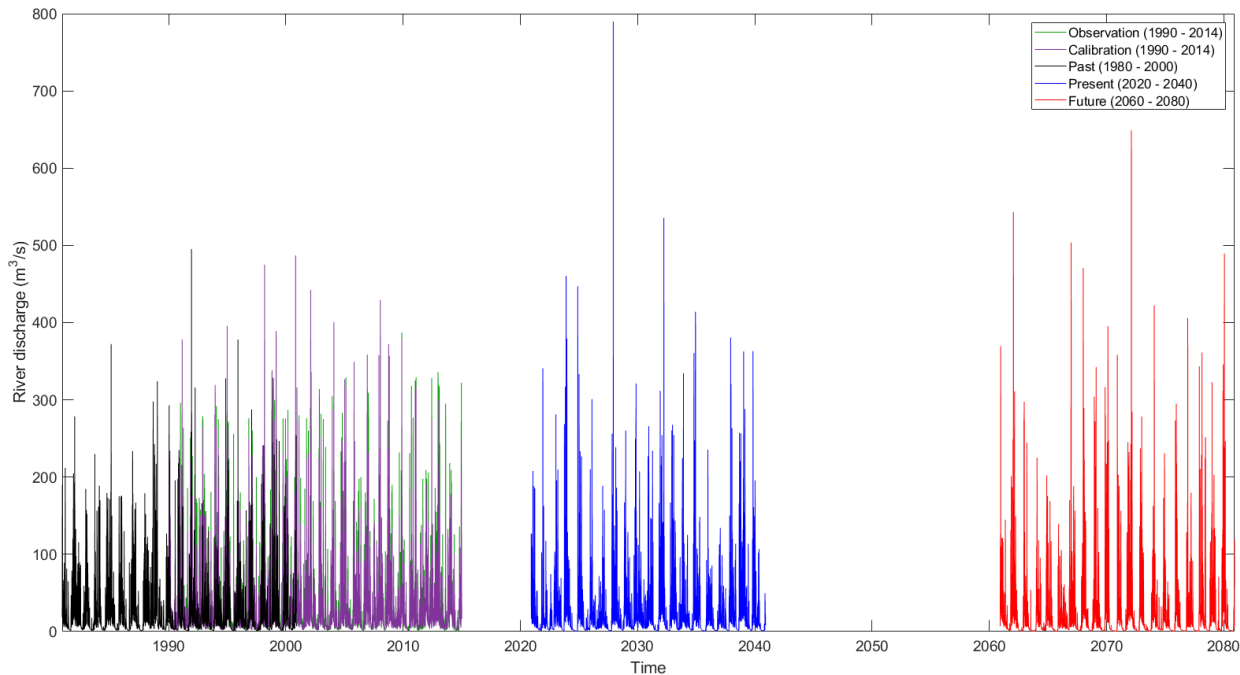
Flooded area (km²)



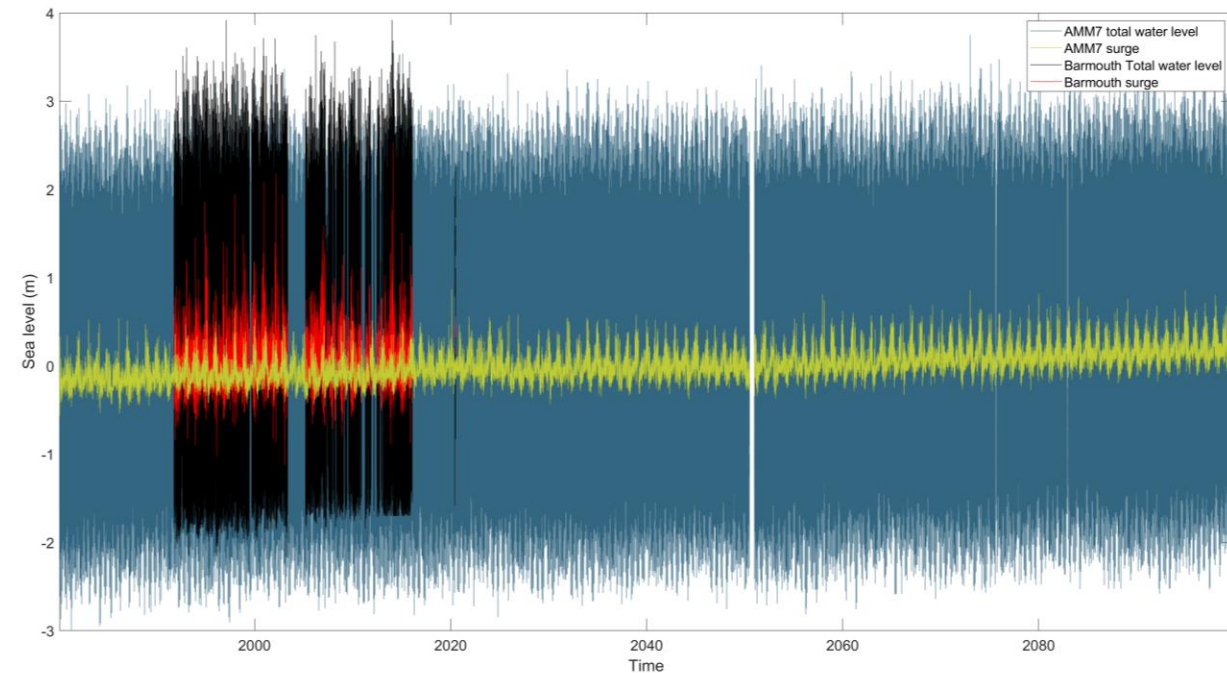
*Tide – river lag?.....*  
*Surge shape?....*  
*Clustered events?....*

## Is compound flooding likely to change?

- 12 of the 60 km HadGEM3-GC3.0 GCM PPE for RCP8.5 were downscaled to a 2.2 km local Convection Permitting Model.
- Rainfall data were used to force a distributed hydrological model (DECIPHeR) of the **Dyfi Estuary**, (Coxon et al. 2019).
- 10,000 calibration runs forced with observed rain and evap. to simulate hourly discharge. 100 best parameter sets were used with UKCP18 data to simulate baseline, near and far future discharge.



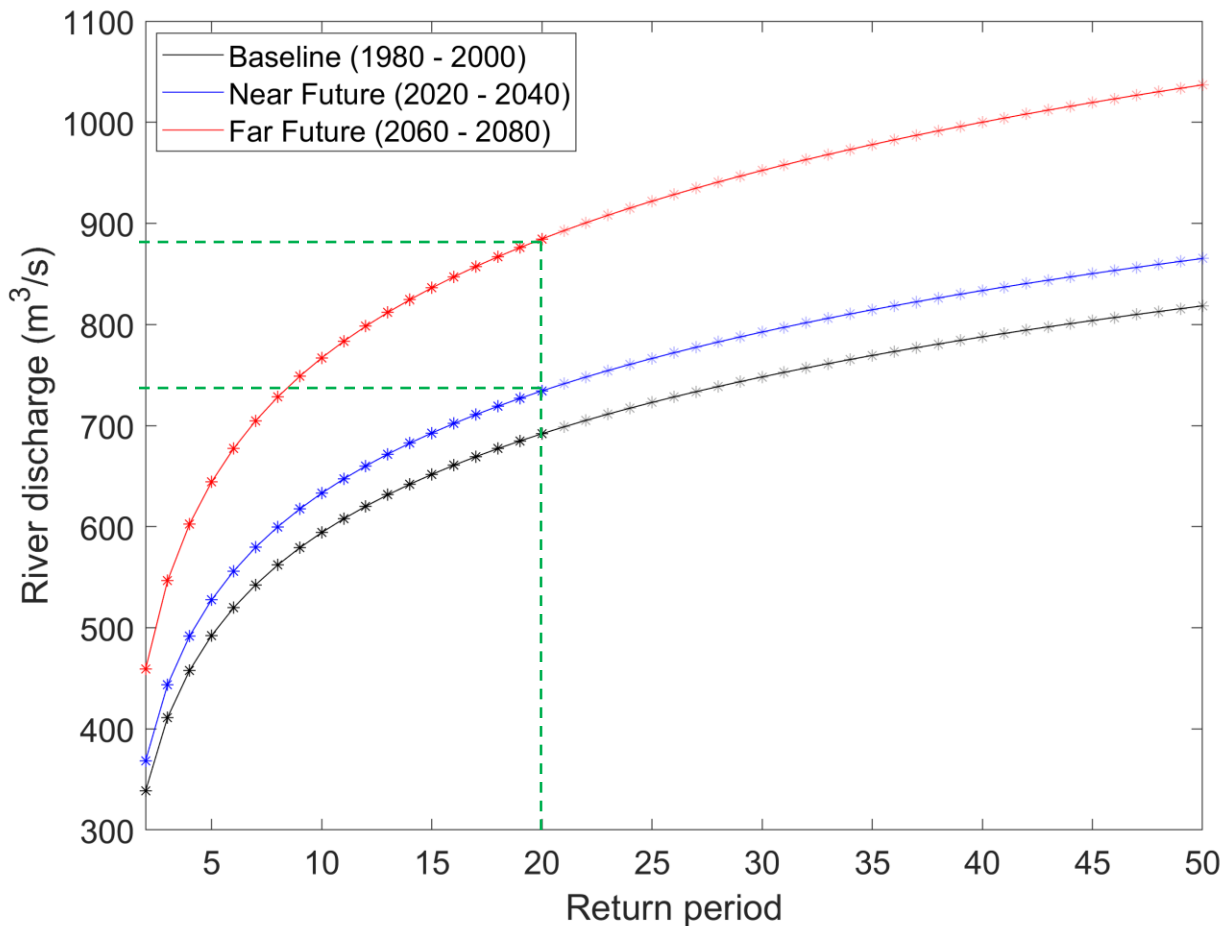
- 12 of the 60 km HadGEM3-GC3.0 GCM PPE for RCP8.5 were applied to 12km regional climate simulations.
- These were used to drive the regional 7 km NEMO AMM7 (1980 – 2080).
- Model simulations are de-tided using a Doodson filter to generate a residual surge .



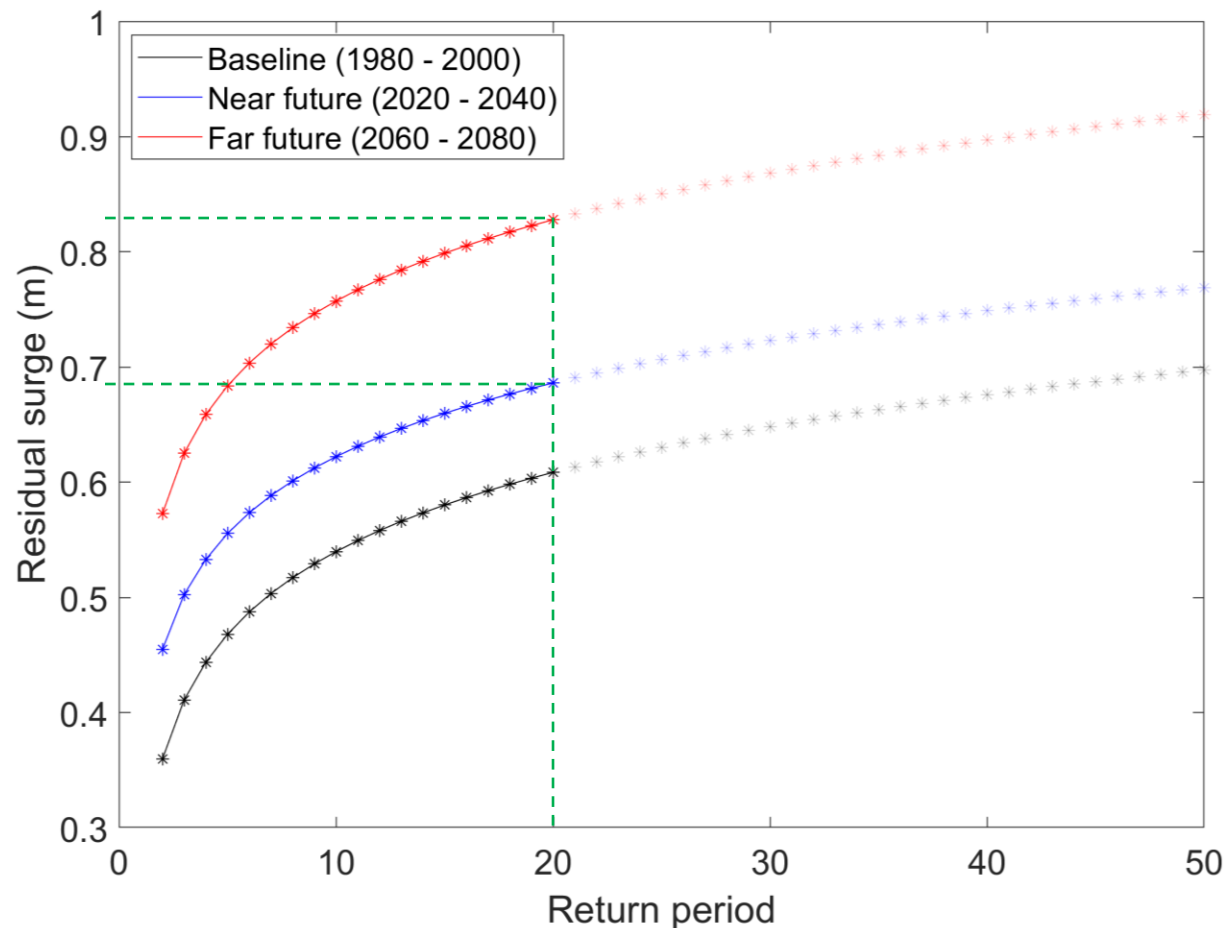
# Is compound flooding likely to change? – return periods

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## Dyfi - River discharge



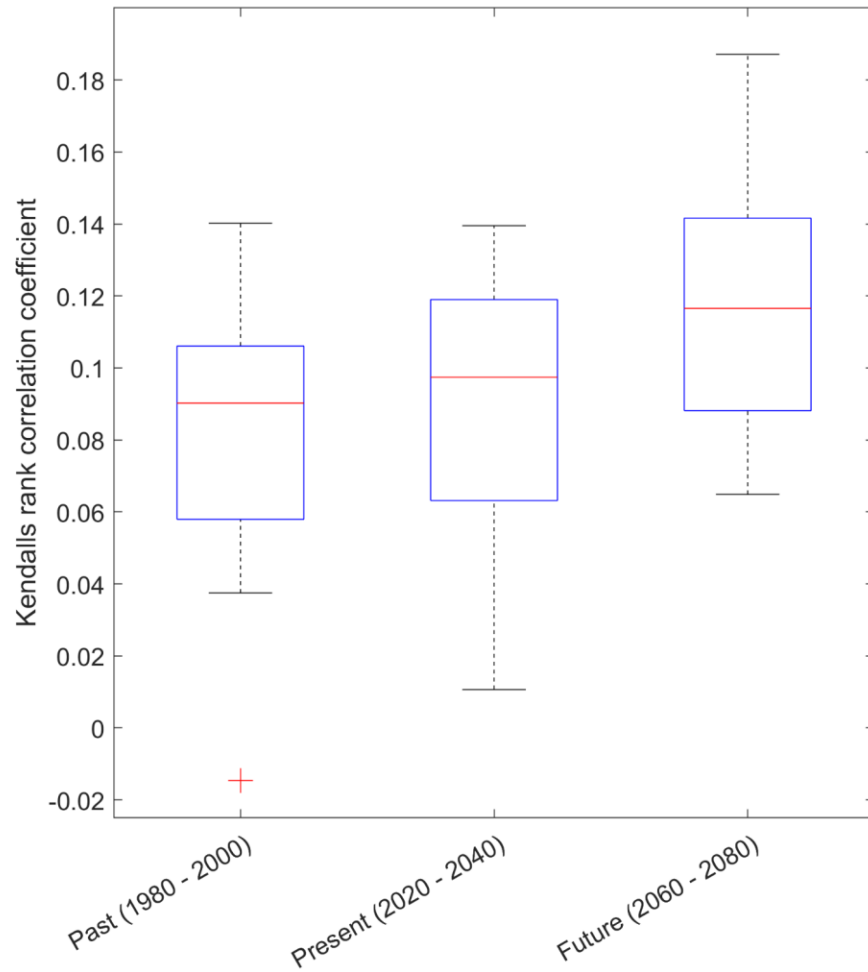
## Dyfi - Sea level



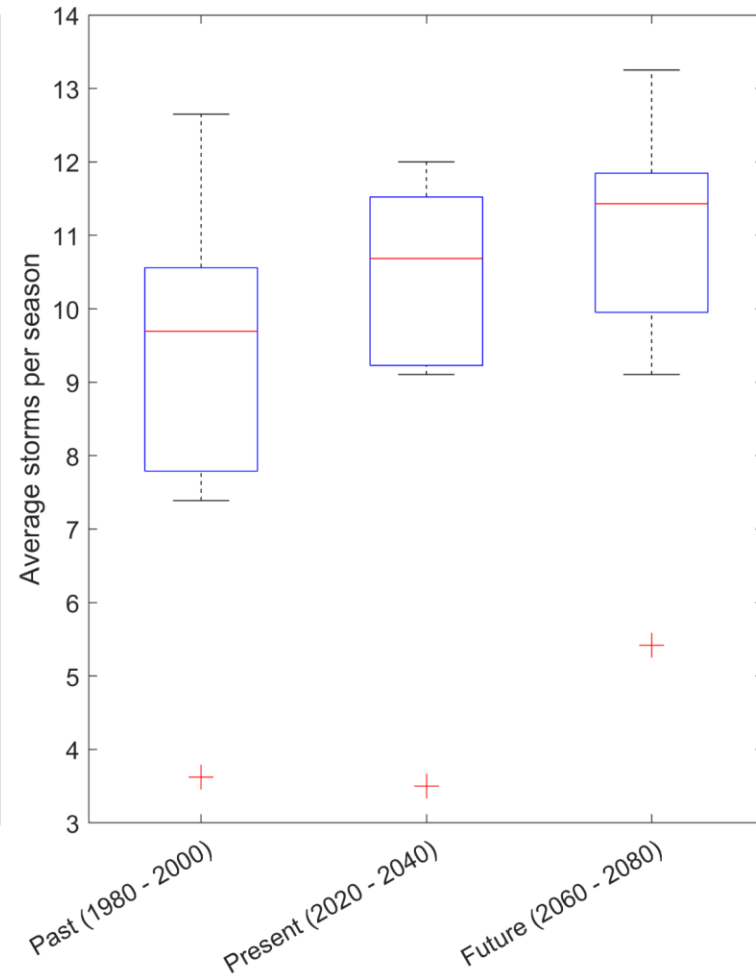
# Is compound flooding likely to change? – future changes in compound events

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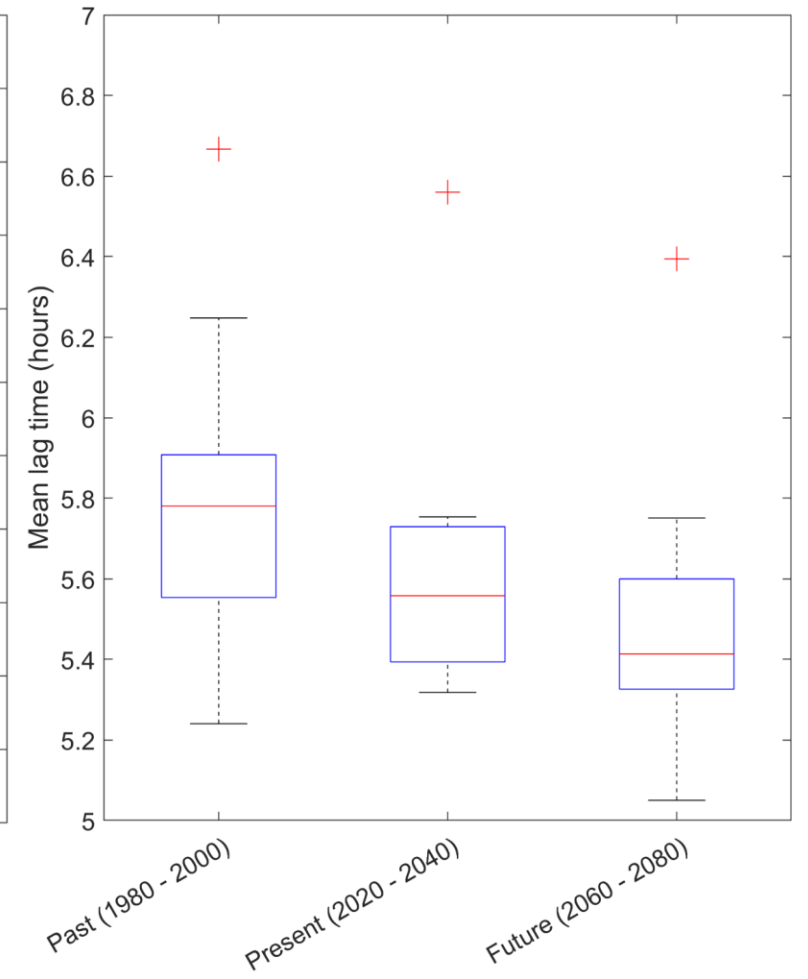
## Dependence



## Average number of compound events



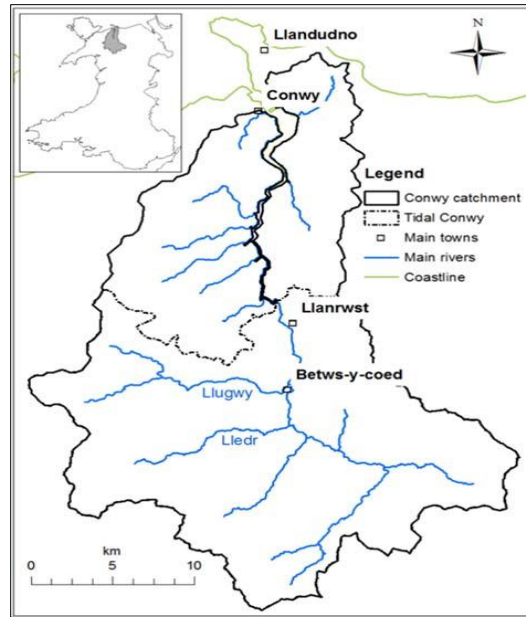
## Lag time



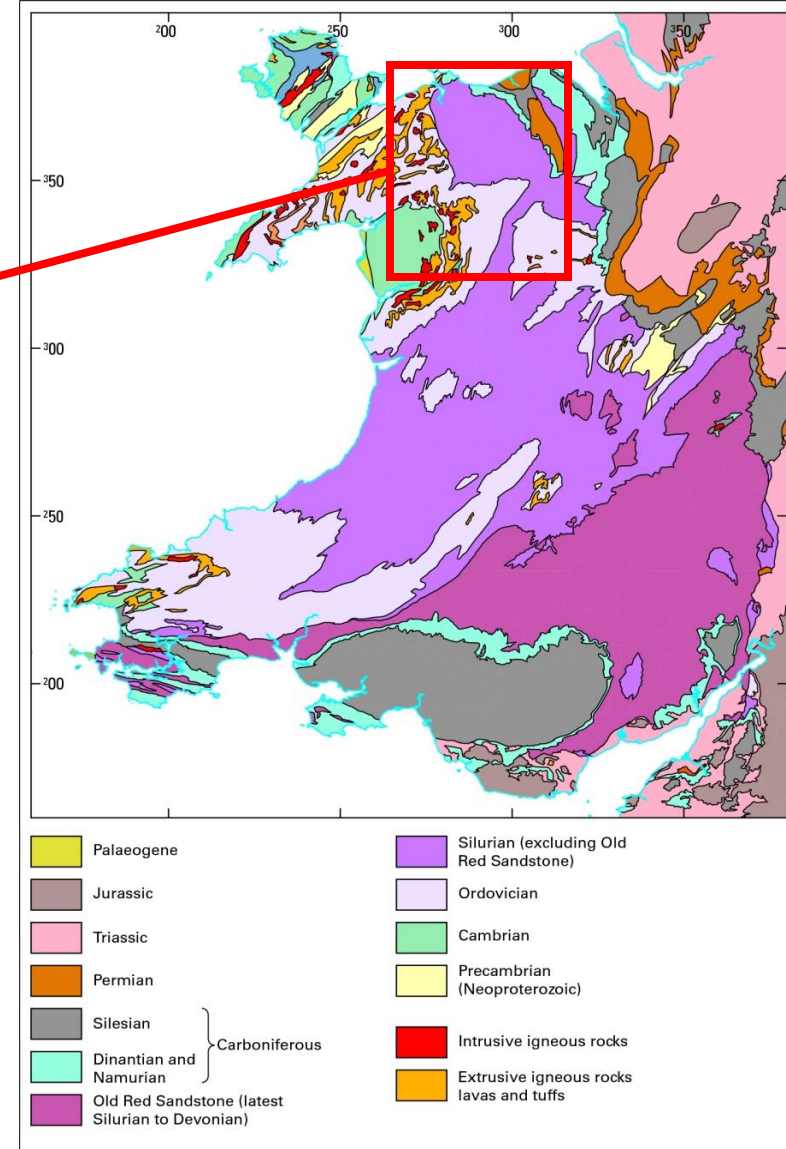
# Potential groundwater impacts



**Envision**  
Developing next generation  
leaders in environmental science



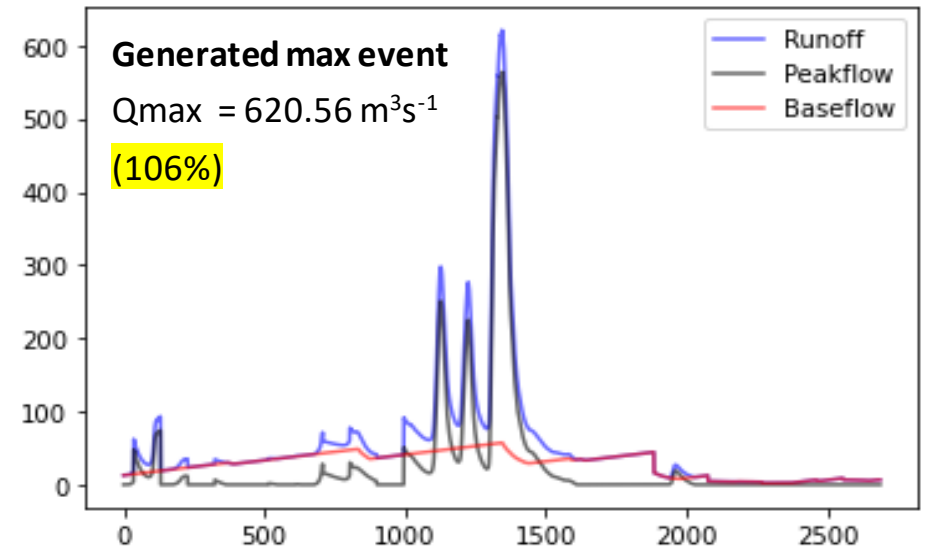
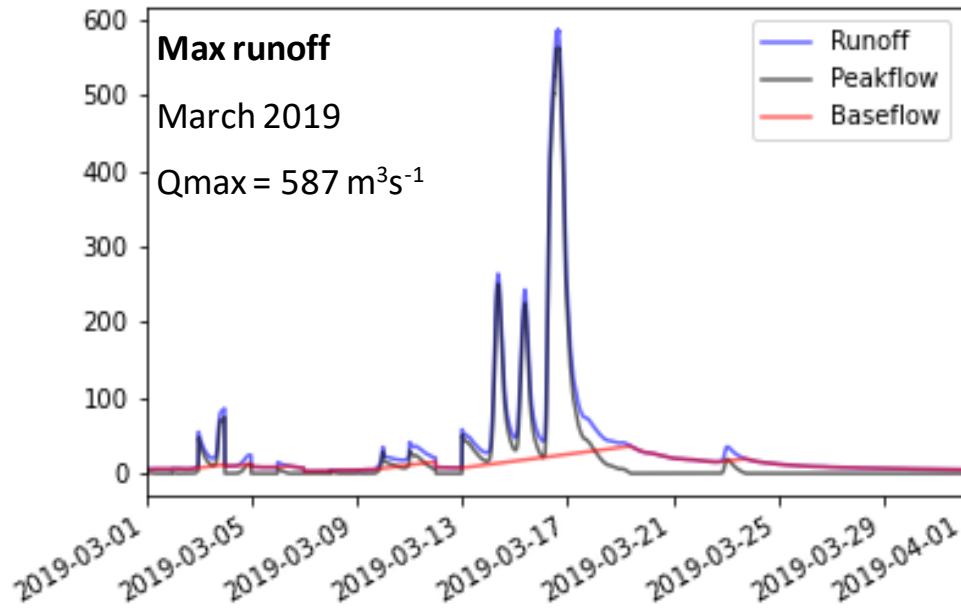
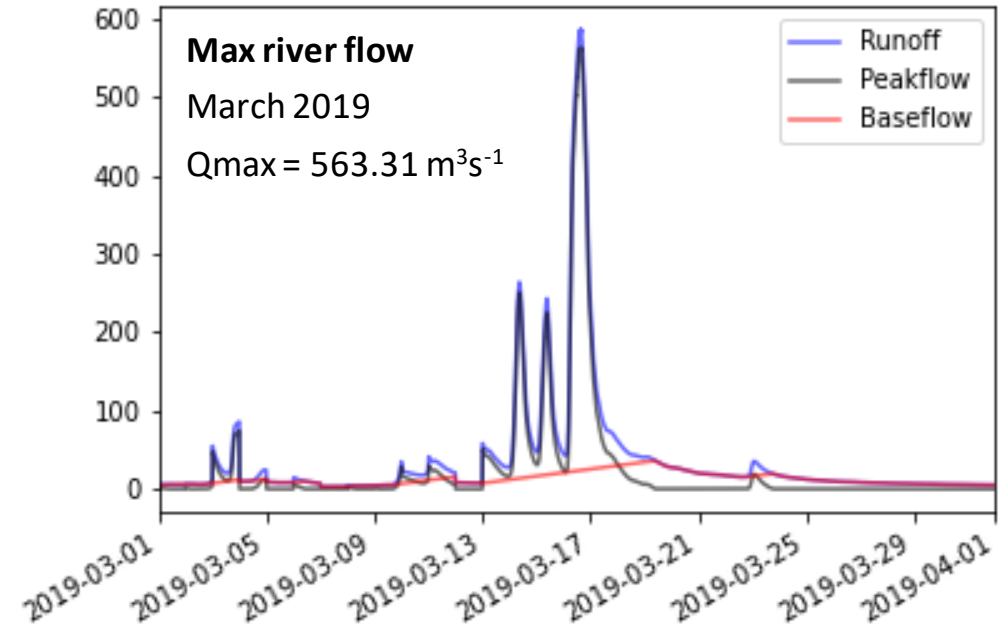
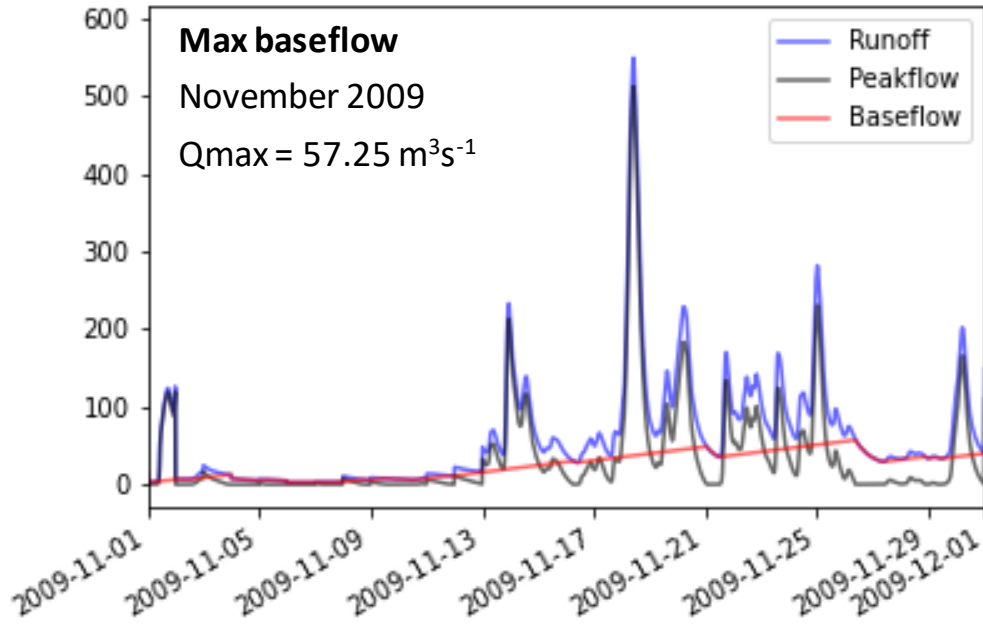
Conwy Catchment Area



Geological Map of Wales  
Source- BGS

Properties	Conwy
Catchment Area	345 km <sup>2</sup>
Rainfall (50 years average)	3700mm
Base Flow Index	0.27
Geology	Thick sequence of mudstones
Permeability of Bed Rock	Very low
Superficial deposits	Clay, Alluvium, Till
Groundwater potential of superficial deposits	Moderate
Aquifer systems	Groundwater occurs within shallow weakly permeable aquifers

# Peak baseflow, runoff and river flow events (1990-2020)



# Summary

## Historic compound event analysis:

- First sub-daily compound flooding analyses ([Lyddon et al. 2022](#)).

## Inundation modelling:

- Estuary DEMs built at 20-50m res for 13 estuaries (not Thames).
- Full catchment DEMS built for Clyde, Conwy, Dyfi, Humber).
- CAESAR-Lisflood inundation models running for all estuaries.
- CL-groundwater model developed for Dyfi, Conwy, Clyde.
- New method for validation of flooding events (Conwy, Dyfi), [paper in-prep](#)
  - New sea-level sensors, Satellite SAR images, inundation records, news articles
- Established tipping points and probabilities of flood drivers in Conwy, Dyfi, Humber ([Harrison et al. 2021](#); [Robins et al. 2022](#))
  - Working on joint-probabilities...

EIDC

## Climate change:

- Collated sea-level and river flow projections downscaled from HadGEM3-GC3.0
- Produced future return periods and compound event analysis ([paper in-prep](#))

