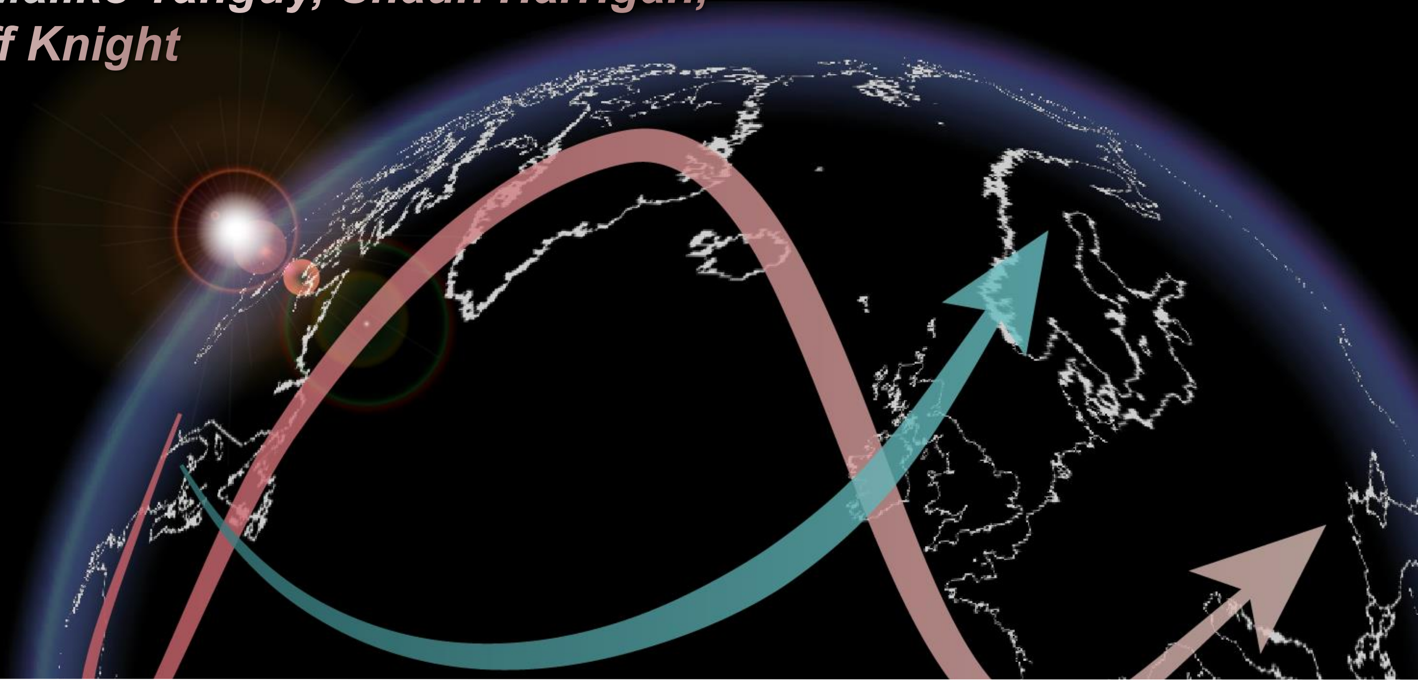
Using the North Atlantic Oscillation to Improve UK Winter Streamflow Forecasts

Katie Facer-Childs (née Smith), Nicky Stringer, Michael Eastman, Maliko Tanguy, Shaun Harrigan, Simon Dadson, Jeff Knight



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Met Office Hadley Centre

ECMWF

Hydro-JULES

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Overview

- Introduction
- Streamflow Forecasting
- ESP Skill
- NAO and Streamflow
- NAO Forecasts
- Hindcast Results
- Case Studies
- Operationalising NAO
- ULYSSES Forecasts
- Next Steps

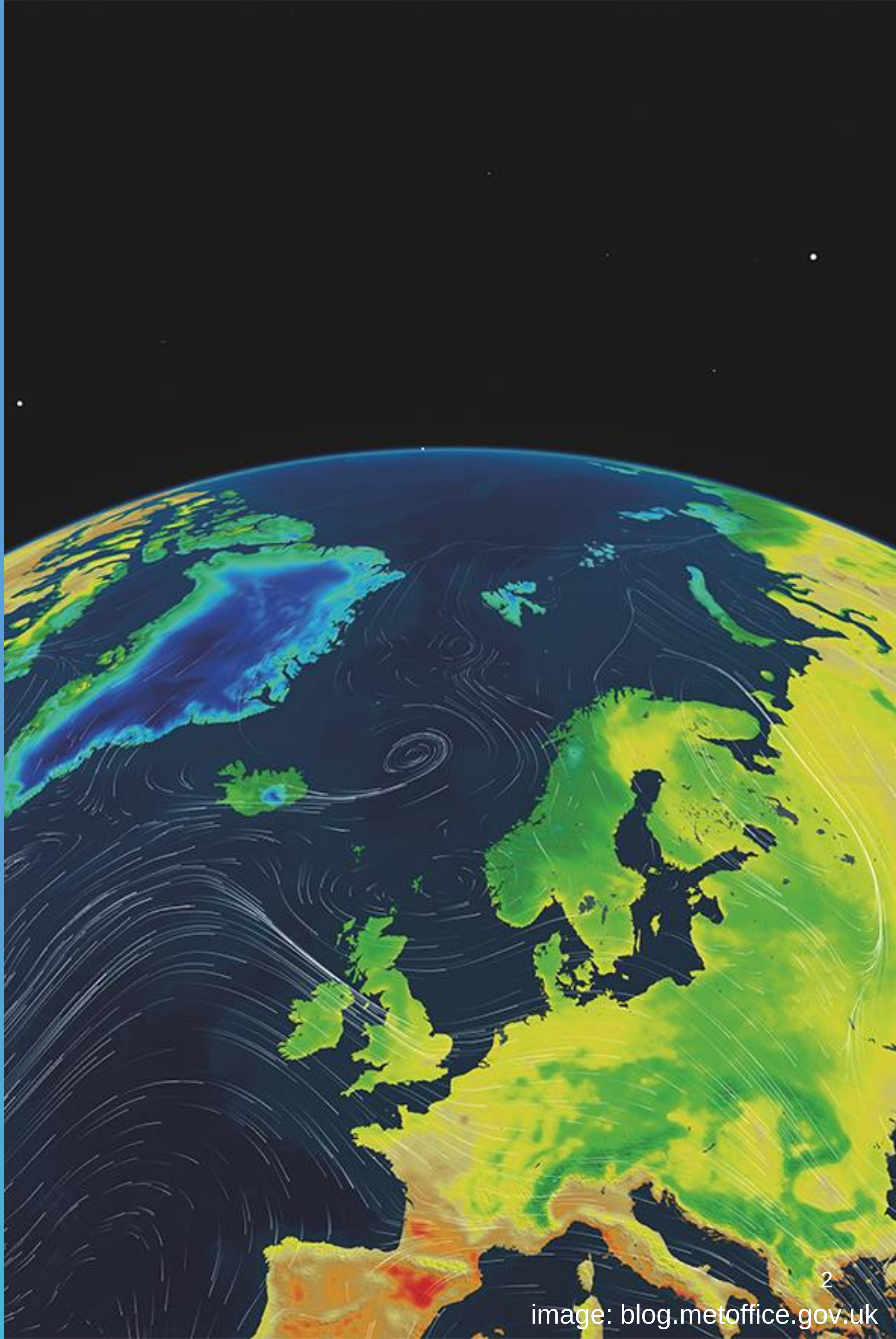


image: blog.metoffice.gov.uk

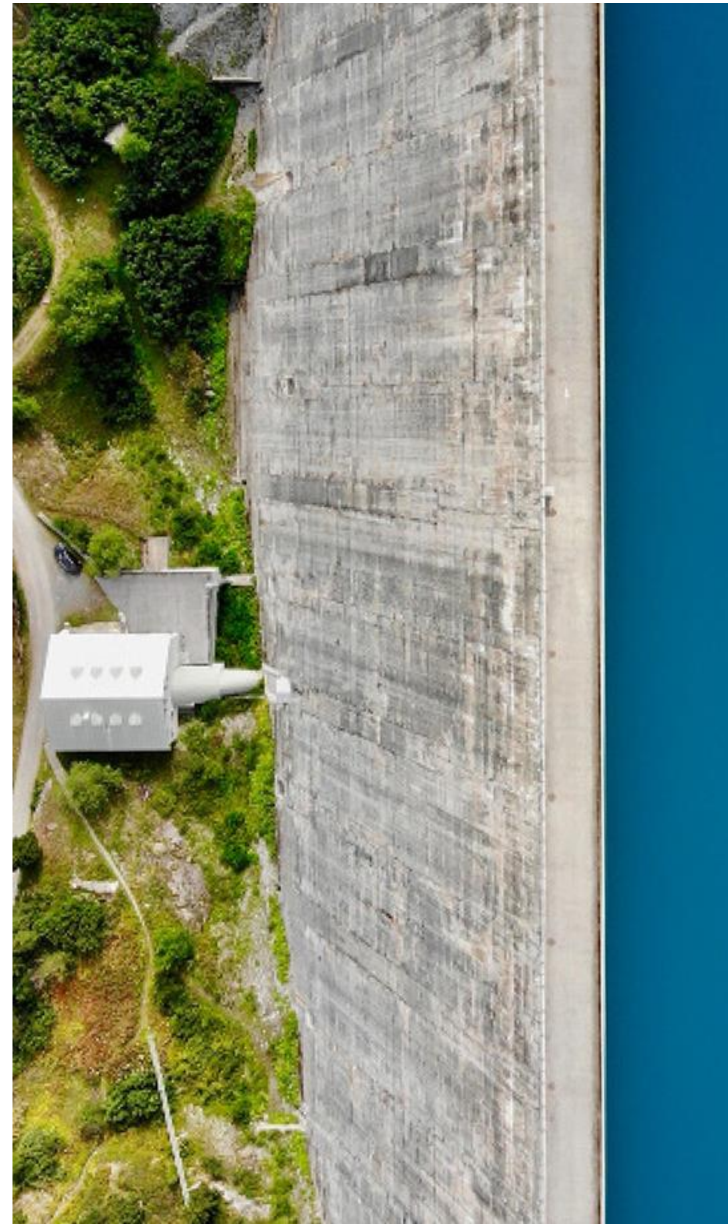
Why Forecast Seasonal Streamflow?

Water Resources Management

Flood Risk Management

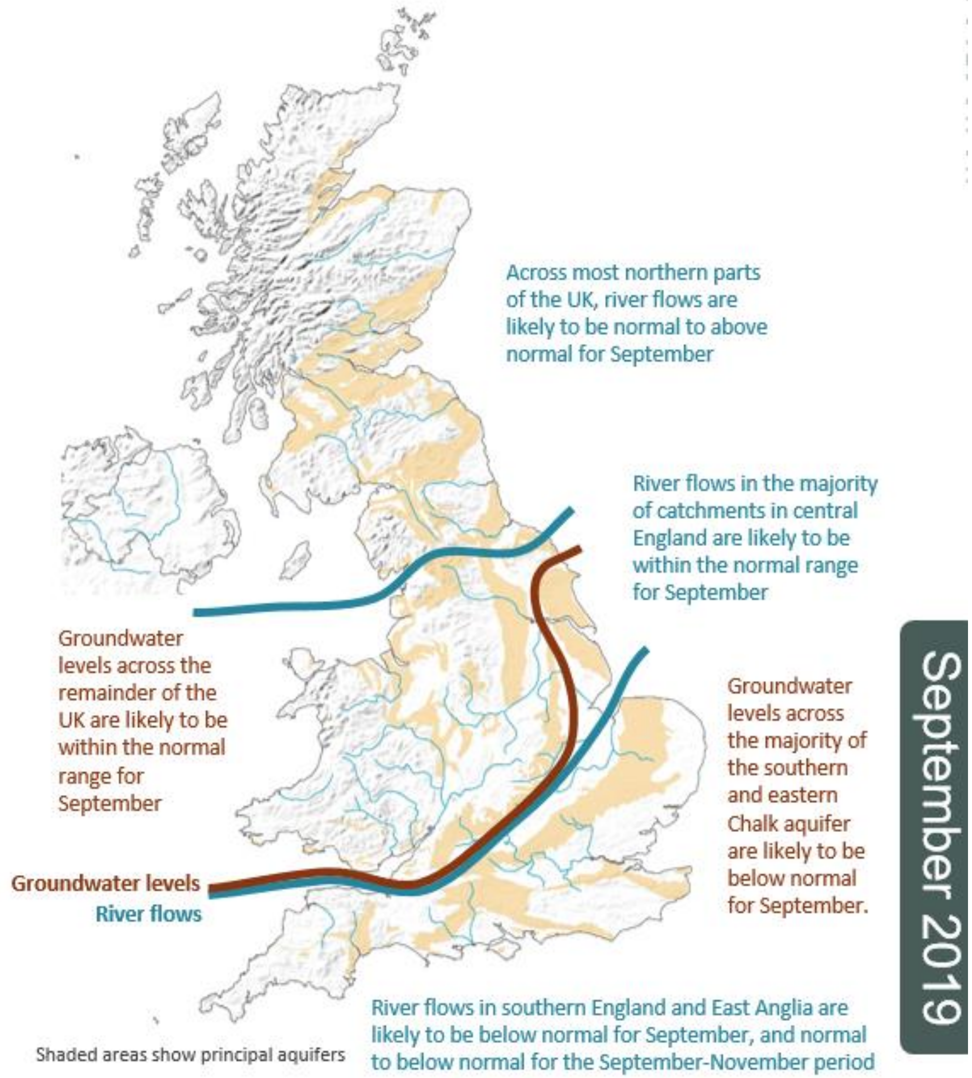
Agriculture

Recreation



Icons: Nikita Golubev; Freepik; dDara from Flaticon.com

- **Launched 2013**
- **3 methods**
  - Persistence & Analogues
  - Ensemble Streamflow Prediction
  - Gridded Dynamic Rainfall
- Ongoing research through NERC projects
  - IMPETUS
  - ENDOWS
  - Hydro-JULES

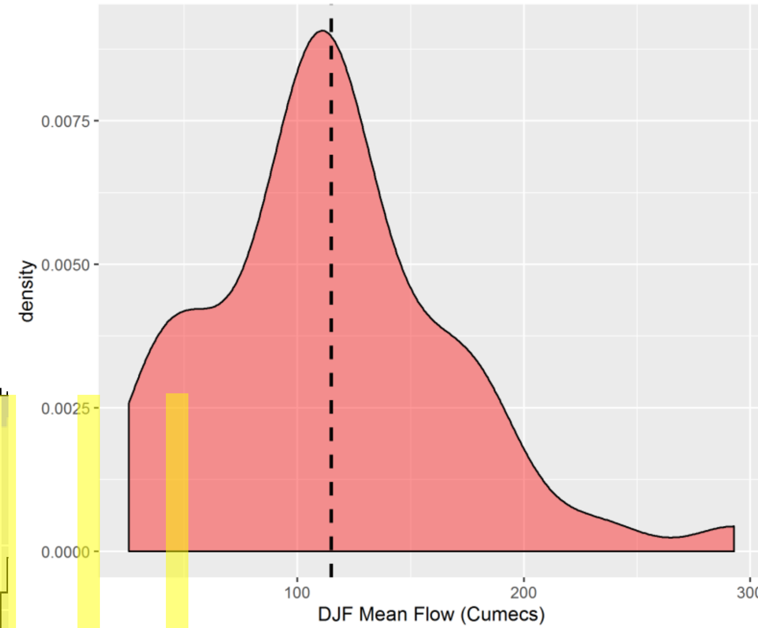


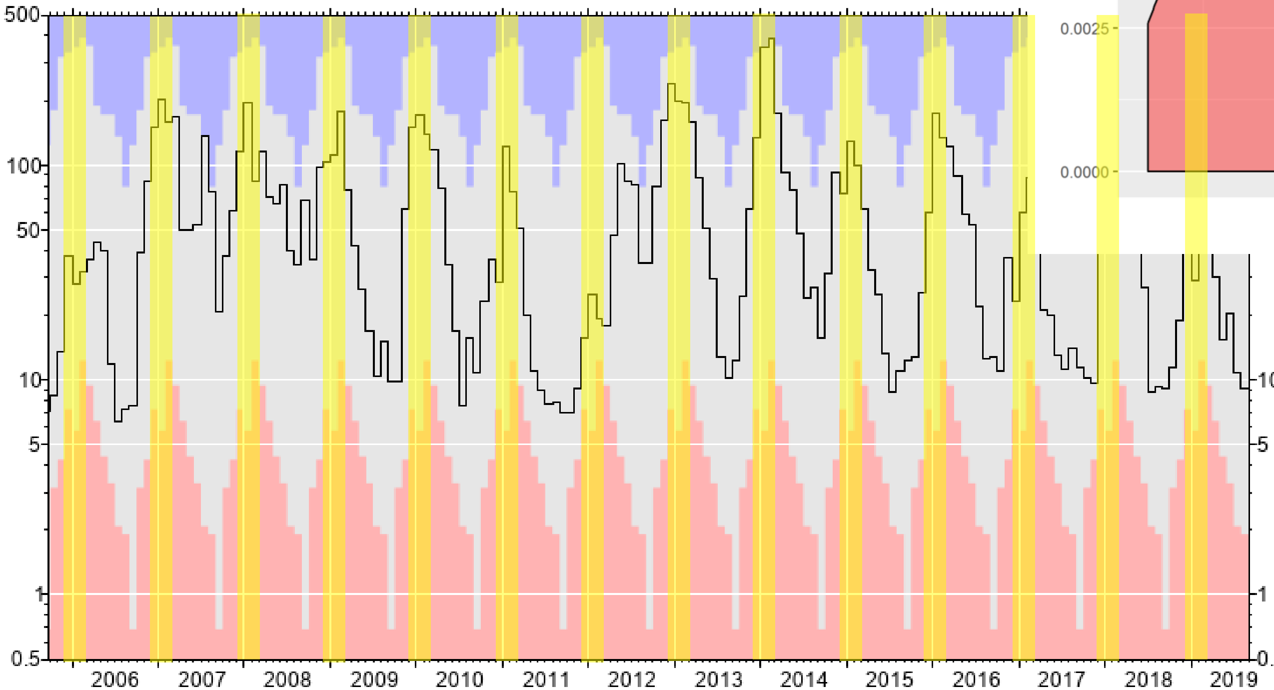
Streamflow Forecasting

"Climatology"

Simplest method of forecasting.

Uses only streamflow data.





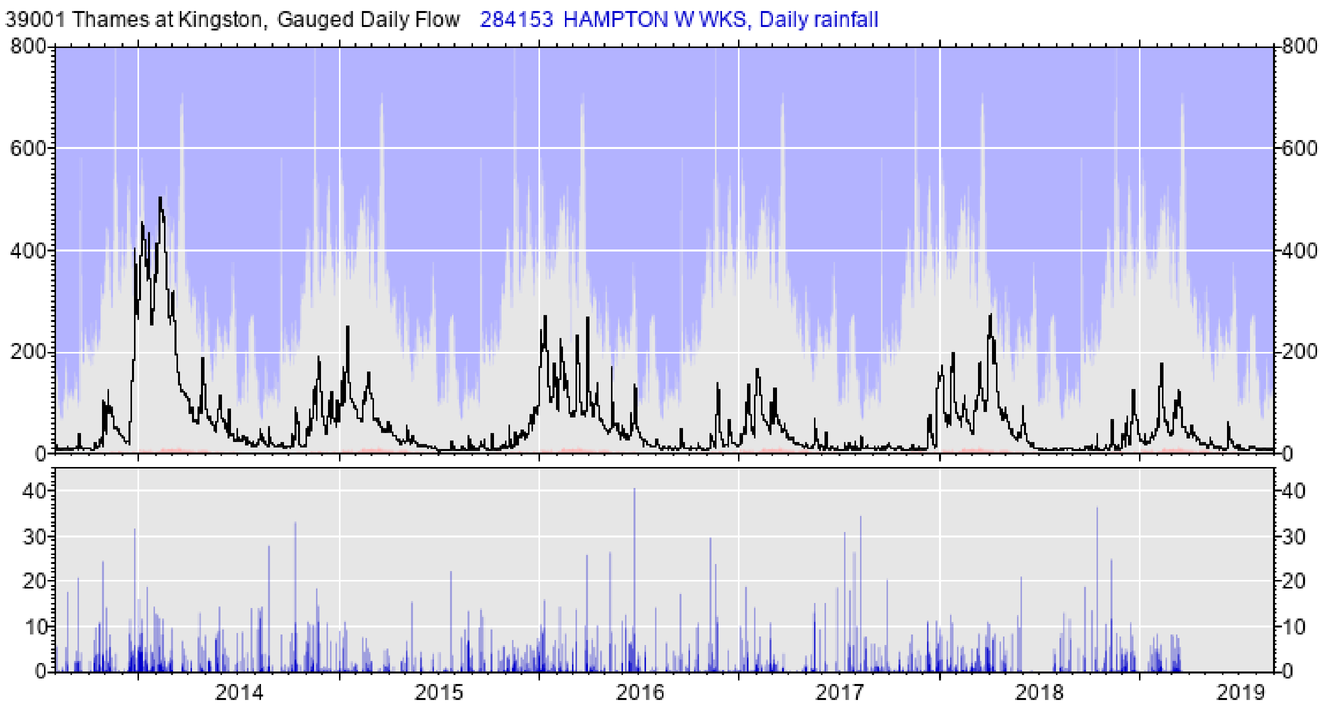
Provides a probability distribution of flows.

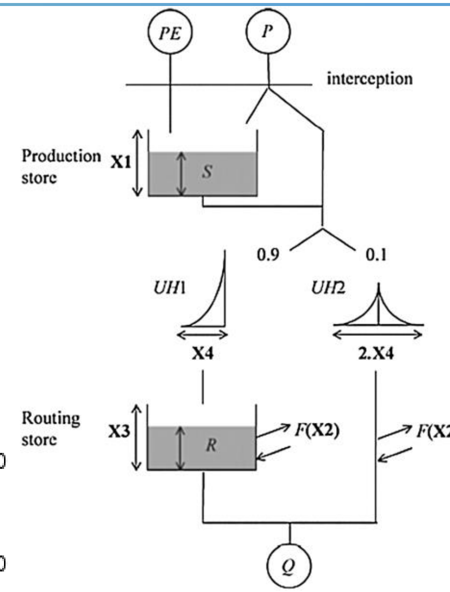
Can calculate deterministic mean if required.

Ensemble Streamflow Prediction (ESP)

A step further than Climatology.

We know the initial conditions of the catchment.





Model flow until present day using observed climate data

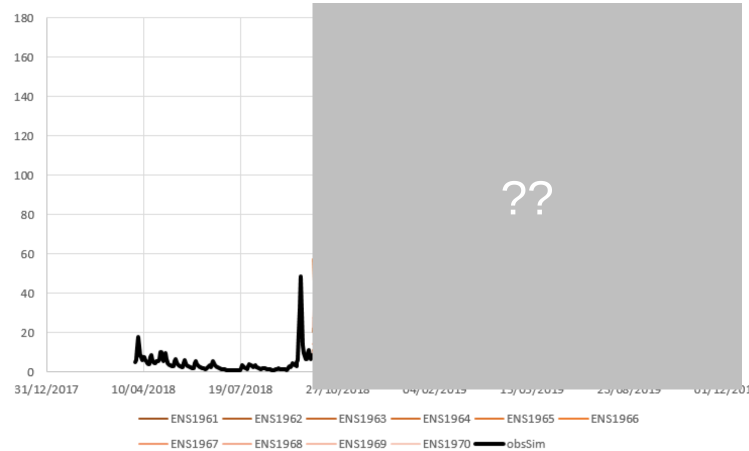
(Rainfall and PET)

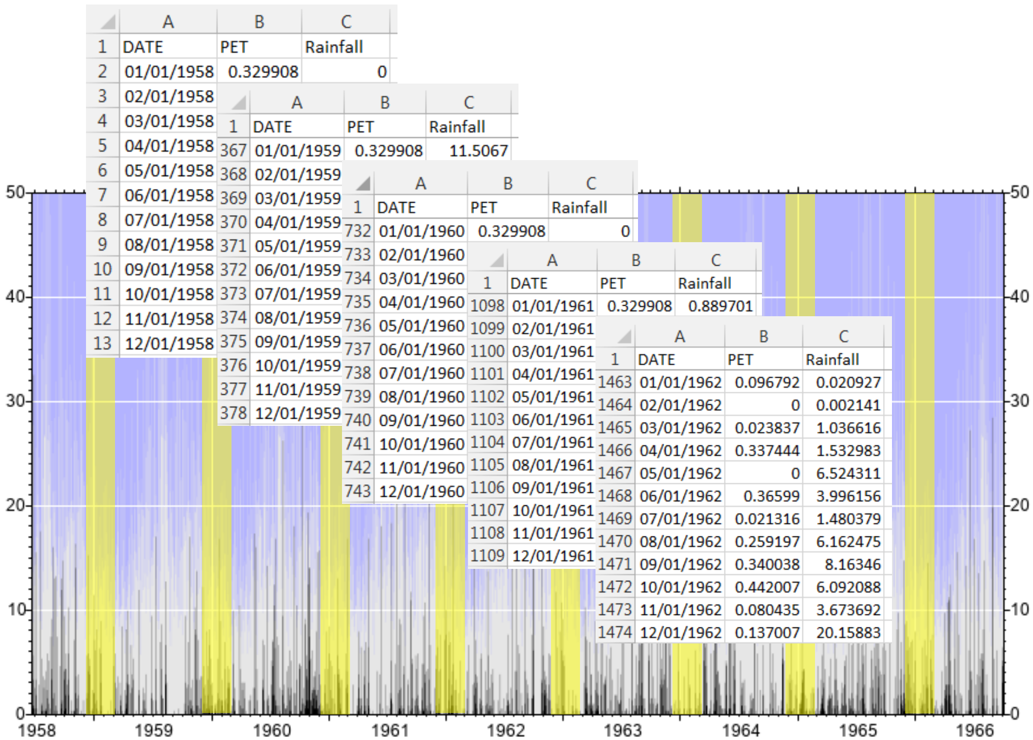
Ensemble Streamflow Prediction (ESP)

Then drive the model with climate data from each historic year.

Initial Streamflow Conditions

Ensemble of Streamflow Forecasts





	A	B	C
1	DATE	PET	Rainfall
2	01/01/1958	0.329908	0
3	02/01/1958		
4	03/01/1958		
5	04/01/1958		
6	05/01/1958		
7	06/01/1958		
8	07/01/1958		
9	08/01/1958		
10	09/01/1958		
11	10/01/1958		
12	11/01/1958		
13	12/01/1958		

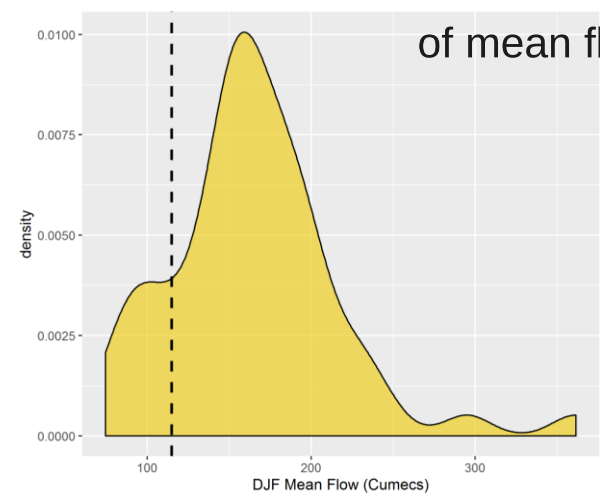
	A	B	C
1	DATE	PET	Rainfall
367	01/01/1959	0.329908	11.5067
368	02/01/1959		
369	03/01/1959		
370	04/01/1959		
371	05/01/1959		
372	06/01/1959		
373	07/01/1959		
374	08/01/1959		
375	09/01/1959		
376	10/01/1959		
377	11/01/1959		
378	12/01/1959		

	A	B	C
1	DATE	PET	Rainfall
732	01/01/1960	0.329908	0
733	02/01/1960		
734	03/01/1960		
735	04/01/1960		
736	05/01/1960		
737	06/01/1960		
738	07/01/1960		
739	08/01/1960		
740	09/01/1960		
741	10/01/1960		
742	11/01/1960		
743	12/01/1960		

	A	B	C
1	DATE	PET	Rainfall
1098	01/01/1961	0.329908	0.889701
1099	02/01/1961		
1100	03/01/1961		
1101	04/01/1961		
1102	05/01/1961		
1103	06/01/1961		
1104	07/01/1961		
1105	08/01/1961		
1106	09/01/1961		
1107	10/01/1961		
1108	11/01/1961		
1109	12/01/1961		

	A	B	C
1	DATE	PET	Rainfall
1463	01/01/1962	0.096792	0.020927
1464	02/01/1962	0	0.002141
1465	03/01/1962	0.023837	1.036616
1466	04/01/1962	0.337444	1.532983
1467	05/01/1962	0	6.524311
1468	06/01/1962	0.36599	3.996156
1469	07/01/1962	0.021316	1.480379
1470	08/01/1962	0.259197	6.162475
1471	09/01/1962	0.340038	8.16346
1472	10/01/1962	0.442007	6.092088
1473	11/01/1962	0.080435	3.673692
1474	12/01/1962	0.137007	20.15883

Provides a probability distribution of mean flow

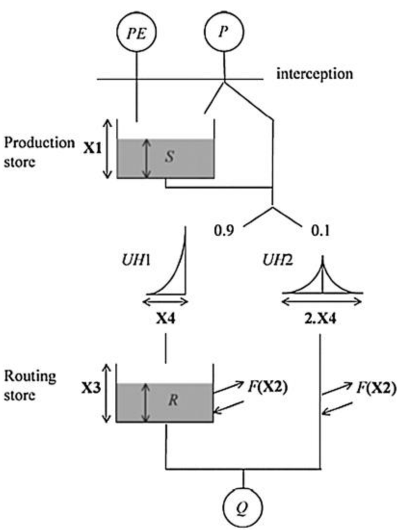


Dashed line = mean of climatology

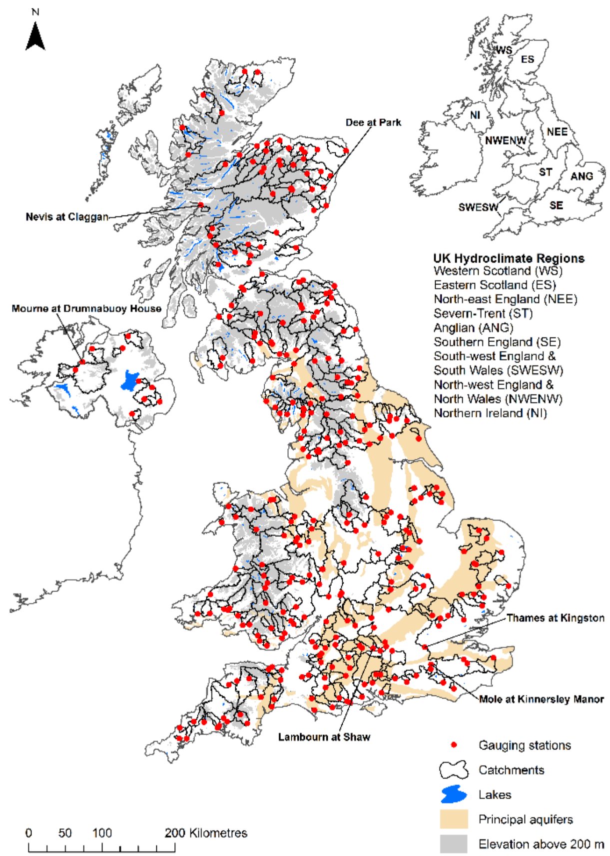
Ensemble Streamflow Prediction Skill

Ensemble Streamflow Prediction UKHO Model Setup

IMPETUS IMPROVING PREDICTIONS OF UK DROUGHT

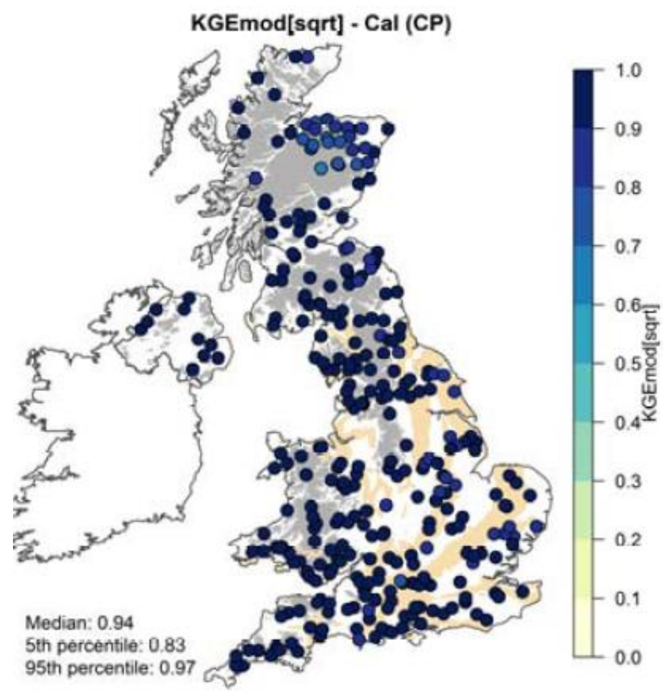


airGR



314 UK catchments

Calibrated over 1983-2014 using inbuilt automatic calibration function, optimising modified KGE

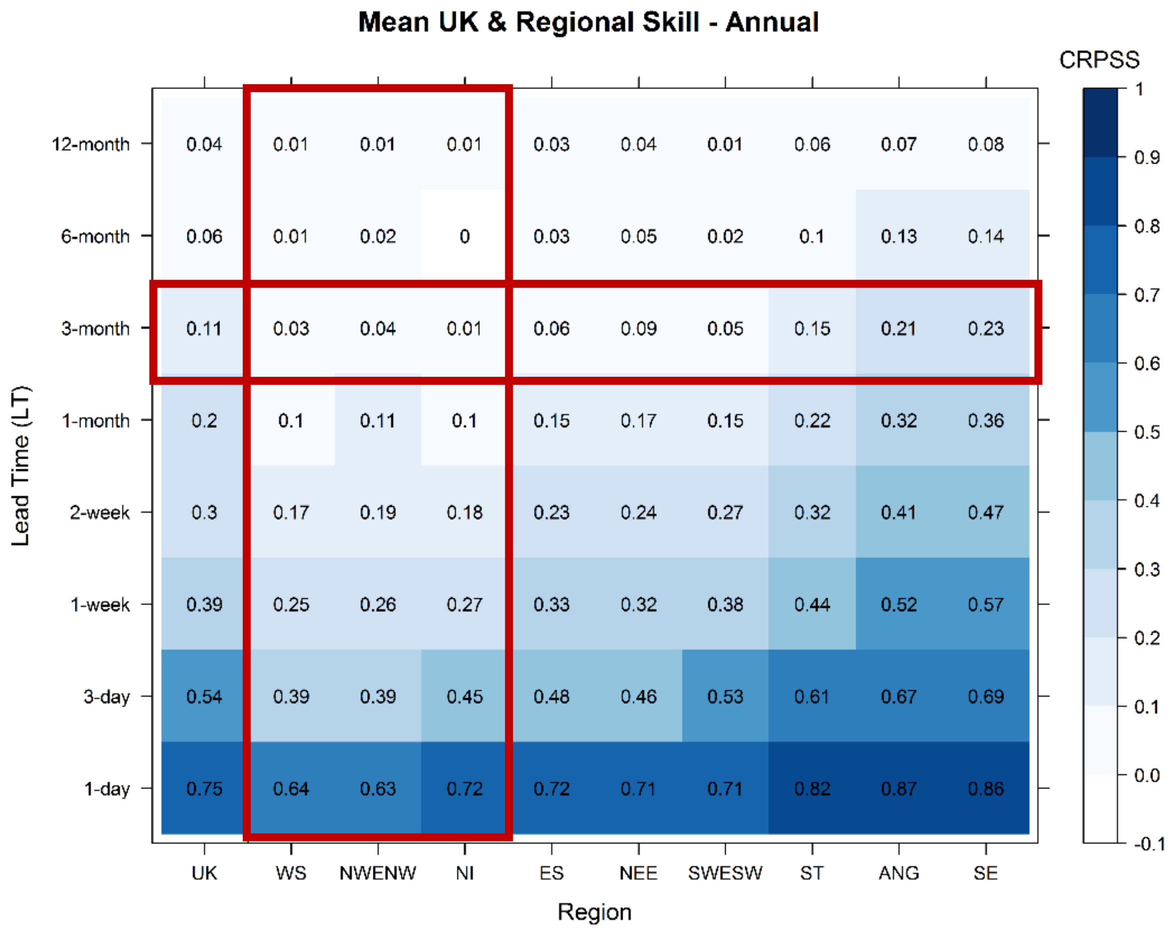


Harrigan, *et al.* (2018) Benchmarking ESP skill in the UK, HESS

Ensemble Streamflow Prediction UKHO Skill

Skill at a seasonal lead time is minimal on average across the year.

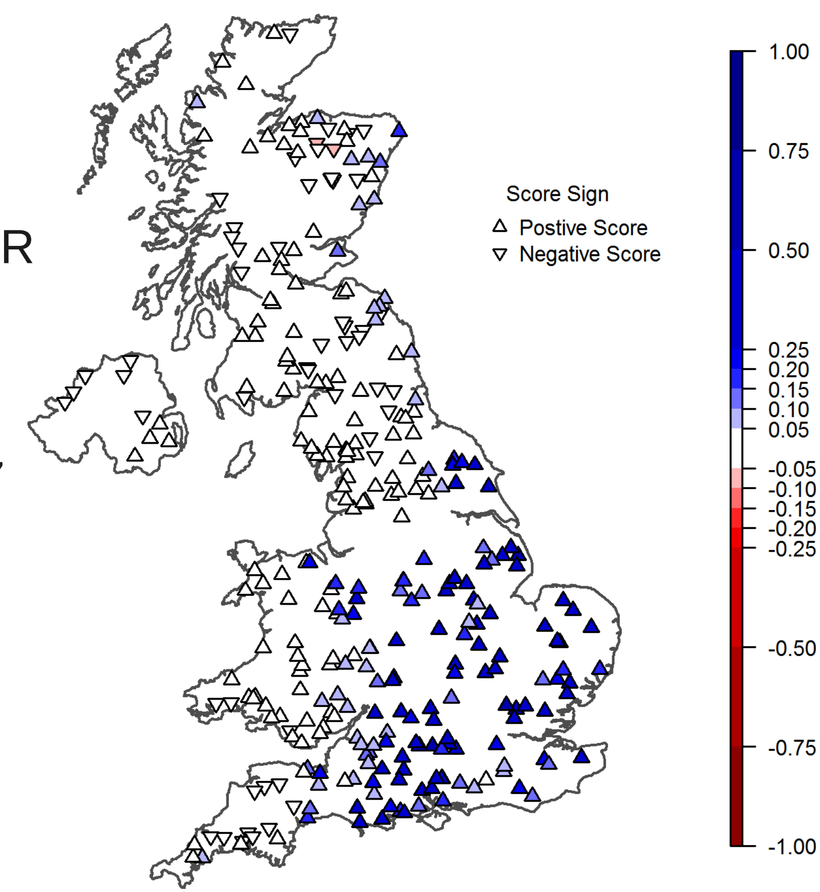
Especially low in the Northwest

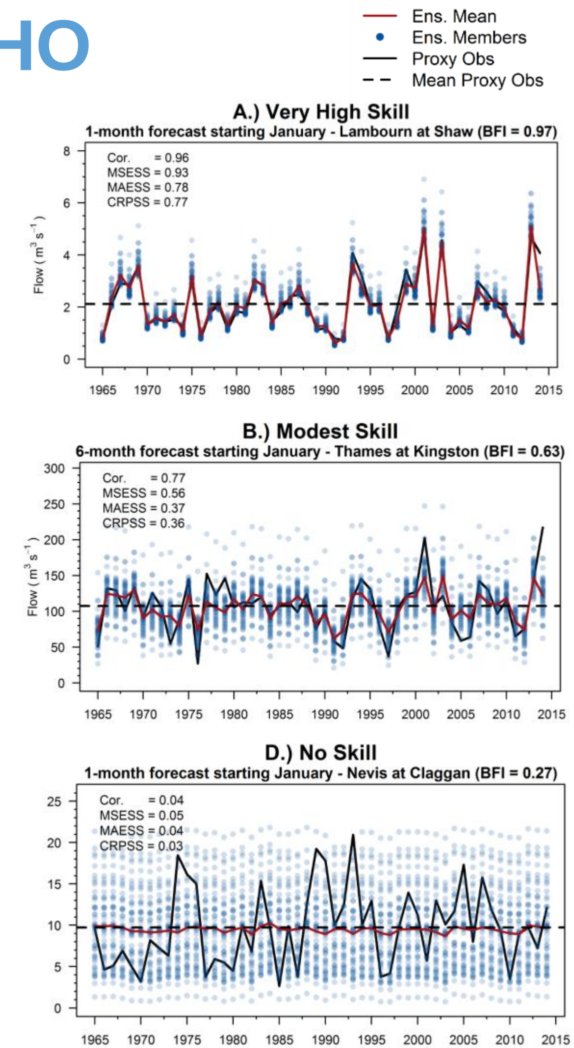


Harrigan, *et al.* (2018) Benchmarking ESP skill in the UK, HESS

Ensemble Streamflow Prediction UKHO Skill

DJF CRPSS for ESP v Clim





ESP at a seasonal lead time IN WINTER is quite skilful in the southeast.

Max CRPSS of 0.77 in the Lambourn

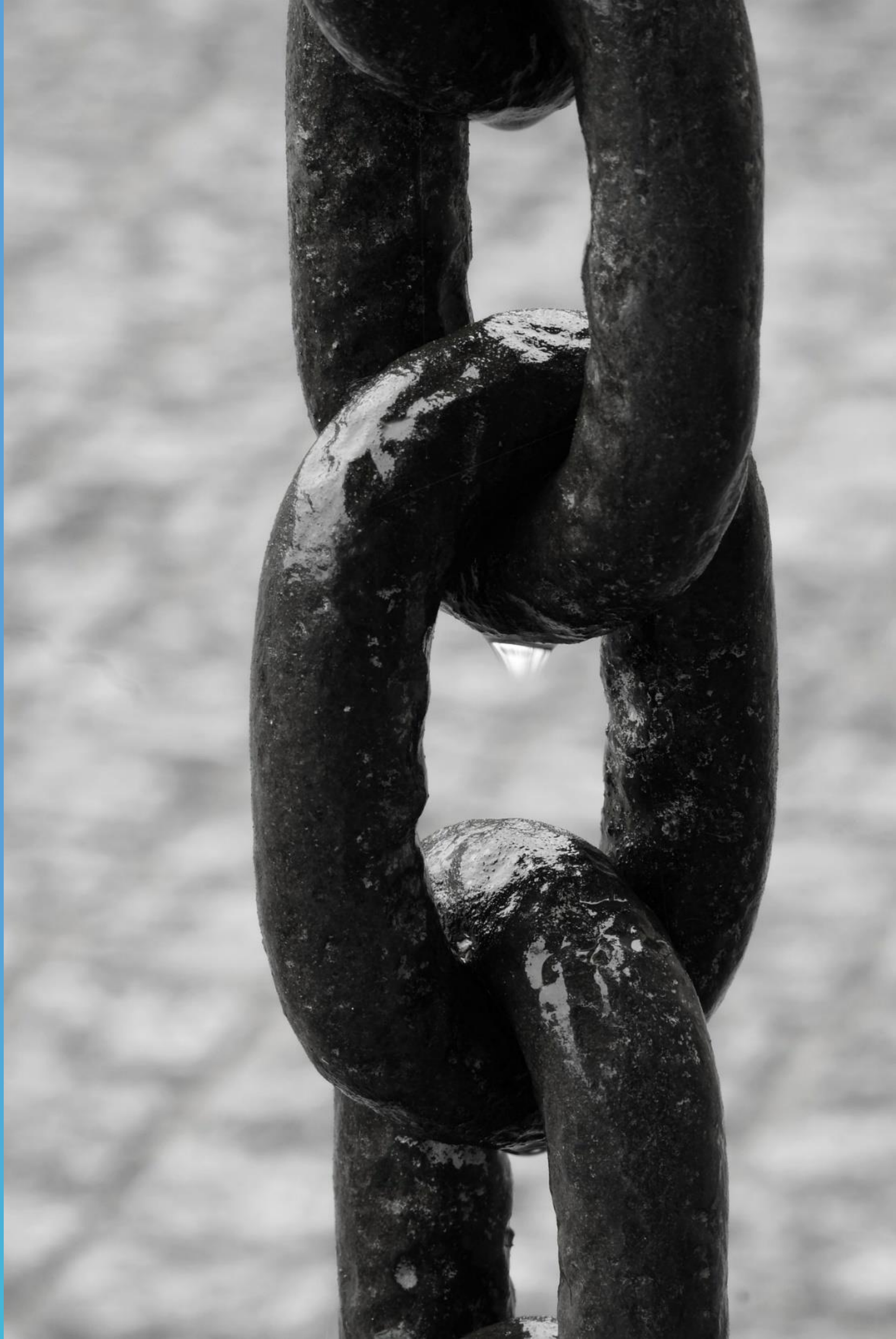
No skill in the northwest (CRPSS 0.03)

Harrigan, *et al.* (2018) Benchmarking ESP skill in the UK, HESS

Why?

- ESP skill over climatology is driven by initial conditions in southeast (high storage)
- Northwest highly responsive to rainfall
- Need to incorporate some form of meteorological forecast in NW
- But, forecasts of atmospheric circulation patterns are more skilful than forecasts of precipitation itself

North Atlantic Oscillation and UK Streamflow



NAO in the UK

Dominant atmospheric circulation pattern in winter

Large pressure differences in Atlantic = +ve NAO

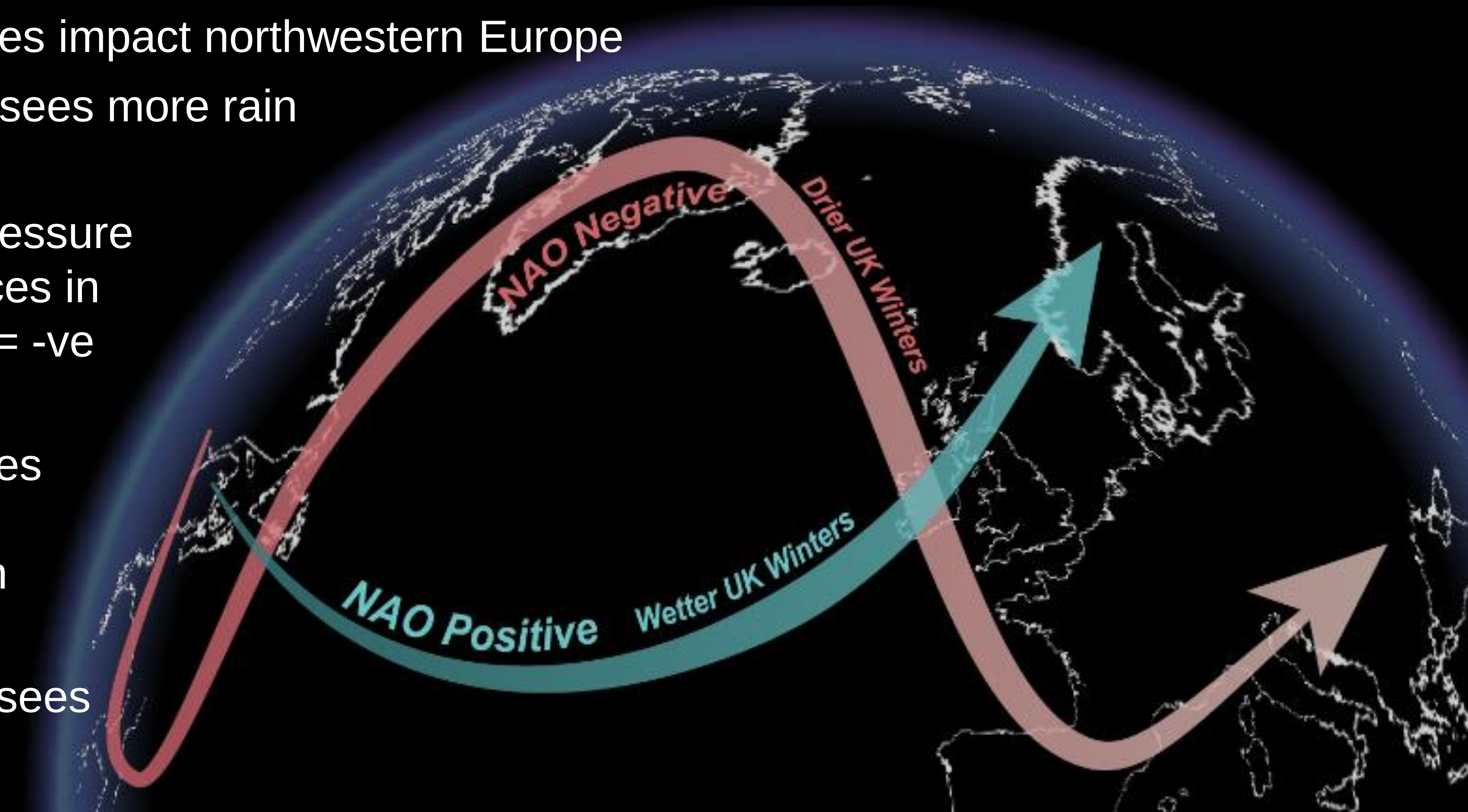
Westerlies impact northwestern Europe

NW UK sees more rain

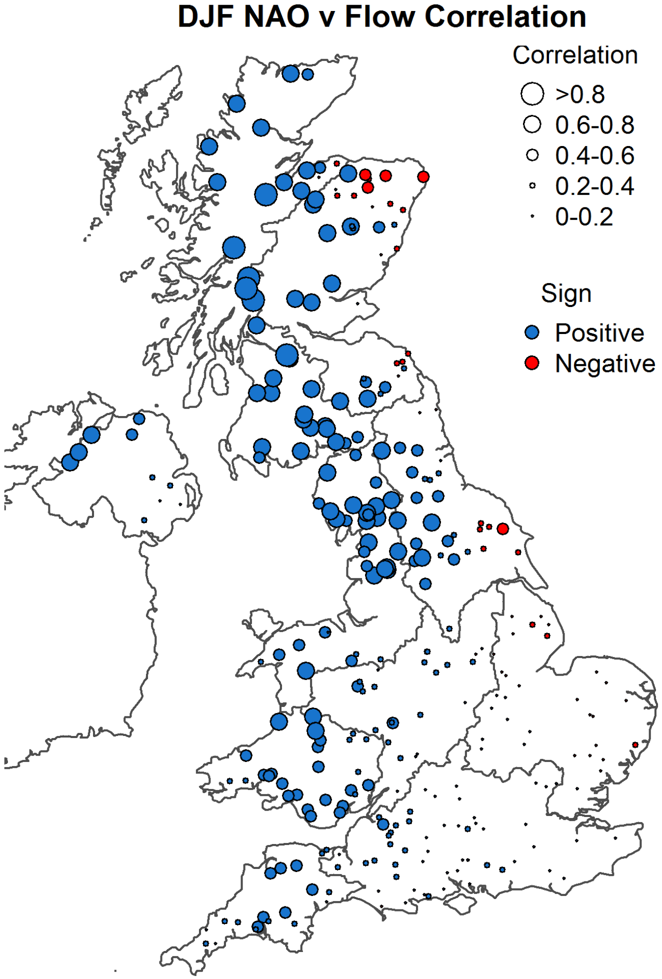
Small pressure differences in Atlantic = -ve NAO

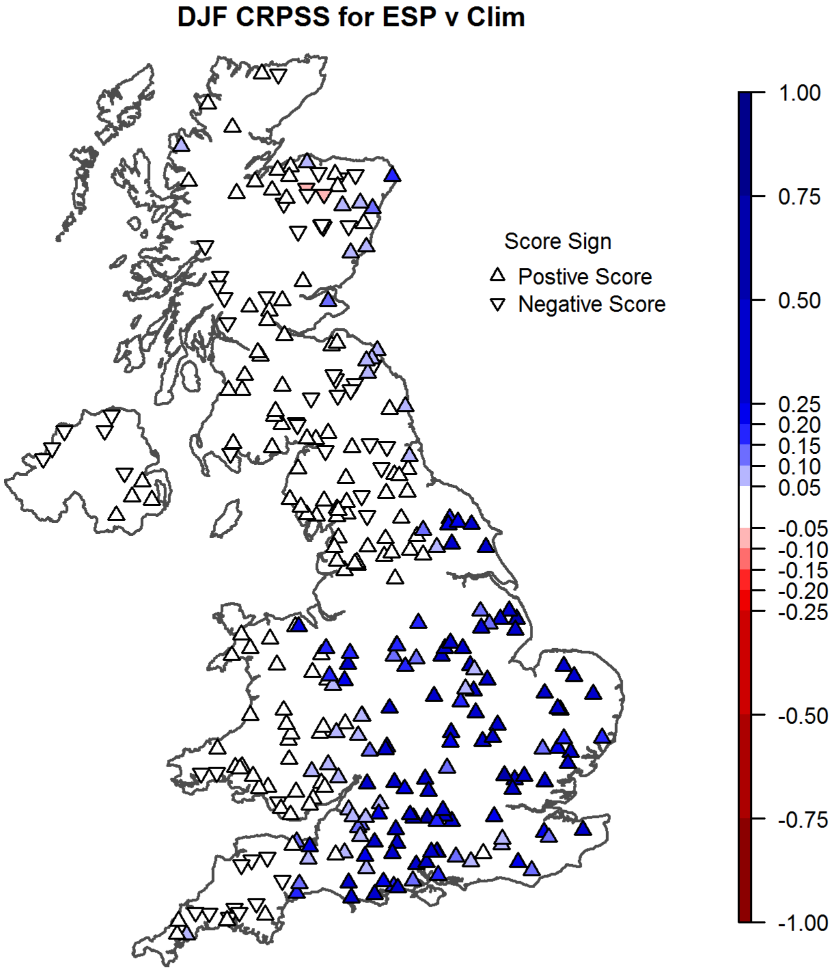
Westerlies impact southern Europe

NW UK sees less rain

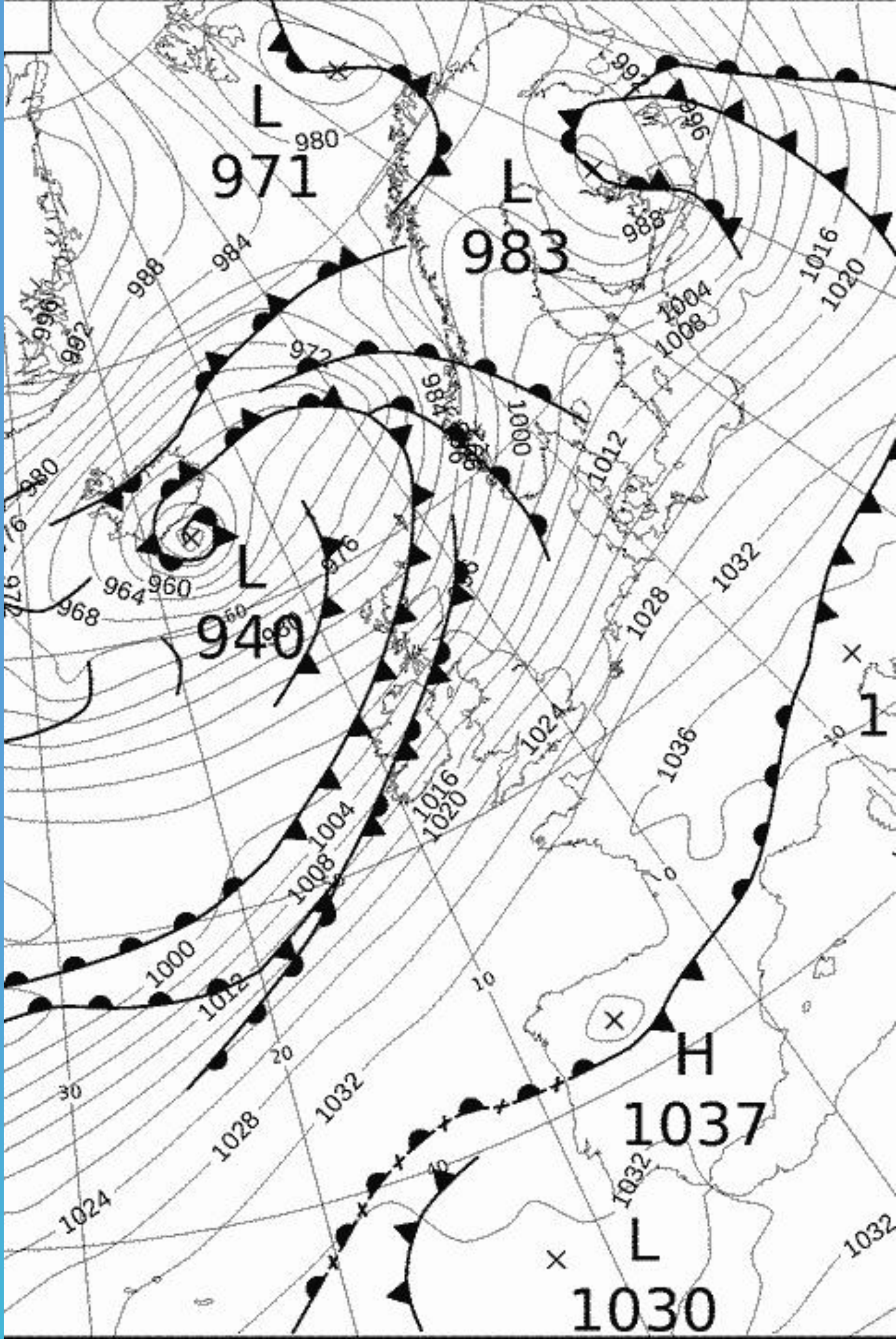


NAO in the UK & Streamflow



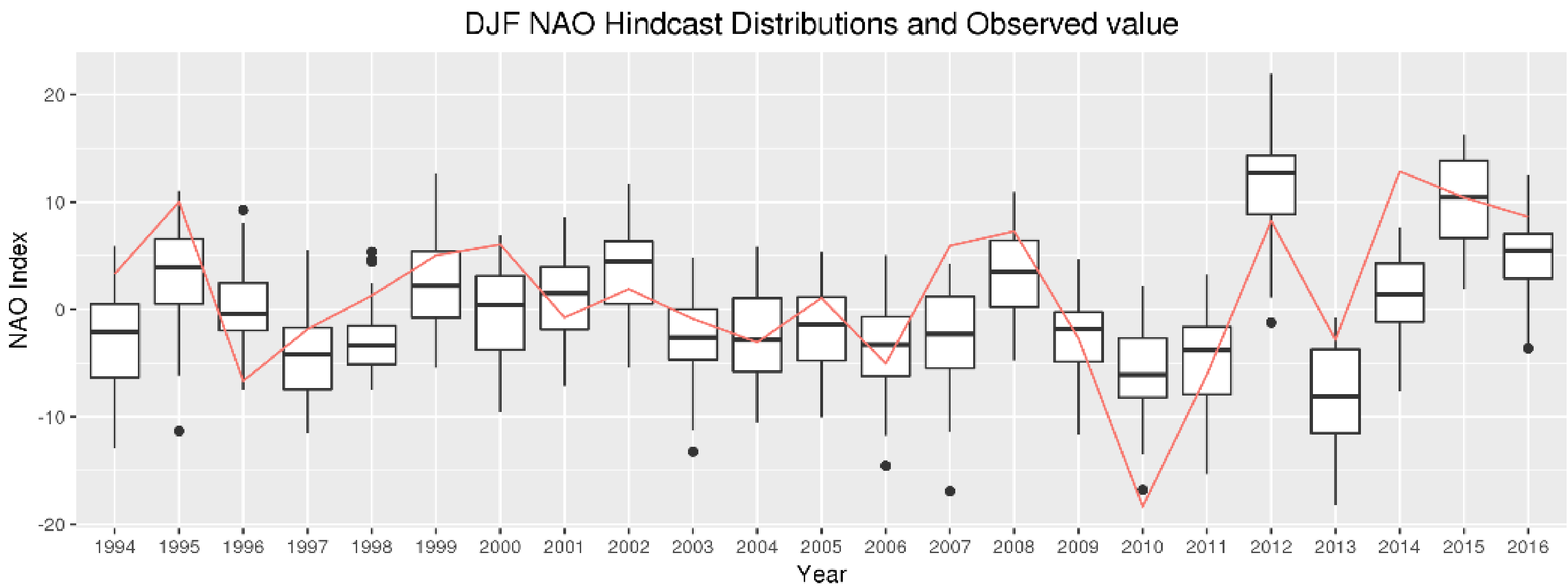


North Atlantic Oscillation Analogue Forecasting



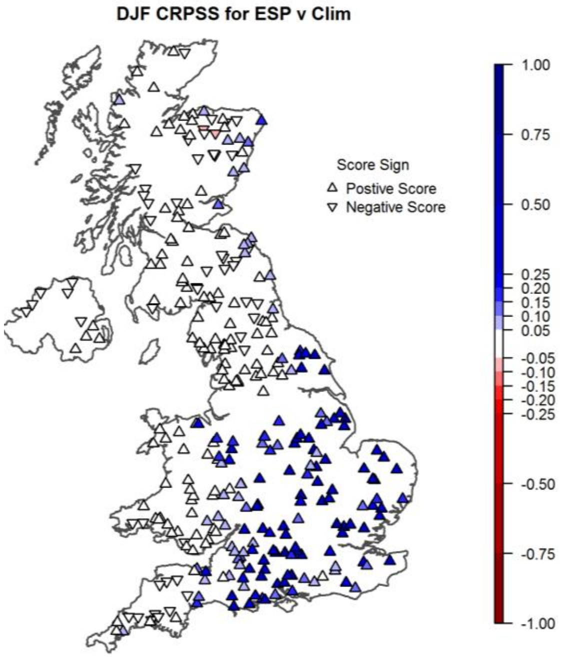
51 NAO hindcasts from the Met Office Glosea5 model

Rescale NAO hindcasts to increase variability of hindcast ensemble mean and include extreme events → Take each adjusted hindcast value of DJF average NAO → Find a non-consecutive DJF sequence where average observed NAO = hindcast value → e.g. December 1992, January 2003, February 1965 → Repeat 10 times per NAO hindcast = 510 analogue date sequences → Extract catchment averaged rainfall and PET for each sequence → Run each data sequence through GR4J as a DJF hindcast



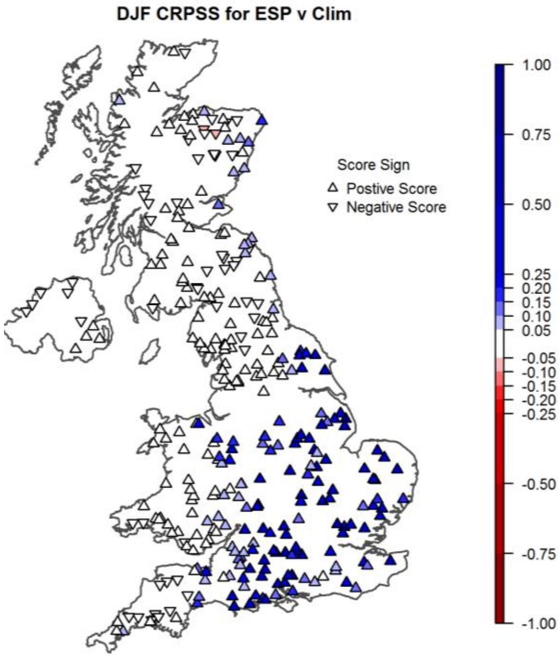
NAO driven ESP Hindcast Results

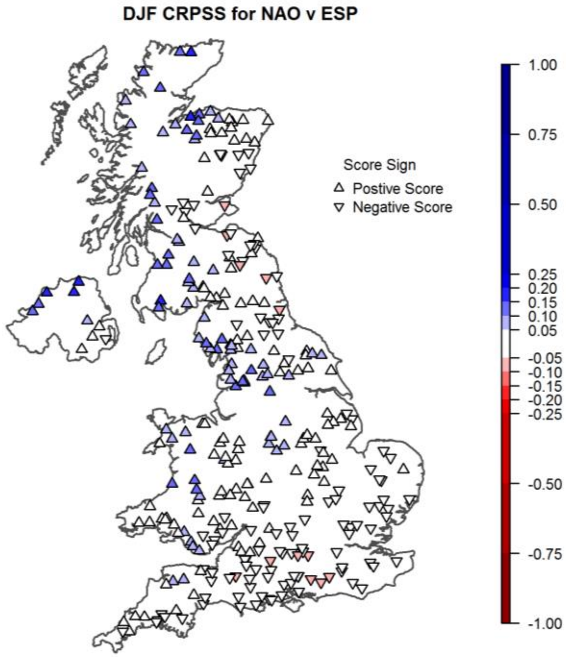
CRPSS



ESP skilful in southeast

CRPSS



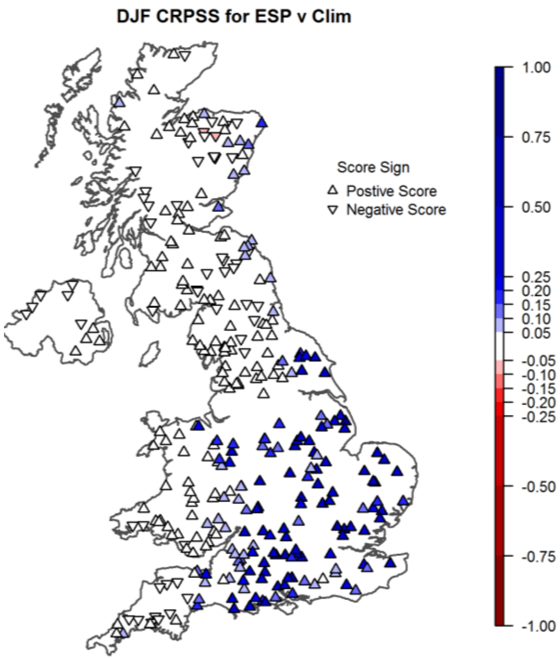


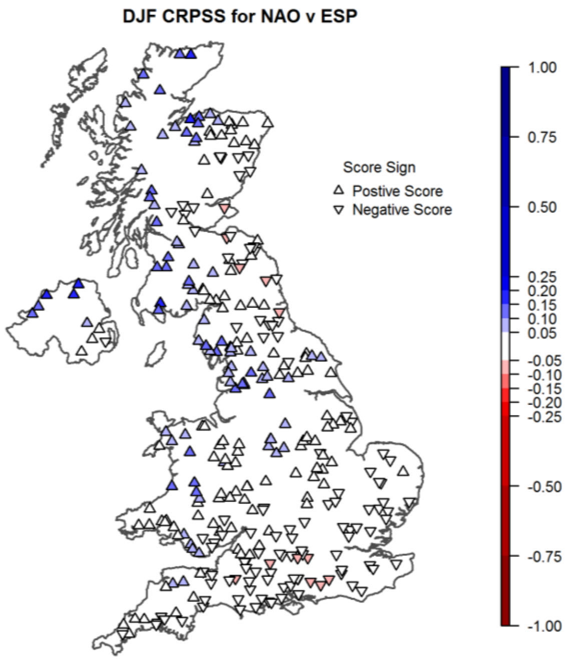
ESP skilful in southeast

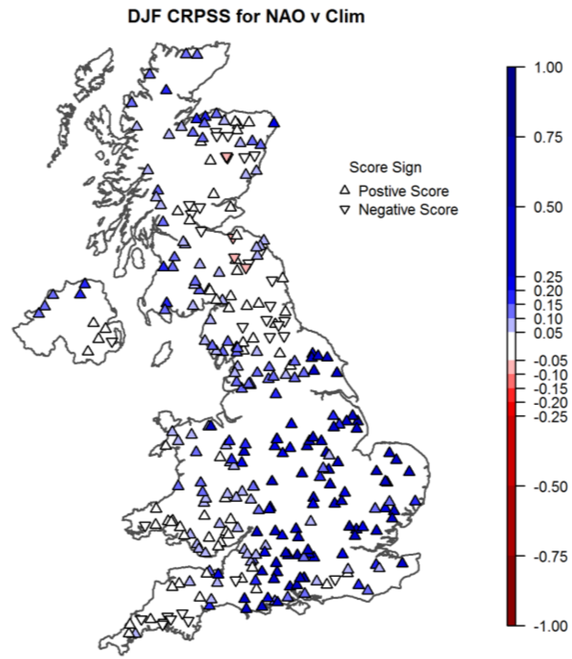
Increased skill in northwest

Moderate increases: CRPSS ~0.2 over ESP

CRPSS







ESP skilful in southeast

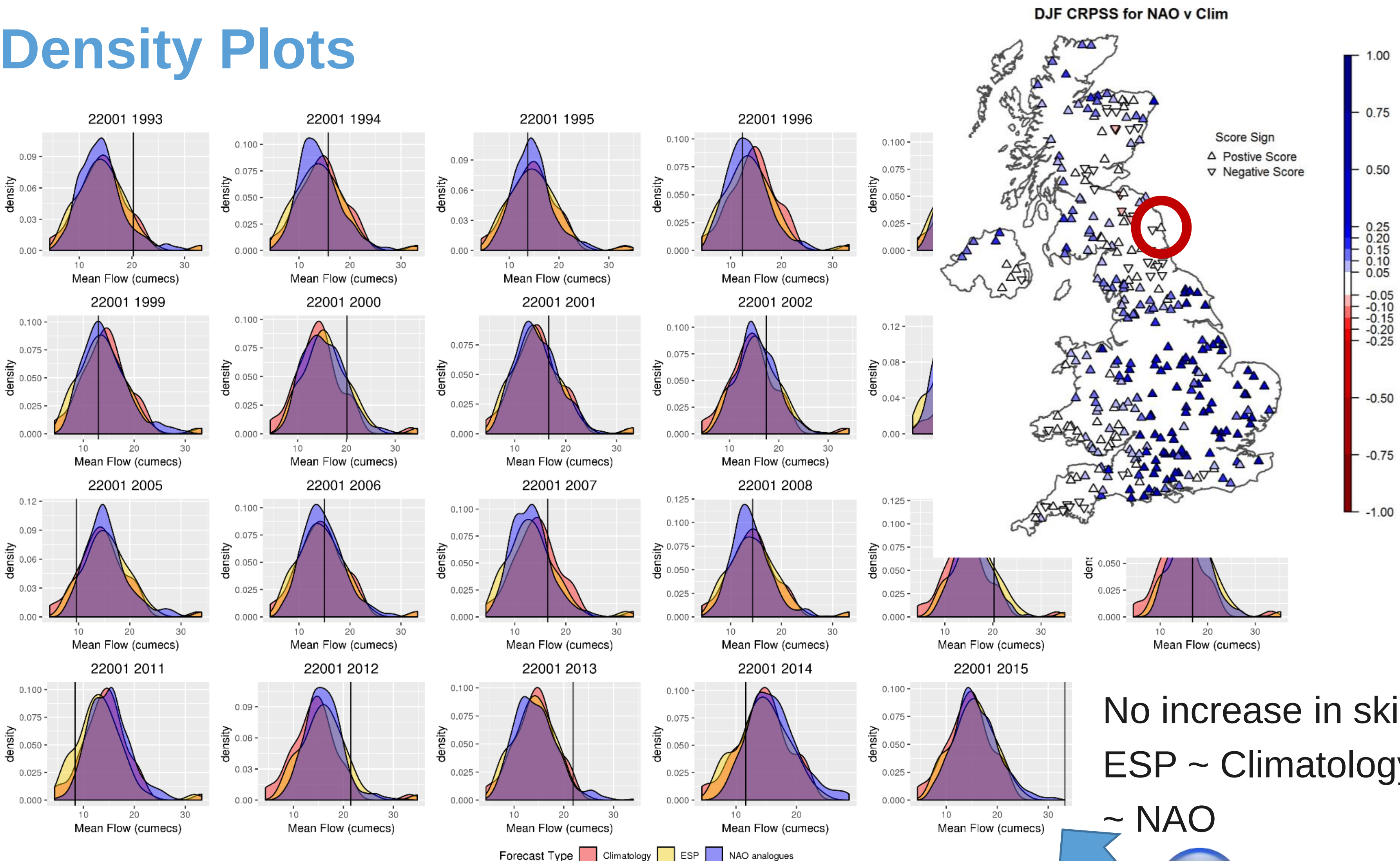
Increased skill in northwest

Moderate increases: CRPSS ~0.2 over ESP

Combined skill over much of the country

Exceptions in northeast and far southwest

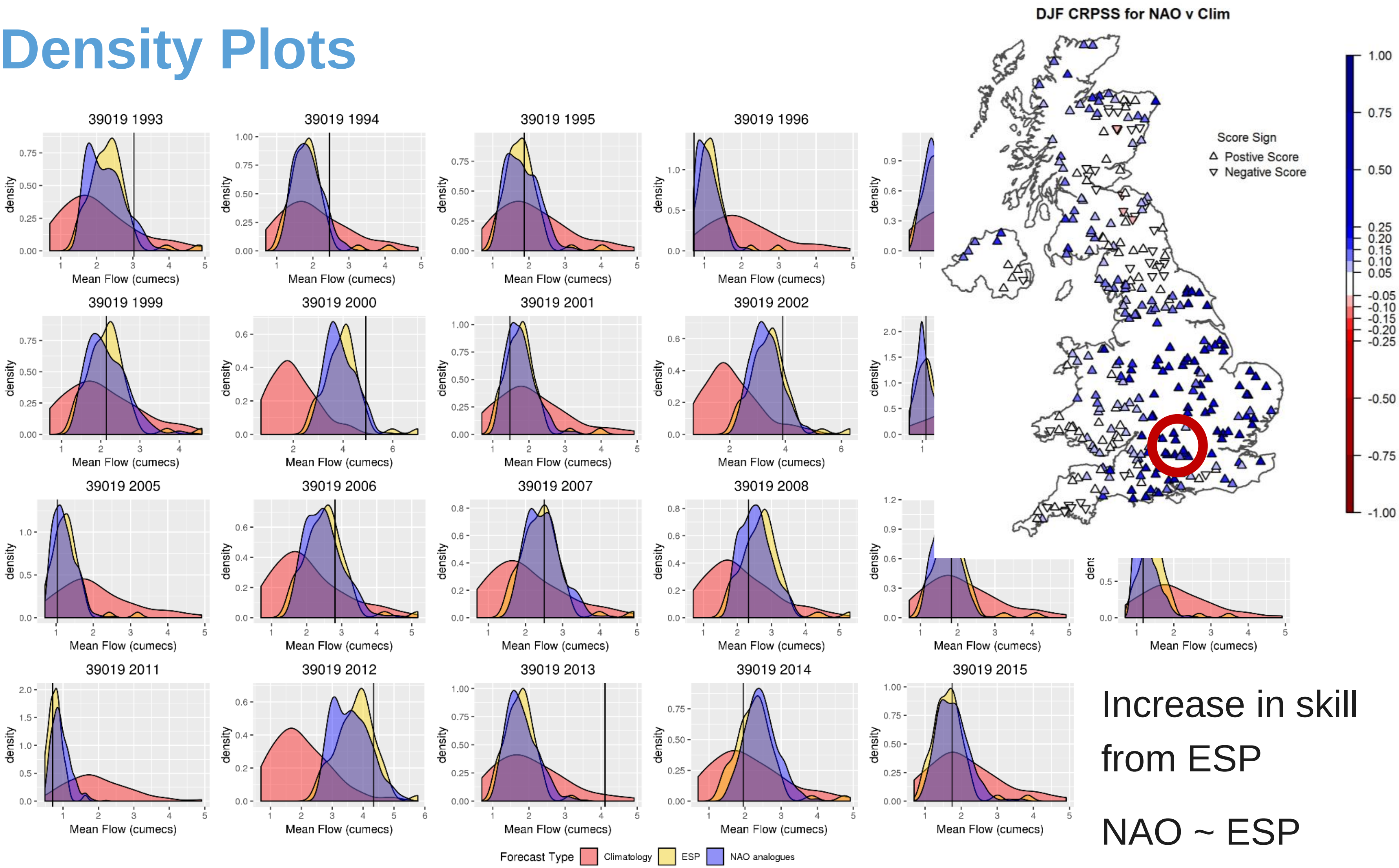
Density Plots



No increase in skill

ESP ~ Climatology ~ NAO

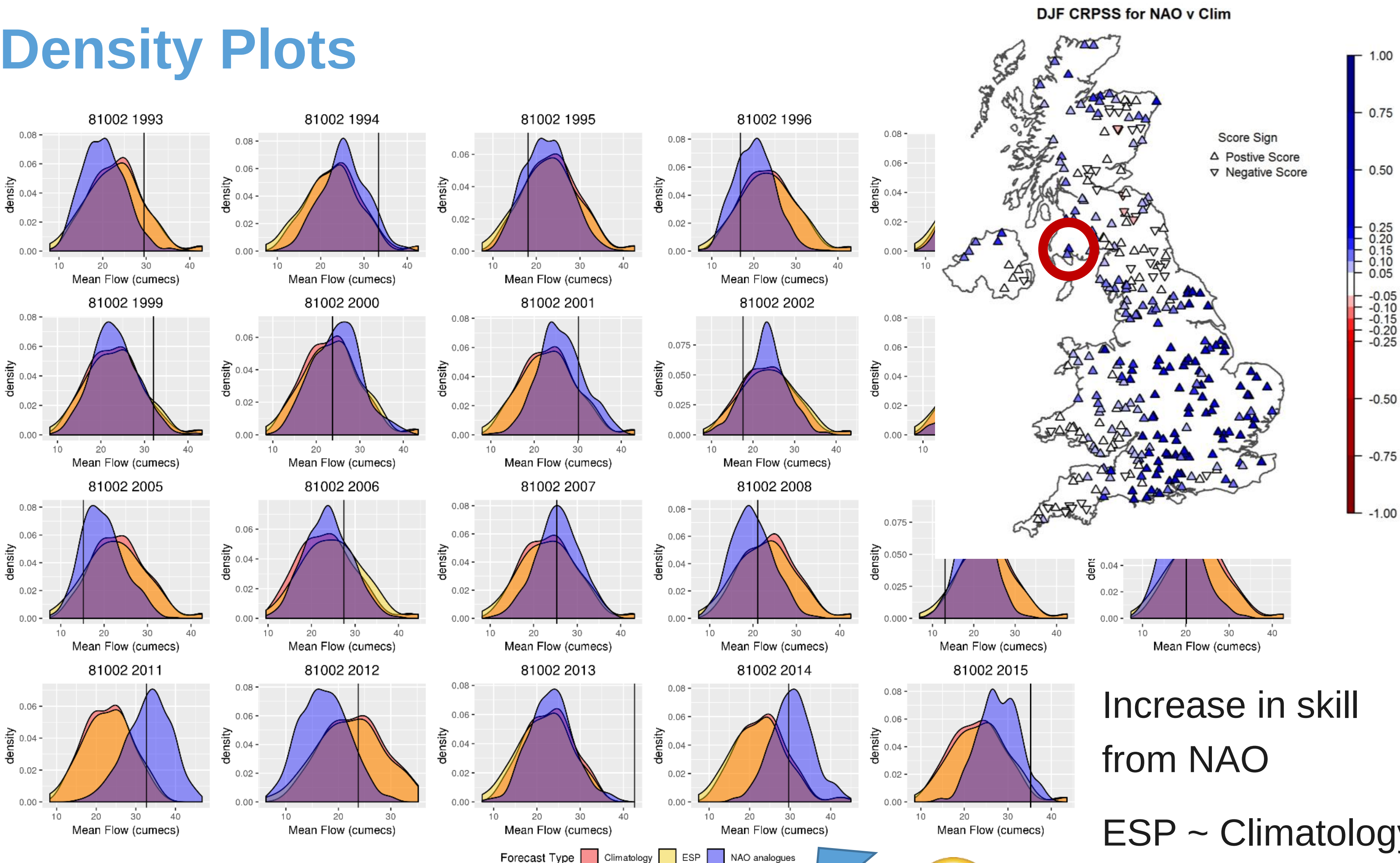
Density Plots



Increase in skill from ESP

NAO ~ ESP

Density Plots



Increase in skill from NAO

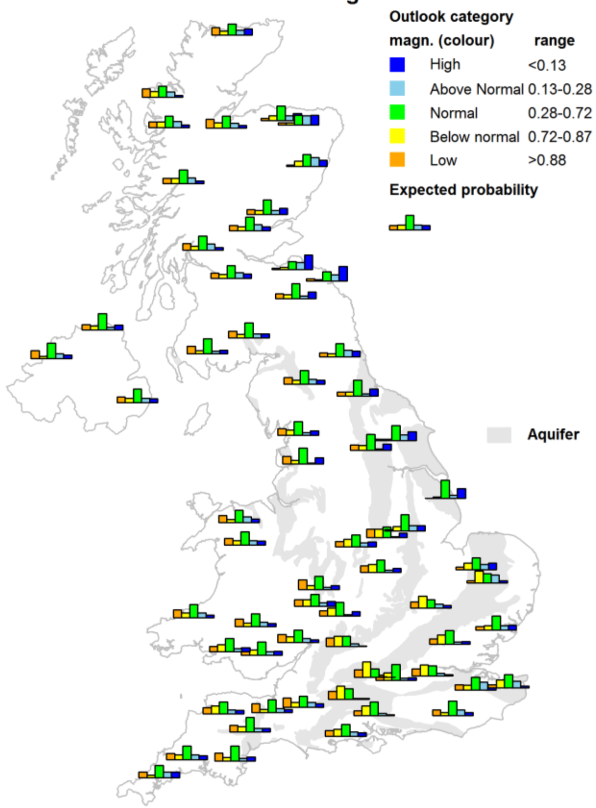
ESP ~ Climatology

Case Studies

2010-2011 (-ve NAO) [-3.3 CRU, -18.4 adjusted Glosea5]

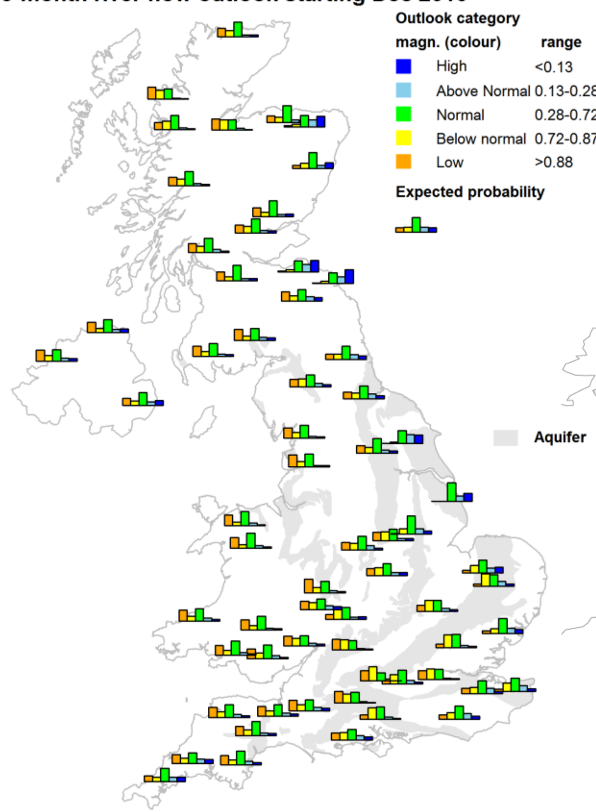
Standard ESP

3-month river flow outlook starting Dec 2010

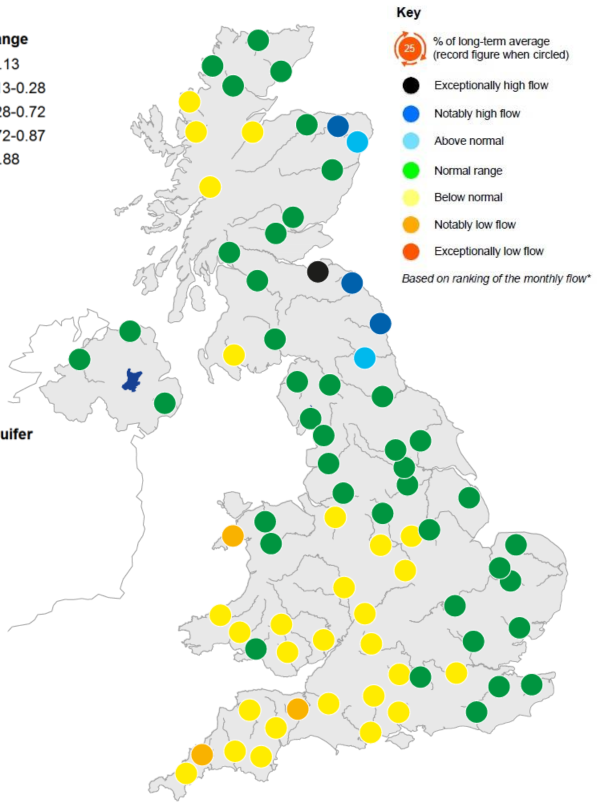


NAO driven ESP

3-month river flow outlook starting Dec 2010

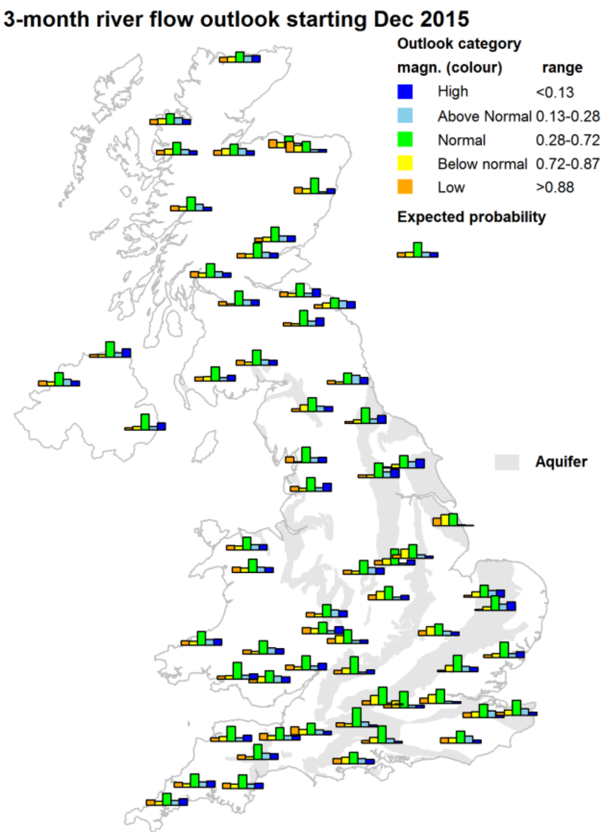


Observed Flow

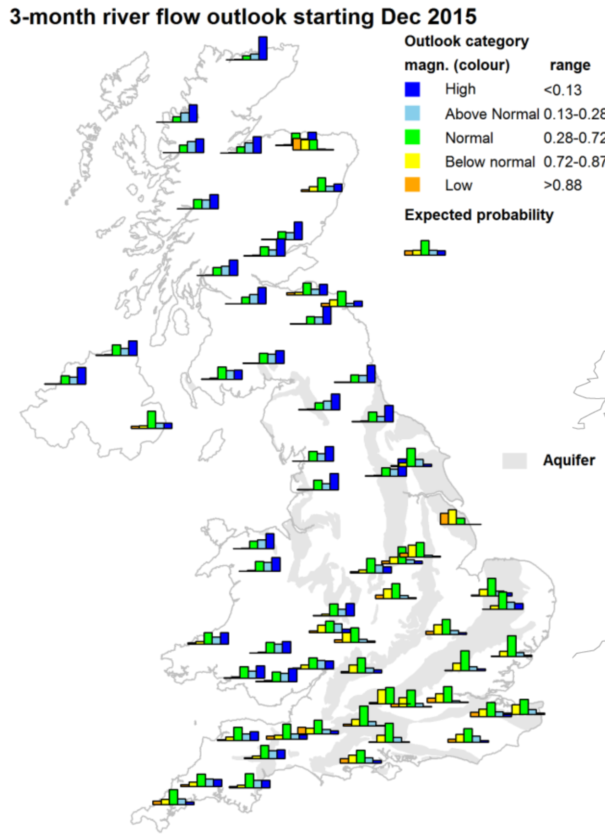


2015-2016 (+ve NAO) [2.3 CRU, 8.6 adjusted Glosea5]

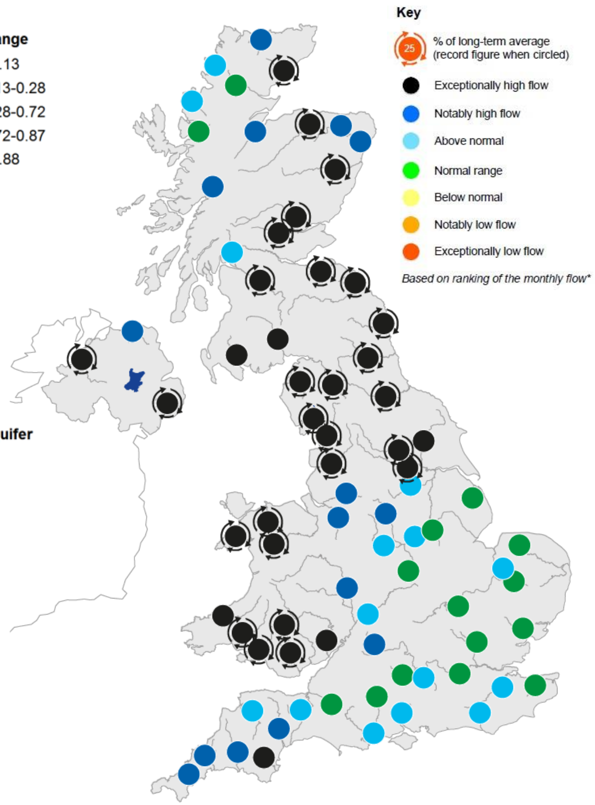
Standard ESP



NAO driven ESP



Observed Flow



Operational-ising the NAO forecasts

Operationalising the NAO forecasts

Run for:

Dec-Feb
Jan-Mar
Feb-Apr

UK Centre for Ecology & Hydrology
Met Office
Environment Agency

Outlook based on modelled flow from North Atlantic Oscillation historical climate analogues

New Winter NAO analogue forecasts – In Development

Period: December 2020 – February 2021
Issued on 06.12.2020 using data to the end of November

This page shows the results of the GR4J hydrological model run using historical climate analogues, resampled according to the forecast North Atlantic Oscillation (NAO) index. Please see the next page for details on the method.

Global weather patterns can affect UK weather during the coming season and their influence acts to shift the chances of the categories in the Outlook. For December-January-February, among other drivers, a moderate to strong La Nina is likely to affect the latter part of the winter. An increased chance of mild westerly winds means a greater likelihood of Atlantic weather systems bringing impacts from wet, windy or even stormy conditions.

Dec-Jan-Feb Precipitation anomaly (Northwest UK)

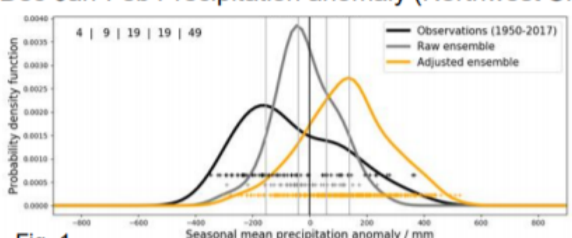


Fig. 1

River flows are likely to be above normal in the northern and western parts of the UK, as well as in parts of southern England. Flows in central and south-eastern England are likely to be within the normal range.

Dec-Jan-Feb 2020 NAO Driven River Flow Outlook

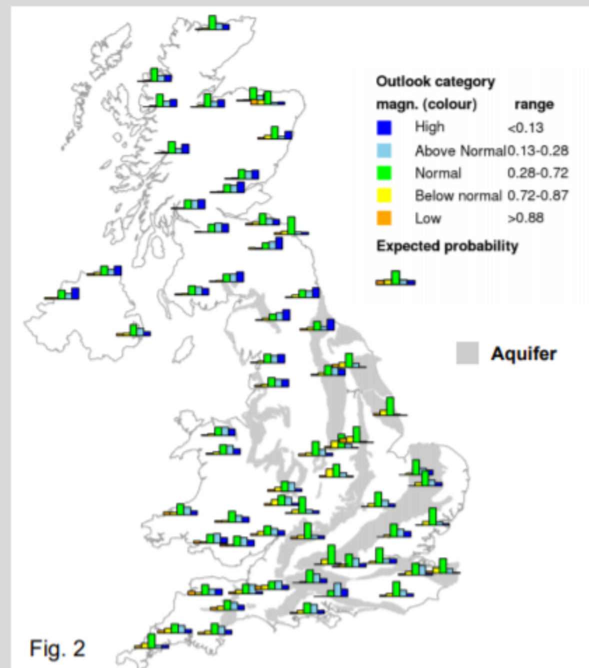


Fig. 2

This outlook is based on ensembles of historical sequences of observed climate (rainfall and potential evapotranspiration), resampled according to the NAO index, that form input to a hydrological model. The outputs are the likelihoods of different outcomes for the average river flow over the three month winter forecast period at each location. The simulations are generated by the GR4J conceptual rainfall-runoff model calibrated on observed flows.

Figure 1 shows the distribution of individual outcomes (shown as crosses) and the consequent likelihood of different amounts of precipitation in the Northwest UK (as a difference from the long-term average). The black line shows the likelihood based only on past climate, using observations from 1950-2017. The grey line shows the output from the Met Office GloSea long-range prediction system. The orange line shows the GloSea outputs adjusted to correct for known under-prediction of the size of weather signals. The numbers in the top left represent the percentage of adjusted outcomes that fall into five categories that are equally likely based on the observational climate distribution (shown by the vertical grey lines on the graph).

Figure 2 shows the outlook distribution for 64 catchments across England and Wales. Each bar plot represents the likelihood of the simulated river flow compared to the historical river flow, for the same n-month period. The probabilities fall within five categories, classified as: low, below normal, normal, above normal and high.

The Hydrological Outlook UK provides an outlook for the water situation for the UK over the next three months and beyond. For guidance on how to interpret the outlook, a wider range of information, and a full description of underpinning methods, please visit the website: www.hydoutuk.net

RIVER FLOW FROM NAO ANALOGUES

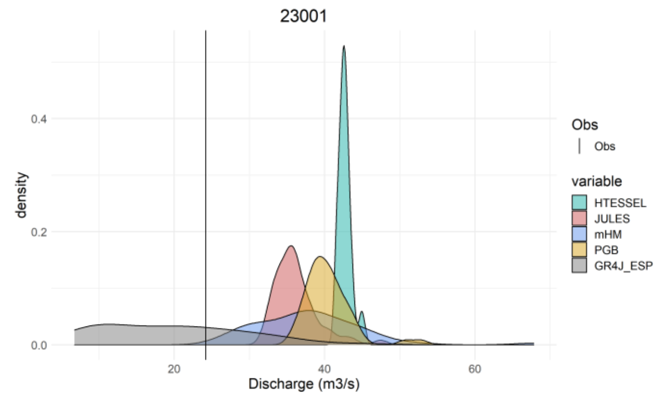
December 2020

ULYSSES Multi-Model Seasonal Forecasts

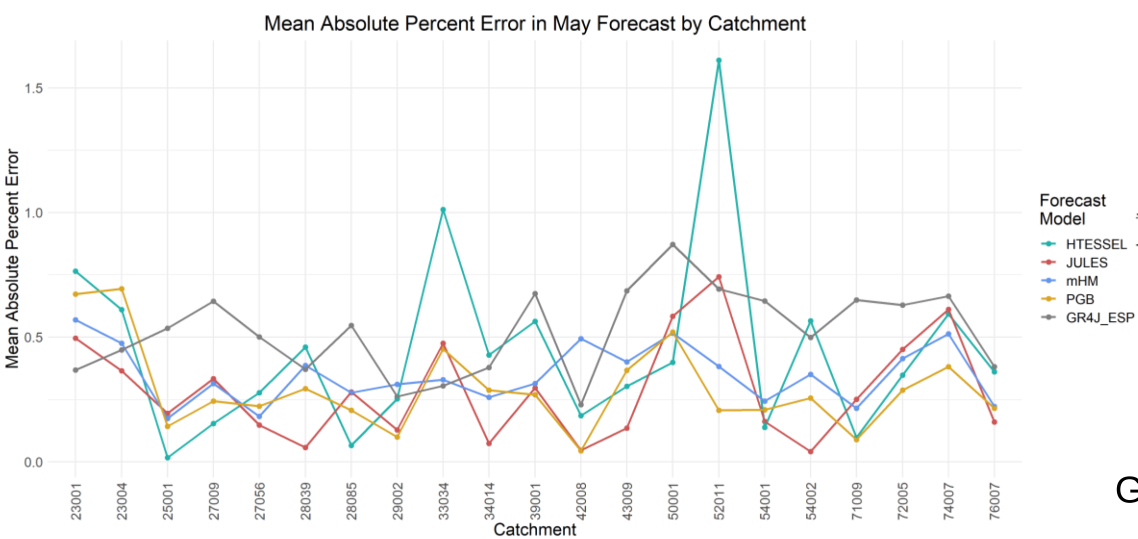
Comparing ULYSSES Global Hydrology Model Forecasts with ESP – May 2021

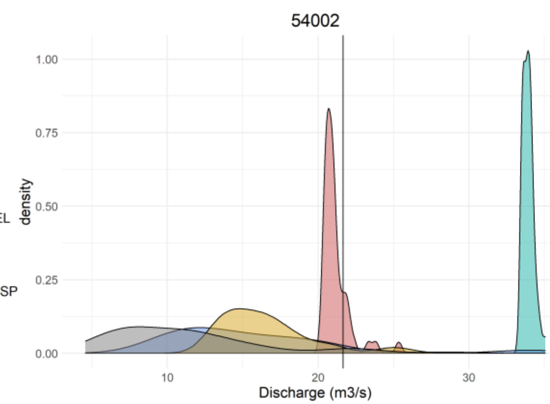
Calculated error metrics for each of the 4 ULYSSES models (HTESSEL, JULES, mHM, PGB) and the GR4J ESP for the May 2021 one-month forecast.

Performance varied a lot by catchment, but generally the ULYSSES models showed lower error than ESP.



JULES and HTESSEL show “sharp” forecasts, mHM and ESP have wider distributions, PGB in between

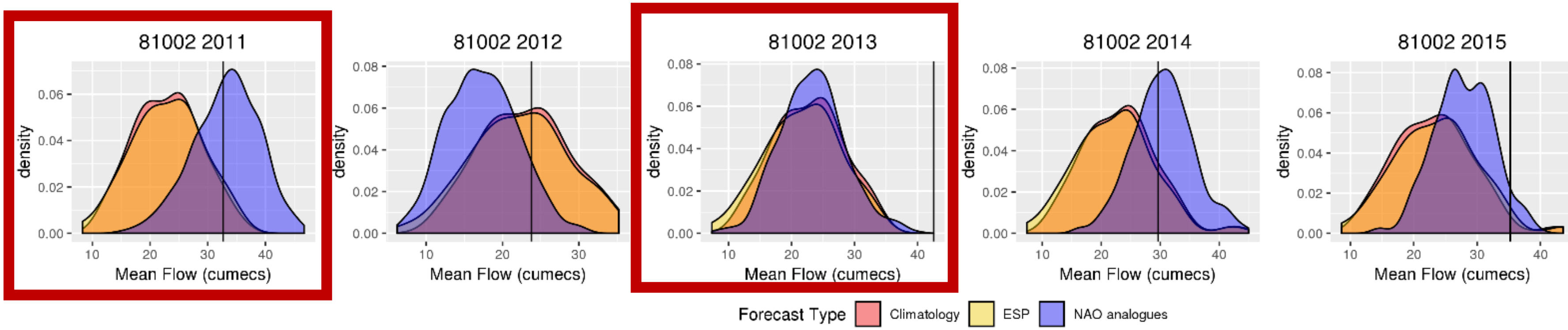


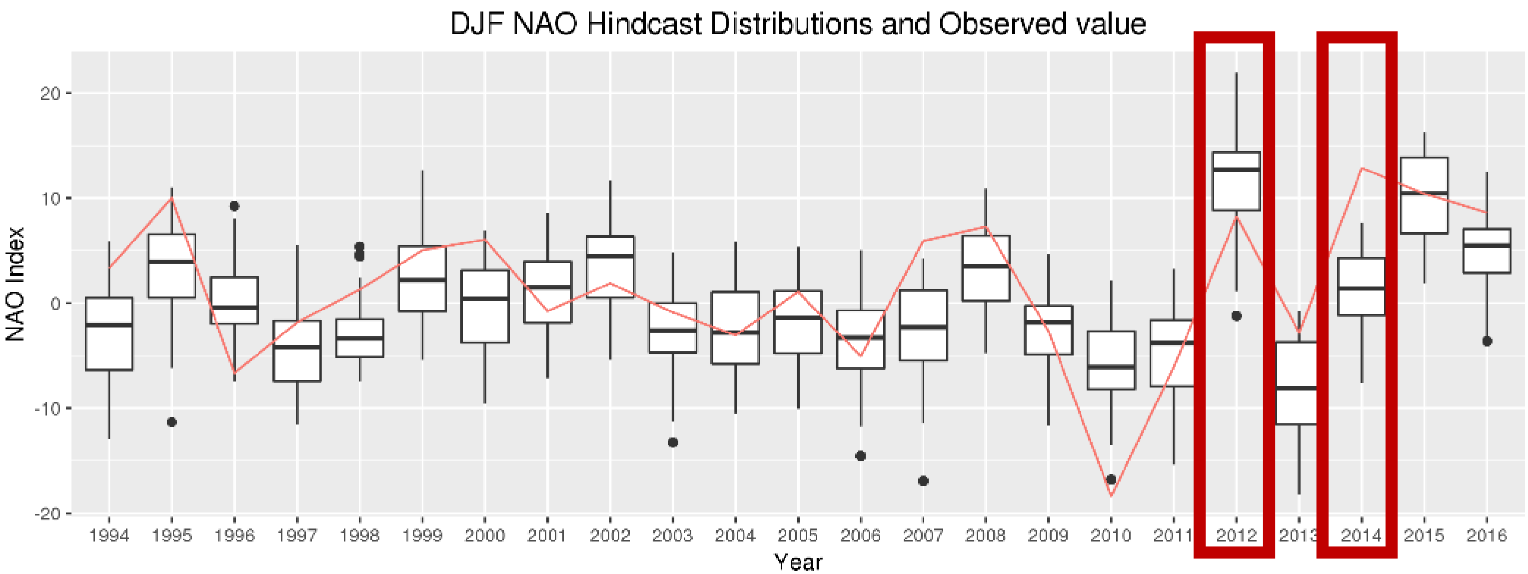


Generally JULES and PGB perform the best, HTESSEL is often too wet

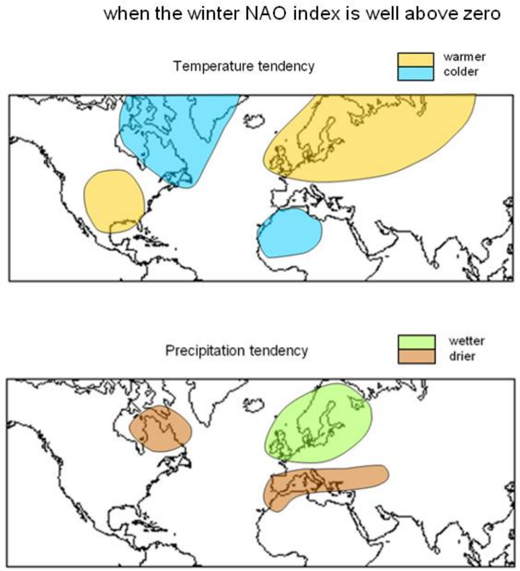
Next Steps

Error Research – Can we Predict NAO ESP Predictability?



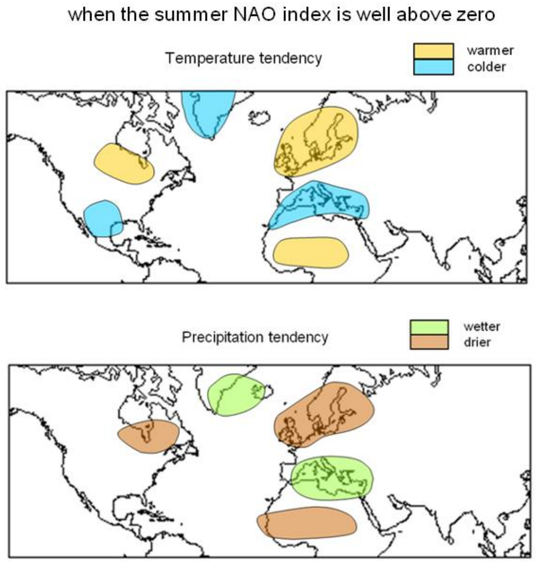


Using NAO analogues for all seasons



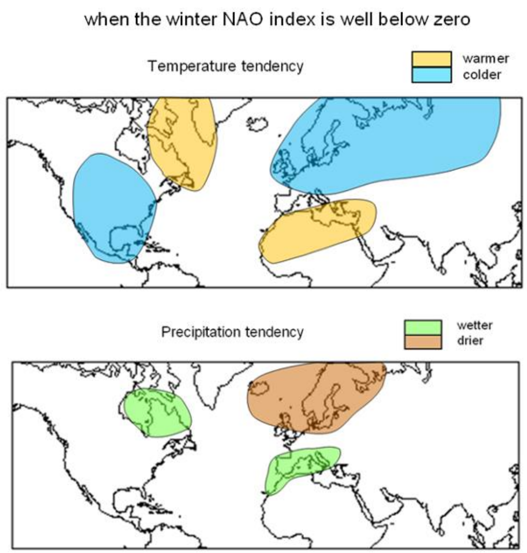
Winter +ve NAO

= warm & wet



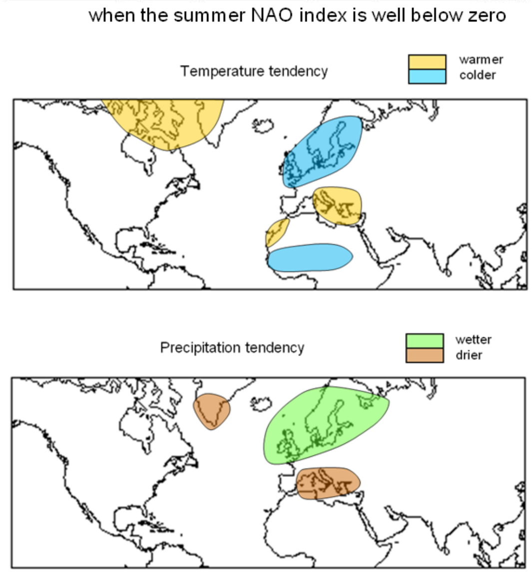
Summer +ve NAO

= warm & dry



Winter –ve NAO

= cold & dry



Summer –ve NAO

= cold & wet

Further work with JULES

- Run a catchment-based JULES in "ESP" mode
- Consider feasibility of running JULES operationally as part of the UK Hydrological Outlook
- Explore the ULYSSES hindcast data for more robust conclusions on climate forecast driven global hydrology model skill in the UK
- Work on model blending and data assimilation – more from Michael next!

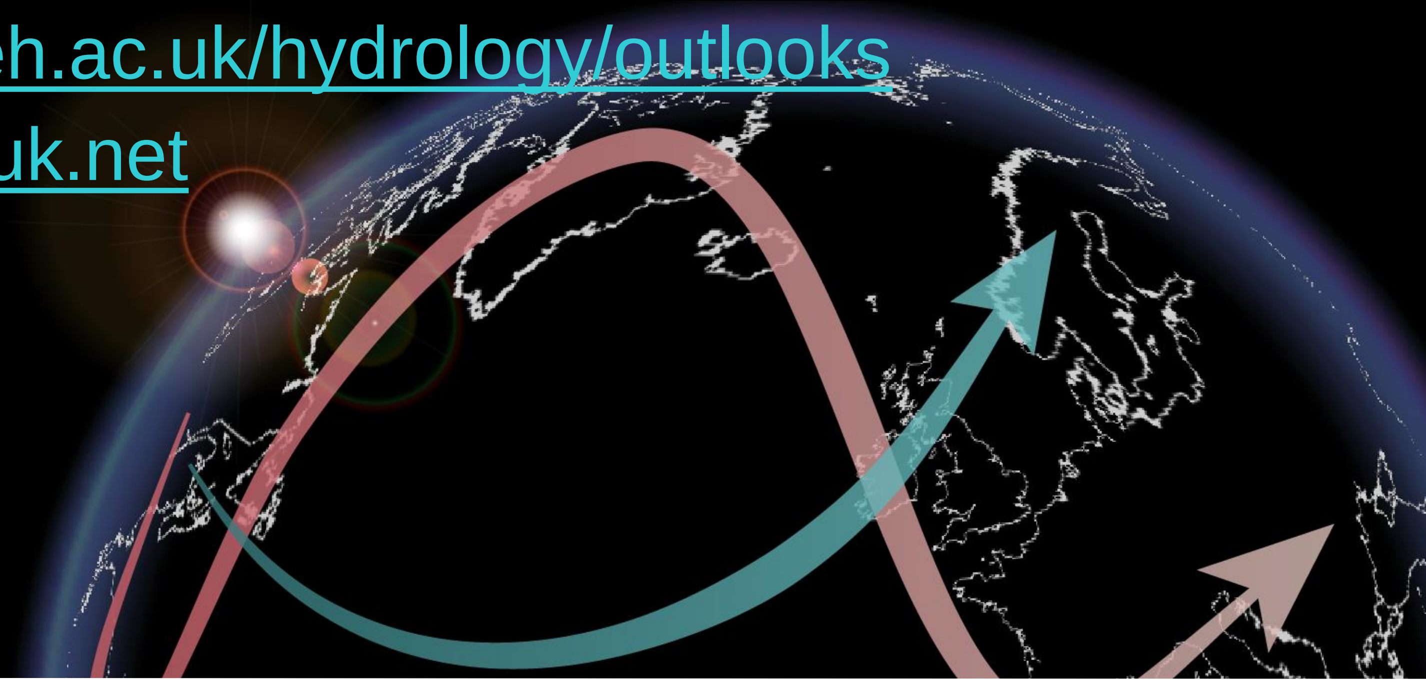
Thank you for listening

katsmi@ceh.ac.uk

@KFacerChilds

https://eip.ceh.ac.uk/hydrology/outlooks

www.hydoutuk.net



Hydro-JULES | UK Centre for Ecology & Hydrology | British Geological Survey | National Centre for Atmospheric Science, Natural Environment Research Council