Mapping Spatio-Temporal Variability in NAO Rainfall Signatures

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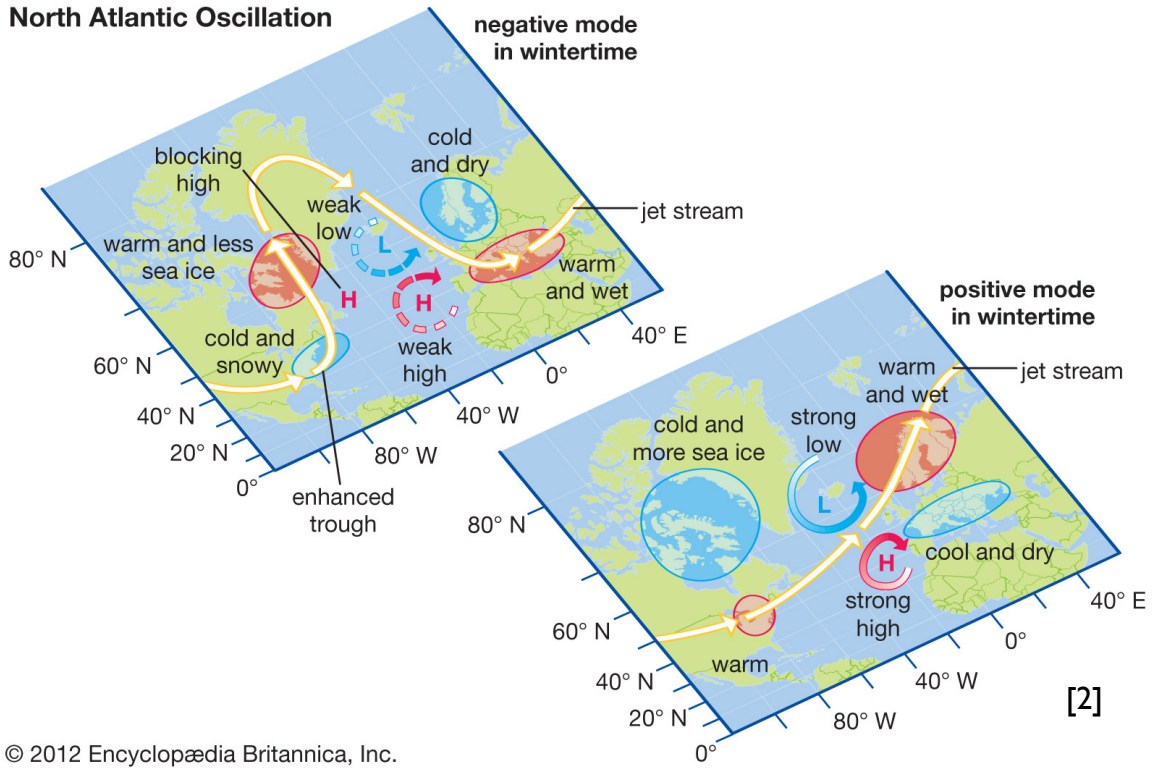
Contents

The North Atlantic Oscillation

- The North Atlantic Oscillation (NAO) has long been recognised as the leading/first mode of climate variability in the North Atlantic region (Hurrell & Van Loon, 1997; Rodwell *et al.*, 1999).
- The NAO teleconnection is defined by the difference in sea level pressure (SLP) between the Icelandic low-pressure action point and the Azores anticyclone.
- Depending on conditions at these two locations the NAO fluctuates between Positive (NAO+) and Negative (NAO-) phases (Hurrell *et al.*, 2003):



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NAO & Rainfall in GB

- **NAO+ and NAO- phases are known to produce characteristic precipitation patterns in Britain:**
  - During the winter in the north-west of the country positive NAO-rainfall correlations are often reported.
  - Meanwhile in the southern and eastern regions of Great Britain weaker negative NAO-rainfall correlations are found.
  - In the summer months NAO-rainfall correlations are typically negative for most of Great Britain.

(Wilby *et al.*, 1997; Folwer & Kilsby, 2002; Burt & Howden, 2013; Rust *et al.*, 2018; Hall & Hanna, 2018; West *et al.*, 2019)

This Study

In this study we aimed to map long-term spatio-temporal historic rainfall signatures using high-resolution Standardised Precipitation Index time series data for Great Britain (Data Source – Tanguy *et al.*, 2017).

1. Average Monthly Rainfall Signatures:

- Firstly, we mapped the distinctive average monthly rainfall signatures of the NAO (i.e. the average spatial distribution of rainfall under NAO+ and NAO- phases per month).
- This analysis shows how the effect of the NAO in rainfall varies in space and time (on average).
- We then statistically examined these average signatures using the Getis-Ord Gi* statistic to explore the structure and significance of the spatial patterns.

2. Space-Time Hot Spot Analysis:

- Secondly, we explored the spatial structure of monthly NAO rainfall signatures across a long historical time period (Jan 1900-Dec 2015) using the Getis-Ord Gi* statistic.
- In doing so we identified the frequency of significant hot/cold spot occurrence allowing us to understand the consistency in the spatial signature of the NAO in rainfall over time.

Data

- Two key datasets were used in the analysis:

1. The North Atlantic Oscillation Index (NAOI):

- The monthly NAOI used in this study was calculated by NCAR (NCAR, 2021) using a Principal Components approach (thus avoiding the limitations associated with station-measured SLP data – Pokorná & Huth, 2015).
- NAO+ phases were identified where the monthly NAOI was >0.502, and NAO- phases where the NAOI was <-0.503 (months between these values were removed from the analysis).

2. Standardised Precipitation Index (SPI):

- To represent rainfall, the SPI was used – calculated with a one-month accumulation period (SPI-1). This was downloaded from UK CEH (Tanguy *et al.*, 2017).
- The SPI-1 data used in this study has a 5km spatial resolution covering Great Britain.
- The SPI-1 data represents monthly rainfall conditions (wet/dry) relative to the standard period 1961-2010.

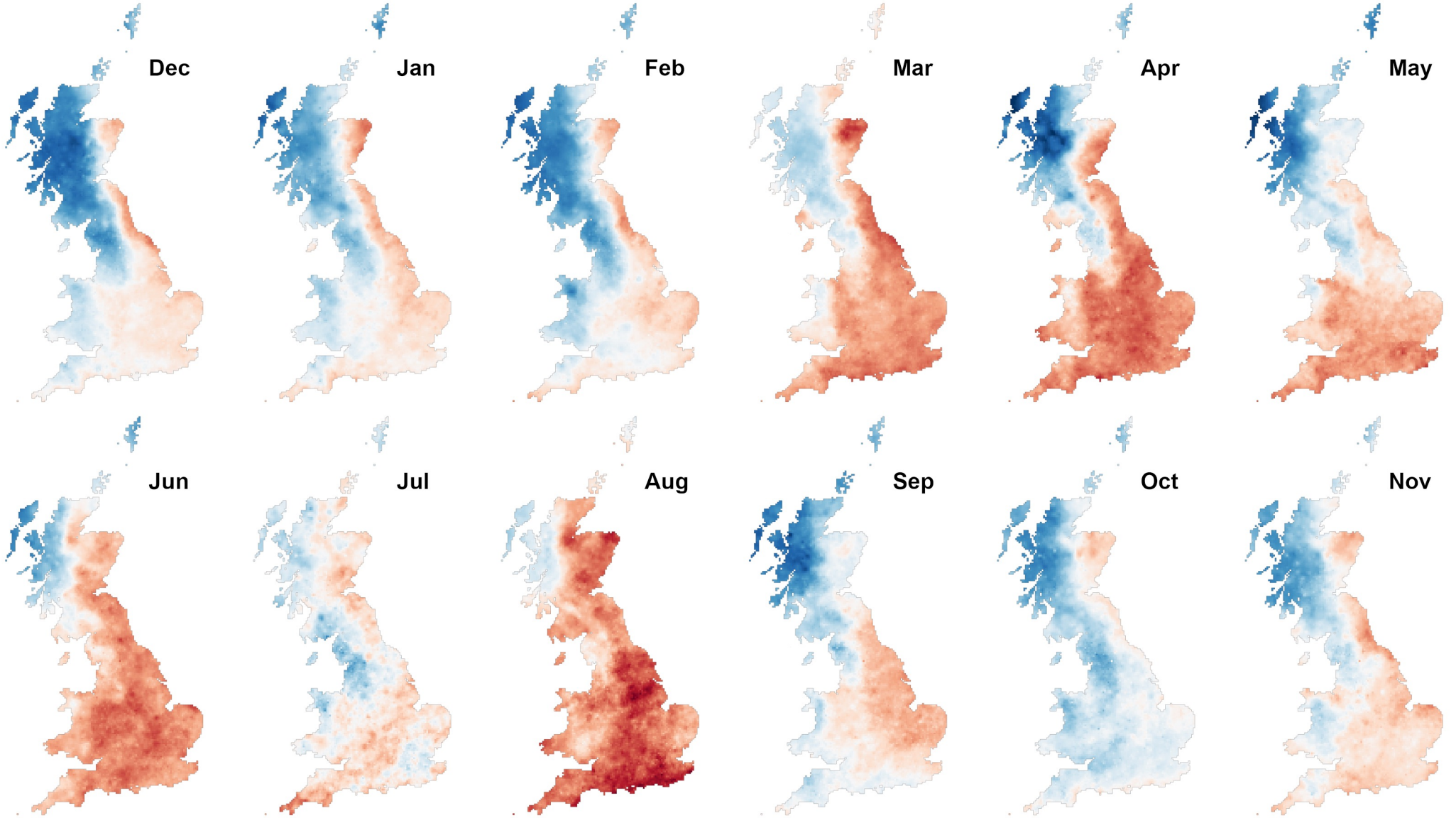
1. Monthly Average SPI

- Using the 5km gridded SPI-1 dataset we first mapped the average monthly SPI-1 under NAO+ and NAO- conditions (as previously defined).
- The results of this analysis are shown on the following two slides.

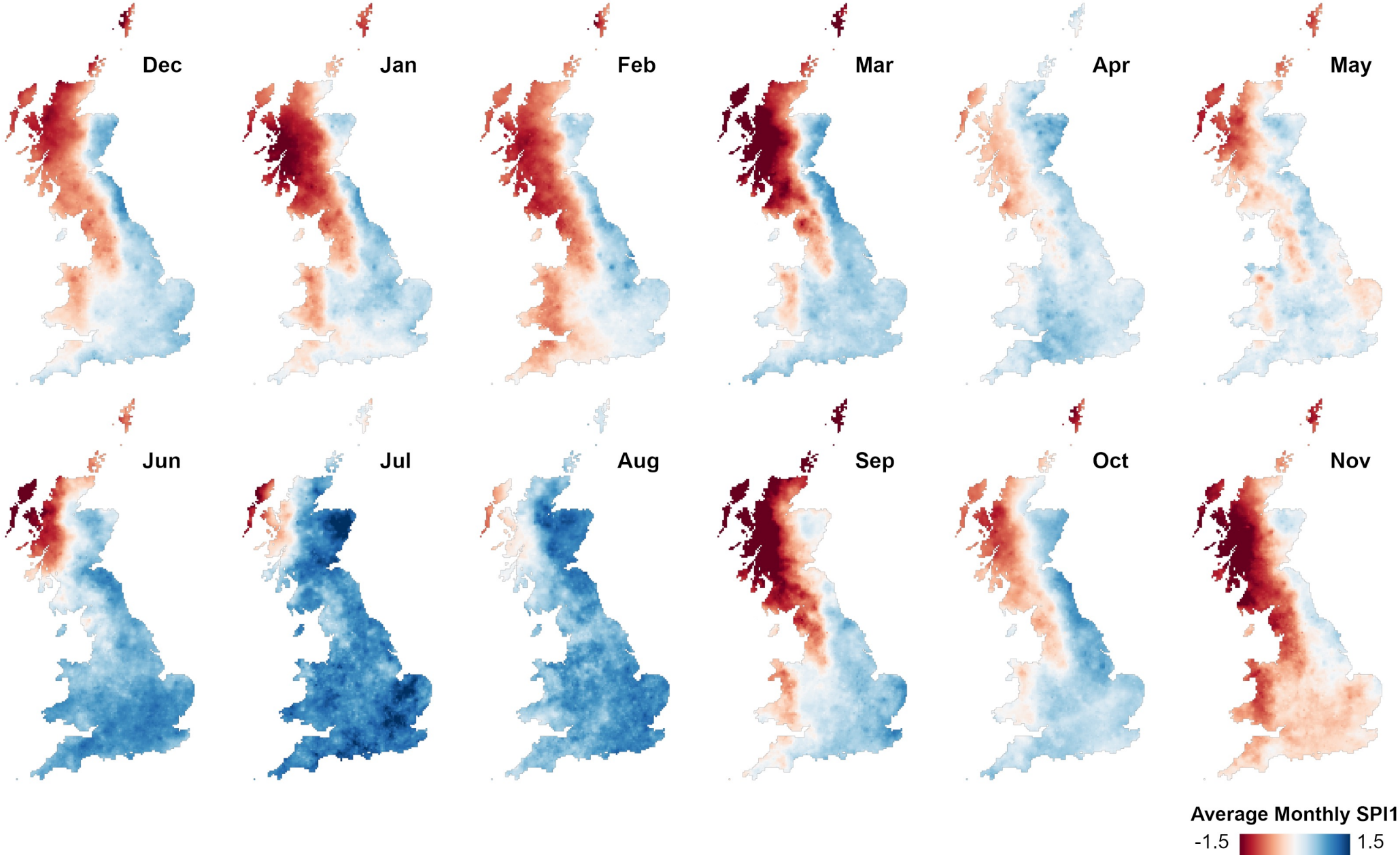
- Under NAO+ conditions the north-west regions on average have higher/positive SPI-1 values indicating wet conditions, and under NAO- average conditions the region is notably dry (negative SPI1 values).
- The inverse average wet/dry response, albeit weaker, is seen in the southern and eastern regions.

- Moving through to the summer months the average NAO-rainfall response becomes more spatially homogenous and the inverse to the wet/dry response in the north-west during winter.

Average SPI: NAO+



Average SPI: NAO-



Monthly Average SPI – Getis Analysis

- We then analysed the statistical significance of the average monthly spatial signatures using the Getis-Ord Gi* statistic (Getis & Ord, 1992).
- The Getis-Ord Gi* statistic is commonly used in health and crime spatial analyses to explore significant hot spots (high value clusters) and cold spots (low value clusters).
- The statistic indicates whether the spatial clustering of high/low values is more pronounced than would be expected in a random distribution of those same values (Esri, 2021).

- Hot spots in this context represent clusters of 5km grid squares (defined using an edges-corners rule) where the SPI-1 values are significantly high, whilst cold spots represent the inverse (low SPI-1 values).
- The Getis-Ord Gi* statistic therefore allows for the identification of statistically significant wet/dry (high SPI1/low SPI-1) spatial patterns to be identified.

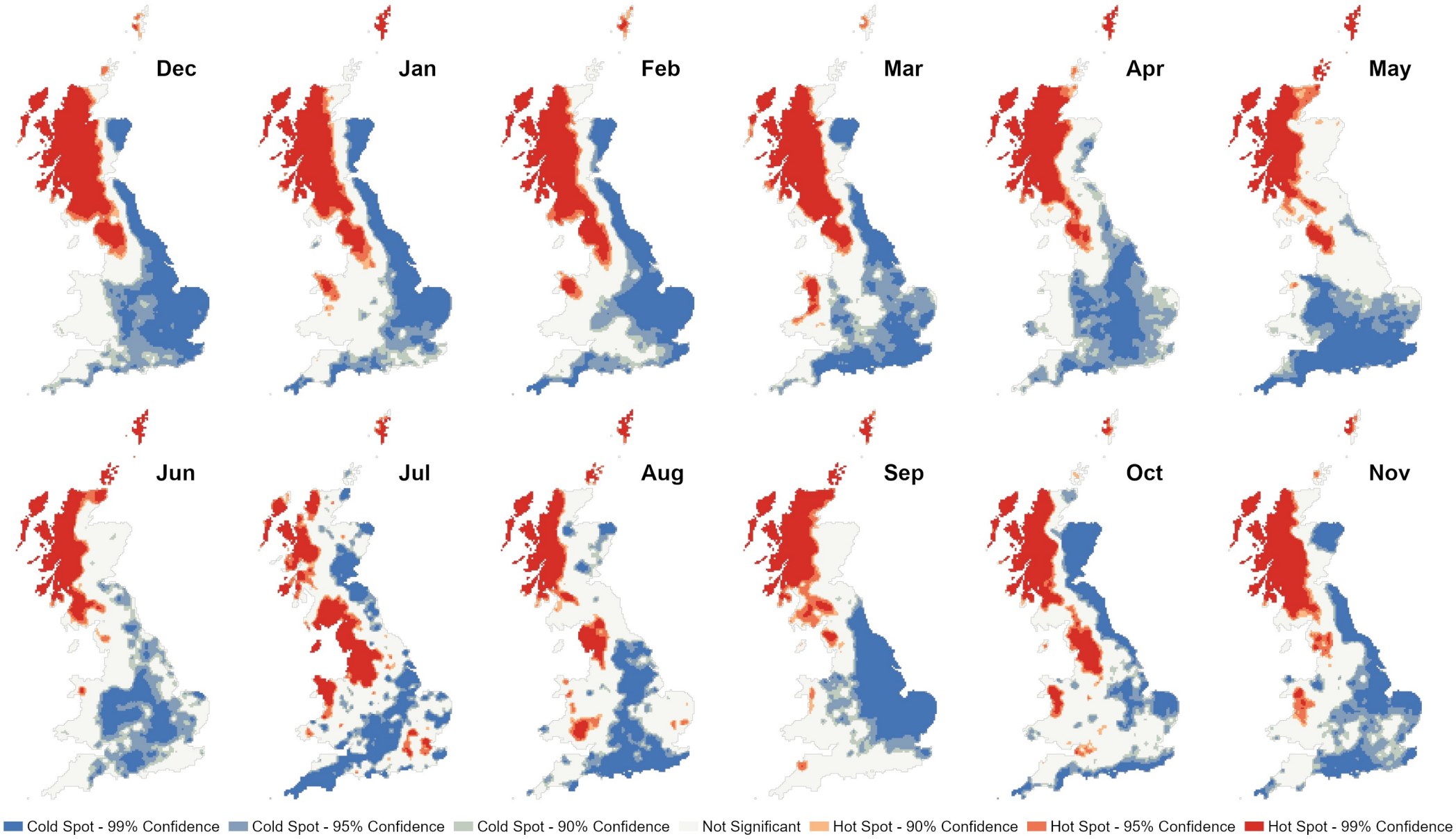
Monthly Average SPI – Getis Analysis

- The results of the Getis-Ord Gi* analysis on the monthly average rainfall signatures is shown on the following two slides.

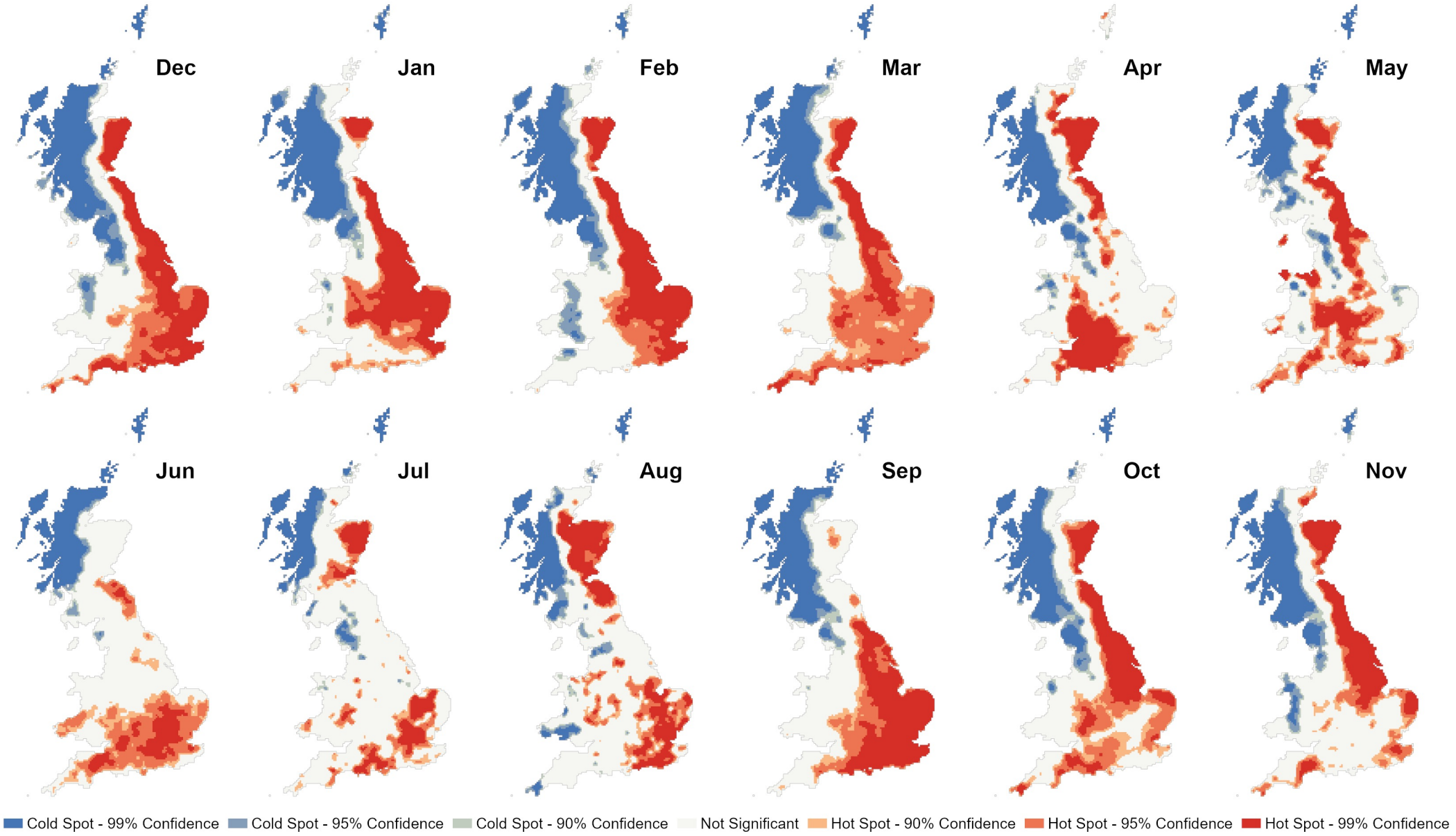
- The north-west/south-east 'wet/dry spatial divide' previously noted in the winter months is marked by the location of spatially extensive hot/cold spots.
- The Getis-Ord Gi* result identifies that the spatial pattern we detect in average winter rainfall under NAO+ and NAO- phases is statistically significant.

- However, as previously noted the spatiality in wet/dry conditions is more homogenous across the country during summer.
- In other words, the 'spatial divide' observed in winter is diluted in summer.
- As a result, the occurrence of significant hot/cold spots is more spatially variable.

Getis Analysis: NAO+



Getis Analysis: NAO-



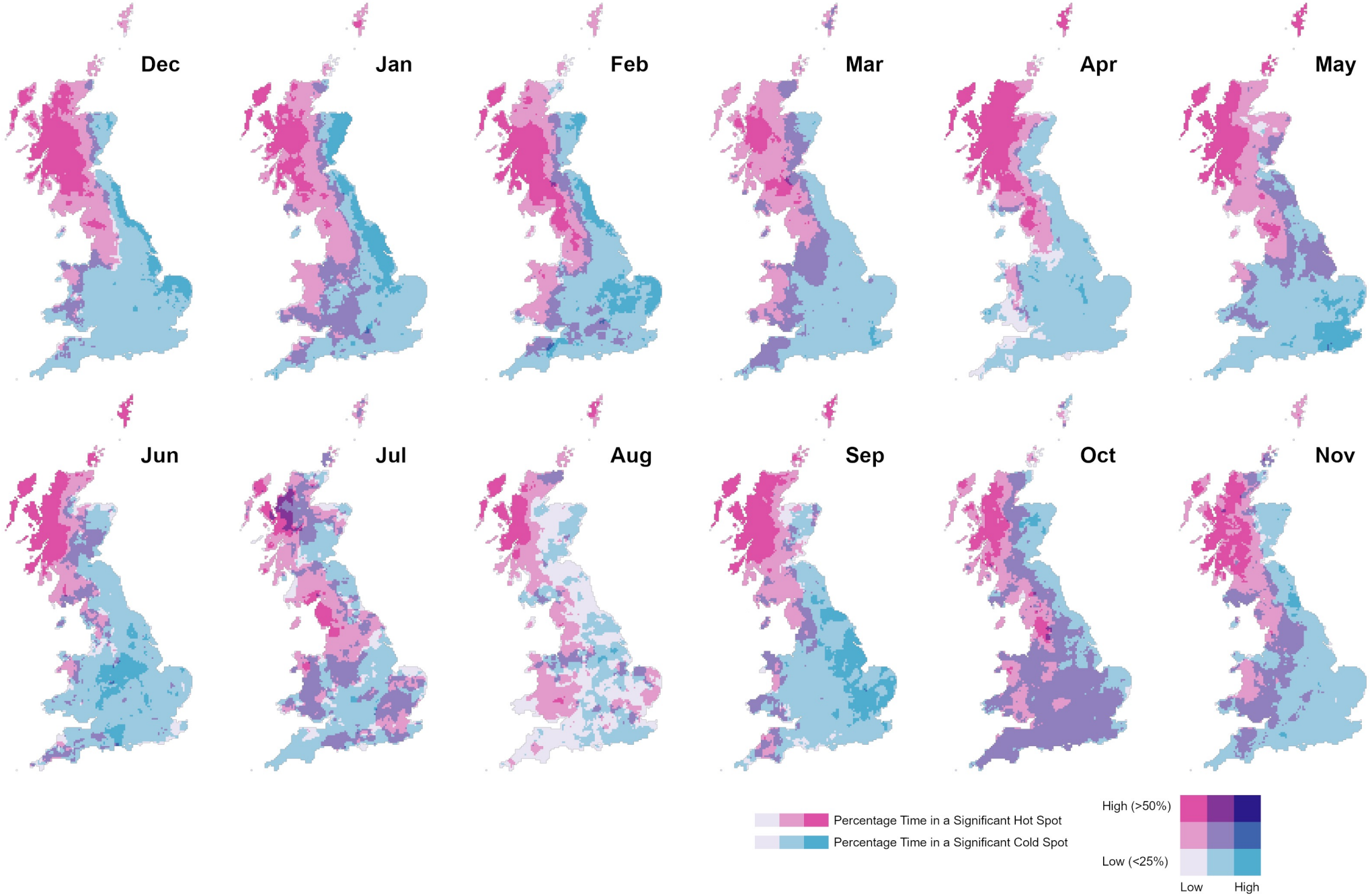
2. Space-Time Hot Spot Analysis

- The results on the previous slides show that the spatial pattern detected in winter NAO-rainfall responses is statistically significant with extensive north-west/south-east hot/cold spots.

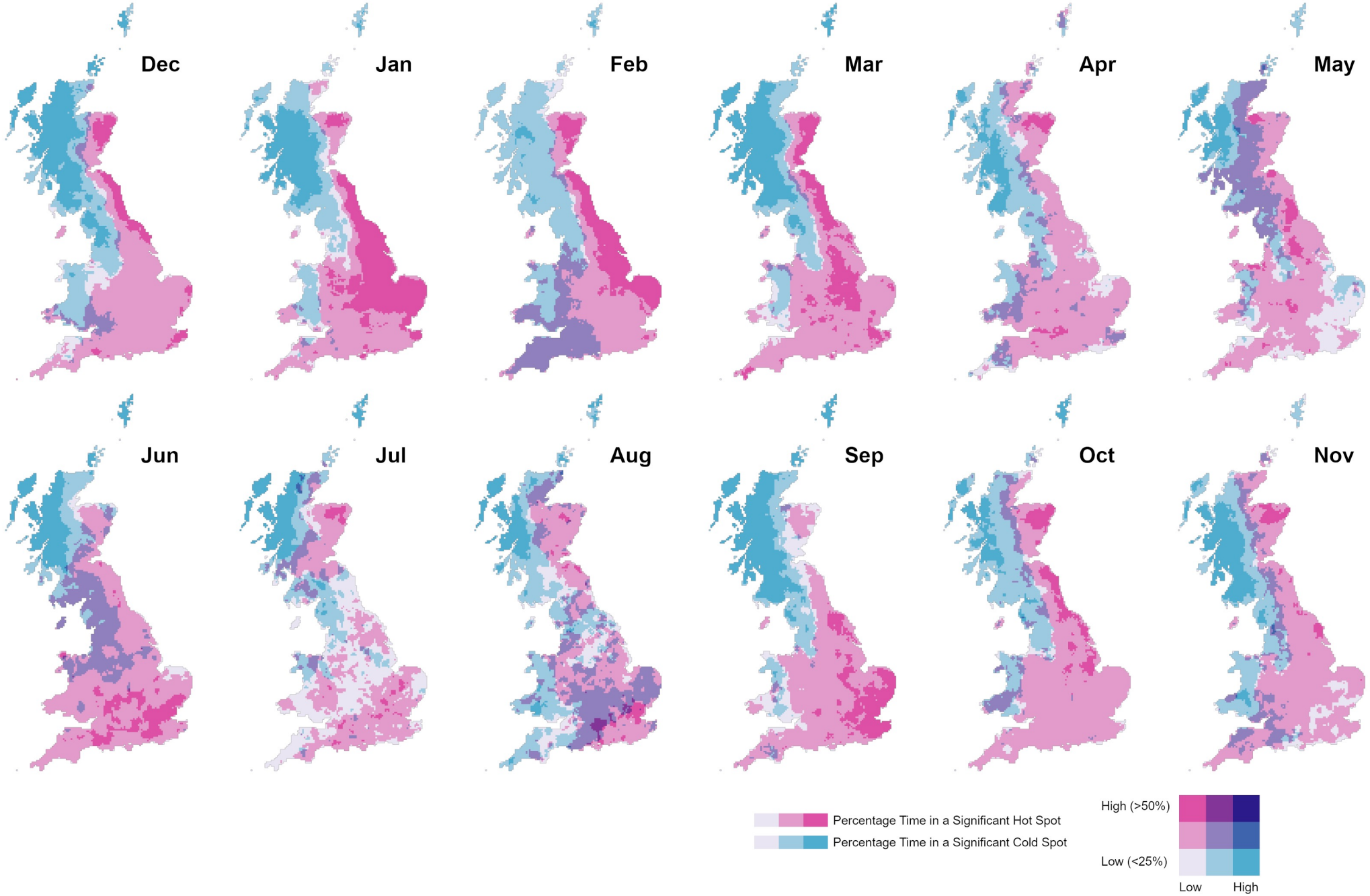
- The final phase of this analysis aimed to explore the consistency of this statistically significant spatial response across time (i.e. the period Jan 1900-Dec 2015).
- To do this a data array was created containing the gridded SPI-1 values for each month under each NAO phase.
- The Getis-Ord Gi* statistic was then calculated on each SPI-1 data layer within the array and the frequency of significant hot/cold spot occurrence mapped.

- The results of this analysis are shown on the next two slides - the mapped results show the percentage of time each 5km grid square was in a statistically significant hot spot (a cluster of high/wet SPI-1 values) or cold spot (a cluster of low/dry SPI-1 values).

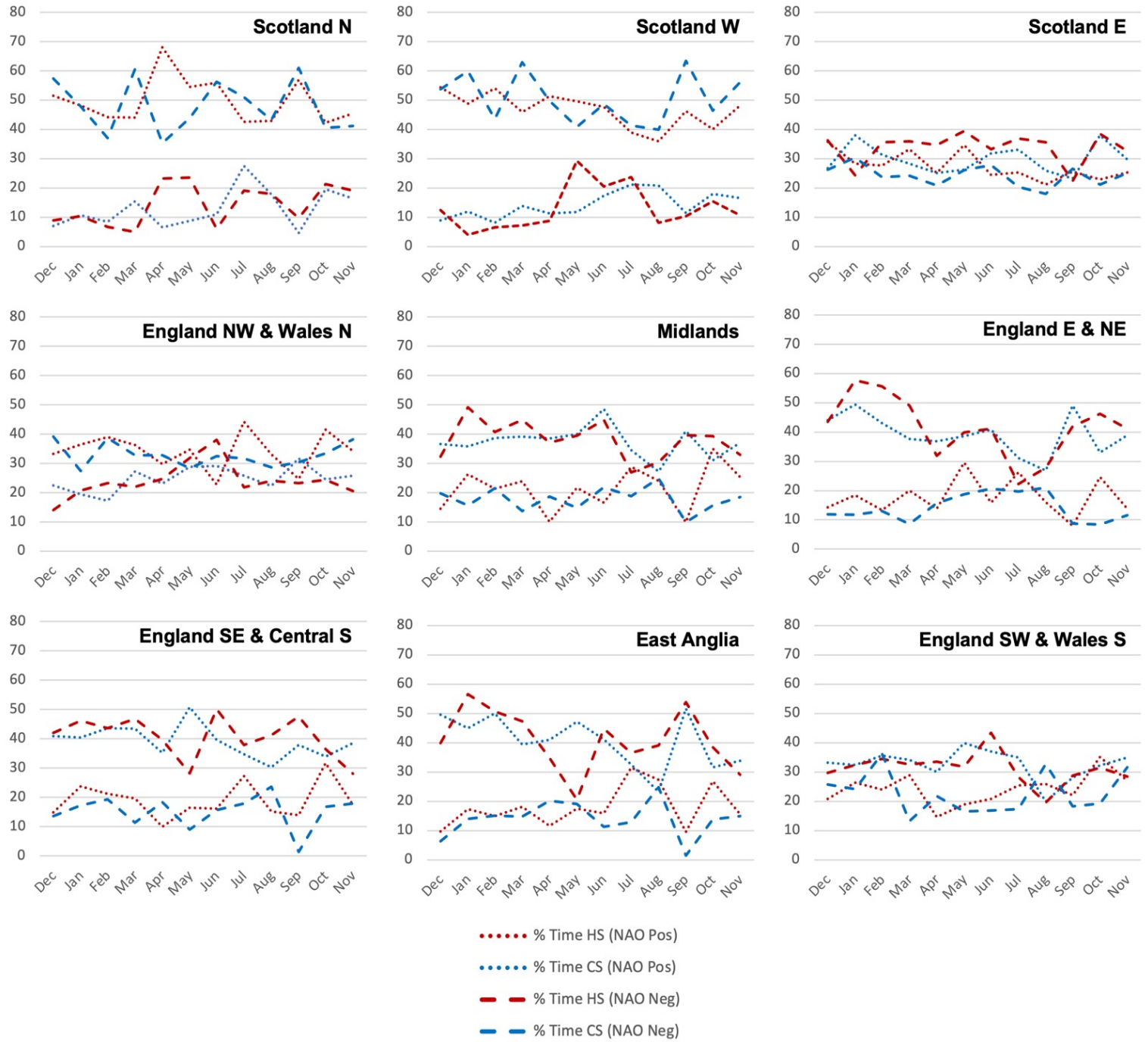
Space-Time Hot Spot Analysis: NAO+



Space-Time Hot Spot Analysis: NAO-



Space-Time Hot Spot Analysis: Regional Analysis



Regional averages of the results mapped on the previous two slides are shown here for the 9 Met Office Climate Districts.

Space-Time Hot Spot Analysis

Winter Months:

- In some regions, looking across the temporal record, the NW/SE opposing response appears to have a relatively high degree of spatio-temporal consistency, for example Scotland North and West, are in a significant hot/cold spot for a relatively high proportion of the time period analyzed.
- This suggests that there is a higher probability that NAO+ and NAO- phases will result in this winter NW/SE statistically significant spatial pattern.

- However, it should be noted that in winter some regions also show small or no differences between the occurrence of significant hot/cold spots, for example Scotland East and England North West and Wales North. Therefore, the effect of the NAO in producing significant wet/dry spatial patterns in these regions is more limited.

Space-Time Hot Spot Analysis

Summer Months:

- As in the previous average rainfall analysis the occurrence of hot/cold spots across the time record is much more spatially variable in the summer months.
- As a result, fewer distinctive patterns are found in the space-time hot spot analysis.
- Most regions show little difference in the occurrence of hot/cold spots in the summer months, with the expectation of Scotland North and West.

Summary

- Our analysis demonstrates a novel application of the Getis-Ord Gi* statistic which allows for statistically significant spatial wet/dry patterns in the monthly SPI data to be mapped for each NAO phase.

- In the winter months in particular, this analysis reveals statistically significant opposing rainfall responses, which appear to have long-term spatio-temporal consistency (over the period Jan 1900-Dec 2015 analysed in this study).
- This is important because as winter NAO forecasting skill improves, the findings of our research enable a more spatially reliable estimate of the likely impacts of NAO-influenced rainfall distribution.

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Image Sources

1. Cover Image - https://www.metoffice.gov.uk/weather/learn-about/weather/atmosphere/north-atlantic-oscillation
2. NAO Phases - https://www.britannica.com/science/North-Atlantic-Oscillation