Royal Geographical Society with IBG
Advancing geography and geographical learning

Lesson 3: Uncovering teleconnection patterns for Europe

Lesson objectives

- To use the online NOAA climate analysis tool to evaluate seasonal correlations between the North Atlantic Oscillation (NAO), rainfall and temperature across northwest Europe
- To use the same tool to explore lagged correlations (and hence potential predictability) of seasonal rainfall and temperature anomalies across the same region

Setting the scene

The El Niño Southern Oscillation (ENSO) is the most important mode of climate variability linked to extreme weather worldwide (Table 1). Here, 'mode' is defined as a recurrent pattern of regional atmospheric and/or ocean circulation that emerges from the apparently chaotic energy, mass and momentum transfers in the climate system. When the tropical Pacific is warmer than average, predictable areas of drought occur in northeast Brazil, east Australia, Indonesia and India, whereas flooding occurs in Peru, Ecuador, parts of the United States. During La Niña the ocean is cooler than average, with patterns of drought and flood now swapped (e.g. there is drought in Peru).
For a brief introduction to El Nino and La Nina see this online animation.

Table 1. Modes of climate variability and their dominant periodicity. Source: Wilby (2017)

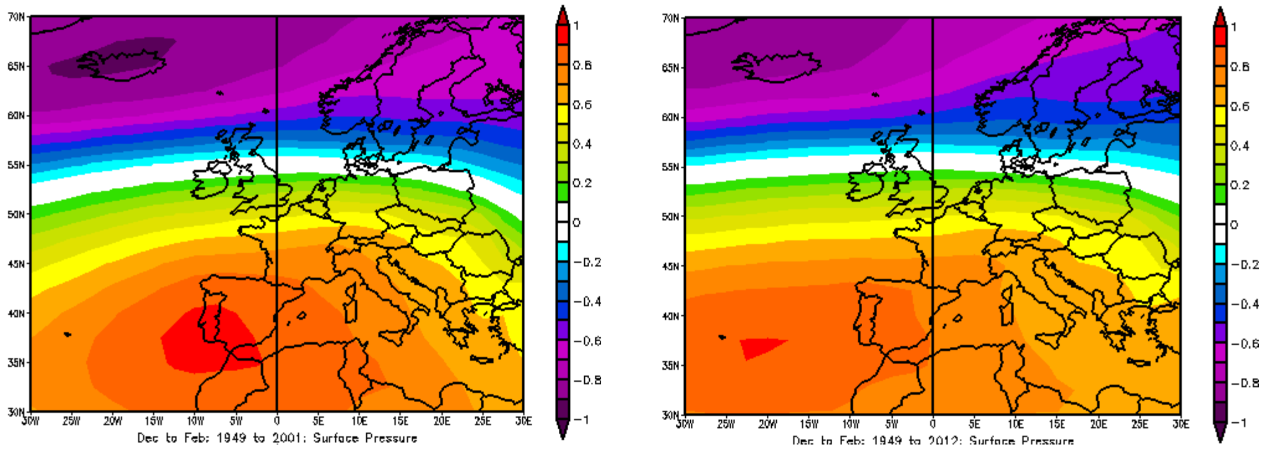
Mode	**Definition**	**Periodicity (years)**
Antarctic Oscillation (AAO) also known as the Southern Annular Mode (SAM)	Oscillation in the surface atmospheric pressure gradients and associated speed of the upper westerly vortex around the south pole.	5-7
Atlantic Multi-decadal Oscillation (AMO)	A coherent pattern of variability in SSTs across the North Atlantic basin.	60-80
Arctic Oscillation (AO)	As for the AAO but around the north pole.	0.5-3
El Niño-Southern Oscillation (ENSO)	Oscillations in the state of the ocean-atmosphere system in the Pacific equatorial region, manifested by warm (El Niño) and cold (La Niña) surface water phases.	2-7
Indian Ocean Dipole (IOD)	Oscillation in the SSTs of the Indian Ocean. During positive (negative) phases SSTs and precipitation in the western Indian Ocean are above (below) average whereas the eastern Indian ocean is cooler (warmer) and drier (wetter) than average.	1.5-10
North Atlantic Oscillation (NAO)	Oscillation in the state of the ocean-atmosphere system in the north Atlantic. During positive (negative) phases there are large (small) pressure differences between the Azores High and the Atlantic Low near Iceland with strong (weak) westerly winds and advection of the Gulf Stream.	5-8
Pacific Decadal Oscillation (PDO)	Oscillation in SSTs in the North Pacific, manifested by positive (negative) phases when waters are anomalously warm (cold) along the Pacific coast yet cold (warm) in the North Pacific.	20-30

The North Atlantic Oscillation (NAO) is the dominant mode of climate variability affecting Europe. This recurrent pattern is characterised by lower than average atmospheric pressure over Iceland and higher than average over the Azores. The **Jones NAO index** is based simply on the pressure difference between these two points (Figure 1, left). Others apply more sophisticated statistical methods such as Principal Components Analysis (PCA) to extract patterns of pressure anomalies over the Northern Hemisphere (Figure 1, right). Both the Jones and PCA indices reveal strong west to east airflows across Europe during positive NAO years. This lesson demonstrates the power of correlation for uncovering relationships between the Jones index and local weather.

Figure 1. Correlation between winter surface (1000 mb) pressure and two NAO indices

Jones NAO index

PCA NAO index



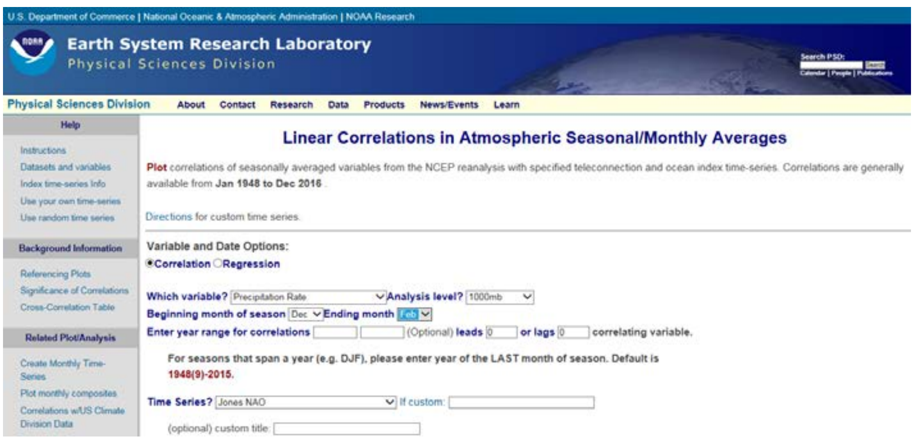
The data

Sea surface temperature (e.g. ENSO) and atmospheric indices (e.g. Jones NAO) are updated every month by the US Climate Prediction Center. Such indices can be related to gridded estimates of surface temperature and precipitation to reveal teleconnection patterns – correlations between slowly varying ocean-atmosphere conditions and regional weather.

This lesson uses publicly available atmospheric circulation indices and climate data from:

(a) The NOAA Earth System Research Laboratory (ESRL) climate data correlation page: http://www.esrl.noaa.gov/psd/data/correlation/

Figure 2. ESRL interface showing selections for correlating the winter (Dec to Feb) precipitation rate versus Jones NAO



(b) The Jones NAO index produced by Phil Jones and Tim Osborn at the Climatic Research Unit, University of East Anglia: https://crudata.uea.ac.uk/~timo/datapages/naoi.htm

(c) Met Office seasonal and annual rainfall totals for 10 UK regions (HadUKP): http://www.metoffice.gov.uk/hadobs/hadukp/

Tasks

1. **Which season (DJF, MAM, JJA, or SON) and area(s) in Europe have the strongest correlation between the Jones NAO and precipitation rate?**
   Use the ESRL tool as a group to explore spatial pattern of correlations between the seasonal '**Jones NAO**' index and '**Precipitation Rate**' across northwest Europe. Use the settings for 'Which variable?', 'Beginning' and 'End' month as shown in Figure 2 (for winter).

   Under 'Plot Options' use the follow settings to replicate the area and projection in Figure 1:
   a) Select the default *Color?* and *Shading Type*;
   b) Ignore *Override default contour interval?* and *Scale Plot Size(%)*;
   c) Select 'Custom' for *Plot Region/Type*;
   d) Enter '30' for *lowest lat* and '70' for *highest lat* use;
   e) Enter '-30' for *western most longitude* and '30' for *eastern most longitude*;
   f) Select 'Cylindrical Equidistant' for *Select projection for CUSTOM*;
   g) Ignore *Choose height range for CROSSECTION*;
   h) Click 'Create plot' to generate the map;
   i) Note the areas with largest and smallest correlation (these are given at the base of the page as 'Global Maximum' and 'Global minimum' values respectively).

   After generating a map for winter, repeat steps a) to i) for spring by changing the *Beginning month of season* from 'Dec' to 'Mar', and *Ending month* from 'Feb; to 'May'. Then repeat for summer (beginning 'Jun', ending 'Aug') and autumn (beginning 'Sep', ending 'Oct').

   Overall, which season and location(s) have the strongest correlations between the Jones NAO and Precipitation Rate?

   Take it further: Repeat the process but this time search for the strongest seasonal correlations between Jones NAO and European 'Air Temperature'.

2. **What is the statistical significance of correlations between NAO and precipitation?**
   The ESRL tool derives the correlation coefficient *r* for every grid-point in the chosen domain using data spanning 1948 to 2016 (or a sub-set within). Use your chosen date range to establish the sample size (*n*). Use a table of critical values (or enter the strongest *r* and *n* values into an online Pearson calculator[1]) to determine the statistical significance of the strongest correlation from Task 1.

   Take it further: Using the same value for *n*, determine the threshold *r* for statistical significance at $p<0.01$. That is the correlation that could have occurred by chance 1% of the time. Vary the start and end dates of your analysis (and hence the sample size). How stable are the *r* values when estimated from different sub-sets of the data?

3. **Which <u>month</u> and location(s) in Europe has the strongest <u>*lagged*</u> correlation between the Jones NAO and Precipitation Rate?** Select the season returning the most highly correlated Precipitation Rate with NAO from Task 1. Vary 'leads' between 0 and 4 months

[1] See for example *Social Science Statistics*: http://www.socscistatistics.com/pvalues/pearsondistribution.aspx

(where 0 month lead is for NAO and precipitation compared using the same seasons, 1 month lead is the NAO index for the month immediately before [i.e. leading] the target precipitation season, and so forth). When and where is the lagged correlation strongest?

Take it further: Repeat the process but this time search for the strongest *lagged* correlations between spring European precipitation and ENSO using the Niño3.4 index (a measure of sea surface temperature anomalies in the central Pacific Ocean). How do the patterns and significance of correlations for ENSO compare with the NAO?

4. **What is the strength of the correlation between the winter NAO and rainfall over Northwest England?**
The link between the NAO and UK rainfall is known to be strongest in upland areas in winter months due to the enhancement of orographic precipitation. Download the Microsoft Excel file ‘L2_Data_HadUKP.xls’, the accompanying ‘Datasheet 3’.

Fill in the missing cells in Table 2. Then calculate the Spearman rank correlation coefficient (using the equation in Box 1) between winter Jones NAO and winter precipitation over Northwest England and Wales (NWEP) (Figure 3) during 1997-2016.

Table 2. Winter Jones NAO index and Northwest England and Wales precipitation (NWEP)

Year	Jones NAO	NWEP (mm)	NAO rank	NWEP rank	Difference (*d*)	Difference squared (d^2)
1997	-0.46	206	15	18	-3	9
1998	0.65	291.6	10	11	-1	1
1999	1.55	309.8	8	8	0	0
2000	2.28	390.4	2			
2001	-0.44	278.7	14	13	1	1
2002	1.02	309.8	9	8	1	1
2003	0.17	246.7	13	14	-1	1
2004	-0.63	325.9	17	6	11	121
2005	0.28	218.4	12	16	-4	16
2006	-0.72	175.6	18			
2007	1.76	383.2	6			
2008	1.70	381.9	7	5	2	4
2009	-0.47	200.9	16	19	-3	9
2010	-3.12	211.6		17		
2011	-1.07	235	19	15	4	16
2012	2.18	295.3	4	10	-6	36
2013	0.47	313.2	11	7	4	16
2014	2.19	428.4		2		
2015	2.06	288.8	5	12	-7	49
2016	2.33	552.9		1		
					Sum d^2	
					Spearman *r*	
					Sample (*n*)	
					Degrees of freedom (*n*-2)	
					Critical *r*	

Figure 3. The homogeneous rainfall regions of the UK.
Source: Met Office Hadley Centre

Box 1. Equation for the Spearman rank correlation coefficient *r*
The Spearman rank correlation coefficient gives the strength of *association* between two variables *x* and *y* (Box 1) but does not establish *causation* between them. This is because the test does not tell whether *x* causes *y* or *y* causes *x*. Moreover, the correlation between *x* and *y* could be due to a third variable *z* related to both. The correlation could also have occurred by chance. $$r = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}$$ where *i* is the i^{th} paired values in a data set of ranked variables ($x_1, x_2 \ldots x_n$) and ($y_1, y_2 \ldots y_n$), each with *n* values and differences $d_i = y_i - x_i$ between paired ranks. The degrees of freedom is the number of pairs minus two (i.e. $n - 2$).

Refer to a table of critical values for Spearman *r*. Enter the degrees of freedom in Table 2, then establish whether your correlation is significant at the 0.05 confidence level[2].

5. What is the expected rainfall over Northwest England when the NAO is strongly positive or strongly negative?
Use the data in Table 2 to create a scatterplot with the Jones NAO as the independent variable and NWEP precipitation as the dependent variable. Add the best fit line.

Estimate the winter rainfall total over Northwest England if (a) the NAO is strongly negative (NAO = -3) or (b) the NAO is strongly positive (NAO = +3). How reliable are winter rainfall estimates over this range?

Take it further: Write down THREE societal implications of shift to more persistent positive NAO phases.

[2] http://webspace.ship.edu/pgmarr/Geo441/Tables/Spearman%20Ranked%20Correlation%20Table.pdf

Plenary
Return to the main lesson question: what is the strength and significance of correlations between the NAO and weather across northwest Europe? Ask the students to review the evidence gathered from Tasks 1 to 5. In what seasons and regions of Europe might there be *useful* predictability of rainfall and/or temperature anomalies? Consider the difference between *statistical* and *practical* significance of correlations.

Divide the group into three sets. Ask each sub-team to list what preparatory actions might be taken by (a) farmers, (b) water companies, or (c) power utilities using long range weather forecasts. Compile a table of ideas in a final plenary discussion.

Further reading
For an operational system for global and continental scale seasonal forecasting, see: the International Research Institute for Climate and Society Seasonal Climate Forecasts
http://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts/