Modes of Variability affecting southwestern Europe

Belén Rodríguez-Fonseca[1,2], María Jesús Casado[3], David Barriopedro[1,2]

1 Departamento de Física de la Tierra, Astronomía y Astrofisica I, Facultad de Físicas, Universidad Complutense de Madrid, Spain

2 Instituto de Geociencias, IGEO, UCM, Consejo Superior de Investigaciones Científicas, Spain

3 Agencia Estatal de Meteorología, AEMET, Madrid, Spain

Introduction

Atmospheric variations may result from external forcing, but also naturally from internal interactions between components of the climate system. A closer inspection of the spatial structure of the atmospheric variability, in particular on seasonal and longer time-scales, shows that it occurs predominantly in preferred large-scale and geographically anchored spatial patterns, known as teleconnection patterns (TP). TP can vary in intensity and position at seasonal, interannual and decadal time scales (Wallace and Gutzler, 1981; Trenberth et al., 1998; Quadrelli and Wallace, 2004). They are regional in nature and shaped by wave processes, reflecting zonal mean anomalies and connections via other components of the climate system, especially the ocean (Liu and Alexander, 2007). Thus, TP are related to circulation types (Casado et al., 2008) and have an impact on other atmospheric surface variables such as temperature and precipitation.

Southwestern Europe, where the Iberian Peninsula is located, is mainly under the influence of the subtropical Azores high pressure system. This subtropical anticyclone exhibits meridional displacements along the seasonal cycle, inducing changes in the mean climatic conditions of this area.

The most important TP affecting the southwestern Europe is the North Atlantic Oscillation (NAO; Trigo et al., 2002), which is associated with changes in the meridional gradient between the subpolar and subtropical pressure systems. NAO explains a large part of the precipitation variability over Europe, mainly in winter, in such a way that positive phases of this oscillation are associated with an increase of precipitation over northern Europe and a decrease towards the south-western European continent. NAO also affects temperature, winds and other variables impacting climate and society. Apart from NAO, other TP affecting Europe are the East Atlantic/Western Russia (EA/WR), East Atlantic (EA) and Scandinavian (SCAND) patterns (García-Herrera and Barriopedro, 2017).

The atmosphere responds to other components of the climate system through excited Rossby waves and localized eddy–mean flow interactions, which can both result in regional teleconnection patterns (Liu and Alexander, 2007). Due to the large heat capacity of water when compared to the atmosphere, ocean subsurface can store energy for several months and release it later as latent and sensible heat fluxes which, in turn, can alter the global circulation of the atmosphere, triggering in this way, teleconnections. Sea surface temperature (SST) variability is used as a measure of the associated oceanic energy to be released. This is the basis of seasonal to decadal predictability (s2d). In particular, El Niño is the leading natural variability mode at global scale, determining most of the year-to-year global climate variability, including its impact on southwestern Europe (Brönnimann et al., 2007). Its Atlantic counterpart, with similar dynamics, is the Atlantic Niño, which is the main source of SST variability in the Tropical Atlantic at interannual time scales (Polo et al., 2008). Both, Atlantic and Pacific Niños are very much linked and cannot be considered as independent modes of variability (Rodriguez-Fonseca et al., 2009; Martín-Rey et al., 2014; Martín-Rey et al., 2015; Polo et al., 2015). Also, Tropical North Atlantic (TNA) variability cannot be isolated from ENSO (García-Serrano et al., 2017) and has a significant influence on the atmospheric circulation of the Atlantic-European sector and in particular in the Iberian Peninsula in both early winter and spring (Rodríguez-Fonseca et al., 2006).

Climate models are generally able to simulate the gross features of many of the modes of variability, and to provide useful tools for understanding how they might change in the future (Müller and Roeckner, 2008; Handorf and Dethloff, 2009). The most recent IPCC report includes a chapter devoted to the analysis of climate phenomena, in particular the main modes of variability, and their relationship with current and future regional climate (IPCC, AR5, Christensen et al., 2013).

In the former CLIVAR-Spain assessment, Rodríguez-Fonseca and Rodríguez-Puebla (2010) discussed the studies about atmospheric teleconnection patterns affecting the Iberian Peninsula, including possible predictability, with special emphasis in the NAO, and analyzing interactions with the ocean. Since then, a great progress has been made on the development of applications on subseasonal to decadal forecasts (s2s and s2d, Vitart et al., 2012). The availability of results from the Climate system Historical Forecasting Project (CHFP; Tompkins et al., 2017) and the Coupled Model Intercomparison Project (CMIP5), together with very active investigations in both operational and research communities, have improved and will continue to enhance our abilities to make skillful predictions and projections in the region. The present review collects most of the works dealing with TP affecting the Euro-Mediterranean region done from 2010, with special attention to internal vs. forced variability, predictability at different timescales and future projections.

Patterns affecting Southwestern Europe atmospheric variability and potential precursors

New studies have been done in the last years relating NAO with winter precipitation, winds and temperature, including extremes over the western Mediterranean region (Vicente-Serrano et al., 2009; Lorenzo et al., 2008; Jerez et al., 2013; Casanueva et al., 2014 Vicente-Serrano et al., 2009; Lorenzo et al., 2008). Also during this season, recent studies have found how positive phases of the NAO could act as precursors of explosive cyclones affecting Europe (Gómara et al., 2014).

Apart from NAO, recent studies point to combinations with other TP, as SCAND and EA, to explain climate variability in the region (Comas-Bru and MacDermott, 2014). From a more regional perspective, patterns such as the Mediterranean Oscillation (MO) and the Western Mediterranean Oscillation (WeMO) (Martin Vide and López-Bustins, 2006; Vicente-Serrano et al, 2009; Lana et al., 2016) are also important in the description of the atmospheric variability of the southwestern Europe. Together with the NAO, the westerly index (Barriopedro et al., 2014), a measure of the frequency of westerly winds over the English Channel, have been found to explain the drought variability across Europe (Vicente-Serrano et al. 2016).

In seasons other than winter, the NAO presents a less zonal structure due to the weakening of the extratropical jet, and other TP may be more influential on European climate (García-Herrera and Barriopedro, 2017). For example, during autumn, global atmospheric patterns project better on an EA-like pattern, whose structure and associated impacts depend on the background mean flow, therefore experiencing low-frequency oscillations. Thus, its annular structure has been active in the most recent decades, while a wave-4 pattern was dominant in the decades before (King et al., 2017). As compared to the winter NAO, the leading mode of variability in high-summer (July-August), also known as the summer NAO, is more regional and shifted northwards. Different to the winter NAO, its largest impacts over the Iberian Peninsula are detected, although weak, in maximum temperatures (Favà et al., 2016).

There is a clear non-stationary relationship between the winter NAO and European precipitation (Hertig et al., 2015). Several hypotheses have been formulated to explain this non-stationarity, including modifications in the meridional pressure gradient (Zveryaev, 2006), North Atlantic air-sea dynamics and variability in the Atlantic Meridional Overturning Circulation (AMOC) (Walter and Graf, 2002; Gómara et al., 2016), solar activity (Gimeno et al., 2003) and variability in the NAO pressure centers (Haylock et al., 2007; Vicente-Serrano and Lopez-Moreno, 2008).

In winter, the NAO is also modulated by ENSO, whose teleconnections over Europe might involve both a tropospheric pathway and a stratospheric one (Butler et al., 2014). The persistence of the wintertime ENSO signal in the stratosphere and air-sea interactions in the North Atlantic allow the winter ENSO signal to persist until the following spring (Herceg-Bullick et al., 2017). In this season, although El Niño influence on the North Atlantic has been related to a negative phase of the NAO (Brönnimann et al., 2007; Vicente Serrano et al., 2008, García-Serrano et al., 2011), this influence has been found to be non-stationary on time, depending on the slowly variant background of the ocean (Greatbach et al., 2004; Zanchettin et al., 2008; López-Parages and Rodriguez-Fonseca, 2012; López-Parages et al., 2015; López-Parages et al., 2016; King et al., 2017). In this way, the state of multidecadal variability of the north Atlantic SST determines the effectiveness of ENSO teleconnection. Moreover, two ENSO flavours have been reported, referred to as Eastern Pacific (EP) and Central Pacific (CP), with different winter teleconnections over Europe (Calvo et al., 2017). Their influence on southwestern Europe has also changed with time, being the EP warm events during negative Atlantic Multidecadal Oscillation (AMO) periods the combination with the largest impacts on European rainfall (López-Parages et al., 2016). Also, the Tropical North Atlantic region (TNA) has a significant influence on the atmospheric circulation in the Atlantic-European sector and in particular in the Iberian Peninsula in early winter and spring, also in relation to ENSO (Frankignoul et al., 2003; Rodríguez-Fonseca et al., 2016; King et al., 2017).

The impact of the Atlantic Niño decaying phase is mainly determined by the climatological jet stream's position and intensity, showing an arching pattern over the North Atlantic region during summer–autumn, and a zonally oriented wave train during autumn–winter (García-Serrano, 2011). Nevertheless, summer Atlantic Niño presents different impacts on summer Mediterranean climate depending on the state of the rest of the tropical oceans (Losada et al., 2012). Mediterranean SST anomalies also influence the Northern Hemisphere atmospheric circulation (García-Serrano et al., 2013; Sahin et al., 2015) affecting late summer temperatures.

Finally, at decadal time scales, the AMO (Ortiz Bevia et al., 2016; Zampieri et al., 2017) has been found to influence the length of the summer in southern Europe (Peña-Ortiz et al., 2015) and weather regimes at Mediterranean region in summer. Also, a coupling between Indian and southern European summer rainfall has been found after the late 1970s (Lin et al., 2017).

In addition to the ocean, other predictors are being defined for the better assessment of TP. The stratosphere (Scaife, 2005; Palmeiro et al., 2017), the Madden Julian Oscillation (Cassou, 2008; Schwartz et al., 2017), Eurasian snow cover (Orsollini et al., 2016), and the Arctic sea-ice extension (García-Serrano et al., 2015) have been pointed out to be determinant for the correct assessment of predictability in the Euro-Atlantic sector at subseasonal timescales.

Predictions and Future Projections

The evidence for potential seasonal predictions of the winter NAO has recently increased (Scaife et al., 2014; Athanasiadis et al., 2017), while a similar progress has not been achieved for other seasons or TP. Multiple studies have shown a potential for improved North Atlantic predictability at seasonal timescales based on two main predictors: ENSO and sudden stratospheric warming (SSW) events (Barriopedro and Calvo, 2014; Domeisen et al., 2015; Butler et al., 2016).

There are suggestions of extended skillful predictions of the NAO one year ahead with two sources of skill for the second-winter forecasts: the climate variability in the tropical Pacific region and the effect of solar forcing on the stratospheric polar vortex strength (Dunstone et al., 2016).

Multi-model decadal prediction exercises (Doblas-Reyes et al., 2013) have demonstrated the large potential for useful interannual-to-decadal prediction of European climate (Guemas et al., 2015; Lienert et al., 2017). The forecast information comes mainly from the warming trend in the case of temperature, but also from the AMO.

The Mediterranean is considered a 'hot spot' for climate change, due to the expected warming and drying of the region. While thermodynamically-induced changes due to greenhouse gases (GHG) forcing are robust, there are considerable uncertainties in the future projections of atmospheric circulation and variables related with dynamical processes, e.g., precipitation (Shepherd, 2014), so that large ensemble simulations are essential to estimate the probabilistic distribution. Regarding future projections of TP, Gonzalez-Reviriego et al. (2014) have found a positive trend for the NAO and a negative trend for the SCAND pattern under future SRES A1B climate change scenario. This result is in line with recent multi-model studies of NAO (Gillett and Fyfe, 2013) showing a small positive response of boreal winter NAO indices to GHG forcing. NAO will continue to influence precipitation and temperature in coming decades (López-Moreno et al., 2011), with the positive winter NAO trend in the future potentially leading to an increase in the frequency of dry conditions in the Iberian Peninsula. Moreover, as the simulations indicate a steady increase in temperature (see Serrano and Camino, this issue), winters classified as "cold" in the 21st century will be noticeably rarer compared with recent decades.

Bladé et al. (2012a, 2012b) examined the future summer NAO trend in CMIP3 models. They found an overall positive trend, albeit with a large spread in magnitude, which accounts for a large fraction of the projected multi-model mean precipitation reduction in northwest Europe. These changes should also lead to modest precipitation increases in the Iberian Peninsula, where the observed correlation between the SNAO and summer precipitation is weakly positive, partially offsetting some of the thermodynamically-induced drying in the region. However, this effect is not captured by the CMIP3 models, because those models do not correctly represent the surface signatures of the summer NAO.

Climate regime shifts are projected under future scenarios including a strengthening and eastward extension of the North Atlantic storm track towards western Europe (Feng et al., 2014). The atmosphere-ocean coupling shapes distinct responses of Atlantic Niño under GHG forcing (Mohino and Losada, 2015) with uncertainties in ocean circulation changes accounting for much of the projected spread in storm tracks (Woollings et al., 2012).

Regional future projections indicate a generalized increase of heatwaves and drought severity in the region (Jacob et al., 2014; Vicente-Serrano et al., 2014). Despite this, Atmospheric Rivers (ARs), which trigger intense precipitation and floods over continental areas, are projected to transport an increased amount of vertically integrated water vapor, producing extreme precipitation along the Atlantic European Coasts from the Iberian Peninsula to Scandinavia (Ramos et al., 2016). In relation to explosive cyclones, although most of them occur north of southwestern European region, abrupt southward shifts of the NAO, modulated by changes in the AMOC, could lead to more frequent events over the subtropical European regions (Gómara et al., 2016).

Similarly to the last decades, in the 21st century, multidecadal fluctuations of the oceans are expected to act as a switch for global teleconnections, enhancing predictability during certain decades (López-Parages et al., 2015). In this way, the decadal variability that will accompany the projected forced changes in the Mediterranean region should be considered in the development of future climate outlooks (Mariotti et al., 2015).

Acknowledgements
The authors would like to thank all the Spanish community working on teleconnections affecting southwestern Europe for the effort done in the last seven years, regardless of the reduction of national funds. Also, the authors would like to thank Francisco Doblas-Reyes and Ileana Bladé for their contributions in the text.

References
Athanasiadis, P. J., Bellucci, A., Scaife, A. A., Hermanson, L., Materia, S., Sanna, A., ... & Gualdi, S. (2017). A Multisystem View of Wintertime NAO Seasonal Predictions. J. Climate, 30(4), 1461-1475.

Barriopedro, D., Gallego, D., Alvarez-Castro, M. C., García-Herrera, R., Wheeler, D., Pena-Ortiz, C., and Barbosa, S. M. (2014). Witnessing North Atlantic westerlies variability from ships' logbooks (1685–2008). Clim. Dyn., 43(3-4), 939-955.

Barriopedro D., Calvo N., 2014. On the relationship between ENSO, Stratospheric Sudden Warmings and Blocking. J. Climate, 27 (12), 4704 - 4720, doi: 10.1175/JCLI-D-13-00770.1

Bladé, I., Fortuny, D., van Oldenborgh, G.J. and Liebmann, B. (2012a). The summer North Atlantic Oscillation in CMIP3 models and related uncertainties in projected summer drying in Europe. J. Geophys. Res.: Atmospheres (1984–2012) 117 (D16).

Bladé, I., Liebmann, B., Fortuny, D. and van Oldenborgh, G.J., 2012b. Observed and simulated impacts of the summer NAO in Europe: implications for projected drying in the Mediterranean region. Clim. Dyn., 39 (3-4), 709-727.

Brönnimann, S., Xoplaki, E., Casty, C., Pauling, A., & Luterbacher, J., 2007. ENSO influence on Europe during the last centuries. Clim. Dyn., 28(2-3), 181-197.

Butler, A. H., Arribas, A., Athanassiadou, M., Baehr, J., Calvo, N., Charlton-Perez, A., Déqué, M., Domeisen, D. I. V., Fröhlich, K., Hendon, H., Imada, Y., Ishii, M., Iza, M., Karpechko, A. Yu., Kumar, A., MacLachlan, C., Merryfield, W. J., Müller, W. A., O'Neill, A., Scaife, A. A., Scinocca, J., Sigmond, M., Stockdale, T. N. and Yasuda, T., 2016. The Climate-system Historical Forecast Project: do stratosphere-resolving models make better seasonal climate predictions in boreal winter?. Q.J.R. Meteorol. Soc., 142, 1413–1427, doi:10.1002/qj.2743.

Calvo, M. Iza, M.M. Hurwitz, E.Manzini, C.Peña-Ortiz, A.H. Butler, C.Cagnazzo, S. Ineson, and C.I. Garfinkel., 2017. Northern Hemisphere Stratospheric Pathway of different El Niño flavors in Stratosphere-Resolving CMIP5 models. J. Climate, 30, 4351–4371, doi: 10.1175/JCLI-D-16-0132.1

Casado, M.J., Pastor, M.A., Doblas-Reyes, F.J., 2008. Euro-Atlantic circulation types and modes of variability in winter. Theoretical Applied Climatology, 96, 17-29, doi: 10.1007/s00704-008-0036-2.

Casanueva Vicente, A., Rodríguez Puebla, C., Frías Domínguez, M. D., & González Reviriego, N., 2014. Variability of extreme precipitation over Europe and its relationships with teleconnection patterns.

Cassou, C., 2008. Intraseasonal interaction between the Madden-Julian oscillation and the North Atlantic Oscillation. Nature, 455(7212), 523.

Christensen, J. H., Kanikicharla, K. K., Marshall, G., & Turner, J. (2013). Climate phenomena and their relevance for future regional climate change.

Comas-Bru, L., & McDermott, F., 2014. Impacts of the EA and SCA patterns on the European twentieth century NAO–winter climate relationship. Quarterly Journal of the Royal Meteorological Society, 140(679), 354-363.

Doblas-Reyes, F. J., Andreu-Burillo, I., Chikamoto, Y., García-Serrano, J., Guemas, V., Kimoto, M., ... & Van Oldenborgh, G. J., 2013. Initialized near-term regional climate change prediction. Nature communications, 4, 1715.

Domeisen, D. I., Butler, A. H., Fröhlich, K., Bittner, M., Müller, W. A., & Baehr, J., 2015. Seasonal predictability over Europe arising from El Niño and stratospheric variability in the MPI-ESM seasonal prediction system. J. Climate, 28(1), 256-271.

Dunstone, N., Smith, D., Scaife, A., Hermanson, L., Eade, R., Robinson, N., ... & Knight, J., 2016. Skilful predictions of the winter North Atlantic Oscillation one year ahead. Nature Geoscience, 9(11), 809-814.

Favà, V., Curto, J. J., & Llasat, M. C., 2016. Regional differential behaviour of maximum temperatures in the Iberian Peninsula regarding the Summer NAO in the second half of the twentieth century. Atmospheric Research, 182, 319-334.

Feng, S., Hu, Q., Huang, W., Ho, C. H., Li, R., & Tang, Z., 2014. Projected climate regime shift under future global warming from multi-model, multi-scenario CMIP5 simulations. Global and Planetary Change, 112, 41-52.

Frankignoul, C., Friederichs, P., & Kestenare, E., 2003. Influence of Atlantic SST anomalies on the atmospheric circulation in the Atlantic-European sector. Annals of Geophysics.

García-Herrera and Barriopedro., 2017, in review. Climate of the Mediterranean and North Africa. Oxford Research Encyclopedia of Climate Science, doi: 10.1093/acrefore/9780190228620.013.509

García-Serrano, J., Polo, I., Rodríguez-Fonseca, B. and Losada, T., 2013. Large-scale atmospheric response to eastern Mediterranean summer-autumn SST anomalies and the associated regional impact. Clim. Dyn., Vol 41 - 9-10, pp. 2251 - 2265, doi: 10.1007/s00382-013-1940-4.

García-Serrano, J., Frankignoul, C., Gastineau, G., & De La Càmara, A., 2015. On the predictability of the winter Euro-Atlantic climate: lagged influence of autumn Arctic sea ice. J. Climate, 28(13), 5195-5216.

García-Serrano, J., Cassou, C., Douville, H., Giannini, A., & Doblas-Reyes, F. J., 2017. Revisiting the ENSO teleconnection to the tropical North Atlantic. J. Climate, (2017).

García-Serrano, J., Rodríguez-Fonseca, B., Bladé, I., Zurita-Gotor, P., & de La Cámara, A., 2011. Rotational atmospheric circulation during North Atlantic-European winter: the influence of ENSO. Clim. Dyn., 37(9-10), 1727-1743.

Gillett, N. P., and Fyfe, J. C., 2013. Annular mode changes in the CMIP5 simulations. Geophysical Research Letters, 40(6), 1189-1193.

Gimeno, L., de la Torre, L., Nieto, R., García, R., Hernández, E., and Ribera, P. , 2003. Changes in the relationship NAO–Northern hemisphere temperature due to solar activity. Earth and Planetary Science Letters, 206(1), 15-20.

Gómara, I., Rodríguez-Fonseca, B., Zurita-Gotor, P., & Pinto, J. G., 2014. On the relation between explosive cyclones affecting Europe and the North Atlantic Oscillation. Geophysical Research Letters, 41(6), 2182-2190.

Gómara, I., Rodríguez-Fonseca, B., Zurita-Gotor, P., Ulbrich, S., and Pinto, J. G., 2016. Abrupt transitions in the NAO control of explosive North Atlantic cyclone development. Clim. Dyn., 47(9-10), 3091-3111.

Gonzalez-Reviriego, N., Rodriguez-Puebla, C., & Rodriguez-Fonseca, B. (2015). Evaluation of observed and simulated teleconnections over the Euro-Atlantic region on the basis of partial least squares regression. Clim. Dyn., 44(11-12), 2989-3014.

Greatbatch, R. J., Lu, J., & Peterson, K. A., 2004. Nonstationary impact of ENSO on Euro-Atlantic winter climate. Geophysical research letters, 31(2).

Guemas, V., García-Serrano, J., Mariotti, A., Doblas-Reyes, F., and Caron, L. P., 2015. Prospects for decadal climate prediction in the Mediterranean region. Quarterly Journal of the Royal Meteorological Society, 141(687), 580-597.

Handorf, D., & Dethloff, K., 2009. Atmospheric teleconnections and flow regimes under future climate projections. The European Physical Journal-Special Topics, 174(1), 237-255.

Haylock, M. R., Jones, P. D., Allan, R. J., and Ansell, T. J., 2007. Decadal changes in 1870–2004 Northern Hemisphere winter sea level pressure variability and its relationship with surface temperature. J. Geophys. Res.: Atmospheres, 112(D11).

Herceg-Bulić, I., Mezzina, B., Kucharski, F., Ruggieri, P., & King, M. P., 2017. Wintertime ENSO influence on late spring European climate: the stratospheric response and the role of North Atlantic SST. Int. J. Climatol..

Hertig, E., Beck, C., Wanner, H., & Jacobeit, J., 2015. A review of non-stationarities in climate variability of the last century with focus on the North Atlantic–European sector. Earth-science reviews, 147, 1-17.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J.-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B. & Yiou, P., 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. Reg. Environ. Change, 14, 563-578, doi:10.1007/s10113-013-0499-2

Jérez, S., Jimenez-Guerrero P., Montávez, J.P. Trigo, R.M., 2013. Access Impact of the North Atlantic Oscillation on European aerosol ground levels through local processes: a seasonal model-based assessment using fixed anthropogenic emissions. Atmos. Chem. Phys., 13, 11195–11207, doi:10.5194/acp-13-11195-2013

King, M. P., Herceg-Bulić, I., Kucharski, F., & Keenlyside, N., 2017. Interannual tropical Pacific sea surface temperature anomalies teleconnection to Northern Hemisphere atmosphere in November. Clim. Dyn., 1-19

Lana, X., Burgueño, A., Martínez, M. D., & Serra, C., 2016. Complexity and predictability of the monthly Western Mediterranean Oscillation index. Int. J. Climatol., 36(6), 2435-2450.

Lienert, F., and Doblas-Reyes, F. J., 2017. Prediction of interannual North Atlantic sea surface temperature and its remote influence over land. Climate Ramos, A. M., Tomé, R., Trigo, R. M., Liberato, M. L., & Pinto, J. G., 2016. Projected changes in atmospheric rivers affecting Europe in CMIP5 models. Geophysical Research Letters, 43(17), 9315-9323. Dynamics, 48(9-10), 3099-3114.

Lin, Z., Liu, F., Wang, B., Lu, R., & Qu, X., 2017. Southern European rainfall reshapes the early-summer circumglobal teleconnection after the late 1970s. Clim. Dyn., 48(11-12), 3855-3868.

Liu, Z., & Alexander, M., 2007. Atmospheric bridge, oceanic tunnel, and global climatic teleconnections. Reviews of Geophysics, 45(2).

López-Moreno, J. I., Vicente-Serrano, S. M., Morán-Tejeda, E., Lorenzo-Lacruz, J., Kenawy, A., and Beniston, M., 2011. Effects of the North Atlantic Oscillation (NAO) on combined temperature and precipitation winter modes in the Mediterranean mountains: observed relationships and projections for the 21st century. Global and Planetary Change, 77(1), 62-76.

López-Parages, J., Rodríguez-Fonseca, B., 2012. Multidecadal modulation of El Niño influence on the Euro-Mediterranean rainfall. Geophysical Research Letters, 39(2).

López-Parages, J., Rodríguez-Fonseca, B., Terray, L., 2015. A mechanism for the multidecadal modulation of ENSO teleconnection with Europe. Clim. Dyn., 45(3-4), 867-880.

López-Parages, J., Rodríguez-Fonseca, B., Dommenget, D., & Frauen, C. (2016). ENSO influence on the North Atlantic European climate: a non-linear and non-stationary approach. Clim. Dyn., 47(7-8), 2071-2084.

Lorenzo, M.N., Taboada, J.J. and Gimeno, L., 2008. Links between circulation weather types and teleconnection patterns and their influence on precipitation patterns in Galicia (NW Spain). Int. J. Climatol. 28, 1493–1505, doi: 10.1002/joc.1646.

Losada, T., Rodríguez-Fonseca, B. and Kucharski, F., 2012. Tropical Influence on the Summer Mediterranean Climate. Atmospheric Science Letters, Vol. 13, pp. 36 - 42, doi: 10.1002/asl.359.

Mariotti, A., Pan, Y., Zeng, N., & Alessandri, A., 2015. Long-term climate change in the Mediterranean region in the midst of decadal variability. Clim. Dyn., 44(5-6), 1437-1456.

Martin-Vide, J., & Lopez-Bustins, J. A., 2006. The western Mediterranean oscillation and rainfall in the Iberian Peninsula. Int. J. Climatol., 26(11), 1455-1475.

Martín-Rey, M., Rodríguez-Fonseca, B., Polo, I. and Kucharski, F., 2014. On the Atlantic-Pacific Niños connection: a multidecadal modulated mode Clim. Dyn., doi: 10.1007/s00382-014-2305-3.

Martín-Rey, M., Rodríguez-Fonseca, B. and Polo, I., 2015. Atlantic opportunities for ENSO prediction. Geophysical Research Letters, 42, doi:10.1002/2015GL065062.

Mohino, E., & Losada, T., 2015. Impacts of the Atlantic Equatorial Mode in a warmer climate. Clim. Dyn., 45(7-8), 2255-2271.

Müller, W. A., and Roeckner, E., 2008. ENSO teleconnections in projections of future climate in ECHAM5/MPI-OM. Clim. Dyn., 31(5), 533-549.

Orsolini, Y. J., Senan, R., Vitart, F., Balsamo, G., Weisheimer, A., & Doblas-Reyes, F. J., 2016. Influence of the Eurasian snow on the negative North Atlantic Oscillation in subseasonal forecasts of the cold winter 2009/2010. Clim. Dyn., 47(3-4), 1325-1334.

Ortiz Bevia, M. J., Ruiz de Elvira, A., Alvarez-Garcia, F. J., & Tasambay-Salazar, M., 2016. The multidecadal component of the Mediterranean summer variability. Clim. Dyn., 47(9-10), 3373-3386.

Palmeiro, F. M., Iza, M., Barriopedro, D., Calvo, N., & García-Herrera, R., 2017. The complex behavior of El Niño winter 2015–2016. Geophysical Research Letters, 44(6), 2902-2910.Polo, I., Martín-Rey, M., Rodríguez-Fonseca, B., Kucharski, F. and Mechoso, C.R. (2015). Processes in the Pacific La Niña onset triggered by the Atlantic Niño. Clim. Dyn., 44, 115-131, doi: 10.1007/s00382-014-2354-7.

Peña-Ortiz C., Barriopedro D., García-Herrera R., 2015). Multidecadal Variability of the summer length in Europe. J. Climate, 28 (13), 5375-5388, doi: 10.1175/JCLI-D-14-00429.1.

Quadrelli, R., and Wallace, J. M. (2004). A simplified linear framework for interpreting patterns of Northern Hemisphere wintertime climate variability. J. Climate, 17(19), 3728-3744.

Trigo, R. M., Osborn, T. J., & Corte-Real, J. M. (2002). The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. Climate Research, 20(1), 9-17.

Pinto, J. G. , 2016. Projected changes in atmospheric rivers affecting Europe in CMIP5 models. Geophysical Research Letters, 43(17), 9315-9323.

Rodríguez-Fonseca, B., Polo, I., Serrano, E., & Castro, M., 2006. Evaluation of the North Atlantic SST forcing on the European and Northern African winter climate. Int. J. Climatol., 26(2), 179-191.

Rodríguez-Fonseca, B., & Rodríguez-Puebla, C., 2010. Teleconexiones climáticas en el entorno de la Península Ibérica. Predictabilidad y cambios esperados. Clima en España: pasado, presente y futuro. Informe de evaluación del cambio climático regional, CLIVAR-España, 1-85.

Rodríguez-Fonseca, B., Suárez-Moreno, R., Ayarzagüena, B., López-Parages, J., Gómara, I., Villamayor, J., Mohino, E., Losada, T., Castaño-Tierno, A., 2016. A Review of ENSO Influence on the North Atlantic. A Non-Stationary Signal. Atmosphere, 7(7), 87.

Rodríguez-Fonseca, B., Polo, I., García-Serrano, J., Losada, T., Mohino, E., Mechoso, C.R., and Kucharski, F., 2009. Are Atlantic Niños enhancing Pacific ENSO events in recent decades? Geophysical Research Letters, Vol. 36, L20705., doi 10.1029/2009GL040048.

Rodríguez-Fonseca, B., Polo, I., Serrano, E., & Castro, M., 2006. Evaluation of the North Atlantic SST forcing on the European and Northern African winter climate. Int. J. Climatol., 26(2), 179-191.

Rodríguez-Puebla, C., Encinas, A.H., García-Casado, L.A., Nieto, S., 2010. Trends in warm days and cold nights over the Iberian Peninsula: Relationships to large-scale variables. Climatic Change, 100.667-684.

Rodríguez-Puebla, C., Nieto, S., 2010. Trends of precipitation over the Iberian Peninsula and the North Atlantic Oscillation under climate change conditions. Int. J. Climatol., 30.1807-1815.

Şahin, S., Türkeş, M., Wang, S. H., Hannah, D., & Eastwood, W., 2015. Large scale moisture flux characteristics of the mediterranean basin and their relationships with drier and wetter climate conditions. Clim. Dyn., 45(11-12), 3381-3401.

Scaife, A. A., Knight, J. R., Vallis, G. K., & Folland, C. K., 2005. A stratospheric influence on the winter NAO and North Atlantic surface climate. Geophysical Research Letters, 32(18)

Scaife,A. A., Arribas, A., Blockley, E., Brookshaw, A., Clark, R. T., Dunstone, N., ... & Hermanson, L. (2014). Skillful long-range prediction of European and North American winters. Geophysical Research Letters, 41(7), 2514-2519.

Schwartz, C., & Garfinkel, C. I., 2017. Relative roles of the MJO and stratospheric variability in North Atlantic and European winter climate. J. Geophys. Res.: Atmospheres, 122(8), 4184-4201.

Shepherd T.G., 2014. Atmospheric circulation as a source of uncertainty in climate change projections. Nature Geoscience, 7, 703–708, doi:10.1038/ngeo2253

Tompkins, A.M., M.I. Inés Ortiz de Zárate, R.I. Saurral, C. Vera, C. Saulo, W.J. Merryfield, M. Sigmond, W.-S. Lee, J. Baehr, A. Braun, A. Butler, M. Déqué, F.J. Doblas-Reyes, M. Gordon, A.A. Scaife, Y. Imada, M. Ishii, T. Ose, B. Kirtman, A. Kumar, W.A. Müller, A. Pirani. T. Stockdale, M. Rixen and T. Yasuda., 2017. The Climate-system Historical Forecast Project: providing open access to seasonal forecast ensembles from centers around the globe. Bull. Amer. Met. Soc., doi:10.1175/BAMS-D-16-0209.1.

Trenberth, K. E., Branstator, G. W., Karoly, D., Kumar, A., Lau, N. C., and Ropelewski, C., 1998. Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. J. Geophys. Res.: Oceans, 103(C7), 14291-14324.

Trigo, R. M., Osborn, T. J., & Corte-Real, J. M., 2002. The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. Climate Research, 20(1), 9-17.

Vicente-Serrano S.M., García-Herrera R., Barriopedro D., Azorin-Molina C., López-Moreno J.I., Martín-Hernández N., Tomás-Burguera M., Gimeno L., Nieto R., 2016: The Westerly Index as complementary indicator of the North Atlantic oscillation in explaining drought variability across Europe. Clim. Dyn., 47(3), 845–863, doi:10.1007/s00382-015-2875-8.

Vicente-Serrano, & R. M. Trigo (Eds.) 2011. Hydrological, Socioeconomic and Ecological Impacts of the North Atlantic Oscillation in the Mediterranean Region. Springer, Netherlands.

Vicente-Serrano, S., Beguería, S., López-Moreno, J., El Kenawy, A., and Angulo, M., 2009. Daily atmospheric circulation events and extreme precipitation risk in Northeast Spain: the role of the North Atlantic Oscillation, Western Mediterranean Oscillation and Mediterranean Oscillation, J. Geophys. Res.-Atmos., 114, D08106, doi:10.1029/2008JD011492.

Vicente-Serrano, S. M., and López-Moreno, J. I., 2008. Nonstationary influence of the North Atlantic Oscillation on European precipitation. J. Geophys. Res.: Atmospheres, 113(D20).

Vicente-Serrano S., Lopez-Moreno J-I, Beguería S., Lorenzo-Lacruz J., Sanchez-Lorenzo A., García-Ruiz J.M., Azorin-Molina C., Morán-Tejeda E., Revuelto J., Trigo R., 2014. Evidence of increasing drought severity caused by temperature rise in southern Europe. Environmental Research Letters, 9 (4), http://dx.doi.org/10.1088/1748-9326/9/4/044001

Vitart, F., Robertson, A. W., & Anderson, D. L., 2012. Subseasonal to Seasonal Prediction Project: Bridging the gap between weather and climate. Bulletin of the World Meteorological Organization, 61(2), 23.

Wallace, J. M., and Gutzler, D. S., 1981. Teleconnections in the geopotential height field during the Northern Hemisphere winter. Monthly Weather Review, 109(4), 784-812.

Walter, K., and Graf, H. F., 2002. On the changing nature of the regional connection between the North Atlantic Oscillation and sea surface temperature. J. Geophys. Res.: Atmospheres, 107(D17).

Woollings, T., Gregory, J. M., Pinto, J. G., Reyers, M. and Brayshaw, D. J., 2012. Response of the North Atlantic storm track to climate change shaped by ocean–atmosphere coupling. Nature Geoscience, 5 (5). pp. 314-317, doi: 10.1038/ngeo1438

Zampieri, M., Toreti, A., Schindler, A., Scoccimarro, E., and Gualdi, S., 2017. Atlantic multi-decadal oscillation influence on weather regimes over Europe and the Mediterranean in spring and summer. Global and Planetary Change, 151, 92-100.

Zanchettin, D., Franks, S. W., Traverso, P., & Tomasino, M., 2008. On ENSO impacts on European wintertime rainfalls and their modulation by the NAO and the Pacific multi-decadal variability described through the PDO index. Int. J. Climatol., 28(8), 995-1006.

Zveryaev, I. I., 2006. Seasonally varying modes in long-term variability of European precipitation during the 20th century. J. Geophys. Res.: Atmospheres, 111(D21).