Changes in the frequency of the Weather Regimes over the Euro-Atlantic and Mediterranean sector and their relation to the anomalous temperatures over the Mediterranean Sea

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Received: 22/04/2013
Accepted: 18/11/2013

Abstract
An exercise has been carried out to assess to what extent the Euro-Atlantic Weather Regimes (WR), described from the ERA-interim Reanalysis in the summer season, projects onto a pool of AGCM-AMIP simulations in which sea surface temperatures (SST) are prescribed from observations. Although the model simulations present some biases in the spatial structure and seasonality of WRs, exhibiting also less variability, they are able to capture main WR over the region in summer season: +Middle East –Middle East, +NAO, -NAO. WR paradigm is used to quantify changes in the atmosphere under warmer/colder than normal conditions over the Mediterranean Sea. To address this problem, firstly, changes in the frequency and spatial pattern are evaluated versus the spread of the ensemble. A change in the spatial pattern of –NAO is found with higher (lower) pressures centred over France when conditions over the Mediterranean are warmer (colder) than normal. Changes in frequency in the ensemble mean along the season are also evaluated and compared with the signal to noise ratio over the whole season. When temperatures over Mediterranean Sea are warmer (colder) than normal significant changes of WR frequency are: i) more (less) frequency for the -Middle East in June/July ii) shift of the frequency of occurrence for the WR associated with +NAO and iii) less (more) occurrence of –NAO in September-October. Despite the limitation, the analysis suggests that extreme conditions over the Mediterranean basin could modulate WR frequencies, which could have an impact on European weather conditions. Further analysis need to be performed in order to isolate the atmosphere variability forced by the Mediterranean Sea.
Key words: Weather Regimes, Mediterranean Sea, frequency of occurrence, AGCM-AMIP simulation.

Cambios en la frecuencia de los Regímenes de Tiempo sobre la región Euro-Atlántica y Mediterránea y su relación con las temperaturas anómalas sobre el Mar Mediterráneo

Resumen
Se ha llevado a cabo un ejercicio para evaluar hasta qué punto los Regimenes de Tiempo (RT) sobre la región Euro-Atlantica, descritos a partir del Reanálisis ERA-interim en la estación de verano, se proyectan en un grupo de simulaciones AGCM-AMIP en las cuales las temperaturas superficiales

ISSN: 0214-4557
http://dx.doi.org/10.5209/rev_FITE.2013.v25.43438

del Mar observadas han sido prescritas. Aunque las simulaciones presentan errores sistemáticos en la estructura espacial y la estacionalidad de los RT, exhibiendo menos variabilidad, son capaces de capturar los principales RT sobre la región en verano: +Middle East –Middle East, +NAO, -NAO. En este trabajo se usa el paradigma de los RT para cuantificar cambios en la atmósfera bajo condiciones de las Temperaturas del Mar Mediterráneo por encima/debajo de la media. Para abordar este problema, primeramente se evalúan los cambios en la frecuencia y la estructura espacial versus la dispersión del conjunto. La estructura espacial del patrón –NAO muestra mayores (menores) presiones centradas sobre Francia cuando las condiciones sobre el Mar Mediterráneo son más cálidas (frías) de lo normal. Cambios en la frecuencia de la media del conjunto a lo largo de la estación estival también han sido evaluados y comparados con el ratio señal/ruido. Cuando las temperaturas sobre el Mar Mediterráneo son más cálidas (frías) de lo normal, los cambios significativos de la frecuencia en los RT son: i) más (menos) frecuencia de ocurrencia en el RT –Middlle East en Junio/Julio ii) cambio estacional en la frecuencia de ocurrencia de los WR asociados con +NAO y iii) menos (más) ocurrencia de –NAO en Septiembre-Octubre. A pesar de las limitaciones, los análisis sugieren que condiciones extremas sobre la cuenca mediterránea podrían modular frecuencias en los RT, los cuales tienen un impacto en las condiciones del tiempo en Europa. Se necesitan análisis específicos para poder aislar la variabilidad de la atmósfera forzada por las variaciones de la temperatura en el Mar Mediterráneo.

Palabras clave: Regímenes de Tiempo, Mar Mediterráneo, frecuencia de ocurrencia, simulación AGCM-AMIP.

Normalized reference

Polo, I., Ullmann, A., Fontaine, B., Losada, T, Roucou, P. (2013). Changes in the frequency of the Weather Regimes over the Euro-Atlantic and Mediterranean sector and their relation to the anomalous temperatures over the Mediterranean Sea. Física de la Tierra, vol. 25, 103-121.

1. Introduction

Weather Regimes (WRs) describe the preferred states of the atmosphere that are peaks in the probability density function of the phase-space (Vautard 1990; Michelangeli et al., 1995). Low frequency variability can be interpreted as a change in amplitude/frequency of the WRs or in the transitions between them (Ghil and Robertson 2002; Cassou et al., 2004). Most of the works characterizing the WR over the North Atlantic-Europe region are based in the boreal winter season finding that four main WRs can be defined by Sea Level Pressure (SLP) as: *positive NAO* or zonal regime, *negative NAO* or Greenland anticyclone, *Blocking regime* with anomalous high over Scandinavia and *Atlantic ridge,* with positive anomaly over North Atlantic and negative over Northern Europe (Cassou et al., 2004; Ullmann and Moron, 2007). Similar WRs have been found in boreal summer (Fereday et al., 2008). WRs are useful tools for understanding variability and teleconnections. On the one hand, some works have suggested that changes in the frequency of the WR over North Atlantic could be teleconnected with some global phenomena, which could be acting as precursor such as the Madden-Julian Oscillation in the Pacific (Cassou, 2008) and Sea Surface Temperatures (SST) over Indo-West Pacific Ocean (Moron and Plaut, 2003; Sanchez-Gomez et al., 2008) or the Atlantic Multidecadal Oscillation (AMO, Sutton and Dong, 2012). On the other hand, WRs over the Euro-Atlantic and Mediterranean sector have been associated with the rainfall over West Africa (Polo et al., 2011). The former authors have found that increased (decrease) of frequency of summer –NAO (+NAO) is associated with wet (dry) events over West Africa. Additionally, these WRs have also been associated with warm (cool) SST over the Mediterranean Sea. In this way, it is suggested that anomalous SST over the Mediterranean Sea could be a precursor of changes in WR and in turn of some part of the West African Monsoon variability (Polo et al., 2011).

The Mediterranean Sea is a very small basin but it has been shown some examples where it is able to alter the atmosphere by different processes. For instance, Garcia-Serrano et al (2013) have shown a baroclinic response and a barotropic circumglobal response from Atmospheric General Circulation (AGCM) sensitivity experiments when imposing warmer/colder conditions over the Mediterranean Sea. Feudale and Shukla (2011) have suggested that the anomalous warming over the Mediterranean Sea for the 2003 case of study could have played a feedback role in the heat wave in the European area.

Using simulations, several authors have evidenced the influence of Mediterranean SST onto West African Monsoon, not only at interannual scales (Polo et al., 2008; Mohino et al., 2011; Fontaine et al., 2010, Garcia-Serrano et al., 2013) but also at intraseasonal scales (Gaetani et al., 2010). In particular, Fontaine et al, (2010) have found that a warmer eastern Mediterranean Sea increases the specific humidity in the low-levels and the northeasterly moisture flux, strengthening the convergence in low levels. Therefore the Mediterranean Sea temperatures could modulate West African rainfall at different timescales.

Xoplaki et al (2003) have discussed the variability modes affecting the SST over the Mediterranean Sea using linear methods. However the Mediterranean Sea is located under the influence of many different pressure systems, therefore the interaction can be no linear. We use WR paradigm in order to understand the atmospheric situation in summer under anomalous conditions of surface temperature in the Mediterranean basin. We used May to October season for exploring the months before and after the core of the boreal summer June-July-August.

We posed the following questions: do the WRs found in the Reanalysis dataset project onto the Atmospheric Model Intercomparison Project (AMIP) simulations? Do the features of the summer WR over the Euro-Atlantic and Mediterranean Sector change from anomalous warm and cold conditions over the Mediterranean Sea? If so, WR changes could help in the future to understand impacts on the region.

Therefore, this work is a first attempt to understand the changes in WR from anomalous warm and cold conditions of the Mediterranean basin. The paper is structured as follows: first the data and the methodology are described in section 2. Section 3 describes the Results. Firstly the projection of SLP from AGCM-AMIP simulations onto the reanalysis WR is assessed. Changes in the frequency for anomalous warm and cold conditions over the Mediterranean Sea are evaluated. A discussion about the implications and proposed further work is addressed in section 4. Finally the main conclusions are sumarized in section 5.

2. Methods and Data

2.1. Data and Model

We have analysed 5-days mean Sea Level Pressure from ERA-40 reanalysis dataset (Uppala et al., 2005) and the outputs of four AMIP-type simulations with two AGCMs: three integrations with IPSL atmospheric model (LMDz4 atmosphere, Hourdin et al., 2006) and one integration with UCLA v7.3 model (Mechoso et al., 2000; Richter et al., 2008) for the period 1957-2000 (see Mohino et al., 2011 for details in the simulations). UCLA-AGCM has been run in the UCM institution in the framework of the African Monsoon Multidisciplinary Analyses (AMMA) EU-project, therefore the model will be referred to as UCM-model. IPSL model is part of the CMIP5 exercise and it has been also used for study the atmospheric variability. For instance, in relation with the rainfall over West Africa (Mohino et al., 2011). Besides, it has been shown to be an appropriated tool for evaluating the impacts from sensitivity experiments (Losada et al., 2010; Fontaine et al., 2010). In particular, UCM-model has been shown to capture the observed connection between warmer Mediterranean SST and increased rainfall over the Sahel after 1970s (Mohino et al., 2011).

The two models have climate resolution; the resolution is 2.5 x 2 longitude-latitude with 29 vertical sigma levels for UCM and 1.25 x 2.5 with 39 vertical levels for IPSL. The UCM model outputs consist of 5-days mean from one simulation where the SST is prescribed from ERSSTv2 dataset (Smith and Reynolds, 2004) as boundary conditions. It has been assumed climatological Sea Ice concentrations. We have used only one UCM simulation because from the ensemble simulations, only one member was available at 5 days time resolution. We have 3 simulations from the IPSL ensemble at daily time resolution.

We have used a timeseries of the SST averaged over the Mediterranean region [30N-46N, 8W-60W] from ERASSTv2 dataset. Standardized anomalies over the period 1957-2005 are shown in figure 3.

2.2. Methods

2.2.1 Self Organizing Maps

There are several methods for characterizing WR, cluster analysis is the most common one (Vautard, 1990; Michelangeli et al., 1995), although recent studies have pointed out the Self Organizing Method (SOM, Kohonen 2001) as a useful technique for typifying the atmosphere in multiscale and more complete way (Mangiameli et al., 1996; Johnson and Feldstein, 2010).

We have used the same WR identification described in Polo et al (2011). The former authors have shown that the WRs and in particular the methodology of

SOM could investigate the connection between tropics and extra tropics and its variability. The characterization of the WR with SOM is based on neural networks and it allows us to understand the WR as peaks in the continuum of atmospheric conditions (see Polo et al., 2011 for more details). We have followed the SOM methodology and the associated diagnostics in order to make comparison.

In the SOM methodology, the algorithm presents the input data to a layer of Neurons, which describes the positions on the two-dimensional grid that contains the representative patterns. The neurons have associated a weight vector with the same dimension as the input data. The neurons are orderly disposed in a regular lattice, and a global-map shape is defined describing a topological map. Then a linear initialization is performed, which implies that the weight vectors are initialized in an orderly fashion along the linear subspace spanned by the two leading eigenvectors of the covariance matrix of the training input data. Then an initial neighborhood function and initial learning rate are defined. The batch training algorithm trains the data and two processes take place: (i) the best-matching unit (BMU) is sought in each training step using the minimum Euclidean distance criterion between the neurons and the input data and (ii) the weight vectors of the BMU and its defined neighborhood are updated. The neighborhood function and the learning parameter are also updated. The iterative phase is repeated until the convergence of the parameters. More details are available in Vesanto et al. (2000). After determining the representative patterns, each daily field is classified to one of the SOM patterns using the criterion of minimum Euclidean distance; therefore, each observation in the input data is associated with one and only one neuron via a weight vector. Later on, following the definition of WRs, a criterion of persistence is imposed to keep only patterns that occur at least two consecutive days (Polo et al., 2011). The number of SOM is a compromise between the detailed within WR and the simplicity we want to obtain. The number 25 was a good choice for the observational study (Polo et al., 2011). The model simulation will exhibit less variability and therefore, 25 patterns are perhaps not necessary. However we want to evaluated how good the simulations represent the observed variability and discriminate the WR that are interesting in the model world but also present in the Reanalysis (observation) world. This is useful for future works considering model outputs and WR method.

2.2.2 Pre-processing and Projection

In this work, the projection has been done with the SOM provided by Polo et al (2011), which will be referred to as WR-reference. These have been performed considering SLP, 700hPa geopotential height and 700hPa specific humidity of daily data of ERA-interim for the May to October seasons of the period 1989-2008. We use the WR-reference from ERA-interim data instead of calculating the WR from the model outputs because we want to make comparison with the most realistic data (i.e. reanalysis), therefore understanding how good the model reproduce the patterns from Polo et al (2011). Other studies have already used reanalysis as a benchmark for GCMs when 'projecting' atmospheric circulation structures (Ullmann et al., 2013). In addition WRs defined by Polo et al (2011) are very consistent and comparing with them seems natural and appropriate for further investigations.

The data pre-processing and the projection for the four SST-forced AGCM simulations is the following: i) computation of the 5-day mean (there is not overlapping in the sequence) ii) the data for the 4 simulations is re-gridded in the ERA-interim grid iii) the seasonal cycle is not removed, just the linear trend and the long term mean. The SLP data is standardized. iv) the data for the 4 simulations is spanned in the subspace of the 2 leading modes from ERA-interim (Polo et al., 2011). v) Every input data (from the 4 simulations) is projected. Projection is based on the euclidian distance criterion between neurons and input data, using the same constriction than the one used to construct the WR-reference, that is, one state of the atmosphere can belong only to one WR which is the closest one in the phase-space of the two leading eigenvectors of the covariance matrix (Kohonen, 2001; Vesanto et al., 2000). Input data is attributed to a SOM, as the minimal distance to one of the 25 neurons vi) we imposed a condition of spatial correlation between the input data and the WR-reference being significant according to a t-test at 95% confidence level.

Note that some WR are not appearing in the simulation data, this is because this WR are very rare (low frequency ~1%) in the observations and/or not significant enough in the projection (i.e. no event is close enough to this neuron). However, every input data has associated with one WR. We have first projected all the data from the 4 simulations on to WR-reference (section 3.1) but also analysis is shown from the projection of the Ensemble mean (section 3.2).

SLP is the only variable available in the simulation and used along the work. Because of the limitation of the variables available in the data, the results here have to be taken with some caution. However, the SLP will allow us to stress better the WR changes because SLP is more sensitive to both thermal conditions at the surface and to air mass variability in the atmospheric column. Notice that the WR-reference come from SOM computations considering several variables (Polo et al., 2011), therefore the SLP pattern is some how coherent and related to geopotential height and specific humidity at 700hPa. Thus, the projection is also expected to be consistent in the mid-low atmosphere.

3. Results: Weather Regimes in AMIP simulations

In this section we describe the WR over the Euro-Atlantic sector when the SLP from the AMIP simulations is projected. Later, we address the question of how the character of the WR from the projection changes considering two periods under different conditions: years with SST above and below normal condition over the Mediterranean Sea.

3.1. SLP AMIP simulations projected onto observed WR

We have projected summer SLP from each experiment onto observed WRs and averaged the 4 simulations to get an ensemble mean (see details in the methodology section, figure 1).

Four main significant WR familes project on the observations: WR1 defined as the anticyclonic pattern over the Eurasia/Middle East and low pressure over Iceland (hereafter +ME, fig. 1.WR1), occurring mainly at the beginning and the end of the season. WR25 (fig.1d) is complementary to WR1, and describes an opposite phase with positive anomalies over Iceland and negative ones over Eastern Europe and middle East (hereafter -ME, fig. 1. WR25). –ME pattern occurs from June to October. Note that WR24 is a neighbor of –ME, but the former shows a cyclonic pattern centered over Europe/Mediterranean (hereafter –EM, fig. 1.WR24) basin and occurs in May-Jun. WR5 pattern (similar to WR15 and WR20 in the same column) shows a tripole-like structure with negative centers over Greenland and Middle East and positive anomalies over north Atlantic and Western Europe, following the tilt of the continental shape and the storms-track, resembling the positive NAO-like pattern (hereafter +NAO, fig. 1.WR5). +NAO occurs from May to August. WR21 (similar to WR16 and WR11 in the same column) can be described as the negative phase of the NAO-like pattern (-NAO, fig. 1.WR21), which appears at the end of the summer from August to October.

The frequency of occurrence along the season for each WR can be seen in figure 2. The most frequent patterns are –ME and +ME, while +NAO and –NAO patterns occur less frequently but show more varieties of patterns within the same family.

Although the ensemble shows good agreement with the most frequent WR in the observations (comparing fig.1 and fig.1 in Polo et al., 2011), the simulations have a bias in the seasonal cycle as well as in the frequencies of those WRs (comparing fig. 2 and figure 2.c in Polo et al., 2011). In particular, it seems that +ME and –ME are occurring along the whole season, while +NAO and –NAO occur in June-August but with less frequency of occurrence.

Next section is devoted to evaluate significant differences in the WR when the Mediterranean Sea is under extreme conditions.

3.2 Changes of WR characteristics under extreme conditions over the Mediterranean basin.

In order to evaluate the changes in the WR under extreme conditions over the Mediterranean Sea, we have calculated an Index, which is the SST averaged over the region [8W-41E; 30N-46N] (hereafter MedIndex, figure 3). Anomalies are standardized and the linear trend has been removed.

The positive anomalies over the Mediterranean Sea occur in the 1960s and 2000's, while the negative values are found 1970s and 1980s. This decadal signature suggests that the SST over the Mediterranean Sea has a large thermal inertia and/or can be modulated by other decadal oscillations (i.e. Mediterranean SST and the AMO are related, Marullo et al., 2011).

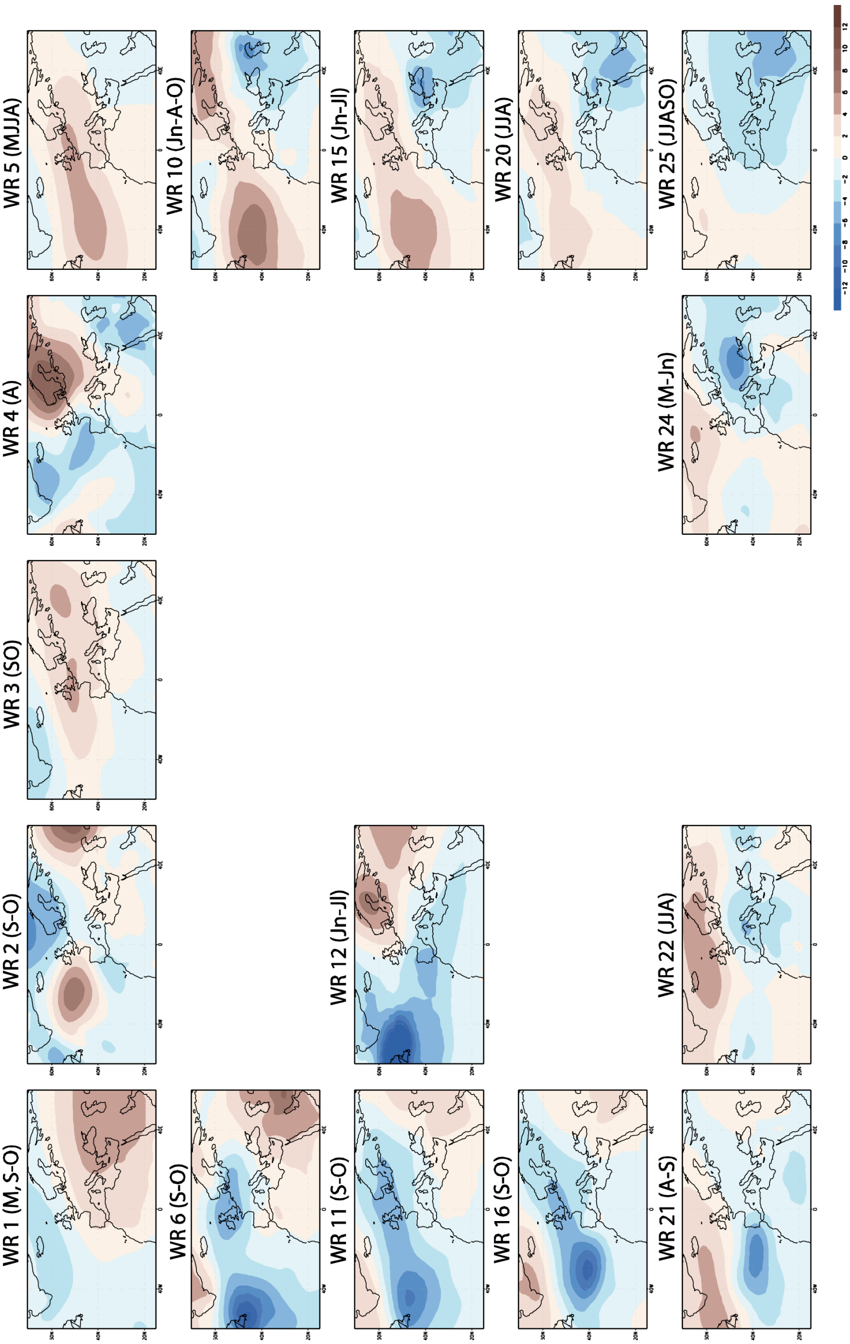

Fig. 1. Weather Regimes projection: WR as the result of projecting the 5-days mean SLP from the four simulations onto the WR defined by Polo et al. (2011) from SOM method. The WR is the average of the projection for four simulations (see methods for details). Shaded areas corresponds to the SLP anomalies referred to the long-term mean (in hPa) characteristic of the WR. The WR are disposed as in the original grid 5x5 neurons from Polo et al. (2011) in order to make comparisons.

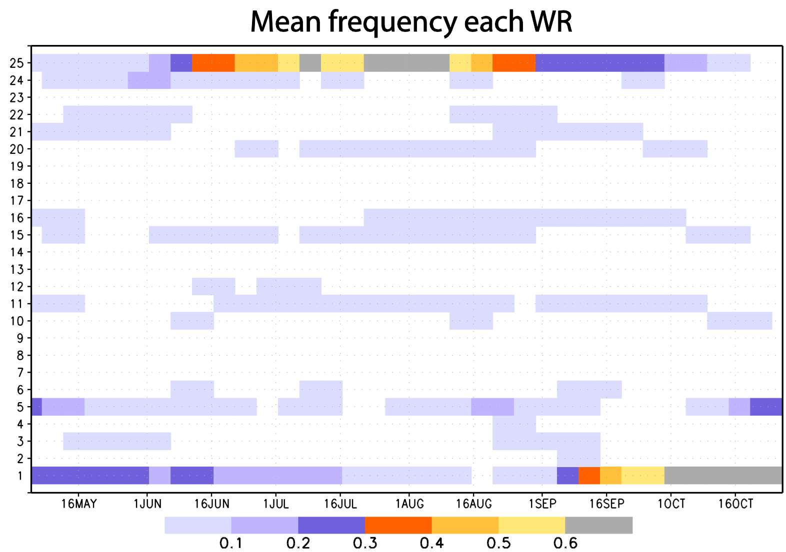

Fig. 2. Frequency for each WR: Seasonal cycle of the frequencies from May to October (x-axis) of each WR. The frequency is the result of averaging the frequency of the 4 simulations.

NAO index has been superimposed (fig. 3 green line) for summer season revealing that there is not a linear relationship between indexes (i.e. positive NAO in 1960s and negative NAO in the 2000s, the correlation between indexes is -0.1).

3.2.1 Signal to noise ratio

We have created two pools of years (13) of positive (red bars in figure 3) and negative (blue bars in figure 3) Mediterranean SST and checked the significant difference in the ensemble by calculating the signal to noise ratio for number of days for a particular WR.

Figure 4a shows the signal (difference of total number of days of occurrence between positive and negative MedIndex) and the noise (spread of the ensemble calculated as the standard deviation) for each WR. There are some significant changes, in particular more number of days for +ME and –EM and less number of days for –NAO when the MedIndex exhibits positive years in comparison with negative years.

Changes in the spatial patterns are also occurring for those opposite pool of years: in particular the WR representing –NAO (WR11 and WR21) shows an increase in the SLP over France-central Europe when the Mediterranean Sea is warmer than normal (figure 4 b,f). These changes in the spatial structure could have a potential regional impact over the region.

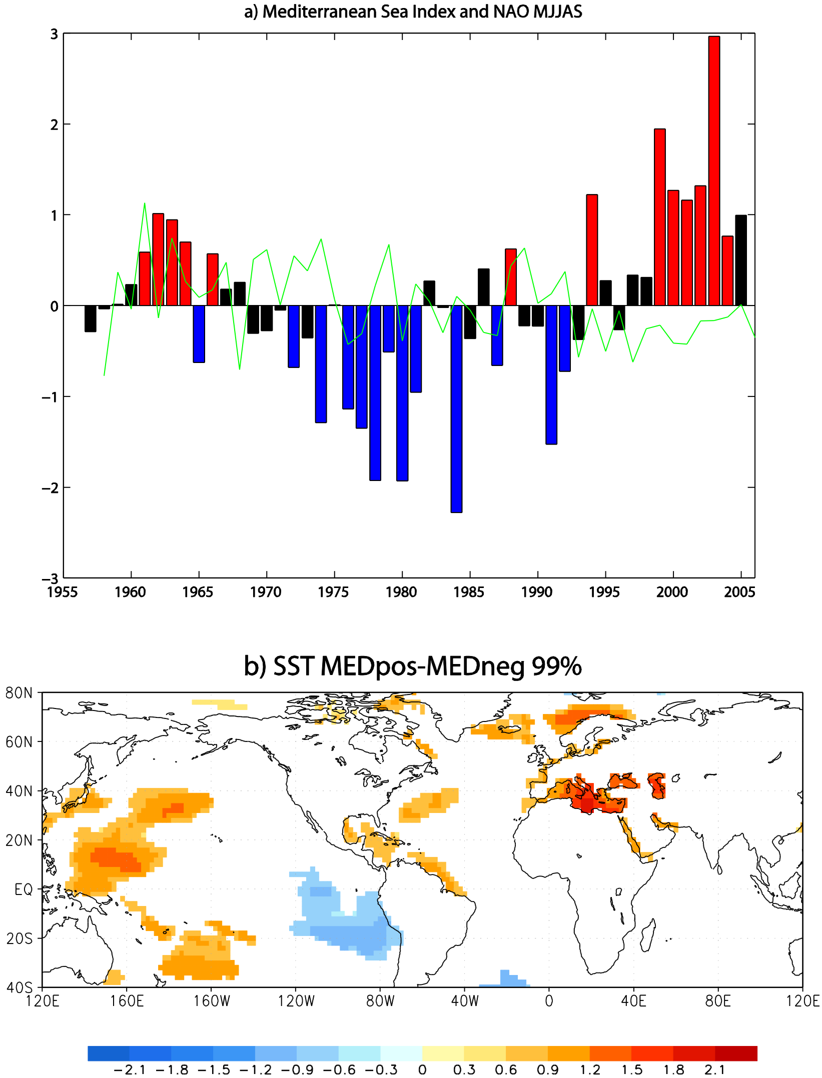

Fig. 3. Mediterranean SST Index and global spatial pattern: a) SST averaged over the area [8W-41E; 30N-46N] from May to September. The index has been detrended and standardized. Blue and Red bars corresponds to the years chosen for defining cold and warm anomalous Mediterranean SST. Superimposed is the NAO index (green line) for the same season. b) SST Composite maps of positive minus negative years of temperature anomalies over the Mediterranean Sea in May-September (Index from figure 3a).Only the significant areas (in C) have been shaded from a t-test at 99% of confidence level.

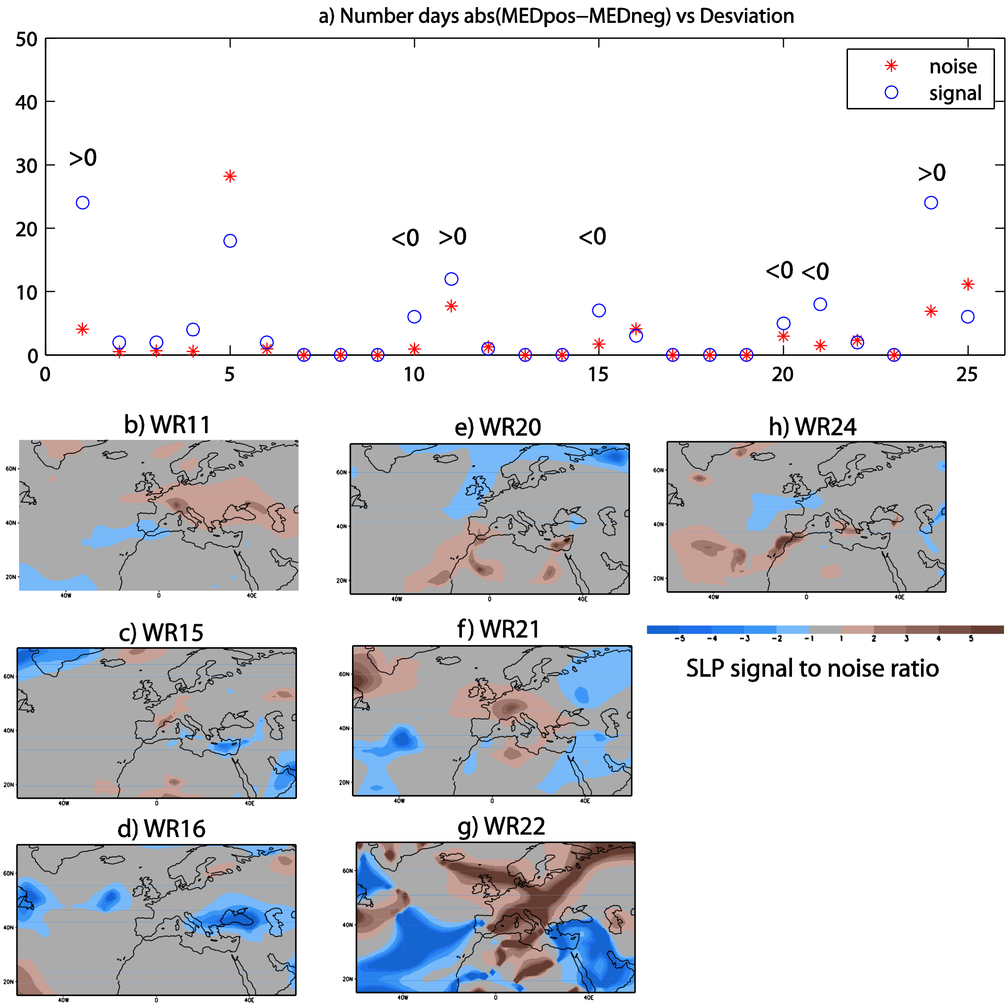

Fig. 4. Signal to noise ratio for the difference between warm and cold Mediterranean SST. a) Difference in number of days for a particular WR between years of positive and negative Mediterranean SST (blue circle) and the spread within the ensemble (red star). In black is the sign of the signal for some of the WR where the change is significant. b) Ratio between SLP difference between years of positive and negative Mediterranean SST and the spread within the ensemble for WR1. e)-h) Same as b) but for other WRs.

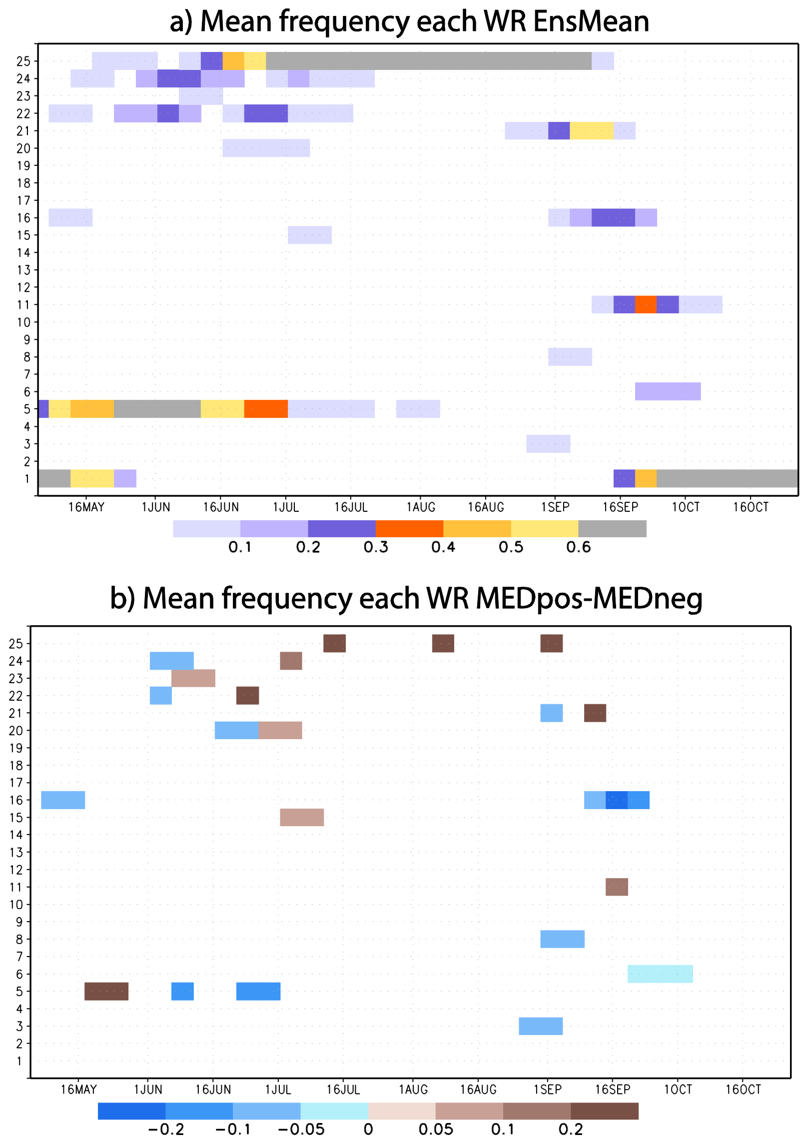

Fig. 5. Seasonal cycle of frequency and changes for the Ensemble Mean. a) Same as Figure 2 but for the ensemble mean of the 4 simulations. b) Difference of frequency between years of positive minus negative Mediterranean SST for the ensemble mean. Only significant values are plotted according with a Monte Carlo test with 10000 realizations at 90% significant level.

3.2.2 The Ensemble mean

In order to remove inter-ensemble variability, which can be interpreted as another aspect of the internal variability of the atmosphere, we have calculated the SLP projection onto the WR from the observations for the ensemble mean field (not shown). The projection shows similar patterns to figure 1 but with small amplitudes. Besides some of the WR are missing in the ensemble mean.

In particular, for the seasonal cycle (figure 5a), three WR are highlighted +ME, -ME and +NAO (WR 1, 25, 5). The rest of the WR are less frequent and they are confined in a particular part of the season (comparing figure 2 and figure 5a). In particular –NAO (WR 11, 16, 21) occurs now at the beginning and at the end of the season and +EM (WR24) occurs at the beginning of the summer.

Changes in frequency are evaluated along the season for each WR. Only the significant changes have been shaded according with a Monte Carlo test with 10000 realizations at 90% significant level (similar to Polo et al., 2011).

Under conditions of positive SST anomalies over the Mediterranean Sea, the changes in frequency for the ensemble mean reveals: i) an increase of frequency of -ME in JJA (WR25) ii) A significant shift of the +EM (WR24) from June to July iii) Shift in the frequency of WRs associated with +NAO (WR 5, 20, 21, 22) and iv) a less frequency of occurrence of –NAO (WR 6, 16) in September-October.

4. Discussion

This work is a first step for evaluating Mediterranean impacts of the WR over the Euro-Atlantic. The ensemble used here represents the main observed WR characterized in the Euro-Atlantic sector. One of the striking results suggested from an ensemble of 4 simulations used here is that under warmer (colder) than normal conditions over the Mediterranean Sea, the frequency of occurrence for –NAO decreases (increases) at the end of the summer season, in September-October.

We have tested with the Reanalysis data by computing the WR from ERA-40 data with 5-days means SLP for the summer season and with another clustering method (k-means, see Michelangeli et al., 1995; Ullmann and Moron, 2007). The 4 main patterns (figure 6) are consistent with the most frequent patterns described in ERA-interim (Polo et al., 2011). We have computed as well the changes in frequency for years of positive and negative SST anomalies over the Mediterranean Sea (Table 1). Significant changes in –NAO are found when Mediterranean SST anomalies occur. This is in agreement with the model results, giving robustness to the idea that those changes are SST-driven.

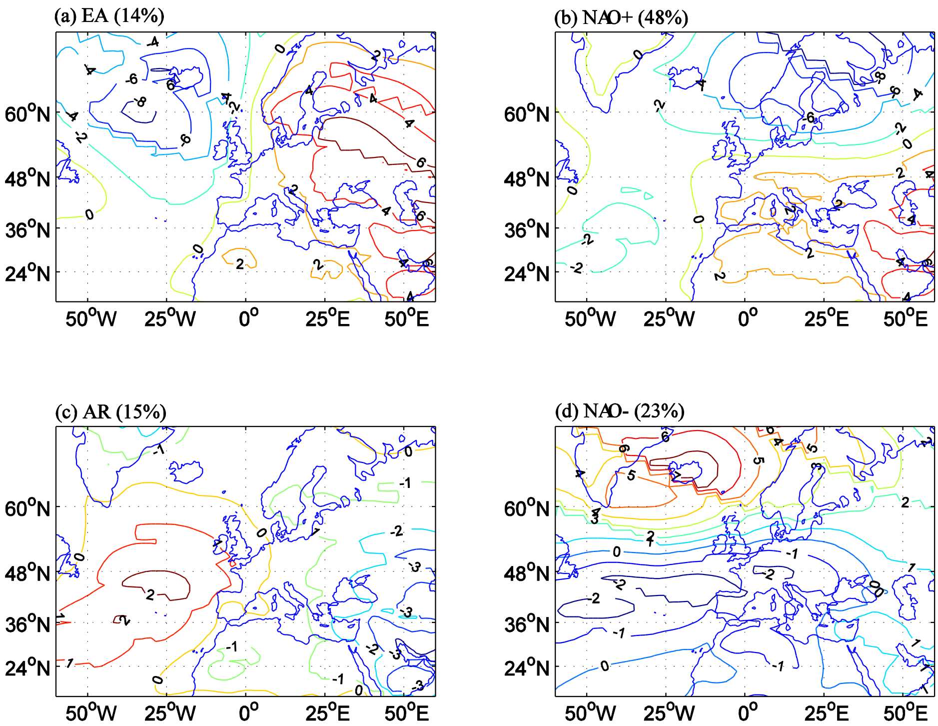

Fig. 6. WR from ERA40 Reanalysis data and k-means clustering. WR as a result of clustering the 5-days SLP data from ERA40 Reanalysis for the period 1957-2005 for the summer season May to October and k-means methods. The contours show SLP anomalies in hPa. a) East-Atlantic b) positive NAO c) Atlantic Ridge d) negative NAO.

As the simulations are global, from a composite of years we cannot assure that the only forcing comes from the Mediterranean basin. However, those SST anomalies over the Mediterranean Sea are highlighted from the rest of the globe; figure 3b shows the Composite SST map for positive minus negative values of the MedIndex at 99% confidence level. Warm anomalies are found over the Pacific and Atlantic Warm pool, which are areas that potentially impact the extratropics (Cassou, 2008).

The fact that the frequency of certain WRs decrease and other increase in the ensemble mean should be interpreted as a reduction of internal noise due to the external forcing (i.e. Mediterranean SST). However, it is difficult to directly attribute the change in frequency to the Mediterrenan conditions. Analysis of specific sensitivity experiments should be done in order to isolate the Mediterranean forcing. Experiments used by Garcia-Serrano et al (2013) will be analysed to understand the impact over the Euro-Atlantic region.

Further work is of course necessary to understand the proper impact of changes in the WR frequency described here, and further calculations will be made to provide the precipitation changes and surface patterns associated with each WR showing significant change in time. Besides, the methodology used along the work has also several limitations. The first one comes from the chosen data: SLP projection is insufficient to describe WRs in a region of high variability in both atmosphere and the ocean such as the Euro-Atlantic sector. Additional calculation with geopotential height at different levels should be done. The second limitation is the time-step of the data: the election of 5-days mean, due to the availability of the data, clearly filters out many WRs described in Polo et al (2011). Despite these restrictions, this work provides some evidence that WR changes are associated with SST variations mainly over the Mediterranean Sea.

Table 1. Frequency for the ERA-40 WR. Number of days and percentage (in parenthesis) for the occurrence of each WR defined in figure 6. The significant difference in frequency at 95% of confidence level from a t-test is highlighted

Ndays(%)	**MEDpos**	**MEDneg**	**DIFF (in %)**
EA	57(17)	68(14)	3
+NAO	49(14)	57(12)	2
AR	168(49)	219(47)	2
-NAO	50(14)	124(26)	-12
Total days	**324**	**468**	

5. Conclusions

Main conclusions are summarized as follows:

- Projection of the SLP from four AGCM-AMIP simulations onto the WR described from the ERA-interim Reanalysis in the summer season and the period 1989-2000 has shown similarities in the spatial structure for the 4 families of patterns: +Middle East and –Middle East, -NAO, +NAO.
- The most frequent patterns are +Middle East and +Iceland –Middle East, these two patterns explain more than 30% of the occurrence.
- The spatial pattern of the WR –NAO exhibits a higher (lower) SLP over France when conditions over the Mediterranean Sea are warmer (colder) than normal.
- Changes in number of days of occurrence have been observed between the years of positive and negative Mediterranean SST compared with the spread in the ensemble. In particular more (less) frequency of +MiddleEast and –NAO (+NAO).

- Analysis of the ensemble mean shows different seasonal cycle of the WR compared with the mean of the ensemble. In particular some of the WR occurring in JJA are internal variability in the ensemble.
- Changes in frequency of occurrence of the ensemble mean when temperatures over Mediterranean Sea are warmer (colder) than normal are found: i) more (less) frequency of WR -ME (WR25) ii) a shift of more (less) frequency of occurrence in July compared with June is found of WR which consist in a low pressure centered over East Europe iii) shift of the frequency for WR of the +NAO positive family (WR 22, 21, 5) and iv) less (more) occurrence of –NAO in September-October (WR 16, 6).

The less occurrence of the –NAO at the end of the season could be a consequence of the SST anomalies over the Mediterranean Sea. We need to further explore this possibility by analyzing sensitivity experiment in order to isolate the Mediterranean forcing to the atmospheric conditions. Understanding the possible driver role of the Mediterranean Sea could be important to better assess the extreme conditions and their impacts.

6. Acknowledgements

We are very grateful to the editor and the reviewer for their useful comments that helped to substantially improve the manuscript. This study has been partially funded by the EU-AMMA project. Based on French initiative, AMMA was built by an international scientific group and is currently funded by a large number of agencies, especially from France, UK, US and Africa. It has been the beneficiary of a major financial contribution from the European Community's Sixth Framework Research Programme. Detailed information on scientific coordination and funding is available on the AMMA International website http://www.amma-international.org. Irene Polo has been supported by a postdoctoral fellowship funded by the Spanish Government. T. Losada is currently supported by the postdoctoral program of the campus CYTEMA of the ''Universidad de Castilla-La Mancha''.This work has been also possible thanks to the Spanish projects: Tropical Atlantic Variability and the Climate Shift (TRACS-CGL2009-10285) and MOVAC.

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