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Dual Influence of Atlantic and Pacific SST anomalies on the North Atlantic/Europe Winter Climate

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Abstract. Clustering analyses are used in both NCEP Reanalyses and model simulations to identify relationships between the low frequency variability of the zonal wind jet at 200hPa (U200) over the North Atlantic-Europe domain and the geographical distribution of the Sea Surface Temperature (SST) anomalies. For winter months over the 1959-1998 period, the U200 signature of the two phases of the North Atlantic Oscillation (NAO) is captured from NCEP in a cluster pair associated with the North Atlantic SST tripole. The classification also extracts a "La Niña"mode related to a strong ridge off Europe and reduced jet over the Azores. Model results confirm this dual oceanic association while exaggerating the ENSO influence. The role of the Atlantic SSTs is confirmed in model experiments where climatological SSTs are prescribed in the other basins. Tropical anomalies dominate the Atlantic SST signals and are linked to fluctuations of the jet consistently with the NAO phase.

Introduction

The influence of oceanic surface conditions in shaping midlatitude atmospheric variability over the North Atlantic/Europe (NAE) domain is difficult to extract due to a very low signal-to-noise ratio of the midlatitude dynamics. Based on model results, the impact of Atlantic SSTs has been suggested ([*Rodwell et al*, 1999],[*Venske et al*, 1999]) at interannual timescale, but the atmosphere response is still highly model dependent (influence of tropical [*Robertson et al*, 2000] vs extratropical [*Peng et al*, 1997] Sea Surface Temperature (SST) anomalies, type of the atmospheric adjustment...).

In this short article, our goal is to isolate the spatio-temporal structures of the global oceanic anomalies which have the strongest link to the main atmospheric variability modes over the NAE sector. The SST-forcing signal is investigated using the ARPEGE model [*Déqué et al*, 1994] (T63 resolution, 31 vertical levels) and a series of ensemble simulations [*Cassou and Terray*, 2001]. As described in the latter paper, an ensemble of 8 multidecadal GOGA (Global Ocean Global Atmosphere) integrations has been carried out using global monthly varying SSTs and Sea Ice Extents (GISST, [*Rayner et al*, 1997]) from 1947 to 1998. Another 4-member ensemble hereafter referred to as AOGA (Atlantic Ocean Global Atmosphere) has also been conducted over the same period, the interannual oceanic forcing being restrained to the entire Atlantic Ocean (down to 45^oS). The potential relationship between oceanic and NAE atmospheric anomalies is investigated using cluster analyses. The method used in the following study is based on the k-means clustering algorithm as detailed in [*Michelangeli et al*, 1995]. The statistical robustness of the cluster solution is tested by the so-called Classificability Index (CI) and the reproducibility is assessed by subsampling the total dataset.

The k-means algorithm is applied to winter monthly means (December-January-February) zonal wind at 200 hPa (hereafter U200) over the NAE sector ($80^oW/30^oE - 10^oN/80^oN$) from 1959 to 1998. The choice of U200 as variable to be classified is justified by [*Peng et al*, 1997] conclusions which show that the model atmosphere responses to SSTs are crucially dependent on the background flow especially the strength and position of the upper-tropospheric midlatitude jet. Concatenated GOGA experiments and concatenated AOGA experiments provide two independent datasets thus yielding respectively 960 maps ($40years \times 3months \times 8simulations$) and 480 maps ($40years \times 3months \times 4simulations$) on which the clustering algorithm is run separately. A similar analysis is carried out using NCEP Reanalysis [*Kalnay et al*, 1996] over the same period i.e. 120 maps ($40years \times 3months$) in order to assess the degree of realism of the simulated atmospheric behavior.

U200 regimes from NCEP Reanalyses

The cluster analysis is first applied on NCEP U200 winter monthly maps. The CI shown in Fig.1a lies within the noise bounds except for k=2 and k=3. The case k=3 which departs the most significantly from the noise model output [*Michelangeli et al*, 1995], is further commented. The time history of the occurence of the three U200 climate regimes accounting respectively for 32.5%, 40% and 27.5% of the total sample size is used to build composites both for the classified variable (U200) and the associated ones (SST, Sea Level Pressure (SLP) and precipitation fields). The events for the composite construction is based on outputs from the hypergeometric statistical test [*Martineu et al*, 1999] which defines the years significantly represented in each cluster. In this context, "event" refers therefore to the months belonging to a given cluster for these selected years. Pointwise statistical significance of the composite value is assessed at the 95% level of confidence, using a 2-tailed T-test, the number of degree of freedom being set to its most restrictive value given by the number of years included in the composite. Composites of the first two U200 regimes (CL1 and CL2, Fig.1bc) show a fairly symmetrical quadripolar structure with maximum anomalies zonally elongated between $25^oN - 65^oN$ around 40^oW. The third regime (CL3, Fig.1d) is dominated by three lobes with maximum values slightly west of the Azores. A weakened jet there is concurrent with strengthened regime close to Iceland and off the

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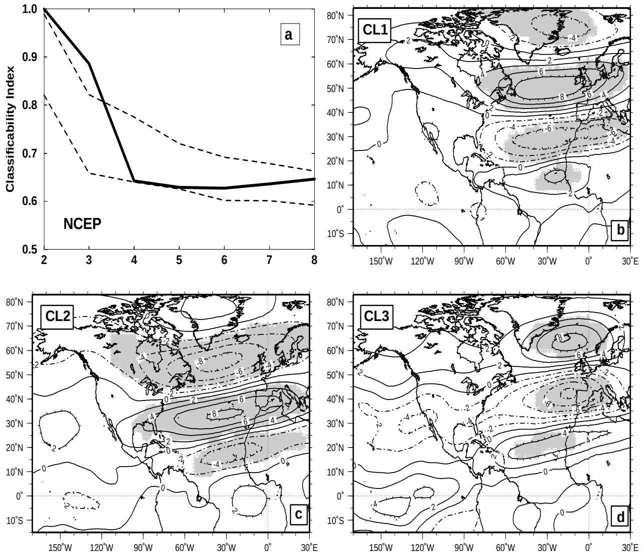

Figure 1. a) Classifiability Index (heavy solid) and confidence intervals (dotted bounds) calculated from a noise model as a function of a number of clusters k for NCEP Reanalysis, bcd) U200 composites for the 3 U200 NCEP winter clusters. Shading stands for significant anomalies using a 2-tailed t-test at the 95% level

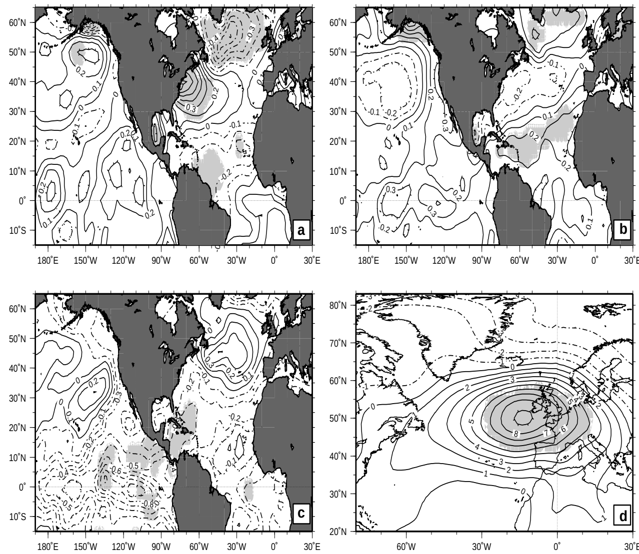

Figure 2. SST composites (abc) for the 3 U200 NCEP clusters. MSLP composite (d) for CL3. Shading stands for significant anomalies using a 2-tailed t-test at the 95% level

Saharan coast. Whereas CL1 and CL2 seem to be Atlantic limited, CL3 exhibits coherent features over the Pacific with enhanced westerlies along the Equator and reduced subtropical jet off California.

The associated SST composites (Fig.2abc) display rather symmetrical features in the North Atlantic Ocean for CL1 and CL2, exhibiting the well known SST tripole [*Deser and Blackmon*, 1993]. This cluster pair reflects the jet displacement consistent with the two phases of the North Atlantic Oscillation (NAO) [*Wallace and Gutzler*, 1981] as confirmed by SLP and precipitation composites (not shown). CL3 mainly outlines the Atlantic jet association with La Niña events. Clear cold conditions cover most of the tropical Pacific (Fig.2c) whereas marginally significant signals emerge from the Atlantic Ocean. These are confined to the Caribbean Sea and equatorial band and have been demonstrated to be related to ENSO [*Enfield and Mestas-Nunez*, 1999] via the so-called atmospheric bridge paradigm. The SLP signature for CL3, whose composite is shown in Fig.2d, displays enhanced anticyclonic regime off the Irish coast. This pattern is reminiscent of the East Atlantic pattern [*Wallace and Gutzler*, 1981].

Results from NCEP thus reveal a significant regional response over the NAE region only for La Niña phase suggesting the asymmetry of the NAE atmospheric signal with respect to the ENSO phase [*Chen*, 1982]. Stronger La Niña impacts are also outlined by [*Halpert and Ropelewski*, 1992] who comment significant cold temperature anomalies and reduced rainfall over western Europe as captured by the East Atlantic regime (CL3) (not shown).

Global SST impacts

Clustering is now applied to the GOGA data with stable classification for k=2 only. The 2 U200 composites charts (CL4 and CL5, Fig.3ab) exhibit high symmetry with a meridional tripole centered around $30^{o}W$. Maximum amplitude and significance occur in the central lobe zonally elongated from Florida to Spain and flanked by two secondary poles of opposite signs. CL4 and CL5 bear a strong resemblance with CL1 and CL2 from NCEP over the NAE domain, although the northernmost branches are less intense and less significant in the model (spatial correlation between NCEP and GOGA modes respectively equal to 0.80 and 0.89). The Atlantic modes tend actually to be more hemispheric in the model than in nature. Although less significant, rather symmetrical U200 anomalies appear between both clusters over the equatorial and the North extratropical Pacific concomitant with Atlantic signatures.

The most significant relationships between the model NAE dynamics and the oceanic fluctuations are linked to

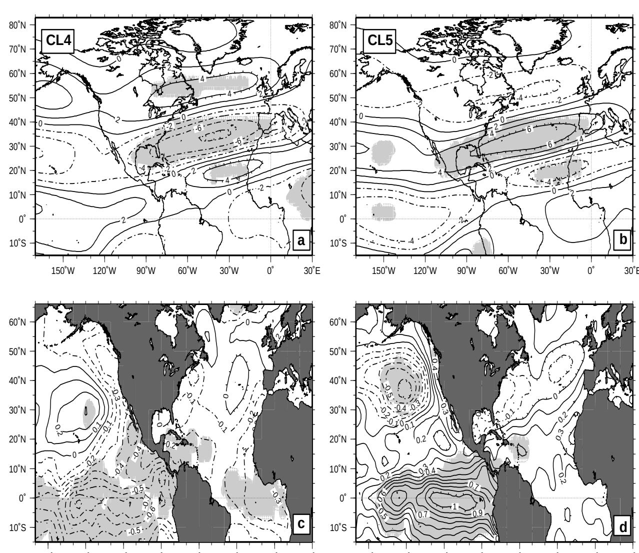

Figure 3. ab) U200 composites for the 2 U200 GOGA winter clusters, cd) Associated SST composites. Shading stands for significant anomalies using a 2-tailed t-test at the 95% level

ENSO. SST composites (Fig.3cd) depict that reduced (enhanced) jet over the Azores mainly occurs during La Niña (El Niño) events. Simultaneous signals are also present in the North Atlantic. Whereas the SST composite corresponding to CL5 is reminiscent of the North Atlantic tripole (compare Fig.2b and Fig3b), SST coherence for CL4 is restricted to the tropical band and recalls the ENSO remote oceanic signal in the Atlantic. Composites on GOGA SLP (not shown) reveal a NAO-like pattern with maximum loading and significance over the Azores High. As midlatitude teleconnection patterns are mainly barotropic and as we have seen that GOGA clusters are similar to their observed counterpart CL1 and CL2 from NCEP, CL4 and CL5 are logically linked to respectively the positive and the negative simulated NAO phase. The precipitation composite (not shown) associated with CL4 (CL5) exhibits a large band of reduced (enhanced) rainfall from the Caribbean Islands to western Europe following the negative(positive) U200 lobe in Fig.3a(3b) and corresponding to a reduced (enhanced) storminess along this path.

These results suggest that in the model, both tropical Atlantic SSTs and ENSO variability are linked to anomalous atmospheric circulation over the NAE domain. The ENSO connection seems to be dominant and symmetrical with respect to its sign. GOGA clustering confirms observational results regarding the potential role played by the Atlantic tropical SSTs over the NAE domain. Their role is now further investigated by applying cluster analysis onto the AOGA ensemble.

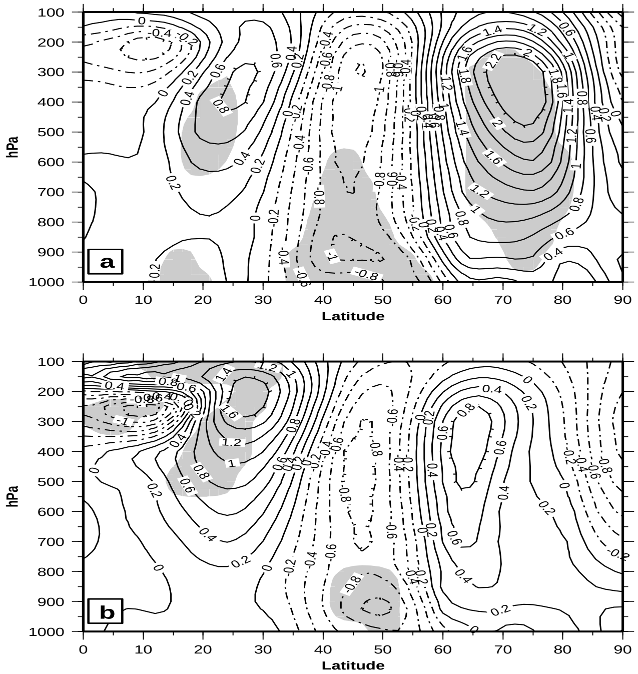

Figure 5. Meridional wind composite as a function of height from the equator to the North pole averaged over the $75^oW - 50^oW$ longitude band for a) NCEP CL2 and b) AOGA CL7. Shading stands for significant anomalies using a 2-tailed t-test at the 95% level

Atlantic SST impacts

Similarly to the GOGA experiments, stable classification of U200 winter states from the AOGA data occurs only for k=2. U200 composites (CL6 and CL7) resemble their GOGA counterparts in terms of both amplitude and spatial structure (Fig.4ab). This U200 pattern is indeed the intrinsic main variability mode of the ARPEGE model and is linked to the simulated NAO. Both SST composites (Fig.4cd) are dominated by significant anomalies within the tropical belt. Maximum values are captured in the Caribbean Sea and Gulf of Guinea. Cooling (warming) in the tropical Atlantic is related to weakened (strengthened) jet over the Azores and is associated with reduced (enhanced) rainfall along the Equator and the South Atlantic convergence zone in a very symmetrical way (not shown). Midlatitudes oceanic patterns are reminiscent of the complete North Atlantic SST tripole although values and significance are quite weak. This may suggest that the model is more sensitive to tropical oceanic anomalies than midlatitude ones which may be considered as the signature of the atmosphere response to tropical SST forcing.

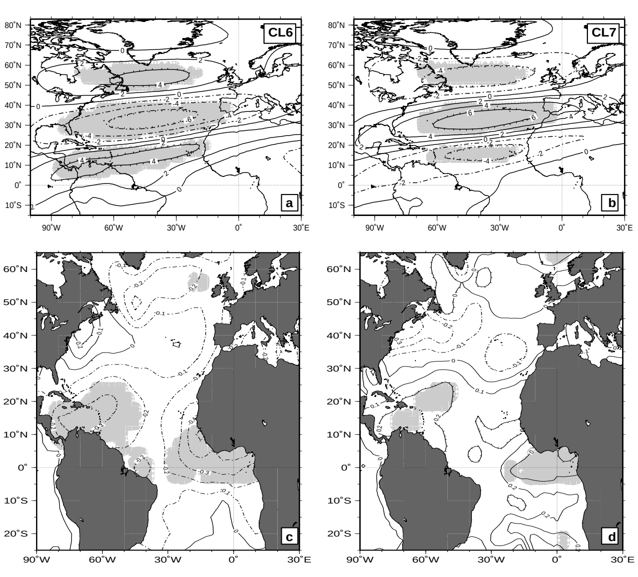

Figure 4. Same as Fig.3 but for AOGA

AOGA and GOGA experiments give similar results regarding their U200 states and their associated SST pattern in the tropical Atlantic. This questions first the role of La Niña direct impacts versus the role of the concomitant cold SST anomalies located in the Tropical Atlantic. Indeed, it is interesting to note that some selected years within the composites are common both in GOGA and AOGA classifications. The seasonality of the ENSO-NAE connection as well as the North Atlantic SST impact should be investigated to further address these questions. Second, the absence of significant signals beyond 30^oN opens up the issue on the role played by SST anomalies at such latitudes. Compositing surface flux from AOGA clusters tends to show that extratropical fluxes signatures are strong and tend to reinforce or create the midlatitude branches of the tripole. It is worth noting however that such a diagnostic should call for caution following [*Barsugli and Battisti*, 1998] conclusions.

Discussion

This study has brought some evidence that the winter NAE atmospheric variability is related to anomalous oceanic conditions both in the North Atlantic and the Pacific, a finding supported by observations and model results. The asymmetrical perspective adopted here shows that Pacific connexions during ENSO years are stronger during La Niña conditions than during El Niño ones, especially in NCEP. In the model, the symmetry with respect to the sign of ENSO is overestimated. Besides, the simulated atmospheric pattern associated with La Niña events projects too much onto the positive phase of the model NAO whereas in reality the ENSO-NAE connection affects the EA regime. A possible mechanism for the NAE sector response to La Niña events might involve the positive phase of the Tropical North Hemisphere arching pattern which is excited in the model during cold events and which extends eastward towards Europe [*Cassou and Terray*, 2001]. Such a perturbation involves the North Atlantic cyclogenesis which initiates a positive feedback through mean flow transient eddies interactions. The dependence of the anomalous eddy forcing on the mean state might explain the asymmetry of the ENSO connection. Results also highlight the importance of the tropical Atlantic SST anomalies: colder (warmer) than normal SSTs there tend to be associated with the positive (negative) phase of the NAO. The tropical-extratropical interaction may involve the local Atlantic Hadley with enhanced (reduced) ascendance over the Northern South American continent and subsidence around 30^oN. Changes in the Hadley cell activity can perturb the stationary wave and the subtropical jet strength. Composites of anomalous meridional wind averaged over 75^oW and 50^oW from the Equator to the pole as a function of height tend to support such an hypothesis, especially for the warm tropical Atlantic conditions as shown in Fig.5. In both NCEP and AOGA, warm tropical Atlantic SSTs are associated with enhanced upper-tropospheric southerlies from 10^oN to 30^oN and concomitant northerlies from 40^oN to 60^oN. This leads to stronger momentum convergence around 30^oN which reinforces the climatological subtropical jet. Symmetrical features appear for cold SSTs over the tropical Atlantic basin but are less significant, thus suggesting nonlinear atmospheric responses to the tropical oceanic conditions.

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