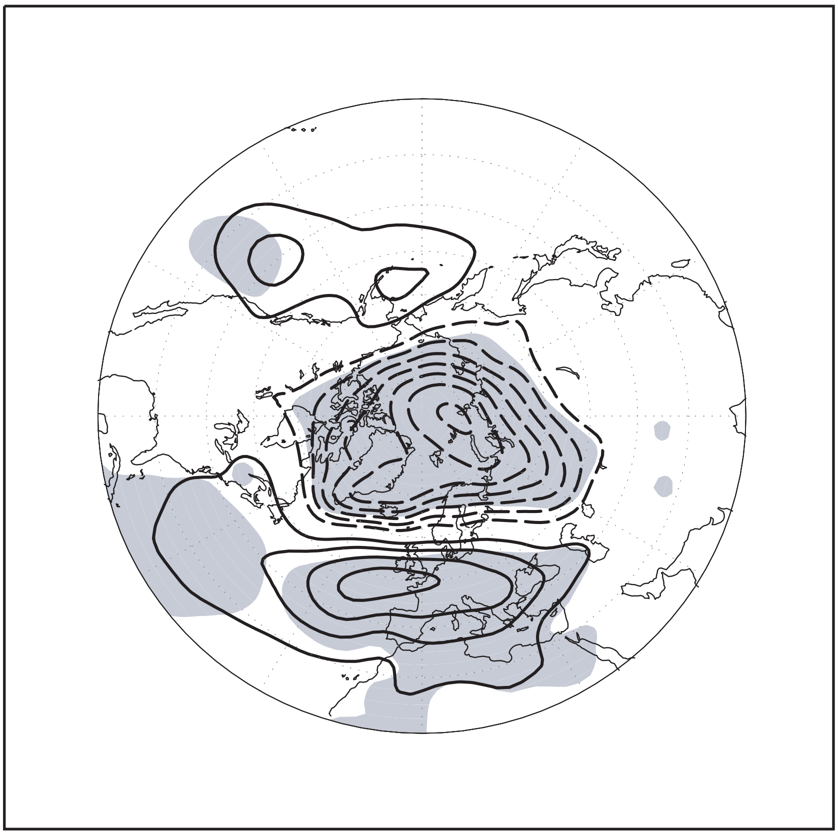
Max-Planck-Institut für Meteorologie

REPORT No. 331



NORTH PACIFIC - NORTH ATLANTIC RELATIONSHIPS UNDER STRATOSPHERIC CONTROL?

by

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HAMBURG, Oktober 2001

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North Pacific-North Atlantic relationships under stratospheric control?

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Abstract

Based on a linear regression/correlation analysis of monthly mean atmospheric sea level pressure data from NCEP reanalysis (1948-2000) we find a significant anticorrelation between pressure in the northern North Atlantic and North Pacific only if the stratospheric circulation is in the "strong polar vortex" regime, but not when the vortex is weak. Since general circulation models in most cases are biased towards the strong vortex regime, they tend to reproduce this anticorrelation already in the mean. The pattern of the "Arctic Oscillation" is shown to be mainly the result of mean surface pressure differences between the two stratospheric regimes. It does not represent a pure physical mode of variability. The typical southwest-northeast tilt of the node line of the North Atlantic Oscillation found with linear analyses in Northern Hemisphere winter is due to a superposition of correlation patterns based on physical processes (a strictly meridional dipole and the pattern resulting from planetary wave refraction in the strong vortex regime) and those produced by the (nonlinear) switch from one stratospheric regime to the other. This result underlines the necessity of the application of non-linear statistics or the restriction of linear statistics to variations in the stable (quasi-linear) environment of natural regimes.

ISSN 0937-1060

1 Introduction

After decades of relative silence, the North Atlantic Oscillation (NAO) and its significance for the Eurasian weather and climate enjoys a renaissance. However, even today the fundamental mechanisms of this important variability mode of the Northern Hemisphere climate seem to be understood only incompletely and large research programmes and conferences give this phenomenon high priority.

The NAO, either based on simple indices like the anomalous pressure difference of the two centers of action involved, the Azores High and the Icelandic Low, or on more sophisticated methods like Empirical Orthogonal Functions (EOFs) in the North Atlantic sector, is claimed to be quite well reproduced by the current climate models (atmospheric models alone: *Barnett* [1985]; *Glowienka-Hense* [1990]; coupled ocean-atmosphere models: *Paeth et al.* [1999]) and, if the sea surface temperature is prescribed as observed during the last century, also the historic behaviour of a lowpass filtered NAO index can be reproduced [*Rodwell et al.*, 1999; *Latif et al.*, 2000].

However, if the whole Northern Hemisphere is included in the analysis, certain differences between the models and observations appear mainly in the relationships between the North Pacific and the North Atlantic. *Osborn et al.* [1999] studied the behaviour of the Hadley Centre's coupled climate model (HadCM2) in terms of its simulation of the North Atlantic Oscillation. In the simulated data, they found significant correlation between the atmospheric circulation over the North Pacific and an index of the NAO, while no signal was apparent in the observations (see their Figure 3). In another climate model (ECHAM3) *May and Bengtsson* [1998] found similar results and *Ulbrich and Christoph* [2000] mentioned a strong and stable anticorrelation between the Icelandic and Aleutian centers of action in a long integration of the ECHAM4 model coupled to the OPYC ocean. Again, there is clearly missing evidence for any such relations in observations. Only *Honda et al.* [2001] found in NCEP reanalysis data from the years 1973 to 1994 a highly significant anticorrelation between the Aleutian and the Icelandic lows, which is restricted to late winter, February to March. *Deser* [2000] and *Ambaum et al.* [2001] presented clear evidence that, even though leading EOFs of the atmospheric pressure fields show structures which would suggest a connection between the North Pacific and the North Atlantic, the local variables are not statistically significantly correlated. However, all above mentioned studies made no separation between months with super- or subcritical Rossby velocities.

A large fraction of climate variability is due to transitions between different circulation regimes, and these transitions may encompass non-linear processes [e.g. *Corti et al.*, 1999; *Palmer*, 1999; *Perlwitz et al.*, 2000]. An example of such non-linear processes is the upward propagation or downward reflection of planetary waves depending on the strength of the westerlies in the lower extratropical stratosphere in winter [*Charney and Drazin*, 1961]. If the zonal mean wind is smaller than the wave number and longitude dependent critical Rossby velocity, planetary waves can further propagate upward, otherwise they are reflected and superpose to the tropospheric flow. In the case of a strong polar night vortex this can lead to a significant change of mid tropospheric geopotential patterns few days later [*Perlwitz and Graf*, 2001a], while there is no significant lag correlation from stratospheric to tropospheric circulation during a weak vortex episode. Since most climate models used so far tend to overestimate the stratospheric zonal wind in winter on the Northern Hemisphere, the simulated circulation may have greater probability to be in a regime different from the preferred regime of the observed natural system, and the simulated response to external forcing (e.g., greenhouse gases, volcanic aerosols, solar and ozone changes) may result in other anomaly patterns and/or amplitudes than observed [*Perlwitz et al.*, 2000].

To see if the results of the above mentioned models may be attributed to a model bias resulting from the too strong polar vortex, and the results of *Honda et al.* [2001] are due to the very strong polar vortex in late winter (mainly during the years they included in their data set) we performed a correlation/regression analysis on a monthly basis divided into months with either observed strong or weak zonal winds in the lower stratosphere. We consider an extended cool season from November to April as that used by *Thompson and Wallace* [1998], *Corti et al.* [1999] and *Deser* [2000].

2 Data and Data preparation

The data were obtained from the National Centers for Environmental Prediction (NCEP) reanalysis data set [*Kalnay et al.*, 1996]. We used the wintertime (N,D,J,F,M,A) monthly means of sea level pressure (SLP) and zonal wind at 50 hPa with a horizontal grid resolution of 2.5^o lat. $\times$ 2.5^o long., north of 20^o N, covering the period 1948-2000. The seasonal cycle of the SLP fields was removed by subtracting the long term mean of each month. Next, we detrended the data by subtraction of the five year running mean at each grid point. This way we reduce the influence of possible data inhomogeneities on time series analysis.

We constructed three sets of detrended data: A first one including all detrended data from 1950 to 98 (288 months). A second set includes only the months when $0 < \overline{u}_{50}(65^o\text{N}) < 10\,\text{m}\,\text{s}^{-1}$, where $\overline{u}_{50}(65^o\text{N})$ is the 50 hPa zonal mean zonal wind at 65^o N. We consider this the Weak Vortex Regime (WVR, 72 months). A third one including only the months when $\overline{u}_{50}(65^o\text{N}) > 20\,\text{m}\,\text{s}^{-1}$. We consider this the Strong Vortex Regime (SVR, 87 months). The wind was not detrended and the seasonal cycle was not removed. The regime thresholds are somewhat arbitrary, but roughly reflect critical Rossby velocities for zonal wave number two near the polar circle.

We further constructed indices of the NAO, the strength of the Azores High and of the Icelandic Low. The NAO index is simply the difference of the SLP normalized to their standard deviation of the grid points closest to Ponta Delgada (Azores) and Reykjavik (Iceland). The Azores High index is the mean of the four data points of SLP closest to Ponta Delgada, and the Icelandic Low index is the mean of the four data points closest to Reykjavik.

3 Results

Table 1 shows the number of months selected as SVR or WVR during the boreal cold season (November-April). Clearly SVR is concentrated to the main winter months (DJF), while the WVR most frequently occurs during the late winter/early spring

(March and April). Such a clear separation will not be found when the SVR and WVR selection is based on standard deviations as e.g. in *Perlwitz et al.* [2000], but we feel that fixed, even though not very well defined, thresholds are in better agreement with the existence of fixed critical Rossby velocities for specific wave numbers and latitudes. We checked if the WVR results possibly may be determined by the large number of cases in April by repeating the analyses without the April data and found no evidence for this.

For each of the three data sets (all data, weak and strong polar vortex) we computed the regression(isolines)/correlation(shading) maps of the SLP upon the NAO index (Figures 1 and 2). The regression values are in hPa per one standard deviation of the above defined NAO index. The standard deviation has been calculated for each case. It is 1.79, 1.97, 1.57 for all data, SVR and WVR, respectively.

In all three cases the dominant role of the North Atlantic pressure seesaw is evident as expected. Figure 1 is coherent with a similar analysis of observed data by *Osborn et al.* [1999]. However, there are significant differences between the WVR (Figure 2, *left*) and the SVR (Figure 2, *right*) mainly over the North Pacific. The SLP in the western part of the Aleutian Low is positively correlated with the NAO index ($r_{max.} = 0.39$) under SVR conditions. A remainder of this signal is seen in Figure 1 for all data. We adopted a threshold for shading of 0.1 for the correlation in the case of all data (288 months), and the threshold of 0.2 for the WVR (73 months) and SVR (87 months). The two thresholds are statistically significant at the 95% confidence level for time series with 250 and 65 independent terms (degrees of freedom), respectively. We have performed no calculations to assess the field significance of the correlation.

The differences between Figure 1 and Figure 2 (*right*) are coincident with the major differences between observations and simulations found by *Osborn et al.* [1999] (see their Figure 3). Clearly there is no significant correlation between the NAO index and SLP over the North Pacific when the stratospheric westerlies are weak (Figure 2, *left*).

The significant correlation over the North Pacific in the SVR may give some explanation for the significant correlation between the PNA and the NAO, found in the above mentioned GCM simulation studies. These models all have a strong bias towards a too cold and strong polar vortex and therefore already in the mean tend to reflect the behaviour which in the natural system only is observed for strong vortices.

Perlwitz and Graf [2001a] showed with a single wave analysis (SWAN) of 10 day low pass filtered NCEP reanalysis data from 1958-1999 for November till April that planetary waves of zonal wave number (ZWN) 1 are refracted equatorward and downward at the strong westerlies in SVR, but not in WVR. In the WVR ZWN1 generates wave disturbances in the stratosphere.

The analysis of correlation/regression between the SLP field and an NAO index is only partly reasonable and we did it mainly in order to compare our results with those of other authors. Since the pressure of the Icelandic Low is not in perfect anticorrelation with the Azores High, any physical interpretation may be complicated if the single centers of action each have their own specific contribution to the global field. We therefore also studied the regression/correlation of the North Atlantic centers of action separately. Figure 3 *(left and right)* contains the analysis results for the WVR and the SVR, respectively, for the Azores High. In order to reduce statistical noise of the

Azores pressure index, we took the mean of the pressure of the four data points near to Ponta Delgada (Azores), i.e. in the region of maximum correlation between our NAO index and the pressure field from Figure 2.

In the subtropics there is a distinct difference between the two stratospheric regimes in the area of significant correlation of SLP with the Azores High. This area is smaller in the WVR and is extended over all North Africa in the SVR instead of being restricted to subtropical Northwest Africa as in the WVR. This already showed up in the analysis with the NAO index, indicating that the contribution of the strength of the Azores High to the variability of the NAO is a dominating factor. Between 35^o and 45^o N over the western North Pacific a positive correlation appears in the SVR which is not apparent in the WVR. It is found right where the in phase correlation between NAO and SLP is seen in Figure 2 *(right)*, but is weaker both in correlation and in amplitude. Hence, here the Azores High is not the only contributor.

The clearest differences between SVR and WVR exist over the North Atlantic and over the Arctic. In the SVR the connection between the Azores High and the Icelandic Low is much stronger (by a factor of two based on the regression over Iceland) and also the correlation is clearly different with maximum absolute correlation $|r|_{max.} = 0.59$ in the WVR versus $|r|_{max.} = 0.67$ in the SVR. The correlation/regression is very much concentrated on the Icelandic Low in the SVR, whereas it is much weaker and extended over the whole Arctic in the WVR.

Figure 4 *(left and right)* shows the regression/correlation based on the Icelandic Low for the WVR and the SVR, respectively. As for the Azores High, we took the mean of the pressure of the four data points near to Reykjavik (Iceland), in the region of maximum anticorrelation between our NAO index and the pressure field from Figure 2 *(left and right)*.

Globally the two vortex regimes present the same differences as those mentioned above for the Azores High. However, in the SVR, the connection of the SLP over the North Pacific with the Icelandic Low (Fig. 4, *right*) is stronger than the connection with the Azores High (Figure 3, *right*), as may be deduced from the respective regression/correlation maps.

In all maps presented here, the regression coefficients have been normalized to the standard deviation of the time series onto which the regression is done. Hence, the squared correlation coefficients represent the variance explained by the teleconnection patterns shown in each map. With this interpretation one can see that the SVR (Figure 4, *right*) is associated with a larger amount of SLP variance than the WVR (Figure 4, *left*). This may help to understand why the leading SLP pattern obtained by a Principal Component Analysis is closer to the regression patterns shown in Figure 2 *(right)* and Figure 4 *(right)*.

In order to see if smaller variance in the WVR may result from the large number of April months in the respective data subset, we repeated the analysis excluding the April months. Figure 5 *(left and right)* shows the regression/correlation maps based on the NAO index and the pressure over the Icelandic Low, respectively. Considering a time series with 39 independent terms (the maximum possible in this case) the correlation is significant at 95% level for absolute values above 0.3 (0.27). Comparing Figure 2 *(left)* with Figure 5 *(left)*, and Figure 4 *(left)* with Figure 5 *(right)*, there is no evidence that the main pattern features of the WVR may result from the large number of April months in the respective data subset.

4 Linear versus non-linear studies

In the non-linear paradigm presented here for the dynamical link between tropospheric and stratospheric circulation, the NAO appears in both vortex regimes as an exact meridional seesaw of atmospheric mass over the North Atlantic. However, there are important differences between the two regimes. In the SVR, the meridional pressure gradient and the anomaly amplitudes over the North Atlantic are stronger, and the Azores High extends more over North Africa. Another important difference is the appearance of a significant correlation between the SLP over the Northwest Pacific and the NAO when the vortex is strong (Figure 2, *right*).

In some linear studies (e.g., *Perlwitz and Graf* [1995], *Kodera et al.* [1999], *Deser* [2000] and *Castanheira et al.* [2001]), the tropospheric circulation pattern associated with the strength of the winter polar vortex presents a northwest-southeast oriented dipole over the North Atlantic. As mentioned above, the NAO patterns obtained in our study are characterized by a strictly meridional dipole in both vortex regimes. The same orientation was found by *Kodera et al.* [1999] for the NAO with the linear influence of the polar vortex removed (see their Figure 3b). The orientation of the pressure dipole may imply important features on the advected properties and is, therefore, a crucial parameter. Its physical background must be understood to avoid misinterpretations of climate change and sensitivity.

Based on our results, the patterns obtained in linear studies must be influenced by the difference between the mean tropospheric circulation in the two vortex regimes. Figure 6 presents the difference between the mean SLP fields of the two vortex regimes (SVR-WVR). Statistically significant (local t-test) negative differences appear mainly north of the Polar Circle, and in the midlatitudes over the Euro-Atlantic region significant positive differences are found. Negative anomalies extending over the whole polar cap imprint a zonal character to the difference pattern [*Deser*, 2000]. However, very contrasting pressure gradients are found over the North Pacific and the North Atlantic. A much stronger pressure gradient representing a southwest-northeastward tilt of streamlines is observed over the Euro-Atlantic region. This feature compares well with Figure 5a of *Perlwitz and Graf* [1995]. The southwest-northeastward streamline tilting is also shown in Figure 3c (left-hand column) of *Kodera et al.* [1999]. We are aware that in this study we are considering an extended winter (Nov.-April), while the above cited authors considered only the months of December to February. However, Figure 6 compares also well with figure 2 (middle) of *Deser* [2000] and with Figure 7c of *Perlwitz and Graf* [2001b] who used the same extended cool season.

Our figure 6 compares also fairly well with the EOF pattern of SLP presented by *Thompson and Wallace* [1998] (see their Figures 1 and 2), a pattern that was named "Arctic Oscillation" (AO). As already referred this AO pattern presents a more zonal character (mainly due to the Arctic center [*Deser*, 2000]) than that shown by all NAO patterns presented here. The AO pattern, which is most clearly defined near the surface (SLP) must be influenced by the difference of the mean pressure of the two regimes over the Northern Hemisphere. The application of simple EOF analysis would emphasize this coherent pattern and, as a consequence, the AO index represents variance due to vortex regime changes.

Figures 7a,b and c) show the first EOFs for the three considered cases: all data, SVR and WVR data subsets, respectively. The EOF based on all data explaining 19.1% of total variance is very close to those found by *Thompson and Wallace* [1998] (see their Figures 1 and 2). The best agreement is achieved when we compare our pattern with the pattern they computed for intraseasonal variability. However, using detrended data, as done here, leads to a relative enhancement of the Icelandic Low inside the broad Arctic center. The EOFs based on the WVR and SVR data subsets (explaining 18.1% and 20.8% of total variance) are very close to the regression patterns upon the normalized NAO index shown in Figure 2 *(left and right)*, respectively. The time series of the projection onto the EOF pattern based on all data (Figure 7a) reflects the vortex regime changes (Figure 6) as well as the teleconnection between the North Pacific and North Atlantic under SVR conditions (Figure 7b). It is the vortex regime changes that contribute to the clearer separation between PC1 and PC2 based on all data than within the regime subsets.

As stated above, the EOF pattern for the SVR is close to the regression pattern in the SVR regime (Figure 2, *right*). However, the EOF pattern presents a SW-NE tilt of streamlines over the Atlantic-European region, whereas in Figure 2 *(right)* a more zonal flow is observed. The applied statistical methods can explain the differences. The EOF analysis produces the pattern that explains the maximum coherent variability, including, possibly, several different variability mechanisms. In the present case, the EOF analysis captures the variability mechanism leading to the zonal North Pacific North Atlantic connection as well as the variability mechanism leading to the meridional North Atlantic teleconnection. On the other hand, the regression pattern in Figure 2 *(right)* is based on a meridional index defined over the North Atlantic. Such index must be more sensitive to the local meridional variability mechanism.

In three-dimensional linear analyses (e.g. CCA or SVD derived coupled modes of stratospheric and tropospheric circulation used by *Perlwitz and Graf* [1995], *Kodera et al.* [1999], *Deser* [2000], *Castanheira et al.* [2001] and *Perlwitz and Graf* [2001b]) that account for vertical planetary wave propagation, the obtained patterns must also be influenced by the mean difference as well as by the differences in the teleconnection mechanisms operating under each vortex regime, leading to the typical SW-NE tilt of the node line of the coupled tropospheric pattern over the Euro-Atlantic region. Hence, our results suggest that linear analysis, i.e. the neglect of the existence of different regimes of planetary wave propagation, may lead to a mix of dynamical features with the mean state of the different regimes. Only taking into account the non-linear transition between the regimes, as done here, will allow for the isolation of variability mechanisms.

5 Concluding discussion

Our analysis showed that obviously stratospheric circulation controls the correlation between the North Atlantic and the North Pacific pressure patterns. A teleconnection between SLP over the North Pacific and the North Atlantic is found during the SVR (Figure 2, *right*), but not when the polar vortex is weak (WVR). The connection between the NAO and the North Pacific SLP is established mainly through the Icelandic Low (see Figures 3 and 4). This connection may result from an amplitude enhancement of zonal wave number 1 in high latitudes, due to the tropospheric trapping of this wave by reflection at the strong zonal winds in the lower stratosphere. The statistical association of this teleconnection with the NAO (Figure 2, *right*) is dominated by the Icelandic Low and no underlying physical mechanism of the NAO is necessarily implied.

As was shown by *Perlwitz and Graf* [2001a], in the WVR tropospheric planetary waves of zonal wave number 1 will influence the stratospheric circulation but not vice versa. However, in the SVR a zonal wave number 1 disturbance will exert an influence on the stratosphere and the stratospheric circulation acts back on the troposphere with maximum lag correlation at about 6 days. Their Figure 5 suggests that finally a tropospheric circulation anomaly results with opposite signs over Iceland and the Aleutians. The time lags of the linear correlation allow the conclusion that this process takes about 8-10 days and may, thus, be responsible for the quasi simultaneous anticorrelation in a monthly analysis. This the more since, due to the feedback between transient eddies and planetary waves over the North Atlantic and North Pacific, phase and amplitude of the planetary waves are kept quasi constant.

Whereas the North Pacific-North Atlantic teleconnection may finally result from planetary wave zonal mean flow interaction, we may hypothesize that Hadley-Ferrel-Cell interactions control the strength of the meridional NAO. More work, including analysis of daily data, will be needed to test this hypothesis.

The results here obtained for the SVR also suggest that the result of *Osborn et al.* [1999], which shows a connection between the NAO and North Pacific SLP simulated by the HadCM2, may be due to a bias of the model towards a Strong Vortex Regime. The same holds for other model studies mentioned in the introduction.

The strong anticorrelation of the Aleutian and Icelandic lows found by *Honda et al.* [2001] seems not to be connected to the strength of the polar vortex in a straightforward manner. Although they find a strong simultaneous anticorrelation between the two centers of action, lag correlation showed that the process starts, well before the maximum correlation, in the Aleutian region and includes horizontal Rossby wave propagation.

Another significant result of our analysis concerns the pattern structure of the NAO. If the analysis takes into account that strong and weak polar vortex represent two different regimes of atmospheric circulation, the NAO pattern appears as a strict meridional dipole. This result corresponds with findings of *Castanheira et al.* [2001] that an NAO like strictly meridional dipole over the North Atlantic is an Eigensolution of the equations of motion linearized around a layered atmosphere at rest. However, some differences in the correlation/regression patterns are observed between the two stratospheric vortex regimes. The teleconnection over the North Atlantic appears to be stronger during the SVR and the Azores High extends farther over North Africa.

The difference between the mean SLP fields of the two vortex regimes (Figure 6) shows a spatial structure close to that of the first EOF of SLP when computed over the whole extratropical Northern Hemisphere [*Thompson and Wallace*, 1998]. The characteristic southwest to northeast tilt of the isobars over the Euro-Atlantic region, found in these patterns, is also obtained when the SLP EOF is computed only over the Euro-Atlantic region in winter [*Glowienka-Hense*, 1990]. The same results from three-dimensional linear studies of the related lower stratospheric and tropospheric circulations [*Perlwitz and Graf*, 1995; *Kodera et al.*, 1999; *Deser*, 2000; *Castanheira et al.*, 2001; *Perlwitz and Graf*, 2001b]. In all these studies the NAO patterns over the Euro-Atlantic region are oriented in the same way in winter: SW-NE. However, the similarity of those patterns with the mean difference pattern between the two vortex regimes obtained here (Figure 6) suggests that the linear statistical methods that were usually applied may be sensitive to a mix of different dynamical mechanisms. This result has important consequences if the internal mechanisms and the external forcings leading to changes between the two vortex regimes are different and/or they operate largely independent from those which determine the strength of the north-south oriented NAO. In this case we must study the forcings of the meridional NAO separately during the WVR and the SVR. However, two different mechanisms may remain relevant under SVR conditions: The zonal North Pacific-North Atlantic connection (suggested to work via planetary waves) and the North Atlantic connection between the subtropics and the subpolar latitudes. Different analysis methods may be needed to study these relationships and to distinct between the different mechanisms.

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Table 1: Case numbers of WVR ($0 < \overline{u}_{50}(65^oN) < 10\,m\,s^{-1}$) and SVR ($\overline{u}_{50}(65^oN) > 20\,m\,s^{-1}$) for each month of the cool season (November to April) .

		N	**D**	**J**	**F**	**M**	**A**	Total
W	1951-74	4	3	2	5	9	17	40
V	1975-98	2	2	1	2	9	16	32
R	All Period	6	5	3	7	18	33	72
S	1951-74	1	9	13	11	4	0	38
V	1975-98	2	13	16	12	5	1	49
R	All Period	3	22	29	23	9	1	87

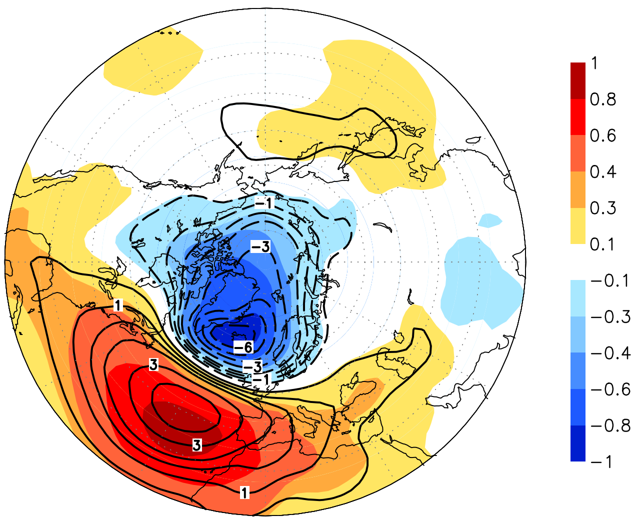

Figure 1: Correlation(shading)/regression(isolines) pattern between the standardized NAO index [Ponta Delgada (Azores) - Reykjavik (Iceland)] and the SLP, based on the detrended monthly means of the extended cool season (November-April), for the period 1950-98. The regression values are in hPa per one standard deviation of the NAO index. Negative contours are dashed and the zero contour line has been suppressed. Contour interval is 0.5 for absolute values smaller than 2.0 and 1.0 for absolute values greater than 2.0.

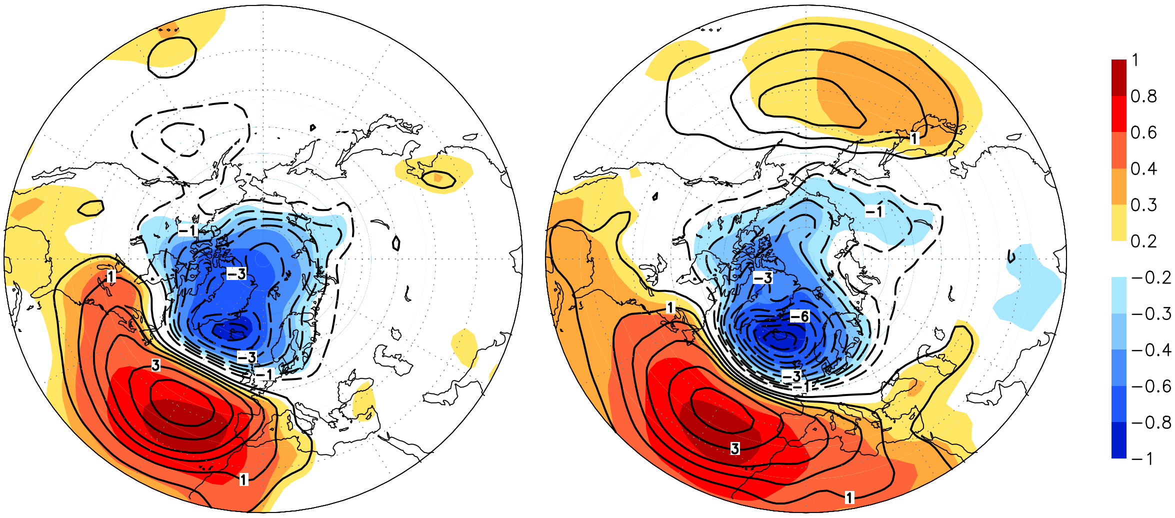

Figure 2: As in figure 1 but considering *(left)* only the months with $0 < \overline{u}_{50}(65\,^{\circ}\mathrm{N}) < 10\,\mathrm{m\,s^{-1}}$, i.e., the WVR; *(right)* only the months with $\overline{u}_{50}(65\,^{\circ}\mathrm{N}) > 20\,\mathrm{m\,s^{-1}}$, i.e., the SVR. Note that the minimum value of significant correlation was changed.

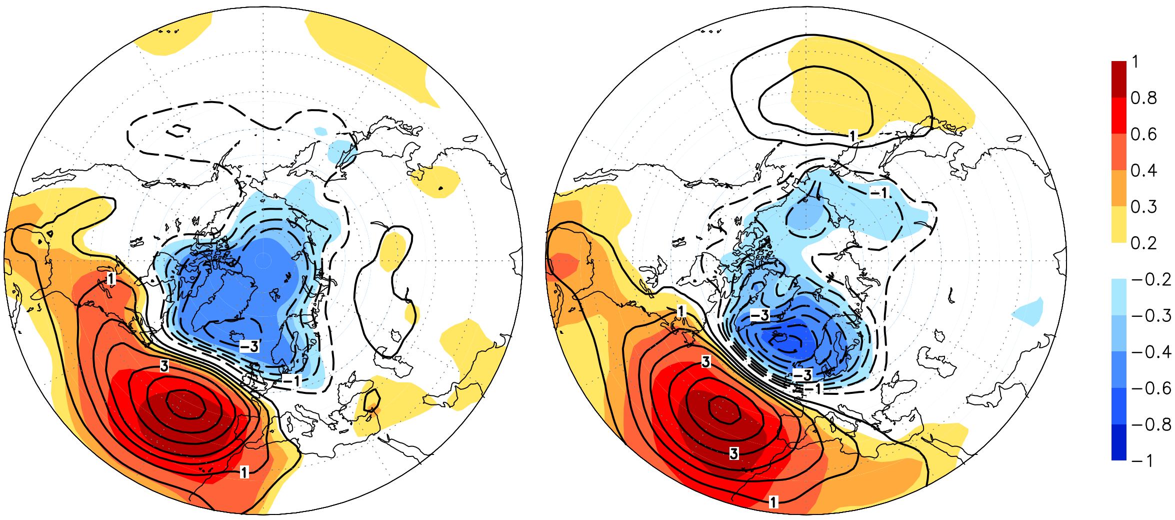

Figure 3: Correlation/regression patterns between the averaged pressure at four grid points near Ponta Delgada (Azores) and the SLP, in the WVR *(left)* and SVR *(right)* cases. The four grid points considered are in the region where is maximum the correlation with the NAO index (see figure 2). The maximum absolute correlation near Iceland is 0.59 and 0.67 in the WVR and SVR, respectively.

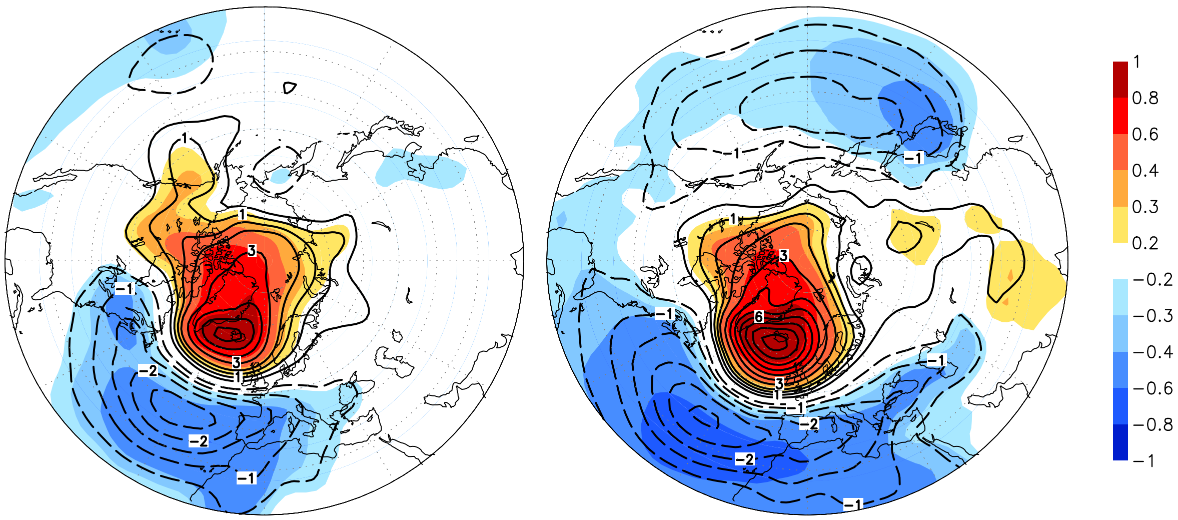

Figure 4: As in figure 3 but considering four grid points near Reykjavik (Iceland). Contour interval is 0.5 for values smaller than 2.0 and 1.0 for values greater than 2.0. The maximum absolute correlation near Azores is 0.60 and 0.70 in the WVR *(left)* and SVR *(right)*, respectively.

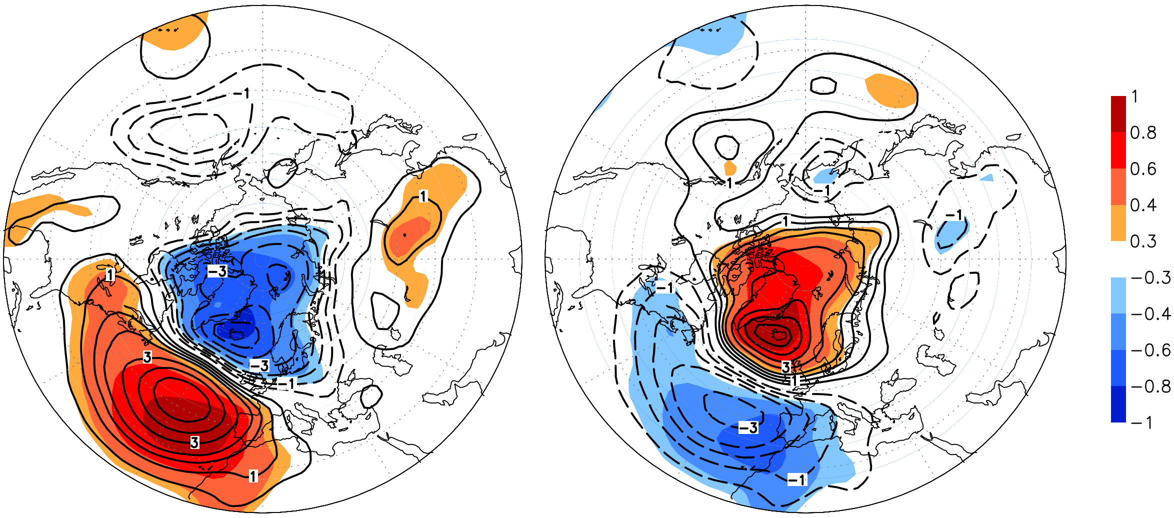

Figure 5: Correlation/regression maps for WVR. *(left)* as in Figure 2 and *(right)* as in Figure 4 but without the April months. Contour interval is 0.5 for absolute values smaller than 2.0 and 1.0 for absolute values greater than 2.0. We used a correlation threshold of 0.3 that is statistically significant at the 95% confidence level for a time series with 30 independent terms.

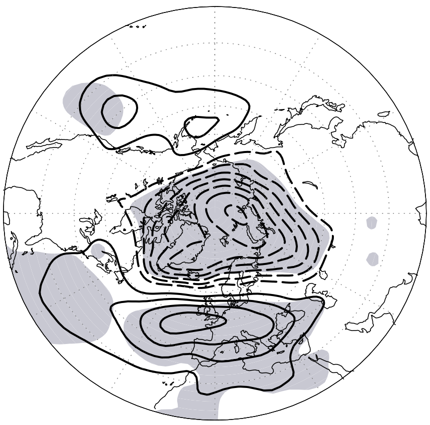

Figure 6: Difference between the mean SLP in the two vortex regimes (SVR-WVR). Contour interval is 0.75 mb. Negative contours are dashed and the zero contour line has been suppressed. The shading indicates where the mean difference is significant at least at the 95% confidence level.

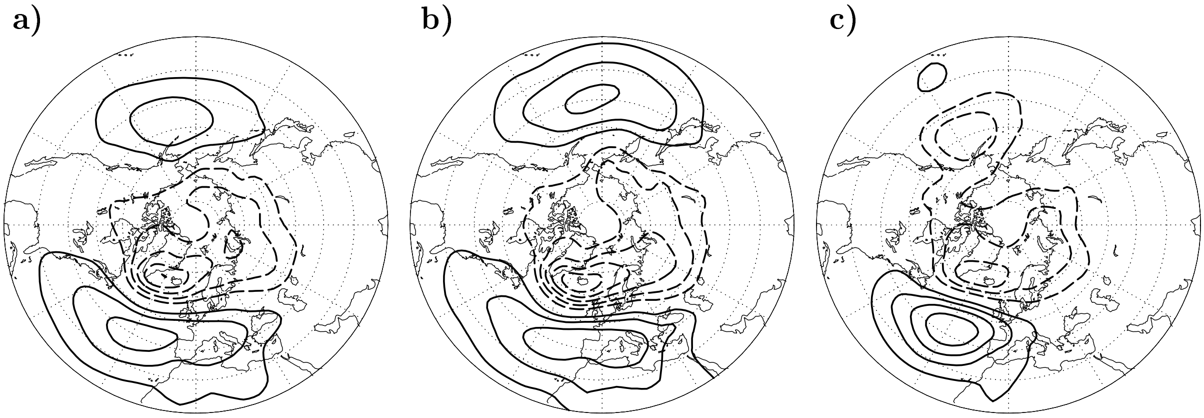

Figure 7: Leading EOFs of monthly detrended SLP anomalies poleward of 20° N based on: a) all data, b) SVR data subset, and c) WVR data subset. They explain 19%, 21%, and 18% of the total variance of the respective data sets. The patterns has been obtained by regressing the monthly SLP anomalies upon the leading PC in each data set. Contour interval is 0.75 mb per standard deviation of the appropriate PC.

ISSN 0937 - 1060