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Pacific centre of the Arctic Oscillation: product of high local variability rather than teleconnectivity

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ABSTRACT

The North Pacific centre appears to be the weakest link in the concept of the Arctic Oscillation (AO), mainly because of its very low correlations with the other two centres, located over the Arctic and in the North Atlantic. Its latitudinal position and horizontal extent differ considerably in dependence on whether a covariance or correlation matrix is used as an input to principal component analysis. In the correlation-based analysis, the Pacific centre is much weaker and shifted 15° southwards. The teleconnectivity of the Pacific centre in the covariance- and correlation-based solutions is widely dissimilar. The coincidence of the covariance-based Pacific centre with an area of a high local variability and the lack of its correlations with remote areas imply that the Pacific centre of the AO is a result of a high local variability rather than teleconnectivity. This idea is supported by a simple three-component artificial example.

1. Introduction

Thompson and Wallace (1998) found out that the leading mode of unrotated principal component analysis (PCA) of covariance matrix of wintertime (November to April) monthly sea level pressure (SLP) anomalies in the Northern Hemisphere (NH) bears a signature of a circumpolar (annular) mode, and called it Arctic Oscillation (AO). The AO is composed of three centres of action, one residing over the pole, and the other two with the opposite polarity at the locations of the Azores high and the Aleutian low. In this paper, the three centres are in turn referred to as Arctic, Atlantic and Pacific.

It is mainly the Pacific centre that differentiates the AO from the North Atlantic Oscillation (NAO), which consists of a dipole with centres over the Azores high and Icelandic low. The Pacific centre, however, appears to be the weakest link in the concept of the AO: Deser (2000) notes its insignificantly low correlations with the other two action centres, which is supported by Ambaum et al. (2001) in their analysis of a simple three-component system mimicking the AO. Wallace and Thompson (2002) argue that the teleconnectivity of the Pacific centre is weak because the Pacific–Atlantic correlation is blurred by another fluctuation with the opposite polarity in the Pacific and Atlantic sector. According to Honda and Nakamura (2001), the AO appears to be a combination of the NAO with the Icelandic–Aleutian seesaw. In light of the ongoing debate on whether the hemispheric or sectorial view (represented by the AO and NAO concepts, respectively) of the NH low-frequency circulation variability is to be preferred (e.g., Deser, 2000; Wallace, 2000; Ambaum et al., 2001; Monahan et al., 2001; Christiansen, 2002a,b; Itoh, 2002; Wallace and Thompson, 2002; Watanabe, 2004), the understanding of the nature of AO's Pacific centre appears to be important. This contribution provides an alternative explanation of why the Pacific centre appears as a part of the AO although it is uncorrelated with the other two centres.

2. Data

The database consists of monthly mean SLP anomalies on a regular 5° by 5° grid extending from 20°N northwards for the winter half-year (November to April) in period 1948–1999. This enables us to follow the definition of the AO by Thompson and Wallace (1998) as closely as possible. The SLP data are taken from the NCAR daily dataset (Trenberth and Paolino, 1980; updated).

In order to compensate for the unequal grid spacing, a quasi-equal-area (QEA) grid is used. We decided not to create a true equal-area grid because this would require some kind of spatial interpolation, which might introduce a bias into the data. The way the QEA grid is constructed is described in Huth (2006). Its basic idea is that each grid point should represent as closely as possible the same area; because the polar cap is included in the analysis as a separate grid box, the area common to all grid points should be that of the polar grid box. At each latitude, appropriate numbers of points are retained or deleted from the original grid so that the distribution of the retained ones along a latitude circle is as uniform as possible. The total number of

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points in the QEA grid corresponding to a 5° latitudinal spacing is 700. The results based on the QEA grid are almost identical to the analysis of cosine weighted data when the latter makes sense, that is, for PCA of a covariance matrix (cf. Huth, 2006).

3. Results

It is a well-known fact that the unrotated PCA of the covariance matrix of SLP results in the AO pattern (Thompson and Wallace, 1998), whereas rotated PCA leads to the NAO (Dommenget and Latif, 2002). The Pacific centre of the unrotated pattern concentrates along the 50°N parallel around its crossing with the date line, that is, in the area of the Aleutian cyclone, and its zonal extent is rather limited. We performed several different variants of orthogonally rotated PCA (using the Varimax rotation algorithm) with the numbers of principal components (PCs) that comply with the criteria set out in literature (O'Lenic and Livezey, 1988) and range from 4 to 15. Regardless of the number of retained PCs, the loading patterns of the relevant rotated modes display the Arctic and Atlantic centres only, with the hints of the Pacific centre being very weak or even missing, and unstable (not shown).

If the variance varies considerably across the analysis domain, the loading patterns resulting from the covariance and correlation matrices may differ. This is the case of NH SLP, as shown in Fig. 1. The unrotated analysis of the correlation matrix also leads to an annular-like pattern; however, with features different from the covariance matrix. Most notably, the Pacific centre is considerably weaker, more zonally elongated, and shifted southwards by about 15° from the position of the Aleutian cyclone towards the subtropical anticyclonic belt. (The loading patterns based on covariance and correlation matrices have already been displayed by Dommenget and Latif (2002), but without discussing implications for the NAO versus AO debate.) On the other hand, the rotated correlation-based loading patterns bear fairly strong similarity to those of the covariance matrix, exhibiting virtually no signs of the Pacific centre (not shown).

The difference in the location and character of the Pacific centre between the covariance and correlation matrix calls for the analysis of its teleconnectivity. One-point correlation maps of SLP with the base points located at the primary and secondary Pacific centres of the correlation matrix-based loading pattern are displayed in Fig. 2a and b. Both of them are teleconnected, although rather weakly, with a belt extending from northern Alaska to central Canada, but not at all with the areas where the Atlantic and Arctic centres are located. The correlation map for the Pacific centre of the covariance-based PCA (Fig. 2c) yields a totally different picture: in fact, it forms a monopole with very weak correlations in the Arctic area and near-zero correlations where the Atlantic centre is located. The only hints of a stronger teleconnectivity appear in subtropical Pacific areas at 20°N (and possibly further southwards), which is irrelevant for this study. If the square root of one-point covariance is plotted instead correlations (Fig. 2d), the negligible teleconnectivity in the Atlantic area is retained, whereas a non-negligible covariability emerges around the Icelandic cyclone and the east Asian-Pacific sector of the Arctic.

Given a very low teleconnectivity between the Pacific and other two centres of the AO, the question may be raised why, in spite of it, the Pacific centre becomes a part of the AO pattern? A general answer is provided by Ambaum et al. (2001) who clearly demonstrate that two variables (gridpoint values in our case) can be highly loaded on the same PC even if they are uncorrelated. A more specific answer is provided by the map of standard deviations of monthly mean SLP (Fig. 3): The Pacific centre in the unrotated covariance-based analysis coincides with an area of very high variability. The variability there is high enough to outweigh its fairly low correlations with the other two action centres and, hence, to attain high covariability with at least parts of one of them (the Arctic centre; cf. Fig. 2d).

4. Artificial example

In this section, it is demonstrated by using an artificial example that high local variability may result in forming a strong centre in

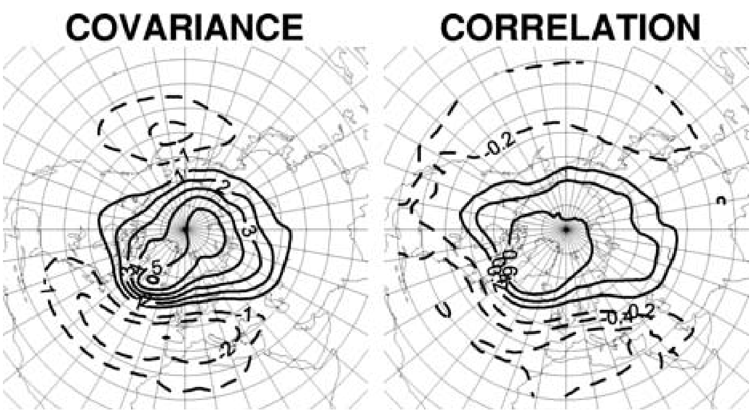

Fig. 1. Loadings of the leading PC of unrotated solution for the covariance (left) and correlation (right) matrix. Contour interval is 1 hPa for (left), 0.2 for (right); the zero contour is omitted, and negative contours are dashed.

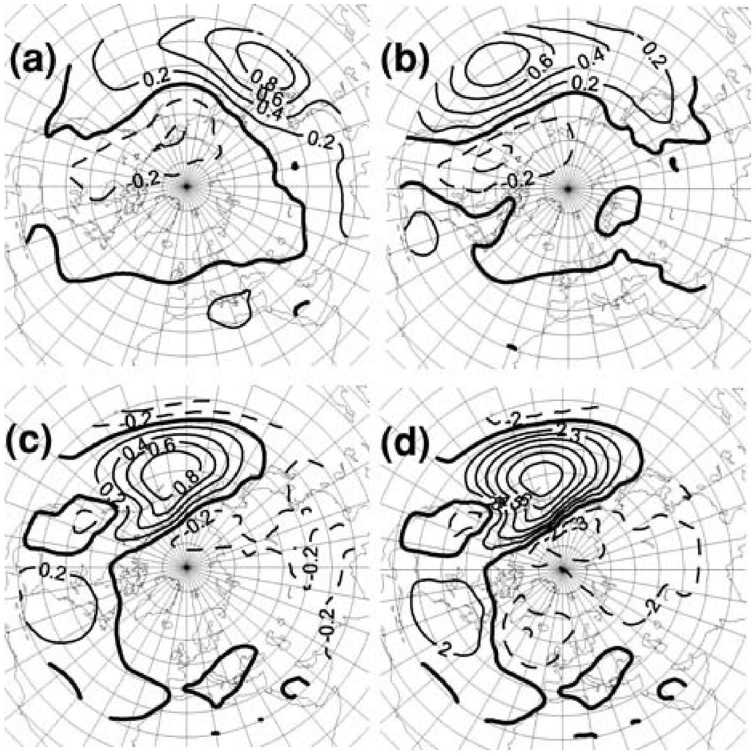

Fig. 2. One-point correlation maps with base points (a) 30°N, 145°E (main Pacific centre in the correlation-based solution), (b) 30°N, 150°W (secondary Pacific centre in the correlation-based solution), (c) 50°N, 170°W (Pacific centre in the covariance-based solution) and (d) map of square root of covariance with the base point 50°N, 170°W. Contour interval is 0.2 in (a)–(c) and 1 hPa in (d); the ±1 hPa contours are omitted in (d); the zero contour is bold in all panels.

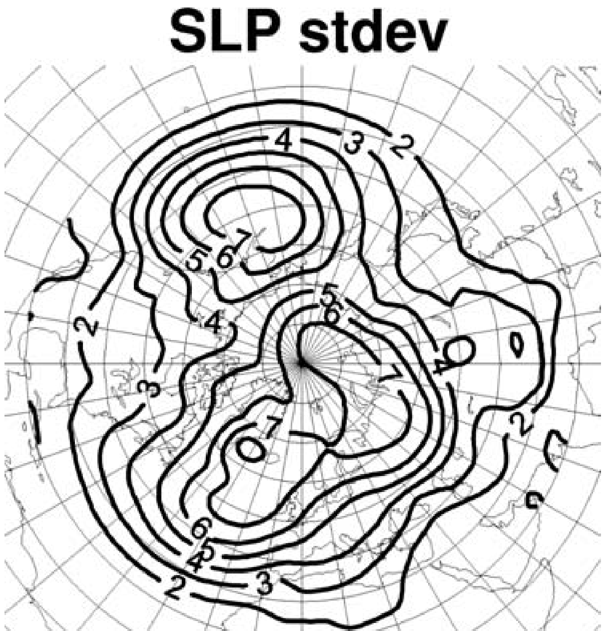

Fig. 3. Standard deviation (in hPa) of monthly mean SLP anomalies.

Table 1. Correlations between the components in the artificial example of the AO

Variables	Correlation
ATL × ARC	−.66
ARC × PAC	−.21
ATL × PAC	+.13

the PC loading pattern even in the presence of fairly low correlations. The example, in its construction similar to those presented in Ambaum et al. (2001), Dommenget and Latif (2002) and Itoh (2002), consists of three components (variables), mimicking the three AO centres and, for simplicity, being identified by abbreviations ATL, ARC and PAC to be reminiscent of the three AO's centres.They are normally distributed random variables, with zero mean, and are set to be correlated consistently with real values presented, for example, in Deser (2000) (Table 1). The standard deviations of the ATL and ARC variables are equal to one, whereas that of the PAC variable is changed in the range from 0.5 to 2 to simulate the effect of the increasing local variance. The unrotated PC loadings for different values of the PAC standard deviation are presented in Table 2. Clearly, the local variability of the little correlated PAC centre strongly affects the shape of the AO-like PC (i.e. the PC where the signs of the centres correspond to reality: the sign of ARC is opposite to ATL and PAC), which is always the leading mode. Low local variance leads to the loading pattern with a very weak PAC centre. The increase of its local variance results in its growing importance and for an extremely high local variability (standard deviation of PAC equal to 2), the AO-like PC is strongly dominated by the PAC centre.

Table 2. Loadings of the AO-like PC for different values of standard deviation of the PAC variable (standard deviations of the ATL and ARC variables are kept equal to one)

PAC *SD*	ATL	ARC	PAC
0.5	.909	−.912	.109
0.8	.900	−.911	.234
1.0	.875	−.898	.409
1.1	.839	−.874	.561
1.25	.715	−.773	.899
1.5	.429	−.511	1.407
2.0	.234	−.320	1.985

5. Conclusions

The Pacific centre appears to be the weakest link in the concept of the AO, mainly because of its low teleconnectivity with the Arctic and Atlantic action centres. Its position, intensity, and zonal extent considerably differ between the PCs derived from the covariance and correlation matrix. The different nature of the Pacific action centre in the covariance and correlation analysis is underlined by its teleconnectivity: the one-point correlation maps with base points at the action centres provide diametrically dissimilar pictures. These serious discrepancies are manifestations of a sensitivity of the Pacific centre of the AO, and hence of the AO itself, to the options of PCA. The discrepancies give us a warning that the real existence of the feature in question may be doubtful, and that it may constitute an artifact of the statistical method. It is surprising that almost no attention has so far been paid to the AO defined from the correlation matrix, although there is no a priori reason why to prefer covariance to correlation in the definition of the AO. No justification for choosing the covariance at the expense of correlation has been provided in any relevant study of the AO.

The Pacific centre of the covariance-based AO coincides with the area of very high monthly SLP variability. That is why it appears as a part of the AO pattern in spite of its low correlations with the Arctic and Atlantic centres. The effect of a high local variability in the presence of low correlations on the appearance of the AO is demonstrated and confirmed on a simplified three-component example. The Pacific centre of the AO can thus be considered a result of a high local variability rather than its teleconnectivity.

Wallace and Thompson (2002), in their response to Ambaum et al.'s (2001) paper, also investigate the nature of the Pacific centre of the AO and ask whether it is real or artifact. Contrary to this paper, they conclude that the presence of the Pacific centre is real. They argue that its insignificant correlations with the Atlantic centre stems from the fact that the anomalies of the first two leading PCs cancel each other in the area of the two centres: Whereas PC1 (AO) has loadings of the same sign there, loadings of PC2 (resembling the Pacific / North American pattern) are of opposite signs. However, from the point of view of PCA methodology, the spread of a strong signal into two (or more) components warns us that the unrotated analysis may not be appropriate for interpretation, calling for attempting a rotation (which is not performed by Wallace and Thompson (2002)). Therefore, the interpretation of the Pacific centre as a result of high local variability, provided in this paper, is more plausible.

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