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ARCTIC OSCILLATION VERSUS NORTH ATLANTIC OSCILLATION: ARGUMENTS BASED ON THE PRINCIPAL COMPONENT ANALYSIS METHODOLOGY

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1. INTRODUCTION

A debate has started recently on what should be considered the leading mode of Northern Hemisphere (NH) wintertime circulation variability in the troposphere. There are two competing concepts: the North Atlantic Oscillation (NAO), having been described in 1930's and since then being a subject of many studies; and the Arctic Oscillation (AO), first described by Thompson and Wallace (1998). The NAO has two action centers of opposite polarity, located at the place of the Icelandic cyclone and the Azores anticyclone. It can be detected by means of one-point correlation maps (Wallace and Gutzler 1981) and rotated principal component analysis (PCA; Barnston and Livezey 1987). The AO was originally defined as the leading mode in unrotated PCA of monthly sea level pressure (SLP). It possesses three action centers, two of them over the Atlantic and Pacific Oceans at the place of the Azore anticyclone and Aleutian cyclone, respectively, the third one, of the opposite polarity, covering the Arctic. Because of its spatial characteristics, the AO is also called Northern Annular Mode.

The similarity of the AO and NAO patterns in the Euro-Atlantic sector a high correlation between their time series have stimulated the debate on which of the two oscillations is primary and should be given preference in the description and interpretation of the NH SLP variability. One of the alternative views sees the NAO as a regional manifestation of the planetary-scale annular structure of the AO (Thompson and Wallace 1998), whereas the other considers the NAO as a real mode of atmospheric variability and suspects the AO of being a statistical artifact. The existence of the AO has mainly been supported by its links with circulation in lower stratosphere, its similarity with circulation in the Southern Hemisphere, high congruence of its long-term trends with trends in various climatic elements, and hemispheric-wide impacts it has on surface climate conditions (Thompson and Wallace 1998, 2000, 2001; Thompson et al. 2000). Fyfe et al. (1999) identified the AO in outputs of a general circulation model by the same methodology as Thompson and Wallace (1998). On the other hand, the preference for the NAO is suggested by low correlations of the Aleutian center with the other two and the inconsistency of the AO with PCA of other tropospheric variables (Deser 2000, Ambaum et al. 2001); the annular nature of the AO and its link to stratospheric circulation have also been doubted (Perlwitz and Graf 2001).

In this study we examine how the selection of the similarity matrix entering PCA (correlation or covariance) and the decision whether to rotate principal components (PCs) or not affect the leading mode of SLP variability. We also discuss which of the two oscillation concepts complies better with guidelines of the correct use of PCA methodology.

2. DATA

The database consists of monthly mean SLP fields on a regular 5° by 5° grid extending from 20°N northwards for the winter half-year (November to April) in period 1948 to 1999. This allows 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). A quasi-equal-area (QEA) grid is used to compensate for an uneven spatial distribution of gridpoints, which causes problems in PCA because it exaggerates the influence of data-rich areas (Karl et al. 1982). The QEA grid mimicks a true equal area grid but does not require interpolation from gridpoints. Its construction is described in Huth (2003). The outputs of PCA based

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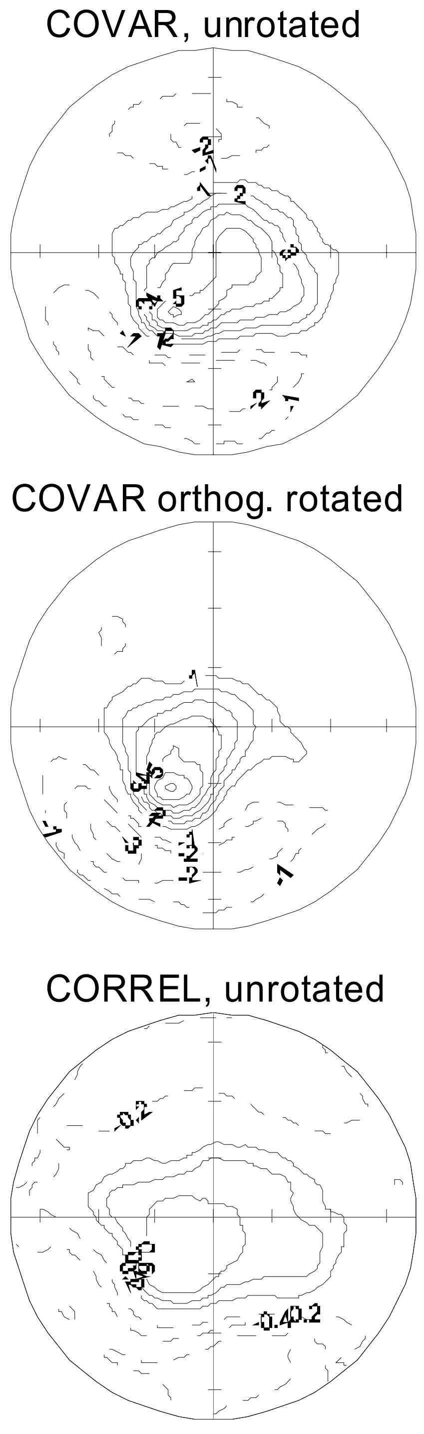

Figure 1. Projections of loadings of the first PC of monthly SLP for a covariance / correlation matrix and an unrotated / rotated solution. The maps show Northern Hemisphere north of 20°N; the Greenwich meridian points downwards. Negative contours are dashed, the zero contour is omitted, the contour interval is 1 hPa / 0.2 for a covariance / correlation matrix.

on the QEA grid are almost identical to those based on the cosine-weighted grid if the covariance matrix is used. To obtain rotated solutions, those numbers of PCs are retained and rotated that comply with the criterion of O'Lenic and Livezey (1988). The results are, nevertheless, little sensitive to the number of rotated PCs. The orthogonal VARIMAX procedure is used for rotation.

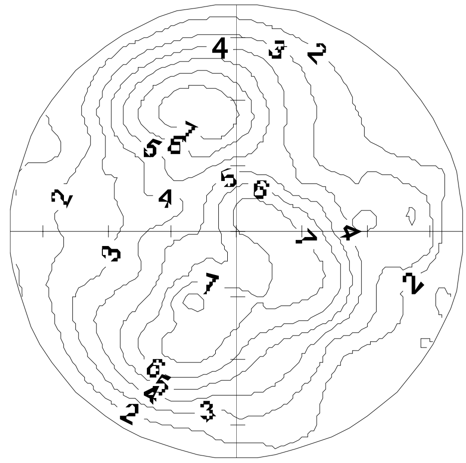

Figure 2. Standard deviation (in hPa) of monthly mean SLP anomalies

3. EFFECT OF SIMILARITY MATRIX

Figure 1 presents the loadings of the first PCs of SLP variability, showing the difference between the covariance and correlation matrix, and between the unrotated and rotated solution for the covariance matrix.

First let us discuss the effect of the choice of the similarity matrix. The major difference concerns the Pacific center: whereas for the covariance matrix, it is almost as strong as the Atlantic center and located along 50° N, for the correlation matrix the Pacific center is much weaker (the correlation slightly exceeds 0.3, but in the Atlantic center, it is over 0.7), shifted by 10° to 15° southwards, and spatially more extensive. A southward shift can also be observed for the Atlantic center. The Arctic center is flatter for the correlation matrix, and its shapes are different between the two matrices. The difference between the PC patterns stems from an uneven spatial distribution of variance. The map of standard deviations of SLP anomalies in Fig. 2 clearly indicates that the Pacific center in the pattern for the covariance matrix coincides with the area of very high variability. This means that the Pacific center of the AO is a result of a high variance in that region,

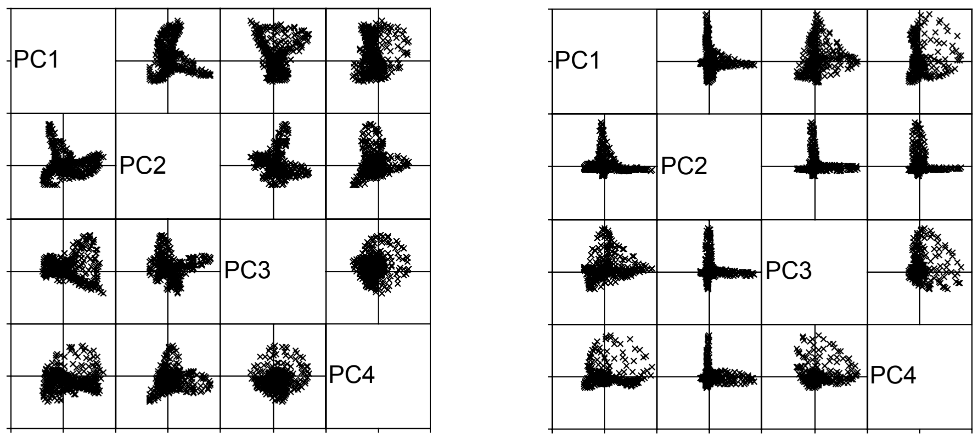

Figure 3. Scatterplots of the four leading PCs for the covariance matrix and for the unrotated (left) and rotated (right) solutions. The units on the PC axes are 8 hPa.

rather than of a joint variability with the other two centers.

4. EFFECT OF ROTATION

In Fig.1, one can easily see that the rotation results in a disappearance of the Pacific center from the pattern, and a shrinkage of the Arctic centre, which concentrates much more in the Atlantic sector for the rotated PC. This effect of rotation on the leading SLP variability mode has already been presented by Dommenget and Latif (2002). We can see that the unrotated PCA produces the AO, whereas the rotated PCA results in the NAO.

The key concept in the interpretation of PCs is the 'simple structure'. The PCs can be reasonably interpreted in terms of the original variables, only if the information from each variable is concentrated into (that is, each variable is loaded on) as few PCs as possible. Such a state is called a 'simple structure'. In other words, simple structure requires that the majority of PC loadings be near zero. The degree of simple structure can be estimated from the pairwise PC scatterplots: in the presence of a strong simple structure, data points are aligned closely along the PC axes. More information about the concept of simple structure can be found e.g. in Richman (1986) and in textbooks on PCA and factor analysis, e.g. Reyment and Jöreskog (1996).

The scatterplots for the four leading PCs of the covariance matrix, both for the unrotated and orthogonally rotated solutions, are shown in Fig. 3. There is only a weak simple structure in the unrotated PCs: the points are spread far from the axes and only little alignment along them can be observed. Moreover, several plots (e.g., PC1 vs. PC2 and PC1 vs. PC3) show signatures of alignment along lines tilted to the PC axes; this suggests a need for a rotation. On the other hand, the simple structure in the orthogonally rotated PCs is considerably stronger. For some pairs of PCs, the alignment along the axes is almost perfect (e.g., PC1 vs. PC2, PC2 vs. PC3, PC2 vs. PC4), and also for the others, it is without doubt better than for the unrotated solution.

Because the rotated PCs possess much stronger a simple structure, they should be given preference to the unrotated PCs when the results of PCA are to be interpreted. Another reason for preferring rotated solution is presented by Aires et al. (2002) who demonstrate a potential incapability of unrotated PCs to uncover the true variability modes and a strong tendency for unrotated PCs to mix the real modes together, suggesting that an extreme care must be taken in giving unrotated PCs a physical interpretation.

For the above reasons, the interpretation of the leading PC of SLP variability as a regionalized mode localized over the Euro-Atlantic domain, that is, the NAO, should be given preference to interpreting it as a hemispheric annular mode, the AO.

5. CONCLUSIONS

- The unrotated solution produces the modes with AO features, whereas the rotated solution produces the mode with NAO features.

- In unrotated solutions, the Pacific center is strong enough only in PCA of the covariance matrix; for the correlation matrix, it is much weaker than the Atlantic and Arctic centers.

- The strength of the Pacific center in unrotated PCA of the covariance matrix, i.e., in the original definition of the AO by Thompson and Wallace (1998), results from a high variance of SLP in that region rather than a joint variability with the other two centers.

- The interpretation of variability in terms of the AO, which is a result of unrotated PCA, is doubtful because of a lack of simple structure in the unrotated solutions.

These findings lead to the conclusion that rotated PCs should be given preference to the unrotated ones in interpreting modes of circulation variability in the Northern Hemisphere and that the AO does not appear to be an intrinsic mode of SLP variability. This result is complemented with and supported by recent studies by Deser (2000), Ambaum et al. (2001), Aires et al. (2002) and Dommenget and Latif (2002). Based on the arguments of the PCA methodology, the concept of the NAO is more relevant and should be preferred to the AO.

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