Notes and Correspondence

551.543.3 (261.7 +267)

Apparent absence of the quasi-biennial oscillation in sea level pressure in the South Indian and South Atlantic oceans

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(Received 18 March 1980; revised 13 August 1980)

Summary

Monthly mean sea level pressure over the Indian and South Atlantic oceans can be represented adequately by a few uncorrelated pressure fields derived using principal component analysis. Apart from a major, and general, field both zonal and meridional compensatory pressure systems appear to occur over this region of the Southern Hemisphere (approximately 10°W to 60°E and 20°S to 40°S). The time series of these fields were submitted to spectral analyses, and apart from an oscillation centred at 20 months in the third component there was no evidence suggesting the existence of the quasi-biennial oscillation in the pressure data. This result conflicts with those for rainfall over southern Africa, and sea level pressure and sea surface temperature around Australia.

1. Introduction

The behaviour of pressure patterns at sea level has not received very much attention over the Southern Hemisphere. Objective studies have been doubtless hampered by the scantiness of pressure data. It is felt that sufficient data are now available over the oceans surrounding southern Africa to permit a meaningful analysis to be carried out. The work described in this paper supplements, for the Southern Hemisphere, similar research reported by Kidson (1975a, b), Trenberth (1975), Dyer (1979); Kidson took a coarser grid on a global basis over a ten-year period.

2. The Data

Monthly means of sea level pressure (SLP) were obtained from the Weather Bureau in Pretoria for a grid system based on 10° intervals over both the Atlantic and Indian oceans. Pressure over the continent was not brought into the analysis because the reduction of pressure from plateau to sea level is no longer considered valid. The period of analysis is from 1951 to 1977 and over this period monthly mean values of SLP were available.

3. Analysis

We were interested in decomposing the total pressure field into its component fields, if such exist. For obvious reasons, it would be advantageous if these fields were uncorrelated. The SLP matrix of 324 rows (months) by 19 columns (grid points) was submitted to a principal component analysis to achieve this aim. Since there are no mixed units in the data matrix, the eigenvectors were extracted from the covariance matrix. The elements of the 19 by 19 eigenvector matrix give rise to 19 sets of grid values which, when suitably plotted, describe the required pressure anomaly patterns that can be ascribed to each of the 19 principal components (Grimmer 1963). We did not want to waste a component in the description of the seasonal cycle, so this phenomenon was removed from the data prior to the component analysis. This was done by obtaining the long-term mean for SLP for each month and subtracting them from each appropriate set of 27 months. The final analysis was therefore carried out on deviations from the seasonal pattern.

A visual inspection of the behaviour of the principal components, which are time series consisting of 324 terms, suggested that some of them possessed degrees of quite ordered variation. These series were therefore submitted to spectral analysis. There were two reasons for doing this, of which the first was to determine whether or not the series did contain any significant temporal variations. Secondly, bearing in mind that the components are uncorrelated, it would be interesting to see whether oscillations of specific wavelengths were associated with one component only.
In other words, do the pressure fields have individually associated wave patterns, or do they have oscillations in common over time? For the first possibility the components may then have extracted some factors on the basis of the presence of particular ordered temporal variations. In the second instance, different spatial patterns of pressure anomalies would have similar temporal behaviour. The spectral analysis was of the conventional type using a Parzen window and has been described elsewhere recently (Dyer 1976).

4. RESULTS

(a) Components analysis

Details relating to some of the eigenvalues obtained for the eigenvectors extracted from the covariance matrix of sea level pressures (SLP) are given in Table 1. It is often difficult to decide how many components to treat as useful contributions to an analysis. We have used a plot of the natural logarithms of the eigenvalues against their respective numbers to obtain a cut-off for the number of components to consider (Craddock and Flood 1969). This criterion suggests that seven components may be worthy of interpretation. The first seven eigenvalues account for some 92% of the total SLP variance. This percentage is very similar to that obtained by Trenberth (1975) from an analysis of sea-surface pressure in the vicinity of Australia.

<table>
<thead>
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<th>No.</th>
<th>Eigenvalue</th>
<th>% total variance</th>
<th>Cum %</th>
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<tr>
<td>1</td>
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<tr>
<td>4</td>
<td>3.76</td>
<td>5.9</td>
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<td>5</td>
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<td>87.8</td>
</tr>
<tr>
<td>6</td>
<td>1.49</td>
<td>2.3</td>
<td>90.1</td>
</tr>
<tr>
<td>7</td>
<td>1.28</td>
<td>2.1</td>
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</tr>
</tbody>
</table>

Figure 1. The first eigenvector has all its elements of equal sign. Whilst most of the area is associated with this vector, the centre of action is over the southern part of the Atlantic with particularly strong gradients northwards.

Eigenvector 1 is shown in Fig. 1.

All the eigenvector elements are positive and their field is a general one with negative gradients from the southern part of the Atlantic to both the north and north-eastward. Bearing in mind that the sign of the elements is arbitrary this vector describes the movement of air mass from the cold south toward the equator over the Atlantic and around the tip of the subcontinent into the
Indian Ocean. Also, of course, it is a measure of the gradients within the zonal westerlies, and is similar to the field of total variance over the two oceans.

Figure 2. The second eigenvector represents a strong compensatory situation between the two oceans, with strong meridional gradients also existing over each of them.

Eigenvector 2 is shown in Fig. 2.

This field shows a strong interaction between the South Atlantic and south Indian oceans. A strong vortex over the Indian Ocean is well compensated by a centre over the South Atlantic. Strong zonal (between the oceans) and meridional (within each ocean) movement of air masses is reflected in this pattern by virtue of the steep contour gradients that exist over this pressure field. The centre over the South Atlantic is probably associated with the lows that are found therabouts in the mid-latitudes.

Figure 3. Three areas of the oceans are highlighted by the third component. Compensation accompanied by severe gradients exists between the mid-oceans and the area immediately off the tip of the subcontinent.

Eigenvector 3 is shown in Fig. 3.

The Indian Ocean and South Atlantic highs feature in this pattern together with compensation for both centred at about 20°E. Very steep gradients exist from both oceans toward the south of the continent and represent a corresponding transport of air mass from both the east and west. The south-westers experienced over the southern coastal areas of the subcontinent are also clearly represented by this field, as are the south-easterlies. The degree of symmetry within the pattern is quite striking, right down to the zero contours over the oceans.
Eigenvector 4 is shown in Fig. 4.
This pattern is not unlike that for eigenvector 3. A vortex over the southern Indian Ocean, but displaced farther south than in the previous pressure field, has compensation again off the tip of the African subcontinent. Again we see severe pressure anomaly gradients over the southern area of the Indian Ocean. Under this situation the transport of air masses takes place, most strongly, only east to west, or west to east, but not both at the same time as in the conditions represented by the eigenvector 3.

Eigenvector 5 is shown in Fig. 5.
Here the pressure anomaly field is associated very much with the South Atlantic Ocean. Severe gradients exist between the mid-latitude low, bottom left-hand corner, and the high pressure system. A falling off in anomaly values from the high toward the north-east is probably associated with the tropical lows sometimes found over that part of the subcontinent. However, the picture is not very definite.
Eigenvector 6 is shown in Fig. 6.

Emphasis is returned again to the Indian Ocean where a zonal partition is seen to exist. The vortex off the east coast of Africa is associated with the coastal to continental highs which arise in this region from time to time. The features of this map tend to represent more localized effects with a reversal, or compensation, existing farther out over the ocean and a corresponding travel of air mass from east to west and vice versa.

Eigenvector 7 is shown in Fig. 7.

This field also represents a situation existing over the Indian Ocean. It accounts for little of the total variance and shows a weak compensatory system down the east coast of the subcontinent. The field as a whole is a fragmented one. However, such an orientation of the pressure anomalies can give rise to unusual weather conditions over the interior. This pattern, and to a certain extent the one given by eigenvector 6 as well, is somewhat similar to those experienced during August 1979, which brought about some severe thunderstorms.
(b) Spectral analysis of pressure components

The spectra were based on time series containing 324 terms, and covariances truncated at a maximum lag of 80 with the series detrended in each case. The first PC’s spectrum has a significant peak, five per cent level, at 5-7 months. This might be a harmonic of the annual cycle still coming through. The spectrum for PC2 has significant peaks at 80, 7-3 and 3-7 months. The first of these, in the region of 6-7 years, has been noted in a number of geophysical variables, e.g. lake levels and volcanic dust. The second wave appears to be meaningless, whilst the third might, again, be associated with the annual cycle. An 80-month wave is also found in PC3’s spectrum together with one at 20 months. A peak centred on a wavelength of 20 months seems a little on the low side for the quasi-biennial oscillation although Trenberth (1975) took it to be in the range 20–33 months. The remaining are all similar in that they have no more peaks than would be expected by chance, although it may be of interest that the 80-month peak is again present in the spectrum of PC6.

We then carried out cross-spectral analyses on the set of pressure component time series. The results obtained from these runs were as equally negative as those for the univariate cases.

5. Some concluding remarks

Monthly means of SLP can be well represented by seven uncorrelated components accounting for approximately 92% of the total variance. The first three PCs have relatively large eigenvalues and they, alone, account for something like 77% of the total pressure variance. These seven components appear to represent pressure situations that are physically meaningful because they can be linked to the general pressure patterns over the oceans. It is worth noting, also, that the pressure scheme over the Indian Ocean is associated with more of the components than is the case for the Atlantic. This provides further evidence of their reliability since it is known that the Indian Ocean high is more active than the South Atlantic one. Of the seven components presented only one is general, all the others representing compensatory systems either between the oceans, or within them. It is felt that these pressure fields together with, perhaps, those not considered in this paper will lend themselves to analogue forecasting. For this we have in mind both pressure and rainfall, and into the work, already commenced, will be brought lead and lag relationships between the two variables.

Spectral analysis of the time series of the components proved rather unrewarding. Although similar waves were evident in more than one component’s spectrum, they appeared to be associated with the annual cycle. We remain somewhat mystified by the fact that the biennial oscillation found by Trenberth (1975), for SLP data in the vicinity of Australia, does not appear in our pressure data. Bearing in mind that the sub-tropical high pressure belt is common to both Australia and southern Africa, and that this oscillation has been found in southern Africa’s rainfall data (Tyson et al. 1975) we rather expected it to appear in the present SLP data set. Its absence from the SLP, and presence in rainfall may possibly be due to the altitude of the subcontinent. Therefore, perhaps it will be found in the analysis of upper-air data which is at present being studied. Anybody interested in the Southern Hemisphere would find a rewarding exercise in combining the pressure data of Trenberth (op. cit.) with that used in this paper, try to fill in the grid point values between the two sets, and then carry out a spatial analysis in an attempt to determine where its presence in the vicinity of Australia weakens toward southern Africa.

Acknowledgments

I wish to acknowledge financial support for this research from the CSIR and Water Research Commission.

References


1979 Rainfall along the east coast of southern Africa, the southern


The accuracy of Gadd’s modified Lax–Wendroff algorithm for advection

551.509.313

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(Received 10 April 1980; revised 10 November 1980)

Gadd (1978) has reviewed the Lax–Wendroff approximation to the advection equation

\[
\partial \theta / \partial t = -u \partial \theta / \partial x
\]  

(1)

and described a modification that is simple, but gives significantly reduced phase speed errors and compares favourably with fourth-order accurate schemes. In this note we show that Gadd’s algorithm is second-order accurate, but close to an approximation that is third-order accurate and has fourth-order accurate phase speeds. The analysis is based on the dispersion relation for the finite difference equation. This highlights the well-known fact that high orders of accuracy in the calculation of individual terms do not guarantee accurate solutions. A leap-frog, or time centred, approximation to the two-dimensional equation that has a fourth-order accurate dispersion relation is also presented. It is interesting because it is not a naive combination of two one-dimensional versions, and it has similar stability properties to Gadd’s algorithm.

The dispersion relation is usually obtained by substituting solutions of the form \( \exp(i(\sigma t - kx)) \), where, for simplicity, it is supposed that there are only two independent variables \( x \) and \( t \), and deriving

\[
\sigma = \sigma(k) \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)
\]

For Eq. (1)

\[
\sigma = uk \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)
\]

When functions of the form \( \exp(i(\sigma t - kx)) \) are substituted in the finite difference equation \( \tilde{\sigma} \) will only appear as the product \( \tilde{\sigma} \delta t \) and \( k \) as the product \( k \delta x \). The dispersion relation takes the form

\[
\tilde{\sigma} \delta t = \delta t \tilde{\sigma}(k \delta x) \quad . \quad . \quad . \quad . \quad . \quad (4)
\]

where, as in the continuous case, the function \( \tilde{\sigma} \) depends on other variables, e.g. \( u \), but now also \( \delta x \) and \( \delta t \). The approximation is defined to be \( n \)th order accurate if

\[
\tilde{\sigma} = \sigma + O((k \delta x)^{n+1}) \quad . \quad . \quad . \quad . \quad (5)
\]