Aust. Met. Mag. 31 (1983) 77-83 551.557.3

The 'scissors' effect: anisotropic and ageostrophic influences on wind correlation coefficients.

C. E. Buell* and R. S. Seaman†
*Science Applications, Inc., Colorado Springs, CO, USA
†Australian Numerical Meteorology Research Centre, Melbourne

(Manuscript received July 1982; revised October 1982)

An explanation is sought for systematic departures of observed wind component correlation coefficients from those expected for geostrophic flow in a horizontally homogeneous and isotropic atmosphere. These departures are such that the elongated contours of the zonal and meridional component coefficients are rotated towards one another like scissors. The effects of anisotropy, inhomogeneity and ageostrophy are considered from a theoretical standpoint. It is concluded that both anisotropy and ageostrophy could in principle contribute to the observed 'scissors'. Data from both North America and Australia suggest anisotropy is the main contributor, but the effect of ageostrophy is not negligible. The systematic contribution of anisotropy may be interpreted in terms of the poleward eddy transport of angular momentum.

Introduction

Recently, Seaman and Gauntlett (1980) pointed out that some observed wind component correlation coefficients on isobaric surfaces show systematic departures from those expected in an homogeneous, isotropic, geostrophic flow, and (p. 220) raise the question as to whether the primary responsibility for the departures is due to inhomogeneity, anisotropy or ageostrophy. In this report we consider these possibilities in some detail and conclude that: (a) the primary responsibility lies in anisotropy, that (b) ageostrophy has some effect, but that (c) the effects of inhomogeneity are of a somewhat different character.

Homogeneous, isotropic and geostrophic case

In the following discussion, homogeneity implies that the covariance of geopotential between points P and P′ depends only upon the vector displacement of P′ from P, and does not depend upon the location of P. Isotropy implies that the two-point covariance of geopotential is independent of the direction of the line PP′.

In the homogeneous, isotropic, geostrophic case, the two-point geopotential and wind component correlation coefficients on isobaric surfaces may be expressed by the formulae (Buell 1960)

$$
\begin{aligned}
r_{hh} &= \exp(-Q/2) \\
r_{uu} &= (1-\eta^2/H^2)\exp(-Q/2) \\
r_{vv} &= (1-\xi^2/H^2)\exp(-Q/2) \qquad \ldots 1 \\
Q &= (\xi^2+\eta^2)/H^2
\end{aligned}
$$

where:

r_{hh} is the correlation coefficient relating the geopotential at P (first subscript) with the geopotential at P′ (second subscript);

r_{uu} and r_{vv} are the corresponding zonal and meridional wind correlation coefficients;

(ξ, η) are the eastward and poleward coordinates of P′ relative to P; and

H is a scale parameter (of the order 1000 km).

The formula for r_{hh} is an empirical one which fits observed data reasonably well. The formulae for r_{uu} and r_{vv} follow from that for r_{hh}, using the assumption of geostrophy.

It follows that $r_{uu}=0$ on the lines $\eta = \pm H$, that $r_{vv}=0$ on the lines $\xi = \pm H$, and that the elongated contours of r_{uu} and r_{vv} are oriented respectively in the west-east and south-north directions (Fig. 1). Correlation coefficient functions as defined by Eqn 1 are used in many practical objective analysis schemes.

Observed patterns of r_{uu} and r_{vv} from four regions (North America, Caribbean, India and Australia) were examined by Seaman and Gauntlett (1980). These all approximated Fig. 1, but deviated systematically so that in the northern hemisphere the major axes of the r_{uu} and r_{vv} contours were rotated

*Dr Buell died on 7 February 1983.

Fig. 1 Schematic illustration of the contours of r_{uu} (thick full lines) and r_{vv} (dashed lines), and the scale parameter H, under homogeneous, isotropic and geostrophic conditions (after Buell 1960).

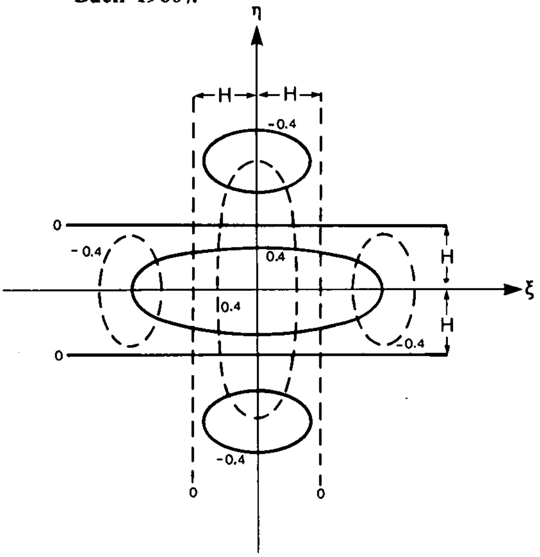
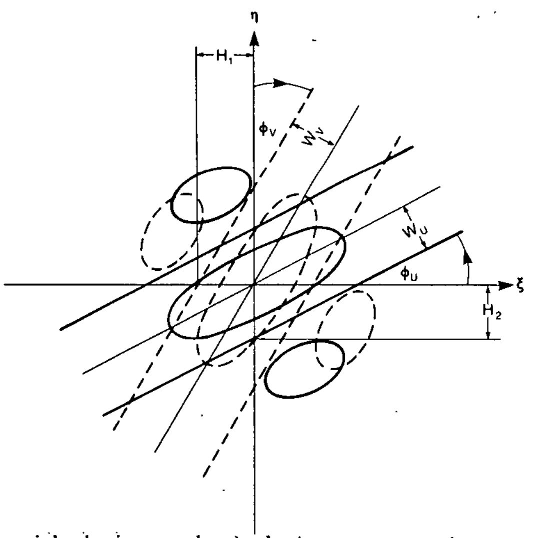


Fig. 2 Schematic illustration for the northern hemisphere of the contours of r_{uu} (thick full lines) and r_{vv} (dashed lines), and the parameters H_1, H_2, ϕ_u, ϕ_v, W_u and W_v for homogeneous and geostrophic, but anisotropic conditions (see text for explanation).



anticlockwise and clockwise respectively (the opposite in the southern hemisphere). In other words, in the northern (southern) hemisphere, the major axes of the r_{uu} and r_{vv} contours are rotated in opposite senses towards a southwest-northeast (northwest-southeast) orientation (Fig. 2). This is what we will call the 'scissors' effect, and we will confine our attention to this phenomenon.

We shall now successively relax the assumptions of isotropy, homogeneity and geostrophy, and consider the effects upon the contours of r_{uu} and r_{vv}.

Anisotropy

In this section, we relax the assumption of isotropy, but still assume homogeneity and geostrophy. The geostrophic equations in terms of departures from the mean are

$$\lambda u = -g\partial h/\partial y$$
$$\lambda v = +g\partial h/\partial x \qquad \ldots 2$$

at the point P, and with primed quantities at the point P′. The co-ordinates x and y, are respectively eastwards and poleward, and λ is the Coriolis parameter. Forming the products of these relations at P and P′, taking means, and interchanging the order of differentiation and averaging one obtains, in terms of covariances,

$$\lambda\lambda'(\overline{uu'}) = g^2\partial^2(\overline{hh'})/\partial y\partial y'$$
$$\lambda\lambda'(\overline{vv'}) = g^2\partial^2(\overline{hh'})/\partial x\partial x' \qquad \ldots 3$$

Expressing covariances in terms of correlation coefficients $\overline{uu'} = \sigma_u\sigma_u' r_{uu}$, $\overline{vv'} = \sigma_v\sigma_v' r_{vv}$, $\overline{hh'} = \sigma_h\sigma_h' r_{hh}$, assuming that all standard deviations are constant (homogeneity), and using the co-ordinate transformation ($\xi = x' - x$, $x_o = x$, $\eta = y' - y$, $y_o = y$ so that $\partial f/\partial x' = \partial f/\partial\xi$, $\partial f/\partial x = \partial f/\partial x_o - \partial f/\partial\xi$, etc.), and using $\partial r_{hh}/\partial x_o = 0$, $\partial r_{hh}/\partial y_o = 0$ (another aspect of homogeneity) one obtains

$$r_{uu} = -S_2S_2'\partial^2 r_{hh}/\partial\eta^2$$
$$r_{vv} = -S_1S_1'\partial^2 r_{hh}/\partial\xi^2 \qquad \ldots 4$$

where $S_2 = g\sigma_h/\lambda\sigma_u$, $S_1 = g\sigma_h/\lambda\sigma_v$ are scale factors and similarly for S_2' and S_1'.

In the anisotropic case, the contours of r_{hh} are not circles but ellipses (Seaman 1982, Fig. 5a), so that

$$r_{hh} = \exp(-Q/2)$$
$$Q = \xi^2/H_1{}^2 + 2r\xi\eta/H_1H_2 + \eta^2/H_2^2 \qquad \ldots 5$$

The scale parameters in the x and y directions are denoted by H_1 and H_2. These are the same on the L_x and L_y used by Stefanick (1981). The parameter r, which is involved in the shape and orientation of the elliptical contours, can be shown (forming $\overline{uv'}$ from Eqn 2 assuming homogeneity, then using Eqn 5 to express r_{hh}, and finally letting P′ approach P) to be the negative of the correlation between u and v at a fixed point. From a synoptic aspect, the parameter r is associated with the tilt observed in waves on the westerlies.

The equations (5) are now substituted into Eqn 4 and P′ allowed to approach P. This entails a neglect of the effect upon anisotropy of the variation of Coriolis parameter. For $P' \to P$, r_{uu} and $r_{vv} \to 1$. This implies that $S_2 = H_2$ and $S_1 = H_1$, so that

$$r_{uu} = \{1 - (r\xi/H_1 + \eta/H_2)^2\}\exp(-Q/2)$$
$$r_{vv} = \{1 - (\xi/H_1 + r\eta H_2)^2)\}\exp(-Q/2) \ldots 6$$

It follows from Eqn 6 that the loci of $r_{uu} = 0$ and $r_{vv} = 0$ are respectively

$$\eta = (-r\,H_2/H_1)\xi \pm H_2$$
$$\xi = (-r\,H_1/H_2)\eta \pm H_1 \qquad \ldots 7$$

Thus for anisotropic conditions the zero lines $r_{uu}=0$ and $r_{vv}=0$ (and the elongated contours) are rotated from west-east and south-north in opposite senses (Fig. 2, drawn for northern hemisphere and positive r). This is indeed the scissors effect. The anticlockwise angle ϕ_u between the line $r_{uu}=0$ and the ξ direction, and the clockwise angle ϕ_v between the line $r_{vv}=0$ and the η direction are given by

$$\tan\phi_u = -r\, H_2/H_1$$
$$\tan\phi_v = -r\, H_1/H_2 \quad \ldots 8$$

An alternative parametric description of the elliptical contours of r_{hh} (Seaman 1982, Fig. 2) uses polar co-ordinates d and θ, and parameter E^2 and ϕ, so that, for a Gaussian form of r_{hh}

$$r_{hh} = \exp(-0.5d_*^2/H^2)$$
where $d_*^2 = d^2(\cos^2(\theta-\phi)/E^2 + E^2\sin^2(\theta-\phi))$.

The parameters E^2 and ϕ are defined respectively as the length ratio of major to minor axis, and the orientation of the major axis (clockwise from north). The values of E^2 and ϕ are insensitive to the form of r_{hh}, and are readily measured from contours of observed correlation coefficients of geopotential. By transforming the above representation of r_{hh} to cartesian co-ordinates (ξ,η), and equating coefficients of ξ^2, $\xi\eta$ and η^2 to those in Eqn 5, it follows that

$$\tan\phi_u = (E^2-E^{-2})\sin\phi\cos\phi/(E^2\sin^2\phi + E^{-2}\cos^2\phi)$$
$$\tan\phi_v = (E^2-E^{-2})\sin\phi\cos\phi/(E^2\cos^2\phi + E^{-2}\sin^2\phi) \quad \ldots 9$$

The equations (9) enable observed values of E and ϕ to be used to estimate the ϕ_u, ϕ_v corresponding to homogeneous and geostrophic flow.

Inhomogeneity

The assumption of homogeneity is now also relaxed to the extent that the standard deviations σ_h and σ_h' are permitted to vary with the locations of P and P′. However, we still assume that $\partial r_{hh}/\partial x_o = 0$ and $\partial r_{hh}/\partial y_o = 0$. Then Eqn 4 becomes

$$r_{uu} = A_2A_2'r_{hh} + (S_2'A_2 - S_2A_2')(\partial r_{hh}/\partial\eta) - S_2S_2'(\partial^2 r_{hh}/\partial\eta^2)$$
$$r_{vv} = A_1A_1'r_{hh} + (S_1'A_1 - S_1A_1')(\partial r_{hh}/\partial\xi) - S_1S_1'(\partial^2 r_{hh}/\partial\xi^2) \quad \ldots 10$$

where $A_2 = (S_2/\sigma_h)(\partial\sigma_h/\partial y)$, $A_1 = (S_1/\sigma_h)(\partial\sigma_h/\partial x)$ and similarly for A_2', A_1'. The above imply that for $P'\to P$, one has $A_2{}^2 + (S_2/H_2)^2 = 1$ and also $A_1{}^2 + (S_1/H_1)^2 = 1$.

To be practical, consider A_1, A_2, S_1, S_2 as locally constant. This drops out the middle terms on the right of Eqn 10. Now substitute the value of r_{hh} using Eqn 5 to obtain

$$r_{uu} = [1-(1-A_2{}^2)(r\xi/H_1 + \eta/H_2)^2]\exp(-Q/2)$$
$$r_{vv} = [1-(1-A_1{}^2)(\xi/H_1 + r\eta/H_2)^2]\exp(-Q/2) \quad \ldots 11$$

The zero lines are now spaced at $\pm H_2/\sqrt{1-A_2{}^2}$ and $\pm H_1/\sqrt{1-A_1{}^2}$ while their slopes remain unchanged. We conclude that the major effect of inhomogeneity does not influence the scissors, but lies in the spacing of the lines $r_{uu}=r_{vv}=0$.

Ageostrophy

The assumption of geostrophy may be relaxed by considering the simplified equations of motion

$$\partial U/\partial t + U(\partial U/\partial x) + V(\partial U/\partial y) - \lambda V = -g(\partial H/\partial x)$$
$$\partial V/\partial t + U(\partial V/\partial x) + V(\partial V/\partial y) + \lambda U = -g(\partial H/\partial y) \quad \ldots 12$$

where H is geopotential (not the scale parameter used earlier). One then proceeds to substitute $U=\bar{U}+u$, $V=\bar{V}+v$, $H=\bar{H}+h$, where $\bar{U}$, $\bar{V}$, $\bar{H}$ are mean values, and thence obtain the equations for the mean motion and by subtracting these, the equations for the departures from the mean.

The resulting expressions may be written as

$$X_1 + Y_1 + Z_1 + T_1 = -g(\partial h/\partial x) \quad \ldots 13$$

$$X_2 + Y_2 + Z_2 + T_2 = -g(\partial h/\partial y) \quad \ldots 14$$

where

$$X_1 = (\partial\bar{U}/\partial x)u - (\lambda - \partial\bar{U}/\partial y)v$$
$$X_2 = (\lambda + \partial\bar{V}/\partial x)u + (\partial\bar{V}/\partial y)v$$
$$Y_1 = \bar{U}(\partial u/\partial x) + \bar{V}(\partial u/\partial y)$$
$$Y_2 = \bar{U}(\partial v/\partial x) + \bar{V}(\partial v/\partial y)$$
$$Z_1 = u(\partial u/\partial t) - u(\overline{\partial u/\partial t}) + v(\partial u/\partial y) - v(\overline{\partial u/\partial y})$$

$$Z_2 = u(\partial v/\partial x) - u(\overline{\partial v/\partial x}) + v(\partial v/\partial y) - v(\overline{\partial v/\partial y})$$

$$T_1 = \partial u/\partial t,\quad T_2 = \partial v/\partial t$$

Equations 13 and 14 are evaluated at P and at P′ and the average of the products are found. One must now consider all four of the products obtainable since each of $\overline{X_1X_1'}$, $\overline{X_1X_2'}$, $\overline{X_2X_1'}$, $\overline{X_2X_2'}$ will contain all of $\overline{uu'}$, $\overline{uv'}$, $\overline{vu'}$, $\overline{vv'}$, so that $\overline{uu'}$, $\overline{vv'}$ must now be obtained by solving the system of equations.

Each of these four equations will contain 81 terms on the left. The reduction of this system of equations is tedious and involves many assumptions and approximations. The basic assumptions are that the mean values of terms of first and third degree in the departures are zero, and the fourth degree terms may be approximated as

$$(\overline{abcd}) = (\overline{ab})(\overline{cd}) + (\overline{ac})(\overline{bd}) + (\overline{ad})(\overline{bc}).$$

There are two other major types of approximations. The first is to neglect obviously small terms. The second is to neglect covariance terms which are too complex to appear clearly in the component correlation coefficient patterns. The end result is that the loci of $r_{uu}=0$ and $r_{vv}=0$ are given by

$$\eta = -(r+a)(H_2/H_1)\xi \pm H_2A/\sqrt{A^2 - A_2{}^2} \quad \ldots 15$$

$$\xi = -(r-b)(H_1/H_2)\eta \pm H_1 B/\sqrt{B^2 - A_1{}^2} \quad \ldots 16$$

where

$$a = (\partial\bar{V}/\partial y)/\lambda + [\bar{U}(\partial\sigma_v/\partial x) + \bar{V}(\partial\sigma_v/\partial y)]/\sigma_v\lambda \quad \ldots 17$$

$$b = (\partial\bar{U}/\partial x)/\lambda + [\bar{U}(\partial\sigma_u/\partial x) + \bar{V}(\partial\sigma_u/\partial y)]/\sigma_u\lambda \quad \ldots 18$$

$$A = 1 + (\partial\bar{V}/\partial x)/\lambda$$
$$B = 1 - (\partial\bar{U}/\partial y)/\lambda$$

and where as before

$$A_1 = (S_1/\sigma_h)(\partial\sigma_h/\partial x)$$
$$A_2 = (S_2/\sigma_h)(\partial\sigma_h/\partial y)$$

One then concludes that ageostrophy affects the scissors and the spacing of the zero lines. The line spacing is affected by the geometry of the mean flow through the expressions A and B. The relative magnitudes of the effects, upon the scissors, of ageostrophy and anisotropy will depend upon the magnitudes and signs of a and b, relative to r. This aspect will be discussed at the end of the following section, where we examine observed data.

Observed data

In the preceding sections it has been shown that anisotropy and ageostrophy affect both the scissors and the spacing of the zero lines, but inhomogeneity affects only the spacing. We now examine observed values of the scissors parameters ϕ_u and ϕ_v, and enquire whether anisotropy or ageostrophy is the principal influence. This is done, in different ways, using data sets from North America, and from Australia.

North America

Data used in Cooley (1959) were provided by Dr Cooley and contours of r_{uu} and r_{vv} were drawn for each location. The first column of Table 1 contains the last three digits of the station index (location of the point P). The measured angles ϕ_u and ϕ_v are tabulated in columns 2 and 3, and the measured perpendicular distances W_u and W_v, from P to the respective zero lines appear in columns 4 and 5. It was particularly difficult to determine accurately the values of ϕ_u, and ϕ_v, even in the interior of the data area. It is estimated that the error in ϕ_u and ϕ_v may be as large as 3°, while that of W_u and W_v is of the order of 20 km. Where zero is listed, it is simply because there was no compelling reason to prefer a non-zero value.

If anisotropy were the only factor affecting the scissors and zero line spacing, it would follow from Fig. 2 that

$$W_u = H_2\cos\phi_u$$
$$W_v = H_1\cos\phi_v \quad \ldots 19$$

Combination of Eqns 8 and 19 leads to the following constraint upon ϕ_u, ϕ_v, W_u and W_v when only anisotropy is present

$$\ln(\sin 2\phi_u) - \ln(\sin 2\phi_v) - 2\ln(W_u) + 2\ln(W_v) = 0 \quad \ldots 20$$

The closeness with which Eqn 20 is satisfied by the values in columns 2 to 5 of Table 1 is therefore a test of the validity of the hypothesis that anisotropy is the major factor in the scissors effect.

Values of the four left hand elements of Eqn 20 were computed from measurements of ϕ_u, ϕ_v, W_u, W_v at each station, and were subjected to a weighted least squares adjustment to satisfy that equation. The weights 1, 1, 10, 10 were used to reflect the relative lack of confidence in the angular measurements. Adjusted values of ϕ_u, ϕ_v, W_u and W_v are listed in columns 6 to 9, and the corresponding values of H_1, H_2 and r in columns 10 to 12.

The adjusted values indicate a rather mixed situation. Where the adjustments to ϕ_u and ϕ_v are only a degree or two, one might consider the measured values compatible with anisotropy. Otherwise, one is inclined to the view that ageostrophy may also be important. Counting cases, the adjustments to ϕ_u and ϕ_v are both less than three degrees at sixteen of the twenty-seven stations. At four other stations, the measured and adjusted values of ϕ_u and ϕ_v are all small (seven degrees or less).

(Note: The alert reader will recognise that the above adjustment procedure will not work for ϕ_u and ϕ_v equal to zero. To overcome this difficulty, a value of 1° was assigned to these cases.)

Table 2 is similar to Table 1 except that it is for different levels and seasons over Omaha, USA. The correlation coefficients were computed by the Sandia Corporation (Albuquerque, USA) in connection with a study of fall-out winds by the Federal Civil Defence Agency from five years of serially complete wind observations provided by the US Weather Bureau. The results in these cases are about the same as the results from Table 1. The adjusted values of ϕ_u and ϕ_v are close to the unadjusted values in about half of the cases. We exclude the 850 mb level since the terrain to the west of Omaha rises to above the 850 mb level, making reliable measurements impossible. Another item seen from the values of W_u, W_v or H_1, H_2 is the gradual increase in these parameters with increasing height, especially between the 200 and 100 mb levels. An additional column headed r^o_{uv} has been added to Table 2 containing the observed correlation coefficients between the u and v wind components over Omaha. All values are positive. The values of r^o_{uv} tend to be larger than those of $|r|$. The standard deviation of the sampling errors for r^o_{uv} is about 0.05. The difference between $|r|$ and r^o_{uv} exceeds this value only for 300 mb, winter, and 500 mb, summer (850 mb being excluded for the reasons given above).

Overall, Tables 1 and 2 suggest that anisotropy is probably the major influence, but ageostrophy also needs to be considered.

Table 1. Measured and adjusted values of ϕ_u, ϕ_v, W_u, W_v and computed values of H_1, H_2, r over the United States, 500 mb, winter. Values of ϕ_u, ϕ_v are in degrees, of W_u, W_v, H_1, H_2 in thousands of km.

	Measured				Adjusted				Computed		
Index	ϕ_u	ϕ_v	W_u	W_v	ϕ_u	ϕ_v	W_u	W_v	H_1	H_2	|r|
250	5.0	9.0	0.78	1.33	4.0	11.4	0.79	1.32	1.34	0.79	0.118
258	8.0	7.5	0.78	1.31	4.8	12.7	0.80	1.28	1.31	0.80	0.137
259	4.0	8.0	0.99	1.20	4.6	7.0	0.98	1.21	1.22	0.99	0.099
265	12.5	10.0	0.92	1.17	9.0	13.9	0.93	1.14	1.19	0.94	0.198
270	6.5	5.0	1.09	1.26	4.7	6.9	1.01	1.23	1.24	1.02	0.100
274	13.0	8.0	1.06	1.00	10.9	9.5	1.07	0.99	1.01	1.09	0.179
278	14.0	6.5	1.00	0.98	10.0	9.0	1.01	0.97	0.98	1.02	0.167
327	0.0	7.0	1.09	1.16	5.1	5.9	1.08	1.17	1.17	1.08	0.096
340	4.0	4.0	0.93	1.13	3.3	4.8	0.94	1.12	1.17	0.94	0.070
353	11.0	11.0	0.90	1.14	8.8	13.9	0.91	1.13	1.17	0.92	0.195
365	6.0	0.0	0.95	1.19	4.9	7.0	0.99	1.18	1.19	0.99	0.103
374	7.0	8.0	1.07	1.09	7.3	7.7	1.07	1.09	1.10	1.08	0.131
386	11.5	7.5	1.06	1.07	9.4	9.2	1.07	1.06	1.07	1.08	0.161
445	11.0	6.5	1.11	1.06	9.1	7.9	1.12	1.04	1.06	1.13	0.148
469	13.0	11.0	1.02	1.18	10.5	13.6	1.03	1.17	1.20	1.06	0.212
476	9.0	6.0	1.08	1.14	7.1	7.6	1.09	1.13	1.14	1.10	0.129
493	11.5	2.0	1.11	1.13	5.0	4.5	1.16	1.09	1.09	1.16	0.083
506	3.5	7.0	1.13	1.07	5.1	4.8	1.11	1.09	1.09	1.12	0.086
537	0.0	4.0	1.09	1.00	4.4	3.9	1.08	1.01	1.01	1.08	0.072
576	10.0	5.0	1.01	1.16	6.4	7.7	1.03	1.13	1.14	1.04	0.124
655	0.0	7.0	1.01	1.12	4.7	6.0	1.00	1.13	1.13	1.01	0.093
662	7.0	9.5	1.13	1.10	8.3	8.0	1.12	1.11	1.12	1.13	0.143
681	7.0	5.0	1.13	1.11	6.1	5.7	1.14	1.10	1.11	1.14	0.104
734	0.0	2.0	1.20	0.94	2.9	1.0	1.19	0.94	0.94	1.20	0.040
747	0.0	3.0	1.22	1.06	3.5	2.6	1.21	1.07	1.07	1.22	0.053
764	7.0	3.0	1.12	1.09	4.9	4.3	1.14	1.07	1.08	1.14	0.080
785	10.0	2.0	1.10	0.98	5.3	3.7	1.13	0.94	0.96	1.14	0.077

Table 2. Measured and adjusted values of ϕ_u, ϕ_v, W_u, W_v, and computed values of H_1, H_2, |r| over Omaha, NB, USA. Values of ϕ_u, ϕ_v are in degrees, of W_u, W_v, H_1, H_2 in thousands of km. The column headed r^o_{uv} contains the observed coefficients over Omaha.

	Measured				Adjusted				Computed			Observed
Level	ϕ_u	ϕ_v	W_u	W_v	ϕ_u	ϕ_v	W_u	W_v	H_1	H_2	|r|	r^o_{uv}
					Winter							
850	-8.0	2.0	0.94	0.88								
500	10.5	6.0	1.00	1.22	6.7	9.3	1.02	1.21	1.21	1.03	0.139	0.099
300	13.0	12.5	1.14	1.14	12.9	12.6	1.14	1.13	1.16	1.18	0.226	0.148
200	14.0	6.0	1.17	1.29	7.6	9.6	1.19	1.26	1.28	1.21	0.160	0.141
100	8.5	9.5	1.60	1.37	10.4	7.8	1.59	1.38	1.39	1.61	0.158	0.180
					Summer							
850	6.0	13.0	0.94	0.90	8.9	8.7	0.92	0.92	0.93	0.93	0.155	0.237
500	9.0	9.5	0.94	1.10	8.0	10.7	0.94	1.09	1.11	0.96	0.165	0.068
300	7.0	5.0	1.37	1.18	6.9	5.1	1.37	1.18	1.18	1.38	0.104	0.099
200	6.5	9.0	1.39	1.08	9.6	6.1	1.37	1.10	1.10	1.38	0.134	0.170
100	6.0	9.5	1.69	1.33	9.2	6.2	1.66	1.37	1.37	1.69	0.133	0.118

Australia

Here we examine the geopotential correlation coefficient data from Seaman (1982) and the wind coefficient data from Seaman and Gauntlett (1980). These references provide values of E and ϕ (from observed geopotential coefficients) and ϕ_u and ϕ_v (from observed wind coefficients).

All the above parameters were obtained by

Table 3. The parameters E, ϕ, ϕ_u and ϕ_v (cols 1 to 4) obtained from geopotential correlation coefficients between pairs of extratropical stations in the Australian area, and the parameters ϕ_u and ϕ_v (cols 5 and 6) similarly obtained from wind correlation coefficients (see text for details). Units of ϕ, ϕ_u and ϕ_v are degrees.

	From geopotential coefficients				From wind coefficients	
	E	ϕ	ϕ_u	ϕ_v	ϕ_u	ϕ_v
500 mb winter	1.25	129	-21	-24	-11	-23
500 mb summer	1.15	111	- 9	-13	-10	-14
200 mb winter	1.23	128	-19	-23	- 7	-21
200 mb summer	1.40	99	- 7	-22	-10	-24

translating to a common origin all available two-point correlation coefficients for extratropical stations, and objectively fitting the contours. The values of E, ϕ, ϕ_u and ϕ_v therefore represent an 'average' for the extratropical Australian region, with local variations removed. The geopotential and wind data sets were for the same period (1962–73), but did not include exactly the same station pairs. The wind coefficients were available only at 500 and 200 mb.

If anisotropy were the only factor affecting the scissors, the geopotential coefficient parameters E and ϕ, and the wind coefficient parameters ϕ_u and ϕ_v, should be related by Eqn 9. Observed values of E and ϕ (columns 1 and 2 of Table 3) have been substituted in the right side of Eqn 9. The ϕ_u and ϕ_v, 'predicted' on the basis of anisotropy (columns 3 and 4) are compared with the observed (columns 5 and 6). There is agreement within three degrees for six of the eight entries, the exceptions being the ϕ_u in winter. It therefore appears that, as with the United States data, anisotropy is the major factor influencing the scissors, but ageostrophy probably cannot be neglected.

The role of ageostrophy can be further investigated by evaluating the contribution of ageostrophic terms in Eqns 15 and 16. The contribution of ageostrophy to the scissors is determined by the values of a and b relative to r. The terms on the right sides of Eqns 17 and 18 depend upon (i) the geometry of the mean flow, and (ii) the relation of the mean flow to the gradients of the component standard deviations. The first terms on the right of Eqns 17 and 18 are the individual contributors to the divergence of the mean flow. They may therefore be expected to have opposite sign; their likely effect is to rotate the zero lines further in opposite directions, but they will 'snip' the scissors only if a and −b are the same sign as r. The second terms of Eqns 17 and 18 would normally have the same sign because σ_u and σ_v usually have similar gradients. However, the square bracketed quantities may be written as $(\bar{V} \cdot \nabla\sigma_v)$ and $(\bar{V} \cdot \nabla\sigma_u)$, and therefore depend upon the sine of the angle between the vector mean wind and the contours of σ_u and σ_v. Particularly at 200 mb, this angle, and the corresponding second terms of Eqns 17 and 18 would be expected to be small.

Means and standard deviations of wind components at Australian rawinsonde stations for the relevant levels and seasons are available from Maher and Lee (1977). These may be supplemented by data from Seaman and Draudins (1975), for some stations which observe wind but not temperature. It is evident upon plotting these data, that both terms on the right of Eqns 17 and 18 vary considerably from place to place over Australia. Some 'order of magnitude' calculations show that the first terms on the right of Eqns 17 and 18 are usually less than 0.10, and the second terms usually less than 0.05. It is inconclusive whether the first terms will snip or open the scissors.

On the other hand, Maher and Lee (1977) also indicate that over extratropical Australia the one-point correlation coefficient between u and v (a close approximation to the magnitude of r) ranges from about 0.10 to 0.40. It therefore appears that a and b are usually smaller than r, but by no means negligible. These relative magnitudes are again consistent with the hypothesis that anisotropy is the main effect on the scissors, but that ageostrophy is not unimportant.

Conclusions

Theoretical considerations lead one to conclude that anisotropy (elliptical contours of r_{hh}) is capable of explaining the scissors effect while ageostrophy also has an effect which may be significant. The effect of inhomogeneity is not in the scissors as such but in the spacing of the lines $r_{uu}=0$ or $r_{vv}=0$.

Data from both the North American and Australian areas indicate that in somewhat more than half the cases, anisotropy almost completely explains the observed scissors. In the remainder, anisotropy is only a partial explanation, suggesting that ageostrophy is probably not insignificant. Some order of magnitude calculations of the ageostrophic terms appear to confirm the latter suggestion.

If it is accepted that the scissors effect is primarily a result of anisotropy, it follows that the sense of rotation implied by ϕ_u, ϕ_v is determined by Eqn 7, and therefore by the sign of the parameter r. Under geostrophic conditions, r is closely approximated by $(-r_{uv})$. As indicated by Newell et al. (1972), r (using the eastward-poleward convention for u and v) is predominantly positive in both hemispheres from the surface to 100 mb. This in turn is a manifestation of the well-known poleward eddy transport of angular momentum. One would therefore expect from Eqn 7 that the scissors would rotate towards southwest-northeast throughout most of the northern hemisphere, and vice versa for the southern hemisphere. The foregoing argument lends some confirmation to the speculation in Seaman and Gauntlett (1980) that the origin of the scissors is, at least in part, global in nature.

Acknowledgments

We wish to thank F. J. Gauntlett and N. E. Davidson of the Australian Numerical Meteorology Research Centre, and the two journal reviewers for detecting a few errors and making several constructive suggestions.

References

Buell, C. E. 1960. The structure of two-point wind correlations in the atmosphere. *J. Geophys. Res., 65,* 3353–66.

Cooley, D. S. 1959. *The specification of and prediction of 500 mb height and wind.* Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Mass.

Maher, J. V. and Lee, D. M. 1977. Upper Air Statistics, Australia, Surface to 5 mb, 1957 to 1975. *Met. Summary,* Bur. Met., Australia, 202 pp.

Newell, R. E., Kidson, J. W., Vincent, D. G. and Boer, G. J. 1972. *The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes.* The MIT Press, 258 pp.

Seaman, R. S. and Draudins, I. M. 1975. Statistics on the simultaneous variation of wind in time and space — Australian region, 20 000 and 40 000 ft. *ANMRC Technical Report No. 1,* 16 pp.

Seaman, R. S. and Gauntlett, F. J. 1980. Directional dependence of zonal and meridional wind correlation coefficients. *Aust. Met. Mag. 28,* 217–21.

Seaman, R. S. 1982. A systematic description of the spatial variability of geopotential and temperature in the Australian region. *Aust. Met. Mag. 30,* 133–41.

Stefanick, M. 1981. Space and time scales of atmospheric variability. *J. Atmos. Sci. 38,* 988–1002.