A quantitative comparison of variations on isobaric and isentropic surfaces in the Australian region

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Spatial and temporal correlation coefficients of temperature, wind components, geopotential and Montgomery potential were computed for sixteen station pairs on isobaric and isentropic surfaces, using a twelve-year period of Australian upper air data. The isentropic coefficients mostly exceeded the corresponding isobaric coefficients for temperature and wind components, but the isobaric coefficients of geopotential mostly exceeded the isentropic coefficients of Montgomery potential. The differences in the corresponding coefficients were usually less than 0.05, but vertical interpolation errors are likely to have biased the results against the isentropic coefficients.

Introduction

The idea of using isentropic rather than isobaric coordinates for analysis and prediction has had many proponents over the last half century, dating from the pioneering work of Rossby et al. (1937), and Namias (1938). Briefly expressed, the basic argument favouring the use of isentropic surfaces is that they tend to approximate material surfaces more closely than do constant pressure surfaces, and that isentropic flow patterns therefore tend to be more coherent in space and time. An additional advantage of isentropic surfaces is the provision of better vertical resolution in the vicinity of strongly baroclinic zones, than elsewhere. An historical perspective and discussion of the isentropic concept may be found in Bleck (1973). In that reference, the common objections to the use of isentropic surfaces (e.g. intersection of the surfaces with the ground, handling of superadiabatic lapse rates etc.) are also critically discussed.

From the aspect of objective analysis, Shapiro and Hastings (1973) concluded that the prime advantage of interpolation along isentropic surfaces 'stems from the characteristically large-scale variations of atmospheric pressure, temperature, wind velocity, thermal stability and vertical wind shear . . . as compared to the fine-scale structure of these variables on isobaric surfaces'. This claim was made in the context of cross-sectional analysis of situations containing fronts, using the United States rawinsonde network.

In summary, the advantages of an isentropic framework for analysis and prediction (both by objective numerical and subjective manual methods) have been demonstrated in strongly baroclinic situations. However, a practical choice between the two frameworks should take into account their performances over the total range of synoptic situations. There appear to have been few studies to compare the isentropic and isobaric approaches over an extensive data base. While spatial autocorrelations of different parameters on isentropic surfaces have been computed by several authors (e.g. Bleck and Haagenson 1968; Bleck 1974; Boyle 1981), no direct comparisons appear to have been made with corresponding isobaric statistics. Bleck (1974) compared the respective predictions, from 50 base times, of the then US National Meteorological Center northern hemisphere primitive equations model (analysis on pressure surfaces, prediction on sigma surfaces), and a limited area primitive equations model in which both analysis and prediction were performed on isentropic surfaces. The results favoured the former model, but it was suggested that the differences in the domain of integration and in vertical resolution (among other things) may have been more important than the differences between isentropic and isobaric coordinates.

In this report, we approach the problem from the standpoint of objective analysis addressing in a statistical sense the sort of proposition quoted above from Shapiro and Hastings (1973). Using a substantial data base, we compute spatial and temporal variations of several elements on both isobaric and isentropic surfaces, over a range of levels, seasons and station separations. In the next section we detail the data base and methodology. Then follows a discussion of the results and tentative conclusions.

Data base and processing

Magnetic tapes for all available radiosonde and upper wind flights from Australian stations poleward of latitude 30 for the period 1962 to 1973, were obtained from the Bureau of Meteorology. These data were checked and a very few gross errors removed. Data for this 12-year period were then considered for a total of 16 station pairs, with separations ranging from 341.6 to 854.0 km (Table 1). For each station pair in each season, means, variances and correlation coefficients were computed for several elements, both on standard isobaric surfaces and on corresponding isentropic surfaces. The isentropic surface (θ = constant) 'corresponding' to a specified isobaric surface (p = constant), was defined as the isentropic surface (with an integer value of θ) upon which the sample mean pressure (for the particular station pair and season) was closest to p. This sample mean was usually within 4 mb of p. The spatial correlation coefficient for a station pair on an isobaric surface, and that on the corresponding isentropic surface, were based upon exactly the same set of simultaneous ($\pm$1 hour) soundings. The specific elements studied were as follows:

(i) On isobaric surfaces: temperature (T), zonal and meridional wind components (u, v) and geopotential (ϕ).

(ii) On isentropic surfaces: temperature, zonal and meridional wind components, and Montgomery potential ($M = \phi + c_p T$ where c_p is the specific heat of dry air at constant pressure).

The correlation coefficients for geopotential and Montgomery potential were compared with each other because the latter is the isentropic counterpart of the former, in the geostrophic wind equation. However, the comparisons of like elements (wind components or temperature) are perhaps more convincing criteria, particularly from the aspect of initialising primitive equations models based upon wind and temperature.

In addition to correlation coefficients of simultaneous data for station pairs, isentropic and isobaric coefficients were computed at each station for a 24-hour lag. The two types of coefficient (from simultaneous data for a station pair, and from lagged data at a single station) will henceforth be referred to as 'space' and 'time' coefficients.

For each sounding the values of all elements on isentropic surfaces, with the exception of M, were obtained by logarithmic interpolation from the reported values at pressure levels. The standard reporting levels are shown on the abscissa of Fig. 1. The values of Montgomery potential were obtained by vertical integration of the hydrostatic equation in the form

$$\frac{\partial M}{\partial \theta} = \frac{C_p T_v}{\theta} \approx \frac{C_p T}{\theta}$$

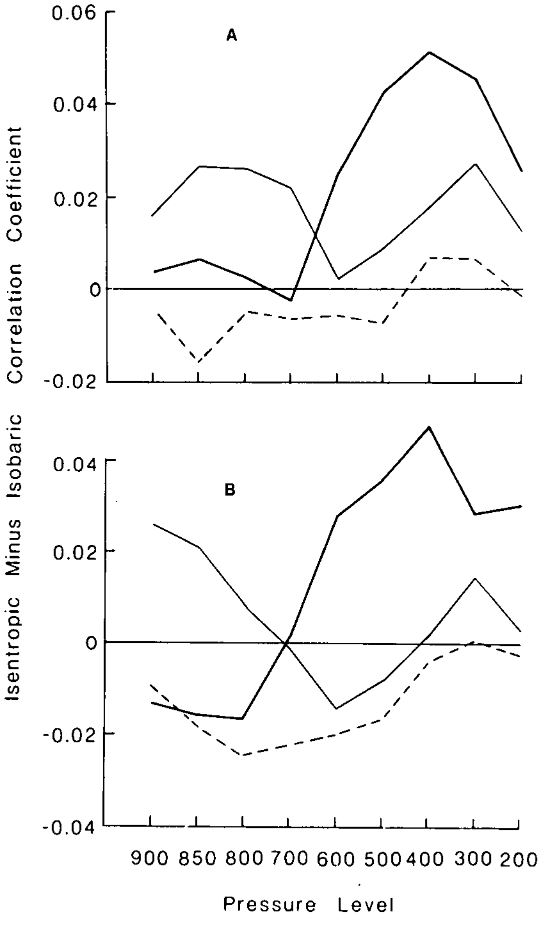
where T_v denotes virtual temperature. For further details of the integration procedure see Gustafson (1964).

Table 1. Station pairs, locations and separations.

Station pair	Lat. (S)	Long. (E)	Sep. (km)
Guildford Kalgoorlie	31°56′ 30°46′	115°58′ 121°27′	536.5
Guildford Esperance	31°56′ 33°49′	115°58′ 121°53′	590.8
Guildford Albany	31°56′ 34°57′	115°58′ 117°48′	376.1
Kalgoorlie Esperance	30°46′ 33°49′	121°27′ 121°53′	341.6
Kalgoorlie Forrest	30°46′ 30°51′	121°27′ 128°06′	635.1
Esperance Forrest	33°49′ 30°51′	121°53′ 128°06′	670.6
Esperance Albany	33°49′ 34°57′	121°53′ 117°48′	395.3
Forrest Woomera	30°51′ 31°09′	128°06′ 136°48′	829.7
Woomera Adelaide	31°09′ 34°57′	136°48′ 138°32′	452.3
Adelaide Mount Gambier	34°57′ 37°49′	138°32′ 140°46′	376.2
Adelaide Wagga	34°57′ 35°06′	138°32′ 147°30′	816.4
Williamtown Wagga	32°49′ 35°06′	151°50′ 147°30′	473.4
Williamtown Laverton	32°49′ 37°53′	151°50′ 144°45′	854.0
Mount Gambier Laverton	37°49′ 37°53′	140°46′ 144°45′	349.8
Mount Gambier Wagga	37°49′ 35°06′	140°46′ 147°30′	673.5
Laverton Wagga	37°53′ 35°06′	144°45′ 147°30′	395.2

An important shortcoming of this study was the non-availability of significant level information in the archived soundings. The vertical interpolation errors in the determination of values on isentropic surfaces, therefore, are likely to have been greater than they would have been had significant level data been available. The discrepancy would be most marked in those situations where sudden changes in lapse rate occurred midway between standard reporting levels. The magnitudes of the vertical interpolation errors are difficult to quantify. They depend upon vertical structure functions (mean square differences as a function of vertical separation) which are themselves not well known for separations much less than 100 mb. About all that can be said is that the random errors of interpolation will result in the correlation

Fig. 1(a) Isentropic minus isobaric spatial correlation coefficient averaged over all seasons and station pairs. Thick full line — temperature; thin full line — average of zonal and meridional wind; dashed line — Montgomery potential minus geopotential.
(b) As in (a), for time correlation coefficients.



coefficients on isentropic surfaces being underestimated. To this extent the isobaric-isentropic comparisons to follow are likely to be biased against the latter, and the isentropic correlation coefficients should be regarded as lower limits to the true values.

Results

The differences between corresponding isobaric and isentropic correlation coefficients were mostly not statistically significant when individual pairs were considered. However, the signs of the differences were fairly consistent. When the coefficients were averaged over one or more of the influencing factors (levels, seasons, or station pairs), a more coherent pattern emerged.

The very general picture, corresponding to the most extensive averaging of both the space and time coefficients, is shown in Table 2. The isentropic correlation coefficient is greater than the corresponding isobaric coefficient for both temperatures and wind. However, the correlation coefficient of Montgomery potential on an isentropic surface tends to be slightly less than that of geopotential on an isobaric surface. The foregoing statements are also true for a large majority of the samples for individual station pairs, levels and seasons; it appears that at least the sign of the difference is unlikely to be due to sampling fluctuations. On the other hand, while the sign of the isentropic minus the isobaric coefficient is fairly consistent, the magnitude of the difference (usually less than 0.05) corresponds to only a small difference in explained variance.

Table 2. Isentropic minus isobaric correlation coefficient averaged over all stations, levels and seasons.

	Space coefficients	Time coefficients
Temperature	0.0225	0.0139
Wind	0.0176	0.0054
Geopotential and Montgomery potential	−0.0031	−0.0131

In Figs 1(a) and 1(b) we have averaged over seasons and stations, but not over levels. It is difficult to detect much systematic variation between levels, apart from a suggestion that for temperature the isentropic correlation coefficient exceeds the isobaric correlation coefficient by more at higher levels.

In Table 3 the averaging has been performed over levels and stations, but not over seasons. The isentropic spatial correlation coefficients of temperature and wind exceed the corresponding isobaric coefficients in all seasons. On the other hand, the isentropic spatial correlation coefficient of Montgomery potential is less than the corresponding isobaric coefficient of geopotential in all seasons. For the 24-hour lag coefficients, similar conclusions apply except for wind. While the absolute values of both spatial and time coefficients tend to be greatest in autumn, there is no apparent systematic seasonal variation in the isobaric-isentropic differences.

Figures 2(a) to 2(d) show the results of averaging spatial correlation coefficients over levels and seasons. They indicate that the differences between the isobaric and insentropic spatial correlation coefficients do not depend much upon station separation and/or orientation of the line joining a station pair. Nor do the differences between the isobaric and isentropic time correlation coefficients (not shown) depend in any syetematic way upon the latitude of the station.

Table 3. Isentropic and isobaric correlation coefficients, and their differences, averaged over all levels and stations.

		Summer		Autumn		Winter		Spring	
		Space	Time	Space	Time	Space	Time	Space	Time
	θ	0.6906	0.6448	0.7820	0.7043	0.6946	0.4886	0.7191	0.5683
Temperature	p	0.6683	0.6231	0.7632	0.6906	0.6719	0.4861	0.6952	0.5502
	θ-p	0.0223	0.0217	0.0188	0.0137	0.0227	0.0025	0.0239	0.0181
	θ	0.6381	0.5296	0.7022	0.5575	0.6847	0.5041	0.6840	0.5273
u-component	p	0.6168	0.5125	0.6728	0.5444	0.6758	0.5125	0.6689	0.5256
	θ-p	0.0213	0.0171	0.0294	0.0131	0.0089	−0.0084	0.0151	0.0017
	θ	0.4816	0.3668	0.5532	0.3495	0.5846	0.2493	0.5421	0.2159
v-component	p	0.4643	0.3614	0.5316	0.3477	0.5667	0.2447	0.5244	0.2260
	θ-p	0.0173	0.0054	0.0216	0.0018	0.0179	0.0046	0.0177	−0.0101
Montgomery	θ	0.8081	0.7111	0.8688	0.7843	0.8360	0.6731	0.8354	0.6771
potential	p	0.8145	0.7258	0.8724	0.7958	0.8363	0.6824	0.8900	0.6937
Geopotential	θ-p	−0.0064	−0.0147	−0.0036	−0.0115	−0.0003	−0.0093	−0.0546	−0.0166

Concluding remarks

The correlation coefficients in this study were the usual product-moment coefficients computed on the basis of deviations from the sample means. Such coefficients are strictly applicable to objective analysis, only when the first guess is the climatological mean. In practice a first guess which is better than the climatological mean is usually available, and the corresponding correlation coefficient should be based upon deviations from such a typical first guess. To compute the latter sort of coefficient would have entailed some assumption about the way in which the first guess was derived. We have preferred to make the alternative assumption that the *differences* between the isobaric and isentropic coefficients do not depend crucially upon the first guess.

From the aspect of objective analysis — and with the above reservations — the results on balance favour the isentropic framework, but the differences are rather small. It therefore appears that the clear advantages of isentropic coordinates for objective analysis, which were demonstrated by Shapiro and Hastings (1973) for frontal cases over the United States (see 'Introduction'), may not apply to the same extent over the total range of synoptic situations with the conventional observing network density of southern Australia. However, as explained earlier, the non-availability of significant level data from the soundings has biased the results against isentropic coordinates. We therefore consider that the foregoing results should provide some encouragement for further research into isentropic analysis and prediction in the Australian region.

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Fig. 2(a) Isentropic (crosses) and isobaric (dots) spatial correlation coefficients of temperature versus separation, averaged over all levels and seasons.

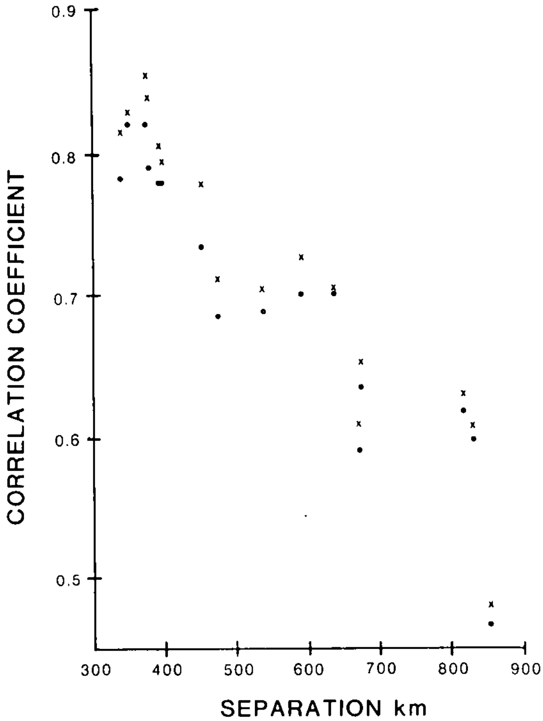

Fig. 2(b) As in (a), for Montgomery potential (crosses) and geopotential (dots).

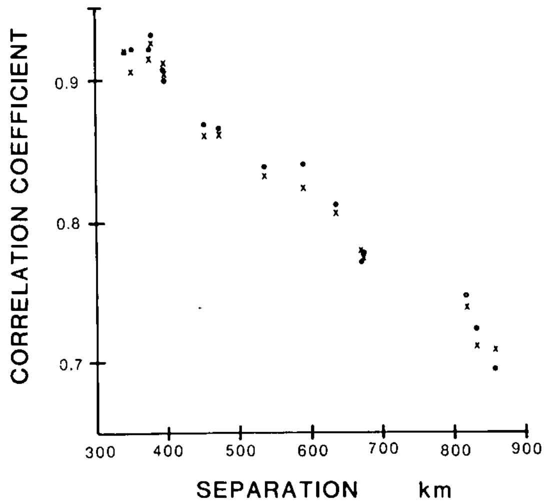

Fig. 2(c) Isentropic (upper) and isobaric (lower) spatial correlation coefficients of zonal (preceding decimal point omitted) wind component versus separation and orientation. Axes are graduated in 200 km intervals.

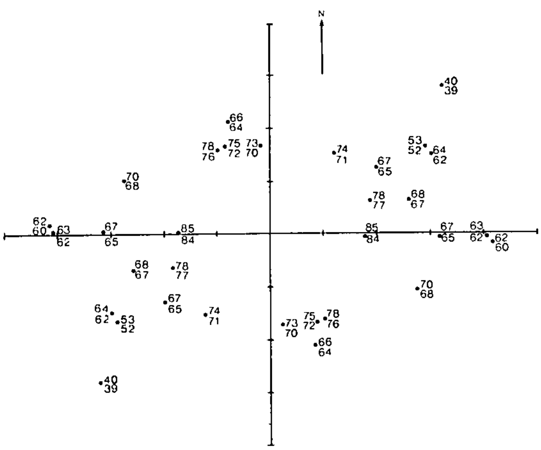

Fig. 2(d) As in (c), for the meridional wind component.