

A NOTE ON THE SUB-TROPICAL JET STREAM IN THE AUSTRALIAN REGION

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ABSTRACT

Using data previously obtained by Muffatti(1963) and Weinert (1968) for the years 1956 to 1961 and new data covering the period 1962 to 1968 auto-correlation functions of wind speed along the axis of the sub-tropical jet stream at 200 mb in the Australian region have been estimated. From these functions seasonal values of a longitudinal length scale have been evaluated. It is found that the form of the auto-correlation function shows similarity between seasons and that there is a systematic variation in length scale with maximum values in autumn and spring and minimum values in summer and winter.

1. INTRODUCTION

The pioneering studies of the sub-tropical jet stream in the Australian region by Gibbs (1952), Radok and Clarke (1958) and others established that this feature is near 200 mb at all times of the year. Subsequent work has confirmed this fact (e. g. Spillane, 1968). Regular reliable 200 mb analyses have been prepared on a daily basis since 1956. Data collected in the years 1956 to 1961 formed the basis of a comprehensive climatology of the jet stream by Muffatti(1963) and Weinert (1968). The basic data set used in these two studies was extended a further 7 years to include the period 1962 - 1968 and these data form the basis of the results presented here. The aim has been to establish the climatological wind speed structure along the jet axis at 200 mb.

The approach adopted has been to estimate seasonal auto-correlation functions for wind speed along the axis of the jet stream. These may be interpreted in a similar manner to auto-correlation functions in the theory of turbulence (e. g. Batchelor, 1953) permitting inferences about the statistical structure, principally through a length scale.

The length scale defined here is in many respects analogous with the "Mischungsweg", discussed by Taylor (1935), which is associated with much smaller scales of turbulence. It can be considered as defining a scale of longitudinal processes associated with the sub-tropical jet stream (This kind of scale is often thought of as the greatest distance by which two points may be separated and still have a reasonable correlation in wind speed).

The concept of the auto-correlation function also has implications for current methods of numerical analysis as this function is closely related to a weighting function involved in a technique in current use.

2. METHOD OF ANALYSIS

The basic data consisted of the latitude and speed of the jet stream core at each 10° of longitude between 100°E and 180°E . These were extracted from the daily 2300Z 200 mb charts. For the years 1956 to 1961 Muffatti and Weinert defined the axis as coinciding with the northernmost maximum of wind speed in the westerlies at each longitude. The analysis for the 1962 to 1968 period used a slightly different criterion. Following Krishnamurti (1961) the axis was assumed to be continuous. The procedure adopted was to lay a sheet of clear plastic over the 200 mb chart and trace a continuous axis on the sheet. The data were then extracted. The plastic sheet, still bearing the tracing, was placed over the next chart and the process repeated. In this way the previous positions were used to maintain a consistent history of the jet axis.

As will be seen later the two methods produced, in some respects, significantly different results. The reason is that often the core speed of the sub-tropical jet may drop so low as to make its identification in the restrictive sense of the first method difficult. In this case the polar jet stream may be at times defined as the sub-tropical jet. The second method permits a more consistent identification, both because of the available history and the use of data from longitudes other than that being considered. The effect of these differences is probably to displace the mean jet stream positions to higher latitudes and to decrease the down-stream correlation of wind speeds for the 1956 to 1961 data.

The data were divided into four seasons; summer (December to February), autumn (March to May), winter (June to August) and spring (September to November). This gave sample sizes large enough to obtain reliable statistics, while meaningfully grouping the data. For each season an auto-correlation function $R(a)$ was estimated for wind speeds, where 'a' is an arc length on the axis. $R(a)$ is estimated by evaluating the sample correlation coefficients between points 10° of longitude apart (one lag), 20° apart (two lags) and so on up to the maximum possible, 80° apart (eight lags). The number of pairs obtained from any one day's data would vary from eight for one lag, to one, for eight lags. The length of the jet axis joining data points was approximated by the length of the arc of the great circle joining the two points. The value of 'a' will thus vary from day to day and segment to segment as the latitude of the jet axis varies. It was found that in any given season, 'a' had a standard deviation varying from 0.1a for one lag to 0.03a for eight lags.

A length scale L , defined by
$$L = \int_0^\infty R(a) da$$

was estimated for each season of each year using a method similar to that employed by Cramer (1959). This involved a simple trapezoidal type integration up to a value of $R(a)$ which was statistically not different from zero; larger values of 'a' were considered not to contribute significantly to L . The cut-off criterion was determined by forming a t-variate with ν degrees of freedom, $t = R(\nu / (1-R^2))^{1/2}$ (e.g. Spiegel, 1961). The value of R was assumed statistically different from zero if t was greater than the 97.5 percentile of Student's t distribution with ν degrees of freedom. Serial correlation between observations will make ν significantly less than the actual sample size, N , and following O'Mahony (1960) $\nu = N(1-R_S^2)/(1+R_S^2)$ was used, where R_S is the serial correlation coefficient.

3. RESULTS

Figure 1 summarises the values of L obtained. The values between 1956 and 1961 are on the average somewhat lower than the later ones and rather more erratic. The reason for this is because of the poorer down-stream correlation discussed in the previous section. The period 1962 to 1968 shows distinct maxima in autumn and to a lesser extent in spring, and minima in winter and to a lesser extent in summer. These features are reflected in the seasonal averages shown in Figure 2, which shows a similar, but less marked pattern for the 1956 - 1961 data. In general, despite the larger values of L , there is less variability in the 1962 - 1968 data as indicated by the standard deviations given in Figure 2. The ratio of the standard deviation of L to its mean is about $1/5$; thus, although there is a year to year variability, for practical purposes the value of L is reasonably estimated by the seasonal mean.

The consistency in the winter values of L shown for both data analysis techniques is indicative of the fact that the sub-tropical jet stream is better defined in the Australian region in this season so that both methods, under these conditions, give similar results.

In Figure 3 the estimates of $R(a)$ are plotted against a/L for all estimates with $v \geq 100$. This presentation is preferred to a plot of $R(a)$ versus ' a ', as it showed less scatter of data and hence greater similarity. From these plots no consistent differences in the shape of $R(a)$ can be determined either from season to season or between the 1956 - 1961 and 1962 - 1968 data sets.

Other studies involving auto-correlation functions for this level of the atmosphere by Murgatroyd (1969) and Spillane (1969) have found auto-correlograms of the form

$$R(\tau) = e^{-p\tau} \cos(q\tau)$$

where τ is a time lag and p and q are non-dimensional constants which describe the data for a Eulerian coordinate system.

Spillane found that a "frozen turbulence" hypothesis is not inconsistent and on this basis a form

$$R(a) = e^{-\alpha a/L} \cos(\beta a/L)$$

may be postulated. Although the system analysed here only approximates to an Eulerian one, it would be Eulerian if the position of the axis remained unchanged. In Figure 3 the curves which have been fitted to the data have the functional form of Eq.(1). Values of $\alpha = 0.6$ and $\beta = \pi/6$ were found to give the best fit.

4. CONCLUSIONS

If $R(a)$ has a form similar to Eq. (1) then it would have a minimum and negative value at $a = 4.4L$, implying a regular separation between maxima and minima of wind speeds of this order. On the average this separation ranges from about 8,400 km in winter to 15,500 km in autumn. However, the form of $R(a)$ is not well established beyond $3L$ and these values should be viewed with caution.

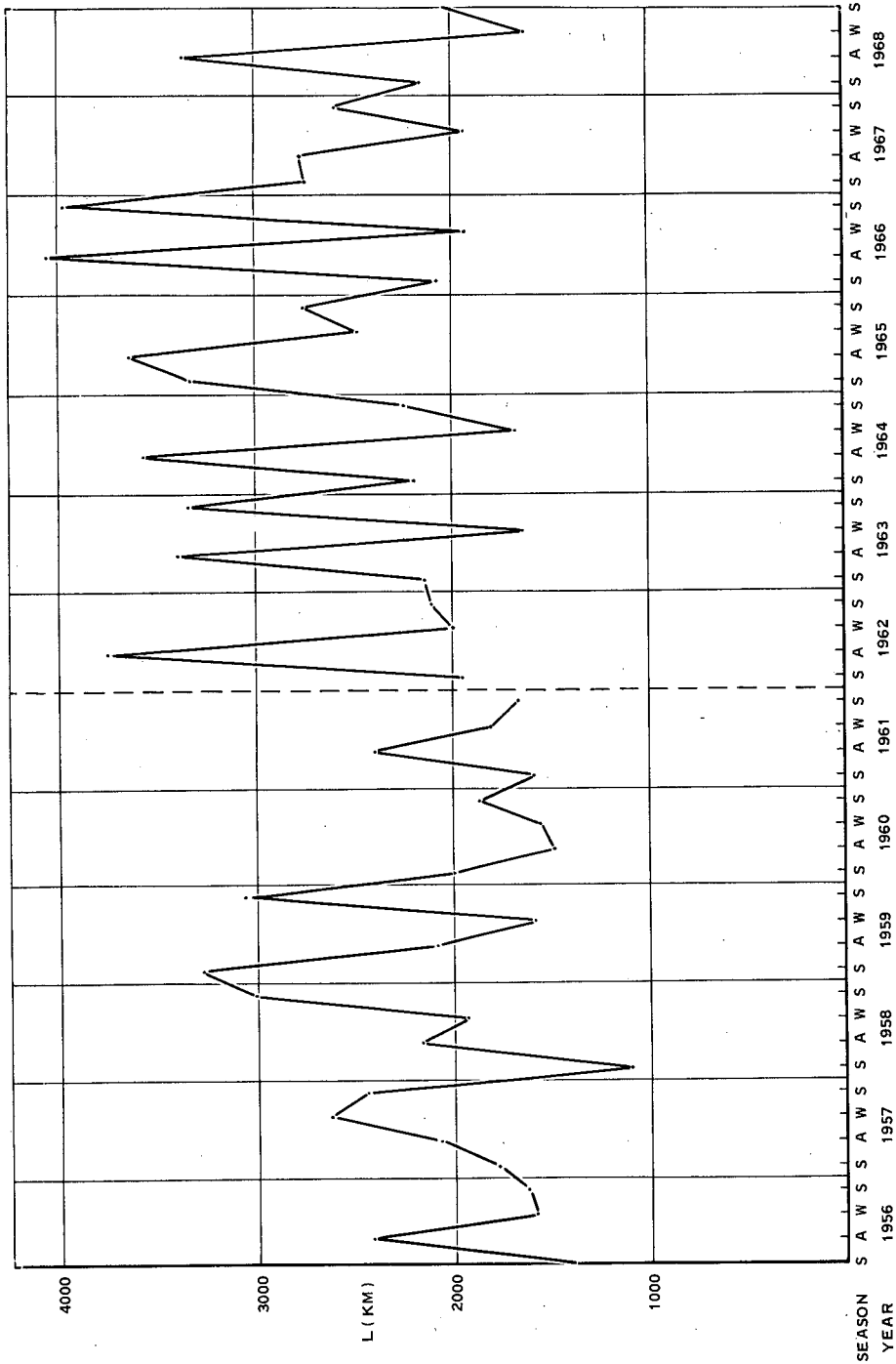


Fig. 1 Estimated values of the longitudinal length scale of the sub-tropical jet stream in the Australian region. To the left of the broken line Muffatti and Weinert's data has been used, to the right new data. Four estimates for summer (S), autumn (A), winter (W) and spring (S) are made each year.

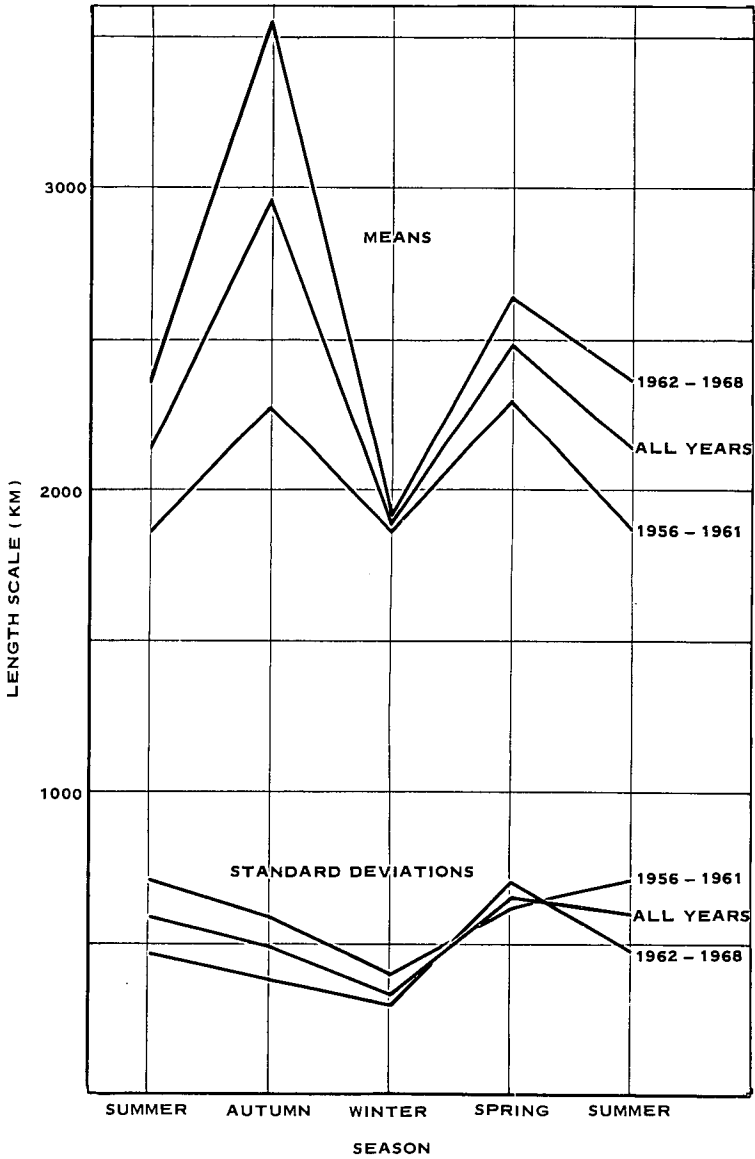


Fig. 2 The means and standard deviations of length scale for each season. This has been subdivided into the years 1956-1961 (Muffatti and Weinert's data), 1962-1968 (the new data), and all years, 1956-1968.

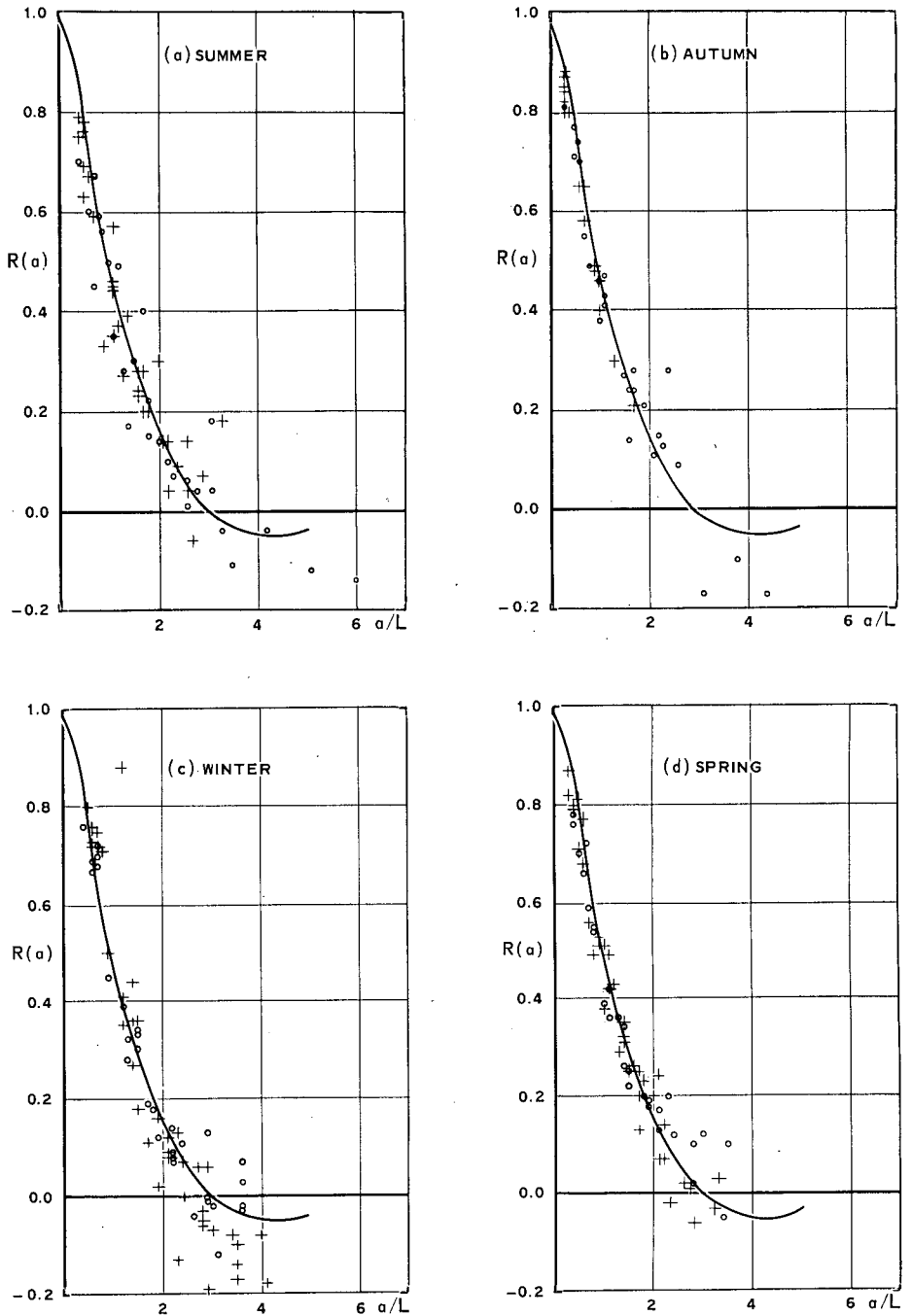


Fig. 3 Estimates of $R(a)$ for all years with number of degrees of freedom greater than 100, grouped by season. The dots are for the years 1956-1961 (Muffatti and Weinert's data), and the crosses 1962-1968 (the new data). The curve is $R(a) = e^{-0.6a/L} \cos(\pi a/6L)$.

The form of $R(a)$ has some application in numerical analysis techniques which employ influence functions. The weighting factor W discussed by Maine (1966) has a definition very similar to that of $R(a)$; however, its form

$$W(a) = (r^2 - a^2)/(r^2 + a^2)$$

where r is an influence radius, is different from that of $R(a)$. The appropriate length scale for W is

$$L = \int_0^r W(a) da$$

$$= 0.556r$$

Figure 4 compares $R(a)$ and $W(a)$. It can be seen that there are basic differences in their shapes. At 200 mb, on the jet core, in the direction of the jet axis a weighting function with a form similar to Eq. (1) is probably more realistic than Eq. (2). Further, more complex analysis is required to determine the shape of W in the transverse directions.

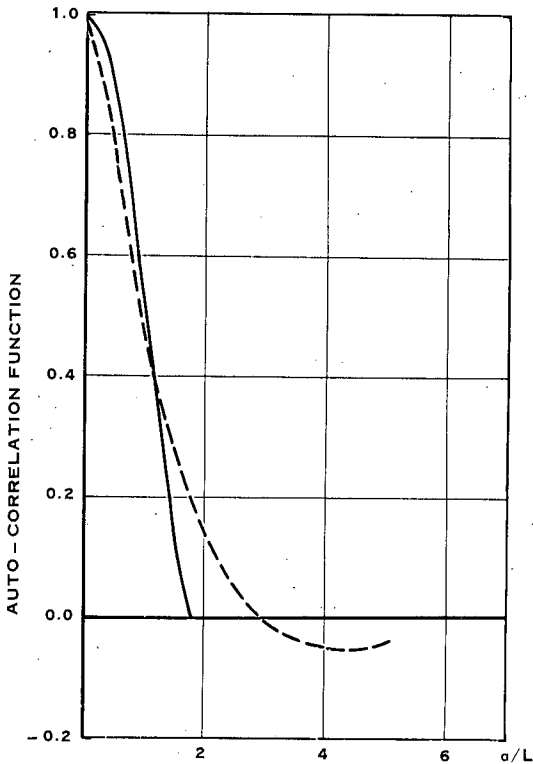


Fig. 4 Comparison of $W(a)$ (full line) with $R(a)$ (broken line). See text for details.

The general conclusions of this study are that the longitudinal auto-correlation function of wind speed along the jet axis shows similarity from season to season. A suitable functional form is given by Eq. (1), at least out to $3L$. The longitudinal length scale has a seasonal variation with high values in autumn and spring and low values in summer and winter. The two forms of data analysed used have produced significantly different values of L , but the form of $R(a)$ is similar. It is possible that Muffatti and Weinert's data are polluted to some extent with other than sub-tropical jet stream observations.

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