Developments in the Radiowave Drifts Technique for Measurement of High-Altitude Winds

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(Manuscript received 21 September 1978, in final form 10 February 1979)

ABSTRACT

The drifts technique derives wind vectors from correlation analysis of spatial and temporal sequences of radiowave field strength at ground level. The paper examines the bases of the analysis, and presents a new method (simplified Gaussian correlation analysis) suitable for large-scale processing. Evaluation of the quality of derived winds vectors by means of internal consistency measurements is described. Methods of editing are surveyed, and a new method, based on the normalized time discrepancy, is demonstrated. Methods for securing maximum yield of winds vectors from raw data are described. The use of microprocessors for immediate data processing is outlined. Comparisons of winds obtained by the partial reflection technique with other experimental techniques are examined.

1. Introduction

This paper discusses some recent developments which have led to the emergence of the partial reflection "radiowave drifts" technique (Fraser, 1965; Gregory and Rees, 1971), as a powerful and economical tool for the measurement of winds in the altitude region 60–120 km. Three main topics are discussed: 1) analysis of raw data, including choice of analysis method, maximizing of yield of results, problems of editing and verification through internal consistency checks; 2) improvements in data processing, notably through the application of microprocessors; and 3) validity of winds derived by this method. The paper will not discuss technical and organizational aspects of the partial reflection method since a survey of the subject has been given (Gregory, 1978). Also, some mathematical analyses will be omitted, since these also are available (Meek, 1978).

2. Treatment of data

a. Theoretical approaches

Figs. 1a and 1b illustrate the sampling at ground level of a diffraction pattern formed by partial or total reflection of radiowaves incident on the lower ionosphere. The essentials of the experimental arrangements have remained unchanged since the work of Mitra (1949), save for the substitution of an equilateral triangle in place of a right-angle triangle as the geometry of the sampling points (Barber, 1957). The physical device at each of the sampling points is one or more half-wave dipoles, and the sides of the equilateral triangle are customarily between one and two radio wavelengths, e.g., 150–300 m. The data sequences comprise values of radiowave field strength, as shown in Fig. 2, and these are treated to determine drift velocities from the times of passage of similarities over the sampling points.

The theoretical basis of the treatment remains essentially as it was established by Briggs *et al.* (1950). A new formulation, which included some alternative methods of analysis, was given by Fedor (1967). Briggs *et al.* evaluated two velocities—"apparent" $\mathbf{V}'$ and "true" $\mathbf{V}$—as well as other characteristics of the pattern, by means of "full correlation analysis" (FCA). This treatment, as extended by Phillips and Spencer (1955), postulates that the diffraction pattern, when seen by an observer moving with it at the true mean drift velocity of magnitude V and direction ϕ, is described by elliptical contours of constant correlation. The axes of the ellipse are identified as x and y directions, at right angles, along which the spatial scales of the pattern are a and b, respectively. The drifting pattern is also observed to change with a time scale of c, and the major axis of the ellipse has a geographic orientation θ.

To determine the spatial and temporal characteristics of the pattern, measurements of radiowave field strength can be made at a series of locations at the same instant of time. These observations can be correlated to yield a coefficient $\rho(x,y,0)$, where (x,y) represents the separation vector of the sampling points. Similarly, a pattern observed at a fixed location, but at varying times, will yield the coefficient $\rho(0,0,t)$.

To describe the variations of ρ with x, y and t, two assumptions are customarily made. The first is that the spatial and temporal variations have the same statistics except for differing scale factors, so that all can be described by a single function, i.e., $\rho=F(x,y,t)$. The second,

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which includes the description of the pattern in terms of ellipses, is that if values of the argument are not too large, the surfaces of constant correlation in x, y, t space are ellipsoids. With these assumptions, the correlation coefficient obeys the relation

$$\rho(x,y,t)=F\left(\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{t^2}{c^2}\right), \qquad (1)$$

where F has the value of unity for $x=y=t=0$, and is assumed to decrease monotonically.

When measurements are being made from a fixed reference system, the effect on the observed correlation function is as if the observer were moving backward at the drift speed of the pattern. For a fixed observer, the correlation function takes the form

$$\rho(x',y',t)=F\left[\frac{(x'-Vt\cos\phi')^2}{a^2}+\frac{(y'-Vt\sin\phi')^2}{b^2}+\frac{t^2}{c^2}\right], \qquad (2)$$

where (x',y') define the separation vector in the fixed system, depicted in Fig. 3. When transformed to geographic coordinates (r,s), where

$$x'=r\cos\theta+s\sin\theta,$$
$$y'=-r\sin\theta+s\cos\theta,$$

the correlation function becomes

$$\rho(r,s,t)=F\left[\frac{(r\cos\theta+s\sin\theta-Vt\cos\phi')^2}{a^2}+\frac{(-r\sin\theta+s\cos\theta-Vt\sin\phi')^2}{b^2}+\frac{t^2}{c^2}\right]. \qquad (3)$$

This last expression gives the value of correlation between amplitudes at a pair of ground locations, with orientation and spacing according to the vector (r,s), and with time separation t.

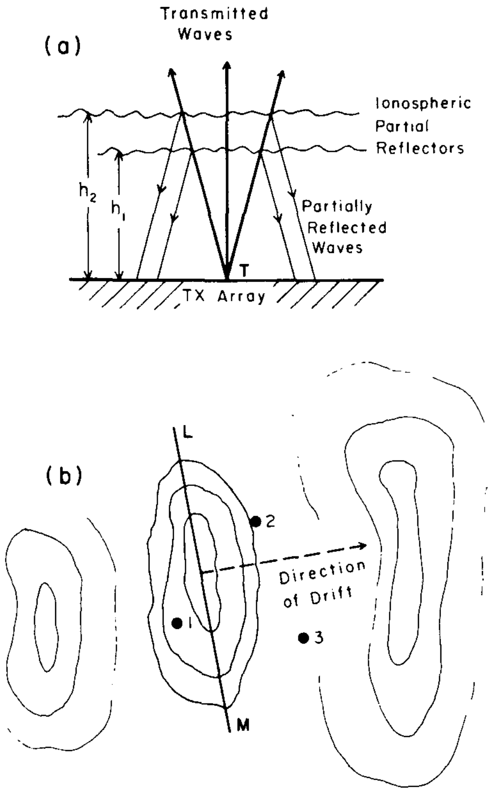

FIG. 1. Partial reflection geometry (a) and diffraction pattern (b) of reflected waves (contours of constant radiowave amplitude) drifting over sampling points 1, 2, 3.

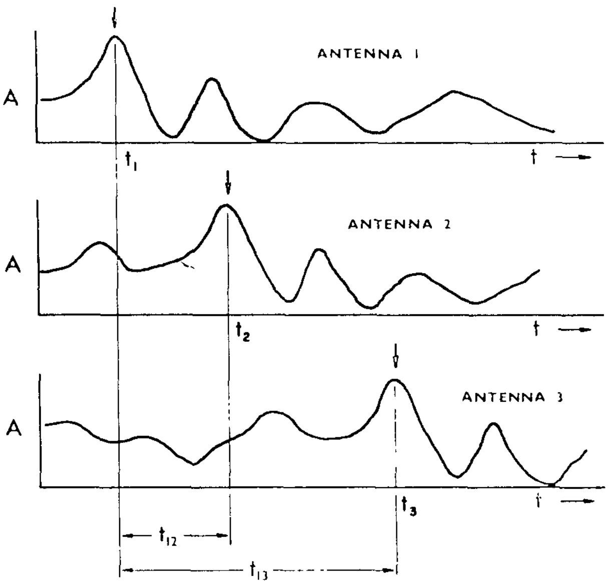

FIG. 2. Data sequences of amplitude A, available at points 1, 2, 3 of Fig. 1b.

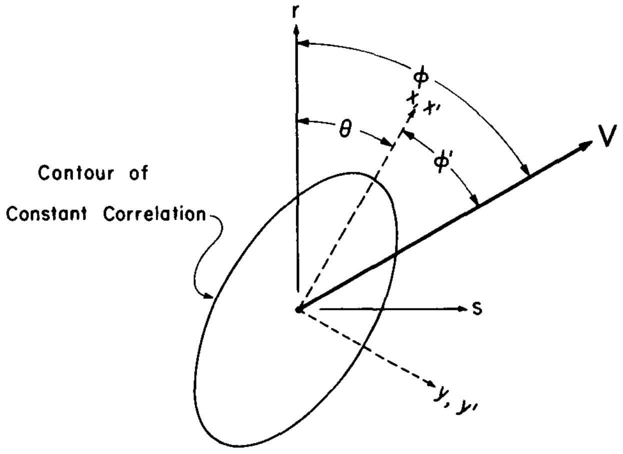

FIG. 3. Coordinate system applicable to correlation ellipse.

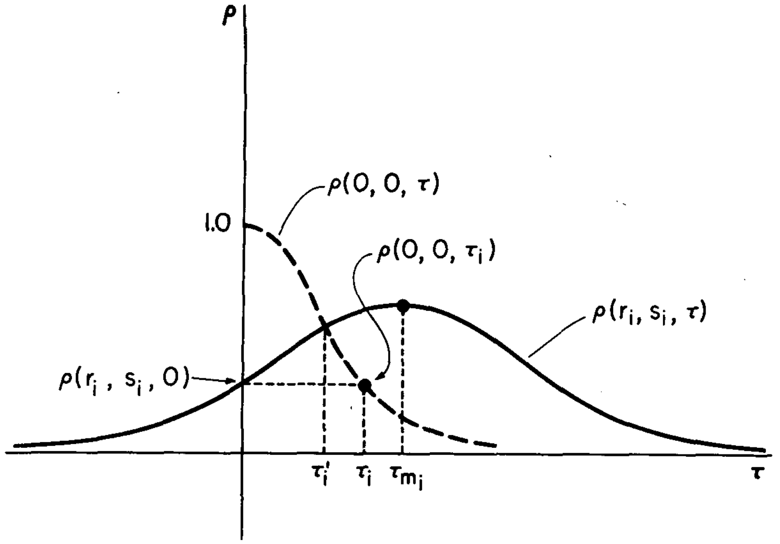

FIG. 4. Idealized autocorrelogram (dotted) and cross-correlogram (solid) for two data sequences of amplitudes.

It will be noted that the experimental arrangement outlined in Fig. 1b provides for only three sampling points, and thus three sets of values r, s. This limitation characterizes nearly all radiowave winds installations in current use, with the exception of the multipoint sampling array established by Briggs *et al.* (1969) at Adelaide. For economic reasons, future installations are expected to be limited to three sampling points.

The treatment accorded to the function F has varied. Briggs *et al.* (1950) avoided a definition of it by utilizing particular points on correlograms, e.g., as determined by values of lag intervals τ for equal correlations. Fig. 4 shows an autocorrelogram $\rho(0,0,\tau)$, and one cross-correlogram $\rho(r_i,s_i,\tau)$. If the autocorrelogram is the same for all antennas or is a mean of all three, then it may be utilized with the three available cross-correlograms, evaluated at zero lag, to produce the three equations

$$\rho(0,0,\tau_i)=\rho(r_i,s_i,0)\,; \quad i=1,\,2,\,3. \tag{4}$$

Another set of three equations can be derived by noting the time at which the auto- and cross-coefficients are equal, i.e.,

$$\rho(0,0,\tau_i')=\rho(r_i,s_i,\tau_i')\,; \quad i=1,\,2,\,3. \tag{5}$$

By equating the maximum of the cross-correlogram at lag τ_m to the autocorrelogram, a further three sets can be obtained:

$$\rho(0,0,\tau'')=\rho(r_i,s_i,\tau_{mi})\,; \quad i=1,\,2,\,3. \tag{6}$$

There are thus available nine equations with which to calculate five parameters in the form V, ϕ, θ, a/c, b/c. In order to change the latter ratios into actual magnitudes, a reference value of time correlation is required. Various authors have used values of $\rho(0,0,\tau)=0.5$, or $\exp(-0.5)$.

An alternative approach to the form of the correlation function has been adopted by Fedor (1967). He assumes that the correlation function F is Gaussian, so that Eq. (3) becomes

$$\rho(r,s,t)=\exp\left\{-\frac{1}{2}\left[\frac{(r\cos\theta+s\sin\theta-Vt\cos\phi')^2}{a^2}+\frac{(-r\sin\theta+s\cos\theta-Vt\sin\phi')^2}{b^2}+\frac{t^2}{c^2}\right]\right\}. \tag{7}$$

We have termed this approach Gaussian correlation analysis (GCA). In application, a least-squares fit of experimental values of ρ to (7), using the central portion of the data, that is, around correlation maxima, is made.

The assumption of a Gaussian form for the correlation function permits a simpler procedure than least-squares fit (Meek, 1978). It is evident, from Eq. (7), that all Gaussian correlograms (auto and cross) have the same width at a fixed fraction of the maximum value. A set of equations can be developed from only the width of the autocorrelograms, and the position and magnitudes of the maxima in the cross-correlograms. Their solution requires less computation than a least-squares fit. This form of analysis will be referred to as simplified Gaussian correlation (SGCA). [For details of the derivation of vectors, using any of these methods, see Meek (1978).]

We note at this point that one set of values utilized in SGCA, namely, the lag intervals τ_m for the maxima in the cross-correlograms, is also utilized in a prior editing process, to be discussed in Section 2c.

For completeness, we refer to the "apparent" velocity $\mathbf{V}'$ mentioned earlier. This velocity is essentially that of the drift of a "line of maximum" (Ratcliffe, 1954) across the sampling points. The line may be assumed to be straight and at right angles to the direction of drift, as LM in Fig. 1b, or it may be at any angle, and finally may be curved. For a line such as LM, three equations can be written, of the form

$$\tau_{ij}=\frac{d_{ij}}{|\mathbf{V}'|}\cos\alpha, \tag{8}$$

where τ_{ij} is the elapsed time between passage over sampling points ij, d_{ij} the separation (in known direction) of the points, and α the angle between the drift vector $\mathbf{V}'$ and the direction of d_{ij}. A statistical treatment of the values of $\mathbf{V}'$ derived over a suitable interval may be desirable (Gregory and Meek, 1976), particularly if the time interval τ_{ij} for a supposed single line of maximum is replaced by $\tau_{m_{ij}}$, the lag interval for maximum correlation (see Fig. 4). Discussion of treatment of values of $\mathbf{V}'$ will not be pursued here, since this form of velocity does not allow for intrinsic change of the drifting diffraction pattern. Consequently, $|\mathbf{V}'|$ is greater than the true velocity $|\mathbf{V}|$ by some 10–30% (Golley and Rossiter, 1970; Meek, 1978).

However, $\mathbf{V}'$ may sometimes be determined when $\mathbf{V}$ is not available, e.g., when the solution for the latter has no physical interpretation. The magnitude of $\mathbf{V}'$ is unaffected by filtering of data (Chandra and Briggs, 1978). It is readily available at an early stage of analysis, e.g., after evaluation of time lags for maximum cross-correlation.

b. *Choice of analysis method*

If raw data, for example, of the form illustrated in Fig. 2, yield correlograms as in Fig. 4, the basic FCA method is adequate. However, experience in the application of the drifts technique in various locations has revealed marked differences in the correlograms obtained on a majority of soundings (Meek *et al.*, 1979). Thus data from Adelaide and Ottawa yield a larger proportion of correlograms which are nearly Gaussian, or at least monotonically decreasing, than do data from Saskatoon. As examples of what may be encountered at the latter location, though not typically so, we show Fig. 5.

The existence of data which on correlation do not produce the simple forms postulated in FCA or GCA raises several questions. It is desirable that wind observations be continuous, e.g., to evaluate tidal components of motion. However, the derived wind vectors are usually not continuous in time or in altitude, due to both the unsuitability of some raw data for correlation analysis, and the characteristic variations of occurrence of partial reflections (Gregory, 1961). Hence, attention must be focussed on securing a maximum yield of vectors from raw data.

A second, and related, question concerns data quality since it is possible to increase yield of data at the expense of quality, and vice versa. These questions imply choices of methods of analysis and, in turn, lead to requirements for assessing the relative performances of different methods. The requirements may be extended to include the early rejection of data which will not yield acceptable vectors.

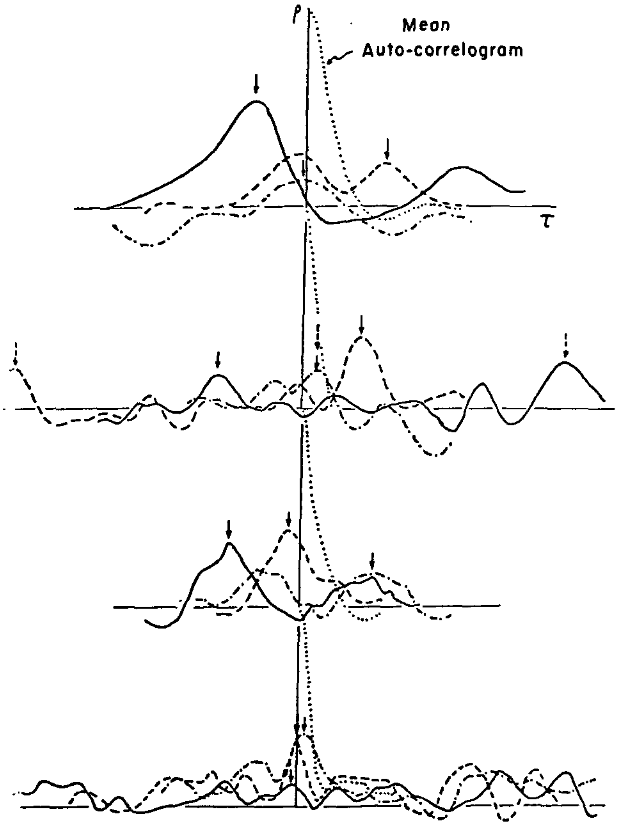

FIG. 5. Actual correlograms obtained at Saskatoon, showing multiple maxima.

In respect to the choice of methods—FCA, GCA and SGCA—there are no principles which can serve as a guide to determine which is "best" for application to a particular block of data. It is necessary to apply the methods in turn to the same block of data and then to compare the results.

For an installation in a new location, a choice of method initially will be aided by plotting correlograms from representative data. From these, it will be evident whether the use of minimal information, i.e., single points on the correlograms, as in FCA, is likely to be satisfactory; or whether the Gaussian approach, with least-squares fit or in simplified form, is more desirable. A comparison of the three methods, applied in turn to the same block of representative data, can be made as described below, and at the same time, the yield of wind vectors may be compared.

In the foregoing comments, it has been tacitly assumed that the "true" value of wind vector $\mathbf{V}$ is desired, as a basis for dynamical studies. The influence of experimental parameters on the "true" value is now becoming known, e.g., spacing of sampling points (Golley and Rossiter, 1970) and incidental or intentional filter-

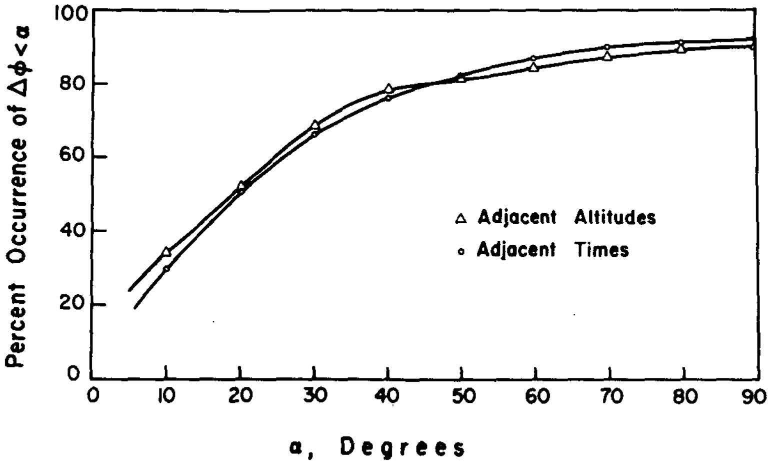

FIG. 6. Cumulative distribution of angle differences between vectors adjacent in altitude and time.

ing of data (Chandra and Briggs, 1978). An associated quantity, the "characteristic" velocity $\mathbf{V}_c$ (Briggs *et al.*, 1950) which describes the intrinsic change of the moving pattern, has not yet been embodied into dynamical studies.

c. Comparisons of vectors

We now describe a technique for comparison of assemblages of wind vectors, e.g., derived either by different methods of analysis of the same raw data or by the same method from different blocks of raw data.

In routine operation of a drifts installation which is not associated with other experimental techniques for winds measurements, it is necessary to devise measures of internal consistency of data. We have made use of comparisons of pairs of wind vectors in adjacent altitude increments, e.g., 57–60 versus 60–63 km, or in successive time intervals of, say, 3 min duration. Vector differences are calculated, and either the magnitude, $|\mathbf{V}_1-\mathbf{V}_2|/|\mathbf{V}_1+\mathbf{V}_2|=\Delta V/V$, of the difference, or the angle $\Delta\phi=|(\phi_1-\phi_2)|$ is used. Assemblages of differences are built up from blocks of data, and displayed as cumulative distributions. Examples may be seen in Figs. 6 and 7. The block of data used in the examples has produced similar distributions despite the possible occurrence of physical processes which might make them dissimilar, e.g., gravity waves or wind shear.

Figs. 8 and 9 show how such distributions reveal the difference in quality of data from different locations. Selected blocks of Saskatoon and Ottawa data were subject to a closely similar analysis. A comparison of distributions shows that the Ottawa data produced a much smaller proportion of larger angle and magnitude differences, and are thus "better" than the Saskatoon data. The manner of utilizing one block of data, to reveal the effects of changes in procedures of analysis, will be evident.

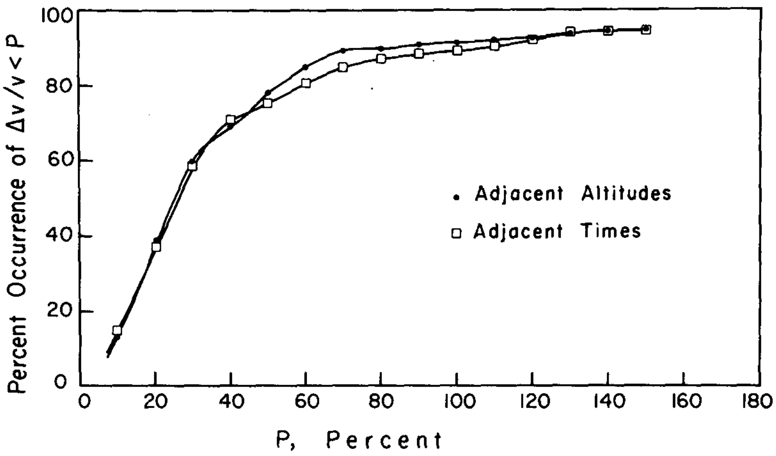

FIG. 7. Cumulative distribution of magnitude differences between vectors adjacent in altitude and time.

d. Editing of data

As noted above, it is desirable that raw data which will not yield acceptable values of wind velocity be identified at an early stage of analysis and not further processed. The factors which make data unuseable include insufficient signal strength, radio interference, and dominant randomness of the diffraction pattern. Usually, it is only excessive signal that can be treated, e.g., by control of receiver gain, to improve data quality.

1) EXISTING PROCEDURES OF EDITING

Some or all of the following procedures of editing have been incorporated in analysis by most users of the method:

(i) A calculation of the standard deviation (SD) of each data sequence. This is designed to reveal the "depth of fading" of the signal. A minimum value of SD is chosen as acceptable, after experience with data for the particular location. We have used a SD of 10 units in a range of 255 units of digitized data.

(ii) A test of the form of autocorrelation function: specifically, that it does not decrease sharply due to noise. Our criterion has been that at a lag of 0.6 s, i.e., $\rho_{ii}>0.6$.

(iii) A test of the magnitude of cross-correlation coefficients. We have set a minimum value of ρ_{ij} at between 0.1 and 0.3; the chosen minimum being determined in conjunction with another quantity (see Section 2d).

2) THE NORMALIZED TIME DISCREPANCY

An additional method of editing has been devised. It is based on the axiom that for any three unique instants of time t_1, t_2 and t_3, the intervals obey the relationship

$$t_{12}+t_{23}+t_{31}=0. \qquad (9)$$

In methods of analysis that identify unique instants, for example, by visual inspection of analogue records for "similar fades" at the three sampling points, this relation holds. Thus each instant could correspond to the passage of a "line of maximum" in the pattern across the sampling points (Ratcliffe, 1954). When correlation techniques are employed, the value of τ_m, the lag interval for maximum, is effectively determined by contributions from all parts of the data sequence. Thus $\sum\tau_{m_{ij}}$ may not add to zero. We define the normalized time discrepancy (NTD) as

$$\mathrm{NTD}=\frac{|\sum \tau_{m_{ij}}|}{\sum|\tau_{m_{ij}}|}, \qquad (10)$$

a quantity having a range from 0 to 1.

The use of the NTD is based on the following considerations. The passage of a "line of maximum" produces an NTD equal to zero. Again, if the correlation function $\rho(r,s,t)$ has the form of Eq. (3), it can be shown (Meek, 1978) that the NTD is theoretically zero. Intuitively, it is to be expected that as actual conditions depart from either of these possibilities, the NTD will increase. Since there is no unique relation between a value of NTD and the associated wind vector, NTD's must be used in relation to assemblages of data.

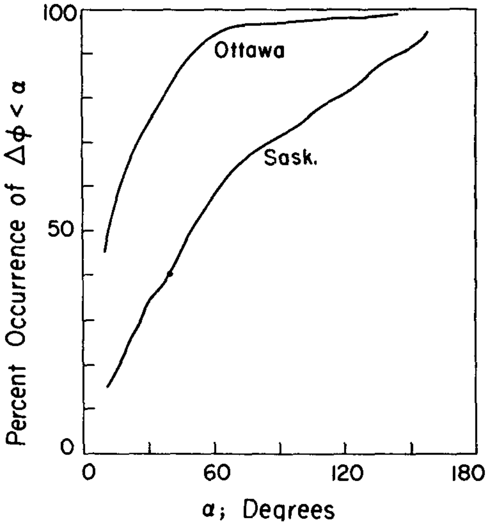

FIG. 8. Comparison of vector angle differences, Ottawa and Saskatoon.

A first use is to demonstrate the existence of differences in data quality. This may be done by means of cumulative distributions, as described in Section 2b. The NTD is available at an early stage in the processing of each record. Also, fewer variants of analysis are involved. Fig. 10 shows its application to Adelaide, Ottawa and Saskatoon data, the superiority of Adelaide data being well-illustrated.

The usefulness of the NTD in editing rests on the expectation that a large NTD is associated with unaccept-

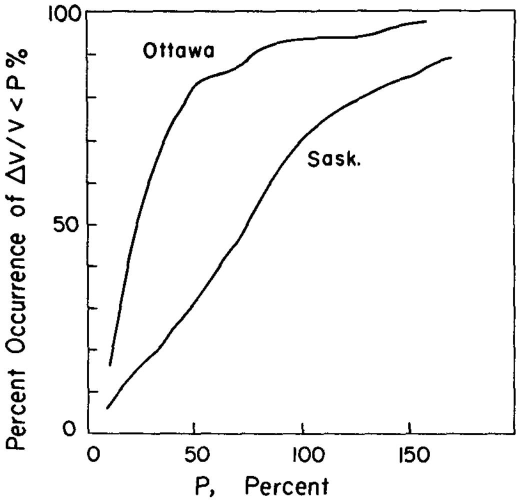

FIG. 9. Comparison of vector magnitude differences, Ottawa and Saskatoon.

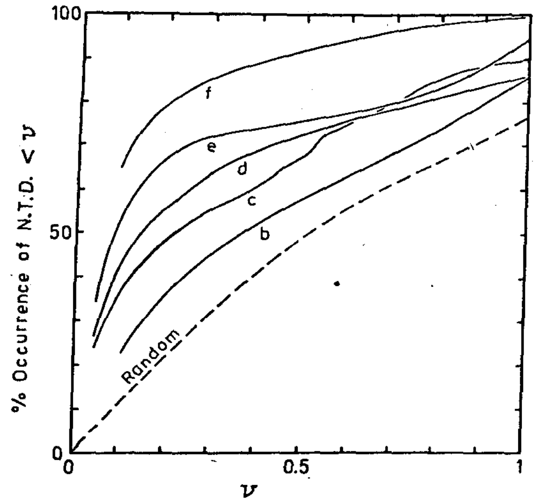

FIG. 10. Distribution of normalized time discrepancy (NTD) for representative data from (b), (c), (d) Saskatoon, (b–d) (successive variants of analysis), Ottawa (e) and Adelaide (f).

able data, since the assumptions of FCA require that the NTD$=0$. A test of the association between NTD and apparent velocities has been made. The standard error of apparent velocities was compared with NTD, and the above expectation confirmed. In respect to true velocities, the application of NTD in editing data processed by FCA or SGCA currently rests on an empirical basis. A further empirical matter involves the need to compromise between yield of data and quality of results. However, it is possible to make a systematic choice of the value of NTD which, if exceeded, will dictate rejection of data. For typical data, successive values of NTD can be applied, and distributions of $\Delta\phi$ and $\Delta V/V$ formed, as described in Section 2b. The change in yield, taken in conjunction with the relative proportions of unacceptable vectors, will indicate a suitable value of NTD. An example of this procedure, as applied to correlograms with multiple peaks, is given in Section 2d.

Finally, use may be made of the fact that the NTD is zero for FCA or GCA. A set of three actual times for maximum cross-correlation, $\tau_{m_{ij}}$ can be least-squares fitted to Eq. (8) for apparent velocity. From the latter, amended time delays are derived for which NTD$=0$. SGCA may then proceed, using the values of $\rho_{\max_{ij}}$ which were associated with the unmodified times $\tau_{m_{ij}}$.

e. *Yield of data*

In an effort to maximize yield of wind vectors, a number of investigations have been made by us of points of detail in analysis. We discuss here only two of these.

1) SELECTION OF $\tau_{m_{ij}}$

The correlograms of Fig. 5 are examples of unpromising data from which acceptable vectors are to be obtained if possible. The question is whether any combination of the lag times $\tau_{m_{ij}}$ for the various maxima in the three data sequences will yield an acceptable vector. The NTD may be utilized for such an investigation. It is possible to combine the various lag times $\tau_{m_{ij}}$ in a systematic manner, and then to select that combination which yields the lowest NTD. This approach has not proved profitable in routine processing. Utilization of NTD has proved worthwhile when there are not more than two maxima in any one cross-correlogram, and a single maximum in at least one of the three. Two criteria are applied. The first is that, when two maxima, a and b, appear in one cross-correlogram, the ratio ρ_a/ρ_b must be more than a specified value, e.g., 1.8 for Saskatoon data. The second criterion is the value of NTD which may not be exceeded. If two of the three correlograms each have two maxima, a value of NTD<0.1 must be obtained from the larger peaks in each. If only one correlogram has two maxima, a value of NTD<0.2 is required, while if all show single maxima NTD<0.3 is acceptable. (The arrows in Fig. 5 show those peaks which have been identified using the above procedure.)

2) SELECTION OF MAXIMUM LAG

The existence of multiple maxima in correlograms is at variance with the basic postulates of correlation analysis. The reason for the occurrence of such maxima can only be hypothesized, and approaches to the problem reflect this situation. Thus, dispersion analysis has been investigated by some workers (Jones and Maude, 1972). Meek (1978) has devised a criterion for maximum lag, based on the assumption that some of the maxima in the correlograms can be treated by the method of FCA and that the remainder can be ignored in consequence. The basis of his method is that due to lapse of time on scale c and to spatial change on scales a and b, at velocity **V**, the correlograms will necessarily decay to below significance, e.g., to $<e^{-2}$, beyond some maximum lag. Using the minimum cross-correlation coefficient at zero lag, and any chosen value of the autocorrelation, the value of maximum lag at the significance level can be simply evaluated. By limiting the lag interval to this value, substantial savings in computation result.

3. Data processing

If wind observations are to be made continuously, it is almost essential that the receiving equipment be linked directly to a computer, since the alternative is the recording of large quantities of raw data. While such a linkage has been possible for some time, it introduced unwelcome complexities. Progress in minicomputer and microcomputer development has now led to easier application. In particular, microprocessors can be readily interfaced with winds receiving equipment. We outline a microprocessor system (Fig. 11) developed and utilized by us, which performs all logical operations and also reduces raw data to final winds vectors. It thus sub-

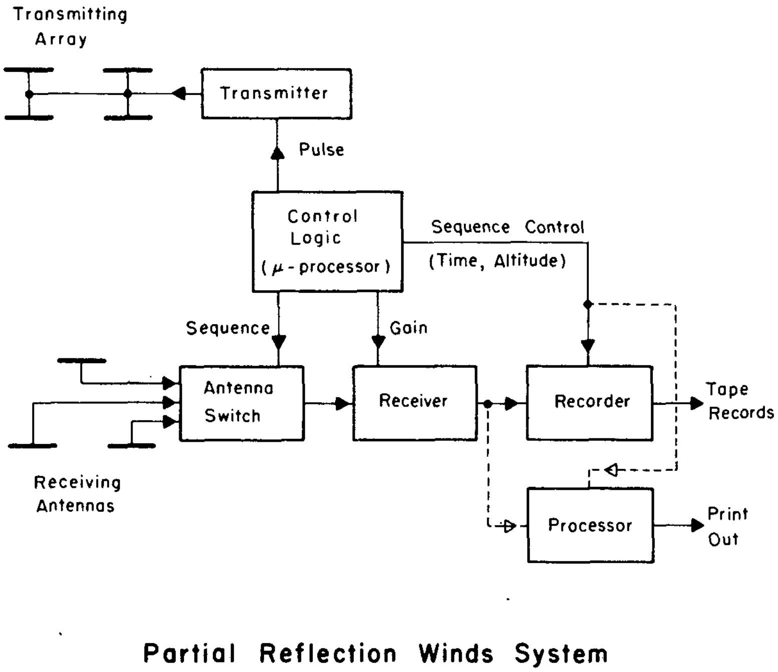

FIG. 11. Block diagram of winds system, based on micro-processor control and data analysis.

stantially reduces the total effort of data processing, e.g., in respect to the staff required.

Two commercially available microprocessors are used, one as a satellite of the other. The main processor, of 32 kilobytes capacity, is programmed in machine language to control the logical functions of the system. It also performs the first steps in binary correlation. The second, an 8K Basic machine, is assigned to analysis using the SGCA method. The following are among the functions of the first processor:

1) Control of transmitter pulsing, antenna switching, change of receiver gain during "echo return" period and final tape recording.

2) Assembly of data sequences, for each altitude increment and each antenna.

3) Conversion of data sequences in the second function to binary by reference to their mean.

4) Establishment of receiver gain for groups of altitude increments, using mean values from immediately previous data.

5) Correlation of binary sequences from the antennas. (This part of the correlation process comprises a count of the number of bit matches, from -15 to $+16$ lags for cross-correlations, and from 0 to $+15$ lags for auto-correlations.)

The second processor accepts the output of 5) above and evaluates correlation coefficients as a function of lag. These are edited, e.g., for noise, and a search is performed for appropriate maxima. A least-squares fit to time delays, weighted by value $\rho^2_{\max}$, is used to establish the condition that NTD$=0$, and the SGCA is then utilized to determine the wind vectors. These are returned to the first processor for output on magnetic tape or as desired. The system produces wind values and related parameters every 5 min for a maximum of 32 altitude increments, and operates continuously. (A comparison with an earlier winds system, which recorded raw data sequences on magnetic tape for later processing elsewhere, may be of interest. A standard 1200 ft reel of tape, which previously sufficed for less than two days, will now serve for two months if required.)

4. Validity of winds data

Previous sections have dealt with measures of internal consistency of data, e.g., through comparisons of data adjacent in altitude or time. However, it is desirable that the results of "drift" measurements be compared with those from other techniques, particularly since the physical processes which result in the formation of any diffraction pattern are nearly always unknown.

Experimental comparisons are necessarily limited by the differences in the time and space scales on which data are obtained by the individual techniques. In respect to the radiowave drifts technique, the area from which reflections are received is usually no more than a few tens of kilometers in diameter. A primary requirement of an experiment for comparing partial reflection techniques with other winds techniques, therefore, is that it be conducted using a common volume of this order of dimension. Few experiments to date have met this criterion. Those which do so most closely have been carried out by Vincent *et al.* (1977). The comparison technique was either rocket dropsonde or falling sphere. The spatial separation between the regions of measurement varied from less than 20 km to more than 100 km. The time period of observation was essentially that of the falling sensor. Vincent *et al.* (1977) were able to investigate winds in the 60–90 km altitude region, and found a substantial measure of agreement between the two techniques. They concluded that the partial reflection drifts method appears to be capable of measuring neutral wind velocities in the mesosphere with good height and time resolution.

Since experimental comparisons which fulfill requirements for a common volume are not available for altitudes of ~90–120 km, it is necessary to exercise judgment as to the validity of results in this region. We can attempt here only to summarize our experience at one midlatitude location (52°N, 106°W) where the raw data are less amenable to treatment than in some other locations. Between 1969 and 1973, a body of winds data was obtained from soundings, initially three within 30 min around noon, and later, up to 12 in 1 h around noon (Gregory and Manson, 1975a). Velocities were "apparent," not "true." Median profiles were identified with the prevailing wind for the hour, and were assembled into weighted means for the week, and finally, grouped by months. Due to limited observations, tidal components were not removed. Despite their obvious deficiencies, these data proved to be compatible with existing models of global winds (Groves, 1969), as interpreted for our location; and further, suggested reasonable modifications to such models. Planetary wave action associated with stratospheric warmings was traceable in a consistent manner to above 100 km (Gregory and Manson, 1975b).

Improvements in techniques of observation and analysis now permit continuous recording. (At altitudes below ~80 km, data are usually not available during night hours.) Data are processed to yield "true" velocities and are analyzed for tidal motions (up to 24 h period), gravity waves (1.5–10 hours), winds (as a daily mean) and planetary waves (>1.5 days). We have examined a further body of data with respect to its general characteristics above and below 90 km, on the assumption that the verification of Vincent *et al.*, (1977) will apply at our location. There is an essential continuity of behavior of mean wind, up to the limit of observation (~115 km). Gravity waves and tides, as represented by means for appropriate periods, also show characteristic changes with altitude, some expected and some unexpected (Stening *et al.*, 1978). These changes do not in any way suggest that mean values of velocities are invalid in the upper altitude range, i.e., above 90 km.

It remains an acceptable comment that no guarantee can be given as to the validity of a single wind determination at any altitude by this technique. However, a single wind determination has little significance for modern dynamical studies of the atmosphere, present requirements being for spatial and temporal means of the various motions. We conclude that despite lack of knowledge of the partial reflection processes involved, the drifts technique does yield useable wind data throughout the mesosphere and into the lower thermosphere.

Acknowledgments. The work described herein is supported by the National Research Council of Canada, the Atmospheric Environment Service of Canada, and the University of Saskatchewan through the Institute of Space and Atmospheric Studies. Computational facilities have been made available by the National Center for Atmospheric Research, which is sponsored by the National Science Foundation.

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* Unpublished material available from the authors.