A GENERAL COMPUTER PROGRAMME ON THE ANALYSIS OF MOVING PATTERNS IN GEOPHYSICS

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Abstract

A general computer programme to study the moving diffraction patterns in geophysics viz. the patterns caused by (i) the reflection/partial reflection/scattering of radio waves from ionized layers/sharp gradients in ionization/irregularities/ atmospheric turbulence, (ii) scintillations due to ionospheric irregularities and (iii) scintillations due to irregularities in solar wind. The highlights of the programme are (1) it provides all the well known methods viz. the time delay method, the full correlation method and the cross-spectral method in a single programme and (2) the inputs are the three spaced receiver amplitude data series or the auto and cross correlation functions and the coordinates of the three receivers.

Introduction

Radio remote probing of ionosphere is more than fifty years in existence. A simple method of studying the dynamics of ionized atmosphere (ionosphere) was reported by Mitra (1949) which is referred to as the 'spaced receiver method'. In this experiment amplitude fading of the radio echoes returned from ionosphere are recorded simultaneously at three closeby receivers (non-collinear) and from the time delays observed in similar features one derives the velocity. More rigorous mathematical treatment of the derivation of velocity was attempted by Briggs et al. (1950) which is now the basis of computations used elsewhere and is known as the full correlation analysis. Jones and Maude (1965) preferred to Fourier analyse the fading records and determine velocities at different fading frequencies. These are the three basic approaches in the analysis of the moving diffraction patterns at ground.

Spaced receiver method is being used widely these days as the method is extended to mesosphere employing the partial reflection echoes, to satellite scintillation records in determining the velocities in F-region as well as to the interplanetary scintillation records (IPS) in determining solar wind velocities. A recent development has been its role in meteorology by studying the fading of vhf echoes from lower atmosphere caused due to atmospheric turbulence (Rottger et al. 1978, Rottger and Vincent 1978).

With the availability of large computers the approach of analysing spaced fading/scintillation records has changed drastically. The manual similar fade method of Mitra has become obsolete with the digital recording systems in use. A general computer programme of the full correlation analysis was developed by the Radio Physics Group of the University of Adelaide. It has been modified to include the power spectrum analysis of Jones and Maude (1965) as well as the filtering of data to perform correlation analysis following Sprenger and Schminder (1969). The aim is to present all the varieties of analyses accomplished by a single programme. The basic theories of the various methods of data reduction are described in Section 1. This is followed by an outline of the computer programme and the description of various subroutines in Section 2. A few hints for users are also described in Section 2. Finally the programme is attached in Section 3.

Section 1

Methods of Data Reduction

The fluctuations recorded in the closely spaced receiver technique have similarities but with displacement in time relative to each other. The similarities are regarded as an evidence of the passage of ionospheric irregularities across each antenna in turn. The delays are used to yield drift velocities and other characteristics of the ground diffraction pattern. There are three different approaches of analysing records. They are: (a) the time delay method, (2) the correlation method, and

(3) the cross-spectral method.

1.1 Time Delay Method

Mitra (1949) gave a simple method of estimating the drifts of ionospheric irregularities which consists in comparing the similar features of three closely spaced fading records. He made the following assumptions:-

(i) Ground diffraction pattern does not vary with time at any point and moves with a uniform velocity V during the course of an observation.

(ii) The diffraction pattern is isometric, i.e. its average characteristics remain same in all the directions.

(iii) The diffraction pattern on the ground does not change in shape as it moves.

The diffraction pattern on the ground can be represented by means of contours of constant amplitude R_1, R_2, R_3 etc., moving with velocity V in a direction which makes an angle θ with X-axis (Fig.1). Let N, C and E be the three receiving sites. As different contours pass over these sites, the signal strength of these sites will fluctuate with time. A maximum of signal will be recorded at any aerial when contour passes over the receiver tangentially. The locus of the tangential points along the direction of drift is called the line of maximum aplitude and under the assumptions made earlier that when diffraction pattern is isometric and fairly large as compared to the location sites of the receivers the line

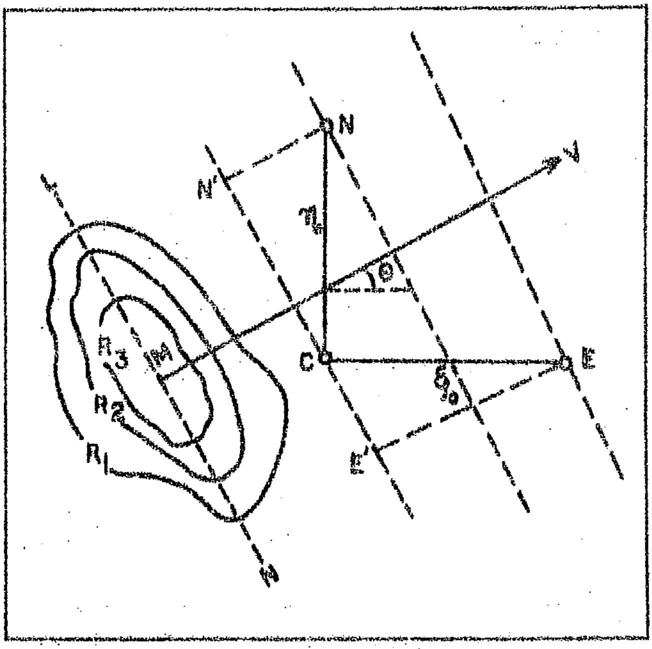

Fig.1 Sites of receivers (N, C, E) and contours of constant amplitude.

of maxima will be a straight line perpendicular to the direction of movement. When considering the maxima of a fading pattern, one can replace the contours of constant amplitude by the line of maximum amplitude and following relation can be written from the simple trigonometrical considerations:-

Let T_x and T_y be the time lags between the similar fades of aerials C and E and the aerials C and N respectively,

$$T_x = \frac{\xi_o \cos \theta}{V} \qquad (1)$$

$$T_y = \frac{\eta_o \sin \theta}{V} \qquad (2)$$

when $\xi_o = \eta_o = d$

$$\text{then } V = \frac{d}{\left(T_x^2 + T_y^2\right)^{1/2}} \qquad (3)$$

$$\text{and } \theta = \tan^{-1} (T_y/T_x) \qquad (4)$$

Drift components along X and Y directions are given by:

$$V_x = V \cos \theta \qquad (5)$$

$$V_y = V \sin \theta \qquad (6)$$

The speed V thus obtained is the speed with which the ground diffraction pattern moves on the ground. This is divided by 2 to give the movement of the irregularities in the ionosphere on the assumption of point source and this has been experimentally verified (Felgate 1970). The values of drift speed and direction thus obtained do not contain correction due to change in the irregularities itself and are therefore termed as apparent drift velocities and denoted by V'. Drift direction is measured with respect to north and is denoted by ϕ.

Equations (3) and (4) are valid only for isosceles right angled triangle. Equations for a general shape of a triangle are given below. Suppose distance between aerials C and E is d_1 and between aerials C and N is d_2 and the angle between CE and CN is γ. Let T_x and T_y be the time delays as explained above and direction of drift speed makes an angle θ with CE.

$$\text{Then } V = \frac{d_1 \sin\gamma}{\left\{\frac{d_1^2}{d_2^2} T_y^2 - 2T_x T_y \cos\gamma + T_x^2\right\}^{\frac{1}{2}}} \qquad (7)$$

$$\text{and } \theta = \cos^{-1}\left(\frac{T_x V}{d_1}\right) \qquad (8)$$

A more precise method to determine drift velocity would be to utilise the time delays between all the three pairs of records by means of least square method. This is the procedure followed in the present computer programme.

Sprenger and Schminder (1969) suggested another variant of the method where velocities are derived from individual time delays and averaged. This is known as Variant-2 method, whereas the original Mitra's method is known as Variant-1.

1.2 Full Correlation Method of Analysing Spaced Fading Records

In the correlation method of analysis, auto and cross-correlation coefficients of amplitude of pairs of records are used to deduce the apparent drift speed, the true drift speed, the direction of drift and the size of the ground diffraction pattern.

(a) Method of Briggs, Phillips and Shinn:- Briggs et al. (1950) developed a method for separating the steady and random components of the drift. The term 'random drift' means the rate at which the pattern changes its shape. This method assumed that:

(i) the diffraction pattern is isotropic,

(ii) the space and time variations are identical, and

(iii) drift speed remains the same during the course of the record.

The auto and cross-correlation curves for the fading records are shown in Fig.2. Briggs et al. (1950) have defined four velocity parameters to describe the movement of ground diffraction pattern in terms of correlation coefficients.

(i) Fading velocity V_c':- This is the velocity with which the diffraction pattern would move in the absence of random changes to produce total observed fading. In terms of the correlation function, it is the ratio of space shift to time shift that would produce the same change in correlation.

If this time shift is T_1 for the observation made at distance ξ_{r1} apart we have:

$$\rho(\xi_{r1}, 0) = \rho(0, T_1)$$

$$\text{and } V'_c = \frac{\xi_1}{T_1} \qquad (1)$$

where ρ = correlation function. V'_c depends on both the true drift velocity on the **random** changes of the pattern for an isotropic pattern it is independent of direction but will vary with direction if the pattern is anisotropic.

(ii) True drift velocity V:- V is the velocity of an observer who experiences slowest fading in the received signal. This is called steady drift speed as whatever slow fading is now experienced is on account of the random changes in the diffraction pattern.

If distance ξ_{r1} is moved in the time τ_1 by the observer to experience the least fading then:

$$V = \xi_{r1}/\tau_1 \qquad (2)$$

(iii) Characteristic velocity V_c:- This represents a measure of the random change in pattern. V_c is the value of V'_c found by an observer moving with velocity V. By definition V_c is the ratio of space shift to time shift needed to produce same change in R,

$$\text{i.e. } V_c = \xi_0/\tau_1 \qquad (3)$$

where $\rho(\xi_0, 0) = \rho(\ _0, \tau_1)$.

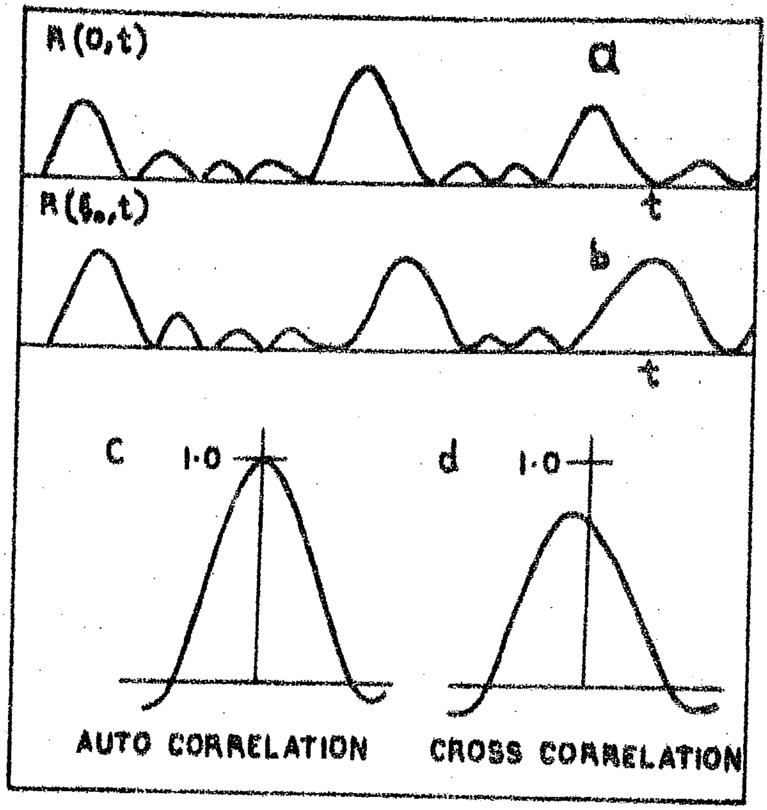

Fig.2 (a) and (b) show amplitude records at two fixed points say x=0 and x= 0· (c) shows auto-correlogram corresponding to (0,). (d) shows cross-correlogram.

(iv) Apparent drift velocity V':- This is the velocity of the diffraction pattern experienced by a fixed receiver on the whole, without taking into account any random changes in the pattern. If τ_0 be the time delay for the cross-correlation peak between two receivers at $x = 0$ and $x = \xi_0$.

Then $V' = \xi_0 / \tau_0$ (4)

Briggs et al. (1950) have shown that for an isotropic diffraction pattern:

$$V_c'^2 = V_c^2 + V^2 \quad (5)$$

$$V_c'^2 \simeq VV' \quad (6)$$

$$\text{Hence } VV' = V_c^2 + V^2 \quad (7)$$

$$\text{or } V' = V + (V_c^2/V) \quad (8)$$

$$= V\left[1+(V_c/V)^2\right] \quad (9)$$

Thus $V' \geqslant V$ and the contribution due to random variation within the pattern is equivalent to (V_c^2/V), which has a direction same as that of V, as V_c^2 has no particular direction.

(b) Extension of BPS method to Anisotropic Diffraction Pattern

Briggs et al. (1950) assumed that diffraction pattern on the ground is isometric, so that its statistical properties show a circular symmetry. But in practice diffraction pattern on the ground is statistically anistropic, so that contours of constant correlation are not circular.

When the pattern has a finite structure in all the direction, the situation is not so serious but error may still arise if it is not completely isometric. The pattern near the magnetic equator is highly elongated and special care must be taken while deducing the various parameters. Phillips and Spencer (1955) extended the work of Briggs et al. (1950) to anisotropic diffraction pattern.

The contours of constant amplitude for an anisometric pattern can be assumed to be concentric ellipses for simplicity and will be concentric circles in the case of an isometric pattern. This type of pattern can be produced from statistically isometric pattern by stretching it in one direction. Distortion of this type may be represented by a characteristic ellipse similar to the contours of constant correlation. The complete information regarding the anistropy of the pattern can therefore be described in terms of the axial ratio and orientation of the characteristic ellipse.

Determination of characteristic ellipse:- From the fading records at three points situated at the corners of isoceles right angled triangle OBA (Fig.3 bottom) where OA = OB = a and angle OBA = 90°, one can obtain auto-correlation functions (0, 0, τ) for a number of values of τ . Plot of this function against τ will give the time correlogram. Next, cross-correlogram is determined between the fading records of the aerials O and A, A and B and O and B. These are denoted by a', b' and c' in Fig.3 (top).

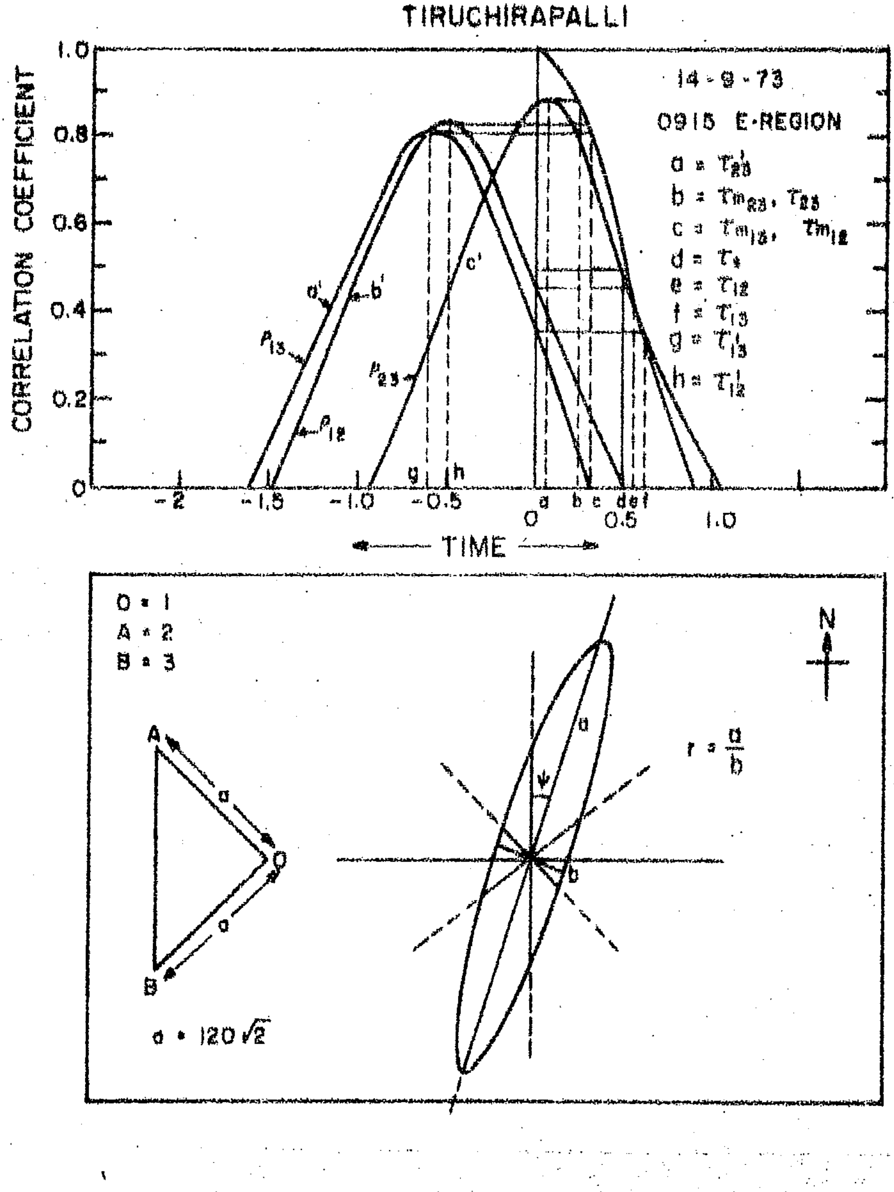

Fig.3 (Top): The auto and cross-correlograms for the fading records obtained on 14-9-73. (Bottom): Geometry of the antennae O, A and B and characteristic ellipse and axial ratio and orientation of the ellipse.

The values $\rho(a, o, o)$, $\rho(o, a, o)$ and $\rho(a, -a, o)$ of the cross-correlation coefficients at time t = 0 are converted to the equivalent time shifts τ_1, τ_2 and τ_3 respectively, on the auto-correlogram for the same values of ρ. Thus, by the definition of fading velocity V_c' as given by Briggs et al. (1950):

$$(V_c')_{OA} = a/\tau_1 = u$$

$$(V_c')_{OB} = a/\tau_2 = v \qquad (10)$$

$$\text{and } (V_c')_{AB} = a\sqrt{2}/\tau_3 = w$$

which are the fading velocities in three different directions defined by the spaced points where fadings are observed. The simplest example of spacings in these directions which have a fixed correlation is given by putting $\tau = 1$ which gives correlation $\rho(0, 0, 1)$, the spacings are then equal to V_c'.

Thus polar plot of V_c' would give rise to an ellipse of constant correlation conferred at 0. The known values of V_c' give the length of semi-diameter of the ellipse for the three directions. This is sufficient to determine the axial ratio r and orientation ψ of minor or major axis. The method consists in marking the values of u, v and w on the axis X = 0, Y = 0 and X = -Y on both positive and negative sides. A smooth ellipse is drawn through these six points using the fact that the diameter of ellipse bisecting the chord, bisects all chords parallel to it (see Fig.3 bottom). The values of semi-major and semi-minor axis are read to get the axial ratio 'r' and the orientation angle ψ with respect to particular axis is also noted.

Mathematical relations for r and ψ :- Phillips and Spencer (1955) have shown that the axial ratio r and orientation angle ψ of the major axis of the characteristic ellipse by the following relations:-

$$r^2 = \frac{R + (P^2+Q^2)^{\frac{1}{2}}}{R - (P^2+Q^2)^{\frac{1}{2}}} \tag{11}$$

$$\text{and } \psi = \tfrac{1}{2} \tan^{-1} (P/Q) \tag{12}$$

$$\text{where } P = \tau_1^2 + \tau_2^2 - \tau_3^2$$

$$Q = \tau_1^2 - \tau_2^2$$

$$R = \tau_1^2 + \tau_2^2$$

These relations hold for an isosceles right angled triangle of receivers and can be modified for any other geometry of the receiving aerials.

Phillips and Spencer (1955) extended the method of Briggs et al. (1950) to anisometric case by contracting the space coordinates along the direction of elongation by the axial ratio r and then applying the correlations to the derived direction and speed by factors which are function of r and ψ as given by the following equations:

$$\tan(\phi-\phi_a) = \frac{(r^2-1)\tan(\phi_a-\psi)}{1 + r^2 \tan^2(\phi_a-\psi)} \tag{13}$$

$$\text{and } V_a = V' \cos(\phi-\phi_a) \tag{14}$$

To calculate the true drift speed one has to find V'_c along the direction of the drift given by the equation:

$$(V'_c)_v = \frac{1+(r^2-1)\cos^2\Psi}{1+(r^2-1)\cos^2(\phi-\Psi)} (V'_a)^2 \qquad (15)$$

and $V = (V'_c)^2_v / V'$ (16)

(c) Further Modification by Fooks to Phillips and Spencer Method

Fooks (1965) has suggested two modifications to use the correlation method of analysis.

(i) Mean auto-correlation function from the three fading records should be used to reduce statistical deviations.

(ii) To use an alternative method of finding times τ_{12}, τ_{21} and τ_{23} in which only the top portion of cross-correlation is used and hence values are less affected by statistical variations. This is given by:

$$\tau^2_{12} = (\tau')^2_{12} + (\tau_m)^2_{12} \qquad (17)$$

where τ'_{12} is the displacement of the maximum of the cross-correlogram and τ_m is the corresponding time shift on mean auto-correlation curve (Fig.3 top). In a similar manner τ_{13} and τ_{23} can be calculated. This equation was derived by Briggs et al. (1950) for isometric pattern. Kelleher (1965) has shown that this relation is valid for anisotropic case also. The advantages of Fooks's modification are:

(1) It uses the points at higher level on the correlation

functions and hence results are less affected by statistical deviation, and

(2) Using the equation (17) V' always comes higher than V and thus removes the occurrence of negative V_c^2.

Average size of irregularities in the pattern:- Fooks (1965) has given a method to derive the values of semi-major and minor axes 'a' and 'b' from V_c' values. The ellipse has the dimension of velocity and can be converted to distances to give the average size and shape of the irregularities in the pattern. This is achieved by multiplying the V_c' by half correlations time (i.e. the value of time displacement required to give = 0.5 on the mean auto-correlograms).

1.3 Cross-spectral Method

Jones and Maude (1968) developed a method to find the variation of velocity with fading frequency. A fading curve may be thought of as the sum of a number of sinusoids of different amplitude and different phases relative to one another. A fourier analysis on such a curve would resolve it into the sine functions of which it was composed, giving the amplitude and phase of each component present. Thus by performing such an analysis on the curves obtained from three receivers, one could find the amplitudes and relative phases of the various Fourier components, present in all three records. These phase shifts could then be converted into time shifts and using the aerial separations, the velocity and direction of motion of the individual Fourier components can be found out. If components with different frequencies are moving under the influence of steady wind, and there is no random motion, then the diffraction pattern would move steadily over the ground and all Fourier components derived from Fourier analysis on three fading records would have the same speed and fading directions.

Random variations of signal strength or noise might also occur or be picked up by the receiving equipment and it is the limitation of simple Fourier analysis as described above that it could not distinguish between the required signal and the unwanted noise. There has, however, been considerable development in methods of Fourier analysis which avoid this difficulty.

Modified Fourier Analysis

The ionosphere may be compared to an amplifier of unit amplification, one fading curve being thought of as an input and second as an output. If the amplifier has a linear characteristic the whole operation is known if the phase change and amplification are known for all frequencies. For example, if the input is:

$$x(t) = a \sin (2\pi ft + \phi) \qquad (1)$$

and output will be $y(t) = aG(f) \sin (2\pi ft + \phi + P(f))$ (2)

and the operation is defined by the functions G and P which may be written as:

$$H(f) = G(f)e^{ip(f)} \qquad (e)$$

If the relationship between y and x is perturbed by a disturbance 'n', the measured response must then be subjected to some sort of elaborate filtering procedure in order to find estimates of gain and phase shift. Goodman (1957) examined such a system on the assumption that x, y and n were stationary Gaussian noises, with x and n statistically uncorrelated with each other. His analysis showed that from the input spectrum $S_x(f)$ and the input-output cross-spectrum $S_{xy}(f)$ with suitable smoothing, one could recover the frequency response function in the form:

$$H(f) = S_{xy}(f)/S_x(f) \qquad (4)$$

as though there were no disturbance n.

Following Tukey (1949), Goodman established methods of estimating spectra S_x, S_y and S_{xy} from finite sampled records of x and y and of estimating the frequency response function H.

In the case of ionospheric drift, out of three fading curves, one from aerial 1 is taken as input and that of aerial 2 as output and response function of the ionosphere is found for each Fourier component present in the fading curves, i.e. phase difference P_{12} between two curves is obtained. Similarly P_{13} and P_{23} can be obtained.

Methods of Calculation

Given the finite records (amplitude) x(t), y(t) and z(t) for the three fading records obtained at closely spaced receivers of the D_1 method, the cross spectral analysis involves following six steps:-

(1) Calculation of covariance functions

(2) Correction of covariance functions for means and trends

(3) Calculation of 'raw' spectral estimates

(4) Smoothing to give the final spectral estimates

(5) Computation of estimated gain and phase of frequency response function

(6) Calculation of velocity and direction from the phase differences.

The three fading records are read at particular sampling interval of time t = h say, so that the corresponding "Nyquist frequency" is $f_o = h/2$. Goodman et al. (1961) have shown that t should not be chosen so small that the whole spectral weight is crowded down to the bottom of one or two points. Further to minimise distortion due to aliasing, h must be small enough to ensure that the continuous data have no appreciable power above f_0. A value of about 0.25 secs was found convenient for the records taken at Tiruchirapalli (4.8°N).

The cross-spectral estimates at a given frequency 'f' are given by:

$$S_{jk}(f) = C_{jk}(f) - iQ_{jk}(f) \qquad (5)$$

and the phase $P(f) = -Q_{jk}(f) / C_{jk}(f)$ (6)

Phase difference can be converted into time shift as

$$\tau_{jk} = P_{jk} / 2\pi f \qquad (7)$$

Any pair of time shifts for one frequency may be converted into a velocity and direction in the same way that one converts the time shifts of the simple Mitra method (1949).

In a plane wave, wave-numbers add vectorially, so that the wave number along the line between aerials J and K separated by a distance x_{jk} will be $K_{jk} = P_{jk}/x_{jk}$ and the vector addition of two such values will give the vector wave number K in the direction of the motion which has a velocity $v = 2\pi f/K$. If x_{12} and x_{13} are at right angles to each other this simplifies to:

$$= 2\pi f / \left[\left(\frac{P_{12}}{x_{12}}\right)^2 + \left(\frac{P_{13}}{x_{13}}\right)^2 \right]^{\frac{1}{2}} \qquad (8)$$

and the angle ϕ with respect to x_{12} given by:

$$\phi = \tan^{-1} \left(\frac{P_{12}}{x_{12}} \; \frac{x_{13}}{P_{13}} \right) \qquad (9)$$

V should be divided by a factor two in order to get the velocity in the ionosphere. An example of the results obtained by this method as applied to the fading records at Tiruchirapalli are shown in Fig.4.

1.4 Full Correlation Method with Filtering the Fading Records

Sprenger and Schminder (1969) suggested that the similar-fade method is necessarily confined preferably to the short-period

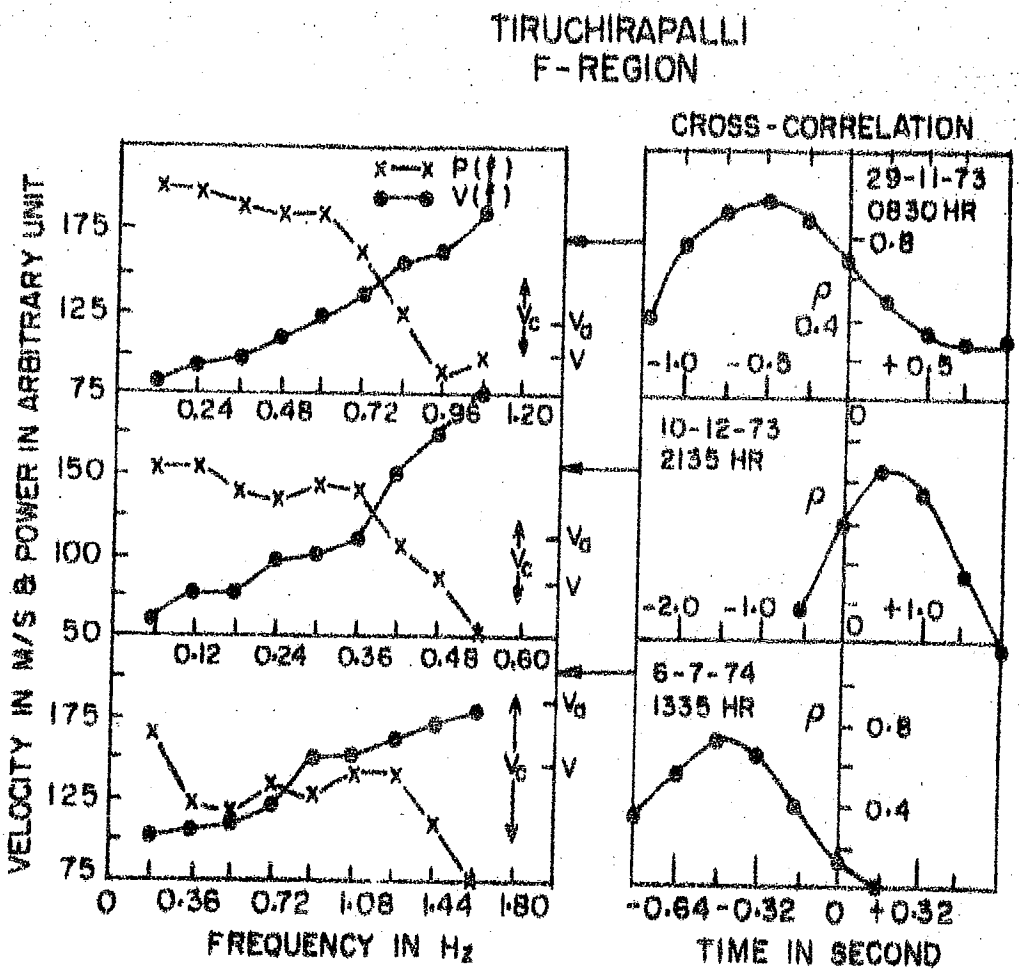

Fig.4 Power and velocity plotted against fading frequency for a few F-region examples showing increase of velocity with fading frequency. Cross-correlation functions along E-W are also plotted.

components of the fading and that, therefore, its result may not be a priori comparable with the results of correlation analysis which includes the long period fading component as well. Further, they mentioned that there are close relationships between similar fade and correlation analysis results, if correlation analysis is performed after submitting the original fading record to a mathematical filter which suppresses the long-period fading components.

In order to study the behaviour of these short-period fading components separately Sprenger and Schminder (1969) suppressed the long period fading components before subjecting the records to correlation analysis. This has been achieved by transforming the original fading functions X(t), Y(t) and Z(t) according to

$$x(t) = X(t) - \frac{1}{\tau_f} \int_{t-\tau_f/2}^{t+\tau_f/2} X(t)\, dt$$

and analogously for y(t) and z(t).

The deviation from a running mean is calculated over a given time interval T_f which is centred on the time t of the respective amplitude value. The new functions x(t), y(t) and z(t) are then used for the computation of the correlation function. This procedure acts as a high pass filter with a cut-off frequency $F_f = 1/\tau_f$ and suppresses fading components with frequencies F F_f.

Sprenger and Schminder (1969) compared cross-correlograms for these filtered series of amplitudes. It was found that the width of the correlation function decrease systematically with the increasing cut-off frequency but the time shifts of the maxima of cross-correlation function remained nearly unchanged i.e. the apparent drift speed V_a did not change with fading frequency. They also calculated the steady drift speed V and the characteristic drift speed V_c, using relations given by Briggs et al. (1950). The steady drift V showed a distinct increase with the increasing frequency of the fading component whereas the random drift V_c showed only a slight decrease. Sprenger and Schminder (1969) questioned the credibility of the usual correlation analysis.

Chandra and Briggs (1978) applied various low pass and high pass filters to partial reflection echoes and reported true velocity increasing with use of high pass filters and decreasing with use of low pass filters. It was also shown by them mathematically that the filtering would change the true drift velocity and this would not necessarily be taken as an evidence of dispersion. However, a change in the apparent drift speed when the records are subjected to filtering would imply a real dispersion in the data.

Example of the modified auto and cross-correlation functions with running mean type low pass and high pass filters alongwith the original auto and cross-correlation functions for a sample fading records at Tiruchirapalli is shown in Fig.5.

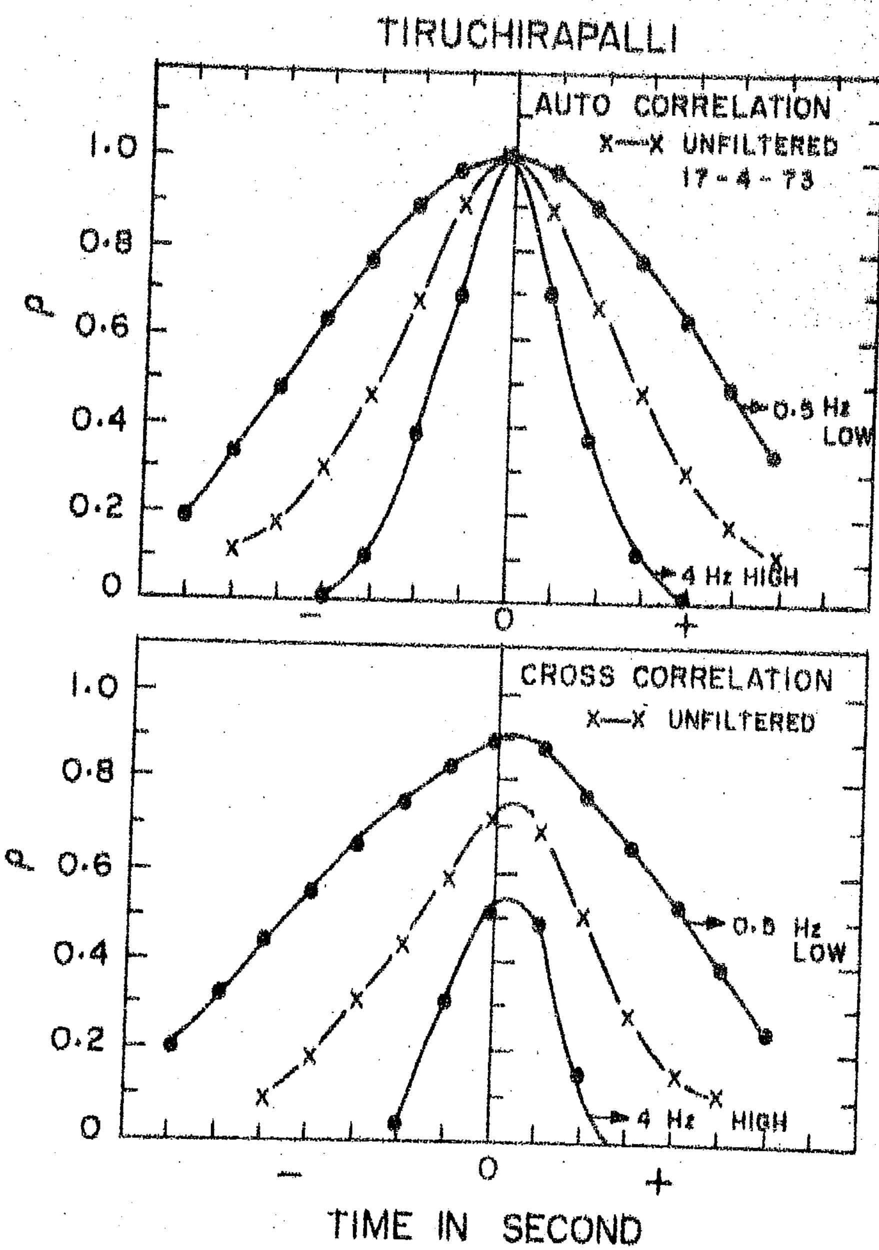

Fig.5 Typical auto and cross correlations without filter as well as after filtering through a high pass filter with cut-off frequency at 4 Hz and low pass filter with cut-off frequency at 0.5 Hz.

Section 2

Description of the Computer Programme

2.1 Outline of the Computer Programme

(a) Full Correlation Analysis

1. Compute difference vectors from the receiver coordinates.
2. Calculate auto and cross correlation functions at different time lags from the amplitude series (calling subroutine corlat).
3. Fit quadratic near the peak of the cross-correlation functions and determine the maximum cross-correlation from the zero derivative as well as the time lag for maximum cross correlation.
4. Find the time lag in auto-correlation function for equivalent value of the correlation (calling subroutine TauCF).
5. From these time shifts determine the characteristic ellipse representing the average size of the ground diffraction pattern (subroutine Mats is used in simplifying the calculations). Methods of Fooks is used.
6. From the three pairs of time shifts for maximum cross correlation and the difference vectors compute the apparent drift direction and speed (find the three vectors and the perpendicular to them from the origin gives the velocity vector).

2.2 Description of Subroutines

1. Subroutine Meanet (A, M, N, B, C)

   A = amplitude data of different receiver channels

   M = number of the receiver channels

   N = number of data samples

   B = mean of different amplitude series

   C = variance of different amplitude series

This subroutine is called to compute mean and the variance of the different amplitude series so that records where signal to noise ratio is very low or where the signal is in saturation are automatically removed.

2. Subroutine Corlat (J_1, J_2, J_3, N SHIFT, I FLAG)

   J_1, J_2, J_3 are used to distinguish different auto and cross correlation functions. For example $J_1 = J_2 = J_3$ means auto-correlation function. J_1=1 and J_2=2 would mean the cross-correlation function between the data of receivers 1 and 2.

   N Shift = Lags required in calculating correlation functions.

   I FLAG equal to 1 means error (due to the denominator being zero or imaginary).

3. Subroutine TAUCF (RHOMAX, TAU, NOKAY)

   RHOMAX = Certain value of correlation function

   Tau = time lag for equivalent correlation value in the auto-correlation function

NOKAY = 1 Programme proceeds

NOKAY = 2 Prints error (If the desired value of the correlation function is less than the mean autocorrelation function at maximum time lag).

This subroutine is called to estimate time lag in the autocorrelation function for certain value of correlation. For example the time lag for half correlation and the time lag for maximum cross-correlation functions are needed in the analysis.

4. Subroutine MATS (S, A, NSPEC, MISS)

S = Input in the form of quantities which are function of the receiver geometry and the time lags

A = 3 coefficients evaluated

NSPEC = 3

MISS = 1 error (due to very odd values of coefficients A)

MISS = -1 proceed further for calculations.

This subroutine is called to simplify the calculations of the parameters of the ellipse representing the average size of the ground diffraction pattern following the method of Phillips and Spencer (1955) and Fooks (1965).

5. Subroutine ARGUS (Z, B1, B2, FM, ERR, LL, C1, C2, E1, E2)

Z = three directions defining the three receiver separations

B1 = velocity computed from the approximate method

B2 = direction computed from the approximate method

FM = three values (receiver separations divided by the time shift for maximum correlation along that direction)

ERR = three quantities (receiver separation divided by the square of the time shift for maximum correlation along that direction)

LL = number of iterations

C1 = velocity from the least square fit method

C2 = direction from the least square fit method

E1 = error in velocity determination

E2 = error in direction determination

This subroutine is called for more accurate determination of the velocity on the basis of least square fit method, starting from the simple velocity. Maximum of eight iterations or a lower limit in the least square are the criterion. It also computes the errors in the velocity determination.

6. Subroutine Disper (DTHETA, CPS, CMF, NSHICF, CX, CY, DELTAT, TITLE1, TITLE2, RX, NSHIFA, TAUM, CRM, DR, VD, PHS, PERIOD, YV, YD)

DTHETA = three directions of receiver separations

CPF = three cross-correlations in positive time lags

CRM = three cross correlations in negative time lags

NSHIFC = lags in cross correlation functions

CX = three receiver separation components along x direction.

CY = three receiver separation components along y direction.

T = time interval between data samples

TITLE1 for record identification
TITLE2

RX = mean autocorrelation function

NSHIFA = lags in autocorrelation function

TAUM = three time shifts for maximum cross-correlation functions

CRM = the maximum values of the three correlation functions

DR = the three receiver separations

VD = velocity

PHS = direction

PERIOD = wave period

YV = velocity for each Fourier component

YD = direction for each Fourier component

This subroutine is called to estimate the cross-spectra and from the phase lags for different Fourier frequencies compute the velocity.

7. Subroutine MOVAVE (X, RM, N, L, KI)

X = input data

RM = output (filtered data)

N = number of data points

L = filter width in terms of the number of data values

KI = 1, low pass filter

= 2, high pass filter

= 3, high pass in terms of percentage

This subroutine is called to filter the amplitude series. This is a simple running mean type filter and can be used for low

2.3 Some Useful Hints to Users

1. Full-correlation Analysis

Amplitude data or the correlation functions can be used as input depending upon the suitability. For experimenters where the signal to noise ratio is likely to be low such as partial reflections below 70 km or IPS records, hf noise may cause spikes at the origin of the auto-correlation functions and lower the cross-correlation functions. It is advised to normalise such correlation functions. One can smooth the autocorrelation function and the value of zero time be raised to one. Same normalization factors will apply for cross-correlation functions also.

The optimization of the sample record and the sampling interval would change from experiment to experiment. Chandra et al. (1972) have shown a minimum length of about 12-15 fades and 4-5 samples per fade as adequate. Too long a record is not necessarily a better criterion (Meek et al. 1979). For partial reflection fading records a length of one minute is considered most appropriate. For reflections near equatorial region even half a minute of record is more than adequate due to rapid fading.

2. Similar Fade Method

Due to the digital recordings used commonly these days it is difficult to apply similar fade methods from such recordings. Variant-1 method can be applied from the time shifts for maximum cross-correlations. However for Variant-2 it is difficult to estimate time shifts for each fade in the record. Chandra (1979) has suggested an easy method as an alternative for this purpose. The record length can be divided into 15-20 small parts and normal correlation analysis applied to each of them. The time shifts for maximum cross-correlations can be used to determine Variant-2 velocities.

2. Studying Velocity Variation with Fading Frequency

Eventhough the cross-spectral method is quick to give velocity at various Fourier components, its interpretation is rather doubtful. Full correlation analysis using filters can be used in a better way to study the velocity variation with frequency. Amplitude data or alternately the correlation functions can be used to filter as shown by Chandra and Briggs (1978).

Acknowledgement

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```
      PROGRAMME TC COMPUTE IONOSPHERIC DRIFT PARAMETERS
      COMMON/CATA/NSETVI (20),PI,PID2,PIM2,PID2M3,RDTDG,ERADEQ,FLAT
     1,OGTRD
      COMMON/A/NDATA(3),IDATA(3,423),NCMISE (3)
      COMMON/B/ IRHO(20,3),AMNACF(21),AMINRH     ,MAXTAU,DELTAT,NHLFW(3)
     1,NIRHO(3)
      CCMMON/C/CR(3),CTHETA(3)
      COMMON/H/RMEAN(4),STC(4)
      REAL NCLASH
      DIMENSICN IRSTOR (42),RRX(20)
      DIMENSICN RRHO(20,3),RIRSTO (42)
      DIMENSICN VIM(3),VID(3)
      DIMENSICN TD(3),TM(3),TCDSQ(3),TAUM(3),CRM(3)
      DIMENSICN CXS(3),CYS(3),RX(50),ERR(3)
      DIMENSION CPF(50,3),CMF(50,3)
      DIMENSION CX(3),CY(3),DX(3),DY(3),DRSQ(3),DR(3)
     1      ,CTHETA(3),SN2DTH(3),CS2DTH(3)
      DIMENSICN SM(3,4)
      DIMENSICN ROM(3)
      DIMENSICN IE(16)
      DIMENSICN PERIOD(50),YV(50),YD(50)
      DIMENSIOND(423),DD(3,423) ,DDD(423)
      REAL ICATA
      READ  100,KI
    1 READ(5,100,END=999 ) N,IDAY,IMONTH,IYEAR,ITIME,IEND,SHIFT,ALPHA,
     1ISEQ,PLOAT,DELTA
  100 FORMAT I6I4,F4.2,A3,I3,F4.0,F5.2)
      IF(KI.EQ.0)  PRINT   11111
      IF(KI.EC.1)  PRINT   11112
      IF(KI.EQ.2)  PRINT   11113
11111 FORMAT(1H2,'WITHOUT FILTER'//)
11112 FORMAT(1H2'CUTPUT WITH LOWPASS FILER'//)
11113 FORMAT('2 OUTPUT  WITH  HIGH  PASS  FILTER'//)
      PRINT 100,N,ICAY,IMONTH,IYEAR,ITIME,IEND,SHIFT,ALPHA,ISEQ,PLOAT,DE
     1LTA
C      IEND MEANS NUMBER OF AUTO AND CROSS COEFF. (NOT USED IN THIS PROG)
C      ISHIEFT MEANS DIST REQUARED FOR PLOTTING CURVE(NOT USED IN PRO7R14
C      ALPHA MEANS F REGICN OR E REGION AND FREQUENCE
C      ISEQ MEANS NUMBER OF SETS
C      PLOT MEANS PLOTTING CURVE (NOT USED IN PROGRAMME)
C     DELTA MEANS TIME INTERVAL IN SECONDS  USED FOR AMPLITUDE SCALIN7
  110 READ 115,(ICATA(1,I),I=1,N)
  111 READ 115,(ICATA(2,I),I=1,N)
  112 READ 115,(ICATA(3,I),I=1,N)
  115 FORMAT (20F4.0)
      IF (KI.EC.0)  GO TC 1117
      DO113J=1,3
      DO113I=1,N
  113 DD(J,I)=ICATA(J,I)
      LLLL=0
```

```
      DO 1000 KKK=1,10
      LLLL=LLLL+4
      DO117J=1,3
      DO118I=1,N
  118 D(I)=DC(J,I)
      CALL MCVAVE (D,DDD,N,LLLL,KI)
      DO117I=1,N
      IDATA(J,I)=DDD(I)
  117 CONTINUE
 1117 DO 105 I=1,20
  105 NSETVI(I)=1
      PI=3.1415926536
      PID2=1.5707963268
      PIM2=6.2831853072
      PID2M3*4.7123889803
      RDTDG=57.295779511
      DGTRD= 1.7453292519E-02
      ERADEQ=6378.388
      FLAT=.99663299663
C     X AXIS TO NORTH,Y AXIS TO EAST
CC    CTHETA  IS  MEASURED  FROM SOUTH
      CR (1)=120.
      CR (2)=120.
      CR (3)=120.
      CTHETA(1)=180.
      CTHETA(2)=00.00
      CTHETA(3)=90.
      NMISSD=0
      NHLF=3
      NDATA(1)=N
      NDATA(2)=N
      NDATA(3)=N
      NSHIFC=19
      NSHIFA=19
      DELTAT=DELTA
      KERROR=10
    3 DO 4 I=1,3
      DUM1=CTHETA(I)*DGTRD
      CX(I)=CR(I)*COS(DUM1)
      CXS(I)=CX(I)
      CY(I)=CR(I)*SIN(DUM1)
    4 CYS(I)=CY(I)
      IF (CX(1).EQ.0. AND.CX(2).EQ.0.0.AND.CX(3).EQ.0.0) GO TO 60
C     GET DIFFERENCE VECTORS
      KVECT=0
      DO 5 I=1,2
      JDUM=I+1
      DO 5 J=JDUM,3
      KVECT=KVECT+1
      DUM1=CX(J)-CX(I)
```

```
      DUM2=CY(J)-CY(I)
      DX(KVECT)=DUM1
      DY(KVECT)=DUM2
      DRSQ(KVECT)=DUM1**2+DUM2**2
      DR(KVECT)=SQRT(DRSQ(KVECT))
      DTHETA(KVECT)=ANGLRN (ARCTAN(DUM1,DUM2),0.0,PIM2)
      TNDTH=DUM2/DUM1
      TNSQDT =TNDTH**2
      DUM1=1.0+TNSQDT
      SN2DTH(KVECT)=2.0*TNDTH/DUM1
      CS2DTH(KVECT)=(1.0-TNSQDT )/DUM1
    5 CONTINUE
      MAKE THREE AUTO FUNCS AND AVERAGE THEM IN AMNACF(100)
      DO 9 I=1,3
      CALL CORLAT (I,I,I,NSHIFA ,ISAT)
      IF(ISAT.NE.1)GO TO 8891
      KERROR=9
      WRITE(6 ,84)KERROR
      GO TO 58
 8891 CONTINUE
      DO 8 KM=1,NSHIFA
      RRHO(KM,I)= IRHO(KM,I)/1000000.
    9 CONTINUE
      DUM1=1.0E+06
      RX(1)=1.E6
      AMNACF(1)=DUM1
      DO 10 I=2,NSHIFA
   10 RX(I)= (IRHO(I,1)+IRHO(I,2)+IRHO(I,3))/3.0
      DO 11 I=2,NSHIFA
      DUM2=(FLOAT(IRHO(I,1))+FLOAT(IRHO(I,2))+FLOAT(IRHO(I,3)))/3.0
      AMNACF(I)=DUM2
      IF(DUM1.LE.DUM2)GO TO 12
      DUM1=DUM2
   11 CONTINUE
      I=NSHIFA
   12 IF(I.GE.4)GO TO 13
      KERROR=8
      WRITE(6,84)KERROR
   13 IF(I.GE.NSHIFA )GO TO 14
      MAXTAU=I-1
      GO TO 15
   14 MAXTAU=I-2
   15 AMINRH =AMNACF(MAXTAU)
      CALL TAUACF (5.0E+05,TMHALF,NOKAY)
      IF(NOKAY.EQ.1)GO TO 16
      KERROR=7
      WRITE(6 ,84) KERROR
      GO TO 58
   16 CONTINUE
      AMONRH =AMINRH /1000000.
```

```
      DO 17KM=1,NSH961
   17 RRX(KM)=RX(KM)/1000000.
      PRINT 8892,(RRX(KM),KM=1,NSHIFA)
 8892 FORMAT(/1X,19F6.2/)
C     MAKE CROSS FUNCS AND FIND TIMES
      KVECT=0
      NZEROL =NSHIFC -1
      NZEROP =NSHIFC +1
      NTOP=NZEROL +NSHIFC
      MCOUNT=0
      DO 43 I=1,2
      JDUM=I+1
      DO 42 J=JDUM,3
C     FOOKS#S RHO12 EQUALS CORRLAT (2,1)
      KVECT=KVECT+1
      CALL CORLAT(J,I,2,NSHIFC,ISET)
      CALL CORLAT (I,J,3,NSHIFC,ISET)
C     REVERSE IRHO(3) INTO IRSTOR
      DO 18 K=1,NZEROL
      L=NZEROP -K
   18 IRSTOR (K)=IRHO(L,3)
      DO 19 K=NSHIFC ,NTOP
      L=K-NZEROL
   19 IRSTOR (K)=IRHO(L,2)
      MCOUNT=MCOUNT+1
      IF(MCOUNT-2)20,21,22
   20 MCO=1
      GO TO 23
   21 MCO=3
      GO TO 23
   22 MCO=2
   23 CONTINUE
      DO 24 K=1,NSHIFC
      CPF(K,MCO)=IRHO(K,2)
      CMF(K,MCO)=IRHO(K,3)
   24 CONTINUE
C     IRSTORE NOW CONTAINS FOOKS#SIRHO(I,J),POS AND NEG
      DO25 KM=1,NTOP
   25 RIRSTO (KM)=IRSTOR (KM)/1000000.
C     FIND POSITION OF MAXIMUM
      MAX=IRSTOR (1)
      K=1
      DO 26 L=2,NTOP
      IF (MAX.GE.IRSTOR (L)) GO TO 26
      MAX=IRSTOR (L)
      K=L
   26 CONTINUE
      IIMN=IABS(K-NSHIFC)
      IF(IABS(K-NSHIFC ).LE.NSHIFC -3)GO TO 27
      KERROR=6
```

```
      GO TO 59
CC   FIT QUADRATIC TO FIVE POINTS AND SOLVE FOR ZERO DERATIVE
   27 CF=FLOAT(IRSTOR(K+2))-2.0*FLOAT(IRSTOR(K))+FLOAT(IRSTOR(K-2))
      CG=FLOAT(IRSTOR(K+2))-FLOAT(IRSTOR(K-2))
      CH=FLOAT(IRSTOR(K+1))-FLOAT(IRSTOR(K-1))
      CK=FLOAT(IRSTOR(K+1))-2.0*FLOAT(IRSTOR(K))+FLOAT(IRSTOR(K-1))
      P=(CF-4.0*CK)/24.0
      Q=(CG-2.0*CH)/12.0
      R=-(CF-16.0*CK)/24.0
      S=-(CG-8.0*CH)/12.0
C     FOLLOWING NETWORK FINDS ZERO OF FUNCTION DIFQRTIC
C     WHICH LIES BETWEEN X=-1 AND X=+1
      XA=-1.0
      XB=1.0
       FA=DFQRTI (P,Q,R,S,XA)
      FB=DFQRTI (P,Q,R,S,XB)
      IF (FA*FB) 32,29,28
   28 KERROR=5
      GO TO 59
   29 IF (FA.EQ.0.0) GO TO 30
      XX=XB
      GO TO 36
   30 IF (FB.EQ.0.0) GO TO 31
      XX=XA
      GO TO 36
   31 KERROR=4
      GO TO 59
   32 X=(XA*FB-XB*FA)/(FB-FA)
      FC=DFQRTI (P,Q,R,S,X)
      IF (FC.EQ.0.0) GO TO 35
      IF (FA*FC.LT.0.0) GO TO 33
      FB=(FA*FB)/(FA+FC)
      GO TO 34
   33 FB=FA
      XB=XA
   34 FA=FC
      XA=X
      I F(ABS(XA-XB).GT.0.0001) GO TO 32
   35 XX=X
CC    USE THIS VALUE XX TO ESTABLISH MAX OF RHO
   36 RHOMAX=((((P*XX+Q)*XX+R)*XX+S)*XX+FLOAT(MAX)
      TC(KVECT)=(FLOAT(K-NSHIFC)+XX)*DELTAT
C      FIND WHERE THIS VALUE OF RHO OCCURS ON AMNACF
      CALL TAUACF (RHOMAX,TM(KVECT),NCKAY)
      GO TO (38,37), NCKAY
   37 KERROR=3
      GO TO 59
   38 TCDSQ(KVECT)=TC(KVECT)**2+TM(KVECT)**2
      RHIMAX=RHOMAX/1000000.
      ROM(KVECT)=RHIMAX
```

```
      IF(KVECT-2)39,40,41
   39 TAUM(1)=TD(1)
      CRM(1)=RHOMAX
      GO TO 42
   40 TAUM(3)=TD(2)
      CRM(3)=RHOMAX
      GO TO 42
   41 TAUM(2)=TD(3)
      CRM(2)=RHOMAX
   42 CONTINUE
   43 CONTINUE
C
C     DETERMINE ELLIPSE
CC
      DO 44 KVECT=1,3
      SM(KVECT,1)=1.0
      SM(KVECT,2)=CS2DTH(KVECT)
      SM(KVECT,3)=SN2DTH(KVECT)
      SM(KVECT,4)=TCDSQ(KVECT)/ORSQ(KVECT)
   44 CONTINUE
      CALL MATS (SM,CX,3,MISS)
      IF (MISS.LE.0) GO TO 45
      KERROR=2
      WRITE(6 ,84) KERROR
      GO TO 58
   45 CONTINUE
      A=CX(1)
      B=CX(2)
      C=CX(3)
      DUM1=SQRT(C*C+B*B)
      IF (A.GT.DUM1) GO TO 46
      KERROR=1
      VS=100.
      PHS=0.
      GO TO 59
   46 AAXIS=SQRT(1.0/(A-DUM1))
      BAXIS=SQRT(1.0/(A+DUM1))
      AXRATI =AAXIS/BAXIS
      THETA=ANGLRN (ARCTAN(-B,-C)*0.5,0.0,PIM2)
      IF(THETA.GT.PID2)THETA=THETA-PI
      A=TMHALF*AAXIS
      B=TMHALF*BAXIS
      P=THETA*RDTDG
      AXISMA=A
      BXISMA=B
      NOLNSH=P
C
C     SOLVE FOR DRIFT
C
   47 CONTINUE
```

```
      DO 48 I=1,3
      DUM1=1.0/TD(I)
      CX(I)=CX(I)*DUM1
      CY(I)=CY(I)*DUM1
      CR(I)=CR(I)*DUM1
   48 ERR(I)=CR(I)*DUM1
      IJ4=12
      DO 51 IJ5=1,3
      VIM(IJ5)=SQRT(CX(IJ5)**2+CY(IJ5)**2)
      VID(IJ5)=RDTDG*ARCTAN(CX(IJ5),CY(IJ5))
      IF (IJ4-12) 49,50,51
   49 IJ4=13
      GO TO 51
   50 IJ4=23
   51 CONTINUE
C     SOLAVE FOR MEAN PERPENDICULAR TO CX,CY JOINS
      DUM1=0.0
      DUM2=0.0
      DO 52 I=1,2
      JDUM=I+1
      DO 52 J=JDUM,3
      A=CX(J)*CY(I)-CX(I)*CY(J)
      B=CX(J)-CX(I)
      C=CY(J)-CY(I)
      A=A/(B**2+C**2)
      DUM1=DUM1-A*C
   52 DUM2=DUM2+A*B
      VD=SQRT(DUM1**2+DUM2**2)/3.0
      PHI=ARCTAN(DUM1,DUM2)
      P=PHI*RDTDG
      PHS=PHI
      VS=VD
      DO 58 IJKL=1,2
      PRP=PHI*RDTDG
      IF(IJKL.EQ.1) GO TO 53
      CALL ARGLS (DTHETA,VD,PHI,CR,ERR,LL,B1,B2,E1,E2)
      VD=B1
      VS=B1
      PHS=B2
      PHI=B2
      E2=E2*57.296
      P=PHI*RDTDG
      A=FLOAT(K)
      B2=B2*RDTDG
      IF(KERROR.EQ.1)GO TO 59
C     SLOVE FOR TRUE VELOCITY
   53 CONTINUE
      P=PHI-THETA
      C=COS(P)
      S=SIN(P)
```

```
      IF (ABS(C).GE.1.0E-08) GO TO 54
      V=BAXIS**2/VD
      GO TO 56
 54   A=S/C
      R=AXRATI **2
      IF(R.LT..001)R=200.
      P=ANGLFN (ATAN(A*R )-P,-PID2,PID2)
      PHI=PHI+P
      XK=PHI-THETA
      SS=SIN(XK)
      CC=COS(XK)
      AA=SS/CC
      A=AA*AA
      B=A/R
      C=1.0+B
      S=1.0+B/R
      A=1.0+A
      R=S/A
      B=AAXIS*AAXIS
      S=B*C/(VD*VD)
      IF (R.LE.0.0) GO TO 55
      V=B*SQRT(R)/VD
      RR=R*(A-S)/C
      IF(RR.LE.O.)GO TO 55
      VC=AAXIS*SQRT(RR)
      GO TO 56
 55   KERROR=11
      IF(IJKL.EQ.2) WRITE (6 ,84) KERROR
 56   CONTINUE
      PHI=PHI*RDTDG
      FIFI=PHI
      PHI=PHI*DGTRD
      GORD=SIN(PHI)*V
      EART=COS(PHI)*V
      IF (IJKL.EQ.2) GO TO 57
      VS=VS/2
      V=V/2
      VC=VC/2
      GORD=GORD/2
      EART=EART/2
      PPPP=PI/2-(PPP*PI/180)
      VSNORT =VS*SIN(PPPP)
      VSEAST=VS*COS(PPPP)
      IB(1)=VS
      IB(2)=PPP
      IB(3)=VSNORT
      IB(4)=VSEAST
      IB(5)=V
      IB(6)=FIFI
      IB(7)=EART
```

```
      IB(8)=CORD
      IB(9)=AXISMA
      IB(10)=BXISMA
      IB(11)=NCLNSH
      IB(12)=VC
      PRINT 3210
 3210 FORMAT(4X,'RCM(1)',1X,'ROM(2)',1X,'ROM(3)',3X,'TD(1)',3X,'TD(2)',
     33X,'TD(3)',3X,'IB(1)',3X,'IB(2)',3X,'IB(3)',3X,'IB(4)',3X,'IB(5)',
     43X,'IB(6)',3X,'IB(7)',3X,'IB(8)',3X,'IB(9)'/)
      PRINT 82,(RCM(I),I=1,3),(TD(I),I=1,3),(IB(I),I=1,9)
   82 FORMAT(2X,6(F6.2,2X),9(I5,2X)/)
CC    PUNCH 8888,IDAY,IMONTH,IYEAR,ITIME,ALPHA,ISEQ,(IB(I),I=1,2),
CC   2IB(3),(IE(I),I=4,11),AXRATI,IB(12)
 8888 FORMAT (3I2,I5,A1,I4,2I5,I4,8I5,F6.2,I4)
      VAE=VS
      VTE=V
      FIAE=PPP
      FITE=FIFI
      GO TO 58
   57 B1=B1/2
      V=V/2
      VC=VC/2
      GORD=GCRD/2
      EART=BART/2
      B22=PI/2-(B2*PI/180)
      B1NORT =B1*SIN(B22)
      B1EAST=B1*COS(B22)
      DIFF=ABS(FITE-FIFI)
      IF(VC.(E.0.3) GO TO 90
      GO TO 89
   90 IF(VAE.LT.500.0.AND.VTE.LT.300.0) GO TO 91
      GO TO 89
   91 IF(B1.LT.400.0.AND.V.LT.300.0) GO TO 92
      GO TO 89
   92 DIFF=ABS(FIAE-B2)
      IF(DIFF.LT.40.0) GO TO 93
      GO TO 89
   93 DIFF=ABS(FITE-FIFI)
      IF(DIFF.LT.40.0) GO TO 94
      GO TO 89
   94 IF(ROM(1).LT.0.2.OR.RCM(2).LT.0.2) GO TO 89
      GO TO 95
   95 IF(ROM(3).LT.0.2) GO TO 89
      GO TO 96
   96 CONTINUE
      IB(1)=B1
      IB(2)=B2
      IB(3)=B1NORT
      IB(4)=B1EAST
      IB(5)=V
```

```
      IB(6)=FIFI
      IB(7)=BART
      IB(8)=GORD
      IB(9)=AXISMA
      IB(10)=BXISMA
      IB(11)=NOLNSH
      IB(12)=VC
      IB(13)=E1
      IB(14)=E2
      PRINT 3223
3223  FORMAT(3X,'B1',3X,'B2',7X,'BINORT',1X,'BIEAST',4X,'V',3X,'FIFI',
     13X,'BART',3X,'GORD',1X,'AXISMA',1X,'BXISMA',1X,'NOLNSH',2X,'AXRATI
     2',4X,'VC',6X,'E1',5X,'E2',4X,'LL' )
      PRINT88,(IB(I),I=1,11),AXRATI,(IB(I),I=12,14),LL
  88  FORMAT(/2X,11(I6,1X),2X,F8.3,3(I6,1X),I5)
      PRINT 886
 886  FORMAT(2X,'ACCEPTED' )
      PRINT 5225
5225  FORMAT(7X,'B1',5X,'B2',1X,'BINORT',1X,'BIEAST',6X,'V',3X,'FIFI',
     13X,'BART',3X,'GORD',1X,'AXISMA',1X,'BXISMA',1X,'NOLNSH',2X,'AXRATI
     2',4X,'VC',6X,'E1',5X,'E2',4X,'LL' )
      GO TO 889
  89  PRINT 887
 887  FORMAT (' NOT ACCEPTED')
 889  PRINT88,(IB(I),I=1,11),AXRATI,(IB(I),I=12,14),LL
      DATAST =DELTAT
      LXP1=(NSHIFC +1)/2
      LXP=LXP1-1
      CALL DISPER (DTHETA,CPF,CMF,NSHIFC ,CXS,CYS,DATAST ,TITLE1,TITLE2,
     1RX,NSHIFA ,TAUM,CRM,CR,VD,PHS,LXP,PERIOD,YV,YD)
  58  CONTINUE
      PRINT 366
 366  FORMAT(1X,131('-'))
1000  CONTINUE
      GO TO 1
  59  PRINT 84, KERROR
      XLAST=0.0
      YLAST=24.0
      PRINT 366
      GO TO 1
  60  CONTINUE
      GO TO 62
  61  WRITE (6 ,85)
  62  STOP
 999  STOP
  84  FORMAT(1H0,2X,'KERROR = ',I4)
  85  FORMAT ('0',24HALL INPUT DATA PROCESSED)
      END
```

```
      SUBROUTINE MEANET (A,M,N,B,C)
      DIMENSION A (M,N)
      DIMENSION B (4),C(4)
      DO 2 J=1,M
      IA=0
      IB=0
      DO 1 I=1,N
      IA=IA+A(J,I)
      IB=IB+A(J,I)*A(J,I)
    1 CONTINUE
      B(J)=IA/N
      D=IB/N
      C(J)=D-B(J)*B(J)
      C(J)=SQRT(C(J))
    2 CONTINUE
      RETURN
      END


      SUBROUTINE TAUACF (RHOMAX,TAU,NOKAY)
      REAL IDATA
      COMMON/A/NDATA(3),IDATA(3,423),NOMISE (3)
      COMMON/B/ IRHO(20,3),AMNACF(21),AMINRH      ,MAXTAU,DELTAT,NHLFW(3)
     1,NIRHO(3)
      NOKAY=1
      IF (RHOMAX.GE.AMINRH ) GO TO 1
      NOKAY=2
      GO TO 5
    1 AMINDI =ABS(1.0-RHOMAX)
      K=1
      DO 2 L=2,MAXTAU
      IF (AMINDI .LE.ABS(RHOMAX-AMNACF(L))) GO TO 2
      AMINDI =ABS(RHOMAX-AMNACF(L))
      K=L
    2 CONTINUE
      IF (K.NE.1) GO TO 3
      IF (AMNACF(2).GT.1.0)GO TO 7
      TAU=SQRT(AMINDI /(1.0-AMNACF(2)))
      GO TO 5
    7 TAU=SQRT (AMINDI /(AMNACF(2)-1.0))
      GO TO 5
    3 A=(AMNACF(K-1)-2.0*AMNACF(K)+AMNACF(K+1))/2.0
      B=(AMNACF(K+1)-AMNACF(K-1))/4.0
      C=AMNACF(K)
      IF (ABS(A).GE.1.0E-04) GO TO 4
      C=AMNACF(K)
   16 TAU=(FLOAT(K)-1.0+(RHOMAX-C)/(2.0*B))*DELTAT
      GO TO 5
    4 IF ((B*B-A*(C-RHOMAX)).LT.0.0) GO TO 16
      TAU=(FLOAT(K)-1.0-(B+SQRT(B*B-A*(C-RHOMAX)))/A)*DELTAT
    5 RETURN
      END
```

```
      FUNCTION DFCRTI (A,B,C,D,X)
      DFORTI=(((4.0*A*X+3.0*B)*X+2.0*C)*X+D)
      RETURN
      END


      FUNCTION ANGLRN  (ANGLE,END1,END2)
C     NO SET CALL    NO OTHER CALLS
      IF (END2-END1) 2,9,1
    1 ENDHI=END2
      ENDLO=END1
      GO TO 3
    2 ENDHI=END1
      ENDLO=END2
    3 RANGE=ENDHI-ENDLO
C     NON-INCLUSIVE HIGH END
      ANGLRN =ANGLE
    4 IF (ANGLRN -ENDHI) 6,5,5
    5 ANGLRN =ANGLRN -RANGE
      GO TO 4
C     INCLUSIVE LOW END
    6 IF (ANGLRN -ENDLO) 7,8,8
    7 ANGLRN =ANGLRN +RANGE
      GO TO 6
    8 IF (ANGLRN .GT.ENDHI) GO TO 10
      RETURN
    9 WRITE(6 ,12)
      GO TO 11
   10 WRITE(6 ,13)
   11 WRITE(6 ,14) ANGLE,END1,END2
      STOP
   12 FORMAT(1X,17H ERR FUNC ANGLRNG3X,11H RANGE  ZERO3X,5H STOP)
   13 FORMAT (1X,18H ERR FUNC ANGLRNGE3X,11H CYCLE OPEN3X,5H STOP)
   14 FORMAT(2X,'ANGLE=',E20.10,'END1=',E20.10,'END2=',E20.10)
      END


      FUNCTION ARCTAN (X,Y)
      COMMON/DATA/NSETVI (20),PI,PID2,PIM2,PID2M3,RDTDG,ERADEQ,FLAT
     1,DGTRD
      IF (X) 5,1,6
    1 IF (Y) 3,2,4
    2 WRITE (6 ,8)
      ARCTAN=0.0
      GO TO 7
    3 ARCTAN=PID2M3
      GO TO 7
    4 ARCTAN=PID2
      GO TO 7
    5 ARCTAN=PI+ATAN(Y/X)
      GO TO 7
```

```
    6 ARCTAN=ATAN(Y/X)
    7 IF (ARCTAN.LT.0.) ARCTAN=ARCTAN+2*PI
      RETURN
C
    8 FORMAT (1X,22HARCTAN 0/0, SET=0 RADS)
      END


      SUBROUTINE MATS (S,A,NSPEC,MISS)
C     REDUCES THE AUGMENTED MATRIX S TO PRODUCE THE COEFFICIENTS A
      DIMENSION S(3,4),A(3)
      MISS=-1
      MM=NSPEC+1
      N=NSPEC
      DO 7 I=2,N
      II=I-1
      DO 7 J=1,II
      IF (S(I,J)) 1,7,1
    1 IF (ABS(S(J,J))-ABS(S(I,J)))3,2,2
    2 R=S(I,J)/S(J,J)
      GO TO 5
    3 R=S(J,J)/S(I,J)
      DO 4 K=1,MM
      B=S(J,K)
      S(J,K)=S(I,K)
    4 S(I,K)=B
    5 JJ=J+1
      DO 6 K=JJ,MM
    6 S(I,K)=S(I,K)-R*S(J,K)
    7 CONTINUE
      IF (ABS(S(N,N))-1.0E-10)8,9,9
    8 MISS=1
      GO TO 12
    9 A(N)=S(N,MM)/S(N,N)
      DO 11 I=2,N
      JJ=N-I+1
      B=0.0
      II=N-I+2
      DO 10 K=II,N
   10 B=B+S(JJ,K)*A(K)
      IF (ABS(S(JJ,JJ))-1.0E-10) 8,8,11
   11 A(JJ)=(S(JJ,MM)-B)/S(JJ,JJ)
   12 RETURN
      END
      SUBROUTINE ARGLS (Z,B1,B2,FM,ERR,LL,C1,C2,E1,E2)
      DIMENSION Z(3),B(2),FM(3),ERR(3),FC(3),R(2,1),A(3,2),DF(3),
     1G(2,2)
      B(1)=B1
      B(2)=B2
      ERO=1.E-6
      QQ=1.E10
      LL=0
```

```
    1 DO 2 I=1,3
      ARG=B(2)-Z(I)
      FC(I)=E(1)/COS(ARG)
      A(I,1)=FC(I)/B(1)
       Z12=COS(ARG)
    2 A(I,2)=E(1)*SIN(ARG)/COS(ARG)**2
  332 FORMAT (2X,'FM=',3F12.5)
      DO 3 J=1,3
    3 DF(J)=FM(J)-FC(J)
      DO 4 L=1,2
      R(L,1)=0
      DO 4 J=1,3
    4 R(L,1)=R(L,1)+A(J,L)*DF(J)/ERR(J)**2
      DO 5 L=1,2
      DO 5 K=1,2
      G(L,K)=0
      DO 5 J=1,3
      IF(ERR(J).EQ.0) GO TO 300
    5 G(L,K)=G(L,K)+A(J,L)*A(J,K)/ERR(J)**2
      DET=G(1,1)*G(2,2)-G(2,1)*G(1,2)
      Y1=(G(2,2)*R(1,1)-G(1,2)*R(2,1))/DET
      Y2=(R(1,1)-G(1,1)*Y1)/G(1,2)
      R(1,1)=Y1
      R(2,1)=Y2
      Q1=0
      DO 6 J=1,3
    6 Q1=Q1+DF(J)**2/ERR(J)**2
      Q=ABS(Q0-Q1)
      LL=LL+1
      Q0=Q1
      IF (LL.GE.8) GO TO 8
      IF (Q.LE.ERQ ) GO TO 8
      DO 7 J=1,2
    7 B(J)=B(J)+R(J,1)
      GO TO 1
    8 IF((G(2,2)/DET*Q1).LT.0.0) E1=0.0001
      IF((G(1,1)/DET*Q1).GE.0.0) GO TO 118
      E2=0.0001
      GO TO 218
  118 IF(E1.EQ.0.0001) GO TO 3878
      E1=SQRT(G(2,2)/DET*Q1)
 3878 E2=SQRT(G(1,1)/DET*Q1)
  218 IF(B(1).LT.0) GO TO 219
      C1=B(1)
      C2=B(2)
      RETURN
  219 C1=-B(1)
      C2=B(2)+3.1416
      IF (C2.GT.6.2832) C2=C2-6.2832
  300 RETURN
          END
```

```
      SUBROUTINE CORLAT (J1,J2,J3,NSHIFT,IFLAG)
      COMMON/A/NDATA(3),IDATA(3,423),NOMISE (3)
      COMMON/B/ IRHO(20,3),AMNACF(21),AMINRH     ,MAXTAU,DELTAT,NHLFW(3)
     1,NIRHO(3)
      DIMENSION SGX(2,2),SGMX(2,2),X(425),Y(425)
      REAL IDATA
      IFLAG=0
      NDAT=NDATA(J1)
      DO 1 JXY=1,NDAT
      X(JXY)=IDATA(J2,JXY)
    1 Y(JXY)=IDATA(J1,JXY)
      SX=0
      SY=0
      SSX=0
      SSY=0
      DO 2 JXY=1,NDAT
      SSX=SSX+X(JXY)*X(JXY)
    2 SX=SX+X(JXY)
      IF (J1.EQ.J2) GO TO 4
      DO 3 JXY=1,NDAT
      SSY=SSY+Y(JXY)*Y(JXY)
    3 SY=SY+Y(JXY)
      GO TO 5
    4 SY=SX
      SSY=SSX
    5 DO 7 JD=1,NSHIFT
      NS=JD-1
      NP=NDAT-NS
      SUM=0
      PN=NP
      DO 6 J=1,NP
    6 SUM=SUM+X(J)*Y(J+NS)
      IF((SSX-SX*SX/PN).EQ.0.OR.(SSY-SY*SY/PN).EQ.0)GO TO 19
      IF((SSX-SX*SX/PN)*(SSY-SY*SY/PN).LT.0.0) GO TO 19
      IRHO(JD,J3)=(SUM-SX*SY/PN)/SQRT((SSX-SX*SX/PN)*(SSY-SY*SY/PN))*1.
     1E6+0.5
      XX=X(NDAT-NS)
      YY=Y(JD)
      SX=SX-XX
      SY=SY-YY
      SSX=SSX-XX*XX
    7 SSY=SSY-YY*YY
      GO TO 8
    8 NIRHO(J3)=NSHIFT
      RETURN
   19 IFLAG=1
      RETURN
          END
```

```
      SUBROUTINE DISPER(DTHETA,CPF,CMF,NSHIFC ,CX,CY,DELTAT,TITLE1,TI
     12,RX,NSHIFA,TAUM,CPM,DR,VJ,PHS,LXP,PERIOD,YV,YD)
      DIMENSION PERIOD(LXP),YV(LXP),YD(LXP)
C     SUBROUTINE COMPUTES THE VELOCITY AND DIRECTION,AS A FUNCTION OF
C     OF THE PATTERN RECORDED AT SPACED RECEIVERS
      DIMENSION CPF( 50,3),CMF( 50,3),X(050),Y(050),CP(050),CM(050),
     1AXY(050),SXY( 50),AMP( 50),PH( 50),CXY( 50),QXY( 50),SCXY( 50),
     2SQXY( 50),CR(3),CR(3),ERR(3),RX( 50),PX( 50),SPX( 50),CPS( 50),
     4CMS( 50),TAUM(3),CPM(3),A12( 50),P12( 50),A23( 50),P23( 50),
     5DTHETA (3),CX(3),CY(3)
      RAD=180./3.141593
      XX=-1.
      MAXLAG=NSHIFC -1
      PI=3.1415927
      LLAG=MAXLAG+1
      C=PI/MAXLAG
      IF(NSHIFC .NE.NSHIFA ) PRINT 6
    6 FORMAT(///1X,112H****THE POWER SPECTRUM IS INCORRECT BECAUSE O
     1DIFFERENT LAGS IN THE AUTO AND CROOS CORRELATION FUNCTIONS*****
      RX(1)=0.5*RX(1)
      RX(LLAG)=RX(LLAG)*0.5
      DO 8 IH=1,LLAG
C     FOR T.1.D.DISPERSION ANALYSIS INTERVAL IS IN MINUTES.
    8 RX(IH)=RX(IH)/1.E6
      DO 114 NJ=1,3
      MA=MAXLAG*2+1
      IF(NJ-2) 11,14,16
   11 PRINT 12,DELTAT
   12 FORMAT(1H1,5X,22H RECORD IDENTIFICATION,        5X,20H DATA TIM
     1NTERVAL=F6.3,'SECOND',20H TEST FOR DISPERSION/)
      PRINT 13
   13 FORMAT(/1X,39H CROSS CORRELATION OF RECEIVERS 1 AND 2/)
CC 13 FORMAT(
CC   2/5X,11EH NOTE THAT DISPER COMPUTES GROUND PATTERN VELOCITIES.FO
CC   3EFLECTION RESULTS THE IONOSPHERIC VELOCITIES ARE HALF THESE    ,
CC   4/5X,11EH
CC   5                                                               ,//
CC   639H CROSS CORRELATION OF RECEIVERS 1 AND 2)
      GO TO 18
   14 PRINT 15
      GO TO 18
   15 FORMAT(/1X,39H CROSS CORRELATION OF RECEIVERS 2 AND 3/)
   16 PRINT 17
   17 FORMAT(/1X,39H CROSS CORRELATION OF RECEIVERS 1 AND 3/)
   18 DO 25 N=1,LLAG
      CP(N)=CPF(N,NJ)/1.E6
      CM(N)=CMF(N,NJ)/1.E6
      NN=LLAG+1-N
      X(NN)=CM(N)
   25 X(N+MAXLAG)=CP(N)
```

```
      PRINT 22,(X(N),N=1,MA)
   22 FORMAT(1X,19F6.2)
      NNM=2*MAXLAG
      TAUMAX=TAUM(NJ)
      CRMAX=CRM(NJ)
C     DETERMINE THE SHIFT OF THE MAX OF THE CORRN FUNCTION
      IF(CP(2).GT.CP(1)) GO TO 28
      GO TO 34
   28 DO 31 N=2,LLAG
      IF(CP(N).GT.CP(N-1))GO TO 31
      GO TO 29
   29 NSHIF=N-2
      NDIR=1
      GO TO 53
   31 CONTINUE
   34 DO 37 N=2,LLAG
      IF(CM(N).GT.CM(N-1)) GO TO 37
   33 NSHIF=N-2
      NDIR=-1
      GO TO 53
   37 CONTINUE
C     COMPUTE CO AND QUAD SPECTRA AND POWE- SPECT-UM
   53 DO 60 JP=1,LLAG
      AXY(JP)=CP(JP)+CM(JP)
   60 SXY(JP)=CP(JP)-CM(JP)
      AXY(LLAG)=.5*AXY(LLAG)
      AXY(1)=.5*AXY(1)
      SXY(1)=.5*SXY(1)
      SXY(LLAG)=.5*SXY(LLAG)
      DO 65 IH=1,LLAG
      FIH=IH-1
      CXY(IH)=0
      QXY(IH)=0
      TH=Q*FIH
      C1=COS(TH)
      S1=SIN(TH)
      PX(IH)=0
      CN=1.
      SN=0
      DO 65 JP=1,LLAG
      FJP=JP-1
      S=Q*FIH*FJP
      CNS=CN
      CXY(IH)=CXY(IH)+CN*AXY(JP)
      QXY(IH)=CXY(IH)+SN*SXY(JP)
      IF(NJ.EQ.3) PX (IH)=PX(IH)+CN*RX(JP)*2.
      CN=CN*C1-SN*S1
      SN=SN*C1+CNS*S1
   65 CONTINUE
      CHPH=NSHIF*NDIR*PI/MAXLAG
```

```
      DO 67 J=2,LLAG
      CXYS=CXY(J)
      QXYS=QXY(J)
      CHP=CHPF*(J-1)
      CXY(J)=CXYS*COS(CHP)+QXYS*SIN(CHP)
   67 QXY(J)=CXYS*COS (CHP)-CXYS*SIN (CHP)
      SPX(1)=.54*PX(1)+.46*PX(2)
      SPX(LLAG)=.54*PX(LLAG)+.46*PX(LLAG-1)
      SCXY(1)=.54*CXY(1)+.46*CXY(2)
      SCXY(LLAG)=.54*CXY(LLAG)+.46*CXY(LLAG-1)
      SQXY(1)=.54*QXY(1)+.46*QXY(2)
      SQXY(LLAG)=.54*QXY(LLAG)+.46*QXY(LLAG-1)
      KK=LLAG-2
       DO 70 I=1,KK
      J=I+1
      SPX(J)=.54*PX(J)+.23*(PX(J-1)+PX(J+1))
      SCXY(J)=.54*CXY(J)+.23*(CXY(J+1)+CXY(J-1))
   70 SQXY(J)=.54*CXY(J)+.23*(QXY(J+1)+QXY(J-1))
C     AMPLITUDE AND PHASE OF CROSS SPECTRA
      DO 75 J=1,LLAG
   75 AMP(J)=SQRT (SCXY(J)**2+SQXY(J)**2)
      FMD=1./(2.*MAXLAG*DELTAT)
      DO 110 I=1,LLAG
      RAD=180./PI
      AB=ABS(SQXY(I)/SCXY(I))
      PHI=ATAN(AB)
      IF(SQXY(I)) 80,76,95
   76 PH(I)=0.
      GO TO 110
   80 IF(SCXY(I)) 85,85,90
   85 PH(I)=(PHI+PI)*RAD-360.
       GO TO 110
   90 PH(I)=-PHI*RAD
      GO TO 110
   95 IF(SCXY(I)) 100,100,105
  100 PH(I)=(PI-PHI)*RAD
      GO TO 110
  105 PH(I)=PHI*RAD
  110 CONTINUE
C     USE EXPECTED CONTINUITY OF PHASE TO PREVENT TWO PI AMBIGUITY IN
C    1THE P
      DO 109 J=2,LLAG
      IF(PH(J-1).GT.90) GO TO 101
      GO TO 103
  101 IF(PH(J).LT.0.0) GO TO 102
      GO TO 109
  102 PH(J)=PH(J)+360.
      GO TO 109
  103 IF(PH(J-1).LT.-90) GO TO 106
      GO TO 109
```

```
  106 IF(PH(J).GT.0.0) GC TO 107
      GJ TO 109
  107 PH(J)=PH(J)-360.
  109 CONTINUE
      DJ 104 J=2,LLAG
  104 PH(J)=PH(J)+CHPH*(J-1)*57.29
C     STORE AMPLITUDE ANC PHASE OF THE CROSS SPECTRUM FOR EICH PAIR OF
C    1RECJ
      DJ 114 J=1,LLAG
      IF(NJ-2)111,112,114
  111 A12(J)=AMP(J)
      P12(J)=PH(J)
      GJ TO 114
  112 A23(J)=AMP(J)
      P23(J)=PH(J)
  114 CONTINUE
      PRINT 115
  115 FJRMAT (1X,/,9X,'FRECUENCY IN  CYCLE/SECOND,PHASEIN DEGREES,
     1DIRECTICN IN DEGREES CLOKWISE FROM NORTH,PERIOD IN SECONDS',/)
      PRINT 9
    9 FORMAT (1X,/,9X,'THE COHERENCE SQUARE IS COMPUTED FROM THE AVERAG
     1POWER SPECTRUM AND HENCE IS SLIGHTLY INACCURATE')
      PRINT 116
  116 FJRMAT (1X,/,39X,'AMPLITUDE AND PHASE OF CROSS SPECTRA',/,39X,'==
     1==================================',/)
      PRINT 117
  117 FORMAT(1X,'FREC PERIOD WAVE  AMP  PHASE  AMP  PHASE  AMP      PH
     1ASE VELCCITY EFROR  CIRECTION  ERROR POWER COHERENCE  SQUARE'/
     214X,'LENGTH   1-2   1-2   2-3  2-3  1-3 1-3
     3           SPECTRUM  1-2   2-3  1-3')
C     SINCE THE SPECTRA INVARIABLY  FALL TO ALMOST  ZERO 256095 8136 CH
C     NYQUIST FREC,FINAL  RESULTS ARE COMPUTED ONLY TO THIS FREQ
      LLAGU=(LLAG+1)/2
C     COMPUTE VELCCITY AND  DIRECTION OF EACH FOURIER COMPONENT
      DJ 129 J=1,LLAGU
      FREQ=FLOAT (J-1)*FND
CC    PRINT 1001,FREQ
 1001 FORMAT(2X,'1001',F12.5)
      IF(J.EC.1) GC  TO 939
      PER=1./FREQ
  939 IF(ABS(P12(J))-.001)118,118,120
  118 P12(J)=.001
  120 IF(J.EC.1) GO TO 3461
      AG=360.*FREC
      CR(1)=AG*DR(1)/P12(J)
      ERR(1)=CR(1)/P12(J)
      ERR(2)=CR(2)/PH(J)
      CR(2)=AG*DR(2)/PH(J)
      CR(3)=AG*DR(3)/P23(J)
      ERR(3)=CR(3)/P23(J)
```

```
  ERR(1)=ERR(1)*AG
  ERR(2)=ERR(2)*AG
  ERR(3)=ERR(3)*AG
  CALL ARGUSI(THETA,VD,PHS,CR,ERR,LL,V,D,E1,E2)
  D=D*RAD
  ALAMBD =E1/FREQ
  E2=E2*RAD
  K=J-1
  IF(D.GT.360.)D=D-360.
  PERIOD(K)=PER
  YV(K)=V
  YD(K)=D
  V=V/2
1 CONTINUE
  COHERENCE SQUARED
  CO12=(A12(J)/SPX(J))**2
  CO23=(A23(J)/SPX(J))**2
  CO13=(AMP(J)/SPX(J))**2
  IF(J.EQ.1) GO TO 140
  GO TO 135
0 PRINT 131,FREQ,A12(J),A23(J),AMP(J),SPX(J),CO12,CO23,CO13
1 FORMAT(1X,F5.3,       15X,3(F6.2,7X),33X,F8.2,2X,3F5.2)
  GO TO 129
5 PRINT 128,FREQ,PER,ALAMBD,A12(J),P12(J),A23(J), P23(J),AMP(J),
 1PH(J), V,E1,D,E2,SPX(J),CO12,CO23,CO13
8 FORMAT(1X,F5.3,2F7.1,1X,3(F6.2,F7.1),F9.2,F7.2,2F8.2,F7.2,2X,
 1 3F5.2)
9 CONTINUE
  CONTINUE
  CALL GIKPLT(PERIOD,YV,-LXP,-1,8H PERIOD,10H VELOCITY)
  PRINT 300
  FORMAT (45X,'TIME PERIOD IN SECONDS,VELOCITY IN M/SEC.')
  PRINT 301
  FORMAT (33X,'TIME PERIOD IN SECONDS,DIRECTION IN DEGREES CLOCKWISE
 1FROM NORTH')
  RETURN
  END


  SUBROUTINE FOR MOVING AVERAGE,LONG TERM REMOVE & % LTR VALUES   15-12-78
  X = INPUT DATA
  N = NO. OF DATA POINTS
  L = FILTER WIDTH IN TERMS OF THE NUMBER OF DATA POINTS
  KI = 1  MOVING AVERAGE DATA
  KI = 2  LONG TERM REMOVE DATA
  KI = 3     LONG TERM REMOVE DATA IN PERCENTAGE
  SUBROUTINE MOVAVE(X,RM,N,L,KI)
  IF(N.GT.1200) STOP ' NO. OF DATA >1200'
  LHF=L/2
  DIMENSION X(N),RM(N),Y(1200)
```

```
      IF(L.GT.200) STOP' NO. OF MEAN >200'
      LDBL=L*2
      NLHF=N+LHF
      LA=1
      IF(MOD(L,2).EQ.0) LA=2
      DO 10 I=1,LHF
      Y(I)=X(1)
   10 Y(I+NLHF)=X(N)
      DO 15 I=1,N
   15 Y(I+LHF)=X(I)
      SA=0.
      DO 20 I=1,L
   20 SA=SA+Y(I)
      DO 30 I=1,N
      SB=SA
      SA=SA-Y(I)+Y(I+L)
      GO TO (22,24),LA
   22 RM(I)=SB/L
      GO TO 30
   24 RM(I)=(SA+SB)/LDBL
   30 CONTINUE
      GO TO (40,50,70),KI
C
C     KI = 1  MOVING AVERAGE DATA
   40 RETURN
C
C     KI = 2  LONG TERM REMOVE DATA
   50 DO 60 I=1,N
   60 RM(I)=X(I)-RM(I)
      RETURN
C
C     KI = 3  % LONG TERM REMOVE DATA
   70 DO 80 I=1,N
   80 RM(I)=(X(I)-RM(I))*100./RM(I)
      RETURN
      END
```