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SOME ASPECTS OF WIND SHEAR IN THE UPPER ATMOSPHERE

BY

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Some Aspects of Wind Shear in the Upper Atmosphere

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ABSTRACT

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The wind motions responsible for the shearing of sodium vapor trails ejected from rockets in the 70 to 140 km region of the upper atmosphere are subjected to an analysis based on generally accepted theories of hydrodynamic turbulence. The region from 80 to 100 km is of particular interest in that here the predictions of shear turbulence theory are well substantiated. The energy spectrum of the height shear is found to follow the 4/3 power law proposed by Tchen, and is associated with a vertical correlation distance of approximately 6 km. The existence of an isotropic inertial region of maximum scale 3 km, previously indicated by analysis of meteor data, is confirmed. The vertical scale of the turbulent eddies is found to be the atmospheric pressure scale height, a phenomenon which has been observed by others, but which, as yet, has no satisfactory explanation.

1. Turbulence Theory

The complete development of the relationships used in the analysis of wind shear is beyond the scope of this work; the following, used in conjunction with the references quoted, should provide an adequate background for consideration of the subsequent analysis.

1.1 Energy Spectrum Analysis

If there exists in a turbulent flow field a range of scales which receive energy from larger scale motions and pass it on undiminished to smaller scale motions, then, for this so-called inertial (nondissipative) range of scales, the only form of energy spectrum function dimensionally possible is

$$E(k) = \alpha \epsilon^{2/3} k^{-5/3} \qquad \text{(Kolmogoroff, 1941)}$$

where ϵ is the rate at which the turbulent energy is received by (and leaves) the inertial range of scales, k is the wavenumber vector corresponding to the real space scale r, and α is an absolute constant of order unity.

Batchelor (1953) has shown that, for such an inertial region which also possesses the property of isotropy, the fluid velocity differences measured as a function of the separation r follow the relation

$$\overline{[u(x)-u(x+r)]^2} = 4.82\alpha(\epsilon r)^{2/3} \qquad \ldots\ldots\ldots\ldots 1$$

In real space, the energy spectrum function E(r) is defined by

$$E(r) = \overline{[u(x) - u(x+r)]^2} \qquad \ldots\ldots\ldots\ldots 2$$

Tchen (1954) has considered an otherwise isotropic region subjected to a mean shear, and finds that equation 1 is modified, becoming

$$\overline{[u(x) - u(x+r)]^2} = a\, r^{4/3} \qquad \ldots\ldots\ldots\ldots 3$$

where a involves α, ϵ, and the mean gradient. Thus, for what may be termed shear turbulence, in real space

$$E(r) \sim r^{4/3} \qquad \ldots\ldots\ldots\ldots 4$$

1.2 Correlation Analysis

An energy spectrum function equivalent to that based on velocity differences can be formulated from the lateral or longitudinal velocity correlations defined as

$$f(r) = \frac{\overline{u_f(x)\; u_f(x+r)}}{u_f^2}$$

and

$$g(r) = \frac{\overline{u_n(x)\; u_n(x + r)}}{u_n^2} \quad \ldots\ldots\ldots\ldots\ldots 5$$

where $u_f(x)$, $u_f(x + r)$, $u_n(x)$, $u_n(x + r)$ are the turbulent components of the velocity at two points x and $x + r$ respectively, measured parallel (suffix f) and normal (suffix n) to the vector separation r. In isotropic turbulence, $u_f{}^2 = u_n{}^2 = u_o{}^2$, the velocity characteristic of the energy bearing eddies of the Kolmogoroff spectrum.

Introduction to the equation of continuity for incompressible fluids leads to the relation

$$g(r) = f(r) + 1/2\; r \frac{\partial f}{\partial r} \quad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

(von Karman and Howarth, 1938)

between the functions f and g, or, if the turbulence is isotropic in two dimensions only,

$$g(r) = f(r) + r\frac{\partial f}{\partial r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

These functions, f and g, may be called Eulerian space correlation functions, and either may be denoted by $R(r)$. If the range of scales under observation is inertial, then $R(r)$ must depend only on ϵ, and the only form dimensionally possible is

$$u_o^2\ [1 - R(r)] \sim \epsilon^{2/3}\ r^{2/3}$$

i.e. $1 - R(r) \sim r^{2/3}$

(for any given flow field, u_o and ϵ are constant).

Introduction of the relations 6 and 7 above gives, with c a constant

$$f = 1 - cr^{2/3} \ldots\ldots\ldots\ldots 8$$

and $$g = 1 - 4/3\ cr^{2/3} \ldots\ldots 9$$

for three dimensional isotropy

or $$f = 1 - 5/3\ cr^{2/3} \ldots\ldots 10$$

for isotropy in two dimensions only.

Since the variations of the correlation difference function $[1-R(r)]$ with r is the same as that of $E(r)$ in equation 1, we may suppose that the dependence of $[1-R(r)]$ on r will be similarly modified in the presence of a mean shear

i.e. $$[1-R(r)] \sim r^{4/3} \ldots\ldots\ldots 11$$

If, in fact, equation 11 is pertinent, then the relationships between f, g, and r (equations 8, 9, 10) will now become

$$f = 1 - ar^{4/3}$$

and $$g = 1 - 5/3\ ar^{4/3}$$

or $$g = 1 - 7/3\ ar^{4/3}$$

An indication of the degree of isotropy can be obtained by considering the ratio

$$S = \frac{1 - f}{1 - g}$$

For two dimensional isotropy

$S = 0.60$ without mean shear

and $S = 0.43$ with mean shear

For three dimensional isotropy

$S = 0.75$ without mean shear

and $S = 0.60$ with mean shear

The relative importance of mean shear will be indicated by the form of either the energy spectrum function $E(r)$, or the correlation difference function $[1 - R(r)]$.

2. The Practical Application of Turbulence Theory

2.1 The Mean Wind Profile

In applying the relations developed above to the wind vectors measured by means of sodium vapor trails ejected as a tracer into the upper atmosphere, the relative importance of the mean motion must not be overlooked. The velocities used in the energy spectrum and correlation analyses of the previous section must be the turbulent velocities, or departures from the mean motion. In normal correlation analysis, the mean of a set of observations is usually taken as the mean value of the measured data, which, when applied to wind height shear data, would be tantamount to the assumption of a mean wind profile which is constant with height. Such a profile is the exception rather than the rule in meteorological phenomena.

Practically any attempt to prescribe a mean wind profile to the measured winds will be subjective to a certain extent. If one uses a polynomial fit, for example, it must be truncated before it can assume any of the features of the measured profile which are due to the turbulent motions present. From experience based on the measurement of winds in the 75 to 105 km region by means of radio reflections from meteor trails (Elford, 1958, 1964), a quadratic change with height of the mean wind over any given 20 km interval should best describe the contribution of the mean motion without destroying any of the characteristics of the turbulent flow field. In the present analysis, the windspeed/azimuth data are converted to zonal and meridional components, and a polynomial profile of order Z + 1, where

$$Z = \frac{\text{Total height range covered by data(km)}}{20} ,$$

is fitted to each. The profiles thus determined are subtracted from the relevant measured profiles to give zonal and meridional turbulent velocities.

2.2 The Determination of $E(\Delta h)$

The available sodium trail data lists wind speed and azimuth against height, and usually involves irregularly spaced height intervals. The sampling irregularity exists for two reasons:

a) there is an occasional difficulty in absolutely identifying the same point on the trail in consecutive photographs;

b) the wind profile between consecutive observational heights is linear. This is usually obvious from the photographs, and can easily be allowed for in subsequent analysis.

Whereas equal height interval sampling is not absolutely necessary for subsequent reduction, it does simplify the analysis, and so linear interpolation between the listed data points is used to provide a profile with data points spaced 0.2 km in height.

The energy spectrum function is computed as

$$E(\Delta h_i) = \frac{1}{N} \sum_{k=1}^{N} (u_{k+i} - u_k)^2 \quad \ldots\ldots\ldots 12$$

in which

$$N = 5(H_2 - H_1) - i$$

where $i = 1, 2, 3 \ldots N$

such that $\Delta h_1 = 0.2$ km.

$\Delta h_2 = 0.4$ km

etc.

and H_1, H_2 (in km) are the lower and upper bounds respectively of the region for which $E(\Delta h)$ is being determined. Such partitioning of the height range is necessary since there is considerable variation in the characteristics of the flow over the total height range sampled (usually some 70 to 200 km).

Energy spectrum functions may be calculated using

a) zonal turbulent velocities

b) meridional turbulent velocities

and c) turbulent windspeed.

The turbulent windspeed w is defined here as

$$w = \text{measured windspeed} - ((\text{mean zonal wind})^2 + (\text{mean meridional wind})^2)^{1/2}$$

2.4 Correlation Analysis

The two correlation functions f and g defined in 1.2 refer to turbulent velocity components measured parallel and normal to the separation vector. Since vertical velocities in this region of the upper atmosphere are so much less than the associated horizontal components, the magnitude of the vertical component cannot be determined from sodium trail photographs. (Most workers in this field consider the upper limit for mean plus random vertical motions to be some 10 metres/sec). However, we may redefine f and g in terms of the orthogonal zonal and meridional flow fields, with a view to investigating possible isotropy. This has been done by meteorologists in the past, with at least partial success (see, for example, Hutchings (1955)).

The normalizing factors $\overline{u}_f^{\,2}$ and $\overline{u}_n^{2}$ are best estimated by the standard correlation function definition. The correlation functions f and g then becomes

$$f(\Delta h_i) = \frac{\sum_{k=1}^{N} u_{k+i}\, u_k}{\left[\sum_{k=1}^{N} u^2_{k+1} \sum_{k=1}^{N} u_k^{\,2}\right]^{1/2}} \ldots\ldots\ldots\ldots 14$$

where u are the zonal turbulent wind velocities and

$$g(\Delta h_i) = \frac{\sum_{k=1}^{N} v_{k+1}\, v_k}{\left[\sum_{k=1}^{N} v^2_{k+i} \sum_{k=1}^{N} v^2{}_k\right]^{1/2}} \ldots\ldots\ldots\ldots 15,$$

where v are meridional turbulent wind velocities, and N and i are as previously defined for equation 12.

3. Preliminary Results

The analysis of Section 2 has been applied to data obtained from a sodium trail release over the Eglin Air Force Base, Florida (29.6°N, 86.6°W) at 1910 CST on May 21, 1963 (Edwards et al, 1963). In this experiment, wind speed and azimuth were obtained over a height range of 69 to 140 km.

3.1 The Mean Wind Profile

Since the data covers the height range from 69 to 140 km, polynomials of order 4 are fitted to the zonal and meridional measured profiles. These yield mean zonal and meridional profiles

$$u_{mean} = 38.6 - 126h - 244h^2 + 174h^3 + 205h^4$$

$$v_{mean} = -30.4 + 19.8h + 148h^2 - 16.8h^3 - 125h^4$$

where u, v are in metres/sec and h is the normalized height given by

$$h = (2z - z_{min} - z_{max})(z_{min} - z_{max})$$

where z is the height variable

z_{max} the maximum and

z_{min} the minimum heights of the available data, all heights being in kilometers.

Normalization of the height range stabilizes the least squares fitting process, and makes the relative importance of the individual terms of the fitted polynomials more obvious than is the case when the mean velocities are expressed as power series in the actual height z. Results are plotted in Figs.1 and 2.

The meteorological significance of these profiles, in particular the reversal of both the zonal and meridional components above 110 km, cannot be evaluated from consideration of this single firing.

3.2 The Turbulent Wind Profile

As mentioned in Section 2, the 70 to 200 km height range covers a number of characteristically different regions. The wind motions observed below approximately 105 km indicate the presence of small-scale structure, while those above 110 km do not appear to be at all turbulent, even though vertical shear is present. In the results presented here, discussion is confined to the consideration of the region from 80 to 100 km, which has been found to be representative of a turbulent region which can be adequately described by available statistical theories of hydrodynamic turbulence (Blamont and Jager, 1961; Zimmerman, 1962; Roper, 1962).

The measured zonal and meridional profiles, and the deviations from the mean wind for the height range 80 to 100 km are plotted in Figures 3 to 6. Whereas the immediately obvious wavelike nature of the turbulent profile would suggest a wave theory approach as likely to be the most profitable for consideration of the wind motions in this region, applications of available wave theories (e.g., Hines, 1959) have not produced consistent results. The possibility of generation of turbulence in the 80 to 100 km region by vertically propagating gravity waves has been proposed by Hines (1963). The purpose of the present work, however, is not to determine the source of the turbulent energy, but rather to substantiate the evidence that the observed shears characterize a region of hydrodynamic turbulence.

3.3 The Energy Spectrum Functions

The energy spectrum functions for the zonal and meridional turbulent wind profiles for the 80 to 100 km region have been computed using the methods described in Sections 2.2 and 2.3. As can be seen from Figures 7 and 8, the velocity difference spectrum $E(\Delta h)$ and the correlation difference function $[1-f(\Delta h)]$ for the zonal turbulent velocities are completely equivalent. This is not surprising, since both functions are solutions of the same equation

$$F = a \, \Delta h^{m}$$

(see Sections 1.1 and 1.2).

Similarly for the meridional spectra of Figures 9 and 10. The slope m ofthe log log plots of both the zonal and meridional $E(\Delta h)$ (or $[1-R(\Delta h)]$) spectrum functions against height difference Δh is constant at 4/3 for separations Δh up to 3 km, indicative of an isotropic region subject to a mean wind shear (Tchen, 1954).

3.4 Isotropy

Since the energy spectrum functions and the correlation difference functions all follow an established (shear) law at small scales in the height range from 80 to 100 km, it is possible to determine the nature of the isotropy at these scales in this region.

Figure 13, curve A, is a plot of the variation of

$$S = \frac{1-f}{1-g}$$

against Δh.

In the region up to a scale of 3.5 km, S has a value of approximately 0.7, indicating an isotropy lying somewhere between two and three dimensional. The increase in S at scales greater than approximately 3 km is due to the breakdown at this scale of the 4/3 power law in both zonal and meridional spectrum functions.

The function S has been found to be quite sensitive to variation in the parameters specifying the mean wind profiles. For example, if, instead of the fourth order polynomial fits to the total height range of the zonal and meridional data, linear mean wind profiles are fitted over the height range 80 to 100 km only, subsequent spectrum analysis yields the S function of curve B of Figure 13. This curve would indicate the existence of three dimensional isotropy for scales up to 3 km. It is possible that the 4th order polynomial fits are, in fact, attributing a small fraction of the random wind variations to the mean motion. However, in order to correlate spectra obtained for different height strata (as is done in the next section), a continuous mean profile is required, and has therefore been used throughout the analysis.

3.5 Vertical Scale

The vertical scale associated with the turbulent wind structure is conveniently defined by the Δh corresponding to the maximum value of either $E(\Delta h)$ or $[1-R(\Delta h)]$. As can be seen from Figures 7, 9 and 11, which are plotted using zonal, meridional and windspeed turbulent velocities respectively, the vertical correlation distance as defined above is not the same for each component, i.e., the wind motions are not isotropic at the maximum of $E(\Delta h)$. However, for the purpose of comparison with stratospheric and lower mesospheric data, where meridional winds are, for the most part, negligible, consideration need only be given to the zonal energy spectrum.

The variation of vertical scale with height in the stratosphere has been determined by Webb (1964) from a series of Robin soundings at Eglin. His results indicate an exponential increase of the vertical scale with height, from approximately 800 metres at 35 km to 2 km at 55 km. He has extrapolated this exponential to a height of 90 km, and finds a vertical scale of 6 km which is the value determined for this height by Greenhow (1959) from a correlation analysis of wind shears determined by means of radio reflections from meteor trails at Jodrell Bank (53°N).

In order to investigate the change with height of the vertical correlation distance in the 80 to 130 km region, the sodium trail data was subjected to a stepwide analysis, starting with the 75 to 95 km height range, and proceeding via the 80 to 100, 85 to 105, etc. ranges to 115 to 135 km. The maxima of the resultant $E(\Delta h)$ curves were then plotted as the vertical scales at the midpoints of the respective height ranges. The results are shown in Figure 14, together with Greenhow's determination, and the 7.8 km at 94 km (October, 1961) determined from radio meteor trail shears at Adelaids (35°S) (Roper, 1962). The dashed line is Webb's extrapolated variation. While there is excellent agreement with Webb's proposed exponential increase, there is also good agreement between the vertical scales measured at various altitudes for the Eglin firing, and the atmospheric pressure scale height (also shown in Figure 14). This phenomenon has also been observed by others (e.g., Zimmerman (1964)). As yet, no satisfactory explanation for such a dependence has been proposed.

Above 125 km, the magnitudes of the deviations of the measured winds from the mean wind values becomes insignificant. Wind motions at these heights for this particular firing are characteristically nonturbulent.

Conclusions

The techniques of spectrum analysis hased on hydrodynamic turbulence theory can be profitably applied to wind data obtained from sodium trail rocket firings, at least in the height range from 80 to 100 km. The analysis of further firings should indicate whether or not the mean profiles determined as a prelude to spectrum analysis have any meteorological significance.

References

General

Kolmogorff, A., C. R. Akad. Sci. U.R.S.S., 30, 301, 1941.

Batchelor, G. K., The Theory of Homogeneous Turbulence, Cambridge University Press, 1953

Corrsin, S., Jour. Geophys. Res., 64, 2134, 1959

Tchen, C. M., Phys. Rev., 94, 4, 1954

Karman, T., von and Howarth, L., Proc. Roy. Soc., London 164, 192, 1938

Elford, W. G., Plan. and Space Sci., 1, 94, 1958

Elford, W. G., 1964 (unpublished)

Hutchings, J. W., Jour. Met., 12, 263, 1955

Edwards, H. D. et al., Jour. Geophys. Res. 68, 6062, 1963

Blamont, J. E., and De Jagar, C., Ann. de Geophys., 17, 134, 1961

Zimmerman, S. P., Ann de Geophys. 18, 116, 1962.

Roper, R. G., Ph.D. Thesis, University of Adelaide, 1962

Hines, C. O., Jour. Geophys. Res., 64, 2210, 1959

Hines, C. O., Quart. Jour. Roy. Met. Soc., 89, 1, 1963

Webb, W. L., U.S. Army E.R.D.A. - 130 , White Sands, New Mexico. April 1964

Greenhow, J. S., and Neufeld, E. L., Jour. Geophys. Res., 64, 2129, 1959

Zimmerman, S. P., Jour. Geophys. Res., 65, 784, 1964.

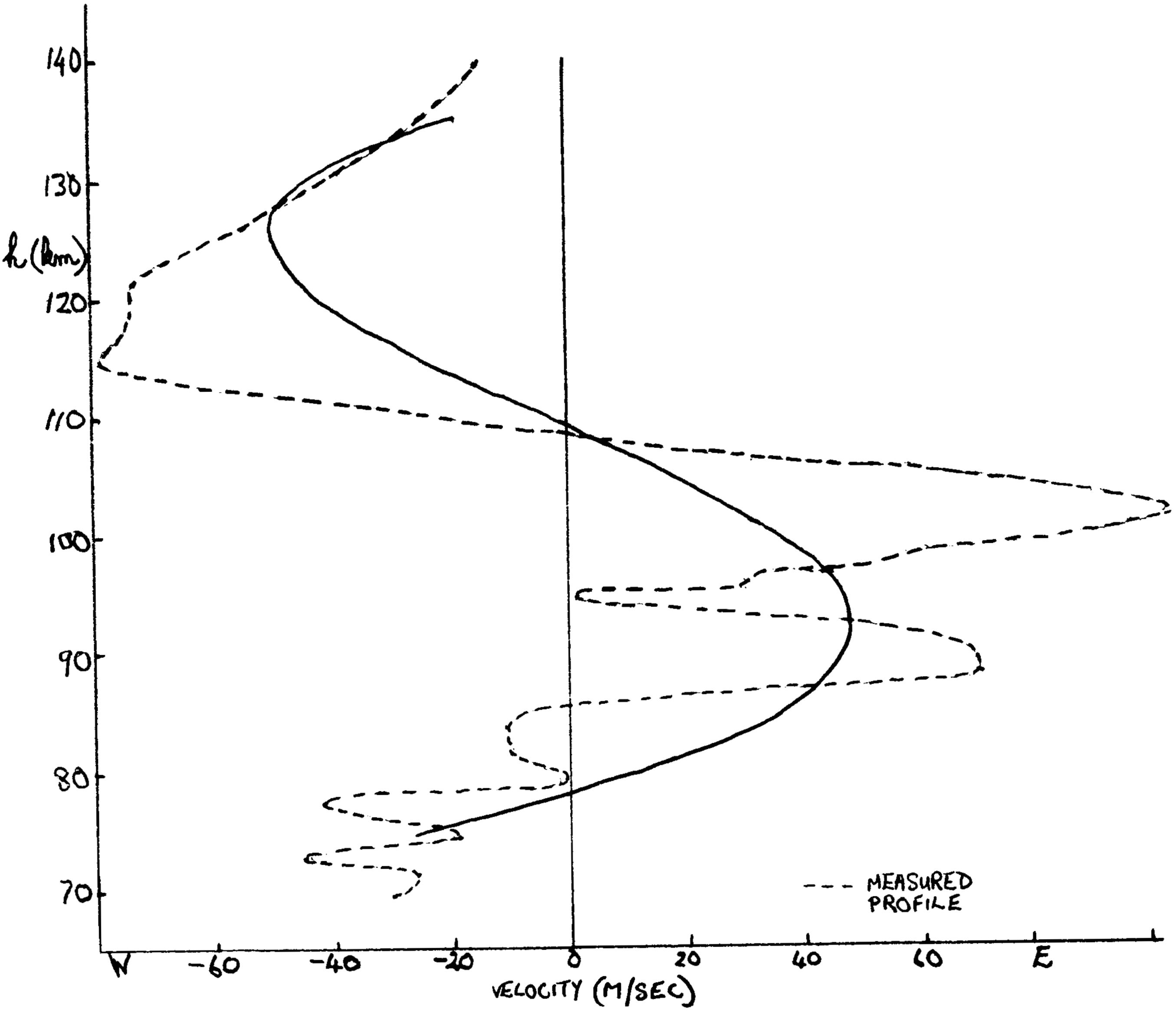

FIG 1. MEAN ZONAL PROFILE

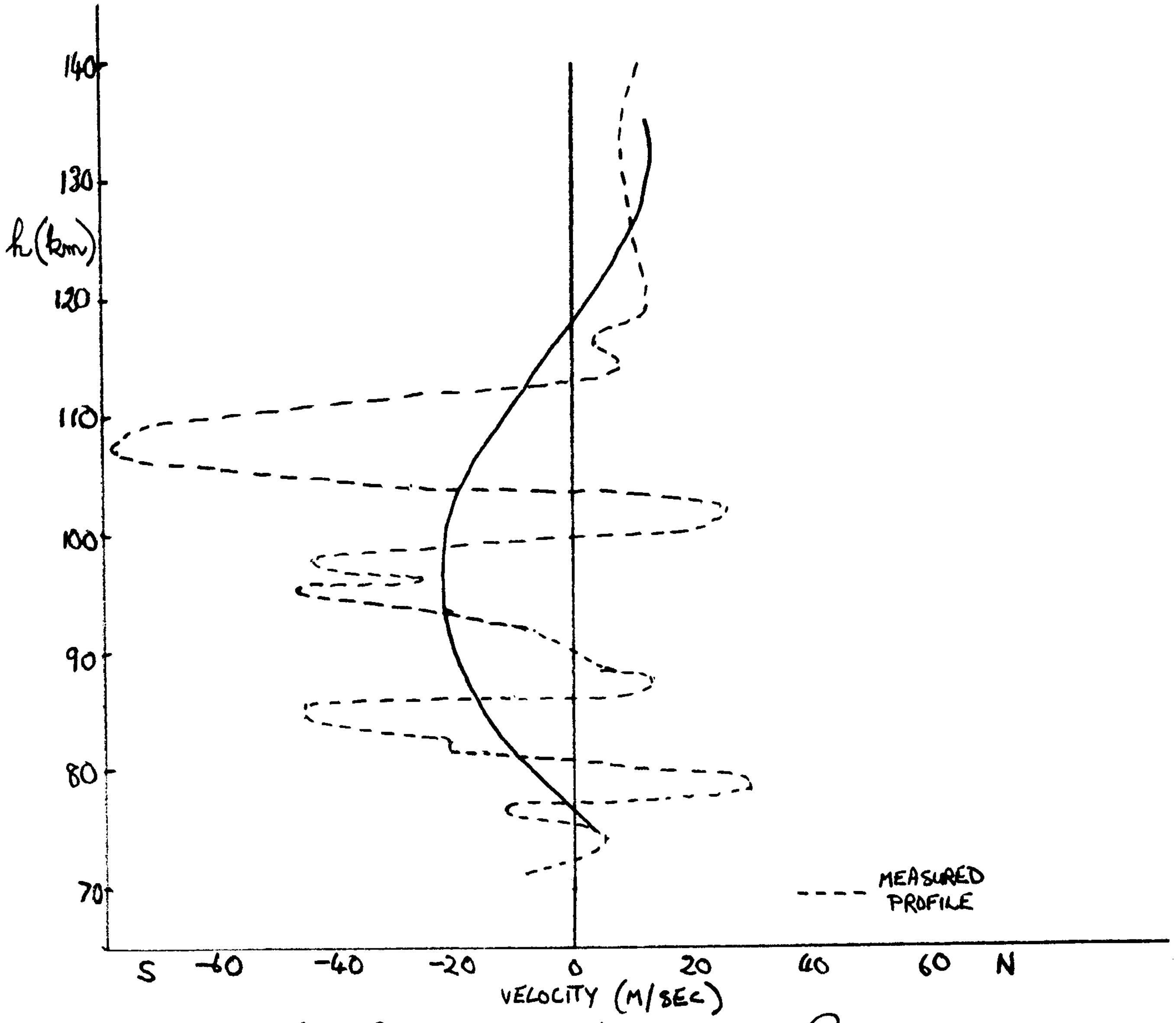

FIG. 2. MEAN MERIDIONAL PROFILE

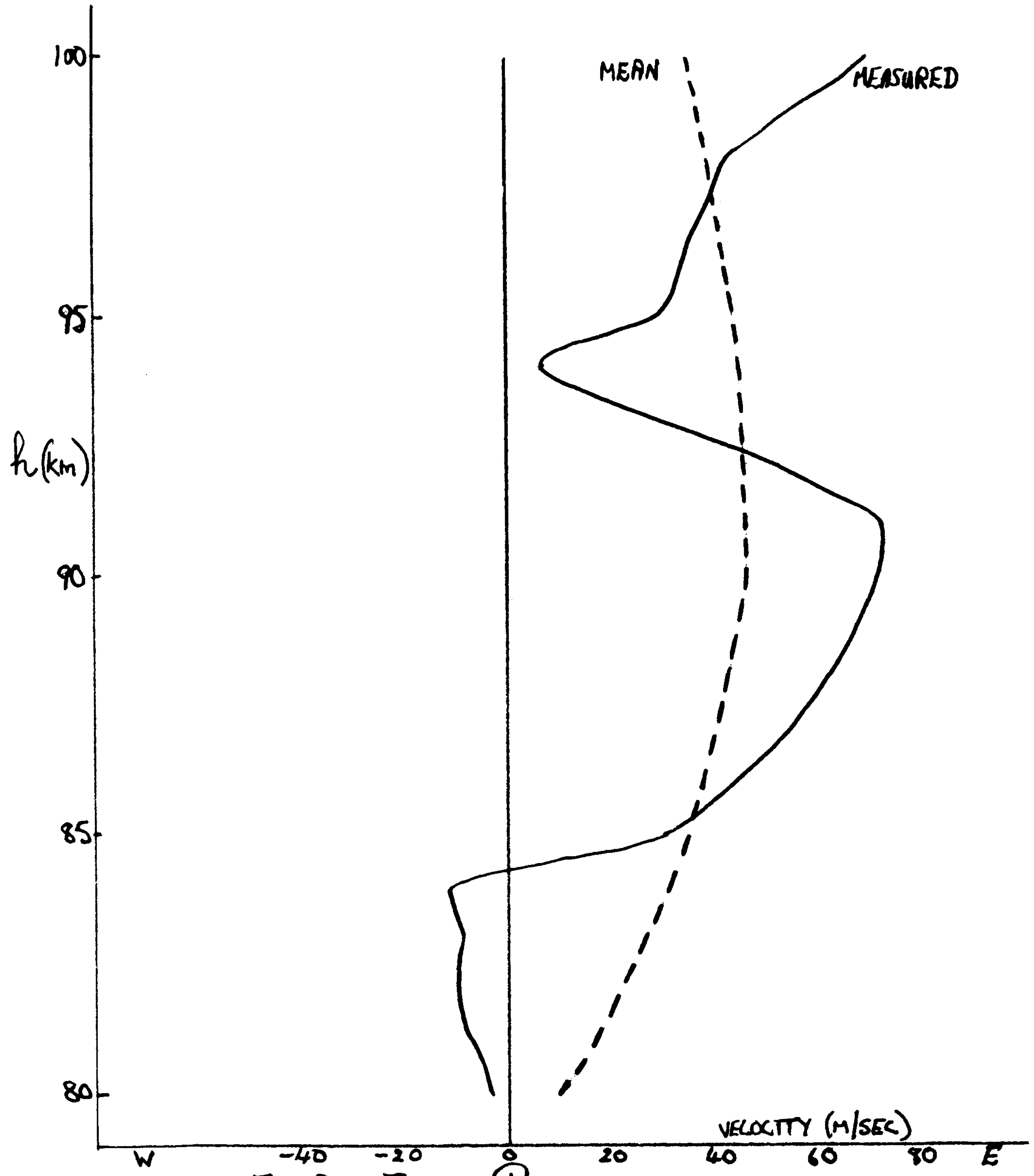

FIG. 3. ZONAL PROFILE, 80-100 KM

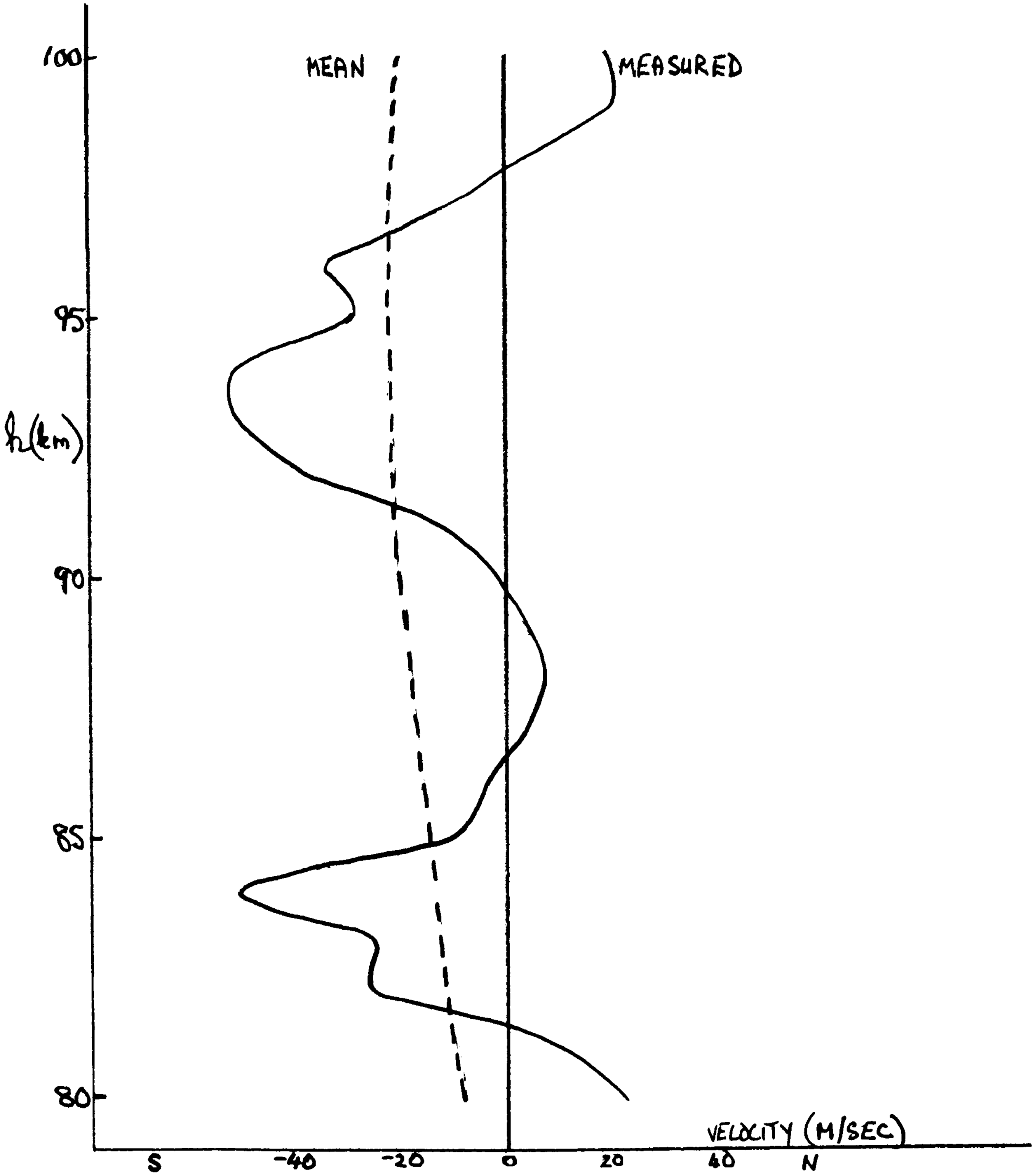

FIG. 4. MERIDIONAL PROFILE, 80-100KM.

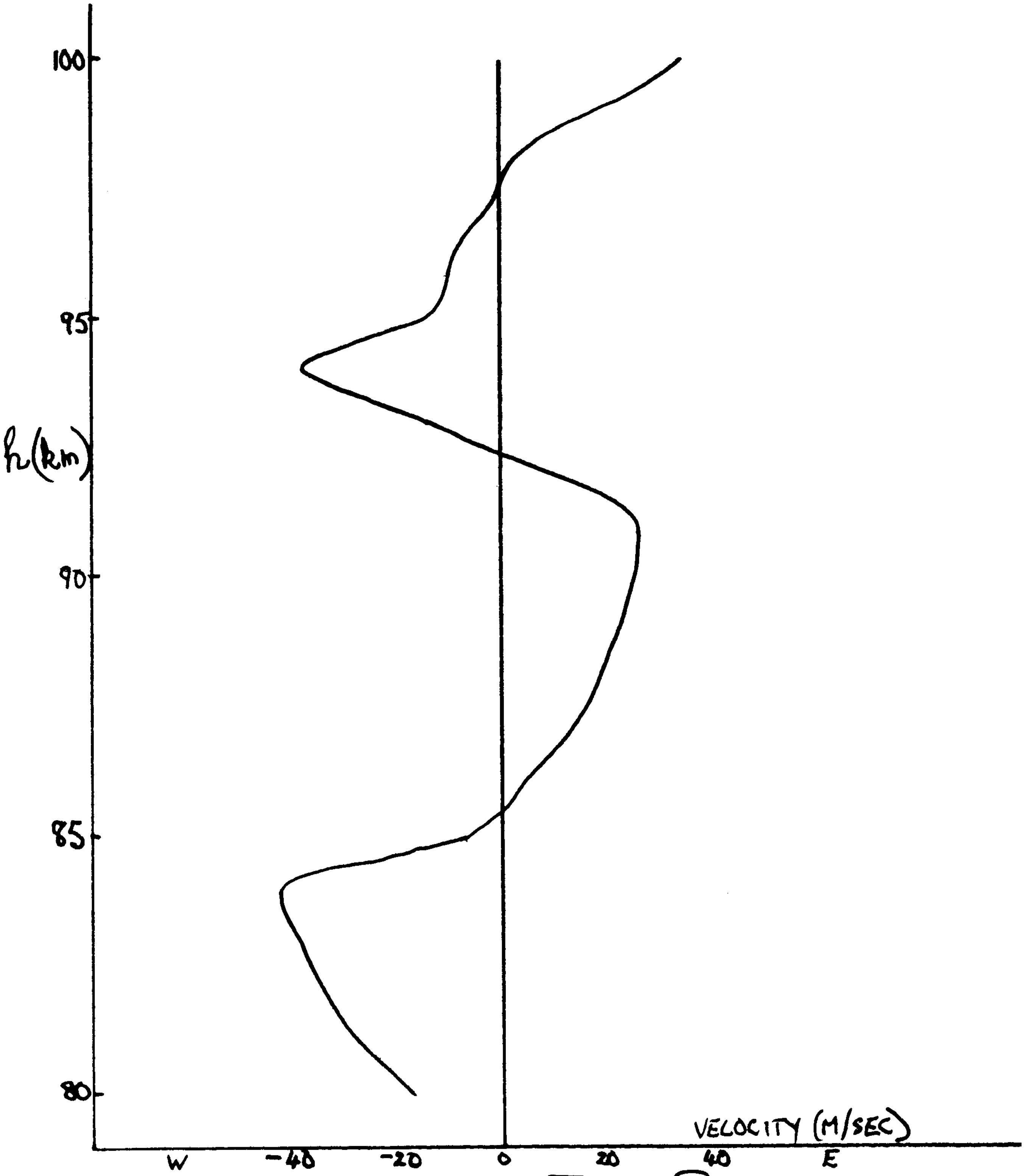

FIG. 5. TURBULENT ZONAL PROFILE

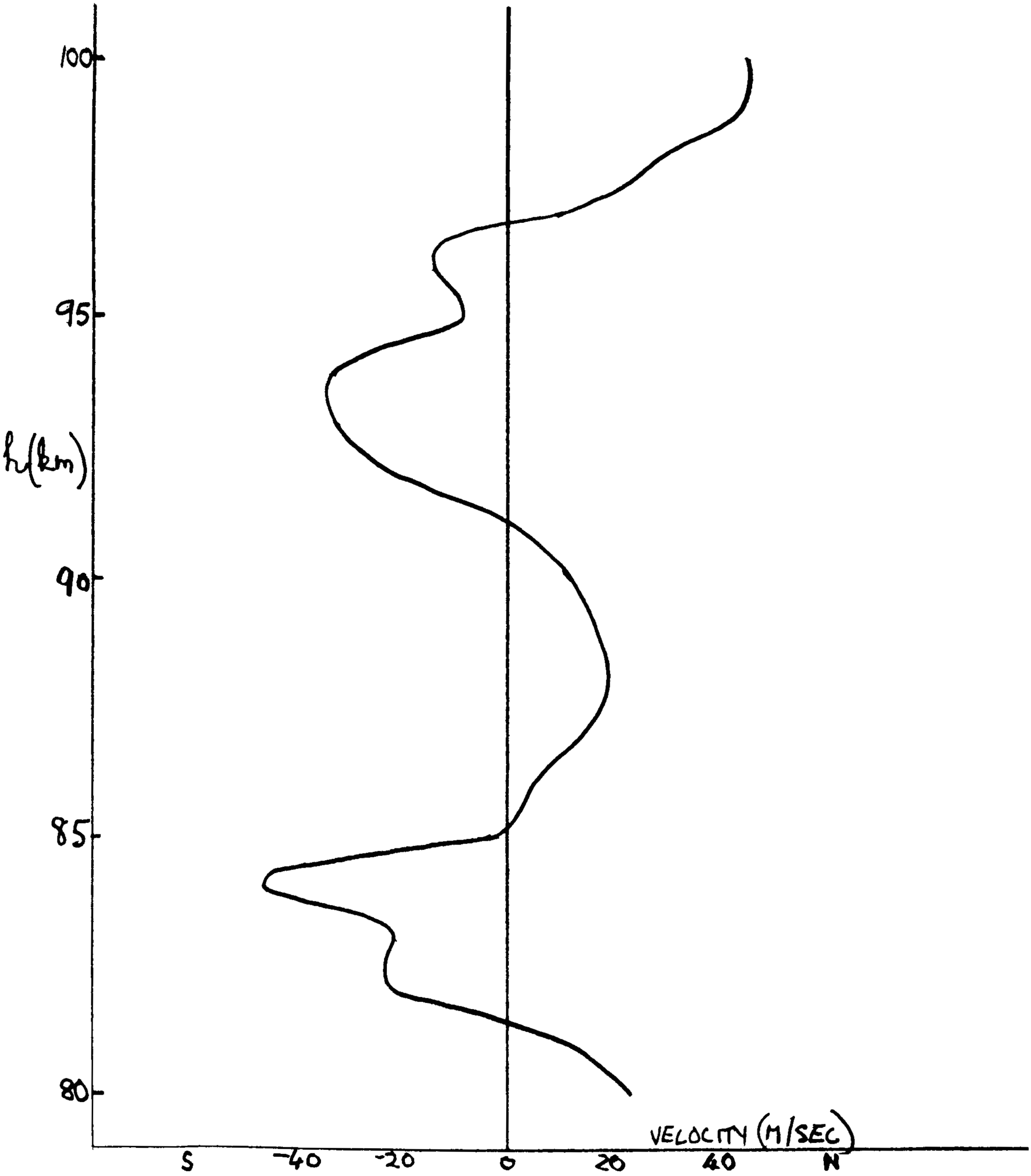

FIG. 6. TURBULENT MERIDIONAL PROFILE

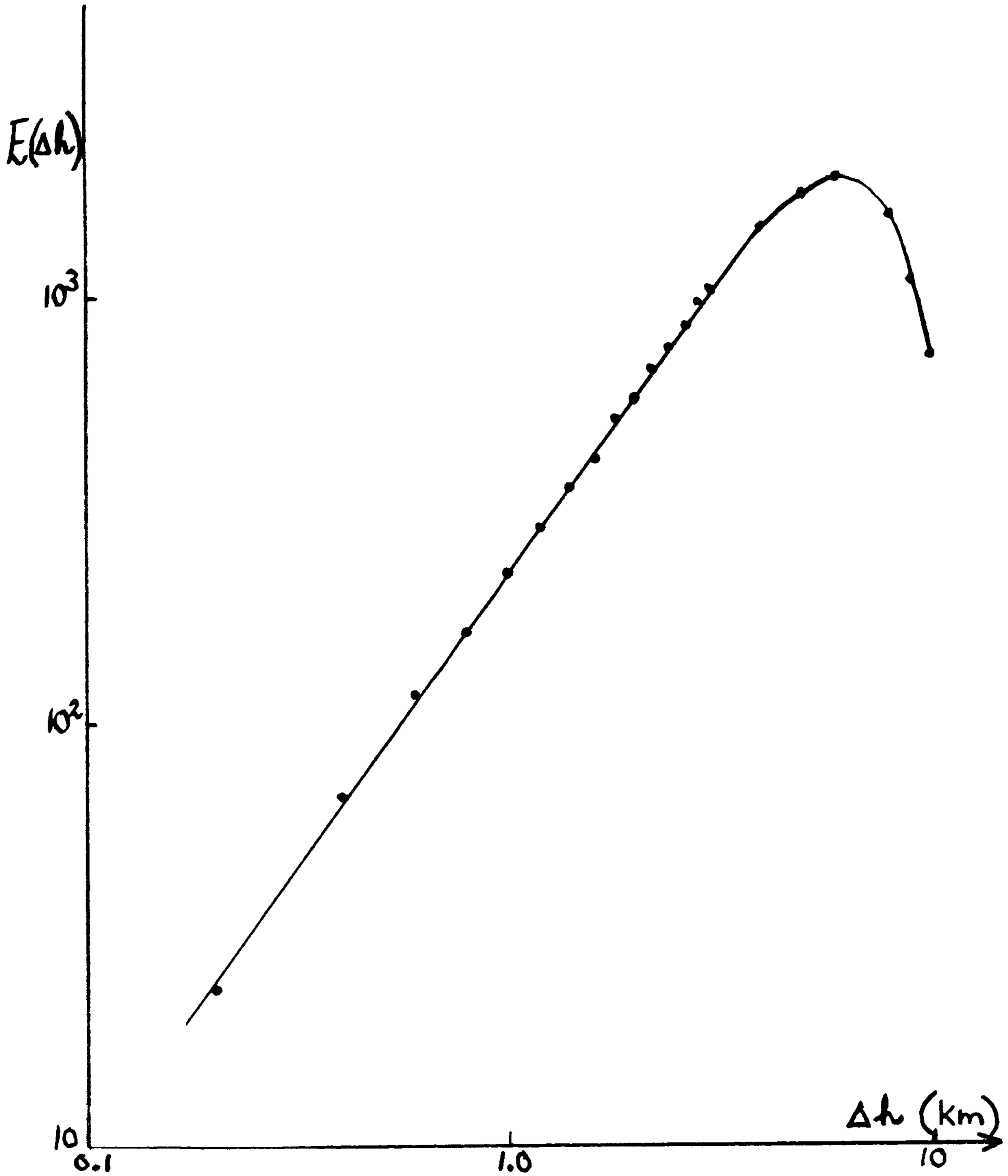

FIG. 7. THE ZONAL ENERGY SPECTRUM FUNCTION

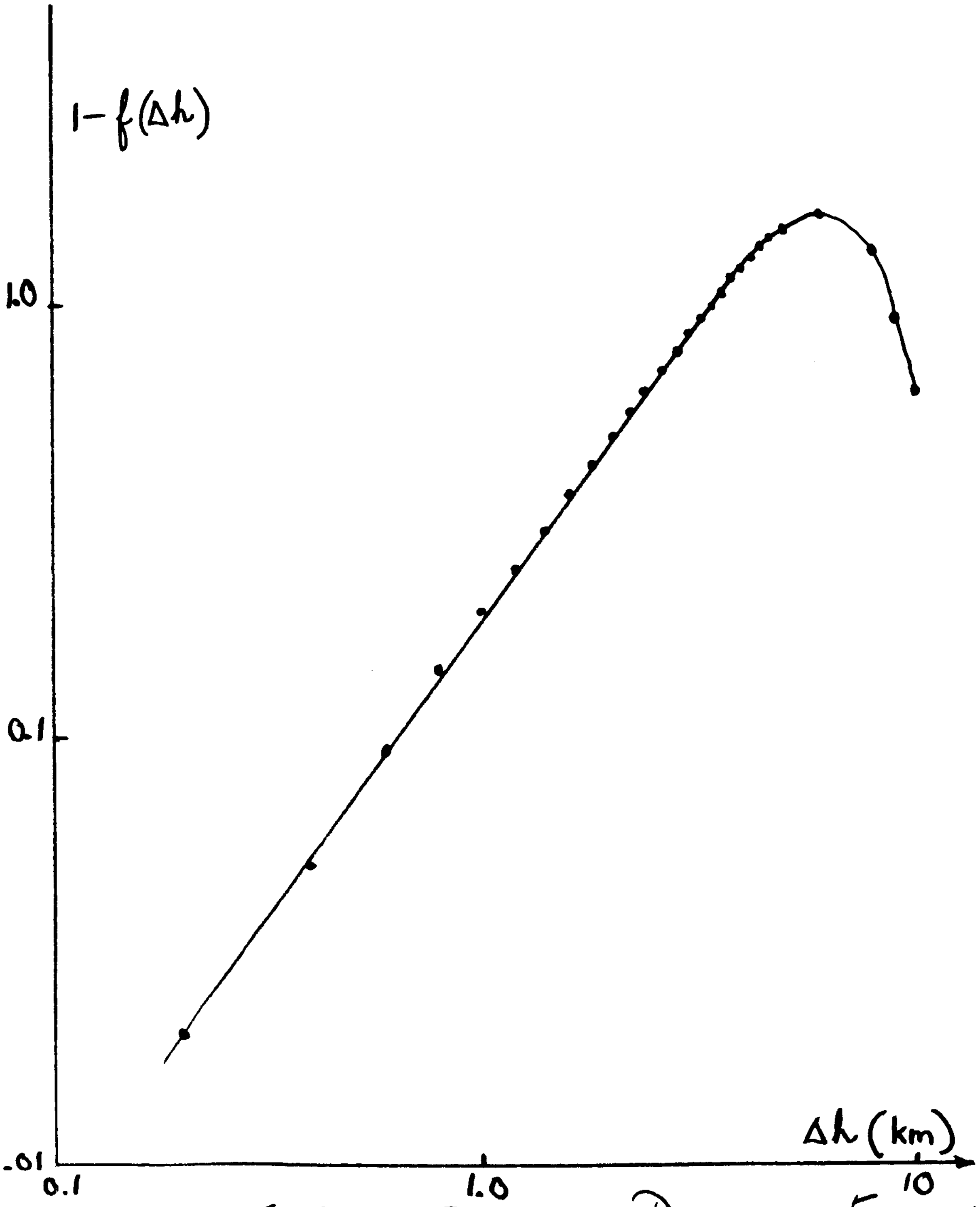

FIG. 8. THE ZONAL CORRELATION DIFFERENCE FUNCTION.

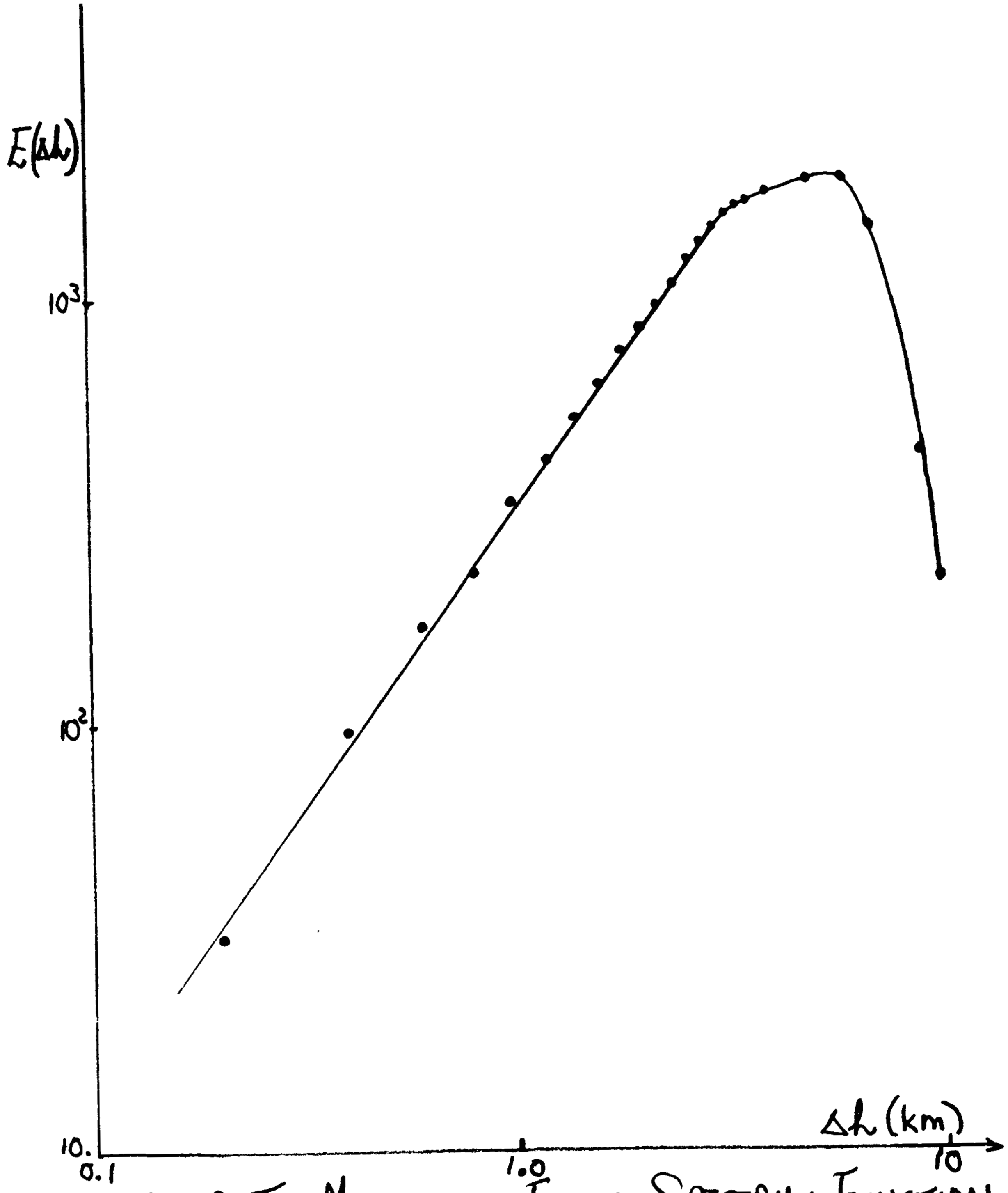

FIG. 9. THE MERIDIONAL ENERGY SPECTRUM FUNCTION.

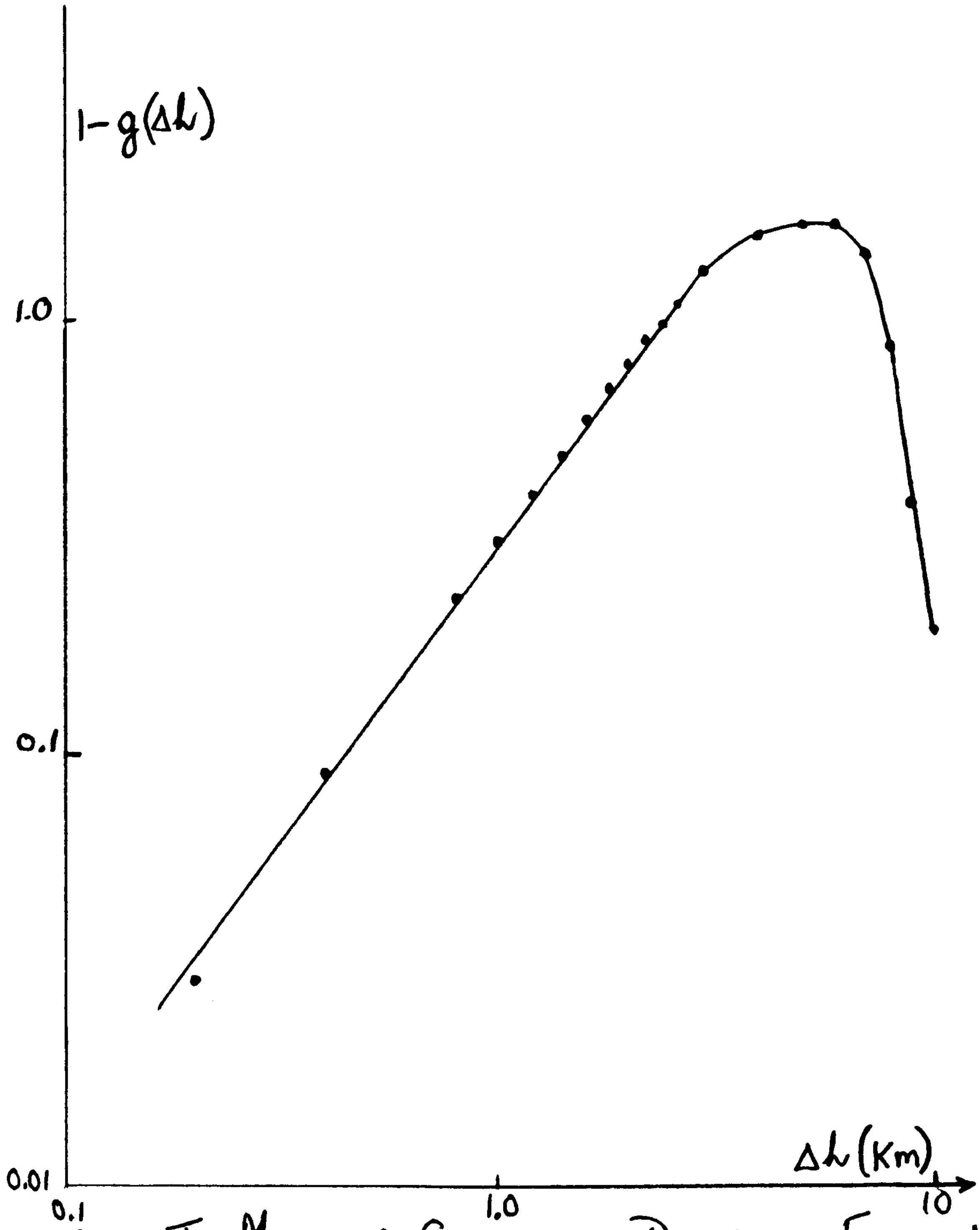

FIG. 10. THE MERIDIONAL CORRELATION DIFFERENCE FUNCTION.

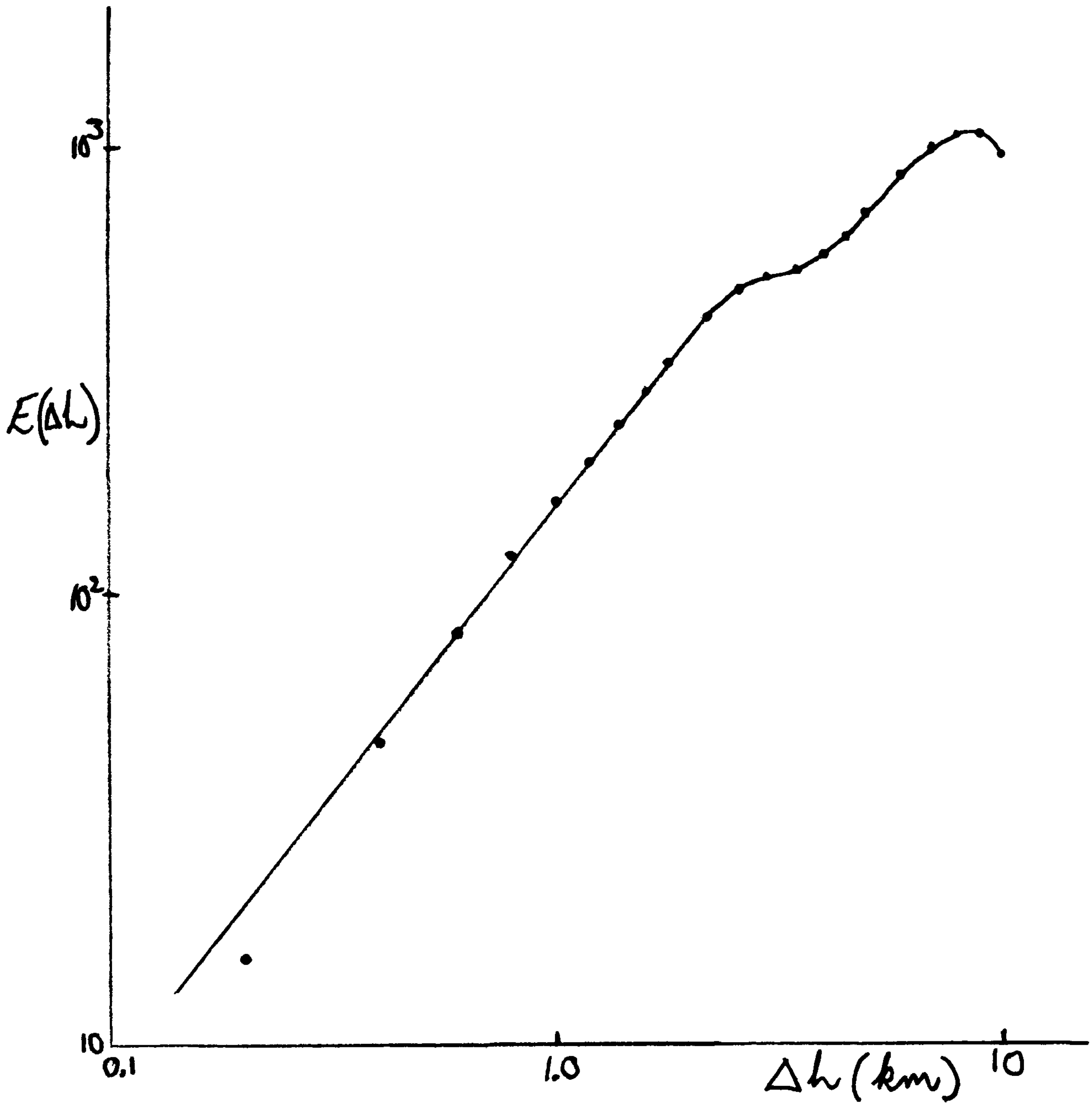

FIG 11. THE WINDSPEED ENERGY SPECTRUM FUNCTION.

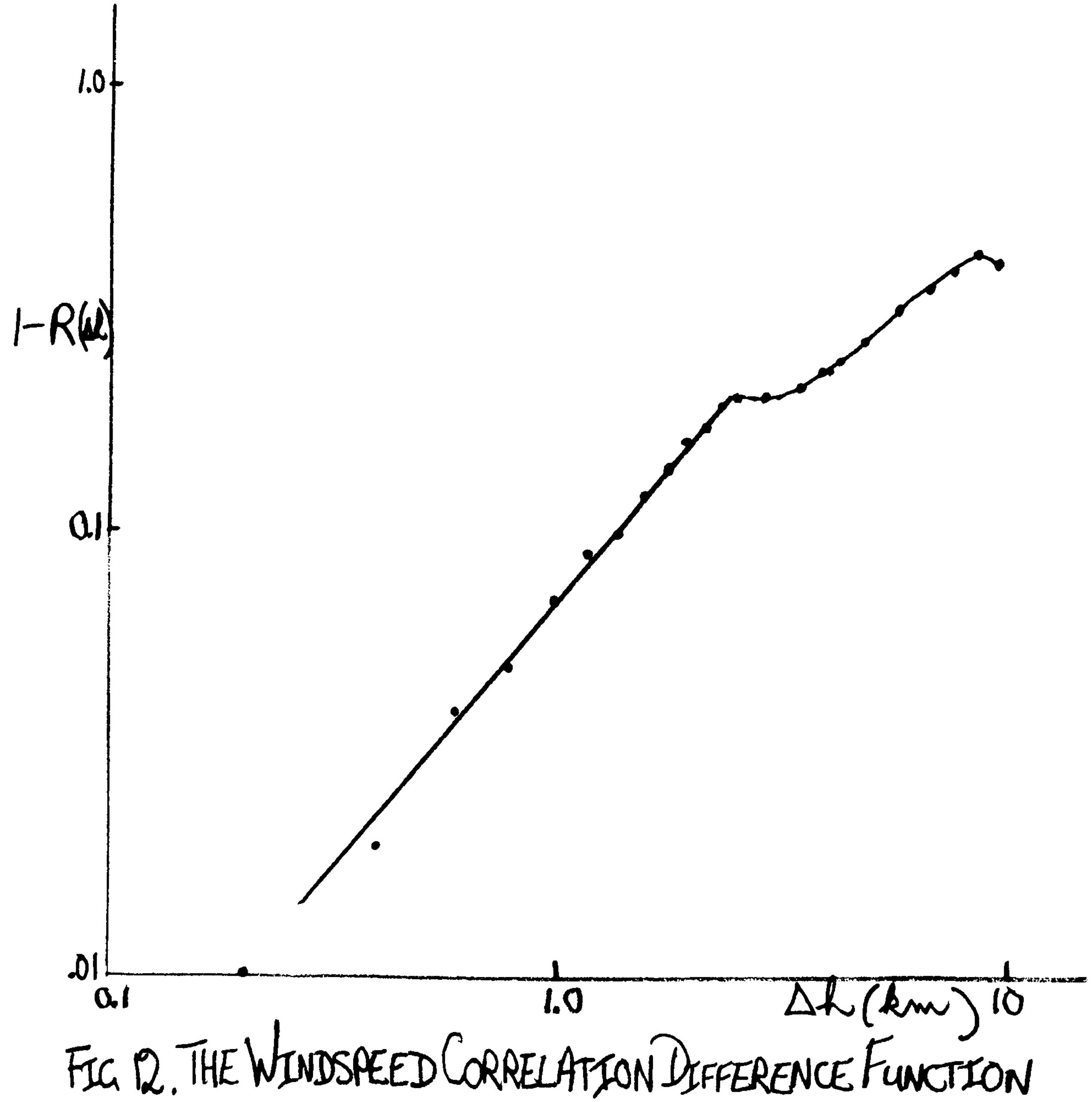

FIG. 12. THE WINDSPEED CORRELATION DIFFERENCE FUNCTION

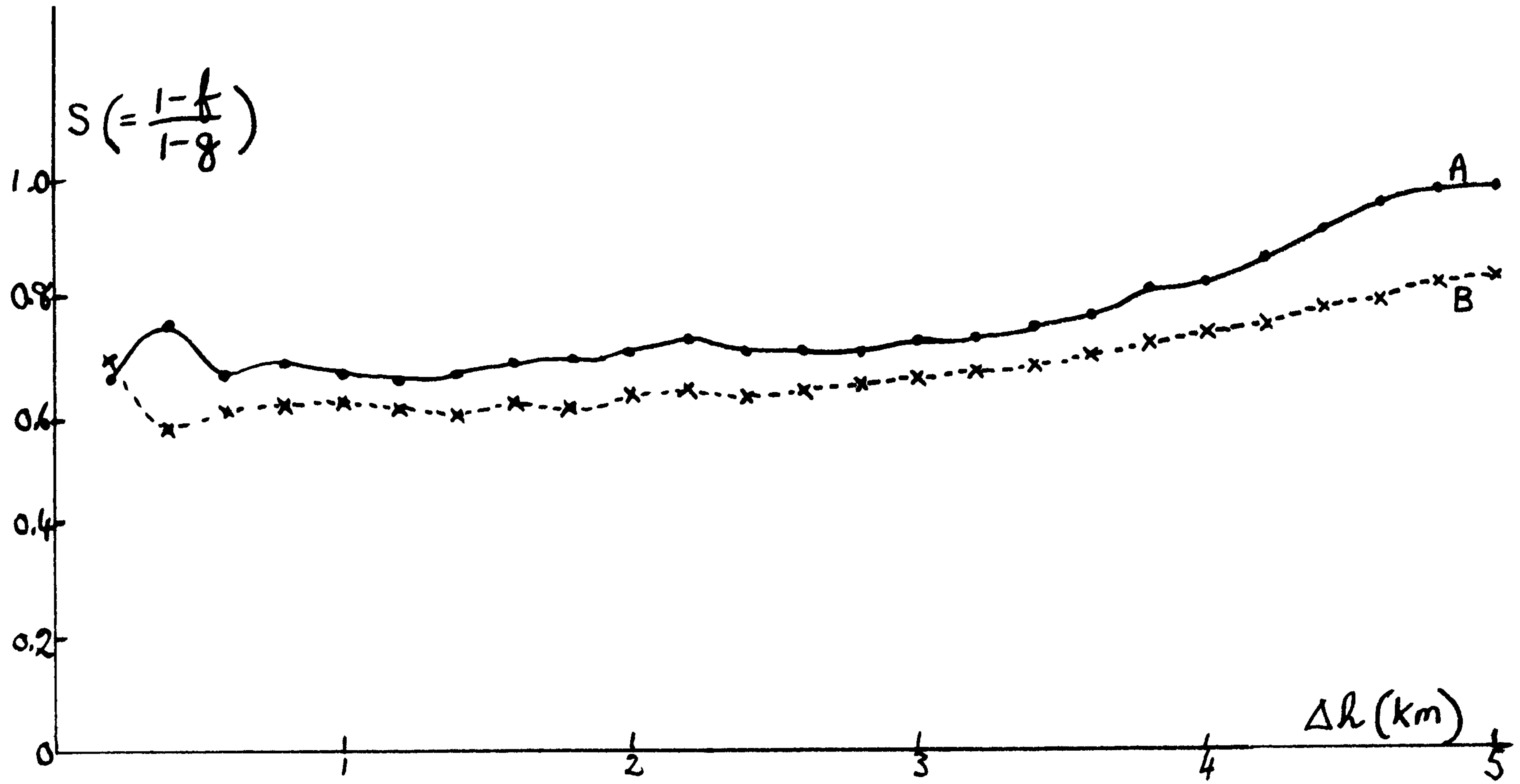

FIG. 13. VARIATION OF THE ISOTROPY PARAMETER "S" WITH SCALE.

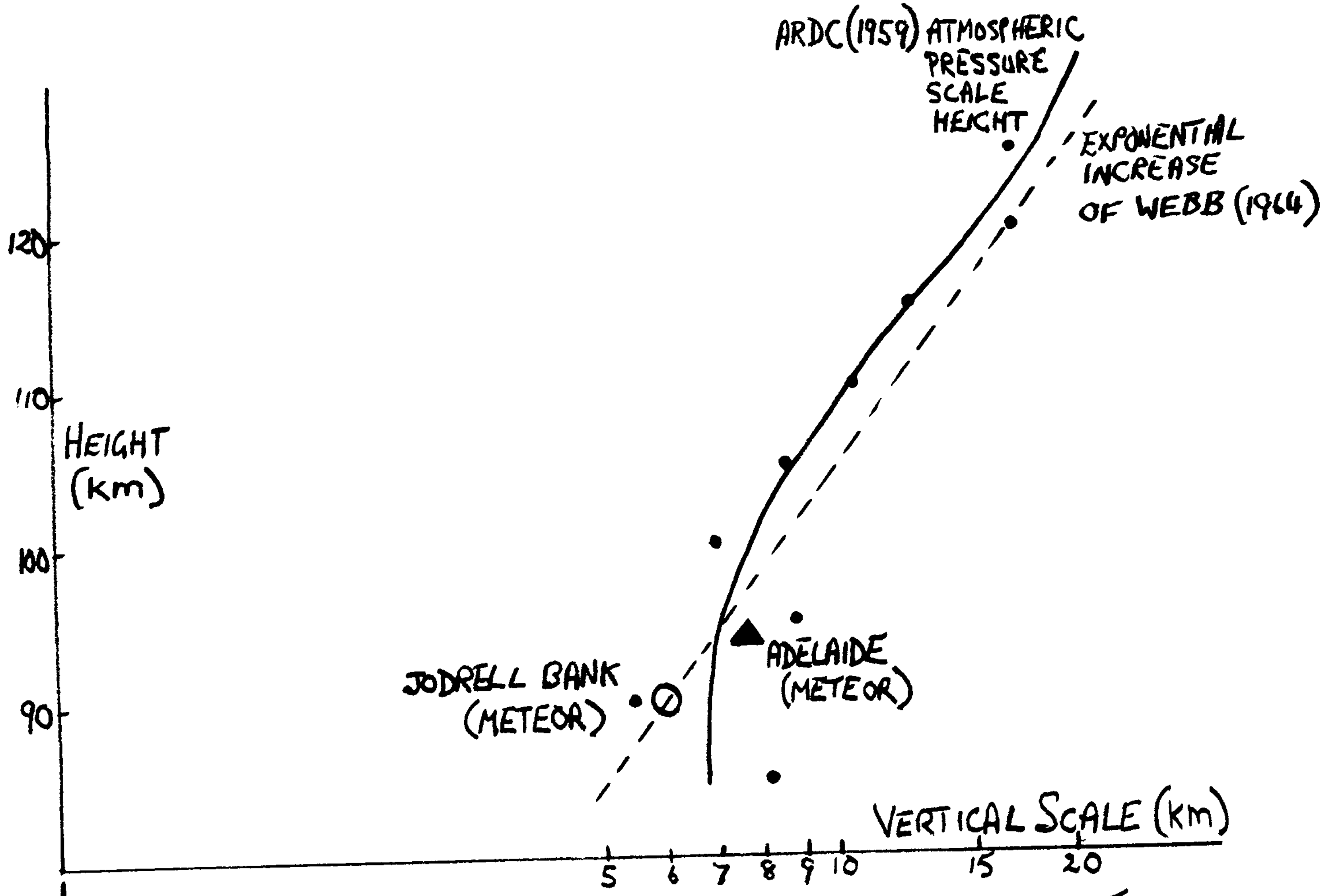

FIG. 14. VARIATION OF THE VERTICAL SCALE OF THE ZONAL TURBULENT WIND COMPONENT WITH HEIGHT

Appendix I

Resume of the Computer Program

The computer program has been written in FORTRAN IV for execution on an IBM 7094, and consists of the following routines:

1. The main program SHEAR which reads and does some processing of the input data (which is punched on cards).

SHEAR calls subroutines

a) FIT, which fits polynomial profiles to the zonal and meridional wind velocity/ height profiles by the method of least squares, utilizing

b) MATS, to solve the set of independent linear equations

c) The total wind speed profile is calculated by TRADE.

d) OUTPUT performs the energy spectrum and correlation analyses, and printout of same.

e) PAGE is a utility routine which turns and numbers the output pages, and prints an appropriate heading on each.

Input Data

The input data is on punched cards, and is read as follows:

1. Header Card; the information punched on this card is printed at the top of each page of output. The full 72 columns can be used for any type of alphanumeric heading.

2. The parameters specifying the mean zonal and meridional profiles. These determine the order of the polynomial fitted to

a) the zonal (punched in columns 2,3) and

b) the meridional (punched in columns 5,6) measured data to determine the mean profile.

e.g., a 5 punched in column 3 will fit a polynomial of the form

$$a_1 + a_2h + a_3h^2 + a_4h^3 + a_5h^4$$

to the zonal wind data.

The maximum allowable value of the subscript i in the a_i above is 10.

3. The height range (must be integral, and in km) over which the energy spectrum and correlation analyses are to be performed. This can be any fraction of the height interval covered by the input data, but must not be less than 10 km unless an appropriate spectral range is punched in column 13. The minumum of the height range interval is punched in columns 2 to 5, the maximum in columns 6 to 9. If OUTPUT is required to produce spectra over height differences to other than a maximum of 10 km, the required maximum height difference can be punched in columns 10 to 13. This entry must not exceed the height range specified in columns 2 to 9. If this last field is left blank, spectra to 10 km are output.

4. The trial data, which must not exceed a maximum to minimum height range of 150 km. The data is punched as year, month, day, hour (local time, 24 hour clock), height (km), windspeed (metres/sec), and azimuth (degrees) as follows

YR	MO	DAY	HOUR	HEIGHT	WINDSPEED	AZIMUTH
3	3	9	14	19	24	29

all integer

must be right adjusted if integer; anywhere in appropriate field if decimal punch is included.

5. After all data of 4. a blank card to flag "end of data".

6. Further height ranges as for 3 as required.

7. a) If a change in the mean wind profile is required a card with a 2 punched in column 1 may be substituted for any of the cards 6, and followed by a card of format 2 above which specified the new profile. This card is then followed by further height ranges (as for 6.) as required.

7 b) If a completely new set of header plus data cards is to be processed after either stages 5, 6, or 7a, a card with a 1 punched in column 1 will return control to the start of the program, which will then read in the new set of data cards sequenced as from 1 above.

APPENDIX II

Listing of the FORTRAN IV Program

```
C     SODIUM TRAIL HEIGHT SHEAR ANALYSIS PROGRAM
C
C     CALCULATES THE ENERGY SPECTRUM FOR TOTAL SHEAR,AND FOR ZONAL AND
C     MERIDIONAL SHEAR COMPONENTS
C
C     READS INPUT DATA AS FOLLOWS
C     A HEADER CARD, PUNCHED WITH DETAILS OF FIRING TIME, ETC.
C     FORMAT 12A6
C     THE PARAMETERS SPECIFYING THE MEAN ZONAL AND MERIDIONAL PROFILES,
C     FORMAT 2I3
C     THE HEIGHT RANGE OVER WHICH ANALYSIS IS TO BE PERFORMED,ZMIN,
C     ZMAX, AND THE MAXIMUM OF THE OUTPUT SPECTRAL RANGE DESIRED.
C     FORMAT  1X2F4.0,I4.
C     SPECTRAL RANGE MUST NOT EXCEED ZMAX-ZMIN.
C     IF NO SPECTRAL RANGE IS SPECIFIED, ZMAX-ZMIN MUST BE GREATER THAN
C     10KM, AND SPECTRA WILL BE OUTPUT TO 10KM.
C     THE TRAIL DATA, YEAR MONTH DAY LOCAL TIME (HOURS AND MINUTES,
C     24 HOUR CLOCK) HEIGHT(KM) WIND SPEED(METRES/SEC) WIND AZIMUTH
C     (DEGREES).
C     FORMAT 3I3,I5,F5.1,2F5.0
C     A BLANK CARD
C     FURTHER ZMIN, ZMAX AS REQUIRED.  IF A 2 APPEARS IN COLUMN 1,
C     PROGRAM WILL READ NEXT CARD AS NEW PROFILE SPECIFICATION, FOLLOWED
C     BY FURTHER ZMIN, ZMAX CARDS.  IF A 1 APPEARS IN COLUMN 1, THE
C     PROGRAM WILL READ NEXT CARD AS HEADER CARD OF A COMPLETELY NEW SET
C     OF DATA.
C
      DIMENSION BZ(10), BM(10)
      DIMENSION RESULT(12),ZI(750),WINDI(750),AZRADI(750),ZONAL(750),
     1ERID(750),            TZONAL(750),TMERID(750)
      DIMENSION TSPEED(750), AW(5)
      COMMON ZI, WINDI,AZRADI,ZONAL,ERID,TZONAL,TMERID ,TSPEED
      C=0.05
      CS=0.000001
      PI=3.1415926
      TWOPI=2.0*PI
  999 NGO=0
      NI=0
      I=0
      NSUM=0
      ZERO=0.0
      READ      (2,1)RESULT
    1 FORMAT(12A6)
   17 READ      (2,4)NP,NC
    4 FORMAT (2I3)
      NFIT=-1
    2 READ(2,3)NGO,ZMIN,ZMAX,NDIFF
    3 FORMAT(I1,2F4.0,I4)
      IF(NGO)19,19,18
   18 IF(NGO-2)999,17,17
   19 CONTINUE
      IF(NDIFF)20,20,21
   20 NDIFF=10
   21 MIN=ZMIN+C
      MAX=ZMAX+C
```

```
        IF(NI)5,5,101
C       TRAIL DATA INPUT
      5 READ      (2,6)MYEAR,MONTH,JOUR,LTIME,Z,WIND,AZDEG

      6 FORMAT(3I3,I5,F5.1,2F5.0)
        IF(MYEAR)100,100,7
      7 I=I+1
        IF(I-1)11,11,8
      8 ZDIFF=Z-ZI(I-1)
        MZ=10.0*Z+0
        LZ=10.0*ZI(I-1)+0
        LDIFF=MZ-LZ
        IF(LDIFF-2)12,11,9
     12 WRITE     (3,6)MYEAR,MONTH,JOUR,LTIME,Z,WIND,AZDEG
        WRITE(3,13)
     13 FORMAT(1X/////1X26HDATA CARDS OUT OF SEQUENCE//////1X20HEXECUTION
       1TERMINATED//////1X)
        PRINT 13
        CALL EXIT
C       INTERPOLATION ROUTINE
      9 NPOINT=LDIFF/2-1
        NSUM=NSUM+NPOINT
        GRAD=(WIND - WINDI(I-1))/ZDIFF
        AZDIFF=AZDEG/57.3-AZRADI(I-1)
        IF(ABS(AZDIFF)-PI)94,94,91
     91 IF(AZDIFF)92,94,93
     92 AZDIFF=AZDIFF+TWOPI
        GOTO94
     93 AZDIFF=AZDIFF-TWOPI
     94 AZGRAD=AZDIFF/ZDIFF
        DO10J=1,NPOINT
        ZI(I)=ZI(I-1)+0.2
        WINDI(I)=WINDI(I-1)+0.2*GRAD
        AZRADI(I)=AZRADI(I-1)+0.2*AZGRAD
        IF(AZRADI(I))95,96,96
     95 AZRADI(I)=AZRADI(I)+TWOPI
     96 IF(AZRADI(I)-TWOPI)98,98,97
     97 AZRADI(I)=AZRADI(I)-TWOPI
     98 CONTINUE
        I=I+1
     10 CONTINUE
     11 ZI(I)=Z
        WINDI(I)=WIND
        AZRADI(I)=AZDEG/57.3
        GO TO 5
    100 NI=I
C       ALL DATA IN. COMMENCE COMPUTATION
        HDIFF=ZI(NI)-ZI(1)
        HPLUS=ZI(NI)+ZI(1)
C       CALCULATE ZONAL AND MERIDIONAL WIND COMPONENTS
        DO201J=1,NI
        ZONAL(J)=WINDI(J)* SIN(AZRADI(J))
    201 ERID(J)=WINDI(J)* COS(AZRADI(J))
    101 NZ=0
        LMIN=10*MIN
        LMAX=10*MAX
```

```
      CALL PAGE(RESULT, ZERO)
      DO104J=1,NI
      LZ=ZI(J)*10.0+C
      IF(LZ-LMIN)104,102,102
  102 IF(LZ-LMAX)103,103,104
  103 NZ=NZ+1
  104 CONTINUE
      WRITE      (3,105)NI,NSUM,ZMIN,ZMAX,NZ,NP,NQ
  105 FORMAT(1X/////1X33HTOTAL NUMBER OF INPUT DATA POINTS I8///1X26HINC
     1LUDING INTERPOLATION OF I5,7H POINTS ////1X45HNUMBER OF DATA POINT
     2S WITHIN THE HEIGHT RANGE F5.0,6H KM TO,F5.0,3H KM I8////1X31HEAST
     3 WEST PROFILE SPECIFICATION I5 ///1X33HNORTH SOUTH PROFILE SPECIFI
     4CATION  I3 ///1X)
      START=1
      CALL PAGE(RESULT,START)
      WRITE      (3,106)ZMIN,ZMAX
  106 FORMAT(1X50HCALCULATED ZONAL AND MERIDIONAL MEAN WIND PROFILES
     110X12HHEIGHT RANGE F5.0,6H KM TO F5.0,3H KM/1H0
     2/10X 6HHEIGHT 10X5HZONAL 13X10HMERIDIONAL 10X10HWIND SPEED /1X/
     31X,18X,3(4X12HDATA    MEAN,4X),/1X/)
      NHITE=(ZMAX-ZMIN)/20.0-C
      NHITE=NHITE+1
      INK=5*NHITE-1
      NFIT=NFIT+1
      IF(NFIT)202,202,203
C     CALCULATE COEFFICIENTS OF MEAN PROFILE POLYNOMIALS
  202 CALL NORMAL(ZONAL,ERID,ZI,NI,BZ,BM,NP,NQ)
  203 CONTINUE
C     DETERMINE AND PRINT OUT MEAN WIND PROFILES
      SUBS=(ZMAX+ZMIN-ZI(1))*5.0+1.0+C
      DO108L=MIN,MAX,NHITE
      IZ=SUBS-FLOAT(L*5)
      J=MAX+MIN-L
      H=J
      S=(2.0*H-HPLUS)/HDIFF+CS
      AZONAL=0.0
      AMERID=0.0
      DO204M=1,10
      AZONAL=AZONAL+BZ(M)*S**(M-1)
      AMERID=AMERID+BM(M)*S**(M-1)
  204 CONTINUE
      MZONAL=AZONAL
      MMERID=AMERID
      MSPEED=SQRT(AZONAL**2+AMERID**2)
      WRITE(3,107)J,ZONAL(IZ),MZONAL,ERID(IZ),MMERID,WINDI(IZ),MSPEED
  107 FORMAT(1XI13,4X,3(  F8.0,4XI4,4X),/1X)
  108 CONTINUE
      CALL PAGE (RESULT,START)
      WRITE(3,109)ZMIN,ZMAX
  109 FORMAT(1X,22HTURBULENT WIND PROFILE,10X12HHEIGHT RANGE F5.0,
     1 6HKM TO F5.0,3H KM/1X/1X,10X6HHEIGHT,10X6HTZONAL,10X11HTMERIDIONA
     2L,10X6HTSPEED/1X)
C     DETERMINE AND PRINT OUT TURBULENT WIND PROFILES
      NH=(MAX-MIN)*5+1
      K=(ZMAX-ZI(1))*5.0+2.0+C
      NK=INK
```

```
      RMSZ=0.0
      RMSM=0.0
      RMST=0.0
      SUMSQT=0.0
      DO112J=1,NF
      TZONAL(J)=0.0
      TMERID(J)=0.0
      K=K-1
      H=ZMAX-0.2*FLOAT(J-1)
      IH=H+0
      S=(2.0*H-HPLUS)/HDIFF+CS
      NK=NK+1
      DO205M=1,10
      TZONAL(J)=TZONAL(J)+BZ(M)*S**(M-1)
      TMERID(J)=TMERID(J)+BM(M)*S**(M-1)
  205 CONTINUE
      TZONAL(J)=ZONAL(K)-TZONAL(J)
      TMERID(J)=ERID(K)-TMERID(J)
      CALL TRACE(J,K)
C     CALCULATE RMS TURBULENT VELOCITIES FOR THE HEIGHT RANGE ZMIN/ZMAX
      RMSZ=TZONAL(J)**2+RMSZ
      RMSM=TMERID(J)**2+RMSM
      RMST=TSPEED(J)**2+RMST
      SUMSQT=SUMSQT+1.0
      IF(NK-INK)112,112,110
  110 WRITE(3,111)IH,TZONAL(J),TMERID(J),TSPEED(J)
  111 FORMAT(1X,10XI4,12XF5.0,11XF8.0,13XF5.0/1X)
      NK=0
  112 CONTINUE
      CALL PAGE(RESULT,START)
      RMSZ=SQRT(RMSZ/SUMSQT)
      RMSM=SQRT(RMSM/SUMSQT)
      RMST=SQRT(RMST/SUMSQT)
      WRITE(3,206)ZMIN,ZMAX,(BZ(I),I=1,NP)

  206 FORMAT(1X10HNORMALIZED
     1        1X12HHEIGHT RANGE10XF7.0,7H KM. TO F7.0,4H KM./1H0/
     2        1X42HCOEFFICIENTS GIVING BEST FIT TO ZONAL DATA/1X/10E11.3)
      WRITE(3,207)(BM(I),I=1,NP)
  207 FORMAT(1X/1X/
     11X/1X47HCOEFFICIENTS GIVING BEST FIT TO MERIDIONAL DATA/1X/1X10E11
     2.3/1X/)
      WRITE(3,208)RMSZ,RMSM,RMST
  208 FORMAT(1X/1X
     1       1X22HRMS TURBULENT VELOCITY/1X/1X10X5HZONALF11.0,11HMETRES/S
     2EC./1X/1X10X10HMERIDIONAL F6.0,11HMETRES/SEC./1X/1X10X10HWIND SPEE
     3D F6.0,11HMETRES/SEC.)
      CALL PAGE(RESULT,START)
      WRITE     (3,113)ZMIN,ZMAX
  113 FORMAT(1X46HENERGY SPECTRUM OF ZONAL WIND HEIGHT VARIATION,
     110X12HHEIGHT RANGE F5.0,6H KM TO F5.0,3H KM/1X)
C     CALCULATE AND OUTPUT ENERGY SPECTRUM FUNCTIONS
      CALL OUTPUT(TZONAL,NF,NDIFF)
      CALL PAGE(RESULT,START)
      WRITE     (3,114) ZMIN,ZMAX
  114 FORMAT(1X51HENERGY SPECTRUM OF MERIDIONAL WIND HEIGHT VARIATION,
```

```
/$ID J02T         RGR    BLDG 11
 $PAUSE
 $EXECUTE        IBJOB
 IBJOB VERSION 2,  7090 - PR - 929
1

0
 $IBJOB          GO
 $IBFTC OUT      M94,XR7
1               OUT
              EXTERNAL FORMULA NUMBER    -    SOURCE STATEMENT    -    INTER
0
       SUBROUTINE OUTPUT(TSPEED,NH,NDIFF)
 C
 C     PRODUCES HEIGHT SPECTRUM AND PERFORMS CORRELATION ANALYSIS.
 C
       DIMENSION TSPEED(750)
       WRITE(3,1)
     1 FORMAT(1X,10X7HDELTA H,5X10HE(DELTA H),
      15X11HCORRELATION,3X13HSIGNIF     1-G   /1X)
       NEND=5*NDIFF
       LINE=0
       DO125K=1,NEND
       LINE=LINE+1
       DELTAH=FLOAT(K)*0.2
       SUM=0.0
       ENERGY=0.0
       ERGX=0.0
       GJPKXJ=0.0
       SQJ=0.0
       SQJPK=0.0
       DO123J=1,NH
       IF(NH-J-K)124,122,122
   122 JPK=J+K
       ENERGY=ENERGY+(TSPEED(JPK)-TSPEED(J))**2
       SUM=SUM+1.0
       GJPKXJ=GJPKXJ+TSPEED(JPK)*TSPEED(J)
       SQJ=SQJ+TSPEED(J)**2
       SQJPK=SQJPK+TSPEED(JPK)**2
   123 CONTINUE
   124 IF(SUM)117,117,118
   117 G=0.0
       SIGNIF=9.99
       GOTO119
   118 ENERGY=ENERGY/SUM
       G=GJPKXJ/SQRT(SQJ*SQJPK)
       SIGNIF=(1.0-G**2)/SQRT(SUM-1.0)
   119 DIFF=1.0-G
       IF(LINE-50)125,125,116
   116 WRITE(3,2)
     2 FORMAT(1H1/1X)
       WRITE(3,1)
       LINE=0
   125 WRITE(3,115)DELTAH,ENERGY,      G,SIGNIF,DIFF
   115 FORMAT(1X,6XF8.1,   7XF8.1  ,8XF8.3,F11.3,F8.2)
       RETURN
       END
```

```
     110X12HHEIGHT RANGE F5.0,6H KM TO F5.0,3H KM/1X)
      CALL OUTPUT(TMERID,NF,NDIFF)
      CALL PAGE(RESULT,START)
      WRITE     (3,115)ZMIN,ZMAX
  115 FORMAT(1X46HENERGY SPECTRUM OF WIND SPEED HEIGHT VARIATION,
     110X12HHEIGHT RANGE F5.0,6H KM TO F5.0,3H KM/1X)
      CALL OUTPUT(TSPEED,NF,NDIFF)
      GOTO2
      END
```

```
$IBJOB          GC
$IBFTC NORMAL   M94,XR7
```

```
              NORMAL
           EXTERNAL FORMULA NUMBER    -    SOURCE STATEMENT    -    INTE

      SUBROUTINE NORMAL (ZONAL,ERID,ZI,NI,BZ,BM,NP,NQ)
C
C     DETERMINES BEST FIT PROFILE TO THE NORMALIZED TOTAL HEIGHT RANG
C
      DIMENSION ZONAL(750),ERID(750),ZI(750),BZ(10),BM(10),ZINORM(750
      DO1J=1,NI
      ZINORM(J)=(2.0*ZI(J)-ZI(NI)-ZI(1))/(ZI(NI)-ZI(1))
    1 CONTINUE
      CALL FIT (ZONAL,NP,BZ,NI,ZINORM)
      CALL FIT (ERID, NQ,BM,NI,ZINORM)
      RETURN
      END
```

```
$IBJOB          GO
$IBFTC TRACE    M94,XR7
```

```
      SUBROUTINE TRACE(J,K)
C
C     CALCULATES TURBULENT WINDSPEED PROFILE
C
      DIMENSION ZI(750)
      DIMENSION WINDI(750),AZRADI(750),ZONAL(750),ERID(750),TZONAL(750),
     1TMERID(750),TSPEED(750)
      COMMON ZI, WINDI,AZRADI,ZONAL,ERID,TZONAL,TMERID ,TSPEED
      TSPEED(J)=WINDI(K)-SQRT((ZONAL(K)-TZONAL(J))**2+(ERID(K)-TMERID(J)
     1)**2)
      RETURN
      END
```

```
$IBFTC FIT     M94,XR7
```

```
      SUBROUTINE FIT (BLOW,NSPEC,A,N,X)
C
C     FITS A HEIGHT PROFILE SPECIFIED BY NSPEC TO THE MEASURED DATA
C     BLOW,DETERMINING THE COEFFICIENTS A BY THE METHOD OF LEAST
C     SQUARES. PROFILE FITTED OVER TOTAL HEIGHT RANGE OF INPUT DATA.
C
      DIMENSION BLOW(750), A(10), X(750), S(10,11)
      DO3J=1,10
    3 A(J)=0.0
      IF(NSPEC)100,100,4
    4 NADD=NSPEC+1
      DO10J=1,NSPEC
      DO10K=1,NADD
   10 S(J,K)=0.0
      DO5J=1,NSPEC
      DO5K=1,NSPEC
      DO5I=1,N
    5 S(J,K)=S(J,K)+X(I)**(K+J-2)
      DO6J=1,NSPEC
      K=0
      DO6I=1,N
      K=K+1
    6 S(J,NADD)=S(J,NADD)+X(I)**(J-1)*BLOW(K)
      CALL MATS(S,A,NSPEC,MISS)
      IF(MISS)100,100,7
    7 WRITE(3,8)
    8 FORMAT(1X75HERROR IN INPUT DATA HAS RESULTED IN MATRIX S BEING UNS
     1UITABLE FOR INVERSION ////1X20HEXECUTION TERMINATED ///////)
      PRINT 8
      CALL EXIT
  100 RETURN
      END
```

```
      SUBROUTINE MATS (S,A,NSPEC,MISS)
C
C     REDUCES THE AUGMENTED MATRIX S TO PRODUCE THE COEFFICIENTS A
C
      DIMENSION S(10,11), A(10)
      MISS=-1
      MM=NSPEC+1
      N=NSPEC
      DO15I=2,N
   70 II=I-1
    7 DO15J=1,II
    8 IF(S(I,J))9,15,9
    9 IF(ABS(S(J,J))-ABS(S(I,J)))11,10,10
   10 R=S(I,J)/S(J,J)
      GOTO 130
   11 R=S(J,J)/S(I,J)
      DO12K=1,MM
      B=S(J,K)
      S(J,K)=S(I,K)
   12 S(I,K)=B
  130 JJ=J+1
   13 DO14K=JJ,MM
   14 S(I,K)=S(I,K)-R*S(J,K)
   15 CONTINUE
      IF(ABS(S(N,N))-1.0E-10)16,16,17
   16 MISS=+1
      GOTO29
   17 A(N)=S(N,MM)/S(N,N)
      DO28I=2,N
      JJ=N-I+1
      B=0.0
      II=N-I+2
      DO25K=II,N
   25 B=B+S(JJ,K)*A(K)
      IF(ABS(S(JJ,JJ))-1.0E-10)16,16,28
   28 A(JJ)=(S(JJ,MM)-B)/S(JJ,JJ)
   29 RETURN
      END
```

```
$IBFTC PAGE     M94,XR7
```

```
      SUBROUTINE PAGE(RESULT,START)
C
C     TURNS PAGE, NUMBERS IT,AND WRITES HEADING AS APPEARING
C     ON RESULT CARD.
C
      DIMENSION RESULT(12)
      IF(START)1,1,2
    1 NOP=0
    2 NOP=NOP+1
      WRITE     (3,3)RESULT,NOP
    3 FORMAT(1H1/1X12A6,30X4HPAGEI5//)
      RETURN
      END
```

APPENDIX III

SAMPLE DATA AND COMPUTER OUTPUT

```
63   5 21 1910105.6  140   130
63   5 21 1910105.8  130   128
63   5 21 1910107.0  125   132
63   5 21 1910108.0   92   140
63   5 21 1910109.0   50   160
63   5 21 1910110.0   42   240
63   5 21 1910111.0   56   250
63   5 21 1910113.0   60   262
63   5 21 1910114.0   84   274
63   5 21 1910115.0   68   270
63   5 21 1910117.2   72   282
63   5 21 1910125.0   45   286
63   5 21 1910130.0   30   296
63   5 21 1910135.0   14   310
63   5 21 1910140.0   15   316
                                                  ←BLANK CARD
7
8                                                 ← E O F
```

```
PRELIMINARY PAPER EGLIN DATA, MAY 21, 1963.  16/9/64.    PROFILE,5,5.
   5  5
    80 100
  63   5 21 1910 69.0    34   255
  63   5 21 1910 70.6    31   256
  63   5 21 1910 71.0    27   270
  63   5 21 1910 72.4    43   272
  63   5 21 1910 72.6    20   290
  63   5 21 1910 77.0    41   256
  63   5 21 1910 80.4    25   358
  63   5 21 1910 82.0    08   310
  63   5 21 1910 82.4    28   202
  63   5 21 1910 83.6    27   200
  63   5 21 1910 84.0    54   190
  63   5 21 1910 85.0    54   194
  63   5 21 1910 85.4    30   108
  63   5 21 1910 88.0    60   080
  63   5 21 1910 91.6    76   095
  63   5 21 1910 95.0    50   178
  63   5 21 1910 96.0    40   120
  63   5 21 1910 96.6    54   150
  63   5 21 1910 97.6    40   115
  63   5 21 1910 99.0    42   084
  63   5 21 1910 99.6    64   078
  63   5 21 1910100.0    58   070
  63   5 21 1910100.8    65   069
  63   5 21 1910102.0    80   079
  63   5 21 1910103.0    93   094
  63   5 21 1910104.0   115   104
  63   5 21 1910104.2   111   120
  63   5 21 1910105.0   129   122
```

```
 TRIAL ANALYSIS.  EGLIN DATA, MAY 21, 1963.  15/9/64.    PROFILE,5,5.



TOTAL NUMBER OF INPUT DATA POINTS     356

INCLUDING INTERPOLATION OF  313 POINTS

NUMBER OF DATA POINTS WITHIN THE HEIGHT RANGE  80. KM TO 100. KM     101

EAST WEST PROFILE SPECIFICATION    5

NORTH SOUTH PROFILE SPECIFICATION  5
```

TRIAL ANALYSIS. EGLIN DATA, MAY 21, 1963. CONTINUOUS PROFILE,5,5.

CALCULATED ZONAL AND MERIDIONAL MEAN WIND PROFILES HEIGHT RANGE

HEIGHT	ZONAL		MERIDIONAL		WIND SPEED	
	DATA	MEAN	DATA	MEAN	DATA	MEAN
100	70.	34	20.	-21	72.	40
99	56.	37	21.	-21	60.	43
98	42.	39	4.	-22	42.	45
97	39.	41	-11.	-22	41.	47
96	34.	43	-35.	-22	48.	49
95	31.	45	-28.	-22	42.	50
94	6.	46	-51.	-22	52.	51
93	31.	46	-51.	-21	59.	51
92	55.	47	-38.	-21	67.	51
91	73.	47	-13.	-21	74.	51
90	72.	46	-1.	-20	72.	50
89	67.	45	4.	-19	67.	49
88	62.	43	8.	-18	63.	47
87	55.	41	5.	-18	55.	45
86	44.	39	-4.	-16	44.	43
85	31.	36	-9.	-15	32.	39
84	-12.	33	-53.	-14	54.	36
83	-9.	29	-25.	-13	27.	32
82	-10.	24	-26.	-11	28.	27
81	-8.	19	10.	-10	12.	22
80	-3.	14	23.	-8	23.	16

TRIAL ANALYSIS. EGLIN DATA, MAY 21, 1963. CONTINUOUS PROFILE,5,5.

TURBULENT WIND PROFILE HEIGHT RANGE 80.KM TO 100. KM

HEIGHT	TZONAL	TMERIDIONAL	TSPEED
100	35.	41.	42.
99	19.	42.	26.
98	2.	26.	16.
97	-3.	11.	31.
96	-10.	-12.	32.
95	-14.	-6.	29.
94	-40.	-29.	8.
93	-16.	-29.	31.
92	8.	-16.	58.
91	26.	8.	62.
90	25.	19.	52.
89	22.	24.	45.
88	18.	27.	38.
87	13.	24.	33.
86	4.	13.	30.
85	-6.	7.	27.
84	-45.	-38.	18.
83	-39.	-12.	-5.
82	-35.	-14.	0.
81	-28.	20.	3.
80	-18.	31.	10.

```
 TRIAL ANALYSIS.  EGLIN DATA, MAY 21, 1963.  15/9/64.    PROFILE,5,5.
NORMALIZED HEIGHT RANGE               80. KM. TO   100. KM.

COEFFICIENTS GIVING BEST FIT TO ZONAL DATA
 0.386E 02 -0.126E 03 -0.244E 03  0.174E 03  0.205E 03


COEFFICIENTS GIVING BEST FIT TO MERIDIONAL DATA
 -0.304E 02  0.198E 02  0.148E 03 -0.168E 02 -0.125E 03
 RMS TURBULENT VELOCITY
          ZONAL        22.METRES/SEC.
          MERIDIONAL   23.METRES/SEC.
          WIND SPEED   17.METRES/SEC.
```

```
     TRIAL ANALYSIS.  EGLIN DATA, MAY 21, 1963.   CONTINUOUS PROFILE,5,5.

   ENERGY SPECTRUM OF ZONAL WIND HEIGHT VARIATION          HEIGHT RANGE  80.

            DELTA H      DELTA V**2      CORRELATION     SIGNIF     1-G

            0.2            24.3             0.979         0.004     0.02
            0.4            64.9             0.943         0.011     0.06
            0.6           113.7             0.900         0.019     0.10
            0.8           169.4             0.851         0.028     0.15
            1.0           230.7             0.797         0.037     0.20
            1.2           297.1             0.739         0.047     0.26
            1.4           369.4             0.676         0.056     0.32
            1.6           450.4             0.604         0.066     0.40
            1.8           534.8             0.525         0.076     0.47
            2.0           619.9             0.449         0.084     0.55
            2.2           703.2             0.374         0.091     0.63
            2.4           789.0             0.297         0.097     0.70
            2.6           877.1             0.217         0.102     0.78
            2.8           964.9             0.136         0.106     0.86
            3.0          1054.0             0.053         0.108     0.95
            3.2          1133.4            -0.023         0.109     1.02
            3.4          1209.9            -0.099         0.109     1.10
            3.6          1285.2            -0.176         0.107     1.18
            3.8          1360.8            -0.257         0.104     1.26
            4.0          1436.0            -0.342         0.099     1.34
            4.2          1507.0            -0.429         0.092     1.43
            4.4          1567.1            -0.514         0.083     1.51
            4.6          1614.3            -0.597         0.073     1.60
            4.8          1681.4            -0.651         0.066     1.65
            5.0          1745.7            -0.696         0.060     1.70
            5.2          1804.0            -0.735         0.053     1.74
            5.4          1852.3            -0.766         0.048     1.77
            5.6          1885.5            -0.788         0.045     1.79
            5.8          1897.3            -0.800         0.043     1.80
            6.0          1880.3            -0.801         0.043     1.80
            6.2          1863.6            -0.795         0.044     1.80
            6.4          1847.4            -0.783         0.047     1.78
            6.6          1827.7            -0.762         0.051     1.76
            6.8          1803.8            -0.730         0.057     1.73
            7.0          1775.0            -0.690         0.065     1.69
            7.2          1740.9            -0.642         0.073     1.64
            7.4          1701.2            -0.588         0.082     1.59
            7.6          1656.5            -0.528         0.092     1.53
            7.8          1608.4            -0.466         0.100     1.47
            8.0          1555.6            -0.401         0.108     1.40
            8.2          1497.1            -0.333         0.116     1.33
            8.4          1432.6            -0.263         0.122     1.26
            8.6          1361.9            -0.190         0.128     1.19
            8.8          1285.1            -0.116         0.132     1.12
            9.0          1202.6            -0.040         0.135     1.04
            9.2          1114.7             0.038         0.136     0.96
            9.4          1020.5             0.120         0.135     0.88
            9.6           920.9             0.207         0.133     0.79
            9.8           819.6             0.296         0.128     0.70
           10.0           733.6             0.372         0.122     0.63
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TRIAL ANALYSIS.  EGLIN DATA, MAY 21, 1963.   CONTINUOUS PROFILE,5,5.

ENERGY SPECTRUM OF MERIDIONAL WIND HEIGHT VARIATION          HEIGHT RANGE

            DELTA H       DELTA V**2      CORRELATION    SIGNIF     1-G

             0.2            31.3             0.973        0.005     0.03
             0.4            94.1             0.917        0.016     0.08
             0.6           164.4             0.853        0.028     0.15
             0.8           241.7             0.781        0.040     0.22
             1.0           326.3             0.701        0.052     0.30
             1.2           418.3             0.612        0.064     0.39
             1.4           515.2             0.518        0.076     0.48
             1.6           616.0             0.420        0.086     0.58
             1.8           723.6             0.316        0.094     0.68
             2.0           825.3             0.219        0.100     0.78
             2.2           935.1             0.116        0.105     0.88
             2.4          1052.2             0.008        0.107     0.99
             2.6          1175.9            -0.104        0.106     1.10
             2.8          1305.7            -0.219        0.103     1.22
             3.0          1429.3            -0.325        0.097     1.33
             3.2          1534.6            -0.411        0.091     1.41
             3.4          1614.7            -0.479        0.085     1.48
             3.6          1667.7            -0.535        0.079     1.54
             3.8          1711.0            -0.582        0.074     1.58
             4.0          1741.1            -0.617        0.069     1.62
             4.2          1756.8            -0.641        0.066     1.64
             4.4          1758.3            -0.656        0.065     1.66
             4.6          1745.6            -0.662        0.064     1.66
             4.8          1776.6            -0.680        0.062     1.68
             5.0          1836.6            -0.715        0.056     1.72
             5.2          1878.5            -0.733        0.054     1.73
             5.4          1900.7            -0.735        0.054     1.74
             5.6          1902.8            -0.723        0.056     1.72
             5.8          1885.6            -0.699        0.061     1.70
             6.0          1853.4            -0.666        0.066     1.67
             6.2          1809.8            -0.625        0.073     1.63
             6.4          1751.9            -0.573        0.081     1.57
             6.6          1679.1            -0.510        0.090     1.51
             6.8          1592.6            -0.435        0.100     1.44
             7.0          1494.3            -0.350        0.109     1.35
             7.2          1385.9            -0.257        0.117     1.26
             7.4          1269.8            -0.156        0.123     1.16
             7.6          1149.0            -0.051        0.127     1.05
             7.8          1028.4             0.057        0.128     0.94
             8.0           912.5             0.164        0.126     0.84
             8.2           802.4             0.266        0.121     0.73
             8.4           697.1             0.366        0.114     0.63
             8.6           598.6             0.459        0.105     0.54
             8.8           508.4             0.544        0.094     0.46
             9.0           427.7             0.620        0.083     0.38
             9.2           357.9             0.684        0.072     0.32
             9.4           302.8             0.735        0.063     0.27
             9.6           260.1             0.774        0.056     0.23
             9.8           231.1             0.801        0.050     0.20
            10.0           219.4             0.812        0.048     0.19
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   TRIAL ANALYSIS.  EGLIN DATA, MAY 21, 1963.   CONTINUOUS PROFILE,5,5.

  ENERGY SPECTRUM OF WIND SPEED HEIGHT VARIATION          HEIGHT RANGE  80.

                 DELTA H      DELTA V**2      CORRELATION    SIGNIF     1-G

                   0.2          15.1            0.993        0.001     0.01
                   0.4          47.1            0.979        0.004     0.02
                   0.6          83.2            0.964        0.007     0.04
                   0.8         122.0            0.947        0.011     0.05
                   1.0         161.5            0.930        0.014     0.07
                   1.2         200.6            0.914        0.017     0.09
                   1.4         240.7            0.898        0.020     0.10
                   1.6         286.9            0.879        0.024     0.12
                   1.8         337.0            0.859        0.028     0.14
                   2.0         382.2            0.841        0.031     0.16
                   2.2         421.0            0.827        0.034     0.17
                   2.4         455.3            0.815        0.036     0.19
                   2.6         483.4            0.805        0.038     0.20
                   2.8         502.9            0.799        0.039     0.20
                   3.0         512.5            0.797        0.040     0.20
                   3.2         517.8            0.796        0.040     0.20
                   3.4         528.9            0.793        0.041     0.21
                   3.6         542.8            0.789        0.042     0.21
                   3.8         561.7            0.783        0.043     0.22
                   4.0         584.0            0.775        0.045     0.22
                   4.2         606.6            0.768        0.046     0.23
                   4.4         628.3            0.761        0.048     0.24
                   4.6         650.9            0.755        0.049     0.25
                   4.8         679.5            0.746        0.051     0.25
                   5.0         712.5            0.734        0.053     0.27
                   5.2         748.8            0.722        0.056     0.28
                   5.4         785.1            0.710        0.058     0.29
                   5.6         818.7            0.700        0.060     0.30
                   5.8         847.5            0.692        0.062     0.31
                   6.0         870.6            0.686        0.063     0.31
                   6.2         894.8            0.680        0.065     0.32
                   6.4         919.4            0.674        0.066     0.33
                   6.6         943.4            0.668        0.068     0.33
                   6.8         968.1            0.661        0.069     0.34
                   7.0         996.2            0.653        0.071     0.35
                   7.2        1023.8            0.645        0.073     0.35
                   7.4        1048.3            0.638        0.075     0.36
                   7.6        1070.2            0.630        0.077     0.37
                   7.8        1088.9            0.623        0.078     0.38
                   8.0        1103.4            0.616        0.080     0.38
                   8.2        1114.0            0.608        0.082     0.39
                   8.4        1121.1            0.600        0.084     0.40
                   8.6        1120.2            0.593        0.086     0.41
                   8.8        1114.6            0.588        0.087     0.41
                   9.0        1103.8            0.585        0.089     0.42
                   9.2        1087.7            0.584        0.090     0.42
                   9.4        1066.1            0.586        0.090     0.41
                   9.6        1039.0            0.590        0.090     0.41
                   9.8        1007.8            0.596        0.090     0.40
                  10.0         973.4            0.603        0.090     0.40
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