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WINDS IN THE 70-200 KM HEIGHT RANGE

by

R. G. Roper

Goddard Space Flight Center
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R. G. Roper

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WINDS IN THE 70-200 KM HEIGHT RANGE

Over the past few years, a concerted onslaught has been made to determine the meteorology and physics of the upper atmosphere. The behavior of the region below 80 km has received considerable attention from the meteorological rocket network, and from numerous groups working with high level balloons, and rocket borne techniques such as, for example, the falling sphere and grenade experiments.

The region above 200 km has been sounded for many years by various radio techniques, but little is known about the neutral atmosphere at these heights. Our knowledge of the physics of this region is gradually being increased by data made available by satellite experiments, but the term wind (in the meteorological sense) has little meaning at these altitudes.

Between these two regions lies something of a "no man's land," at least as far as routine observations on a synoptic basis are concerned. Winds in the region from 80 to 100 km have been derived from the drifts of radio meteor trails, and from 90 to 120 km E layer ionization radio measurements have given some indication of drifts in this layer. However, it was not until the sodium vapor rocket technique was developed in the 1950's that a means for observing overall the drifts in the 70 to 200 km height range became available.

Whereas the meteor winds have been shown to be a true translation of the neutral atmosphere, the relationship between E layer drifts and (neutral atmosphere) winds has not yet been satisfactorily established. The chemiluminescent (tri methyl aluminum or TMA type) trail rocket technique shows the E region providing wind information in the range from 90 to 140 km; since these trails luminesce without solar illumination, it has been possible to perform time series firings involving the launching of several rockets in sequence throughout the night, and these can be correlated with both meteor winds (see Appendix II) and E layer drifts. However, to date such correlations have been restricted to qualitative comparisons - nowhere have the three techniques been applied simultaneously.

Although the use of the sodium vapor trail is restricted to twilight hours (night firings of sodium have produced results in the 90 to 140 km height range, but not with the consistency of luminosity exhibited by TMA releases), the fact that this technique is the only one that can produce wind results for the full range from 70 to 200 km makes it worthy of detailed consideration.

The most exhaustive treatment to date is that by Kochanski.

"The most outstanding characteristics of the apparent motion are pronounced velocity oscillations in the 70 to 130 km layer; they reach a maximum near 105 km, and attenuate at greater heights. A quiescent zone appears from 140 to 190 km, where, despite an increase of speed with height, the rate at which velocity changes with elevation is small. An attempt is made to resolve the apparent motion into various constituents by assuming that the observed drift represents a sum of three types of motion superimposed on one another: A general drift, tidal components, and internal gravity waves. The derived quantitites seem to explain vertical shear distribution and other phenomena. It is estimated that in the 90 to 125 km layer the contributions of the three constituents to the observed motion are: Gravity waves, 40%; general drift 34%; tidal components 26%. Above 130 km, the term representing a sum of the general drift and tidal components assumes a still more dominant role, and at 160 km its contribution to the observed motion is 85%."

(Abstract, "Atmospheric Motions from Sodium Cloud Drifts," by Adam Kochanski, Jour, Geophys. Res.,<u>69</u>, 17, 3651, 1964).

As pointed out by Kochanski, the behavior of these trails is such that any meaningful analysis requires the consideration of at least two, and perhaps better, three separate regions, namely, the height range from 70 to 110 km, characterized by "pronounced velocity oscillations," and by the appearance of globular structure in the trail photographs; the transition region from 110 to 140 km, where the shears gradually attenuate; and the quiescent zone above 140 km, with windspeed gradually increasing with height.

The 70 to 110 km Region

Considerable controversy has raged about the interpretation of atmospheric motions in the 70 to 110 km region. One factor contributing to these disputes has been the immediate "obviously turbulent" appearance of the sodium vapor trails below 105 km, with a very sharp cut-off of the globular structure at this height. The early releases by Blamont (1961) showed this structure on both the up and down legs of the trajectory, while those firings for NASA by the Geophysics Corporation of America (E. Manring, J. Beddinger) which yielded information on both legs showed the immediate structure only on the up leg. Most experimenters would now agree that the <u>immediate</u> appearance of the globules is brought about by instability in the <u>ejected</u> vapor, being a result of the thermite type release. The difference between the French and U. S. releases is that while the French payload continuously ejects vapor throughout the trajectory above 70 km, the GCA payload is designed to burn only on the upleg, and any material deposited on the lower downleg is not being ejected, but rather diffuses out of the container. Whether the flow of ejected material is or is not unstable depends on the medium into which the vapor flows; in particular, its inherent stability and kinematic viscosity. The rapid increase of the kinematic viscosity results in an effective damping of ejection instability at 110 km and above. There is also evidence that the 105 km level is significant in terms of the buoyancy stability of the neutral atmosphere (Justus, 1965).

Although the immediate breakup of the trail is a consequence of the two phenomena of ejection and atmospheric stability, the subsequent growth of the trail, at least after a period of some 10 seconds, depends on atmospheric properties alone. Groves (1963) has considered the problem of initial expansion of grenade releases to ambient pressure, and finds elapsed times of 8 seconds adequate at these altitudes. Vapor eject could be expected to be a less energetic phenomenon, and require less time to reach ambient than a grenade explosion, and so the initial time lag of 10 seconds proposed here should well suffice. Thus the measurement of globule growth provides a tool for the investigation of small scale atmospheric motions in this region. Unfortunately, the techniques of globule growth measurement, which are subject to the many variables inherent in the exposure and processing of film and its subsequent densitometry, lag to some extent the development of theories of diffusion of atmospheric contaminants (see, for example, Cote, 1962), and results produced to date have not always been consistent.

Some observations by Rofe (1961) are worthy of note. By optical tracking of the position of the glows resulting from grenade releases, Rofe has observed motions which he attributes to a "Benard type" cell regime, with dimensions 500 meters at 90 km, increasing to 1 km at 100 km. The development of a reliable point release payload, coupled with high resolution photography and closely controlled film processing and analysis techniques, would appear to be the most logical approach to the furtherance of these diffusion studies.

Both the continuous tracer rocket technique and the multi-station radio meteor technique (Greenhow and Neufeld, 1959; Roper, 1962) provide wind shear data which may be subjected to analyses based on accepted theories of homogeneous and shear turbulence. The basic limitation in the sodium trail data is that the determination of a mean drift (composed of prevailing wind and tidal components) for any given firing can be only subjective; the vapor trail does, however, define an instantaneous profile which cannot be obtained via radio meteors.

By combining a knowledge of the prevailing and tidal components determined from meteor results (Roper and Elford, 1965a, 1965b) with the data obtained from vapor trail firings, it has been possible to further the application of turbulence theory to the rocket data (see, for example, Roper 1964). One interesting point arising from comparison of the spaced station radio meteor results and the vapor trail analyses is that the average height shears measured by the meteor technique are consistently less than the vapor trail shears. The time averaged turbulent shear measured at Adelaide (35°S) at a mean height of 93 km by the meteor method is 8 m/sec/km. (Average of 13 monthly means for December 1960 to December 1961) while the instantaneous vapor profile average shear at the same height is 15 m/sec/km (22 firings 1959-1964, Kochanski, 1964). Note that, because of the characteristic non linearity of the turbulent shears, one must specify the height difference across which the gradient is measured; the figures given are the RMS velocity differences across a height difference of 1 km. The difference between the radio meteor and vapor trail gradients is not readily explained, since both methods give comparable values for the RMS deviations of all measured velocities from the mean (this RMS value being interpreted as the characteristic velocity of the large scale irregularities feeding the turbulence), a property just as fundamental as the turbulent gradient.

From consideration of the atmospheric motions determined by both the radio meteor (see Appendix I) and vapor trail techniques, the following picture of the energy transport emerges for the region from 75 to 105 km

Tidal Oscillations ⟶ internal gravity waves ⟶ turbulent dissipation

The energy source (the diurnal tidal wind component) has been directly correlated with the sink (turbulent dissipation) from meteor trail data, as shown in Figure 1. (From Roper, 1963, and Elford and Roper 1965b). This same data has been extrapolated to yield the scales of the energy bearing eddies of an inertial turbulence spectrum, and the 7 km vertical, and 200 km horizontal dimensions are those of the eddies expected to be generated by internal gravity waves (Hines, 1960). This would indicate that the source of this internal gravity wave energy is the diurnal component of the tidal oscillation.

Above 110 km

The characteristics of the transition region (110 to 140 km) and the quiescent region above have been treated in detail in the previously mentioned paper by Kochanski. However, some further material presented by Rosenberg, Justus and Edwards at the A.G.U. meeting of April, 1965 (Washington, D. C.) provides additional information on the role of tidal winds above 105 km. From several time series vapor trail releases, Rosenberg et al have found that the dominant vertical

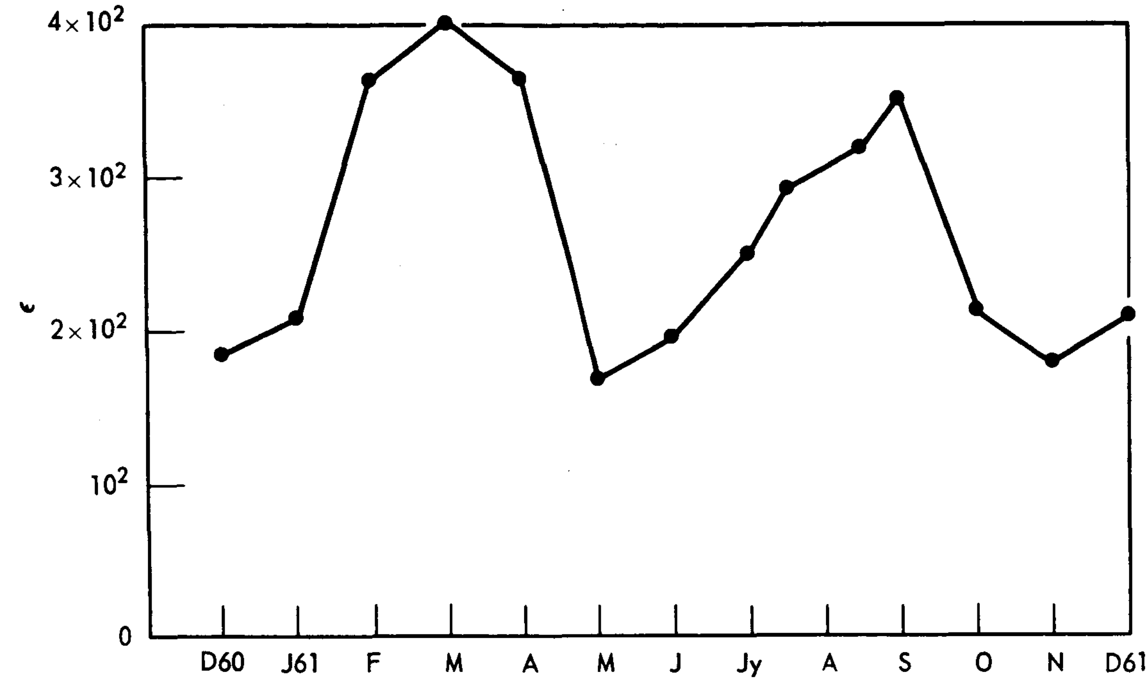

Figure 1a–The Seasonal Variation of the Turbulent Dissipation Rate ϵ (Ergs/Gm/Sec)

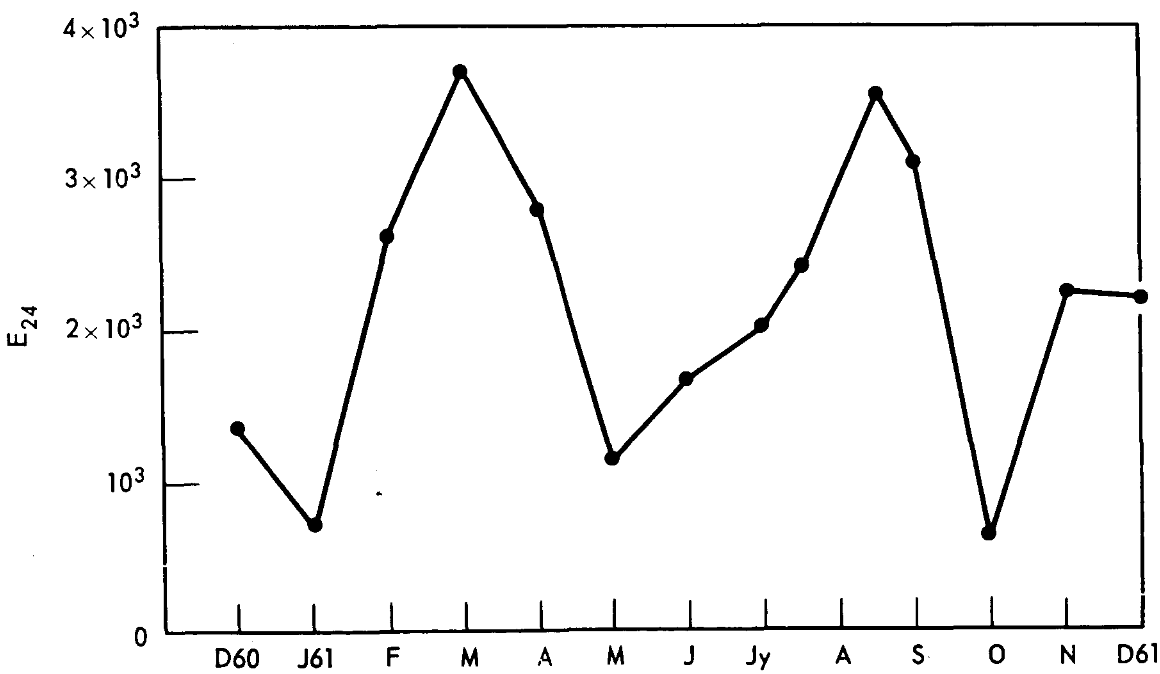

Figure 1b–The Seasonal Variation of the 24 Hour Wind Energy
E_{24} ($=u^2 + v^2 + w^2$ (meters/sec)^2)

wavelength is that of the 12 hour component, and that the phase of this component progresses downward with time, in keeping with an upward propagation of tidal energy. Although the Adelaide meteor data (80 to 100 km) is characterized by a rather irregular semi-diurnal component (compared with the smoother seasonal variation of the 24 hour oscillation), the 12 hour component shows a consistent increase with height, and could well be the dominant mode above 110 km.

An attempt by Manring et al (1964) to explain the character of periodic winds in the height range 85 to 135 km from consideration of 29 vapor trails can be criticized on several grounds. Any analysis that yields always a sequence of monotonically increasing Fourier components as a "best fit" to observational data is highly questionable, especially when one considers that in this case the data is time sequentially biased on a diurnal scale and lumps results from several seasons. The model is quite untenable with results produced by the radio meteor method (Roper and Elford, 1965) and the time series profiles of Rosenberg cited above. A detailed analysis of the Manring data has been performed by Hines (1965), with results much more in keeping with those inferred from other data sources.

The Future

Besides the furtherance of diffusion studies suggested earlier in this report, the recommendations made by Haurwitz (1964) and Kochanski (1964) for the future program of upper atmosphere investigations adequately describe the needs of both atmospheric physicists and upper atmosphere meteorologists. The tool which will yield the most information on prevailing and tidal winds in the shortest time for the least expenditure is the radio meteor technique, but this is limited to the 20 km slab of the atmosphere from 80 to 100 km. A manual describing the Adelaide meteor wind equipment and data reduction techniques is available (Roper, 1965). At the time of writing, only the Adelaide equipment (Dr. W. G. Elford, University of Adelaide) is operating on a routine basis, but equipments at present gathering data at Boston (Dr. Arnold Barnes, Air Force Cambridge Research Laboratories) and at Palo Alto (Dr. Alan Peterson, Stanford Research Institute) should be fully operational by the end of this year (1965). In addition, measurements of meteor winds are being contemplated at College, Alaska (Dr. Dharmbir Rai, Mr. Jerry Hook, Geophysical Institute).

The future of the chemiluminescent type of rocket release seems to lie in its use for correlation between winds and other ionospheric phenomena (electron density, magnetic field fluctuations, noctilucent clouds, aurorae). If a technique for measuring vapor drift during daylight hours could be devised, more information on tidal components could be obtained; however, the expense of this technique (even though it is a relatively inexpensive high altitude rocket experiment) precludes its use on anything like an hour to hour, or even synoptic, basis. Some further information on large scale eddy dimensions may be obtained from simultaneous firings from points separated by some 50 to 200 km. However, further experiments of this type should await the assessment of such firings as have already been made.

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APPENDIX I

ATMOSPHERIC TURBULENCE IN THE METEOR REGION**

by

*R. G. Roper

1. The Mean Flow

The determination of upper atmosphere winds in the height range 70-100 km by means of radio reflections from the ionized trails of meteors is a well established technique.[1-3] These winds as measured at Adelaide over the past ten years have been shown to be well correlated in space and time, and to repeat annually. The flow is characterized by predominantly horizontal motion, height shear, and diurnal and semidiurnal variation. There is also evidence of the existence of an 8 hour component.

Previous methods of wind analysis applied to meteor trail drifts have been somewhat restricted by the assumptions necessary to make the reduction possible using desk machine calculators. To ascertain the magnitude of the height shear, arbitrary stratification of the height range into 10 km intervals centered on 80, 90 and 100 km was used. The wind for a given hour for any given strata was taken as the least squares fit to the horizontal projection of the line of sight drifts measured in that hour (over several days) within the appropriate height range. Vertical motion was assumed to be zero, since the line of sight drift of overhead echoes is usually small. A Fourier series truncated at the 2nd harmonic was then fitted to these hourly vectors to determine prevailing, 24 and 12 hour components. The results of this procedure as applied to the data for July 1961 are shown in the first two diagrams. Figure 1 gives the variation of the east-west component as a function of height and time. At 80 km the variation is almost solely diurnal, while at 100 km the semidiurnal component predominates. The north-south component of Figure 2 shows a similar variation, but here there is evidence of a twelve hour component at all levels.

Over the past six months, a computer program has been developed which utilizes the analysis proposed by Groves.[4] The versatility of this reduction is

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**Paper presented at the Congress of the Australian and New Zealand Association for the advancement of Science, Canberra, January 1964.

DIURNAL VARIATION OF WINDS FOR JULY, 1961

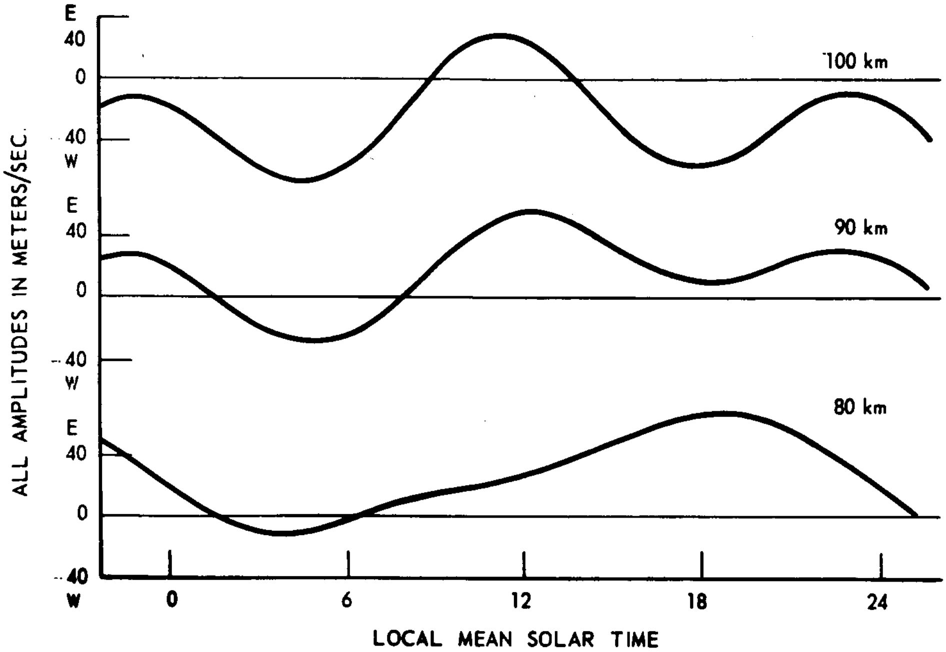

Figure 1–Zonal Component

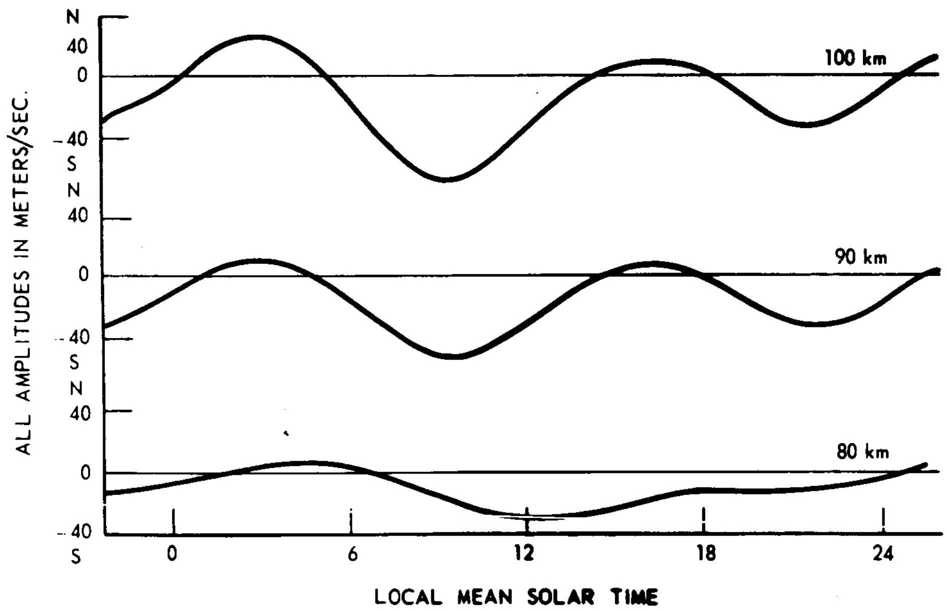

Figure 2–Meridional Component

such that not only height/time profiles, but also vertical winds and periodic component spectra can be obtained. Preliminary results are most encouraging, and have been reported by Elford at this conference.

2. Deviations from the Mean

In addition to the mean motions, observations made from a single station can give information about the characteristics of the large scale random motions. The wind vectors as measured by the meteor method show apparently random fluctuations, however, it is found that the distribution of the velocity fluctuations indicates a preferred value which is, in fact, the RMS of the observed fluctuations. This is shown by Figure 3, which depicts the horizontal projections of the observed wind vectors, the least squares fit vector and the deviations from same for the hour 0600 to 0700, December 1952. The most probable value of the velocity characteristic of the large scale fluctuation is 30 m/sec, and is associated with a mean wind speed of 86 m/sec. This characteristic velocity defines the turbulent velocity U_0 of the large scale eddies.

If narrow beam antennae are used instead of an all sky system as at Adelaide, further properties of the large scale fluctuations can be measured from a single station. Provided that the transmitting antenna illuminates only a region of sky small in comparison with the scale of the disturbance, a time correlation can be determined, and from this and the characteristic velocity, a length parameter can be defined which gives a measure of the scale of the eddy.

Figure 4 shows such a time correlation as measured at Jodrell Bank by Greenhow and Neufeld.[5] The correlation function $g(\tau)$ is compounded from the wind velocities measured at time t and time $t + \tau$ over a continuous 24 hour period. Although the characteristic time T_0 over which velocities are well correlated should be defined as

$$T_0 = 2 \int_0^\infty g(\tau)\, d\tau$$

to be consistent with the generally accepted definition of eddy size, it is convenient to propose a characteristic time T defined by the zero of the correlogram. From this time and the characteristic velocity, the simple relationship

$$L = U_0 T$$

yields an eddy scale L of 150 km (reference 5).

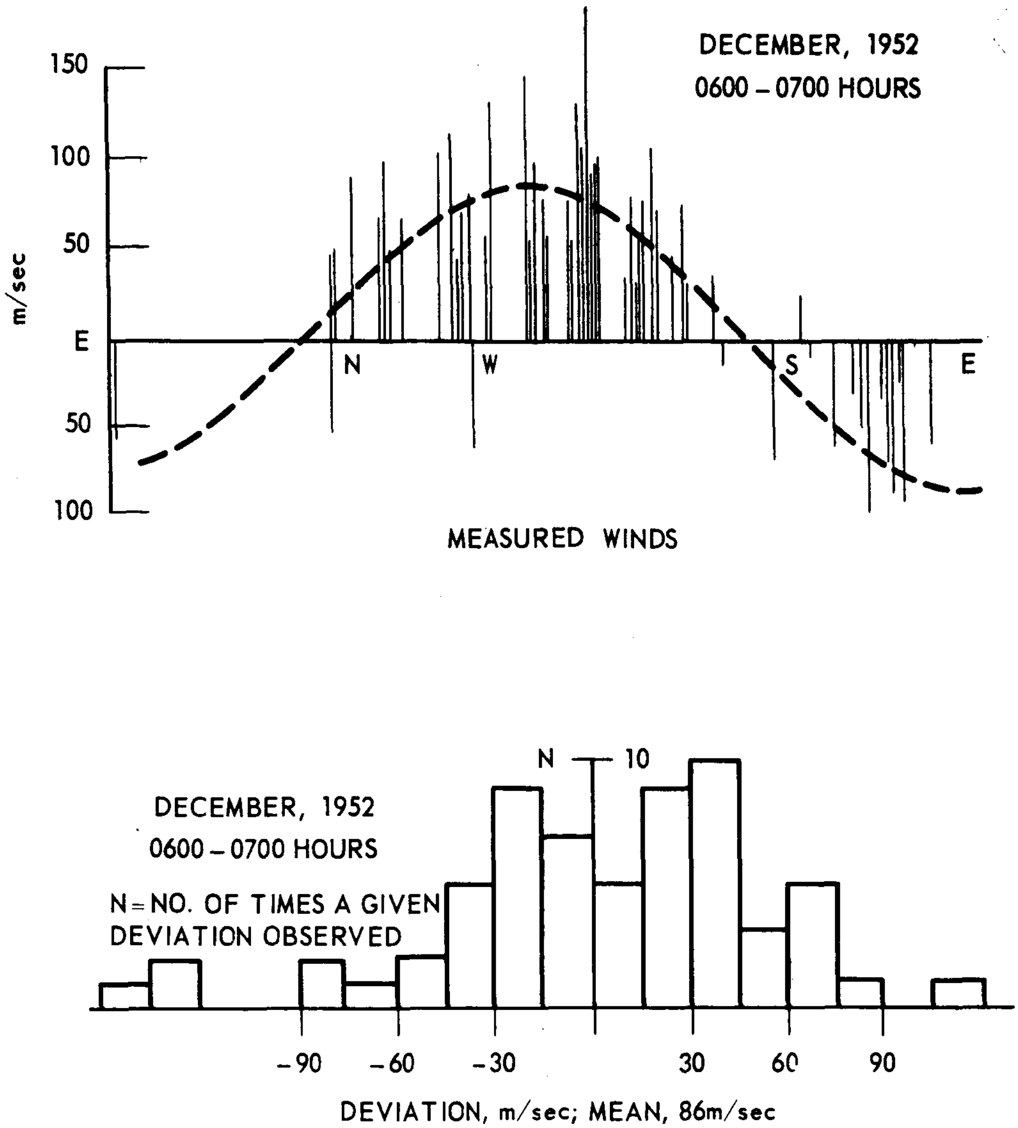

Figure 3—Velocity Deviations from the Mean Wind

Greenhow reports that "there is no dependence of the turbulence upon the mean flow, turbulent velocities up to 40 m/sec having been measured when the mean wind speed was zero." Investigations at Adelaide indicate that the turbulence is dependent upon the rate of change of the mean wind speed with height and time, rather than the absolute magnitude of the mean wind at any given time.

Ogura[6] has considered the time correlation problem, and has derived relationships between the turbulent and mean flow velocities which involve the time τ and the correlation difference $1-g(\tau)$. When the turbulent velocity U_0 is less than the mean velocity U, then

$$1 - g(\tau) \sim \tau^{2/3}$$

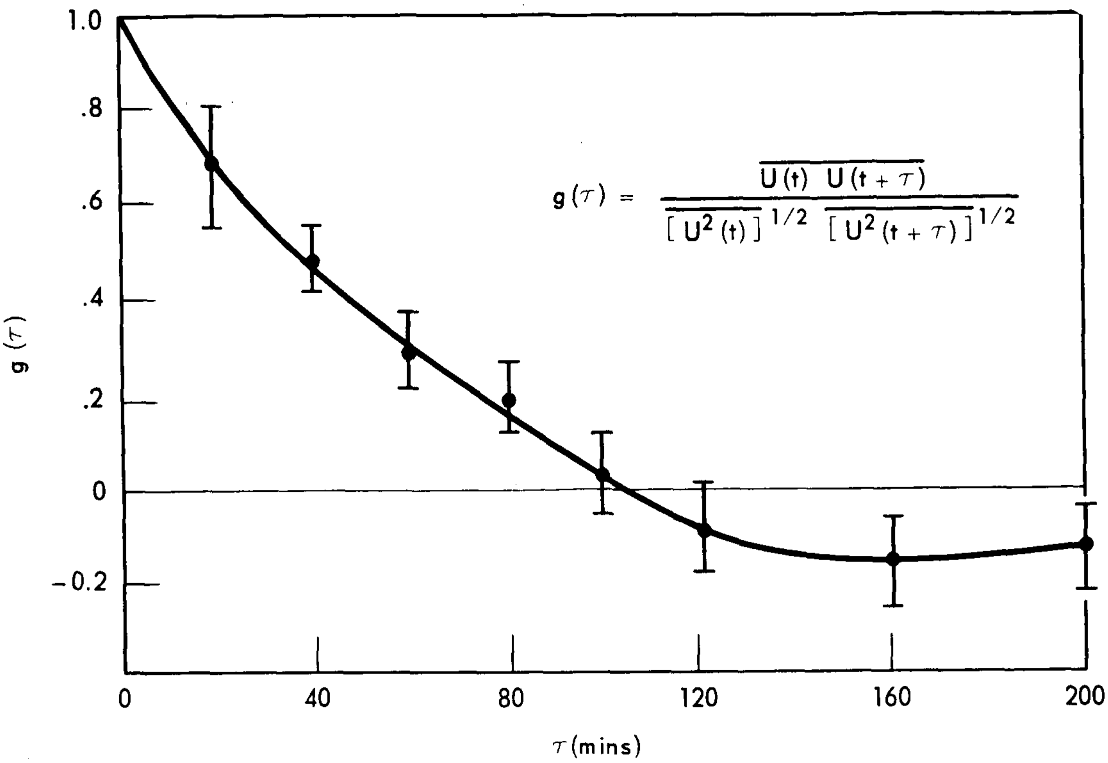

Figure 4–Autocorrelation function (Greenhow)

and for $U_0 > U$

$$1 - g(\tau) \sim \tau$$

Figure 5 shows a log/log plot of the correlation difference formed from Greenhow's results against the time interval τ. The least squares fit straight line to these points has a slope of 0.66, indicating that the turbulent velocity is less than that of the mean flow when averaged over an interval large in comparison with the time constant of the turbulence.

3. The Meteor as an Optical Tracer

For turbulence investigations in the 70-110 km region, the trails left by very bright visual meteors provide convenient optical tracers. Unfortunately, the occurrence rate of such meteors is exceedingly low, but a few have been photographed.

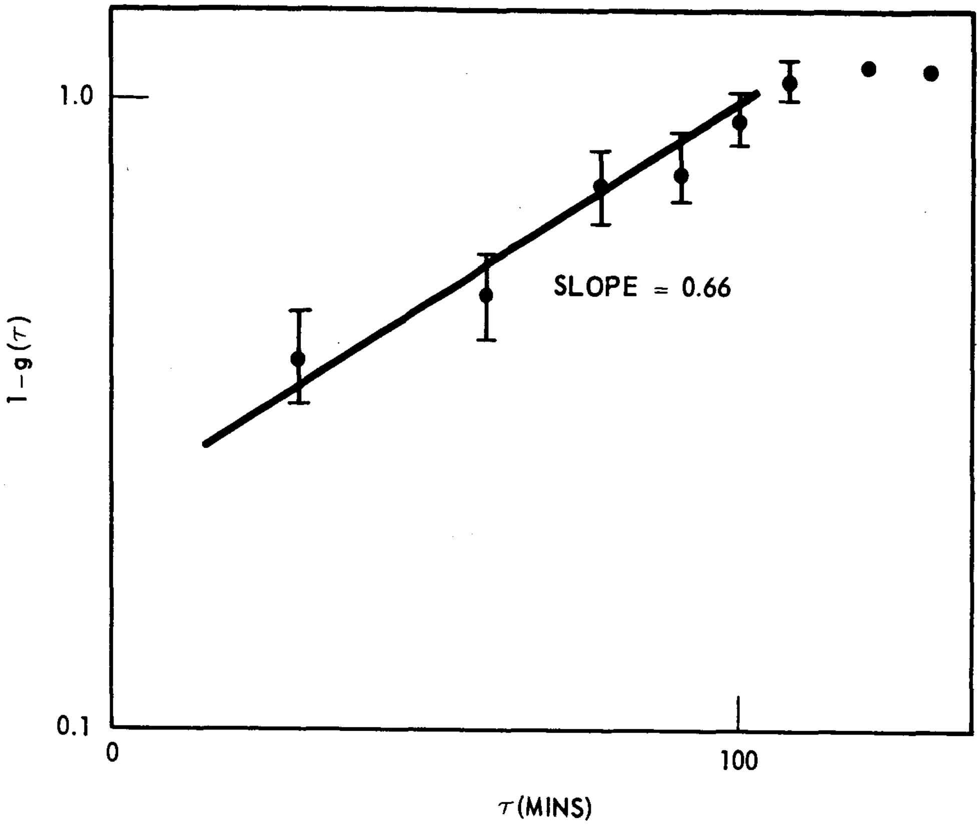

Figure 5–Time correlation (after Greenhow)

A trail photographed by Liller and Whipple [7] is of interest in that several exposures were taken and a wind profile constructed from these observations (Figure 6). A meteor leaving such a persistent smoke trail would be expected to have a turbulent wake, which limits its usefulness in the determination of small scale fluctuations, but the large scale shearing of the trail is well defined. A correlogram of the variation with height of the wind velocities measured yields a vertical correlation distance of 6.5 km. The line of sight observations of radio meteors (zenith angle ~ 45°) carried out by Greenhow yield a correlation distance of order 100 km, indicating that the large scale eddies are distinctly anisotropic, with a vertical dimension of some 6 km, and a horizontal scale of the order of hundreds of kilometers.

4. The Meteor as a Radio Tracer

Since the much smaller but far more frequent radio meteors would not be expected to contribute to the turbulent energy, they provide a useful tool for investigating the small scale irregularities. However, there are two factors which limit the suitability of these trails for the determination of small scale

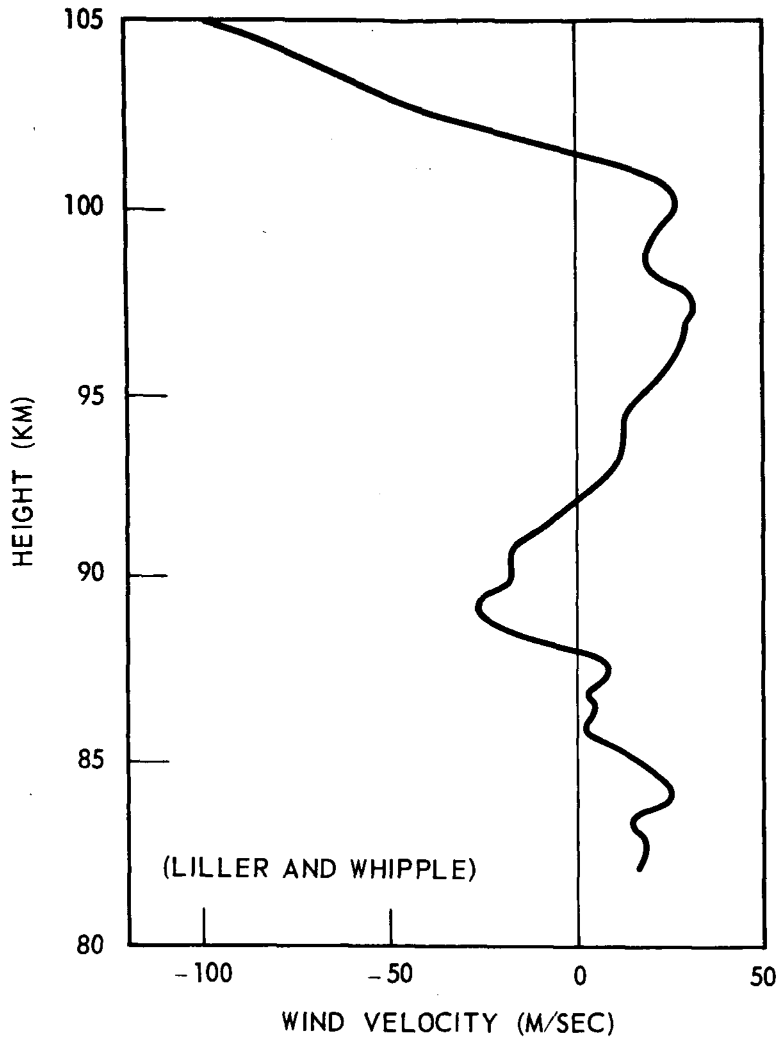

Figure 6–Wind profile from photographic meteor

properties. The first is the problem of resolution. For a straight trail at a range of 150 km, and a radio frequency wavelength of 11 meters (as used at Adelaide), the main contribution to the radio energy reflected from the trail comes from a segment of the trail about the specular reflection point of length approx. 700 meters. Once the trail has been slightly deformed, however, trail lengths of 50 meters or so produce useable reflections, and it is not certain whether the separation limitation of 700 metres is absolute.

The second limitation is the reflection point motion caused through trail rotation by wind gradients (Figure 7). Whereas the change in the line of sight distance is small, even in terms of the radio wavelength being used, the reflection

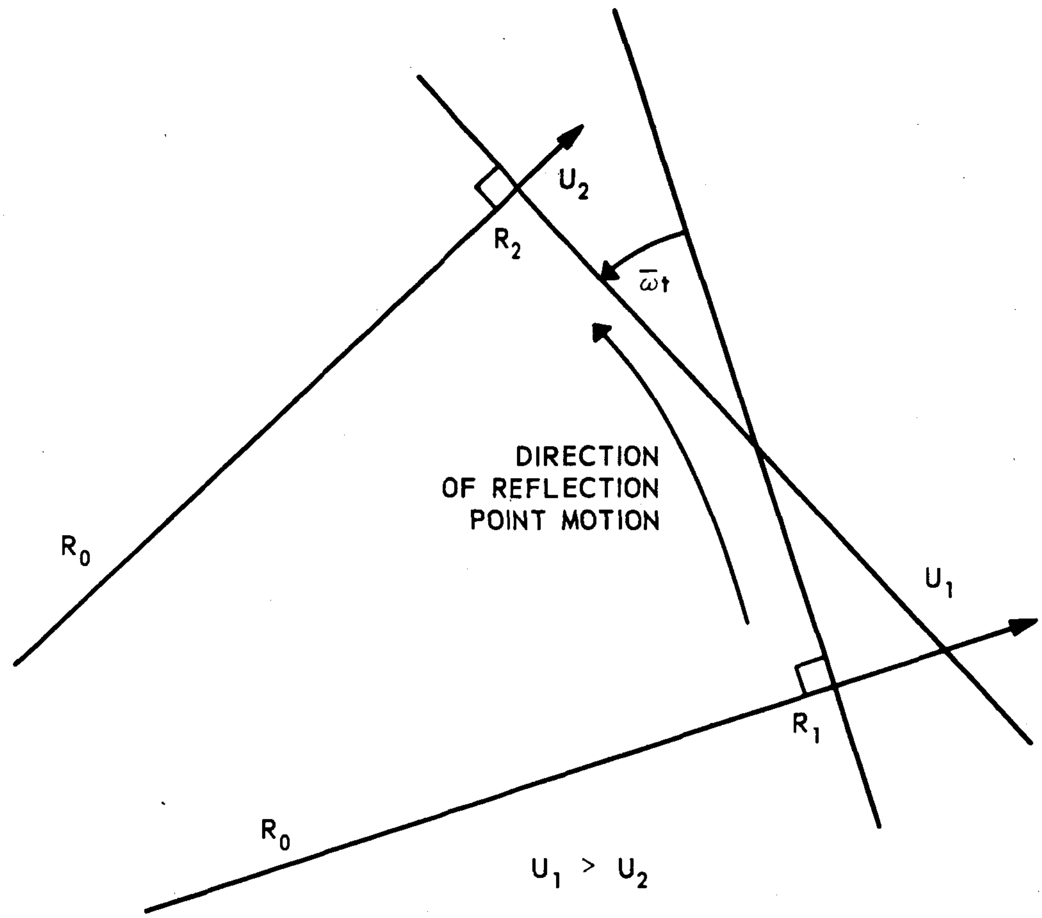

Figure 7—Geometry of reflection point motion

point can move several kilometers along the trail in less than a second; the rate of occurrence of such motions for measurements made in December 1960 is shown in Figure 8. In any investigation of meteor trails in which a knowledge of the absolute position of the reflection point is important, the possibility of reflection point motion should not be overlooked.

5. An Investigation of Trail Shears

Since radio reflection from meteor trails is specular, the spacing of receivers on the ground will enable separate portions of the trail to be examined simultaneously.

Figure 9 shows the layout of the Adelaide 3 station system. A fourth station also in operation during 1961 does not appear in this diagram. The information relating to trail formation and subsequent line of sight drift is transmitted from

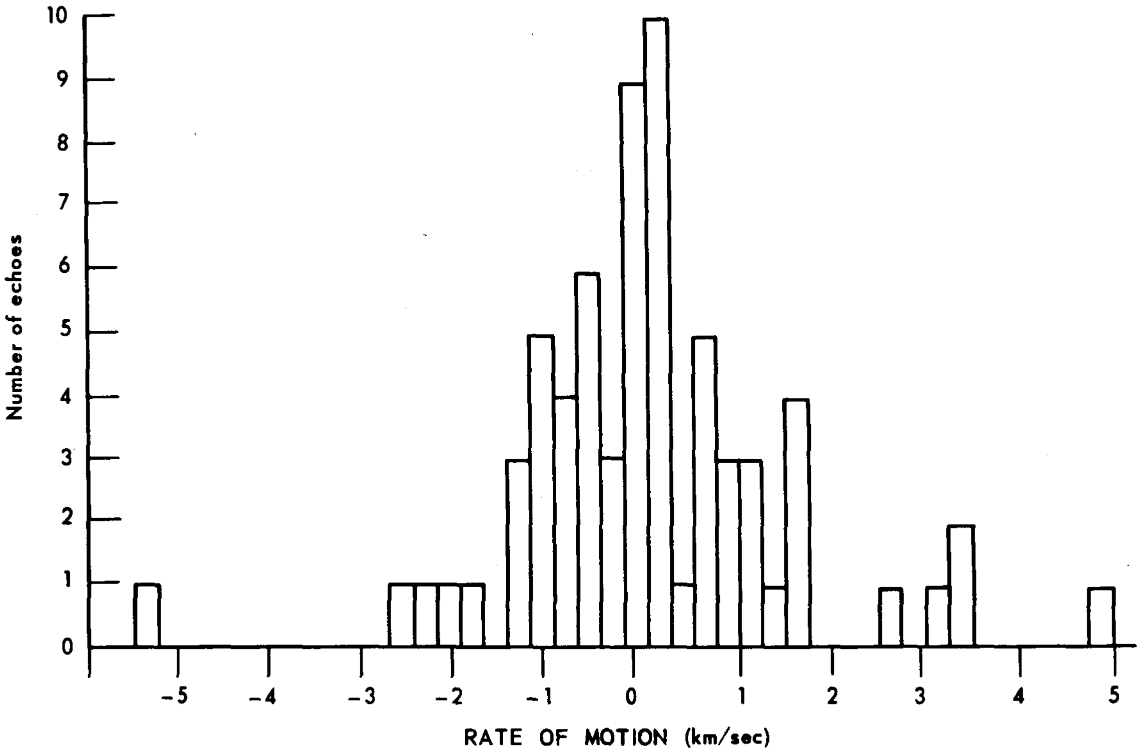

Figure 8—Motion of reflection point along trail. (December, 1960)

each outstation and recorded at the main station at St. Kilda. From the build-up of the echo pattern at each station, and the determination of the azimuth, elevation and range of the trail as measured from the main station, the absolute position of the trail in space is determined. In particular, the separation of reflection points is measured, and from the Doppler record the line of signt drift of each point is known. Bearing in mind the limitations placed on the separation by the geometry of the receiving system and the subsequent behavior of the trail after formation, shears can be determined over a range of separations from some 500 meters to 3 km. Note that in compounding the turbulent shears, the line of sight component of the mean motion at each reflection point must be subtracted from the measured drifts.

The relationship between the velocity $U(x)$ measured at a point x and the velocity $U(x+\xi)$ measured at a point distance ξ from x is given by Batchelor[8] as

$$\overline{[u(x) - u(x+\xi)]^2} = 4.82\,\alpha(\epsilon\,\xi)^{2/3}$$

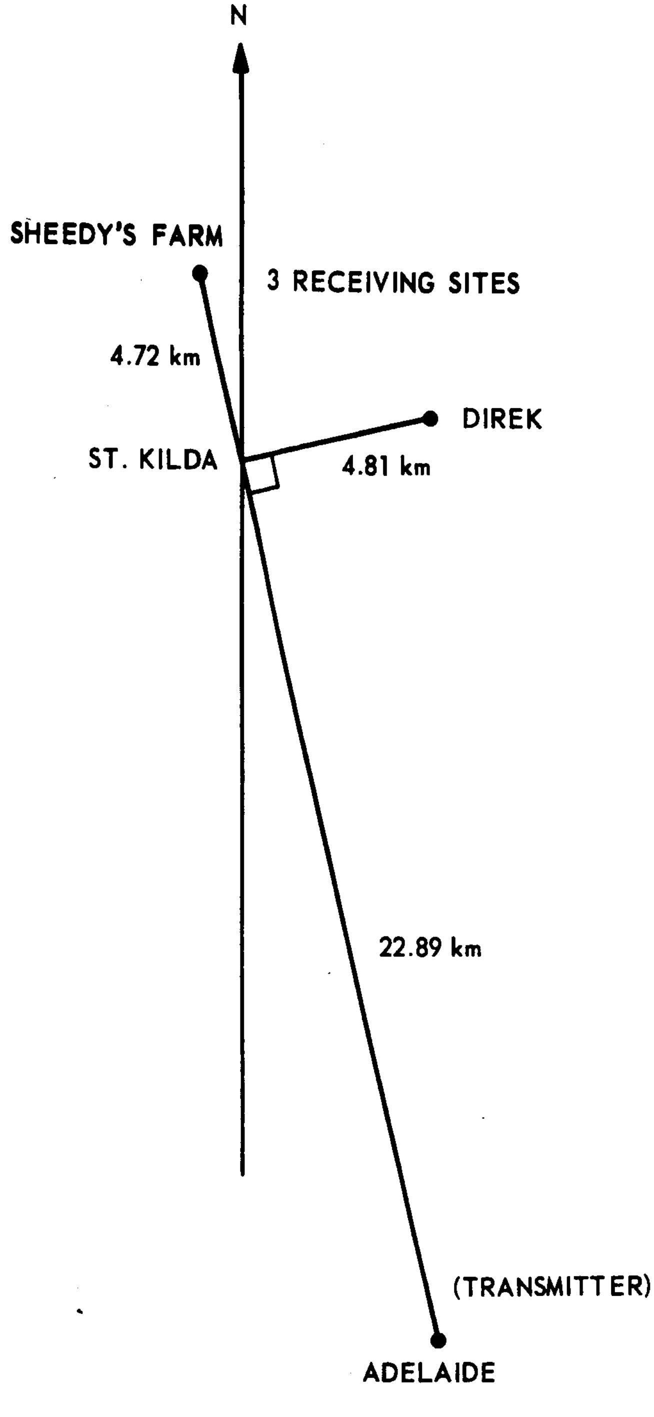

Figure 9—The Adelaide 3-station System, 1961

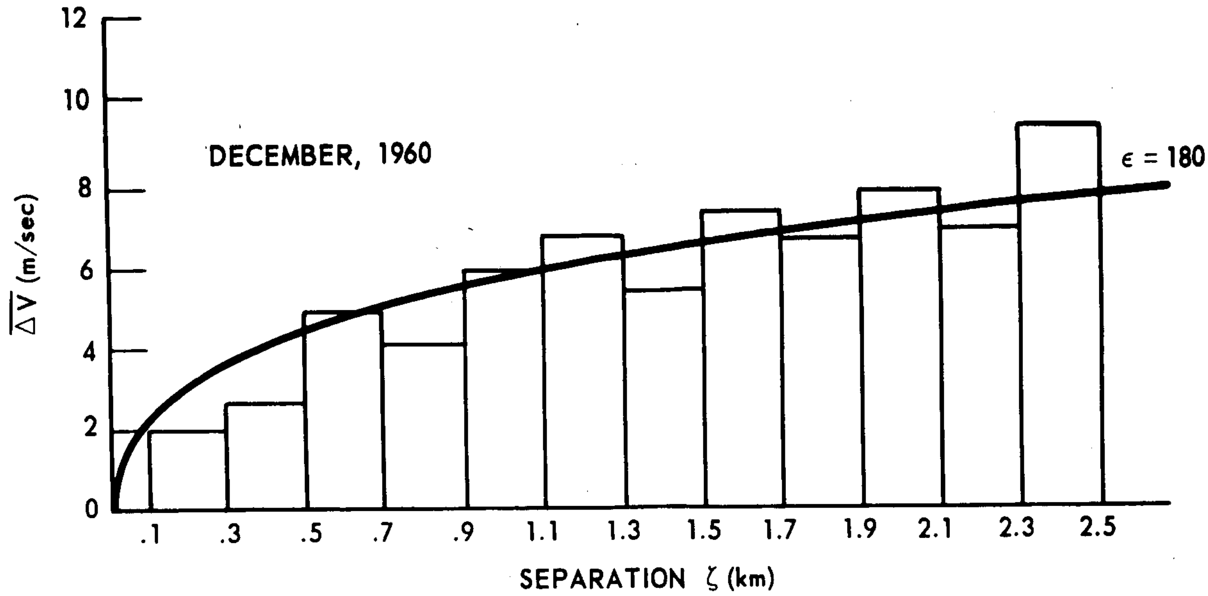

Figure 10–Variation of velocity difference with separation

for a region of isotropic turbulence. ϵ is the rate of dissipation of turbulent energy; α is a constant of order unity, and the bar symbol denotes averaging over a time interval large in comparison with the time constant of the turbulence. If α is taken as 1.0, and the RMS velocity difference measured over separation ξ as $\overline{\Delta v}$, then

$$\epsilon = \frac{(\overline{\Delta v^3})}{10\xi}$$

The variation of the RMS turbulent velocity difference with separation for December 1960 is shown in Figure 10. At separations greater than 500 meters the agreement with the theoretical curve for an isotropic region of dissipation rate 180 ergs/gm/sec is quite good.

If the RMS deviation from the mean flow of the measured line of sight drifts is taken as the characteristic velocity of the large scale disturbances, their characteristic scale can be determined from the equation defining the rate of dissipation of turbulent energy, since ϵ is a constant of the inertial spectrum. One must remember here that the RMS velocity deviation characterizes the flow field as measured by line of sight observations, as did Greenhow's characteristic velocities, and is not the true horizontal velocity of the large scale eddies, since these eddies are distinctly anisotropic.

For a characteristic velocity of 26 m/sec, and a value of ϵ of 180 ergs/gm/sec as measured for December 1960, the scale of the large eddies is calculated as 100 km.

The best fit curves to the histograms of velocity difference versus separation for each month from December '60 to December '61 show a marked seasonal variation of the rate of dissipation of turbulent energy [9] (Figure 11a). In general, the histograms characteristic of the more turbulent months show a greater scatter of the measured values about the best fit theoretical curve; different curve fitting methods result in some modifications of Figure 11a, but the shape is always that depicted, in which each point represents the result of least squares curve fitting.

Also shown (Figure 11b) are the monthly mean values for the prevailing, diurnal and semidiurnal wind speeds. There appears to be some correlation between the rate of dissipation of turbulent energy and the 24 hour component of the mean wind. It should be noted that the seasonal variation of the 24 hour component is not characteristic of previous years (see Elford[1]) and therefore the variation of the turbulent dissipation rate (if it is dependent on the 24 hour component) is not necessarily characteristic of all years.

6. The Height Shear

The height shear is one of the most interesting properties of the turbulent flow in the meteor region. At the present time, the most widely used method of measuring the height shear is the ejection from rockets of sodium vapor, the trail thus formed being subsequently photographed to enable drifts to be determined.

A French firing has been reported in detail by Blamont [10], with particular emphasis being placed on the shears in the meteor region. Figure 12 shows the variation of the mean square wind velocity difference with height difference for the portions of trail between 86 and 96 km. The open circles pertain to the ascending trail, the closed circles to the descending trail.

Zimmerman [11] has pointed out that, while the slope of the line fitted up to the 6 km separation level was not the 2/3 characteristic of an isotropic inertial region, it was in fact the 4/3 power law predicted by Tchen [12] for an isotropic inertial region subjected to a mean shear. Blamont's results also show a falloff in wind speed correlation at a vertical scale of some 6 km.

The Adelaide meteor results from the 1961 turbulence survey have been subjected to a height shear analysis and Figure 13, the height shear for September, is typical of the results obtained. Because of the limitation imposed by station separation, a height difference of 2 km was the maximum observed directly.

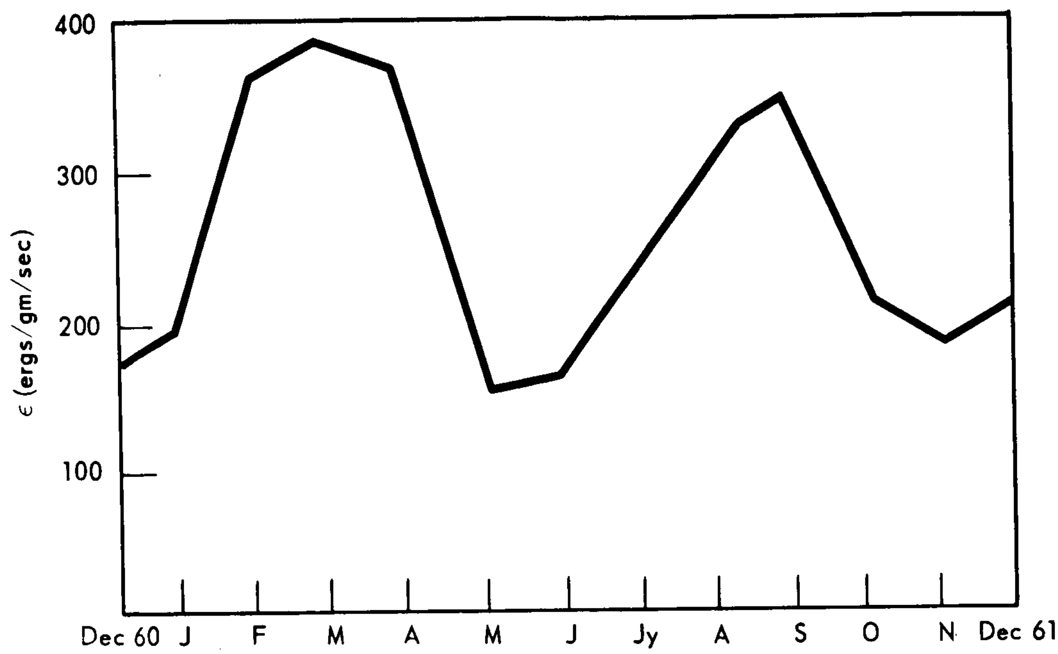

Figure 11a–Seasonal variation of the turbulent dissipation rate at 90 km.

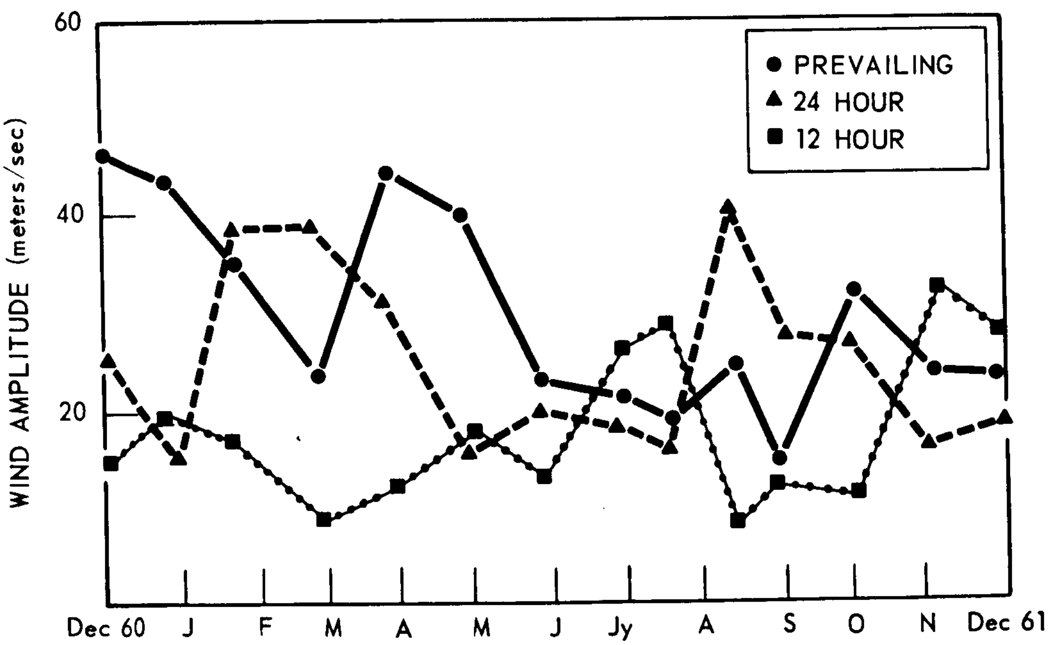

Figure 11b–Components of the mean wind, 85-94 km

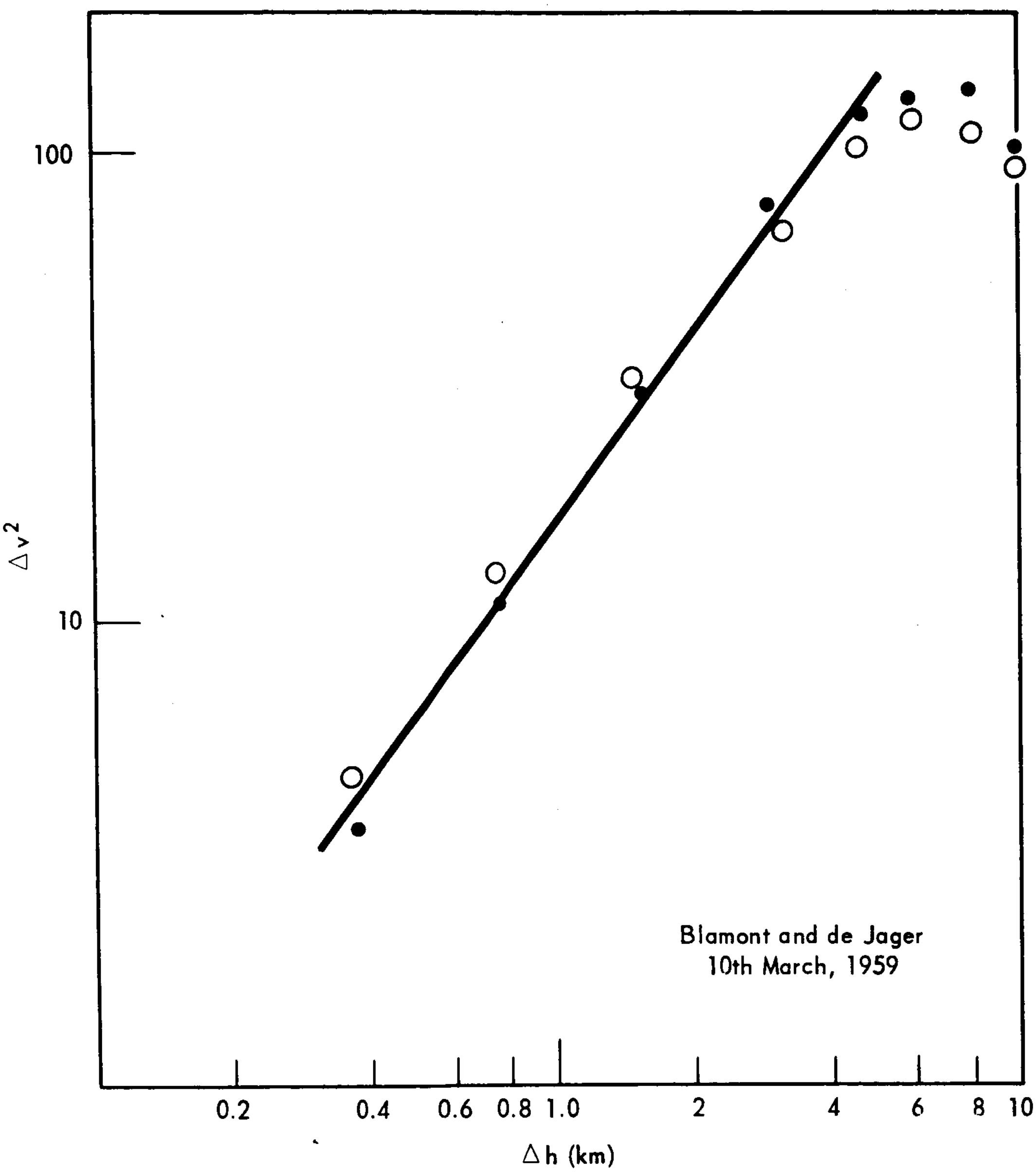

Figure 12–Variation of wind velocity difference with height difference (sodium trail method)

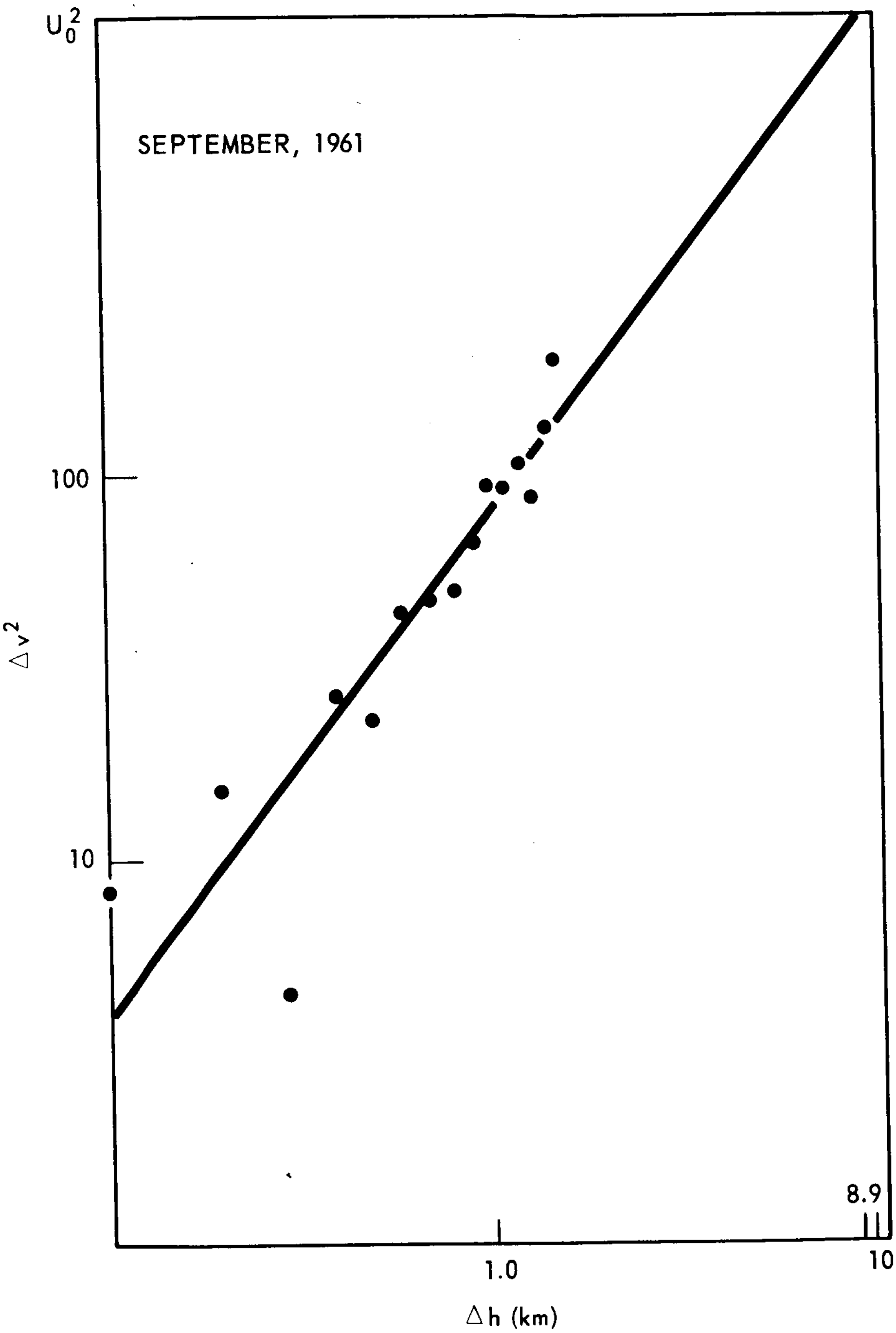

Figure 13–Variation of wind velocity difference with height difference (radio meteor method)

However, extrapolation of the best fit line of slope 4/3 to the velocity characteristic of the large scale eddies leads to vertical correlation distances over all months of from 5 to 9 km. For the September results, extrapolation to a value of Δv^2 of 1600 (corresponding to an RMS turbulent velocity of 40 m/sec) yields a vertical correlation distance of 8.9 km.

7. Vertical Motions

The mean vertical motion in the 80 to 100 km region is, in general, less than ±5 m/sec, with a random fluctuation of the order of ±10 m/sec. These values are considerably smaller than the corresponding horizontal velocities, and are a consequence of what appears to be a highly stable horizontal stratification of the region. The reason why this apparently stable stratification exists is as yet unknown. It is possible that the mesopause may provide a relatively stable boundary, as does the tropopause in the lower atmosphere.

In determining the stability of a thermally stratified atmosphere, it is usual to employ the Richardson number defined by

$$Ri = \frac{g}{\theta} \left(\frac{d\theta}{dT}\right) \left(\frac{\overline{dv}}{dh}\right)^{-2}$$

where θ is the gas potential temperature and $(\overline{dv}/dh)$ the mean height shear.

The turbulent shears associated with the large scale turbulent motions in the meteor region are larger than the mean shears, and the total shear should be used in any determination of the Richardson number. Furthermore, since the height shear is non linear, there will always be some scale at which the Richardson number will become less than the critical value (usually taken as 1). In general, the shears measured at Adelaide by the radio meteor method will result in anisotropic Richardson type instabilities of characteristic scale less than 100 meters. However, on occasions this scale could be expected to extend to 1 km or more. Shear values as high as 30 m/sec/km have been measured on individual meteor trails, and these shears will support Richardson type eddies of scale up to approximately 1.5 km. It should be pointed out that the presence of such eddies of size 1 km as determined from meteor observations is highly variable in space and time, and would be expected to be the exception rather than the rule, whereas the observed globular breakdown of sodium trails is a common occurrence. It would appear that the mechanism producing such globules requires a more detailed explanation than that given here, and probably involves a combination of both isotropic and anisotropic turbulence.

8. The Future

To further the investigation of winds and turbulence in the meteor region, a 50 kw peak pulse output radar and a 1.5 kw C.W. transmitter have been constructed (c. f. 5 kw radar and 300 w C.W. used in the 1961 survey). This will increase the echo rate several fold, and should yield sufficient information to enable the diurnal variation of the turbulent dissipation rate ϵ to be determined. The use of narrow beam antennae is also contemplated as part of the research program, to allow the simultaneous measurement of ϵ and the time constant and scale of the large eddies.

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APPENDIX II

A Qualitative Comparison Of Vapor Trail Time Series Release And Meteor Winds Over The Height Range 80 To 100 km.

In the past, it has been difficult to compare winds observed by the radio meteor method and those calculated from the drift of vapor trail releases from rockets. In particular, the measurement of meteor winds at Adelaide (35°S) involves a process which averages results over a period of many days to produce prevailing and tidal components for a typical day. The resultant meteor wind profile for any given hour is thus considerably smoothed, and does not contain the detail inherent in an "instantaneous" vapor trail profile making correlation difficult. However, with the development of rocket payloads capable of producing luminescent trails without solar illumination (see, for example, Rosenberg et al., 1964), data on height/time variations of winds in the 90 to 140 km region has become available from the rocket experiment. The height/time wind variation for one such series fired from Eglin Air Force Base (30°N) on the evening of December 3, 1962 (Rosenberg et al., 1964) is presented in Figures 1a, 2a. Meteor wind results (Roper and Elford, 1965) from Adelaide (35°S) (in this case for the Southern hemisphere winter month of June, 1961) are plotted for the appropriate time interval in Figures 1b, 2b.

It is unfortunate that time sequence data is available only above 90 km, and that the meteor data is confined to the height range 80 to 100 km. While the 10 km overlap would be more than adequate for the correlation of winds measured simultaneously by the two techniques at the same site, it allows only a very rough comparison to be made between data separated in both space and time.

To show that the meteor results are capable of delineating reasonably detailed structure in both height and time (even though the plots are compounded from prevailing, 24, 12 and 8 hour components only, the zonal (Figure 3) and meridional (Figure 4) profiles for September 1961 are included. In particular, the EW winds of Figure 3 show considerable variation with both height and time.

A more detailed comparison of meteor and vapor trail winds is contemplated, and will proceed as more time series rocket data becomes available.

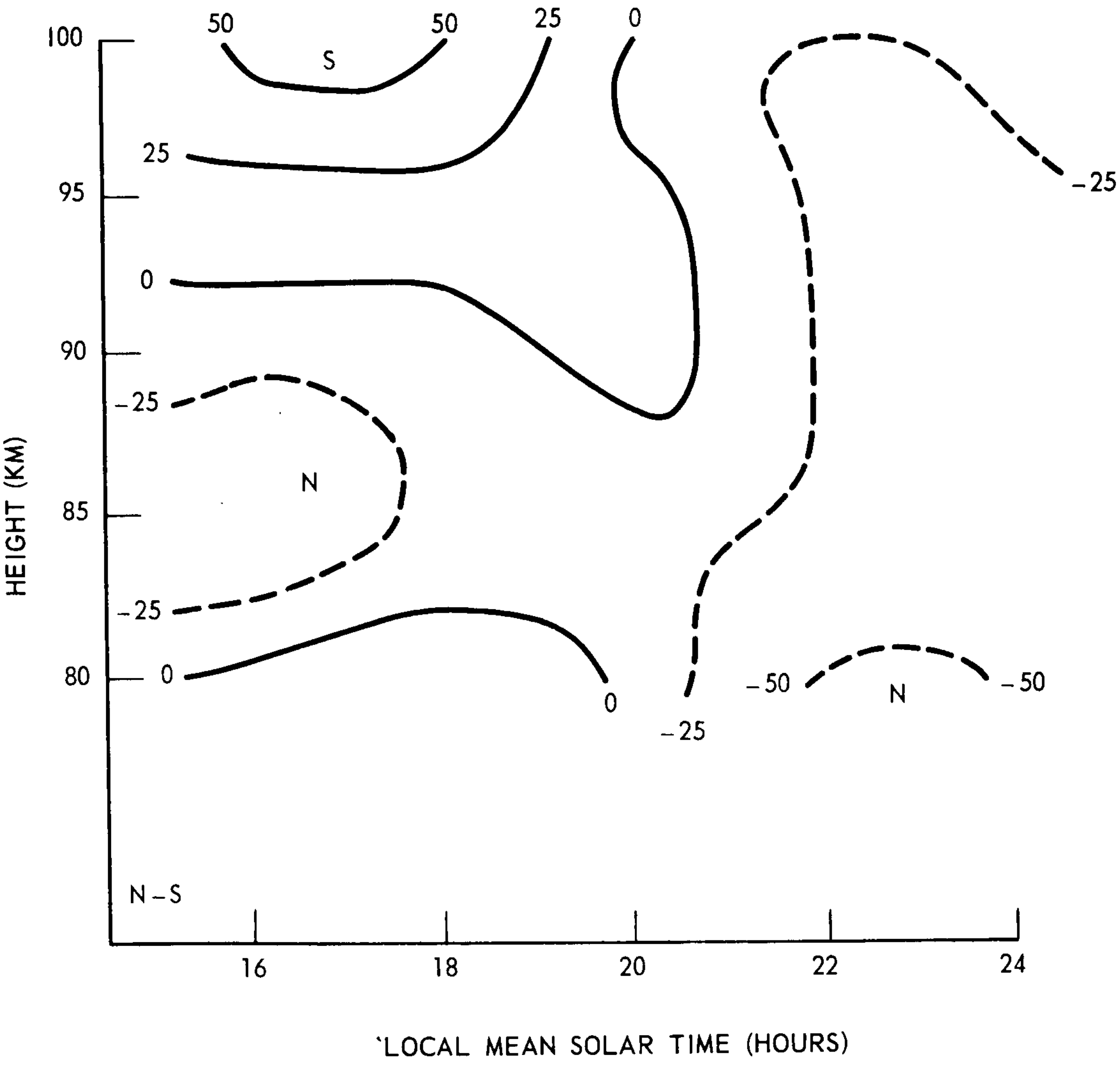

Figure 1a–Meteor Winds, June, 1961 (Adelaide, 35°S)

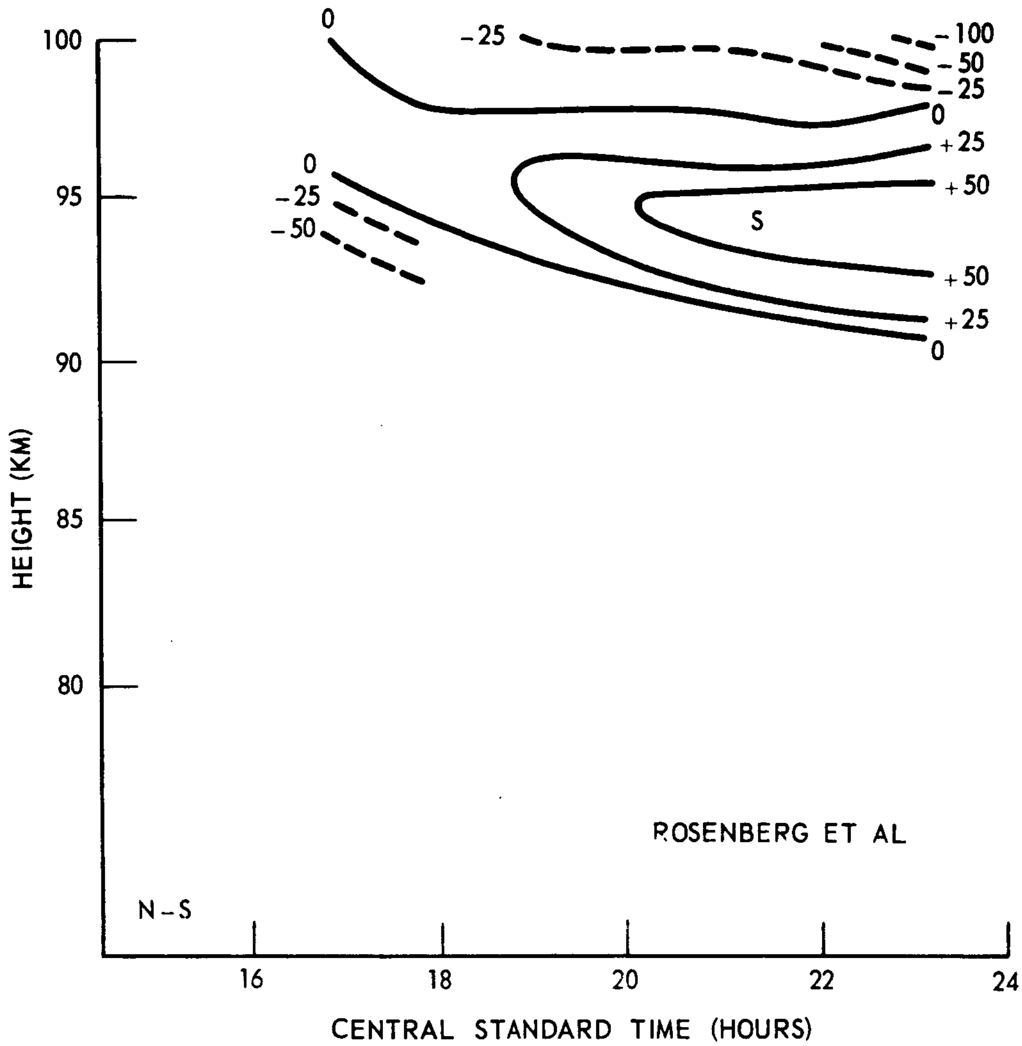

Figure 1b–Rocket Winds, December 3, 1962 (Eglin AFB, 30°N)

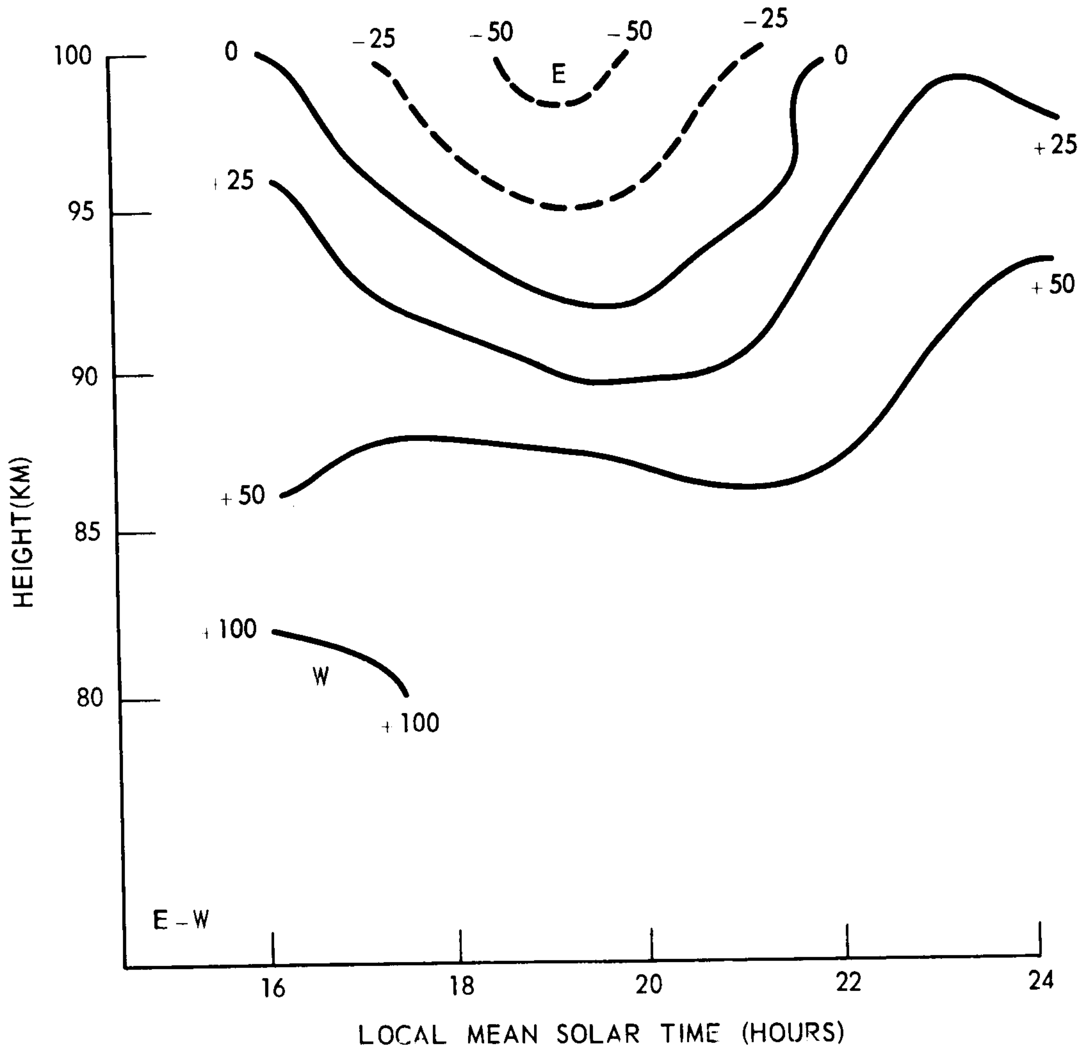

Figure 2a—Meteor Winds, June, 1961 (Adelaide, 35°S)

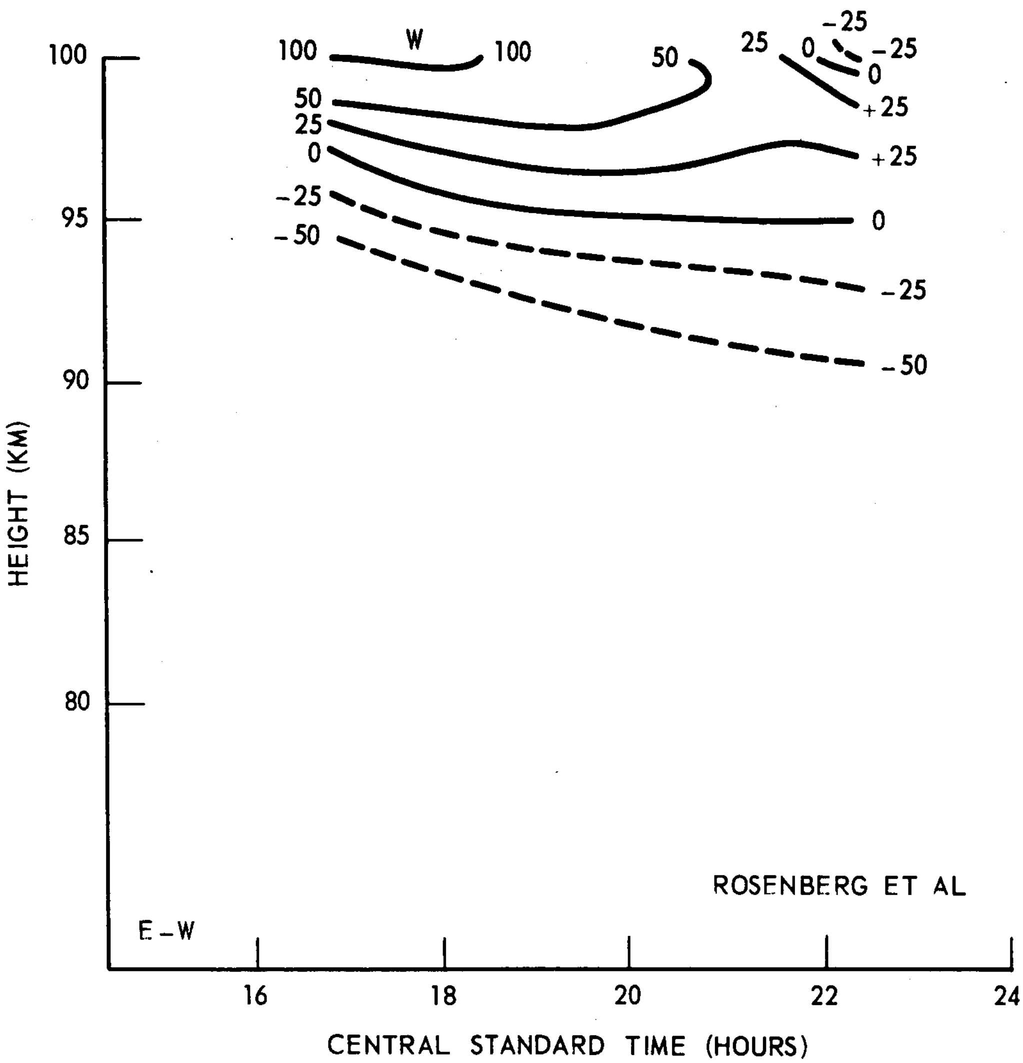

Figure 2b—Rocket Winds, December 3, 1962 (Eglin AFB, 30°N)

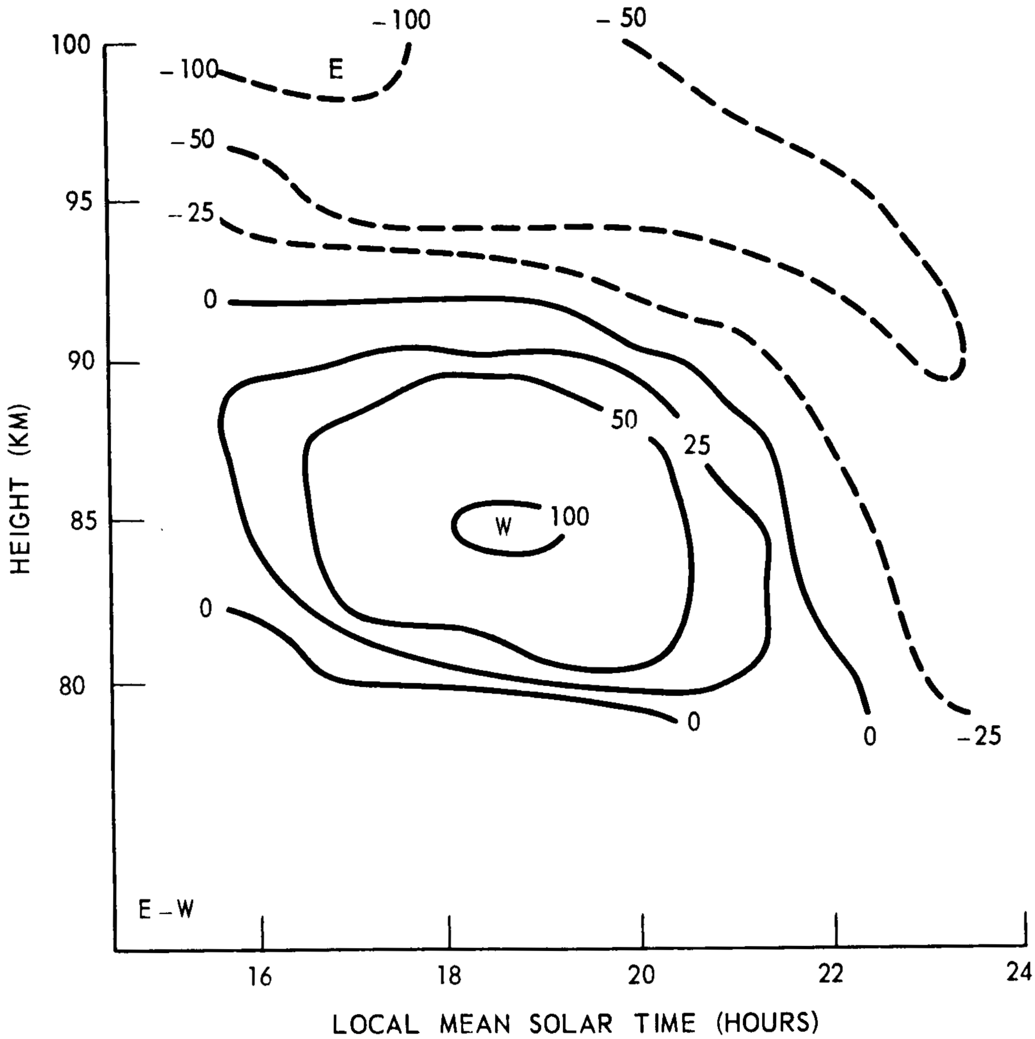

Figure 3–Meteor Winds, September, 1961 (Adelaide, 35°S)

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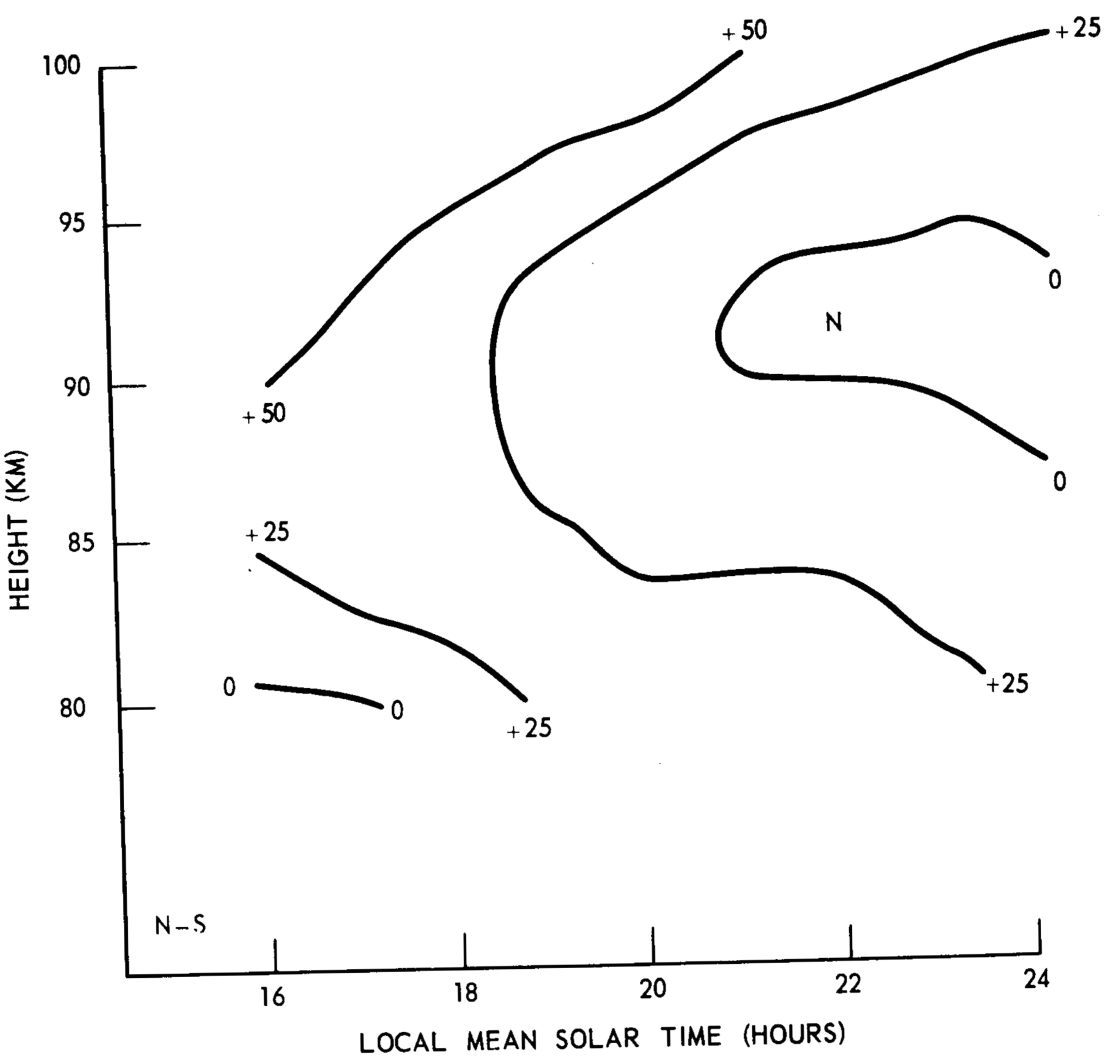

Figure 4—Meteor Winds, September, 1961 (Adelaide, 35°S)