Mesospheric Winds and Waves Over Jicamarca on May 23–24, 1974

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S. Fukao,[1] T. Sato,[1] S. Kato,[2] R. M. Harper,[2] R. F. Woodman,[3] AND W. E. Gordon[4]

The VHF radar at Jicamarca (12.0°S, 76.9°W) was used to probe the mesosphere for 24 hours on May 23–24, 1974. The inferred zonal wind shows a strong eastward prevailing component below 75 km for these winter conditions, as would be expected from the annual and semiannual oscillations. The zonal winds are in good agreement in their region of overlap with rocket observations made at Ascension Island (8.0°S, 14.4°W) for the same period. This is the first direct confirmation that Jicamarca VHF observations are measuring mesospheric winds. Substantial wind oscillations are present, but the lack of nighttime echoes precludes a decomposition into tidal components. The dominant periodicity in the short-period oscillations changes with altitude, with the short-period cutoff decreasing from around 10 min at 70 km to 4 min at 80 km. This suggests both a local energy source for the oscillations and the importance of the background temperature structure in determining the wave characteristics. The variation of echo power with height in the two antennas that were used shows that 2–10 times more power was received on the average in the nearly vertical antenna than in the antenna offset from the vertical by 3.45° at heights below 75 km, suggesting the possibility that a 'partial reflection' mechanism is important in the 55- to 75-km region at a 50-MHz operating frequency. The powers in the two antennas become nearly equal above 75 km, with the possibility that slightly more power is received in the off-vertical antenna. The continuous scattered power becomes very small above 80 km; however, meteor echoes are frequently observed. Equatorial electrojet echoes dominate the echo returns above 85 km.

1. INTRODUCTION

High-powered VHF radars offer a promising new way of measuring winds in the lower and middle atmosphere [Woodman and Guillen, 1974]. The technique makes use of radio wave scattering from turbulent irregularities in the refractive index of the atmosphere as tracers of the background large-scale motions. Recently, specular or partial reflection from thin stable laminae of the refractive index has been shown to be another mechanism responsible for the enhanced reflectivities in the lower atmosphere [Gage and Green, 1978; Röttger and Liu, 1978]. Using the Jicamarca radar located near Lima, Peru (12.0°S, 76.9°W), Woodman and Guillen achieved accuracies of a few centimeters per second in the stratosphere and a few tens of centimeters per second in the mesosphere for velocity measurements with a time resolution of about 1 min. This high resolution has allowed the detection of gravity waves with periods as short as the Brunt-Väisälä period. Further work using the same technique at the Jicamarca radar has been reported by Rastogi and Woodman [1974], Rastogi and Bowhill [1976a, b, c], and Rüster et al. [1978].

The initial observations, however, were generally limited to one altitude at a time. The observations presented here were made simultaneously at 8 stratospheric and 12 mesospheric heights using a newly installed data processing system which improved the Jicamarca data acquisition capability by nearly 2 orders of magnitude. As the observations were essentially continuous for nearly 24 hours on May 23–24, 1974, one of the obvious possibilities is to determine the vertical profile of mean winds and the vertical propagation properties of the dominant atmospheric waves. The stratospheric echoes have already been analyzed, and a diurnal oscillation with downward phase progression was found to dominate in the lower stratosphere, while a semidiurnal oscillation was observed to

[1] Department of Electrical Engineering, Kyoto University, Kyoto 606, Japan.
[2] Ionosphere Research Laboratory, Kyoto University, Uji 611, Japan.
[3] National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo, Puerto Rico 00612.
[4] School of Natural Sciences, Rice University, Houston, Texas 77001.

dominate near the tropopause [Fukao et al., 1978]. In this paper we will present some further results concerning the mesospheric echoes that have been obtained since Harper and Woodman [1977] reported the preliminary results.

2. OBSERVATIONAL TECHNIQUE

The observational technique and antenna configuration have been discussed by Harper and Woodman [1977] and Fukao et al. [1978]. They are described briefly below.

1. Twelve heights spaced at 2.5-km intervals over the 62.5- to 90-km region were observed simultaneously in each of two antennas for about 24 hours on May 23–24, 1974. The height resolution of the experiment was about 4 km.

2. At each height the returned signal was digitally filtered over 128 successive pulses, or about 0.11 s. The complex autocorrelation function was calculated at 16 time delays at the 0.11-s increments in real time and averaged for about 1 min before writing on magnetic tape.

3. One antenna was pointed in a quasi-vertical direction (about 0.36° to the southwest), while the other was offset from the vertical by angles of 3.45° and 0.15°, respectively, toward the west and north [Fleisch, 1976].

The digitally filtered mesospheric signal to noise ratios are frequently of the order of unity, and thus proper noise estimation and subtraction are important. We have estimated the noise in two ways.

1. During the observations the transmitter was turned off for 1 min out of every 30 min, and the sky noise was processed in the same way as when the transmitter was on. This gives a good estimate of the sky noise but does not allow for the possibility of receiver recovery effects due to the transmitter pulsing.

2. The sky noise is very wide band and thus contributes only to the zero time delay of the autocorrelation function. The signal correlation time is relatively long in the 62.5- to 70-km region, and thus it is easy to estimate the signal power at the zero time delay by extrapolating the values at the neighboring four time delays. The extrapolated values always fall below the measured value, and the difference between the two gives an estimate of the uncorrelated white noise. The noise power thus estimated does not vary with height, although it does vary with receiver gain and local time. Thirty-minute means of the

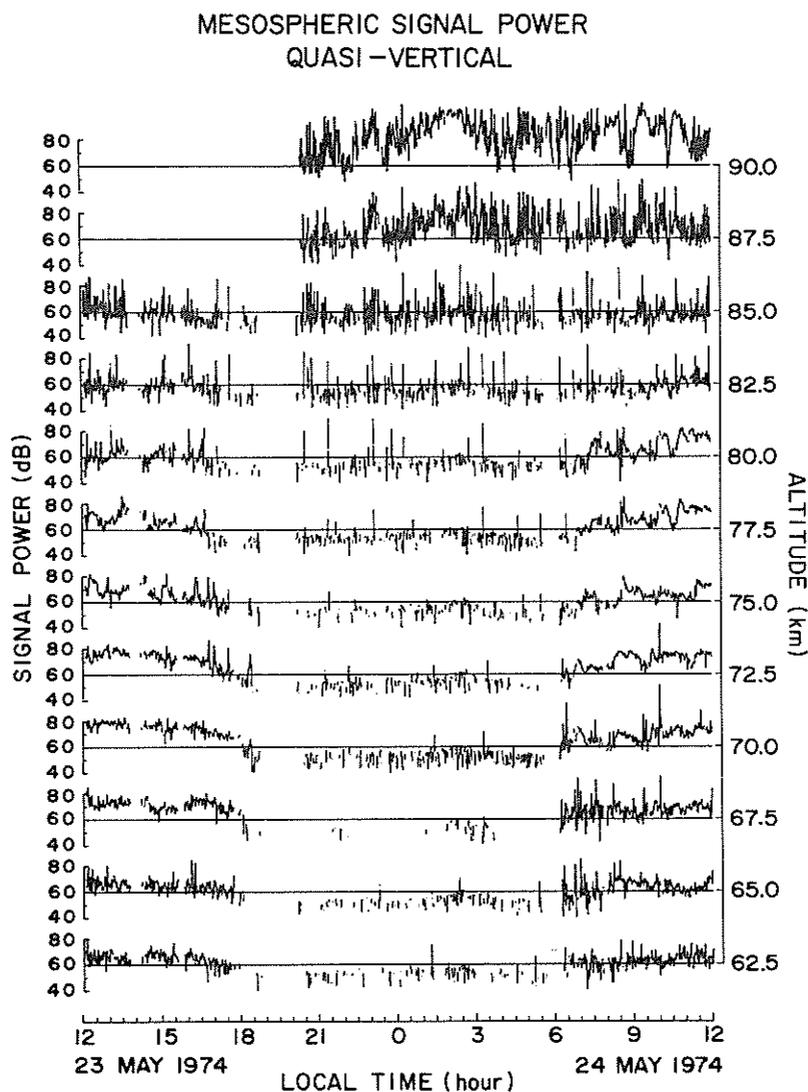MESOSPHERIC SIGNAL POWER
QUASI-VERTICAL

Fig. 1. Estimate of mesospheric signal power in the quasi-vertical direction. The ordinate is relative power in decibels with an arbitrary reference level. There are no data at 87.5 and 90 km before about 2000 LT on May 23, 1974.

noise estimated in this manner agree well, with a difference of less than 1 dB, with the noise power that was directly measured every 30 min by turning off the transmitter. This indicates that the receiver recovery effects were at most of the order of 25% and thus cannot affect any of the conclusions to be presented here. The extrapolated noise estimates were used in analyzing the data.

During the observations themselves and in the later analysis, care was taken to look for coherent spread F echoes that could have contaminated the mesospheric echoes. There was no indication of such echoes during the experiment.

3. SIGNAL CHARACTERISTICS

Figure 1 shows the signal power as a function of time at the 12 mesospheric heights for the quasi-vertical antenna. The altitude region over which measurements were taken was moved upward by 5 km near 2000 LT, thus explaining the lack of data at 87.5 and 90 km before that time. Below 80–82.5 km the echo power variations show features that have been reported in previous measurements [*Woodman and Guillen*, 1974; *Rastogi and Woodman*, 1974; *Rastogi and Bowhill*, 1976c].

1. Signal power above the noise level is only observed

during the daylight hours. The nighttime signal levels that are inferred are consistent with random errors expected in the estimation of the noise power. In particular, the 5- to 7-dB increase in the power that is observed at all heights near 0300 LT is the result of a strong increase in the sky noise temperature as the galactic center passed through the antenna beam.

2. The signal power at a given height can vary rapidly during the day. However, the mean signal power tends to vary with time according to the solar zenith angle.

3. Profiles of the mean signal power as a function of height generally maximize between 70 and 77.5 km and show a minimum at 80–82.5 km.

Strong spikelike echoes are frequently observed above 80 km. These echoes appear to be best described as short bursts, lasting probably much less than the time resolution of 1 min, since they never seem to continue into the next minute's data, which are superimposed on the generally weak background. These echoes can be clearly seen in Figure 1, especially at 85 and 87.5 km. As opposed to the solar zenith angle variation in the echo power at the lower heights, the spikelike echoes persist throughout the night.

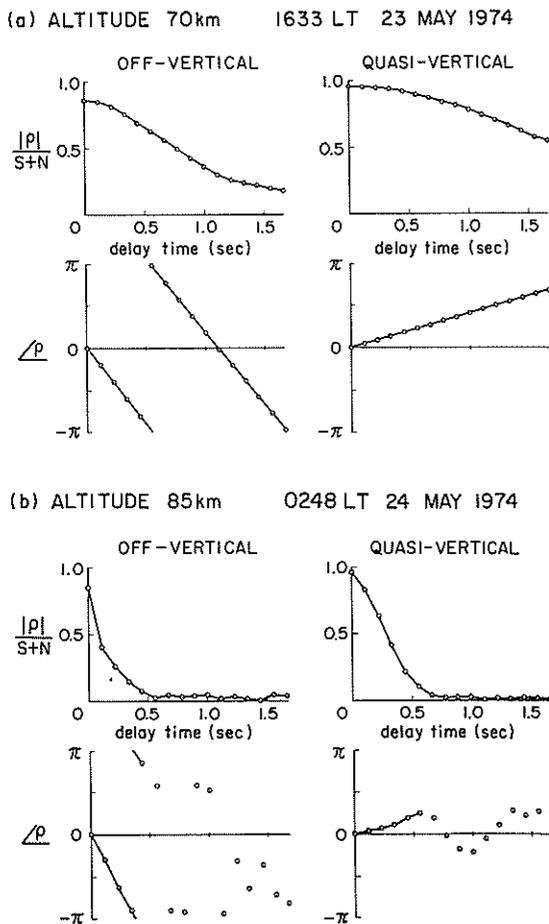Figure 2 shows examples of complex autocorrelation func-

Fig. 2. Typical complex autocorrelation functions for the off-vertical and quasi-vertical antennas that are received at (a) 70 km and (b) 85 km. The abscissa shows delay times.

tions, shown as amplitude normalized to the zero lag and phase, measured above and below 80 km. The data from above 80 km show a minute's data when a spikelike echo was received. The correlation times observed for the spikelike echoes are of the order of 0.1–0.2 s. This value seems too short for the signal to be due to coherent scattering from turbulent fluctuations in the electron density [Rastogi and Bowhill, 1976c], since it requires vertical velocity fluctuations of the order of 10–15 m s^{-1}.

The characteristics of the spikelike signals suggest to us that they are possibly due to echoes from meteor trails in the main or side lobes of the antenna. The echoes persist throughout the night. A meteor source should show a minimum in the evening hours and a maximum in the morning hours. There is some indication of this in the data, especially if the apparent rise in the mean power at 90 and 87.5 km after midnight were due to very frequent arrival of meteors. The correlation time of 0.1–0.2 s is consistent with the decay time of underdense meteor echoes at 50 MHz [Nowak, 1967].

However, the equatorial electrojet seems to be largely responsible for the echo power at 90 and 87.5 km. Figure 3 compares the echo power (smoothed by a 10-min low-pass filter) with the geomagnetic H component from Huancayo (12.0°S, 75.3°W) for the same period. The strong correlation during 0800–1100 LT indicates that the echoes of this period are associated with the equatorial electrojet. This correlation can be seen only above 85 km. No clear correspondence can be

seen at the broad maximum of echo power around 0200–0500 LT. This power maximum could possibly be due to the above mentioned maximum occurrence frequency of meteor trails, but it could also result from an electrojet-associated instability which did not result in large current flows due to the low nighttime electron densities. These echoes should be more fully investigated in future measurements using shorter digital filtering times and writing the filtered signal directly on magnetic tape for later processing.

Since the background signal above 80 km is generally very weak and we do not know if a given spikelike echo enters through the main lobe or a side lobe, we have not attempted to process the data above 80 km except in the determination of the hourly mean zonal winds, where we felt that the antenna lobe uncertainties might average out. However, we do not feel that the zonal wind data above 80 km are particularly trustworthy.

Below 80 km the autocorrelation amplitudes in general decrease with increasing time delay, with the phase changing approximately linearly with time while the correlation is significant as is illustrated in Figure 2. This indicates that the signal spectra are generally single peaked and symmetric. Thus the echoes can usually be parameterized by power, correlation time (or, equivalently, spectral width), and Doppler velocity. The signal characteristics below 80 km have been discussed extensively [Rastogi and Woodman, 1974; Rastogi and Bowhill, 1976c; Harper and Woodman, 1977].

The ratio of the power received in the quasi-vertical and off-vertical antennas gives some clue as to the scattering mechanism. For example, Gage and Green [1978] and Röttger and Liu [1978] have recently shown that the power received in a vertically pointing antenna is usually much stronger than that in an antenna directed off the vertical in the troposphere and lower stratosphere. They have suggested that specular or partial reflection from thin stable laminae of the refractive index can cause these enhanced reflectivities.

Figure 4 shows the mean powers that were received in the quasi-vertical and off-vertical antennas as a function of height. The noise levels in the two antennas were 65.1 and 64.1 dB, respectively, indicating approximately equal system sensitivity. It is clear that about a factor of 10 more power is received in the quasi-vertical antenna at stratospheric heights, supporting the partial reflection hypothesis. However, the separation of the two beams at Jicamarca, only 3.45°, is much smaller than that used in the experiments of Gage and Green [1978] and
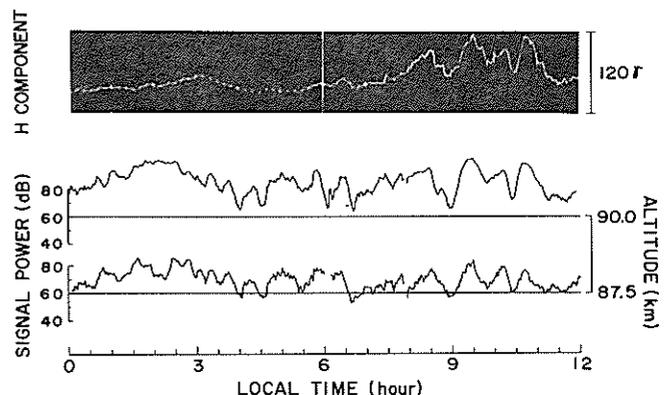

Fig. 3. Comparison of signal power (a 10-min low-pass filter is applied to the logarithm of power) at 90 and 87.5 km and magnetic H component record at Huancayo (12.0°S, 75.3°W) for 0000–1200 LT on May 24, 1974.
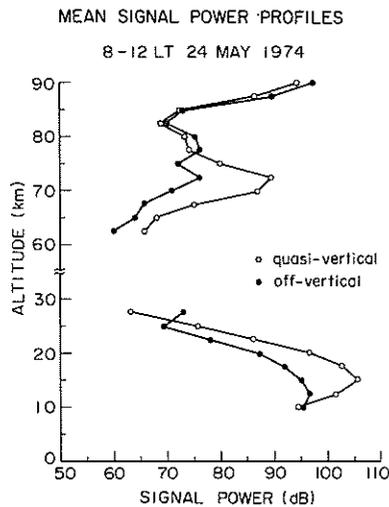
MEAN SIGNAL POWER ·PROFILES

8-12 LT 24 MAY 1974

Fig. 4. Mean signal power versus height in the quasi-vertical and off-vertical antennas for 0800–1200 LT on May 24, 1974.

Röttger and Liu [1978], and in fact, both of the Jicamarca beams fall within the 'vertical' antenna beam widths used in the previous experiments. This suggests that the partial reflection is very highly aspect sensitive and that most of the power received by a relatively broad antenna pointing approximately vertically will come from the vertical direction.

The quasi-vertical antenna sees a factor of 2–10 more power than the off-vertical antenna in the lower mesosphere. The powers in the two antennas become approximately equal by 75 km, with the possibility that the off-vertical antenna sees slightly more power above 75 km.

A successful theory of the scattering mechanism will have to explain this aspect sensitivity as well as the correlation between signal power and signal correlation time observed by *Rastogi and Bowhill* [1976c]. In our data the signal correlation time is observed to increase with signal power at heights below 70 km in both antennas. This correlation is not observed above 70 km in the 1-day data that we have analyzed. This suggests a possible change in the geometry of the scatterers, from layered structures below 70 km to more scattered irregularities above on this day.

Rastogi and Bowhill [1976c] assumed that the scattering in the lower mesosphere was from turbulence-enhanced electron density fluctuations at a scale size of 3 m. They then showed that the increase in signal correlation time that is observed to occur along with increased signal power in the mean Jicamarca data could be explained if stronger turbulence were occurring in narrower layers. The turbulent layers had to be of the order of 30 m thick so that a range of wave numbers, with the turbulent enhancements strongly wave number dependent at Jicamarca's frequency, could contribute to the scattering.

Some aspect sensitivity is inherent in the Rastogi-Bowhill model, since the ray path length through a horizontal layer is shorter for the vertical than for the off-vertical antenna by about 0.2%, allowing the vertical antenna to scatter from a slightly larger wave number range. However, it is not clear that the implied aspect sensitivity is sufficient to explain the observations.

We would like to call attention to the possibility that the scattering is occurring off of sharp gradients in the electron density over distances of the order of one wavelength, or 6 m. These 'partial reflections' either could be from very narrow regions of at least 1-km horizontal extent, possibly occurring

at the nonturbulent-turbulent interfaces that are implied in the Rastogi-Bowhill model, or could be from smaller irregularities which would have to be elongated by about a factor of 5 in the horizontal direction over the vertical direction in order to explain the aspect sensitivity that we observe, a possibly continuous transition from one region to another as viscous effects become more important with increasing height. Each of these mechanisms has been invoked to explain partial reflection observations at much lower frequencies [*Belrose*, 1970; *Vincent*, 1973], but at a scale size of 6 m the difficulties of sustaining a narrow interface against small-scale turbulence are much greater.

The correlation time of the signals that we observe, which is considerably shorter than the incoherent scatter time, suggests that the scatterer is in a turbulent medium. However, the signal correlation time is observed to increase with strong signal power. This could possibly indicate that a relatively more stable nonturbulent-turbulent interface allows larger gradients to exist. The signal correlation time is generally longer in the vertical antenna than in the off-vertical antenna. However, as the signal correlation time varies as the signal power and the signal power is greater in the vertical antenna, the significance of this difference is not clear. It is clear that future theoretical work should attempt to explain the aspect sensitivity of the observed signals below 75 km.

The circuit which normally equalizes the transmitted power in the two antennas at Jicamarca was not working during the experiment, and thus we cannot be sure of the relative transmitted powers in the two antennas, though an attempt was made to keep the powers reasonably equal, and they probably did not differ by a factor of 2. Thus the slightly greater power in the off-vertical antenna above 75 km is possibly not significant, although it does not conflict with partial reflection evidence at much lower frequencies of enhanced power in the off-vertical direction at heights above 80 km [*Vincent and Belrose*, 1978]. This feature of the scattering needs to be confirmed by

MEAN ZONAL WIND PROFILES
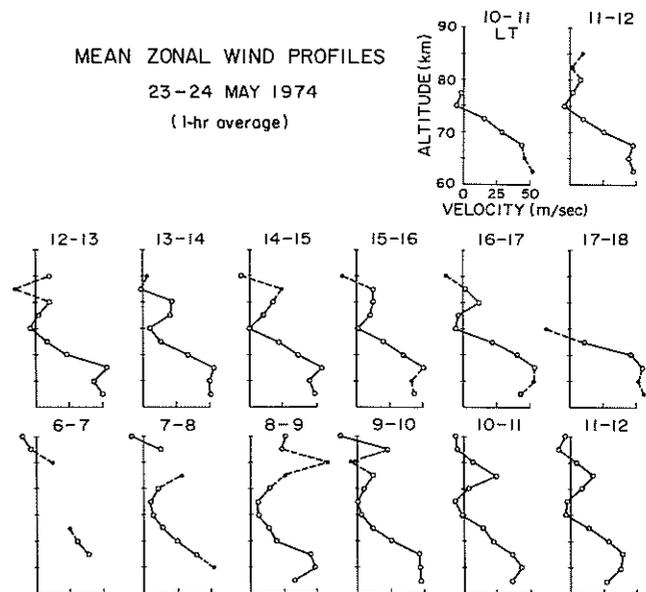
23–24 MAY 1974

(1-hr average)

Fig. 5. Hour average of the zonal velocity versus height for May 23–24, 1974. Velocities are positive eastward. Open circles indicate averages of more than 30 data points that are contained in a period indicated at the top of each profile, while solid ones are the averages of 10–30 data points. No average is plotted if the number of data is less than 10 within the 1-hour interval.

future experiments at Jicamarca in which the transmitted powers are carefully monitored throughout the experiment.

4. PREVAILING AND TIDAL ZONAL COMPONENTS

Line of sight velocities were estimated by the moment method used by *Woodman and Guillen* [1974] from the 0.11-s time delay of the autocorrelation function. Because the quasi-vertical antenna was not truly vertical and as we did not measure the meridional wind component during this experiment, we do not feel that we can derive uncontaminated vertical velocities from the present data for discussing prevailing and tidal components and will confine our discussion of these long-period components to the zonal wind.

Zonal winds were calculated from the line of sight velocities by a simple transformation which assumes that the vertical velocities in the scattering volumes of the two antennas are equal:

$$U_y = -(V_{ov}^{los} - V_v^{los})/\sin 3.45° \qquad (1)$$

where U_y is the zonal wind and V_{ov}^{los} and V_v^{los} are the line of sight velocities in the off-vertical and quasi-vertical antennas, respectively. The assumption of equal vertical velocities does not introduce significant errors into the estimation of prevailing and tidal components due to the large horizontal scale of these variations relative to the antenna separation. However, the assumption must be reexamined in dealing with shorter-period oscillations.

Figure 5 shows hourly mean profiles of the zonal wind velocity versus height. Data were not included in the average when the signal to noise ratio fell below 0.1. Velocities could only be determined during the daylight hours in general.

The region below 75 km is characterized by strong eastward winds throughout the period of measurement. The observed winds agree in both general sense and magnitude with those that would be expected for a winter observation at a low-latitude station from the annual and semiannual wind oscillations (I. Hirota, private communication, 1978). This strong eastward prevailing component for winter conditions allows us to check the Jicamarca mesospheric wind measurements against those by the meteorological rocket technique.

Figure 6 shows a comparison of the average zonal wind profile from the period 0900-1200 LT on May 24, 1974, and the rocket observations made at Ascension Island (8.0°S, 14.4°W) over the April-June 1974 period [*U.S. Department of Commerce*, 1974]. The longitudinal dependence of the mean zonal flow is thought to be small, so that we can compare the results. It is apparent from Figure 6 that the profiles show general continuity in their region of overlap. To our knowledge, this is the first direct confirmation that the mesospheric measurements at Jicamarca are measuring the atmospheric winds.

The winds at each height also show variations from hour to hour. For example, the winds at 67.5 and 70 km change by 15 and 25 m s^{-1}, respectively, over the 1200-1800 LT period on May 23 and return to an intermediate value by the morning of May 24. These velocity changes suggest the possibility that there are substantial tidal oscillations present in the data. However, we have not been able to analyze the data successfully for prevailing, diurnal, and semidiurnal components.

As there has been considerable discussion of why the Jicamarca measurements have not detected the propagating $S_{1,1}$ diurnal tide that is clearly observed in measurements above 80 km at Arecibo [*Mathews*, 1976], we attempted fits to prevailing and diurnal components only. In this case, substantial diurnal

amplitudes were inferred, but the phase variation with altitude shows no consistent pattern.

Arecibo has recently extended its measurements to heights of around 65 km [*Harper*, 1978]. Arecibo scattering does not depend on turbulent enhanced irregularities or partial reflection but rather is volume incoherent scatter from the ambient electrons. In a winter measurement on December 7, 1977, about 6 months after the May 23–24 Jicamarca experiment to compensate for the different hemispheres, wind profiles were obtained at Arecibo in both the zonal and the meridional components. Here, as in the Jicamarca measurements, the Arecibo zonal wind profiles show strong eastward prevailing winds up to heights of about 80 km. No propagating diurnal tide is visually evident in the zonal wind component for these winter conditions at Arecibo, although downward propagating winds with a vertical wavelength of about 20 km can be inferred visually in the meridional component. This is not unexpected, since classical tidal theory predicts that the meridional wind oscillation associated with the $S_{1,1}$ diurnal tide should be larger than the zonal wind oscillation at low latitudes. At Jicamarca's latitude the meridional oscillation should be approximately twice as large as the zonal oscillation.

Given the good agreement of the Jicamarca zonal wind profiles with the rocket data, their general agreement with Arecibo data for the same season, and their general agreement with the expected prevailing wind behavior in the winter season, we do not feel that the lack of a clearly identifiable dirunal tide in winter observations at Jicamarca prejudices the measurements. We would, however, expect Jicamarca to observe the diurnal tide in general in summer and equinox measurements, particularly in the meridional wind component.

5. SHORT-PERIOD WAVES

Figure 7 gives contours of isopower spectral density versus Doppler shift (or, equivalently, line of sight velocity) and time
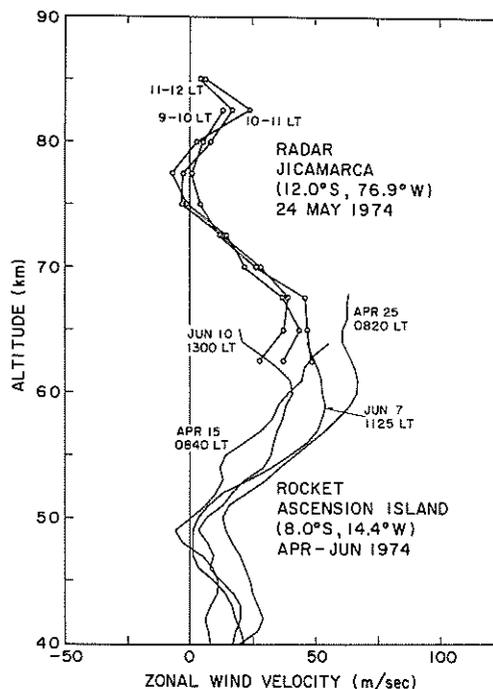
Fig. 6. Comparison of zonal wind velocities by radar at Jicamarca (0900–1200 LT on May 24, 1974) and rockets at Ascension Island (April–June 1974).
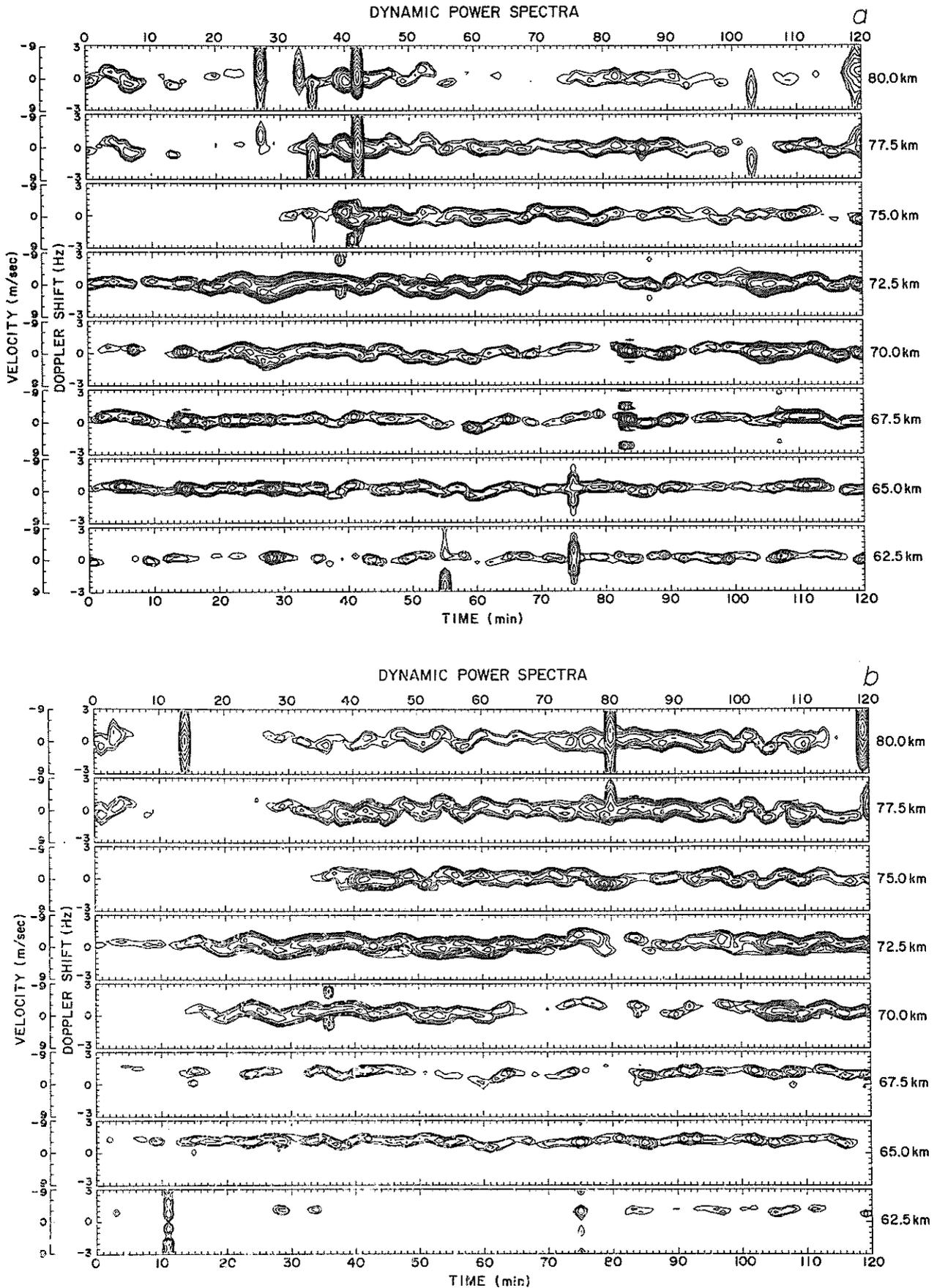
Fig. 7. Contour plots of dynamic power spectra of scattered echoes at the (a) quasi-vertical and (b) off-vertical antenna directions for 0800–1000 on May 24, 1974. The ordinates are Doppler shift from center frequency and equivalent line of sight velocity. Contours are drawn at 2-dB intervals.
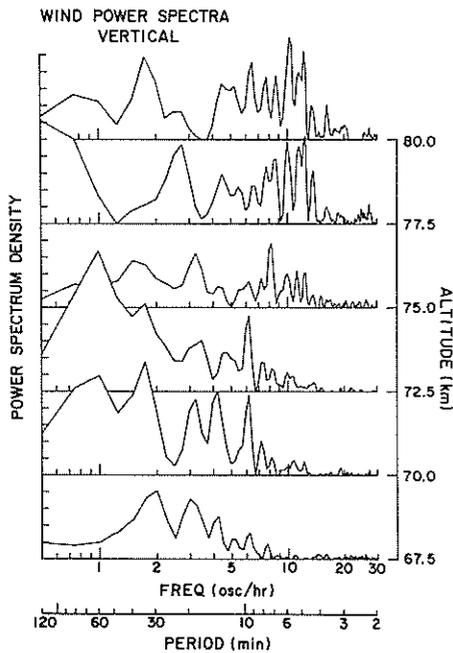
WIND POWER SPECTRA
VERTICAL

Fig. 8. Power spectra of vertical wind velocities at 67.5–80 km for 0800–1200 LT on May 24, 1974.

for the period 0800–1000 LT on May 24 for both the quasi-vertical and the off-vertical antenna. The contour levels are logarithmic, each succeeding level representing a 2-dB change in power. This form of representation shows the velocity oscillations and echo power well, but care must be exercised in interpreting the spectral width, since we have not shown contours below a minimum level. This can make strong echoes of the same shape as weaker ones appear wider in frequency. Figure 7 does indicate that most of the echoes are single peaked, at least to within the contour level of a factor of 1.6. The very broad, strong echoes which appear near minutes 35 and 40 at 77.5 and 80 km are possibly examples of the meteor trail echoes which are often observed above 80 km.

Figure 7 suggests that the dominant periodicity in the short-period oscillations changes with height. This is confirmed by Figure 8, which shows the power spectra of the vertical wind oscillation for 0800–1200 LT on May 24. Of particular interest is the short-period cutoff, which decreases with increasing

altitude from a period of around 10 min at 70 km to a period of about 4 min at 80 km. The 5-min periodicity which is very strong above 75 km is not observed below that height.

The general characteristics of the oscillations below 75 km agree well with previous measurements near 70 km at Jicamarca [*Rastogi and Woodman*, 1974; *Rastogi and Bowhill*, 1976c]. Except for the one case shown by *Harper and Woodman* [1977], there is no detectable phase difference between the oscillations in the two antennas below 75 km. *Rastogi and Bowhill* [1976c] assumed that the vertical velocities in the two antenna scattering volumes were equal and that any differences in the velocities measured in the two antennas must be due to horizontal winds; i.e., they assumed that there was no uncorrelated vertical velocity 'noise.' They then determined the mean amplitude ratio of the horizontal and vertical wind oscillations and used this ratio in the gravity wave equations for an isothermal atmosphere to derive the horizontal and vertical wavelengths of the 10- to 15-min-period oscillations observed near 70 km. They determined that the oscillation must correspond to a surface wave with no vertical phase propagation and horizontal wavelength of the order of 200–400 km.

The oscillations observed above 75 km on this day differ from those observed below that height both in their shorter period and in the fact that a 1- to 2-min phase difference frequently exists between the oscillations in the two antennas. This can be seen in Figure 9, for example, from 0800 to 0820 LT or from 0850 to C910 LT. When a phase difference is observed, the oscillation is observed to occur first in the vertical antenna and then later in the antenna offset toward the west. The amplitudes of the velocity oscillations are very nearly equal in the two antennas. A cross-correlation analysis indicated no phase difference with altitude in either antenna over the 5-km altitude range through which the oscillations can usually be traced.

The 5-min period of the oscillations is very near the Brunt-Väisälä period for an isothermal atmosphere. This suggests that the oscillations are largely vertical, which would explain the nearly equal amplitudes of the oscillations observed in the two antennas, since they are essentially equally sensitive to vertical motions. The simplest interpretation of the data, which assumes that the oscillations observed in both antennas are due only to the vertical velocity, suggests a horizontal scale of the order of 10–25 km during times when a 1- or 2-min phase delay is observed and a much longer horizontal scale at
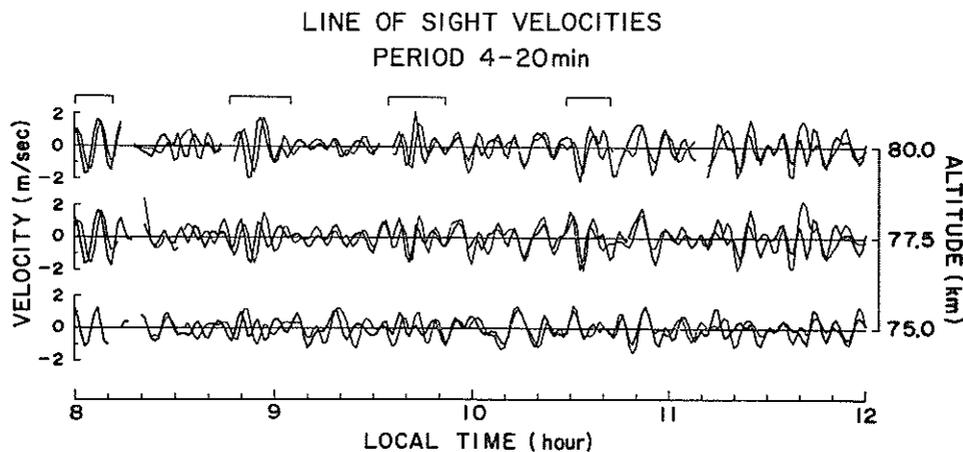
LINE OF SIGHT VELOCITIES
PERIOD 4–20min

Fig. 9. Line of sight velocities after 4- to 20-min band-pass filter. Thick line is for quasi-vertical, and thin line is for off-vertical antenna directions. Horizontal bars show the periods when a clear phase difference can be seen.

other times. The mean zonal winds that we infer over the 75- to 80-km region are very small, so that the observed phase differences cannot be explained by drift with the background wind unless the constant phase surfaces are nearly aligned east-west, a possibility which we of course cannot rule out.

It has been suggested (R. Hyde, private communication, 1978) that the dominant short-period oscillations that are observed at Jicamarca are largely buoyancy, or Brunt-Väisälä, oscillations in a nonisothermal atmosphere. The Brunt-Väisälä period for an isothermal atmosphere is about 5 min. However, the mean temperature gradient in the lower mesosphere is of the order of -2 to -3 K km^{-1}. A negative temperature gradient causes a less stable atmosphere, i.e., less buoyancy, and thus a longer period of oscillation. A temperature gradient of -5 to -6 K km^{-1} is necessary for the Brunt-Väisälä period to be of the order of 10 min. Since it is felt that the echoes that we observe are coming from a few narrow layers, this temperature gradient is probably not difficult to achieve locally. Regions of large negative temperature gradient, being the least stable against turbulence, are the most likely to produce the electron density irregularities which cause the scattering that we observe.

We can find few compelling reasons to reject this suggestion on the basis of our data. The absence of an atmospheric response at a period of 5 min below 75 km, even though it is being forced at that period from above, suggests a complicated buoyancy structure. The horizontal structure, particularly the westward phase propagation at 80 km, remains difficult to explain in terms of a buoyancy oscillation. The recent photographic results of *Moreels and Herse* [1977] show large-scale wave systems. Future measurements in which the three velocity components are determined at Jicamarca should help our understanding of the relative contributions of buoyancy oscillations, surface waves, Kelvin-Helmholtz instabilities, and internal gravity waves to the complicated dynamics of the mesosphere.

6. CONCLUSIONS

Twenty four hours of Jicamarca data on May 23–24, 1974, have been analyzed. The following conclusions can be drawn.

1. The zonal wind shows a strong eastward prevailing component below 75 km for these winter measurements. The sense and magnitude of the winds are in general agreement with what would be expected from the annual and semiannual oscillations. A comparison of the Jicamarca zonal winds with winds determined by rocket shots from Ascension Island for the same period shows good agreement in the region of overlap. This is the first confirmation that the Jicamarca radar is measuring winds in the mesosphere.

2. There is no clear evidence in these winter data of the $S_{1,1}$ diurnal tide.

3. The dominant period in the short-period oscillations varies with altitude. This indicates to the authors a local energy source for the waves.

4. Sporadic spikelike echoes are frequently observed above 80 km. These echoes persist throughout the night and have correlation times of the order of 0.1–0.2 s. These echoes appear to be due to meteor trails, though this conclusion should be confirmed by future measurements. Above 85 km the equatorial electrojet dominates the echo returns.

5. The ratio of the scattering cross section in the quasi-vertical and off-vertical antennas, which are only separated by 3.45°, varies with altitude at mesospheric heights. Relatively stronger power is received in the quasi-vertical antenna at the lowest heights, while the off-vertical antenna possibly receives more power at the heights around 77.5 km. The aspect-sensitive scattering below 75 km suggests the possible importance of a partial reflection mechanism at these heights.

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