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Remote probing of *D*-region irregularities

H CHANDRA* and R A VINCENT
Department of Physics, University of Adelaide, Adelaide, South Australia 5001
* On leave from Physical Research Laboratory, Ahmedabad 380 009.

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Abstract. The nature of the *D*-region irregularities responsible for partial reflections is studied using amplitude, phase and range information taken at Buckland Park, South Australia, utilising a 178-dipole receiving array. Stratifications with distinct layer type structures below 80 km are noticed. A major part of the echo amplitude consists of specularly reflected signals.

Keywords. Partial reflections; *D*-region; irregularities.

1. Introduction

Partial reflections have been used to estimate electron densities in the *D*-region by several investigators (Gardner and Pawsey 1953; Fejer and Vice 1959; Belrose and Burke 1964; Gregory and Manson 1969; Pradhan and Shirke 1976) and more recently to measure neutral winds (Fraser 1968; Stubbs 1973; Gregory and Rees 1971; Vincent and Stubbs 1977; Manson *et al* 1978). However, investigations to study the nature of irregularities responsible for partial reflection have been relatively few (Gregory 1961; Austin and Manson 1969; Manson *et al* 1969; Fraser and Vincent 1970; von Biel 1971; Schlegel *et al* 1978). The 178-dipole array at Buckland Park, South Australia offers an ideal opportunity for some of the investigations of this type and experiments have been conducted recording range as well as simultaneous amplitude and phase measurements to gather information about the nature of *D*-region irregularities. Lindner (1975) studied the angular spread, fading rate and phase coherency from simultaneous amplitude and phase measurements of the echoes from a few heights selected by means of a controllable gate and recorded at adjacent rows of 11 dipoles each. He concluded from these observations, conducted during 1977, that the daytime *D*-region has distinct properties below and above 85 km. With introduction of a scanning gate and digital recording system introduced in 1972 it was possible to have measurements of amplitudes simultaneously at several heights. Since 1975 it has also been possible to measure phase at different heights digitally and thus height profiles of some of the parameters such as fading period, RMS phase deviations and Rice parameter, etc., were obtained. Results of simultaneous amplitude and phase measurements are discussed in this paper.

2. Experimental set-up

The experimental arrangement at Buckland Park has been described in earlier reports, viz., Briggs *et al* (1969) for the transmitting and receiving aerials and Stubbs (1973) for the digital amplitude recording simultaneously at different heights using a scanning gate. To measure phase simultaneously at different heights the equipment was suitably modified. The oscillator frequency for the transmitter (1·98 MHz) and for the local oscillator of the receiver (2·43 MHz) were derived from a single crystal oscillator. An extra phase sensitive receiver was built and the phase difference of 2π was digitised over 64 levels.

Two phased arrays, giving beam widths of $\pm 4{\cdot}5°$, of 89 dipoles each were used, one for recording amplitude and the other for recording phase. Gaussian shaped pulses of width 25 μ sec and peak power of 20 kW were transmitted at a pulse repetition frequency of 50 Hz. Twenty ranges each separated by 1 km were sampled at a rate of 5 Hz. Observations were conducted on a few days during the month of June 1975. A sample length of 3 min interval has been counted as one single observation and separate observations were conducted so as to cover the 60–80 km, 70–90 km and 80–100 km height ranges.

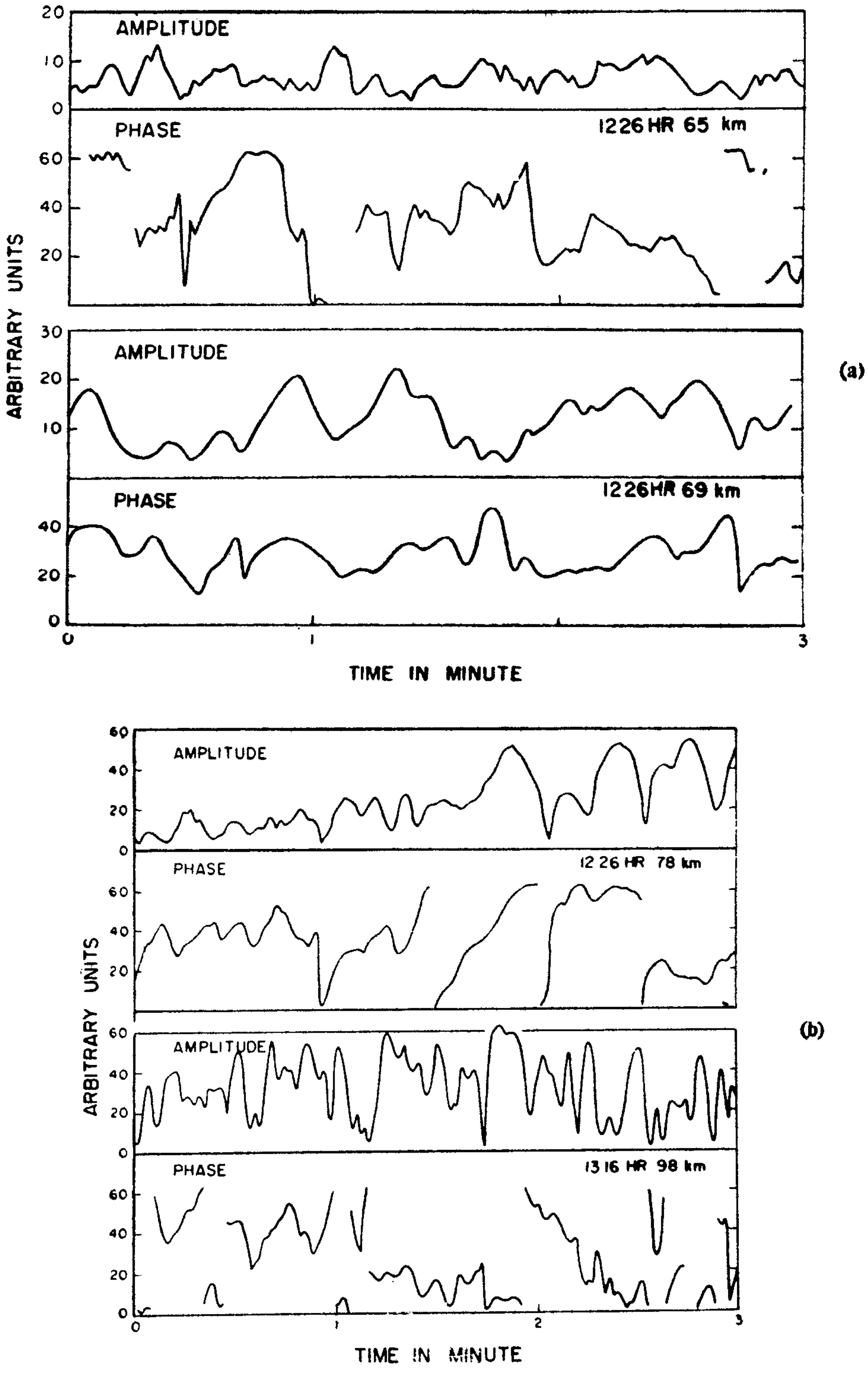
3. Example of amplitude and phase records

In order to show the characteristics of the partial reflected signals examples of the simultaneous amplitude and phase measurements at a few selected heights are shown in figure 1. Phase variations of 65 km are around 2π and due to fast changes in phase one finds fairly rapid amplitude fluctuations. At 69 km phase is quite stable (around $\pi/2$) and one finds a slow fading rate also. At 78 km there is smoothly varying phase change of more than 4π but the fading is not very rapid. However, at 98 km even though the total phase changes in a duration of 3 min are not more than 2π, due to very rapid and random changes in phase one also finds very fast fading in amplitude.

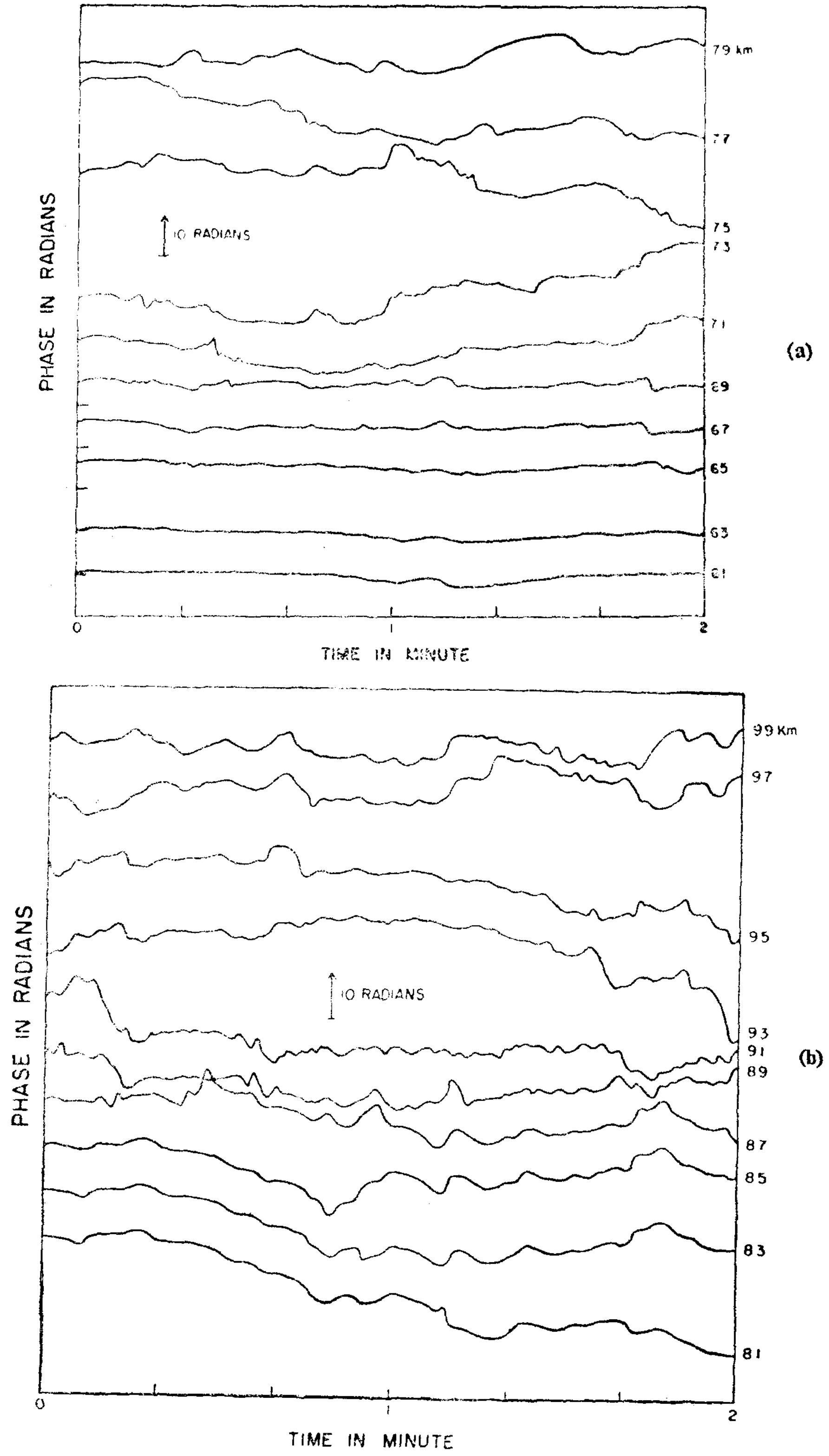
Examples of phase variations at every alternate km are shown in figure 2a (61–79 km) and 2b (81–99 km). Here the continuous phase data are shown in order to eliminate the instrumental 2π phase jumps. These plots again indicate very stable phase behaviour below 69 km.

4. Improved height resolution from amplitude and phase data

Phase information, along with amplitude information, permits an improvement in the height resolution. Austin *et al* (1969) have shown that due to finite pulse width what one obtains is the ‘moving average’ of the echo that would have resulted from a very short pulse. If both amplitude and phase information is available this smoothing process may be inverted by standard Fourier methods. They also applied this technique to *D* and *E* region data and an improvement of a factor of two in resolution was expected, provided, a good signals-to-noise ratio is maintained. Due to the pulse width of 25 μ sec, one is limited to a height resolution of 4 km from amplitude data alone. From the known receiver response to the pulse and using the amplitude and phase data, it is possible to deconvolve the pulse in order to improve the height resolution. We expect a resolution of



Figures 1a and 1b. Examples of simultaneous amplitude and phase measurements recorded at Buckland Park on 29 June 1975.



Figures 2a and 2b. Examples of simultaneous phase measurements at different heights recorded at Buckland Park on 29 June 1975. (a) 1224 hr, (b) 1316 hr.

about 2 km even though the measurements are made at every kilometre. Figure 3 illustrates this point. The amplitude information shows a broad peak around 66–67 km and some evidence of peaks at 76 km and 79 km. The phase information shows four different levels in its altitude variation. The deconvolved amplitude data, however, show clearly four peaks at 64 km, 69 km, 75 km and 78 km.

5. Heights of irregularities from amplitude and phase data

In order to estimate the heights of the *D*-region irregularities from the digital data, the deconvolved amplitude data were scanned and the maxima in amplitude noted from five successive scans. The number of maxima occurring during 3 min

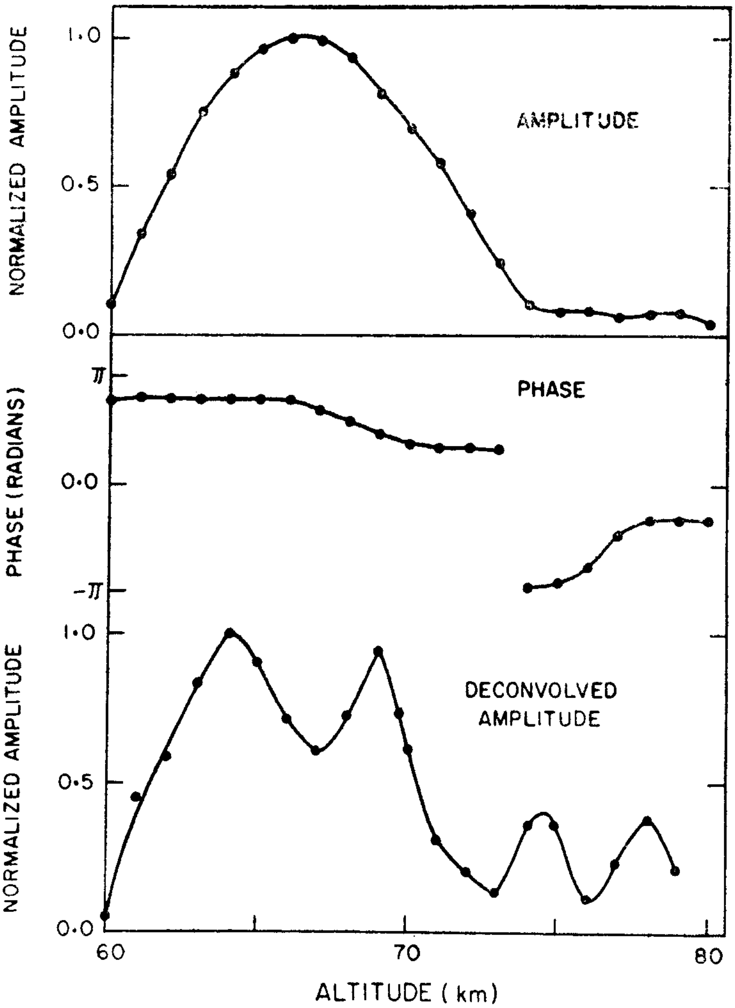


Figure 3. Altitude variation of amplitude, phase and the deconvolved amplitude recorded at Buckland Park on 29 June 1975. 1238 hr x mode.

of time was thus obtained separately at every 1 km interval. Figure 4 shows a comparison of the percentage occurrence of the maximum as a function of altitude between 60–80 km obtained from deconvolved amplitude data and also obtained from amplitude only data both averaged from several observations conducted over an hour period. At least five maxima are seen from deconvolved data in this range, whereas the raw data show only three or four peaks. The main difference is observed around 70 km where a broad peak is noticed from the raw data but two clear peaks in the deconvolved data. The heights of the irregularities deduced in this way are presented in figure 5 which includes the results of figure 4 upto 80 km and observations at 13·16 hr and for 80 to 100 km range. Above 80 km the stratifications are comparatively less and thicker as compared to the stratifications below 80 km. This agrees with the findings of Gregory and Vincent (1970) who analysed data taken at Christchurch, New Zealand.

6. Height profiles of Rice parameter

From the amplitude data, the probability distributions were studied in a way similar to that followed by von Biel (1970). Amplitude data, after corrections, if any, for the base level were normalised, and grouped into six cells ranging from 0·0 to 1·0. These experimentally observed amplitude probability distributions were compared sequentially with seventeen theoretically precomputed distributions with the parameter a ($\sqrt{2}$ times Rice parameter) ranging from 0·0 to 3·0 in steps of 0·2. To find the best fit the χ^2 test was adopted similar to that followed by von Biel (1971). To compensate for the very high values of χ^2 which would arise when

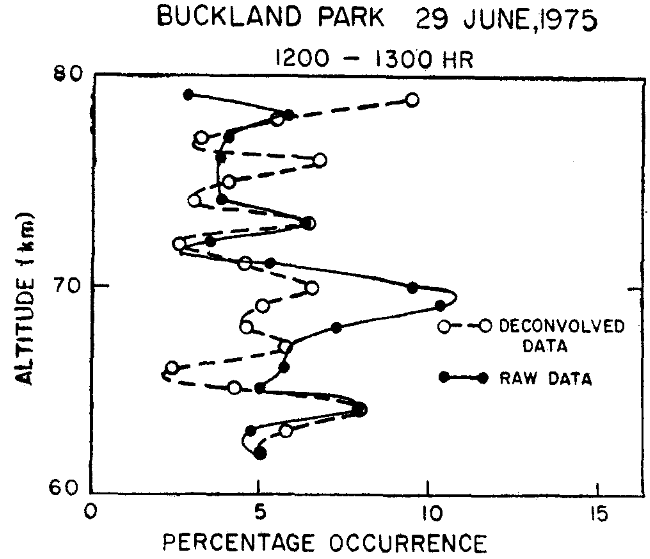


Figure 4. A comparison of the referred heights of reflections obtained from the amplitude only and from deconvolved amplitude data recorded at Buckland Park on 29 June 1975.

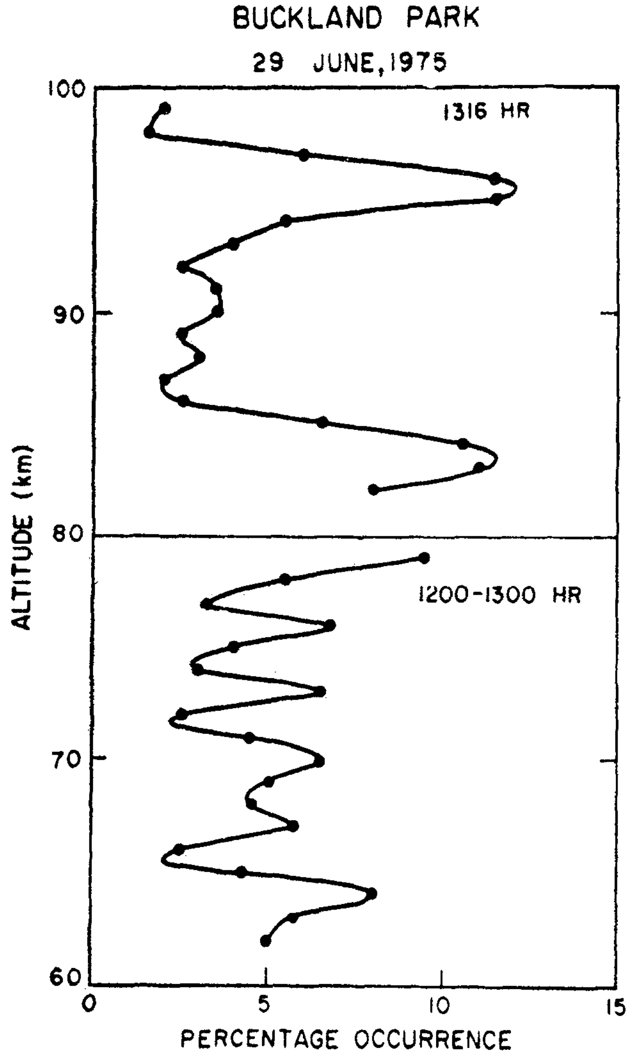
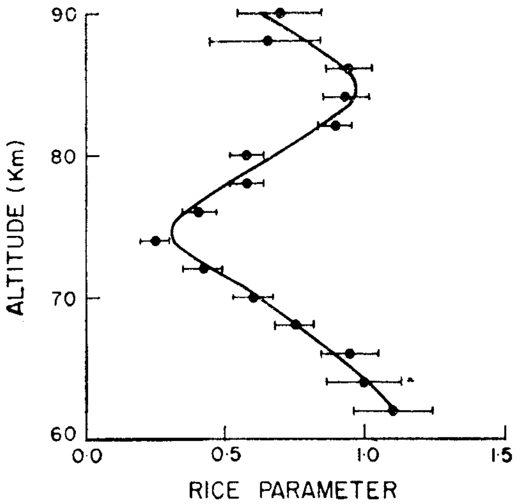
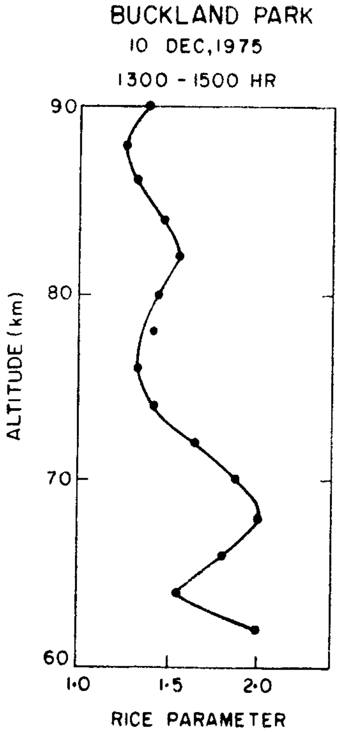


Figure 5. Preferred heights of reflections at Buckland Park averaged for the data recorded on 29 June 1975.

there are very few values of high amplitudes (for Rayleigh distribution) or low amplitudes (for normal distribution) the last two and the first two cells were combined together respectively. Mean values of the Rice parameter obtained from obervations on two days during June are shown as a function of altitude (figure 6a). The bars indicate the standard error in mean. A very significant change of Rice parameter with altitude is noticed. The value being one from 61 to 65 km and then decreasing with altitude showing a minimum at 75 km. The Rice parameter again increases steadily and shows a peak around 85 km. It should be noted that in practice it is difficult to distinguish between distributions whose Rice parameters lie in the range 0 to 1·0. The essential point is that those echoes



(a)



(b)

Figure 6a. Altitude variation of the Rice parameter at Buckland Park during June 1975.

Figure 6b. Altitude variation of the Rice parameter at Buckland Park on 10 December 1975.

for which $a \leqslant 1$ are due mainly to random scattering processes while those echoes for which a is found to be greater than 1, contain a significant specular component.

Another example of the height variation of Rice parameter from a large number of observation, on 10 December 1975 is shown in figure 6b. Clear maxima at 68 km and 82 km are noticed, the value being larger at 68 km than at 82 km. These results are different from the results of von Biel (1971), Mathews *et al* (1973) and Newman and Ferraro (1976) which indicate Rayleigh distribution below 80 km and Rice distribution above 80 km. However, recent results at Tromso reported by Schlegel *et al* (1978) show very high Rice parameter around 60–65 km and Rayleigh-type distribution in the range 70–90 km. A sample profile of the Rice parameter obtained at Woomera on 21 March 1974 from amplitude data is shown in figure 7. This shows a sharp maximum of Rice parameter at 70 km (about 1·5) and values less than 0·5 at both lower and higher altitudes. This indicates a strong coherent layer type reflection from 70 km.

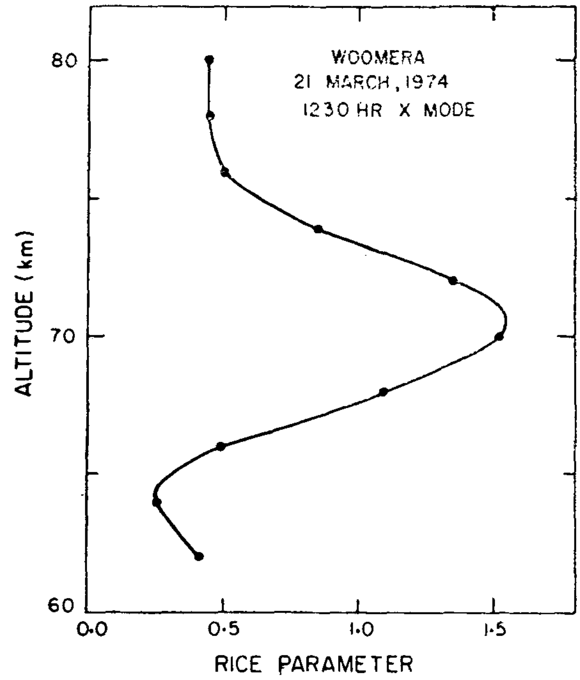


Figure 7. Altitude variation of the Rice parameter at Woomera on 21 March 1974.

7. Comparison with RMS phase deviations

The phase data were studied by computing RMS phase deviations (without any detrending) at each height for 3 min sample lengths. A comparison of the height profiles of the Rice parameter, percentage occurrence of the maximum both from the raw and deconvolved amplitude data and RMS phase deviations is shown in figure 8 for a single observation at 12 14 hr. The maxima in the percentage occurrence of maximum in deconvolved amplitude data are nearly coincident with the location of the minima in the RMS phase deviations. The maxima in Rice parameter however do not coincide always with the maxima in occurrence. Thus the heights of the *D* region irregularities can be estimated more precisely by digitally recording phase data which has best resolution.

8. Height of irregularities from range time records

In addition to the digital amplitude and phase recordings, range time recordings were also made on 35 mm film on some other days using a phased array of 89 dipoles, covering the range 60–110 km and with 1 km height markers. The features of records often showed layer type structures below 80–85 km during daytime hours and considerable patchy structures above 80–85 km. In particular, a layer type reflection around 70 km featured regularly. During night

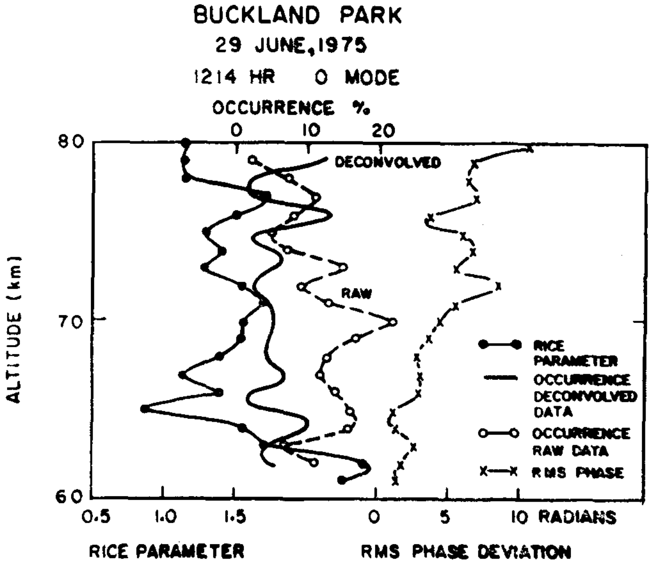


Figure 8. Altitude variation of Rice parameter, percentage occurrence of the maximum both from raw and deconvolved amplitudes and of RMS phase deviation at Buckland Park on 29 June 1975.

time hours layer type structures at 90 km and 105 km were often seen. Examples of strong layer type structure has been reported by Chandra and Vincent (1977).

Occurrence of reflections at different heights obtained from film records earlier for the month of July 1972 are shown in figure 9 for daytime and night time hours separately. Even though the height resolution is limited one still sees clearly successive maxima suggesting stratifications, the maxima occurring at 63, 67, 72, 78, 85, 92 and 97 km. These match comparably well with the lower boundary of the stratifications reported by Gregory (1961) at Canterbury, viz., 55, 61, 66, 74, 86 km. Furthermore the stratifications seem most distinct in the lower region, below 80 km.

9. Discussions

Results described here as well as in the earlier reports based on the partial reflection experiments conducted both in New Zealand (Gregory 1961) and Australia (Smith *et al* 1965) clearly indicate stratifications in the lower ionosphere in the mid-latitudes of southern hemisphere. Recent echo power measurements of the incoherent backscatter radar at 50 MHz conducted at twelve mesospheric heights in the 60–90 km region over Jicamarca also indicate that the echoing regions are not continuous in space but at well-defined heights (Harper and Woodman 1977). Thus, evidence for the preferred heights of reflection is now fairly strong. However, the basic mechanisms for these layer-type structures are not yet understood. The possible reasons to account for these layer-type structures could be the strong gradients in ionization and/or association with the dynamics of the mesopause

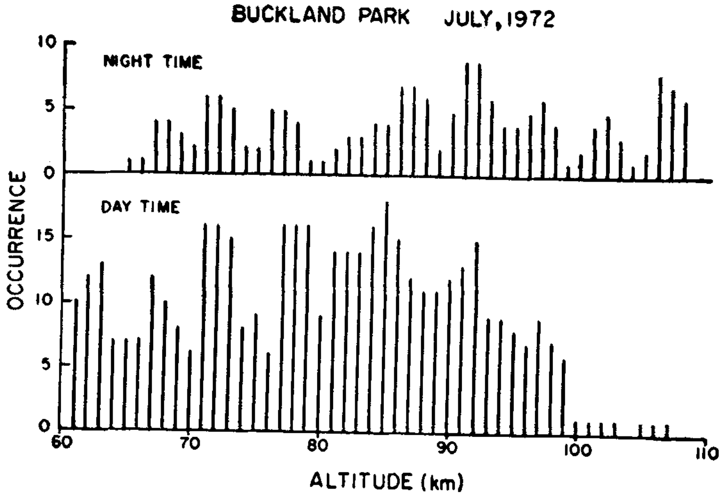


Figure 9. Altitude variation of the percentage occurrence of reflection obtained from the range time records at Buckland Park during July 1972.

such as turbulence. The metallic ions of meteor origin could be a possible candidate to explain long lasting layer-type structures. However, simultaneous observations of additional parameters-like electron density and winds would be desirable to understand the reflection process from *D*-region irregularities.

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