Aust. J. Phys., 1975, **28**, 171–84

The Nature of *D*-region Scattering of Vertical Incidence Radio Waves. II* Experimental Observations Using Spaced Antenna Reception

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Abstract

Statistical properties of the ground diffraction pattern formed by ionospherically reflected radio waves are used to examine models of the angular spectra of reflections from the ionospheric *D*-region. In the daytime two distinct height regions characterized by differing reflection mechanisms are identified within the *D*-region. Below 85 km the angular spectrum of reflected waves frequently contains coherent components, whereas a spectrum of incoherent or randomly phased components is characteristic of reflections from the region above 85 km. There is evidence which suggests the presence on many occasions of isolated moving reflectors in the reflecting 'ionospheric screen'. Both the mean angular spread and the fading speed of waves partially reflected from the *D*-region show an increase with increasing height of reflection.

1. Introduction

Many experiments for studying the properties of the lower ionosphere employ ground-based radio techniques involving the observation (first reported by Gardner and Pawsey 1953) of the weak partial reflections of radio waves from this region. The reliability of deductions made from such experiments often depends on assumptions regarding the reflection and absorption coefficients involved which, in turn, depend on the nature of the diffractive reflection or scattering processes occurring in the ionosphere. Very few direct investigations of the nature of the scattering processes have been made.

In this paper the nature of the reflection or scattering process is investigated and new experimental observations are presented. These investigations have involved comparing measured statistical properties of the ground diffraction pattern with statistical properties theoretically predicted for the different assumed reflection models discussed in Part I (Lindner 1975, present issue, pp. 163–70). The experimental procedures which were adopted are described in Section 2 and some results and their interpretation are presented in Section 3. Finally in Section 4 the results are compared with those of other workers.

2. Experimental Procedures

The experimental work described in this paper was carried out at Buckland Park, South Australia (34° 38′ S., 138° 37′ E.). The receiving and transmitting antenna arrays at the Buckland Park field station have been described by Briggs *et al.* (1969).

* Part I, *Aust. J. Phys.*, 1975, **28**, 163–70.

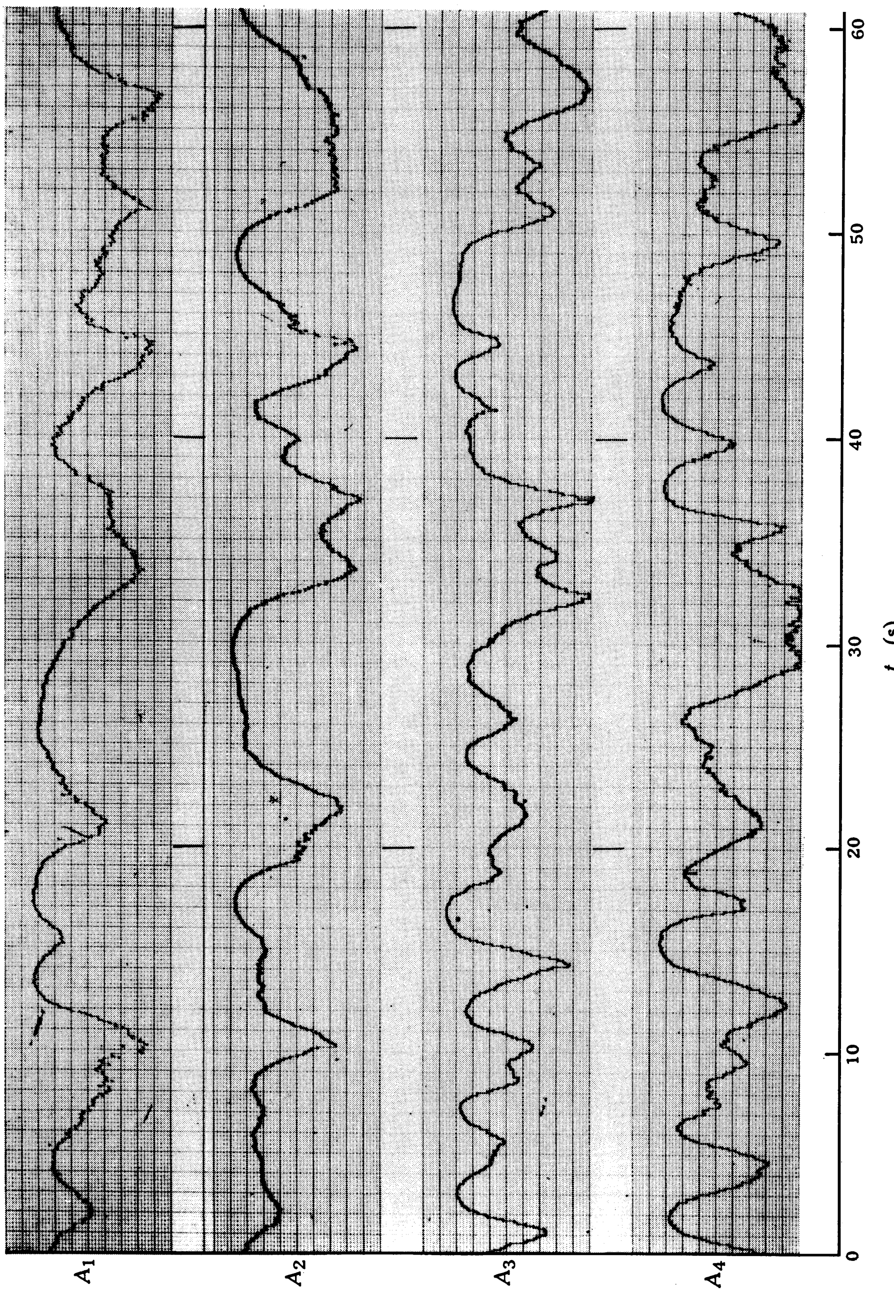

Fig. 1*a*. A 1 min segment of chart record for a 90 km reflection, showing various amplitudes recorded for studying scattering models.

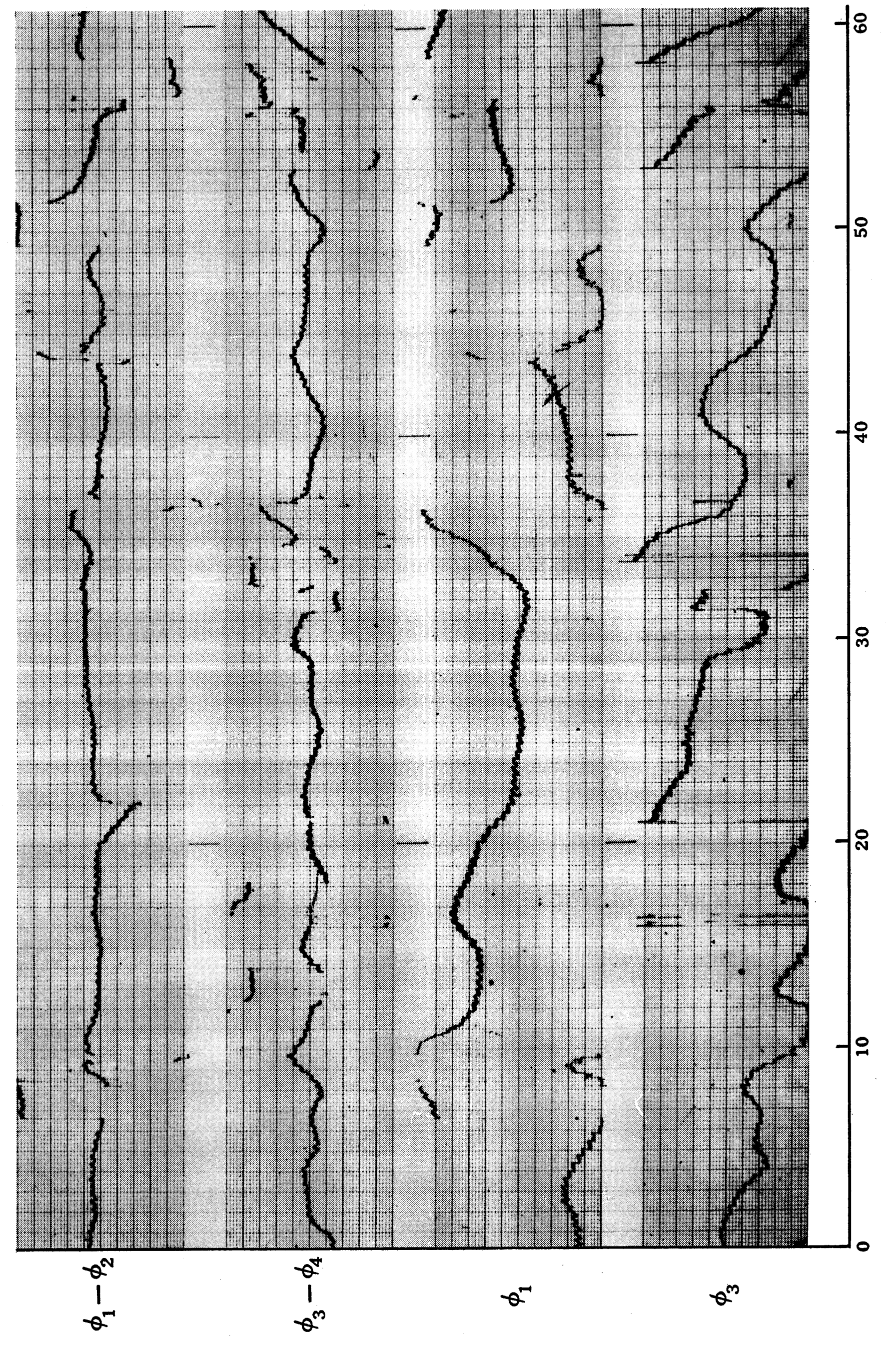

Fig. 1*b*. A 1 min segment of chart record (corresponding to that in Fig. 1*a*), showing associated phase results.

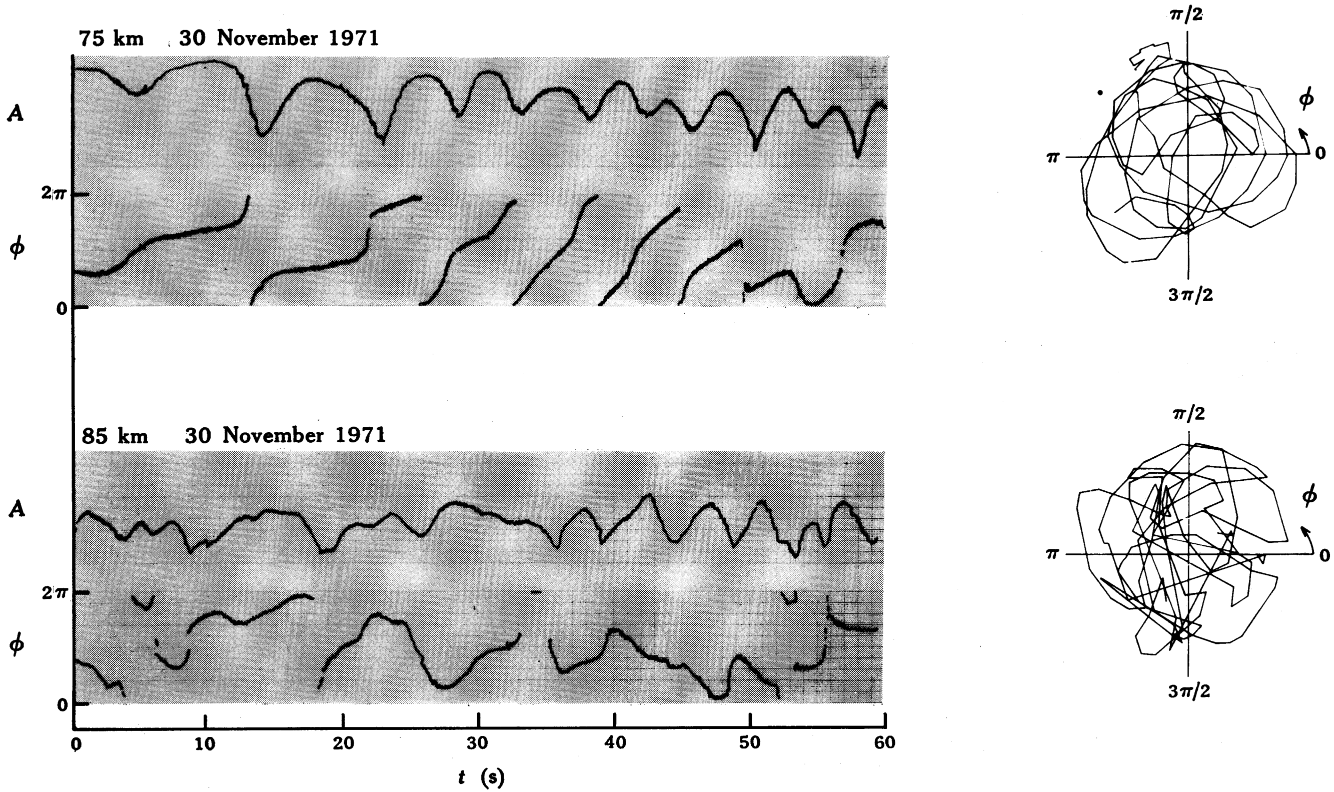

Fig. 2*a*. One min segments of chart records for the indicated heights and dates, showing amplitude and phase results and corresponding phasor representation.

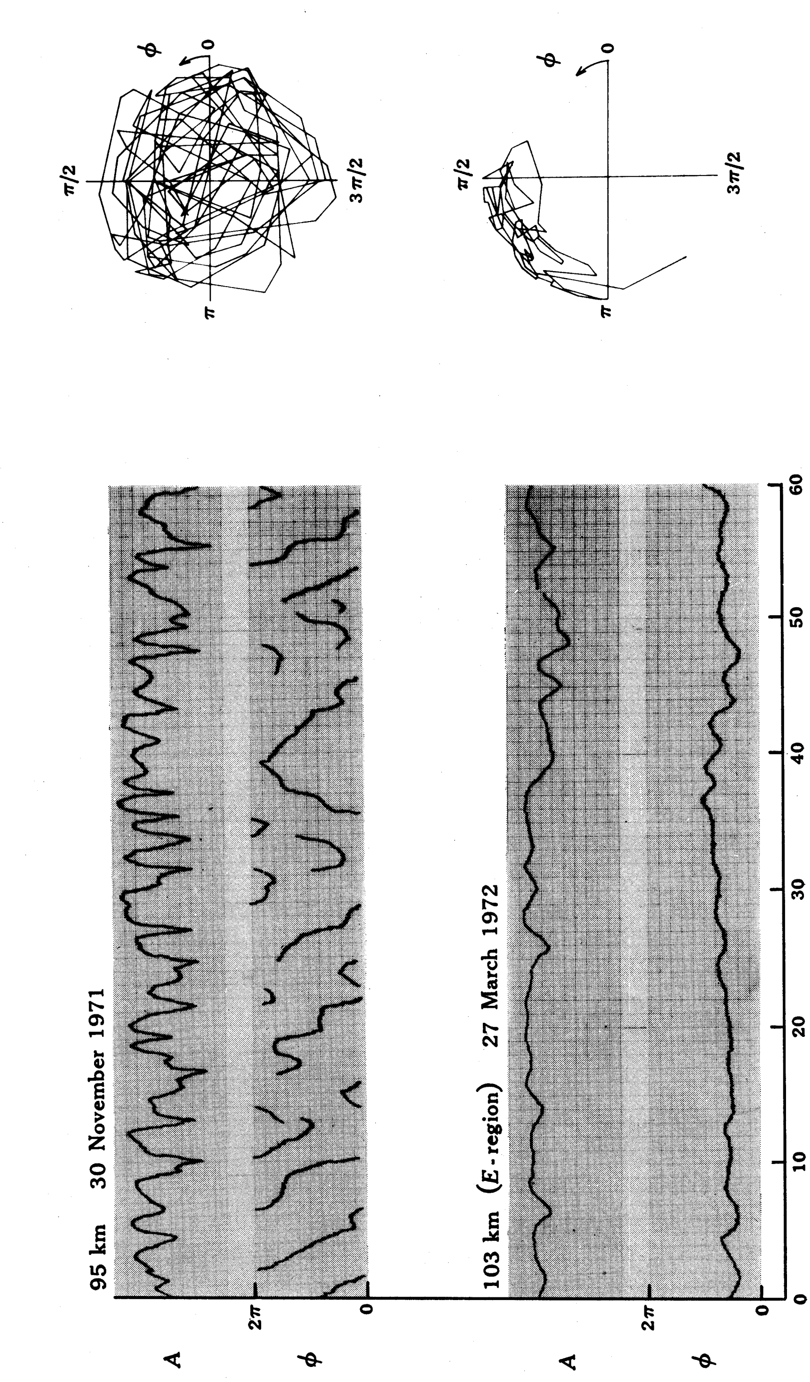

Fig. 2*b*. One min segments of chart records for the indicated heights and dates, showing amplitude and phase results and corresponding phasor representation.

A pulsed transmitter of 50 kW peak power operating at 1·98 MHz was employed for vertical incidence transmission together with elements of the receiving array to study the weak partial reflections from within the height range 60–100 km.

To simulate the spaced pair of antennas in the two-dimensional model described in Part I, each 'antenna' in fact consisted of a row of 11 linearly aligned dipoles connected in parallel. Such an arrangement resulted in the 'antenna' so formed having a beamwidth (to half-power) of $\pm 4°$ in the vertical plane parallel to the row of constituent elements, and a wide beamwidth in the orthogonal vertical plane, i.e. it was sensitive mainly to incoming radiation confined to a vertical plane normal to the row of constituent elements. Since the beam was not strictly two-dimensional, computed values of θ_0 which are $\lesssim 4°$ should strictly be regarded as the angular spread of the distribution obtained by projecting the three-dimensional angular spectrum of waves actually present onto a plane. It is thought, however, that corrections to θ_0 to allow for this effect would be relatively small in practice.

A gate which was able to select echoes from any desired range was used to monitor suitable echoes occurring from within the *D*-region. The variations of amplitude and phase of gated echoes could be simultaneously recorded for both receiving 'antennas' by using a multiplexing system and a single receiver. The method of phase recording was similar to systems described by other workers (McNicol and Thomas 1960; Fraser and Vincent 1970) which are derived from the method of Findlay (1951). In the present system phase fluctuations were converted into proportionate DC voltage variations. A solid state difference amplifier was employed to generate an output proportional to the phase difference between a pair of spaced antenna rows. Initially only phase and phase difference information was recorded to enable estimates of the angular spread to be made. Subsequently, for the purposes of studying scattering models, the phase difference between a pair of spaced antenna rows together with the amplitude for each antenna row and the phase variation for one row was recorded on a multi-channel pen recorder. In fact four rows (two orthogonal pairs) were generally employed to investigate possible azimuthal asymmetries in the spectrum of reflected radio waves.

Amplitude, phase and phase difference information was subsequently digitized from the chart records, and the data were then processed on a computer. Figs 1*a* and 1*b* show some typical chart records used to study *D*-region scattering models.

3. Results

Phasor Diagrams

Before discussing the quantitative results it is interesting to consider some results which give a qualitative indication of the nature of the scattering process. The wave field at a point on the ground and at one instant of time may be represented by a phasor drawn from an arbitrary origin. A record of the path of the end point of this phasor as time advances provides a simple and direct graphical representation of the nature of the fluctuations of the complex wave field. For example, a reflection consisting of a strong specular component of constant amplitude and phase in the presence of weaker randomly phased components would be expected to produce a pattern looking rather like a 'ball of wool' displaced some distance from the origin. For a completely randomly phased spectrum of components, a 'ball of wool' centred on the origin could be expected, as the phase of the resultant signal would be evenly distributed over 0–2π. In general the randomness of the pattern obtained is related to the randomness of the received signal.

Many phasor diagrams were constructed from digitized chart records with the aid of a computer controlled plotter. Some examples are shown in Figs 2*a* and 2*b*. They illustrate the fact that returns from various heights can exhibit markedly different properties. Segments of chart record from which these plots were obtained are shown adjacent to each plot. The length of the observing period was the same for all phasor diagrams shown, so that valid comparisons of the differences between the diagrams can be made. It can be seen from the examples illustrated in Figs 2*a* and 2*b* that:

(i) The phasor diagram for 103 km (Fig. 2*b*, *E*-region total reflection) shows characteristics typical of a strong specular signal in the presence of weak randomly phased contributions.

(ii) The diagram for 95 km (Fig. 2*b*, weak partial reflection) shows a typical case where no coherent contribution to the received signal is evident, and a 'ball of wool' centred close to the origin is obtained.

(iii) While a randomly phased signal would be expected to have its phase uniformly distributed over the range 0–2π, the converse may not be necessarily true. In particular the record for 75 km (Fig. 2*a*, weak partial reflection), while having its phase almost uniformly distributed over 0–2π, could be accounted for by a coherent reflection from an irregularity drifting steadily in range. By contrast, the 95 km record (Fig. 2*b*) which also has its phase uniformly distributed over 0–2π is unlikely to result from such a phenomenon, as the phase varies quite incoherently, often exhibiting random 'jumps', and the phasor shows no tendency to rotate systematically.

(iv) The 'randomness' of the received signal increases with increasing height of reflection. This is not peculiar to the particular examples reproduced here, but is a fairly general result. (The *E*-region is excluded from this generalization, for in this case a total reflection process occurs which is quite distinct from *D*-region partial reflection processes.)

Initial Observations of Angular Spread

Initially measurements of angular spread θ_0 were made using the expression

$$\theta_0 = \lambda\langle|\phi|\rangle/2\pi d$$

(equation (24) of Part I), where λ is the wavelength, d the separation of two rows of antennas, and $\langle|\phi|\rangle$ the mean phase difference between the rows. Observations of this type were made between February and November 1971, and the results are shown in Fig. 3. It can be seen that for all months the mean value of θ_0 increased with height from 60–85 km, and that the increase became more rapid above that height. There is some evidence for a maximum in the angular spreading near 90 km and a decrease above this height but, as the results for only two months (June and September) show the decrease, this result must be treated with caution. It is clear from the diagram that the month of June was exceptional in that the values of θ_0 were much larger than usual. In general it was found that the winter months June, July and August showed increased variability of θ_0 as compared with other months.

These initial observations are similar to those (described in the following subsection) which were obtained using more sophisticated methods. This supports the assertion made in Part I that the simple formula for θ_0 given above (i.e. equation (24) of Part I) provides a reliable method for determining the angular spreading of partial reflections from the *D*-region.

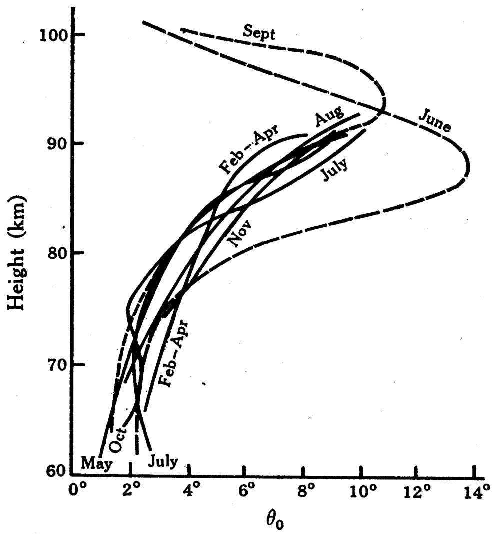

Fig. 3. Variation of angular spread θ_0 with height of reflection measured during the period February–November 1971.

Model Investigations

The suitability of the two theoretical models described in Part I is now examined. Model 1 assumes a continuous distribution of randomly phased reflected rays, while model 2 assumes such a distribution in the presence of a steady specular component. For ease of reference, a summary is given below of the equations for the angular spread θ_0 and the amplitude coherence ratio b that were derived in Part I for these two reflection models.

For model 1 we have the equations (15), (21) and (25) of Part I:

$$\theta_0 = (\lambda/2\pi d)\{-\ln(\rho_{A^2})\}^{\frac{1}{2}}, \qquad (1a)$$

$$\theta_0 = (\lambda/2\pi d)\{-\ln(\ln(1-2{\cdot}914\,\rho_{\mathrm{D}}^2)+1)\}^{\frac{1}{2}}, \qquad (1b)$$

$$\theta_0 = (\lambda/\sqrt{2}\,\pi d)\{-\ln(\cos\langle|\phi|\rangle)\}^{\frac{1}{2}}. \qquad (1c)$$

For model 2 we have the equations (36), (30), (29) and (32) of Part I:

$$b = \langle|\phi|\rangle^{-1}\{2(1-\rho_A)/\pi\}^{\frac{1}{2}}, \qquad (2a)$$

$$b = \rho_{\mathrm{D}}^{-1}\{2(1-\rho_A)/\pi\}^{\frac{1}{2}}, \qquad (2b)$$

$$\theta_0 = (\lambda/\sqrt{2}\,\pi d)\{-\ln(\rho_A)\}^{\frac{1}{2}}, \qquad (2c)$$

$$\theta_0 = (\lambda/\sqrt{2}\,\pi d)\{-\ln(\rho_\psi)\}^{\frac{1}{2}}. \qquad (2d)$$

Equation (2d), which in theory would allow the angular spread to be determined from a measurement of the correlation between phases at spaced receivers, has not been used in practice owing to difficulties in interpreting sudden phase changes, particularly in records with relatively incoherent phase variations.

In comparing the angular spreads calculated from Bramley's (1951) theory (which assumed high correlation between spaced sampling antennas) with the angular spreads calculated from the generalized theory of Part I, it is found that there is excellent agreement when the correlation is high but that, when correlation is relatively low, the theory of Bramley tends to underestimate the angular spread θ_0.

Table 1 summarizes the results obtained for θ_0 (model 1) or b and θ_0 (model 2) by evaluating the indicated expressions (1a)–(2c). It is found that generally a result falls into one of the following categories: (A), model 1 is appropriate; (B), model 2 is appropriate; (C), neither model is appropriate; (D), asymmetry for the orthogonal observing planes is evident.

In the present investigations it is found to be important to distinguish between two height regions within the *D*-region, and the boundary between these is best placed at ~85 km. The following summary of the classification of all results obtained supports the validity of this distinction:

Height within *D*-region	Proportion of results in category (A)	(B)	(C) or (D)
<85 km	50%	26%	24%
$\geqslant 85$ km	81%	2%	17%

The few *E*-region results (those results in Table 1 with (*E*) following the height entry) obtained for heights above 85 km have not been included. A notable feature of the results is the infrequent occurrence of a specular component above 85 km, and model 1 is generally applicable in this height regime. Below 85 km the results fit model 1 more often than model 2, but a specular component (model 2) is often present. For both height regions there are a significant number of records for which neither model is appropriate. Cases of azimuthal asymmetry (category D) account for less than 1% of occasions and have been combined with category (C) in the above tabulation.

It is possible that the results could be influenced by time variations in absorption and reflection coefficients, while the models assume that all variations are produced by interference effects between rays at different angles. Taking this into account, it is suggested that the percentages listed above for agreement with model 1 (category (A) results) might be regarded as an upper limit, while those for model 2 (category (B) results) might be regarded as a lower limit. A point which is significant is that all the records which are not in agreement with model 1 must have had some coherent or specular contribution, but in some cases this specular component may not have had the fixed phase and amplitude required for precise agreement with model 2. If all records which are not in agreement with model 1 are classified as having some specular component (not necessarily a statistically stationary situation) then we find (sum of results for categories (B), (C) and (D)) that 19% of the records for heights above 85 km and 50% of those for heights below 85 km must have contained some form of specular contribution. It would thus appear to be well established that a significantly greater occurrence of specular or coherent contributions occurs in the lower part of the *D*-region. While recognizing the possibility that the above-mentioned 'masking' effects due to variable absorption and reflection coefficients

Table 1. Scattering model values for angular spreads and amplitude coherence ratios

Local time (h)	Observing plane	Height (km)	Model 1 θ_0 equation (1a)	θ_0 (1b)	θ_0 (1c)	Model 2 b equation (2a)	b (2b)	θ_0 (2c)
			30 November 1971					
1600	E–W	80	3·4°	3·1°	3·3°	0·8°	1·5°	4·8°
1615	E–W	73	2·0	3·1	3·6	0·6	1·2	3·6
1619	E–W	85	11·9	7·2	9·9	0·7	1·9	15·8
1625	E–W	95	5·8	3·6	—	0·3	2·3	8·8
			1 December 1971					
1155	E–W	72	2·2	1·7	2·4	0·8	2·0	3·5
1155	N–S	72	1·8	3·4	2·7	0·6	0·8	2·7
1205	E–W	82	8·9	5·2	7·0	0·8	2·2	13·2
1205	N–S	82	10·8	—	5·8	1·0	1·1	13·9
1345	E–W	90	7·3	5·0	5·0	1·0	2·0	10·9
1345	N–S	90	8·1	—	6·5	0·9	1·0	12·7
1450	E–W	75	1·6	1·8	2·1	0·7	1·6	2·9
1450	N–S	75	2·3	1·8	1·7	1·0	1·7	3·1
1500	E–W	80	7·2	3·3	3·0	1·5	2·6	9·9
1500	N–S	80	3·2	—	2·1	1·4	0·6	5·4
1510	E–W	83	11·3	5·6	13·1	0·5	2·2	14·9
1510	N–S	83	9·1	—	5·6	1·0	1·2	13·8
			13 December 1971					
1200	E–W	100 (*E*)	5·4	4·4	4·6	0·8	1·7	7·6
1200	N–S	100 (*E*)	4·4	3·8	4·8	0·7	1·7	6·6
1206	E–W	88	6·9	6·0	6·1	1·0	1·9	11·8
1206	N–S	88	8·2	7·7	6·7	0·9	1·5	11·1
1210	E–W	95	13·5	10·7	16·7	0·6	1·8	19·3
1210	N–S	95	16·6	15·0	16·3	0·7	1·6	22·4
1215	E–W	90	10·9	7·2	9·7	0·8	2·0	15·5
1215	N–S	90	14·1	11·2	9·7	1·0	1·8	20·4
1420	E–W	88	6·8	5·5	5·9	0·9	1·8	10·1
1420	N–S	88	10·2	6·8	5·7	1·1	1·8	12·2
1428	E–W	95	6·7	5·6	4·2	1·1	1·7	9·7
1428	N–S	95	3·4	4·2	4·5	0·6	1·3	5·2
1435	E–W	88	7·5	6·0	6·0	0·8	1·8	10·6
1435	N–S	88	8·6	—	7·3	0·8	1·5	13·2
			15 December 1971					
1430	E–W	82	6·3	4·7	7·0	0·7	2·0	9·8
1430	N–S	82	9·7	—	9·0	0·7	1·4	13·7
1435	E–W	90	9·0	7·5	9·5	0·6	1·7	12·6
1435	N–S	90	9·3	9·1	12·9	0·5	1·7	14·4
1440	E–W	88	8·2	7·7	9·1	0·8	1·7	13·0
1440	N–S	88	9·2	9·5	—	—	1·6	14·6
1447	E–W	100 (*E*)	5·9	4·4	5·1	0·9	1·9	8·8
1447	N–S	100 (*E*)	4·6	4·9	7·3	0·5	1·5	7·0
1540	E–W	90	7·0	5·7	11·3	0·5	1·7	9·2
1540	N–S	90	6·9	—	10·5	0·5	1·2	9·7
1542	E–W	96	10·3	9·4	10·5	0·6	1·7	14·5
1545	E–W	104 (*E*)	3·3	2·3	2·2	1·2	2·0	4·8
1545	N–S	104 (*E*)	2·3	2·5	2·8	0·8	1·6	4·1
1550	E–W	90	4·9	3·7	5·5	0·7	1·8	7·1
1550	N–S	90	7·0	8·7	7·8	0·6	1·4	9·8
1555	E–W	95	9·6	—	9·1	0·7	1·5	13·3
1555	N–S	95	11·2	—	10·8	0·6	1·5	15·7
1600	E–W	75	4·3	4·3	2·1	1·5	1·5	6·1
1600	N–S	75	2·1	4·5	2·9	0·8	1·0	4·2
1610	E–W	85	6·1	6·8	4·9	0·9	1·5	9·1
1610	N–S	85	9·7	13·2	4·9	1·2	1·6	13·6

Table 1 (*Continued*)

Local time (h)	Observing plane	Height (km)	Model 1 θ_0 equation (1a)	θ_0 (1b)	θ_0 (1c)	Model 2 b equation (2a)	b (2b)	θ_0 (2c)
			16 March 1972					
1015	E–W	85	7·8°	4·9°	7·4°	0·9°	2·3°	11·8°
1015	N–S	85	8·8	5·5	8·3	0·8	2·2	12·9
1020	E–W	75	4·8	2·7	2·7	1·3	2·2	6·2
1020	N–S	75	4·4	3·8	3·2	1·2	1·7	6·7
1025	E–W	95	11·2	5·1	17·2	0·5	2·7	15·6
1025	N–S	95	18·9	18·8	23·2	0·6	1·6	26·6
			27 March 1972					
1155	E–W	93	9·2	4·8	10·4	0·6	2·3	14·1
1155	N–S	93	9·3	6·1	9·7	0·6	1·9	13·3
1210	E–W	83	3·2	3·0	4·1	0·7	1·7	5·3
1210	N–S	83	2·7	2·3	2·3	0·9	1·7	4·0
1215	E–W	78	3·4	2·9	3·2	0·8	1·6	4·8
1215	N–S	78	2·9	2·8	2·5	1·0	1·6	4·4
1220	E–W	90	6·9	5·2	7·4	0·7	1·9	10·1
1220	N–S	90	7·1	6·0	8·0	0·6	1·7	9·9
1225	E–W	83	2·3	2·1	2·7	0·8	1·7	3·7
1225	N–S	83	2·7	2·5	2·6	0·9	1·7	4·4
1345	E–W	78	4·5	5·0	2·6	1·2	1·3	6·1
1345	N–S	78	4·9	3·4	2·5	1·5	2·0	7·1
1350	E–W	72	2·2	1·3	2·0	1·0	2·6	3·6
1350	N–S	72	3·0	2·0	1·2	2·4	2·5	5·3
1355	E–W	70	4·5	2·4	3·0	1·1	2·5	6·3
1355	N–S	70	2·6	1·4	1·9	1·2	2·9	4·2
1400	E–W	88	9·0	10·4	10·9	0·6	1·5	12·3
1400	N–S	88	5·8	5·9	5·2	0·8	1·5	8·2
1405	E–W	95	8·0	5·2	—	0·4	2·1	12·3
1405	N–S	95	5·6	3·0	15·3	0·4	2·5	8·3
1415	E–W	80	8·2	9·5	6·7	0·8	1·5	11·5
1415	N–S	80	4·1	4·4	4·0	0·8	1·4	6·0
1420	E–W	72	2·0	1·9	2·5	0·5	1·2	2·2
1420	N–S	72	2·5	3·0	1·9	1·1	1·3	3·8
1425	E–W	103 (*E*)	1·2	0·3	1·1	0·9	4·8	1·7
1425	N–S	103 (*E*)	2·3	0·3	0·5	3·2	7·2	2·6
1430	E–W	95	15·0	10·2	17·6	0·5	1·8	21·3
1430	N–S	95	13·1	8·9	9·8	0·7	1·8	18·2
1440	E–W	90	7·0	6·0	9·2	0·5	1·6	9·2
1440	N–S	90	9·5	—	11·1	0·6	1·3	14·6
1445	E–W	85	8·7	—	8·5	0·7	1·3	11·6
1445	N–S	85	8·3	—	6·9	0·8	1·4	11·5
1450	E–W	103 (*E*)	1·0	0·3	0·1	2·7	4·3	1·4
1450	N–S	103 (*E*)	1·0	0·3	0·4	2·1	4·5	1·4
1455	E–W	78	4·6	4·6	4·4	0·8	1·6	7·0
1455	N–S	78	3·6	3·6	2·7	1·0	1·4	5·0
1535	E–W	78	2·0	2·4	3·7	0·5	1·5	3·6
1535	N–S	78	3·3	3·2	8·3	0·4	1·7	5·5
1540	E–W	90	—	9·3	9·6	0·8	2·0	—
1540	N–S	90	9·8	6·2	8·6	0·7	1·9	13·1
1545	E–W	95	10·5	8·0	11·3	0·6	1·8	14·6
1545	N–S	95	11·5	7·4	17·4	0·5	1·9	17·6
1550	E–W	88	8·1	4·6	9·2	16·0	2·2	11·3
1550	N–S	88	9·0	5·5	10·7	0·6	2·1	13·0

may be more pronounced above 85 km, it is felt that this would not account for the marked difference observed for the two height regions. The fact that many of the records can be classed as having some specular component (although not in accordance with model 2) suggests that the condition for model 2 that there be one large specular component of constant amplitude, phase and direction of arrival is rather restrictive. However, it would appear that little can be gained by adding further degrees of freedom to the model, as it is well known that several specular components with independently varying phases are indistinguishable from a continuous spectrum of randomly phased waves (Goldstein 1958). Thus those results (category C) which are classified as fitting neither model can be succinctly categorized as representing one or more of the following situations:

(i) up to three or four separate specular components are present (if there were more, the results would fit the random model reasonably well);

(ii) the specular component(s) have directions of arrival which vary with time;

(iii) the specular component(s) have time-varying amplitudes;

(iv) the specular component(s) may not constitute a large fraction of the power returned, contrary to the assumption made in model 2 that we have $b > 1$.

It is considered that the results of Table 1 concerning signal-to-noise ratios furnish evidence for the existence of specular components with time-varying directions of arrival. This evidence arises from the observation that the value of b as determined from phase differences (equation 2a) is generally lower than the value calculated from amplitude statistics (equation 2b). A steady specular component whose direction of arrival varied with time would not be expected to affect the amplitude statistics to a great extent, but the mean absolute phase difference would be increased, producing a lower value of b from equation (2a). This effect is particularly evident for the *E*-region results of 27 March 1972 given in Table 1, for on a qualitative basis the corresponding chart records would be classed as certainly being due to a specular reflection. It is suggested that the presence of horizontally moving specular reflectors in the ionosphere is a plausible explanation for these effects (cf. Fraser and Vincent 1970).

A very small occurrence ($<1\%$) has been encountered of what have been termed 'asymmetric' records, i.e. asymmetric in the sense that either different models are appropriate for the two orthogonal observing planes or, in the case of model agreement, the magnitude of the angular spread or coherence ratio differs greatly for the orthogonal observing planes. Varying degrees of 'model asymmetry' and 'coherence ratio asymmetry' might be expected depending on the geometrical aspect of a fairly steady specular reflection with respect to the two orthogonal observing planes. Asymmetry of the angular spread when a random model fits both planes could be explained by an elongation of reflecting irregularities in a preferred direction.

These investigations have clearly demonstrated that *D*-region partial reflections exhibit a decrease of coherence with increasing height of reflection. The determinations of angular spread shown in Table 1 and measurements of amplitude fading speeds (determined from mean intervals between amplitude maxima) show a related variation with height. Fig. 4*a* is a scatter plot of angular spreads obtained from the scattering model results, while Fig. 4*b* is a scatter plot which summarizes some daytime fading periods measured during 1971. The wide range of periods for heights below ~80 km is consistent with the scattering model results, the longer-period fading being identified with coherent reflections, and the shorter-period fading being associated with the less coherent reflections. Above 80 km short periods of ~3 s are predominant, and again this is consistent with the high proportion of records for this region which have been classed as randomly phased in the scattering model investigations. If the ionospheric drift velocity is assumed to be constant to the first order then the fading speed becomes inversely proportional to the scale of the ground diffraction pattern which, in turn, is inversely proportional to the angular spread θ_0. Thus rapid fading should correspond to large values of angular spread, and thus the height variations of the amplitude fading periods and of the angular spreads are consistent with each other and with the scattering model results.

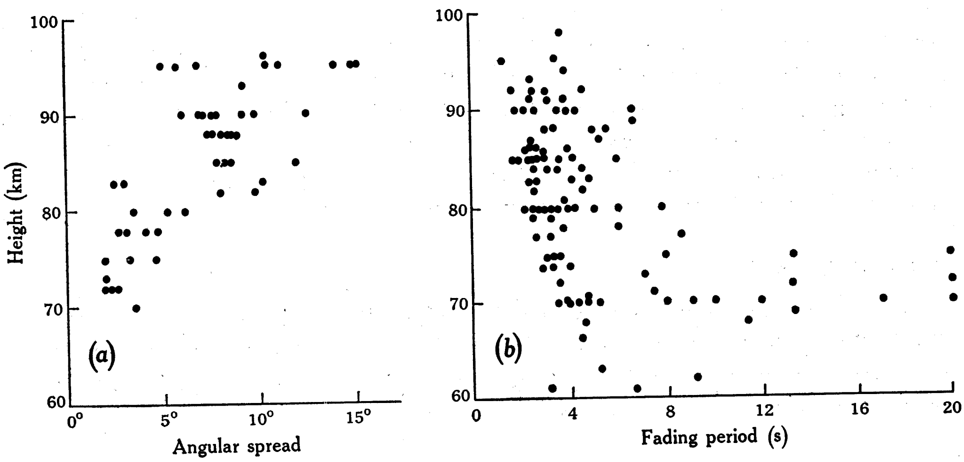

Fig. 4. Scatter plots of results obtained for *D*-region partial reflections measured in scattering model investigations, showing (*a*) angular spreads measured during the period November 1971–March 1972 and (*b*) daytime fading periods measured during 1971.

4. Discussion and Conclusions

Although there is a general paucity of experimental evidence concerning the nature of *D*-region scattering, nevertheless some useful comparison of the present results with observations of other workers is possible. Vincent and Belrose (1972) found in Ottawa, Canada, that the angular spread of partial reflections showed a slight increase with increasing height of reflections up to 85 km and then a sharp increase above ~85 km. Fraser and Vincent (1970) observed that the phase coherence of partial reflections at Christchurch, New Zealand, was generally much higher in the 70–79 km height region than in the 80–89 km region. The present results are consistent with these findings.

Gregory and Vincent (1970) reported that the vertical thickness of *D*-region scattering regions observed at Christchurch was generally substantially greater in the 80–90 km height interval than for reflections received from below this region. Such a situation is consistent with there being a greater number of independent reflected components from above 80 km, resulting in less coherent echoes from that region.

Although the present results and the results of most other workers in this field are consistent they appear to be quite incompatible with the results of von Biel (1971). These results, based on studies of amplitude distributions of fading records obtained at Christchurch and interpreted using the theory of Rice (1945), are in direct contrast with the conclusions reached in the investigations presented here, for an increase of coherence with increasing height of reflection was reported. Although the two sets of results correspond to somewhat different latitudes it is unlikely that this can account for the different conclusions arrived at in the two studies. Since the results of von Biel are inconsistent with observations made at the same place (Christchurch) by other workers (Fraser and Vincent 1970; Gregory and Vincent 1970), they must be regarded as suspect.

In summary, the results presented here are consistent with a decreasing coherence of partial reflections with increasing height of reflection in the *D*-region. A sharp transition in this sense has been found at ~85 km. It is considered that the 85 km level marks a boundary between two fairly distinct regions within the *D*-region. The lower region is characterized by relatively large-scale ionospheric irregularities producing fairly coherent reflections of small angular spread and slow fading periods, and the upper region is characterized by relatively small-scale irregularities producing many randomly phased components and resultant reflected signals of large angular spreads and rapid fading rates. Evidence suggesting the presence of isolated horizontally moving reflectors has been found on many occasions.

Acknowledgments

This work was supported by the Australian Research Grants Committee, the Radio Research Board and the University of Adelaide. Many useful comments and criticisms were made by Dr B. H. Briggs and Dr R. A. Vincent of the Physics Department of the University of Adelaide.

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Manuscript received 18 October 1974