REGULAR VARIATIONS IN THE SCINTILLATIONS OF RADIO SOURCES WITH SEASON, TIME OF DAY, AND SOLAR DISTANCE

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Summary

The fluctuations of eight sources observed in transit at Fleurs, near Sydney, at a frequency of 85 Mc/s in the period 1955–59 are analysed for systematic variations with time and with angular distance from the zenith and from the Sun. The observations cover a wide range of zenith angles. The only significant systematic variation is found to be a diurnal effect, with maxima near noon and midnight and minima near dawn and dusk.

The diurnal effect can easily be confused with an equivalent directional effect, namely, a dependence on angular distance from the Sun and from the antisolar point. (A dependence on solar distance has already been found for scintillations of very small sources; it has been associated with interplanetary scattering.) The evidence in favour of a diurnal, rather than a directional, effect rests on the finding that the strength of the fluctuations depends systematically on the difference in right ascension between source and Sun but not on declination. This result supports the inference of an ionospheric origin of the scintillations.

The daytime peak, which is not observed, for instance, at Cambridge and Manchester, cannot be explained as a low altitude phenomenon. Its existence suggests either a marked latitude dependence of the *E*-layer irregularities or a real difference in their distribution in the northern and southern hemispheres.

I. Introduction

Amplitude fluctuations of radio sources have been studied since the discovery of the first known source in the constellation of Cygnus. When no correlation was found in the fluctuations observed simultaneously at two points separated by the order of 100 km or more, such fluctuations were described as scintillations and attributed to irregular refraction in the ionosphere.

Scintillation observations and theory have been summarized and discussed by Booker (1958). Scintillations occur typically at the rate of a few every minute; generally, their amplitude increases with zenith angle. All observers have found a night-time maximum in the strength of scintillations; Australian observers have, in addition, found a noon maximum of similar magnitude. Booker has pointed out that the corresponding observations (Bolton, Slee, and Stanley 1953) were taken "at low angles of elevation in a generally equatorward direction". The same observers reported a seasonal effect comparable with the diurnal effect.

More recently, a directional effect has been discovered. Hewish, Scott, and Wills (1964) found that the strength of scintillations increased towards the Sun for a number of radio sources that are, characteristically, of very small angular size. These scintillations were ascribed to diffraction by the extended solar corona. Another possible diffracting region could occur in the direction diametrically opposite

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TABLE 1

STRENGTH OF SCINTILLATIONS FOR EIGHT SOURCES, FROM OBSERVATIONS AT FLEURS IN THE PERIOD 1955–59

Source (Designation) IAU HM* / MSH / 3C Common Name	Position* (1950·0) R. A. Dec.	Mean Monthly Scintillation Index and Number of Observing Days† Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
16S6A 475 16–61	$16^h11^m15^s$ $-60°59'$	(13%) 15	9% 23	15% 21	17% 22	(8%) 8	13% 23	7% 20	9% 27	(7%) 13	(9%) 17	(13%) 12	(9%) 6
13S6A 417 13–62	$13^h43^m27^s$ $-60°18'$	7% 32	10% 27	10% 25	14% 23	(8%) 9	7% 23	(7%) 18	(8%) 14	(11%) 9	(8%) 12	13% 25	9% 23
05S4A 186 05–43 Pictor A	$05^h18^m24^s$ $-45°49'48''$	25% 30	9% 28	4% 25	(8%) 12	(2%) 2	(36%) 3	(10%) 13	4% 26	10% 27	12% 66	18% 60	21% 27
03S3A 119 03–31 Fornax A	$03^h20^m36^s$ $-37°23'$	9% 67	8% 68	12% 65	16% 57	(6%) 15	7% 59	8% 96	5% 114	9% 96	11% 123	10% 88	13% 54

09S1A 302 } 09−14 } 218 } Hydra A	$09^h15^m41^s\cdot2$ $-11°52'58''$	22% 38	23% 51	26% 58	15% 69	15% 61	17% 57	19% 56	18% 37	26% 42	21% 65	12% 25	17% 34
12N1A 379 } 274 } Virgo A	$12^h28^m16^s\cdot9$ $+12°39'57''$	9% 36	16% 51	19% 66	22% 66	30% 64	13% 88	17% 86	23% 64	26% 32	24% 23	8% 25	7% 32
05N2A 194 } 144 } Taurus A	$05^h31^m31^s$ $+21°59'02''$	22% 38	10% 39	9% 56	14% 59	12% 44	16% 50	18% 67	17% 90	9% 66	15% 69	18% 26	30% 29
19N4A 591 } 405 } Cygnus A	$19^h57^m44^s\cdot4$ $+40°37'26''$	45% 21	30% 37	14% 82	19% 89	33% 68	48% 110	48% 117	37% 126	28% 94	27% 95	26% 64	40% 27

* Positions quoted are the positions given by Howard and Maran (1965) in their source headings.

† Monthly mean values based on fewer than 20 observing days are enclosed in parentheses; they have been excluded when data from several sources are superposed.

to the Sun, due to the Earth's magnetic and plasma tail set up by the solar wind. The possible effect of such a region could clearly become confused with midnight scintillations.

It is the purpose of the present paper to investigate anew the regular variations in the scintillations of "large" ($\gg 1''$ arc) radio sources as observed near Sydney and to separate, as far as possible, diurnal effects, seasonal effects, and effects related to the angle of the source from the Sun and zenith.

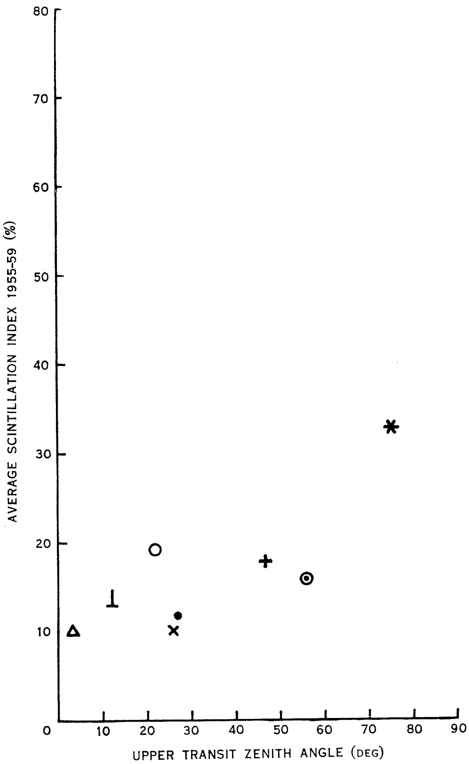

Fig. 1.—Zenith angle dependence of the mean scintillation index, 1955–59, for eight sources. △ 03S3A, Fornax; ⊥ 05S4A, Pictor; ○ 09S1A, Hydra; × 13S6A; ● 16S6A; + 12N1A, Virgo; ⊙ 05N2A, Taurus; * 19N4A, Cygnus.

II. Observations

The amplitude fluctuations of eight radio sources were observed at transit with the east–west arm of the 85·5 Mc/s Mills cross at Fleurs, near Sydney (33°52′ S.), in the period May 1955 to December 1959. They have already been used by one of us (Slee 1962) to show a partial correlation between monthly indices of scintillation and geomagnetic activity. The half-power beamwidth of the aerial was 50° arc in the north–south direction and 36′ arc in the east–west direction. The latter beamwidth limited the sampling time for each transit to $2\frac{1}{2}$ min at declination $\delta = 0°$ and to 5 min at $\delta = 60°$. The total power from the east–west arm was recorded over a bandwidth of 0·25 Mc/s with post-detector smoothing of about 2 sec and at a chart speed of 3 in/hr.

Details of the eight sources used in the present analysis, and their mean monthly scintillation indices, are listed in Table 1; the indices are plotted in

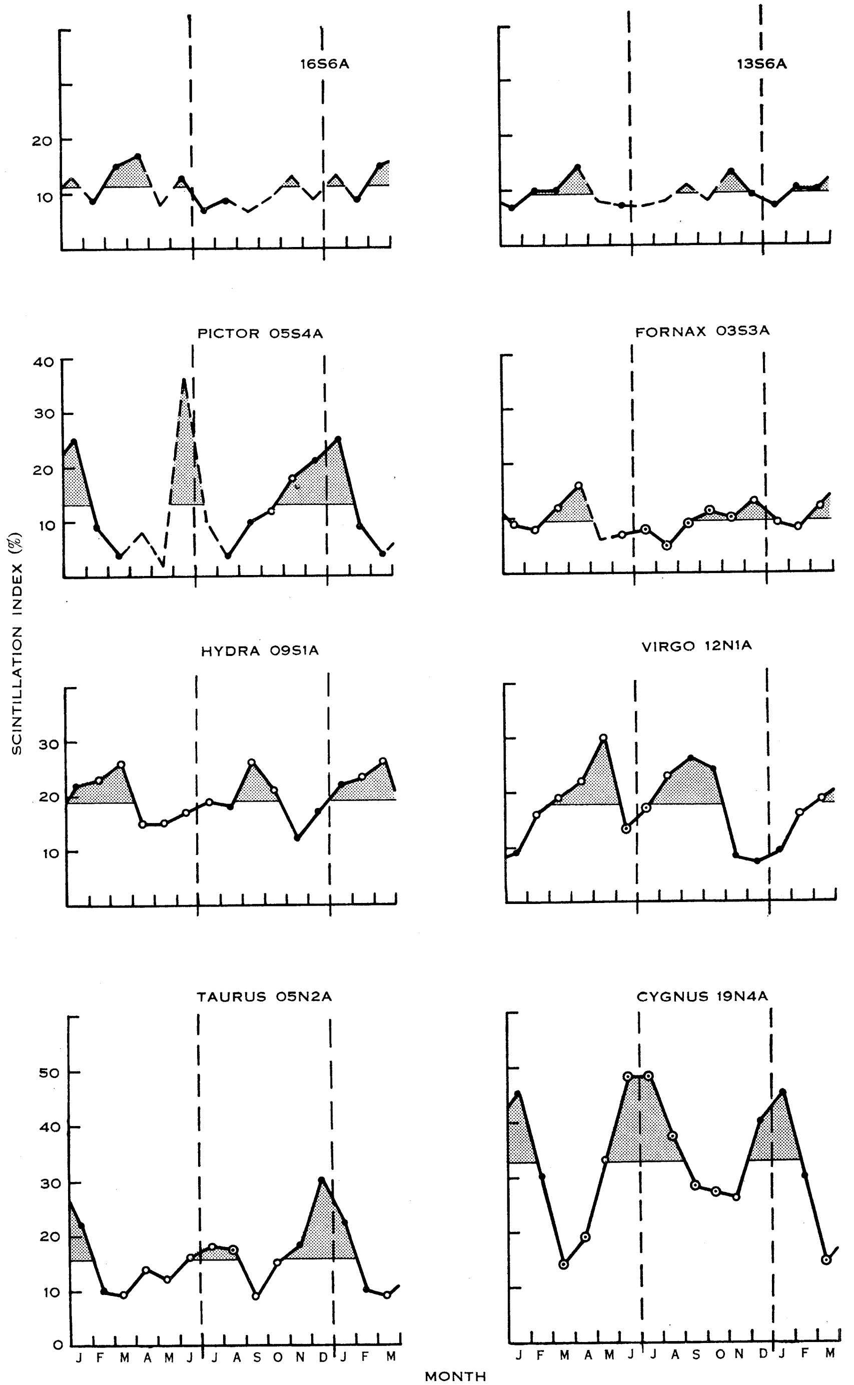

Fig. 2(*a*).—Variation of mean monthly scintillation index with month in the year. The "weight" of each monthly mean value is indicated by: ---- (no point plotted), < 20 observing days; ● (on full lines), 20–40 days; o (on full lines), 40–80 days; ⊙ (on full lines), > 80 days. The shaded areas represent periods of above-average scintillations.

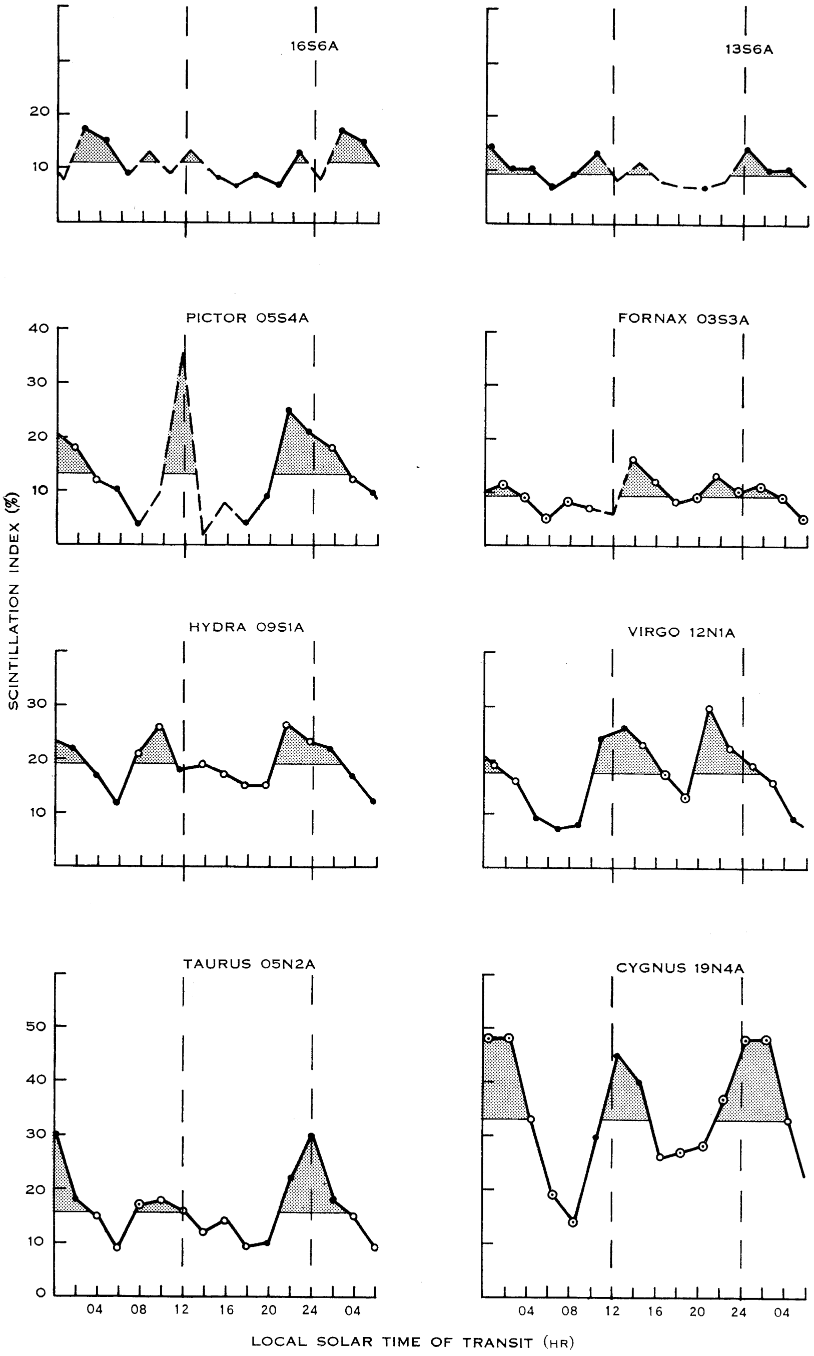

Fig. 2(*b*).—Variation of mean monthly scintillation index with transit time. The "weight" of each monthly mean value is indicated by: ---- (no point plotted), < 20 observing days; ● (on full lines), 20–40 days; o (on full lines), 40–80 days; ⊙ (on full lines), > 80 days. The shaded areas represent periods of above-average scintillations.

Figure 2(*a*). The scintillation index is defined as the percentage ratio of the largest deviation from the mean signal amplitude to the value of this latter quantity.

The June value for Taurus (05N2A) is probably affected by the occultation of this source by the solar corona at that time.

III. Zenith Angle Dependence

Quite generally, the strength of ionospheric scintillations is expected to increase with zenith angle because of the attendant lengthening of the path through the diffracting region. Such increases, which are pronounced only at large values of the zenith angle, have been observed, for instance, at Cambridge and at Manchester.

The present observations are shown graphically in Figure 1; each point corresponds to a different source. In looking for a systematic zenith angle dependence, one has to assume that the intrinsic scintillating properties are the same for all sources. Most sources have scintillation indices in the range 10–20%; only one point, that for Cygnus, shows a marked increase in the strength of scintillations, again at a large zenith angle. The points do not allow a smooth line to be drawn through them. (One point in particular, that for Hydra, seems abnormally high; Slee (1955) has already drawn attention to other unusual features in the variability of this source.) They do not warrant, therefore, a comparison with Booker's (1958) theoretical curves for zenith angle dependence.

In the present analysis, we often need to combine the scintillation data of several sources; to avoid domination by low altitude sources, we shall henceforth make frequent use of a normalized scintillation index obtained by dividing the percentage fluctuation by the annual mean percentage fluctuation. The possibility of making a direct correction for zenith angle effects seems unjustified, owing to the scatter in Figure 1, which may itself be due to variations in the diffracting layers with latitude (cf. Aarons, Mullen, and Basu 1964).

IV. Diurnal and Seasonal Dependence

Figures 2(*a*) and 2(*b*) show how the scintillation index varies with month in the year and with local solar time respectively. It is clear from these figures that those sources showing marked modulation have two maxima and two minima within one day or one year. This double-peaked structure is not obvious in two sources (16S6A and 13S6A), which transit within about 30° of the zenith and whose average scintillation index is low ($\approx$ 10%); however, it is pronounced for Pictor (05S4A), which transits at 12° from the zenith, and for all sources with transit altitudes up to about 45°. Thus, the double structure is *not* confined to observations at low altitude.

Inspection of Figures 2(*a*) and 2(*b*) already suggests that the peaks and troughs coincide rather better in local time than they do in months. The superposition of the normalized scintillation indices for all eight sources in Figure 3 shows rather convincingly that there is a definite diurnal effect, with maxima near noon and midnight and minima near dawn and dusk. A seasonal effect, if any, would be very much smaller than the diurnal one. This trend is emphasized by taking the average of the indices for the eight sources (see Fig. 4). The actual percentage indices of Figure 4(a) are dominated by the strong scintillations of the low altitude sources; the mean normalized indices of Figure 4(b) should give a truer average over all sources.

Our conclusion that the main temporal variation is a diurnal one agrees with that of Ryle and Hewish (1950); theirs was based on 16 months observations of four northern sources. However, in the present case, the diurnal variation has a noon as well as a midnight maximum, and dawn and dusk minima rather than one minimum at about 16 hr.

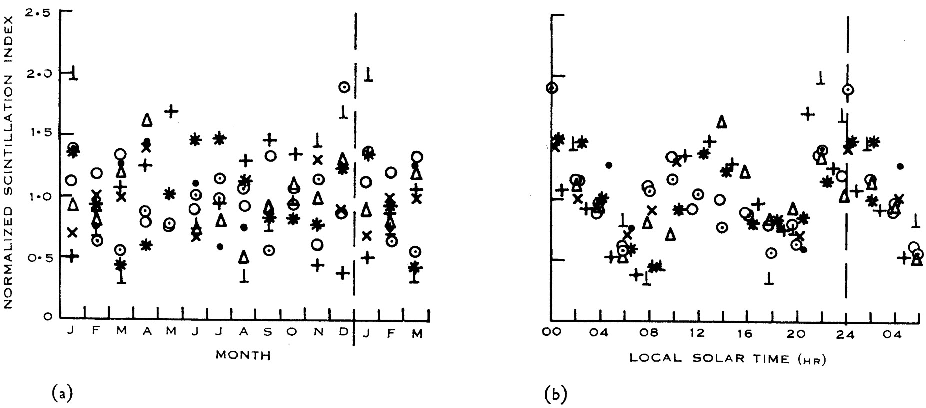

Fig. 3.—Superposed plot of normalized monthly scintillation indices for eight sources against (a) month and (b) local solar time. ● 16S6A; × 13S6A; ⊥ 05S4A, Pictor; △ 03S3A, Fornax; ○ 09S1A, Hydra; + 12N1A, Virgo; ⊙ 05N2A, Taurus; * 19N4A, Cygnus.

Bolton, Slee, and Stanley (1953) reported a seasonal variation of the scintillation index of similar amplitude to the diurnal effect. This result was obtained from low altitude observations ($\lesssim 10°$) of the three northern sources in Virgo, Taurus, and Cygnus during 1947–51; it does not agree with the much smaller upper limit of any seasonal effect indicated by the present eight-source averages. We, therefore, present our results for Virgo, Taurus, and Cygnus separately in Figure 5. There is indeed a suggestion of a seasonal variation of similar amplitude, though not as distinct as the diurnal variation (the September minimum, in particular, is more pronounced in the Bolton, Slee, and Stanley observations). This seasonal effect is most likely an apparent effect, because the corresponding, and much more definite, diurnal variation (Fig. 5(b)) is almost identical with that for all eight sources of the present analysis (Fig. 4(b)); the lack of any systematic seasonal variation in the eight-source results is reflected in the random scatter of points in Figure 3(a) and in the noise-like wave form of Figure 4(b). It seems, therefore, that the pseudo-seasonal effect for Virgo, Taurus, and Cygnus must be due to the particular values of right ascension at which these sources occur.

This hypothesis can be further tested if we assume that each of the three sources has a diurnal variation given by $1+A\cos(\pi/6)t$, where t is the transit time in hours. The depth of modulation A for the three sources is taken from Figure 2. When the effects of the three theoretical diurnal variations are superimposed on a monthly basis, making proper allowance for the different months corresponding to a given transit time, one obtains an apparent seasonal effect, shown in the broken line of Figure 5(*b*). This curve is similar to, though of smaller amplitude than, the apparent seasonal variation observed. The difference between the observed and calculated normalized monthly scintillation indices is not sufficiently systematic to determine

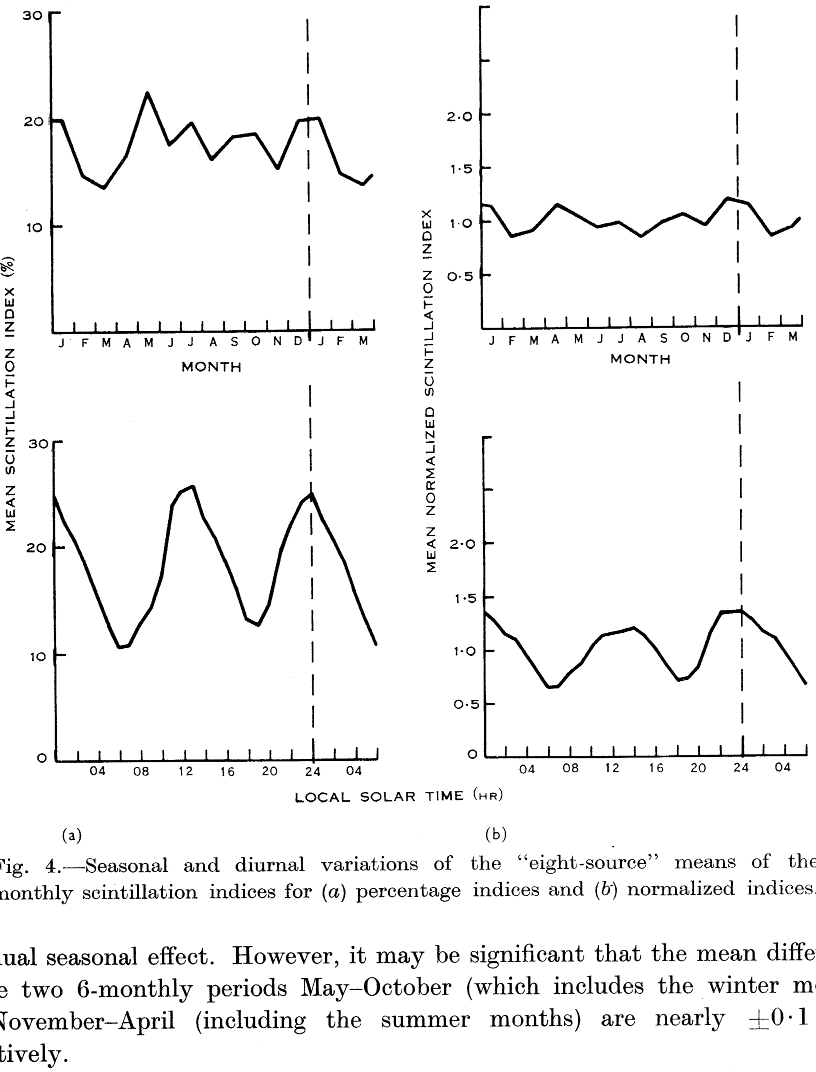

Fig. 4.—Seasonal and diurnal variations of the "eight-source" means of the monthly scintillation indices for (*a*) percentage indices and (*b*) normalized indices.

a residual seasonal effect. However, it may be significant that the mean differences for the two 6-monthly periods May–October (which includes the winter months) and November–April (including the summer months) are nearly $\pm 0 \cdot 1$ units respectively.

V. Dependence on Angular Distance from the Sun

It was mentioned in Section I that Hewish, Scott, and Wills (1964) have discovered scintillations whose strength increases towards the Sun. These scintillations occur in sources of very small angular size ($< 1''$ arc) and are ascribed to scattering in the extended corona of the Sun. A similar effect may well occur towards the antisolar point, the general direction in which the Earth's magnetic plasma tail extends. Now, the closest approaches of a source to the Sun and to the antisolar point correspond to noon and midnight transit respectively. These are, of course, the very times around which we have just found the strongest scintillations to occur. It seems advisable, therefore, to re-examine the variations in the strength of fluctuations, this time for their dependence on distance from the Sun and from the antisolar point.

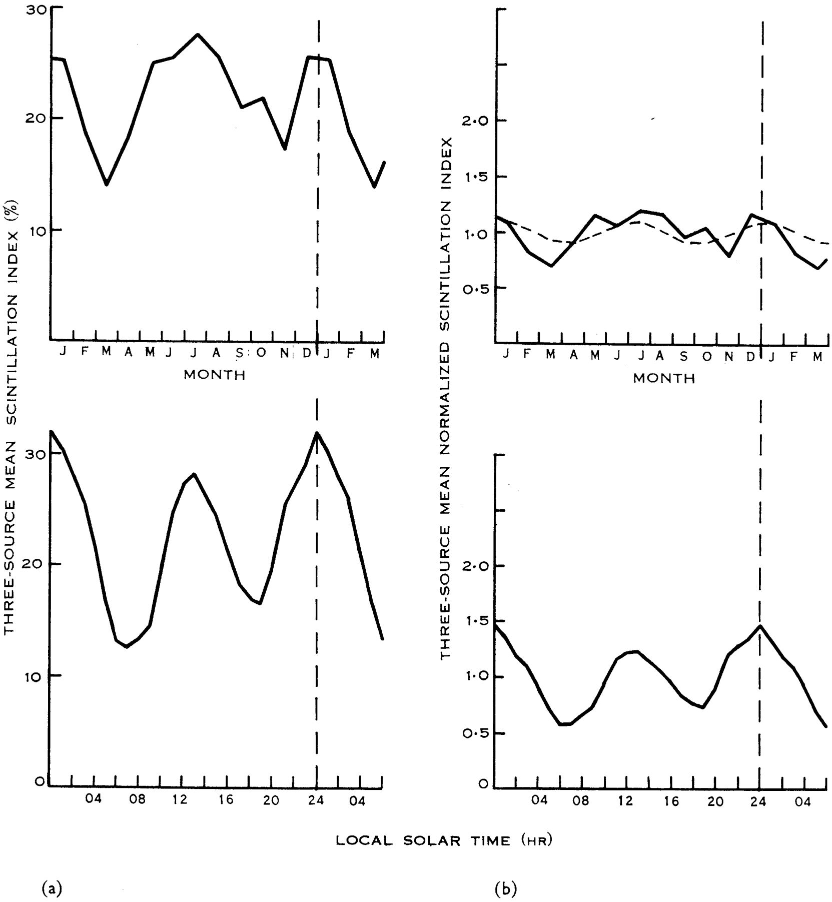

Fig. 5.—Seasonal and diurnal variations of a "three-source" mean of the monthly scintillation indices for (*a*) percentage indices and (*b*) normalized indices. The three sources are Virgo, Taurus, and Cygnus. ---- theoretical curve.

Accordingly, we show in Figure 6 the distribution of above- and below-average scintillations in a spherical coordinate system with the Sun and the antisolar point as poles. In this frame of reference, the Earth's north and south poles oscillate between $\pm 23\frac{1}{2}°$ in latitude. The zero of the longitude scale is chosen so that the north and south poles are at longitudes of 90° and 270° respectively.

The distribution shows approximate quadrant symmetry. The stronger scintillations seem to occur in solar and antisolar polar caps above about 50° latitude

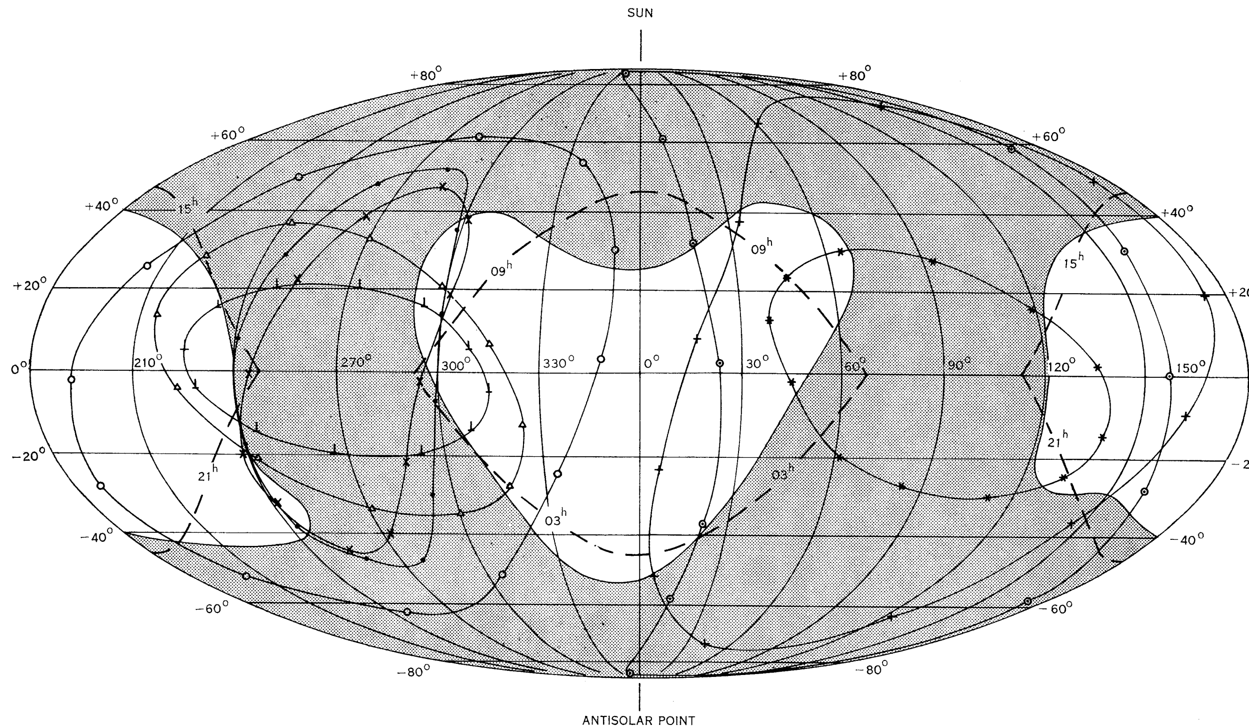

Fig. 6.—Distribution of above-average (shaded) and below-average scintillations in spherical polar coordinates, with the Sun and antisolar point as poles, plotted on equal-area projection. The broken lines enclose time zones of 3 hr on either side of noon (90° and 270° meridians at positive latitudes) and midnight (90° and 270° meridians at negative latitudes). ● 16S6A ($16^h\cdot19$, $-60°\cdot98$); × 13S6A ($13^h\cdot72$, $-60°\cdot30$); ⊥ 05S4A, Pictor ($05^h\cdot31$, $-45°\cdot83$); △ 03S3A, Fornax ($03^h\cdot34$, $-37°\cdot38$); ○ 09S1A, Hydra ($09^h\cdot26$, $-11°\cdot88$); + 12N1A, Virgo ($12^h\cdot47$, $+12°\cdot67$); ⊙ 05N2A, Taurus ($05^h\cdot53$, $+21°\cdot98$); * 19N4A, Cygnus ($19^h\cdot96$, $+40°\cdot62$).

and in two low latitude regions around the meridians through the Earth's north and south poles. There is indeed a suggestion here that the strength of scintillation depends in a regular manner on solar distance.

This regular directional dependence must be compatible with the previously demonstrated regular diurnal dependence. Therefore, we plot local solar times in the spherical coordinates of Figure 6. In that frame of reference, noon and midnight correspond to the 90° and 270° meridians at positive and negative latitudes respectively. All solar times within 3 hr of noon and midnight are contained within the broken lines† in Figure 6. As might be expected, most of the shaded area, representing above-average scintillations, lies within these lines. The time lines thus illustrate the mutual consistency of the diurnal and solar-distance hypotheses.

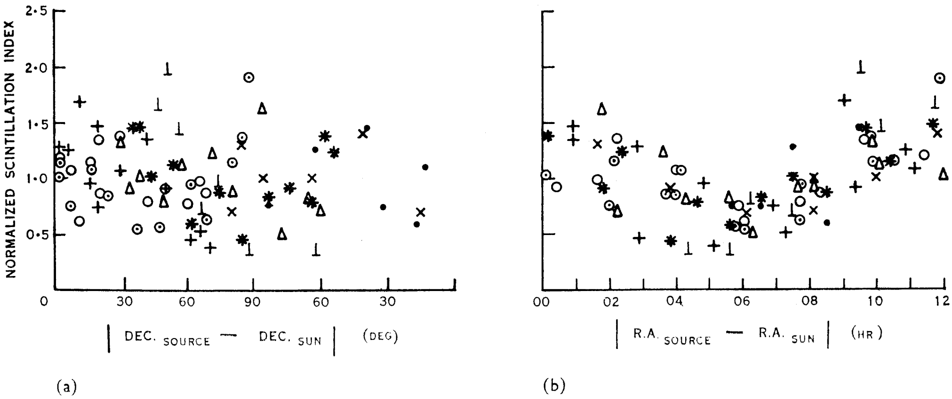

Fig. 7.—Dependence of normalized mean monthly scintillation indices of eight sources on the corresponding monthly values of the angular distance between source and Sun in (*a*) declination and (*b*) right ascension. ● 16S6A; × 13S6A; ⊥ 05S4A, Pictor; △ 03S3A, Fornax; ○ 09S1A, Hydra; + 12N1A, Virgo; ⊙ 05N2A, Taurus; * 19N4A, Cygnus.

It remains to decide whether the diurnal or the solar-distance dependence of the normalized scintillation index is the primary and physically significant one.

Figure 3(*b*) and the local-time plots of Figure 4 show that the strength of scintillations depends on the relative right ascensions of source and Sun. Now, if the basic effect were a solar-distance effect, then there should be a similar dependence of the strength of scintillations on the relative declinations of source and Sun. Figure 7(*a*) shows that this is not so.

We conclude, therefore, that the scintillations are controlled predominantly by a diurnal variation rather than by the angular distance of the Sun.

VI. Conclusions

From the preceding analysis of transit observations of the scintillations of eight radio sources, we arrive at the following conclusions.

† The lines drawn in the figure are the low latitude envelopes to the three curves that correspond to the indicated times at the equinoxes (one curve) and the solstices.

(1) The only pronounced, regular variation of the normalized scintillation index is with local time. The time dependence is quasi-sinusoidal, of 12 hr period, with maxima near noon and midnight and minima near dawn and dusk. Any other regular variation with time (e.g. with season) or with direction (e.g. with angular distance from Sun and antisolar point) must be much smaller than the diurnal variation. An apparent seasonal effect comparable in amplitude with the diurnal effect, detected by Bolton, Slee, and Stanley (1953) in the mean scintillation index of the three sources in Virgo, Taurus, and Cygnus, seems to be accounted for largely by the diurnal effect.

(2) The double-peaked diurnal variation of (1) occurs in the present observations over a wide range of zenith angles ($\approx 10°–75°$). Therefore, it can no longer be regarded as a low altitude phenomenon (Booker 1958). In particular, if, following Wild and Roberts (1956), we associate the night-time scintillations with spread-F and the daytime scintillations with sporadic-E, then the present observations suggest that the presumed thin layers (~ 1 km) which are responsible for sporadic-E are as efficient in producing scintillations at any zenith angle as are spread-F irregularities. The double-peaked diurnal variation observed near Sydney (geographic latitude approx. 34° S., geomagnetic latitude approx. 42° S.) contrasts with the single night-time maximum consistently obtained by observers in England (at geographic latitudes approx. 52°–53° N., geomagnetic latitudes approx. 55°–56° N.). There seems to be insufficient information at present to decide whether these different diurnal effects can be explained as geographic or geomagnetic latitude effects (the latter have been found in satellite scintillations; cf. Aarons, Mullen, and Basu 1964), or whether there are significant differences in the E-layer irregularities in the northern and southern hemispheres.

(3) There is a close relation between the local time of observation and the angular distance of a source from the Sun or antisolar point. Thus, any source property that varies systematically with time of day will also vary systematically with solar distance. In order to separate diurnal and solar-distance effects of a source property, it is necessary to consider separately the dependence of the observed property on the differences between source and Sun in right ascension and declination respectively.

VII. Acknowledgments

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VIII. References

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