TRANSEQUATORIAL V.H.F. TRANSMISSIONS AND SOLAR-RELATED PHENOMENA

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Abstract

Radio and ionospheric data are analysed to determine the influences of solar–geophysical phenomena on transequatorial v.h.f. transmissions along a European–Southern African circuit. Results over six years show a close dependence on sunspot number. The observed correlation with sudden ionospheric disturbances indicates periodic solar-dependent defocusing of transequatorial signals by the ionosphere, while the combined effects of neutral winds and the position of the magnetic equator appear to control the seasonal behaviour of the transmissions.

I. Introduction

Long-range (7500 km) v.h.f. transequatorial propagation (TEP) experiments at 34, 40, and 45·1 MHz between Athens, Greece (lat. 37·7° N., long. 24·0° E.), and Roma, Lesotho (29·7° S., 27·7° E.), have recently been reported by Carman *et al.* (1973).‡ The 34 and 45·1 MHz c.w. transmissions were propagated for 5 min each hour of the day while the 40 MHz signals originated from the Greek Police FM network. The previous paper contained a detailed discussion of the analysis of fading characteristics and the relationship with electron density profiles, as determined by Alouette and Isis topside sounders, and also included a brief historical survey with references to other reviews. In the present note the same data are analysed with regard to synoptic variation of occurrence and strength of signal, especially in relation to sunspot number and sudden ionospheric disturbance (SID).

II. Experimental Data

The basic TEP data observed at Roma are given in Figure 1. The histograms show the presence probability, i.e. the proportion of days in the month when signals were recorded at any time during each 24 hr period. It can be seen that the maximum presence occurred during the equinoxes in 1970–71 for all three frequencies. The 40 and 45·1 MHz signals almost vanished during the June solstice and, although the 40 MHz transmission reached a much less marked minimum during the December solstice, the 34 MHz signals tended to decrease less than the higher frequencies during both solstices. In January and February 1971 the presence probability of 34 MHz

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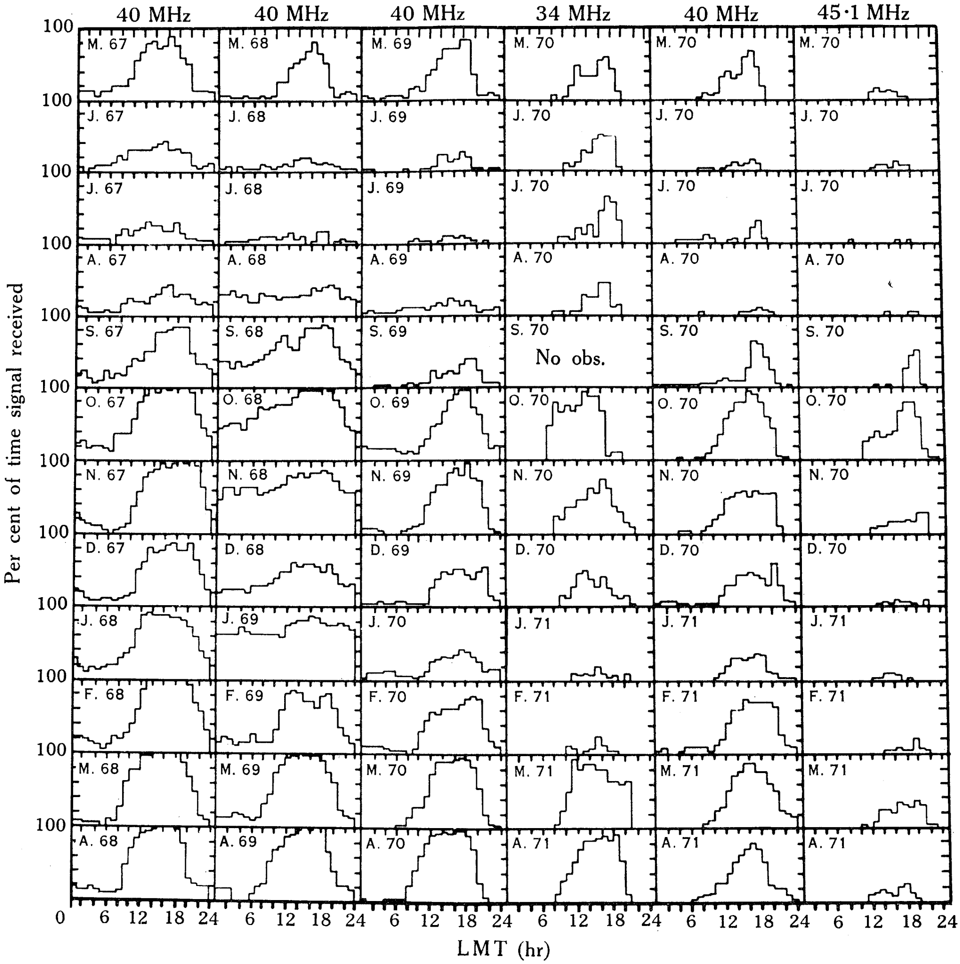

Fig. 1.—Histograms showing the proportions of time the 34, 40, and 45·1 MHz signals were received at Roma.

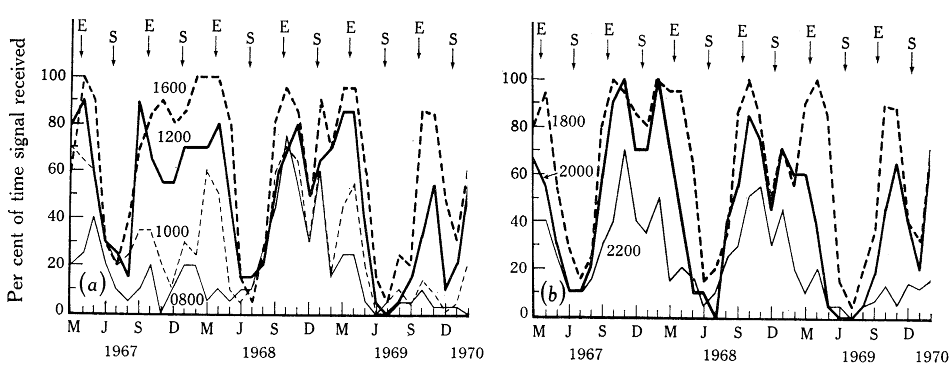

Fig. 2.—Curves for the indicated hours (LMT) showing the diurnal (*a*) development and (*b*) decay of 40 MHz TEP reception at Roma during the 36 months between March 1967 and February 1970. The arrows indicate the times of equinox and solstice.

TEP appears to be lower than that for 40 MHz, but it is known that signals were lost during those months due to antenna preamplifier failure and the data are unreliable; the December histogram indicates the general behaviour for that solstice.

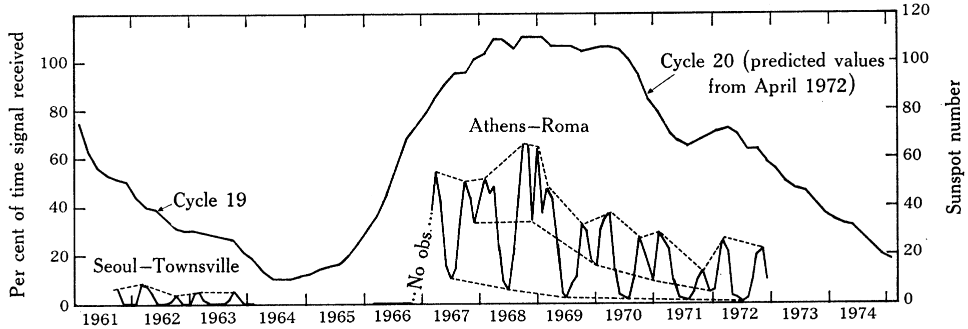

Fig. 3.—Comparison of the variations of TEP occurrence with Zürich sunspot number over 12 years. The dashed curves are the envelopes of maximum and minimum signal occurrence during the equinoxes and solstices respectively. The 48 MHz data for the Seoul–Townsville circuit are from Gibson-Wilde and Carman (1964).

The growth of 40 MHz TEP during morning hours and its decay during evening hours are illustrated in Figure 2. Between 1200 and 2000 hr LMT the curves almost coincide. Significant differences in occurrence during the June and December solstices are evident in all the curves for particular hours, except most of those for the morning hours. For 21 of the 36 months plotted, the signal before 1200 hr is present for less than 20% of the days of the month, which suggests a low presence probability before noon unless near a sunspot maximum (see Fig. 1).

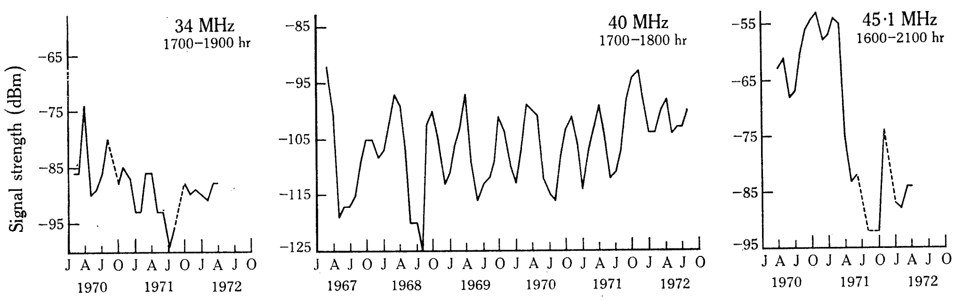

Fig. 4.—Seasonal variation of the recorded signal strength at 34, 40, and 45·1 MHz averaged over each month for the daily time intervals (LMT) indicated. The comparatively low signal strength at 40 MHz was partly due to lower transmitted power but mainly due to damping by the relatively large time constant of the 40 MHz recorder. (Note dBm = $10\log_{10}$ (power in milliwatts).)

III. Analysis and Results

(a) *Solar–Geophysical Influences*

The variation of the presence probability of signals with sunspot number is illustrated in Figure 3. This composite figure compares 48 MHz data recorded at Townsville (19·3° S., 146·8° E.) from FM transmitters at Seoul, Korea (Gibson-Wilde and Carman 1964), and the 40 MHz signals received at Roma. The dashed curves show the envelopes of maximum signal occurrence during equinoxes and minimum occurrences during the December and June solstices. The 40 MHz maximum envelope follows the curve of sunspot number sufficiently closely to reflect the subminimum and

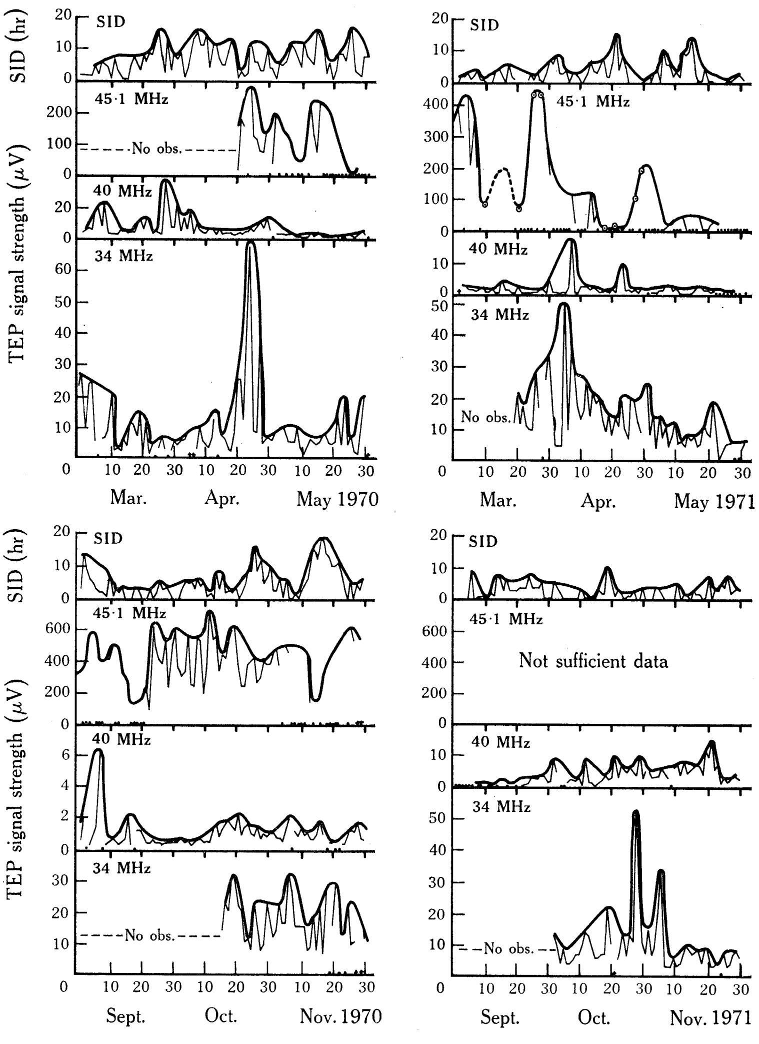

Fig. 5.—Comparisons for 1970 and 1971 of the characteristics of aggregate SID occurrence with the fading of TEP signal strength. The graphs illustrate correlations between SID and TEP variations of two periodicities, 12–13 days and 3–4 days.

submaximum of 1971–72 in the latter curve. Since all three envelopes are converging to a minimum, one can predict that the 40 MHz signal will almost, if not completely, vanish during the next solar minimum. The strong dependence of TEP on sunspot number that is evident in Figure 3 leads to the conclusion that solar control is a general characteristic of this kind of transmission. Figure 4 shows that signal strength has a similar equinoctial character to signal occurrence. Here the plotted points were obtained by averaging over each month for the respective daily time intervals indicated in the figure.

A different picture of TEP occurrence is obtained, however, if the average signal strength for each day is examined, as can be shown by a statistical analysis of the data contained in Figure 5. This figure compares SID characteristics in 1970 and 1971 with the fading of signal strength at three frequencies. The SID data were obtained from NOAA Solar Geophysical Data Prompt Reports, and aggregate occurrences were estimated by counting the number of hours per day that SID's were observed by the various stations. If more than one station reported SID occurrence the overlapping time was counted only once. No attempt was made to take account of such recorded factors as "importance", "wide spread index", or "type". Despite the many simplifications in the method of analysis, it was apparent that a periodic behaviour existed. A first rough estimate obtained by counting the number of peaks in the envelope of maximum SID occurrence in Figure 5 resulted in an average period of 12·5 days for the four seasons investigated. A similar estimate for the actual maximum to minimum variation gave an average period of 3·5 days. The reliability of these assumed periods was then tested by employing time series moving averages to produce scatter diagrams. The resulting trend lines in these diagrams had the following slopes.

Period (days)	Slope of trend	Chance probability (%)
3·5	−0·029	10
12·5	−0·046	13

Since the deviation of each slope from zero is a measure of the probability that the period is due to chance, we see that the reliabilities of the two periods are 90% and 87% respectively. From the nature of the data considered, a 90% significance may be accepted and hence it can be concluded that a period of about 3–4 days does exist in the present sample. On the other hand, a further test appears to be necessary to establish the validity of the 12·5 day period. The curve in Figure 6 is the mean of approximately 30 periods produced by averaging SID occurrences on successive days, each point in the averaged sets being separated by 12·5 days. The curve clearly supports the existence of a 12–13 day period in the envelope of maximum SID occurrence.

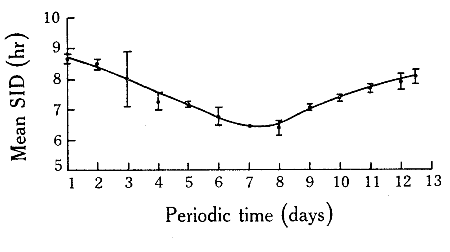

Fig. 6.—Mean cyclic SID occurrence based on a 12·5 day period. The error bars are the standard deviations of the plotted points averaged over approximately 30 days.

Further inspection of Figure 5 leads to the speculation that the variations in TEP signal strength are related to those in aggregate SID occurrence. Thus it is possible that there exist three periodic types of TEP intensity which are related to solar activity: (1) a seasonal variation with maxima during the equinoxes (Fig. 4), (2) a slow periodic variation with maxima every 12–13 days (Fig. 5), and (3) a more rapid periodic variation with maxima every 3–4 days (Fig. 5). Representative correlation coefficients r (with the corresponding significance levels) for the two periods and three frequencies are set out below.

Period (days)	r (significance) for signals 34 MHz total	40 MHz total	45·1 MHz total	45·1 MHz afternoon
3–4	—	—	−0·122 (90·5%)	−0·028 (<75%)
12–13	−0·104 (89%)	−0·103 (91%)	−0·137 (91·5%)	−0·34 (99·9%)

Since evening flutter of the signal along the present TEP path is much more apparent at 45·1 MHz than at the lower frequencies (Carman *et al.* 1972), it seemed worth while to include values of r for 45·1 MHz signals received before 1800 hr LMT. Taking 90% as the acceptance limit, it is clear that the total TEP analysed over a whole day correlates best with a 12–13 day SID cycle at the highest frequency. The 45·1 MHz afternoon signal, with a significance of 99·9%, is highly correlated with a 12–13 day SID variation. On the other hand, the correlation of the 3–4 day SID with the 45·1 MHz signal is just significant for the total signal but not at all for the afternoon signal.

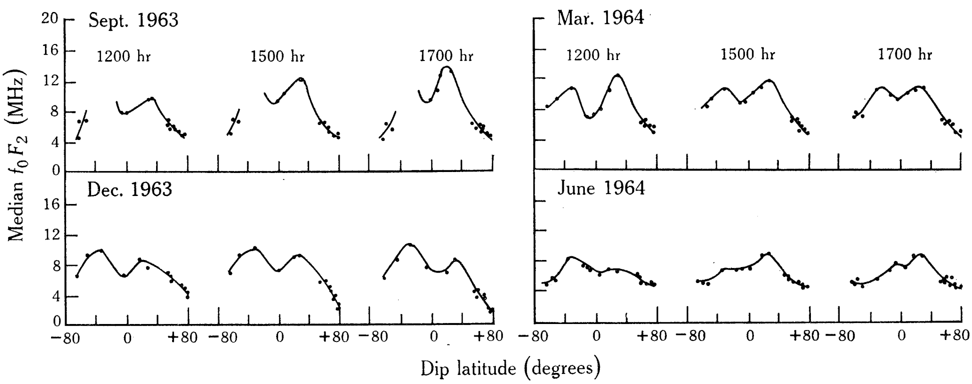

Fig. 7.—Variation of monthly median values of f_0F_2 with dip latitude for three afternoon hours during the indicated months in 1963–64.

Sudden ionospheric disturbances are caused by X-rays from solar flares increasing the ionization in the lower ionosphere. They are characterized by increased absorption of short wave radio signals resulting in short wave fadeout (see e.g. Reid (1967) for a detailed discussion of ionospheric disturbances). The large-scale effects of solar flares produce the periodicity in SID that is evident in Figure 5. One might look for an explanation of the 13-day fades by studying the passage of active regions across the Sun's disc. However, from synoptic behaviour so far reported it is by no means expected that TEP signal strength will closely follow the same periodicity. Such a correlation, and especially an *inverse* correlation, could only arise from either absorption or defocusing in the ionosphere and, in order to determine which of these two factors predominates, further investigation of the correlation between SID and signal occurrence is presently being carried out.

(*b*) *Seasonal Behaviour*

In his analysis of seasonal variations, Gibson-Wilde (1967) showed that there was a relationship between the symmetry in the equatorial anomaly (see e.g. Lyon 1963; Rao and Malthora 1964) during equinoxes and the occurrence of the Townsville TEP of Figure 3. The decreased occurrence during the solstices could likewise be related to asymmetry in the position and magnitudes of the anomaly peaks. A similar behaviour for the European–African circuit is shown in Figure 7, where the monthly median values of $f_0 F_2$ (taken from CRPL (1964–68)) for the indicated months are plotted for that circuit. The concentrations of electron density on either side of the magnetic equator are generally well developed during the equinoxes and December solstice, although some asymmetry occurs in the latter period. On the other hand, during the June solstice the anomaly peaks are weakly developed and rather more asymmetrical in position and magnitude. This must be regarded as a general characteristic of the equatorial ionosphere influencing TEP for African and Far-Eastern circuits.

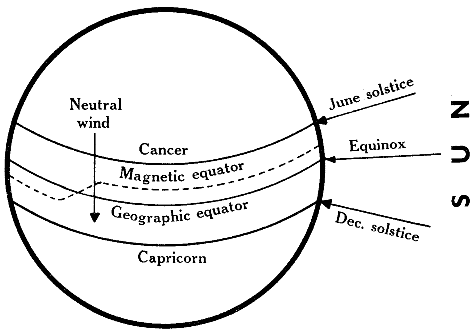

Fig. 8.—Schematic diagram illustrating the influences of the neutral wind and other geophysical factors on the seasonal behaviour of TEP.

In Figure 2 of their paper, Carman *et al.* (1973) have compared TEP transmissions from Oahu to Raratonga with the Athens–Roma circuit and have shown that Nielson's (1969) reported higher reception in June than December was reversed and more marked for the latter circuit. That the Pacific and African circuits have reversed solstitial reception can be explained in terms of relative positions of the magnetic and geographic equators. However, in order to account for the greater difference in reception on the African circuit it is necessary to introduce a further factor. Figure 8 illustrates how the north–south neutral wind described by Hanson and Moffett (1966) could be such a factor. Vertical electrodynamic forces would remove electrons from the neighbourhood of the magnetic equator and subsequent downward diffusion would result in symmetrical enhancements to the north and south. When the subpolar point lay to the north of the magnetic equator, as during the June solstice, this would increase the northern ionization, but the neutral wind would move this excess ionization southward, tending to fill the trough over the equator. During the December solstice the neutral wind and the increased ionization due to the southern track of the subpolar point would combine to produce an increased enhancement south of the magnetic equator, as is evident from Figure 7. This would explain the behaviour on the African circuit. For the Pacific circuit, the southward position of the magnetic equator together with the *southward direction* of the neutral wind would combine to produce the reverse effect.

IV. Acknowledgment

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V. References

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