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Low Temperate Zone Sporadic-E: Seasonal and Diurnal Variations at Rarotonga

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Abstract

The seasonal variations of strong E_s occurrence as a function of diurnal period have been obtained for the Pacific station of Rarotonga (21°·2 S). The seasonal characteristics depend markedly on local time with afternoon E_s activity showing large deviations—equinoxial enhancements and summer peaks occurring before solstice—from those expected from the formation processes currently understood.

1. Introduction

Sporadic-E observations at low latitudes are important because it is necessary to establish to what extent E_s behaviour controlled by formation mechanisms appropriate to the temperate zone—vertical wind shear and gravity waves— is influenced by other factors; for example, processes associated with the equatorial electrojet. One type of study is morphological surveys yielding patterns of occurrence of E_s. Such studies of E_s occurrence employ various techniques: swept-azimuth HF backscatter sounders, oblique scatter on communication circuits as well as standard vertical sounders (ionosondes). Thus, Dueño (1962) used a dual frequency oblique sounder in a survey of E_s over two years at Mayaguez (18° N geographic, +28° geomagnetic). Several morphological surveys have analysed data from a global network of ionosonde stations. The ionogram parameter usually employed in such work is $f_o\,E_s$—the highest frequency for which a mainly continuous reflection is present for ordinary ray propagation. Some early analysis procedures scaled $f\,E_s$, the top observed frequency (approximately half the electron gyro-frequency higher than $f_o\,E_s$). Thomas and Smith (1959) presented maps of sporadic-E occurrence for $f_o\,E_s \geqslant 5$ MHz compiled from 1948 to 1954 for the major geographic zones while Huang (1966) gave high resolution $f_o\,E_s \geqslant 5$ MHz occurrence (daily) for summer months over four years for Taipei (25° N, +14°). An extensive analysis was given by Rawer (1962) of $f_o\,E_s \geqslant 5$ MHz occurrence over four years for the low latitude stations Dakar (15° N geographic, +22°), Djibouti (12° N, +7°), Ibadan (7° N, +11°) and Nhan Trang (12° N, +1°). Such surveys have revealed only the broad features of the temporal characteristics of sporadic-E, and it is important to recognize the limitations of ionosonde surveys, hourly sampling and limited spatial information of an inherently quasi-random phenomenon.

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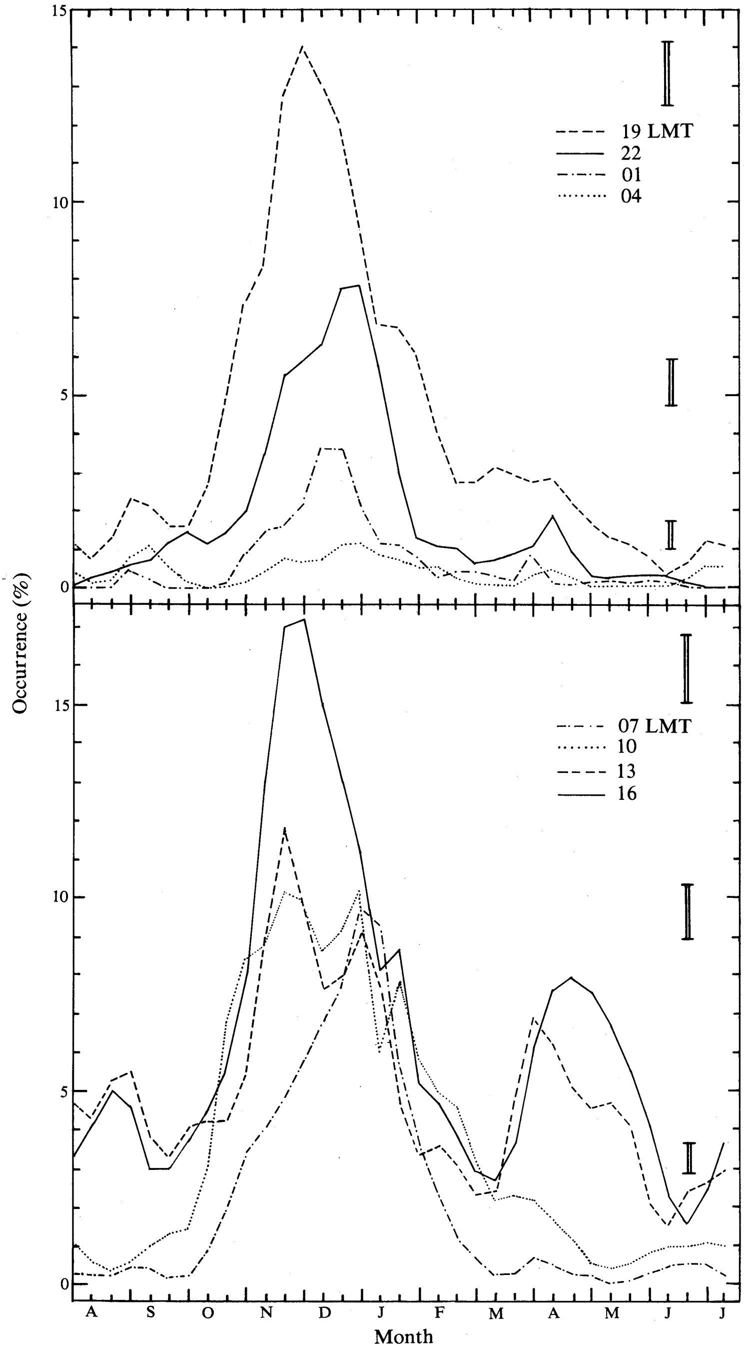

Fig. 1. Average seasonal occurrence $6 \leqslant f_0\ E_s < 8$ MHz with sampling frequency of three per month. Large pips represent days 1–10 for each month. To reduce sampling noise a (1, 2, 1) weight smoothing has been included. Representative uncertainty bars in the percentage occurrence (calculated from the statistics of the 10 year data) are shown to the right of the plots.

It was shown in a recent survey (Baggaley 1985) of 32 years of daytime E_s for the subtropical Southern Hemisphere Pacific station Rarotonga (21° S, 200° E; −22° geomagnetic) that the seasonal behaviour showed important departures from that expected on the basis of control by solar related processes. The major findings were that $f_o\,E_s \geqslant 5$ MHz and $f_b\,E_s \geqslant 4$ MHz ($f_b\,E_s$ is the blanketing frequency—the lowest ordinary ray frequency at which the E_s layer becomes transparent) showed enhancements 10–14 LMT one month before summer solstice and in April as well as features in mid-August. The present study employs a high diurnal resolution to more closely examine the seasonal characteristics of E_s for the Rarotonga station.

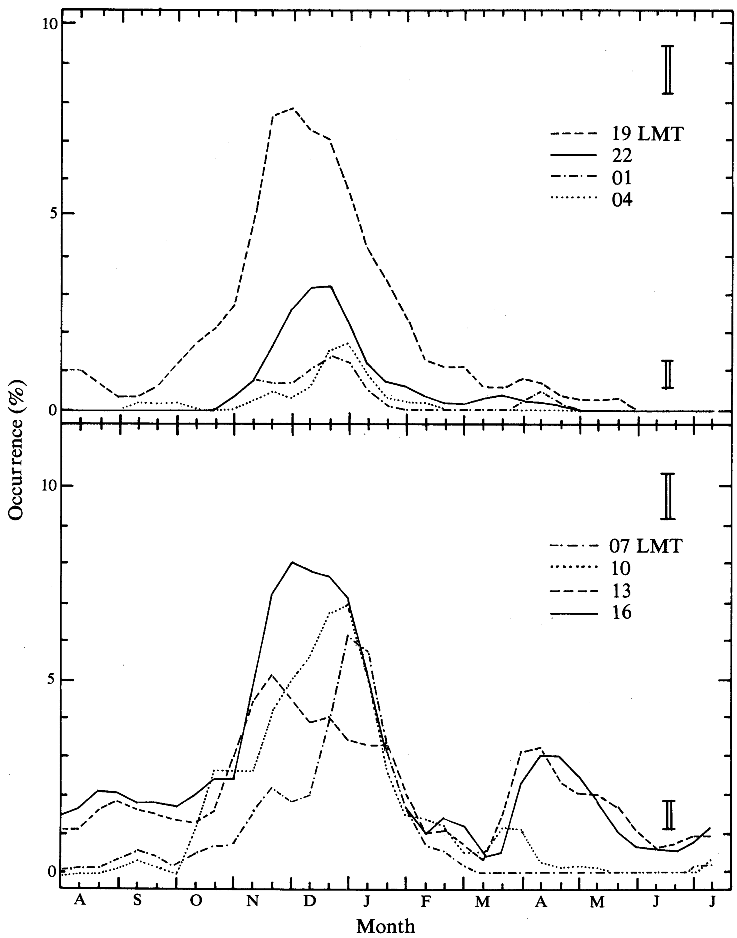

Fig. 2. As for Fig. 1, with $f_o\,E_s \geqslant 8$ MHz.

2. Analysis

To achieve some measure of understanding of the mechanisms responsible for the seasonal structure of E_s evident in ionogram data, it is necessary to examine the diurnal behaviour in detail. Because of hourly sampling and limited record length, the inherent fluctuations in E_s data impose restrictions on the statistical treatment possible. From tabulated hourly values of $f_o\,E_s$ at Rarotonga from January 1970 to

March 1980 the average occurrence (irrespective of E_s classification) was obtained at 10 day intervals and for each of eight 3 h diurnal periods 0–2, 3–5 to 21–23 LMT. The average occurrence for each 10 day interval over the years, expressed as a percentage, was calculated for each diurnal period (labelled for convenience 1, 4, 7, ..., 22 LMT). Each final percentage represents therefore about 300 possible entries.

To achieve meaningful results in studies of E_s it is important to prevent daytime contamination by the normal E region by employing a limiting frequency well above noon $f_o E$. (For Rarotonga the summer solstice noon value of $f_o E$ varies from 3·5 MHz at solar minimum to 4·5 MHz at maximum.) To assess such effects the analysis was carried out by employing two frequency intervals:

$$6 \leqslant f_o E_s < 8 \text{ MHz}, \qquad f_o E_s \geqslant 8 \text{ MHz}.$$

The results shown in Figs 1 and 2 indicate that the seasonal behaviour of E_s can be quite different for different times of day. Two important features are clear above the inherent fluctuations in data (compare the uncertainty bars):

(i) A large autumn enhancement in E_s activity occurs which is restricted to the two afternoon periods 13 and 16 LMT.

(ii) Although the summer peak in activity occurs near the solstice for most diurnal periods, there are significant deviations: the peak for afternoon and evening periods 13, 16 and 19 LMT all occur about 1 month early ($\sim$ November 20).

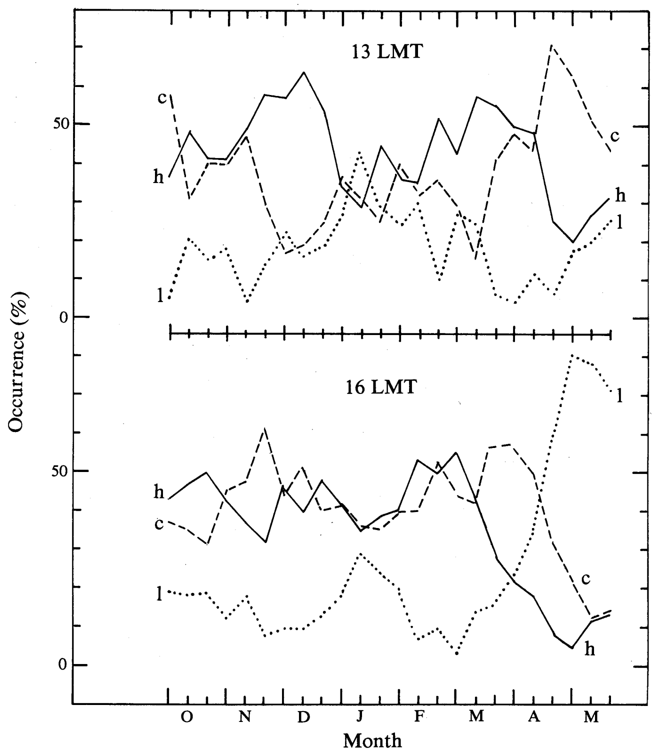

Fig. 3. Seasonal changes in the proportion of each type of E_s: l (low), c (cusp) and h (high). The sampling frequency was three per month.

No distinction as to the type of E_s was made in the above analysis. Classification of E_s depends on the appearance of the E_s echo trace on an ionogram with eight types recognized. At low latitudes during daytime four distinct types are expected:

(i) type l (low), with the E_s trace below the regular E layer;

(ii) type h (high), with the E_s trace above the height of maximum ion density of the regular E layer;

(iii) type c (cusp), a symmetrical cusp at or below $f_o E$;

(iv) type q (equatorial), non-blanketing and diffuse over a wide frequency range.

In any particular zone, E_s of a different type is predominant at characteristic times of day and season. A test was made to determine whether any significant change of E_s type appeared to be associated with the seasonal enhancements in overall rate. For Rarotonga, E_s type was not scaled for the period of tabulated data 1970–80. Since the autumn enhancement is dominant, data were analysed from October to May for the interval 1961–5. Results are shown in Fig. 3 for the two separate afternoon periods (13 and 16 LMT). Type q E_s is rare at Rarotonga: for type q dominant the average daytime occurrence through the year is about 0·5% and on individual 10 day intervals is always <3%. It is clear from Fig. 3 that the autumn enhancements in 13 and 16 LMT activity cannot be identified with any corresponding change in E_s type.

3. Discussion

At the low latitude Southern Hemisphere Pacific station Rarotonga, a marked increase in afternoon E_s activity as described by $f_o E_s$ occurrence occurs in autumn with a smaller enhancement in spring. In addition, the summer peak in afternoon and evening $f_o E_s$ takes place well before the solstice date. The equinoxial enhancements appear symmetrically placed 110 days before and after summer solstice. The features, which appear not restricted to any particular E_s type, are seen in separate data sets: $6 \leqslant f_o E_s < 8$ MHz and $f_o E_s \geqslant 8$ MHz. These results are surprising: the factors important in E_s production—the background normal E ionization, the influx of meteoric material and vertical wind shear characteristics—show no marked changes which can be associated with the observed seasonal features. An analysis was made of median $f_o E$ for Rarotonga for the same 10 day intervals, extended over 1970–80: the seasonal daytime behaviour was a smooth function showing well-known solar control. The seasonal influx of meteoroids is well understood in terms of known streams and sporadic material (McKinley 1961). The Southern Hemisphere characteristics of mean winds (Manson *et al.* 1985), tides (Forbes 1984) and the velocity amplitude variances of atmospheric gravity waves (Ball 1981) do not suggest any obvious association.

The equatorial electrojet is a strong eastwards electric current flowing in the daytime E region arising from atmospheric solar dynamo effects. Although the electrojet is known to be responsible for E region plasma instabilities and irregularities, observed via ionosondes as type q E_s, such phenomena are restricted to latitudes of about $\pm 3°$ centred on the geomagnetic equator. At Rarotonga (geomagnetic $-21°$), type q E_s is dominant for only about 0·5% of the time throughout the year and is of too rare an occurrence to determine any significant seasonal variation.

The candidate responsible for the seasonal behaviour of E_s at subtropical Rarotonga is most unlikely to be the equatorial electrojet and is more probably to be found in some unidentified tidal mode.

This report presents further evidence that the processes governing the formation and aeronomy of sporadic-E are complex: there are factors important in controlling E_s occurrence that are not yet identified. In seeking an understanding of temperate latitude E_s, the detailed seasonal characteristics of E_s at other stations in the low latitude temperate zone are necessary before realistic approaches to modelling these types of E region irregularities can be attempted.

Acknowledgments

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