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Changes in the Frequency Distribution Characteristics of Ionosonde E_s Parameters during Major Meteor Activity

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Abstract

The probability of occurrence of both $f_o E_s$ and $f_b E_s$ in excess of ionosonde limiting frequency has been examined for two Southern Hemisphere stations at periods of recurrent annual meteor shower activity and periods of no shower influx. The analyses show that marked changes occur in probabilities for high values of $f_o E_s$ and $f_b E_s$ indicating structural modifications to E_s layers.

1. Introduction

One type of ionospheric E region irregularity found at temperate latitudes is known to be produced by the redistribution of meteoric ions forming thin plasma layers (clouds) of limited horizontal extent (Whitehead 1972). Though the mechanism of formation of this sporadic-E ionization (E_s) is broadly understood (i.e. the wind-shear theory of Whitehead 1961) several features remain ill defined. Observational data on E_s clouds are available from a global network of swept-frequency static h.f. sounders (ionosondes). The parameters describing E_s ionization are defined by ionogram traces: $f_o E_s$ is the highest reflection frequency for the ordinary propagation mode and $f_b E_s$ the frequency below which blanketing of ionospheric layers at greater heights occurs. Published data for a given ionosonde provide hourly sampling of $f_o E_s$ and $f_b E_s$. In seeking a measure of plasma cloud characteristics, no simple well-defined ionosonde parameter suffices. Instead, it is known (Reddy and Mukunda Rao 1968) that $f_b E_s$ is broadly representative of the average background ionization density of a cloud, with $f_o E_s$ dependent on the peak ionization density of enhanced regions within a cloud.

Although the meteoric source of temperate latitude E_s has long been recognized and although meteor ions have been identified during meteor showers (Goldberg and Aikin 1973), the expected close association between meteor influx and E_s recorded on ionograms has been difficult to establish. It is clear that the complex aeronomy governing E_s production can lead observationally to a rather indirect relationship between the two phenomena. For this reason studies aimed at associating $f_o E_s$ or $f_b E_s$ with increases in meteoric activity have yielded inconsistent conclusions (Neuzil 1955; Triskova 1974; Hedburg 1976; Sinno 1980).

It is important to recognize two distinct types of meteor-related E_s. The deposition rate of meteoric ionization directly due to many individual meteors may be sufficiently high to produce, at a given station, a continuous reflection maintained during a high

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activity shower: this is a rare occurrence. The majority of temperate latitude E_s events are produced by the redistribution of the reservoir of lower thermosphere meteoric ions by the action of wind shears in the presence of the geomagnetic field producing ionization irregularities. Ellyett and Goldsbrough (1976) employed the terms $2E_m$ and $3E_m$ for the classes of immediate and delayed sporadic-E. The present paper is concerned with the latter events.

In previous work on meteor–E_s associations, ionosonde data have been analysed to yield the occurrence (in per cent) of $f_o E_s$ or $f_b E_s$ above a specified limiting ionosonde probing frequency. Thus Sinno (1980) employed limiting frequencies of 4 or 5 MHz for $f_o E_s$ depending on the station. In the present work a greater depth of information is provided on the characteristics of E_s by studying the cumulative occurrence as a function of probing frequency for two specific periods of the year: at the epoch of a major meteor shower and at a period when shower activity is absent.

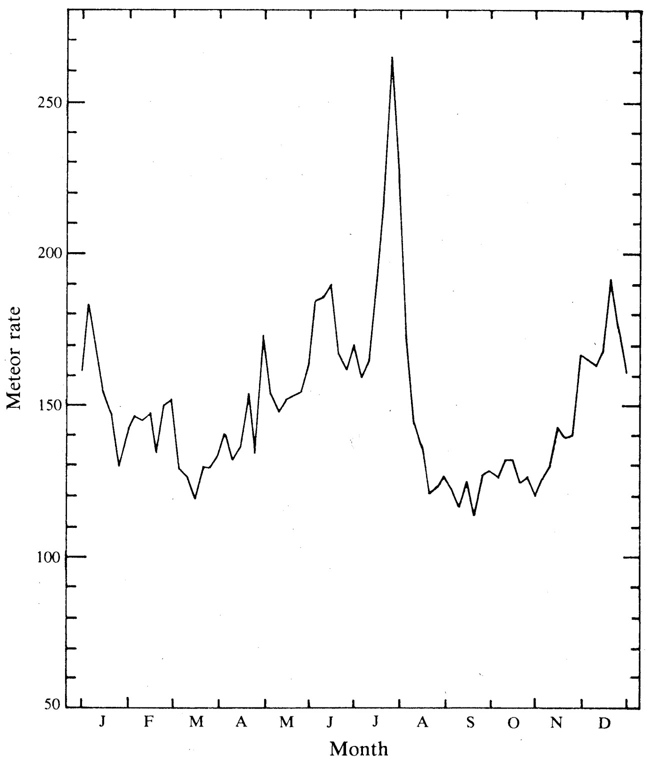

Fig. 1. Seasonal variation of radar meteors obtained at Christchurch (geographic 172°·5, −43°·5) obtained from the $3\frac{1}{2}$ years data of Ellyett and Keay (1961) and Keay and Ellyett (1969). The ordinate is the mean hourly rate between 00 and 12 LMT over 5 day intervals. Each abscissa mark represents the start of a month.

2. Data Analysis and Results

Fig. 1 shows the seasonal variation of radar meteor activity recorded at Christchurch (geographic 172°·5, −43°·5) employing a 69 MHz monostatic system with an omnidirectional antenna system sensitive to diverse meteor radiants on the celestial hemisphere. The hourly rates are composed using $3\frac{1}{2}$ years data between 1960 and 1965 (Ellyett and Keay 1961; Keay and Ellyett 1969) and are the mean values between 00 and 12 LMT when the major diurnal influx occurs. Radar surveys achieve a greater statistical significance than is possible with less sensitive visual observations, and Fig. 1 can be taken as representative of the seasonal variation of meteoric influx in the Southern Hemisphere. Although minor meteor streams can be identified, the large activity in late July due to the Capricornids–Southern Delta Aquarids complex at southern declination is dominant. For analysis the periods July 15–August 5 and May 15–June 5 were selected. Two criteria dictated this choice: (i) the latter period is devoid of major Southern Hemisphere meteor shower activity and (ii) the two periods are placed roughly symmetrically about the winter solstice enhancement of E_s occurrence (which is characteristic of temperate latitude behaviour).

One area of interest is the time interval involved in the redistribution of meteoric material to produce ionization irregularities following meteoric injection. Therefore separate analyses of occurrence versus limiting frequency in the range 1 to 11 MHz in steps of $0 \cdot 5$ MHz for both $f_o E_s$ and $f_b E_s$ were performed for four diurnal periods: 00–05, 06–11, 12–17 and 18–23 LMT. Published hourly values of $f_o E_s$ and $f_b E_s$ were examined daily for Christchurch (ionosonde, geographic $172° \cdot 5$, $-43° \cdot 2$) and Rarotonga (ionosonde, geographic $200° \cdot 3$, $-21° \cdot 2$).

Since meteor showers are annually recurrent, an accumulation of data for the two seasonal periods over many years would be expected to yield distributions of high statistical significance. Therefore 25 years data for 1958–82 were used for Christchurch, and the 22 years 1958–79 for Rarotonga (this station closed April 30, 1980).

The important aspect of this study is the question of a difference between the occurrence versus limiting frequency distributions for the July–August (shower) and the May–June (non-shower) periods. Consequently the parameter examined was the ratio, for any specific limiting frequency, of the occurrence for the shower period to the occurrence for the non-shower period. Plots are presented in Fig. 2 showing this ratio with all lowest ordinate values being

$$P(fE_s \geqslant 1\ \text{MHz, shower})/P(fE_s \geqslant 1\ \text{MHz, non-shower}).$$

Two points are clear: (i) the occurrence for all E_s (i.e. $fE_s \geqslant 1$ MHz) during May 15–June 5 exceeds the shower period by about 6% for both stations for all times; (ii) some plots show progressively greater occurrence with increasing limiting frequency. This behaviour is apparent in the $f_o E_s$ data for Christchurch 12–17 LMT (Fig. 2*a*) and for Rarotonga 18–23 LMT (Fig. 2*c*) and also in the $f_b F_s$ data for Christchurch 00–05 (Fig. 2*b*) and Rarotonga 06–11 and 18–23 LMT (Fig. 2*d*). The increase is especially marked for $f_b E_s$ Christchurch 00–05 LMT where $P(f_b E_s \geqslant 4$ MHz) in the shower period is a factor of 4 greater than at non-shower times.

3. Discussion

It is clear from these findings why previous work has yielded inconsistent results. For example, a survey carried out for either station for daytime of occurrence $\geqslant 4$ MHz would find no significant change in either $f_o E_s$ or $f_b E_s$.

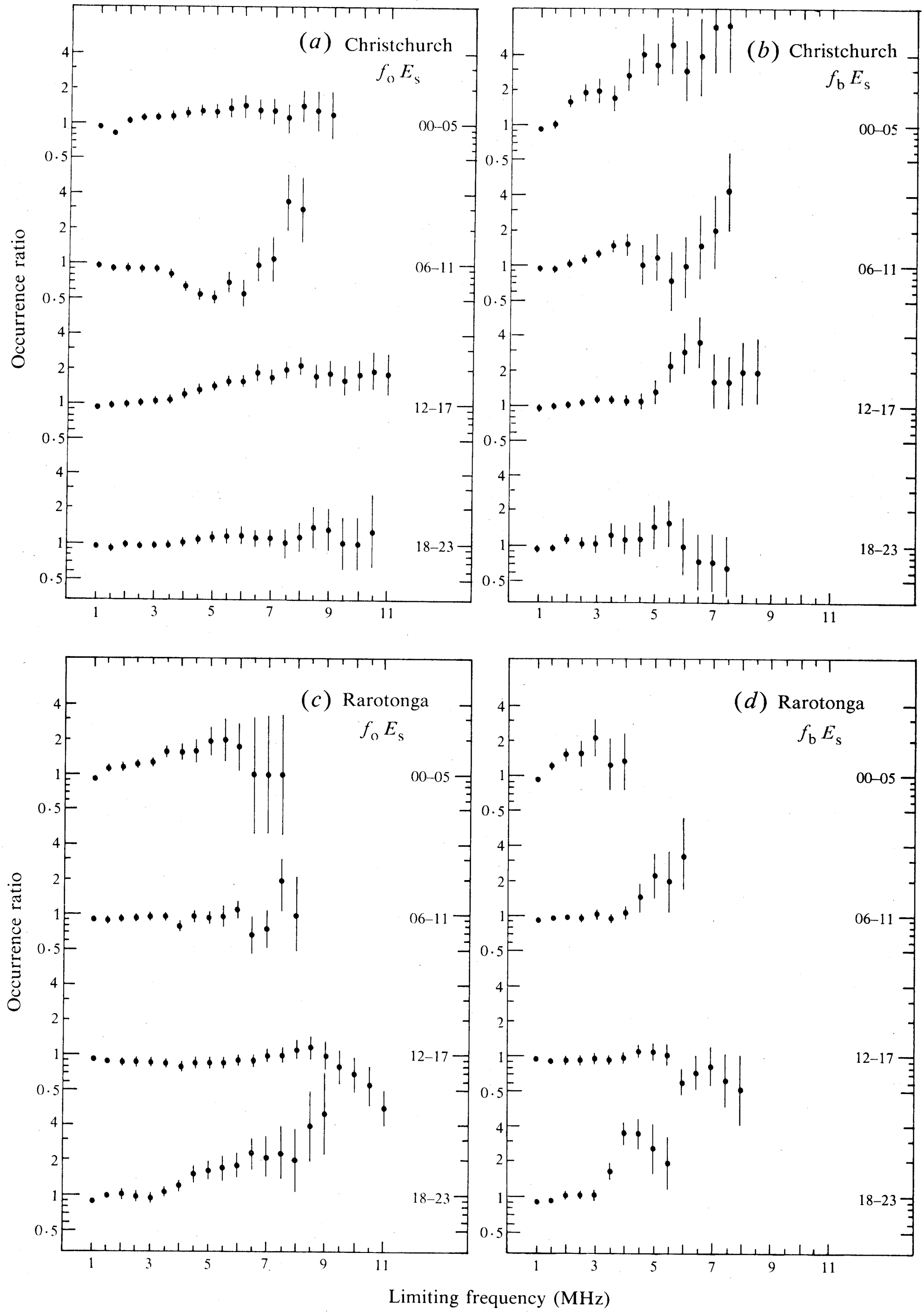

Fig. 2. Ratio of occurrence probability for meteor shower period to that for non-shower period shown for four separate diurnal times (LMT): (*a*) Christchurch $f_o E_s$; (*b*) Christchurch $f_b E_s$; (*c*) Rarotonga $f_o E_s$; and (*d*) Rarotonga $f_b E_s$. Data for Christchurch and Rarotonga are for 25 and 22 years respectively.

One factor which can influence ionogram scaling when either $f_o E_s$ or $f_b E_s$ is low is the minimum ionosonde frequency limit f_{min}. Thus, any gross changes in f_{min} between the two separate seasonal periods will affect occurrence values. Analyses were carried out over the two decades to ascertain the seasonal variations of f_{min}. It was found that for both stations f_{min} showed average changes between shower and non-shower periods of less than 0·1 MHz. Any effects on the observed ratios of occurrence will therefore be negligible for all data.

The deposition rate of meteoric species into the lower thermosphere depends on latitude and is dependent on the cosine of the shower radiant zenith angle. At radiant transit the zenith angle for the Southern Delta Aquarids is 26° for Christchurch and 4° for Rarotonga. A difference of only 10% is therefore expected in the meteoric influx at the two stations.

Scaling procedures under closely maintained international standards have been a feature of the ionogram reductions carried out by the Physics and Engineering Laboratory Geophysical Observatory, Christchurch.

It is clear that marked changes occur in the cumulative frequency distributions of both $f_o E_s$ and $f_b E_s$ at periods of increased meteor influx. Many data show large increases in occurrence as the limiting ionosonde frequency is increased. Although an increased meteor influx leads to no change in weak E_s events, the results indicate large increases in the presence of high ambient density clouds (as indicated by increased intense $f_b E_s$ values) accompanied usually by an increase in high density enhanced irregularities (as indicated by augmented $f_o E_s$ values) within clouds. This enhancement does not occur for all diurnal periods however, nor is the behaviour the same at both stations (a characteristic not unexpected since the thermospheric wind structure yielding E_s is not the same at subtropical and temperate latitudes). The findings indicate no clear pattern resulting from the diurnal variation of meteoric influx. This result is consistent with the aeronomy of the meteoric species responsible for E_s ionization. Above 100 km the species are maintained in unbound form with metal ion ionization times being much shorter than their neutralization lifetimes. Additionally, ion residence times are limited by eddy diffusion (with coefficient D_e) to the order of H^2/D_e, where H is the scale height, thus yielding lifetimes of a few days.

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