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Nocturnal Sporadic-E Activity at Two Southern Hemisphere Stations over Three Solar Cycles

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Abstract

Analyses are presented of monthly values of the occurrence of the ionospheric parameters $f_b E_s$ and $f_o E_s$ for the South Pacific stations Christchurch and Rarotonga over three complete solar cycles. For each station both pre-midnight and post-midnight data show seasonal variations similar to daytime with the high latitude station showing a winter enhancement. Data fluctuations of scales longer than a year are very pronounced compared with variations in other ionospheric parameters. No correlations exist between any of the data sets and either the sunspot number R_Z or geomagnetic index. Long-term variations in $f_b E_s$ and $f_o E_s$ are uncorrelated at a particular station.

1. Introduction

Sporadic-E ionization is a result of the vertical compression of positive ions in the ionospheric E region into thin sheets of horizontal scale about 100 km by the action of tidal winds operating in the presence of both the geomagnetic field and the height variation of the neutral collision frequency. This wind-shear mechanism first proposed by Whitehead (1961) has been successful in explaining many features of the temperate latitude sporadic-E parameter E_s. Internal gravity waves and turbulence modify the regular wind pattern so that the resulting ionization formation is sporadic. Individual sheets contain pronounced small scale horizontal irregularities. The participating ions are known from mass-spectrometer rocket flights to be meteoric, mainly Mg^+, Si^+ and Fe^+ created either directly from meteor ablation or indirectly by charge transfer from O_2^+ and NO^+ produced by daytime photoionization. Clearly, long residence times are required for such ions to exist in the nighttime lower E region. The vertical extent of sheets (1–3 km) results from a balance between the compressional forces and diffusion, while ion lifetimes are limited mainly by the effects of downward diffusion.

Routine vertical swept-frequency data have been available for many years from an international network of ionospheric sounder stations. The parameters available from the scaling of ionogram records are hourly values of $f_o E_s$ (ordinary-wave top penetration frequency in MHz) and $f_b E_s$ (blanketing frequency in MHz). A problem in interpreting ionosonde E_s data has always been that the parameters do not uniquely define any single physical quantity associated with a sporadic-E cloud. However, it is known that $f_b E_s$ is a measure of a cloud's ambient ionization, while $f_o E_s$ is determined by both the ionization density and the structure within a cloud. With data

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recorded at hourly intervals each station supplies a localized sampling at a rate comparable with the typical lifetime of a cloud. However, sufficient data may be present in a long series of records for a particular station to reveal a coherent picture of temporal characteristics of E_s activity as defined by a parameter. Of importance, for example, is the association between E_s occurrence and solar activity or geomagnetic activity. Thus previous work has established that temperate zone daytime $f_b E_s$ occurrence has a close in-phase association with sunspot number (Reddy and Matsushita 1968), while $f_o E_s$ shows little such dependence (Baggaley 1971). Reviews of the morphology and aeronomy of sporadic-E activity have been given by Whitehead (1970, 1972).

In order to provide information on long-term E_s characteristics the present study reports the occurrence of nocturnal $f_b E_s$ and $f_o E_s$ at two stations in the Southern Hemisphere over a period of three solar cycles. Such extended series of processed nighttime observations have not appeared before in the literature.

2. The Data

Scaled hourly values of $f_o E_s$ and $f_b E_s$ were examined for each day for the Southern Hemisphere temperate latitude ionosonde station Christchurch ($-43°\cdot 6$ geographic, $-48°\cdot 1$ geomagnetic) for the period January 1947 to December 1982 and the subtropical station Rarotonga ($-21°\cdot 2$ geographic, $-20°\cdot 7$ geomagnetic) for the period January 1949 to its closure in April 1982. The mean monthly percentage occurrences P of $f_o E_s \geqslant 4$ MHz and $f_b E_s \geqslant 2$ MHz were obtained for the two nocturnal periods 19^h–23^h LMT, pre-midnight (evening), and 00^h–04^h LMT, post-midnight (morning). Each month encompassed therefore 150 or 155 scaled values, a number sufficiently large to minimize sampling errors. There are conflicting factors governing the selection of the above limiting frequencies. Although the nocturnal ambient E-region ionization density is low so that $f_o E$ is generally $\leqslant 0\cdot 5$ MHz for the relevant periods, broadcast interference renders information unreliable if $f_x E_s$ (x = o or b) is chosen to be $\leqslant 2$ MHz. A pronounced signature is required to represent fluctuating E_s activity. No discrimination in either height or E_s classification was included although auroral-type E_s was discounted. Consistent scaling procedures under international recommendations and the use of carefully monitored equipment have been a feature of the ionogram reductions for these stations.

3. Results

The seasonal variations of occurrence P are shown for Christchurch and Rarotonga in Figs 1*a* and 1*b* respectively. Examination indicates that the seasonal variations show no solar cycle dependence and are similar to typical daytime seasonal characteristics. Morning and evening patterns are similar, while for Rarotonga the winter enhancement which features in the higher latitude station results is not evident.

Fig. 2 shows the long series of data with the strong seasonal cycle removed by using a 12 month running mean plot. Power spectrum and cross-correlation analyses were performed on the data. Several features are clear. Irregular fluctuations are present in all parameters, fluctuations much greater than in other ionogram parameters. No association with solar cycle or with aaS index (a daily magnetic index representing Southern Hemisphere activity and derived from the magnetic records obtained at Australasian magnetic observatories) is present for either $f_o E_s$ or $f_b E_s$ at

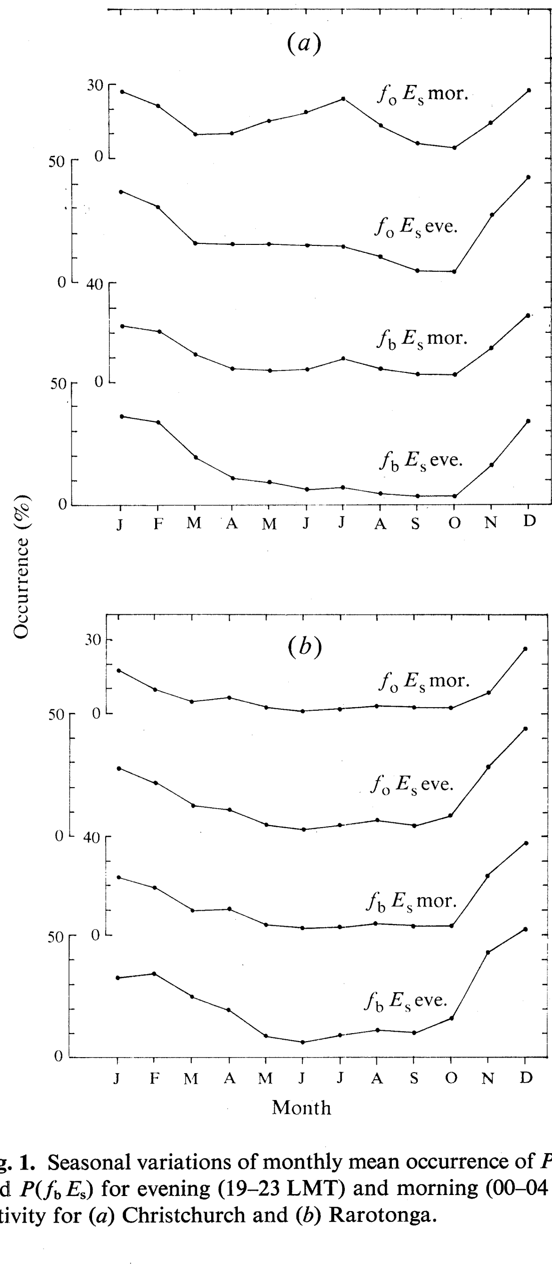

Fig. 1. Seasonal variations of monthly mean occurrence of $P(f_o E_s)$ and $P(f_b E_s)$ for evening (19–23 LMT) and morning (00–04 LMT) activity for (*a*) Christchurch and (*b*) Rarotonga.

either station. At a given station evening and morning long-term variations are similar, being described by a correlation coefficient r of $+0\cdot91$ and $+0\cdot92$ for $P(f_o E_s)$ and $P(f_b E_s)$ for Christchurch and $+0\cdot82$ and $+0\cdot60$ respectively for Rarotonga. Since the mean lifetime of individual E_s plasma clouds is known to be about one hour (Derblom 1981), the evening and morning data are unlikely to refer to the same events. There is, therefore, a general nocturnal factor which controls long-term variations; however, this represents a process which is of limited scale since Christchurch and Rarotonga fluctuations are quite uncorrelated for all parameters ($r < 0\cdot2$).

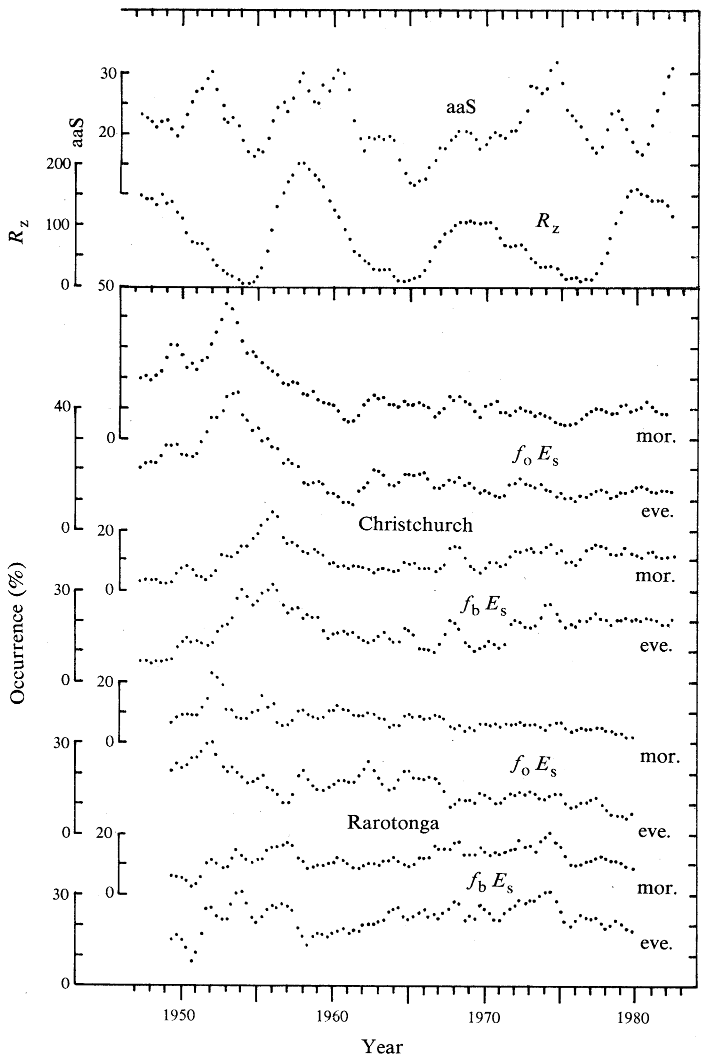

Fig. 2. Long-term variations of occurrence of $P(f_o E_s)$ and $P(f_b E_s)$ obtained with seasonal oscillations removed by a 12 point running mean smoothing. The data are plotted at four month intervals. Also shown are smoothed values of the Zurich sunspot number R_Z and the Southern Hemisphere magnetic index aaS.

Furthermore, for both evening and morning at Rarotonga, $P(f_o E_s)$ is uncorrelated ($r < 0 \cdot 2$) with $P(f_b E_s)$. For Christchurch the enhanced activity from 1950 to 1958 results in a marked lag in the $P(f_o E_s)$–$P(f_b E_s)$ cross-correlation spectrum of about three years. However, for the remaining years no correlation between $f_o E_s$ and $f_b E_s$ exists.

In order to illustrate long-term fluctuations in different seasons, Fig. 3 for Christchurch and Fig. 4 for Rarotonga are presented. Summer season is represented by the mean of December and January, autumn by the mean of March and April, winter by the mean of June and July, and spring by the mean of September and

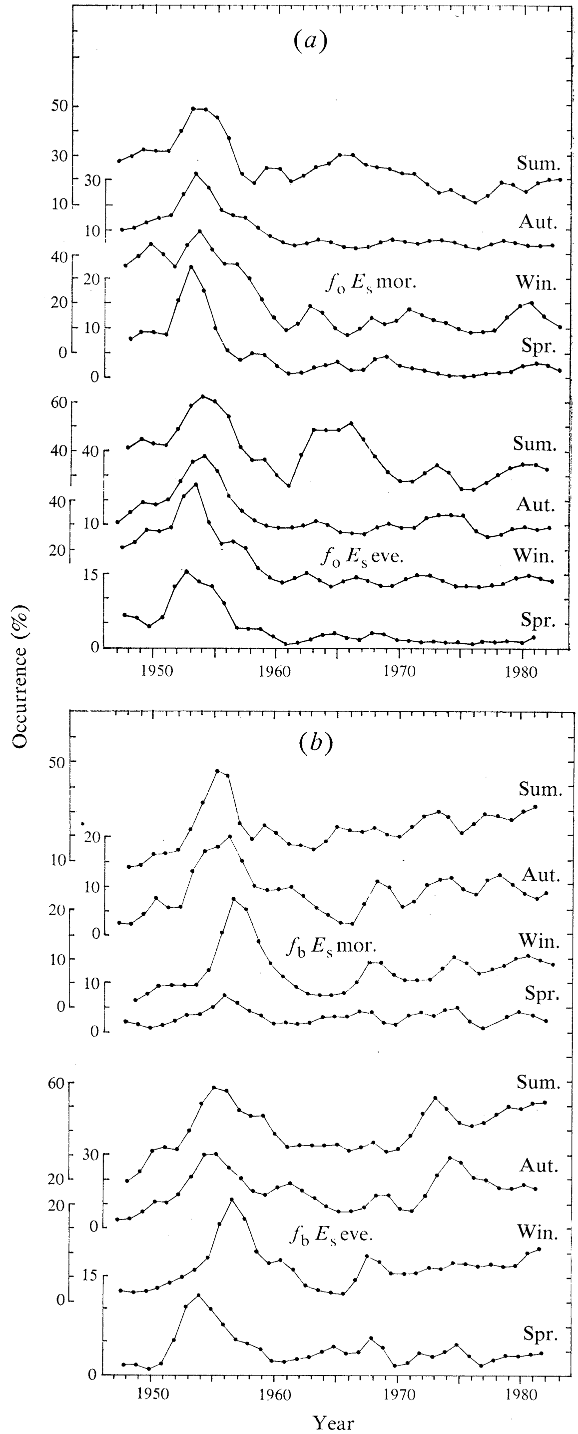

Fig. 3. Long-term characteristics of seasonally selected (*a*) $P(f_o E_s)$ and (*b*) $P(f_b E_s)$ for evening and morning activity at Christchurch. For ease of interpretation a three point (1, 2, 1 weight) smoothing is employed.

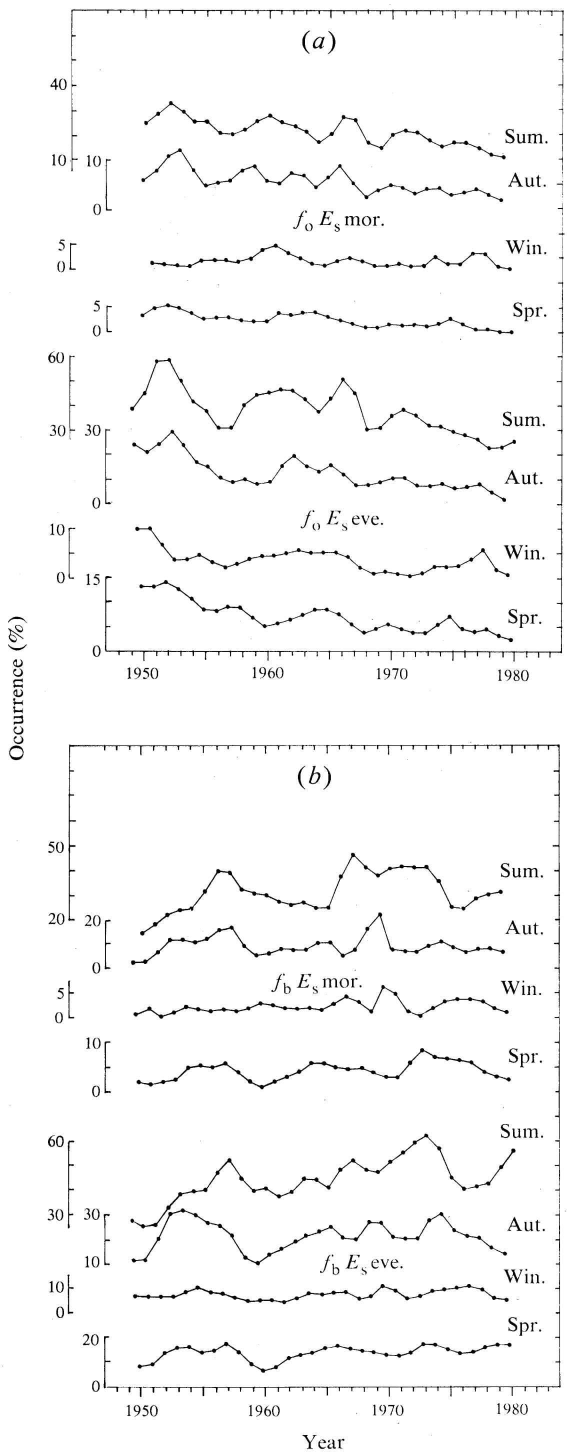

Fig. 4. Long-term characteristics of seasonally selected (*a*) $P(f_o E_s)$ and (*b*) $P(f_b E_s)$ for evening and morning activity at Rarotonga. For ease of interpretation a three point (1, 2, 1 weight) smoothing is employed.

October. The results of spectral analyses show that the close association between morning and evening data for a given parameter and station holds for all seasons. Taking all data, evening occurrence exceeds morning for both parameters and for both stations. For Christchurch $P_{\mathrm{eve}}/P_{\mathrm{mor}} = 1 \cdot 24$ and $1 \cdot 64$ for $f_o E_s$ and $f_b E_s$, while for Rarotonga $P_{\mathrm{eve}}/P_{\mathrm{mor}} = 1 \cdot 94$ and $1 \cdot 84$ respectively. For a confidence limit of 95% r is $0 \cdot 32$ for 36 data points. The values of the correlation coefficient shown in Table 1 are therefore highly significant with, however, the Rarotonga values of $P(f_o E_s)$ for autumn and winter showing only a weak association. For Christchurch two analyses were performed, one for all 1947–82 data and one for only 1959–82 to determine if the enhanced activity 1950–8 was dominating the correlation. With the exception of the Christchurch 1950–8 data all data sets have a correlation scale of less than one year.

Table 1. Correlation coefficient r between evening and morning $P(f_x E_s)$

Location	f_x	Period	Sum.	Aut.	Win.	Spr.
Rarotonga	f_o	1949–80	0·83	0·38	0·42	0·68
	f_b	1949–80	0·75	0·76	0·63	0·60
Christchurch	f_o	1947–82	0·71	0·81	0·82	0·74
	f_o	1959–82	0·53	0·59	0·67	0·70
	f_b	1947–82	0·82	0·71	0·91	0·63
	f_b	1959–82	0·74	0·61	0·68	0·62

The seasonal data can be examined to determine if the patterns of long-term fluctuations are similar for a given parameter and station at different seasons. For Rarotonga all associations between seasonal data are insignificant, all with $r < 0 \cdot 2$. Similarly there exists no association between $P(f_o E_s)$ and $P(f_b E_s)$ for any season and nocturnal period. For Christchurch the large scale enhancement in activity for 1950–8 produces a significant season-to-season correlation in the total 1947–82 data. However, selecting the 1959–82 data results in correlation coefficients below the significance level for season-to-season associations and $P(f_o E_s)$–$P(f_b E_s)$ associations.

These results show that, except for the Christchurch 1950–8 data, there are no years of overall high or low activity, that the scale of fluctuations is shorter than the length of a season and that $P(f_o E_s)$ and $P(f_b E_s)$ fluctuate independently.

4. Discussion and Summary

Analysis of the ionosonde parameters $f_o E_s$ and $f_b E_s$ can provide useful information on sporadic-E ionization characteristics only if certain criteria are satisfied. It is necessary that $f_x E_s$ should exceed the normal E-region critical frequency $f_o E$ to prevent the possibility of blanketing of high altitude E_s by the ambient E region. Since, for the diurnal periods studied here, we have $f_o E \leqslant 0 \cdot 5$ MHz, contamination of records is minimal. For the reduction of ionogram records, consistent scaling procedures have been maintained (in the records of both stations) since 1947 under strict international procedures by the same institution. Some early ionogram records have been recently rescaled producing values consistent with the original readings (A. Stanbury, personal communication 1983). For ionosonde maintenance, close monitoring of ionosonde equipment has been maintained, with the effects of changes to ionosonde type in July 1956 and to recording film type in July 1969 being monitored. No associated changes appear in the scaled data. In addition there is no evidence in the ionogram records of any significant changes in system signal-to-noise ratio (A. Stanbury, personal communication 1983).

The seasonal variations of nocturnal E_s activity as indicated by dominant summer $f_o E_s$ and $f_b E_s$ occurrence are similar to the daytime signatures expected for stations in corresponding zones. The subtropical zone station Rarotonga shows an absence of any winter enhancement. Although daytime $f_o E_s$ and $f_b E_s$ occurrence is known to show a clear winter enhancement at temperate latitudes, such a feature is only obvious in the morning rather than evening period in Christchurch nocturnal results.

In the 36 years of recording Christchurch data and the 31 years for Rarotonga there are no associations with either solar activity as measured by the Zurich sunspot number R_Z or geomagnetic activity as measured by the aaS index. The fluctuations both in $P(f_o E_s)$ and in $P(f_b E_s)$ at the two stations are quite independent, a consequence of the substantial variation with geographic location of the wind-shear pattern responsible for E_s irregularities. The time scales of such fluctuations are less than the length of a season as measured both by the time for auto-covariance coefficients to fall to zero and by the lack of coherence between seasonal data.

Although evening and morning data are unlikely to refer to ionosonde records from the same individual E_s events, there exists a close correlation between monthly mean activity for the two diurnal periods demonstrating the operation of a nocturnal controlling factor of limited global extent. Selected data confirm that such a control operates at all seasons. At both stations and for both parameters evening activity exceeds morning. For all data the Christchurch ratio P_{eve}/P_{mor} is $1 \cdot 64$ and $1 \cdot 24$ for $f_b E_s$ and $f_o E_s$ respectively, while for Rarotonga the ratio is $1 \cdot 84$ and $1 \cdot 94$ respectively.

The long-term variations of $P(f_b E_s)$ and $P(f_o E_s)$ for a given nocturnal period and station are largely uncorrelated. This lack of association demonstrates that the presence of a high blanketing frequency, considered representative of a high ambient ionization density in an E_s layer, is not coupled over long periods with a high top penetration frequency, considered representative of the maximum plasma density in ionization irregularities and their distribution within an E_s layer (Reddy and Mukunda Rao 1968).

The only comparable study in the literature has been the morphological survey (Reddy and Matsushita 1968) devoted to the characteristics of the blanketing parameter for eight years data during the falling half of one solar cycle. The survey using data for several stations in both hemispheres concluded that nighttime (22–03 LMT) monthly values of mean $f_b E_s$ showed a positive association with R_Z for some stations, whereas the occurrence $P(f_b E_s) \geqslant 2$ MHz showed no coherent behaviour, in accord with the present findings.

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