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Effect of auroral substorms on the ionospheric range spread-F enhancements at high southern midlatitudes using real time vertical-sounding ionograms

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ABSTRACT

A comprehensive study has been undertaken on the effect of magnetic substorm onsets (as deduced from the auroral hourly electrojet AE-index) on the occurrence of high midlatitude (or sub-auroral latitude) ionospheric range spread-F (Sr). Unlike the previous reports real-time ionograms were used in this analysis thus eliminating ambiguities stemming from the correlating secondary evidence of spread-F with auroral substorms. The Australian southernmost ionosonde station Hobart (51.6°S geom.) proved to be uniquely suitable for the task as being sufficiently close to the southern auroral zone. Sr was assigned in km to each hourly nighttime ionogram at two sounding frequencies: Sr1 (at 2 MHz) and Sr2 (at 6 MHz) for four months in 2002: January and June (representing southern summer and winter solstices), and March and September (representing autumn and vernal equinoxes). It is evident that the southern winter solstitial period (June) is associated with high endemic midlatitude spread-F activity. All other seasons are closely linked with temporal sequences of enhanced spread-F activity following substorm onsets.

For the first time it was possible not only find a simultaneous occurrence pattern of these diverse phenomena but to deduce numerical characteristics of the response of midlatitude ionosphere to the global auroral stimulus. Excellent case events, hitherto unpublished, are shown illustrating the presence of the AE peaks (in nT) being ahead of Sr peaks (in km) by a time shift Δt (in h). Sr1 magnitude showed a significant correlation with the magnitudes of the preceding AE with a correlation coefficient (r) of 0.51 (probability of the occurrence by chance less than 0.01). Sr2 peaks were more sensitive to auroral disturbances but were not correlated with the AE magnitude variations. The time shift (Δt) was on average 4 h with a standard deviation of 3 h.

The general pattern in the occurrence of magnetic substorms and spread-F is very similar. A number of corresponding peaks of the AE-index and Sr fluctuations were identified. The sub-auroral ionosphere response tends to last longer than the initiating auroral disturbance (hysteresis effect). The simultaneous quiescent periods in the auroral and sub-auroral ionospheres have been encountered on at least 14 days.

1. Introduction

It appears that there is a shortage of the original ionograms spread-F study, at frequent time intervals, over a wide range of latitudes. Previous studies of this type were based on the hourly qualifying symbols (from the tables of ionospheric parameters), thus lacking the information on the magnitude of instantaneous spread-F. The first higher time resolution quantitative study of midlatitude ionosphere was conducted by Hajkowicz (2007) using real ionograms from a range of latitudes in the Australian longitudinal sector.

In his study ionograms from a standard vertical-incidence ionosonde chain (nine Australian stations), obtained over a wide range of southern latitudes (in geom. lat. range: 23–52°S), were digitally scanned at 5-minute intervals at nighttime (18-06 LT) for 13 months (January 2004–January 2005). An important parameter of the F-region, so-called range spread-F (Sr), was for the first time quantified in km. Maximum in Sr was recorded at a sounding frequency of 1.8 MHz for each night and for each ionosonde station.

The high spatial and temporal resolutions of ionograms made it possible to define four mid-latitude ionospheric activity regions prominent in the southern winter (the June solstice). The sub-auroral region 1 (geom. lat. $\geq 52°$S) was characterised by consistently high spread-F (average Sr $\approx$ 100 km) on over 80% of the observed nights. There was a sharp equatorward boundary in the spread-F activity in a latitudinal range: 52–48°S followed by the

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region 2 (44–48°S) which exhibited a peak in Sr (≈ 50 km) in winter only, observed on half of the nights. A weak winter activity was observed in the next region 3 (42–43°S) with Sr less than 20 km on one third of the nights. The region 4 (23–36°S) was characterised by a strong peak in Sr again in winter, centred at about 30°S (average Sr ≈ 70 km) on 80% of the nights. This pattern in the occurrence of spread-F appears to have a global character as the enhanced spread-F activity is observed in the Japanese sector in the local summer (i.e. the June solstice) as reported by Sinno and Kan (1980), and Hajkowicz and Minakoshi (2003).

The result of the previous study showed that the sub-auroral region 1, represented by the vertical incidence ionograms obtained at the southernmost Australian station Hobart, has a distinct morphology largely different from other midlatitude stations. The present report concerns this station only, providing a more complete study of the sub-auroral ionosphere. The effect of auroral disturbances on subauroral spread-F is considered for the first time using real time ionograms.

2. Method and results

The standard vertical-incidence ionograms from Hobart (42.9°S and 147.3°E geog., and 51.6°S geom.), obtained at hourly intervals at night (18-06 LT or 08-20 UT), were analysed for four months in 2002, representing different seasons: January and June – the southern summer and winter solstices, March and September for the equinoctial periods The digital ionosonde station was operated and uniformly calibrated by the Australian Ionospheric Prediction Service (IPS).

Fig. 1 shows a typical ionogram recorded at Hobart. Unlike in the previous analysis (Hajkowicz, 2007) two range spread-F parameters were specified for each ionogram: Sr1 for the lower sounding frequency of about 2 MHz, and Sr2 for the higher frequency of about 6 MHz. Sr2 was defined for the sounding frequency just before the trace started to rise rapidly. This frequency, due to the diurnal nature of ionograms, changed from 6 to 5 MHz. Thus a more complete evaluation of the range spread-F over a sounding frequency range was provided (Sr1 only was used in the previous study). Since this is one of the first numerical studies of spread-F it is important to define the reliability of this parameter.

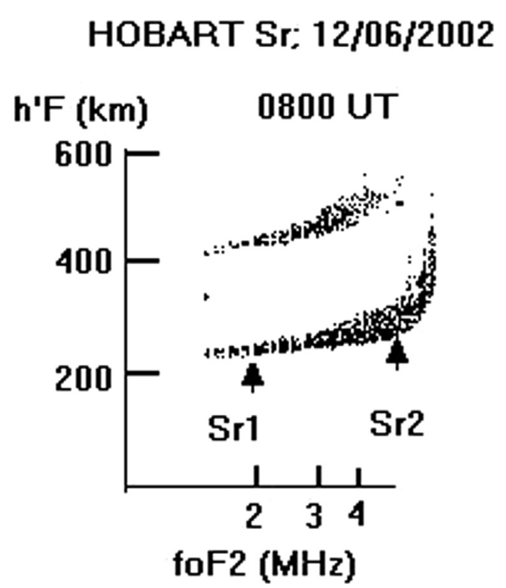

Fig. 1. An example of the range spread-F recorded at the vertical incidence ionosonde frequency sweep at 2.0 MHz (Sr1) and 6.0 MHz (Sr2) at 08UT (18 LT, LT = UT + 10 h).

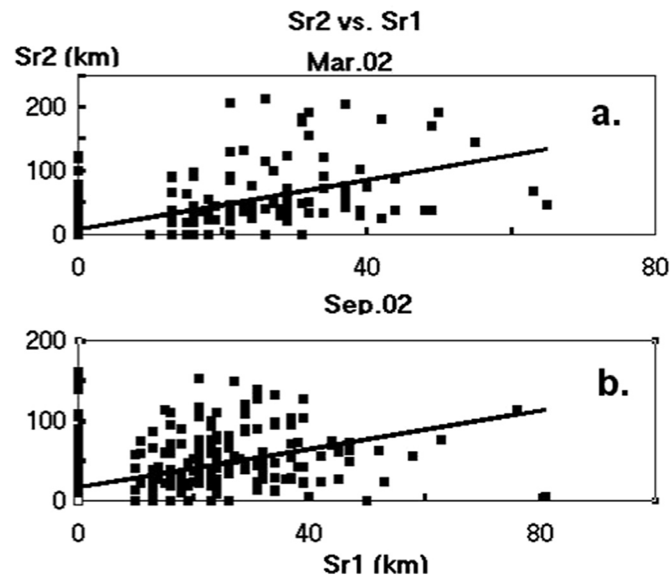

Fig. 2. The scatter diagram of the association between the high (Sr2) and low (Sr1) ionosonde sweep frequency during equinoctial months. The linear extrapolation are also provided.

Unlike other tabulated ionospheric parameters (e.g. h'F, foF2) the calculation of Sr was based on the arbitrary choice of the sounding frequencies at which Sr was found. On the whole this parameter was not affected by the blanketing frequency due to sporadic-E (fbEs). The uniform part of range spread-F, as shown in Fig. 1, was used to derive a specific value of Sr from the bottom to the top of the range spread. The striated traces of spread-F, sometimes observed over the main trace, were filtered out. The nature of this type of analysis would allow accuracy of about 10 km. This is a considerable advancement over the study based on simple absence or presence of spread-F derived from the tabulated qualifying parameters (these parameters refer to the inability to define foF2 at the high end of the frequency scale due to spread-F).

Since the previous study (Hajkowicz., 2007) was based on the value of Sr1 alone it is important to define the association between Sr1 and Sr2 as depicted in a scatter form (and in a linear approximations of Sr1 vs. Sr2) as shown in Fig. 2; examples for the equinoctial periods are given. On the whole, there is some significant linear relation between these parameters except in January 2002 where no correlation was detected (cf. Table 1).

Spread-F was rarely recorded at the lower end of the ionosonde frequency sweep only (Sr2 = 0) whereas occurrence of Sr2 only (when Sr1 = 0) was around 10% except in June when it reached 34%. On the whole Sr2 appears to be a more sensitive parameter in the detection of spread-F hence the future numerical evaluation of this disturbance should include at least two readings of the disturbance magnitude. The large value of ny in June may be linked with a different nature of spread-F in the winter solstice as discussed in Section 1 – large Sr is then endemic for a range of

Table 1
The characteristic parameters of the association between Sr1 and Sr2 for various months: *n*—number of data points, *r*—correlation coefficient, *y*—linear extrapolation of the association between Sr2 (*y* axis) and Sr1 (*x* axis), *ny*—percentage occurrence of Sr2 only (Sr1 = 0), *nx*—percentage occurrence of Sr1 only (Sr2 = 0).

Month	*y*	*n*	*r*	*ny* %	*nx* %
Mar.	1.95 x + 7.1	377	0.65	11	2
Sep.	1.20 x + 15.9	390	0.50	16	2
Jan.		403	0.10	7	1
June	1.70 x + 55.6	405	0.50	34	2