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Study of sporadic-E clouds by backscatter radar

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Abstract. It is shown that swept-frequency backscatter ionograms covering a range of azimuths can be used to study the dynamics of sporadic-E clouds. A simple technique based on analytic ray tracing can be used to simulate the observed narrow traces associated with E_s patches. This enables the location and extent of the sporadic-E clouds to be determined. The motion of clouds can then be determined from a time sequence of records. In order to demonstrate the method, results are presented from an initial study of 5 days of backscatter ionograms from the Jindalee Stage B data base obtained during March–April 1990. Usually 2–3 clouds were observed each day, mainly during the evening and up to midnight. The clouds lasted from 1–4 h and extended between 30°–80° in azimuth and 150–800 km in range. The clouds were mostly stationary or drifted generally westward with velocities of up to 80 m s^{-1}. Only one cloud was observed moving eastward.

1 Introduction

Sporadic-E layers are most likely due to vertical shear in the horizontal east-west wind and they occur in clouds with scale sizes between 10–1000 km. The vertical thickness of E_s layers is typically between 0.6 km and 2 km, while their preferred heights vary between 90–120 km (Whitehead, 1989). E_s characteristics have been studied extensively by various remote sensing techniques which include vertical incidence sounding, oblique sounding, incoherent scatter and ground backscatter (Whitehead, 1989). This study shows how results from analytical ray tracing can be used in a straightforward manner to study the location, extent and dynamics of E_s clouds with a backscatter radar. An initial study of E_s layers is presented to demonstrate this method using backscatter ionograms obtained by a backscatter sounder which is part of the frequency management system of the Jindalee over-the-horizon radar facility at Alice Springs in Northern Australia (Earl and Ward, 1987). While all the previous backscatter studies of E_s (Tanaka, 1979; Kolawole and Derblom, 1978; Harwood, 1961) were carried out with a fixed frequency radar, this study presents E_s results based on swept frequency ionograms from the existing Jindalee Stage B database. Ionograms covering 5 days during March–April 1990 were used to develop methods of mapping the extent of E_s clouds and studying their dynamics.

During this period, backscatter ionograms were obtained for eight beams covering approximately 90° of azimuth. Generally four sets of ionograms were obtained every hour. Thus an estimate of the location and extent of E_s clouds could be obtained from each set of ionograms. From a time sequence of sets the velocity and drift direction could be studied.

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2 Observations of E_s clouds

The effects of reflections (or forward scattering) from E_s layers appear quite often on backscatter ionograms. Because the E_s layers are very thin and occur in patches or clouds embedded in the background ionosphere, the echo traces which they produce are usually superimposed on the normal backscatter ionogram traces, appearing as a trace with group ranges that are nearly constant with frequency. A variety of trace forms occur, and examples of pronounced sporadic-E traces are shown in Fig. 1. Figure 1a, b and d shows a well-defined sporadic-E trace at ranges between 1000 and 2000 km while Fig. 1c shows three distinct sporadic-E traces in the 400–1700 km range indicating that several E_s clouds were present at this time. In the first two cases the background ionosphere is quite strong with F-region traces extending beyond 30 MHz whereas in Fig. 1c and d the background ionosphere is much weaker. The thickness of the traces varies. In Fig. 1b and d it approaches 1000 km at some frequencies whereas in a and c the thickness is no more than a few hundred

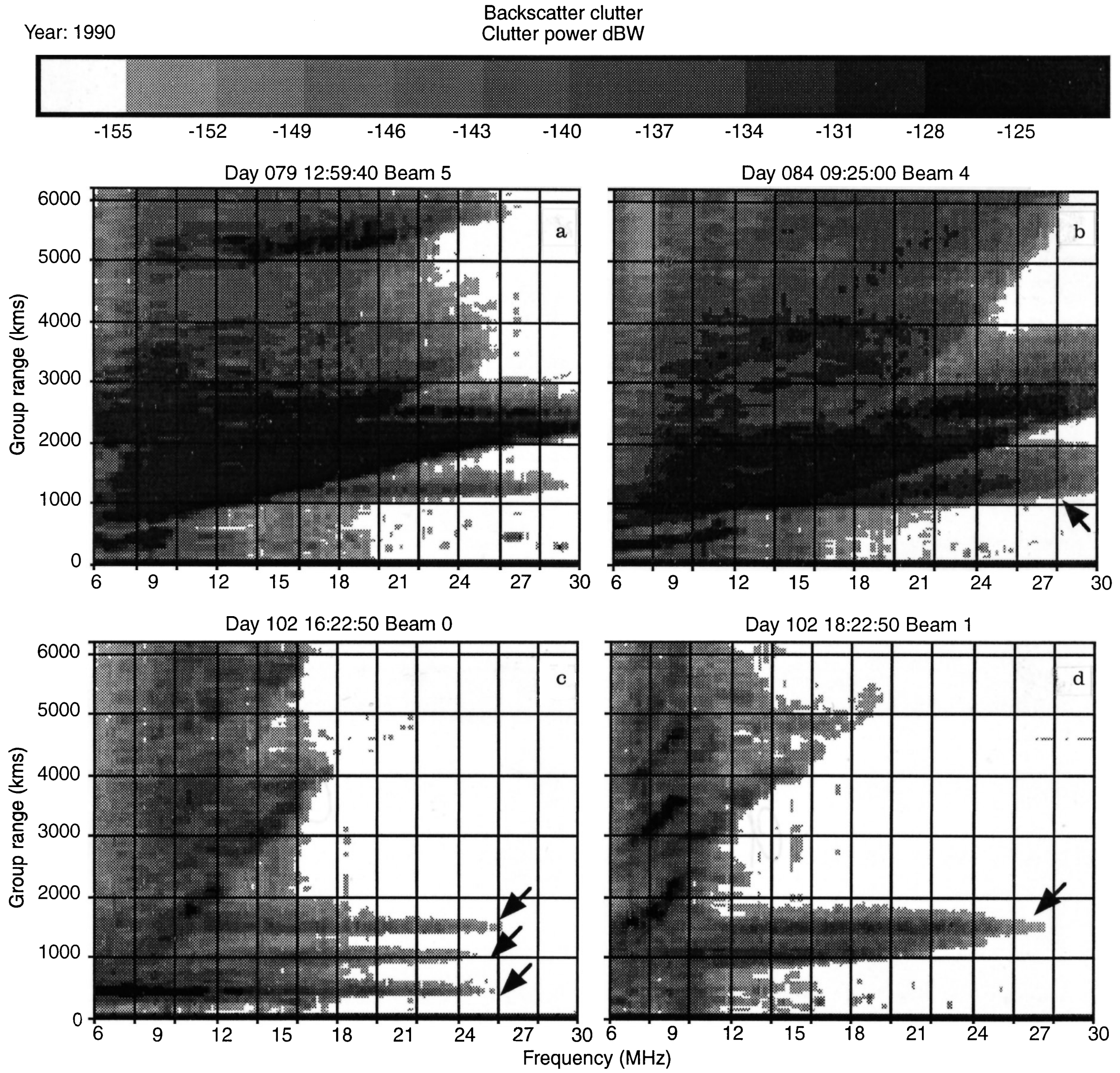

Fig. 1a–d. Examples of Jindalee backscatter ionograms with pronounced sporadic-E echoes (*arrows*). Times are in UT

kilometres. Times at which ionograms were recorded are shown in UT. Local time at the longitude of the radar site near Alice Springs in 930 h ahead of UT. Sporadic-E traces are not always as pronounced as those shown in Fig. 1 and some examples are shown in Fig. 2 which relate to cases discussed in detail later in this study.

Figure 2a shows a backscatter ionogram obtained on day 84 in which a relatively thick sporadic-E trace is observed between 1200–1800 km up to a frequency of 27 MHz. The signal strength of this trace is much less than that of the prominent F-region trace. Figure 2b is from day 102. It shows a relatively strong, narrow, sporadic-E trace just beyond 1000 km range and extending more than 10 MHz beyond the F-region trace at the same range. There is also a weaker second sporadic E trace at a greater range. Figure 2c, d shows two backscatter ionograms obtained on day 115, 1990 on two different beams and at slightly different times. Both show a thin sporadic-E trace at a range just less than 1000 km which extends only 2–3 MHz beyond a very pronounced F-region trace. In Fig. 2 evidence of E_s propagation can also be seen at ranges below 500 km.

2.1 *Simulation of E_s effects*

In order to examine the effect of sporadic-E layers, a single, horizontally stratified E_s layer of unlimited extent has been used. For convenience a quasi-parabolic layer has been assumed and the analytical ray-tracing program, QPSHEL (an analytical ray-tracing program using multiple quasi-parabolic layers, Dyson and Bennett, 1989), used to calculate the corresponding backscatter ionogram trace. Figure 3 shows the result for a layer 1 km thick, centred at a height of 100 km and with a critical frequency of 5 MHz. The ionogram was calculated utilising Jindalee

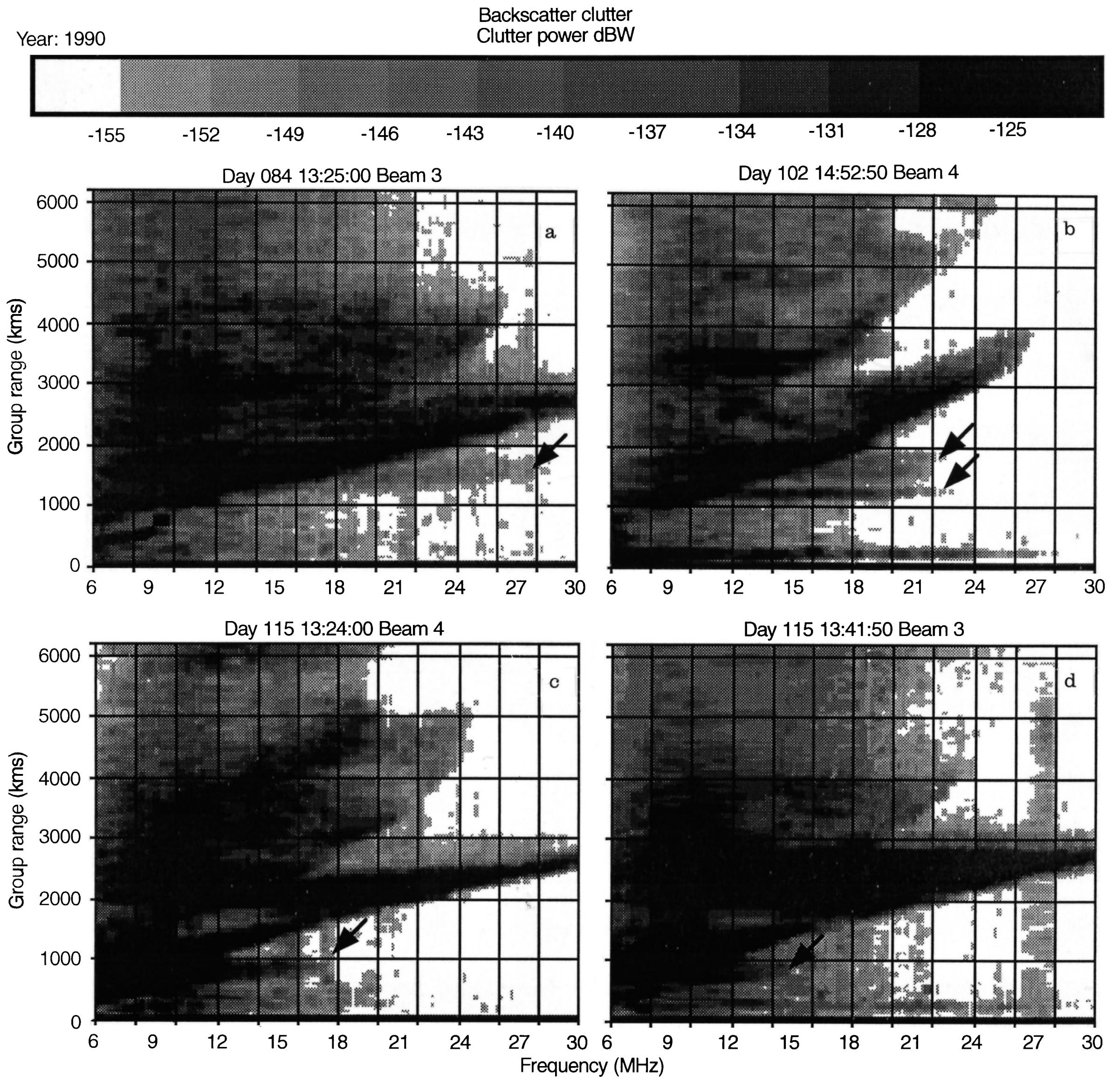

Fig. 2a–d. Examples of Jindalee backscatter ionograms with sporadic-E echoes from specific events discussed in detail. Times are in UT

antenna information. Also shown in Fig. 3 is a curve representing the elevation angle as a function of group path.

If the E_s layer is limited in horizontal extent so that it subtends a limited range of elevation angles at the transmitter, the backscatter ionogram trace will consist of only a segment of the ionogram trace synthesised for the unlimited layer. This is illustrated in Fig. 3 for an E_s layer reflecting rays launched at elevation angles between 5° and 8°. The echo trace is now just a narrow segment which will be superimposed on the echo traces of the background ionosphere giving an ionogram similar to examples shown in Figs. 1 and 2.

The exact shape, thickness and frequency range of the E_s trace will depend on the height and critical frequency of the layer, and on the spatial extent and location which determines the range of elevation angles of rays reflected by the layer. The actual thickness of the layer (assuming it lies in the range 0.5–5 km) has little effect on the E_s traces. If the layer height and critical frequency are uniform within the E_s cloud and they can be measured by a vertical or an oblique sounder, then the size and position of the E_s cloud in the direction of the ray path can be determined by simple geometrical calculations from the observed range of group paths of the E_s trace.

2.2 *The behaviour of E_s clouds*

The spatial extent of sporadic-E clouds can be estimated from the eight backscatter ionograms obtained simultaneously for propagation at different azimuth angles. Two examples are presented from the observations obtained on days 84 and 102. Figure 4 shows an example of a sporadic-E cloud located using the method outlined in Sect. 2.1. The sporadic-E layer height was determined

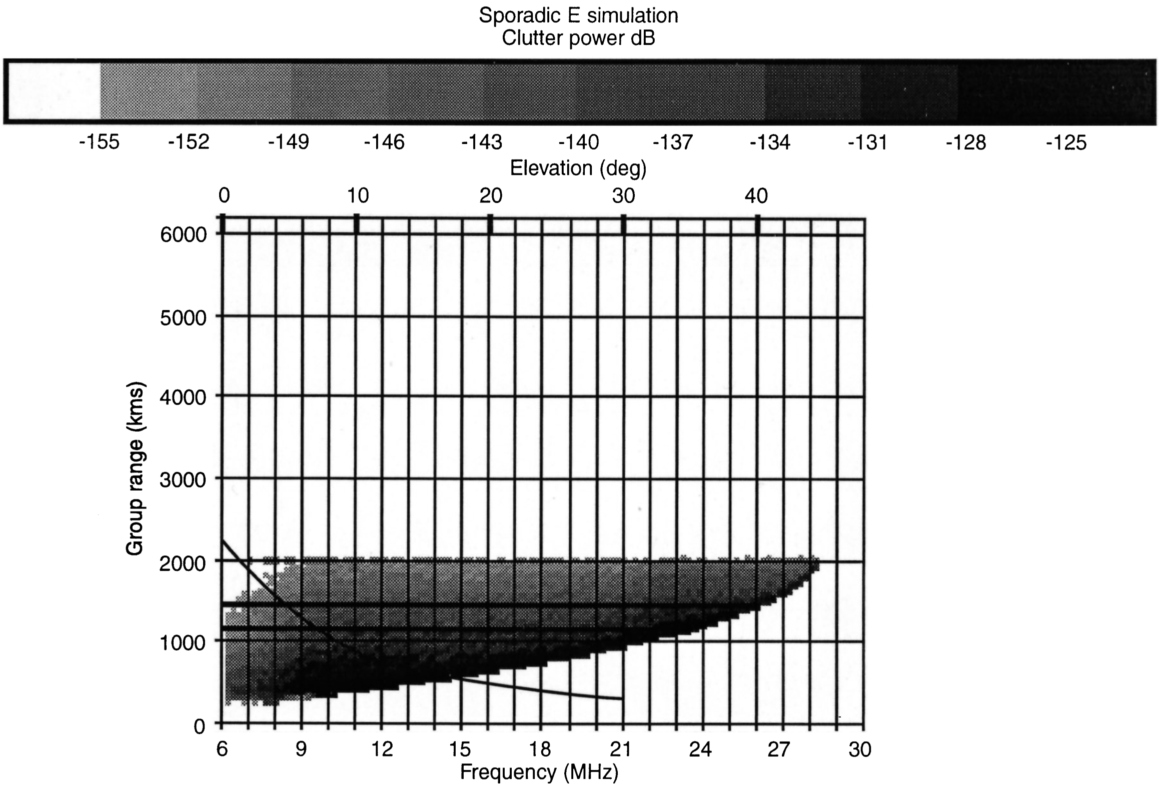

Fig. 3. Backscatter ionogram signature for a single blanketing sporadic-E layer. The *curved line* shows the variation of elevation angle with group range (scale at top of Fig.). The *dark horizontal lines* show boundaries of the echoes for a sporadic-E patch illuminated by rays transmitted between 5° and 7° elevation

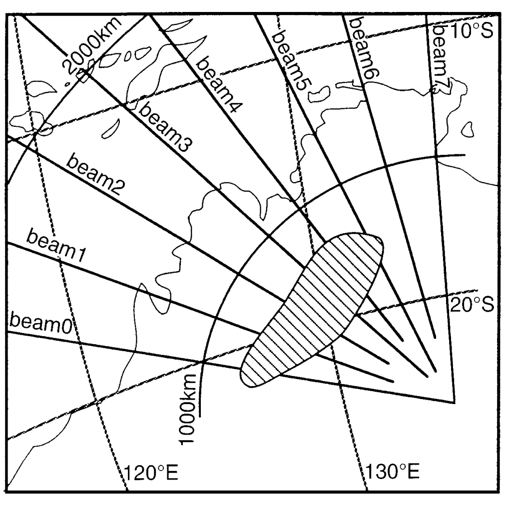

Fig. 4. Sporadic-E cloud above northern Australia on day 84, 1990 at 1330 UT. The *radial lines* out of Alice Springs indicate the directions of each of the 8 radar beams

using oblique ionograms obtained over the Alice Springs–Darwin path. While this height may not necessarily be exactly the same for other azimuths, the assumption of a constant height does not introduce large errors. The azimuth angles of the different beams of the backscatter sounder are also shown in Fig. 4.

In this example, the E_s cloud was observed on six of the eight azimuthal beams of the backscatter sounder. The extent of the cloud was between 500–800 km in range and 30°–80° in azimuth. Figure 2a shows the backscatter ionogram observed with beam 3 at this time.

Another example is shown in Fig. 5 for day 102, 1990 at 1445 UT. This time several patches of sporadic-E were observed at different azimuth angles and at different distances from the backscatter radar. The two distinct E_s traces observed on beam 4 near this time are shown in Fig. 2b. (While there is some suggestion of structure in the more distant trace, this was not evident on adjacent beams.)

The evolution, and dynamics of E_s clouds can be studied from backscatter data obtained by the different radar beams over a period of time. Velocities can be determined by plotting the locations of the sporadic E clouds, as illustrated in Figs. 3 and 4, and calculating the distance traversed by clouds over a period of time. The accuracy of the velocities obtained in this way is about 10%. The evolution of a cloud can conveniently be displayed as a table showing the maximum frequency, f_mE_s, reflected from the cloud for each beam as a function of time.

An example is shown in Table 1 where it is evident that two clouds were observed. Each one extended about 30–80° in azimuth and lasted about 2 h. These f_mE_s results were obtained at approximately 15 min intervals during the period 1200–1630 UT on day 115, 1990. It is apparent from the table that two large distinct sporadic-E clouds formed during this period. The first moved off southwestward with a velocity of 80 m s^{-1} to be followed by a

Table 1. Table showing the maximum frequency (f_mE_s) reflected from sporadic-E clouds for each beam, as a function of universal time, day 115, 1990. (Times refer to the beginning of a 15-min period, i.e. 13 refers to the period 1300–1314 UT)

Beam	Universal time																
	12				13				14				15				16
7														12			
6		13	13										12	12			
5	15	15	16	16	14								16	16	15	17	14
4	16	19	20	19	19	15						12	17	17	19	20	17
3		15	20	19	19	16	14					15	19	21	22	20	17
2		16	15	18	17	17	16	14				13	19	21	19	17	14
1						17	17	16	14				13	13	18	15	17
0										17	16	14	15	15	16	17	18

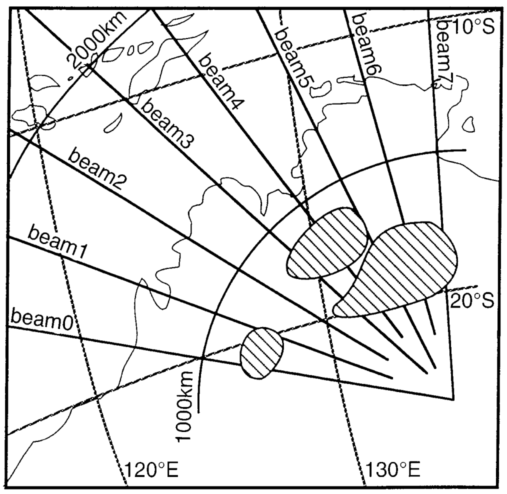

Fig. 5. Sporadic-E cloud above northern Australia for day 102, 1990 at 1437 UT

second which remained essentially stationary throughout its growth and delay.

Figure 2c shows the backscatter ionogram observed at 1324 UT on beam 4. At the next observation time, an E_s trace very similar in form to that of Fig. 3 was observed on beam 3 (Fig. 2d). At this time there was no discernable corresponding E_s trace on beam 4. There is apparent movement of this E_s cloud. Notice that the determination of f_mE_s depends upon the threshold level chosen. It is also complicated by signal contributions due to antenna side lobes.

3 Discussion

The formation and movements of E_s clouds were studied for 5 days during the period March–April, 1990. While the aim of this preliminary study was to develop techniques for the study of sporadic-E using the Jindalee radar system, some general comments on sporadic-E can be made from the observations.

Usually, 2–3 clouds were observed each day, mainly during the evening and up to midnight. The observed clouds extended between 30–80° in azimuth and 150–800 km in range. Whilst there is a lack of other comparable measurements with which to compare our results in detail, we note that these cloud sizes are in agreement with fixed frequency backscatter results obtained in the northern hemisphere (Tanaka, 1979). The life times of the clouds detected in this study were between 1–4 h. Tanaka (1979) observed similar lifetimes during winter but in summer observed clouds to last for up to 10 h. Harwood (1961) observed average lifetimes of 2 h.

The clouds observed in this study were either stationary or drifted generally westward with velocities of up to 80 m s^{-1}. On one occasion we observed an eastward velocity of about 150 m s^{-1} which was inconsistent with the other results. The average drift velocities observed by other workers were around 50 m s^{-1} and the drift direction was usually west to southwest (Tanaka, 1979; Kolawole *et al.*, 1978; Harwood, 1961).

4 Conclusions

The backscatter sounder ionograms obtained as part of the Jindalee Frequency Management System contain a wealth of information on ionospheric structure and behaviour in the northwest Australian region. While these ionograms can be very complicated and difficult to interpret, this initial study has shown that they can readily be used to study the behaviour of sporadic-E layers, particularly their spatial extent, motion and evolution with time. Though analytical ray tracing has limitations, we have shown that it can produce the narrow traces associated with E_s patches and thus enable us to determine the location and extent of sporadic-E clouds.

In this initial study of 5 days in March–April 1990, 2–3 clouds were observed each day, mainly during the evening and up to midnight. The clouds lasted from 1–4 h and extended between 30–80° in azimuth and 150–800 km in range. The clouds were mostly stationary or drifted westward with velocities of up to 80 m s^{-1}.

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