

Atmospheric Ion Scatter

Radar Specification

Atmospheric magnetic field

Observations of low latitude spread-F using ST mode of the Indian MST radar

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The ST mode of the Indian MST radar was utilized to conduct observations on the coherent back scatter from the field-aligned F-region irregularities at the low latitude station, Gadanki (13.47°N, 79.18°E). This was made possible since the antenna array is so oriented as to permit the radar beam scan in the magnetic north-south plane. The first observations made on the night of 3-4 July 1992 when strong spread-F was noted on the ionograms recorded at the SHAR Centre about 100 km east of Gadanki, are presented. The basic characteristics of the Doppler spectra and range-time-intensity (RTI) maps are essentially the same as those of equatorial spread-F reported for Jicamarca. The irregularities are confined to a range-extent defined by sharp boundaries on either side. The signal-to-noise ratio is found to vary with range from -10 to +10 dB, which, even on normalizing to the system sensitivity, is somewhat lower than that observed at Jicamarca. The mean radial velocity transverse to the magnetic field and the velocity spread derived from the Doppler spectra range from -20 to 60 ms⁻¹ and 10 to 60 ms⁻¹, respectively. The drift velocities are found to be consistent with the progressive time delays observed in the onset of the signal returns with increasing range. The observations presented here suggest that the underlying plasma instability processes are essentially same as that operating at the equator.

(178 pp)

1 Introduction

The phenomenon of equatorial and low latitude spread-F is interesting both from the points of view of plasma physics and radio communications. Major advances have been made in its understanding through radar, rocket and satellite observations coupled with theoretical and numerical simulation studies¹⁻¹⁰. From these advances, a basic picture has emerged on the plasma processes leading to the generation and evolution of the equatorial spread-F (ESF) irregularities. According to this, the ESF irregularities are known to be generated in the post-sunset bottomside F-region through plasma-fluid-type Rayleigh-Taylor instability mechanism under certain favourable conditions. The evolution of the ESF irregularities, leading to a wide range of scale sizes, seems to involve the operation of a hierarchy of instabilities as first suggested by Haerendel¹¹ and later developed by many workers⁹. In the non-linear regime, the instability evolution process leads to the development of irregularities in the form of plasma depletions or bubbles¹². The bubbles so generated steepen on their top, get polarized and rise to the topside of the ionosphere through enhanced electrodynamic drift. By this mechanism, it was possible to explain how the ESF irregularities could occur both in the bottom side and topside of the F-region.

The most significant observations on the occurrence and development of ESF, which motivated

much of the theoretical and simulation work, were provided by the high power coherent VHF backscatter radar at Jicamarca^{2,3}. While considerable insight has been gained on the basic processes, much has yet to be understood on the finer aspects of the initiation and evolution of the ESF. The ST mode operation of the Indian MST radar has offered a unique opportunity to delineate, for this low latitude region, the characteristics of the small scale (3 m) F-region irregularities in terms of their onset, evolution and dynamics. In this paper, we present the radar observations made on the night of 3-4 July 1992, providing information on the backscatter power, radial velocity transverse to the magnetic field and its spread in the range-time domain.

2 Experimental technique and data processing

The Indian MST radar is a highly sensitive VHF phased array radar designed to operate at 53 MHz in coherent backscatter mode with an average power aperture product $7 \times 10^8 \text{ Wm}^2$. The system, described in some detail by Jain *et al.*¹³ has been developed in two phases. In the first phase it was operated in ST mode using partial system with central one quarter (16 × 16) of the Yagi antenna array and 16 driver units of the transmitters, each driver unit feeding one sub-array of 16 Yagis. The receiver, signal processing and other related subsystems are essentially the same as for the MST mode. The radar operates under instruc-

tions from a PC-AT based radar controller which executes an experiment as per the data given in the form of an experiment specification file.

The radar, while meant primarily for the MST application, was intended to be used also for coherent backscatter study of the ionospheric irregularities. Accordingly, the orthogonal phased antenna arrays are so aligned as to permit the radar beam to scan $\pm 20^\circ$ off zenith with a resolution of 1° in the magnetic N-S and E-W planes. The nominal direction, looking transverse to the magnetic field at 330 km is 14.8° off zenith towards magnetic north¹⁴. The specifications of the radar in ST mode and the experiment specification file used for the coherent backscatter study of the spread-F are presented in Table 1. At present, the MST radar signal processor, which treats the coded and uncoded signals in the same manner, is used also to process the backscatter signals from the spread-F irregularities. This produces a certain limitation on the unambiguous range-Doppler window, since the MST signal processor uses coherent integration of a minimum of 4 pulses. Hence, when an inter-pulse period (IPP) of 4 ms is used for an unambiguous range window of 600 km, the Doppler window is limited to ± 31.25 Hz instead of ± 125 Hz. This has not turned out to be too serious a limitation, since the velocities encountered in the present experiment remained within the unambiguous limits of ± 88.44 ms⁻¹.

An example of the Doppler spectrum derived from the on-line FFT (Fast Fourier Transform) of the complex amplitude samples of the backscattered signal is shown in Fig. 1. The spectrum is highly structured and appears to arise from irregularities developed to

the saturation level. The three low order (0th, 1st and 2nd) moments of the spectrum provide information on the total signal power, mean radial velocity and the velocity spread. The spectrum contains noise as background and it needs to be removed as a first step to compute the moments. The average noise level for each range bin is estimated as is normally done in the case of MST signal following the method of Hildebrand and Sekhon¹⁵. The median level of the noise floor is found and subtracted from all the range bins of the spectral frame. The next step is to determine the spectral window containing the signal. For this, the Doppler bin having the peak power is identified and a 7-point template is run across on either side to find the window limits where the running average falls to 3 dB above the noise level. Once the signal window is fixed, the three spectral moments are computed the same way as done for the MST signal¹⁶.

3 Observations and discussion

Figure 2 shows the Doppler spectra taken on 4 July 1992 during 00:41:46-01:16:05 hrs IST for the height range 363-396.6 km. The spectra are highly structured with several prominent peaks as has been observed at Jicamarca. The multi-peaked spectra could arise when there exist discrete scattering centres inside the finite resolution cell of the scattering volume. The spectral intensities are highly modulated both in height and time as reported for Jicamarca and seen more clearly in Fig. 3.

The signal power variations with height and time are presented in Fig. 3 for two observational time slots 21:42:06-22:15:24 hrs IST on 3 July 1992 and 00:41:41-01:17:22 hrs IST on 4 July 1992. The hori-

Table 1—Radar specifications for the ST mode and the parameters used for the spread-F experiment

Frequency	: 53 MHz
Average power-aperture product	: 4.8×10^6 Wm ²
No. of Yagi antennas	: 256 (16 × 16)
Effective aperture	: 3661 m ²
Beam width	: 4.6°
Beam direction used	: 14.8° (to <i>B</i> field)
Inter-pulse period (IPP)	: 4 ms
Pulse width	: 32 μ s
No. of coherent integrations	: 4
No. of FFT points	: 128
No. of incoherent integrations (on-line)	: 1
Height coverage	: 75-600 km
Height resolution	: 4.8 km
Velocity range	: ± 88.4 ms ⁻¹
Velocity resolution	: 1.38 ms ⁻¹
Time resolution	: 2 s

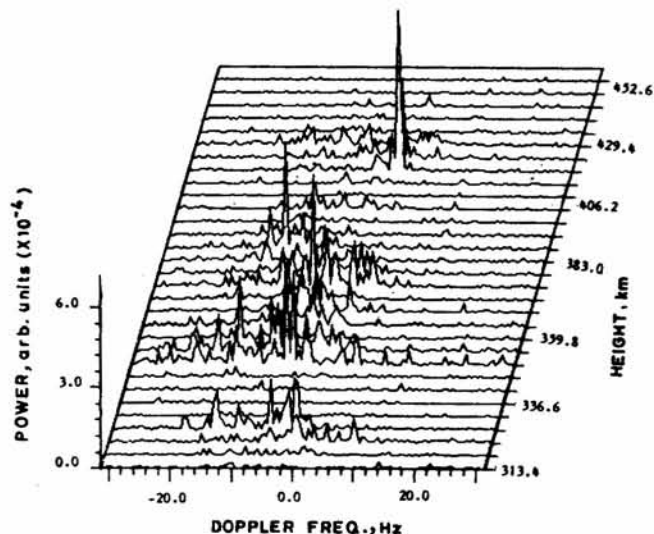


Fig. 1—Example of isometric plot of Doppler spectra (Spectral power is in arbitrary units, Date: 4 July 1992; Time: 00:45:29 hrs IST)

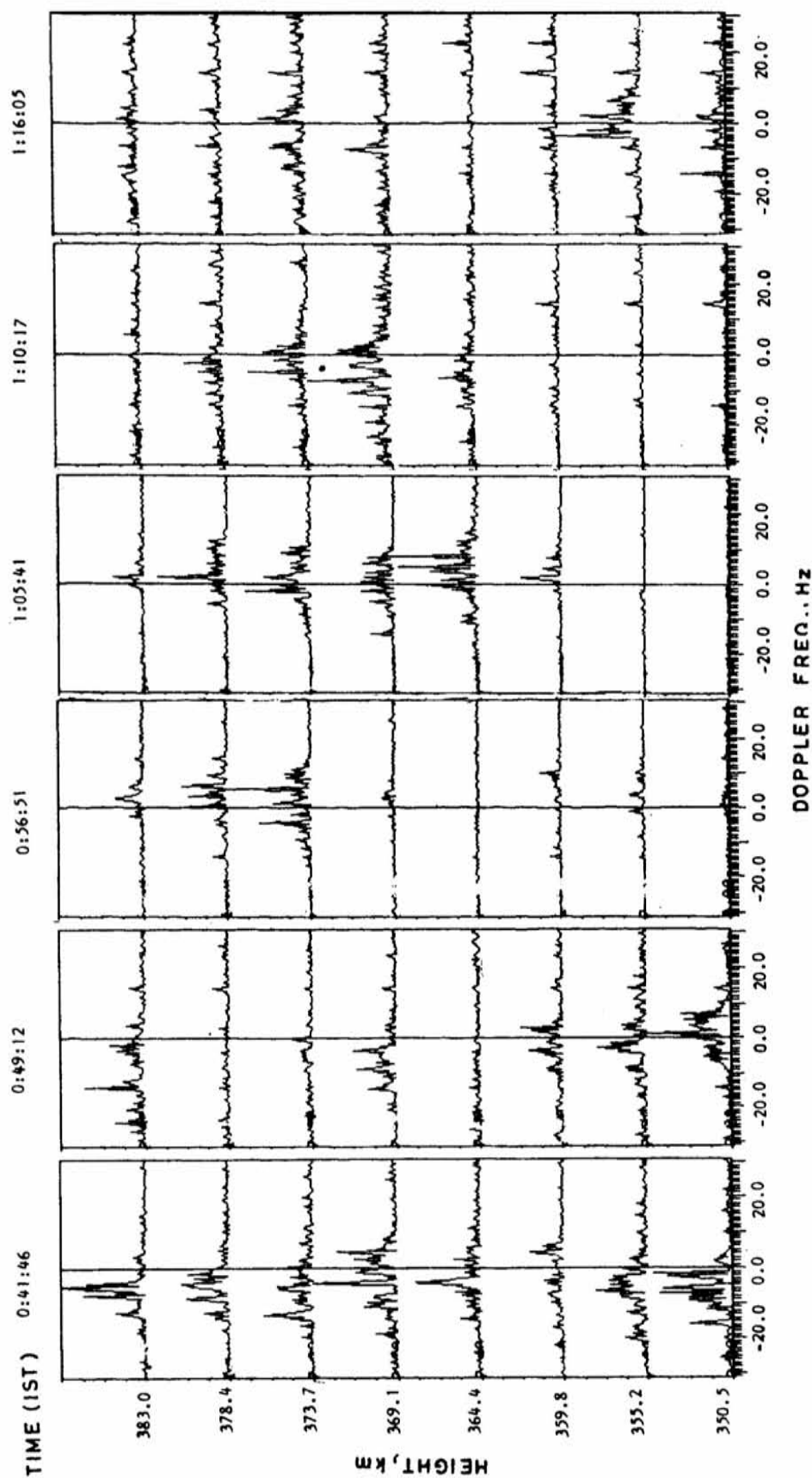


Fig. 2.—Range-time sequence of Doppler spectra for 00:41:46-01:16:05 hrs IST (Spectral power is in linear arbitrary scale)

zontal dotted line shown against each height represents 0 dB level of the SNR and one vertical division between successive lines corresponds to 23 dB. The noise power in the SNR calculation corresponds to the coherent integration filter bandwidth of 62.5 Hz. For both observational periods, the maximum signal level above the noise floor is found to be of the order of

20 dB. During the second observational period, the power variations show quasi-periodic fluctuations with periods of about 10-20 min in the height range of 350-400 km. For this height range, the dominant periods for the gravity waves reaching from below are expected to be above 30 min. The observed fluctuations may, therefore, have to be regarded as intrinsic to

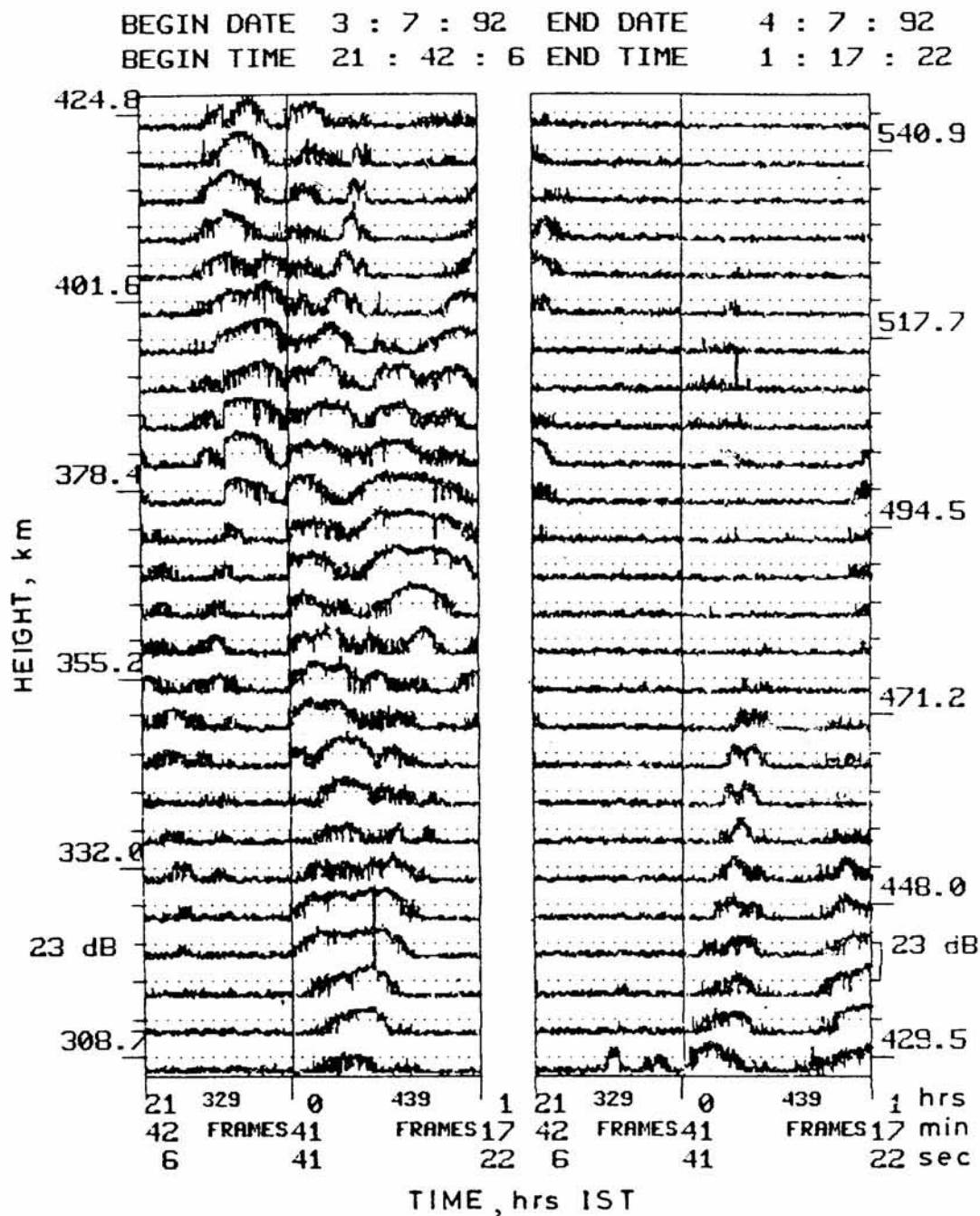


Fig. 3—Variation of signal power with height and time for two observational periods, 21:42:06-22:15:24 hrs IST and 00:41:41-01:17:22 hrs IST. [The time scale shows start times of the sequential cycles of observations. The horizontal dotted line represents the 0 dB SNR and one vertical division corresponds to 23 dB]

the evolution and decay processes of the instability itself rather than modulation by the gravity waves. The power patterns clearly show that there is a progressive time delay in the onset of spread-F above about 400 km. The observed time delays correspond to the vertical rise velocities of the irregularities ranging from 60 to 80 ms^{-1} . It would be instructive to correlate the power patterns with the simultaneous observations of spread-F as seen on the ionograms shown for 2200 hrs IST on 3 July 1992 and 0100 hrs IST on 4 July 1992 in Fig. 4(a) and (b). The vertical extents of spread-F at 2200 and 0100 hrs IST are about 330–470 km and 300–400 km, respectively and these match

quite well with the corresponding height ranges of the radar backscattered signal. This correspondence between the spread-F and the field-aligned radar backscatter supports the view that large and small scale irregularities coexist during a spread-F event.

The variation of the drift velocity, transverse to the magnetic field, as function of height and time is shown in Fig. 5. The observed drifts are scattering centre phase velocities and they may be same as or differ from the bulk plasma drift. The velocity is mostly upward above about 400 km and is significantly greater for the second observational period. The peak velocity is of the order of 60 ms^{-1} and is consistent with the progressive time delay observed with height in the occurrence of spread-F. Below 400 km, a downward velocity of the order of 10–20 ms^{-1} is also clearly seen along with the dominant upward motion of the irregularities at higher heights. This velocity being of the same magnitude as that of the bulk plasma motion in the bottomside F-region, it appears that while the irregularities move upwards into the topside, the layer as a whole has a downward motion. Thus the spread-F seems to extend downwards through bulk plasma motion and upwards through the fast-rising plasma depletions from the region of its generation. Since the observations have missed the initiation time in both the time slots, it is not possible to provide the time history for the evolution of the spread-F.

Figure 6 shows the variation of the half width (δV) of the velocity spectrum as function of time and height. The value of δV is found to be generally in the range of 10–30 ms^{-1} , barring a few cases in the topside where it reaches as much as 60 ms^{-1} . The variation in both time and height is found to be much less as compared to that of the mean velocity. It attains more or less a peak level almost with the onset of spread-F which is consistent with the view that the instability, once sets in, develops to a non-linear level quite quickly.

The preliminary observations presented here show that the basic characteristics of the small scale (3 m) irregularities are essentially the same as those reported for Jicamarca. There are, however, some differences, as seen in the modulation of the received signal power, which need to be confirmed with larger data base. Using MU radar located at a midlatitude near Kyoto, Fukao *et al.*¹⁷ have reported that the signal spectra are Gaussian in shape and the irregularity drifts are more uniform in time and space as compared to those observed here and at Jicamarca. The quasi-periodic fluctuations with periods of about 12 min reported by them¹⁷ and interpreted as Brunt-Vaisala oscillations are about the same as those noted from the present observations.

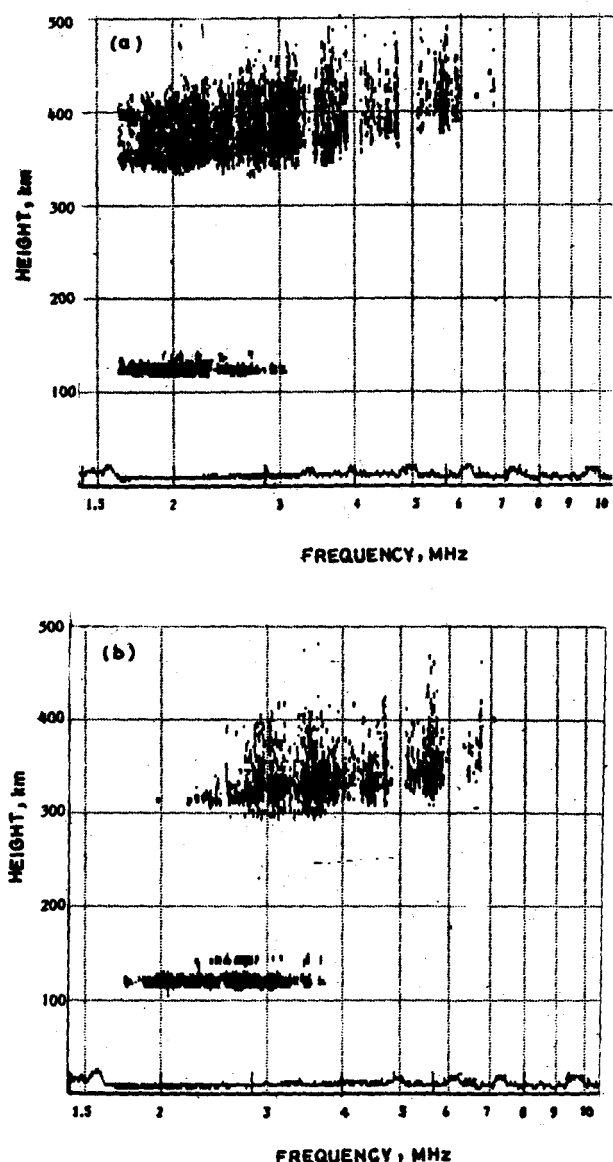


Fig. 4—Ionograms taken at (a) 2200 hrs IST on 3 July 1992 and (b) 0100 hrs IST on 4 July 1992 at SHAR centre during the spread-F event

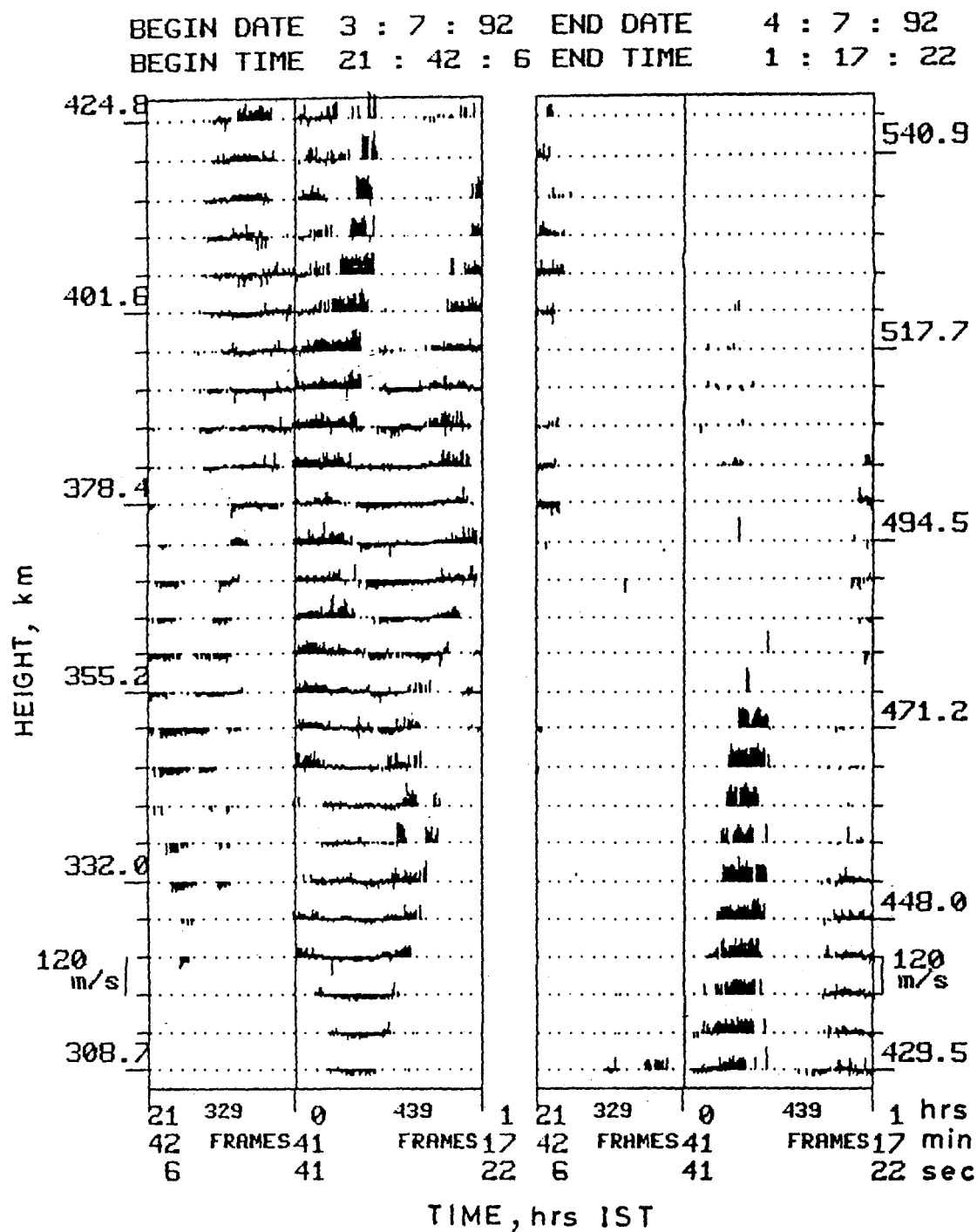


Fig. 5—Variation with height and time of the radial velocity of the irregularities in the direction transverse to the magnetic field (One vertical division corresponds to 120 ms^{-1})

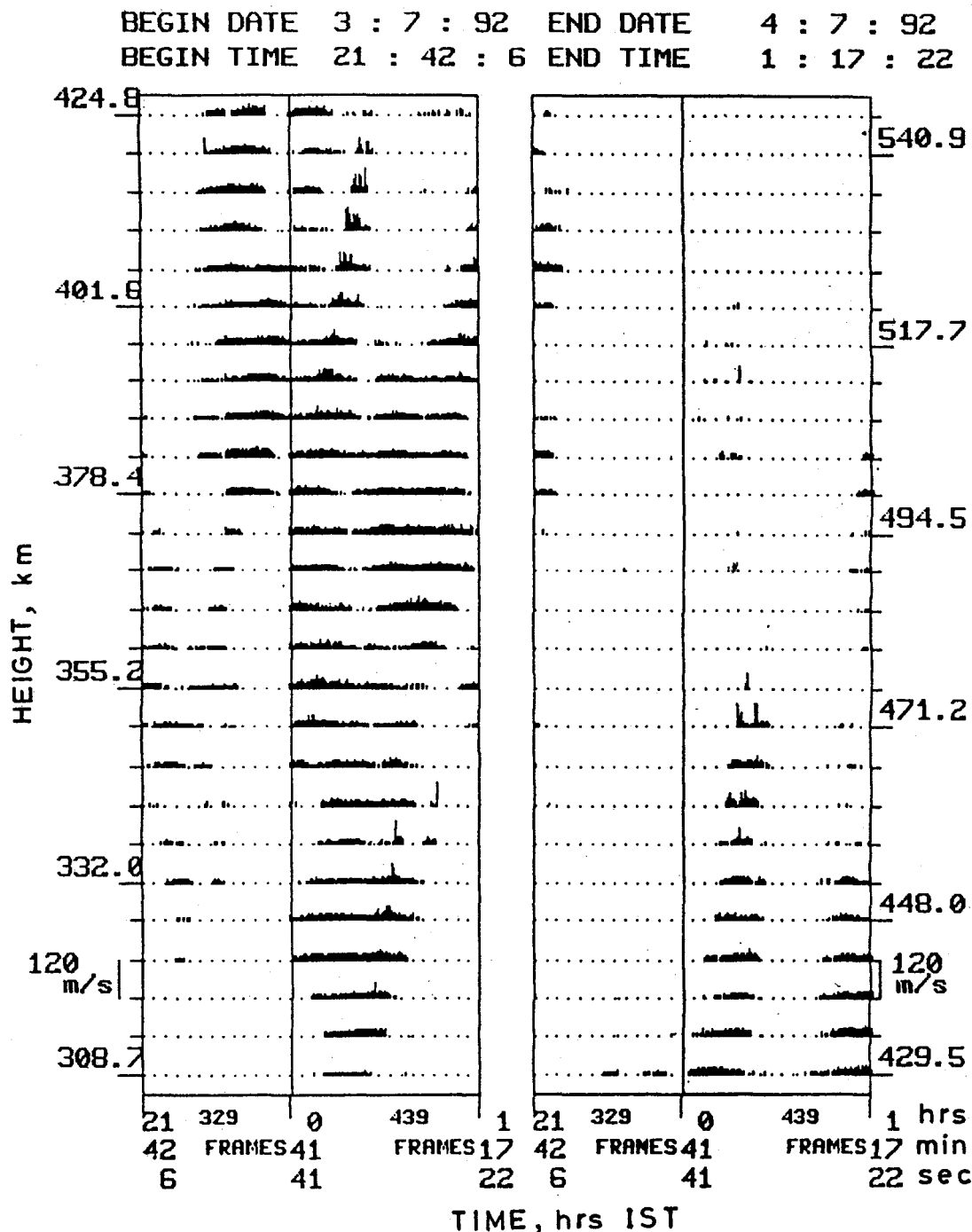


Fig. 6—Variation with height and time of the velocity-spread represented by the width of the Doppler spectrum (One vertical division corresponds to 120 ms^{-1})

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