CHARACTERISTICS OF THE INVERTED-*V* EVENTS OBSERVED BY THE KYOKKO SATELLITE

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Abstract: Measurements of both upward and downward electron fluxes on the KYOKKO satellite have revealed following characteristics of the inverted-*V* events.

(1) Inverted-*V* events have various durations from a few tens of seconds up to several minutes. Existence of the long-duration structure with nearly constant energy of the monoenergetic peak indicates that the inverted-*V* structure is stable rather than transient and also that the equipotential contours of the electric field for acceleration of auroral electrons are extensive in longitude and have a meridional cross-section that is *V*-shaped.

(2) The source region of inverted-*V* electrons seems to be on the closed field lines as well as on the open field lines.

(3) Inverted-*V* events occur at all local times except around noon and at higher latitudes in the dayside hemisphere, although the occurrence frequency is least in the morning sector (0300–1200 MLT). They occur most frequently at invariant latitudes of 65°–70° in the premidnight sector under disturbed conditions.

1. Introduction

Acceleration of auroral electrons to the keV-energy range is one of the major problems in magnetospheric and auroral physics. Various rocket and satellite observations (*e.g.*, ARNOLDY *et al.*, 1974; LUI *et al.*, 1977; MENG, 1978) have shown that the energy spectra of precipitating electrons which produce discrete auroral arcs have monoenergetic peaks in the 1 to 10 keV energy range. The peak energy has been found to show an inverted-*V* variation in the energy-time spectrogram (FRANK and ACKERSON, 1971). In addition, FRANK and GURNETT (1971) have suggested that the inverted-*V* precipitation in the dusk auroral region is produced by direct electrostatic acceleration of magnetosheath electrons. BURCH *et al.* (1976) also have suggested that electron distribution functions in the inverted-*V* events in the 1200–1800 MLT quadrant are well described by Maxwellian primary electron beams which have been accelerated through an electrostatic potential and that these events occur in the regions magnetically connected to the plasma sheet as well as to the magnetosheath. LIN and HOFFMAN (1979) have found that inverted-*V* events occur at all local times in the auroral as well as the polar cap latitudes and that most of the energy and pitch angle structures can be interpreted as electrons accelerated by an electrostatic field which is created by anomalous resistivity. Recent particle and field observations from the S3-3 satellite (MIZERA and FENNELL, 1977; CLADIS and SHARP, 1979; MOZER *et al.*, 1980) have suggested the argument that such parallel electric fields for particle acceleration exist at altitudes of several thousand km above the auroral ionosphere.

It is the purpose of this study to investigate further characteristics of the inverted-*V* events and to supplement the previous studies. The data used are from the electron spectrometer (ESP) on board the KYOKKO satellite which was launched on February 4, 1978, into an orbit of 65.3° inclination, the apogee and perigee being 3978 km and 641 km respectively. Because of the semi-polar orbit the high-latitude part of the satellite track grazes nearly constant *L*-shells, scanning a wide range of local times. Therefore the KYOKKO observations have provided us with interesting precipitation patterns which show longitudinal as well as latitudinal variation, in contrast with the earlier observations by polar-orbiting satellites. A brief description of instrumentation is given in Section 2. Observational results are presented in Section 3. Discussion and conclusion are given in Sections 4 and 5 respectively.

2. Instrumentation

Since the electron spectrometer (ESP) on board the KYOKKO satellite is described in detail elsewhere (MUKAI and HIRAO, 1978), only a brief description is given below.

ESP consists of two identically-designed sensors and a common electronics for control and processing of data. Each sensor is composed, essentially, of a fan-shaped collimator, a hemispherical electrostatic analyzer and a channel electron multiplier. The field of view, the geometrical factor and the energy resolution of the sensor are $4° \times 14°$, 1.5×10^{-3} cm^2 str and 4%, respectively. The energy is swept in an exponentially-decaying form from about 10 keV down to a few eV during one second. The repetition rate of energy scanning is 1 Hz at high bit rate or 0.25 Hz at the low bit rate. The output pulses of the channel electron multiplier are amplified, discriminated and shaped, and are counted successively every 62.5 ms or 125 ms to produce a 9-point spectrum over the whole energy range. Two sensors are installed to look toward opposite directions parallel to the main axis of the satellite. As the main axis of the satellite is controlled to be aligned along the geomagnetic field line, the two sensors measure the electron fluxes around pitch angles of 0° (precipitation) and 180° (upward flux) simultaneously. Although the two sensors were designed to have identical performance, the pre-flight test revealed the detection efficiency of the sensor 2 to be lower than that of the sensor 1 by a factor of 2 to 7 depending on the measured energy.

3. Observational Results

The data studied here were obtained over the northern auroral region at altitudes of 2500–4000 km for 486 passes during the periods of March to April 1978 and of September 1978 to January 1979. Several examples of typical inverted-*V* events are presented in Figs. 1–3 which show the energy-time spectrograms with the energy fluxes at Revs. 2360, 593 and 859 respectively. In each figure the data of sensor 1 (lower two panels) and sensor 2 (upper two panels) correspond to the downward and upward electron fluxes, respectively. Figure 1 displays an inverted-*V* precipitation that occurred

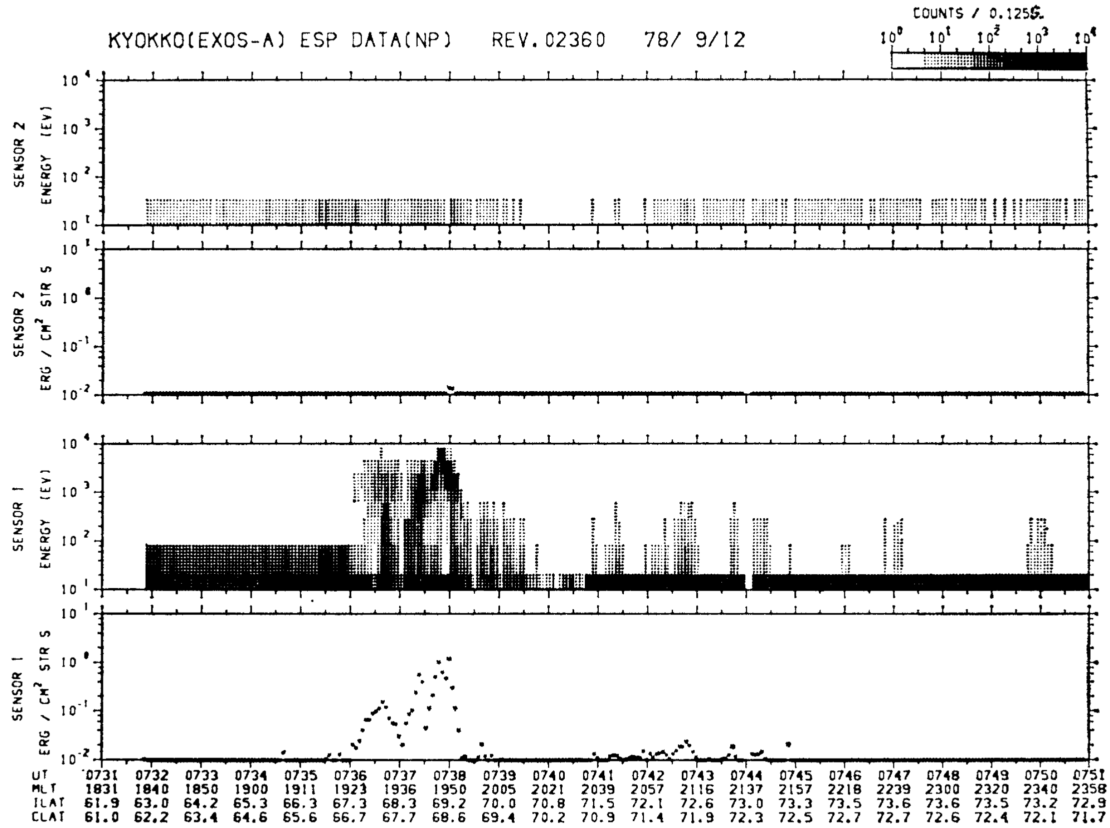

Fig. 1. Energy-time spectrogram and energy flux for Rev. 2360. The data of sensor 1 and sensor 2 correspond to the precipitating and upward electron fluxes, respectively. In the energy-time spectrogram the ordinate is the electron energy, and the abscissa is UT. The detector response is represented as intensity. The bottom three rows are the dipole magnetic local time, the invariant latitude and the conjugate geomagnetic latitude.

around 1950 MLT at an invariant latitude of about 69° when the satellite traversed the auroral oval toward higher latitudes with a small change of magnetic local time (1930–2000 MLT). Hence, Fig. 1 shows a latitudinal profile of auroral electrons which is similar to the earlier observations by the polar-orbiting satellite (*e.g.*, FRANK and ACKERSON, 1971). The monoenergetic peak seen in the sensor 1 energy-time spectrogram as a narrow black band at higher latitudes than the diffuse precipitation region is a typical characteristic of the inverted-*V* event. The spatial extent of this inverted-*V* event is about 200 km. Figure 2 shows several inverted-*V* events with various durations which range from 16 to about 200 s. The first inverted-*V* precipitation in Fig. 2 can be found at the higher latitude part in the diffuse precipitation region as the satellite was traversing the auroral oval toward higher latitudes at pre-midnight. Also in Fig. 2, an inverted-*V* event with long duration can be found at 1323–1324 UT in addition to several other inverted-*V* events with shorter duration. The width of this structure is about 400 km, and the invariant latitudes during this event vary by only 0.1° from 67.9° to 68.0°. A longer inverted-*V* event, in which invariant-latitudinal variation is about 1°, can be found to be embedded in the diffuse precipitation region (1327–1330: 30 UT in Fig. 2). These long-duration inverted-*V* events are often found when the satellite was skimming along the auroral oval. Figure 3 shows another exam-

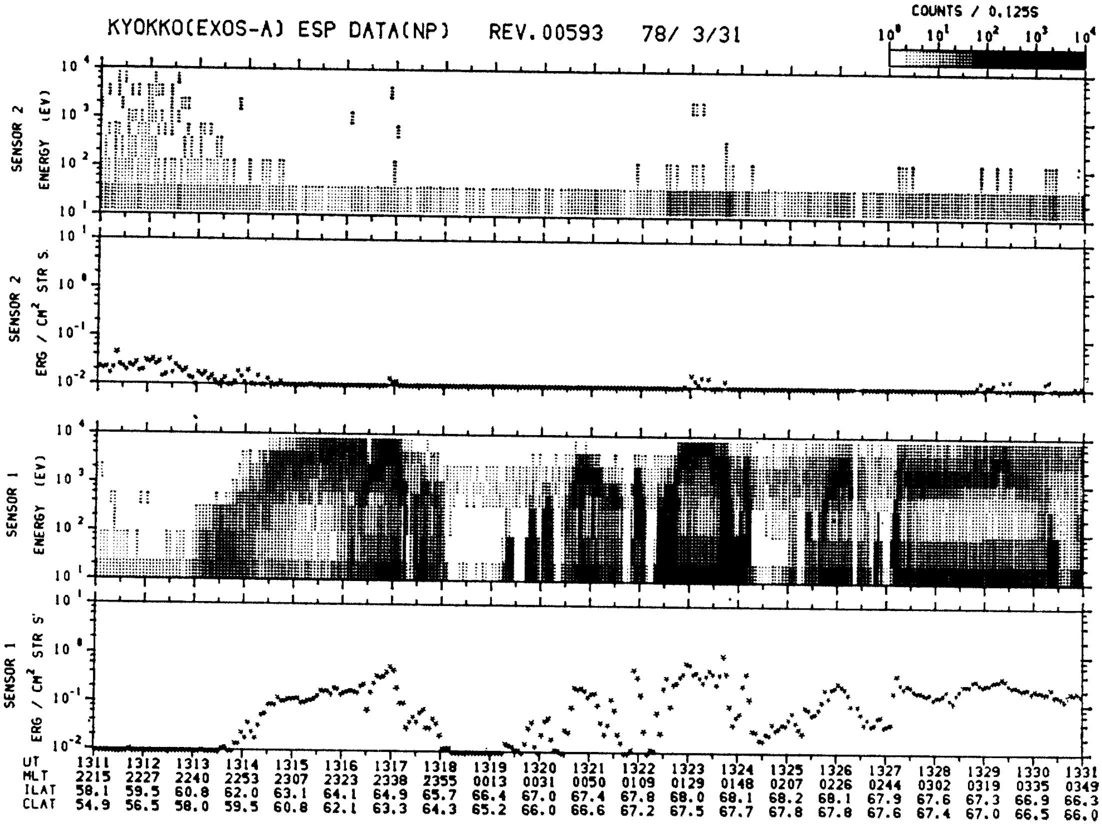

Fig. 2. Same as Fig. 1 for Rev. 593.

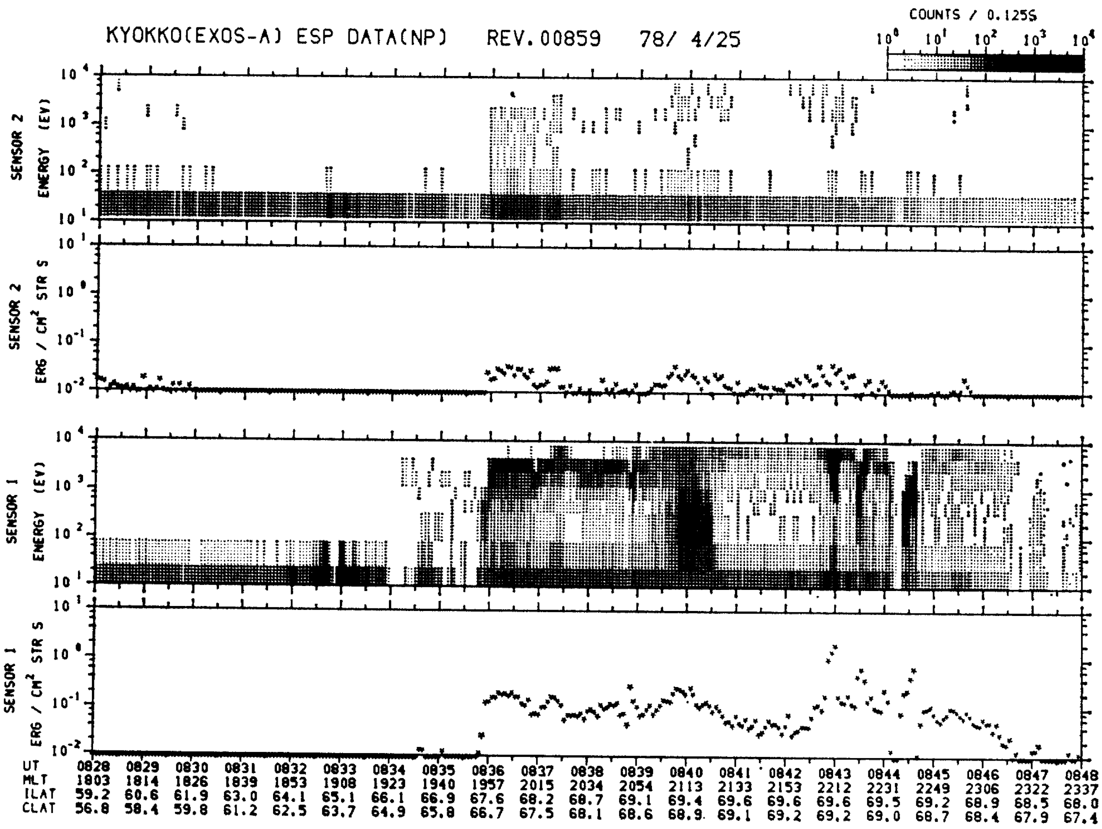

Fig. 3. Same as Fig. 1 for Rev. 859.

ple. A long-duration inverted-*V* event with some fine structures can be seen when the satellite suddenly encountered intense precipitation at 0836 UT (1957 MLT, 67.6° invariant latitude) and then moved (perhaps) almost along the auroral arc until 0844: 10 UT (2231 MLT, 69.5° invariant latitude). In Fig. 3, another inverted-*V* event is found during 0844: 20–0846: 30 UT.

Because of its semi-polar orbit the KYOKKO satellite has observed inverted-*V* events with various durations which are summarized in Fig. 4. Only that part of the precipitation pattern which shows an inverted-*V* event is displayed in each panel. The panels from (a) to (e) are ordered so that the duration, that is, the spatial extent, becomes longer. It should be noted, however, that the change of the invariant latitude is only a few degrees at most even in the longest inverted-*V* event. It is also interesting to note that the peak energy remains nearly constant in the long-duration inverted-*V* event. Some fluctuation in the peak energy can be seen in panel (e), but this is because the satellite passed along the multiple arcs which were also moving, just after a substorm onset at Rev. 2595, October 4, 1978 (KANEDA *et al.*, 1980).

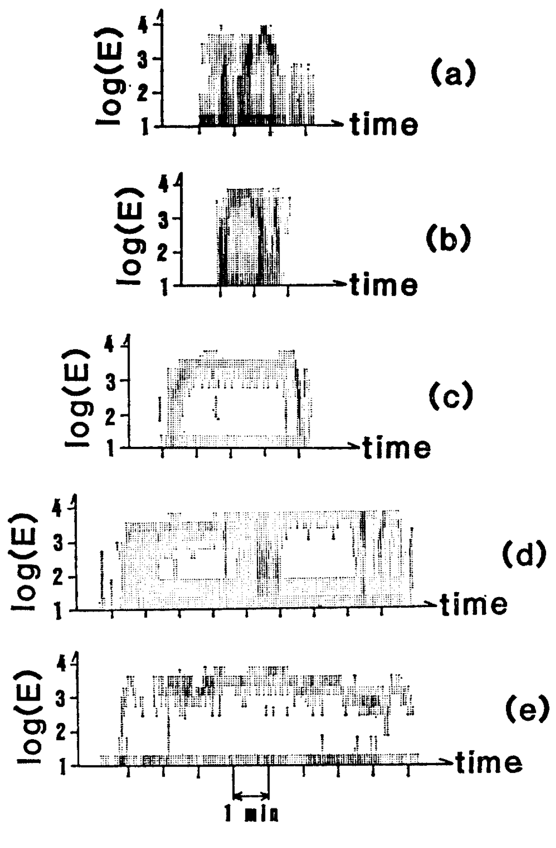

Fig. 4. A summary of energy-time spectrograms of inverted-V precipitations with various durations.

Figure 5 shows spatial occurrence maps of inverted-*V* events for the geomagnetic conditions of $Kp \geq 3-$ and $Kp \leq 2+$, respectively. It should be noted that the KYOKKO satellite could not attain an invariant latitude higher than about 79°. The observation times for these data are almost equally distributed in magnetic local time. Inverted-*V* events occur at all local times and at higher latitudes in the dayside hemisphere, although the frequency of occurrence is least in the MLT range of 0300–1200. They are detected

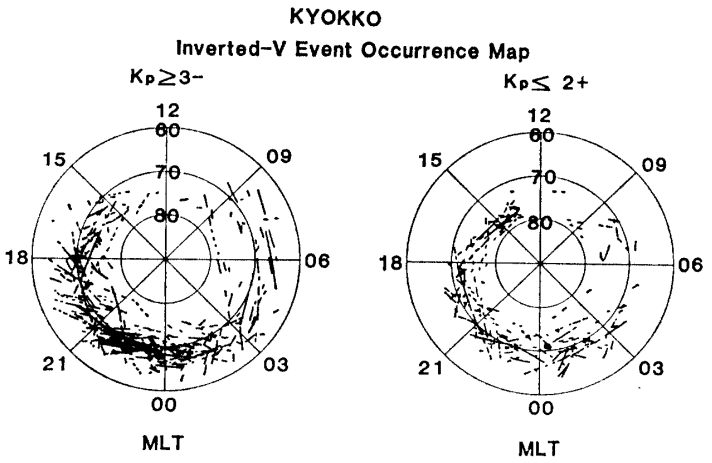

Fig. 5. Spatial occurrence maps of inverted-V events for the geomagnetic conditions of $Kp \geq 3-$ *and* $Kp \leq 2+$. *Magnetic local time (MLT) and circles of constant invariant latitudes are shown for reference.*

more frequently as the Kp-index increases. The low-latitude boundary appears to follow the auroral oval. The average latitudinal width of inverted-V events is about 1°. The longitudinal extent varies from a narrow one of several tens of km up to about several thousands of km. Under disturbed conditions ($Kp \geq 3-$), inverted-V events occur most frequently at invariant latitudes of 65°–70° in the pre-midnight sector; They were detected in about 80% of the orbital passes traversing this region. Under relatively quiet conditions ($Kp \leq 2+$), inverted-V events occur at higher latitudes than under disturbed conditions, while the frequency of occurrence is nearly constant in the MLT range of 1300–0200 through midnight. A further notable feature is that inverted-V events do not occur around noon. A clear asymmetry in the frequency of occurrence can be seen between morning and afternoon, especially under relatively quiet conditions.

4. Discussion

The existence of long-duration inverted-V events indicates that this structure is stable rather than transient. The inverted-V structure is generally interpreted as due to precipitating electrons accelerated by a quasi-static electric field parallel to the magnetic field. The monoenergetic peak energy is suggestive of the electrostatic potential difference along the magnetic field line between the observation point and the source region. The durations of inverted-V events provide us with information on the configuration of the electric field, if the duration shows spatial extent rather than temporal variation. As shown in Figs. 1–4, inverted-V events which the KYOKKO satellite has observed have various durations because of the semi-polar orbit of the satellite, while the change of invariant latitudes is only a few degrees at most during one event. That is, an inverted-V event with shorter duration shows a latitudinal profile while a longer duration one shows a longitudinal profile. The monoenergetic peak energy is nearly constant for a long duration event, in contrast to the shorter event which really shows an inverted-V shape. In addition, most of the parallel electric field must exist above altitudes of 4000 km, since the monoenergetic peak energies which the KYOKKO satellite has observed at altitudes of 2500–4000 km are comparable to those observed previously by lower-altitude rockets and satellites (*e.g.*, ARNOLDY *et al.*, 1974; FRANK and ACKERSON, 1971). This is consistent with recent ion and electron observations from the S3-3 satellite (MIZERA and FENNELL, 1977; CLADIS and SHARP, 1979; GHIELMETTI *et al.*, 1978).

Upward electron fluxes are interpreted as secondary electrons and degraded primaries, and therefore, can have a continuous energy spectrum below the energy of the primary precipitating electrons. Figures 1–3 and the data obtained from other orbital passes show that some inverted-*V* precipitation events are accompanied by upward electrons with energy comparable to the primary energies and other events are not, although direct comparison of the sensor 2 data with the sensor 1 is difficult because of the difference between the detection efficiencies of two sensors noted in Section 2. It is a problem to be solved in future as to whether this fact indicates directly the existence of the parallel electric field below the satellite altitudes.

FRANK and ACKERSON (1971) and FRANK and GURNETT (1971) have suggested that the inverted-*V* events occur on open field lines and that the source region is the magnetosheath. On the other hand, BURCH *et al.* (1976) and LIN and HOFFMAN (1979) have suggested that these events occur on closed field lines as well as on open field lines and also that the source region is not only the magnetosheath but also the plasma sheet. Our observations seem to support the latter argument, because the inverted-*V* events occur at the poleward detached region of the precipitation zone (probably on the open field lines) as well as even in the midst of the diffuse precipitation region (on the closed field lines, *e.g.*, Fig. 2).

The spatial occurrence map shown in Fig. 5 is consistent with the earlier statistical study of inverted-*V* events (LIN and HOFFMAN, 1979). Inverted-*V* events occur at all local times except around noon and at higher latitudes in the dayside hemisphere, which is similar to the occurrence of the optical aurora (FELDSTEIN, 1966; LUI *et al.*, 1975) and of the large-scale field-aligned current (IIJIMA and POTEMRA, 1978). The region of inverted-*V* events roughly coincides with the upward current region obtained by IIJIMA and POTEMRA (1978).

5. Conclusion

Both upward and downward electron fluxes along the geomagnetic field lines have been measured in the energy range of a few eV up to 10 keV by means of the electron spectrometer on board the KYOKKO satellite which was launched on February 4, 1978, into an elliptical orbit of 65.3° inclination. Because of the semi-polar orbit the KYOKKO observations have provided us with interesting patterns which show longitudinal as well as latitudinal variation. The main results are as follows.

(1) Inverted-*V* events have various durations from a few tens of seconds up to several minutes. Existence of the long-duration structure with nearly constant energy of the monoenergetic peak indicates that an inverted-*V* structure is stable rather than transient and also that the equipotential contours of the electric field for acceleration of auroral electrons are extensive in longitude and have a meridional cross-section that

is *V*-shaped.

(2) The source region of inverted-*V* electrons seems to be on the closed field lines as well as on the open field lines.

(3) Inverted-*V* events occur at all local times except around noon and at higher latitudes in the dayside hemisphere, although the frequency of occurrence is least in the morning sector (0300–1200 MLT). Their locale roughly coincides with the upward current region obtained by IIJIMA and POTEMRA (1978). Inverted-*V* events occur most frequently at invariant latitudes of 65°–70° in the premidnight sector under disturbed conditions.

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