Microburst Precipitation Phenomena

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Auroral zone microburst electron precipitation is reviewed. It can be shown from existing data that microbursts represent a major precipitation form on the dayside magnetosphere. Balloon X-ray data indicate that microbursts are periodic and they are small-scaled. Rocket and satellite data indicate that microbursts may consist of substructures and that microburst precipitation is fractionally more enhanced along the magnetic field direction. The source of electrons appears to be nearby, $\leq 4R_e$ from the surface of the earth. Microbursts are correlated to VLF and magnetic micropulsations. Study of microburst phenomena should lead to better understanding of wave-particle interaction mechanisms responsible for electron precipitation.

1. Introduction

This article reviews microburst precipitation phenomena. “Microburst” is a term used by ANDERSON and MILTON (1964) to describe the short, impulsive auroral zone electron precipitation of durations ~ 0.25 second. ANDERSON and MILTON (1964) have shown by means of a systematic study of auroral X-rays from precipitated energetic Van Allen electrons that during daylight hours the electron precipitation occurs primarily in the form of microbursts. Thus, microburst precipitation represents a major perturbation in magnetospheric electron population.

Direct detection of precipitation bursts with ≤ 1 second duration of electrons with ≥ 40 keV energies was made by an Injun 3 experiment (O'BRIEN, 1964). These bursts have subsequently been identified as microburst electrons (MILTON and OLIVEN, 1967; OLIVEN *et al.*, 1968). Microburst electron precipitation events have also been detected by a rocket experiment from Fort Churchill ($L=8$) (LAMPTON, 1967). The Injun 3 and the rocket data provide the only data available concerning microburst pitch-angle distributions and the primary electron energy spectra.

The rapid precipitation bursts of microbursts could be indicating that the first and second adiabatic invariants are violated. The study of microbursts could lead to important clues on the fundamental wave-particle and plasma interaction processes of relevance to understanding the particle loss mechanism in the magnetosphere. It is worth noting that impulsive electron precipitation with time scales ≤ 1 second is not limited to auroral latitudes. WINCKLER *et al.* (1962) have shown that X-rays detected over Minneapolis ($L=3.5$) during a storm consisted of similar rapid pre-

cipitation structures. Microburst-like precipitation structures have been detected subsequently in subauroral latitudes by ROSENBERG *et al.* (1971), ZUHLIN *et al.* (1972), TREILHOU *et al.* (1973), and FOSTER and ROSENBERG (1976). Electron precipitation with ≤ 1 second structures is also observable in visual auroras (CRESSWELL and DAVIS, 1965) and those precipitation forms which are confined to local hours near midnight (EVANS, 1967; PARKS *et al.*, 1967).

2. Observations

2.1 Temporal characteristics

Examples of microbursts in electron precipitation phenomena are shown in Figs. 1 and 2. The temporal properties of microbursts can be summarized as follows:

2.1.1 Microburst widths

As shown in the top panel of Fig. 1, which is taken from ANDERSON and MILTON (1964), microbursts are characterized by a ~ 0.25 second duration. Subsequent studies by ANDERSON *et al.* (1966) indicate that microbursts have durations from ~ 0.1 – 0.6 seconds. This result has been substantiated by BROWN (1973). Statistical study of X-ray data obtained by omnidirectional detectors indicate that nearly 85% of all microbursts detected have durations between 0.1 and 0.3 second. Note that microbursts occur in singles, doubles, and in trains of more than 10. A central theoretical question is concerned with the meaning of microburst duration.

2.1.2 Microbursts and Pulsations

When groups of two or more microbursts occur, the groups tend to be separated by 5–15 seconds. Individual microbursts in these groups are spaced ~ 0.6 second apart. The microbursts are superposed on 5–15 second periodic X-ray pulsations. An example showing this is in the middle panel of Fig. 1 (taken from PARKS, 1967). An interesting theoretical question here concerns the relationship between microbursts and the 5–15 second period pulsations (the X-ray pulsations are correlated with similar periodic magnetic micropulsations and visual auroral pulsations).

2.1.3 Substructures

Microbursts may consist of substructure as indicated in the rocket data of LAMPTON's (1967) which is shown in the bottom panel of Fig. 1. The existence of these substructures that are only a few tens of millisecond in duration indicates that microbursts may be generated locally in the ionosphere (more on this will be discussed in a later section). Additional evidence of microburst substructures is given in PARKS (1974).

2.1.4 Injun 3 data

Microburst structures are observable at small and large pitch-angles as indicated in Fig. 2 (from OLIVEN *et al.*, 1968). This figure shows that the structures are more prominent at small pitch-angles (180° detector). Whereas only a factor of two increase in fluxes is seen in the perpendicular direction (90° detector), the fluxes along the magnetic field (180° detector) increase by an order of magnitude.

Fig. 1. Microburst precipitation structures as revealed in the X-ray and rocket electron data.

2.1.5 Periodicities

It can be seen in the top panel of Fig. 1 that microbursts occur nearly periodically. Figure 3 shows some Fourier analysis results of microburst trains. The top left panel shows the results originally shown in ANDERSON and MILTON (1964). A weak but significant peak is observed at 0.6 second period (compare this spectrum

Fig. 2. Microburst electron precipitation structures observed by the Injun 3 satellite.

Fig. 3. Fourier analysis results of microburst trains to show the periodic properties.

to the one on the right which was obtained from analyzing random count-rates of a radioactive source). The bottom left panel shows results from analyzing microburst trains from highly collimated detectors (from PARKS *et al.*, 1965). Here a significant period was detected at ~ 1.2 seconds. The bottom right hand panel shows the results taken from BROWN (1973) and represents "very intense" microburst events. A significant period was found around 0.6 second.

2.2 Spatial characteristics

2.2.1 Occurrence in local time

Microbursts are primarily detected in the daytime, from ~ 0600 –1800 local time.

The top panel of Fig. 4 shows the percentage of time when X-ray fluxes detected on balloons showed microburst structure (the data sample here represents more than 1,000 hours of X-ray data obtained in Alaska and Canada during 1961–1974). This result shows a high detection probability for microbursts in the early morning hours just after local dawn. It is interesting to note that X-ray microbursts have not been observed before local dawn and after local dusk (except for an isolated event described by VENKATESAN *et al.*, 1968, that occurred around 0430 local time).

2.2.2 Occurrence in longitude and latitude

The bottom panel of Fig. 4 shows the latitudinal region where microbursts were detected by Injun 3 as reported by OLIVEN *et al.* (1968). This figure shows that microbursts occur even at 0200 local hours. However, it is not obvious that data obtained in a moving vehicle can be used to unambiguously sort out microbursts from other rapid precipitation forms that characterize the precipitation phenomena near midnight and the early morning hours (see PARKS *et al.*, 1968).

Fig. 4. Diurnal, latitudinal, and longitudinal information on microburst precipitation. Note that the VLF wave activity has similar occurrence pattern.

2.2.3 Spatial extent of microbursts

Auroral electron precipitation phenomena are substorm associated and therefore the precipitation region can be world-wide. Microburst precipitation is only one of the many varieties of forms that occur in smaller regions within the large precipita-

Fig. 5. Microbursts observed by narrow directional X-ray telescopes. Those events that have arrows over them cover 18 km in the lateral direction at 100 km electron stopping heights. The small cross-correlation coefficients between various telescopes indicate that microbursts are small-scaled.

tion region. Microburst precipitation is restricted to a few-hour region centered around 0700 local hours. Individual microbursts are even smaller, covering regions ≤ 80 km at 100 km heights. Sometimes microbursts cover regions smaller than about 18 km (PARKS, 1967).

The top panel of Fig. 5 shows microbursts detected by directional telescopes (PARKS, 1967). The events that are marked with an arrow were detected only within the field of view of the vertical telescope. Since these events were not evident in the detectors that viewed 30° from the zenith, one can assign an upper limit dimension to these events taking into account the individual telescope geometry factors. PARKS (1967) deduced that their dimensions are ≤ 18 km. The bottom panel shows the results of cross correlating the various detector outputs. The small correlation coefficient centered around zero lag shows that microbursts detected by the various detectors are not correlated with a high degree of coherency and confirms that individual microbursts are small-scaled. Note that the slight oscillatory behavior in the coefficient is a contribution from microburst periodicities. (Here 30 lags corresponds to a period of 0.75 seconds.)

BARCUS *et al.* (1966) and TREFALL *et al.* (1966) have also attempted to determine the individual microburst dimensions. Using omnidirectional detectors flown on two balloons, they deduced that microburst events cover regions ≤ 200 km, a conclusion based on the fact that microburst events on two balloons are not correlated when the two balloons are separated by more than 200 km in the lateral direction. That microbursts are small-scaled is also deduced by BROWN *et al.* (1965). Two balloons flown from conjugate regions of the northern hemisphere detected microburst events at the same time but the individual events were not correlated. This lack of correlation supports the view that individual microbursts cover limited regions of the sky.

2.3 Motions

It is not known with certainty whether motions are associated with individual microburst events. The microburst precipitation region has been observed to move from west to east with a speed of ~ 250 meters/second (PARKS, 1967). There is also evidence (see Figs. 2 and 3, PARKS, 1967) that individual microbursts are in rapid motion, of the order of 10–100 km/second. However, this result is not yet conclusive and needs to be studied further.

2.4 Energy and pitch-angle distributions

Pitch-angle distributions of microbursts obtained by the rocket experiment of LAMPTON's (1967) are shown in the upper panel of Fig. 6. For both of the electron channels indicated, the pitch-angle distribution at the rocket height is of the "loss cone" shape. Note that the pitch-angles sampled are from about 30° – 90° . The pitch-angle distribution taken at time 230 seconds represents data before enhancement of precipitation fluxes. Data at 270 and 274 seconds are for enhanced precipitation periods and for microbursts, respectively. According to these results, the electron

Fig. 6. Pitch-angle distribution of electron precipitation during microburst events. Primary electron energy spectra are shown as well.

pitch-angle distribution remains peaked strongly at 90° at all times. It can be seen, however, that enhanced precipitation is fractionally greater at smaller pitch-angles.

Pitch-angle distribution cannot be constructed from the Injun 3 data because the measurements included only pitch-angles along (180°) and perpendicular to (90°) the geomagnetic field. Figure 2, however, clearly demonstrates that enhanced precipitation during microbursts is considerably more intense along the magnetic field direction. As noted, in some events microburst fluxes were only evident in the 180° detector.

Electron energy spectra from the rocket data (LAMPTON, 1967) are shown on the bottom panel of Fig. 6. The spectra here represent those electrons detected at small pitch-angles by the axial detector. The spectrum at Flight Time (FT) 280–300 represents the energy spectrum of enhanced electron precipitation fluxes. This energy spectrum is nearly identical with the energy spectrum of precipitated fluxes taken during peak microburst events. In both cases, e-folding energy is ~ 30 keV. (Injun 3 was not instrumented to measure electron energy spectra.)

Energy spectra of microbursts have also been studied by means of bremsstrahlung X-ray data (HUDSON *et al.*, 1965; BARCUS and ROSENBERG, 1966). These agree with the above results.

2.5 Cross-correlation analysis

LAMPTON (1967) has cross-correlated the microbursts in the 60–90 keV energy channel against those in 90–150 keV and 150–300 keV energy channels. The top panel of Fig. 7 shows the results for the main microburst events. It is evident that in this analysis the 60–90 keV microbursts were systematically detected later than the 90–150 keV microbursts by about 10 milliseconds.

Cross-correlation analysis made on weak microburst events that were detected in the early part of the flight is shown on the bottom panel of Fig. 7. Here, the 150–300 keV energy channel detected microbursts earlier by about 0.26 seconds than those in the 60–90 keV energy channel, and 90–150 keV energy channel detected microbursts earlier by about 0.1 second than the microbursts in the 60–90 keV energy channel.

These results led LAMPTON (1967) to conclude that the microburst electron source is close to the earth. Interpreting the time delays as representing transit delay times of electrons from the source to the rocket altitude where the measurements were made, and assuming that microburst precipitation (acceleration) occurs simultaneously at all energies, LAMPTON (1967) deduced source locations for the two cross-correlation results to be $2 \pm 2R_e$ and $22 \pm 6R_e$ from the rocket. The first was interpreted as the northern hemisphere source (where the rocket was flown), and the second was interpreted as the southern ionospheric source. Evidently, the weak microbursts detected in the early part of the flight originated in the southern hemisphere and propagated into the northern hemisphere (on closed field lines), where they were detected.

Fig. 7. Cross-correlation results of microburst electrons in the different energy channels.

2.6 Microburst correlation to substorms, VLF's, and magnetic impulses

Auroral zone electron precipitation occurs when trapped fluxes increase in the magnetosphere during magnetic bays. During precipitation, VLF wave activity is also enhanced. Figure 8 shows such a correlation for the event observed on August 17, 1967 (the VLF data here were recorded by the Stanford group at Siple Station, Antarctica; the data were kindly provided by Dr. Ho, Fig. 8 first appeared in WINCKLER, 1974). The X-rays here consisted of microbursts. That electron precipitation and VLF wave activity was correlated has been known for some time (see, for example, GURNETT and O'BRIEN, 1964).

Correlation between VLF and electron precipitation was sought at a finer time scale by MILTON and OLIVEN (1967) and by OLIVEN *et al.* (1968). The top panel of Fig. 9 shows microbursts detected simultaneously by a balloon-borne X-ray detector and direct electron microburst measurements made by Injun 3. This figure also shows VLF wave spectrum. Rising tone events were active during microburst observations but a one-to-one correlation was not found. It is interesting to note that the VLF risers here have durations similar to microbursts.

An extremely good correlation was observed between whistlers and X-ray bursts (microbursts) at Siple Station (ROSENBERG *et al.*, 1971; FOSTER and ROSENBERG, 1976). The results shown in the middle panel of Fig. 9 show a one-to-one corre-

Fig. 8. Correlated events observed in trapped electron increases, precipitated fluxes that include microbursts, magnetic bays, and VLF wave activity.

spondence between the X-ray and VLF bursts. The rising tone VLF bursts detected here appear similar to those detected by MILTON and OLIVEN (1967).

Micropulsation activity increases during substorms and therefore it is expected that micropulsation and electron precipitation will be correlated. Like the VLF wave activity, however, the micropulsations in general do not show a one-to-one correlation except in rare cases. The one instance when good correlation was found is shown in the bottom panel of Fig. 9. Here, one sees that X-ray microbursts and magnetic micropulsation impulses occurred together (McPHERRON *et al.*, 1968).

Fig. 9. Fine-scale correlation of VLF and magnetic impulses with individual microburst events.

3. Conclusion

Characteristics of microbursts deduced from balloon-borne experiments and those revealed in a rocket and a polar satellite indicate that a major electron loss process on the dayside magnetosphere is associated with the microburst precipitation phenomena. All information that we have at the present time comes from electrons of energies ≥ 40 keV. There is no information for energies below 40 keV. Nor is there any direct information on microbursts for regions higher than several hundred kilometers from the surface of the earth.

At this time, virtually nothing is known about microburst mechanisms (there is only one short note by COPPI, 1965, on microburst theory). However, the observation of microburst correlation with VLF waves, micropulsations, and substorms, and the fact that microburst-like precipitation is also evident in visual auroral forms, indicate that a fundamental plasma process is at work here. Future observations of microburst phenomena should delineate more clearly the role of microburst precipitation in the overall particle acceleration and precipitation scheme in the magnetosphere.

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REFERENCES

- ANDERSON, K.A. and D.W. MILTON, Balloon observations of X rays in the auroral zone, 3, High time resolution studies, *J. Geophys. Res.*, **69**, 4457-4470, 1964.
- ANDERSON, K.A., L.M. CHASE, H.S. HUDSON, M. LAMPTON, D.W. MILTON, and G.K. PARKS, Balloon and rocket observations of auroral-zone microbursts, *J. Geophys. Res.*, **71**, 4617-4629, 1966.
- BARCUS, J.R. and T.J. ROSENBERG, Energy spectrum for auroral-zone X rays, 1, Diurnal and type effects, *J. Geophys. Res.*, **71**, 803-823, 1966.
- BARCUS, J.R., R.R. BROWN, and T.J. ROSENBERG, The spatial and temporal character of fast variations in auroral-zone X-rays, *J. Geophys. Res.*, **71**, 125-141, 1966.
- BROWN, R.R., Observations of narrow microburst trains in the geomagnetic storm of August 4-6, 1972, *J. Geophys. Res.*, **78**, 1727-1729, 1973.
- BROWN, R.R., J.R. BARCUS, and N.R. PARSONS, Balloon observations of auroral-zone X rays in conjugate regions, 2, Microbursts and pulsations, *J. Geophys. Res.*, **70**, 2599-2612, 1965.
- COPPI, B., Role of plasma instabilities in auroral phenomena, *Nature*, **205**, 998, 1965.
- CRESSWELL, G.R. and T.N. DAVIS, Observations on pulsating auroras, Goddard Space Flight Center Preprint Series, X-612-65-485, Nov. 1965.
- EVANS, D.S., On the observation of a 10-cps periodicity in the flux of auroral electrons (abstr.), *Trans. Amer. Geophys. Union*, **48**, 72, 1967.
- FOSTER, J.C. and T.J. ROSENBERG, Electron precipitation and VLF emissions associated with cyclotron resonance interactions near the plasmopause, *J. Geophys. Res.*, **81**, 2183-2192, 1976.
- GURNETT, D.A. and B.J. O'BRIEN, High-latitude geophysical studies with satellite Injun 3, 5, Very-low-frequency electromagnetic radiation, *J. Geophys. Res.*, **69**, 65, 1964.
- HUDSON, H.S., G.K. PARKS, D.W. MILTON, and K.A. ANDERSON, Determinations of the auroral-zone X-ray spectrum, *J. Geophys. Res.*, **70**, 4979-4982, 1965.
- LAMPTON, H., Daytime observations of energetic auroral-zone electrons, *J. Geophys. Res.*, **72**, 5817, 1967.
- McPHERRON, R.L., G.K. PARKS, F.V. CORONITI, and S.H. WARD, Studies of the magnetospheric

- substorm, 2, Correlated magnetic micropulsations and electron precipitation occurring during auroral substorms, *J. Geophys. Res.*, **73**, 1697–1713, 1968.
- MILTON, D.W. and M.N. OLIVEN, Simultaneous satellite and balloon observations of the same auroral zone precipitation event, *J. Geophys. Res.*, **72**, 5357, 1967.
- O'BRIEN, G.J., High latitude geophysical studies with Injun 3, 3, *J. Geophys. Res.*, **69**, 13–43, 1964.
- OLIVEN, M.N., D. VENKATESAN, and K.G. MCCracken, Microburst phenomena, 2, Auroral-zone electrons, *J. Geophys. Res.*, **73**, 2345–2353, 1968.
- PARKS, G.K., Auroral zone microbursts, substructures, and a model for microburst precipitation, *Proc. Int. Conf. on X-rays in Space*, Calgary, Alberta, Canada, August 14–21, p. 849–874, 1974.
- PARKS, G.K., Spatial characteristics of auroral-zone X-ray microbursts, *J. Geophys. Res.*, **72**, 215–225, 1967.
- PARKS, G.K., D.W. MILTON, and K.A. ANDERSON, Auroral zone X-ray bursts of 5- to 25-millisecond duration, *J. Geophys. Res.*, **72**, 4587, 1967.
- PARKS, G.K., F.V. CORONITI, R.L. MCPHERRON, and K.A. ANDERSON, Studies of magnetospheric substorm, 1, Characteristics of modulated energetic electron precipitation occurring during auroral substorms, *J. Geophys. Res.*, **73**, 1685–1696, 1968.
- PARKS, G.K., H.S. HUDSON, D.W. MILTON, and K.A. ANDERSON, Spatial asymmetry and periodic time variations of X-ray microbursts in the auroral time zone, *J. Geophys. Res.*, **70**, 4975–4978, 1965.
- ROSENBERG, T.J., R.A. HELLIWELL, and J.P. KATSUFRAKIS, Electron precipitation associated with discrete very low frequency emissions, *J. Geophys. Res.*, **76**, 8445, 1971.
- TREFALL, H.J., W.E. BJORDAL, S.L. ULLALAND, and J. STADSMA, On the extension of auroral-zone X-ray microbursts, *J. Atmos. Terr. Phys.*, **28**, 225–233, 1966.
- TREILHOU, J.-P., A. SAINT-MARC, G. GASSET, A. BOUTONNET, I.A. JOULINE, and K.H.D. KANONIDI, Auroral and subauroral research by balloon-borne and ground-based measurements, in *European sounding-rocket and related research at high latitudes*, *ESRO SP-97*, 87, 1973.
- VENKATESAN, D., M.N. OLIVEN, P.J. EDWARDS, K.G. MCCracken, and M. STEINBOCK, Microburst phenomena, 1, Auroral-zone X-rays, *J. Geophys. Res.*, **73**, 2333–2343, 1968.
- WINCKLER, J.R., Investigation of electron dynamics in the magnetosphere with electron beams injected from sounding rockets, Invited Paper presented at Int. Conf. on X-rays in Space, Calgary, Alberta, Canada, August 14–21, 1974.
- WINCKLER, J.R., P.D. BHAVSAR, and K.A. ANDERSON, A study of the precipitation of energetic electrons from the geomagnetic field during magnetic storms, *J. Geophys. Res.*, **67**, 3717–3736, 1962.
- ZUHLIN, I.A., J.-P. TREILHOU, and J. GASSET, Roentgen bremsstrahlung at sub-auroral latitudes, *Cosmic Res.*, **11**, 441, 1972.