Proceedings of the Iowa Academy of Science

Volume 74 | Annual Issue Article 31

1967

Omnidirectional Electron Intensity Contours in the Earth's Outer Radiation Zone

Harry D. Owens
University of Iowa

Omnidirectional Electron Intensity Contours in the Earth's Outer Radiation Zone

HARRY D. OWENS [1]

Abstract. Intensity contour maps of the outer radiation zone for omnidirectional intensities of electrons with energies greater than 40keV, 230 keV, and 1.6 MeV are presented for the time period October, 1962, through January, 1963. The manipulations applied to the Explorer 14 data are discussed along with the salient features and advantages of this presentation.

Analysis of the data accumulated by the satellites Explorers 1, 3, and 4 and Pioneers 3 and 4 enabled the mapping of the gross features of the earth's trapped radiation zones.

What was shown was that there are large intensities of electrons and protons in the vicinity of the earth. Any reasonably large volume contains approximately the same number of electrons as protons, but a study of the distribution of these particles as a function of their energy permits identification of two regions or zones (see Figure 1). The inner zone contains energetic protons ($E \gtrsim 30$ MeV), and is centered at a distance of about 1.8 earth radii. The outer zone is populated with energetic electrons ($E \gtrsim 1$ MeV), and is centered at about 4 earth radii. These zones are more popularly referred to as the Van Allen belts. (1)

Later satellites with more sophisticated instrumentation and longer lifetimes provided comprehensive information concerning time variations of charged particle intensities and spectra in the zones. Outer zone data from one of these satellites, Explorer 14, is presented here in a way which facilitates study of the temporal variations of the omnidirectional electron intensities. A discussion of the method by which this presentation is developed forms the substance of this paper.

The Explorer 14 satellite was launched October 2, 1962, and transmitted data to August 8, 1963. Temporary interruption of the data transmission occurred during January. The apogee and perigee altitudes of its orbit on October 4 were approximately 100,000 and 300 kilometers, respectively; the orbital period was 36.4 hours. (2)

Omnidirectional intensity is defined as the number of particles passing through a sphere of cross-section one square centimeter in one second.

[1] University of Iowa, Department of Physics and Astronomy, Iowa City, Iowa 52240.

Several kinds of particles would pass through such a sphere in the outer zone—neutral and ionized molecules, alpha particles, protons, and electrons. In addition, these particles would have kinetic energies ranging from zero to several million electron volts. If in that second only the electrons among the several different kinds of particles entering were counted, and of the electrons only those having kinetic energy greater than 230 keV, then this number would be called the omnidirectional intensity of electrons with energy greater than 230 keV.

The University of Iowa experiment on the Explorer 14 satellite consisted of four Geiger-Mueller tubes. These detectors were designed to count the number of particles having an energy sufficient to penetrate to their active volumes. The counting rates of the detectors are proportional to an omnidirectional intensity of electrons having a kinetic energy greater than this threshold energy for penetration.

It was shown sixty years ago that charged particles can be confined by a dipole field. (3) Considerable background information is required to explain the trapping mechanism. It does, however, depends on the convergence of magnetic field lines.

The geometry of the magnetic field lines surrounding a magnetic dipole is familiar to most. It is an elementary experiment to

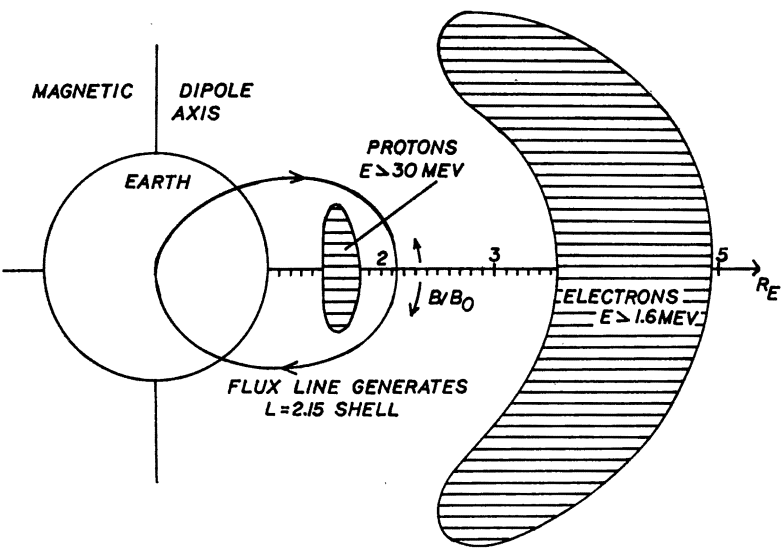

Figure 1. Approximate spatial position of the energetic particle intensities which characterize the radiation zones.

sprinkle iron filings on a sheet of paper over a magnet. The filings tend to orient themselves along magnetic field lines.

Space physicists rotate a field line around the magnetic dipole axis. The resulting donut-shaped surface is called an L-shell. The magnetic equatorial plane is the plane which contains the origin of the magnetic dipole and is perpendicular to the dipole axis. The L = 2.15 shell intersects the magnetic equatorial plane at a geocentric radial distance of 2.15 earth radii (see Figure 1) (assuming a perfect dipole field centered at the earth's center). The

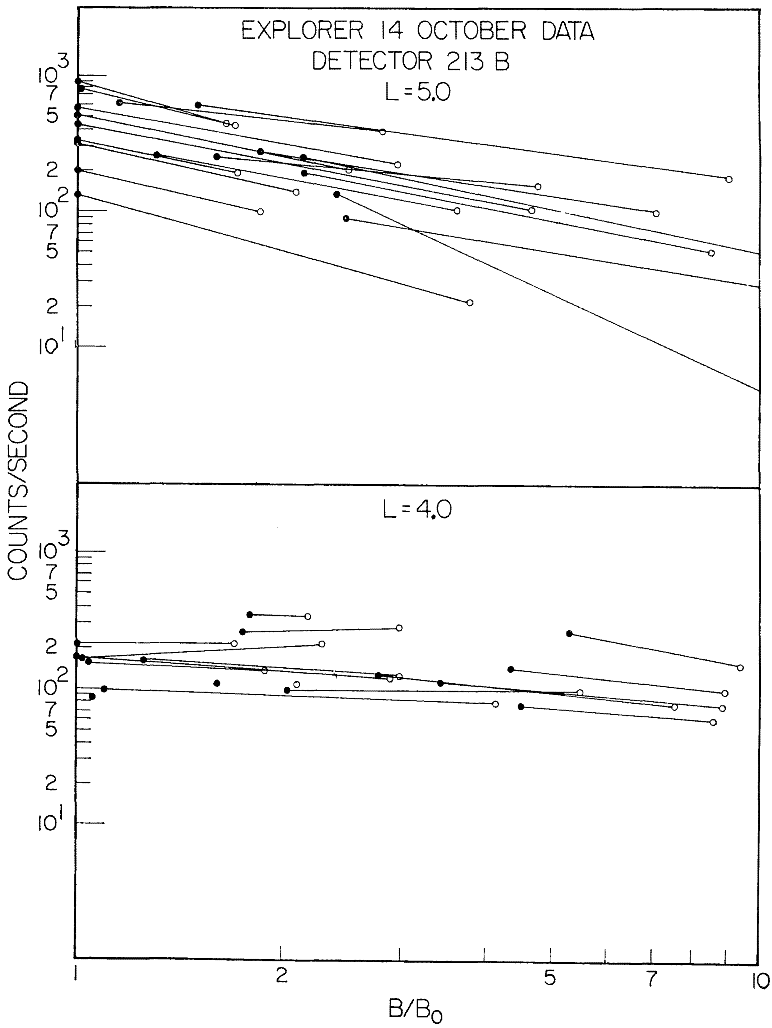

Figure 2. Detector response along the L = 4 and L = 5 shells.

variable, L, is one of two coordinates useful in space physics research. The scalar value of the magnetic field, B, along a magnetic field line is sometimes used as the other coordinate. We have used the variable B/B_0, where B_0 is the value of B at the magnetic equator on a given L-shell.

The omnidirectional intensity of electrons in a dipole field can reasonably be expected to depend on the quantity B/B_0. Experimentally this is found to be the case, and it presents a problem in determining the time variations of particle intensities.

Figure 2 shows a way to determine the dependence of the detector counting rates on B/B_0. For a given L-shell, the particle intensity decreases as B/B_0 increases. The satellite when approaching the earth may cross the L-shell at a high B/B_0 value and record a relatively low intensity. After passing through its perigee point the satellite moves outward from the earth, and again crosses the L-shell. This time, however, the satellite may cross at a low B/B_0 and record a higher intensity. Uncompensated, this could result in an erroneous representation of the time variation. The difficulty is to graphically portray the temporal variations of the electron intensities after removing the dependence of the detector counting rate on the position of the satellite (i.e., upon B/B_0 along a given L-shell).

To remove this dependence, a value for the mean slope was found from graphs similar to Figures 2 and 3. Data from inward and outward passes for each orbit are connected by lines. Data from the four Geiger-Mueller tubes were plotted at L-values of 4, 5, 6, and 7 for all ten months. In this way the mean slope could be determined as a function of time. Linear interpolation was invoked in order to provide slopes at intermediate values of L; linear extrapolation was invoked in order to provide slopes for L-values below $L = 4$ and above $L = 7$.

The B/B_0 correction is one of two manipulations used on the Explorer 14 data. The other correction recognizes that the Geiger-Mueller counters are not perfect threshold detectors.

To correct for this, the counting rate of a detector is divided by a quantity "ϵg." The "g" is the geometric factor of the tube; it tube in counting electrons and on the electron spectrum being sampled. Earlier papers have tended to assume an average spectrum for the ten months of data and so compute "ϵ." (4, 5) We have calculated the form of the spectrum and then an "ϵ" for each data point.

Figures 4 and 5 are two of the intensity contour maps which result from plotting the intensity at every L over the L-value

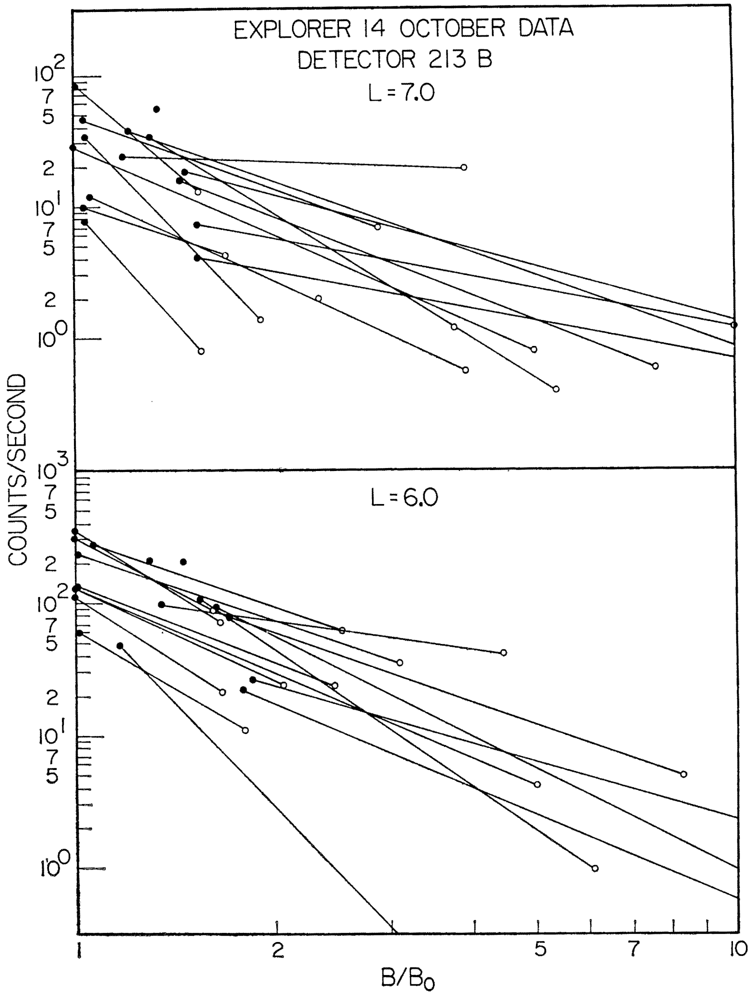

Figure 3. Detector response along the L = 6 and L = 7 shells.

range extending from 3.0 to 8.0 as a function of time. The B/B_0 and "ϵg" corrections are essential to make full use of the data. There is one set of data every 1.5 days. The criteria for connecting points of constant intensity are:

1. Each line represents an intensity of either 1 ,2, 5, or 7 times a power of ten. Intensities on any day are low at low L-values and increase to a maximum and then decrease with increasing L-value unless explicitly indicated. A contour encloses the number which represents its intensity.

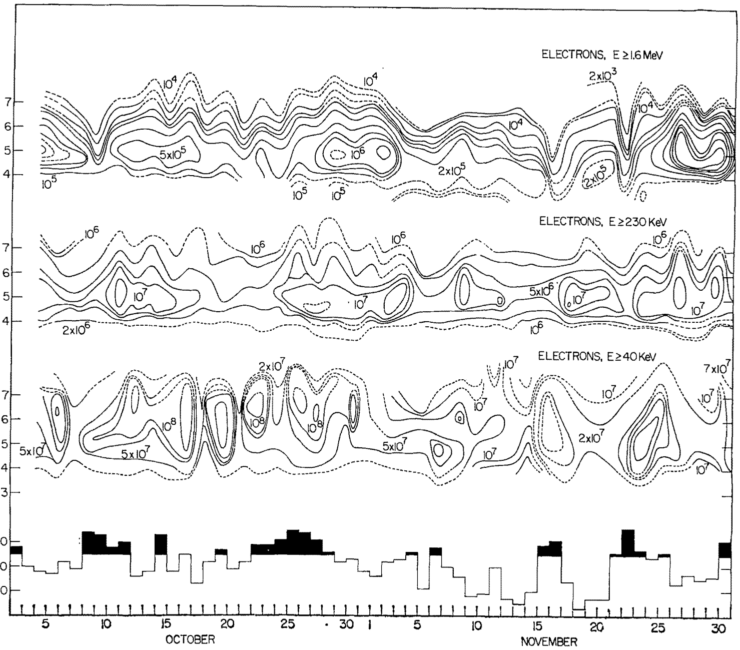

Figure 4. October and November omnidirectional intensity contours.

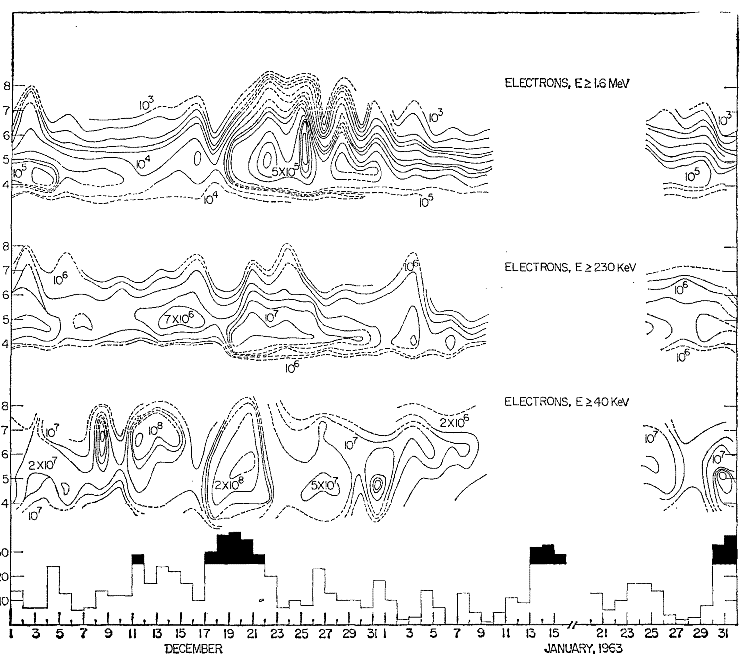

Figure 5. December and January omnidirectional intensity contours.

2. Time variations are assumed to be greater than or equal to the period of the satellite.

3. Dashed lines are used to connect or close contour lines where data is missing. All the contours lying above $L = 7$ or below $L = 4$ are dashed as the slope of the B/B_0 graphs was not calculated for these regions directly, but extrapolated.

The K_p daily sum is a measure of the disturbance of the earth's magnetic field. A shaded area on the graph indicates that during that day ground-based measurements of the earth's field changed greatly. The interaction of charged particles from the sun with the earth's magnetic field would cause such a disturbance, and so a close correlation between the K_p sum and the charged particle observations is expected. Earlier attempts to show the correlation between satellite observations of charged particle events with the K_p sum were attempted by plotting the intensity at a fixed L-value versus time. A rough though positive correlation could be made. (6, 7) The effect of the two present corrections is to provide a more comprehensive observational basis for this correlation.

These graphs are valuable in that they display a great deal of information at once. Easily visible, for example, is the nature in which a geomagnetic disturbance is reflected in the three charged particle intensities. Intensities of electrons with energies greater than 40 keV characteristically show rapid (~ 1 day) increases followed by a decrease to pre-storm intensities at a similar rate. A geomagnetic storm, which is usually associated with a high K_p daily sum, appears two to four days before the appearance of an increased intensity of higher energy electrons. Storm-time maximum intensities are typically 2×10^8 electrons/cm^2-sec for electrons with energies greater than 40 keV, 2×10^7 electrons/cm^2-sec for electrons with energies greater than 230 keV, and 10^6 electrons/cm^2-sec for electrons with energies greater than 1.6 MeV.

Perhaps the most important advantage is that these contours provide an overall view of the events in the outer radiation zone. Whereas other presentations may give specific information unobtainable from this treatment, there is a tendency to become lost amid the graphs; unable to see the forest for the trees. For the uninitiated, at least, this presentation gives a birds-eye view of the electron preserve called the outer Van Allen belt.

ACKNOWLEDGMENT

I wish to thank Dr. L. A. Frank for his original suggestion which led to this work.

Literature Cited

1. Van Allen, J. A., March, 1959, Sci. Am., Volume 200, No. 3, page 39-47.
2. Frank, L. A., Van Allen, J. A., Whelpley, W. A., and Craven, J. D., March 15, 1963, J. Geophys. Res., Volume 68, No. 6, page 1573.
3. Stormer, C., 1907, Arch. Sce. phys. et naturelles, Volume 24, page 317-364.
4. Frank, Van Allen, Whelpley, and Craven, op. cit., page 1575.
5. Frank, L. A., Van Allen, J. A., Hills, H. K., June 1, 1964, J. Geophys. Res., Volume 69, No. 11, page 2173.
6. Frank, Van Allen, Hills, op. cit., page 2186.
7. Frank, L. A., April 1, 1965, J .Geophys. Res., Volume 70, No. 7, page 1608.