

1997

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J B. Blake

D N. Baker

Niescja E. Turner
Trinity University

K Ogilvie

R P. Lepping

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Repository Citation

Blake, J. B., Baker, D. N., Turner, N., Ogilvie, K. W., & Lepping, R. P. (1997). Correlation of changes in the outer-zone relativistic-electron population with upstream solar wind and magnetic field measurements. *Geophysical Research Letters*, 24(8), 927-929.

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Correlation of changes in the outer-zone relativistic-electron population with upstream solar wind and magnetic field measurements

J. B. Blake¹, D. N. Baker², N. Turner², K. W. Ogilvie³, and R. P. Lepping³

Abstract. A study has been made of the correlation of the population of relativistic electrons in the outer-zone magnetosphere with the properties of the solar wind (speed, density, magnetic field) during a solar minimum period. The study is based upon observations made in the Spring of 1995 with sensors aboard 1994-026 and WIND. It is found that a large relativistic electron enhancement depends upon a substantial solar-wind speed increase associated with precursor solar-wind density enhancement, and, in particular, upon a southward turning of the interplanetary magnetic field.

Introduction

Over twenty years ago, it was discovered that the population of relativistic electrons in geostationary orbit ($L \approx 6.6$) was clearly modulated with the 27-day synodic period of the Sun. This modulation was most evident around the time of solar minimum, and the modulation was driven in some unknown fashion by high-speed solar-wind streams (Paulikas and Blake 1976, 1979; Baker *et al.* 1978). Additional studies have been carried out subsequently (Baker *et al.* 1986, 1994), but these analyses have been made in the absence of comprehensive measurements of the highly time variable solar wind impinging upon the Earth's magnetosphere. With the launch of the WIND spacecraft, the necessary measurements now are routinely available. In this Letter, we present a first report on the continuous correlation of solar-wind properties with the state of the relativistic electron population in the Earth's magnetosphere.

Instrumentation and Spacecraft

WIND provides a continuous record of solar-wind speed and density, and of the interplanetary magnetic field (Ogilvie *et al.* 1995, Lepping *et al.* 1995), except for the rare occasions when WIND passes through the magnetosphere near perigee. Spacecraft 1994-026 ($\sim 62^\circ$ inclination with the argument of perigee fixed at 270° , $1.15 \times 7.2 R_E$ orbit, ≈ 12 -h period) measures the outer-zone relativistic electron population in four outer-zone passages per day with four integral energy channels from >1.5 MeV to >8.5 MeV. The *s/c* covers all L values from 2 to beyond the trapping boundary every orbit. Orbit-integrated doses (which are directly related to orbit-integrated electron

fluences) are a concise way to view the electron population above a threshold energy averaged over an entire orbit. We are interested here in global effects—the behavior of the outer zone electron population as a single system. The inbound and outbound passes of 1994-026 in the radiation belt are temporally close together; therefore, the two observations are summed and a 12-h value for the electron environment is derived. The focus has been upon measurements made in early 1995, when, for several successive solar rotations, high-speed solar-wind streams strongly modulated the relativistic electron population in the outer zone, and when WIND data are available.

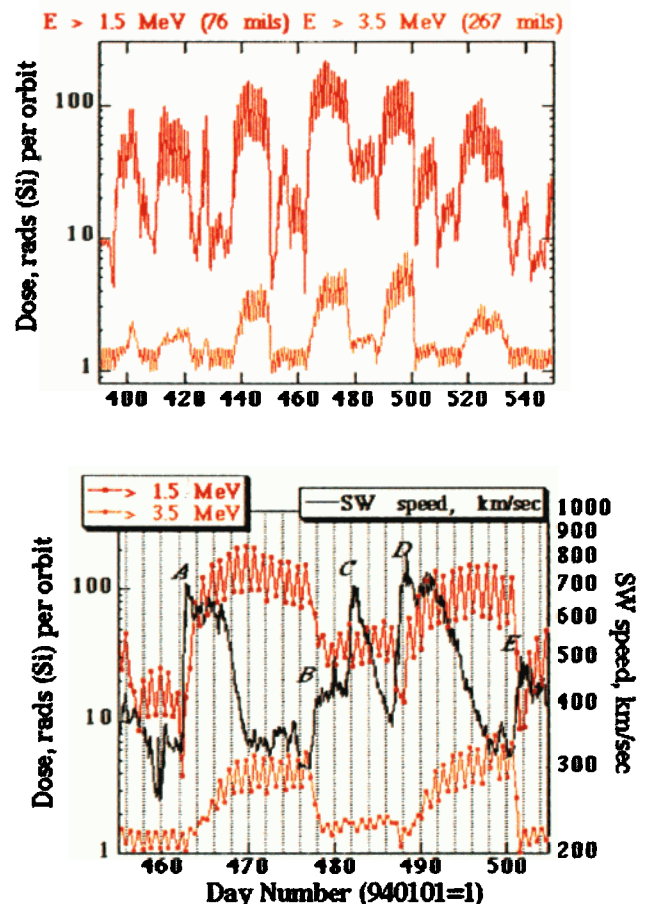


Figure 1. The upper panel shows the time history of outer-zone relativistic electron population during a 160-day period in the Spring of 1995. The plot is in units of dose per 12-hour orbit; the two channels are labeled by both the electron threshold energy and nominal electron range in aluminum. The bottom panel shows the solar-wind speed plotted from WIND and the radiation intensity from 1994-026 plotted for a portion of the interval shown in the top panel.

¹Space Sciences Department, The Aerospace Corporation, Los Angeles California.

²Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado.

³NASA/Goddard Space Flight Center, Greenbelt, Maryland.

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Observations

Figure 1a shows the run of radiation belt data for approximately a 160-day period during the first half of 1995. Two instrumental features should be noted. First, the oscillatory behavior seen in the temporal sequence is due to the fact that the magnetic latitude (B/B_0) varies systematically from one orbit to the next because of tilt of the Earth's dipole with respect to the s/c orbital plane. The synchronism between the orbital period and the rotational period of the Earth ensures that this intensity modulation is maintained. A high time variability and clear periodicity are present. Just prior to the large increases, it is common to see a brief, large decrease. The rise time in the >3.5 -MeV electron channel is noticeably longer than that in the >1.5 -MeV channel, whereas the fall times are comparable.

In Figure 1b the solar-wind speed from WIND and the radiation-belt data from 1994-026 are plotted for the central time period of the interval shown in Figure 1a. The five large, abrupt increases in solar-wind speed are labeled A through E. It can be seen that two of the increases, A and D, were of the type described earlier (Paulikas and Blake 1979, Baker *et al.* 1994); at onset, the radiation intensity dropped substantially for a brief period (~ 12 h), followed by a more gradual, energy-dependent increase. Cases B and E also show a radiation decrease near the time of the onset of the high-speed wind.

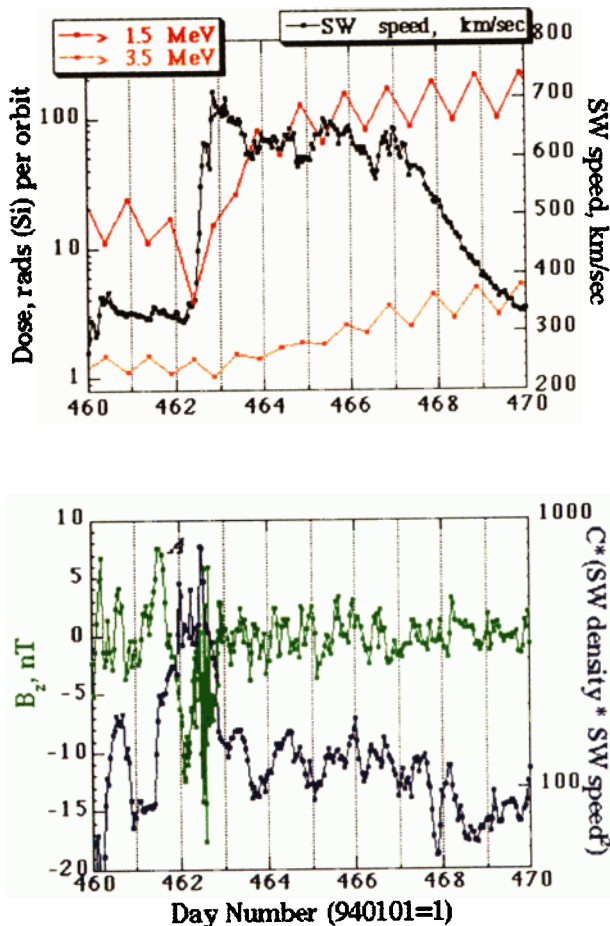


Figure 2. The data from Fig. 1 are plotted in the top panel on an expanded time scale for the Case A time period. In the bottom panel, the quantity $\rho_{sw} v_{sw}^2$ is plotted, suitably scaled, as well as the z component of the interplanetary magnetic field.

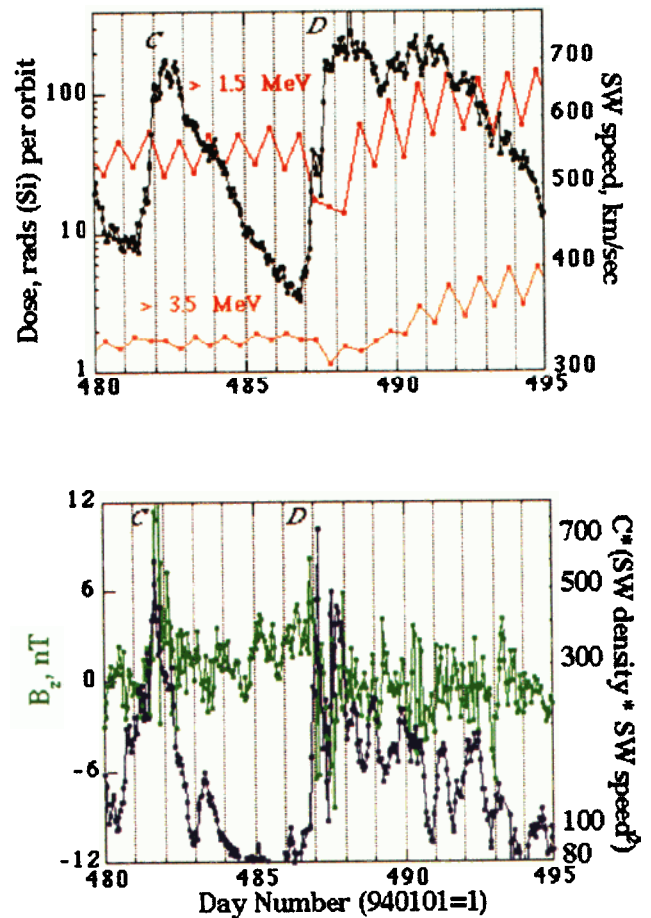


Figure 3. The two panels are similar to those in Fig. 2, showing the observations for Cases C and D.

However, associated with Case B, there was no intensity increase, and for Case E, a modest increase was seen only in the >1.5 -MeV channel. However, in both Cases, B and E, the increase in solar-wind speed was relatively small. Case C is quite different from the others. The solar-wind speed increased to a high value without an initial decrease and subsequent increase in radiation intensity.

Figure 2a shows the time period around Case A on an expanded timescale; Figure 2b shows $\rho_{sw} v_{sw}^2$, suitably scaled, and the z-component of the interplanetary magnetic field. The pressure pulse ahead of, and during, the rise in solar-wind speed and the southward turning of the interplanetary field appear as precursors of the loss of the energetic electrons. Figure 3a,b is similar for Cases C and D in that a pressure pulse leads the solar-wind speed increase, but the response of the energetic electrons is quite different. In particular, in Case C, there is no observable effect of the high-speed solar wind upon the population of energetic electrons. However, the interplanetary field turned northward in Case C rather than southward as in Case D (and Case A).

Discussion

The five cases plotted in Figure 1b may be summarized as follows.

Case A: There was a large increase in the solar-wind velocity, a large pressure pulse, and a southward turning of the inter-

planetary field. The relativistic electrons first strongly decreased over a few hours, and then increased over the next several days to a level much higher than prior to the arrival of the high-speed solar wind.

Case B: Similar to Case A except that the solar-wind speed increase was much smaller. It appears to have been inadequate to cause a large increase in the relativistic electron intensity, although an initial rapid decrease was seen.

Case C: The solar-wind increase was much greater than that in Case B, and the interplanetary field turned northward rather than southward. Relativistic electrons were neither lost nor accelerated.

Case D: This case is similar to Case A.

Case E: This event is similar to Case B, although the solar-wind velocity was somewhat larger. The relativistic electrons showed an obvious increase following the decrease.

Over a dozen examples were observed in the Spring of 1995. What we have shown here is representative, with the cause and effect relationship being clearer when there is large increase in the solar-wind speed followed by a several day period without a subsequent increase in solar-wind speed. Isolated events avoid the complexity of multiple factors. The southward turning of the interplanetary magnetic field seems to be a key factor. If the interplanetary magnetic field turns southward, a high-speed stream and leading pressure pulse have a strong effect on the energetic electron population in the Earth's magnetosphere. If the field turns clearly northward, the effect of the high-speed stream is nil. It has been argued that the southward turning of the magnetic field is associated with substorm-injected electrons in the energy range from a few tens to a few hundred keV (Baker *et al.* 1996) that can serve as a seed population for subsequent acceleration to relativistic energies. However electrons are present that could be further accelerated whether or not the field turns southward, *cf.* Case C. It seems that the process is more complex than simply providing an energetic electron seed population by means of a substorm(s). Note also that the loss process can occur without subsequent acceleration of electrons to relativistic energies. The brief period of decreased fluxes (the electron loss) suggests perhaps an adiabatic process engendered by the pressure pulse; the limited data from 1994-026 precludes an investigation of this surmise.

It appears that for Space Weather purposes, measurements of the solar-wind speed and density, along with the interplanetary magnetic field would permit forecasting near solar minimum the overall intensity of the outer-zone relativistic electron population.

Acknowledgements. This work was supported at the Aerospace Corporation under NASA Cooperative Agreement 26979B, and at the University of Colorado by NAG5-2635.

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- J. B. Blake, Space Sciences Department, The Aerospace Corporation, P. O. Box 92957, MS: M2/259, Los Angeles CA 90009-2957. (e-mail: blake@dirac2.dnet.nasa.gov)
- D. N. Baker, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO. (e-mail: baker@lynx.colorado.edu)
- N. Turner, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO. (e-mail: turner@kitron.colorado.edu)
- K. W. Ogilvie, NASA/Goddard Space Flight Center, Greenbelt, MD. (e-mail: u2kwo@lepvax.gsfc.nasa.gov)
- R. P. Lepping, NASA/Goddard Space Flight Center, Greenbelt, MD. (e-mail: u5rpl@lepvax.gsfc.nasa.gov)

(Received October 14, 1996; revised January 7, 1997; accepted February 24, 1997.)