Relativistic Electron Precipitation Patterns in Longitude and Latitude: A Reply to W. R. Sheldon, Et Al.

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16 February 1989

Prepared for

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This report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-85-C-0086-P00019 with the Space Division, P.O. Box 92960, Los Angeles, CA 90009-2960. It was reviewed and approved for The Aerospace Corporation by H. R. Rugge, Director, Space Sciences Laboratory.

Lt Clarence V. Wilcox was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) Program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b DECLASSIFICATION DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) TR-0088(3940-06)-6	5 MONITORING ORGANIZATION REPORT NUMBER(S) SD-TR-89-05
6a NAME OF PERFORMING ORGANIZATION The Aerospace Corporation Laboratory Operations 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Space Division
6c ADDRESS (City, State, and ZIP Code) El Segundo, CA 90245	7b ADDRESS (City, State, and ZIP Code) Los Angeles Air Force Base Los Angeles, CA 90009-2960
8a NAME OF FUNDING SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F04701-85-C-0086-P00019
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
Relativistic Electron Precipitation Patterns in Longitude and Latitude: A Reply to W. R. Sheldon et al.

12 PERSONAL AUTHOR(S)
Baker, D. N. (Goddard Space Flight Center), Blake, J. B. and D. J. Gorney (The Aerospace

13a TYPE OF REPORT	13b TIME COVERED FROM ____ TO ____	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
		1989 February 16	10

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Precipitation fluxes

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

In an earlier paper by the authors, a proposal was made that the precipitation of relativistic electrons from the outer magnetosphere into the Earth's atmosphere could have substantial effects on the chemistry of the middle atmosphere. It has been argued that our earlier estimates of precipitation fluxes may have underestimated the precipitation rates in isolated regions, such as the South Atlantic Anomaly, and overestimated the precipitation in other latitude and longitude sectors. Here, we discuss the factors which influence the longitudinal uniformity of relativistic electron precipitation and the implications of our earlier assumption of uniform precipitation.

20 DISTRIBUTION AVAILABILITY OF ABSTRACT ☑ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code) / 22c OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

12. PERSONAL AUTHOR(S) (Continued)

Corporation), Higbie, P. R., Klebesadel, R. W., and King, J. H. (Los Alamos National Laboratory)

PREFACE

We appreciate very useful conversations with L. B. Callis, M. S. Gussenhoven, and W. R. Sheldon concerning this work. This research was supported by NASA, the U. S. Department of Energy, and by the U. S. Air Force.

In their commentary, Sheldon et al. (1988) point out that the asymmetry of the geomagnetic field relative to the terrestrial surface and overlying atmosphere leads to exceptionally low mirror altitudes for trapped energetic particles with small equatorial pitch angles in the South Atlantic Anomaly (SAA) region. It has been realized for a long time that this feature of the geomagnetic field can result in a strong geographical localization of electron precipitation. Sheldon et al. (1988) therefore conclude that Baker et al. (1987) may have underestimated the precipitation rate of MeV electrons in the South Atlantic Anomaly and overestimated the electron precipitation rate in other latitude and longitude sectors.

In an earlier version of our paper (Baker et al., 1987), we discussed in some detail the issue of non-uniformity of energetic electron precipitation over the outer zone region. We had explicitly noted that the substantial symmetry in the geomagnetic field could give an enhancement in the relativistic electron precipitation in the Southern Hemisphere. We had discussed also that one would not expect precipitation that results from wave-particle interactions to be uniform in longitude, latitude, local time, or time. It is clear that the intensity and energy spectrum of the precipitating electrons will depend upon these and probably other factors. However, the data necessary to model adequately these aspects in any detail, to our knowledge, do not exist. For this reason we decided to restrict our discussion to the simplest case, that of uniform precipitation in latitude and longitude throughout the outer-zone region, recognizing that it must be a great simplification of the real-world situation.

A few specific comments on the effect of the SAA on electron precipitation can be made. The magnitude of the anomaly in the geomagnetic field is a strong function of latitude; by the time the synchronous orbit region is reached, it is small (Gledhill, 1976). A dependence of precipitation rates upon geographic longitude in the synchronous region, where our measurements were made, is not observed (cf., Vampola and Gorney, 1983). Thus, observations referred to by Sheldon et al. (1988) are not characteristic of the situation throughout the outer zone.

The Defense Meteorological Satellite Program (DMSP) spacecraft have made some measurements relevant to this issue. Since the DMSP spacecraft are in a polar, 840-km altitude orbit, their sensor systems respond largely to precipitating particle populations and to particles near the edge of the equatorial loss cone (Gussenhoven et al., 1987). The DMSP electron dosimeter experiment has provided a long-term monitor of the electron environment above several different energy thresholds. Figure 1 shows a yearly averaged (November 1984 - October 1985) map of the measured electron dose $\geq$ 1.0 MeV for the DMSP F7 spacecraft as a function of magnetic latitude and magnetic longitude.

The figure shows quite clearly the strong electron precipitation associated with the SAA: This is the intense patch of energetic particle fluxes extending from 0° to ~-40° geomagnetic latitude and centered at ~30° geomagnetic longitude. [Note that this feature probably also contains a large proportion of high energy protons from the inner zone which are not excluded by the DMSP dosimeter (Gussenhoven et al., 1987).] As stated by Sheldon et al. (1988), the SAA precipitation is a significant feature. However, the DMSP data also show intense bands of >1 MeV electrons at higher latitudes (50°-70°) and extending rather substantially around the Earth in longitude. These are the relativistic electron features that Baker et al. (1987) documented at higher energies and interpreted as being of middle atmospheric significance. Indeed, the DMSP latitudinal pattern shown is very similar to that used by Baker et al. (1987) for their global energy input calculations.

In a study of the global electron relationship, Higbie et al. (1987) compared daily averages of electron fluxes measured on four different spacecraft platforms. This included the Spectrometer for Energetic Electrons (SEE) $\gtrsim$2 MeV data at 6.6 R_E reported by Baker et al. (1987), the >1 MeV DMSP data summarized above in Fig. 1., available $\gtrsim$0.5 MeV electron measurements from the Global Positioning Satellite (GPS) at a 4 R_E circular orbit (inclination ~60°), and >1 MeV electron data from a satellite in a Molniya-type orbit. It was found that virtually every significant flux peak in the SEE data has its counterpart in the DMSP data. Higbie et al. (1987) noted that this correspondence extended also to the GPS and the Molniya data sets. Hence, it was on this basis that it was concluded that there was a truly global, reasonably homogeneous relativistic electron population in the Earth's outer magnetosphere and that there is a remarkably close temporal correlation between electron fluxes measured at DMSP and at geostationary orbit.

We are presently trying to quantify and extend our understanding of the precipitation of relativistic electrons in the outer magnetosphere. We have been carrying out studies with Callis and coworkers (Callis and Natarajan, 1986; Callis et al., 1988) in an attempt to directly relate changes in the middle atmospheric chemistry to enhancements in outer zone relativistic electrons. Such direct correlations, if they exist, clearly are part of the definitive evidence -- the "smoking gun" -- we seek. We are convinced that data from rockets, balloons, and low-altitude satellites collected on a long-term basis are required to resolve the question of the significance of these relativistic electrons within the context of middle atmosphere-magnetosphere coupling. We believe that observations such as described by Sheldon et al. (1988) will be part of the complete story and that, at lower latitudes, effects of the SAA will appear.

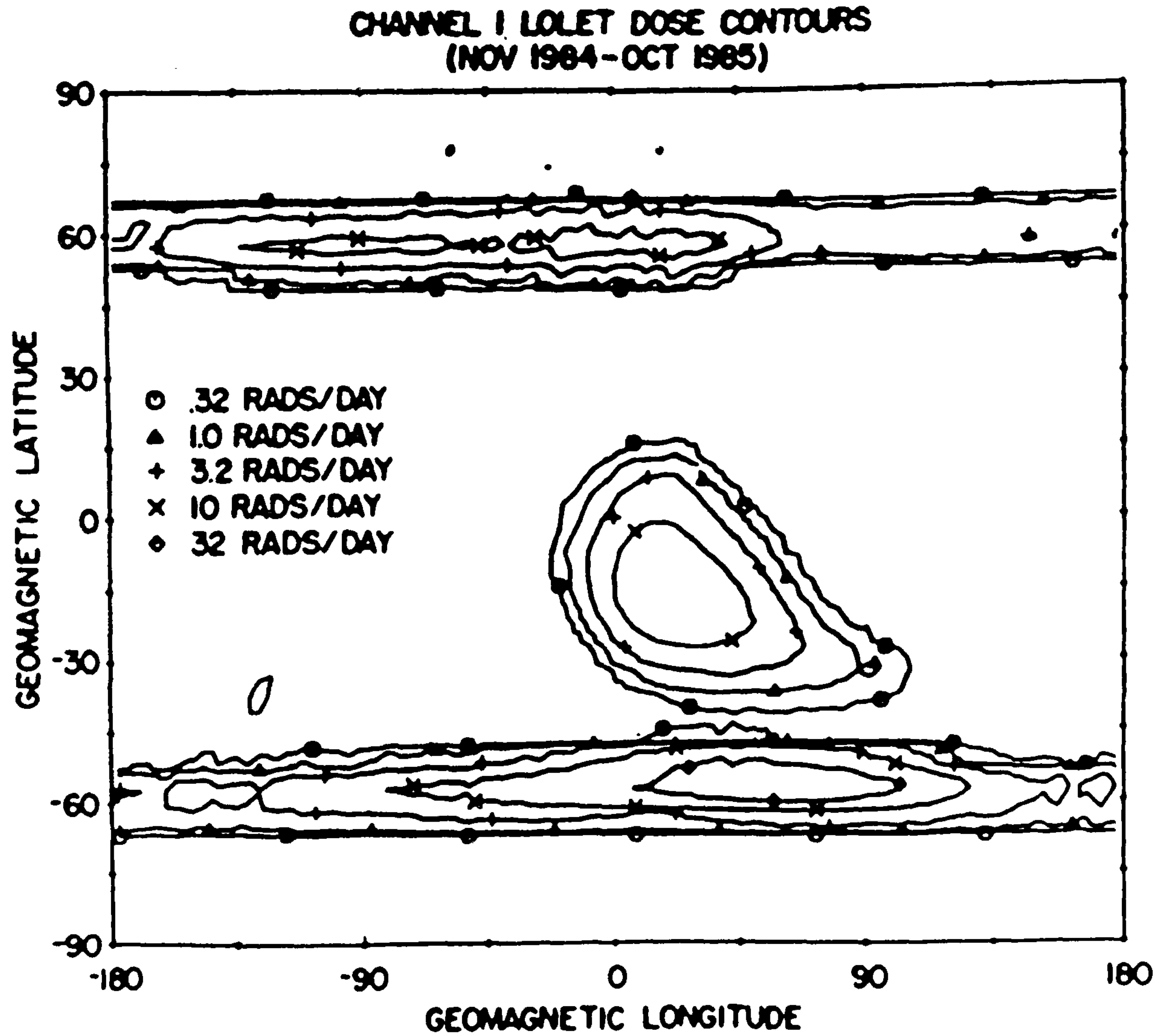

Fig. 1. Map of Energetic Electron Dose as Observed by the DMSP F7 Satellite at Low Altitude Averaged Over One Year (Nov. 1984 - October 1985). In this geomagnetic coordinate system, the horns of the outer radiation belt correspond to bands at geomagnetic latitudes, centered near ±60°. An additional intense region of particle precipitation (due to the Earth's asymmetric magnetic field) is near longitude 30° in the southern hemisphere as discussed in the text. (From Gussenhoven et al., 1987.)

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