ARTICLE IN PRESS

Journal of Atmospheric and Solar-Terrestrial Physics xxx (2017) 1–10

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

# Mapping the South Atlantic Anomaly continuously over 27 years

P.C. Anderson [a,*], F.J. Rich [b], Stanislav Borisov [c]

[a] W. B. Hanson Center or Space Sciences, University of Texas at Dallas, 800 W Campbell Rd. MS WT15, Richardson, TX 75080-3021, USA
[b] M.I.T. Lincoln Laboratory, Group 97, 244 Wood Street, Lexington, MA 02421, USA
[c] Université Catholique de Louvain Center for Space Radiations, Building Marc de Hemptinne, Chemin du Cyclotron, 2, B-1348, Louvain-la-Neuve, Belgium

ARTICLE INFO

*Keywords:*
South Atlantic Anomaly
Radiation belts
Energetic electrons and protons

ABSTRACT

The South Atlantic Anomaly (SAA) is a region of reduced magnetic intensity where the inner radiation belt makes its closest approach to the Earth's surface. Satellites in low-Earth orbit pass though the SAA periodically, exposing them to several minutes of strong radiation each time, creating problems for scientific instruments, human safety, and single event upsets (SEU). For the first time, we are able track the SAA movement continuously over 27 years, using overlapping satellites in similar orbits with similar instruments. The Defense Meteorological Satellite Program (DMSP) spacecraft have been carrying the Special Sensor J (SSJ) precipitating energetic particle spectrometers since 1982. The instruments are susceptible to MeV electrons and protons that pass through the spacecraft skin and instrument case and get counted. This "background" is easily identified and we use it to map the movement of the SAA. Comparison with energetic particle data from the Energetic Particle Telescope (EPT) instrument on the Proba-V spacecraft indicates that the best match with the SSJ data occurs in the energy range above about 2.6 MeV for electrons and above about 29 MeV for protons. The peak flux and extent of the SAA from both the SSJ and EPT instruments are nearly identical in longitude while in latitude, the peak EPT flux is 5° south of the peak SSJ flux. However, the shapes of the SAA in latitude and the locations of the outer radiation belts are nearly identical. We find that the SAA moves 0.06° N/yr and 0.28° W/yr. We also find a difference with the movement and location of the SAA from the contamination by high energy particles on the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) instrument on DMSP F16 (*Shaefer* et al., 2016). However, the SSUSI instrument is located on the opposite side/bottom of the spacecraft and *Shaefer* et al. (2016) estimated that most of the particle noise pulses in the SSUSI instrument are produced by protons greater than about 45 MeV. Thus the contamination in the SSUSI instrument is produced by a different population of particles that the contamination in the SSJ/5 instrument which would lead to differences in movement and location of the SAA. While this study focuses on the SAA movement on a yearly basis, further analysis will allow us to investigate the movement on shorter time scales, the variation of the flux intensity, the spatial extent of the SAA, and the dynamics of the outer radiation belt.

## 1. Introduction

The SAA (Kurnosova et al., 1962) is a region of weakened geomagnetic field centered in southeast South America. Because of the weakened magnetic field, inner radiation belt particles can mirror at lower altitudes increasing the local particle flux. It is thus the region where the inner radiation belt makes its closest approach to the Earth's surface. Satellites in low-Earth orbit pass though the SAA periodically, exposing them to several minutes of strong radiation each time: the International Space Station requires extra shielding to deal with this problem and astronauts on extravehicular activity try to avoid it. The energetic increased particle flux can also produce 'glitches' or noise in astronomical data. For instance, the Hubble Space Telescope is turned off when passing through the SAA. It can cause problems in on-board electronic systems - single event upsets (SEUs), cause premature aging of computer, detector and other spacecraft components, and is said to be the cause of peculiar 'shooting stars' seen in the visual field of astronauts. Fig. 1 shows the location of a number of SEUs observed on the UoSAT-2 spacecraft in 1988 and 1989 (Underwood, 1990). Also plotted are the geomagnetic field strength contours at 700 km (the spacecraft altitude) for the year 1989 as calculated by the International Geomagnetic Reference Field (IGRF) geomagnetic field model. It is very clear that most of the SEUs

* Corresponding author.
*E-mail addresses:* phillip.anderson1@utdallas.edu (P.C. Anderson), frederick.rich@ll.mit.edu (F.J. Rich), stanislav.borisov@uclouvain.be (S. Borisov).

https://doi.org/10.1016/j.jastp.2018.03.015
Received 7 July 2017; Received in revised form 10 December 2017; Accepted 20 March 2018
Available online xxxx


Please cite this article in press as: Anderson, P.C., et al., Mapping the South Atlantic Anomaly continuously over 27 years, Journal of Atmospheric and Solar-Terrestrial Physics (2017), https://doi.org/10.1016/j.jastp.2018.03.015

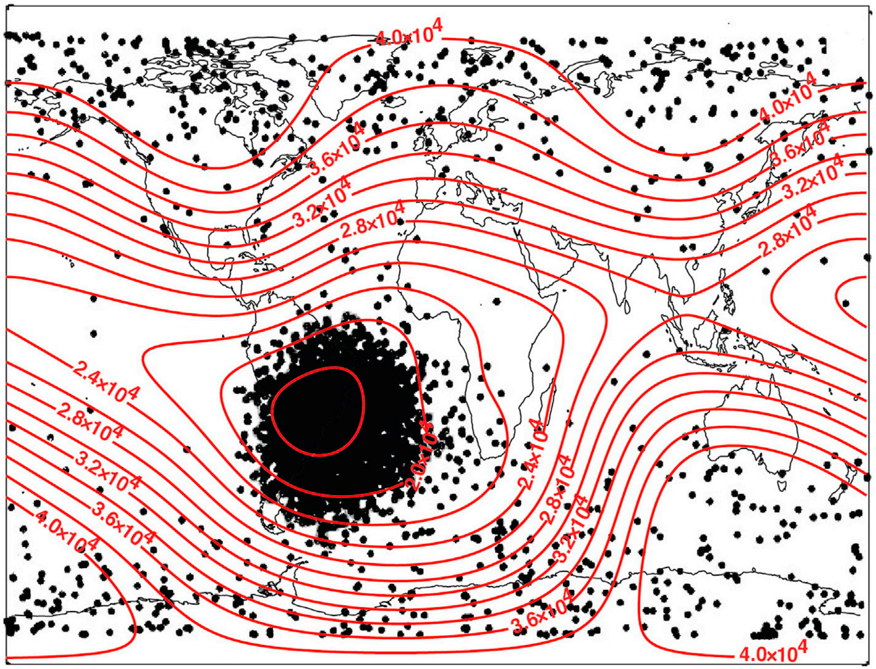


**Fig. 1.** The location of a number of SEUs observed on the UoSAT-2 spacecraft in 1988 and 1989. The red lines are contours of geomagnetic field strength at 700 km and the numbers indicate the strength of the magnetic field in nT. [adapted from Underwood (1990)]. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

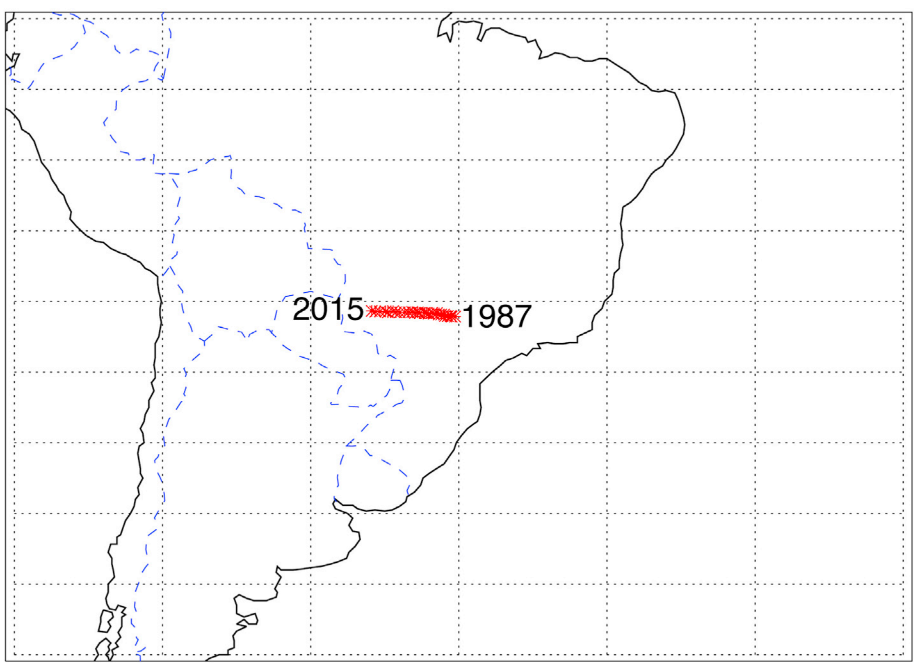


**Fig. 2.** The location of the geomagnetic field minimum for the years of 1988 through 2015.

occur within the SAA (the other geographically distributed SEUs are likely caused by galactic cosmic rays). It is thus very important to understand the dynamics of the SAA and how the variation in the Earth's geomagnetic field and the radiation belts affects the strength and location of the energetic particle fluxes.

At present the strength of the Earth's magnetic field is decreasing by about 5% every hundred years (Merrill and McElhinny, 1983); in the SAA, the strength of the magnetic field is decreasing ten times as fast. The location of the minimum geomagnetic field within the SAA is also known to show a secular variation with time, associated with the changing of the magnetic moment, moving steadily westward and northward. Fig. 2 shows the yearly variation of the geomagnetic field minimum as calculated by the epoch appropriate IGRF at 800 km (the nominal altitude of our energetic particle measurements) for the years of 1988 through 2015. The movement is not exactly linear in latitude and longitude (indeed there are also short term variations); the movement is approximately 0.204° GLON west and 0.13° GLAT north per year. While the location of the peak in energetic particle flux is close to the geomagnetic field minimum, it also depends on the particle distribution in the radiation belts, the energy of the observed particles, and the altitude of