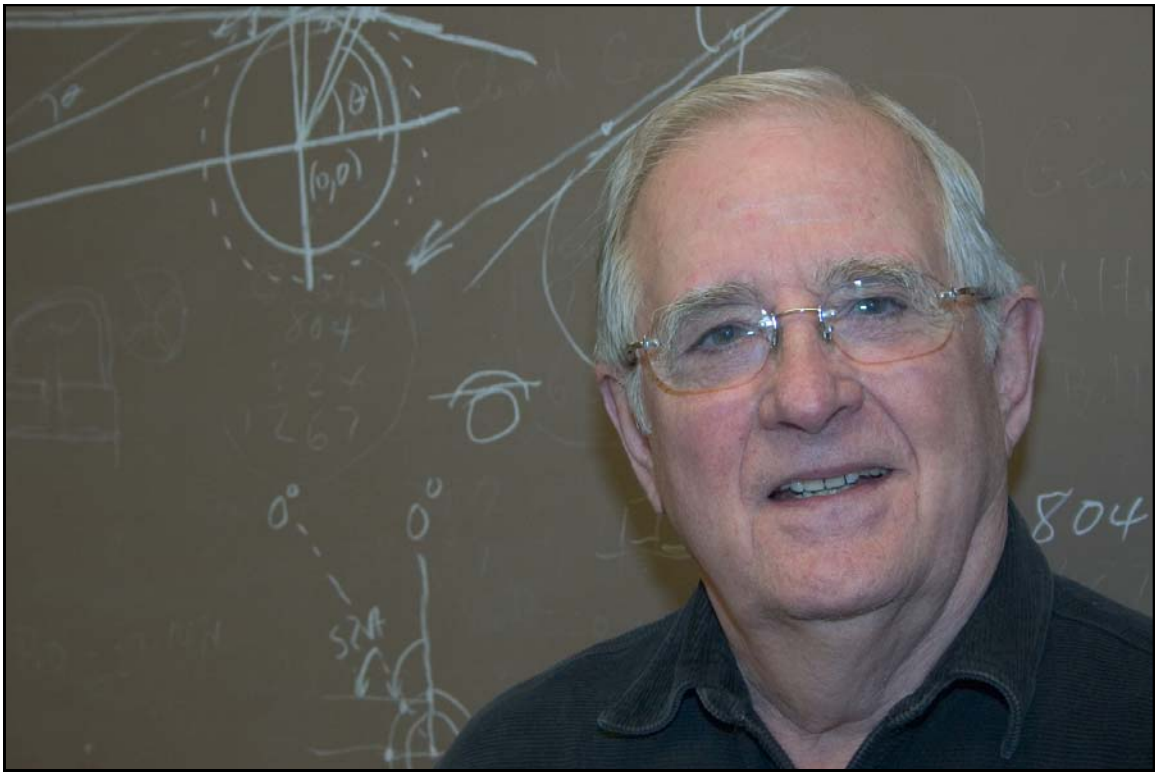

A Proposal To Investigate the Steady-State Interaction of the Outer Van Allen Belt with the Atmosphere

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Abstract—A manuscript describing the steady-state interaction of the outer belt with the atmosphere has been prepared. A team of investigators with developed rocket payloads has been assembled and an Expression of Intent to investigate this interaction with rocket flights from Halley Bay, Antarctica has been submitted to the Coordinating Board of the International Polar Year (IPY). A proposal to develop an electron/X ray detector for the rocket payload has been submitted to NASA. The goals of this proposal have been attained to the extent possible.

A MAXIMUM IN THE FLUX OF OUTER BELT ELECTRONS trapped in the geomagnetic field is observed at L = 4. (This field line crosses the equator 4 Earth radii from the center of the Earth.) A calculation by our UH group[1] of the equatorial pitch angle (EPA) of trapped electrons mirroring at 100 km at L = 4 vs. E. Longitude defines the drift loss cone (DLC) for this L-shell: electrons that diffuse (or scatter) to values of EPA less than the maximum value (6.5° at L = 4) become temporarily trapped; they continue to bounce between their northern and southern conjugate points until eastward drift transports them to a location where they are at, or below, 100 km, an altitude where electron mean-free-paths are sufficiently short that interaction with the atmosphere occurs.

During the decade following its discovery, the outer belt was found to have a large transient population, with abrupt increases at times of geomagnetic activity, followed by a steady decrease to the background level over the next ten days or so. However, the sink for this enormous quantity of electrons was not identified. Global electron data from low-altitude satellites became available only some three decades after the radiation belts were discovered. These data, shown in Figures 1 and 2 from the DMSP[2] and SAMPEX[3] satellites respectively, strongly suggest that outer belt electrons are lost in the atmosphere, since large coherent electron fluxes are observed so close to the Earth. Comparison of these satellite data to the UH calculation at L = 4 facilitate their interpretation, as shown in Fig. 3.

The UH calculation has been elaborated by introducing an additional line to indicate the extent to which the DLC is populated with trapped electrons. The placement of this line is based on measurements made with rocket-boosted, parachute-deployed payloads flown by our UH research group at Siple Station, Antarctica, and at Kerguelen, two L = 4 locations in the southern hemisphere. The calculation with this modification included, indicating that the DLC is about half filled with electrons, is shown in Fig. 3A. Comparing the satellite data shown in Figs. 1 and 2 to the L = 4 crossing points of these satellites shown in Figs. 3B and 3C, indicates that they are trapped electrons in the DLC, or at slightly higher altitudes, just prior to diffusing into the DLC.

Since the DLC is only about half filled, it follows that loss of electrons is a two-step process. Diffusion of electrons to increasingly smaller values of EPA (i.e., increasingly more field aligned as they cross the equator) probably caused by interactions with electromagnetic waves, drives them into the DLC, but very few of them interact with the atmosphere as a result of this process; they are transported into the atmosphere almost entirely by subsequent eastward drift in the DLC. As a consequence, almost all outer belt electrons are lost by interaction with the atmosphere between E. Longitudes of 260° and 20° at L = 4. There are several consequences to this interaction, since the very energetic outer belt is dumped as a steady-state collision in such a restricted region. As can be seen in Fig. 2, the outer belt is rather limited in latitudinal extent, so the collision of the outer belt with the atmosphere occurs principally over the Weddell Sea and somewhat to the east, as shown in Fig. 4, where this Outer Belt-Atmosphere

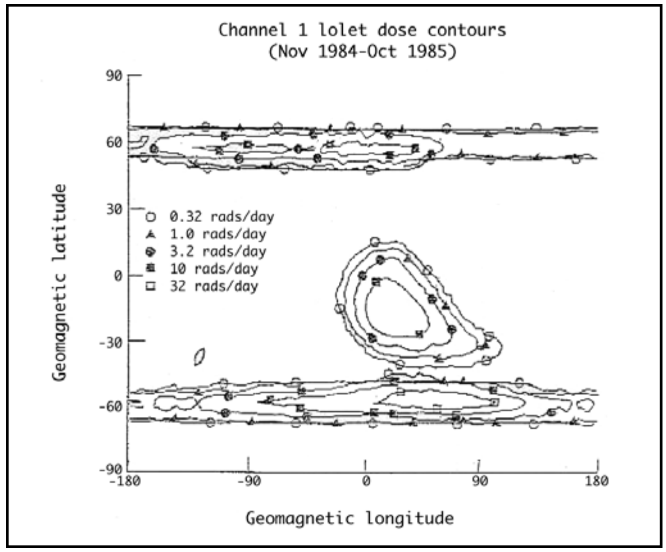

Figure 1. Data from the DMSP dosimeter[2] due to energetic electrons (> 1 MeV); average daily dose rate for the year November 1984–October 1985. The satellite was in a circular polar orbit at an altitude of 840 km. Compare the maximum average daily dose rate at a geomagnetic latitude of 60° (L = 4) of > 32 rads/day to the *annual* maximum allowable radiation dose for an astronaut of 25 rads. The nearly circular region of high intensity at near-equatorial latitudes is attributed to inner Van Allen belt particles and is of no interest for this study.

Interaction Region is labeled the OB-AIR.

In addition to being confined to a restricted geographic region, the OB-AIR is restricted in altitude, as well, since individual collisions with atmospheric molecules involve mirroring electrons that are traveling horizontally when they interact. The properties of the OB-AIR are: (1) a unique atmospheric domain is created, (2) a boundary layer in the Sun-Earth system is formed, (3) a large flux of backscattered electrons is generated, and (4) the trapped population at locations other than the interaction region is forced to altitudes well above the ionosphere, as shown in Fig. 5.

Goals of the Project

The goals of this project were to (1) prepare a manuscript describing the interaction of the outer belt with the atmosphere, (2) assemble a team of investigators to conduct an investigation of this region using sounding rockets, (3) prepare a proposal to conduct the rocket flights, and (4) begin the development of an electron/X-ray detector for the rocket payload.

Results

An article describing the interaction of the outer belt with the atmosphere was prepared. It was submitted to *Nature*; after a great deal of communication on the paper, an editorial decision not to publish was made. The article will need to be reformatted for publication elsewhere.

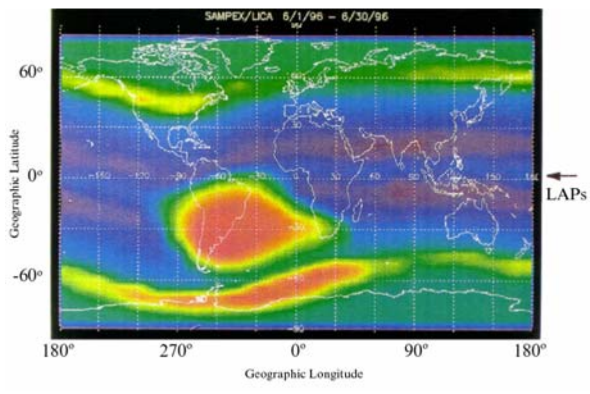

Figure 2. Data from the SAMPEX satellite: Plate 1 of their paper.[3] The satellite was in a nearly polar orbit at an inclination of 82°, and the orbit was almost circular with altitudes varying from 520 to 670 km. The peaks near ± 60° are produced by outer radiation belt electrons > 500 keV. The "warm spot" south of Greenland cannot be caused by trapped electrons since they would mirror below ground level in Antarctica. The prominent feature centered over South America is caused by particles of the inner belt and is of no interest here.

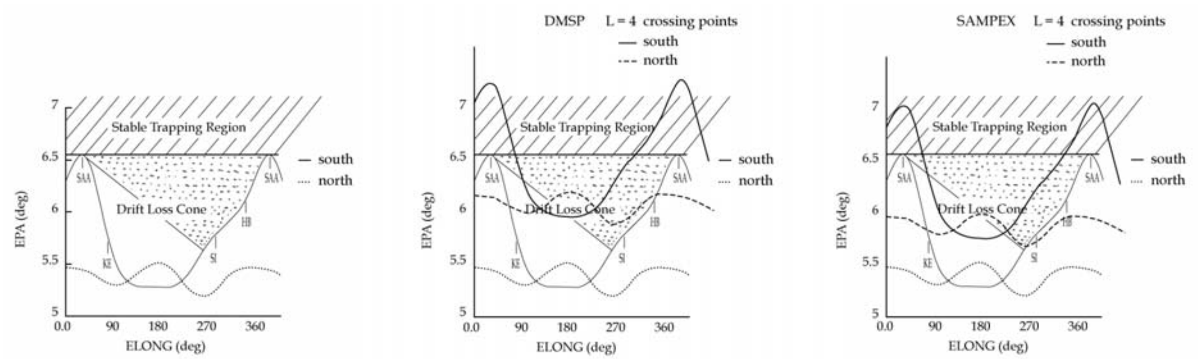

Figure 3. (A) Calculation of the equatorial pitch angle (EPA) of electrons mirroring at 100 km altitude at L = 4 as a function of longitude for both hemispheres;[1] the 100 km mirror points in the south are indicated by a solid line and those in the north by a dotted line. Shown are the Stable Trapping Region (STR) and Drift Loss Cone (DLC); in the STR an electron can drift around the Earth without encountering the atmosphere; in the DLC, it cannot. Only about half of the DLC is estimated to be populated with trapped electrons. Also shown are the locations of Kerguelen (KE), Siple Station (SI), Halley Bay (HB), and the South Atlantic Anomaly (SAA); SAA is where the surface value of the geomagnetic field is a minimum.

(B) The same calculation with the L = 4 crossing points of the DMSP satellite overlaid. It can be seen for both hemispheres that the calculation gives an accurate description of the data shown in Fig. 1. The southern region of peak intensity at 0°-90° geomagnetic longitude (270°-50° E. longitude) occurs when the satellite is in the STR and the upper and eastern portions of the DLC; east of the peak, the decrease in intensity is rapid as the satellite, in only a few degrees in longitude, samples the western portion and near the empty portion of the DLC; west of the peak, the decrease is more gradual as increasingly deeper regions of the DLC are sampled; also, the region of lowest intensity is predicted at geomagnetic longitudes of 180° ± 20° (110° ± 15° E. longitude). In the northern region of peak intensity, electron fluxes are lower than in the south since a lower portion of the DLC is sampled; the abrupt decrease east of the peak corresponds to satellite locations in the "shadow" of the absorbing atmosphere in the southern hemisphere; the more gradual decrease west of the peak corresponds to the more westerly portion of the DLC, including the portion estimated to be empty. Perhaps, the dip in the peak at the northern geomagnetic latitude of 60° at around the geomagnetic longitude of -40° (260° E. longitude) is due to sampling the deepest portion of the DLC by the satellite at that location.

(C) The same calculation with the L = 4 crossing points of the SAMPEX satellite overlaid. The data of Fig. 2 are described quite well. Peak intensities in the southern hemisphere correspond to passage of the satellite through the STR and the eastern portion of the DLC, with a more rapid decrease east of the peak, corresponding to the most western portion of the DLC and the portion estimated to be empty; westward from the peak corresponds to increasingly deeper locations in the DLC. The intensity in the north is predicted to be much lower than in the south, since the crossing points just skirt the filled portion of the DLC and become negligibly small between the conjugates of Siple Station and Kerguelen (southeast Quebec and Arkangel on the White Sea in Russia, respectively, where the crossing points are in the "shadow" of the southern atmosphere. An interesting exception in Fig. 2 is the isolated "warm spot" just south of Greenland; it is perhaps the only observation of precipitating electrons in Fig. 2.

Investigators with fully developed detectors needed for the experimental payload were located and, after the scientific basis of the project was described to them, agreed to participate in the project and the proposal. Also, further discussions were conducted with Dr. Mike Pinnock of the British Antarctic Survey (BAS) and his colleagues. BAS has the only research station capable of the scientific and logistic support needed for the project. They support the project strongly and are prepared to offer the transportation of equipment and personnel to their base at Halley Bay, Antarctica, as well as food, lodging, and laboratory space for the rocket team as their contribution to the collaboration. In addition, Dr. Pinnock offered to travel to the U.S. to discuss any outstanding questions with NASA rocket engineers and to indicate to U.S. program managers the support of BAS for the rocket campaign.

Discussions with project managers at federal agencies indicated there are no research opportunities available for the rocket project at this time. A re-organization at NASA placed support for rocket expeditions temporarily on hold. However, there were two encouraging developments. (1) A research initiative, the International Polar Year (IPY), was announced for 2007-2008; our project appears to be ideal in this regard. An "Expression of Intent" to propose our project has been filed with the IPY Coordinating Board. (2) A NASA Research Announcement (NRA) for the program entitled "Living With a Star Targeted Research and Technology" was amended to include interest in "the radiation belt slot region and the adjacent outer zone flux peak around the magnetic L-shell value = 4." Discussions with the project manager for this program indicated that support was not available for the rocket expedition we envisioned, but that there was possible support for instrument development. A proposal to develop the electron/X-ray detector to investigate the outer belt interaction with the atmosphere was made in response to this NRA. A UH team to develop this detector was organized in the Physics Department, including Dr. Keijan Lan, an expert in accelerator instrumentation, and Jeffrey Chancellor, a graduate student in physics. Separate (non-ISSO) support was found for these two individuals to attend a conference in October 2004 on state-of–the–art particle/photon detectors; discussions with vendors there indicated that a detector suitable for the rocket payload could be developed with components presently available.

The fact that outer belt electrons interact with the atmosphere while traveling horizontally was considered to be a potentially important aspect of the interaction phenomenon; therefore, we investigated this question using the FLUKA radiation transport code, a Monte Carlo program. Usually isotropic electron fluxes are assumed for calculations of electrons interacting with the atmosphere; here, calculations were performed assuming both horizontal and isotropic fluxes for comparison. It was found that horizontal interactions result in electron penetration of the atmosphere to much more shallow depths (65 km altitude [horizontal] vs. 40-50 km [isotropic], a difference of ≈ 4 scale heights),[3] and that horizontal primary electron fluxes cause about ten times more backscattering compared to isotropic fluxes. An article on this topic has been written and submitted to *Advances in Space Research*.

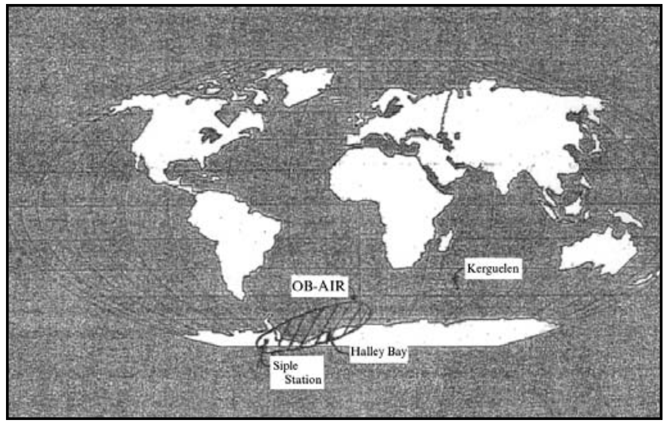

Figure 4. The Outer Belt–Atmosphere Interaction Region (OB-AIR). The region of steady-state interaction of the outer Van Allen belt with the atmosphere. Energetic electrons transfer a great deal of energy here, probably causing the greatest non-photonic energy input to the atmosphere, except for the largest solar proton events. Note the estimated variation in the western boundary of this region. A more remote location to conceal a region the size of the Sahara Desert can hardly be imagined. It is possibly the largest unexplored feature on the Earth's surface.

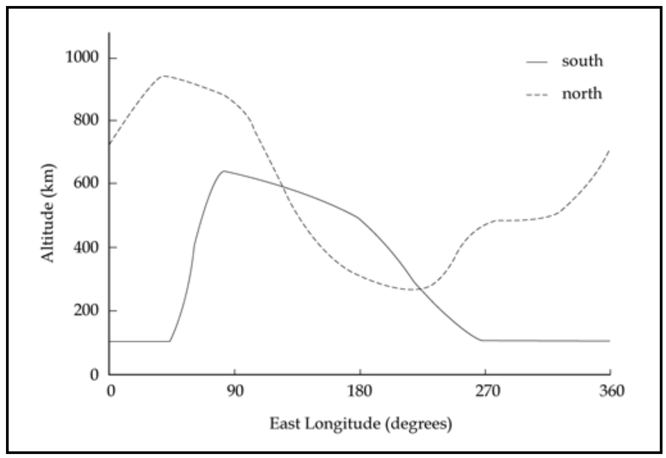

Figure 5. The altitude of the outer belt as a function of longitude at L = 4; specifically it is the altitude of the filled portion of the Drift Loss Cone (DLC) determined from Fig. 3A. It is at an altitude of 100 km in the interaction region, the OB-AIR.

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[2]M. S. Gussenhoven et al. "New Low-Altitude Dose Measurements" IEEE *Trans*. Nuc. Sci. NS-34 (1987): 676-79.

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Sheldon, W. R., V. Andersen, and L. S. Pinsky. "Monte Carlo Study of Secondary Electrons and X-Rays Produced by Vertical vs. Horizontal Arrival of Precipitating Electrons at the Top of the Atmosphere," Joint Assembly of American Geophysical Union and Canadian Geophysical Union, Montreal, Canada, May 17–21, 2004.

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Funding and Proposals

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"Rocket Investigation of the Steady-State Collision of the Outer Belt with the Atmosphere," Expression of Intent For Activities in IPY [International Polar Year]. This proposal will be considered by the Joint Committee for IPY 2007-2008 in 2005. Their recommendation will be useful in proposals to agencies for funding.