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Van Allen Probe Database of Near-Equatorial Electric Drift Measurements: the Gateway to Informed Modeling of Plasma Transport in the Earth's Inner Magnetosphere

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Abstract

Even very close to Earth, plasma transport observations are inconsistent with the theoretical picture in which the large-scale electric field is a superposition of corotation and convection electric fields. The instruments onboard the Van Allen Probes are the first to be accurate enough to measure the electric drift around the magnetic equator, even below 3 Earth radii. They provide much-needed ground truth in a region of space historically deprived from in-situ electric field measurements. Therefore, the Van Allen Probe database of near-equatorial electric drift measurements represents our first opportunity (1) to further our understanding of the coupling between the magnetosphere and the ionosphere at middle and low latitudes and (2) to fully question, confirm, or disprove the validity of various models and assumptions that have been made to describe plasma transport in the Earth's inner magnetosphere. In the following, we present the latest advances in understanding plasma transport in the Earth's inner magnetosphere enabled by the analysis of Van Allen Probe electric drift measurements.

1. Introduction

The electric drift $\mathbf{E} \times \mathbf{B}/\mathrm{B}^2$ plays a fundamental role as the velocity shared by all particles that constitute a plasma, regardless of their mass, electric charge, and energy. Close to Earth, within the plasmasphere, the magnetic field can be described with great accuracy. The electric field is more difficult to appraise, for two main reasons:

(1) The electric field is variable and it can arise from lots of different processes (Earth's rotation, ionospheric motions including the ionosphere wind dynamo, plasma flows in the magnetosphere, etc. [1]).

(2) In-situ electric field measurements are challenging [2]. This is particularly true closest to Earth where spacecraft pass through perigee with maximum speed $\mathbf{V_{SC}}$ in a strong magnetic field $\mathbf{B}$. Spacecraft motion generates an electric field $\mathbf{V_{SC}} \times \mathbf{B}$ that can constitute more than 95% of the measured electric field close to Earth, and that quantity should be subtracted from measurements to describe the electric field in an inertial frame of reference. That is why measurements need to be extremely accurate to detail electric fields close to spacecraft perigee.

2. Van Allen Probe Database of Near-Equatorial Electric Drift Measurements

The Van Allen Probes have an apogee at ~ 5.8 Earth radii, a perigee at ~ 600 km, a period of ~ 9 h and an inclination of ~ 10°. The apogee location is slowly drifting so that it takes a bit less than 2 years to scan all local time sectors.

We created a database of electric drifts in a frame of reference fixed to the stars from more than two years of spin-period-averaged (~12s) electric [6] and magnetic [7] field measurements by both Van Allen Probes, starting September 2012 (from 23 September 2012 to 31 December 2014) [3, 4, 5].

The database covers all magnetic local time sectors for different Kp indexes. Although the magnetic activity was mostly quiet for the time interval selected (with 80% of the measurements sampled when Kp ≤ 2 and |Dst| ≤ 20 nT), several tens of magnetic storms were observed. In particular, we found 72 intervals of AE-defined storms and 55 Dst-defined storms [8] between the end of September 2012 and the end of December 2014.

3. First Results

3.1 Quiet-Time Electric Drift

The first works focused on deriving typical electric drift values below 3 Earth radii, putting aside information relative to the variability of the electric drift in the inner magnetosphere [3,4,5]. First, we demonstrated that the instruments onboard Van Allen Probes had the accuracy required to deliver consistent evaluations of the electric drift in a frame fixed to the stars (**Figure 1**). Then, we reported on two significant departures from the traditional picture of corotation with the Earth during quiet times. (1) We showed the existence of a typical corotation lag of the order of 5 to 10% below L ~ 2.6, consistent with previous findings from the IMAGE satellite [9, 10]. (2) We showed that the magnetic local time dependence of the electric drift was consistent with that of the ionosphere wind dynamo below L ~ 2 and with that of a solar wind-driven convection electric field above L ~ 2. These results are in agreement with previous findings from the IMAGE satellite [11] and from particle observations from the Van Allen Probes [12].

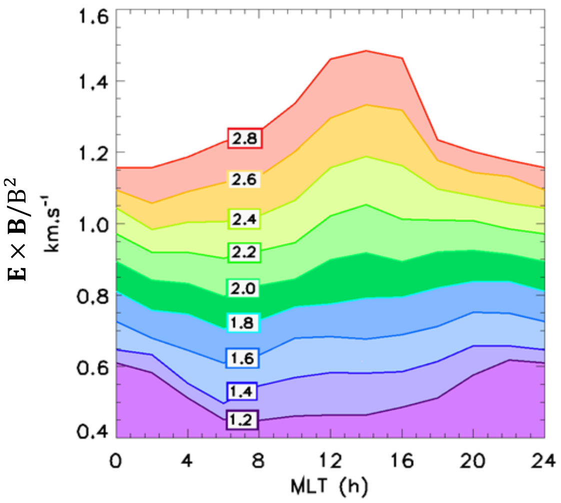

Figure 1. Typical values of the electric drift in a frame of reference fixed to the stars as a function of magnetic local time. The different equatorial radial distances from L = 1.2 to L = 2.8 are indicated in the boxes. The values have been derived from a statistical analysis of more than two years of Van Allen Probe electric and magnetic field measurements (adapted from [4]).

An illustration for the significance of this research: Multiple peaks in the spectrum of inner belt energetic electrons have been observed at low altitude above the South Atlantic Anomaly since the 60s [13]. The high energy resolution of the Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE) instruments abroad the Van Allen Probes [14] revealed that peaks in the energetic electron spectra below 1 MeV were in fact ubiquitous features of the entire inner radiation belt below L~3 [15] (the "zebra stripes"). Different theories have been proposed and they all involve a different *ad-hoc* electric field model. All those models could not be tested at the time due to the lack of reliable in-situ measurements. The only way to further progress on this research topic is to perform an analysis of Van Allen Probe electric drift measurements devoted to the generation of "zebra stripes". This will be the object of future work.

3.2. Electric Drift Dynamics During and After Geomagnetic Storms

We also initiated the analysis of electric drift dynamics during and after geomagnetic storms by studying Sub-Auroral Polarization Streams (SAPS) [16]. When measured in the ionosphere in the Earth's corotating frame, SAPS are persistent and latitudinally narrow (< ~5° in magnetic latitude) bands of rapid westward ion drifts (> 500-1000 m/s) present at sub-auroral latitudes in the evening local time sector, from approximately 18 to 02 MLT. SAPS result from the earthward motion of the hot ion and electron components of the plasmasheet during periods of enhanced convection. Conjugate observations demonstrated that SAPS extend along magnetic field lines in the absence of significant field-aligned potential drops [17]. When observed in space, SAPS are mostly the object of case studies, because of the lack of reliable in-situ measurements.

We created a database of 200+ near-equatorial SAPS observations [18]. An example is provided **Figure 2**. In that case, the amplitude of the SAPS electric drift is ~ 5 times greater than usual [19], with a westward drift of the order of 40 km.s-1. A speed of 40 km.s-1 corresponds to the drift velocities of particles of ~100-200 keV at L=4.

We found that SAPS are always observed when energetic electrons have penetrated below L=4 [20,21]. Then, we demonstrated that the description of particle dynamics during injections is improved when including SAPS potentials in the large scale electric field picture.

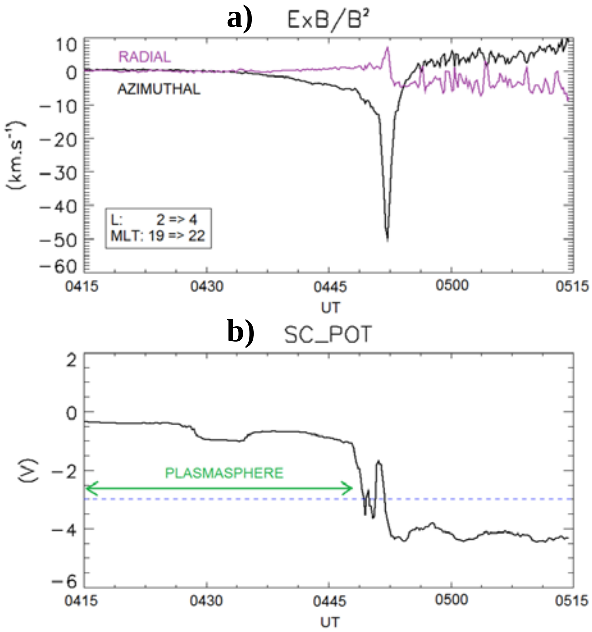

Figure 2. A super SAPS observed by Van Allen Probe A on 13/03/30 at L ~ 4 and 21 MLT. The panel **a)** presents the two components of the electric drift (radial in purple, and azimuthal in black), as a function of universal time (UT). The panel **b)** shows the spacecraft potential during the same time interval. The azimuthal component of the electric drift peaks to a local minimum value smaller than -40 km.s-1 at the plasmasphere boundary layer (indicated by the sharp decrease in spacecraft potential).

4. Concluding Remarks

So far, (1) we have described the electric drift departure from corotation below L=3 during quiet times and (2) we have presented the spatial and temporal features of 200+ SAPS observations by the Van Allen Probes. In both cases, these results provided insights on peculiar particle observations which defied traditional theories.

During and after geomagnetic storms, the equatorial electric drift is expected to vary on a broader range of temporal and spatial scales, from high to equatorial latitudes [22]. Future work will focus on the combined effects of the solar-wind/magnetospheric dynamo, and the ionospheric disturbance dynamo.

5. Acknowledgements

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