High Energy Electrons at Low Latitudes: Is Their Connection with Thunderstorms Possible?

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Abstract. This work is dedicated to a study of near-equatorial electron distribution in the ionosphere under the radiation belts. Sporadic 100 keV electron splashes have been registered at near-equatorial latitudes. The longitudinal dependence has been found in the distribution of these splashes. The results have been compared with satellite data of thunderstorms registration, through this it was found that the areas of electron registering coincide morphologically with near-equatorial atmospheric systems. It is discussed that lightning charges could be one of causes of such electrons. The lithospheric-ionospheric coupling could be an extra source of energetic electrons near the equator.

Introduction

Nowadays, large experimental data sets of charged particle fluxes in the ionosphere have been collected. This allows us to study a new level of phenomena – fine structure of Earth's radiation belts and fine scale ionospheric phenomena.

The energy spectrum of radiation belts has a feature: there should be no electrons at L<1.2 on near-equatorial latitudes (except the SAA). As well, there should be neither E_{dc} nor VLF-waves in normal conditions. However, some times ago, in 1990th, some structures of electrons with an energy of tenth-to-hundreds keV were detected onboard the MIR orbital station at L < 1.2 (low latitudes) [*Grigoryan et. al.,* 1997]. Moreover, it is shown in *Bratolyubova-Tsulukidze et al.* [2001] that some electron splashes have been registered earlier, since 1960th in different experiments.

In the other hand, thunderstorms are the reason of many different ionospheric phenomena, for example electromagnetic waves including VLF-waves; neutron bursts; optical emissions ("red sprites", "blue jets") etc. [*Grigoryan et al.,* 2004]. In this article, only electron-connected phenomena are discussed. This direction in the space research is popular enough now [*Prech et al.,* 2002]. The connection between electron fluxes and whistlers generated by lightning flashes was revealed in the 1960th, for auroral latitudes [*Dungey*, 1963]. The connection between electron fluxes and lightning flashes at L > 2.0 was verified, for example, by [*Inan et al.,* 1988]. In this paper, we study only the effects at L ≤ 1.2.

It is known that lightning discharge is a source of VLF-waves in the ionosphere. The electrons of radiation belts can interfere with these waves and change there pitch-angles (but not energy). This leads to electron precipitation into the atmosphere in about ten minutes for an inner radiation belt [*Trakhtenherts et al.*, 2002]. This time is much lower to longitudinal drift time, thus the energetic particles disappear in the atmosphere near to its source. Therefore, we can connect the place where electrons disappeared approximately with the place of a source of intensive VLF-waves.

Experimental setup

The data of three space experiments was used to study this phenomenon.

SPRUT-V and RYABINA-2 devices onboard the MIR OS detected splashes in 1991.

The INTERCOSMOS-24 satellite (Russian-Czechoslovak International Satellite) functioned from 1989 till 1993 at a high-inclination orbit. The SPE-1 device onboard this satellite measured charged particles including electrons.

The KOLIBRI-2000 microsatellite was an international school and scientific Russian-Australian microsatellite. It was launched at a spring of 2002. Its scientific project included coordinated measurements with the SCORPION device onboard the International Space Station (ISS). The APF device onboard this satellite had four electron detectors.

The electron fluxes with energies of tens-to-hundreds keV have been measured in all these experiments. Some extra parameters of these space experiments are given in Table 1. These experiments are described in [*Bratolyubova-Tsulukidze et al.*, 2001; *Tamkovich et al.*, 2004*; Kudela et al.*, 1992].

Table 1.

Experiment	Year	Altitude and orbit inclination	Instruments	Electrons measured
KOLIBRI-2000 microsatellite	03-04.2002	<350 km, 51.6°	APF	>75 keV, >300 keV, >600 keV
INTERCOSMOS-24 satellite (‘ACTIVE’)	1989 – 1993	500-2500 km, 82.6°	SPE-1	18-480 keV
MIR Orbital Station	1991	400 km, 51.6°	SPRUT-V	>75 keV, >300 keV, >600 keV
MIR Orbital Station	1991	350-400 km, 51.6°	RYABINA-2	>100 keV, >500 keV

Results

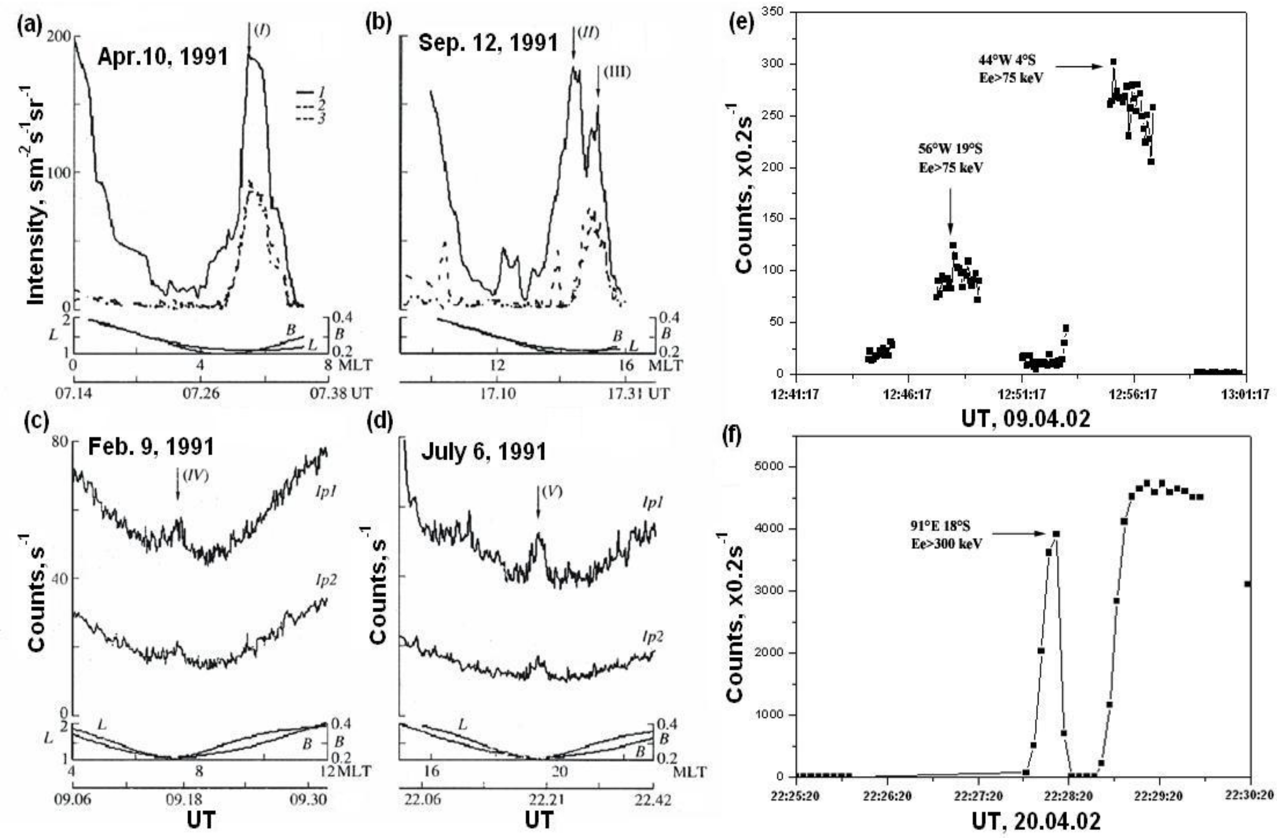

Figure 1. Electron flux splash detection by SPRUT-V (a, b) (E_e>75 keV (1), E_e>300 keV (2), E_e>600 keV (3)), RYABINA-2 (MIR OS) (c, d) (E_e>100 keV (Ip1), E_e>500 keV (Ip2). Intensity peaks are pointed by arrows (I) – (V). The variations of module B and L are shown at the same axis), and APF (KOLIBRI-2000) (e, f) (E_e>75 keV, E_e>300 keV. Intensity peaks are pointed by arrows. Coordinates and energies are given for each peak).

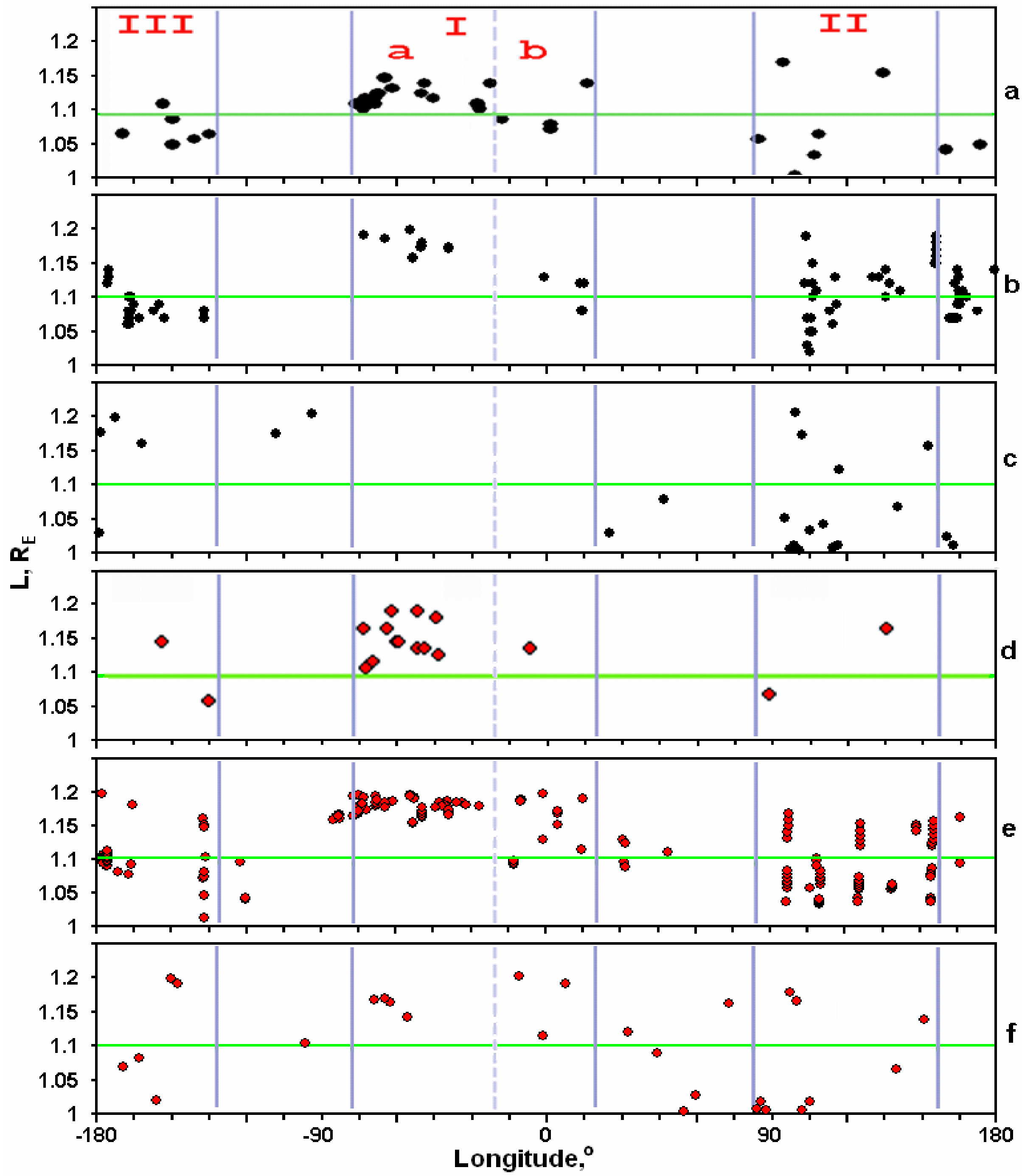

Figure 2. Longitudinal distribution of electron intensity peaks on L<1.2:
a – SPRUT-V, b – SPE-1, c – APF (E_e > 300 keV); d – SPRUT-V, e – SPE-1, f – APF (E_e > 75 keV).

The sporadic electron flux splashes were registered onboard the KOLIBRI-2000 at 1.2<L<2.0 (middle latitudes) as well as at L<1.2 (near-equatorial latitudes). This phenomena was similar to those found in SPRUT-V and RYABINA-2 data obtained earlier onboard the MIR orbital station. The similar splashes at different altitudes have been found in data of the SPE-1 device onboard the INTERCOSMOS-24 satellite. The examples of registrations of such phenomena are shown in Fig.1.

Different devices measured similar splashes on a small noise level. The intensity of peaks varies from tens to hundreds particles per second. The duration of peaks varies from tens of seconds to minutes. The difference of the peak shape is connected to the difference of the methods of particle detection (the detection of bremsstrahlung of high-energy electrons by the RYABINA-2 device and direct measurements of electrons by semiconductor counters (SPE-1) and Geiger counters (SPRUT-V, APF)). In spite of different years and instruments used, altitudes of phenomena observed at these experiments are similar to each other. All experiments have shown similar distributions of flux intensity peaks (see Fig.2).

One can see that peaks are placed mostly in 3 longitudinal intervals: I (80°W–50°E); II (90°E–130°E); III (130°E–180°–100°W). This division was proposed at first time in *Bratolyubova et al.*, [2001]. In this paper, the authors reported about a gap between the II and III intervals. In later experiments, electron splashes were detected between the II and III intervals. The II and III intervals are close to each other. The SAN MARCO-D satellite data shown that in the III interval, E_{dc} is placed higher (mostly >400 km) than in other intervals (mostly <300 km) and VLF-waves in the III interval have a greater intensity.

The main feature of the I interval is an absence of splashes at L<1.1. The source of hundreds-keV-electrons at 1.1<L<1.2 could be the inner radiation belt (cyclotron resonance), but at L<1.1, there are no known mechanisms to accelerate electrons to such energies. The I interval is nonuniform and could be divided into two parts – Ia and Ib.

Electron energy spectra have been calculated in all three longitudinal intervals at altitudes of 500-1100 km using the SPE-1 data (Fig. 3). It is shown clearly that the spectrum in the I interval differs from the II and III intervals. The electron flux at low L in the I, especially in the Ia longitudinal interval is small – it shows that electron splashes give the great part in electron flux in that region. The data absence at longitudes –80°…–15° at L<1.1 may be explained by the fact that at high altitudes this region occupies a very small longitudinal interval.

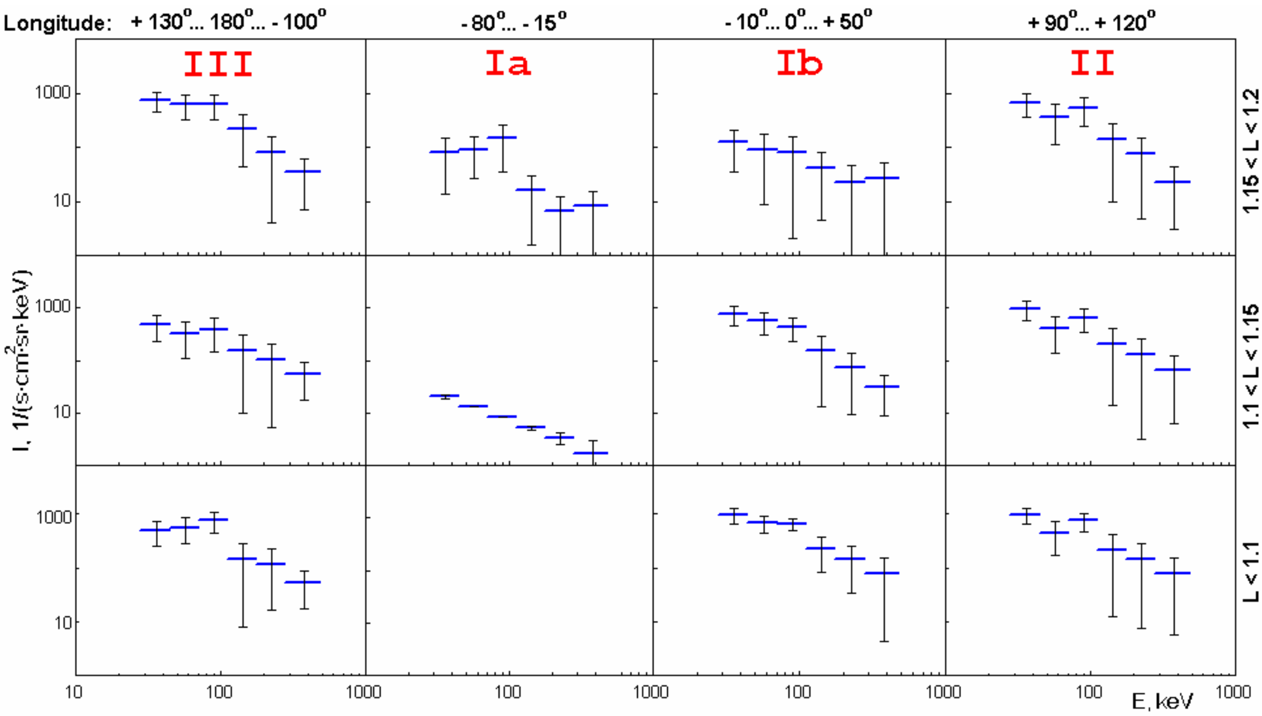

Figure 3. Differential electron spectra in three main longitudinal intervals by SPE-1. The statistic error bars are given for each peak.

Discussion

Unfortunately, there are no direct measurements of lightning splashes and charged particles simultaneously until now except the SAMPEX experiment [*Blake et al.*, 2001]. Nevertheless, this experiment functioned at L = 1.3–1.9. In other experiments only marginally interactions between thunderstorms and the charged particle precipitation are measured. As it was already noted, energetic electrons at L<1.2 disappear in the atmosphere in about ten minutes near to the place they were precipitated (the longitudinal drift time is more at the same altitudes). We can also say that the areas where electrons are precipitated are the areas with intensive VLF -waves. We consider that the only mechanism of electron precipitation in the atmosphere at near-equatorial latitudes is the interaction between electrons and low-frequency electromagnetic emission. The waves of such low frequency could be produced by lightning discharges during thunderstorms [*Inan et al.*, 1988]. Another source of VLF-waves in the ionosphere can be an earthquake (Fig. 4f) [*Galperin et al.*, 1990; *Biryukov et al.*, 1996]. Experimental areas of intensive splash registration coincide morphologically with near-equatorial atmospheric systems (Fig. 4e) [*Christian et al.*, 1999]; therefore, we can consider these systems as a cause (maybe as a main cause) of electron splashes.

It is shown in Fig. 4 that near-equatorial atmospheric system distribution area with an earthquakes distribution area cover all places where electron splashes have been registered.

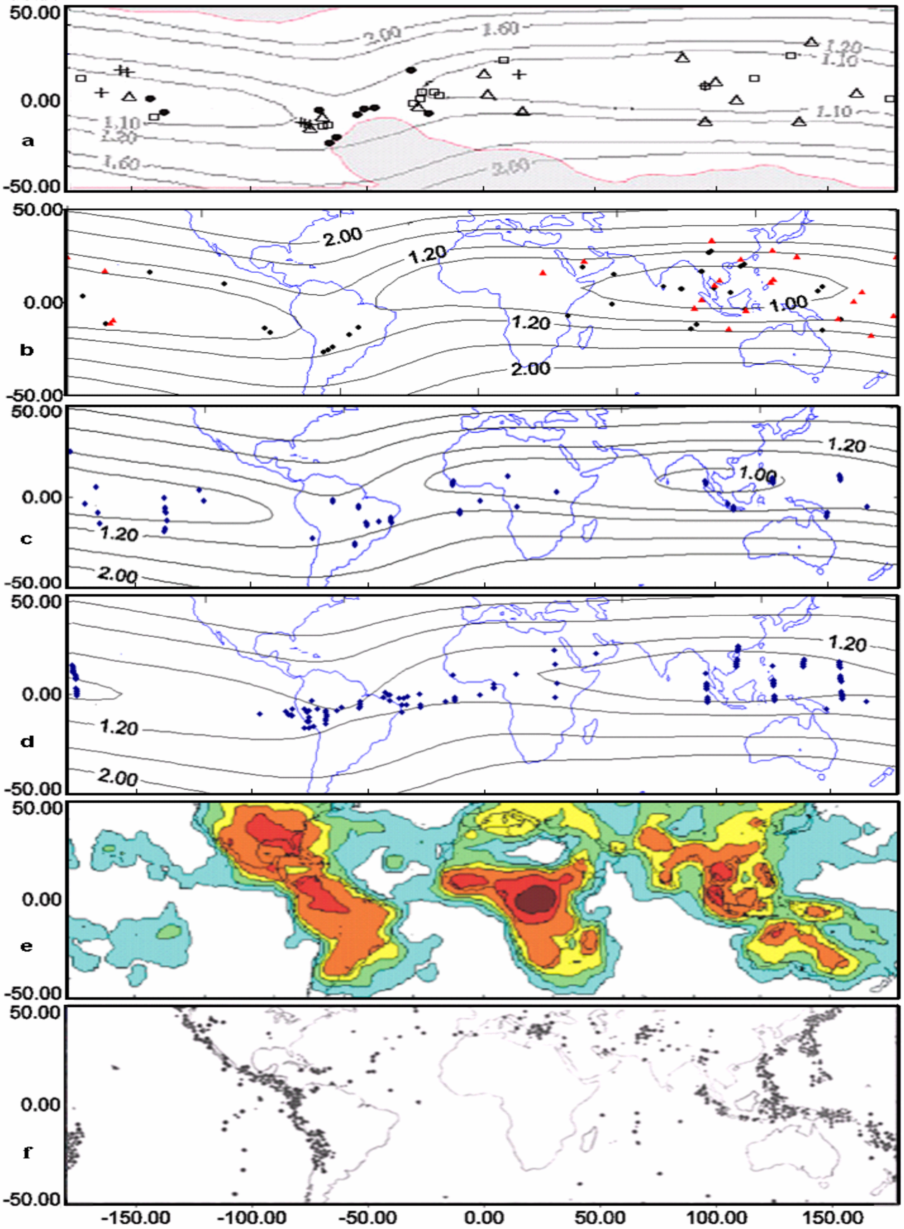

Figure 4. a) Electron flux distribution (E_e> 300 keV, >500 keV) by RYABINA-2 and SPRUT-V.
b) Electron peak distribution (E_e>75 keV, E_e>300 keV) by APF.
c) Electron peak distribution (E_e = 30-500 keV) by SPE-1 at altitudes 500-800 km.
d) The same at 800-1100 km.
e) The map of global atmospheric systems by the satellite (1995 – 1996).
f) The distribution of earthquakes with magnitude > 7.

Conclusion

The results of a study of energetic electron distributions in the atmosphere are presented. This data was collected by several space experiments in different years, by different instruments and at different altitudes. In these experiments, sporadic tens-to-hundreds-keV-electron flux splashes were registered at near-equatorial latitudes at L<1.2. The distribution of splashes observed has a clear longitudinal dependence – there are three main areas of registering such peaks. Differential electron spectra have been calculated at these areas. The spectra differ for different areas. The first area could be divided into two parts.

The mechanism of inner radiation belt electron cyclotron resonance with VLF-waves as a main source of electrons observed under the radiation belts is discussed. Thunderstorms could be a main source of VLF-waves. Ionospheric-to-lithospheric connections could play an additional role in this mechanism – earthquakes are known as a cause of VLF-wave generation in the ionosphere, thus could be another source of electron splashes.

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