

Reply to reviewer #4

We thank the reviewer for the comments. We try to address all of them and clarify the relevant issues.

The authors made some clarifications and I mostly agree with each piece of observation. However, the scenario of magnetosheath jets accelerating >30 keV electrons at low L is still not supported by concrete evidence of the direct causal relation. (1) The authors admit that there are no electric field data, no other days of events despite a frequent occurrence of jets, and no acceleration at other locations or energies. (2) Other possible scenarios aren't firmly ruled out because most of the FEEs occurred during the PC index increase and substorms. Currently the proposed scenario is a speculation at best. I suggest to weaken the abstract and conclusion. Those sections should clearly state that (1) there is no direct evidence that supports electron acceleration by magnetosheath jets and (2) PC index increase and substorms could also contribute to acceleration.

...

The PC index increased at 13 UT and substorms started at 16 UT. Except for the 1245 UT FEE, all other FEEs occurred during the PC index increase or substorms. As in the SuperMAG plots, the high-latitude magnetic field increased at all MLT (indicating convection enhancements) or more pronounced near midnight (substorms). How do the authors rule out the possibilities that the FEEs after 13 UT are affected by the PC index and substorms?

We agree with the reviewer that the proposed scenario, in particular no.4 and no.5 (Lines 607-612), “*is not supported by concrete evidence of the direct causal relation*”. Note that we fully expressed this in the final conclusion of the manuscript (Lines 631-635):

“Summarizing, from the experimental data available, the existing scenario cannot be supported firmly. It might also be that another unknown mechanism is responsible for the FEE enhancements during magnetic quiet periods. In this sense, further experimental studies and *in situ* observations of electric fields at *L*-shells from 1.1 to 2 as well as of dayside auroral precipitations are required.”

In the abstract of the revised manuscript, we add:

“However, the scenario cannot be firmly supported because of the lack of experimental data on electric fields at the heights of electron injections. This should be a subject of future experiments.”

However, we cannot agree with the reviewer’s statements that

“*most of the FEEs occurred during the PC index increase and substorms*”
and “*PC index increase and substorms could also contribute to acceleration.*”

The first injections of >30 keV electrons at 1250 and 1315 UT (see Table 1) were not preceded or accompanied by any notable activity in PC and AE indices (see Figure 3). Hence, those injections were definitely not related to any disturbances at polar and auroral latitudes. Other FEEs from Table 1 were accompanied by enhancements in PC index but they were not related to a substorm because the increase of AE index from 1600 UT to ~ 1730 UT was originated from the dayside stations and, thus, it was definitely not a substorm.

We expected that these important issues had been addressed clearly enough both in the manuscript and in our reply to the comments from the previous review. It seems, the Reviewer did not completely understand our explanations or, perhaps, did not agree with them, despite of a lot of graphic materials putted in the Supplement, where the magnetometer data from SuperMag

were presented in Figures S1 and S2. Below, we reply to the relevant comments with more details.

I There was no substorm activity from 1200 UT to ~1730 UT

In the previous reply, we pointed out a systematic error originated from a single station, which permanently showed a disturbance of ~ 100 nT during successive days. That station is T41 (Kiana) locating at the low-latitude edge of the auroral oval ($glon=199.6^\circ$, $glat=67^\circ$, $mlon=-105.55^\circ$, $mlat=65.62^\circ$). Let's look at Figure 1R below, which shows examples of magnetic data plots for different time moments on 1 August 2008. The T41 (marked by red asterisk) was situated in different local time sectors. When the station is at night side (for example, at 10 UT and after), it is easy to mistake the T41's signal for a substorm signature. However, the T41's magnetic vector did not change from 0 UT (local noon) to 16 UT (local dawn), while neighboring stations showed random temporal variations rather than typical substorm dynamics. The substorm onset never occurs at dayside, and hence there is no substorm signature at all during the whole interval. The same feature at other UT times and days was shown in the previous reply. It seems that the T41 magnetic data were erroneously represented.

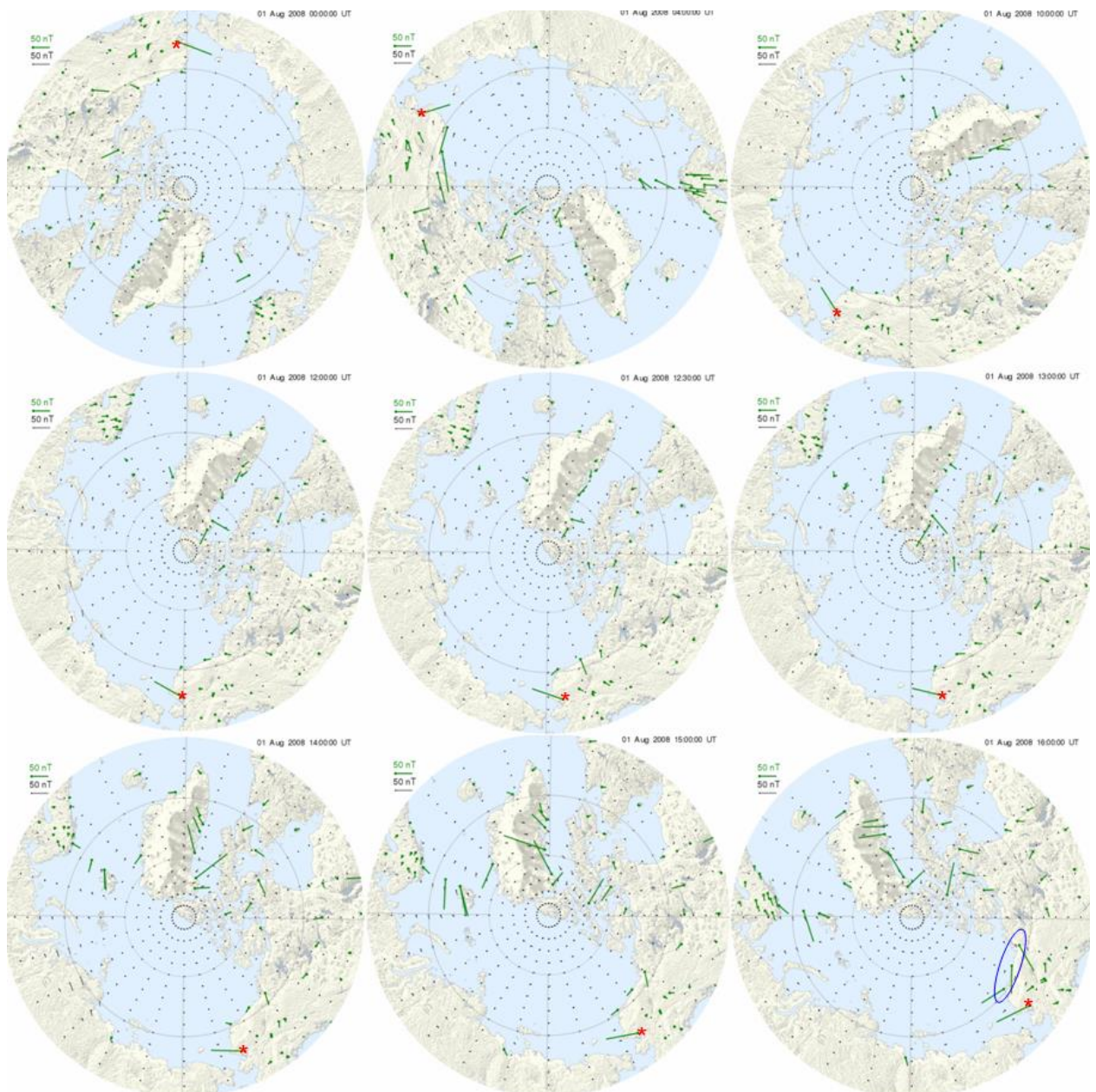


Figure 1R. Magnetic data vectors provided by SuperMag at high geomagnetic latitudes ($>60^\circ$). Plots are shown for different times (0 UT, 4, 10, 12, 12:30, 13, 14, 15 and 16 UT) on 1 August. Red asterisk indicates T41 (Kiana) station. Three stations inside the blue contour are BRW, KAV and INK stations.

In order to understand the reason of this strange feature, we check magnetic records of this station and other three stations BRW (Barrow), KAV (Kaktovik) and INV (Inuvik), which are located at the polar edge of the auroral oval at mag. latitude around 71° (they are inside the blue oval in Figure 1R). In Figure 2R, the higher latitude stations recorded a negative bay in the north-south component after 16 UT in the dawn sector (between 3.5 and 5 LT at 16 UT). While the T41 did not see any prominent disturbance in the auroral oval. Hence, we can conclude the following:

1. The vector representation of T41 in polar coordinates (Figure 1R) is wrong because it contradicts to the time profiles (Figure 2R).
2. If T41 is eliminated from the consideration then the most prominent magnetic activity occurs on the dayside from 14 UT and later by 1730 UT, the activity spread to the nightside through the dawn and dusk sectors (see Figure S2 in Supplementary materials). This dynamics does not definitely proper for substorm.

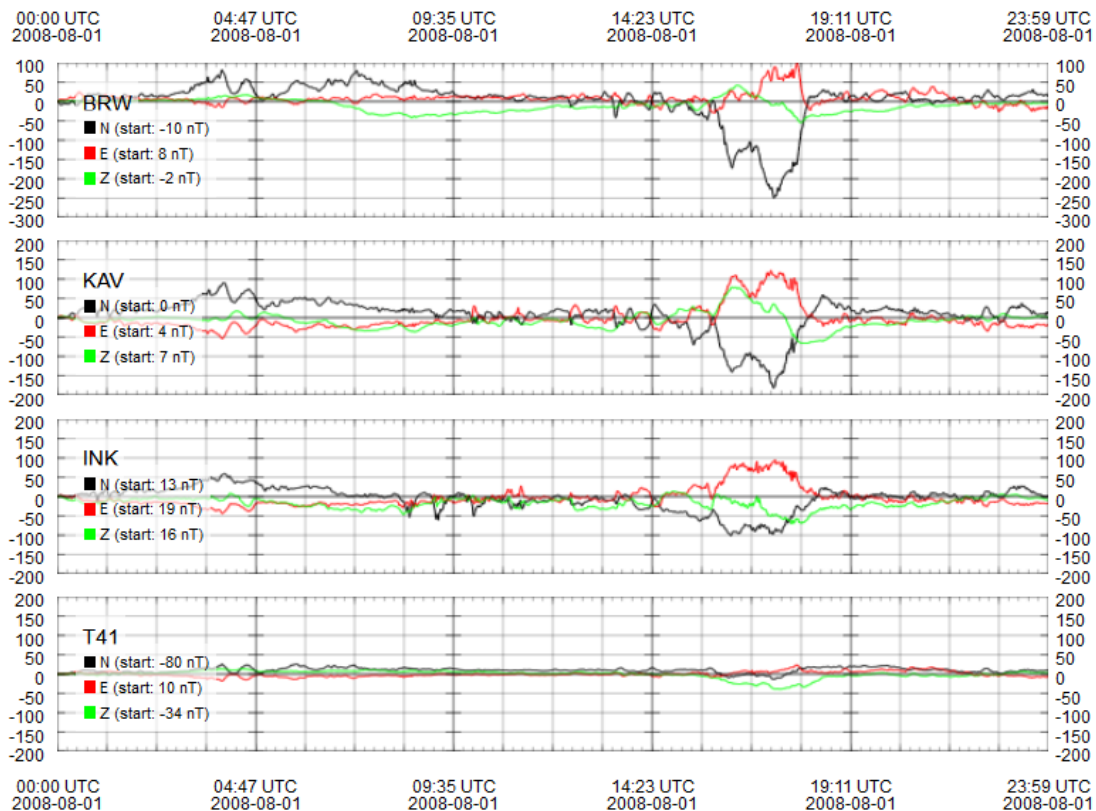


Figure 2R. The magnetometer data for BRW(70.5°), KAV(71.4°), INK(71.4°) and T41(65.5°) stations.

II The increase of PC index results from magnetospheric compressions

The PC index is a measure of the energy inflow from the solar wind into the Earth's magnetosphere and describes magnetic disturbances due to ionospheric and field-aligned currents at the polar cap. The PC and AE indices are a measure of geomagnetic disturbances in different regions (polar cap and auroral zone), so the PC index does not represent substorms in the same way as the AE index.

In order to clarify this very important issue, we add the following paragraph around Figure 3: “As shown in Figure 3, the polar cap PCN index started to increase after 1300 UT under northward IMF. After 1400 UT, the moderate polar cap activity (PCN~1.5-2 mV/m) indicates intensification of the R1 field-aligned currents in the dawn and dusk magnetosphere (Troshichev et al., 2016). It should be noted that the weak and moderate PC-index activity can be also produced by changes in the solar wind dynamic pressure (Lukianova, 2003). Hence, the enhanced PCN during 1300 - 1600 UT might indicate the compressions of dayside magnetosphere. However, from Figure 3, it is difficult to identify appropriate solar wind drivers for interpretation of the polar cap activity at that time. From analysis of SuperMag magnetic data, we found that the magnetic variations dominated on the dayside, dawn and partially dusk sectors from 1300 to 1700 UT (see Figures S1 and S2 in supplementary material). Hence, the enhancement of PCN index from 1300 to 1600 UT resulted rather from compressions of the dayside magnetosphere.”

Hence, we can rule out the PC increase as a driver because in the present case, the PC increase is a manifestation of the magnetospheric compression.

III The substorm-like event was originated from dayside magnetosphere compressions

The auroral activity in AE index after 16 UT resembled an isolated substorm. However, analysis of the SuperMag data (see Figure S2 in Supplementary materials) shows that the magnetic activity occur mainly on the dayside. In the manuscript, we wrote in the second paragraph of Discussion section:

“It is important to note that the intensification of AE index from 1600 to 1800 UT was originated from magnetic activity at high latitudes on the dayside (see Figure S2 in Supplement). The dayside activity results from the multiple magnetospheric compressions (see Figure 6). In this context, the substorm should be rather considered as a “substorm-like” event related to compressions of the dayside magnetosphere.”

Actually, this was our reply to the comments from the previous review. In the present review, the Reviewer ignores the arguments presented in our reply and again arises this problem.

We will very appreciate the Reviewer for indication of any mistakes in our argumentation.

Concerning “*no acceleration at other locations or energies*”.

We wrote in Introduction that other authors concluded that the injection mechanism operating at low L shells is totally different from that operating at high L shells, and energy range is also different. It does not depend on substorm occurrence!

It is very hard to imaging that energetic particles can be transported from the plasmashet at $L \sim 10$ to the inner range at $L \sim 1.1$ within 30 minutes. Actually, it is impossible because the ExB drift speed is limited. This is why we should not need to consider the dynamics of the outer radiation belt. This important issue as well as other relevant effects has been considered in the Discussion of original manuscript. However, the Reviewer totally ignored our arguments. Unfortunately, the Reviewer insists to use this wrong idea for criticism of our results.

Concerning “*no other days of events despite a frequent occurrence of jets*”, we wrote in Introduction that the external drivers (solar wind / foreshock pressure pulses and jets) are only necessary but not sufficient for FEE injections.

In order to conduct the similar study one should find a time interval, which is satisfied to the following requirements:

1. FEE enhancement
2. THEMIS should be in right place (dayside magnetosheath during Northern summer)
3. Conditions for jet generation should be satisfied
4. Quiet solar wind conditions with quasi-steady dynamic pressure and northward IMF

5. Quiet geomagnetic conditions: no storms and/or substorms.

Apparently, it is extremely difficult to satisfy all these conditions simultaneously. For instance, there are only 1 or 2 geomagnetic quiet days per month.

This is why the statistical study is almost impossible. Among a few case events found in 2007 - 2009, this one is most representative. Namely, several FEE enhancements were observed during geomagnetic quiet. Other cases were accompanied by a single FEE enhancement.

The key suggestion in our scenario is about the electric field of a few mV/m at $L < 1.5$. It is important evidence that we really don't have (it is unlikely that anyone will ever have this evidence). Experimental observation of electric fields at low heights could never be conducted in the past and it would hardly be conducted in the nearest future.

The statements "*the scenario of magnetosheath jets accelerating >30 keV electrons at low L* " is incorrect. We never use this formulation in the manuscript. Such a simplified view essentially misstates our ideas about deep electron injections during the transient foreshock.

The authors mentioned that the first FEE was at 1245 UT. But the paper doesn't show a magnetosheath jet at that time. The dynamic pressure at TH-C was constant, and the magnetic field increase at GOES was after 1255 UT. How do the authors explain that the 1245 UT FEE is caused by a magnetosheath jet?

First of all, the statement "*and the magnetic field increase at GOES was after 1255 UT*" is a rough distortion of the data presented. In the original manuscript, we clearly indicated magnetospheric compression and precipitations:

"From 11 to 13 UT, one can see several increases of a few nT observed by GOES and/or THEMIS at ~1125, ~1200, ~1245 and ~1300 UT (Figure 6b)."

"in Figure 11, we find two cases of geomagnetic pulses followed by intense dayside precipitations of the hot plasma at 1105 UT and 1145 UT."

Hence, the first FEE enhancements were preceded by the dayside magnetospheric compressions and high-latitude precipitations. It is very important to point out here that the response of FEE to the solar wind drivers is not instant. In Discussion, we estimate that "the earthward drift of energetic electron across the magnetic field lines from $L = 1.2$ to $L = 1.1$ takes up to 40 min". Hence, if the FEE is observed at 1250 UT (see Table 1) then the impact (compression and precipitations) should occur earlier.

The fact that TH-C as well as ACE did not detect any enhancements of the dynamic pressure in the solar wind from 1100 to 1320 UT (both right upstream of the subsolar bow shock and far upstream) has very important meaning: the driver of magnetospheric compression was not located in the solar wind. Then what is the origin of the compressions and precipitations? Up to now, we know only two possible phenomena: 1). Pressure pulses in the subsolar foreshock and 2). Magnetosheath plasma jets. From 11 to ~1320 UT, there was no subsolar foreshock (see Figure 5). Hence, only magnetosheath plasma jets could cause the compression of the dayside magnetosphere.

29 **1. Introduction**

30 Deep injections of tens to hundreds of keV particles into the inner radiation belt, i.e. drift shells
31 $L < 3$, during quiet or weak geomagnetic activity have recently become one of the main issues of
32 radiation belt dynamics (e.g., Park et al., 2010; Zhao and Li, 2013; Turner et al., 2017). Injection
33 or transport of particles implies violation of adiabatic motion and changing of L-shell. The cause
34 of nonstorm injections has not yet been understood.

35 The mechanisms responsible for the violation of adiabatic motion of energetic particles at low L
36 were a subject of recent studies. The studies presented some intriguing challenges for current
37 models of energetic particle injections. Observations showed that tens to hundreds of keV
38 electrons penetrate deeper than MeV energy electrons (e.g., Zhao and Li, 2013). The keV-energy
39 electrons can often penetrate down to the slot region separating the inner and outer radiation
40 belts ($L \sim 2.5 - 3.5$) and into the inner radiation belt at $L < 2$ (e.g., Turner et al., 2017). Moreover,
41 the deepest penetrations of energetic electrons were revealed even below the inner radiation belt
42 at $L < 1.2$ (Asikainen and Mursula, 2005; Suvorova et al. 2012; 2013; Dmitriev et al., 2017).

43 From a comparison of deep penetrations of electrons and protons, Zhao et al. (2017a) have
44 revealed principle differences in these phenomena suggesting different underlying physical
45 mechanisms responsible for deep penetrations of protons and electrons. Particularly, deep proton
46 penetration is consistent with convection of plasma sheet protons, and deep electron penetration
47 suggests the existence of a local time localized mechanism. Moreover, Turner et al. (2015; 2017)
48 showed that the deep injections of electrons at $L < 4$ resulted from a different mechanism than
49 injections observed at higher L shells. Particularly, Turner et al. (2015) hypothesized that the
50 mechanism could be related to wave activity in the Pi2 frequency range, which usually serves as
51 an indicator of substorm activity. Overall, dynamics of the tens to hundred keV electrons at low
52 L-shells is very different from dynamics of both protons and electrons at higher L-shells and also
53 in higher energy range. The electron injections at $L < 3$ cannot be explained by an enhanced

54 convection electric field, convection of plasma sheet electrons or inward radial diffusion (e.g.,
55 Turner et al., 2017; Zhao et al., 2017a)

56 The ability of energetic electrons to penetrate deeply in the inner zone and below is still puzzling.
57 An answer to the question may be found by investigating the relation of deep injections of
58 energetic electrons to solar wind parameters, geomagnetic activity indices and other parameters
59 of magnetospheric and ionospheric responses (Suvorova, 2017; Zhao et al., 2017b). Rapid
60 enhancements of electron fluxes in the inner zone and below have been known for a long time in
61 association with strong magnetic storms (e.g., Krasovskii et al., 1961; Savenko et al., 1962;
62 Pfizter and Winckler, 1968). However, increased statistics have revealed that deep injections of
63 keV-energy electrons may occur frequently, and furthermore, regardless of storm strength
64 (Tadokoro et al., 2007; Park et al., 2010; Zhao and Li, 2013; Suvorova et al., 2013, 2016).

65 The statistical study by Suvorova (2017) showed that electron injections into the forbidden zone
66 ($L < 1.2$) are relatively rare and occur mostly during magnetic storms and substorms. But
67 sometimes, they also occur during nonstorm conditions and weak substorm activity. This fact is
68 consistent with the recent finding of “quiet” injections in the inner radiation belt mentioned
69 above. A case of “quiet” injections of energetic electrons at $L < 1.2$ is in the focus of our study.

70 Here, we summarize the main characteristics of the electron injections into the very low L-shells
71 from several papers (Suvorova and Dmitriev, 2015; Suvorova, 2017; Dmitriev et al., 2017). The
72 quasi-trapped energetic electron population in the forbidden zone, referred to as forbidden
73 energetic electrons (FEE), can be characterized as transient with highly variable fluxes. The
74 behavior of FEE is similar to keV energy trapped electrons in the inner radiation belt with flux
75 enhancements in response to magnetic storms (e.g., Tadokoro et al., 2007; Dmitriev and Yeh,
76 2008; Zhao et al., 2017a). Simultaneous measurements of particles by satellites at different
77 altitudes provided clear evidence that the forbidden zone enhancements of energetic electrons
78 were caused by fast penetration of the inner belt electrons (Suvorova et al., 2014). As known, an
79 important role in fast transport of particles during storms is played by magnetic and electric field

80 perturbations. Such perturbations are usually associated with the influence of magnetospheric
81 substorms, or nighttime processes of magnetic field dipolarizations in the magnetotail (e.g.,
82 Glocer et al., 2011). However, substorm signatures in the magnetic field in the low- L region ($L <$
83 2) have never been observed.

84 The most probable mechanism of the FEE injections was suggested as the ExB drift (Suvorova et
85 al., 2012), and most of researchers consider and model an electric drift of inner belt electrons in
86 the ExB fields, even though the electric field must be very high (e.g., Zhao and Li, 2013; Lejosne
87 and Mozer, 2016; Selesnick et al., 2016; Su et al., 2016). According to simulation results of
88 Selesnick et al. (2016), the electric field of ~ 5 mV/m can provide deep injections at $L < 1.3$. There
89 is no explanation for penetration of a strong electric field to such low L -shells. What is more
90 important, there is no reliable information on electric fields at heights of 500-2000 km, because
91 measurements there are difficult, and, as a consequence of this, empirical electric field models
92 are limited and do not provide the results below $L \sim 2$ (e.g., Rowland and Wygant, 1998; Matsui
93 et al., 2013). The most modern research suggests that the actual strength of penetration electric
94 fields can be stronger than any existing electric field model at $L < 2$ (Su et al., 2016).

95 A relation between the FEE injections and geomagnetic activity was studied in (Suvorova et al.,
96 2013; 2014). It seemed for a while that intense geomagnetic activity like auroral substorms was
97 one of the necessary factors for deep electron injections, and the storm-time Dst -variation did not
98 control the FEE occurrences (Suvorova et al., 2014). It was suggested that substorm-associated
99 strong electric field can penetrate to the low L region, thereby creating the conditions for fast
100 earthward transport of trapped electrons in crossed E and B fields. Note that recent modeling of
101 the ExB transport mechanism at $L < 1.3$ demonstrated that the mechanism can successfully
102 operate in the low L region (Selesnick et al., 2016).

103 However, after that, many FEE events were found during moderate and weak auroral activity,
104 which was typical for pre-storm (initial phase) or even non-storm conditions and, moreover, high
105 AE index does not always guarantee injections (Suvorova and Dmitriev, 2015). Indeed,

106 statistically, such a casual relationship with substorms was not confirmed (Suvorova, 2017).
107 From total statistics of ~530 days with FEE enhancements collected during two solar cycles,
108 more than three dozen days without essential substorm activity were found. These “quiet” events
109 occurred over past decade from 2006 to 2016. The FEE enhancements in that case were observed
110 only in low energy range of tens of keV.

111 It is important to mention that one interesting feature was unexpectedly found from the statistical
112 study. It is that the most favorable conditions for the FEE enhancements arise in the period from
113 May to September independently on geomagnetic activity level. A second, minor peak of the
114 occurrence appears in the December - January period. Suvorova (2017) suggested an important
115 role of the auroral ionosphere in the occurrence of FEE injections. The peculiar annual variation
116 of the FEE occurrence rate was explained by a change in conductance of the auroral ionosphere.
117 The conductance depends directly on the illumination of the noon sector of the auroral zone. A
118 seasonal variation (summer-winter asymmetry) of dayside conductance was demonstrated by
119 Sibeck et al. (1996). As known, the high-latitude ionosphere is better illuminated during solstice
120 periods, with that the illumination of the northern region is higher than the illumination of the
121 southern one because of the dipole axis offset relative to the Earth’s center. This fact can explain
122 an existence of two peaks of the FEE occurrence with the major one during the northern summer
123 period.

124 External drivers from the solar wind should trigger some processes in the magnetosphere-
125 ionosphere system that might result in the electron injections into the forbidden zone. However,
126 the external drivers are necessary but often not sufficient for FEE enhancements to occur. If the
127 auroral ionosphere is sunlit, then impact of external drivers more likely results in the electron
128 injections into the forbidden zone. In this case, the factor of the dayside auroral ionosphere
129 conductivity is sufficient, and it comes to the fore during weak geomagnetic activity. The
130 relevant processes in the magnetosphere-ionosphere chain during magnetic quiet are still unclear.
131 A comprehensive analysis of the solar wind drivers and magnetospheric response may help us to

132 lift the veil. In this paper, we study prominent FEE enhancements during nonstorm condition on
133 August 1, 2008 in order to determine their possible drivers in the solar wind. Note that this event
134 is a subset (1%) of the total statistics collected by Suvorova (2017) during various conditions,
135 from magnetic quiet to extremely strong geomagnetic storms.

136

137 **2. Observations on August 1, 2008**

138 **2.1. Forbidden Electron Enhancements**

139 Figure 1 shows large enhancements of the >30 keV electron fluxes at low latitudes on August 1,
140 2008. The data were compiled from all orbital passes of five NOAA/POES satellites. The
141 electron fluxes in the energy ranges >30 , >100 and >300 keV were measured by the MEPED
142 instruments boarded on each satellite. The MEPED instrument includes two identical electron
143 solid-state detector telescopes and measures particle fluxes in two directions: along and
144 perpendicular to the local vertical direction (Evans and Greer, 2004). The data shown in Figure 1
145 are from the 0-degree telescope oriented along the orbital radius-vector (i.e. vertically), so that it
146 measured quasi-trapped particles near the equator and precipitating particles in the auroral region.
147 The forbidden zone is defined as $L < 1.2$ in the longitudinal range from 0° to 260°E (or 100°W)
148 that is beyond the South Atlantic anomaly (SAA). The drift L-shells are calculated from IGRF-
149 2005 model. Figure 1a shows the observations of >30 keV electrons at 0 - 12 UT. At that time,
150 the satellites passed the same regions but they did not detect any FEE enhancements. Figure 1b
151 shows the interval 12 - 24 UT, when fluxes of >30 keV quasi-trapped electrons in the forbidden
152 zone increased by 3 orders of magnitude above a background of $\sim 10^2$ ($\text{cm}^2 \text{ s sr}^{-1}$).

153 We have selected FEE enhancements with intensity $>10^3$ ($\text{cm}^2 \text{ s sr}^{-1}$). As found previously, the
154 flux enhancements at low latitudes are peculiar to the quasi-trapped energetic electrons
155 (Suvorova et al., 2012). In contrast, enhancements of electrons precipitating at low latitudes are
156 very rare, weak and short. During the event, precipitating electron fluxes in the forbidden zone
157 did not increase (not shown). Fluxes of the precipitating and quasi-trapped >100 keV electrons

158 and >30 keV protons did not increase also (not shown). The quasi-trapped electrons are
159 mirroring at heights below the satellite orbit (~ 850 km) in a region of $\pm 30^\circ$ latitudes, and drift
160 eastward with a rate of 17° - 19° per hour toward the SAA area, where they are lost due to
161 scattering in the dense atmosphere.

162 Figure 2 and Table 1 present main characteristics of 15 FEE enhancements detected along
163 equatorial passes of NOAA/POES satellites (P2=MetOp2, P5=NOAA-15, P6=NOAA-16,
164 P7=NOAA-17, P8=NOAA-18). The fluxes kept at the enhanced level for several hours. We
165 analyze the peak fluxes in the FEE enhancements (time, local time, longitude, and L-shell).
166 Positions of the satellite orbital planes provided a good coverage of the entire local time (LT)
167 range: 9 - 21 LT (P2 and P7), 5 - 17 LT (P5 and P6), and 2 - 14 LT (P8). The coverage allows
168 determining the injection region with uncertainty of approximately 2 h. The first FEE
169 enhancement was observed at ~ 1250 UT in Central Pacific at night time (2 LT), and the last
170 (enhancement number F15) was detected at ~ 2310 UT near the western edge of SAA at day time
171 (17 LT). As seen in Figure 2a,b, the FEE enhancements peak at minimal L-shells, i.e. at the
172 equator. The fluxes decrease quickly with growing L. This pattern corresponds to a fast radial
173 transport (injection) of electrons from the inner radiation belt. Note that pitch-angular scattering
174 of electrons gives different profiles: the fluxes should be minimal at the equator and grow with
175 L-shell.

176 It was shown statistically that electron deep injections into the forbidden zone occur in the
177 midnight - morning sector (Suvorova, 2017). During typical geomagnetic disturbances, nighttime
178 FEE enhancements are observed shortly after local injections and near an injection site, while
179 subsequent FEE enhancements at daytime are already the result of azimuthal drift of electrons
180 injected at nighttime. Hence, the nighttime (~ 2 LT) enhancements F1 and F4 of >30 keV
181 electron fluxes indicate approximately the time of injection, respectively, at ~ 1250 and ~ 1430
182 UT or a little bit earlier. After 1530 UT, enhancements were observed at daytime (numbers F7,
183 F9, and F11-15) and are therefore associated with drifting electrons.

184 All remaining enhancements F2, F3, F5, F6, F8 and F10 of >30 keV electron fluxes were
185 observed in the early morning (5 LT) for a long time interval of ~ 4 h that lead us to suspect that
186 the enhancements were observed near the injection site. Nevertheless, we examine the
187 assumption about drift by comparing these enhancements with the injection time for numbers 1
188 and 4 in Table 1. For the enhancements F1 and F2, 30 keV electrons injected at 1250 UT must
189 drift $\sim 35.4^\circ$ of longitude in order to reach the observing satellite P5. It takes ~ 112 min with the
190 drift rate of $19^\circ/\text{h}$ for 30 keV electrons at $L\sim 1.2$. However, the observed time difference between
191 F1 and F2 is only 25 min that is too short for drifting from the longitude of F1 to the longitude of
192 F2. The enhancements F1 and F3 have the longitudinal difference of 26° for 1 h that is much
193 larger than 19° produced by the drift of ~ 30 keV electrons. In case of higher energy electrons
194 (e.g., ~ 50 keV), the flux should have decreased notably due to falling energy spectrum.

195 Likewise, one can infer that the enhancement F4 also did not result in the enhancements F5 and
196 F6 and certainly not in the enhancements F8 and F10. Therefore, the specific longitudinal and
197 local time distributions of the enhancements indicate multiple injections during about 4.5 h in the
198 sector of 0 - 6 LT, and the injection region was confined within 3 h of local time over central and
199 eastern Pacific. In general, these characteristic of injections are in well agreement with those
200 found from the statistics (Suvorova, 2017).

201

202 **2.2. Upstream Solar Wind Conditions**

203 An intriguing aspect of these FEE injection events is that they occurred under quiet, nonstorm
204 conditions, characterized by $Dst/SYM-H \sim 0$ nT and $AE < 100$ nT (see Figure 3). We examine
205 solar wind parameters to search for drivers inducing such deep electron injections. We focus on a
206 comparison between the solar wind parameters measured far upstream and near the bow shock
207 and on their influence on the magnetospheric magnetic field during the period of interest. Global
208 indices of geomagnetic activity and upstream solar wind from the OMNI database in GSM
209 coordinates are shown in Figure 3.

210 As seen in Figure 3, the solar wind speed and density smoothly varied around averages of 400
211 km/s and 6 to 4 cm^{-3} , respectively, that resulted in gradual change of the dynamic pressure P_d
212 from 2 to 1 nPa. The interplanetary magnetic field (IMF) can be characterized as weakly
213 disturbed by small-scale structures because of chaotic variations of the magnetic field
214 components and discontinuities, particularly during the first half of the day. Also, in this period,
215 the B_z component was predominately positive. Later, there was a short interval from 1500 to
216 1800 UT, when IMF orientation was relatively steady with a continuous negative B_z of about -2
217 nT. The AL index increased between 16 and 18 UT with a peak of -250 nT. The 1 min $SYM-H$
218 index was > -10 nT throughout the whole day, indicating there was no geomagnetic storm.

219 Overall, the OMNI magnetic and plasma parameters can be characterized as almost undisturbed
220 in the period of the FEE enhancements from 1200 to 2300 UT. Obviously, the weak auroral
221 activity at ~ 1700 UT could not result in extremely deep injections of the energetic electrons,
222 which started much earlier, around 1300 UT. Whereas, looking on the PC index, which
223 represents magnetic activity in the northern (PCN) and southern (PCS) polar caps (Troshichev et
224 al., 1988), one can see a clear disturbance, particularly in the northern polar cap [during that](#)
225 [period](#).

226 [As shown in Figure 3, the polar cap PCN index started to increase after 1300 UT under](#)
227 [northward IMF. After 1400 UT, the moderate polar cap activity \(PCN \$\sim 1.5\$ -2 mV/m\) indicates](#)
228 [intensification of the R1 field-aligned currents in the dawn and dusk magnetosphere \(Troshichev](#)
229 [et al., 2016\). It should be noted that the weak and moderate PC-index activity can be also](#)
230 [produced by changes in the solar wind dynamic pressure \(Lukianova, 2003\). Hence, the](#)
231 [enhanced PCN during 1300 - 1600 UT might indicate the compressions of dayside](#)
232 [magnetosphere. However, from Figure 3, it is difficult to identify appropriate solar wind drivers](#)
233 [for interpretation of the polar cap activity at that time. From analysis of SuperMag magnetic data,](#)
234 [we found that the magnetic variations dominated on the dayside, dawn and partially dusk sectors](#)
235 [from 1300 to 1700 UT \(see Figures S1 and S2 in supplementary material\). Hence, the](#)

236 enhancement of PCN index from 1300 to 1600 UT resulted rather from compressions of the
237 dayside magnetosphere.

238 This raises the question of actual solar wind characteristics at the near-Earth location during the
239 event. The FEE enhancement event under the nonstorm condition and mild, ordinary solar wind
240 properties presents intriguing challenge to current understanding of the energetic particle
241 injections, which usually are associated with intense substorm activity. From the characteristic
242 PC-index behavior, we suspect the actual solar wind parameters affecting the magnetosphere
243 may be different from those predicted by OMNI. Fortunately, the near-Earth THEMIS mission
244 can provide necessary reliable information on upstream conditions.

245

246 **2.3. THEMIS foreshock observations**

247 During the time interval from 1200 to 1800 UT, the THEMIS-C satellite (TH-C) moved from the
248 subsolar region (17.2, -0.3, -5.9 Re GSM) toward dusk (18.1, 3.4, -5.9 Re GSM) (see Figure 4).
249 From the TH-C plasma and magnetic measurements (Figure 5), we infer that the probe was
250 located upstream of the bow shock, whose average subsolar position was estimated as ~ 14.6 Re
251 for $Pd \sim 1.5$ nPa (Fairfield, 1971). Figure 5a shows measurements of the THEMIS-C/FGM
252 fluxgate magnetometer in GSM coordinates with a time resolution of ~ 3 s (Auster et al., 2008)
253 and the ion spectrograms from THEMIS-C/ESA plasma instrument (McFadden et al., 2008). The
254 ion spectrogram clearly demonstrates that hot ions (~ 1 keV) are of the solar wind origin and
255 magnitudes of magnetic field components correspond to IMF components in Figure 3. The
256 magnetic field components measured in situ by TH-C are compared with those predicted by
257 OMNI and shown in Figure 5b. Also, Figure 5c presents the IMF cone angles, between the IMF
258 vector and the Earth-Sun line, for both magnetic data sets. In Figure 5d, dynamic pressure for
259 OMNI, ACE and TH-C are compared.

260 We evaluate characteristics of the upstream solar wind structures actually affecting the
261 magnetosphere during the period of the FEE enhancements. From 1100 UT to 1320 UT, three
262 TH-C magnetic components demonstrated small-amplitude variations, and the Bz component
263 had northward direction. During this time, there were discrepancies between magnetic
264 components of the TH-C and OMNI data caused mostly by time shift of ~10-15 min, so that TH-
265 C observed arrival of the solar wind structures at earlier time than that predicted by OMNI. With
266 time correction, one can achieve better consistency in the two magnetic data sets except the
267 difference in the Bx components about 1310 UT.

268 In Figure 5c, the OMNI cone angle dropped below 30° between 1330 and 1520 UT that
269 corresponded to quasi-radial IMF orientation (IMF is almost along the Earth-Sun line), whereas
270 cone angle variations detected by TH-C were very different from the OMNI data. After 1500 UT,
271 the OMNI data do not match the TH-C observation any more, even with time correction. About
272 ~1320 UT, ~1400 UT and after 1440 UT, the in-situ observation of THEMIS shows large-
273 amplitude fluctuations with duration of tens of minutes in three magnetic components and cone
274 angle (Figure 5a, c). The observed large magnetic fluctuations are ultralow-frequency (ULF)
275 waves, and they are a typical signature of the upstream region of quasi-parallel bow shocks, so-
276 called foreshock (e.g., Schwartz and Burgess, 1991). In addition, in the same time intervals, the
277 plasma spectrogram shows enhancements of suprathermal ion fluxes with energy of >10 keV
278 (upper panel in Figure 5a). This is another distinguishing signature of the foreshock, known as
279 diffuse ion population, which is always observed together with the upstream ULF waves
280 (Gosling et al., 1978; Paschmann et al., 1979). Hence, the upstream foreshock waves and diffuse
281 ions observed by TH-C in the subsolar region are associated distinctly with a radial or quasi-
282 radial IMF orientation in the undisturbed solar wind. Note, that the longest foreshock interval
283 (1435 - 1550 UT) associated with the quasi-radial IMF orientation was observed by ~20 min
284 later than that predicted by OMNI.

285 After 1520 UT, the prediction and in-situ data mismatch greatly. The TH-C satellite observed
286 several IMF discontinuities and alternation between spiral and radial orientations of the IMF
287 vector, while the OMNI magnetic field does not change the spiral orientation from 1520 to 1740
288 UT. The foreshock returned to the subsolar region periodically and more frequently in the
289 interval 1600 - 1730 UT than in the earlier period 1320 - 1440 UT. This behavior indicates the
290 transient subsolar foreshock.

291 Note, these two time intervals of frequent foreshock transitions differ in the Bz component: $B_z >$
292 0 at 1320 - 1440 UT and $B_z < 0$ at 1600-1700 UT. It's natural, that the southward Bz results in
293 the weak auroral activity during the later interval. Nevertheless, the changing direction of IMF
294 has the effect on the magnetic activity in the northern polar cap during the both interval (see the
295 PC index in Figure 1).

296 Figure 5d demonstrates large difference in solar wind dynamic pressure acquired from the TH-C
297 probe, the ACE upstream monitor and OMNI data. The ACE data are shifted by 60 min. In
298 contrast to OMNI and ACE, TH-C observed strong fast fluctuations in the dynamic pressure
299 during intervals of subsolar foreshock (see Figure 5c). Note that ACE shows in average a smaller
300 pressure than OMNI predicts, and it is more close to the TH-C observations. The fluctuations in
301 the TH-C measurements are characterized by pressure pulses, which exceed sometimes the
302 dynamic pressure from ACE (e.g., at 1320-1330, 1350, 1420, 1440, 1530 and etc.). The pulses
303 were originated from plasma density enhancements because the plasma velocity remained
304 practically constant at that time (not shown). Similar foreshock phenomenon was described by
305 Fairfield et al. (1990). Apparently, the foreshock pressure pulses were further transported by the
306 solar wind to the magnetosheath and could affect the magnetopause. Similar foreshock pressure
307 pulses and their compression effects in the magnetosphere-ionosphere were reported by
308 Korotova et al. (2011).

309

310 **2.4. Magnetospheric magnetic field perturbations**

311 We use magnetic field and plasma measurements in the magnetosphere from the other three
312 THEMIS probes and GOES-12, GOES-10 satellites in order to examine a magnetospheric
313 response to the pressure pulses in the subsolar foreshock, which forms each time with arrival or
314 departure of magnetic flux tubes with quasi-radial IMF orientation. Positions of the TH-B, TH-D,
315 TH-E and GOES-12 satellites in the X-Y GSM plane for the period from 1200 to 1800 UT are
316 shown in Figure 4. We used the model of Lin et al. (2010) to calculate magnetopause position.
317 The OMNI data at 1600 UT are used as input data for the model. The GOES-12 and GOES-10
318 satellites moved from morning to noon (7 - 13 LT and 8-14 LT, respectively). The TH-E and
319 TH-D probes moved outward from prenoon to postnoon, and the TH-B probe moved inward in
320 the afternoon-dusk sectors.

321 Figure 6 shows variations of the Bz component measured by the TH-E, TH-D, and TH-B probes,
322 the magnetic field strength at geosynchronous orbit (GOES-12, -10), the ion spectrogram from the
323 TH-D satellite and the SYM-H index from 1100 to 1800 UT. The THEMIS magnetic data were
324 detrended using the Tsyganenko T04 geomagnetic field model (Tsyganenko and Sitnov, 2005)
325 and IGRF-2005 model (see Figure 6b). The IGRF model describes the Earth's main magnetic
326 field and the T04 model represents magnetic fields from the magnetospheric currents.

327 As seen in Figure 6 (a, e), characteristics of magnetic field and hot plasma indicate that three
328 THEMIS probes were located inside the dayside magnetosphere, a region of strong magnetic
329 field with the magnitude ranging from 40 to 150 nT and low-density of hot (>10 keV) ions.
330 Three THEMIS probes and GOES observed significant perturbations in the magnetic field with
331 increase/decrease of order of several to tens of nT (Figure 6 a-c). After 1600 UT, the largest
332 (negative) amplitudes were observed by TH-D, which was mostly close to the magnetopause.

333 From 11 to 13 UT, one can see several increases of a few nT observed by GOES and/or
334 THEMIS at ~1125, ~1200, ~1245 and ~1300 UT (Figure 6b). From 1300 to 1500 UT, there are a
335 few characteristic decreases and increases with duration of 20-30 min observed by all probes.
336 The magnetic field increases correspond to magnetospheric compressions, and the decreases are

337 magnetospheric expansions (e.g., Dmitriev and Suvorova, 2012). Prominent magnetic “dimple-
338 hump” structures are indicated by dashed lines (as 1, 2, and 3) and their peaks are listed in Table
339 2. We select peak-to-peak amplitudes exceeded ~ 5 nT in the GOES data (Figure 6c). The
340 dimple-hump structures show the largest amplitudes up to 15 nT in THEMIS data (Figure 6b).

341 After 1600 UT, the TH-D probe observed fast magnetic variations. At that time, the probe was
342 approaching the magnetopause and moving ahead of the TH-E probe (see Figure 4). Note, that
343 the fast magnetic fluctuations are not always seen in SYM-H index because of a low time
344 resolution (1 min). Figure 6e presents the ion spectrogram from TH-D. One can see several
345 short-time intrusions of dense and cold plasma with spectrum typical for the magnetosheath.
346 Moreover, at ~ 1700 and 1710 UT, the magnetospheric field measured by TH-D with positive B_z
347 suddenly overturned to negative B_z for a moment that indicated a magnetosheath encounter.
348 Time moments of peaks in the magnetosheath plasma pressure are indicated by lines 4-10 in
349 Figure 6 and listed in Table 2.

350 As seen in Figures 6b-d, THEMIS magnetic observations well correlate with magnetic field
351 variation observed by GOES-12,-10 in the whole interval. Time of some magnetic peaks
352 coincides well with accuracy of 1 min (e.g., at ~ 1200 , 1300 and 1420 UT), while others
353 demonstrate various delays of 2 - 6 min between different satellites (see Table 2). In Table 2, we
354 also list foreshock pulses related to the magnetic peaks observed in the magnetosphere (see
355 Figure 5d). Comparing the time moments of magnetic peaks and foreshock pressure pulses, we
356 found that the latter often preceded the first ones by one to few minutes.

357 As we have found, the magnetic variations associated with expansion-compression effects could
358 not be caused by the pristine solar wind pressure variations, which were gradual and small
359 during the interval (see Figures 3 and 5). The magnetic perturbations can be related to the
360 foreshock pressure pulses. Unfortunately, THEMIS was not located in the magnetosheath from
361 1200 to 1600 UT, but an analysis of the later interval (1600-1800 UT) can provide important
362 information about penetration of the foreshock pressure pulses through the magnetosheath.

363

364 **2.5. Magnetosheath plasma jets interacting with the magnetopause**

365 Figure 7 shows the magnetic field and plasma parameters observed by TH-D, TH-E and TH-C
366 during the interval 1530-1800 UT. In addition, magnetic measurements from GOES 12, IMF
367 cone angle from ACE and TH-C, and dynamic pressure from TH-C are shown. After 1530 UT,
368 the TH-D and TH-E probes have observed magnetic field increases associated with the
369 compression effect (Figure 7d). After 1600 UT, TH-D was approaching the magnetopause and
370 started observing occasionally magnetosheath plasma in the magnetosphere, as seen in the ion
371 spectrogram (e.g., lines #4 – 7 and 10, Figures 7b). After 1700 UT, the probe twice encountered
372 the magnetosheath region as indicated by lines #8 and #9. The magnetosheath plasma can be
373 recognized as dense and cold (<1 keV) ion population.

374 As seen in Figure 7 (panels b and d), not all magnetic peaks are accompanied by plasma
375 penetrations. During the interval, the outermost probe TH-C observed occasionally the foreshock
376 phenomena, such as diffuse ions (≥ 10 keV), ULF waves and pressure pulses (panels a, e, f). As
377 one can see, most of the magnetic peaks at panel d and/or magnetosheath ions at panel b were
378 preceded by the foreshock pressure pulses within 1-5 min (panel f), for example at ~ 1549 , ~ 1611 ,
379 ~ 1625 UT and etc. (see Table 2). There are exceptions for plasma penetrations #6 at 1648 UT
380 and #7 at 1651:30 UT. Note that those events were preceded by IMF discontinuities as one can
381 find in rotation of the cone angle (panel e) at 1645 and 1650 UT, respectively.

382 Figure 8 shows characteristics of magnetosheath plasma in details for three intervals 1600-1630,
383 1630-1700, and 1658-1728 UT. Since plasma charge neutrality means equal density of ions and
384 electrons, Figure 8 presents parameters of the ion component only (panels a-d). Total pressure
385 (P_{tot}) and density (D) of the solar wind plasma measured far upstream by the ACE monitor are
386 also shown for comparison in panels (b, c). The time period from 1600 to 1630 UT is shown in
387 panels (a1-g1). The probes TH-D and TH-E observed magnetic field variation as a specific
388 dimple-hump pattern from 1609 to 1615 UT (panels f1, g1), similar to the variations indicated by

389 lines #1 - #3 in the earlier interval (see Figure 6). This magnetic variation is preceded by the
390 dimple-hump variation in the foreshock pressure as observed by TH-C at 1607 to 1611 UT (see
391 Figure 7f).

392 The dimple-hump variations are followed by penetration of the magnetosheath ions into the
393 magnetosphere as observed by TH-D at 1614 to 1616 UT (#4 in Table 2). At 1614 - 1616 UT,
394 TH-D was located in the magnetosphere but it observed cold ions (~ 100 eV - 3 keV) and
395 electrons (< 1 keV, not shown) of the magnetosheath origin (Figure 8, panel a1). The plasma has
396 maximal speed of > 200 km/s and high density of $3-9$ cm $^{-3}$ that result in the high total pressure of
397 $1.5 - 1.8$ nPa (panels b1-d1). Its dynamical characteristics distinctly exceed the solar wind
398 parameters with density of $4 - 5$ cm $^{-3}$ and total pressure of ~ 1.1 nPa (panels b1, c1). The internal
399 structure of plasma forms 3 prominent pressure pulses between 16:14:50 and 16:16:00 UT, a
400 central pulse is dominated by magnetic component (panel f1) and two lateral pulses are
401 dominated by dense plasma components (panel c1). Two plasma density enhancements produced
402 a diamagnetic effect seen as a characteristic decrease of magnetic field (panel f1). At the outer
403 edge of the plasma structure, the anti-sunward velocity ($V_x < 0$) reached high value of -100 km/s,
404 indicating that the local plasma flow struck and interacted with the magnetopause (panel d1).
405 The V_z component demonstrates a maximal value in southward direction (-200 km/s). Three
406 rotated velocity components V_x , V_y and V_z indicate that vortex-like plasma structure propagated
407 along the magnetopause toward south and dusk. This dense and high-speed plasma structure is
408 analogous to the large-scale magnetosheath plasma jet studied by Dmitriev and Suvorova (2012).
409 The jets are defined as intense localized fast ion fluxes whose kinetic energy density is several
410 times higher than that in the upstream solar wind and duration is longer than 30 sec (Dmitriev
411 and Suvorova, 2015; Plaschke et al., 2018).

412 Panels (a2-g2) in Figure 8 show magnetosheath plasma penetrations #5 - #7 during the time
413 period from 1630 to 1700 UT. The plasma structures #5 and #6 (panel a2) have a short duration
414 and are characterized by extremely high density of 16 and 12 cm $^{-3}$, respectively, that well explain

415 the compression effects in magnetic measurements from TH-E and TH-D (panels f2, g2).
416 Prolonged plasma structure #7 has lower density of $4 - 9 \text{ cm}^{-3}$ and did not produce a notable
417 compression in accordance with to TH-E magnetic measurements (panel g2). Note that the
418 structure #5 was preceded by a foreshock pulse observed at ~ 1637 UT while there were no
419 foreshock pulses before the structures #6 and #7.

420 It is important that inside each plasma structure, we reveal a dense plasma core, which is
421 characterized by enhanced speed of ~ 150 or ~ 220 km/s with a dominant V_z component (negative
422 or positive). These parameters, typical for plasma jets, formed pressure of high magnitude, which
423 exceeded the upstream solar wind pressure by 50-80 % (panel b2). The magnetosheath plasma
424 jets interacted with the magnetopause that resulted in penetration of the magnetosheath plasma
425 into the magnetosphere (Dmitriev and Suvorova, 2015). The amount of penetrated plasma can be
426 comparable with estimates of the total amount of plasma entering the dayside magnetosphere
427 (Sibeck, 1999).

428 During the last period at 1658 - 1728 UT shown in panels (a3-g3), we have an excellent
429 opportunity to examine plasma parameters in the magnetosheath region adjacent to the
430 magnetopause. Panels (a3-f3) show two cases of magnetopause distortions followed by short
431 intervals of the magnetosheath from ~ 1700 to 1701 UT and from 1711 to ~ 1715 UT. The TH-D
432 probe at distance of ~ 10.8 Re and ~ 13 LT suddenly crossed the magnetopause and moved into
433 the magnetosheath, where $B_z < 0$ (panel f3). Plasma in both magnetosheath intervals has
434 extremely high density ($\sim 20 \text{ cm}^{-3}$) and high velocity (≤ 200 km/s). In the magnetosheath, one can
435 see local pressure pulses around ~ 1700 UT and ~ 1712 UT (lines #8 and 9). For #9 case, TH-E
436 observed a small shallow hump of the magnetic field of a few nT between two depletions at 1707
437 and 1715 UT (panel g3). The last event (#10) shown in Figure 8c is a short penetration of
438 magnetosheath plasma accompanied by a small perturbation in the magnetospheric field
439 observed at ~ 1724 -1725 UT (panels e3, f3). The density and pressure of this structure did not

440 exceed the solar wind parameters (panel b3-d3). Note that foreshock pressure pulses preceded by
441 few minutes the magnetic peaks and plasma structures #8, #9 and #10 as seen in Figure 7.

442 Thus, we found typical characteristics of dense and fast plasma jets in all intrusions of the
443 magnetosheath plasma into the magnetosphere and in the magnetosheath itself. Most of the
444 penetrating magnetosheath jets correspond to the foreshock pressure pulses. All jet-related
445 plasma structures caused local compression effects at the dayside. This finding raises further an
446 interesting question about spatial distribution of geomagnetic field response to the impact of
447 foreshock pressure pulses on the dayside magnetopause during very quiet geomagnetic
448 conditions at 1300 - 1600 UT.

449

450 **2.6. Global ground-based magnetic variations**

451 The global dynamics of geomagnetic field perturbations was studied using 1-min magnetic data
452 provided by an INTERMAGNET of ground magnetometers ([http://www.intermagnet.org/index-](http://www.intermagnet.org/index-eng.php)
453 [eng.php](http://www.intermagnet.org/index-eng.php)). We used magnetic stations located at geomagnetic latitudes below $\sim 60^\circ$ (Table 3),
454 where a significant effect of different propagation time of MHD waves in the magnetosphere was
455 almost hidden at 1 min resolution. We grouped magnetic stations in meridional and latitudinal
456 chains.

457 Figure 9 presents relative variations of horizontal (H) component measured at equatorial and low
458 geomagnetic latitudes (from 0° to $\sim 20^\circ$) in the interval from 1100 to 1600 UT. The stations are
459 arranged in local time from morning to postmidnight. The GOES-12 and detrended TH-D
460 magnetic data are shown at bottom. Four magnetic field pulses of different amplitudes are seen
461 around ~ 1200 , ~ 1335 - 1345 , ~ 1422 - 1430 and ~ 1545 - 1550 UT practically at all stations. The last
462 three pulses correspond to those selected from THEMIS data at ~ 1334 , ~ 1421 and 1547 - 1550
463 UT (#1 - #3, see also Table 2). Moreover, one can see the same pattern of magnetic variation

464 “dimple-hump” in both ground-based and satellite observations. An earlier magnetic pulse of a
465 smaller amplitude at ~1200 UT is also seen in the GOES-12 and TH-D data.

466 It is interesting, that the magnetic pulse at 1200 UT is simultaneously (within the accuracy of ~1
467 min resolution) observed in all local time sectors. However, the other three enhancements were
468 observed in different LT sectors at slightly different time. The time difference varies from ~2
469 min to ~10 min. The time delay depends on the time moment when a jet interacts with the
470 magnetopause in a given latitude-longitude sector (Dmitriev and Suvorova, 2012).

471 We draw attention to the fact that low-latitude HON and PPT stations, which were located in the
472 predawn sector (2-5 LT) from 1300 to 1500 UT, demonstrate the best coincidence (with a delay
473 of ~1 min) of magnetic peaks #1 and #2 with those observed by THEMIS near noon. Nighttime
474 and daytime stations (PHU, GZH, KNY, KDU, GUA, MBO, ASC, TSU, BNG, AAE, ABG)
475 observed these peaks with ~3 - 5 min delay. The longest delay (~7 min) for pulses #1 and #2 is
476 found at morning/prenoon stations KOU and VSS (~9 - 11 LT).

477 As we have showed above, the FEE injections (F1 - F6 in Table 1) occur from ~2 to 5 LT. So,
478 we present meridional chains of stations in the predawn and midnight sectors (Figure 10). All
479 magnetic pulses are well recognized from 0° to 60° of geomagnetic latitude. In midnight and
480 predawn sectors, the magnetic pulse at ~1200 UT peaks practically simultaneously everywhere.
481 Magnetic peak #1 around ~1333 UT was delayed by ~7 min at midlatitudes (30°-60°) in the
482 midnight sector (left panel) and by ~5 min in the predawn sector (right panel). The pulse #2
483 shows a smaller delay (~3 min) at midlatitudes. The magnetic peak #3 at most stations in both
484 sectors is observed around ~1545 UT, that is 2 min earlier than at TH-E and 1 min later than at
485 GOES (see Table 2).

486 Thus, the ground-based magnetic observations at low and middle latitudes demonstrate similarity
487 in the magnetic variations of “dimple-hump” pattern with the satellite observations in the dayside
488 magnetosphere. It should be noted that the magnetic peaks are not regular and are characterized
489 by periodicities of tens of minutes that distinct them from magnetospheric quasi-periodic ULF

490 waves with periods 1 – 600 s. Hence, the variations observed in the geomagnetic field should
491 result from pressure pulses of the subsolar foreshock and/or magnetosheath origin.

492

493 **3. Discussion and Summary**

494 In this work, using NOAA/POES and THEMIS satellites we investigated an unusual case of
495 deep injections of >30 keV electrons at $L < 1.2$ and corresponding upstream conditions during
496 quiet day on August 1, 2008. Strong FEE enhancements with intensity of up to $\sim 10^5$ (cm² s sr)⁻¹
497 were observed by POES above central and eastern Pacific for a long time from ~ 1300 to 2300
498 UT. With analysis of longitudinal and local time distributions of the enhancements we identified
499 a series of nightside injections occurred in the sector of 2 - 5 LT during the period from ~ 1300 to
500 ~ 1700 UT (Figure 2). We found that the first 6 injections (Table 1) occurred before
501 intensification of auroral activity started at 1600 UT, and hence, cannot be related to the
502 substorm. Two injections occurred during the interval of weak auroral activity at 1600 - 1800 UT.
503 It is important to note that the intensification of AE index from 1600 to 1800 UT was originated
504 from magnetic activity at high latitudes on the dayside (see Figure S2 in Supplement). The
505 dayside activity results from the multiple magnetospheric compressions (see Figure 6). In this
506 context, the substorm should be rather considered as a “substorm-like” event related to
507 compressions of the dayside magnetosphere.

508 We found that from 11 to 18 UT the magnetosphere was not completely quiet. Prominent
509 magnetic variations on the dayside were observed by THEMIS and GOES satellites and by
510 ground-based magnetometers from INTERMAGNET network. The variations correspond to
511 magnetospheric expansions and compressions. Comparative analysis of the THEMIS, OMNI and
512 ACE data showed that the geomagnetic perturbations were not driven by the dynamic pressure of
513 the pristine solar wind. Note that significant discrepancies between the OMNI data and THEMIS
514 near-earth observations under quasi-radial IMF were reported frequently (e.g., McPherron et al.,

515 2013; Suvorova and Dmitriev, 2016). THEMIS observations show firmly that geomagnetic
516 perturbations were rather related to changes in the IMF cone angle and pressure pulses in the
517 subsolar foreshock.

518 We demonstrated that in the magnetosheath, foreshock pressure pulses could be transformed to
519 fast and dense magnetosheath streams, so-called jets. We found that 5 out of 7 magnetosheath
520 jets were preceded by the foreshock pressure pulses. These results support well the previous
521 findings that the plasma jets are typical consequence of the foreshock dynamics and variations in
522 the IMF orientation (e.g., Fairfield et al., 1990; Lin et al., 1996; Archer et al., 2012; Dmitriev and
523 Suvorova, 2012; 2015; Plaschke et al., 2018). In addition, similar effects of the foreshock
524 pressure pulses and magnetosheath jets in the magnetosphere were reported (e.g., Sibeck and
525 Korotova, 1996; Korotova et al., 2011; Heitala et al., 2012).

526 In the present case, the amplitude of magnetic variations was not very high: from a few nT at
527 ground to 15 nT at THEMIS. It should be noted that such magnetic perturbations are too weak to
528 produce deep injections of >30 keV electrons below the radiation belt. On the other hand, the
529 interaction of jets with the magnetopause can result also in penetration of the magnetosheath
530 plasma inside the dayside magnetosphere (Dmitriev and Suvorova et al., 2012, 2015).
531 Precipitation of hot magnetosheath and/or magnetospheric plasma into the dayside high-latitude
532 ionosphere can cause intensification of dayside aurorae. Vorobjev et al (2001) analyzed dayside
533 auroral transient events at latitudes equatorward of the auroral oval (below 76°). They found that
534 the dayside aurora brightening was related to localized magnetospheric compressions driven by
535 abrupt changes in the foreshock (but not by variations in the pristine solar wind dynamic
536 pressure). Recent comprehensive and statistical studies present observations of dayside aurora
537 brightening related to localized magnetopause indentations (Han et al., 2018) and caused by
538 magnetosheath high-speed jets (Wang et al., 2018). Additionally, Han et al. (2016) provided
539 direct evidence that the source of precipitating particles in the dayside aurorae was the
540 magnetosheath plasma (sometimes mixed with magnetospheric plasma). Thus, these studies

541 showed that the jet impact is responsible for transient dayside aurora, which provides
542 enhancements in conductivity of the auroral ionosphere on the dayside.

543 In order to find signatures of particle precipitations at high latitudes we conducted an additional
544 analysis of hot plasma precipitations in the auroral region at L -shells from 7 to 15 during the time
545 of interest. The energy fluxes of hot plasma (from 50 eV to 10 keV) were measured by
546 POES/TED plasma spectrometer. Figure 11 demonstrates magnetic observations of THEMIS
547 and GOES, and POES observations of the energy fluxes of auroral precipitations and FEE
548 injections. We consider intense precipitations with the threshold of $0.5 \text{ (erg cm}^{-2} \text{ s}^{-1}\text{)}$, which is
549 several times higher than the background. One can see that from 11 to 16 UT, the hot plasma
550 precipitated mainly on the dayside (12 – 16 LT) while after 16 UT, the precipitations occurred
551 practically at all local times both on the day and night sides.

552 The first FEE injection (F1) at ~ 1250 UT was preceded by several geomagnetic pulses observed
553 by GOES-12 and TH-D. The pulses were not very prominent because at that time, GOES-12 was
554 located in the morning sector and TH-D was inside the geosynchronous orbit. One can see that
555 some of pulses were accompanied by dayside auroral precipitations of the hot plasma. Note that
556 POES satellites have 100 min orbital period and, hence, they can miss some of localized
557 precipitations. On the other hand, when a jet hits the magnetopause, the magnetosheath plasma is
558 not necessarily penetrating into the dayside magnetosphere and, hence, is not precipitating at
559 high latitudes [Dmitriev and Suvorova, 2015]. Nevertheless, in Figure 11, we find two cases of
560 geomagnetic pulses followed by intense dayside precipitations of the hot plasma at 1105 UT and
561 1145 UT.

562 We can propose that the dayside precipitations at high latitudes are associated with the effect of
563 jets piercing the magnetopause. The average flux of jet-related penetrating plasma was estimated
564 as $3 \cdot 10^8 \text{ (cm}^2 \text{ s)}^{-1}$ (Dmitriev and Suvorova, 2015). This particle flux corresponds well to the
565 energy fluxes $>0.5 \text{ erg cm}^{-2} \text{ s}^{-1}$ of precipitating ions with energy of ~ 1 keV measured by
566 POES/TED at high latitudes (see Figure 11). Hence, the jet-related magnetosheath plasma can

567 produce additional ionization and increase conductivity of the high-latitude ionosphere on the
568 dayside.

569 At the same time, FEE enhancements were observed at low latitudes. It has been found that they
570 result from anomalous earthward radial ExB drift from the inner radiation belt (Suvorova et al.,
571 2014; 2016; Selesnick et al., 2019). The drift should take a certain time dT to transport electrons
572 from the inner radiation belt edge (at L -shell $L_1 = 1.2$) to the heights of ~ 900 km (L -shell $L_2 =$
573 $1.1\sim 1.15$):

$$574 \quad dT(s) = 6380 * (L_1 - L_2) / V_{DE} \quad (1)$$

575 where the ExB drift velocity is determined as

$$576 \quad V_{DE} = 0.032 * L^3 * E, \quad (2)$$

577 where L the average L -shell in the first approach and E is azimuthal electric field in mV/m. From
578 equations (1) and (2), we estimate that the earthward drift of energetic electron across the
579 magnetic field lines from $L = 1.2$ to $L = 1.1$ takes up to 40 min under local electric field of ~ 5
580 mV/m. Note that $E \sim 5$ mV/m was obtained from simulations of energetic electron injections at L
581 < 1.3 [Selesnick et al., 2016; 2019].

582 In our case of non-storm conditions, it is hard to imagine that the strong azimuthal E can persist
583 for so long time. Previously, simulations by Su et al. (2016) have showed that it is not necessary
584 for electrons to be transported earthward all the way during a single injection. Hence, we can
585 consider a multi-step radial transport produced by a number of short pulses of E . In this case, the
586 drift from $L=1.2$ to $L=1.1$ requires two or more pulses of ~ 10 min duration that is comparable
587 with the duration of jet-related disturbances. The multi-step process is limited by the time, during
588 which a particle stays in the region of injection. The >30 keV electrons have a long period of
589 azimuthal drift (~ 22 hours) and, thus, they can stay in the region for hours. In contrast, the >100
590 keV electrons with the azimuthal period of ~ 6 h leave quickly the injection region and, thus, do
591 not have enough time to penetrate to the forbidden zone. This effect can explain the absence of

592 high-energy electrons in the FEE enhancements presented. In the case of electric field
593 penetration from high to lower latitudes, the following effect might be important. At higher
594 altitudes (larger L-shells), the azimuthal drift periods of particles decrease dramatically. Hence,
595 the particles escape quickly from the localized region with the enhanced electric field and, as a
596 result, they drift earthward only a little.

597 In this scenario, the first FEE injection requires a long time (~hour and longer) and several
598 pulses of E in order to transport energetic electrons from undisturbed edge of the inner radiation
599 belt to $L \sim 1.1$. Then, >30 keV electrons populate L -shells from 1.15 to 1.1 that makes possible to
600 transport electrons to 900 km heights for a short time of ~ 10 min by one pulse of strong E . The
601 latter pattern is applicable for the FEE injection F2. As one can see in Figure 11, each FEE
602 injection after 13 UT is preceded within <30 min by intense auroral precipitations of the hot
603 plasma.

604 It should be noted that most favorable conditions for FEE enhancements (and, presumably, for
605 penetration of localized electric fields) arise in the period from May to September independently
606 on geomagnetic activity level (Suvorova, 2017) Similar asymmetry in the dayside auroral
607 conductivity was also shown by Sibeck et al., (1996). Our case event on 1 August 2008
608 corresponds well to these favorable conditions. Taking into account our previous finding that the
609 occurrence of FEE enhancements is related to the ionization of the dayside ionosphere at high
610 latitudes (e.g., Suvorova, 2017), the following scenario can be considered:

- 611 1. During quiet solar wind and geomagnetic conditions, the magnetosphere can be substantially
612 disturbed due to transient subsolar foreshock under radial IMF.
- 613 2. Subsolar foreshock pressure pulses and IMF discontinuities result in generation of fast and
614 dense plasma jets in the magnetosheath.
- 615 3. The jets interaction with the dayside magnetopause produces two distinct features in the
616 magnetosphere: geomagnetic pulses due to the compression and magnetosheath plasma
617 penetration.

618 4. Precipitations of the magnetosheath plasma fluxes to the dayside high-latitude ionosphere
619 should result in a local increase of the ionospheric conductivity and an enhancement of electric
620 currents in the dayside ionosphere. The latter should induce transient localized electric fields on
621 the nightside and especially in the postmidnight sector.

622 5. We hypothesize that the induced nightside electric field might penetrate from high to low
623 latitudes (very low L shells) and produce earthward ExB drift of energetic electrons.

624 We should point out that the scenario suffers some shortcomings. The energy flux of auroral
625 precipitations of $\sim 1 \text{ erg}/(\text{cm}^2 \text{ s})$ was observed to be weak relative to that during substorms that
626 results in a relatively weak additional ionization in the dayside ionosphere. It is hard to expect
627 that the weak increase in the ionization can induce strong electric field of $E \sim 5 \text{ mV/m}$. On the
628 other hand, the satellite observations are sparse in space and time and, thus, a satellite might not
629 catch an intense jet-related localized auroral precipitation of ~ 10 min duration. Hence, the
630 experimental information about auroral precipitations on the dayside is still incomplete.

631 Another serious problem is the generation/penetration of electric fields in the inner
632 magnetosphere at low latitudes in the night sector, which is far from complete understanding.
633 The convection electric field of up to 2 mV/m was observed at $L > 2$ during disturbed
634 geomagnetic conditions (Califf et al., 2014; 2017). During magnetic quiet, the convection
635 electric field is apparently smaller ($< 0.5 \text{ mV/m}$). On the other hand, prompt penetrating electric
636 field in the dayside ionosphere at heights $\sim 100 \text{ km}$ was estimated of $\sim 2 \text{ mV/m}$ (Huang, 2008).
637 However, electric field at heights from 1000 to 2000 km did not measured and, thus, its value is
638 unknown. There are also no models predicting strong electric fields in the inner radiation belt
639 and below. As conjugate observations of penetrating transient electric fields are still unavailable
640 for such cases of anomalous particle transport, the exact mechanism of deep electron injections
641 cannot as yet be fully determined.

642 Summarizing, from the experimental data available, the existing scenario cannot be firmly
643 supported. It might also be that another unknown mechanism is responsible for the FEE

644 enhancements during magnetic quiet periods. In this sense, further experimental studies and *in*
645 *situ* observations of electric fields at *L*-shells from 1.1 to 2 as well as of dayside auroral
646 precipitations are required.

647

Data availability.

CDAWEB (<https://cdaweb.gsfc.nasa.gov/index.html>) provide the NOAA/POES energetic particle data, THEMIS magnetic and plasma data, OMNI and ACE solar wind data. Kyoto World Data Center for Geomagnetism (<http://wdc.kugi.kyoto-u.ac.jp/index.html>) provides the geomagnetic indices. The ground magnetogram were collected from INTERMAGNET network (www.intermagnet.org).

Author contributions.

AS, AD and VP processed and analyzed experimental data on energetic particles, magnetic fields and plasma. AS found the event and designed the study. AD developed the software for treatment of the satellite data. VP analyzed ground-based magnetograms and contributed to discussion of results. AS and AD performed the whole analysis of the data, prepared figures and wrote the paper, as well as answered the referees during the evaluation process.

Competing interests.

The authors declare that they have no conflict of interest.

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Table 1 *FEE Enhancements observed by POES satellites*

FEE ID #	POES s/c ID	Observed time hh:mm UT	Longitude deg	LT* h
F1	P8	12:50	-164.2	1.8
F2	P5	13:15	-128.8	5.1
F3	P6	13:53	-138.3	5.1
F4	P8	14:32	169.7	1.6
F5	P5	14:54	-152.7	5.1
F6	P6	15:34	-162.5	5.0
F7	P2	15:44	-98.7	9.3
F8	P5	16:33	-170.1	5.0
F9	P7	16:37	-107.3	9.7
F10	P6	17:12	180.0	4.9
F11	P2	17:24	-123.0	9.4
F12	P7	18:16	-131.0	9.8
F13	P2	19:06	-140.0	9.6
F14	P8	20:30	-105.0	13.8
F15	P6	23:09	-94.5	17.2

* Local time

Table 2 *Timing of Magnetic Field Enhancements and Plasma Pulses from THEMIS and GOES12*

ID #	s/c ID	UT of magnetic peak hhmm:ss	UT of TH-D magnetosheath jet hhmm:ss	UT of TH-C foreshock pressure pulse hhmm:ss
1	TH-D	1333:40		~1328
	TH-E	1333:40		
	TH-B	1333:40		
	G12	1335:40		
2	TH-D	1420:50		~1417
	TH-E	1420:50		
	TH-B	1420:50		
	G12	1420:50		
3	TH-D	1550:30		~1549
	TH-E	1547:30		~1533, 1538
	G12	1544:00		
4	TH-D	1614:05	~1615 - 1616	~1611
	TH-E	1614:05		
	G12	1614:00		
5	TH-D	1638:20	~1640	~1634, 1636
	TH-E	1638:40		
	G12	1639:00		
6	TH-D	1647:45	~1648	absent
	TH-E	1647:45		
	G12	1648:00		
7	TH-D	-	~1651:30	absent
	TH-E	-		
8	TH-D	magnetosheath	~1700:30	~1700
	TH-E	-		
9	TH-D	magnetosheath	~1712 - 1713	~1707
	TH-E	1712:30		
10	TH-D	1722:30	~1725	~1718
	TH-E	1722:30		
	G12	1722:30		

Table 3*Location of Magnetic Stations in Geographic and Geomagnetic coordinates*

Code	Name	GLat ^a	GLon ^a	MLat ^b	MLon ^b
AAE	Addis Ababa	9.0	38.8	5.3	109.9
ABG	Alibag	18.6	72.9	9.5	144.4
ASC	Ascension Island	-8.0	-14.4	-1.4	54.7
ASP	Alice Springs	-23.8	133.9	-34.1	-153.6
BNG	Bangui	4.3	18.6	4.6	89.3
CMO	College	64.9	-147.9	64.8	-102.6
CNB	Canberra	-35.3	149.4	-43.8	-134.5
CTA	Charters Towers	-20.1	146.3	-29.1	-140.7
EYR	Eyrewell	-43.4	172.4	-47.8	-107.0
GUA	Guam	13.6	144.9	4.2	-146.3
GZH	Zhaoqing	23.0	112.5	11.7	-177.1
HON	Honolulu	21.3	-158.0	21.2	-92.7
KAK	Kakioka	36.2	140.2	26.2	-153.3
KDU	Kakadu	-12.7	132.5	-23.2	-156.3
KNY	Kanoya	31.4	130.9	20.7	-161.2
KOU	Kourou	5.2	-52.7	16.1	17.7
MBO	Mbour	14.4	-17.0	21.1	55.8
MCQ	McQuarie Island	-54.5	159.0	-60.9	-116.2
MMB	Memambetsu	43.9	144.2	34.2	-150.9
PET	Paratunka	53.0	158.3	45.6	-138.5
PHU	Phuthuy	21.0	106.0	9.7	176.0
PPT	Pamatai	-17.6	-149.6	-15.2	-76.5
SHU	Shumagin	55.4	199.5	54.1	-103.1
SIT	Sitka	57.1	-135.3	60.1	-83.7
TSU	Tsumeb	-19.2	17.6	-18.3	83.5
VSS	Vassouras	-22.4	-43.7	-12.1	24.6

^a Geographic latitude and longitude^b Magnetic latitude and longitude

FIGURE CAPTIONS

Figure 1. Geographic distribution of >30 keV electron fluxes measured by five NOAA/POES satellites on August 1, 2008 for the time interval (a) 0-12 UT, before the electron flux enhancements and (b) 12-24 UT, during the enhancements. The electrons are detected in vertical direction. In the forbidden zone those electrons are quasi-trapped. The electron fluxes enhanced largely during nonstorm condition after 12 UT. The forbidden zone is bounded by $L=1.2$ (white lines) and located outside of the South Atlantic Anomaly (SAA) at equatorial-to-low latitudes. Drift L-shells are calculated from IGRF-2005 model. The solid black curve indicates the dip equator.

Figure 2. FEE enhancements on 1 August 2008: (a) fluxes of >30 keV electrons in units $(\text{cm}^2 \text{ s sr})^{-1}$, (b) L-shell of enhancements, (c) longitude and (d) local time of peak fluxes (black circles). Measurements within the SAA area are indicated by the open circles. Colorful curves denote NOAA/POES satellites: P2 (black), P5 (pink), P6 (red), P7 (blue), and P8 (green). Horizontal dashed line at panel (b) depicts the lower edge of the inner radiation belt. FEE enhancements peak at the equator (minimal L-shells) that indicates a fast radial transport from the inner radiation belt.

Figure 3. Solar wind parameters from OMNI data and geomagnetic indices on August 1, 2008. From top to bottom: (a) solar wind density (black) and dynamic pressure (blue), (b) solar wind speed, (c) interplanetary magnetic field (IMF) components B_x (blue), B_y (green), B_z (red) and magnitude B (black) in Geocentric Solar Magnetospheric (GSM) coordinates, (d) polar cap magnetic activity index PCN for northern (blue) and PCS for southern (red) hemispheres, (e) auroral electrojet index AE (black), AL (red), AU (green), and (f) storm time ring current variation index SYM-H. The shaded box denotes the time interval from 13 to 23 UT, when the nonstorm FEE enhancements were observed.

Figure 4. Spacecraft positions in GSM coordinates from 1200 to 1800 UT on August 1, 2008. The TH-C probe (blue) was in front of the subsolar bow shock. The TH-E (orange), TH-D (green), TH-B (brown), and GOES 12 (black) were located inside the dayside magnetosphere. The magnetopause position (black curve) was calculated using OMNI data for the upstream conditions at ~ 1600 UT following the model by Lin et al.'s (2010).

Figure 5. Observations of plasma and magnetic field on August 1, 2008. (a) Ion spectrogram (ion flux is in units of $\text{eV}/\text{cm}^2 \text{ s sr eV}$) and IMF vector components in GSM coordinates measured by TH-C, (b) IMF vector components from OMNI data set. Comparison of OMNI and TH-C data: (c) IMF cone angles plotted for OMNI (black) and TH-C (pink), red curve shows TH-C smoothed cone angle. (d) Solar wind dynamic pressure for OMNI (black circle), ACE

(blue curve) and for TH-C (red curve). Grey curve shows TH-C total pressure (sum of dynamic, magnetic and thermal pressures). The ACE data are shifted by 60 min.

Figure 6. Satellite measurements of magnetic field and plasma in the dayside magnetosphere and geomagnetic activity. (a) The Bz-GSM components from THEMIS probes TH-B (brown), TH-E (orange), and TH-D (green). The left y-axis corresponds to the magnetic measurements from TH-B and TH-D, and the right y-axis to TH-E. (b) The detrended magnetic fields for THEMIS. (c) The GOES-12 (black) and GOES-10 (blue) measurements of magnetic field strength (left y-axis) and local time (right y-axis). (d) The SYM-H index; and (e) the ion spectrogram from TH-D (ion flux is in units of $\text{eV}/\text{cm}^2 \text{ s sr eV}$). Dashed lines, numbered from 1 to 10, indicate magnetic and plasma disturbances observed by THEMIS.

Figure 7. Observations of plasma and magnetic field at 1530-1800 UT on August 1, 2008: (a,b) ion spectrograms measured by TH-C, TH-D (ion flux is in units of $\text{eV}/\text{cm}^2 \text{ s sr eV}$), (c) horizontal magnetic field H_p detected by GOES 12 from 10 to 13 LT, (d) magnetic field strengths B_{tot} from TH-D (green) and TH-E (red), (e) IMF cone angles for TH-C (black) and for the ACE upstream monitor (blue). (f) TH-C solar wind dynamic pressure. Dashed lines and numbers 4 - 10 mark plasma structures of magnetosheath ions observed inside the magnetosphere.

Figure 8. Observations of plasma and magnetic field during the intervals 1600 - 1630 UT, 1630 - 1700 UT and 1658 - 1728 UT on August 1, 2008. Panels show from top to bottom: (a) ion spectrogram from TH-D, (b) total pressure P_{tot} measured by the ACE upstream monitor (black) and TH-D (red), (c) plasma density D measured by ACE (black) and TH-D (blue), (d) TH-D measurements of bulk velocity V (black) and its components in GSM coordinates V_x (blue), V_y (green) and V_z (red), (e) transversal components of magnetic field B_x (blue) and B_y (green) from TH-D, (f) magnitude B and B_z component of magnetic field from TH-D, (g) magnitude B and B_z component of magnetic field from TH-E. The magnetosheath plasma penetration is denoted by dashed lines and numbers #4 - #10.

Figure 9. Relative variations in the horizontal component (H) of the geomagnetic field at low geomagnetic latitudes. Local time intervals are indicated near the station codes. The vertical lines depict magnetic peaks #1 - #3 at THEMIS (see Table 2). Bottom panel shows magnetic field B measured by GOES-12 (black) and detrended magnetic field from TH-D (green).

Figure 10. Relative variations in the horizontal component (H) of the geomagnetic field in the midnight (left) and predawn (right) sectors. The geomagnetic latitudes of the stations are indicated near station codes. The vertical lines depict magnetic peaks at THEMIS (see Table 2). Magnetic data from THEMIS and GOES satellites are shown at lower panels on the right.

Figure 11. Dynamics of the geomagnetic field and particles on 1 August 2008: (a) FEE enhancements, (b) plasma precipitation at high latitudes, and dayside magnetic field perturbations observed by (c) GOES-12 (black), TH-D (green) and TH-B (brown). The left y-axis corresponds to GOES-12, and the right y-axis to TH-D and TH-B. The numbers indicate the FEE injections at ~2 and ~5 LT (see Table 1), colors for POES satellite are the same as in Figure 2. Plasma precipitations are shown for the energy flux above the threshold of 0.5 (erg/sm² s) and are grouped in LT: 23 – 24 LT (light gray), 0 – 2 LT (gray), 5 – 6 LT (blue), 12.5 - 15 LT (red points), 15 – 16 LT (violet), and 19.5 – 21.5 LT (green).

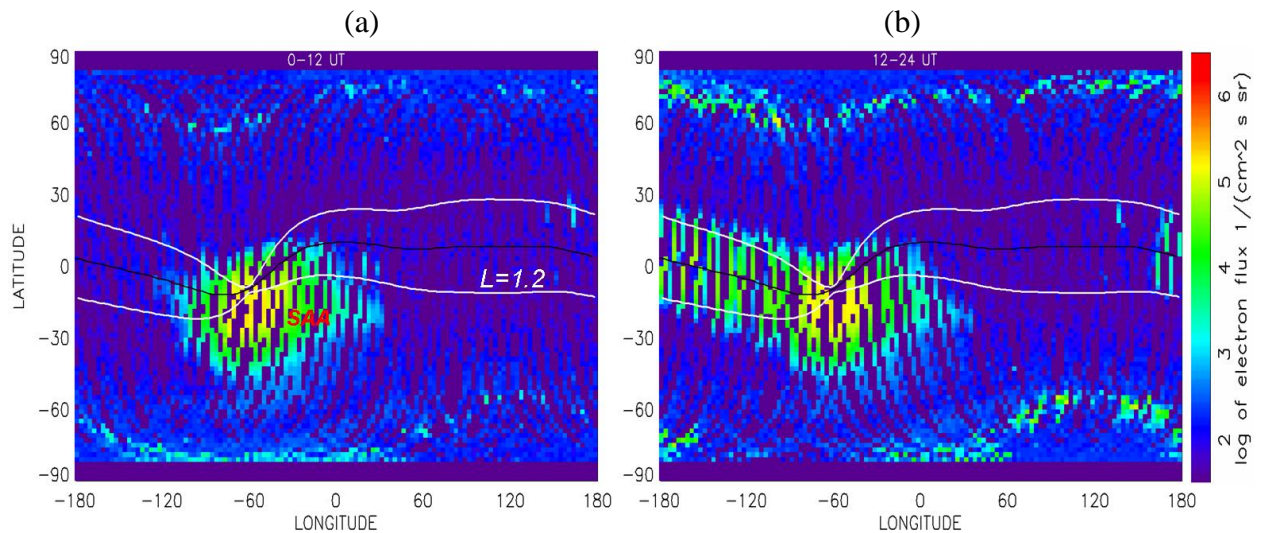


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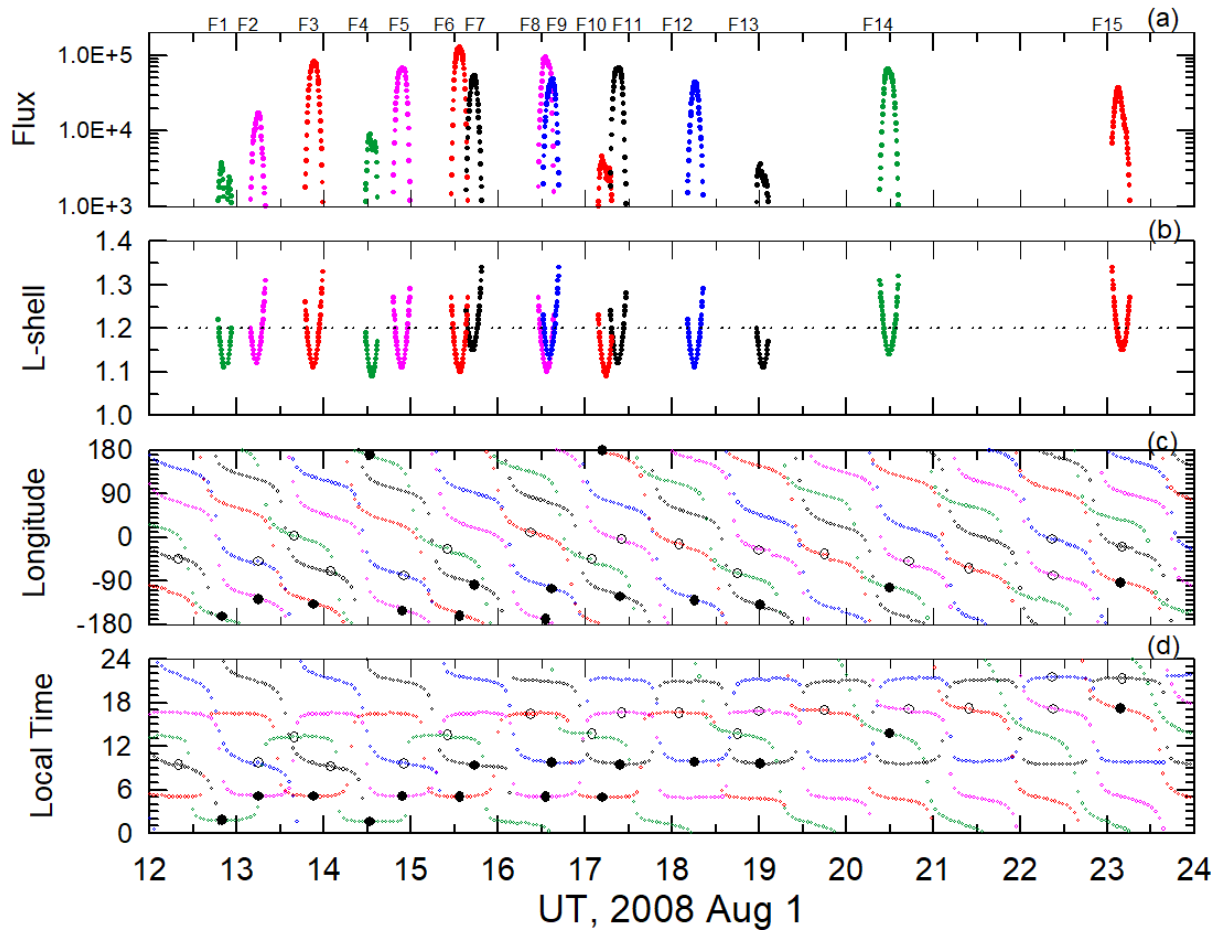


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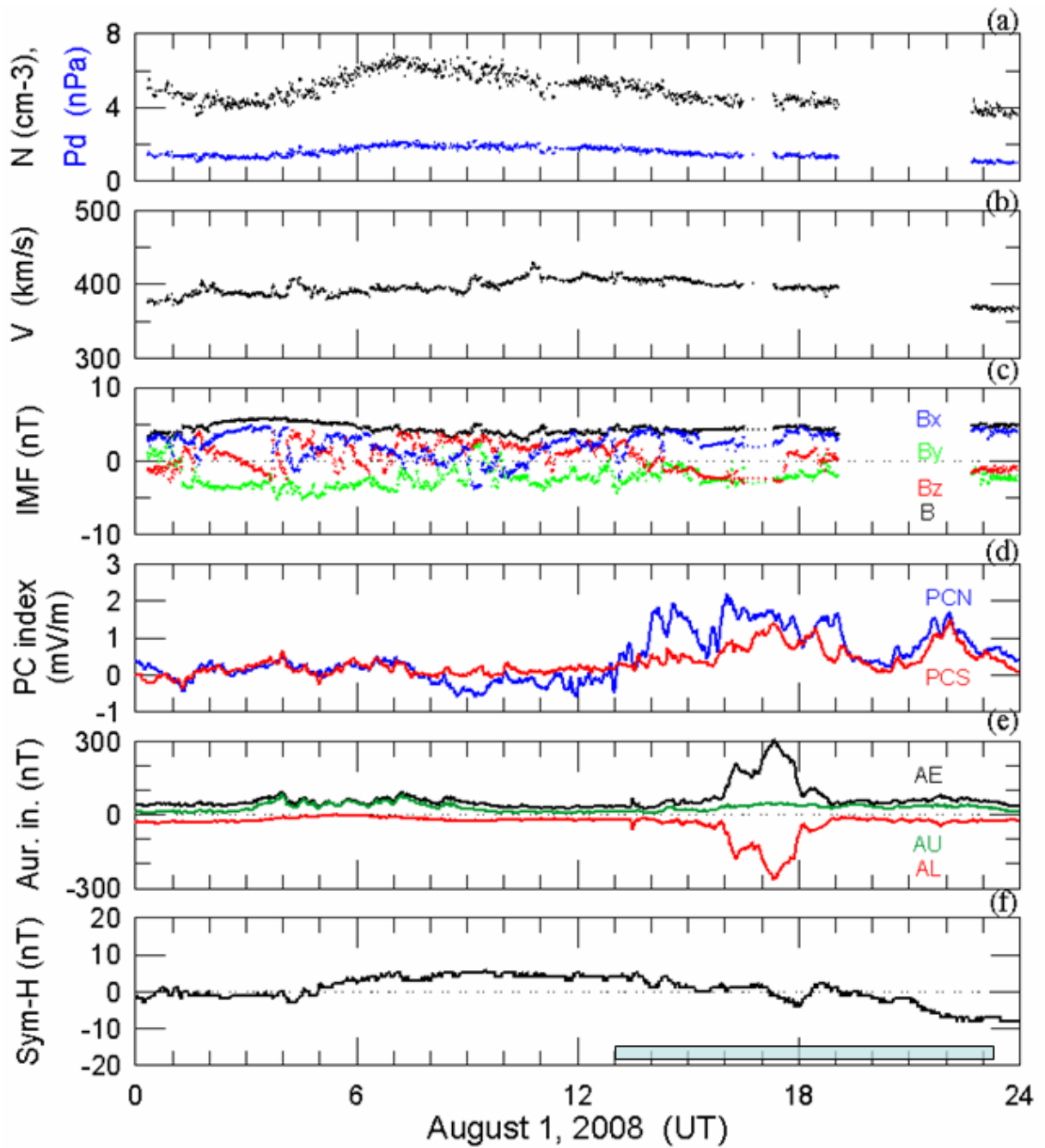


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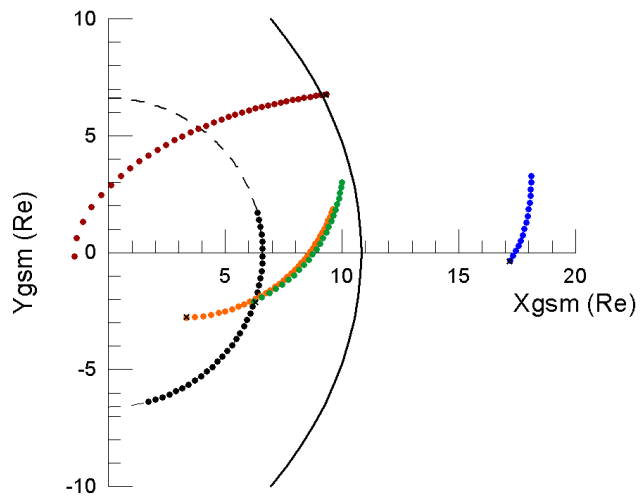


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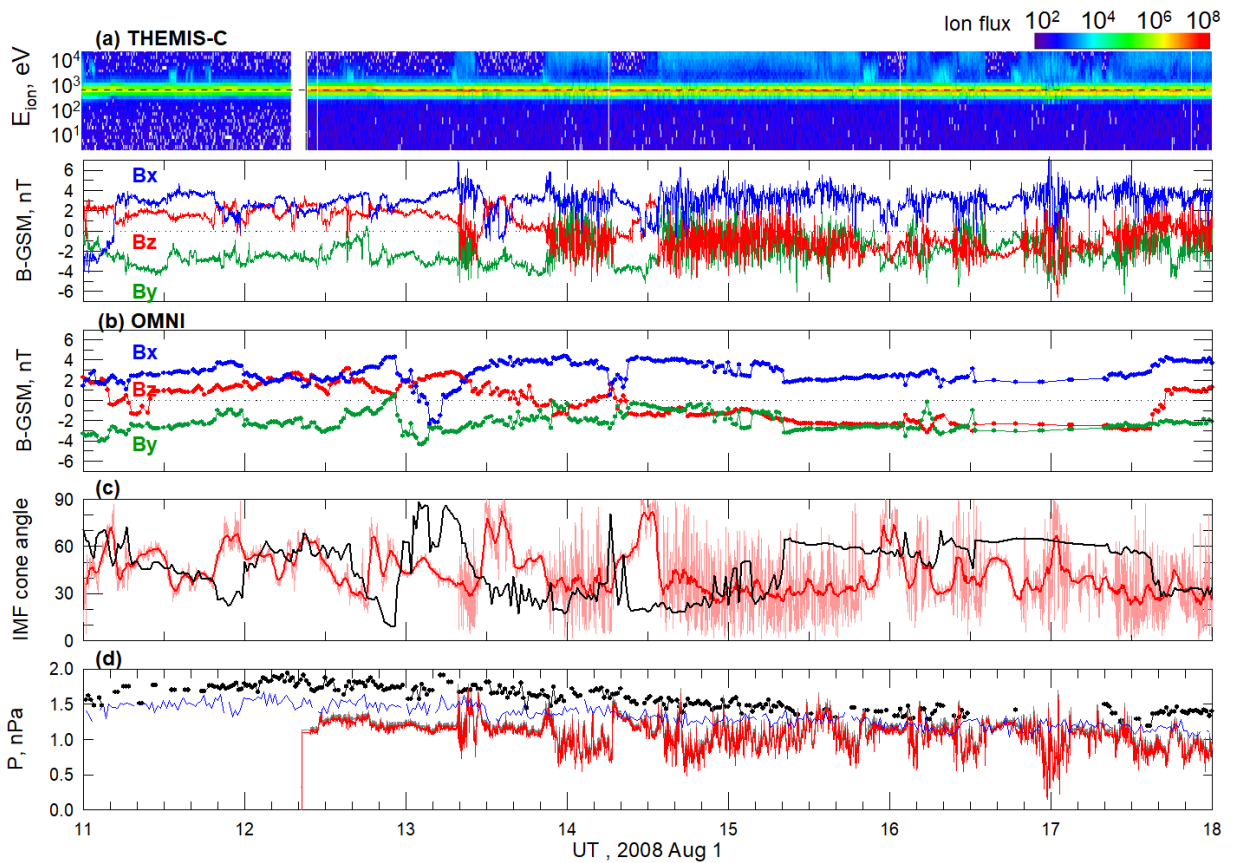


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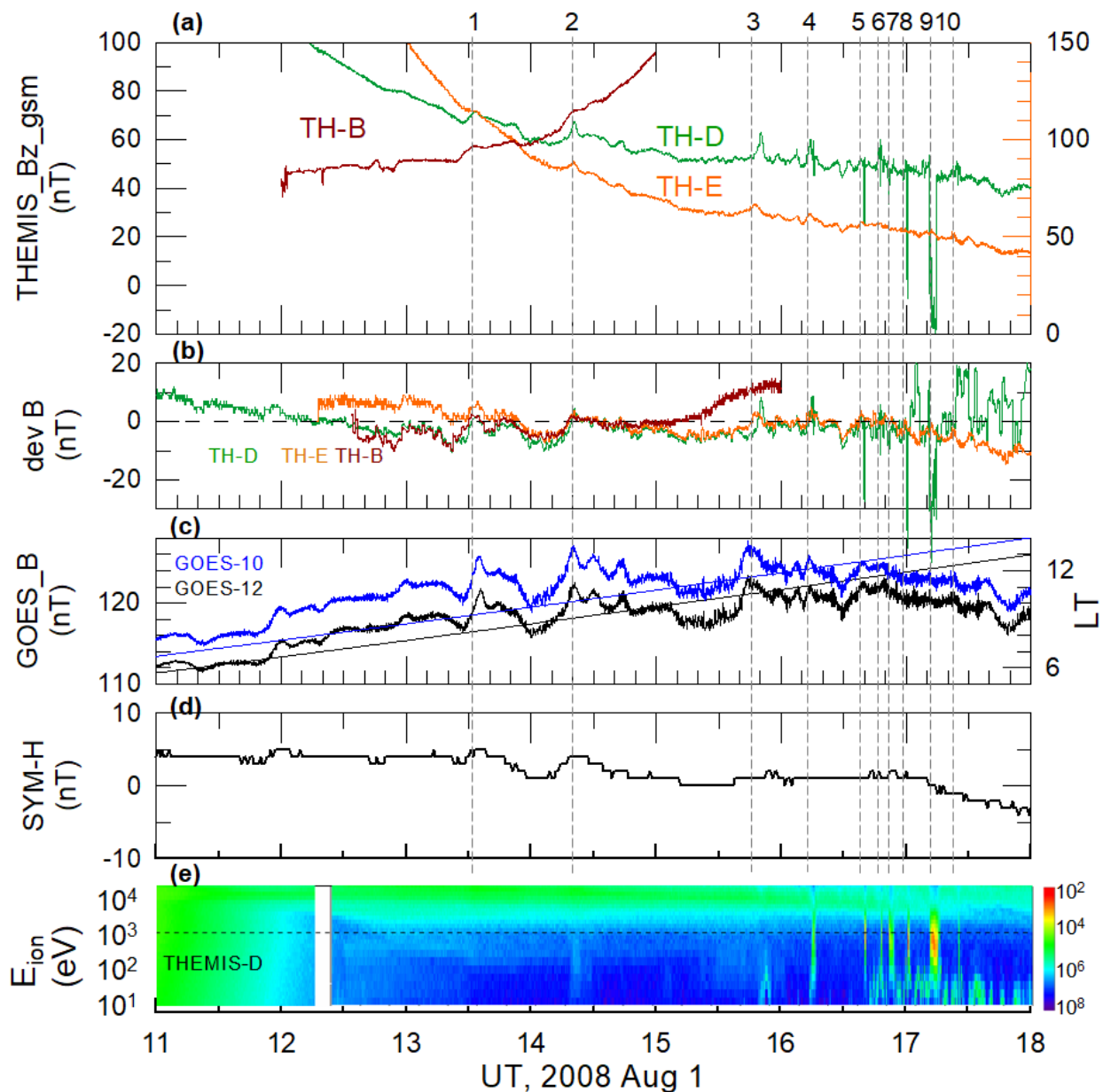


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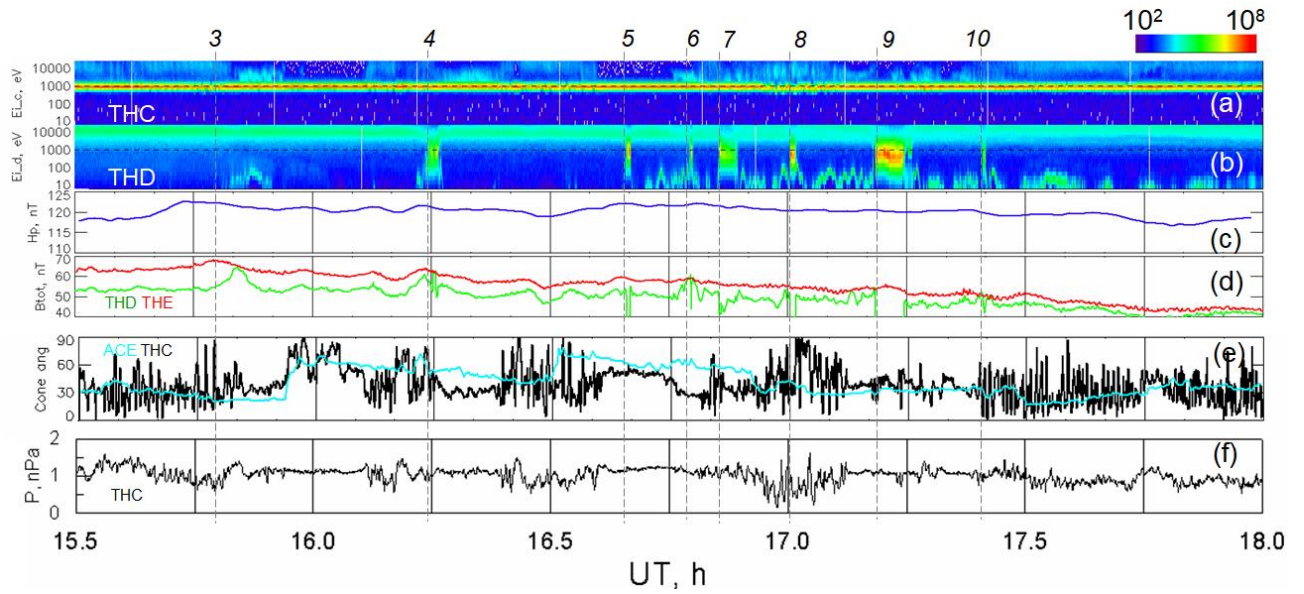


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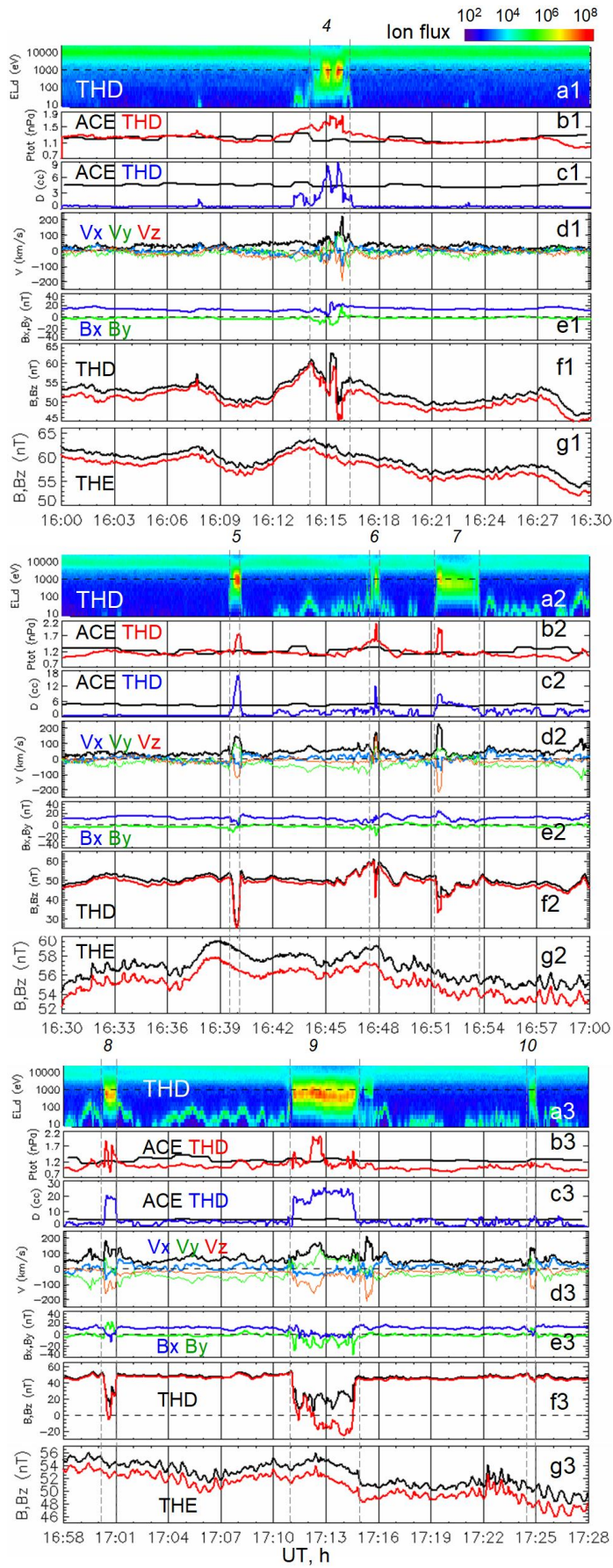


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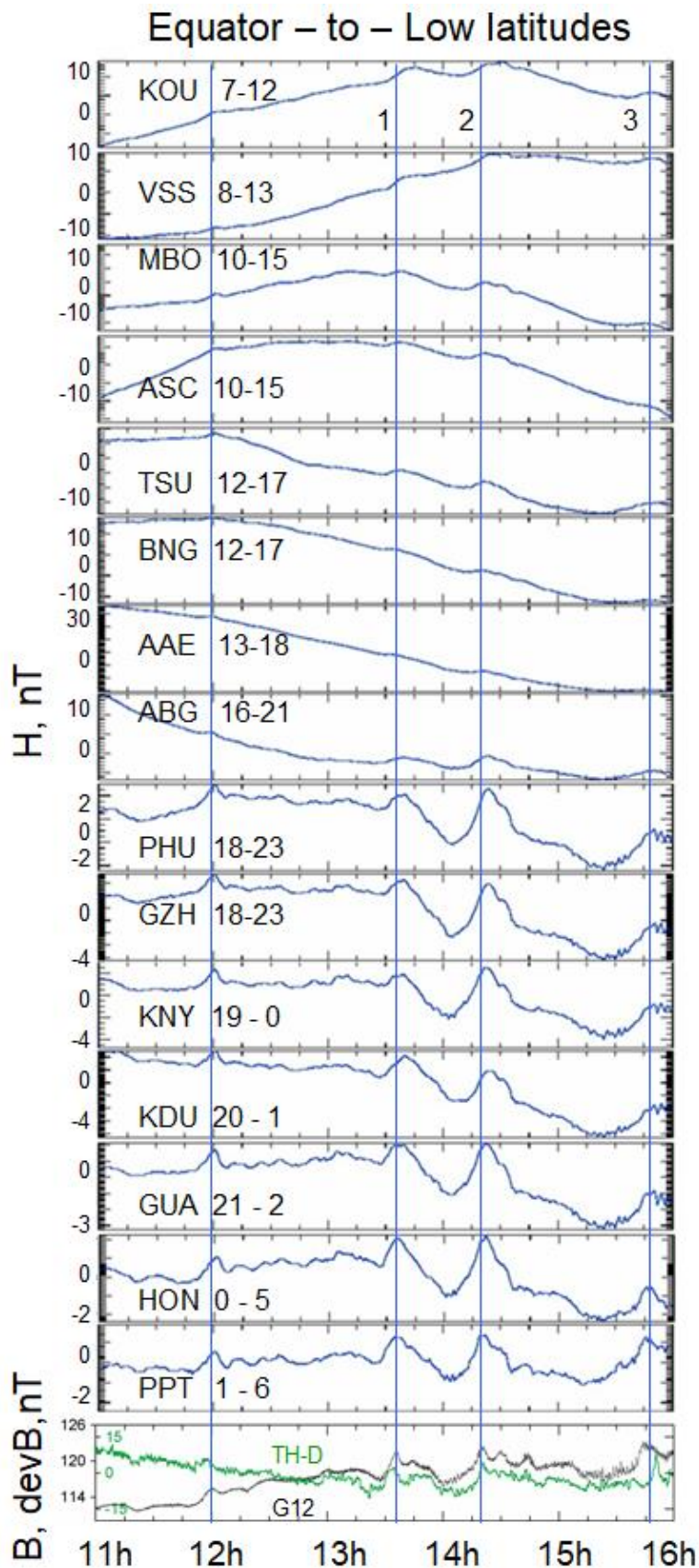


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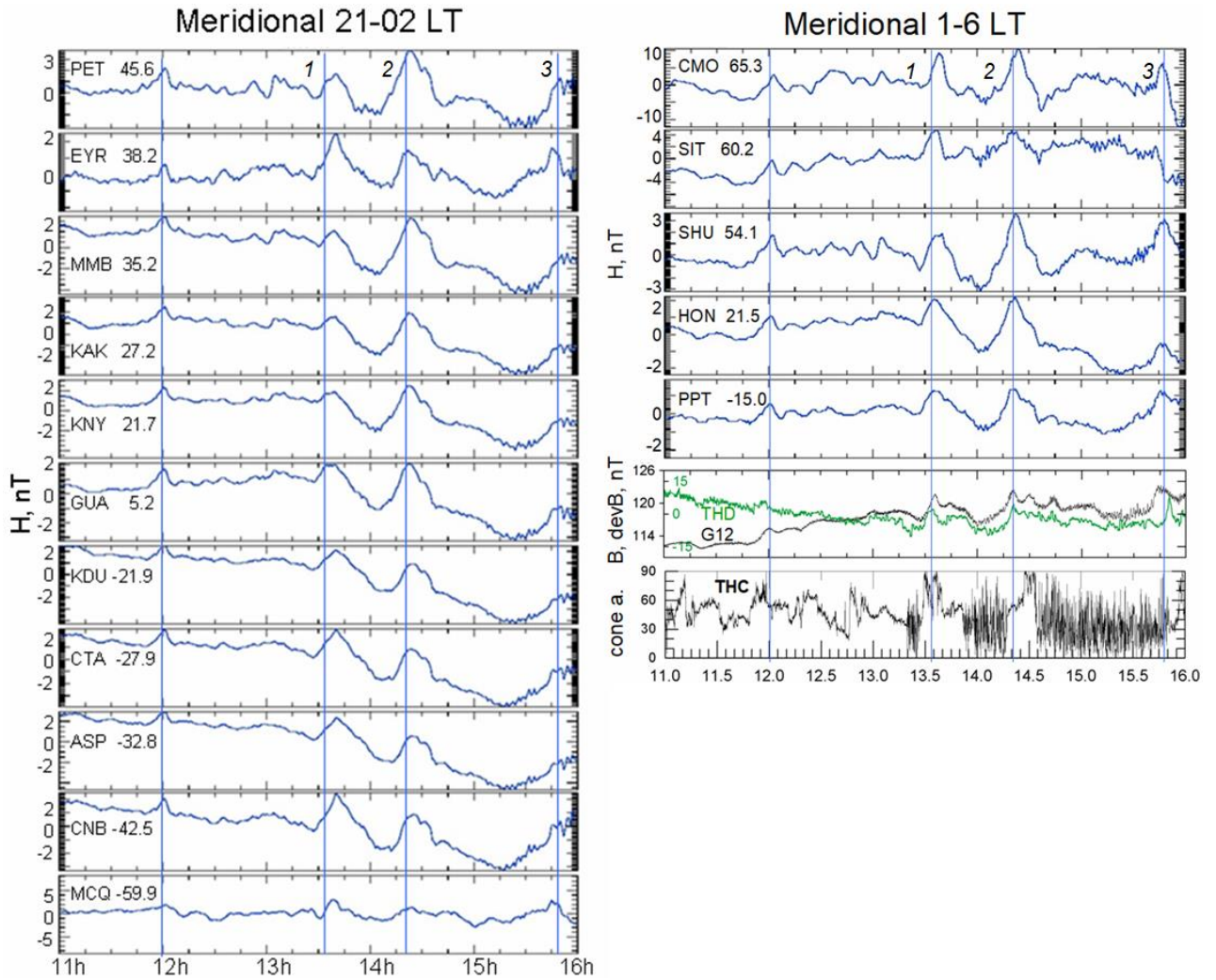


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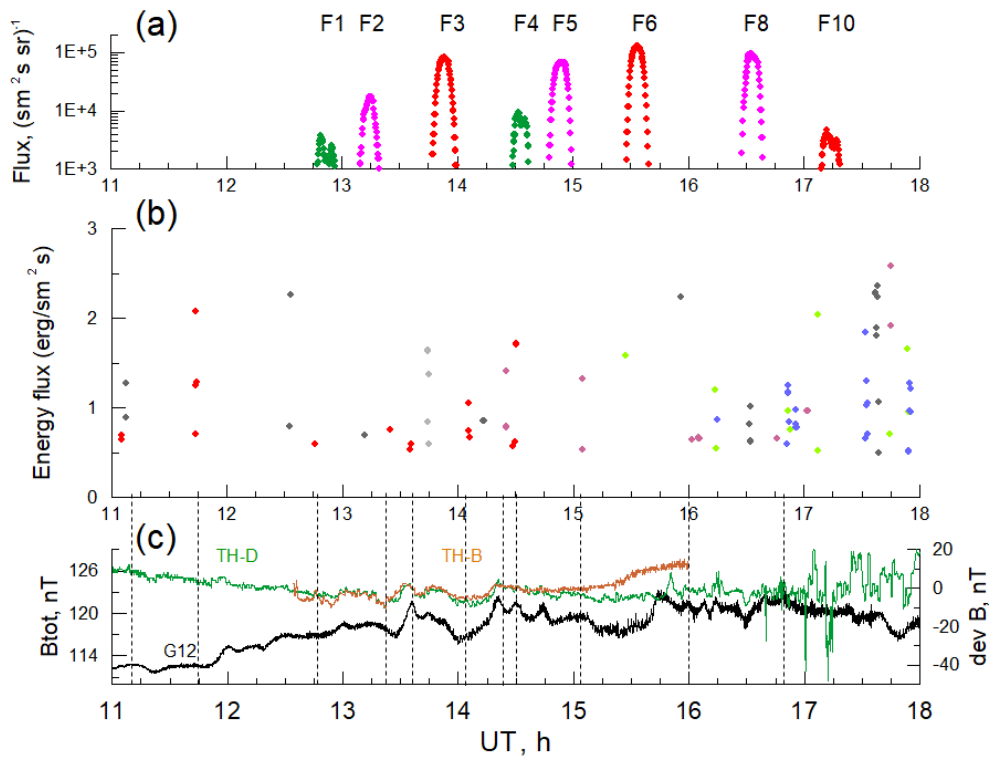


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