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Interactive comment on "Polar substorm on 7 December 2015: pre-onset phenomena and features of auroral breakup" *by* Vladimir V. Safargaleev et al.

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Reply to Referee #2 interactive comments on "Polar substorm on 7 December 2015: pre-onset phenomena and features of auroral breakup" by Vladimir V. Safargaleev et al.

Major comments:

Section "Introduction" is focused on publications from 1990's and older, only some recent Russian papers are referred to. Why poleward boundary intensifications (PBIs) are not discussed here?

- We added short comments on PBIs in Introduction and two papers in References. See also reply to Minor comments, L.27

Section 3.1: Why AE index is not shown anywhere? It would help to put the event into global context, since the local magnetic time in Scandinavia is evening and not close to magnetic midnight.

- We showed AE index in Fig.2 and added short comments in section 3.1 General overview. . .

l. 170: "The substorm was preceded by two negative variations in the H-component at KIL and SOD with repetition period of about 15 minutes (see Fig.2a middle panel)." (1) Give the times in the text. (2) If two events are separated by 15 min, this shouldn't be called repetition period.

- We would like to indicate the interval in the figure. Text is changed to: The substorm was preceded by two negative bays in the H-component at KIL and SOD at separation of about 15 minutes (interval is indicated with gray in Fig.2a). This variation is similar to a sinusoid and for brevity, hereinafter, we will use the term "repetition period" for the interval between two consecutive extremes (maxima or minima). These negative declinations . . ..

Discussion of SuperDarn data in Section 3.2. is deficient. "...enhancement of the plasma flow in polar cap started at 17:04 UT, reached maximum at 17:08-17:10 UT(diagram d in Fig.4) and lasted until T0. One more flow enhancement took place at 16:52 UT, i.e. 15 minutes before the first one". If the intention is to make the readers confirmed that 15-min periodicity exists in SuperDarn data, then there should be either time series of velocities or all the panels, not just a few selected ones. Furthermore, it is not explained if the vectors represent l-o-s velocities or mapped velocities. In addition, typically IMF data is shown before discussing ionospheric responses. Now IMF data comes only in Figure 6.

- We add panels in the figure. Now it shows the flow evolution at 2 min resolution. Vectors represent gridded line-of-sight velocities. The appropriate comment is added to figure caption. In our research we moved “from ground to solar wind”, i.e. we looked for the variations in IMF which might cause convection enhancements by taking into account both the time delay and presumable shape of variation – two negative excursions at $\sim$15-min separation. For this reason, IMF data are discussed and shown in the text after discussing the plasma flow variations in the ionosphere.

l. 192: “The increase of F-region electron density at about T0 looks like a signature of the polar patch associated with the reconnected flux tubes drifting across the polar cap from the cusp to the magnetotail”. – If the polar cap patch is formed on the dayside, near cusp, it takes a long time for this patch to drift over the polar cap to ESR. Please make that estimate.

- Rewritten as following: Assuming that the patch was originated in the cusp region at the moment of first flow enhancement, one get the patch propagation time from the cusp to ESR beam to be $\sim$ 40 min. Buchau et al. (1983) showed that patches drift antisunward with the background plasma flow ($\sim$1000 m/s that gives SuperDARN for the case considered). Thus, the distance between patch origin and place of patch detection is about 2500 km that corresponds approximately to the distance between statistical cusp position and the ESR beam.

l. 204: “Thus, the southward turning of IMF Bz could reach the magnetopause 20 min after registration onboard THC, and the ionospheric convection is expected to respond in _ 20 min after that (Hairson and Heelis, 1995).” – 20 min sounds a long time. Previous estimates of a global response have ranged from just seconds [Ridley et al., 1998] to 10 –15 min [e.g. Cowley and Lockwood, 1992]. However, if we use these numbers, they amount to 40-min delay, and then IMF variations at 16:15 and 16:30 UT correspond to 16:55 and 17:10 UT on the ground. I didn’t see these numbers used in later discussion.

- As we mentioned in section 1.2 “The magnetospheric response time to the variation in the solar wind can vary from a few minutes to several hours.” It is difficult to say what value should be taken for particular situation. Ridley et al. (1998) average estimation is up to 16.4 min. This estimation as well as estimation by Cowley and Lockwood (1992) is not dramatically smaller than 20 min estimation by Hairson and Heels (1998). In our research we moved “from ground to solar wind”, i.e. we looked for the variations in IMF which might cause convection enhancements by taking into account both the time delay and presumable shape of variation – two negative excursions at $\sim$15-min separation. That is why we used the numbers in previous discussion, only.

L. 294: “on the observation of the 15-minutes periodicity.” Some features are obviously separated by 15 min, some 12 min.

- We added the following remark in Section 5.3 The estimation of period depends on a number of factors, such as data resolution, subjectivism in the choice of the way of estimation (e.g. when we estimated repetition period of convection enhancements in polar cap and auroral activity over SOD), uncertainty in definition of the moment of max /min variations (e.g. when we estimated period as interval between two consecutive maximal declinations in H and Bz components), etc. So, it really is a period of 15$\pm$2 minutes, i.e. “close to 15 min” period. Thus, the term “15 min periodicity” is general and does not mean an exact value.

Section 4.1, Figure 5. While the apparent vortices in equivalent current (which may be artefacts of data analysis in regions where they are no magnetometers) may only tentatively be associated with up- or downward FACs, why not the AMPERE data shown in Figure 5c is not discussed here?

- Figure 5 shows ESR data. Distribution of equivalent currents is shown in Fig.7b and AMPERE data are shown at the same figure. See, as well, our comments to Referee’s minor comments, L.115. It was important for us to define the location of presumable footprints of FACs relatively auroras. It was easy to do by the use IMAGE data because

AMPERE gives only a general view of FACs position.

l. 412: “The convection enhancements were caused by negative deviations of IMF Bz component” – This needs more convincing discussion in the paper, see my comments above.

- Enhancement of antisunward ionospheric convection across the polar cap is traditionally connected with reconnection initiated by southward turning of IMF Bz component (e.g. Ruohoniemi and Greenwald, 1998).

l. 413: “Two weak variations in H-component might be the ground signature of global oscillations of the magnetospheric cavity excited by periodic erosion of the dayside magnetopause in the course of periodic reconnection” – Very unclear and hypothetical claim. Firstly, high- or low-latitude H-component? Secondly, I have not found any evidence in the data of PERIODIC reconnection. Two southward turnings of IMF Bz, separated roughly by 15 min, doesn’t make the IMF behaviour periodic. The claim is repeated in Conlusions, on l. 436.

- Rewritten as following: Two weak variations in H-component at KIL and SOD might be the ground signature of global oscillations of the magnetospheric cavity (see Fig.9). The oscillations might be excited by periodic erosion of the dayside magnetopause in the course of periodic reconnection (e.g. Agapitov et al., 2009). The conclusion regarding periodic reconnection is based on periodic enhancement of plasma velocity in the polar cap (see section 3.2).

l. 447: “The onset was accompanied by disruption of the dawn-to-dusk current in the plasma sheet around (X, Y) _ (-16, 16) RE” – With one single satellite showing an increase in the absolute value of the Bx component, one can only conclude that dipolarization has taken place, but it is not possible to pinpoint the location of current sheet disruption.

- Our comments. We would like to remind that in the early years the magnetospheric

studies were based on one single satellite observations. In particularity, the concept of dipolarization was inferred from North-South field behavior (e.g. Miashyta et al., 2000). In the case considered in our paper, GEOTAIL was located slightly southward of the current sheet. The hypothesis is supported not only by the coordinates of satellite position but also by large Bx and near-zero Bz components. At 17:30 UT CEOTAIL showed the DECREASE in the absolute value of Bx (from 25 to 20 nT) while Bz stayed almost constant. This means the decrease of dawn-to-dusk current in the current sheet. We corrected the text as the following: We conclude this from data of the GEOTAIL satellite showing the reduction in the absolute value of the Bx component (e.g. Lui et al., 1992) and dropout of high-energy electrons, enhancement of the westward electrojet and the large positive variation in H-component at low latitudes. In accordance with Lui (1996), current disruption activity is limited both radially and azimuthally to -1 RE. Since the GEOTAIL turned to be sensitive to the changes in Bx and electron flux and was magnetically conjugated with changing electrojet, we suggest that current decrease/disruption took place in the satellite vicinity.

Minor comments: l. 27: “The question is solving on the base of satellite observations” – Difficult to understand

- In the distant magnetotail, the direct comparison of satellite measurements and ground data is hindered by the low accuracy of mapping of magnetospheric processes to the ionosphere because of the complex shape of geomagnetic field lines. In particular, the causal link between the formation of so-called auroral “poleward boundary intensifications” (PBIs) and distant reconnection (e.g. Lyons et al., 1999) is very difficult to test. Note, that some kind of PBIs is regarded as substorm onset trigger (Nishimura et al., 2015). To solve the above problem one needs either appropriate modification of geomagnetic field model. . .

l. 59: “Multiple onsets occur often.” – Give a reference.

- Baker et al. (1996) noticed that multiple onsets occur often.

l. 78: “Samsonov et al. (2017) showed that the typical time for a southward interplanetary magnetic field turning to propagate across the magnetosheath is 14 min.” – Dayside magnetosheath to subsolar magnetopause?

- Yes. We indicate this in the text.

l. 103: “Fourth, we present GEOTAIL satellite data to investigate what process in plasma sheet – current disruption or neutral line formation – is responsible for the substorm onset (section 4.2).” – One satellite cannot give this information (was aim of Themis multi-satellite mission).

- We would like to remind again that in the early years the magnetospheric studies (including substorm disturbances in the magnetotail plasma sheet) were based on one single satellite observations. Nevertheless, we rewrite the sentence as following. “Fourth, we present GEOTAIL satellite data to show that in the case considered the current disruption in plasma sheet is more probable reason for the substorm onset than the neutral line formation (section 4.2).”

l. 111 BJN coordinates and elsewhere: Please specify if you use geographic or geomagnetic coordinates. Geomagnetic should be used.

- We add geomagnetic coordinates of the stations in the cases if only geographic ones are indicated in the text. We would like to retain geographic coordinates too because coordinates on the map in fig.1 and 7b, as well as in fig.3b are geographic.

l. 115 “footprints of localized downward (upward) field-aligned current (FAC) are manifested by quasi-circular clockwise (counterclockwise) equivalent current vortices around location of the upward (downward) FAC (e.g. Palin et al., 2016).” - This is a hypothesis and only valid for certain assumptions.

- Yes. This is assumption, but it is widely used assumption. Additionally, we presented AMPERE satellite data showing the same location of the field-aligned currents as defined from IMAGE magnetometer data (Sections 2 and 5.2).

l. 201: “Assuming the nose of the bow shock at 14 RE” – Where is this estimate based on?

- This estimation is taken from the 4-D Orbit Viewer tool mentioned in the text (L.198).

l. 235: “At this moment the structure was stretched approximately along geomagnetic meridian and had dimension of 170x170 km.” – A bit unclear description.

- Changed to: At this moment the structure was oriented approximately along geomagnetic meridian and had dimension of 170x170 km

l. 260: “decrease in Bx component (indicated by gray shadow) while” - Actually the figure shows increase of Bx. However, the absolute value is decreased.

- We rewrite as “…decrease in absolute value of Bx component (indicated by gray shadow) while…”

l. 265-267: Clarify the discussion, and make clear when dayside and when nightside low-latitude H is referred to.

- Rewritten as following: The increase of H-component at low latitudes in all MLT sectors is traditionally connected with the enhancement of solar wind dynamic pressure which is not occurred in the present case (see Fig.7b and variation in H-component at the dayside station San Juan, SJG, 18.1°N, 293.8°E in Fig.8b). In accordance with Maltsev et al. (1996) and Huang et al. (2004), the cross-tail magnetospheric current also contributes to the Dst variation, i.e., to the H-component at equatorial latitudes. Hence, the magnetic effect of the decrease or disruption of this current in the nightside magnetosphere will be manifested as the H-component increase at low latitude stations located, as well, on the nightside.

l. 356: Spell out IPCL

- … IPCL (irregular pulsations, continuous, long)…

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