Review report for "Swarm Field-aligned Currents During a Severe Magnetic Storm of September 2017"

General comment:

In this paper, the author conducted comprehensive investigations on the evolution of the field-aligned currents (FACs) at different scales during a recent intense geomagnetic storm by using the Swarm level-2 FAC products. However, some conclusions obtained in this study are not well supported by figures presented in the paper and some conclusions are degraded by the data quality, data coverage and methodology used in this study. In addition, some conclusions do not convey any new ideas. Therefore, this paper may have not reach substantial conclusions that suitable for publication. Meanwhile, conceptual and grammatical mistakes are frequently shown in the manuscript. A major revision is needed before the next submission.

Major Comments:

Comments for the Conclusion #1:

1) "The FACs become enhanced starting from the SW shock arrival despite of the prolonged period of the northward IMF. The night-time FAC densities primarily follow the substorm development while the dayside FACs are intensified in response to the SW shock and then stay enhanced. At the peak of substorm, the FAC densities averaged over a track within a given MLT sector, reach 3 $\mu A/m^2$, while the undisturbed level is about 0.2 $\mu A/m^2$."

a) It seems that this sentence is concluded from Figure 4, in which the evolutions of the average upward/downward FACs at four different MLT sectors and at both hemisphere are shown. Indeed, the average values increase after the significant drop of the SYM-H. However, the standard deviations are extremely large in comparison with the averages. If the standard deviations are taken into account, one can say that the FACs do not necessarily increase during the storm.

b) Meanwhile, Figure 4 does not evidently indicate that "the night-time FAC densities primarily follow the substorm development", since the FAC intensity increases when both SYM-H and AL indices decrease and the FAC intensity decreases when both SYM-H and AL indices increase on the night side. Therefore, the night-side FAC evolutions may be modulated by both the geomagnetic storm and substorm. The data shown in

Figure 4 cannot rule out the important role that the geomagnetic storm plays in the modulation of the evolution of the night-time FAC.

2) "The dawn–dusk asymmetry is manifested on the enhanced dusk side downward (R2) FAC on both hemispheres."

a) Although Table 2 shows the responses of FACs in certain MLT sectors on the dawn side are different those in certain MLT sectors on the dusk side, it cannot be concluded as "dawn-dusk asymmetry" since the results based on Table 2 are MLT biased. Perhaps it might be different in other MLT sectors. To better study the dawn-dusk asymmetry, data with better MLT coverage, such as AMPERE data, are useful. Without using data with reasonable MLT coverage, the statement associated with the dawn-dusk asymmetry may be problematic and needed to be removed.

b) It seems that the results in Table 2 are calculated by using 1 Hz FAC data. If so, the upward/downward FACs do not necessary mean R2/R1 (R1/R2) FACs on dawn (dusk) side. Typically, R1/R2 FACs represent large-scale FACs.

Comments for the Conclusion #2:

"The equatorward displacement of FAC sheets (in the north and south and at all MLTs) correlates with the storm intensity as monitored by the SYM-H index. The minimum latitude of the equatorial FAC boundaries is limited to 50° MLat. Displacement of FAC sheets is more gradual and occurs with a considerable time delay compared to the changes in current intensity."

a) The first sentence is not an new idea since it has been well studied in previous studies. For example, Wang et al. (2006) stated that "*The response of the equatorward FACs is found to roughly correlate with the IMF B_z, Dst E_m and ε*". Since the SYM-H index is the high-resolution version of Dst index, the first sentence does not bring anything new to the community. In addition, since only four MLT sectors have been studied in each

hemispheres and they do not cover all MLTs, the content in the parenthesis is not precise enough and may need to be removed.

b) The second sentence also brings nothing new and is not precise enough. For example, after 12 UT on September 8, the equatorward boundary reached <50° MLAT, therefore the statement that "the equatorial FAC boundaries is limited to 50° MLAT" is not precise. In addition, Fujii et al. (1992) stated that "*The equatorward boundary of the FAC system reached as low as 48° MLAT*" although a different storm was studied in their paper. But no new message has been conveyed by the second sentence.

c) For the third sentence:
    a. What do you mean by time delay? Delay with what? Did you show it in any figure and provide any quantitative description in the context?
    b. To study the displacement of the equatorward boundary of FAC you have utilized the 21-s averaged FAC, but to generate Figure 4, I suspect that you have utilized 1-s original data given the very large error bars, so you may not compare the same thing. If you want to substantiate your statement, you may need to use FACs on the same scale (e.g., 150 km or larger scales)

Comments for the Conclusion #3:

"The filamentary structures of high-density FACs are always presented in the Swarm observations. A bipolar structure (i.e. the adjacent upward and downward small-scale FACs), ~80 $\mu A/m^2$, 7.5 km width, is observed in the vicinity of the newly developed westward electrojet just prior the substorm onset. Simultaneous plasma perturbations indicate that the FAC pattern is likely associated with mesoscale auroral arc."

a) Although high-frequency FAC data can be used, cautions are needed when using the high-frequency FAC data. Because the assumptions used to derive the single-satellite FAC data may break down at small scales. Did you apply any data quality control technique for your small-scale FAC data? How? Since you have focused on those very isolated structures, the reliability of data is extremely crucial. Otherwise, your results may be degraded by using unreliable data.

b) The connection between the "bipolar structure" and "enhancement of the electron density" is not obvious. After a careful inspection, it seems that the strong upward portion

of the bipolar structure actually corresponds to the depletion of the electron density (Figure 9), and does not correspond to the enhancement of the electron density.

Minor Comments:

1) **Abstract:**
    a. Page 1, Line 8: Evolution → Evolutions
    b. Page 1, Line 15: "a substantial fraction of R1/R2 FACs is composed of many small-scale currents": May need to be altered, since theR1/R2 FACs are referred to the large-scale currents, which are not necessarily related to the small-scale currents.
2) **Introduction:**
    a. Page 1, Line 29: high latitude → high-latitude
    b. Page 1, Lines 32: Please add some references to support the statement. Also add "the" at the beginning.
    c. Page 2, Line 5: Since the connections between the auroral oval and FACs are still unclear, perhaps you can simplify the sentence to "The large-scale FAC consists of Region 1(R1) and Region 2 (R2) currents …"
    d. Page 2, Line 8: Add "currents/FACs" after "R1/R2" and "R1" and keep it consistent below.
    e. Page 2, Line 19: Please define the spatial scale sizes of "large scale" and "small scale".
    f. Page 2, Line 30: Add some references to support your statement.
    g. Page 3, Line 4: "counterpart" → "counterparts"
    h. Page 3, Line 11: Rephrase the sentence starting at Line 11.
    i. Page 3, Line 13: "compared to" → "as compared to the"; What do you mean by "stationary"?
    j. Page 3, Line 14: "extreme values are often reached" is not precise.
    k. Page 3, Line 15: "focus" → "have focused"
    l. Page 3, Line 16: Please add "For example," before "Utilizing"
    m. Page 3, Lines 25~28: Please rephrase the corresponding statements.
3) Section 2:
    a. Page 4, Line 11: "orbit" → "orbits"

b. Page 4, Line 15: What is the speed of the Swarm satellites?
c. Page 4, Third paragraph: Please simplify this paragraph and only provide the most important information related to the FAC data used in this study.
d. Page 6: Where is the Figure 1b? Also please add one plot showing the orbital coverage at southern hemisphere.

4) Section 3:

a. Please check the verb tense (Also in other sections).
b. Page 7, Line 16: Add the UT to indicate when the IMF Bz turned northward.

5) Section 4.1:

a. Page 9, Lines 23-25: R1/R2 currents typically represent large-scale (e.g., >500 km) FACs. And a 21-point moving window (~150 km) not only captures the large-scale currents but also captures some mesoscale FACs. Thus, the smoothed FAC in Figure 3b has more structures than typical R1/R2 current scheme. If you try to associated the downward/upward currents with R1/R2 currents, a larger moving window (e.g., ~500-km width) is needed. Otherwise, the corresponding discussion does not make too much sense and can be removed.
b. As mentioned in the major comment, the results shown in Figure 4 are significantly degraded by the large error bars. I think that you may have utilized the original 1-Hz data to calculate the results shown in Figure 4. If that is the case, the large error bars may be related to the very intense small-scale FACs as shown in Figure 3a. From you Section 5.1, it seems that you want to investigate the evolution of the large-scale FAC. If so, you need to use the smoothed FAC data rather the original data to conduct the study, which may give you smaller error bars and improve the results. Did you do in this way? If so, you need to mention it in the context. Otherwise, you may need to use the smoothed FAC. If you want to focus on the average FACs, you can also calculate the standard errors, which are the standard deviation divided by the square root of samples, and use them as the errors bars.
c. Page 11, second paragraph: The relative importance of substorm and geomagnetic storm in controlling the nightside FAC evolutions cannot be directly distinguished

according to Figure 4. It might be straightforward to show the correlation between FAC and SYM-H/AL to indicate which one plays a more important role.

d. Page 11, last paragraph: The last two sentence can be removed since they are not directly related to figures shown in the paper.

6) Section 4.2:

a. Please see the second item of the comment for Conclusion #1.

7) Section 4.3:

a. Page 14, Line 12: Please Add some references after "equatorward"
b. Page 14, Line 15: "20-point"? You mentioned "21-point" in Line 19 on Page 10. Please keep it consistent.
c. Page 15, Line 6: After 22 UT on September 7, the SYM-H was not stable.
d. Page 15, Line 9: 04 MLT is probably too prenoon. 04 MLT → 10 MLT?
e. Page 15, Lines 22-24: Please see the third item of the comment for Conclusion #2

8) Section 4.4:

a. Figure 6: Perhaps you could use the shade to highlight the period when SYM-H < -20 nT;
b. Page 20, Line 1: From the IL index, it is difficult to tell that the substorm was in the growth phase when the bipolar FAC was identified since it seems that the IL index was relatively stable at the time when the bipolar FAC was identified.
c. Page 20: Line 12: The difference of 15 μA is not trivial in comparison with your peak FACs (20%~25%), so that the downward and upward currents are not comparable. So this whole sentence may need to be removed.
d. Page 20, Line 13~14: First, FACs at 150-km scale size may not well represent large-scale R1/R2 FACs. Second, From Figure 9a, the bipolar structure is located in the downward FAC rather than between the "large-scale" downward and upward FAC.

9) Section 5.1:

a. First paragraph: I think the content is related to Figure 4, where your results may not really represent the evolution of large-scale FAC, especially you haven't pointed out whether the original data or the smoothed data have been used. Given the large error bars you have presented, it seems that the original data have been used, which are mixtures of FACs on different scales.
b. Last paragraph: See comments for Section 4.2

10) Section 5.2:

a. See the last general comments

References:

Fujii, R., Fukunishi, H., Kokubun, S., Sugiura, M., Tohyama, F., Hayakawa, H., Tsyryda, K., and Okada, T.: Field-aligned currents signatures during the March 13-14, 1989 great magnetic storm, J. Geophys. Res., 97, 10 703–10 715, 1992.

H. Wang, H. Lühr, S. Y. Ma, J. Weygand, R. M. Skoug, et al.. Field-aligned currents observed by CHAMP during the intense 2003 geomagnetic storm events. Annales Geophysicae, European Geosciences Union, 2006, 24 (1), pp.311-324.