Interactive comment on "Space Weather Forecasting: What We Know Now and What Are the Current and Future Challenges?" by Bruce T. Tsurutani et al.

Anonymous Referee #1 Received and published: 21 August 2019

The manuscript "Space Weather Forecasting: What we know now and what are the current and future challenges" submitted to NPG, 2019, by Tsurutani et al., represents overall an excellent summary of the physics background of geomagnetic storms and substorms, solar energetic particle fluxes, enhanced energetic magnetospheric electron fluxes and radiation belt formation, as well as ionospheric TEC changes. The focus is placed on the physics of the different space processes and the interplanetary causes and solar origins.

It is very understandable that a summary on space weather cannot easily cover all aspects (incl. the glossary), ranging from new solar observations from SDO, 3D CME modelling results based on STEREO observations, new heliospheric imaging results for ICMEs also from STEREO, CME/ICME kinematics and new projects (e.g., FLARECAST, HESPERIA, AFFECTS, HELCATS, etc. and also other US and int. projects). However, before publication I suggest to state this in the paper and to add ref. about ongoing projects and literature covering those issues. I am not pointing out special references because they are easy to find through the internet or by browsing the Space Weather Journals of AGU and Int. Journal on Space Weather and Climate. I suggest adding clarifications of the focus and limitations of the paper at the beginning and end of the manuscript, see also the specific comments below. I also suggest to name some books on space weather (e.g., Hanslmeier: The Sun and space weather; Koskinen: The physics of space storms, etc.). Eventually even the title maybe modified to these suggestions to be more specific.

I further suggest adding more specific details on how new missions (PSP, SO) will help answer the addressed questions, or if it is not possible, to leave it out.

With these modifications the paper will certainly be a very good overview on space weather processes, written in a clear way.

We thank the referee for his/her helpful comments. Based on your comments and that of the other referee, we now reduce the usage of the word "forecasting" and speak mainly of the physics of space weather, a point that you have emphasized. This is now in the title of the paper. This was our original intent. We thank you for the references to the Hanslmeier and Koskinen books. We have mentioned those, some earlier ones and one more very recent publication (Buzulukova, 2018) in the Introduction section and state that Space Weather is an extremely broad field and that even those many books have not covered all areas of importance. Our present effort is not only to fill in the cracks but to give a different slant to the topic of Space Weather and what fruitful research can be done today and in the next 10 to 25 years. This is now explicitly stated in the paper.

We now give more specific ideas on how current and future missions could help solve outstanding questions.

Minor comments:

1) p.1, l.11: Since also the solar wind speed plays a role because of E=-v x Bz, I suggest to add the word "major" at the beginning, i.e., "Major geomagnetic storms are caused by ...". Or some similar clarification.

Yes, Corrected.

2) Same p., l.17: I suggest adding a sentence on SEPs because the topic start a little abrupt.

Done. A phrase was added.

3) p.2, l.35: I suggest removing the word "old" by a more elegant sentence stating an evolution of space weather from solar terrestrial research over the years, or something similar. Several space missions over the last decades have made significant progress in terms of interdisciplinary research (SOHO, Cluster, ACE, STEREO, etc.) between the solar, magnetospheric, ionospheric disciplines and space physics in general. And the new data have led to fundamental new insights into solar storms (e.g., CME 3D structure and propagation to Earth).

Okay. Done. The main point that we wanted to make to the reader is that many of the physical phenomena have already been discovered and much of the future work is fine tuning, and understanding of the detailed physics.

4) p. 3, l. 70: I suggest adding "that occur more frequent during ...".

Corrected. Thank you.

5) Same p., next lines: I suggest to rephrase " We will explain to solar scientists ...". There are also solar scientists knowledgeable of space physics.

Yes, corrected. We now address this "to the reader". Sorry. This phrase came when one of us gave a talk on space weather at a meeting and afterwards he was collared by a very prominent solar physicist who thanked the speaker for defining why space weather people talk about ICMEs. This person in the audience did not know.

6) p.6, 1st par.: I suggest to not completely neglect the role of v solar wind here. I see it is addressed later on.

Yes, okay. Done. It should be mentioned to the referee that the variation in V typically ranges from ~400 km/s to 1,000 km/s, a factor of about 2. However the Bsouth component varies from

about 0 nT to say -60 nT for a major magnetic storm. The variation in Bsouth is the greater of the two.

7) P.7, l.180: lASCO has observed by now far more then 10.000 CMEs, but only about 5% are faster than 700 km/s in the plane of sky. Only a very few have speeds of >2.000 km/s and these are coming preferentially from coronal regions above enhanced photospheric fields, so that higher field strengths and compression effects are pronounced. That means only a subset of CMEs produces strong fields in ip space. Please add some clarifications.

Thank you very much for the information. We have paraphrased your comments in quotation marks and have added it to the paper. We did not know this. Very important.

8) p.8, 2nd par.: Results from STEREO observations are missing here. It is also pointed out that new missions will provide new insights, but do they really do for these research topics? And if so, how?

Corrected. Thank you. It is obvious that STEREO should have addressed this issue already (but haven't). In our initial writeup we were only focusing on future missions. A reference to STEREO has been added.

9) p.11, l. 268-272: There are results that relate MC magnetic field structures back to their solar source regions. I suggest including a few sentences.

Corrected.

10) Same p., next par.: Again, how do PSP and SO help specifically?

Corrected. We now mention that they would have to study the same ICME at different distances from the Sun.

11) p.17, l.414: Only "intensities that some MC fields do". Many MCs have weaker fields.

Corrected.

12) Same p., l.422: "having said"?

Corrected.

13) p.18, caption Fig.7: I suggest to write: "A large coronal hole at the ..."

Thank you. Corrected.

14) p.19, l.442-444: LASCO C2 is also included.

Now corrected.

15) p.21, l.480: How will these missions be useful? Be specific.

Amplified and corrected.

16) p.23, l.533: same as 15).

Corrected.

17) p.32, l.724: “stronger”

Corrected.

18) same p., l.727: wording of sentence

Corrected.

19) p.35, l.805-812: I missed some results from STEREO in this context.

Corrected.

20) Same p., 816-824: I suggest including here some sentences on the established drag modelling for CME propagation I the heliosphere.

Corrected.

21) p.37, l.865: “have shown”

Corrected.

22) p.38, l. 887: wording of sentence

Corrected.

23) p.39, caption Fig.18: I suggest adding clarifying text about the shock creation.

Corrected. We have added more explanation of the figure in both the figure caption and within the text.

24) p.42, l.962: I suggest removing the word “poor”. Either there is connection or not.

Corrected.

25) p.50, l.1100: Why is the magnetic profile unlike those of other ICMEs? Please explain.

Corrected. We now mention that the profile is discussed later in the paper. We have expanded that discussion (later in the paper).

26) p.53, caption Fig.29: Please add the date.

Done.

27) p.54, l.1196: Please explain what the averaging time for Bz was to avoid averaging out negative time intervals.

Done. We have also added a comment on magnetospheric reaction timescales.

28) p.55, l. 1225: What is meant by a solar filament in this context? Please explain.

Corrected. This filament is the interplanetary manifestation of the Illing and Hundhausen (1986) CME filament. We now mention this in the text.

29) p.31, caption Fig. 31: Please add the year.

Done.

30) p.57, l.1257-1260: I suggest elaborating things not addressed a little bit, see major comments.

Amended. The details follow.

31) Same p., next par.: I suggest adding the role of V, also for CME arrival time predicC4 tions.

Yes. Okay. Very important. Done.

32) p.58, first 2 lines: But what about forecasting with ENLIL?

To address the issue of using physics based computer codes, data based computer codes and machine learning algorithms, we have made some "Final Comments" at the end of the paper. We have added references to many ENLIL based codes but remark that different codes have different strengths in predicting plasma properties and timing, but they do not address the MC magnetic field direction and intensity, the prime point of this paper. The sheath fields are also not well specified nor tested.

33) Same p., last par.: I suggest adding drag modelling here.

Some references had been added in the Final Comments. Basically one of the ENLIL references states that one has to have imaging data to do real-time studies of deceleration and acceleration. We think the eventual goals would be to model the slow solar wind upstream of the CME so that the slow solar wind can be modeled. This has not been done to our knowledge.

34) p. 59, last lines: I suggest to add some more concluding remarks and references to books on space weather, including recently established forecast models and new projects.

Done. We have added a "Final Comments" section at the very end of the paper. Rather than address details on forecasting models and new space projects, we thought it more important to emphasize model predictions of MC fields at 1 AU and testing which has not been done yet. Also many of the space projects typically do not address the fundamental physical problems mentioned here.

35) p.60, l. 1338: wording of sentence

Thank you. Done.

36) p.67, l. 1530: I suggest adding a statement on GNSS. 37) P.75, l. 1746: Solar activity includes many other phenomena, e.g., CMEs, jets, etc. but here only flares are addressed.

Corrected. We changed the title of ‘Solar activity” to “Solar Flares”. CMEs are discussed separately. We have added a section on GNSS.