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 #2

[Main comments]

In this review paper, the authors summarized observations of space weather phenomena and their physical interpretations. The main topic is about geomagnetic storms and magnetospheric phenomena, which is based on the authors' previous studies, ranging from the arrival of ICMEs and solar wind plasma at the Earth to the resulting geomagnetic and ionospheric storms. Phenomenological understanding is broadly explained, and questions about unresolved problems are described in each section, leading to what to reveal by new space missions like PSP, Solar Orbiter, MMS, Araseand SWARM.

This paper is written not only for space plasma physicists but for non-space plasma readers, like solar physicists and ionospheric scientists. It looks that the authors hope lots of people to read this article and try the unresolved problems with the interdisciplinary cooperation. The terminologies are summarized at the end of the main text, and in each section, histories of the studies are explained, which are useful for beginners and young researchers.

On the other hand, though the title is "Space Weather Forecasting", the manuscript does not cover predictions of solar flares, CMEs, SEPs, GICs and plasma bubbles , as well as social impacts on the infrastructures. The methods using numerical simulations and machine-learning techniques are not well introduced in this paper. It would be more useful for readers if the authors can include the current prediction models and their prediction accuracy in this review paper.

Especially, with a new approach using machine-learning algorithms, probabilistic pre-dictions can be done even if the physical mechanisms are not fully revealed. For accurate forecasting, the full understanding of physical processes are really necessary? If we understand all the nonlinear processes in space weather phenomena, can we forecast them perfectly? It would be also useful for readers if the authors can answer these questions.

We thank the referee for his/her helpful comments in improving this paper. The points that you have raised above are very pertinent and are indeed topics that have not been covered well. To address your specific comment about discussing predictions of solar, interplanetary, magnetospheric and ionospheric phenomena, we have decided to change the tone of the paper to indicate that we are addressing only the knowledge of the physical causes of such phenomena. Our original thought was that we need to know the physical causes before making forecasts/predictions. However the words "forecast/predictions" mean other things to other people (see comments from referee #1) and this can be confusing. We have therefore changed the title of the paper and part of the text to reflect this.

To address some of your other questions about "forecasting" using computer codes and machine learning algorithms, we address it here in detail in a Final Comments section at the end of the paper. Many physics-based codes have been constructed over tens of years.

However most of them have not been tested even using data from past magnetic storms. People has simply assumed that with all the major "physics" put into the codes, that one would be able to predict observations. One of us (BTT) has been involved with a NASA funded project to test the codes for ionospheric total electron content (TEC) data. We have been at this for the last 5 years. We have been using the well-established codes with measured solar wind input and have had the CCMC personnel of the Goddard Space Flight Center run the codes for us. The results have not been good. Basically we are not able to get accurate reproductions of the observations from any of the codes. At this time, we have no idea why we are not getting the predicted results, especially with solar wind, solar and geomagnetic activity index inputs. We have submitted two papers on this topic and as one would expect, the referees are not happy. Well, we are not happy either, but we simply want to report our results so improvements can be made. So to answer one of your questions, the independent reporting on the accuracy of codes in predicting so far is essentially non-existent.

The other referee has mentioned the ENLIL code and related codes. We now reference many of these works. People have tested MC propagation from the Sun to 1 AU but only the solar wind plasma properties and arrival times. The MC itself has not been modelled and tested. This is now stated in the paper.

Concerning machine learning algorithms, that too can be a red herring. Some of us have been studying such applications. Although great claims of success by proponents have been made, actual space weather successes are rare to none. What if the ionosphere is dominated by chaos? Then machine learning will not help. We have added several references to this topic in the Final Comments section (a new section at the end of the paper).

From the above one can see that neither we nor anyone else is really qualified to talk about "forecasting" using computer codes or machine learning algorithms. There have been no tests for the topics addressed in this paper to the knowledge of the authors. On the other hand, we do not wish to put such future studies in a negative light. Perhaps someone will be able to make a verifiable breakthrough. We wish to be positive on this subject. To address the topic of "forecasting", we have made some short comments near the end of the paper.

We are very interested in what atmospheric weather people do and have been following their work closely. They have been diligently working at their problem far longer than space weather people have been. It is interesting to know how they make their predictions. They have many codes at their disposal. They down-select to say the ~25 best ones and then take the mean value! This seems to work well. But why it works leaves a big question? Maybe that is the answer for space weather as well.

We have passed our section of "Final Comments" to the other NASA funded JPL researchers (Xing Meng, Tony Mannucci (P.I.) and Olga Verkhyagladova). They are in agreement with the wording of this section. As mentioned before, we have been examining existing ionospheric TEC codes for the last 5 years.

[Minor comments]

1) [Fig. 7] It looks that the solar image is not from SDO but Yohkoh. SDO does not have a soft X-ray telescope.

We apologize for the error! Thank you very much for the correction. This has been fixed.

2) [Fig. 8] The inner solar image was not taken by a soft X-ray telescope but an EUV telescope of EIT (195A Fe XII). The inner coronal image in the black circle was taken by Mauna Loa coronagraph, while the outer one was by SOHO/LASCO-C2.

Corrected. Thank you. We did not mention the outer coronagraph image previously. We do now.

3) [section 2.4.1] There is a sentence that to determine IMF-Bz component in the sheaths, we need more effort on predicting the slow solar wind plasma and magnetic field, but this statement is obscure. What will be the key to predict the slow solar wind plasma?

Corrected. Thank you. Right now we have no idea on how to determine the properties of the slow solar wind, but as you note this is key to predicting the IMF Bz in sheaths. We have reemphasized this point near the end of the paper.

4) [General comments] There are so many abbreviations like MC, ICME, IMF, CIR,HSS, HCS, HPS, HILDCAA, AE, EIA, EMIC wave, PC wave, RED, PPEF, SSW, SSS, which are difficult for non-space plasma readers to understand.

Yes, we have no solution to this problem other than to put in a Glossary so the reader can go back and forth. Putting in the full spelling of the acronyms will lengthen the paper by a lot.

5) It’s better to show the definition of L value.

Corrected. We have inserted a definition in the text and also added this to the Glossary.