Reviewer report of “June 21 and 25, 2015 CMEs interaction’s results on Earth’s ionosphere and magnetosphere” by Somaiyh Sabri and Stefaan Poedts

This paper discusses magnetosphere and ionosphere disturbances associated with abrupt changes in solar wind parameters, such as CMEs, using the Gorgon Space model, a specialized MHD code for high-energy plasmas.

The referee judges that this manuscript is completely incomplete as a research paper, given the points listed below. Therefore, the referee recommends that this paper cannot be accepted for publication in the present form.

Summary of the review

1. The authors appear to lack knowledge of space science. Before writing their paper, they should fully understand the characteristics of the disturbances caused by CMEs in the magnetosphere-ionosphere system and summarize this in the introduction. They should then point out the shortcomings of previous research and explain the novelty and importance of their research.

2. Research papers should be able to be retested by third parties, and to this end, the input data used in the simulations and the characteristics of the simulations (such as the settings of physical parameters, such as diffusion coefficients and the size of the spatial grid) should be clearly stated in the paper.

3. To be honest, reading this paper left me with the impression that I was grading a poorly written paper by a first-year university student.

Itemized comments

Abstract

1. 9-10: It was discovered that the increased electric potential in the ionosphere is also responsible for accelerating particles.: It is not clear whether the electric field of the ionosphere is effective in accelerating particles.

1. Introduction

1. Overall: When specifying reference papers, it is difficult to understand unless they are enclosed in parentheses.
2. 18-19:*In fact, different settings necessitate the application of specific laws of*

physics.:What exactly does "specific laws of physics" mean?

3. 24-25:*These can contain large out-of-ecliptic magnetic field components and carry interplanetary shocks at their leading edge.*:What are the “out-of-ecliptic magnetic field components”? The component along the solar magnetic axis (z)?
4. 28-29:*If it evolves into a geomagnetic storm, it is referred to as storm sudden commencement (SSC) or a sudden impulse (SI) [Araki, (1994)].*: Nowadays, both are called SCs. (Joselyn, J. A. and B. T. Tsurutani, Geomagnetic sudden impulses and storm sudden commencements, A note on terminology, EOS, 47, 1808-1809, 1990.) From this point on, bow shocks are often discussed, but since the magnetosheath is in the solar wind region, when considering phenomena within the magnetosphere, it is better to summarize the effects of the solar wind on the magnetopause rather than the bow shock.
5. 35-37:*Different studies suggest that the shape and location of the bow shock primarily depend on the dynamic pressure exerted by the solar wind [Merka et al. (2005); Peredo et al. (1995)].*: See Spreiter et al. (1966). The position of the bow shock is not determined by the pressure of the solar wind plasma. (Spreiter, J. R., A. L. Summers, and A. Y. Alksne, Hydromagnetic flow around the magnetosphere, Planet. Space Sci., 14, 223-253, 1966. https://doi.org/10.1016/0032-0633(66)90124-3)
6. 37-38:*In empirical models, it is typically presumed that the pressure of the solar wind is consistent throughout the surface of the bow shock [Jerab et al. (2005); Merka et al. (2005)].*: Same as above.
7. 42-43:*These studies have discovered that the interaction between the shock and the bow shock leads to the formation of a sequence of discontinuities [Pallocchia (2013); Prech et al. (2008)].*: This is about the magnetosheath. It does not address the effects on the magnetosphere or ionosphere. Is there any particular need to mention this in this paper?
8. 51-54:*A convenient method for analyzing the entire system accurately is by utilizing global magnetohydrodynamic simulations, which can simulate the system as a whole in a consistent manner. In this study, the Gorgon code is used to conduct global MHD simulations of Earth's magnetosphere while considering the changing solar wind conditions [Chittenden et al. (2004); Ciardi et al. (2007); Mejnertsen et al. (2016)].*: A Space science group has been conducting global MHD simulation research since the 1990s, and many research results have been produced. The authors completely ignore the results.
9. 58-59:*We need to use the Gorgon-Space code as it enables us to describe the*

magnetohydrodynamic (MHD) plasma in the extensive simulation area.:Same as above. If we are going to conduct MHD simulations now, we should explain their novelty.

10. 61-62:*The ionosphere is the upper part of the Earth's atmosphere, located between 60 and 1000 km in altitude.*: If we treat the ionosphere as a boundary with the MHD fluid, a thin layer around 100 km where electrical conductivity is effective is sufficient. Furthermore, a detailed explanation is needed on how the Gorgon-Space code treats the ionosphere as a boundary condition.
11. 62-65:*The conditions in the magnetosphere are crucial for the physical processes occurring in the ionosphere. So, we are also contemplating the exploration of the magnetosphere-ionosphere system. Physics-based models can assess the state of the magnetosphere-ionosphere by considering the solar wind and interplanetary magnetic field. In this sentence, we examine temporary changes in the field-aligned currents (FAC) in the ionosphere.*: The settings of this code (boundary conditions, initial conditions) should be explained in detail.
12. 71-72:*It also evaluates the consequential effects on the ionosphere, including induced current density, which has a significant impact on communication and space weather.*: This paper does not address GICs.

2.1 **The Gorgon MHD code**

1. "method" section contains only one subsection. There is no need to create subsections.
2. 80-81:*Gorgon employs a comprehensive and clear representation of the resistive semiconservative Magneto-Hydrodynamic (MHD) equations for a plasma that is fully ionized.*: Could you please explain what "semiconservative" means?
3. 85-87:*However, unlike other global magnetospheric codes, Gorgon-Space calculates the magnetic vector potential instead of the magnetic field. This approach guarantees that the field remains divergence-free [Mejnertsen et al. (2018); Eggington et al. (2020)].*:Yagi et al. (20) presented a global MHD model using vector potential. (Yagi, M., K. Seki, Y. Matsumoto, Development of a magnetohydrodynamic simulation code satisfying the solenoidal magnetic field condition, Computer Physics Communications, 180, 9, 2009, 1550-1557, https://doi.org/10.1016/j.cpc.2009.04.010.)
4. 113-114:*These equations include terms for ohmic heating* $\eta|J2|$, *optically thin radiation losses Λ, and electron-proton energy exchange Δpe.* :(Formula and its

explanation) Explain the specific expressions for the parameters (η , Δpe, Λ) that appear in the formula. Or, indicate the reference paper. Furthermore, explain how these parameters are handled in this paper.

5. The pressure is treated separately for protons and electrons, but when these values are input into the model as boundary conditions from the solar wind, it is necessary to explain how this is done.
6. It is necessary to explain from what data source the solar wind upstream of the magnetosphere is taken.
7. The grid spacing and boundary position information of the model are explained.

3 **Numerical results and discussion**

1. 124-125:*In our previous study, ? utilized EUHFORIA to examine how two chosen CMEs spread and interacted with Earth.*:What does "?" mean?
2. In this chapter, Figure 1 is shown, but is not referred to in the text.
3. In Figure 1, CME1 and CME2 are not illustrated.
4. While research is being conducted to determine short-period disturbances in the magnetosphere and ionosphere through MHD simulations, the K index is an index calculated every three hours, so I don't understand the relevance. Is there any point in discussing the K index at all?

3.1 Gorgon-Space

1. 147-148:*This results in the creation of a turbulent region known as the magnetosheath situated between them [Lucek et al. (2005); Burgess and Scholer (2013)].*:Refer to Spreiter et al. (1966).

3.1.1 Magnetospheric Response

2. An explanation of the solar wind data used in this calculation and how it was handled is required.
3. 162-163:*The magnetosphere is influenced by interactions with the solar wind, which can be either viscous or pressure-related according to Newell et al. (2008).*:The physical mechanisms that allow plasma and energy to flow from the solar wind into the magnetosphere are reconnection (Dungey, 1961) and viscous interaction (Axford and Hines, 1961). The pressure reconnection allows momentum to flow in, but not plasma itself.

   Dungey, J. W., Interplanetary magnetic field and the auroral zones, Phys. Rev.

Lett., 6, 47-49, 1961, doi:10.1103/PhysRevLett.6.47.
Axford, W. I., and C. O. Hines, A unifying theory of high-latitude geophysical phenomena and geomagnetic storms, Canadian. J. Phys., 39, 1433-1464, 1961, https://doi.org/10.1139/p61-172.

4. 163-164:*Fig. 3 represents the initial shape of the magnetosphere at the start of the simulation, which correlates with the arrival time of the first Coronal Mass Ejection (CME) at Earth on June 23, 2015.*:Shouldn't it be Figure 2, not Figure 3? The arrival time of the CME to Earth should be listed down to the minute.
5. The explanation of Figure 2 is completely insufficient. The text also does not explain how to read this figure.
6. How is the electrical conductivity of the ionosphere calculated in the calculation?
7. 168-169:*The magnetosphere's features have been altered completely by the simulation.*:It's unclear what this article is saying.
8. Figure 3:The illustration captions are completely inadequate.
   Is it correct to say that this solar wind data was given at the upstream boundary of Figure 2? This is not clearly stated in the text.
   Where does this data come from?
   The date of the data is unknown.
   Is the vector data GSM-based or GSE-based?
9. 172-174:*Decrease in the density of particles and the rise in temperature, which can be seen in Fig. 3, may be connected to the formation of the bow shock.*:It is unclear which part of the density and temperature changes in Figure 3 this refers to.
10. 174-180:*It should be acknowledged that ICMEs lead to the fastest speed and the least negative Bz component at the Earth's orbit. As a result, ICMEs are considered to be the underlying cause of all significant geomagnetic storms that have a Kp index greater than 7. According to Fig. 1, there is a peak in the Kp values between the 22nd and 24th of June, with a value of over 7. Based on this, it is anticipated that the initial coronal mass ejection (CME) will reach. On 23 June, there is a possibility that Earth may be hit by an ICME (interplanetary coronal mass ejection), which in turn could lead to a significant storm. Additionally, due to the presence of numerous CMEs between the dates of June 19 and June 23, 2015, it is possible that this predicted storm is connected to the interaction of multiple ICMEs.*: The referee thinks what this sentence is saying should be included in the solar wind deformation in Figure 3, but the referee has no idea what part of Figure 3 it is referring to. Or, there is too little data shown, so it is unclear what it is trying to say.

11. 183-184:*Fig. 4 illustrates diagrams of the magnetosphere, showcasing the pressure and arrangement of open magnetic field lines on both the X-Z plane and the X-Y plane.*: The diagram also shows closed field lines. An explanation is needed as to where the magnetic field lines originate. Without this, the test cannot be repeated.
12. 184-185:*Afterward, it enables us to display the three-dimensional structure of the magnetosphere's dynamo regions.*: The term "dynamo region" appears suddenly without any explanation. There is no explanation as to why it is necessary to talk about dynamos here.
13. 185-186:*The magnetopause's location and the areas where reconnection occurs on the day and night sides are shown.*: The diagram should show where the reconnection is occurring. The reader doesn't know where the author thinks the reconnection is occurring in this diagram.
14. 186-187:*The magnetopause can be defined as the point where the lowest level of solar wind enters the magnetosphere.*:What is "the lowest level of solar wind"? This term is not a common space science term. It should not be used without explanation.
15. 187-188:*Panel (a) of Fig. 4 displays the Earth's magnetosphere pressure at the time of the initial occurrence of a coronal mass ejection (CME) from the Sun.*: If we want to understand the disturbances that a CME causes in the magnetosphere, we should show the solar wind magnetosphere just before the solar wind disturbance of the CME reaches the magnetosphere. Panel (a) shows the solar wind around the magnetosphere at the time of the solar flare that caused the CME, but this state reflects the solar condition just one day before, so it has no meaning in terms of the disturbances that this CME causes in the magnetosphere.
16. 191-192:*This occurrence may be connected to the magnetic reconnection phenomenon which occurs when the solar wind interacts with Earth's magnetic field.*:There have been many studies on reconnection in the tail, and we need to use these to explain why this disturbance in the XY plane alone can be attributed to reconnection.
17. 197-198:*On the other hand, in Fig. 5, it is evident that the magnetosphere retains its primary function as a shield and maintains its key properties.*: In both CME1 and CME2, the magnetosphere appears to act as a shield. I'm not sure what this sentence is trying to say.
18. 198-200:*In simpler terms, the magnetopause and bow shock of the CME1 experience significant changes in their size and shape, just as predicted.*: The readers probably won't understand what the author is trying to say in this passage.

19. 202-205:*The primary function of the bow shock is to slow down and deflect the high-speed solar wind as it encounters the magnetosphere. The creation of the foreshock occurs when particles are reflected at the shock, resulting in various interactions between waves and particles and the acceleration of particles [Eastwood et al. (2005)]. We have been making efforts to study 205 the acceleration of particles through the interaction of the solar wind with the magnetosphere*: Foreshock disturbances are not specifically addressed in this paper; this paragraph should be discussed in the discussion section.
20. 212-213:*One can infer that the energy from the solar wind is transferred to the Earth's magnetosphere through a process called magnetic reconnection.*: This is too vague to be of any use as an explanation. The results of MHD simulations should be able to concretely show how energy enters the magnetosphere from the solar wind through reconnection.
21. 221-224:*The rate of the magnetic reconnection and also how much energy is transferred is influenced by the speed at which the solar wind flows, the strength of the magnetic field, and its orientation. Subsequently, it was discovered that CME1 triggers a significant tempest on Earth and is accompanied by changes in the magnetic arrangement, increased speed, and pressure of the solar wind enveloping the Earth, as previously anticipated in Fig. 1.*: Same as above.
22. 226: *Figs. 5 showcases the changes in pressure and magnetic field in the vicinity of the Earth upon the arrival of CME2.*:"Figs. 5" should be "Fig. 5".
23. Eq. (6): This equation needs to be explained in the main text. Also, because there is j on both sides, it does not make sense as a physics equation as it is. If the j on the right side is J in Eq. (5), rewrite it as J. The left side should be j_parallel.

3.1.2 Ionospheric Response

1. 235-236:*Field-aligned currents are computed at the initial boundary of the simulation and then transferred onto a distinct spherical grid located on the ionosphere, following the dipole field lines.*:If this study is to be replicated by other people, it is essential to specify where the internal boundaries were placed.
2. 238-239:*Alternatively, the conductance can also be set as a constant value.*:It is unclear whether anisotropy has been taken into account in the conductance of the ionosphere.
3. 241-242:*The ionospheric model utilizes spherical coordinates to allow for the inclusion of larger spatial scales.*:What exactly is this passage saying? The reader has no idea.

4. 248-249:*Equation 7 provides the definition for the current density that is aligned with the magnetic field direction.*:"Equation 7" may be "Equation 6".
5. 249-250:*The current densities that align with the magnetic field lines in the ionosphere, which has resistance, are pulled by the Lorentz force (J ×B).*:Why does the Lorentz force "pull" the current density?
6. 250-254:*This force acts on the plasma and is the main driver of the drag experienced by neutrals on the ionosphere. The magnetosphere contains a force referred to as J ×B which contributes to the flow of current density through the ionosphere. As a result of the stresses caused by the field-aligned currents, which extend from the outer magnetosphere to the ionosphere, a complete flux tube can be transported around the magnetosphere.*: It is very difficult to understand. Please explain it simply. Furthermore, although it is clear that the neutral particle drag in the ionosphere comes from FAC, there is no explanation at all for how the Lorentz force creates FAC.
7. 256-260:*The accumulation of current density aligned with the magnetic field can be attributed to the interaction between the solar wind and the magnetosphere. The predominant energy transfer and alignment of currents in the ionosphere occurred primarily due to the boundary conditions. In order to predict space weather accurately, it is necessary to have a solid grasp of the physics behind these coupling processes. Determining the accuracy of MHD codes in replicating the electric fields in the plasma sheet when the solar winds interact with the magnetosphere is of utmost significance in Space Weather applications.*: This topic has been the subject of much research in space science, and should be summarized in detail in the introduction.
8. 263-263:*In panel (a) of the Fig. 8, the ionospheric field-aligned current is illustrated during the initiation of the first coronal mass ejection (CME) on June 21, 2015 at 08:02.*:The state of the ionosphere at the time of the solar flare that drives the CME reflects the state of the sun about one day before that time. What is the significance of comparing this with the ionospheric FAC immediately after the CME?
9. 267-269:*By examining two panels (a) and (b) in Fig. 8, it becomes evident that when CME1 reaches the Earth, there is a substantial build-up of current density in the ionosphere.*:It is known that the behavior of ionospheric FAC during SC driven by CMEs exhibits PI and MI. Not mentioning this would be extremely ignorant for a Space Science paper.
10. 270-272:*Actually, the energy for FACs originates from the magnetosphere and can*

be determined by computing the value of E.J. If there is a negative quantity, the energy of the plasma is transformed into electromagnetic energy, which then enhances the FACs.: E.J directly generates a current perpendicular to the magnetic field lines. FAC generation requires another physical process. This article reveals a lack of understanding of space science.

11. 276-277:*Furthermore, the fourth panel in Fig. 8 reveals the greatest imbalance in the accumulation of current density between the Northern and Southern hemispheres.* :A diagram of the distribution of FACs in the Southern Hemisphere is not shown.
12. 277:*This probably originates from the electric field generated by convection itself.*: The physical mechanism is not explained and cannot be understood.
13. 284-285:*Since the occurrence of CME1 coincides with other CMEs, it is possible to infer that the interaction between CMEs is the primary factor influencing their geomagnetic effects.*:It doesn't make sense.
14. 296-298:*The elevated electric potential in the ionosphere, which may result from the substorms triggered by the interaction between the solar wind and Earth, can also lead to particle acceleration.* : The referee does not understand how the electric field in the ionosphere can cause particle acceleration. A detailed explanation is requested.
15. 298-299:*This phenomena was pursued in previous section by illustrating Figs. 6, 7, and shown that CME2 does not lead to the high plasma velocity at the magnetosphere.*:Same as above. The physical causal relationship should be explained.

4 Conclusions

1. 310:*As was explained in 310 Sabri et al. (2024), the selected CMEs occurred on June 21 and June 25, 2015.*:It has not yet been published.

References

1. The way references are listed is too simple, making it difficult to access the paper. At the very least, open-access papers should include the DOI or URL.