Review comments for "June 21 and 25, 2015 CMEs interaction's results on Earth's ionosphere and magnetosphere" by Sabri & Poedts, 2024.

In this study, the authors utilized an MHD simulation to investigate the effect of two CMEs on the magnetosphere and the ionosphere. They used the Gorgon-Space code and the EUHFORIA model to show several parameters of the magnetosphere and ionosphere in response to the CMEs. The topic of this study is interesting. However, the reviewer finds there are several substantive issues in this paper that should be addressed before this paper is recommended for publication:

Our reply: *We thank the referee for this review, which has enabled us to clarify the paper and make it more accessible.*

The authors haven't thoroughly described how the simulation was conducted. The correspondence of simulation hours to the CME arrival time was not specified in the paper. Accurate information on the spatial domain of the simulation, as well as the initial settings of the magnetosphere and ionosphere, was also missing.

Our reply: *We thank you for your comments; they have been applied in the updated version of the manuscript. We have updated the manuscript to include clear definitions for CME1 and CME2, along with detailed explanations and a summary in Table 1.*

We agree that the original manuscript lacked sufficient technical detail on the simulation configuration. In the revised version (Section 2, "Method"), we now explicitly state:

The CME injection times: June 21 at 05:01 UT (CME1) and June 25 at 10:51 UT (CME2), based on LASCO/STEREO observations (Table 1).

The arrival times at Earth: June 23 at 00:03 UT (CME1) and June 28 at 12:52 UT (CME2), as extracted from EUHFORIA output at L1.

The spatial domain: Cartesian grid spanning X = [−24, 66] RE, Y = [−40, 40] RE, Z = [−40, 40] RE, with 0.5 RE resolution (180 × 160 × 160 cells).

The ionospheric boundary: A thin-shell model at ~110 km altitude with empirical Pedersen/Hall conductances (Section 2.2).

The interpretation of the results is insufficient. For instance, Panels (c) and (d) of Fig. 4 lack proper description; the changes in the pattern of field-aligned current and cross-polar cap electric potential are not fully discussed. Additionally, a discussion on what is new in the results of this paper compared to other work in this field of research should be included.

Our reply: *We have significantly revised the description of Fig.4. We now explicitly link the observed tail stretching and topological changes (Panels c–d) to nightside* *reconnection dynamics under enhanced solar wind forcing, citing established literature \cite{Baker1996,Hesse2004,Angelopoulos2008}.*

We have rewritten the Introduction and Discussion to emphasise our contribution:

While global MHD modelling of CME impacts is well established, few studies resolve the transient, high-amplitude FAC dynamics during the initial shock compression and the main phase of a storm using a divergence-free ($\nabla \cdot \mathbf{B} = 0$) code such as Gorgon-Space. Our work demonstrates that such models can capture the two-phase ionospheric response (Preliminary Impulse → Main Impulse) and quantify energy coupling via CPCP and FACs—key inputs for space weather forecasting. This bridges heliospheric forecasts (EUHFORIA) to geoeffective impacts (Gorgon-Space), validating an end-to-end chain for operational use.

We have completely rewritten the paragraph first to establish the scientific challenge (the coupled magnetosphere-ionosphere system) and then to position our work. We now clearly state that while global MHD modelling is a well-established technique, our study applies the Gorgon-Space code to investigate a specific, under-resolved problem: the rapid, transient dynamics of Field-Aligned Currents (FACs) in response to specific solar wind drivers.

Besides, while global MHD models like SWMF and OpenGGCM have successfully simulated storm-time magnetospheres, few studies focus on the transient, high-fidelity evolution of field-aligned currents during the initial compression and main phase of CME-driven storms using a $\nabla \cdot \mathbf{B} = 0$ preserving code. Gorgon-Space's vector-potential formulation provides numerical stability during extreme compressions, enabling accurate capture of FAC dynamics that drive geomagnetically induced currents (GICs). This study demonstrates the application of the EUHFORIA–Gorgon-Space chain to fully trace the sequence from CME launch to ionospheric electrodynamic response, offering a validated framework for operational space weather forecasting.

Other Comments:

1. Line 7, two mathematic tools could not have "correlation." The authors should be more accurate if they want to emphasize that the simulation performed well by coupling EUHFORIA and Gorgon-Space.
   Our reply: *We thank the referee for this important clarification. The original wording incorrectly used the term "correlation" to describe the relationship between the EUHFORIA and Gorgon-Space models. As correctly noted, two modelling tools cannot be "correlated"; rather, they are coupled in a physically consistent, end-to-end framework.*

In the revised manuscript, we have removed any such imprecise language. Instead, we now explicitly state that time-dependent solar wind parameters (density, velocity, IMF, thermal pressure) output by EUHFORIA at the L1 point are used as direct, dynamic boundary conditions for the Gorgon-Space magnetospheric simulation. This ensures a self-consistent transfer of heliospheric CME evolution into geospace impact modelling.

The success of the simulation is demonstrated not by "correlation" between codes, but by the physical fidelity of the resulting magnetospheric–ionospheric response (e.g., realistic compression, FAC intensification, CPCP values).

2. Line 8, the "CME1," should be more specific.
   Our reply: *You are right, the manuscript was completely rewritten.*

3. Line 16, the correlation between "Space weather" and the effect of solar wind is confusing, according to the text.
   Our reply: *In the revised manuscript, we have explicitly reframed the narrative to emphasise that:*

   Solar wind (particularly CME-driven disturbances) acts as the driver/input to the geospace system, providing the energy, momentum, and magnetic field orientation that initiate magnetospheric disturbances.

   Space weather refers to the resulting conditions and effects within Earth's magnetosphere-ionosphere system—including magnetospheric compression, enhanced field-aligned currents (>23 MA), elevated cross-polar cap potentials (~160 kV), and subsequent technological impacts (e.g., geomagnetically induced currents, GPS disruptions).

4. Line 25-27, the compression of the magnetosphere in the sentence is repetitive and redundant.
   Our reply: *We thank the referee for this valuable observation. We agree that the original text contained redundant phrasing regarding magnetospheric compression and conflated the cause (dynamic pressure enhancement) with its effect (boundary compression). In the revised manuscript, we applied this comment and edited that paragraph as:*

   Transient structures in the solar wind, such as coronal mass ejections (CMEs) and corotating interaction regions, drive space weather effects by interacting with Earth's coupled magnetosphere–ionosphere system. These transients often carry interplanetary shocks at their leading edges and exhibit strong southward magnetic-field components. A shock impact causes a sudden increase in solar wind dynamic pressure, rapidly compressing the dayside magnetopause and the entire magnetospheric cavity. This impulsive compression produces a *characteristic ground magnetic signature—a sharp, bipolar variation in the horizontal component—known as a Sudden Impulse (SI) \cite{Smith2019}. When the initial compression is followed by sustained energy input (typically via southward IMF-driven reconnection) and the development of a full geomagnetic storm, the event is specifically termed a Storm Sudden Commencement (SC) \cite{Araki1994, Joselyn1990}. Both SIs and SCs pose significant hazards to power infrastructure, as their rapid magnetic field variations can induce extremely high geomagnetically induced currents (GICs) in long conductors \cite{Eastwood2018}.*

5. Line 125, what does the "?" stand for?
   Our reply: *I apologise for the typo; it has been corrected in the updated version.*

6. Line 126, the authors should add a detailed description of EUHFORIA before using parameters, such as the Kp index, derived from the model.
   Our reply: *We thank the referee for this important clarification. We emphasise that this study does not aim to validate or improve Kp forecasting—that methodology was comprehensively addressed in our companion paper (Sabri & Poedts, 2025, Advances in space research), where we validated EUHFORIA's solar wind predictions against in situ measurements and derived Kp via the Newell et al. (2007) coupling function.*

   The primary objective of the present work is fundamentally different: to demonstrate an end-to-end space weather impact chain by feeding EUHFORIA's time-dependent solar wind parameters at L1 directly into Gorgon-Space as boundary conditions. This enables us to simulate the causal sequence:

   CME-driven solar wind → magnetospheric compression/reconnection → field-aligned currents → ionospheric convection potentials quantifying geoeffectiveness through first-principles MHD rather than empirical indices.

   Kp (and Dst/SYM-H in Fig. 1) serve only as contextual diagnostics to classify the two events as "storm" vs. "non-storm" prior to simulation. All physical conclusions (FACs >23 MA, CPCP ~160 kV, tail reconnection signatures) derive solely from Gorgon-Space's self-consistent solution—not from Kp.

7. Lines 129-131, what do "CME1" and "CME2" refer to？ Their properties and how they can be reflected through the EUHFORIA model should be included in the text and figures.
   Our reply: *We thank the referee for this important clarification request. We agree that the manuscript requires explicit identification of the two CME events and a direct presentation of their EUHFORIA-derived properties to justify our comparative analysis. In the revised manuscript, we have implemented the following improvements:*

8. Line 227, thetime when the two CMEs arrived should be clearly shown in Fig. 1. Also, a high Kp index doesn't directly correspond to a magnetic storm; please add other geomagnetic indices to justify the statement.

Our reply: *Explicit event definition: We now clearly state in the Section Introduction that CME1 refers to the 21 June 2015 eruption (launch: 05:01 UT; arrival at Earth: 23 June 00:03 UT) and CME2 to the 25 June 2015 eruption (launch: 10:51 UT; arrival: 28 June 12:52 UT).*

Enhanced Table 1: We have annotated the table rows corresponding to CME1 and CME2 with asterisks and added a footnote explicitly identifying these two events as the focus of our magnetospheric simulations.

We agree that Kp alone is insufficient to define a magnetic storm. We have added new panels to Figure 1 showing the Dst and SYM-H index (a high-resolution proxy for Dst) derived from OMNI/INTERMAGNET data for both events. CME1 shows a deep main phase with SYM-H reaching –200 nT (23 June 06:30 UT), satisfying the standard definition of an intense geomagnetic storm (Dst/SYM-H < –100 nT). In contrast, CME2 shows only a minor depression (SYM-H ≈ –20 nT), confirming its non-storm status despite elevated Kp during the initial compression. We also added a brief discussion in Section 3 clarifying that:

Kp reflects global auroral activity on 3-hour intervals and is useful for space weather alerts; Dst/SYM-H quantifies ring current strength and is the standard metric for storm intensity classification; the combination of high Kp and strongly negative Dst/SYM-H during CME1 justifies our characterisation as a "major geomagnetic storm.

Line 238, what is the empirical relationship to calculate ionospheric conductance?

Our reply: *We have revised the manuscript to clarify the calculation of ionospheric conductivity. As detailed in the updated Methods section, the height-integrated Pedersen (Σ_P) and Hall (Σ_H) conductances are calculated using established empirical relations. The formulation includes a solar EUV-produced background conductance and auroral precipitation enhancements based on the mapped magnetospheric energy flux. This provides the necessary closure for the ionospheric Ohm's law within the magnetosphere-ionosphere coupling module of the Gorgon-Space code.*

9. Line 276, How can Fig. 8 show the difference between the northern and southern hemispheres, as the figure only includes results from the north hemisphere?
   Our reply: *It was edited in the rewritten manuscript.*

10. Line 8, 12, 151, and 155: “sun” -> “Sun.” The word throughout the paper should be in the same format.
    Our reply: *Thanks for your comment; it has been applied.*

11. Line 15: “Sabri et al. (2018); ...Kumar et al. (2024)” -> “(Sabri et al., 2018; ... Kumar et al., 2024)”. Other similar quotes in the paper (i.e., Line 20) should be modified.
    Our reply: *Thanks for your comment. The manuscript was completely rewritten.*

12. Line 25 & 27: “magneropause” -> “magnetopause”.
    Our reply: *It was applied.*

13. Line 66: “Since we” -> “We”; “and investigated” ->, “investigated”; “and find” ->, “and found.”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten*

14. Line 90: “field aligned current” -> “field-aligned current”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten.*

15. Line 134: “CMEs” -> “CME”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten.*

16. Line 135: “provide” -> “provides”
    Our reply: *It was edited.*

17. Line 141: “being introduced” -> “introduced”
    Our reply: *It was applied.*

18. Line 177: “23 June” -> “June 23”
    Our reply: *It was applied.*

19. Line 194: “that” -> “which”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten, and this point was incorporated into the final version.*

20. Line 226: “Figs. 5” -> “Fig. 5”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten, and this point was incorporated into the final version.*

21. Line 298: “This phenomena” -> “This phenomenon”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten.*
22. Line 330: “be related on” -> “be related to”
    Our reply: *Thanks for your comment. The manuscript was completely rewritten.*