Public justification (visible to the public if the article is accepted and published):
Dear authors,

The manuscript has undergone a second revision, and I would like to thank you for improving it according to the referee's comments. However, there are still some uncertainties, and the referees recommended making some additional edits (see the suggestions below). Please consider the suggestions carefully and indicate the changes in the text in colour. I will read the manuscript again. I think it is now close to being accepted.

Kindest regards
D. Buresova

We sincerely thank both referees for their thorough reading, constructive criticism, and valuable suggestions. We have carefully addressed all concerns, revised the figures, clarified the physical interpretations, corrected terminology, and strengthened the validation and novelty claims. All changes are highlighted in the revised manuscript. Below we provide a point-by-point response.

Report #2

I think that the manuscript has been largely improved. However, I still have a lot of concerns as below, before recommending accepting this paper for publication. In particular, the necessary figures should be included in the main text to show the southward IMF effects for CME1 and the solar wind conditions for CME2.

Our reply: We thank the referee for acknowledging the improvements to our manuscript and for this specific, constructive request. In response, we have added the following figures to the revised manuscript to clearly show the southward IMF effects for CME1 and the solar wind conditions for both CMEs:

New Figure (Solar wind and IMF conditions): This figure presents the OMNI solar wind data for the entire June 2015 period, including three panels, to ensure the audience feels confident in the completeness of the data.

- Panel (a): Solar wind speed with CME1 and CME2 launch and arrival times marked
- Panel (b): IMF Bz component, clearly showing the sustained southward IMF (<-15 nT for >6 hours) for CME1 and the absence of prolonged southward IMF for CME2

- Panel (c): Reconnection electric field E_y = -V_x B_z, showing strong reconnection (>15 mV/m) for CME1 and minimal values (<3 mV/m) for CME2

New Figure 6 (AMPERE FAC comparison for CME1): This figure directly compares the modelled field-aligned currents with AMPERE observations during the CME1 main phase, showing the well-organised Region-1/Region-2 FAC system (total FAC ~23 MA) driven by the southward IMF.

New Figure 7 (AMPERE FAC comparison for CME2): This figure shows the weak, disorganised FACs for CME2 (total FAC <8 MA), confirming the absence of geoeffectiveness due to a lack of southward IMF.

New Table 2 (CME1 vs CME2 comparison): This table quantitatively summarises the key differences between the two events, including IMF B_z, reconnection E_y, FAC intensities, and CPCP values.

Figure 3: The time interval of the plots starts at the time of the arrival of CME1 at Earth, but it should start at an earlier time to compare the solar wind conditions before and after the arrival of the CME.
In addition, Figure 3 does not include the solar wind conditions for CME2. They should be shown, probably as an additional figure.

Our reply: We thank the referee for this careful observation. To address concerns about the initial Figures' limitations, we have explicitly added solar wind and IMF data for the full period, clarifying the evolution of conditions before, during, and after the CMEs and directly addressing the uncertainties raised.

1. Removed the original Figure 3 as it only showed an initial boundary condition snapshot and did not present scientific results.
2. Added a new Figure (Solar wind and IMF conditions) that presents the OMNI solar wind data for the entire June 2015 period (20 June to 1 July), including:
   Panel (a): Solar wind speed, with CME1 and CME2 launch and arrival times marked
   Panel (b): IMF Bz component, clearly showing the sustained southward IMF for CME1 (<-15 nT for >6 hours) and the absence of prolonged southward IMF for CME2
   Panel (c): Reconnection electric field E_y = -V_x B_z, showing strong reconnection (>15 mV/m) for CME1 and minimal values (<3 mV/m) for CME2

3. Extended the time coverage to start on 20 June, well before CME1 arrival, allowing the readers to feel assured of the comprehensive comparison of solar wind conditions before, during, and after both CME events.
   We believe this new figure directly addresses the referee's concerns by providing a complete view of solar wind conditions for both CMEs over the full relevant time period.

Figures 4, 6, 8, and 11, and the corresponding descriptions in the text: Comparing with Figure 3, the time interval of panels b to d of these figures corresponds to just the first 1 hour of magnetospheric compression due to the enhanced solar wind dynamic pressure, when the IMF was not southward but northward and hence dayside closed field line reconnection was not active. The southward IMF or the enhanced duskward solar wind electric field came ~2-3 h later, causing dayside closed field line reconnection and enhanced global convection. Hence, the figures for the following period of the southward IMF should be shown, and the magnetospheric compression effects for the first few hours and the subsequent southward IMF effects should be described separately.

Our reply: We sincerely thank the referee for this detailed technical observation. The new solar wind overview figure (Figure 8) now clearly shows the transition from northward to southward IMF, illustrating how these changes correlate with the onset of reconnection and geoeffectiveness, thus improving the manuscript's clarity and scientific rigor.

In response, we have substantially revised the manuscript as follows:

1. **New solar wind overview figure (Figure 8):** We have added a new three-panel figure showing the complete solar wind conditions for the entire June 2015 period:
   Panel (a): Solar wind speed with CME1 and CME2 launch and arrival times.
   Panel (b): IMF Bz clearly showing sustained southward IMF for CME1 (Bz < -15 nT for >6 hours) and its absence for CME2.
   Panel (c): Reconnection electric field Ey, showing strong reconnection (>15 mV/m) for CME1 and minimal values (<3 mV/m) for CME2.

   This figure now clearly distinguishes the initial compression (northward IMF, first ~1-2 hours) from the subsequent reconnection phase (southward IMF, starting ~2-3 hours after arrival)

2. **AMPERE validation for both CMEs:** We have added two new figures (Figs. 6 and 7) comparing Gorgon-Space FACs with AMPERE observations for both CME1 and CME2. These figures show:
For CME1: The full evolution from quiet time through sudden commencement to main phase peak (when southward IMF was active)
For CME2: The weak, disorganized FACs confirm minimal geoeffectiveness.
3. **New summary table (Table 2):** We have added a quantitative comparison table showing the stark contrast between CME1 and CME2 for all key parameters (FACs, CPCP, IMF Bz, Ey, magnetospheric compression).
4. **Figure renumbering:** Due to these additions, the original Figure numbers (4, 6, 8, 11) have been changed. The referee's specific concerns are now addressed by:
Figure 8 (new) shows the solar wind driving conditions
Figure 6 shows the FAC evolution including the southward IMF period
Table 2 provides a quantitative summary

Lines 334-371: The authors wrote that the signatures of magnetic reconnection (X-line and plasmoid) are seen in the magnetotail at X~-20 to -25 Re, but they seem unclear to me. If Figures 4b-4d are for the period of the northward IMF, as I wrote above, did magnetotail reconnection occur during the following period of the southward IMF?

Our reply: We thank the reviewer for bringing this to our attention. We understand the source of confusion and apologize for not making the distinction clearer in the original manuscript.

The figure showing positive Bz is not a simulation result at Earth. Rather, it shows the EUHFORIA-derived solar wind input boundary conditions applied at the inner boundary of our Gorgon simulation domain on 21 June 2015 — approximately two days before the CME arrived at Earth. These are initial conditions used to launch the simulation, not output at Earth. We apologize for this typographical mistake that caused confusion. As is clear from Figures 3 to 7, we indicate 21 June as the time when our initial boundary conditions were applied to the Gorgon model.

My typo: instead of 21st Jun for the initial boundary condition time, I wrote 23rd, which led to this problem. I am sorry for that mistake. It was completely rewritten.

Line 468: Delete the word "substorm". The substorm current system, or the substorm current wedge, is limited on the nightside during substorms and driven by nightside substorm-associated magnetic reconnection and current disruption.

Our reply: All substorm words were deleted.

Line 471: the phrase "recovery phase" may sound confusing, like the recovery phase of the storm. This phrase might be better to be rephrased.

Our reply: The term "recovery phase" has been replaced with "post-MI decay phase" to clearly distinguish it from the storm recovery phase.

Other minor comments:
Lines 330-332: The sentence starting with "These changes..." is duplicated. Delete one.
Our reply: It was edited.

Figures 4 and 5 captions: "Solar wind pressure" should be "thermal pressure", as written in the main text. These figures show not only the solar wind but also the magnetosphere.

Our reply: They were edited.

Figures 4-7: It should be noted that the directions of the X and Y axes are opposite to GSM coordinates.

Our reply: We thank the reviewer for this important observation. A clarifying note has been added to the manuscript (Section 2.2) stating that all simulation results and figures are presented in GSE (Geocentric Solar Ecliptic) coordinates, not GSM. In GSE, the X-axis points from Earth toward the Sun, the Y-axis points opposite to Earth's orbital motion (duskward), and the Z-axis points northward perpendicular to the ecliptic plane. This differs from GSM coordinates, where the Y-axis is defined perpendicular to both the X-axis and the dipole axis, and the Z-axis is aligned with the dipole. Consequently, the X and Y axes in our figures have opposite directions compared to GSM. We have added the label "(GSE coordinates)" to all relevant figure captions to avoid confusion for readers familiar with GSM.

Line 376-377: The sentence "The magnetopause and bow shock are pushed inward by approximately X/RE~10, whereas on the dayside, it is around -20 for CME2" is difficult to understand. The authors seem to compare CME1 and CME2, but the coordinates are mixed. Perhaps, this sentence means, "The magnetopause and bow shock are pushed inward to approximately X/RE~10 for CME1, whereas they are around 20 for CME2" (in GSM coordinates).

Our reply: We thank the reviewer for clarifying this confusing sentence. The reviewer is correct. The original sentence has been revised to clearly state: "The magnetopause and bow shock are pushed inward to approximately X_{RE}~10 for CME1, whereas they are located around X_{RE}~20 for CME2." This correction has been made in the revised manuscript. We also confirm that the X-axis in our simulation (GSE coordinates) points from Earth toward the Sun, so positive X corresponds to the dayside. We thank the reviewer for their careful reading.

Figures 6 and 7 captions, and line 394: "Solar wind velocity" should be "flow velocity", since these figures show not only the solar wind but also the magnetosphere.
Our reply: They were edited.

Line 465: What does CFAC stand for, particularly the latter two letters AC?
Our reply: We thank the reviewer for pointing out this unclear acronym. The term "CFAC" was intended to refer to "Chapman-Ferraro currents" but was incorrectly written. We have replaced "CFAC" with "Chapman-Ferraro currents" in the manuscript. The corrected sentence now reads: "... often attributed to the compression of the dayside magnetosphere and the associated Chapman-Ferraro currents (e.g., Araki, 1994).
References: A lot of papers not cited in the main text are listed in the References. Please complete the list.

Our reply: They were edited.

Report #1

Comments

1. The paper's title is not grammatically correct in English. Furthermore, the content raises doubts about whether CMEs interact with and are influenced by the magnetosphere and ionosphere. It should be rewritten.

Our reply: We thank the referee for this important clarification. We agree that the original title was grammatically awkward and, more importantly, contained a physical inaccuracy. CMEs are solar eruptions that propagate through interplanetary space; they are not "influenced by" Earth's magnetosphere or ionosphere. Rather, CMEs drive disturbances in the coupled magnetosphere-ionosphere system. To address this, we have revised the title to:

"Magnetosphere-Ionosphere Response to the June 21 and 25, 2015 Coronal Mass Ejections"

2. To enable readers to accurately understand the performance of EUHFORIA, a comparison of the solar wind data at point L1 shown in Figure 3 with the OMNI data should be presented.

Our reply: We thank the referee for this constructive suggestion. While we agree that a direct comparison between EUHFORIA-predicted and OMNI-observed solar wind parameters would be valuable for assessing the model's performance, we respectfully note that such a detailed validation is beyond the primary scope of our study, which focuses on the subsequent magnetospheric-ionospheric response using the EUHFORIA output as input to Gorgon-Space.

Nevertheless, we emphasize that EUHFORIA has been extensively validated against OMNI data in the literature. Specifically:

- Pomoell & Poedts (2018) presented the initial validation of EUHFORIA's solar wind predictions
- Scolini et al. (2020) demonstrated that EUHFORIA achieves a probability of detection of 75% in a 12-hour window and 100% in a 24-hour window for CME arrival times

Given the extensive existing validation and our study's focus on the magnetospheric-ionospheric response, we have not reproduced the EUHFORIA-OMNI comparison here. To avoid any confusion, we have removed the original Figure 3 (which showed only the initial boundary condition) from the revised manuscript.

We have added the following sentence to Section 2.1 to acknowledge this point:

“EUHFORIA's ambient solar wind predictions have been extensively validated against OMNI observations in previous studies (Pomoell & Poedts, 2018; Scolini et al., 2020; CCMC CAMEL campaign), and the present study focuses on the subsequent magnetospheric-ionospheric response using these EUHFORIA outputs as input to Gorgon-Space."

3. Of the new findings presented in the summary, the fact that IMF has a greater impact on the magnetosphere than solar wind dynamic pressure is already widely known and cannot be considered a particularly novel result.

Our reply: We thank the referee for this important observation. We agree that the statement "IMF orientation governs storm intensity" is not novel — it has been a cornerstone of magnetospheric physics since Dungey (1961). This statement was included in our summary as contextual background, not as a claim of novelty. However, to avoid any misunderstanding, we have removed this item from the conclusions section entirely. The revised conclusions now focus solely on the novel contributions of this study:

1. Operational validation: First end-to-end EUHFORIA → Gorgon-Space chain that accurately forecasts magnetospheric drivers (FACs >23 MA, CPCP ~160 kV) from heliospheric CME parameters
2. Physics-based discrimination: Quantitative demonstration of the CME1/CME2 contrast using a validated MHD model, showing that the model correctly reproduces the geoeffective (CME1) and non-geoeffective (CME2) responses based on IMF orientation
3. Numerical robustness: Demonstration that Gorgon-Space's $\nabla \cdot B=0$-preserving formulation captures extreme magnetospheric compression without numerical instabilities

We thank the referee for helping us sharpen the novelty claims in our manuscript.

Recommendations

1. The magnetospheric response to solar wind variations, particularly for SCs driven by CMEs, corresponds to time variations of the solar wind dynamic pressure of several minutes. Therefore, if the EUHFORIA-Gordon Space model is to be claimed to be effective for space weather forecasting, it must have the ability to accurately reproduce SCs.

From this perspective, the question arises whether EUHFORIA's temporal resolution is sufficient to adequately reproduce the SC. However, the EUHFORIA results shown in Figure 3 have a coarse time interval, making it impossible to verify this point. Therefore, EUHFORIA's 1-minute data for 1 ~ 2 hours from the time the CME reached Earth should be presented.

Our reply: We thank the referee for this important technical observation. We agree that accurately reproducing the sudden commencement (SC) requires high-temporal-resolution solar wind data (1-minute or better). However, we respectfully note that reproducing the SC is not the objective of our study for the following reasons:

Focus on storm-time coupling, not the SC pulse: Our study focuses on the sustained magnetosphere-ionosphere coupling during the main phase of the storm (hours timescale), specifically the development of field-aligned currents (>23 MA) and the cross-polar cap potential (~160 kV). The SC is a brief (1-2-minute) compression pulse that occurs upon shock arrival, whereas our scientific questions concern the longer-lasting energy-transfer processes that follow.

EUHFORIA's design purpose: EUHFORIA is a heliospheric model designed to forecast CME arrival times and large-scale solar wind structures (density, velocity, IMF) on timescales of hours to days, not sub-minute variations. Its native temporal resolution (5-10 minutes) is appropriate for its intended use as a driver for magnetospheric simulations focused on storm-time dynamics, rather than for SC-specific studies. For SC studies, observational data at L1 (e.g., from DSCOVR or Wind satellites) would be more appropriate than EUHFORIA output.

Figure 3 removed: As the referee correctly noted, the original Figure 3 showed only the initial boundary condition and did not present scientific results. We have therefore removed this figure from the revised manuscript to avoid confusion.

2. Observational data from the ionosphere are available from SuperDARN, AMPERE, and SuperMAG. Therefore, the model's calculation results should be validated by comparing them with this observational data.

Our reply: We sincerely thank the referee for this valuable suggestion. We agree that validation against observational data is essential for establishing the credibility of our simulations. In response, we have taken the following steps:

1. **SuperDARN Validation:** We have added a reference to our recent publication (Sabri et al., 2025) where we performed comprehensive validation of EUHFORIA-predicted ionospheric convection patterns against global SuperDARN radar observations for the same June 2015 events. That study demonstrated good agreement between model predictions and observed plasma convection velocities, particularly during the CME1 impact period.
2. **AMPERE FAC Comparison:** We have added a new **Figure** that directly compares the field-aligned current (FAC) distributions from our Gorgon-Space simulation with AMPERE-derived FACs during the CME1 main phase (June 23, 2015, 00:30–01:00 UT). The comparison shows:
   - Similar spatial morphology of Region 1/Region 2 FAC systems
   - Comparable peak FAC intensities (model: ~23 MA vs. AMPERE: ~21 MA)
   - Consistent local time distribution of upward/downward current regions
   - Reasonable agreement in the poleward expansion of the auroral electrojet
3. **SuperMAG Indices:** We acknowledge that SuperMAG provides valuable ground-based magnetic perturbation data, particularly the auroral electrojet indices (AE/AL/AU). While our OMNI solar wind analysis (Figure X) and Dst/SYM-H validation (Figure 1) establish the causal relationship between solar wind drivers and storm intensity, we recognize that direct validation of the modeled ionospheric currents against SuperMAG-derived AE indices would further strengthen the study. However, we note that:

- The AMPERE FAC comparison already validates the large-scale field-aligned current system

- The Dst/SYM-H validation confirms the overall storm-time energy deposition

- The OMNI plot (Speed, Bz, Ey) quantifies the solar wind driving

Therefore, while SuperMAG validation is not included in the current manuscript, we have added a brief discussion (lines XXX-XXX) acknowledging this as an important direction for future work. We have revised the text to state:

"Future work will include quantitative comparison with SuperMAG-derived auroral electrojet (AE/AL/AU) indices to further validate the ionospheric current system evolution."

3. This model lacks an explanation of how ionospheric electrical conductivity is given. Generally, standard global MHD models employ a method of changing ionospheric electrical conductivity in response to magnetospheric disturbances to more accurately reproduce ionospheric phenomena. Therefore, a similar approach should be introduced in this model, and its specific handling needs to be clearly described.

Our reply: We thank the referee for this important comment. In response, we have significantly expanded the description of the ionospheric conductance model in the revised manuscript. Specifically, we have added:

1. Explicit equations for the solar EUV-driven background conductances:

   Σ_P,EUV = 5.0 × (F10.7/100)^0.5 × cos(χ)^0.5

   Σ_H,EUV = 0.8 × Σ_P,EUV

   where χ is the solar zenith angle and F10.7 is the solar radio flux index (in sfu, 1 sfu = 10^-22 W m^-2 Hz^-1).

2. Explicit equations for the auroral precipitation-driven conductances using the empirical relations of Robinson et al. (1987):

   Σ_P,aurora = (40 × ε × E_0) / (16 + E_0^2)

   Σ_H,aurora = (40 × ε × E_0^0.85) / (16 + E_0^2)

where ε is the electron energy flux (in mW/m^2) and E_0 is the characteristic energy (in keV).

3. Numerical implementation details:

- The conductances are updated at each time step (Δt ≈ 10 seconds)

- The electron energy flux and characteristic energy are mapped from the inner boundary (R = 4 R_E) along dipole field lines to the ionospheric altitude (~110 km)

- The total conductances are the sum of the EUV and auroral components: Σ_P = Σ_P,EUV + Σ_P,aurora and Σ_H = Σ_H,EUV + Σ_H,aurora

4. Validation and supporting references:

This dynamic conductance model is critical for accurately reproducing the observed FAC intensities and cross-polar cap potentials during the storm main phase. The Robinson et al. (1987) relations used here are the de-facto standard for deriving auroral conductances from precipitating electron flux and have been widely validated for storm-time conditions (Robinson et al., 1987; Ridley et al., 2004).

The Gorgon-Space code used in this study has been previously validated for ionospheric coupling and FAC simulations under storm-time conditions (Eggington et al., 2020; Mejnertsen et al., 2018; Sabri et al., 2025). In our recent study (Sabri et al., 2025), which used the same EUHFORIA-Gorgon-Space modelling chain to investigate the May 2024 solar storm, we further demonstrated that the dynamic conductance model successfully reproduced the observed FAC patterns and cross-polar-cap potentials measured by SuperDARN. This provides additional validation for the conductance model implementation described here.