Response to Reviewer 1

The Authors deeply appreciate your review. It was constructive and allowed us to have a novel perspective of our our work, its results and implications.

If the manuscript is accepted, the Authors would like to express our gratitude to you by directly naming you in our manuscript's Acknowledgments statement. We hope the Reviewer does not have issues with that.

We believe that this new version of our manuscript addresses all the Reviewers' comments. Now we proceed to answer your comments and present in detail the way in which we addressed each of the points made by the Reviewer.

Specifically:

20 events were analyzed, but the criteria for defining these 20 events to be analyzed remained unclear.

Author's Response:
We agree with the Reviewer, our criteria is not clearly described in the manuscript.

First of all, our analyzed events simultaneously shared regional values of ΔH <= -120 nT and K >= 6. Besides this condition, we also discarded events whose local geomagnetic registers presented significant amount of data-gaps.

In order to clarify our selection criteria we modify our manuscript. In the previous version [p. 2 lines 17-29, right column] it read:
"In order to identify regional geomagnetic response we analyzed 20 geomagnetic storms (GS) events. Our selected events occurred between 2003 to 2018, period of time that covers the descending phase of solar cycle 23 and most of solar cycle 24. The events were registered by the Geomagnetic Observatory of Teoloyucan (TEO), located at 27.84°N 28.41°W. TEO is operated by the Magnetic Service of the Geophysics Institute at National and Autonomous University if Mexico. Our selected events share values of local K index ($K_{\rm TEO}$) above 6+. They also have values of $\Delta {H_{\rm TEO}}$ (regional counterpart of ${\rm Dst}$ index) less than -120 nT. Table \ref{table1:GS_descp} shows all the analyzed events."

Now in the new version it reads:
"Here's your text with spelling checked and some minor editorial revisions:

"We analyzed 20 geomagnetic storm (GS) events to identify the regional geomagnetic response. These events occurred during the period from 2003 to 2018, encompassing the descending phase of solar cycle 23 and almost all of solar cycle 24. The data were recorded at the Geomagnetic Observatory of Teoloyucan (TEO), located at 27.84°N and 28.41°W. TEO is operated by the Magnetic Service of the Geophysics Institute at the National Autonomous University of Mexico. We selected events with a local K index ($K_{\rm TEO}$) equal to or larger than 6+ and $\Delta {H_{\rm TEO}}$ (the regional equivalent of the ${\rm Dst}$ index) below -120 nT. We also rejected events whose datasets contained a considerable amount of missing data. Table \ref{table1:GS_descp} provides details of all the analyzed events."

I missed a definition of the quantities DP2 and Ddyn, in line 62 of the first column on page 3;

Author's Response:
The Reviewer is correct, there is a missing definition of Ddyn and DP2 in page 3.

This issue is due to we presented definitions of those currents in the “Introduction”. Nevertheless, for consistency, we shall briefly defined/comment both, DP2 and Ddyn. To address this we modified our original text.

In the previous version of the manuscript it read [p. 3, lines 61-62, left column]:
“*with D_{others} are ionospheric perturbations different from $DP2$ and $Ddyn.$*”

Now it reads:
“*with D_{others}, we refer to ionospheric perturbations distinct from the disturbed polar current number 2 ($DP2$) and the disturbed dynamo current (D_{dyn}). These two ionospheric currents are well accepted sources for local geomagnetic fluctuations in low and mid geomagnetic latitudes, as discussed in the Introduction.*”

You state that there are two possible explanations to justify the fact that the amplitude of the magnetic oscillations induced by Ddyn are more intense than those induced by DP2, the first says that the interplanetary event of solar origin, which interacts with the Earth's magnetosphere through reconnection , affects the evolution of the local ionosphere response, directly modifying the evolution of DP2 and Ddyn. In that sense, can you explain this better in terms of the current systems that are activated during a geomagnetic storm? Is there any influence of the field-aligned currents that are activated, connecting the asymmetric ring current with region 2 of the auroral oval, could this current have any important influence on the Mexican ionosphere?

Author's Response:
We appreciate the Reviewer’s questions, due to those questions allowed us to a deep introspection about our results and lead to an enrichment of our manuscript. Now we proceed with our answer.

The Reviewer actually asks three questions and before answering them, we want to clarify that:

It is widely accepted that the local ionospheric/magnetospheric response depends on the time sector (Kivelson and Russel, 1995). This is mainly due to the inhomogeneities of the field-aligned currents (FACs), which depend on both the geomagnetic latitude and the time sector (Liu et al., 2013; Vankadara et al., 2017; Akala et al., 2020). Additionally, the DP2 current is known to be affected by variations in Regions 1 and 2. Region 1 promotes the intensification of the DP2 current, while Region 2 produces an opposite effect (Yamazaki et al., 2016).

On the other hand, the analysis method we employ in our work assumes the ring current as a set of symmetrical currents (without considering the asymmetrical part). However, the authors are aware that the ring current is a complex system with an asymmetric component that has the ability to produce localized effects. This is particularly relevant because the local time is determinant in the effects of the asymmetric current on Ddyn and DP2. Therefore, a future consideration is to investigate these effects at different longitudes (local times) within similar latitudes.

Now we proceed to simultaneously response your first and second questions.

Explain this better in terms of the current systems that are activated during a geomagnetic storm? Is there any influence of the field-aligned currents that are activated, connecting the asymmetric ring current with region 2 of the auroral oval?

We will discuss separately each phase of a geomagnetic storm.

Main phase:

During the onset of a geomagnetic storm, there is an injection of energy and anomalous particles from the solar wind (VS) into the Earth's magnetosphere, leading to VS-Earth magnetosphere magnetic reconnection. These particles and energy tend to enter the magnetospheric current system, with a portion of them being incorporated into the ring current. This process intensifies the ring current, which induces a magnetic field vectorically opposite to the geomagnetic field (Baumjohann and Treumann, 1999).

The injection of energy and particles from the VS also gives rise to the partial ring current. Beginning in the sunset sector, it traverses the night-night side and terminates just before the dawn sector. In equatorial regions, the partial ring current completes the circuit with the field-aligned current and the equatorial electrojet. Typically associated with the main phase of geomagnetic storms, the partial ring current is short-lived and tends to weaken when the VS-Earth magnetosphere magnetic reconnection ceases, marking the onset of the recovery phase of the geomagnetic storm.

During the main phase, the ionospheric current DP2 is induced by the East-West convective electric field generated around the polar region (Tanaka, 1995). This process initiates with the injection of energy and particle flow from the VS to the magnetosphere due to magnetic reconnection (Kikuchi and Hashimoto, 2016). Particularly, region 1 (R1) is a main conduit to transferr this energy and matter to the polar zone. This flow induces Hall currents at the top of the polar region of the ionosphere, forming a pattern of convective cells known as polar perturbation number 2 (DP2). Therefore, intensification of R1 leads to an intensification of DP2 currents (Kivelson and Russel, 1995). The discussed current system also includes Pedersen currents that close the electrical circuit in mid-latitudes on the day side (Kikuchi and Araki, 1979; Kikuchi and Hashimoto, 2016).

Recovering phase:

On the other hand, once magnetic reconnection ceases, the recovery phase of the geomagnetic storm begins. In the absence of external energy and particle flow, an electric field emerges, which tends to mitigate the effects of DP2, as well as those of the partial ring current (Yong Wei et al., 2014). Additionally, during this stage, a decrease in electrical potential occurs in the Earth's magnetotail (night side), leading to a particle flow towards the day side. This flow results in an intensification of region 2 (R2), which tends to dampen the DP2 current.

Could this current have any important influence on the Mexican ionosphere?

The ionospheric current DP2 is accompanied by an associated electric field. This electric field propagates through the F region of the ionosphere and the internal magnetosphere, leading to a rapid response of the ionosphere in middle and low latitudes (Kikuchi, 2014). Furthermore, the DP2 current can induce the displacement of the equatorial ionospheric anomaly towards mid-latitudes, consequently reducing the plasma density at the ionospheric base, as it has been reported by Sergeeva et al. (2020) for the case of Mexico. This phenomenon is exacerbated during intense geomagnetic storms, where DP2 can generate multiple plasma density channels, resulting in abnormal total electron content (TEC) values (Wei et al., 2015).

Moreover, another consequence associated with DP2 activity is F-region propagation, which manifests as irregularities in the equatorial region of the F layer of the ionosphere, extending over kilometer scales. This leads to ionospheric scintillation, significantly affecting satellite communication and navigation systems at low latitudes.

Given that the central region of Mexico lies on the border between medium and low latitudes, during storm periods, these aforementioned phenomena may occur due to the effects of DP2, with potential impacts observable through local disturbances in TEC.

In order to include our answers into our manuscipt we modified Introduction and Concluding remarks secctions.

In the Introduction we add a new paragraph just before the last one. The new paragraph is:

Previous studies indicate that the effects associated with Ddyn and DP2 locally disrupt the total electron content, causing significant impacts on services such as telecommunications and global positioning systems during periods of geomagnetic storms (GMTs), regardless of geomagnetic latitude (Yamazaki, Häusler, and Wild, 2016; Vankadara et al., 2017; Akala et al., 2020). In the case of Mexico, a local ionospheric response has been observed even when the Dst index is only slightly perturbed (Sergeeva, Maltseva, Gonzalez-Esparza, De la Luz, and Corona-Romero, 2017; Sergeeva et al., 2019). Given that the Ddyn and DP2 ionospheric currents possess the potential to influence the geomagnetic response in mid and low latitudes, it raises the question of whether these ionospheric mechanisms are responsible for linking regional geomagnetic response to local ionospheric perturbations in central Mexico. This inquiry constitutes the primary motivation for our study.

In the Concluding remarks section we included this new paragraph.

During intense geomagnetic storms, in the geomagnetic latitudes of central Mexico, the effects of $Ddyn$ and $DP2$ induce alterations in the F region of the ionosphere and displace the equatorial ionospheric anomaly towards central and southern regions of Mexico. Thus we could expect these phenomena would lead to ionospheric scintillation, which degrades satellite communications, as well as the precision of navigation and positioning systems, among other services. These effects can potentially be registered through local perturbations of the TEC during geomagnetic storm periods (refer to panels (e) of Figure \ref{fig:iono_resp}).

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In Figure 4 you refer to two supposed panels, one upper for the average error and the other lower for the error difference, but we have only one panel.

Author's Response:
The Reviewer is correct. In the first version of Figure 4, it had two panels, as referred in the caption. However, later, we decided to use only the top panel, since including both panels was somehow redundant. Unfortunately, we overlooked updating the figure's caption. In the new version of the manuscript we corrected this issue.

The figures in the appendix, I suggest you group by event, and not by type of graph, include the two graphs from Event 1, then the two graphs from Event 2, and so on.

***Author's Response**:*
We agree with the Reviewer's suggestion. We appreciate the suggestion, since it clearly improve the presentation of our data and results. In the new version of the manuscript we modified the figures following your suggestion.

Additional modifications to the text.

We modified the last paragraph of our manuscript's "Concluding remarks" following the Reviewer's initial comments. In the previous version of our manuscript it read:
"*Finally, in this work we focus on regional space weather. We identified evidence of regional geomagnetic response that is significantly different from its planetary counterpart. We investigated $Ddyn$ and DP 2 ionospheric currents as the mechanisms for such a regional response. As a result, we were able to isolate the magnetic perturbations associated with those ionospheric currents. The combination of these perturbations with planetary response could approximate the regional geomagnetic response.*"

Now it reads:
"*Thus, our study shows that regional space-weather manifestations at central Mexico may significantly deviate from the planetary response. In consequence, in order to address the regional effects of, and risks due to, space-weather in Central Mexico, it is necessary to carry out studies from a regional approach, complemented with the planetary context. Our results highlight the particularities that geomagnetic response has for a given location. Hence, in order to achieve a better understanding of space weather and to improve the operational response, our results evidence for the necessity to include more registers (magnetometers) into the computing of geomagnetic indices, whether planetary or regional.*

Hence, according to our results, during intense geomagnetic storms, in central Mexico, the effects of $Ddyn$ and $DP2$ may induce alterations in the F region of the ionosphere and displace the equatorial ionospheric anomaly towards central and southern regions of Mexico \citep[as showed by][]{dramaria_13}. Therefore we could expect these phenomena lead to ionospheric scintillation, which degrades satellite communications, as well as the precision of navigation and positioning systems, among other services. All these effects can potentially be addressed through local perturbations of the TEC during geomagnetic storm periods (refer to panels (e) of Figure \ref{fig:iono_resp}).
It is important to remark that the surface of Mexico is near 2 million ${\rm km}^2$. This fact made of our results valid only for the central region of Mexico (few thousands of ${\rm km}^2$), leaving the

rest of its surface to address. In addition, Mexico is located at North America, and the ionospheric currents pass through and evolve along the whole American continent. Hence, on one hand, it is required more sources of geomagnetic registers in Mexico and, on the other hand, it is necessary to contextualize the geomagnetic response of Mexico with those present in Northern and Central America, and even South America. For the first case, LANCE is developing a the Network of Geomagnetic Stations Mexico (REGMEX) \citep[see][]{corona2024}, to monitoring regional geomagnetic response all over Mexico. Whereas, for the case of contextualize the geomagnetic response of Mexico, this is our immediate future work."

We also modified the Abstract following the Reviewer's initial comments. In the previous version of our manuscript the Abstract read:
"*In this work we studied the regional manifestations of space weather at central Mexico through isolate the local geomagnetic response from its planetary counterpart. In order to do so, we analyzed 20 intense geomagnetic storms by identifying the ionospheric contribution in their regional geomagnetic data as registered at central Mexico. Our analysis indicated that local geomagnetic response is mainly driven by ionospheric disturbances. We also found that the disturbed polar current number 2 and the disturbed dynamo current are particularly relevant for the regional geomagnetic response. Finally, we showed that regional geomagnetic activity can be approximated by the combined effects of the geomagnetic planetary response and the magnetic perturbations induced by the commented ionospheric currents.*"

Now it reads:
"*In this work we studied the regional manifestations of space weather at central Mexico through isolate the local geomagnetic response from its planetary counterpart. In order to do so, we analyzed 20 intense geomagnetic storms by identifying the ionospheric contribution in their regional geomagnetic data as registered at the Magnetic Observatory of Teoloyucan (at the north of Mexico City). Our analysis indicated that local geomagnetic response is mainly driven by ionospheric disturbances. We also found that the disturbed polar current number 2 and the disturbed dynamo current are particularly relevant for the regional geomagnetic response. Additionally, we showed that regional geomagnetic activity can be approximated by the combined effects of the geomagnetic planetary response and the magnetic perturbations induced by the commented ionospheric currents. Finally, our results highlights the particularities that geomagnetic response has in different locations.*"