Letter to Referee #2,

I am thankful to the Referee for their careful reading and many comments. We are learning from the interaction and appreciate the Referee's point of view.

The Referee identified especially two important points. We shall address them in reverse:

2) Regarding Solar EUV: We respectfully disagree with the Referee's statement that the dayside has systematically higher conductance "in every season." As detailed in Section 1.1, explicitly shown in Figure 1, and known very well by the Norwegians who dwell in this part of Earth, there is, on average, no (<1 S) conductance due to solar EUV-induced photoionization poleward of 68 degrees MLAT in the northern hemisphere. The Referee may think of auroral latitudes in the southern hemisphere, where the large distance between the geographic and geomagnetic south poles facilitates some sunlight in the cusp-region during local winter. This study, however, is strictly limited to the northern high-latitude winter (centered on the December solstice). In this 'polar night' sector, the solar zenith angle is large, Sun is usually below the horizon, and solar EUV conductance is negligible (often <1 S). Thus, in the specific context of this study, the dayside cusp is a low-conductance environment compared to the auroral oval.

Now, regarding Alfvén waves and our usage of the word 'drained' regarding energetic particles: We fully accept the referee's point that the cusp is a region of intense energy transfer via Alfvén waves and soft particle precipitation. We did not intend to imply the region is devoid of energy.

However, our use of 'drained' refers specifically to the high-energy (>1 keV) precipitation that generates significant E-region conductance. As we have argued in this paper, we find that the foregoing creates a unique "perfect storm"-scenario for turbulent structuring in the cusp (we reiterate):

1. Alfvén waves, convection, conductivity gradients, etc, actively drive or trigger F-region plasma instabilities.
2. The simultaneous 'draining' of high-energy precipitation means the E-region conductance (a crucial regulator) is low.
3. Subsequently, plasma irregularities preferentially occur, and last longer.

We have revised the text to clarify that while the cusp is energized by waves (a source of structuring), the specific lack of high-energy precipitation prevents the formation of a conductive E-region 'sink,' thereby facilitating the persistence of the turbulence driven by those waves.

1) Regarding “why F-region irregularities need to be triggered by particle precipitation”.

We do not dispute that waves and flows trigger instabilities. In fact, while particle precipitation can trigger instabilities through the creation of conductivity & density gradients, there is no reason to emphasize particle precipitation as a particular triggering process. What we do argue is that, in the lack of an E-region maintained by solar EUV photoionization, particle precipitation provides the crucial role of regulating both the triggering of turbulence and the ambipolar diffusion of turbulent structures.

To repeat: *Particle precipitation regulates occurrence rates of irregularities*. Waves (and other factors, including particle precipitation), work to trigger irregulatities. The Referee's view is therefore not in opposition to our core tenet.

We have gone through the language, making sure that we do not overemphasize particle precipitation as a trigger of plasma turbulence.

Other comments:

- **The referee writes** *"Can the author comment upon how their results be affected by not including a substantial fraction of low-energy (< 100 eV) precipitation? It would be natural to bring this up in the discussion."* **Reply:** These low-energy electrons ionize the F-region, bringing the \eta coefficient even lower, thereby considerably strengthening the findings by making sure that they are *conservative*. I have made a statement to the effect in the revised manuscript (near Line 210).

- **The referee writes** *"(…) there is singular focus on the Pedersen conductivity/conductance throughout the manuscript, but the Hall conductivity/conductance is arguably just as fundamental as (and for some phenomena, more relevant than) the Pedersen. The author should describe why the Pedersen conductivity/conductance is the sole focus of this manuscript (…)"* **Reply:** The Referee is right both in stating that Hall conductance is vital to I-M coupling and in calling for the issue to be addressed in the paper. As particle energies increase, Hall conductance increases disproportionally with respect to Pedersen conductance. Hall conductance affects Alfvén wave reflection and the Hall currents contains a turbulent electrojet. We have edited the manuscript to make our scope clearer (L 95).

- **The Referee writes that** *"The lack of ionization does not necessarily mean the E-region conductance is low — the dayside is, after all, where EUV-related ionization peaks during all seasons. There ought to be some mention or discussion of this point.”* **Reply:** I must again remind the Referee that this study is explicitly dealing with the polar winter night. As we demonstrate in Figure 1, statistically, there is no E-region conductance to speak of in this sector.

- Regarding the GNSS dataset, I have added a sentence to the manuscript confirming that the coverage is continuous with no major temporal gaps.
- A clarification linking the scintillation observations in Prikryl et al. to the diffusion mechanisms described by Vickrey and Kelley is in order. The connection, which I failed to make explicit, is that the Prikryl-climatologies demonstrate the dominant role of seasonal effects in the observed phase fluctuation occurrence rates. We removed the reference to avoid confusion.
- I have explicitly stated the DMSP SSJ energy range (30 eV - 30 keV) in the methodology section to aid the reader. In Section 1.2 we are (and had previously) stated the energy limitations. See also the Discussion near Line 210.
- I have explicitly defined the MLT sectors in the text to reduce ambiguity.

Finally, the following is strictly not relevant to the paper anymore, but I feel it should be explicitly addressed. The referee previously (in their first review) wrote that

"The manuscript seems to philosophically embrace the so-called E, J paradigm in which electric fields and currents are treated as the primary variables. One hallmark of this paradigm is using language that suggests the coupled magnetosphere-ionosphere system can be represented via a lumped-element circuit model or transmission-line theory."

I originally took this to account for the mistaken inference that the Referee claimed the paper relies on a "purely electrostatic description," and I apologize for the mistake. The debate is not new, and I am of the persuasion that magnetohydrodynamics represents a suitable level of abstraction for the global description of the entire heliosphere, including the Sun-Earth interaction, but does not encompass critical kinetic processes, as well as the various roles played by conductivity gradients. The Cowling effect, which we briefly mention in the revised manuscript, is an example, where sharp edges in conductivity create charge-separation and polarization electric fields by changing charge carrier mobilities. Changing the nature of the mathematical abstraction with which we describe space plasmas is a valid and necessary approach for many processes in geospace.

In closing, we are thankful for the exchange and believe the Referee’s many comments have ultimately benefited our manuscript.

Sincerely,
Magnus F Ivarsen