Revision of “Ionospheric Chaos in Solar Quiet Current Due to Sudden Stratospheric Warming Events Across the Europe-Africa Sector” by Irewola Aaron, Oludehinwa et al., submitted to *Annales Geophysicae*

The manuscript under review addresses the intriguing topic of how Sudden Stratospheric Warming (SSW) events influence ionospheric dynamics, particularly through variations in the Sq current and associated entropy metrics. However, the study suffers from several fundamental flaws that undermine its validity and scientific rigor.

The introduction lacks clarity and structure, with redundant points and insufficiently explained concepts. The characterization of the 2009 and 2021 SSW events includes significant inconsistencies in the handling of geomagnetic indices, notably Kp values, which are misrepresented and not accurately contextualized. The methodology for analyzing Sq currents and entropy variations is vague, lacking critical details about data processing and failing to use more robust, standard techniques available in the field.

The results section further reveals a lack of understanding of key ionospheric processes, including the asymmetric and seasonally dependent nature of Sq currents. Misinterpretations of entropy variations and their relationship to current systems cast doubt on the validity of the findings.

Overall, the study does not meet the necessary standards for publication. It requires substantial revisions to clarify the methodology, improve the accuracy of data interpretation, and address the significant methodological oversights. Without these corrections, the conclusions drawn by the authors remain speculative and unsupported. For these reasons, I cannot recommend this paper for publication in its current form. However, I have provided a detailed explanation of the issues outlined above, with the hope that it will assist the authors in improving their work for a future revision.

Introduction

The introduction covers important topics but has some key issues that reduce its clarity and impact. The main concepts, like the effects of SSW (Sudden Stratospheric Warmings) on the ionosphere and the role of nonlinear dynamics, are repeated too often, making the text feel redundant. The structure is also unclear, as ideas like chaos theory and its applications are introduced suddenly without enough explanation or connection to the previous points. Additionally, there are too many citations in a short space, which makes the text harder to follow. To improve, I suggest focusing on the main research question, organizing the ideas in a clearer order, and reducing repetitions. This will make the introduction more concise, engaging, and easier to understand.

- Example: Lines 47-49. "*Climate change also impacts the frequent occurrence of sudden stratospheric warming (SSW), leading to communication disruptions, economic disruptions, transportation disruptions, and fluctuations in energy demand*."

  Since this is part of an introduction, this statement needs further explanation. It describes a scenario that is indirectly elaborated upon much later in the text (lines 75-76). As it stands, this sentence doesn’t work well. It either needs to be better contextualized, briefly explained, and then revisited in greater detail later, or removed entirely and placed after the full explanation.

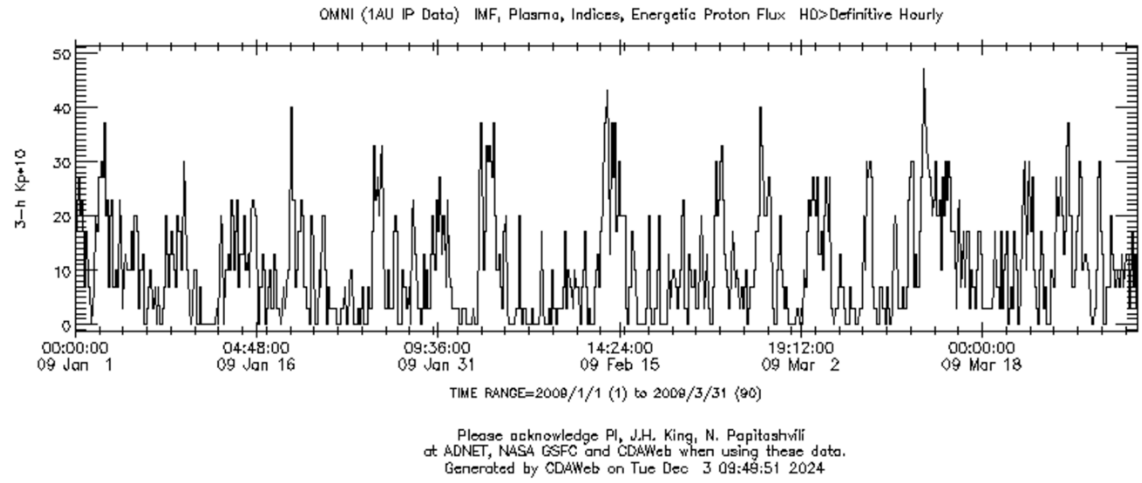
- Example: Lines 93-94. "*The research question of the contribution of SSW formation to the regional ionosphere across the European-African sector needs special attention*."

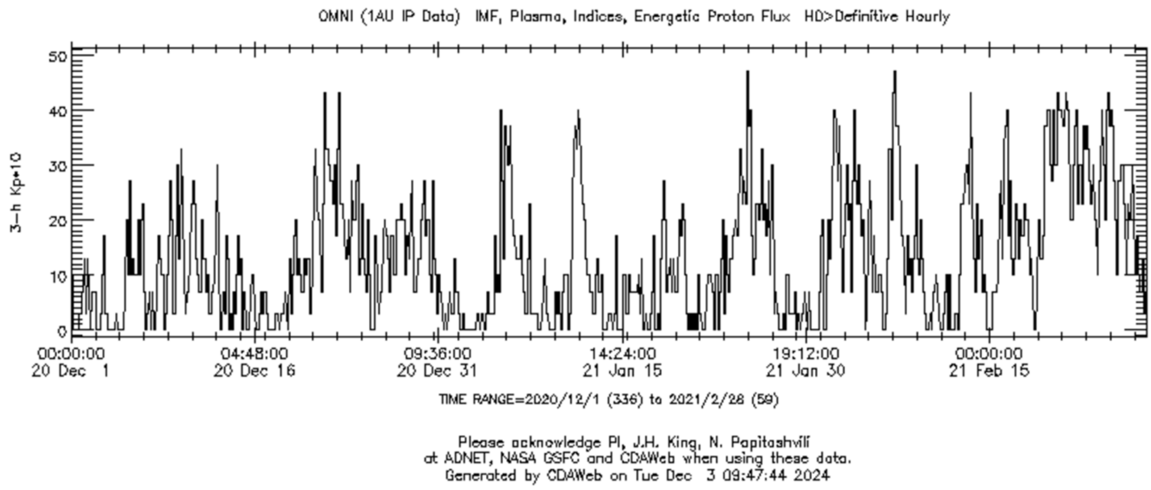
  This statement needs justification. Why is this region of particular interest? Does it have any unique characteristics? What additional insights can we gain by analyzing the response of the Sq current during an SSW event in this specific region?

1.1 Characterization of 2009 and 2021 Major SSW Events

Lines 162-190. It would be better to specify the source of the data used in Figures 1, 2, 3, and 4 at the point of introduction, rather than three pages later. Additionally, the handling of the data and the subsequent claims in this section are problematic. Let me elaborate:

- The Kp index is a planetary three-hour index, yet the values shown in Figures 3 and 4 appear to represent daily averages. This discrepancy should be explicitly addressed in the text, clearly stating that the reported values are likely daily averages and ensuring the associated error is indicated. This clarification is critical, as Kp values can vary significantly throughout the day due to geomagnetic disturbances.
- In both selected periods, the Kp index frequently exceeds a value of 4, which makes the claim that "*During the 2009 SSW event (January–March), the planetary index (Kp) recorded values of Kp<2+*" inaccurate and misleading. The actual Kp trend for this period contradicts this statement. A similar issue arises in the second period, where the authors state that Kp remains below 3+. However, during the latter part of February, for example, Kp consistently reaches or exceeds 4.
- This inconsistency is significant, as it undermines the claim that both periods were characterized by particularly low geomagnetic activity (e.g., Kp<2+). Moreover, the assertion that there was a meaningful difference in geomagnetic activity between the two periods is not supported by the actual Kp trends. This issue must be addressed to ensure the accuracy and reliability of the study's conclusions.





2. Data Acquisition and Method of Analysis

Table 1 presents the magnetic stations used in this study, including both geographic and magnetic coordinates for each station. It is important to note that magnetic coordinates are not fixed over time; they depend on the position of the magnetic pole. Therefore, when reporting them in a table, the reference year should always be specified. This implies that the stations selected in 2009 and 2021 have different magnetic coordinates. Furthermore, when studying the Sq current, the correct coordinates to use are the magnetic ones, not the geographic coordinates. As shown in Figure 5, the stations are not aligned with respect to magnetic coordinates. This discrepancy should be taken into account for accurate analysis.

Lines 236-243: This paragraph describes the source of the data used and introduced earlier. The paragraph should be revised to include information about the data source at the point where the data is first presented and described.

2.1 Ionospheric Solar Quiet Current Sq(H) as Observational Time Series

Lines 242-243: The authors state that they use the H component of the magnetic field. However, there is an issue: some of the observatories used, such as KIV and SOD—possibly others, although I have not verified—provide data in the X, Y, Z reference system. This suggests that either the authors performed a data rotation, transforming the coordinates from the (X, Y, Z) system to the (H, D, Z) system, a process which they did not mention, or they simply calculated the modulus of the H component as $\sqrt{(x^2 + y^2)}$. In this case, they are not working with the H component itself, but rather its intensity. This procedure needs to be explicitly explained. Additionally, where the H component is directly provided, the specific steps taken in processing the data should be clarified.

Lines 245-268:

- Honestly, I am not convinced by the method used to derive the Sq variation from measurements of the horizontal component of the magnetic field. A more standard approach would be to use for example the CHAOS model, which enables the reconstruction of the magnetic field at a specific point in space over time, such as at the location of the observatory. One of the latest version of the CHAOS model can accurately simulate all components of the magnetic field, including secular variation, the crustal field, induced fields, and fields generated by magnetospheric currents. The only component it fails to model is the ionospheric field. Therefore, by simply subtracting the modeled value of H from the real value, the ionospheric field can be obtained, from which the Sq component can then be derived.

- In the method used by the authors, however, it is unclear what the value of BLV represents, how it is calculated, and over which days. If the goal is to remove the background field (i.e., the main field), then it would be more appropriate to work with variational data, which are free from the main field, rather than using absolute magnetic measurements. Additionally, since this step forms the basis for the entire subsequent analysis, I would expect to see at least three or four days with varying Kp values, showing the ionospheric magnetic field component at all observatories. This would help ensure that the resulting structure aligns with expectations and provides meaningful insight.

- Finally, a crucial point is that, even assuming this procedure is correct, the authors claim that the resulting H component of the magnetic field represents the solar quiet daily variation. In reality, not only does this component primarily exist around noon, but not all the selected observatories are capable of recording this contribution to the magnetic field. Stations near the magnetic equator, such as AAB and KRT, are more likely to be influenced by the equatorial electrojet rather than by the ionospheric current system that generates the Sq variation.

Results

The analysis proposed by the authors aims to demonstrate how the properties of the quiet ionosphere (where the perturbation caused by the current system responsible for Sq is observable) tend to change under the influence of Sudden Stratospheric Warming (SSW) events. To support this, the authors introduce the calculation of Fuzzy Entropy applied to time series transformed into a complex network representation using the Horizontal Visibility Graph.

It is generally understood that where stable current systems flow in the ionosphere, these regions will exhibit greater stability, which is reflected in lower entropy values. This is evident in the results presented in Figure 6, where, near the peak variation of the H component—which corresponds not so much to Sq but rather to the presence of the equatorial electrojet (since the station is near the magnetic equator)—entropy decreases. This decrease is due to the current itself stabilizing the ionospheric system.

However, the authors fail to consider that Sq is not symmetric about the magnetic equator and is strongly influenced by seasonal variations. Since Sq depends mainly on solar radiation, it is more intense during the summer months compared to winter. This means that when analyzing data from December, January, and February, Sq will naturally be stronger in the Southern Hemisphere (e.g., Africa) than in the Northern Hemisphere (e.g., Europe). Thus, the presence of a blue zone around local noon in the Southern Hemisphere in Figures 7 and 8 is entirely expected, as it reflects the higher intensity of the current system.

Similarly, the symmetry observed near the equator in March (Figure 9) can be attributed to the equinoctial period, during which the current systems in the two hemispheres become more similar in intensity. A similar trend might have been observed in Figures 10, 11, and 12, but, inexplicably, the authors chose to show only data for the Northern Hemisphere (i.e., Europe).

Additionally, there are days when the distribution of entropy values does not seem to correspond to the current systems responsible for variations in H. This could be probably due to the fact that, contrary to the authors' claims, there are days with a Kp value of 4. Given this, the subsequent analysis attempting to relate these observations to SSW events is unconvincing.

Before establishing any potential connection between entropy variations and SSW events, it is essential to disentangle the seasonal effects and those linked to geomagnetic activity from the entropy variations. Only after accounting for these factors would it be reasonable to explore any potential relationship with SSW events.