Dear Dr. Igo Paulino,
Editor
Annales Geophysicae (ANGEO)

Ref **:** angeo-2019-97
Title **:** Historical Aurora Borealis Observations in Anatolia during medieval period: Implications for the past solar activity
Journal **:** Annales Geophysicae (ANGEO)

Thank you for your constructive and helpful feedback, scholarly comments and timely processing of our submission. I have just revised the manuscript in view of the constructive and helpful editorial and reviewer comments as outlined in detail below and the paper is now ready to resubmit the journal of Annales Geophysicae (ANGEO) titled "Historical Aurora Borealis Observations in Anatolia during medieval period: Implications for the past solar activity". Please find our response (in red) to reviewer's specific comments (in black) step by step below.

I would like to thank the reviewers for their thoughtful comments. Responses to comments are presented in the following pages along with explanations.

Thanks again and looking forward to hearing from you.

Best regards,

Dr. Nafiz MADEN
Corresponding author

***Response to comments from Anonymous Referee #2*:**

General Comments

This article has examined existing auroral catalogues, compiled auroral reports in Anatolia during the medieval period (apparently between 333 and 1143), and evaluated the "strength" of aurora with five criteria in Neuhäuser and Neuhäuser (2015). The compiled catalogue has been compared mainly with the Byzantine climatic records in Haldon et al. (2014) to discuss the solar-terrestrial relationship during this period. This manuscript is moderately interesting, as the Anatolian auroral records have not been comprehensively studied yet, and the author shows almost the opposite trend of solar activity around 774/775 against Neuhäuser and Neuhäuser (2015), using almost the same dataset and method with Neuhäuser and Neuhäuser (2015). However, this manuscript has to get its contents and novelty significantly improved for further considerations, as the auroral classification method is not very appropriate, the scientific discussions are not convincing enough, and the logic of his discussions on the climate change is extremely difficult to follow. Therefore, it is extremely important to improve the scientific novelty of this manuscript (see specific comments 1 and 2) for further considerations for publication in this journal.

***Reply:** I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript.*

Specific Comments

1. Novelty of the Records

The largest issue for this manuscript is its novelty, as the catalogued records are not new, classification methodology is not very appropriate, and scientific discussions are not quite sufficient. In order to improve the originality, the authors should consult not the existing catalogues but the original historical documents. This will let us improve accessibility to the original records improved and even potentially resolve apparent discrepancies in several records. The existing catalogues must not be misunderstood as the source documents, as done in Table 1. Showing an example of historical documents as a figure (see *e.g.*, Figures 1 – 2 of Kataoka et al., 2017; Figures 1 – 2 of Kataoka and Iwahashi, 2017) would be beneficial for the readership to understand what kind of historical records you are using in your article.

***Reply:** Thanks to the reviewer #2 suggestions to improve the scientific content of the manuscript. The goal of this study is to compile a historical Anatolian aurora catalog (hAAC) during medieval period by scanning the available sources and catalogs in literature. The available catalogs present a number of records covering Europe, Japan, China, Russia and Middle East. The aurora observations are collected from different historical text and available catalogs. For that reason, there is no figure like Figures 1 – 2 of Kataoka et al., 2017.*

2. "Strength of the Aurora"

One of the scientific analyses in this article is the evaluation of "strength of the aurora" on the basis of criteria of Neuhäuser and Neuhäuser (2015). However, the author needs to explicitly clarify what the "strength of the aurora" means here. As long as reading Neuhäuser and Neuhäuser (2015), these criteria are not for strength but for likeliness. The strength of aurora is rather associated with the equatorward boundary of the aurora, as it has a good correlation with strength of magnetic storm (Yokoyama et al., 1998; Kataoka and Iwahashi, 2017). In this sense, stronger aurora will appear more southward and contradict the criteria for direction in Neuhäuser and Neuhäuser (2015). The author needs to revise and address the strength of aurora, citing Yokoyama et al. (1998) and Kataoka and Iwahashi (2017).

Reply: *I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript.* The study of Kataoka and Iwahashi (2017) and Yokoyama et al. (1998) is related to extention and auroral belt, respectively, not strength of Aurora. The sentence is revised as "One could decide whether an observation is strong aurorae by considering its color, brightness, dynamics, duration, geomagnetic latitude."

3. The Validity of Criteria

The author needs to seriously consider the validity of the criteria used in this manuscript and if they should be used in his manuscript. While the five criteria are based on (1) night-time (darkness, sunset, sunrise), (2) non-southern directions (northern, NE, NW, E-W, W-E), (3) color (red, reddish, fiery, bloody, green, black), (4) dynamics (fire, fiery), and (5) repetition, these criteria are unfortunately not consistent with observational evidence, as shown in Stephenson et al. (2019). I think the recent criticism makes good sense. Recent fact-based studies show that the equatorward boundaries of the aurora reach 25°, 24°, and 38° magnetic latitudes during the historical magnetic storms in 1770, 1859, and 1958 (Kimball, 1960; Kataoka and Iwahashi, 2017; Kataoka et al., 2019; Kataoka and Kazama, 2019). In the cases of such extreme space weather events, aurorae will be seen even southward from medieval Turkey (45 – 50.1° in magnetic latitude). It is also known that whitish pillar appears equatorward of the red glow during the strong magnetic storms, probably due to field-align currents carried by precipitating electrons (Kataoka et al., 2019). It is also not clear why fire or fiery means dynamics of aurora. The descriptions like "fire" more likely means auroral color and brightness (see Figure 1 of Kataoka and Kazama, 2019). The author needs to address these facts to evaluate validity of these criteria at the very least, if he strongly wishes to use these criteria in his manuscript. Otherwise, the author should not use these "criteria".

Reply: *I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript.* According to the study by Neuhäuser and Neuhäuser (2015), five criteria are implemented to perform the aurora catalogs as night-time (darkness, sunset, sunrise), non-southern directions (northern, NE, NW, E-W, W-E), color (red, reddish, fiery, bloody, green, black), dynamics (fire, fiery), and repetition. One could decide whether an observation is strong aurorae by considering its color, brightness, dynamics, duration, geomagnetic latitude. The observation is classified as potential (N=0), possible (N=1), very possible (N=2),

probable (N=3), very probable (N=4), or certain (N=5) according to the criteria number (N) satisfied (Neuhäuser and Neuhäuser, 2015).

4. Solar Activity around 774/775

In scientific viewpoint, exploiting the discussions on the solar activity around 774/775 would benefit scientific community, as this is quite close to the cosmic ray event in 774/775 (*e.g.*, Miyake et al., 2012; Usoskin et al., 2013; Mekhaldi et al., 2015). The author seems to support the high solar activity (p.11; see also *e.g.*, Usoskin et al., 2013) with the reports and methods used in Neuhäuser and Neuhäuser (2015), whereas Neuhäuser and Neuhäuser (2015) suggested a solar minimum around 774. The author's result may be helpful to reconstruct the solar activity around 774/775, on which we have opposite reconstructions: low solar activity (Neuhäuser and Neuhäuser, 2015) and high solar activity (Usoskin et al., 2013; Stephenson et al., 2019). The author needs to clarify the scientific implications of his article for the solar activity around 774/775, evaluating the validity of the validity of Neuhäuser and Neuhäuser (2015).

Reply: *I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript. Mekhaldi et al. (2015) indicated that these two extreme events (774/775) were five times greater than any other recorded solar storms with instruments. Their findings highlight the importance of studying the possibility of severe solar energetic particle events.*

5. Chronological Coverage

The author should define the survey object, namely the chronological extent of medieval Period and the geographical extent of Anatolia. Re chronological coverage, while the author's survey extent seems consistent with the former half of the Byzantine Empire (330 – 1453) in Haldon et al. (2014), the author should clarify why they stopped surveys in 1143.

Reply: *I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript. Figure 1 is revised according to the Reviewer #1 and #2. Any aurora observations could not be reached up to 1453.*

6. Definition of the Medieval Anatolia

The definition of Anatolia is not clear as well. Geographically speaking, Constantinople is not in Anatolia but situated in the European side. The author needs to address why Asia Minor is exactly specified to be around current Ankara. It is also not very clear where is the border between Anatolia and Middle East. At least, it should not be the modern Turkish border. In my understanding, Edessa and Amida would be better located in the Middle East, rather than Anatolia.

Reply: *I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript. Figure 1 is revised according to the Reviewer*

#1 and #2. The geographical border is changeable in the medieval period due to the wars between Turks and Byzantine Empire. So, the current border is displayed in this map. The places of the Constantinople, Amida, Edessa, Adana and Antioch are correct geographically. The Asia Minor is other name of the Anatolia. So, the record belonging to Asia Minor (exact place not known) is located in the middle of the Anatolia capital of the Turkey.

7. Relationship with Past Solar Activity

The second conclusion in this manuscript states "In Anatolia and Middle East, there was a relatively high auroral activity during the years around 1100 is quite consistent with the naked-eye sunspot observations". However, the naked-eye sunspot observations are mentioned only briefly in in the context of Medieval Maximum (p.12) and periodicity between 1095 and 1204 is usual (Vaquero and Trigo, 2012). Therefore, the author should compare these auroral records with the naked-eye sunspot observations. Moreover, the cycle length during the Medieval Maximum is probably shorter (~9 years) on the basis of ^{14}C data (Miyahara et al., 2008) and their cycle reconstructions are shown in Kataoka et al. (2017). Hence the existing statement for solar cycle length needs to be revised, citing Miyahara et al. (2008) and Kataoka et al. (2017). This enhanced solar activity is also better illustrated, citing the earliest datable sunspot drawing and relevant Korean auroral records in 1128 (Willis and Stephenson, 2001; Willis and Davis, 2014), and contrasted with the Oort Minimum (Usoskin et al., 2007, 2017; see also Inceoglu et al., 2015).

Reply: *Thanks to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript. The second conclusion is revised according to the comments. A detailed information about sun spot observations is added to the manuscript.*

8. Relationship with Climatic Change

While this manuscript is entitled as "Implications for the past solar activity" in its subtitle, the impacts on the climatic change has been emphasized in the manuscript (pp.13-14 and conclusions 5 – 6). However, the logic was extremely difficult to follow and the revision of humidity with auroral record has been applied without scientific explanations. The relationship between solar activity and climatic change in historical time span is not very clear (Vaquero and Trigo, 2012; Lockwood et al., 2017), while we know at least the lightning has correlation with solar rotation (Miyahara et al., 2017, 2018), and galactic cosmic ray fluence have some influence to snowball Earth (Kataoka et al., 2013, 2014) as well as explosive volcanic eruptions (Ebisuzaki et al., 2011). Therefore, the author is strongly recommended to separate their discussions for the climatic change to another article, indicating the solar-terrestrial relationship in short and very long time spans. This separation will make the logic in this manuscript more straightforward and improve its readability.

Reply: *I would like to the Reviewer #2 for the encouraging and constructive comments to improve the quality of the manuscript. This study could be significant constraints for exploration of solar activity on Earth's atmosphere and climate during the historical*

periods previously proved by Bard and Frank (2006). According to the Bard and Frank (2006) solar fluctuations caused climatic changes called Medieval Warm Period (900–1400). The Maunder Minimum (1645-1715) which delineates the coldest part of the Little Ice Age (Eddy, 1976) is depicted by a solar activity reduction, as well as a sunspots scarcity. The Medieval Climate Anomaly characterizing by warmer and drier climate conditions generally related to reasonably prolonged solar activity during the 12th and 13th centuries (Jirikowic and Damon, 1994).

9. Conclusions

Accordingly, the conclusion needs to be modified. The second and third conclusions can be retained only if the author address naked-eye sunspot records appropriately. The fourth conclusion cannot co-exist with the third conclusion, as their coexistence make it unclear what was the main factor: solar activity or intensity of dipole moment and position of geomagnetic pole. The fifth and sixth conclusions should be separated to another article, as well as the discussions on the climate change.

Reply: *I do not agree with the Reviewer #2. So, it is not suitable for removing these conclusions from the manuscript.*

Technical Corrections

Technical corrections shown here are only those with relatively major importance. The author is strongly recommended to send this manuscript grammatical proofreading before resubmission, in order to improve the readability of this manuscript.

Line 28: For Chinese aurorae, cite Kataoka et al. (2017).

Reply: *Ok*

Line 27: For Japanese aurorae, cite Kataoka et al. (2017) and Kataoka et al. (2017). Remove Shiokawa et al. (2005), as this article is about modern instrumental observations.

Reply: *OK*

Line 40-48: Remove this paragraph.

Reply: *OK*

Line 109: The 502 August 22 event appears in the Zuqnin Chronicle too. Cite Hayakawa et al. (2017).

Reply: *OK*

Line 131-155: The first observation in Zuqnin Chronicle should not be 772 but 771/772, namely somewhere between 771 October and 772 September, as the timing of harvest is not specified for a specific crop and there were multiple crops in Anatolia back then (Hayakawa et al., 2017).

Reply: *Revised*

Line 233-236: This statement should be brought somewhere before method, to clarify what the author surveyed.

Reply: *The statement is added to the "Introduction" section.*

Line 263-273: Separate this paragraph to another article.

Reply: *Revised*

Line 293-319: Separate these paragraphs to another article.

Reply: *Revised*

Line 324: "were thought" should be "thought"

Reply: *Revised*

Table 1: Remove it or replace it to a list of historical documents.

Reply: *Revised*

Table 2 and 4: The reference must be revised to the original historical documents.

Reply: *The Reference list is revised.*

Table 5: Remove it.

Reply: *This Figure is important to understand the climate change in Anatolia. So, it should not be removed from the manuscript.*

Figure 1: Remove the modern border and revise the location for Asia Minor.

Reply: *Figure 1 is revised*

Figure 2: Remove it.

Reply: *Again, Figure 2 is important to understand the climate change in Anatolia. So, it should not be removed from the manuscript.*

Figure 3: Define the border of Anatolia and Middle East.

Reply: *Thank you for your comment. The constructive comments by the reviewers are really appreciated. Figure 3 is not a map, but a histogram plot. So, there is no border. The aurora observations are divided in to two panels for Anatolia and Middle east region.*

We thank to you and the Reviewer #1 for the constructive and helpful comments.

Sincerely,
Dr. Nafiz MADEN