Dear Dr. Igo Paulino,
Topical 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 soon.

Best regards,
Dr. Nafiz MADEN
Corresponding author

Detailed Response to Reviewers

***Response to comments from Anonymous Referee #1*:**

General Comments:

With regret, I found that the author has failed to address most of my previous comments or clarify the novelty of this manuscript, while the author's version is slightly better than the virtually unchanged previous version. The author has almost explicitly admitted that he has not consulted the original historical documents for his survey. He has failed to explain the strength of aurora and has not done anything more than repeating what Neuhäuser and Neuhäuser (2015) have written, while their criteria themselves contradict the actual observational evidence (see e.g., Stephenson et al., 2019). With great respect, I have to comment that applying dubious criteria to non-original records would not guarantee a novelty for an academic article, at least in Annales Geophysicae. Overall, I cannot recommend its publication in Annales Geophysicae, unless otherwise the author seriously revises this manuscript from its basis.
Reply: *I would like to thank the Reviewer #1.*

Specific Comments
1. Novelty of the Records

As I commented before, the largest issue for this manuscript is its novelty. What the author has done in this manuscript is to simply recompile the Anatolian auroral reports from the existing catalogs (not from the original historical documents!). Therefore, these presented results are unfortunately not new. The scientific method is currently no more than a repetition of Neuhäuser and Neuhäuser (2015), while the author's outcome for the solar activity around 774/775 contradict what Neuhäuser and Neuhäuser (2015) have concluded. In this case, the only potential novelty of this manuscript is – at best – the emphasis of the high solar activity around 774/775. As long as I understand, "ANGEO publishes original articles and short communications (letters) on research of the Sun–Earth system...". Therefore, the originality of this manuscript is crucially important to let this manuscript get subjected to further considerations.
Reply: *Thank you for encouraging comments to improve the manuscript. The novelty of this manuscript is given below:*
There is no study dealing only with the historical aurora observations recorded in Anatolia. Anatolia have not been studied until now with respect to historical-climatological data and aurora observations. The goal of this study is to compile a historical Anatolian Aurora catalog (hAAC) during the medieval period by scanning the available sources and catalogs in literature.

2. "Strength of the Aurora"

The author must read Neuhäuser and Neuhäuser (2015) more carefully. Neuhäuser and Neuhäuser (2015) have explicitly stated "we establish five criteria for the likeliness of the

event to be an aurora which are selected to distinguish from the other effects" in page 230. As the author has cited "The observation is classified as potential (N=0), possible (N=1), very possible (N=2), N aurora is probable (N=3), very probable (N=4), or certain (N=5) according to the criteria number (N) satisfied". This is not about strength but about likeliness. As the equatorward extension of auroral oval has good correlation with "strength" of magnetic storm (Yokoyama et al., 1998), the "strength" would be better understood with the equatorward extension of auroral oval. Therefore, repeating an excerpt from Neuhäuser and Neuhäuser (2015) does not make any good sense here.
Reply: *I would like to thank the Reviewer #1 for encouraging comments to improve this study. The paragraph is revised according to the recent study performed by Stephenson et al., 2019.*

3. The Validity of Criteria

Even more seriously, the author has entirely failed to address the scientific concern for the validity of Neuhäusers' criteria, only repeating what Neuhäusers described. As I commented previously, their criteria have been seriously doubted with counter-examples (Stephenson et al., 2019). The 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 must not use these "criteria".
Reply: *Thanks to the Reviewer #1 for the constructive comments to improve the quality of the manuscript. The method of Neuhäuser and Neuhäuser (2015) to classify the Aurora observation is removed from the manuscript and the table 2 is revised.*

4. Solar Activity around 774/775

While I appreciate scientific contribution by Mekhaldi et al. (2015) on the extreme solar storm in 774/775, Neuhäuser and Neuhäuser (2015) have claimed "they [their auroral records] cannot support a hypothetical solar super-flare" in page 236, for example. This is almost in an opposite spectrum against Mekhaldi et al. (2015). The author needs to clarify what he can say from Anatolian records for such scientific conflict.
Reply: *I would like to thank the Reviewer #1 for their thoughtful comments. The solar event of 774/775 by Mekhaldi et al. (2015) is removed from the manuscript.*

5. Chronological Coverage

Why "Any aurora observations could not be reached up to 1453"? That must be scientifically explained. Moreover, the title of "medieval Anatolian" should be revised to

“Byzantine” or “Byzantine Anatolian”, given what the author surveyed.
Reply: *Because, 1453 is considered the end of the medieval period by historians. The title of the study is revised as “Historical Aurora Borealis Observations in medieval Anatolia (AD 1-1453): Implications for the past solar activity”.*

6. Definition of the Medieval Anatolia

The author needs to see Figure 1 a little more carefully. Edessa (and probably Amida too) is/are situated outside of the Byzantine territory. More seriously, this figure explicitly shows that Constantinople is situated not in Asia Minor but in “Macedonia”, while majority of the records in the author’s catalog are derived from Constantinople. Therefore, Figure 1 shows that they are not in Anatolia either.
Reply: *The Figure 1 is revised according to the reviewer comments.*

7. Relationship with Past Solar Activity

While I commented on this aspect, the author just cited Willis and Stephenson (2001) without enough explanation. I cannot consider the author’s addition as a “detailed explanation”. Therefore, I have to repeat what I have written previously. 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 14C 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: *I would like to thank the Reviewer #1 for their comments. The paragraph is revised according to the comments.*

8. Relationship with Climatic Change
As I commented previously, the logic was extremely difficult to follow and the revision of humidity with auroral record has been applied without scientific explanations. The author needs to seriously note that the relationship between solar activity and climatic change in historical time span is not very clear (Vaquero and Trigo, 2012; Lockwood et al., 2017). Lockwood et al. (2017) have especially clarified how misleading to explain the Little Ice Age with the Maunder Minimum. They have casted a caveat “The association of the solar Maunder minimum and the Little Ice Age is also not supported by proper inspection and ignores the role of other factors such as volcanoes” in page 2.23 for example. This made me strongly doubt the validity of the author’s discussion for climatological impact. This manuscript cannot be published, unless otherwise the author removes their speculation about the climatic impact.

Reply: *I would like to thank the Reviewer #1 for the encouraging and constructive comments to improve the quality of the manuscript. The "Little Ice Age" is removed from the manuscript.*

9. Conclusion

Accordingly, the fifth and sixth conclusions must be removed, as well as the discussions on the climate change. In the same time, the author needs to clarify which made aurora visible in Anatolia so frequently in the Byzantine period: solar activity or intensity of dipole moment and position of geomagnetic pole.

Reply: *I would like to thank the Reviewer #1 for the constructive comments. The reason of the aurora in Anatolia so frequently is given in the "Results and Discussions" (second paragraph) and "Conclusions" (fourth conclusion) sections. On the other hand, the fifth and sixth conclusions are the important findings achieved from aurora observations besides historical-climatological data. Also, an additional conclusion is added.*

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

Title: “Historical Aurora Borealis Observations in Anatolia during medieval period (AD 1-1453): Implications for the past solar activity”

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

General Comments

In this paper, the author reports an overview of historical Aurora observations reports in Anatolia and Middle East regions in the medieval period based in historical texts, chronicles and aurora catalogs records. The paper presented a relationship between the auroral activity and the past solar activity, the past climatic changes, economy and society living in the remote time.

My view on the paper is that the discussions are interesting, and more discussions and clarifications were made in the revised version and the full paper desire publication in the ANGEO.

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

Major Comments:

All the major comments in the previous version was answered in a proper way, and at this point I do not have any major recommendation.

Reply: *I would like to thank the Reviewer #2.*

Minor issues:

Line 1 (pg 1): In the title would not more correct to add the word “the” before “medieval period”? and also one space after “AD ...”?

Reply: *Revised*

Line 73 (pg 4): In the title of the section 2, I think that the word “Catalog” for the hAAc acronyms should be with “c” instead of “C”.

Reply: *Revised*

Line 231 (pg 10): I suggest changing the sentence “23 different historical aurora records...” for “Twenty-three different aurora records...”.

Reply: *Revised*

Line 357: In the Conclusions section, add the words “the” and “field” just after in the following sentence (check the correct language in this case): “... important information on variations in the geomagnetic field and auroral activity...”

Reply: *Revised*

The last suggestion is to enumerate the pages in the button right side or according to the journal standard.

Reply: *Revised*

We thank to you and the Reviewer #1 and Reviewer #2 for their constructive and helpful comments.

Sincerely,
Dr. Nafiz MADEN

Historical Aurora Borealis Observations in medieval Anatolia (AD 1-1453): Implications for the past solar activity

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Abstract: In this paper, it is reviewed the relationships between the aurora observations, past solar activity and climatic change in Anatolia during medieval period. For this purpose, it is presented two historical aurora catalogs for Anatolia and Middle East regions at various dates by using historical texts, chronicles and other auroral records. The available catalogs in literature are covered records observed in the Europe, Japan, China, Russia and Middle East. There is no study dealing only with the historical aurora observations recorded in Anatolia. The data of the catalog support that there is a considerable relationship between the aurora activity and past strong solar activity. High Aurora activity during the years around 1100 in Anatolia and Middle East is quite consistent with the past solar variability and planetary climatic changes drastically impacting on the economy and human events.

Keywords: Historical aurora records; Solar activity; Climatic changes; Anatolia.

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1. Introduction

A number of researchers presented the low and middle-latitude aurora catalogs (Table 1) from Europe (Mairan, 1733; Frobesius 1739; Fritz, 1873; Schove, 1948; Link, 1962; Dall'Olmo, 1979; Stothers, 1979; Krivsky and Pejml, 1988; Vaquero et al., 2010; Scafetta and Willson, 2013), Arabic countries (Basurah, 2006), Japan (Matsushita, 1956; Nakazawa et al., 2004; Kataoka et al., 2017), and China (Schove and Ho, 1959; Keimatsu,1976; Hayakawa et al., 2015; Kataoka and Iwahashi, 2017). Aurorae are the most majestic luminous phenomenon observed in the sky. The aurora observations were described as "sign", "a fiery shining sign", "a very fabulous sign", "red sky", "a fiery red sky", "sky fire", "a great fire", "a fiery cloud", "a frightful and strange omen", "a fire-like omen", "a bloody spear light", "blaze of light", "a sunlight light". The form of aurorae was defined as "luminous column".

The historical aurora catalogs have been used to recognize the past solar activities (Siscoe, 1980; Silverman, 1992; Schröder, 1992; Schröder 1994; Basurah, 2006; Vazquez et al., 2006; Hayakawa et al., 2015), Earth's climate change (Pang and Yau, 2002; Schröder, 2004; Gallet et al., 2005; Bard and Frank, 2006; Scafetta, 2012) and perception of human civilizations (Schröder, 2004; Gallet et al., 2006; Silverman, 2006). The state of the geomagnetic field and the form of magnetosphere extremely control the location of auroral zone (Korte and Stulze, 2016). The visibility of the aurorae at low latitudes is very scarce and closely connected with the strong geomagnetic storms related to the high-speed solar wind or interplanetary transients (Eather, 1980; Basurah, 2006; Vazquez et al., 2006).

Mairan (1733) presented that the first scientific monography covers a list of 229 historical aurorae during the period of 502-1731. In I852, Wolf noticed that the aurorae

match with periods of high sunspot number, according to the historical aurora catalog including more than 6300 records (Wolf, 1857). Fritz (1873), who listed 77 European Aurora records during 1707-1708, published the historical auroral catalog and separated auroral sightings into five categories based on the latitude and longitude (Schröder, 1994). Link (1962) published a useful aurora catalog seen in European countries based on eight previous catalogs compiled by Frobesius (1739), Mairan (1754), Schoning (1760), Boué (1856), Wolf (1857), Lovering (1868), Fritz (1873) and Seydl (1954).

Vaquero et al. (2010) declared a set of auroral observation of Francisco Salva Campillo who recorded in Barcelona during 1780-1825. This catalog represents a sudden drop in the number of annual auroral observations at about 1793 owing to the secular minimum in solar activity (Vaquero et al., 2010). Scafetta and Willson (2013) studied the historical Hungarian auroral records covering 438 years. They found that the maxima of the auroral observations comply with the maxima in the sunspot records and there is a positive correlation amidst the auroral records, the solar and climate activities.

Neuhäuser and Neuhäuser (2015) are implemented five criteria of likeliness for 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 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). However, Stephenson et al. (2019) showed that these criteria may be adequate for normal aurorae, which cannot be classified as extreme events associated with extreme magnetic storms. Korte and Stolze (2016) showed that

71 the intensity and tilt of the geomagnetic field and high solar activity are closely related to
72 the Aurora occurrence.
73 The available catalogs described above present a number of records covering
74 Europe, Japan, China, Russia and Middle East. There is no study dealing only with the
75 historical aurora observations recorded in Anatolia. Anatolia have not been studied until
76 now with respect to historical-climatological data and aurora observations. The goal of this
77 study is to compile a historical Anatolian Aurora catalog (hAAC) during medieval period
78 by scanning the available sources and catalogs in literature. The catalog could be used to
79 analyze the past solar activity and earth climatic changes impacting on the economy and
80 human events. This research may also contribute to the understanding of public
81 perception of the historical auroras.
82
83 **2. Historical Anatolian Aurora Catalog (hAAC) through medieval period**
84 It is propounded a historical aurora catalog observed only in Anatolia during
85 medieval period collected from Link (1962), Botley (1964), Baldwin (1969), Newton
86 (1972), Stothers (1979), Eather (1980), Melissinos, (1980), Silverman (1998), Dall'Olmo
87 (1979), Andreasyan (2000), Little (2007), Silverman (2006), Neuhäuser and Neuhäuser
88 (2015) resources. In this catalogue, 23 different historical aurora records observed in
89 Anatolia are presented during medieval period in Table 2. The location map of the
90 historical Anatolian observations is given in Figure 1. A number of Anatolian aurora
91 observations are summarized in Table 3. Another collected ancient aurora catalog
92 consisting 45 auroral observations is shown in Table 4 for the Middle East region during
93 the same period using Islamic historical texts, Arabic chronicles and other auroral records
94 given in Table 1. These two catalogues are plotted in Figure 2 and evaluated altogether.

The historical Anatolian and Middle East aurora records overlap through medieval period especially between 1097 and 1129 years (Fig. 3). Also, Chinese and European aurora observations are in harmony with each other in this period (Siscoe, 1980).

In Anatolia, the first auroral observation was done in Constantinople at 333 (Stothers, 1979). Stothers (1979) described these observations as a sky fire according to the works of Aurelius Victor (320-390), who was a historian and politician of the Roman Empire. On the other hand, Eather (1980) described an Aurora observation over Constantinople at about 360 BC during the siege on Byzantium by Philip of Macedonia.

Little (2007) described an aurora observation record in Constantinople at 396: “A fiery cloud was observed from the East while the city darkened. At first, it was small, but later gradually grew and moved towards the city. At last, it terribly enlarged and poised over the entire city. A terrifying flame appeared to hang down. All people stacked to the church, and the place could not receive huge mass”.

According to the Link (1962) and Hayakawa et al., 2017, an aurora appeared in Asia Minor on 22 August 502, Thursday. This aurora was also observed both in Edessa (Botley, 1964) and Palestine after an earthquake (Russell, 1985) based on to the Chronicle of Joshua the Stylite and Chronicle of Zuqnin. Joshua the Stylite described it: “On the 22rd of August this year, on the night preceding Friday, a great fire appeared to us blazing in the northern quarter the all night. It was believed that the whole earth was going to be devastated that night by a fire storm. However, the mercy of our Lord preserved us without damage”. This appearance of the aurora borealis was also reported in Chronicon Edessenum without apocalyptic detail (Trombley and Watt, 2000).

According to the Historia Ecclesiastica of Ptolomaeus Lucensis there was an aurora sighting at a night of 633 in Constantinople (Dall’Olmo, 1979): “A bloody sign

appearing just at that time was sighted. A bloodstained spear and a sharp light were observed on the sky for nearly all night". Theophanes (758/760-817), a Byzantine monk, theologian, and chronicler, reported an observation in 667 winter: "There was a sign which appeared in the sky in the same winter". Theophanes reported another observation in 675-676: "This year a sign was seen in the sky on a Sabbath day" (Turtledove, 1982).

Theophanes recorded three aurora events for 734, 743 June and 744 in Constantinople. The first aurora observation was reported in 734: "A fiery sign shining like a burning brand appeared in the sky in Constantinople". The second aurora observation was recorded by Theophanes in June of 743: "In the northern sky of Constantinople, a sign was observed in the month of June" (Turtledove, 1982). The last aurora record was observed in Constantinople for 744: "In the northern sky, a sign seemed this year, and dust fell in several places" (Turtledove, 1982; Neuhäuser and Neuhäuser, 2015).

Harrak (1999) listed two aurorae records observed near Amida in the early 770s based on the Chronicle of Zuqnin. In the Chronicle of Zuqnin, the first observation was recorded in 771/772, Amida (Turkey): "Another sign was seen in the northern side, and its view gave evidence about the menace of God against us. It appeared at reaping time, while wrapping the whole northern side of the sky from west to east end. It was look like a green sceptre, a red one, a yellow one, and a black one. It was ascending from the ground and changing into 70 shapes, while one sceptre was emerging and another disappearing". The second observation was recorded in the Chronicle of Zuqnin in 773, Amida (Turkey): "In the month of June, on a Friday, another sign that was seen a year ago in the northern region was appeared again this year. It was on Fridays that it used to appear during these three consecutive years, stretching itself out from the eastern side to the western side. The sign would change into many shapes in such a way that as soon as

a green ray vanished, a red one would appear, and as soon as the yellow one vanished, a green would appear, and as soon as this one vanished, a black one would appear" (Harrak, 1999; Neuhäuser and Neuhäuser, 2015). These two observations listed by Harrak (1999) and Neuhäuser and Neuhäuser (2015) based on the Chronicle of Zuqnin were also cited by Dall'Olmo (1979) according to the Chronique de Denys de Tell-Mahré (Chabot, 1895) with different dating. In Constantinople, another aurora observation was recorded in 988: "A luminous star and fiery pillars seen in the northern region of the sky for some nights. They frightened the people who saw them." (Dall'Olmo, 1979).

Matthew of Edessa, who wrote a chronicle, described the events that occurred between the years 952 and 1136, and reported four aurora observations around the year 1100 (Andreasyan, 2000). Matthew of Edessa reported the first aurora observation in the Armenian year 546 (25.02.1097–24.02.1098): "In this year, an odd and horrible signs were observed in the the northern side of the sky. No one had ever seen such an amazing omen so far. In the month of November, the sky kindled and reddened though the air was clear and quiet. The bloody sky was covered with stacks as if clustered on top of one another becoming colorful. The stacks were set to slip through in an easterly direction, dispersed after having gathered, and enveloped the large amount of the sky. Then, the dark redness such an amazing degree reached up to the middle of the sky vault. The savants and sages interpreted this phenomenon that, it was a sign of bloodshed. Actually, terrible events and disasters we included as a short story in our book were soon to be fulfilled."

Krey (1921) described an aurora observation during the siege of Antioch on the account of eyewitnesses and participants in the first crusade: "A great earthquake occurred on the third day before the Kalends of January (30 December 1097), and a very

fabulous sign was noticed in the sky. Northern part of the sky was so red that it appeared as if sun rose to inform the day in the first sight of the night". This observation was also described by Baldwin (1969): "There was an earthquake on December 30th, and a frightening display of the aurora borealis next evening, and in this way God chastised his army, so that we were intent upon the light which was rising in the darkness, yet the minds of some were so blind and abandoned that they were recalled neither from luxury nor robbery. At this time the Bishop prescribed a fast of three days and urged prayers and alms, together with a procession, upon the people; moreover, he commanded the priests to devote themselves to masses and prayers, the clerics to psalms". On the other hand, another aurora was observed on 3 June 1098 at Antioch based on the Link (1962) catalog as a fiery red sky (Silverman, 2006).

The Matthew of Edessa recorded second aurora observation in the Armenian year 547 (25.02.1098–24.02.1099). "In the same year, a new sign appeared in the northern part of the sky. At the fourth hour of the night, the sky appeared more inflamed than before, and a dark red color. This phenomenon lasted from the evening until the fourth hour of the night. Such a terrible omen had never been seen so far. This omen raised upwards gradually and covered the northern portion of the sky with the lines reaching the hills. All stars took a fiery color. This phenomenon was an omen of rage and catastrophe" (Andreasyan, 2000). Botley (1964) reported an auroral observation in Antioch as a blaze of light girdled Pole. Link (1962) dated this observation on September 27, 1098.

In the Armenian year 548 (25.02.1099–24.02.1100) Matthew reported another aurora observation: "A fiery sign of dark red color appeared in the sky in this year. This omen heading from the northern to the eastern part of the sky appeared until the seventh hour of the night and then became black. It was said that this phenomenon was a sign of

bloodshed of Christians. These predictions were truly realized. No favorable omen did not appear since the day when the Franks began their expedition. All omens, however, marked to realize the destruction, death, slaughter, famine and other diverse disasters" (Andreasyan, 2000).

Matthew recorded the last aurora observation in the Armenian year 549 (25.02.1100–24.02.1101): "The northern part of the sky flushed red for the fourth time in this year. The fiery red omen appeared more horrific than the previous one and subsequently changed into black. This fourth appearance coincided with a lunar eclipse. This phenomenon was a sign of the celestial wrath of God over the Christians as previously said by the prophet Jeremiah with these words: "His wrath will blaze up from the northern part of the sky. Indeed, several misfortunes occurred as we never could have expected" (Andreasyan, 2000).

Dall'Olmo (1979) reported an aurora observation based on the Chronicle of Michael the Syrian translated into French by Chabot (1968): "In the year 1108, a light like the sunlight was seen in the middle of the night, and remained about three hours in Djihan region near Adana". Dall'Olmo (1979) was also cited 12 auroral records observed probably in the Middle East from 745 to 1141 (Table 4) according to the Chronicle of Michael the Syrian (Chabot, 1968).

On December 16, 1117, an aurora was recorded in Asia Minor (Link, 1962). In the same date, two observations were also reported in the Middle East (Newton, 1972) and in Palestine (Botley, 1964). These two observations could be same event. Link (1962) described other observations in Asia Minor in the year 1119. This event might be the same record observed in Armenia (Botley, 1964) given in Table 4.

Priest Grigor, who continued the Matthew's Chronicle and recorded events for the years 1136/37-1162/63, added one aurora observation in about the year 1143. In the Armenian year 592 (14.02.1143-13.02.1144) Priest Grigor described the aurora observation: "On Holy Thursday (1 April 1143), an omen forming of a luminous column appeared in the northern portion of the sky. This omen was visible for eight days. Three sovereigns died after the appearance of this phenomenon" (Andreasyan, 2000).

3. Results and Discussions

The main purpose of this study is to present an aurora catalog for the Anatolia during the medieval period. Twenty-three different historical aurora records are presented during the medieval period in Anatolia (Table 2). Another aurora catalog containing 45 records collected from different sources is also given (Le Strange, 1890; Link, 1962; Botley, 1964; Newton, 1972; Dall'Olmo, 1979; Silverman, 1998; Basurah, 2006) for the Middle East region (Table 4). The aurorae were generally seen in the northern and eastern part of the sky. The color of the aurora observations was red, green, yellow and black depending on the height and relative concentrations of the nitrogen and oxygen compounds in the atmosphere (Eather, 1980).

The aurora records strongly correlated to high solar activity (Siscoe, 1980) provide some information about the Sun-Earth interaction as previously proved by Scafetta (2012). They are the longest direct observational records available for studying solar and space weather dynamics. Stronger solar dynamics were realized in aurorae with color green-yellow-red as seen in 772 and 773 in Amida. Miyake et al. (2012) and Usoskin et al. (2013) confirmed the 770s high solar events presenting ^{14}C measurements from the annual rings of the cedar trees in Japan and inappropriate carbon cycle model in German

oak, respectively. The auroral records have also proven itself to be a valuable data source for the investigation of the secular variation of solar activity. Paleomagnetic researchs demonstrate that the recent dipole strength was nearly 50% weaker than it was 2500 years ago (Raspopov et al., 2003). Siscoe and Siebert (2002) indicated that the dipole strength was 1.5 times as large as that of the present value. The position of the geomagnetic latitude and dipole moment might be the reason of observing aurorae in Anatolia so frequently. The average dipole moment for 750 and 1250 are 8.85 10^{22} Am^2 and 8.90 10^{22} Am^2 slightly higher than the present value of 7.78 10^{22} Am^2 (Korte and Constable, 2005; Gallet et al., 2005). According to the Kawai et al. (1965) the axis of geomagnetic dipole could have inclined towards Asia at around the 11^{th}-12^{th} centuries. In addition, the possibility of auroral occurrence at low latitudes could demonstrate changes in the location of the North magnetic pole (Silverman, 1998).

The position of the magnetic poles is the most important factor defining whether the aurora was observed at a geographic region. Palaeomagnetic data provides similar longitude values (85° N, 115° E) for the north geomagnetic pole (Merrill and McElhinny, 1983). The positions of the north magnetic pole have changed from 10° N to 358° N in longitude and between 79° E and 88° E in latitude over the past 2500 years (Ohno and Hamano, 1992). During the interval of 1127–1129, the north geomagnetic pole was located at a geographic latitude of 80° N, and geographic longitudes including East Asia (Merrill and McElhinny, 1983; Constable et al., 2000). According to the Fukushima (1994), the north magnetic pole was located at 81°N in the eastern hemisphere near East Asia (100°E to 130°E) in the medieval period. The north geomagnetic pole of dipole axis

computed from the average spherical harmonic models were 84.8° N and 103.8° E in 1100 (Constable et al., 2000).

The geomagnetic latitude of Amida (Turkey) in the late 8th century to be about 50.1° N (Neuhäuser and Neuhäuser, 2015) based on the Holocene geomagnetic field (Nilsson et al., 2014) and 45° N (Hayakawa et al., 2017) based on the location of the North Geomagnetic Pole over the past 2000 years (Merrill and McElhinny, 1983). According to the Silverman (2006), the geomagnetic latitude of Edessa and Antioch was 41° N and 40° N, respectively. Strong geomagnetic storms, indicating strong solar activity around 770 and 1100 should have been exist in Amida (45° N), Edessa (41° N) and Antioch (40°).

This study could also 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) 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). Damon and Jirikowic (1992) estimated that the rise of global temperature maxima stays below 0.8°C and anomalously high temperatures pursue during the 12th and 13th centuries. Sharma (2002) revisited the issue and proposed that very large solar variations have modulated climate over the past 200 millennia. Gallet et al. (2006) demonstrated that fluctuations in the geomagnetic field might trigger significant climate change impacting on some major societal events in the Middle East at longer time. Also, climate change was a significant component to indicate the Byzantium socio-

economic instability during the Medieval Climate Anomaly. The fall of Constantinople in AD 1204 coincides with a lowest Auroral acitivity in a moderately wet climate condition. The moderately wet climate condition and high aurora activity around 1100 might be more likely to cause the socio-economic growth in Anatolia. Xoplaki et al. (2016) examine the relationship between the climate change and socio-economic development in Byzantine Anatolia. An inverse relationship amidst the aurora records, severe winter and famine is estimated during the years of 1100 in Anatolia. The high aurora activity could be reason of temperature rise during the medieval period in Anatolia. A new low sunspot number and lower aurora activity, which occurring in the period between 2014 and 2025 (Li et al., 2018), might have led to a temporary change in natural environment influencing the general public's attitudes and socio-economic factors. Also, resource scarcity and disparities could also lead to social tensions in the communities in the future.

Haldon et al. (2014) subdivided Medieval into four climatic phases as dry (270-540), very wet (540-750), moderately dry (750-950) and moderately wet (950-1400) depending on archaeological, environmental, climate, high resolution pollen and stable isotope data from sites in central and northwestern Turkey. However, this subdivision should be revised as dry (0-560), very wet (560-725), moderately dry (725-990) and moderately wet (990-1400) as given in Table 5 by using Anatolian and Middle Eastern aurora observations besides historical-climatological data. Affective cold winter, wet climate conditions, drought and famine could be occurred for Asia Minor and Middle East region during 990-1400. It seems that the relatively high auroral activity during the years around 1100 both in Anatolia and Middle East indicates that solar activity must have been intense rather than moderate causing the climate warmer (Fig. 2). In this period, Islamic world was converted into an enlightened center for science, education, medicine, and

307 philosophy as previously stated by Hamilton (1982). An important increase in agricultural
308 production and population seems to have occurred in Anatolia after the year of 1100
309 where the aurora observations are intense (Fig. 2). Vaquero and Trigo (2012) stated the
310 period from 1095 to 1204 as an average solar cycle length. Vaquero et al. (1997) found a
311 250-year cycle in naked eye sunspot observations releted to intense solar activity at
312 around 1100 comparing with aurora events being observed at mid-latitudes during the
313 Medieval Climate Anomaly (Willis and Stephenson, 2001) and historical documents.
314 Miyahara et al. (2008) revealed that the impact of solar variations on climate change is
315 permanent investigating the sun-climate relationship using the ^{14}C content in tree-rings
316 during the Maunder Minimum and the Medieval Maximum Period. Bekli et al. (2017)
317 demonstrated that the naked-eye sun spot observations from 974 to 1278 and aurora
318 records from 965 to 1273 show multiple unusual peaks related to the high solar activitiy
319 at latitudes below 45° N by using Chinese and Korean historical sources. The high aurora
320 activity events associated with great magnetic storms occurred around the maximum
321 phase of solar cycles rather than around the minimum (Kataoka et al., 2017).
322 In the medieval period, the people thought that the aurora was a sign of anger of
323 God, menace, threat, apocalyptic, doomsday, misfortunes, war, slaughter and blodshed.
324 Little (2007) described an aurora observation record in Constantinople at 396: “All people
325 stacked to the church, and the place could not receive huge mass. But after that great
326 tribulation, when God had accredited His word, the cloud began to diminish and at last
327 disappeared. The people, freed from fear for a while, again heard that they must migrate,
328 because the whole city would be destroyed on the next Sabbath. The whole people left

329 the city with the Emperor; no one remained in his house. The city was saved. What shall
330 we say? adds Augustine. Was this the anger of God or rather His mercy"?
331 In the Chronicle of Zuqnin, an aurora observation recorded in 772, Amida (Turkey)
332 was described: "Another sign was seen in the northern side, and its view gave evidence
333 about the menace of God against us. For the intelligent person the sign indicated menace.
334 Many people said many things about it; some said it announced bloodshed, and others
335 said other things. But who knows the deeds of the Lord"?
336 Matthew of Edessa described the aurora phenomenon as a sign of rage,
337 catastrophe, and celestial wrath of God over the Christians and bloodshed of Christians.
338 Matthew of Edessa reported: "These predictions were truly realized. No favorable omen
339 did not appear since the day when the Franks began their expedition. All omens noticed
340 to realize the destruction, death, slaughter, famine and other diverse disasters"
341 (Andreasyan, 2000).
342
343 **4. Conclusions**
344 This study establishing the strong solar activity during medieval period reports the
345 aurora observations recorded both in Anatolia and Middle East region integrating
346 historical-climatological data. The following conclusions can be summarized as follows:
347 1. Historical Anatolian Aurora catalog (hAAc) containing 23 different aurora records
348 provide important information on variations in the geomagnetic field and auroral
349 activity during medieval period.
350 2. In Anatolia and Middle East, there was a relatively high auroral activity during the
351 years around 1100 is quite consistent with the naked-eye sunspot observations
352 related to solar activity as stated by Vaquero et al. (1997) and Bekli et al. (2017).

3. The historical Anatolian Aurora catalog exceptionally promote that there is a remarkable correlation between the past solar activity and aurora activity.
4. The solar activity, intensity of dipole moment and position of the geomagnetic pole might be the most important factors observing aurorae in Anatolia and Middle East regions during medieval period.
5. In the Medieval period, four climatic phases portrayed by Haldon et al. (2014) is revised as dry (0-560), very wet (560-725), moderately dry (725-990) and moderately wet (990-1400) depending on aurora observations besides historical-climatological data.
6. People in medieval Anatolia were believed that the aurora was a sign of celestial wrath of God, menace, threat, apocalyptic, doomsday, misfortunes, war, slaughter, rage, catastrophe and bloodshed.
7. The high and low auroral events associated with solar activity variations provide substantial use of knowledge to design and alleviate the space weather hazards in future.

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TABLES CAPTIONS:

Table 1. Historical Aurora catalogs compiled by different authors.

Table 2. Historical Anatolian Aurora catalogs during medieval period compiled in this study.

Table 3. The number of historical aurora records observed in Anatolia.

Table 4. Ancient aurora observations recorded in Middle East region during medieval period.

Table 5. Summary of Ancient climate change based on the aurora observations and meterological data in Anatolia during medieval period.

FIGURE CAPTIONS:

Figure 1. The location map of the historical Anatolian records during medieval period. Byzantine Empire map: https://www.britannica.com/place/Byzantine-Empire, last access: 12 November 2019.

Figure 2. Comparison of historical aurora observations with climate change and climatological data in Anatolia and neigbouring regions. The upper panel shows the historical data climatic subdivisions, the middle panel shows the aurora observations in Anatolia and Middle East regions and the lower panel shows the land use and population in Anatolia. Historical-climatological and land use data are taken from Haldon et al. (2014).

Figure 3. The number of aurorae records per century observed in the Anatolia and in Middle East.

TABLES

Table 1.

Sources	Number of Observations	Region	Period
Link, 1962	385	Europe	626 B.C. to 1600 A.D.
Link, 1964	209	Europe	1600-1700 A.D.
Stothers, 1979	67	Greece and Italy	480 B.C. to 333 A.D.
Newton, 1972	65	Europe	450-1263 A.D.
Dall'Olmo, 1979	61	Europe	450-1461 A.D.
Keimatsu, 1976	260	China, Korea, and Japan	687 B.C. to 1600 A.D.
Matsushita, 1956	18	Japan	620-1909 A.D.
Basurah, 2006	18	Arabia, North Africa, Spain	800-1600 A.D.
This Study	23	Anatolia	1-1453 A.D.
This Study	45	Middle East	1-1453 A.D.

592 **Table 2.**

#	Date	Location	Description	References
1	333	Constantinople	Sky fire.	Stothers, 1979
2	396	Constantinople	A fiery cloud was seen from the East.	Little, 2007
3	22 Ağustos 502, Thursday	Edessa	A great fire appeared to us blazing in the northern quarter the whole night.	Link, 1962 Botley, 1964 Hayakawa et al., 2017
4	633	Constantinople	A bloody spear and a light of the sky were sighted for nearly the all night.	Dall'Olmo, 1979
5	668	Constantinople	There was a sign appeared in the sky in the same winter.	Turtledove, 1982
6	675	Constantinople	In this year, a sign was seen in the sky on a Sabbath day.	Turtledove, 1982
7	734	Constantinople	There was a sign in the sky which shone like a burning brand.	Turtledove, 1982
8	June 743	Constantinople	In June, a sign appeared on the northern sky.	Turtledove, 1982
9	744	Constantinople	This year, a sign appeared on the northern sky.	Turtledove, 1982
10	771/772	Amida	Another sign appeared in the northern side.	Harrak, 1999 Hayakawa et al., 2017
11	June 773, Friday	Amida	The sign that was seen a year ago in the northern region was seen again in this year, in the month of June, on a Friday.	Neuhäuser and Neuhäuser, 2015
				Harrak, 1999
12	988	Constantinople	Frightened fiery pillars seen in the northern region for some nights.	Dall'Olmo, 1979
13	21 November 1097, Monday	Edessa	A frightful and strange omen appeared in the northern portion of the sky.	Link, 1962
				Silverman, 2006
				Andreasyan, 2000
				Botley, 1964
14	30 December 1097, Friday	Antioch	A very fabulous sign was watched in the sky.	Silverman, 1998
				Baldwin, 1969
				Botley 1964
				Kery, 1921

15	3 June 1098, Saturday	Antioch	A fiery red sky was seen.	Link, 1962 Silverman, 2006 Botley 1964

Table 2 continued.

16	27 September 1098, Monday (10:00)	Edessa	A second omen appeared in the northern portion of the sky at the fourth hour of the night the sky flared up more than it had before and turned a deep red color.	Andreasyan, 2000 Link, 1962
17	27 September 1098, Monday	Antioch	Blaze of light girdled Pole.	Link, 1962 Botley, 1964
18	1099	Edessa	A fire-like omen of a very deep red color appeared in the sky.	Andreasyan, 2000 Link, 1962 Silverman, 2006
19	18 November 1100, Sunday	Edessa	The northern portion of the sky reddened, appearing more frightful and wondrous than the previous phenomenon.	Andreasyan, 2000 Silverman, 2006 Link, 1962
20	1108	Adana	A light like the sunlight was seen in the middle of the night and remained about three hours in Djihan.	Chabot, 1968 Dall'Olmo, 1979
21	16 December 1117, Monday	Asia Minor		Link, 1962 Newton, 1972
22	1119	Asia Minor		Link, 1962
23	1 April 1143, Thursday	Edessa	A sign appeared in the sky from the north in the form of a luminous column	Andreasyan, 2000

Table 3.

#	City	Latitude [Degree, N]	Longitude [Degree, E]	Numbers of observation
1	Constantinople	41.03	28.99	9
2	Edessa	37.17	38.79	6
3	Amida	37.93	40.21	2
4	Antioch	36.2	36.16	3
5	Adana	36.99	35.34	1
6	Asia Minor	39.93	32.85	2
			Total	**23**

609 **Table 4.**

#	Date	Place	Decriptions	References
1	65	Jerusalem		Botley, 1964
2	66	Jerusalem		Botley, 1964
3	400	Byzantium		Link, 1962
4	402	Byzantium		Link, 1962
5	473	Byzantium		Link, 1962
6	474	Byzantium		Link, 1962
7	502 Agust 22	Palestine	A great fire appeared to us blazing in the northern quarter the whole night	Botley, 1964
8	743 June	Syria	A mighty sign appeared in the heavens like columns of fire blazing in June	Chabot, 1968
9	743 September	Middle East	Another sign appeared in September like a flame of fire and spread from the East to the West	Cook, 2001
10	745 January	Middle East	In the middle of the sky, a large column of fire appeared during the night	Chabot, 1968
11	793 May 11-17	Iraq	There occurred a violent wind and overshadowing of the heavens and a redness in the sky, on the night of Sunday	Basworth, 1989
12	817 October 29	Iraq	A reddish glow appeared in the sky and stayed until late at night like a two red columns	Basurah, 2006
13	840 September 24	Middle East	A fiery cloud appeared in the northern part of the sky, moving from east to West.	Dall'Olmo, 1979
14	931 November 9	Baghdad	An intense red glow appeared in the city of Al-Salam (Baghdad)	Basurah, 2006
15	939 October 17	Syria	An intense red glow appeared in the atmosphere coming from North and West	Basurah, 2006
16	1050 Agust 5	Middle East	Through which light shone out broad and glittering, and then became extinguished	Le Strange, 1890
17	1097	Palestine		Botley, 1964
18	1100	Palestine		Botley, 1964
19	1102	Palestine		Botley, 1964

20	1106	Syria		Botley, 1964
21	1110	Syria		Botley, 1964
22	1117 December 16	Palestine		Newton, 1972 Botley, 1964
23	1119	Armenia		Botley, 1964
24	1121 May, Monday	Syria	There appeared a full arc, which had not been observed for many enerations	Botley, 1964
25	1129 January	Middle East	A fire appeared in the northern region. A sort of pillar was stretched toward the south.	Dall'Olmo, 1979
26	1129 March	Middle East	A fire appeared in the northern region. A sort of pillar was stretched toward the south.	Dall'Olmo, 1979

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611 **Table 4. continued**

27	1129 April	Middle East	A fire appeared in the northern region. A sort of pillar was stretched toward the south.	Dall'Olmo, 1979
28	1130 November	Middle East	A burning fire was seen in the northern region	Dall'Olmo, 1979
29	1135 July 21	Middle East	A light like a torch moved from east to West. The light of the moon and of the stars was obscured. A frightful noise followed	Dall'Olmo, 1979
30	1138 October	Syria	A red sign was seen in the northern part of the sky	Botley, 1964
31	1140 June 22	Syria	Red lances were seen in the northern region.	Botley, 1964
32	1141 August	Middle East	Rays of fire were observed in the northern region.	Dall'Olmo, 1979
33	1141 September	Syria	A brightness as bright as the sun broke out in the northeast. It shone as if the sky were on fire.	Botley, 1964
34	1149	Syria		Botley, 1964
35	1150	Palestine		Botley, 1964
36 **37**	1176 September 6 - October 5	Syria	An intense red light appeared in the sky from the East	Basurah, 2006
	1179 May 7	Syria	The sky became cloudy and pillars of fire appeared at the horizon	Basurah, 2006
38	1182	Byzantium		Link, 1962

39	1187 July	Tiberias, Israel		Botley, 1964
40	1223 October 26	Syria	We saw from Bani Helal Mountain (toward the North direction) a hugelight over Gassune; we thought that Damascus was on fire.	Basurah, 2006
41	1264 July 20–30	Syria	Bright glowing columns appeared toward North-West	Basurah, 2006
42	1370 November 27	Jerusalem	A great reddish glow appeared in the sky of Jerusalem	Basurah, 2006
43	1370 November 27	Damascus	A great reddish glow appeared in the sky of Damascus	Basurah, 2006
44	1370 November 27	Homs	A great reddish glow appeared in the sky of Homs	Basurah, 2006
45	1370 November 27	Aleppo	A great reddish glow appeared in the sky of Aleppo	Basurah, 2006

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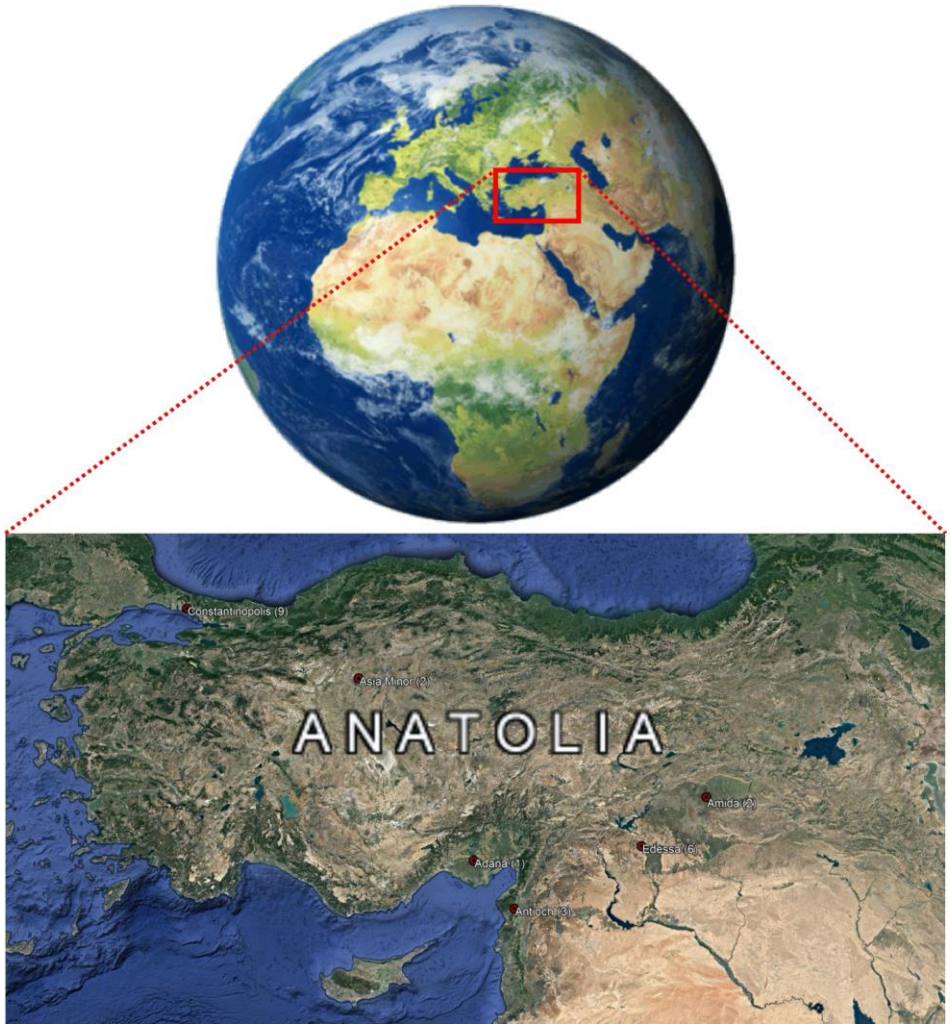
Table 5.

Medieval Period		Climate
Haldon et al. (2014)	**This Study**	
270-540	0-560	Dry
540-750	560-725	Very wet
750-950	725-990	Moderately dry
950-1400	990-1400	Moderately wet

631 **Figures**



632

633 **Figure 1.**

634

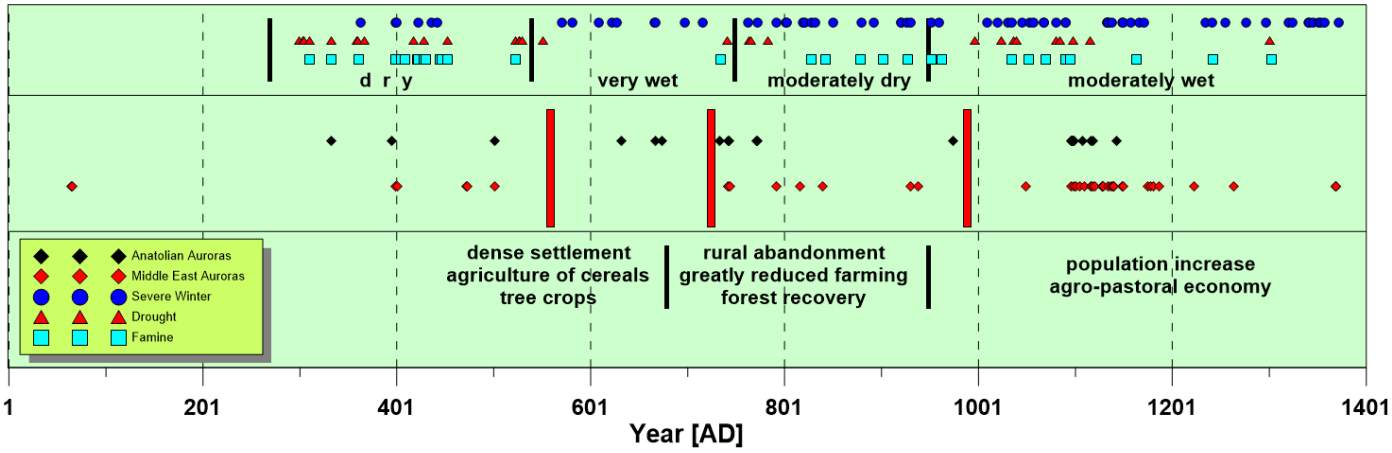
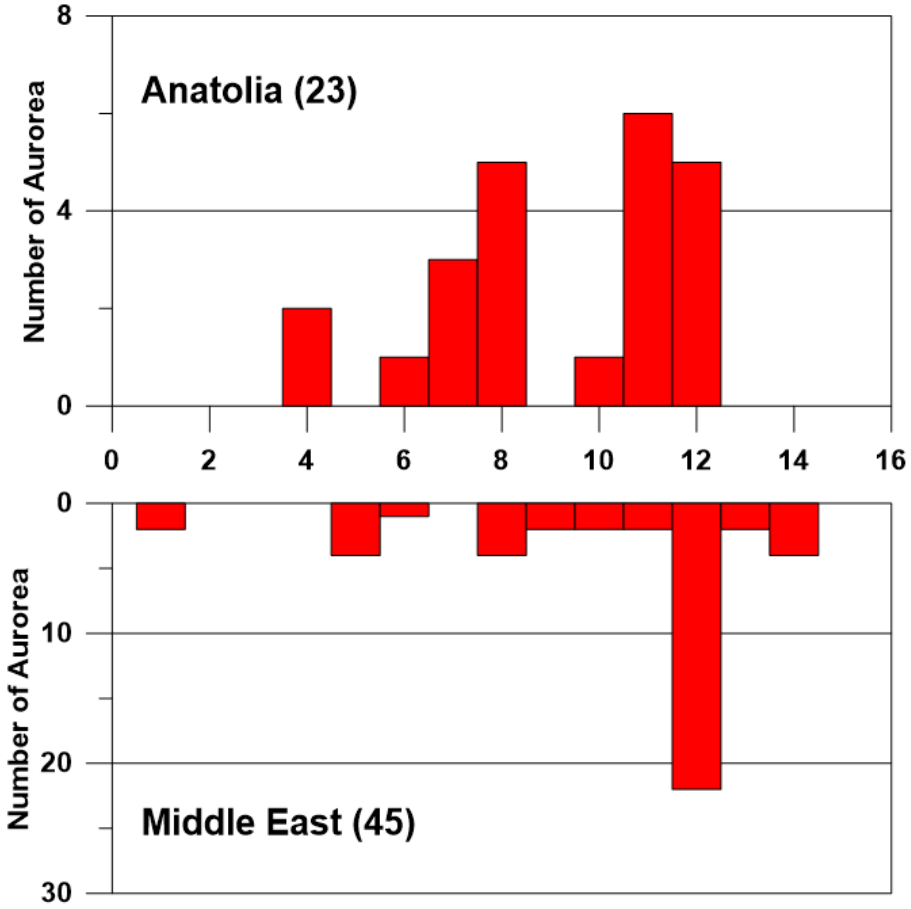

d r y
very wet
moderately dry
moderately wet
Anatolian Auroras
Middle East Auroras
Severe Winter
Drought
Famine
dense settlement
agriculture of cereals
tree crops
rural abandonment
greatly reduced farming
forest recovery
population increase
agro-pastoral economy
1
201
401
601
801
1001
1201
1401
Year [AD]

Figure 2.



638

639 **Figure 3.**