Historical Aurora Borealis catalog for Anatolia and Constantinople (hABcAC) in the medieval period: 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 Constantinople, 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 and Constantinople. The data of the catalog support that there is a considerable relationship between the aurora activity and past strong solar activity. High auroral activity around the extreme solar particle storm in 774/775 and the medieval grand maximum in 1100s in Anatolia and Middle East is quite consistent with the past solar variability reported in other scientific literature.

Keywords: Historical aurora record; Solar activity; Climate change; 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). Korte and Stolze (2016) showed that the intensity and tilt of the geomagnetic field and high solar activity are closely related to the Aurora occurrence. 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. However, these criteria actually contradicted auroral behaviour during the extreme space weather events (Kimball, 1960; Kataoka and Iwahashi, 2017; Kataoka et al., 2019; Kataoka and Kazama, 2019). Indeed, Stephenson et al. (2019) rejected these criteria and their analyses on the basis of multiple counter-examples during the extreme space weather events and confirmed an enhanced solar activity around this

epoch. Recently, such candidate records of mid-latitude aurorae have been intensively investigated (e.g., Usoskin et al., 2013; Stephenson, 2015), due to the discovery of footprints of an extreme solar particle storm in the cosmogenic isotopes around 774/775 (Miyake et al., 2012; Usoskin et al., 2013; Mekhaldi et al., 2015). Their conclusion is consistent with the isotope evidence for the extreme solar particle storm such as the detected ratio of Be^{10} and Cl^{36} (Mekhaldi et al., 2015), latitudinal concentration of C^{14} concentration (Uusitalo et al., 2018), and coincidental spikes of the multiple cosmogenic isotopes in both hemispheres (Büntgen et al., 2018).

The goal of this study is to compile a historical aurora catalog to analyse the past solar activity of interrelated social, economic and climate change impacts during the medieval period. This research may also contribute to the understanding of public perception of the historical auroras. Constantinople and Anatolia have not been studied up to now with regard to historical-climatological data and aurora observations.

2. Historical Aurora Borealis catalog for Anatolia and Constantinople (hABcAC) in the medieval period

It is propounded a historical aurora catalog observed only in Anatolia and Constantinople during medieval period collected from Link (1962), Botley (1964), Baldwin (1969), Newton (1972), Stothers (1979), Eather (1980), Melissinos, (1980), Silverman (1998), Dall'Olmo (1979), Andreasyan (2000), Little (2007), Silverman (2006), Neuhäuser and Neuhäuser (2015) resources. In this catalogue, 23 different historical aurora observations recorded in Anatolia and Constantinople during medieval period are presented in Table 2. The location map of the historical aurora observations is given in Figure 1 and summarized in Table 3. Another collected ancient aurora catalog consisting

45 auroral observations is shown in Table 4 for the Middle East region during the same period using Islamic historical texts, Arabic chronicles and other auroral records given in Table 1. These two catalogues are plotted in Figure 2 and evaluated altogether. The Middle East aurora records and hABcAC 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 this catalog, the first auroral observation was observed in Constantinople at 333. 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). These two observations listed by Harrak (1999) 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 Constantinople and Anatolia during the medieval period. Twenty-three different historical aurora records are presented in Constantinople and Anatolia during the medieval period (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. The low-latitude aurorae of 772-773 are interesting, as being very close to the extreme solar event of 774/775 (Miyake et al., 2012; Usoskin et al., 2013; Mekhaldi et al., 2015). 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. These low-latitude aurorae are quite close from the extreme solar particle storm in 774/775 and support not the solar minimum (Neuhäuser and Neuhäuser, 2015) but high solar activity back then (Usoskin et al., 2013; Mekhaldi et al., 2015; Stephenson et al., 2019). 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 Constantinople and 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.

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.

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 of four climatic phases 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 aurora observations besides historical-climatological data. Bekli et al. (2017) demonstrated that the naked eye sunspot observations from 974 to 1278 and aurora records from 965 to 1273 show multiple unusual peaks related to the high solar activitiy at latitudes below 45° N by using Chinese and Korean historical sources. The high aurora activity events associated with great magnetic storms occurred around the maximum phase of solar cycles rather than around the minimum (Kataoka et al., 2017). 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. An important increase in agricultural production and population seems to have occurred in Anatolia after the year of 1100 where the aurora observations are intense (Fig. 2). In this period, Islamic world was converted into an enlightened center for science, education, medicine, and philosophy as previously stated by Hamilton (1982). Vaquero et al. (1997) found a 250-year cycle in naked eye sunspot observations releted to intense solar activity at around 1100 comparing with aurora events being observed at mid-latitudes during the Medieval Grand Maximum (Willis and Stephenson, 2001) and historical documents. Miyahara et al.

(2008) revealed that the impact of solar variations on climate change is permanent investigating the sun-climate relationship using the ^{14}C content in tree-rings during the Maunder Minimum and the Medieval Maximum Period. Vaquero and Trigo (2012) stated the period from 1095 to 1204 as an average solar cycle length, whereas this needs to be carefully compared with the reconstructed solar cycles on the basis of cosmogenic isotopes (Miyahara et al., 2008; Kataoka et al., 2017). Nevertheless, this period is characterised with numerous records of sunspots and aurorae shown in Vaquero and Vazquez (2009) and supported by Anatolian reports compiled in this article. This is highly consistent with an appearance of a gigantic sunspot in 1128 that caused a serious geomagnetic storm (Willis and Stephenson, 2001) and contrasts well with the Oort Minimum (Usoskin et al., 2017; Inceoglu et al., 2015).

In the medieval period, the people thought that the aurora was a sign of anger of God, menace, threat, apocalyptic, doomsday, misfortunes, war, slaughter and blodshed. Little (2007) described an aurora observation record in Constantinople at 396: “All people stacked to the church, and the place could not receive huge mass. But after that great tribulation, when God had accredited His word, the cloud began to diminish and at last disappeared. The people, freed from fear for a while, again heard that they must migrate, because the whole city would be destroyed on the next Sabbath. The whole people left the city with the Emperor; no one remained in his house. The city was saved. What shall we say? adds Augustine. Was this the anger of God or rather His mercy”?

In the Chronicle of Zuqnin, an aurora observation recorded in 772, Amida (Turkey) was described: “Another sign was seen in the northern side, and its view gave evidence about the menace of God against us. For the intelligent person the sign indicated menace.

Many people said many things about it; some said it announced bloodshed, and others said other things. But who knows the deeds of the Lord”?

Matthew of Edessa described the aurora phenomenon as a sign of rage, catastrophe, and celestial wrath of God over the Christians and bloodshed of Christians. Matthew of Edessa reported: “These predictions were truly realized. No favorable omen did not appear since the day when the Franks began their expedition. All omens noticed to realize the destruction, death, slaughter, famine and other diverse disasters” (Andreasyan, 2000).

4. Conclusions

This study establishing the strong solar activity during medieval period reports the aurora observations recorded both in Anatolia and Middle East region integrating historical-climatological data. The following conclusions can be summarized as follows:

1. Historical Aurora catalog for Anatolia and Constantinople (hABcAC) containing 23 different aurora records provide important information on variations in the geomagnetic field and auroral activity during medieval period. The solar activity, intensity of dipole moment and position of the geomagnetic pole might be the most important factors observing aurorae in Constantinople, Anatolia and Middle East regions.
2. The historical Aurora catalogs exceptionally promote that there is a remarkable correlation between the past solar and aurora activity. In Constantinople, 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 related to solar activity as stated by Vaquero et al. (1997) and Bekli et al. (2017).

3. People were believed that the aurora was a sign of celestial wrath of God, menace, threat, apocalyptic, doomsday, misfortunes, war, slaughter, rage, catastrophe and bloodshed. The lower aurora activity could entail variation in the physical environment and social tensions in the communities inducing the general public's attitudes and socio-economic factors.
4. 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 Aurora catalogs during medieval period used in this study.

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

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

Table 5. Summary of medieval climate change based on the aurora observations and meterological data in Anatolia and neigbouring regions.

FIGURE CAPTIONS:

Figure 1. The location map of the historical Aurora records during medieval period.

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 Constantinople, Anatolia, and 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.

637 **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.	Hayakawa et al., 2017 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

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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**

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 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

659 **Table 4. continued**

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
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

Figures

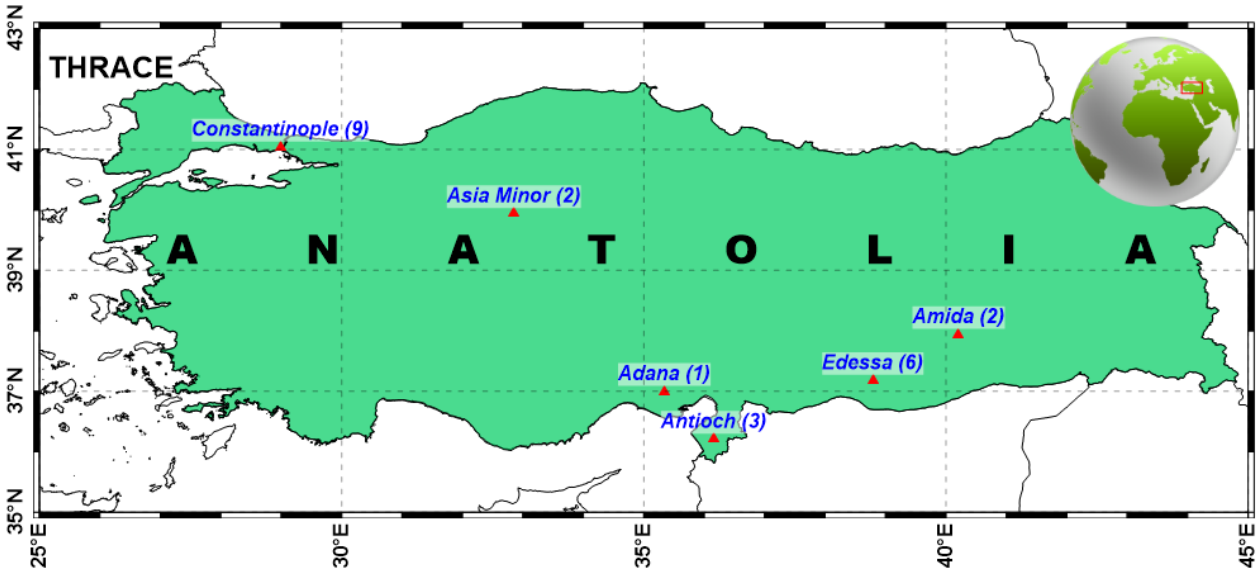
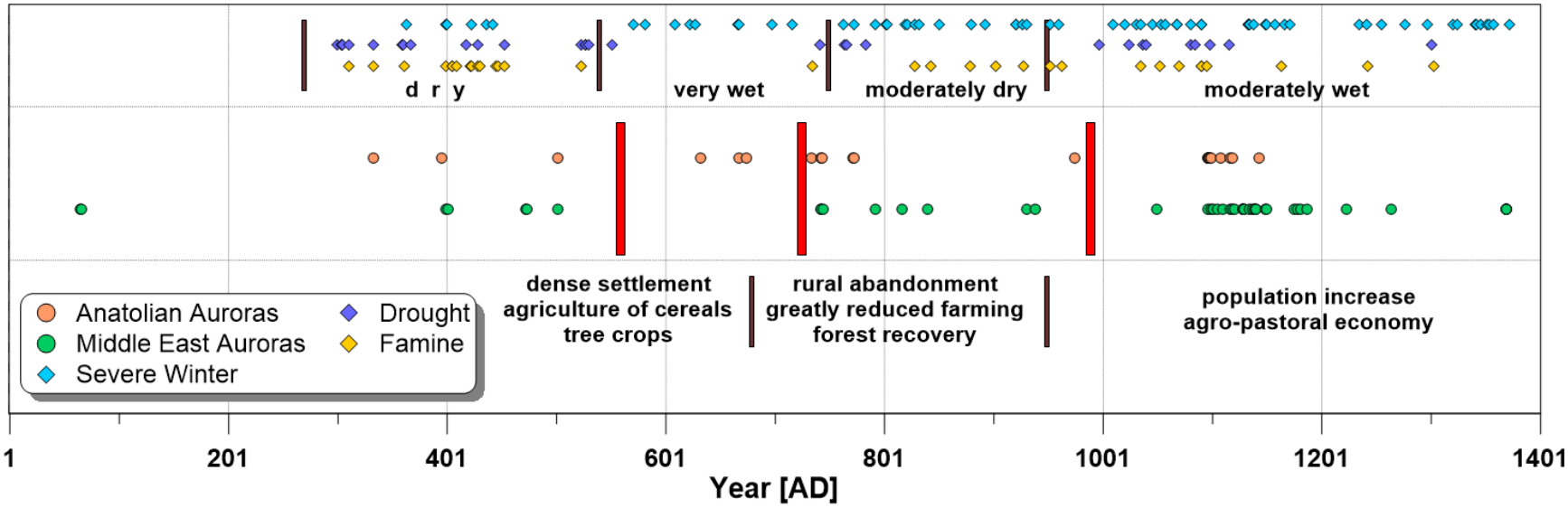


Figure 1.



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683 **Figure 2.**

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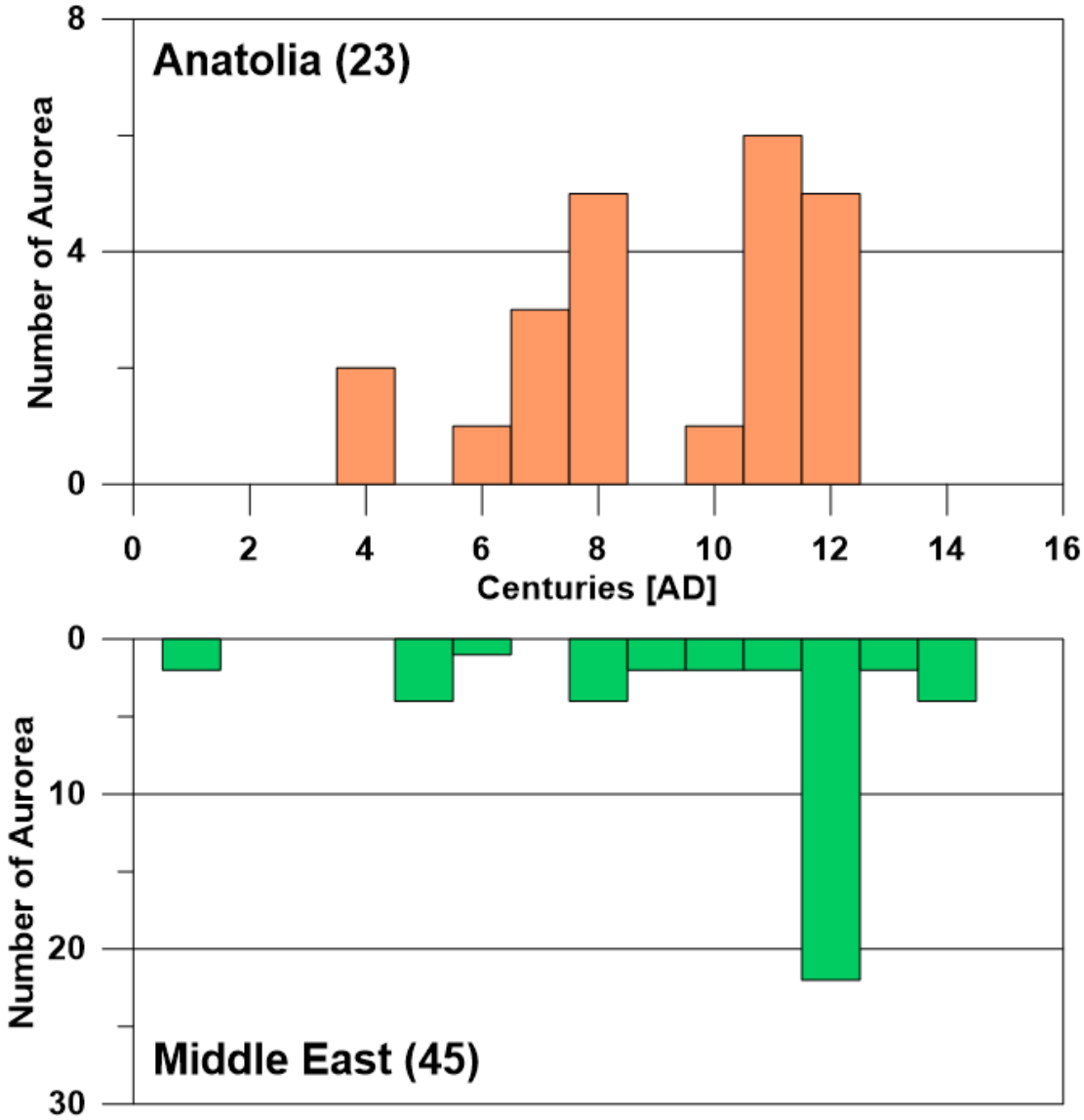

685

686 **Figure 3.**