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Ancient Auroral Records Compiled From Korean Historical Books

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Key Points:

- A new catalog of historical Korean auroral records during 1012–1811 is compiled
- The catalog contains 2013 red auroral records with date, local time, and direction information
- The data set provides valuable support for various studies related to solar-terrestrial space weather and ancient climates

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Abstract Aurora provides an essential diagnostic to spatial and temporal variations of terrestrial space environment and is also an important proxy of solar and geomagnetic activities. Contemporary auroral observations have just continued for more than half a century. Visual auroral phenomena recorded in historical books provide key clues to understand the solar and geomagnetic activities in the long history prior to modern era. In this study, we compiled a new auroral catalog from ancient Korean historical books, including 2013 auroral records with day-level resolution from 1012 to 1811 CE, especially for the records searched from the *Seungjeongweon Ilgi*. The number of auroral records in this new catalog is greatly enlarged compared with previous lists. The occurrence of the aurora in the new catalog is generally consistent with previous data sets. This extended data set provides valuable support for various studies related to solar-terrestrial space weather and ancient climates in the past millennium.

1. Introduction

Since Fritz (1873) first identified an ancient aurora list from historical books, many astronomers and space physicists have constructed regional or global lists of ancient auroral records for different purposes with respective emphasizes, such as Link (1964) for years before 1700, Silverman and Blanchard (1983) for England observations from 1883 to 1931, Lee et al. (2004) from Korea histories in the 11th–18th century, and Hayakawa et al. (2017a) for Chinese ancient records during 1261–1644. Based on these auroral lists, a variety of studies have been done over decades, especially on estimating the ancient solar and geomagnetic activities due to their dominated effect on the aurora occurrence. For example, the auroral records from the Orient played an important role in confirmation of the Maunder Minimum of solar activity (Eddy, 1976). Siscoe (1980) investigated the global aurora occurrence based on five available aurora catalogs and identified the most known grand solar minimums covering more than 2,000 years. He also resolved 80-year and 10-year solar cycle during the Middle Ages, which implies that the solar cycle was then operative. Silverman (1992) analyzed 45,000 visual aurora observations during the past 500 years, examined its secular variation through comparison with other solar and magnetic indices, and confirmed the disappearance of 11-year cycle around the Maunder minimum. González-Esparza & Vuevas-Carnoda (2018) used the naked eye aurora observations from Mexico to determine the amplitude of the 1859 great geomagnetic storm and storm evolution. Furthermore, ancient auroras are also used to investigate the evolution of geomagnetic field (Siscoe & Verosub, 1983) and even assist archeomagnetic dating (Liritzis, 1988).

In those available ancient aurora lists, some of them actually have shown that Korean ancient books recorded a large number of ancient auroras, especially around the Maunder minimum (Dai & Chen, 1980). The Korean auroral records have been actively used in literature to characterize the ancient solar and geomagnetic activities (Hayakawa et al., 2017b; Lee et al., 2004; Willis et al., 1996, 2005, 2007; Willis & Stephenson, 2000, 2001). However, due to the relatively low geomagnetic latitude of Korea peninsula, the current aurora borealis theory if difficult to explain the large number of auroral records especially in the years of extremely low solar activity. Here, we systematically collated the auroral records from three Korean historical books through formatted digital search. Then, we manually checked each entry from original books to get detailed information of azimuth, date, local time, lasting time, and so on Finally, we got 2013 auroral records during 1012–1811 and formed this auroral catalog. In comparison with previous results, this Korean auroral

catalog has several outstanding advantages. First, it was formed based on daily record, which implies that it has time resolution up to 1 day. Second, it was observed from a fixed location with azimuth and local time provided. Third, it has plenty of observations around the Maunder minimum. We expect and believe that the newly created Korean auroral catalog could be used in a variety of researches in the future.

2. Data and Method

2.1. Auroral Records in Korean Chronicles

The Korean chronicles are daily official records of the activities of the kings, the state affairs, and the weather and astronomical phenomena. The existing historical records began in the 1000s and lasted for more than 800 years. Three Korean official historical books: *Koryo-Sa* (918–1391 CE, also named "*gao li shi* (高丽史)" in Chinese or *History of Koryo* in English), *Choson Wangjo Sillok* (1392–1910 CE, also named "*chao xian wang chao shi lu* (朝鲜王朝实录)" in Chinese or *The Veritable Records of the Choson Dynasty* in English) and *Seungjeongweon Ilgi* (1623–1910 CE, also named "*cheng zheng yuan ri ji* (承政院日记)" in Chinese or *The Daily Records of the Royal Secretariat of Joseon Dynasty* in English) were used in this study. These extensive chronicles were all written in Chinese characters.

The most frequently recorded nocturnal sky glows in the above three books are "vapors like fire light" (pronunciation in Chinese: *qi ru huo guang*) (Stephenson & Willis, 2008). In Chinese, fire light (*huo guang*) refers to red light. This implies that these records represent red glows. In previous works, the records "vapors like fire light" are processed as auroras that are usually visible in high-latitude regions of both hemispheres and occasionally visible in mid- and low-latitudes during intense geomagnetic storms. Dai and Chen (1980) first systematically sorted out the auroral records in historical books of China, Korea, and Japan and reported 929 records, among which 588 were recorded in Korea. Then, Zhang (1985) preliminarily interpreted these records as stable auroral red arcs. Conjugate observations definitely reveal that such "vapors like fire light" in the northern nocturnal sky are auroral borealis (Hayakawa et al., 2017b; Willis et al., 1996). Yau et al. (1995) reorganized the auroral records sorted in previous works and published the first comprehensive catalog of auroral records in East Asia in English, contained nearly 850 separate entries. Comparing auroral records in China and Japan with the geomagnetic activity in the 19th century, Willis et al. (2007) propose that the airglow phenomena in the middle and low latitudes is sporadic auroras, as those observed in the United States.

Now, it is widely accepted that the records of "vapors like fire light" and "red vapors" in Korean historical documents refer to visual auroral phenomena. However, apart from the records in the north, a large number of the records of "vapors like fire light", "red vapors" (pronunciation in Chinese: *chi qi*) and "odd red vapors" (pronunciation in Chinese: *chi jin*) appeared in the southern nocturnal sky and were not systematically sorted out in literature. In this work, we compiled a new chronology of such auroral records from the above-mentioned three historical books, including 2013 separate records during 1012–1811 CE.

2.2. Compilation of the Data set

In history, the Korean peninsula and the Chinese dynasties maintained close astronomical communications, and they both followed a unified standard of astronomical observations and judgment. The red aurorae were depicted by the Chinese character "*qi* (气)" (vapors) with different adjectives, including "*chi qi* (赤气)" (red vapors), "*qi ru huo* (气如火)"/"*qi ru huo guang* (气如火光)" (vapors like fire or vapors like fire light), "*ru huo qi* (如火气)" (fire-like vapors), and "*chi jin* (赤祲)" (odd red vapors). These keywords are used to search the auroral records in the three Korean official historical books. Thanks to the National Institute of Korean History, who has digitalized these books in both Chinese and Korean and made them publicly accessible, we can search for data using keywords from the books' websites. Each pages of the books are scanned and labeled with a unique identification number (IDN, e.g., IDN=SJW-A24020230-00200 for the case shown in Figure 1).

First, search the three books with the above five keywords to establish a preliminary data set of 2,211 auroral records (Wei & Wan, 2020), in which there may be false/dummy records or records with incomplete information (date or time). Therefore, it is necessary to set up a series of criteria to eliminate the bad records. The criteria are as follows:

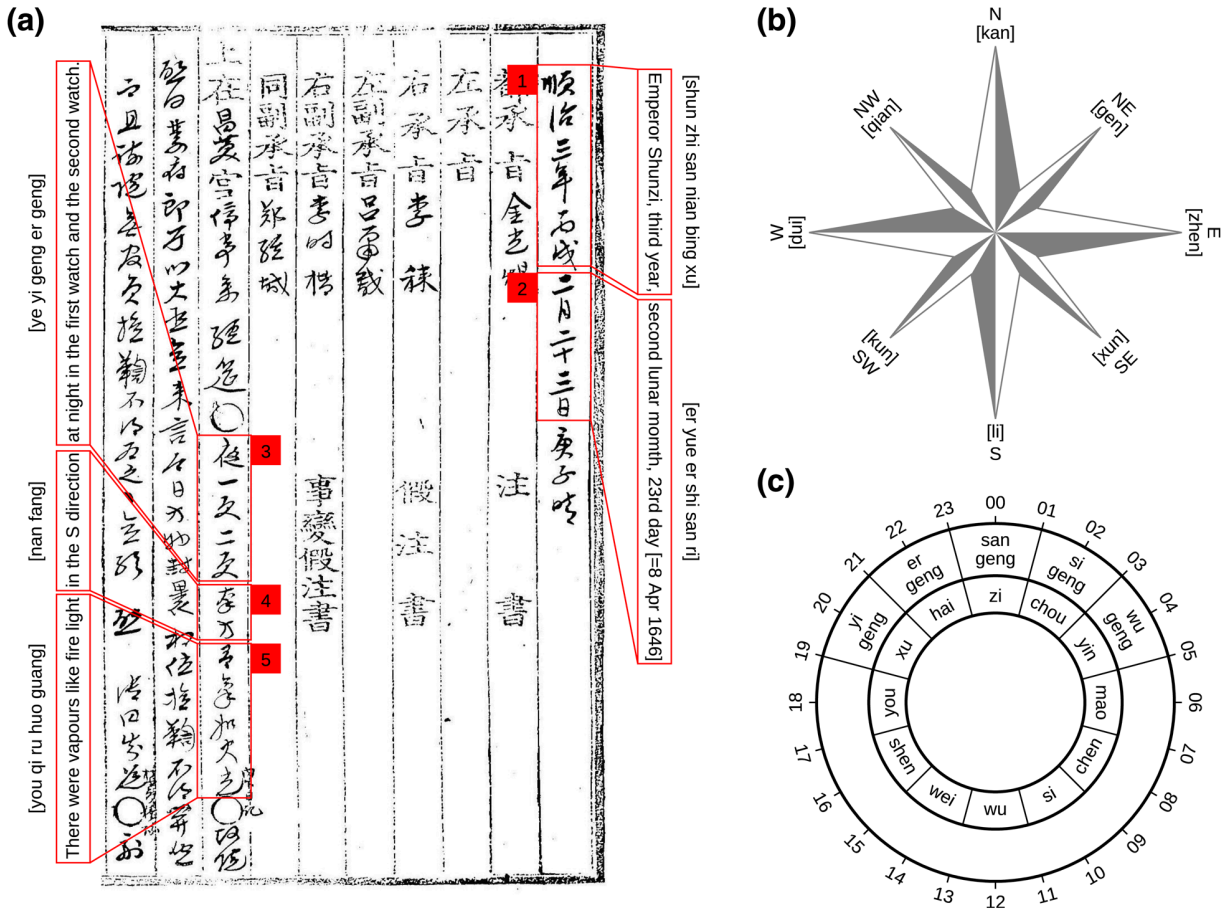

Figure 1. An example of Korean red equatorial auroral record. (a) Part of a page from the Sunjongwon Ilgi containing a red airglow observation. The scanned copy of this record can be accessed at the National Institute of Korean History (http://sjw.history.go.kr/id/SJW-A24020230-00200). (b) Definition of local directions. (c) Definition of local times.

- The record contains one of the keywords and should at least contain date information. Most of the records contain the full information of date, local time, and observed directions.
- The phenomena should be observed at night, that is, 19:00 LT to 05:00 LT, to eliminate the influence of twilight, solar halo, and other light sources such as clouds, planets, stars, comets, and meteors.
- If fire disaster is mentioned in that day, the record is excluded.
- Since there is overlap in time for the three books, records from different books on the same day are merged as one and the IDN's for each book are kept in the data set.

After application of these criteria, the final data set contains 2013 ancient Korean auroral records. Figure 1 shows an example from the *Seungjeongweon Ilgi*. This observation was made in the third year of Emperor Shunzi (the third emperor of the Qing Dynasty), in the second lunar month, and on the 23rd day as shown in the first and second red rectangles in Figure 1a. The lunar month and dates were converted to the Gregorian calendar with the Buddhist Studies Time Authority Databases (https://authority.dila.edu.tw/time/index.php), and the description "*shun zi san nian bing xu er yue er shi san ri*" is equivalent to April 8, 1646. A translation of the red auroral record is highlighted by the 3rd–5th red rectangles. Their Chinese pronunciation are shown in the square brackets, respectively.

For local directions shown in Figure 1b, there are primarily eight directions of *kan*, *gen*, *zhen*, *xun*, *li*, *kun*, *dui*, and *qian* in ancient China, also called "eight trigrams," corresponding to north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW), respectively. It is noted that the four directions NE, SE, SW, and NW are also spelled in Chinese as "*dong bei*," "*dong nan*," "*xi nan*," and

"*xi bei*," respectively, in ancient documents. Denotations such as "*dong bei nan*" in the record should refer to three different directions of E, N, and S, meaning that the aurora occurred simultaneously in the three directions.

For local time, 1 day was divided into 12 regular divisions in ancient China, and their correspondences to local times are shown in Figure 1c. Particularly, the nighttime after sunset and before sunrise was divided into five *geng*'s or five watches, that is, *yi geng* (first watch, 19–21 h), *er geng* (second watch, 21–23h), *san geng* (third watch, 23–1 h), *si geng* (fourth watch, 1–3 h), and *wu geng* (fifth watch, 3–5 h).

3. Results and Discussion

The ancient auroral data set presented in this paper was compiled from three Korean official historical books: *Koryo-Sa*, *Choson Wangjo Sillok*, and *Seungjeongweon Ilgi*. The data set is deposited as an Excel table (Ancient Korean Aurora.xlsx) and the corresponding scanned copies of the original books are deposited as PDF files named after the IDN of each auroral record (IDN.pdf).

The table contains eight columns. The first column showed the index of the record, the second to fourth columns stored the calendar year, month, and date, which were converted to the Gregorian date, the fifth and sixth columns stored the lunar month and lunar date, the seventh column stored the description of the auroral record translated from the original books, and the eighth column stored the IDN, through which the scanned copy of the original texts can be accessed. One can also find the scanned copy of the auroral records from the three Korean official historical books using the following links.

Koryo-Sa: http://db.history.go.kr/id/IDN (e.g., IDN = kr_053_0010_0030_0100_1000)

Choson Wangjo Sillok: http://sillok.history.go.kr/id/IDN (e.g., IDN = waa_10201025_001)

Seungjeongweon Ilgi: http://sjw.history.go.kr/id/IDN (e.g., SJW-C14020201-02000)

Totally, there are 192 records found from *Koryo-Sa*, 536 records from *Choson Wangjo Sillok*, and 1359 records from *Seungjeongweon Ilgi*. After merging duplicate records from either book pair, the final number of the auroral records is 2013. All the original Chinese texts are downloaded from the website of the National Institute of Korean History and deposited to the World Data Center for Geophysics, Beijing, together with the Excel table.

In 2004, Lee et al. (2004) published 788 auroral records (containing one duplicated record on 1537.6.13) from five historical documents of Korea in the 11th–18th century. Most of the records are collected from the three books used in this paper. However, many records are missing in Lee's list due to manual search of the documents and the original Chinese texts are not appended. Benefitted greatly from the digitalization of the three books by the National Institute of Korean History, systematic and complete search can be done to compile a more comprehensive data set.

In compilation of the data set, the auroral records are limited to the descriptions of "*chi qi*" (red vapors), "*qi ru huo*"/"*qi ru huo guang*" (vapors like fire or vapors like fire light), "*ru huo qi*" (fire-like vapors) and "*chi jin*" (odd red vapors), and four criteria are applied to exclude false/bad records. Figure 2 depicts the distributions of the 2013 ancient Korean auroral records. Figure 2a demonstrates that the majority of the auroral records occur between 1,500 and 1,800. There are scarce records before 1,500 and the distribution is in consistent with Lee's list (Lee et al., 2004). After 1,500, more records are found from *Seungjeongweon Ilgi*. Figure 2b shows the seasonal variation of the records. A peak of the occurrence of the aurora appears in the March, which is consistent with the result of Stephenson's work (Stephenson & Willis, 2008). Figure 2c presents the variation of the records with lunar date. It is found that there are fewer records around full moon and more records around new moon, possibly because the moonlight influences the visibility of aurora by naked eyes.

4. Summary

In this work, a new catalog of historical Korean auroral records during 1012–1811 was compiled. The data set contains 2013 red auroral records with date, local time and direction information. The compiled data set is provided as XLSX file which can be opened in Excel or other text editors. The original Chinese texts

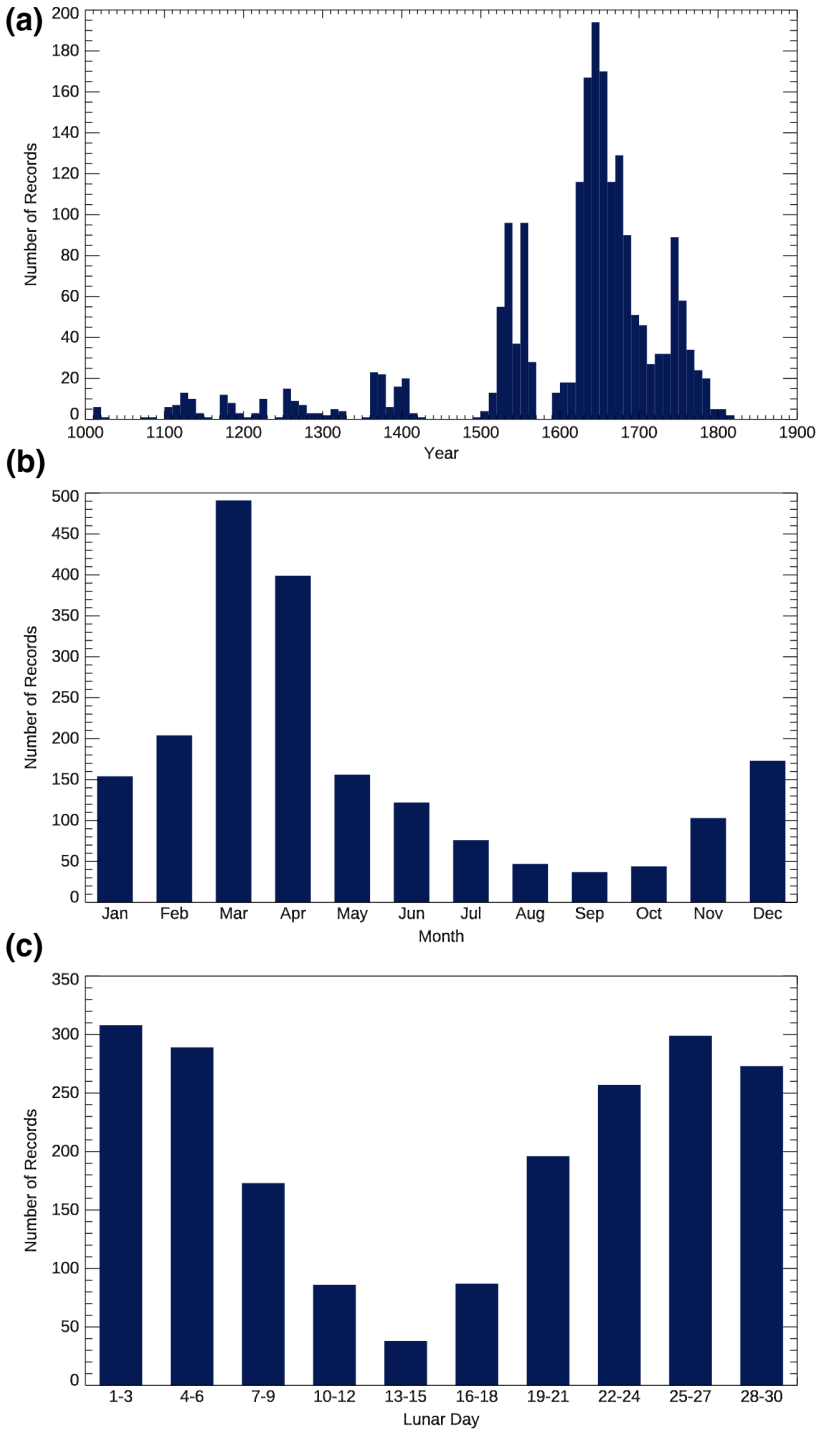

Figure 2. Statistics on the distributions of the ancient Korean auroral records. (a) Histogram of auroral records versus year binned in 10-year intervals. (b) Histogram of auroral records versus month. (c) Histogram of auroral records versus lunar date binned in 3-day intervals.

are provided as PDF files which can be opened in PDF Reader. All these files have been deposited to the World Data Centre for Geophysics, Beijing (http://www.geophys.ac.cn/ArticleDataInfo.asp?MetaId=207, https://doi.org/10.12197/2020GA008) and can be permanently accessed. The data set can be freely used for research and education purposes only. The data set provides valuable support for various studies related to solar-terrestrial space weather and ancient climates.

Data Availability Statement

The list of Ancient Korean Aurora (Ancient Korean Aurora.xlsx) and the corresponding scanned copies of the original books are deposited as PDF files at the World Data Centre for Geophysics, Beijing (http://www.geophys.ac.cn/ArticleDataInfo.asp?MetaId=207, https://doi.org/10.12197/2020GA008) and can be publicly accessed.

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