



Solar activity and climate change recorded in Korean chronicles during the last millennium

Hong-Jin Yang, Rok-Soon Kim, Kyung-Suk Cho
Korea Astronomy & Space Science Institute

June. 5-9, 2023 @Primorsko

Astronomical Heritage of Korea

Period	Dynasty	Astronomical Heritage
30C BC~ AD 2C	Stone, Bronze, Iron Ages	constellations in dolmens, menhirs, and burial accessories, observatory(?)
37 BC ~ AD 668 18 BC ~ AD 660 57 BC ~ AD 935	Goguryeo (高句麗) Baekje (百濟) Silla (新羅)	~ 240 astronomical records - 三國史記 constellations in 25 Goguryeo tombs observatory-Cheomseongdae(瞻星臺), sundials, etc.
AD 918 ~ 1392	Goryeo (高麗)	~ 5,000 astronomical records - 高麗史 constellations in 9 tombs observatory-Chamseongdang(瞻星堂)
AD 1392 ~1910	Joseon (朝鮮)	~ 20,000 astro. records - 朝鮮王朝實錄 observatories, astronomy books, astronomical instruments stone star chart (天象列次分野之圖)



Korean Chronicles & Astronomical Records

KOREA (57 B.C.~A.D.1910)

- **Samguksagi (57B.C.~A.D.935) : ~ 236 records**
(三國史記, the history of the Three Kingdoms)
- **Goryeosa (A.D.918~1392) : ~ 5,000 records**
(高麗史, the history of Goryeo dynasty)
- **Joseonwangjosillok (A.D.1392~1910) : ~ 20,000 records**
(朝鮮王朝實錄, the annals of the Joseon dynasty)

➤ astronomical records in each books covers ~ 15-30% of total articles

Historical records & implications

- real observation records : astronomy, ancient culture

- Solar & lunar eclipses → ΔT (variation of earth rotation), nutation, interpretation of history(position of obs.)
- Sunspot & Aurora → solar long-term variation, global climate change
- Star explosion → epoch of explosion, physical parameters(d , Mag. etc.)
ISM, stellar evolution model, characteristic of star
- Comet, Meteor (shower) → evolution of periodic comet, environment of solar system, interpretation of history

- Historical astronomical records are very useful in other fields as well as in astronomy

Historical sunspot & aurora records

- Korea and China have a long history of records of 黒子-赤氣 現象
- In the western, sunspot was discovered in 1611 by D. Fabricius before than only two sunspot records in Russia (14C)
- Using the historical records we can know the solar activity of the past
- In early observations, sunspot referred as black spot (黒子) and aurora is Jeokgi (赤氣) or red energy

Sunspot : 28BC (China, Han dynasty) / AD640 (Korea, Goguryeo)

Aurora : China 950BC(周)~AD1747 (294 records)

Korea 54BC~AD1910 (~800 records)

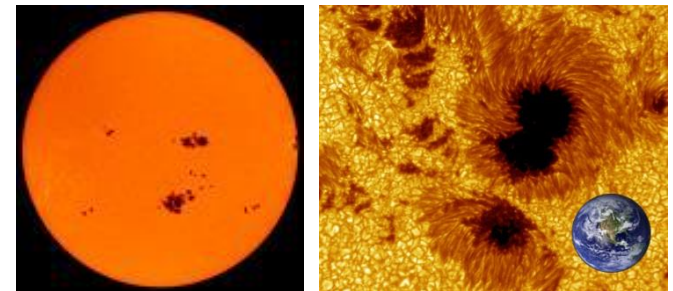
Japan AD620(Shotoku)~1747 (50 records)

Sunspot records

Goryeo dynasty (AD 918-1392) : Sunspot (42) & Aurora (232)

Joseon dynasty (AD1392-1910) : sunspot (17) & Aurora (601)

- 1151 03 31 日中有黑子大如雞卵 (eggs)
- 1171 10 20 日有黑子大如桃 (peach)
- 1185 03 27 日有黑子大如梨 (pear)



Sunspot size ? no < plum < egg < peach < pear

- Joseon Dynasty was in succession to the former Goryeo Dynasty.
- Although Goryeo was replaced by Joseon Dynasty, the astronomical government office and astronomers succeeded in the work of the previous dynasty and continued to observe astronomical phenomena.
- Therefore, Korean historical observations were recorded in chronicles in systematic and successive ways.

Auroral records (Wang et al., 2020)

Joseon dynasty (AD1392-1910) : sunspot (17) & Aurora (601)

(a)

[ye yi geng er geng] at night in the first watch and the second watch.

[nan fang] in the S direction

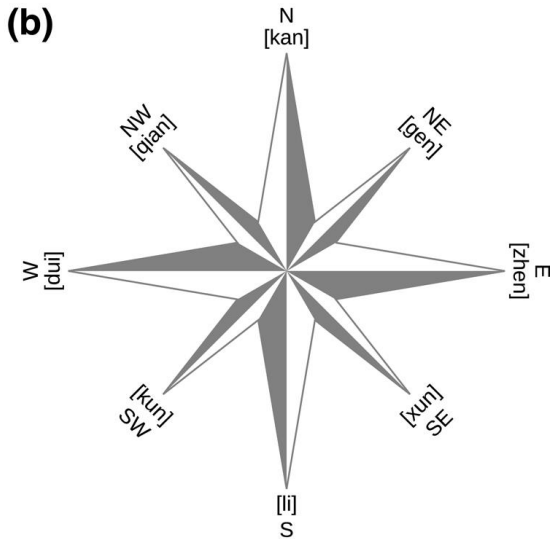
[you qi ru huo guang] There were vapours like fire light

1 2 3 4 5

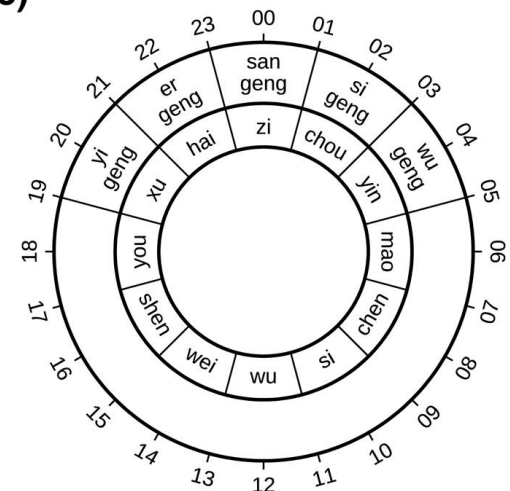
[shun zhi san nian bing xu] Emperor Shunzhi, third year, second lunar month, 23rd day [8 Apr. 1646]

[er yue er shi san ri]

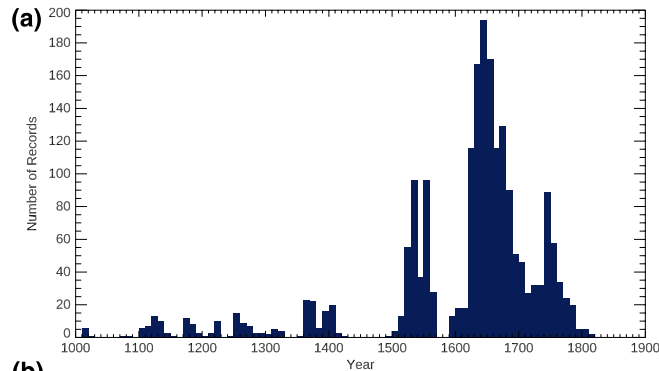
(b)



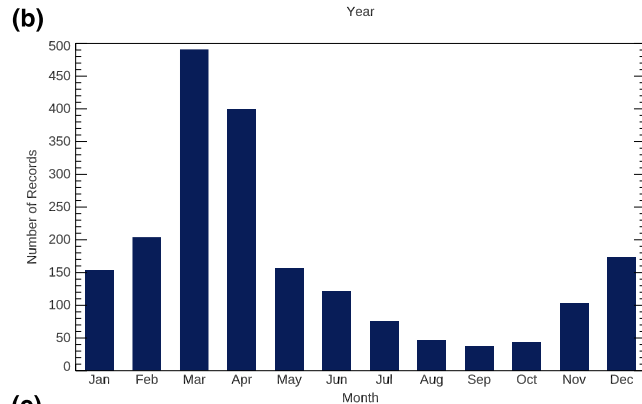
(c)



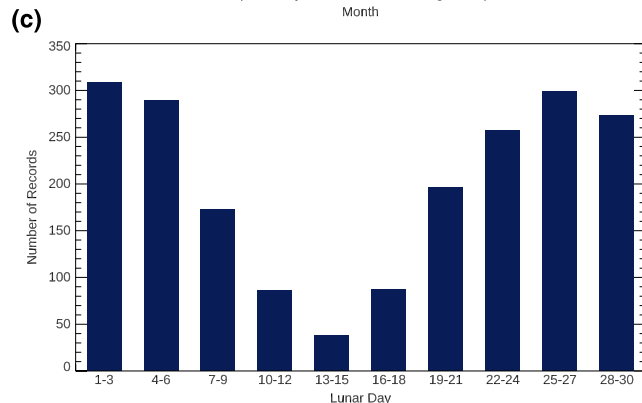
Aurora Statistics



the majority of the auroral records occur between 1,500 and 1,800. There are scarce records before 1,500



the seasonal variation of the records. A peak of the occurrence of the aurora appears in the March



fewer records around full moon and more records around new moon, possibly because the moonlight influences the visibility of aurora by naked eyes.

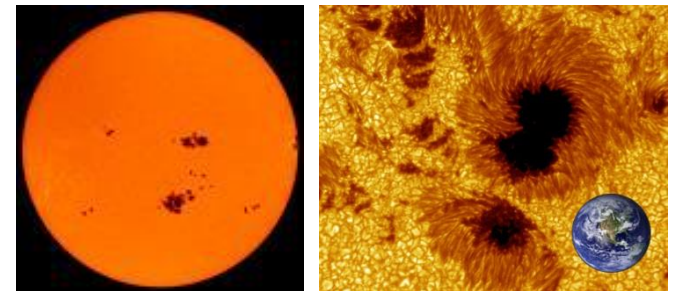
Sunspot and Auroral records

Goryeo dynasty (AD 918-1392) : Sunspot (42) & Aurora (232)

Joseon dynasty (AD1392-1910) : sunspot (17) & Aurora (601)

– Sunspot size (Magnitude)

- 1: Black gas-like structure
- 2: Spot
- 3: Plum
- 4: Egg
- 5: Peach
- 6: Pear



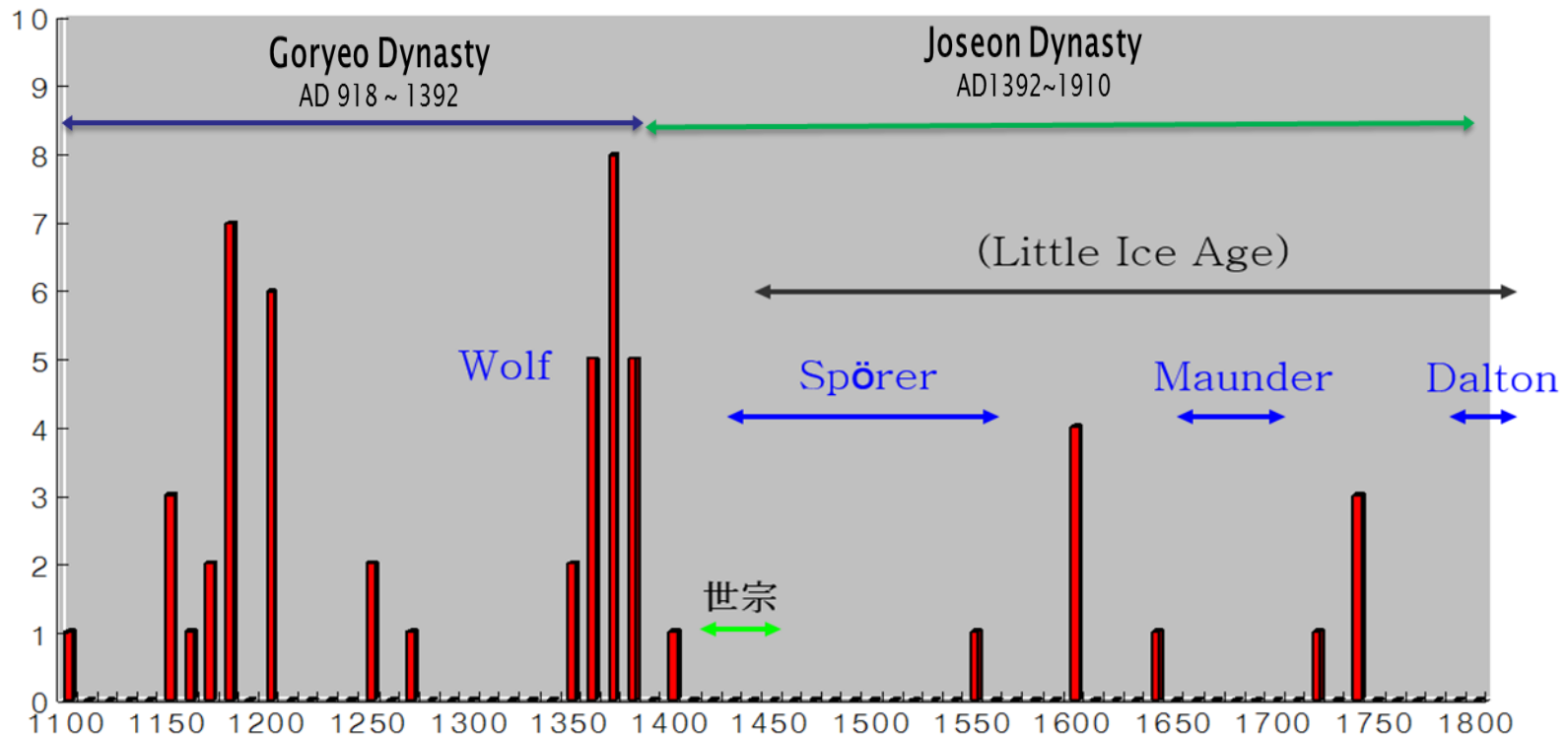
– Aurora extend in direction, length, and duration for red aurora (Magnitude)

- 1: Vapor
- 2: Seen at any direction
- 3: Seen at any both direction / till dawn
- 4: Describe the aurora in detail
- 5: Seen at the whole sky



Historical Sunspot records (918-1392)

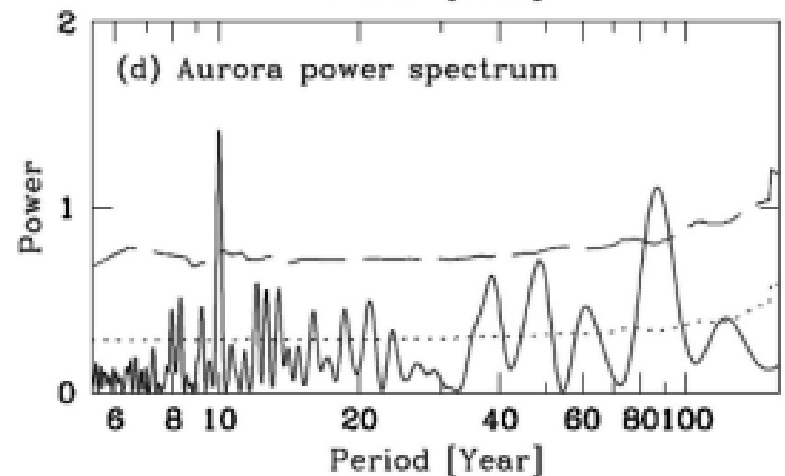
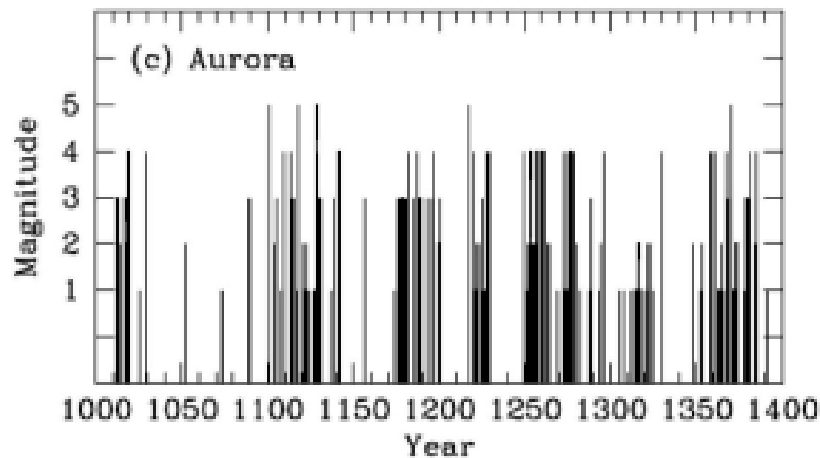
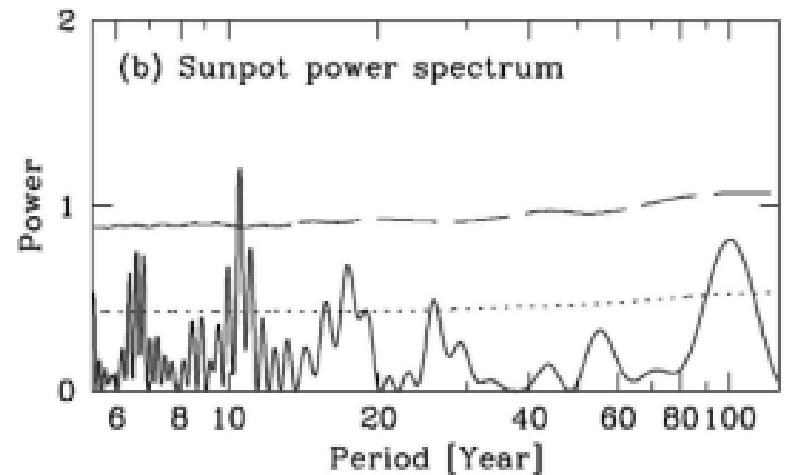
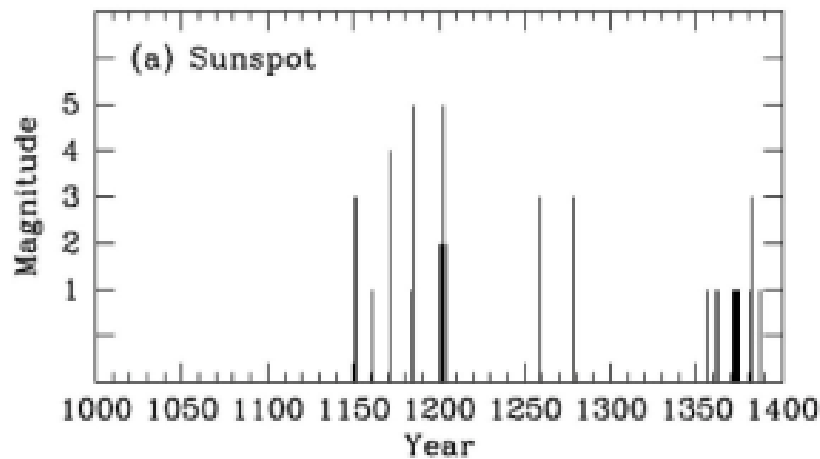
- number distribution of sunspots is well match with the solar activity during the last one millennium.
- indicate that solar activity decrease last one thousand years (918-1910)



Study 1: Short term solar cycle (918-1392)

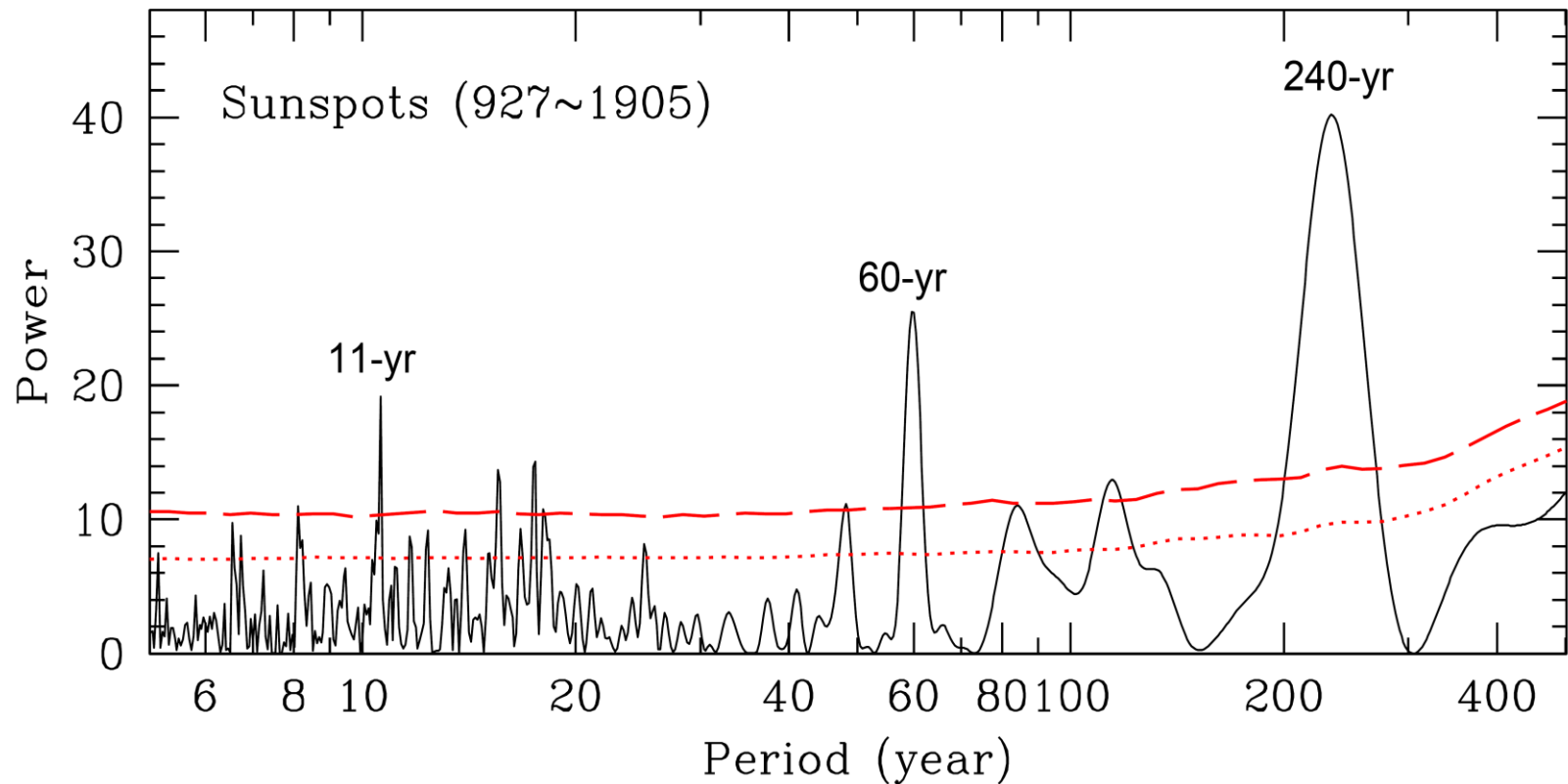
Fourier spectral analysis

- 11 yr solar cycle in the Sunspot and Aurora data



Study 2: Long term Solar cycle (927-1905)

- Korean sunspot records (1151-1743) are not enough in number to investigate the long-term variation of solar activity.
- Add Chinese historical sunspot records (918-1910) to the Korean records.



Power spectrum of Korean and Chinese sunspot records in the last millennium.

Observation of natural phenomenon

- In Korean chronicles, there are amount of meteorological phenomenon such as Drought, Earthquake, Frost, Flood, Rain, Hail, Snow, and so forth. (Fig. 4)
- In order to know the solar activity in detail, we examine the 'Frost' records, which can reflect climate change.
- Korean chronicles, Samguksagi, Goryeosa, & Sillok contain the 38, 48, & 667 Frost records, respectively. (Fig. 5)

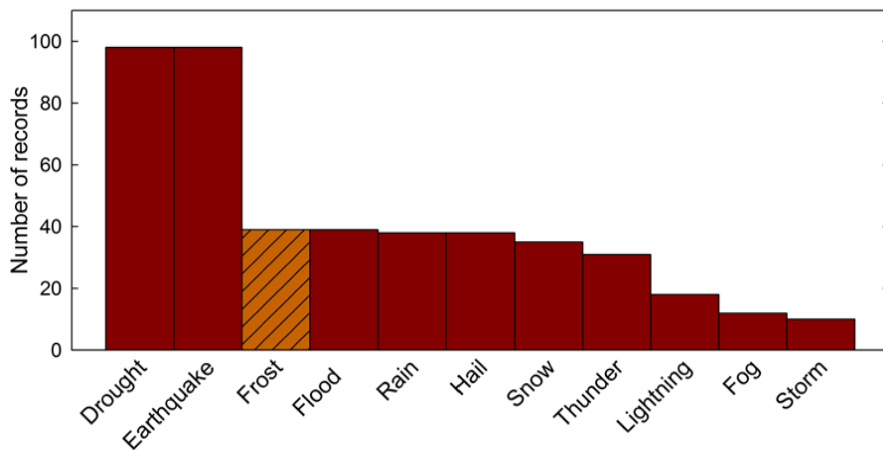


Fig. 4. number distribution of meteorological records in Samguksagi (57BC-AD935)

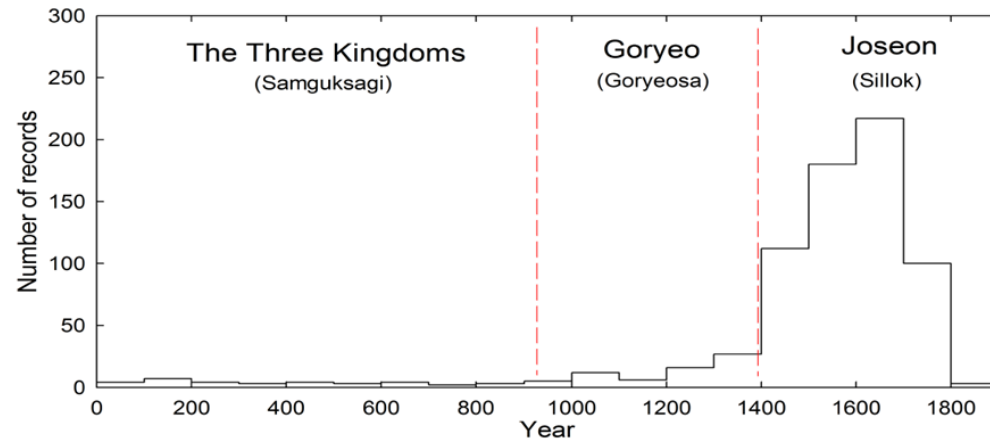
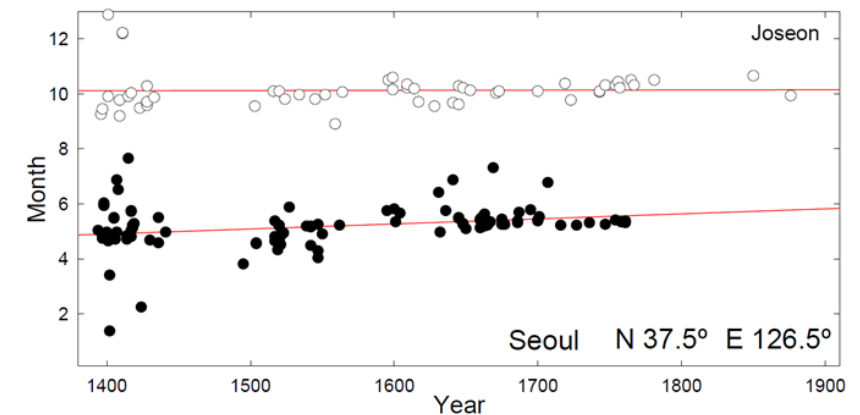
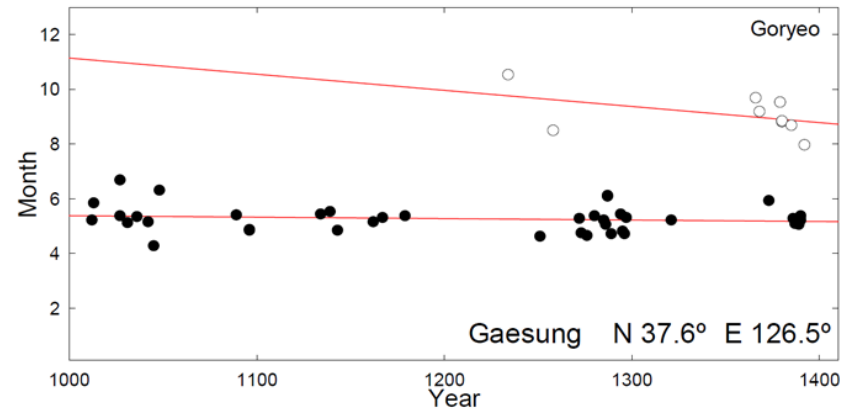
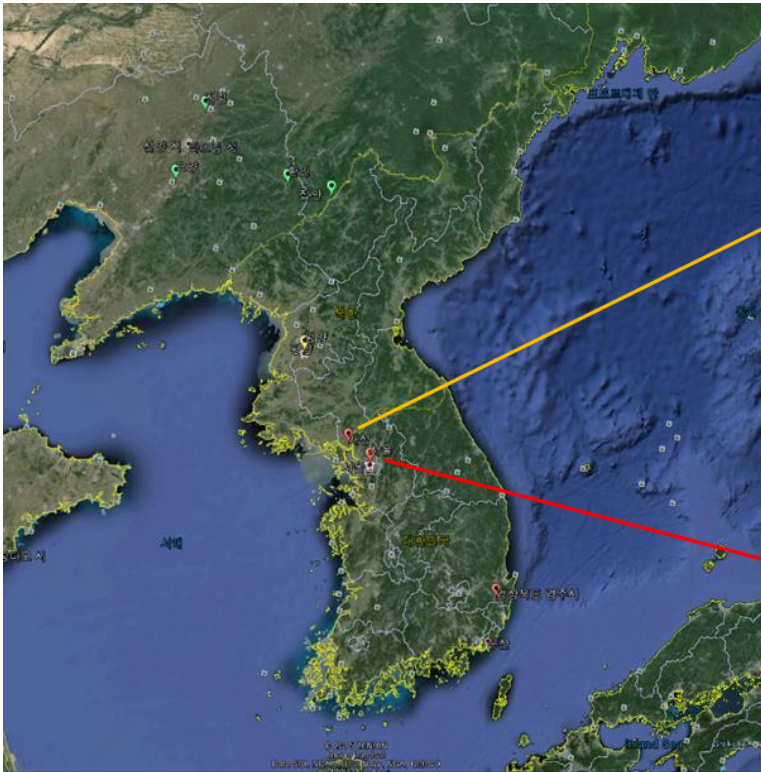


Fig. 5. number distribution of Frost records in Korean chronicles (57BC-AD1910)

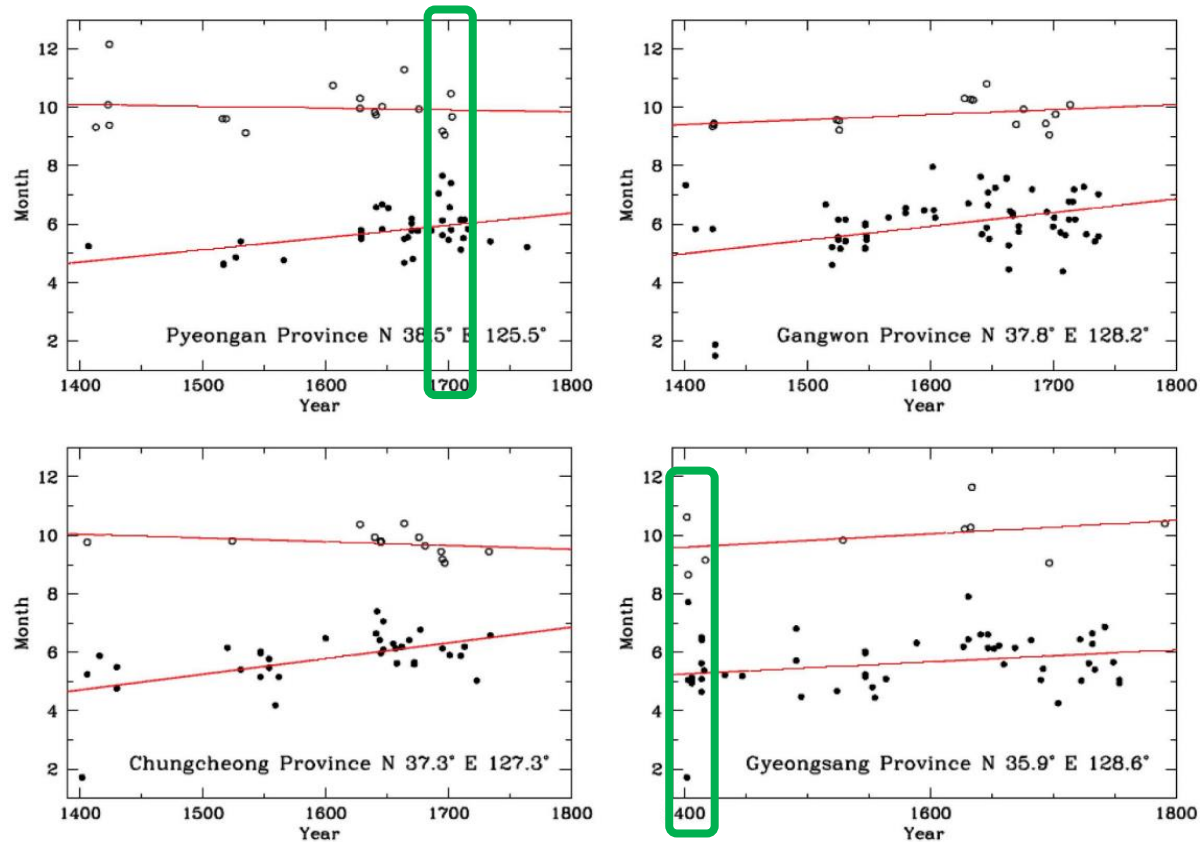
Study 3: Climate change from Korean Forest Record (927-1905)

Historical frost records observation dates of the last frost (Spring) and the first frost (autumn) reflect the temperature at the observation sites.



Study 3: Climate change from Korean Forest Record (927-1905)

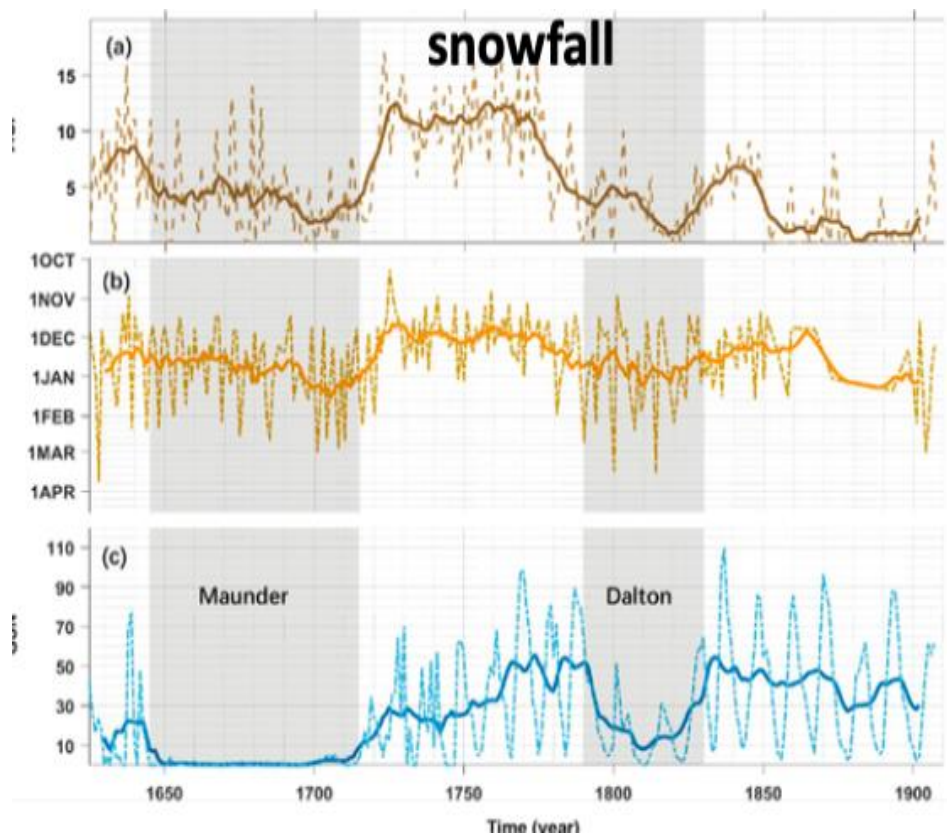
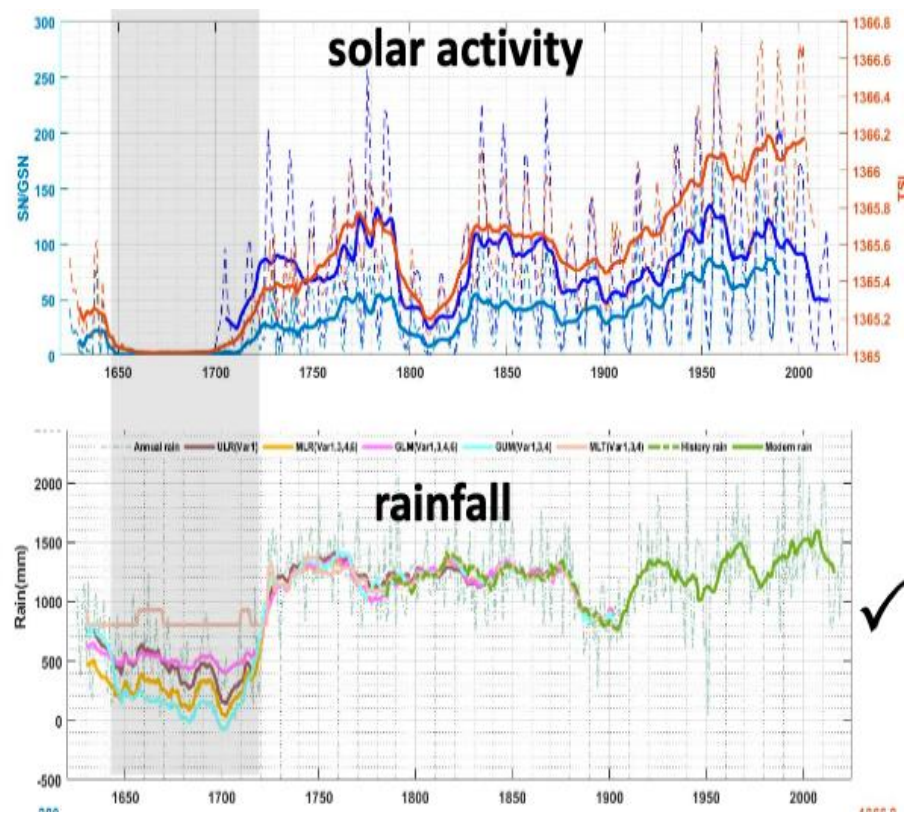
- it is not easy to confirm the climate variation using only the frost records for the Three Kingdoms period due to insufficient records, we need to examine more meteorological records which can be climate indicator



- Two notable cold epochs in the early 15C and the late 17C
- Length of frost-free period gradually became lower from Goryeo to Joseon Dynasties

Study 4: Rainfall and Snowfall records from 1625 to 1907 in Seoul

- Rainfall was extremely low during the Maunder Minimum
- Annual snowfall frequency decreased significantly
- First date of annual snowfall occurrence postponed



- Decrease in solar forcing weakens circulation → less moisture in Seoul
→ Extreme drought in Seoul during the Maunder Minimum (Wang et al., 2023)

Summary & Discussion

- Korean sunspot records Goryeo and Joseon dynasties, dating AD 918-1910 indicate that solar activity decrease last one thousand years.
- find the correlation between Frost records and temperature and also confirm that temperature gradually decrease last one thousand years.
- Sunspot records in Korean & Chinese chronicles show ~240-yr periodic variations and Korean meteorological records show similar pattern

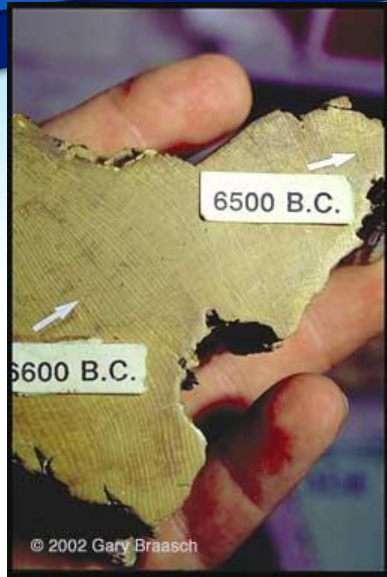
- solar activity have substantial effects on Earth's climate : solar signal
: ~240-yr solar periodic activity (new long-term solar cycle !)



Thank you !



Climate change : Historical change



Tree ring data : warming trend

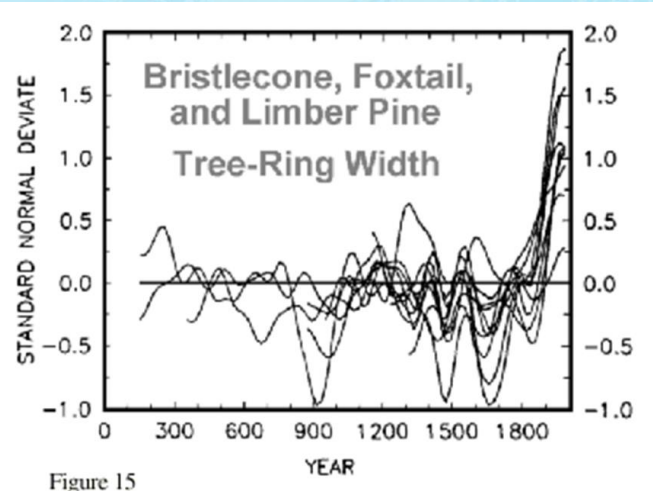


Figure 15

挪威雪线高度
高出海平面

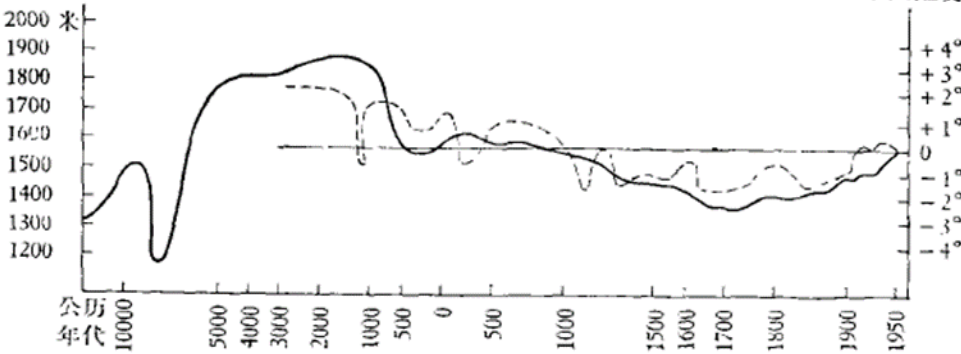


图2 一万年来挪威雪线高度(实线)与五千年来中国温度(虚线)变迁图

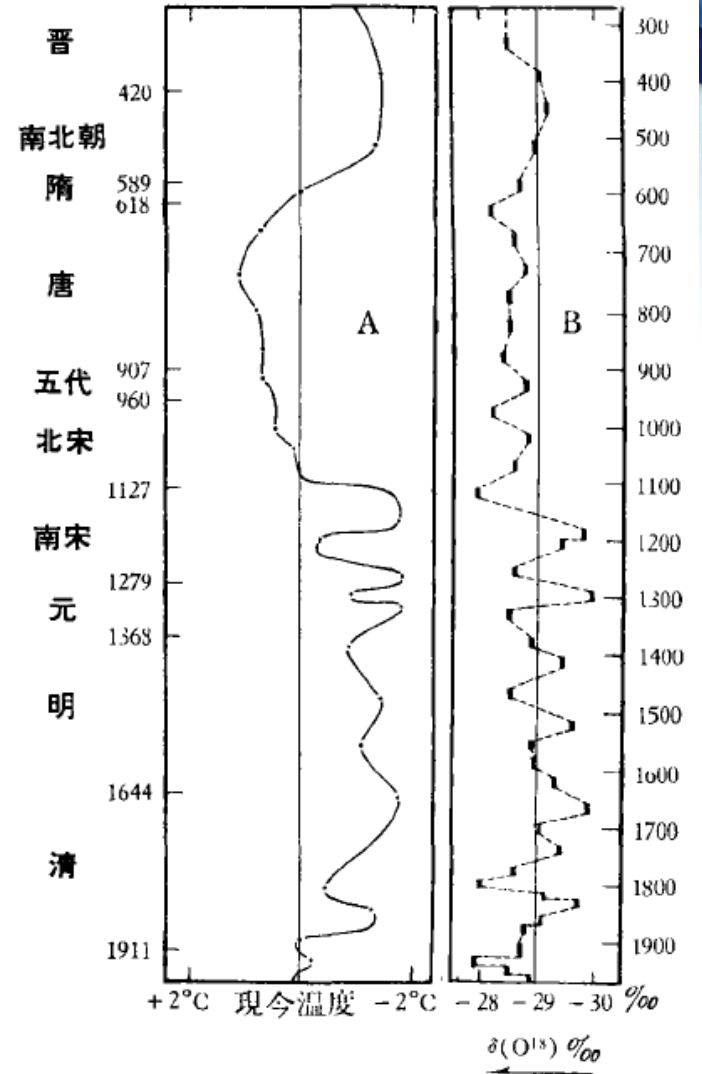


图3 一千七百年来世界温度波动趋势图

A. 从中国物候所得结果。
 B. 从格陵兰冰块所得结果。
 $\delta(O^{18})$ 增加 0.69‰ 则气温增加 1°C。

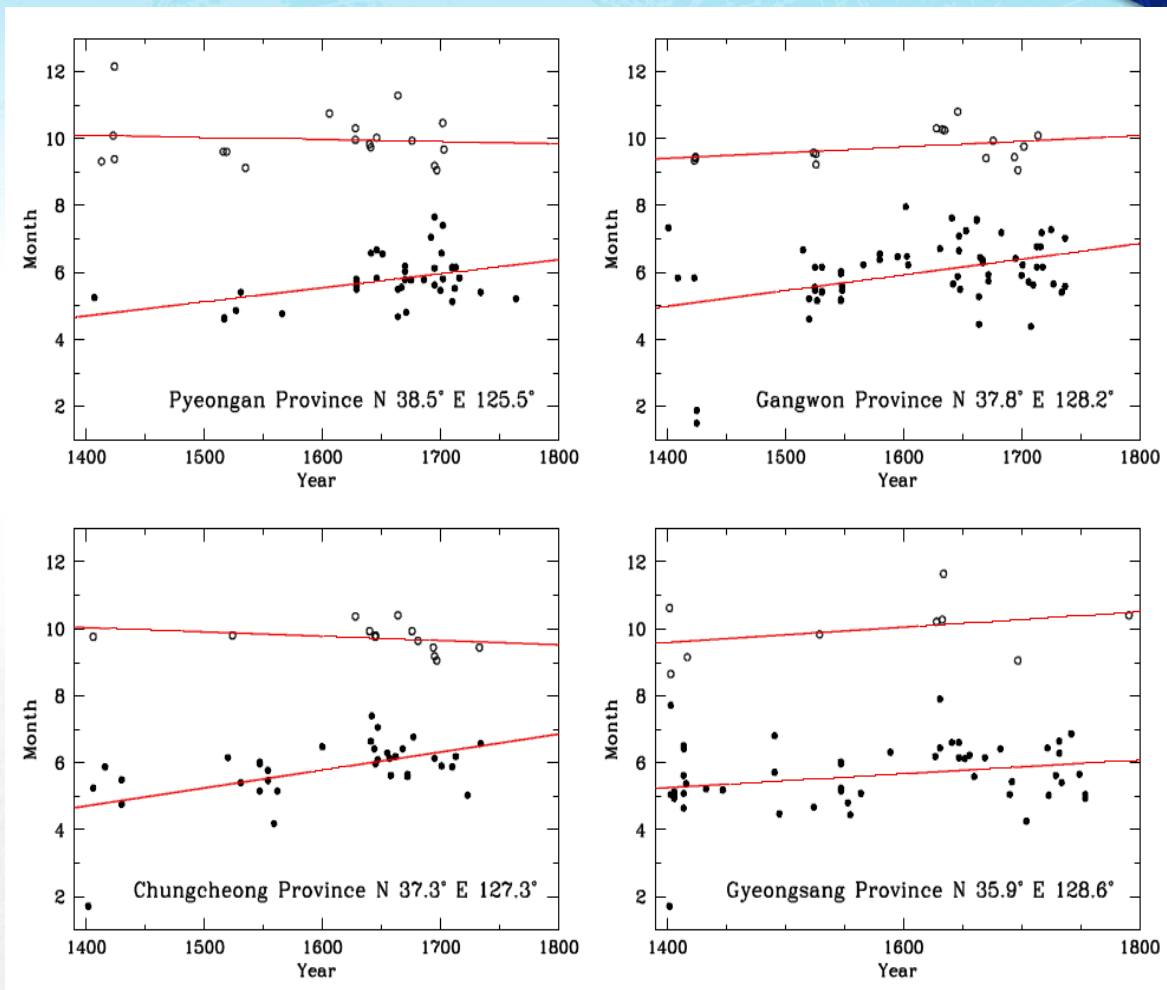
Frost records and temperature

The two cold epochs also appear in the plots of frost observations in four provinces of Korea. These frost records also roughly show that temperature decreased during the Joseon Dynasty.

In particular, the last frost records in spring, which are large in number, show this tendency more clearly.

Figure 5. Temporal distributions of frost records observed in four provinces of Joseon Dynasty. The four provinces are Pyeongan, Gangwon, Chungcheong, and Gyeongsang of Korea.

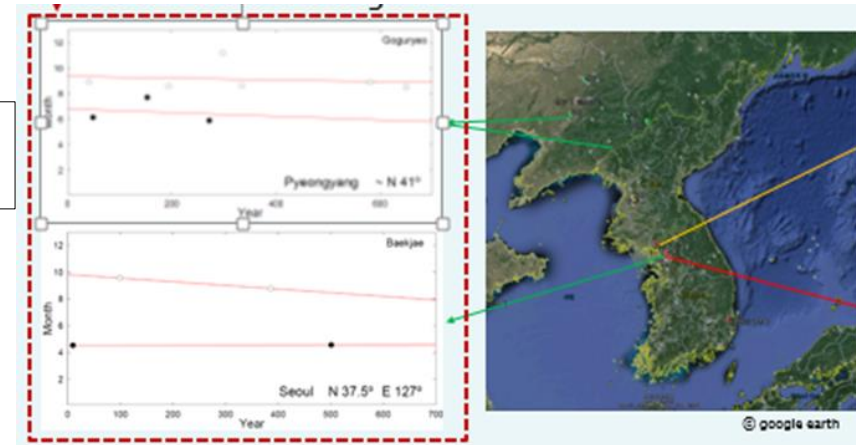
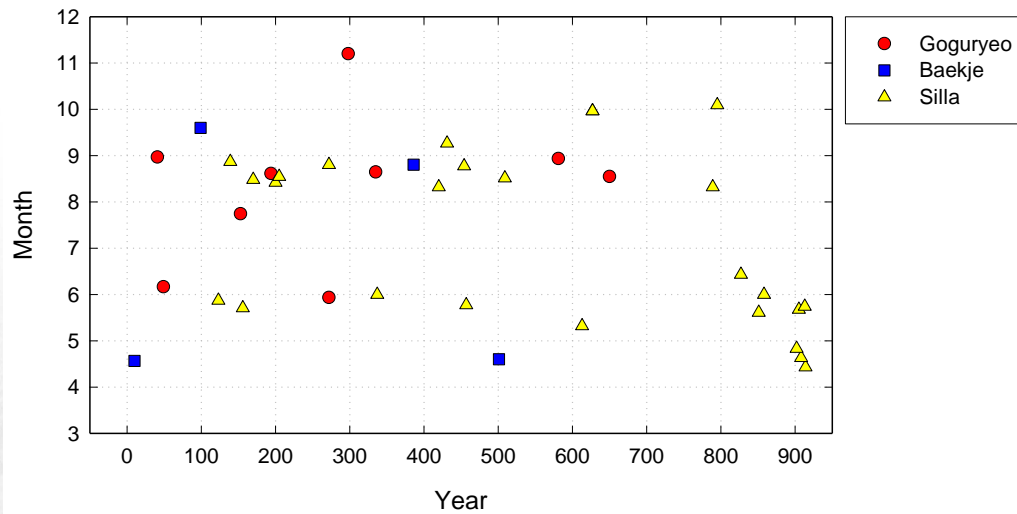
$N38.5^{\circ} E125.5^{\circ}$, $N37.8^{\circ} E128.2^{\circ}$, $N37.3^{\circ} E127.3^{\circ}$, $N35.9^{\circ} E128.6^{\circ}$.



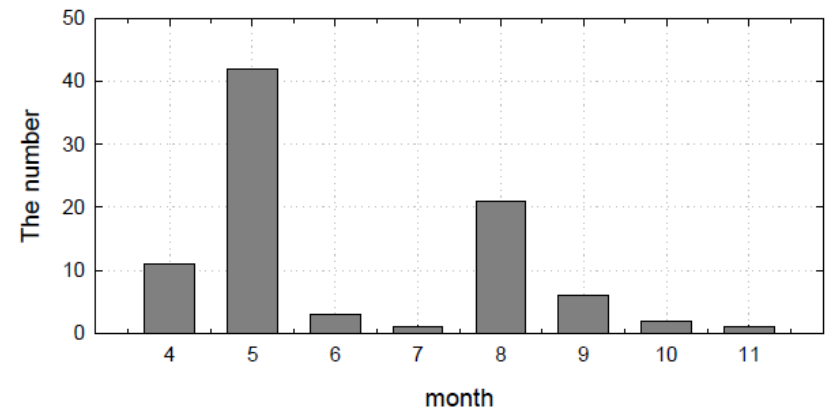
Frost records in the Three Kingdoms period

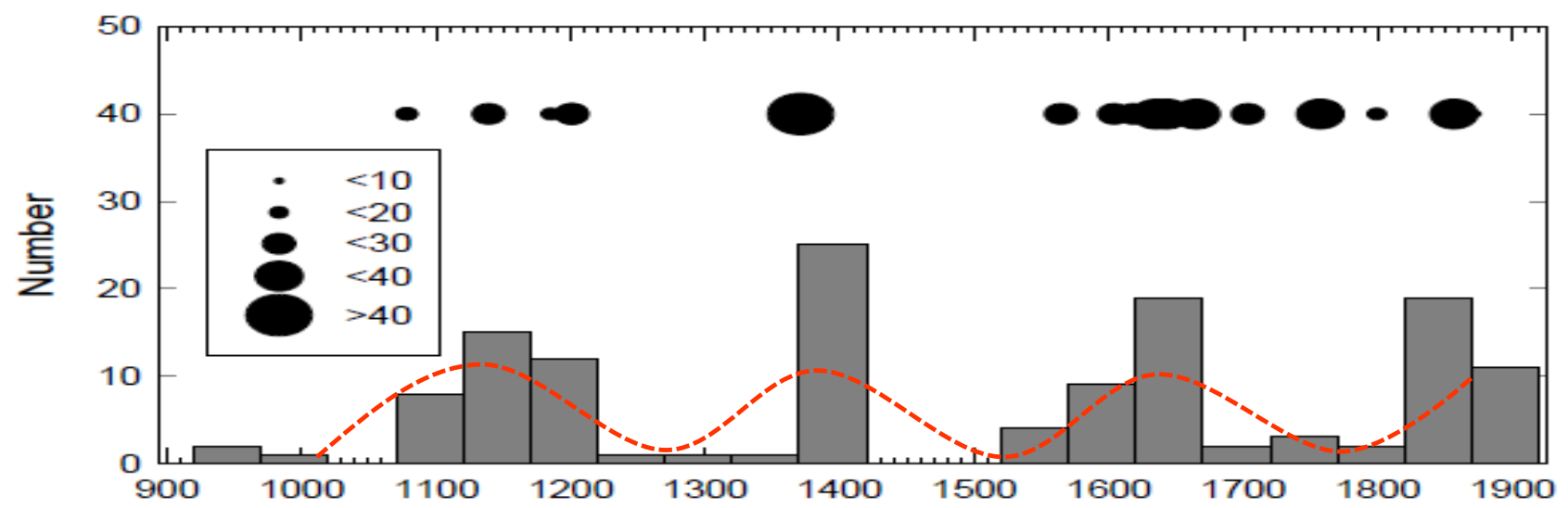
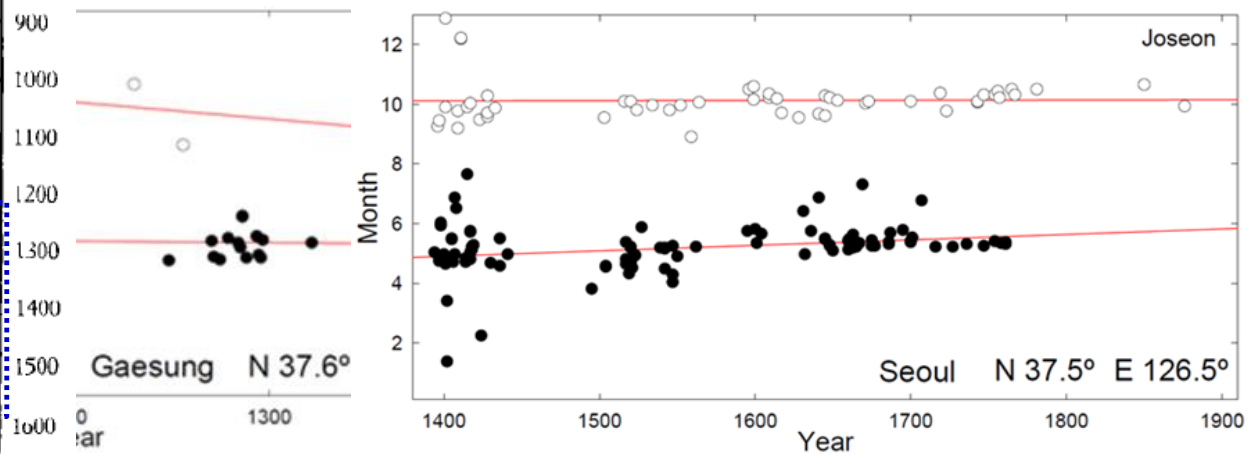
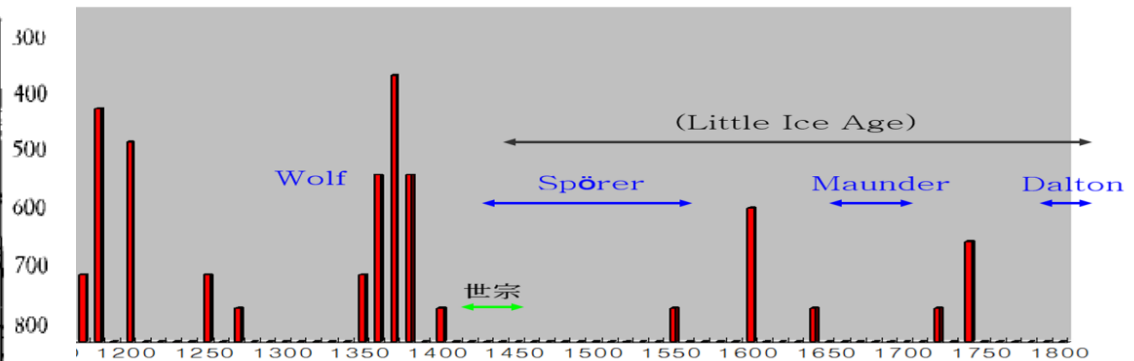
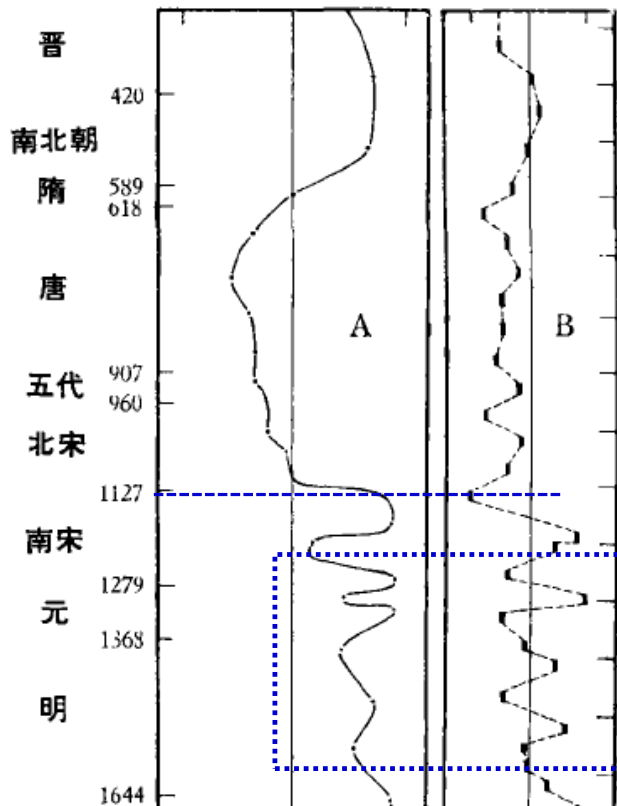
표 1. 삼국사기에 수록된 삼국(신라, 고구려, 백제)의 기상 관련 기사 개수.

	신라	고구려	백제	총합
본문 기사	358	98	112	568
열전 기사	8	1	0	9
총합	366	99	112	577



삼국사기에 기록된 고구려, 백제, 신라의 서리 관측 기록 분포





- Chin
warm
cold
cold
bet
ex

Korean sunspot records are not enough in number to investigate the long-term variation of solar activity.

- Adding Chinese historical sunspot records to the Korean records.

We collected the records of sunspots in Chinese chronicles between 918 and 1910, which correspond to the Korean Goryeo and Joseon Dynasties. These records are from the 'General compilation of Chinese Ancient Astronomical records' (Beijing Observatory, 1988), and there are 134 sunspot records in total during this period, actually spanning over 927-1905.

Meanwhile, the Chinese historical sunspots are advantageous in finding long-period signals because of a lot of records over a long period of time, but they do not contain the reliable short-period information, not showing the 11-year periodicity of solar activity. Therefore, in this study, we use the Chinese sunspot records for the purpose of finding the long periodicity of the solar activity.

927 03 09	4	1185 02 15	1	1372 08 25	1	1624 03 17	3	1851 -- --	1
947 11 26	4	1185 02 27	1	1373 11 15	1	1624 04 15	1	1852 01 19	1
974 03 03	1	1186 05 23	2	1374 03 14	1	1624 -- --	1	1852 03 22	3
1077 03 07	4	1186 05 26	1	1374 03 27	1	1631 02 25	1	1852 04 02	1
1078 03 11	4	1193 12 03	1	1374 03 31	1	1635 02 17	1	1853 05 11	1
1079 01 11	4	1200 09 21	2	1375 03 23	1	1637 -- --	1	1853 05 17	1
1079 03 20	4	1200 12 --	2	1375 10 21	1	1638 09 08	1	1853 06 07	1
1104 -- --	2	1201 01 09	1	1376 01 19	1	1638 12 09	1	1855 01 20	1
1105 12 06	1	1202 12 19	2	1381 03 22	1	1638 -- --	1	1855 -- --	1
1112 05 02	2	1204 02 21	2	1381 03 25	1	1640 04 13	1	1856 02 08	1
1118 12 17	4	1205 05 04	2	1382 03 21	1	1643 02 19	1	1856 08 30	1
1120 06 07	2	1238 12 05	1	1383 01 10	1	1655 04 30	1	1860 12 04	2
1122 01 10	4	1276 02 17	5	1562 -- --	1	1656 -- --	1	1861 03 30	2
1129 03 22	1	1368 01 20	1	1564 08 07	1	1659 06 12	1	1861 11 24	1
1131 03 12	4	1370 01 01	1	1566 01 30	5	1661 07 05	1	1863 03 19	1
1136 11 23	4	1369 12 30	1	1567 -- --	1	1665 02 15	1	1865 07 18	1
1137 03 01	4	1370 04 25	1	1597 06 15	1	1665 02 20	2	1873 02 23	1
1137 05 08	1	1370 10 02	1	1604 03 01	1	1703 08 13	1	1874 12 09	1
1138 03 16	1	1370 10 21	1	1613 03 30	1	1709 -- --	1	1874 -- --	1
1138 03 17	2	1370 12 07	1	1616 10 10	1	1732 05 11	2	1883 12 26	1
1138 11 26	1	1371 01 14	1	1617 01 11	1	1742 07 05	1	1885 07 05	1
1139 03 03	1	1371 03 31	1	1617 -- --	1	1757 06 16	1	1900 02 15	1
1139 11 20	1	1371 06 13	1	1618 05 22	5	1795 -- --	1	1904 02 16	1
1145 -- --	1	1371 11 06	1	1618 04 25	1	1799 04 05	1	1905 02 04	5
1145 -- --	1	1372 02 06	1	1618 06 20	1	1829 04 24	1	1905 10 31	1
1160 09 26	5	1372 04 03	1	1621 05 23	1	1848 05 03	1	1905 -- --	1
1185 02 10	2	1372 06 19	1	1622 05 03	5	1851 12 25	1		