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# Sunspot drawings by Japanese official astronomers in 1749–1750

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## Abstract

Sunspot observations with telescopes in the 18th century were carried out in Japan as well as elsewhere. One of these sunspot observations is recorded in an account called Sansaizusetsu narabini Kansei irai Jissoku Zusetsu (Charts of Three Worlds and Diagrams of Actual Observations since Kansei Era). We have analyzed manuscripts of this account to show a total of 15 sunspot drawings during 1749–1750. These observations are considered to be carried out by contemporary official astronomers in Japan, with telescopes covered by *zongurasus* (< zonglas in Dutch, corresponding to "sunglass" in English). We counted their group number of sunspots to locate them in long-term solar activity and show that their observations were situated near the solar maximum in 1750. We also computed their locations and areas, while we have to admit differences of the variant manuscripts with one another. These observational records show the spread of sunspot observations not only in Europe, but also in Japan, and hence may contribute to crosscheck, or possibly to improve the known sunspot indices.

**Key words:** solar-terrestrial relations — Sun: magnetic fields — sunspots

## 1 Introduction

Solar activity is reviewed and measured by the appearance of sunspots on the solar disc (Vaquero & Vázquez 2009). It was in the early 17th century that telescopic observations for sunspots started to offer scientific datasets from one of the longest-running experiments in human history (Owens 2013). These sunspot observations were used to reconstruct past solar activity. R. Wolf and his successors in Zürich constructed the Zürich number (Wolf number) to cover solar activity since 1700 (Waldmeier 1961). Hoyt and Schatten (1998) included more observations to construct group sunspot number and group number since the 1610s.

Recent studies have revisited the sunspot number and group number (Clette et al. 2014; Svalgaard & Schatten 2016; Vaquero et al. 2016; Willamo et al. 2017), based on recent discussions concering original sunspot drawings and sunspot counting within scientific documents after telescopic observations since the 1610s (e.g., Vaquero 2007; Vaquero & Vázquez 2009; Arlt 2008, 2009, 2011; Arlt & Fröhlich 2012; Cliver & Keer 2012; Diercke et al. 2015; Usoskin et al. 2015; Willis et al. 2013, 2016a, 2016b; Arlt et al. 2016; Carrasco & Vaquero 2016; Senthamizh Pavai et al. 2016; Svalgaard 2017); Carrasco et al. 2018; Hayakawa et al. 2018a, 2018b. Within these datasets, sunspot drawings are of greater value because they contain information not only on sunspot number, but also on their area, distribution, locations, configuration, and so forth (Vaquero 2007; Vaquero & Vázquez 2009).

While most of early sunspot drawings down to the end of the 19$^{th}$ century were from Europe (Vaquero & Vázquez 2009; Vaquero et al. 2016), recent researches of early sunspot drawings from non-European countries have contributed to improve the reconstruction of past sunspot indexes (e.g., Domínguez-Castro et al. 2017; Denig & McVaugh 2017). Thus, Japanese archives may also contribute to this reconstruction by their contemporary sunspot drawings. Hoyt and Schatten (1998) seemed partially aware of sunspot drawings by Kunitomo Ikkansai (國友一貫齋)[1] during 1835–1836 (Yamamoto 1937; Kubota & Suzuki 2003). However, even before his sunspot observations, it is partially mentioned that we had some sunspot observations in Japan in the 18$^{th}$ century (Kanda 1960; Watanabe 1987). One of them involves sunspot drawings in manuscripts of Sansaizusetsu narabini Kansei irai Jissoku Zusetsu, which can be translated as Charts of Three Worlds and Diagrams of Actual Observations since Kansei Era (三際圖説 並寛政以來實測圖説, hereafter, SKJZ). In this article, we examine SKJZ to show their sunspot drawings and relevant records along with their digitalization. We have also counted their group number of sunspots and compared them with contemporary solar activity.

[1] In this article, we show Japanese personal names in orders of family name and first name as seen in the contemporary historical documents.

## 2 Method

SKJZ has two manuscripts with sunspot drawings (KS[2]: v.3, p. 782). Both of them are preserved at Tohoku University in Sendai, Japan, as shown below. We show their references with abbreviation, reference numbers, and hosting library.

MS/K: MS 8-21318-1 in Kano Library of Tohoku University Library.

MS/O: MS 911-17799 in Okamoto Library of Tohoku University Library.

We first introduce the characteristics of these manuscripts and show their sunspot drawings. We then analyze their text to estimate the observer and observational method. Then, we count their group number of sunspots to locate them in the records to long-term solar activity. We also scaled the area of sunspots for their projected area and corrected area, before and after removing any foreshortened effects. In this counting, we grouped sunspots according to the Zürich classification (e.g., Waldmeier 1947; Kiepenheuer 1953).

## 3 Result and discussion

### 3.1 Manuscripts

As described above, we have two manuscripts of SKJZ with sunspot drawings. Colophons of both manuscripts relate their author or compiler with Watanabe Masanami (渡部將南), although his name is not found in other contemporary documents. MS/K consists of 31 folios, while MS/O consists of 27 folios. Their difference is found in additional folios of MS/K (ff. 27b–31a)[3] for drawings of comet observations on 1811 September 15, 1819 July 17, 1824 January 02, and 1825 October 03. On the contrary, we can find two graffiti in red letters in MS/O (ff. 2a–2b).

These manuscripts start with Sansaizusetsu to explain three phases from the ground to the upper sky, generating thunder in Japanese traditional understanding (ff. 1a–4b) and cover both astronomical and meteological observations, such as comets, sunspots, and solar halos from 1758 to 1825. We estimate MS/K and MS/O compiled at least after 1825 and 1803 according to their last date of observations: comet drawing dated 1825 for MS/K and drawing of halo dated 1803 for MS/O. These manuscripts include a considerable number of earlier observations copied from preceding sources, including Watanabe Masanami's works.

[2] *Kokusho Soumokuroku* (Tsuji et al. 2002): A union catalogue for early Japanese books. Note that we have two other variants entitled as Sansaizusetsu (Charts of Three Worlds) without Kansei irai Jissoku Zusetsu (Diagrams of Actual Observations since Kansei Era). As sunspot drawings are included in the section of Kansei irai Jissoku Zusetsu, these variants do not involve sunspot records.

[3] We show the references with their folio number that is shown as "f." for a single folio or "ff." for plural folios. One folio corresponds two pages, which are shown "a" and "b," here.

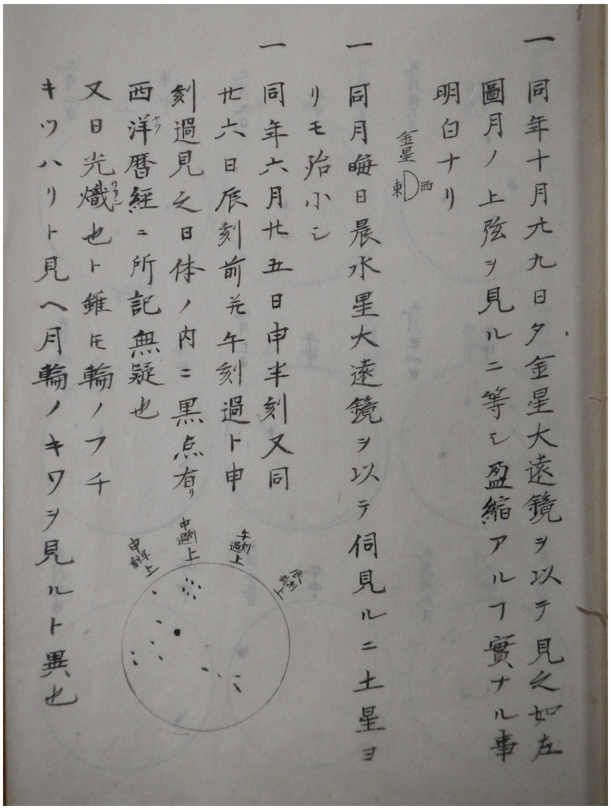
一 同年十月九日夕金星大遠鏡ヲ以テ見之如左
圖月ノ上弦ヲ見ルニ等シ盈縮アルコ實ナル事
明白ナリ
金星 東 西
一 同月晦日晨水星大遠鏡ヲ以テ伺見ルニ土星ヨ
リモ殆小シ
一 同年六月廿五日申半刻又同
廿六日辰刻前午刻過申
刻過見之日体ノ内ニ黒点有リ
西洋暦経ニ所記無疑也
又日光熾也ト雖モ輪ノフチ
キツハリト見ヘ月輪ノキワヲ見ルト異也

**Fig. 1.** Folio with a sunspot drawing from f.9a of MS/K in SKJZ.

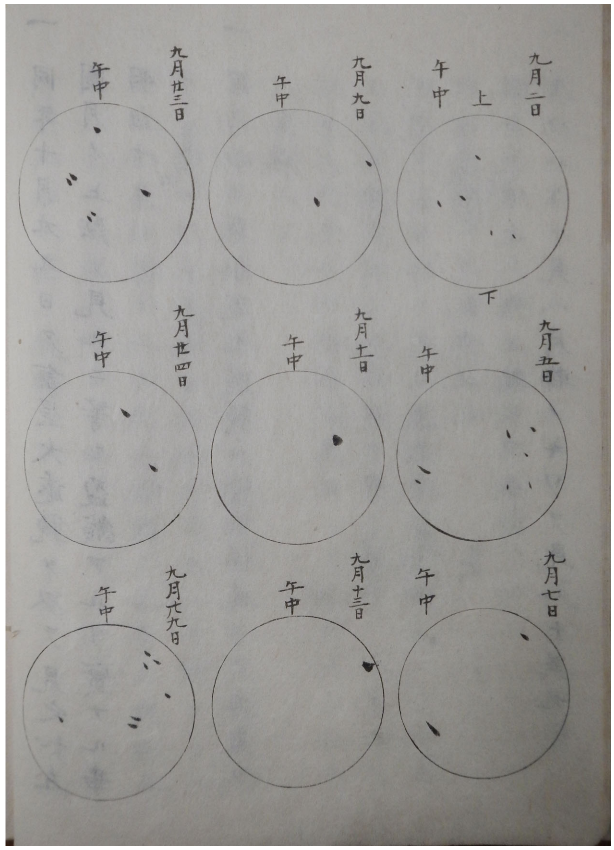


**Fig. 2.** Same as figure 1 but for f.9b of MS/K.

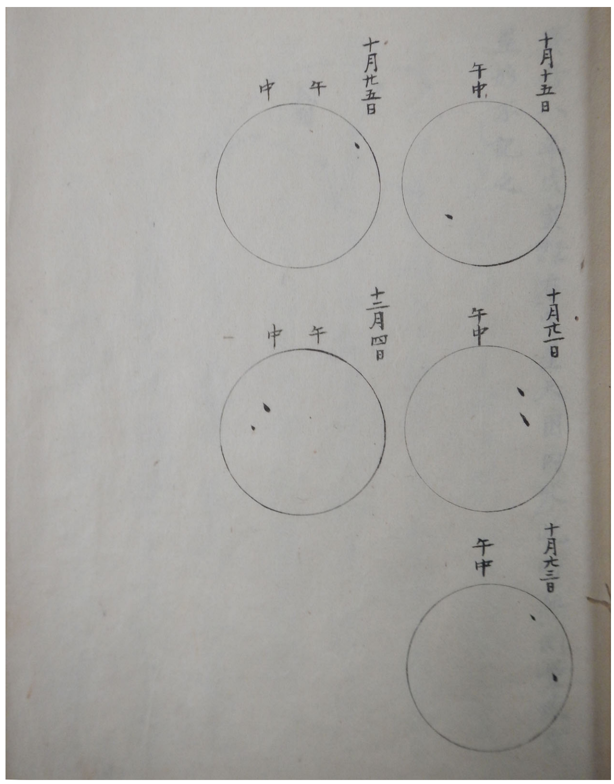


**Fig. 3.** Same as figure 1 but for f.10a of MS/K.

We estimate that the editor of this work should have been someone close to Shogunate Observatory, because they involve several Shogunate observations made in 1749–1750 or 1769–1770 (ff. 8b–10a). One of the possible contributors is Toita Zentaro (戸板善太郎, 1708–1784), found in a correspondence to Yamaji Family in Shogunate Observatory (ff. 12a–12b). Hence, we estimate their editor to be some of successors of Toita Zentaro in the Observatory of the Sendai Fief (仙台藩). The fact that these manuscripts have been preserved in Tohoku University after the Sendai Fief also supports our estimation.

## 3.2 Sunspot drawings

The sunspot drawings are found in ff. 8b–10a both in MS/K and in MS/O as shown in figures 1–6. Each manuscript involves one sunspot drawing (S1) with explanation of sunspot observation (f. 9a) and 14 sunspot drawings (S2–S15) with observational dates in traditional luni-solar calendar. We count their group number and summarize them with their date and local time (LT) converted to that in Gregorian calendar based on the conversion table (Uchida 1992) and reference in table 1. The explanation for S1 is transcribed and translated as follows.

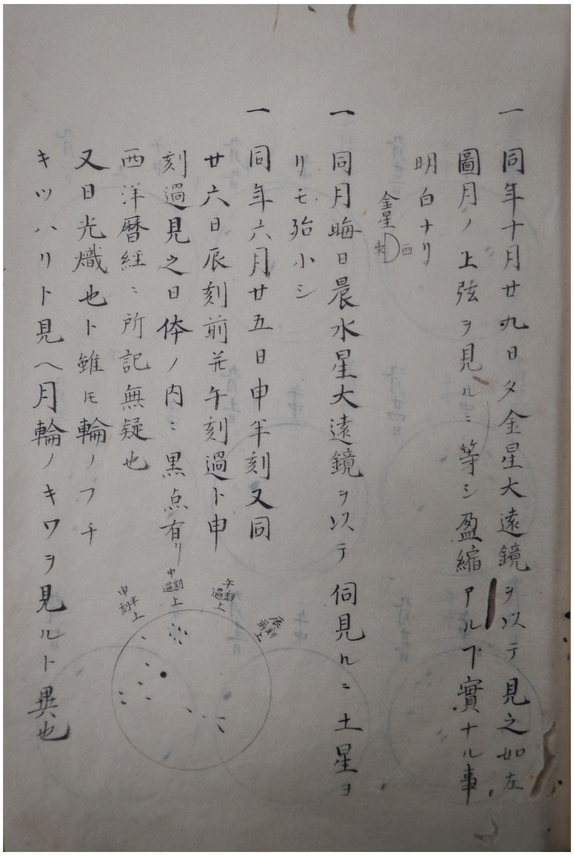


**Fig. 4.** Folio with a sunspot drawing from f.9a of MS/O in SKJZ.

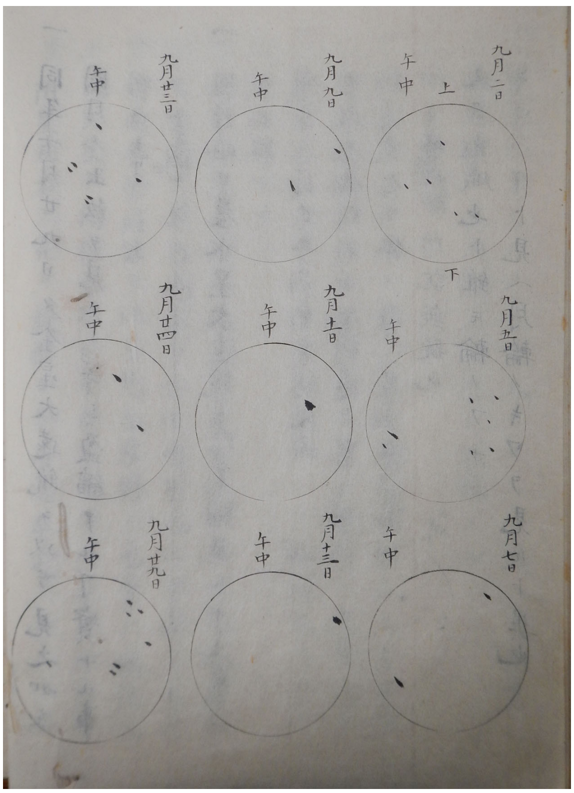

**Fig. 5.** Same as figure 4 but for f.9b of MS/O.

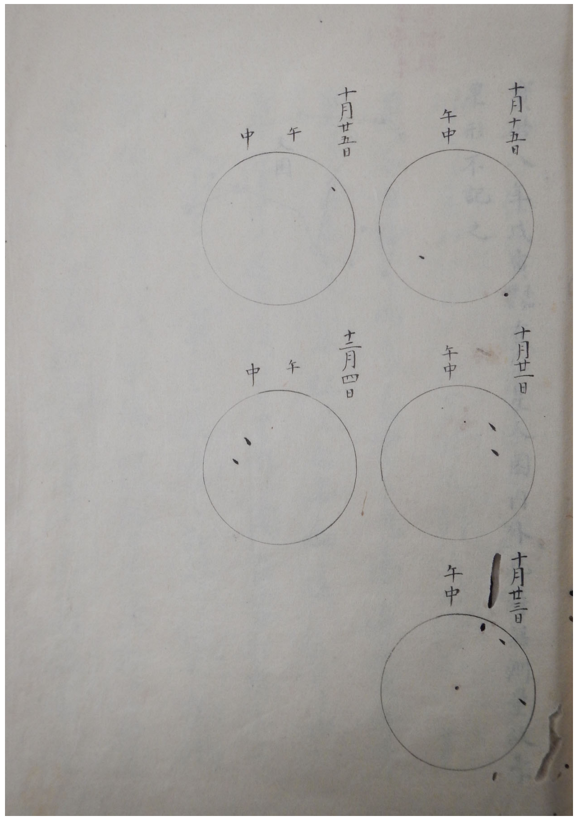

**Fig. 6.** Same as figure 4 but for f.10a of MS/O.

**Table 1.** Sunspot observations in SKJZ.

| ID | Year | Month | Date | MS/K | MS/O | RGC | Reference |
|---|---|---|---|---|---|---|---|
| S1 | 1749 | Aug. | 7 | | | N/A | f.9a |
| S1 | 1749 | Aug. | 8 | | | N/A | f.9a |
| S2 | 1749 | Oct. | 12 | 5 | 5 | 5 | f.9b |
| S3 | 1749 | Oct. | 15 | 6 | 6 | N/A | f.9b |
| S4 | 1749 | Oct. | 17 | 2 | 2 | N/A | f.9b |
| S5 | 1749 | Oct. | 19 | 2 | 2 | N/A | f.9b |
| S6 | 1749 | Oct. | 21 | 1 | 1 | N/A | f.9b |
| S7 | 1749 | Oct. | 23 | 1 | 1 | N/A | f.9b |
| S8 | 1749 | Nov. | 2 | 4 | 4 | 6 | f.9b |
| S9 | 1749 | Nov. | 3 | 2 | 2 | N/A | f.9b |
| S10 | 1749 | Nov. | 8 | 4 | 4 | N/A | f.9b |
| S11 | 1749 | Nov. | 14 | 1 | 1 | N/A | f.10a |
| S12 | 1749 | Nov. | 30 | 2 | 2 | N/A | f.10a |
| S13 | 1749 | Dec. | 2 | 2 | 4 | N/A | f.10a |
| S14 | 1749 | Dec. | 4 | 1 | 1 | N/A | f.10a |
| S15 | 1750 | Jan. | 11 | 2 | 2 | 5 | f.10a |

*Date and group number of sunspots in comparison with raw group counts (RGC) by Vaquero et al. (2016). Note that S1 contains observations of four timings in the same drawing and we could not distinguish them from those in other timing, as further detail was not provided in this drawing in either of variants.

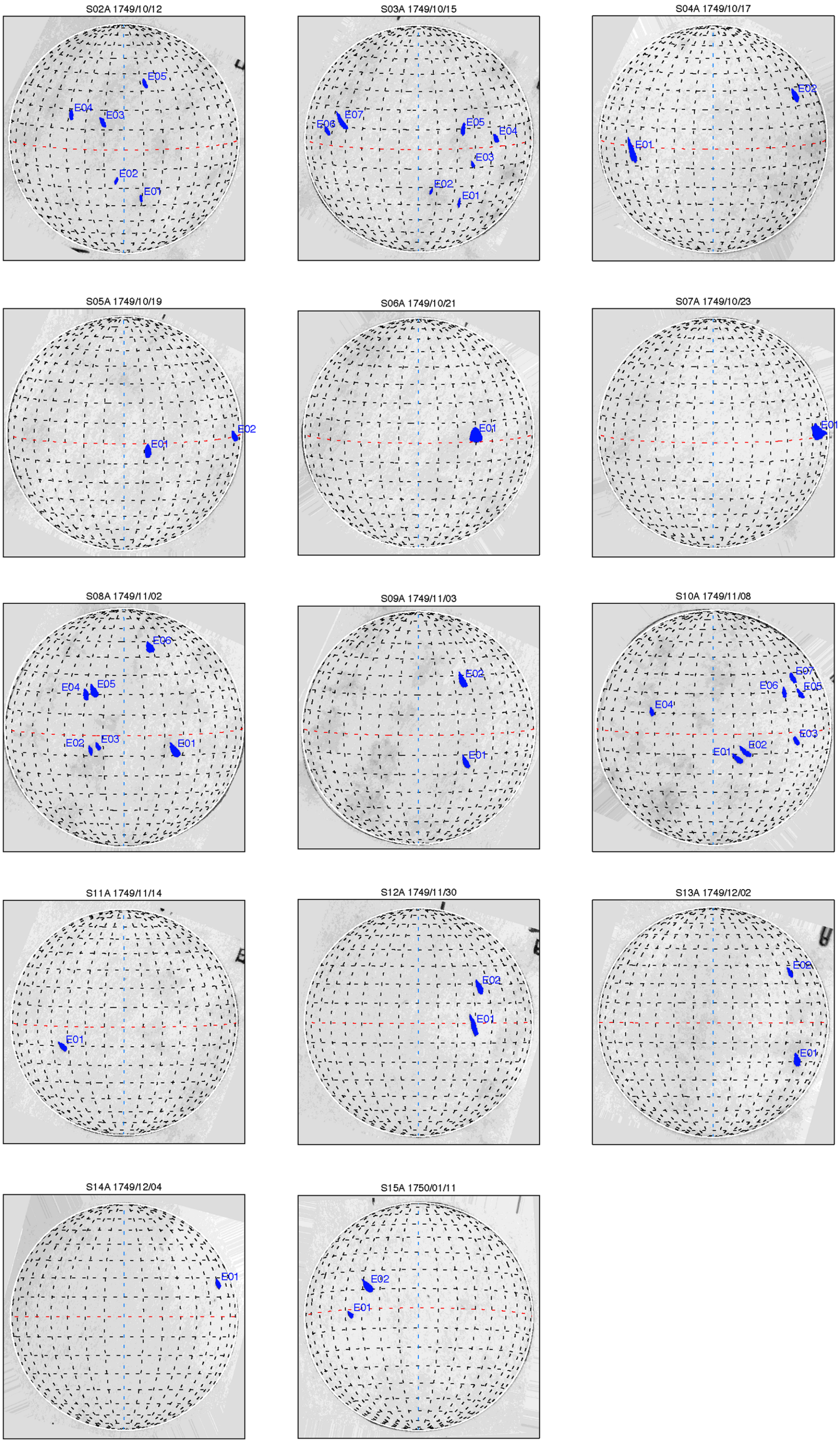


**Fig. 7.** Identification of sunspot groups in MS/K. (Color online)

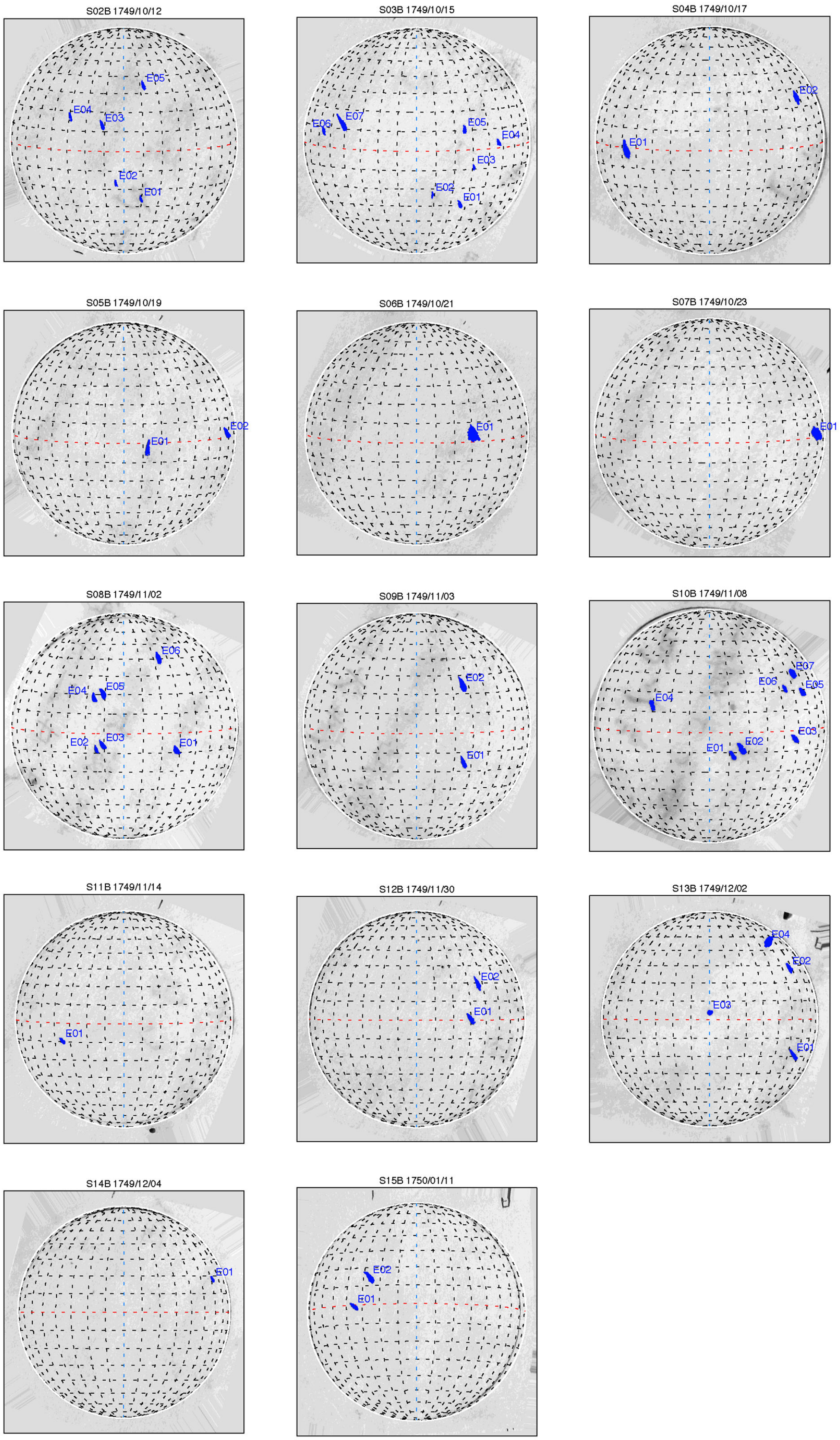


**Fig. 8.** Same as figure 7 but for MS/O. (Color online)

**Table 2.** Area and location of sunspot groups in MS/K and MS/O.

| | Projected area [msh] | Corrected area [msh] | Long. | Lat. | | Projected area [msh] | Corrected area [msh] | Long. | Lat. |
|---|---|---|---|---|---|---|---|---|---|
| | | — MS/K — | | | | | — MS/O — | | |
| S02A_E01 | 426 | 260 | 9.5 | −25.8 | S02B_E01 | 462 | 280 | 9.7 | −25.6 |
| S02A_E02 | 403 | 220 | −3.9 | −15.9 | S02B_E02 | 341 | 190 | −4.2 | −16.7 |
| S02A_E03 | 892 | 460 | −10.9 | 13.7 | S02B_E03 | 645 | 330 | −11.3 | 13.2 |
| S02A_E04 | 747 | 430 | −28.6 | 16.9 | S02B_E04 | 478 | 280 | −29.4 | 16.9 |
| S02A_E05 | 683 | 400 | 12.7 | 34.1 | S02B_E05 | 532 | 320 | 12 | 34.4 |
| S03A_E01 | 434 | 290 | 24.2 | −29.6 | S03B_E01 | 555 | 380 | 26 | −29.7 |
| S03A_E02 | 366 | 210 | 6.9 | −22.3 | S03B_E02 | 355 | 210 | 8.7 | −23.5 |
| S03A_E03 | 318 | 190 | 28.8 | −8.5 | S03B_E03 | 258 | 160 | 30.7 | −9.2 |
| S03A_E04 | 695 | 470 | 43.1 | 4.1 | S03B_E04 | 453 | 330 | 46.4 | 2.8 |
| S03A_E05 | 917 | 500 | 23.5 | 9.6 | S03B_E05 | 559 | 310 | 25.4 | 10.3 |
| S03A_E06 | 637 | 540 | −54.1 | 7 | S03B_E06 | 486 | 440 | −55.8 | 7.8 |
| S03A_E07 | 1632 | 1140 | −43.7 | 12.4 | S03B_E07 | 1475 | 1020 | −42.2 | 12.7 |
| S04A_E01 | 2852 | 2010 | −45.4 | −3 | S04B_E01 | 2153 | 1590 | −46.9 | −1.2 |
| S04A_E02 | 1403 | 1150 | 52.7 | 25.4 | S04B_E02 | 1194 | 1100 | 56.6 | 24.9 |
| S05A_E01 | 1696 | 860 | 11.8 | −3.9 | S05B_E01 | 1441 | 750 | 12.5 | −2.9 |
| S05A_E02 | 990 | 1480 | 70.7 | 0.1 | S05B_E02 | 939 | 1240 | 67.7 | 2 |
| S06A_E01 | 3478 | 1990 | 29.9 | 3.2 | S06B_E01 | 3548 | 2070 | 30.4 | 3.8 |
| S07A_E01 | 3705 | 4670 | 65.5 | 2.4 | S07B_E01 | 2462 | 3450 | 68.2 | 1.7 |
| S08A_E01 | 1878 | 1060 | 25.4 | −7.8 | S08B_E01 | 890 | 510 | 28 | −9 |
| S08A_E02 | 705 | 370 | −16.4 | −7.3 | S08B_E02 | 605 | 310 | −14.1 | −8.2 |
| S08A_E03 | 634 | 320 | −12.7 | −5.4 | S08B_E03 | 878 | 450 | −10.9 | −5.8 |
| S08A_E04 | 978 | 540 | −19.7 | 19.6 | S08B_E04 | 736 | 390 | −16 | 18.2 |
| S08A_E05 | 1387 | 740 | −15.6 | 21.4 | S08B_E05 | 981 | 520 | −11.4 | 20.4 |
| S08A_E06 | 1327 | 930 | 18.1 | 45.8 | S08B_E06 | 1029 | 690 | 23.5 | 40.4 |
| S09A_E01 | 1383 | 790 | 24.7 | −13.9 | S09B_E01 | 1096 | 650 | 25.4 | −15.5 |
| S09A_E02 | 1725 | 1020 | 25 | 27.1 | S09B_E02 | 1623 | 960 | 26.4 | 24.6 |
| S10A_E01 | 1328 | 710 | 12.3 | −12.5 | S10B_E01 | 911 | 470 | 11.7 | −11.5 |
| S10A_E02 | 1193 | 640 | 16.1 | −9.1 | S10B_E02 | 1406 | 730 | 16.2 | −8.3 |
| S10A_E03 | 711 | 510 | 45.1 | −4.3 | S10B_E03 | 784 | 570 | 47.5 | −4 |
| S10A_E04 | 646 | 390 | −32 | 10.4 | S10B_E04 | 952 | 520 | −30.4 | 13.3 |
| S10A_E05 | 735 | 610 | 51.5 | 18.8 | S10B_E05 | 708 | 650 | 57.2 | 18.9 |
| S10A_E06 | 693 | 470 | 40 | 19.8 | S10B_E06 | 483 | 340 | 43.8 | 21.1 |
| S10A_E07 | 826 | 680 | 49.3 | 27 | S10B_E07 | 1013 | 920 | 54.2 | 28.7 |
| S11A_E01 | 1142 | 700 | −33.3 | −10.6 | S11B_E01 | 693 | 430 | −35 | −9.6 |
| S12A_E01 | 2165 | 1240 | 28.9 | −1.6 | S12B_E01 | 1310 | 750 | 30.1 | 0.6 |
| S12A_E02 | 1518 | 960 | 34 | 18.2 | S12B_E02 | 1168 | 760 | 36.6 | 19.4 |
| S13A_E01 | 1629 | 1360 | 50.4 | −19.3 | S13B_E01 | 1140 | 1090 | 55.5 | −19.3 |
| S13A_E02 | 820 | 670 | 47.9 | 25.8 | S13B_E02 | 865 | 890 | 57.2 | 28.4 |
| S14A_E01 | 876 | 890 | 60.3 | 16.9 | S13B_E03 | 604 | 300 | 0.1 | 3.8 |
| S15A_E01 | 647 | 400 | −36.5 | −2.7 | S13B_E04 | 1755 | 2040 | 51.4 | 45.8 |
| S15A_E02 | 1765 | 1020 | −27 | 11.5 | S14B_E01 | 532 | 570 | 61.7 | 17.9 |
| | | | | | S15B_E01 | 928 | 580 | −34.8 | −0.9 |
| | | | | | S15B_E02 | 1446 | 870 | −26.3 | 14.5 |

Original text: 一同年六月廿五日申半刻、又同廿六日辰刻前并午刻過ト申刻過見之、日体ノ内ニ黒点有、西洋暦経ニ所記無疑也、又日光熾也ト雖トモ輪ノフチキッハリト見ヘ月輪ノキワヲ見ルト異也

English translation: In the same year (1749), we observed the black spots within the solar disc on August 07 around 16h LT and on August 08 at around 7h LT, 12h LT, and 16h LT.[4] This is without doubt as found in Seiyo Rekikyo as well. Although the sunlight is intense, the edge of the solar disc can be clearly seen, and is different from that of the lunar disc.

[4] These observational clock hours are reproduced as the caption of S1 with its "upper side (上)" shown.

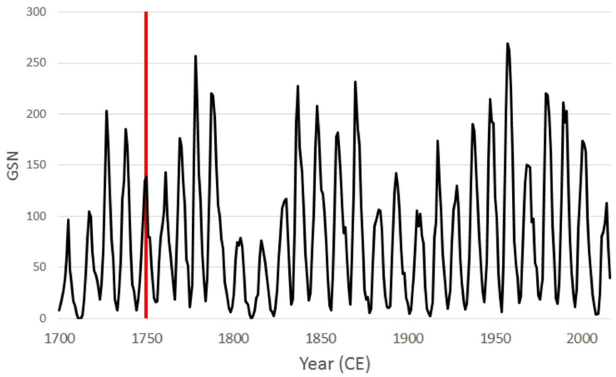


**Fig. 9.** Sunspot drawings in SKJZ in red within the index of yearly sunspot number by Clette et al. (2014). (Color online)

Here, we can find the sunspot observational time and their knowledge on the solar disc. S1 (f.9a) involves sunspot drawings on 1749 August 07–08 in one figure. The other sunspot drawings found in ff.9b–10a are drawn independently with one another, as summarized in table 1. We also identify the sunspot groups, except for that of S1 in these manuscripts, as shown in figures 7 and 8.

Their observational time is described as 12h LT (午中) for each. These drawings reflect not only the location and number of sunspots, but also their area and shape. For example, we found relatively large sunspots in S6 (1749 October 21) and S7 (1749 October 23). From the series of sunspot drawings, it is also possible to roughly align the solar coordinates. We interpret the comments "upper side (上)" and "lower side (下)" on S2 as defineing the direction of panels, which indicates that the drawings are placed such that north at local noon is always up. Note that, nevertheless, further finding of relevant sunspot drawings may change this interpretation, since this document does not provide any further details. Also, the evolution of the spot distribution in the three consecutive drawings from S7 to S9 hints that the Sun's rotation is from the lower left to the upper right (i.e., the rotational axis is oriented from the lower right to the upper left), and thus that the drawings reflect what the Sun looks like, and are not mirror symmetric. Note that we assume that the large spot in the three drawings to be identical, and that this spot rotates over the disk, since it is unlikely that a spot of this size would decay and emerge again in such a short time (4 days). If fact, the P angle in this period (1749 October) is $+25^{\circ}$ to $+27^{\circ}$, which means that the rotation axis for these panels is tilted counter-clockwise from the vertical by $25^{\circ}$ to $27^{\circ}$. Nevertheless, we have to admit that carefully comparing manuscripts MS/K and MS/O would tell us that these drawings seem to have been copied from some original drawings, and that the shape and size of every sunspot seems to be only slightly different. Therefore, we computed the spot locations for both manuscripts, which are summarized in table 2.

### 3.3 Observational instruments and background knowledge in 1749–1750

The observations in 1749–1750, including the sunspot observations in question, seem to have been carried out at the Shogunate observatory. These manuscripts (f.8b) explicitly state that the observations were carried out at Bukou no Sokuryou Goyoujo (武江之測量御用場), i.e., the

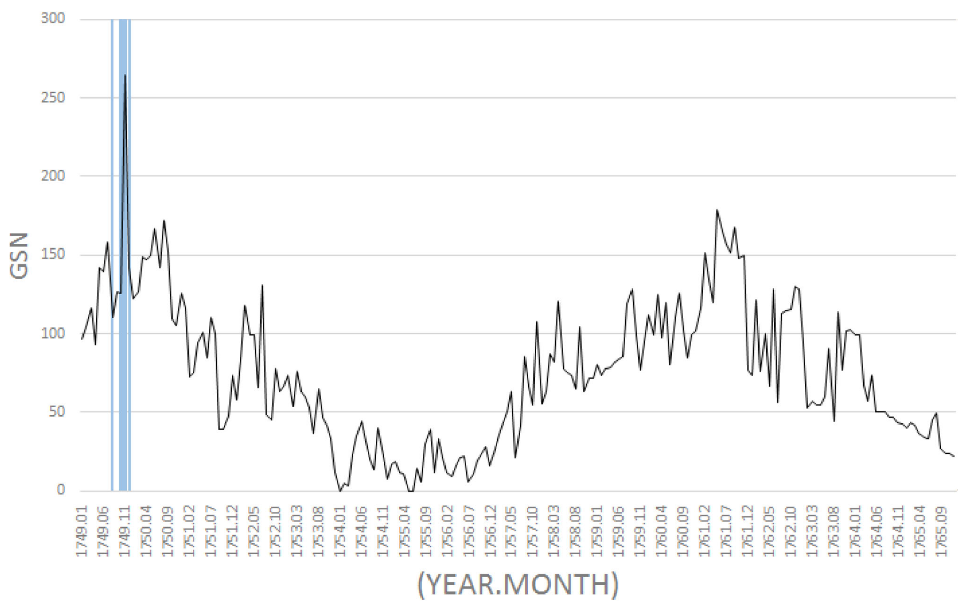


**Fig. 10.** Sunspot drawings in SKJZ within the index of monthly sunspot number by Clette et al. (2014). The coverage of blue color shows where the sunspot drawings in SKJZ are situated. (Color online)

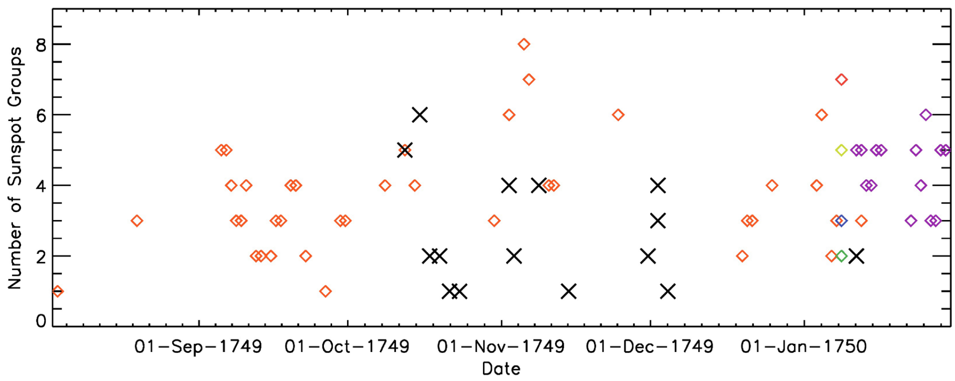


**Fig. 11.** Raw group count of sunspots in the SKJZ in comparison with those by Vaquero et al. (2016). Crosses: raw group count of sunspots in SKJZ. Blue squares: Cassini in Paris. Orange squares: Staudach[5] in Nuremberg. Red squares: Zanotti in Bononia. Purple squares: Hagen in Berlin. Yellow-green square: Danquier in Paris. Green squares: Messier in Paris. (Color online)

Shogunate observatory located at the current Sakuma-cho, Kanda in Tokyo (N35°42′, E139°47′) (Watanabe 1987).

As for telescopes, we have found descriptions of the great glasses (大御眼鏡) or the great telescopes (大遠鏡) without further details (ff.8b–9a). It is well known that contemporary high lord (将軍) Tokugawa Yoshimune (徳川吉宗, r.1716–1745, d.1751) was interested in astronomy and scientific technology in contemporary Europe. He seemed not content with astronomical instruments imported from Europe, and even ordered to make some new instruments, such as astrolabes, for his own observation (Tokugawa Jikki, v.9, pp. 292–293). It is also known that a special instrument, called zongurasu (ぞんぐらす < *zonglas in Dutch), was used as a filtering glass to enable observers to see the Sun, got imported from the Netherlands at least until his death in 1751 (Tokugawa Jikki, v. 9, p. 294). The term zongurasu is a loan-word of zonglas for telescopes in Dutch (Vos 2014). The modern Dutch also have a word "zonneglas," which means "a dark or soot-covered glass used for observation of the Sun" according to the comprehensive dictionary by van Dale (p. 3535). The term *zonglas* is also found for a contemporary eye-tube number 35 made in 1723 within the catalogue for telescopes in the Leiden Observatory during 1656–1859 (Zuidelvaart 2007, p. 166). Therefore, we can fairly well estimate the contemporary observers in the Shogunate Observatory covered telescopes with zongurasus (<zonglas) probably immediately after getting them from the Netherlands.

Their knowledge about sunspots is also influenced by contemporary European astronomy. These manuscripts explicitly mention that they have studied about sunspots from Seiyo Rekikyo (西洋暦経). This book is considered to be an original book of Rekisan Zensho (暦算全書), a Chinese monograph introducing European astronomy and almanac by Méi Wéndǐng (梅文鼎), as described in Tokugawa Jikki (v.9, p. 292).

This fact tells us that the Shogunate astronomers obtained considerable influence from European Astronomy via China. On the contrary, the Shogunate astronomers seem to have learned from ancient Japanese historical documents as well to have adapted terminology of "black spots (黒点/黑點)" found in Japanese Official History in 851 (Hayakawa et al. 2017b), while sunspots in Chinese historical documents are described in different character (黑子) (e.g., Keimatsu 1970; Hayakawa et al. 2015, 2017a, 2017b, 2017c; Tamazawa et al. 2017).

### 3.4 Location in long-term solar activity

We counted the group number of sunspots of the sunspot drawings in SKJZ during 1749–1750, as shown in table 1. While we give only 15 sunspot drawings here, we can locate these sunspot drawings in longer-term sunspot activity. Clette et al. (2014) offered us yearly sunspot numbers since 1611, and monthly sunspot numbers since 1749. These sunspot drawings are contemporary with the earliest stage of the monthly sunspot numbers compiled by Clette et al. (2014). Figures 9 and 10 show where these sunspot drawings are located in comparison with the yearly sunspot numbers and the monthly sunspot number by

5 His name is sometimes spelled "Staudach" (e.g., Clette et al. 2014; Svalgaard & Schatten 2016; Vaquero et al. 2016; Svalgaard 2017) and sometimes "Staudacher" (e.g., Arlt 2008, 2009; Arlt & Fröhlich 2012; Senthamizh Pavai et al. 2016). It is known that Staudach himself signed his own name as "Staudach" (e.g., figure 1 of Arlt 2008) but was also known as "Staudacher", as explained in the correspondence by Gustav Spörer cited in Wolf (1887, pp. 357–358). Both Spörer and Wolf were professional astronomers publishing in German in the nineteenth century. Note that "Staudacher" is a spoken dialect variant in southern Germany and not formal high-German language, which is spoken in Nurnberg as well. The latter basically means "the one from Staudach," where "Staudach" would be a name of place or family. On the other hand, his name is currently known as "Staudacher" in modern German. Therefore, it should be noted that either spelling is possible. We adopt "Staudach" here to keep our article consistent with Vaquero et al. (2016).

Clette et al. (2014). They show that these sunspot drawings during 1749–1750 are near to the solar maximum. This fact explains why there are a relatively large number of sunspots captured in SKJZ. We also found sunspots with large area in S6 and S7 on 1749 October 21 and October 23 as well. They are of great value, since they can fill unrecorded sunspot observations, as shown in table 1 in comparison with Vaquero et al. (2016) (figure 11).

We also computed the area of each sunspot in these manuscripts identified in figures 7 and 8, as shown in table 2 and summarized in figure 12. We calculated the projected area and corrected area, before and after removing any foreshortening effect, for each manuscript and show their variation in figure 12. We also show a histogram of the sunspot area in the projected area and corrected area for both manuscripts. Figures 12 and 13 explicitly show that the sunspot areas in MS/O are relatively smaller than those in MS/K, and hence we need to be careful when discussing the distribution of the sunspot areas. These figures show that the sunspot areas in these manuscripts are mostly up to 2000 msh, except for S07_E01 in projected area and corrected area, and hence agrees with that of modern spots (e.g., Hathaway et al. 2002). S07_E01 is a somewhat extraordinary value of 3500 msh in MS/O and 4700 msh in MS/K in corrected area, while they are 2462 msh in MS/O and 3705 msh in MS/K in projected area (see, Aulanier et al. 2013; Toriumi et al. 2017). This somewhat extraordinary value may have been caused by its location near the solar limb. It is possible to consider that the observer or copyist(s) mistakenly drew a sunspot having a relatively similar shape with that of S06_E01, although it got closer to the solar limb and should have gotten a foreshortening effect in its appearance. While we are not sure about the accuracy of this drawing, it should also be noted that the observational period of 1749–1750 is situated near the solar maximum as shown in figures 7, 8, and 9, and thus it is expected to see larger spots around this time, since the great sunspots

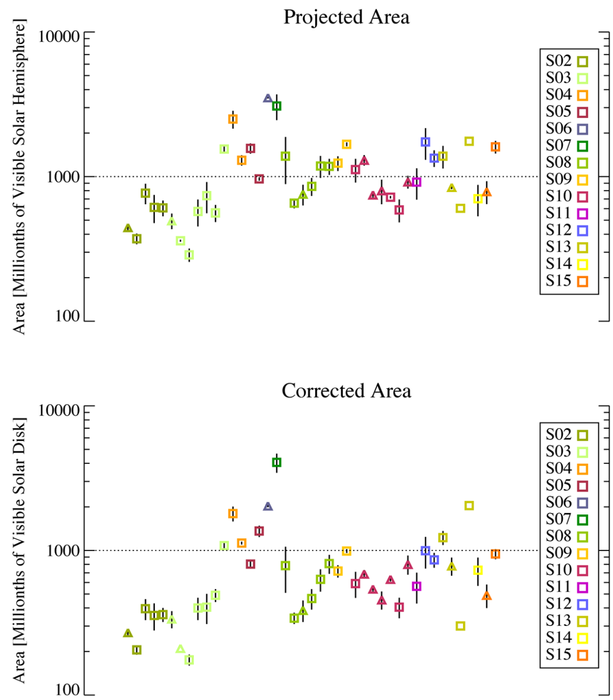


**Fig. 12.** Distribution of the projected area (above) and corrected area (below) of sunspots with the manuscript variation. Basically, upper end of variation indicates the area of MS/K and lower end is MS/O. Their average value is plotted using square markers. On the other hand, triangle markers are used when MS/K is smaller than MS/O. Each color corresponds with the same sunspot on different dates. The element number (e.g., E01, E02, etc.) increases from left side. S13_E03 and S13_E04 don't have any variation because these spots were not found in MS/K. (Color online)

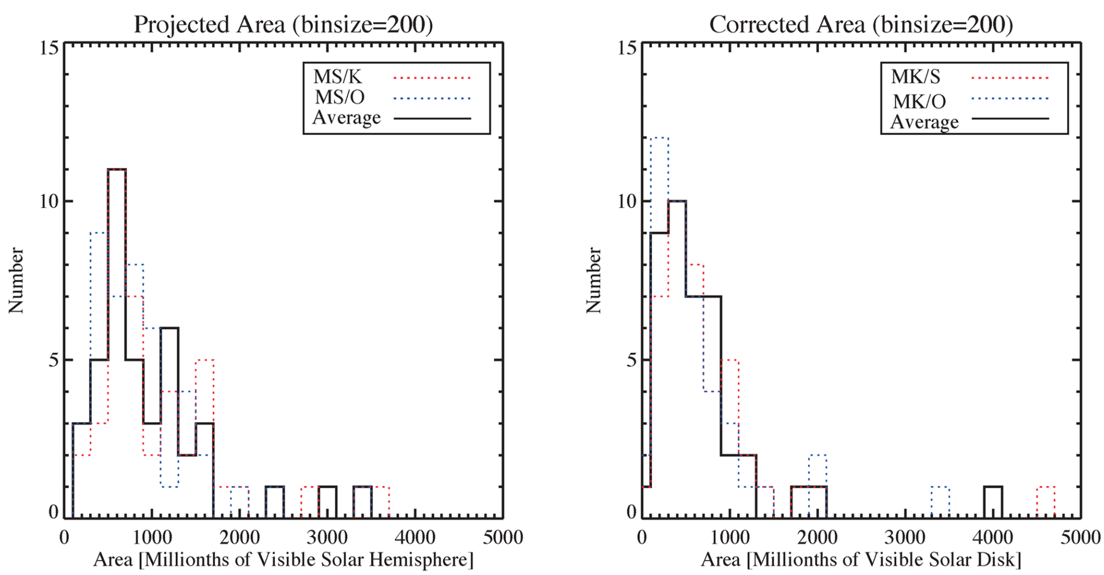


**Fig. 13.** Comparison of histograms of the distribution of the projected area and corrected area of sunspots in MS/K and MS/O. (Color online)

are known to peak at around and slightly after the solar maxima (Heath 1994).

## 4 Conclusion

In this article, we examined sunspot drawings during 1749–1750 based on the manuscripts of SKJZ. We found 15 sunspot drawings in SKJZ that included information not only about their number and location, but also their area and shape. The manuscripts tell us that these observations were carried out at the Shogunate Observatory in Edo (current Tokyo) with telescopes covered by zongrasus. These observations were located near the solar maximum, and hence showed relatively numerous sunspots, and sometimes those with large area. We examined their group numbers, areas, and locations, while needing to admit the differences in the variant manuscripts with one another. These sunspot drawings mostly fall in the dates without known observations registered in the latest database for raw sunspot observations by Vaquero et al. (2016). Therefore, these sunspot drawings can contribute to reconstructing detailed solar activity in the mid-18$^{th}$ century where we are in short of active observations of sunspots. Reconstructing the longer solar cycle in further detail will contribute not only to a further understanding of the long-term solar activity (e.g., Clette et al. 2014; Svalgaard & Schatten 2016; Vaquero et al. 2016; Usoskin 2017), but also to further discussions on solar dynamo theory (e.g., Hotta et al. 2016) or prediction of future solar activity (e.g., Svalgaard et al. 2005; Iijima et al. 2017) in comparison with theoretical studies.

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## Appendix 1. References of source documents

*Tokugawa Jikki*: Narushima Motonao et al. *Tokugawa Jikki* (K. Kuroita, ed.), v.9 (Tokyo: Yoshikawa Kobunkan), 1966.

*Rekisan Zensho*: MS ni05-01614 in the Waseda University Library.

MS/K: MS 8-21318-1 in Kano Library of Tohoku University Library.

MS/O: MS 911-17799 in Okamoto Library of Tohoku University Library.

## Appendix 2. Estimating areas and locations of Sunspots

In order to estimate areas and locations of sunspots, we use the following procedures.

### A.2.1 Circle fitting

First, we cut out each sunspot image (S2–S15) from the two original manuscripts and applied elliptical fitting to each spot image after the background trend was subtracted by the method in subsection 2.2 of Toriumi, Hayashi, and Yokoyama (2014). We have reformed the spot image so that the ellipse would become a circle, and determined the center position and radius of the solar disc.

### A.2.2 Extraction of sunspots

In order to extract sunspots, we made a binary map of each image, leaving only sunspots, and labeled them with numbers. The intensity threshold that we used for each image was

$$Threshold = median - 3\sigma, r. \quad \text{(A1)}$$

### A.2.3 Calculation of sunspot coordinates

The north–south direction of the Sun observed from Earth does not match the vertical orientation of the image because of the inclination of the solar rotation axis with respect to the plane of revolution of Earth (P angle). Therefore, we calculated the P angle at that time from the observational date in table 1, and rotated the image such that the solar north–south would come to the image's vertical. We, then calculated the coordinates on the solar surface while considering the inclination of the solar equator to the ecliptic (B0 angle). In order to calculate these angles, we used the "get_sun.pro" procedure of SSWIDL, which is based on a method in Meeus (1988).

### A.2.4 Calculation of projected area of sunspots

We calculated the projected area of each sunspot with the formula.

$$projected\,area = \frac{(number\,of\,pixels\,composed\,sunspot)}{\pi R^2} \quad \text{(A2)}$$

Here, $R$ means the radius of the corrected circle defined by the circle fitting. The unit of radius is the number of pixels in the reproduced figures.

### A.2.5 Calculation of corrected area of sunspots

We projected each sunspot patch on a planar projection system in which we look down the spot vertically from above. We used "Sanson Projection" for the projection system. Here, the area per pixel is equal everywhere, which is about $1.474 \times 10^6$ [km$^2$] $\sim$ 0.484[mhs]. The area of the sunspot was derived from counting the number of pixels defined as a sunspot in the projected image and converting it into the unit of msh.

## References

Arlt, R. 2008, Sol. Phys., 247, 399
Arlt, R. 2009, Sol. Phys., 255, 143
Arlt, R. 2011, Astron. Nachr., 332, 805
Arlt, R., & Fröhlich, H.-E. 2012, A&A, 543, A7
Arlt, R., Senthamizh Pavai, V., Schmiel, C., & Spada, F. 2016, A&A, 595, A104
Aulanier, G., Démoulin, P., Schrijver, C. J., Janvier, M., Pariat, E., & Schmieder, B. 2013, A&A, 549, A66
Carrasco, V. M. S., & Vaquero, J. M. 2016, Sol. Phys., 291, 2493
Carrasco, V. M. S., Vaquero, J. M., & Gallego, M. C. 2018, Sol. Phys., 293, 51
Clette, F., Svalgaard, L., Vaquero, J. M., & Cliver, E. W. 2014, Space Sci. Rev., 186, 35
Clette, F., Cliver, E. W., Lefèvre, L., Svalgaard, L., & Vaquero, J. M. 2015, Space Weather, 13, 529
Cliver, E. W., & Keer, N. C. 2012, Sol. Phys., 280, 1
Denig, W. F., & McVaugh, M. R. 2017, Space Weather, 15, 857
Diercke, A., Arlt, R., & Denker, C. 2015, Astron. Nachr., 336, 53
Domínguez-Castro, F., Gallego, M. C., & Vaquero, J. M. 2017, J. Space Weather Space Climate, 7, A15
Galilei, G. 1613, Istoria e Dimostrazioni Intorno Alle Macchie Solari e Loro Accidenti Rome, Roma.
Hathaway, D. H., Wilson, R. M., & Reichmann, E. J. 2002, Sol. Phys., 211, 357
Hayakawa, H., et al. 2017a, ApJ, 850, L31
Hayakawa, H., et al. 2018a, A&A, in press (doi: 10.1051/0004-6361/201832735)
Hayakawa, H., Iwahashi, K., Tamazawa, H., Ebihara, Y., Kawamura, A. D., Isobe, H., Namiki, K., & Shibata, K. 2017b, PASJ, 69, 86
Hayakawa, H., Iwahashi, K., Tamazawa, H., Toriumi, S., & Shibata, K. 2018b, Sol. Phys., 293, 8
Hayakawa, H., Tamazawa, H., Ebihara, Y., Miyahara, H., Kawamura, A. D., Aoyama, T., & Isobe, H. 2017c, PASJ, 69, 65
Hayakawa, H., Tamazawa, H., Kawamura, A. D., & Isobe, H. 2015, EP&S, 67, 82
Heath, A. W. 1994, J. Br. Astron. Assoc., 104, 304
Hevelius, J. 1647, Selenographia, sive Lunae Description (Danzig: Andreas Henefeld)
Hotta, H., Rempel, M., & Yokoyama, T. 2016, Science, 351, 1427
Hoyt, D. V., & Schatten, K. H. 1998, Sol. Phys., 181, 491
Iijima, H., Hotta, H., Imada, S., Kusano, K., & Shiota, D. 2017, A&A, 607, L2
Kanda, S. 1960, History of Japanese astronomy before Meiji, ed. The Japan Academy (Tokyo: Japan Society for the Promotion of Science) (in Japanese)
Keimatsu, M. 1970, Annals of Science of Kanazawa University, 7, 1
Kiepenheuer, K. O. 1953, in The Sun, ed. G. P. Kuiper (Chicago: University Chicago Press), 322
Kubota, J., & Suzuki, Y. 2003, Bull. Osaka Economy University, 54, 97 (in Japanese)
Meeus, J. 1988, Astronomical Formulae for Calculators, 4th ed. (Richmond: Willmann-Bell)
Owens, B. 2013, Nature, 495, 300
Senthamizh Pavai, V., Arlt, R., Diercke, A., Denker, C., & Vaquero, J. M. 2016, Adv. Space Res., 58, 1468
Svalgaard, L. 2017, Sol. Phys., 292, 4
Svalgaard, L., Cliver, E. W., & Kamide, Y. 2005, Geophys. Res. Lett., 32, L01104
Svalgaard, L., & Schatten, K. H. 2016, Sol. Phys., 291, 2653
Tamazawa, H., Kawamura, A. D., Hayakawa, H., Tsukamoto, A., Isobe, H., & Ebihara, Y. 2017, PASJ, 69, 22
Toriumi, S., Hayashi, K., & Yokoyama, T. 2014, ApJ, 794, 19
Toriumi, S., Schrijver, C. J., Harra, L. K., Hudson, H., & Nagashima, K. 2017, ApJ, 834, 56
Tsuji, Z., et al. ed. 2002, Kokusho Soumokuroku (Tokyo: Iwanami Shoten), (KS)
Uchida, M. 1992, Nihon Rekijitsu Genten (Tokyo: Yuzankaku) [in Japanese]
Usoskin, I. G. 2017, Living Rev. Sol. Phys., 14, 3
Usoskin, I. G., et al. 2015, A&A, 581, A95
Vaquero, J. M. 2007, Advances in Space Research, 40, 929
Vaquero, J. M., et al. 2016, Sol. Phys., 291, 3061
Vaquero, J. M., & Vázquez, M. 2009, The Sun Recorded through History (New York: Springer-Verlag)
Vos, F. 2014, East Asian History, 39, 153

Waldmeier, M. 1947, Publ. Zürich Obs., 9, 1
Waldmeier, M. 1961, The sunspot-activity in the years 1610–1960 (Zurich: Schulthess)
Watanabe, T. 1987, History of the early modern Japanese astronomy (Tokyo: Koseisha)
Willamo, T., Usoskin, I. G., & Kovaltsov, G. A. 2017, A&A, 601, A109
Willis, D. M., Coffey, H. E., Henwood, R., Erwin, E. H., Hoyt, D. V., Wild, M. N., & Denig, W. F. 2013, Sol. Phys., 288, 117
Willis, D. M., Wild, M. N., Appleby, G. M., & Macdonald, L. T. 2016, Sol. Phys., 291, 2553
Willis, D. M., Wild, M. N., & Warburton, J. S. 2016, Sol. Phys., 291, 2519
Wolf, R. 1887, Astron. Mitt. Zürich, 7, 337
Yamamoto, I. 1937, Isis, 26, 330
Zuidelvaart, H. J. 2007, Telescope from Leiden Observatory and Other Collections, 1656-1859 (Leiden: Museum Boerhaave Communication)