The occurrence time of large solar flares in solar cycles

Tomoki Mizoguchi, Ayumu Watanabe, Shouta Moriuchi, Kayo Hirono, Atushi Nakata, Shunsuke Nakamura, Aki Tanaka, Sayaka Kitora, Kazunari Morimoto, Ibuki Koyama, Maria Nakai, Haruka Koyago, Minoru Inoue, Yuji Katoh, Renma Hata, Ryousei Yaji, Kenji Okunaka & Tomoyasu Tanigawa*

Hyogo Prefectural Sanda Shounkan Senior High School

Abstract

Solar activity shows periodic trends that occur in about 11 year cycles. We investigated the environment in which solar flares occurred for the past four of these solar cycles (spanning about 40 years). The occurrence of a solar flare is directly related with sunspots. During its existence, a sunspot will produce solar flares sporadically. The total energy produced from solar flares that occur in a sunspot can be valued by the “Flare Index”. Therefore, we analyzed the surface area, magnetic type, and calculated the Flare Index for each sunspot. We fund that solar flares occur more frequently after the peak of solar activity during a solar cycle. These results indicate the need for the development of space weather forecasting.

Key words: solar flare, sunspot, solar cycle

1 Introduction

It is important for us to be able to predict the occurrence of solar flares that cause serious damage such as communication disturbances or power failures. (1)

We have made solar observations by making sketches of sunspots and taking photographs of the sun. We researched the relationship between the area and the lifespan of sunspots. We found that sunspots with a long lifespan always have a larger area and more energy. Using this, we can predict when a large scale solar flare will occur. Therefore, we decided to put the following information into one database: flare index, magnetic field type, area of sunspot, time and date, and latitude. This information is necessary to predict the occurrence of large scale solar flares. We used Royal Observatory, Greenwich–USAF/NOAA Sunspot Data and data from the Mount Wilson Observatory (2–4). We wanted to use as much data as we could, to obtain a more accurate prediction. However, only 41 years of data was available.

2 Method

Solar activity shows periodic trends that occur in cycles of about 11 years. The first recorded cycle began in 1755. We focused on data from cycle 21 to cycle 24. Cycle 24 will end in around 2020 so we are using data from cycle 24 until December 2016. Table 1 shows the length of each cycle and how many sunspots occurred in that cycle.

We calculated and classified about 12000 points of data using Microsoft Excel.

Table 1. Cycle length and number of sunspots

Cycle	Term	Number of Sunspots
21	1976/7–1986/9	4021
22	1986/10–1996/6	3222
23	1996/7–2008/12	3013
24	2009/1–2020/12 (estimated)	1642 (as of 2016/12)

2-1 Calculating the flare index

Since 1975, the NOAA meteorological satellite GOES has been collecting data about solar flares. Generally, solar flares are categorized into 5 classes by the magnitude of the energy they release: A, B, C, M and X. A releases the least amount of energy and X the most. The classes increase in magnitude on a scale of multiples of 10 as seen on Table 2.

The flare index is the sum of the energy emitted by a sunspot group. We used formula (1) to calculate the flare index value (FI) of each sunspot group.

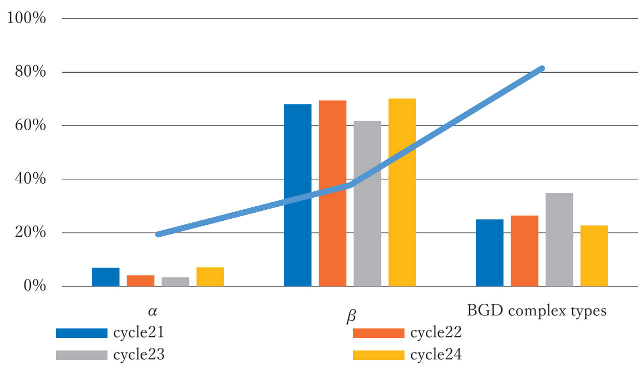

Fig. 1. The occurrence rate of sunspot groups for each magnetic field type The bar graph shows the appearance rate of each magnetic field type (α,β, and BGD complex). The line graph shows the occurrence rate of solar flares from each type.

*Corresponding Researcher: s660368@hyogo-c.ed.jp

Table 2. Solar flares energy

Class	The maximum value of flux 100–800 pm [W/m²]
A	10^{-8}–10^{-7}
B	10^{-7}–10^{-6}
C	10^{-6}–10^{-5}
M	10^{-5}–10^{-4}
X	$> 10^{-4}$

Table 3. Mount Wilson Observatory magnetic field type classification

Type	Characteristic	
α type	Only N or S poles	Simple
β type	N and S pole pairs	↓
γ type	Has opposite poles in penumbra	
δ type	N and S pole pairs exist densely	Complex

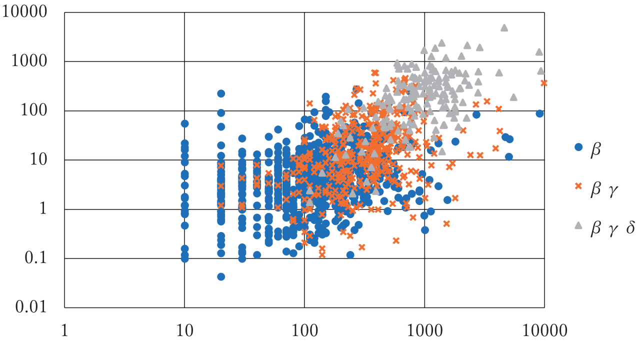

Fig. 2. The relationship between the area and flare index of sunspot groups for cycle 22
Figure 2 shows the relationship between the area and flare index of sunspot groups. The horizontal axis shows the area of sunspot groups in the Northern Hemisphere of the sun in millionths of a solar hemisphere. The vertical axis shows the flare index in w/m^2. From this graph, we can see that large scale solar flares occur in larger area sunspot groups.

$$\mathrm{FI} = \sum(0.1 \times B + C + 10 \times M + 100 \times X) \quad (1)$$

Solar flare classes are determined by the maximum value X –rays that are produced from the entire surface of the sun. This data has always been observed by GOES.

2-2 Magnetic field types and the area of sunspot groups

The magnetic field type of sunspots is related to the occurrence of solar flares. We used the Mount Wilson Observatory magnetic field type classification as shown in Table 3. This classification is based on the magnetic field types of sunspots. There are 4 basic types:α, β, γ and δ. There are also composite types where β, γ and δ types combine. We defined these as BGD complex types.

In general, a sunspot group first has a small area and is α type and then grows into a larger area and a more complex magnetic field type. Some α type sunspot groups disappear without growing into complex types.

We found the final sunspot area and magnetic field type from the data. We classified the sunspots based on their final form. We also made note of the time and latitude when each sunspot group was at its biggest. We mainly used data from

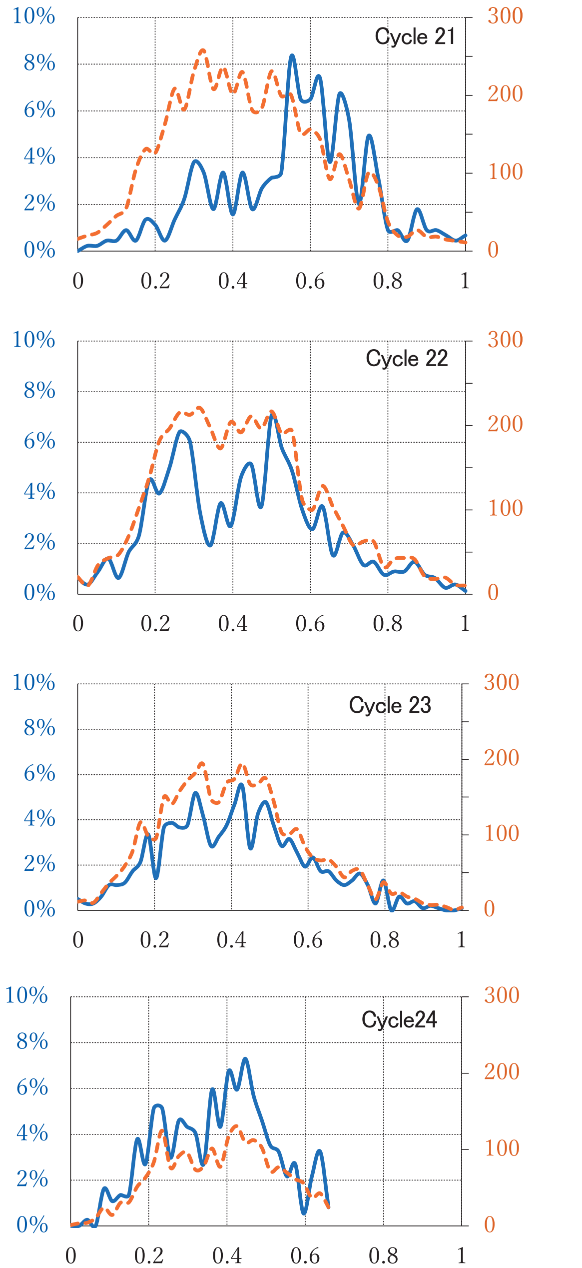

Fig. 3. The occurrence rate of BGD complex types
In the graphs in Figure 3, the left vertical axis shows the percentage of sunspots in one cycle that are BGD complex types. The right vertical axis shows the average relative sunspot number per 3 months. This relative sunspot number represents the sun's solar activity. The horizontal axis shows the time within one cycle. The dashed line shows the relative sunspot number (which indicates how active the sun is). The solid line shows the percentage of sunspots in one cycle that are BGD complex types.

USAF but this contains only magnetic field types since 1981, so we also used data from the Mount Wilson Observatory for sunspots from 1976 to 1980. The number of sunspots varies between the USAF data and the data from Mount Wilson Observatory, so we calculated the number of sunspots from the latitude and occurrence time. We made our own database based on these calculations.

Using this database, it was easier for us to find information about solar flares; for example, when they occurred, their magnitude and the latitude at which they occurred.

3 Results

3-1 The occurrence rate of for each magnetic field type

Figure 1 shows the incidence rate of sunspot groups as a percentage for each magnetic field type in each cycle. We found that most of sunspot groups developed into β types and that there are only a few sunspot groups that grow into BGD complex types. However, these sunspot groups produce solar flares with a probability of more than 80%. From this it is understood that a BGD complex type sunspot groups is closely related to the outbreak of solar flares. These trends can be seen in every cycle.

3-2 The area and flare index of sunspot groups

Figure 2 shows the relationship between the area and flare index of sunspot groups in cycle 22. The correlation coefficient is 0.60 in cycle 22, therefore, there is a clear correlation between the area and flare index of a sunspot group. Figure 2 also shows that βγδ composite types produce large scale solar flares. All the other cycles showed the same relationship. The correlation coefficients of the other cycles were between 0.50 and 0.60.

4 Discussion

The environment of the sunspot was recorded in a single solar cycle.[5] We were the first to reveal the long term environment of the sunspots on the sun. From the results we found a relationship between the occurrence of large scale solar flares and BGD complex type sunspots. We researched when BGD complex type sunspots occur to be able to do space weather forecasting. In Figure 3, the dashed line shows the relative sunspot number which indicates how active the sun is. In cycle 24, the appearance rate of sunspots and the relative sunspot number peaked at the same time. However, this was not the case for the other cycles examined. In these cycles, BGD complex types appear about 1 to 2 years after the peak of solar activity. Therefore, people should exercise caution after the peak of solar activity.

5 Future work

Previously, no database existed containing sunspot group area, flare index, magnetic field type, time and latitude. We created a database with all of this information. We will continue to maintain this database.

We hope that by writing papers like this in English, we can share our findings with other astronomers around the world.

Now, we make sketches of sunspots and take pictures of the sun using a single lens reflex camera. Since April 2017, we have been observing the surface of the sun using a solar telescope and Hα ray filter. We use the videos of the sun taken by the solar telescope with the Hα ray filter to predict the occurrence of large scale solar flares. We will continue to do this in the future. With more information, we hope to be able to more accurately predict the occurrence of large scale solar flares.

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太陽サイクルにおける大規模フレア発生時期

溝口 智貴，渡邉 歩，森内 翔太，廣野 河世，中田 篤志，中村 俊介，田中 暁，木寅 沙也果，森本 一成，小山 息吹，中井 まりあ，古家後 はるか，井上 穂，加藤 優治，畠 廉真，家治 涼聖，奥仲 健司，谷川 智康*

兵庫県立三田祥雲館高等学校

要旨

太陽活動は約11年周期で変化する．私たちは過去4太陽サイクル（約40年間）における太陽フレアの出現状況を調査した．太陽フレアの出現は黒点と密接に関係している．黒点はその存在している間，散発的にフレアを発生させる．1つの黒点が発生させた太陽フレアのエネルギーの総計をフレア指数という．私たちは各黒点の面積，磁気タイプ，フレア指数を明らかにした．私たちはフレアが太陽活動の最盛期のやや後に発生しやすいことを見つけた．これらの結果は宇宙天気予報の向上に役立つ．

重要語句：太陽フレア，太陽黒点，太陽活動サイクル

内容に関する連絡先：s660368hyogo-c.ed.jp