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Cyclic Evolution of Sunspots: Gleaning New Results from Old Data

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Abstract. The records of sunspot number, sunspot areas and sunspot locations gathered over the centuries by various observatories are reanalysed with the aim of finding as yet undiscovered connections between the different parameters of the sunspot cycle and the butterfly diagram. Preliminary results of such interrelationships are presented.

Key words. Sunspots—solar dynamo.

1. Introduction

Much of our knowledge of solar activity in historic times is due to the Zürich relative sunspot number introduced by Rudolf Wolf. He started regular (daily) observations of sunspot number around 1850 and reconstructed the sunspot number to earlier times based on less regular observations. This is the oldest and longest record available of solar magnetic activity. Another long and equally important data set is that of sunspot positions and areas published by Greenwich Observatory since 1874 and now continued by other observatories. In this paper we use these data to find out if there is any relationship between some of the basic parameters describing the distribution of sunspots over the solar cycle. Kodaikanal Observatory recordings are an important component of the Greenwich compilations, so that it is particularly appropriate to publish this paper in the special issue marking the 100th anniversary of Kodaikanal Observatory.

2. Parameters

When sunspot latitudes as tabulated by Greenwich Observatory are plotted versus time one obtains the classical butterfly diagram. The butterfly diagram is a well-studied phenomenon (e.g. Antalova & Gnevyshev 1983, or for the corona Storini & Sykora 1997). For our analysis we first separate the sunspots belonging to each solar cycle using this diagram. With the exception of a very small fraction of the sunspots they can be uniquely assigned to a given cycle in a straightforward manner. Next we add together the areas of all sunspots within a given (narrow) latitude band over a whole sunspot cycle. In this manner we obtain the latitudinal distribution of the sunspot areas averaged over a whole sunspot cycle. This distribution is double-humped, with a maximum each in the southern and northern hemisphere and a minimum at the equator. Next we determine the following parameters (moments) of this distribution, separately for the two hemispheres:

1. total area of the distribution (in the northern and southern hemispheres separately), i.e. the sunspot number integrated over the cycle, n;
2. the mean latitude of the north and south lobes of the distribution, l;
3. the width of each of the lobes, w.

When determining these parameters we neglect the change in the centre-of-gravity of the whole distribution with a 90-year period found by Pulkkinen *et al.* (1999).

3. Relationships

In the next step we check whether there is any relationship between these three parameters for the different solar cycles. This can be done for each hemisphere individually or for the whole sun (by averaging the absolute values of the parameters from both hemispheres). It turns out that the hemispheres and the whole sun exhibit almost the same behaviour, although the scatter is larger for the individual hemispheres. Therefore, for the rest of this paper we consider only the relationships for the whole sun.

In Fig. 1 we plot the mean latitude of the sunspot distribution versus the strength of the cycle. Each triangle represents a solar cycle. Obviously the two quantities are related; the correlation coefficient reads 0.87. The relationship between the width of the distribution and the strength of the cycle is of similar quality (correlation coefficient 0.88).

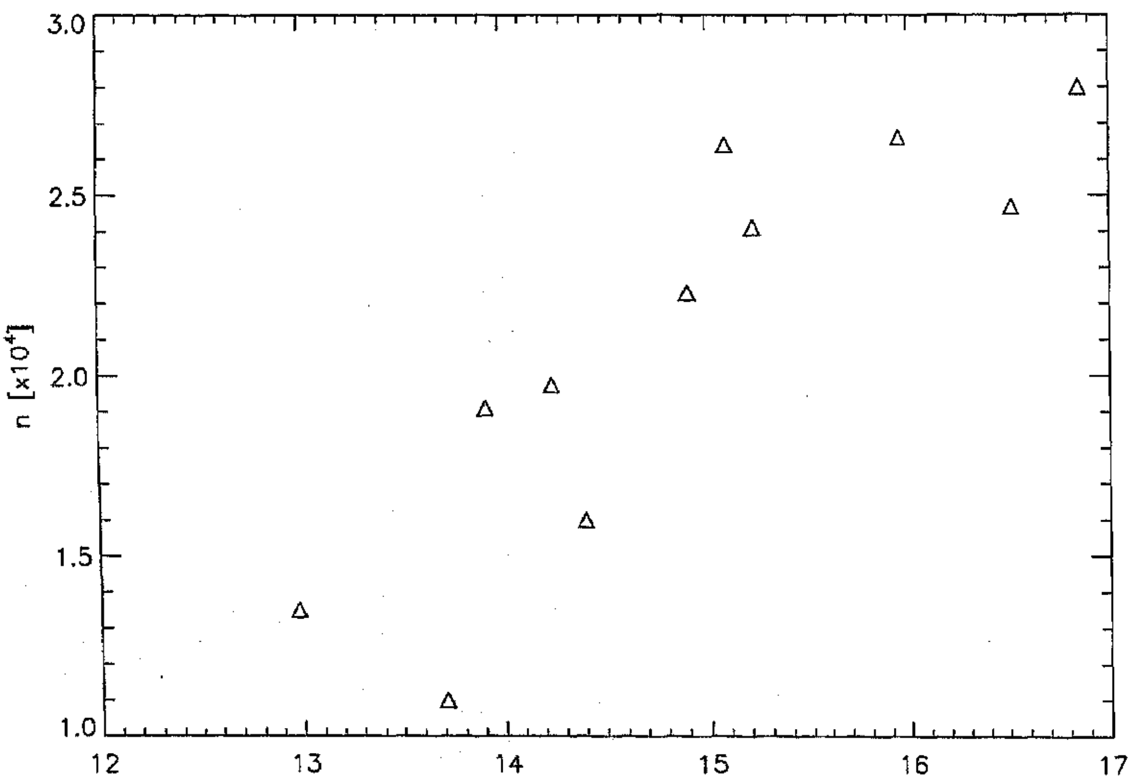

Figure 1. Integrated sunspot number, n vs. mean latitude, l. Each symbol represents a solar cycle.

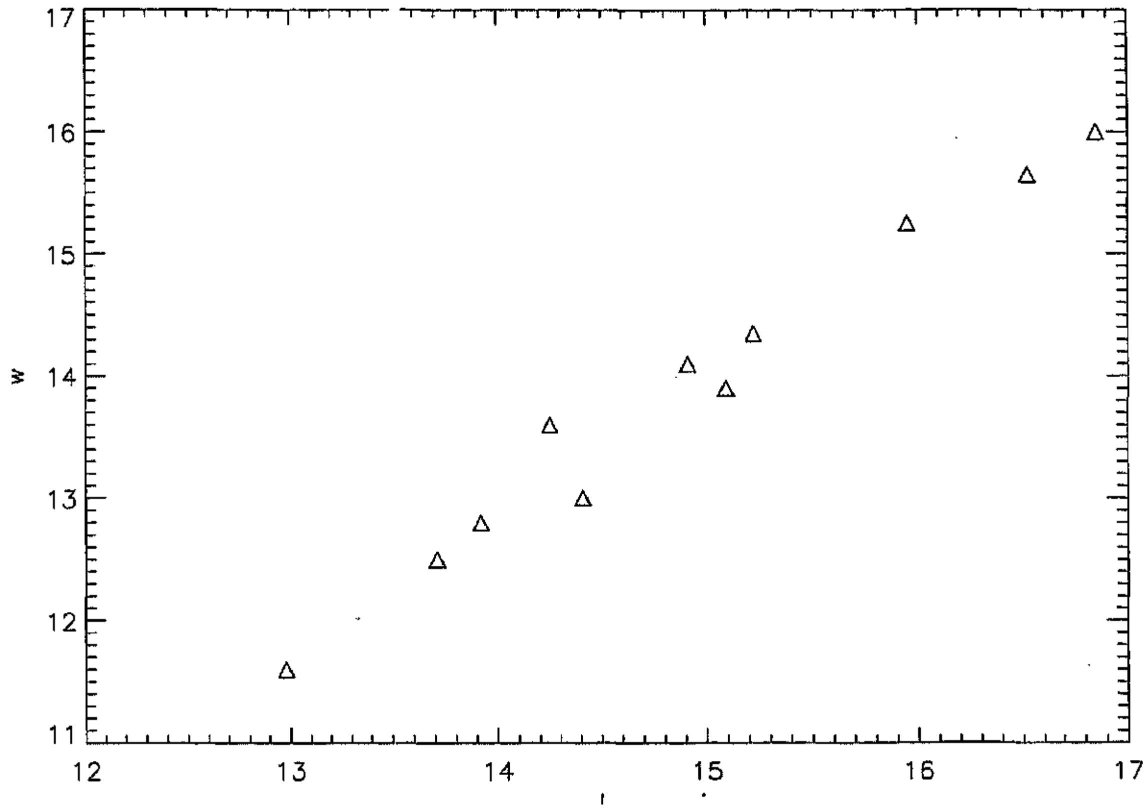

Figure 2. Width of sunspot distribution, w, vs. mean latitude, l.

An even tighter relationship is obtained when we plot the width of the sunspot distribution versus the mean latitude (Fig. 2). The correlation coefficient in this case is almost 0.99.

Both linear and quadratic least-squares fits were made to the data points. Only in the case of the mean-latitude l versus cycle strength n relationship (1) is the fit significantly improved by introducing a quadratic term. In that case the χ^2 value is reduced from 3.5 to 2.9.

The coefficients of the linear fits, which are in general adequate, are:

$$w = -1.388 + 0.562l,$$
$$l = 10.976 + 1.868n,$$
$$w = 4.723 + 1.064n,$$

where w = width, l = mean latitude and n = total sunspot number.

The tightness of the above relationships suggests that they reflect a general property of the solar dynamo. These relations thus represent a new observational constraint that a successful dynamo model needs to reproduce.

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