Latitude Dependence of Solar Activity From a Statistical Study of Flares from 1938 to 1992

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Abstract. A detailed study of solar flares from 1938 to 1992 reveals that flare energy release systematically follows the solar cycle and extends well beyond the main activity zone (MAZ, from −30° to +30°), into higher latitudes. This study also shows that as solar activity progresses from the higher latitudes, at about ±40° in either hemisphere, towards the equator, the maximum energy build-up and release occurs at the upper 'teen' latitudes and then slowly decays into the lower latitudes, near the equator.

1. Introduction

Solar flares constitute the major form of sudden and violent energy release in a spectrum of radiation, from the outer atmosphere of Sun. It is well established that flares result from some form of magnetic energy build-up, storage and sudden relaxation in and around active regions, from the photosphere through the chromosphere and the corona. From the latitudinal drift of solar activity, belief that this energy build-up is a result of some form of deep-rooted interaction between the solar (differential) rotation (in the East - West direction) and large, underlying structures moving in the meridional (equator - pole) direction. Thus flares represent an ultimate signature of interactions that are rooted deep below the visible layers of the photosphere. Hence a statistical study of flares spread over five decades should help in developing a better understanding of the solar dynamo.

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The long-term evolution of solar activity, on time scales of the solar cycle and beyond, has been studied from different perspectives using a variety of short-term surface indicators such as sunspots, plages, and other forms of solar activity (see Howard; these proceedings, for a summary). The latitudinal drift of solar activity, from upper latitude of about ±30° towards the equator (called the Main Activity Zone, MAZ or referred to as The Butterfly Diagram), has been well established (Justin Schove 1983, Harvey 1992). Such studies and consequent modeling have lent themselves to unraveling the mysteries of the solar dynamo and the workings of the solar cycle. The presence of large-scale convective structures beneath the observable photosphere believed to be meridional flows and torsional waves have been related to the observed onset and progress of solar activity, and the resulting modeling of the solar dynamo (Parker 1955a,b, Ward 1965, Howard and LaBonte 1980, Gilman 1981; Yoshimura 1981, La Bonte and Howard 1982, Howard 1983, Dogiel 1983, Giovanelli 1985, Ribes 1986, Snodgrass and Wilson 1987, Kuhn et al. 1987, Wilson et al. 1988). Studies of ephemeral active regions and coronal green line emission have extended the activity beyond the MAZ into the higher latitudes (Altrock 1987, Hiei and Okamoto 1987, Wilson et al. 1988).

In contrast, studies of individual solar activity evolution aim at an understanding of the physical processes that lead to energy build-up and its subsequent release in solar flares (see Keil et. al; these proceedings), while a collective study of solar flares recorded over several solar cycles will help in understanding the global characteristics of energy build-up and release as influenced by the solar dynamo. Here we demonstrate evidence on the latitudinal distribution of energy release as a function of the solar cycle, from a study of over 368,000 flares.

2. The Observational Data Base

Data used in this study were obtained from a NOAA catalogue of 368,290 Hα flares recorded between 1938 and 1992 and x-ray flares recorded between 1982 and 1992 by several observatories around the world and the GOES satellites. While flares recorded in Hα were resolved on the solar disc, the GOES x-ray observations are for an unresolved point-like Sun. This catalogue is available in digital form on a compact disc from NOAA. Flare parameters recorded in the catalogue include the date of flare occurrence, start time, end time, time of maximum brightness, solar coordinates, importance, brightness, completeness of observations, corrected area, x-ray intensity, station name, number of flares per active region, number of brilliant points and eruptive centers and the NOAA/USAF sunspot region numbers. The x-ray intensity given is the peak, full-disk flux measured in the 1 – 8 Å range in units of watts m⁻². Several errors were found in the NOAA digital catalogue. These errors included incomplete records, unusual enitres and missing data. Careful checks were made for these errors and they were corrected, if possible, in accordance with the hard-copy Solar Geophysical Data Reports which are published annually and contain the same information. An extremely small number of data (of the order of 30) was not used as information was incomplete.
3. Analysis

A butterfly diagram of Hα flares is shown panel in Fig. 1. This butterfly diagram closely resembles a sunspot butterfly diagram, and expectedly follows the solar cycle. It reveals several instances of flare activity extending outside of that region ordinarily defined as the MAZ. Most prominent are the North and South extensions between 1957 and 1959 (cycle 19) with flare activity reaching as high as 75° latitude, and the extension reaching as high as 75° North latitude and 65° South latitude between 1963 and 1969 (cycle 20). Solar cycles 21 and 22 also show some extension of activity into the higher latitudes, though the number of flare occurrences above 40° is somewhat less than in cycles 19 and 20. The extensions of activity, between 1957 and 1959, and 1963 and 1969, show no noticeable drift which suggests that these flares are the beginnings of cycles 19 and 20. Altrock (1987) has shown that high-latitude activity regions may persist for over a year at the same latitude.

![Figure 1](image)

Figure 1. A butterfly diagram of all Hα flares from data recorded by several observatories around the world and available from NOAA. Activity cycles 19, 20 and 21 roughly run between the years 1955 – 65, 1965 – 75 and 1975 – 85. Attention is drawn to extension of activity to high latitudes for cycles 19 and 20, and differences in shape of the butterfly wings in each hemisphere, as well as between different cycles. Observations of solar activity were relatively sparse before the beginning of cycle 19.

From the butterfly diagram, it is clear that flare activity continues almost un-
abated throughout the solar cycle. The butterfly diagram also clearly demonstrates the dramatic improvement of flare data observations starting from cycle 19.

Figure 2. A butterfly diagram for all observed x-ray flares using the GOES satellite data, coincident with the Hα flares observed from ground-based observatories. Notice that the flares observed in x-rays (higher energy compared to Hα) do not extend beyond about 45° in either hemisphere.

A butterfly diagram of x-ray flares, Fig. 2, shows the concentration of x-ray flares within the MAZ. A latitudinal distribution of flare energies, as derived from the GOES data, Fig. 3, reveals that most x-ray flares, which require an explosive amount of energy, are found within the MAZ. A majority of x-ray flares extending outside of the MAZ are low energy C-Class flares. Inspection of the graph (Fig. 3) reveals that very few of the over 18,000 x-ray flares recorded extend higher than ±35° in either hemisphere, while even fewer extend higher than ±40°. The area between ±5° also shows very few energetic x-ray flare occurrences, with the largest energy flares being of the low-energy M Class. We have found that most flares which fall within this area are of the C Class. The median of this distribution occurs at 17° in the northern hemisphere and 16° in the southern hemisphere. Approximately all of the high-energy M-Class flares and X-Class flares fall within ±10° of these medians in either hemisphere, suggesting that the majority of high-energy release occurs within ±10° of approximately...
17° latitude in either hemisphere.

![Figure 3](image.png)

Figure 3. Latitudinal distribution of flare energies, as observed with the GOES satellite. Energy distribution is on a logarithmic scale, resulting in what appear to be discrete vertical bars. The spread in the distribution tends to taper towards the teen latitudes at the high energy end. The number of flares drastically drops off above a flux of $10^{-3}$ watts m$^{-2}$.

4. Conclusion

Our preliminary flare analysis has revealed a definite high latitude extension of solar activity (as far as 70° in some instances). These flares which lie outside the MAZ tend to be of short duration, small area and low energy.

Most of the flare energy appears to be released in the mid-latitudes straddling around 17° in either hemisphere. Models that attempt to describe the large scale solar activity should include an explanation of this observed the location of maximum energy release.

Studies of the photospheric vector magnetic field in and around flaring active regions indicate that stressed magnetic field and the resulting magnetic shear is related to the energy release in solar flares. However, from a detailed study of magnetic shear, Hagyard (1990) has pointed out situations in which
(a) magnetic shear decreases right after flares, (b) magnetic shear persists, even after flares, (c) magnetic shear does not show up, despite flares, and (d) shear persists despite non-occurrence of flares. We suggest that these situations may be related to the location of the active region in a particular latitude and the phase of the activity cycle during which the energy build-up and its subsequent release takes place.

References


Group Discussion

Venkatakrishnan: How does one measure the latitude of x-ray flares from GOES data?
Balasubramaniam: GOES observed a point-like Sun. It is the coincident Hα flares that helps to infer the latitude.

Rust: Did you compare the positions of your flare burst episodes with the published positions of the torsional oscillation bands?
Balasubramaniam: Not yet.