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VARIATIONS IN LOW-ℓ SOLAR P-MODES WITH FLARE ACTIVITY

Ashok Ambastha[1] **and H. M. Antia**[2]

[1]*Udaipur Solar Observatory, Physical Research Laboratory, P. O. Box 198, Udaipur 313001, India*
[2]*Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India*

ABSTRACT

We have studied the temporal variation of power in low-ℓ modes and compared it with solar disk integrated flare-index. GONG power spectrum data for the period of May 1995–December 2001 has been used. Variations in the running mean mode power corresponding to $\ell = 0$ modes with different radial orders ($n = 16, 17, \ldots, 28$) are found to be generally stochastic in nature. A comparison of the temporally varying p-mode power with the disk-integrated flare-index does not show any unambiguous correlations.

Key words: Sun: Activity; Sun: Oscillations.

1. INTRODUCTION

The power of solar p-modes has been found to vary on temporal scales of days to several weeks (Chaplin et al. 1995, 1997; Gavryusev & Gavryuseva 1997). The observational variations has been explained by models based on the assumption that the modes are stochastically excited by turbulent convection (Goldreich, Murray & Kumar 1994). However, Chaplin et al. (1997) found excess of excitation events at the highest powers in comparison with the model. They used low-ℓ p-mode data from BiSON to derive the distribution of the observed strengths of the solar oscillations, and reported that some of these features were not explained by stochastically forced, damped harmonic oscillator model. Gavryusev & Gavryuseva (1999) also showed that the running mean power distributions derived from radial mode observations contained large pulse of power. They used a 1010-day long disk-integrated time-series obtained by GONG during June 1995–March 1998, i.e., the period around the solar minimum. A high correlation between temporally varying p-mode power and the coronal mass ejection event number (CME counts) was reported by them. It would be interesting to examine whether other forms of energetic solar events, such as, flares also have similar correlation with the mode power. At the spatial scale of active region, we have found recently that the power in p-modes is larger during the period of high flare activity when compared to that in non-flaring regions of similar magnetic field strength (Ambastha et al. 2003).

Table 1. Flare importance values i used for FI Determination.

Importance	i	Importance	i
SF, SN, SB	0.5	2B	2.5
1F, 1N	1.0	3F, 3N, 4F	3.0
1B	1.5	3B, 4N	3.5
2F, 2N	2.0	4B	4.0

2. FLARE INDEX AND GONG POWER SPECTRUM DATA

In order to determine the effect of flare activity over the scale of the entire solar disk, we use the temporal variation of power in low-ℓ modes for comparison with disk-integrated flare-index. GONG data has been obtained for the period of 1995–2001 covering the ascending phase of the current cycle. We have also obtained CME counts for the period 1996–2003 from LASCO list for a comparison with results of Gavryusev & Gavryuseva (1999).

For quantification of daily solar flare activity, Kleczek (1952) introduced a Flare Index $FI = i \times \tau$ computed over a 24-hour period assuming that this relationship approximately represented the total energy emitted by flares. In this relation, i is the intensity scale of the importance of a flare in H_α and τ is the duration of the H_α flare in minutes. Table 1 lists values of i used for determination of FI from the daily flare listings as provided by Solar-Geophysical Data (SGD). Because the flare observations are not always available over a complete day, it is corrected by dividing by the total time of observations of that day (Atac & Özgüc 2001). Flare index catalogues are available for the period 1936–1986 in Kleczek (1952) and Atac & Özgüc (1998). The FI data for the period of our study here has been taken from Özgüc et al. (2002).

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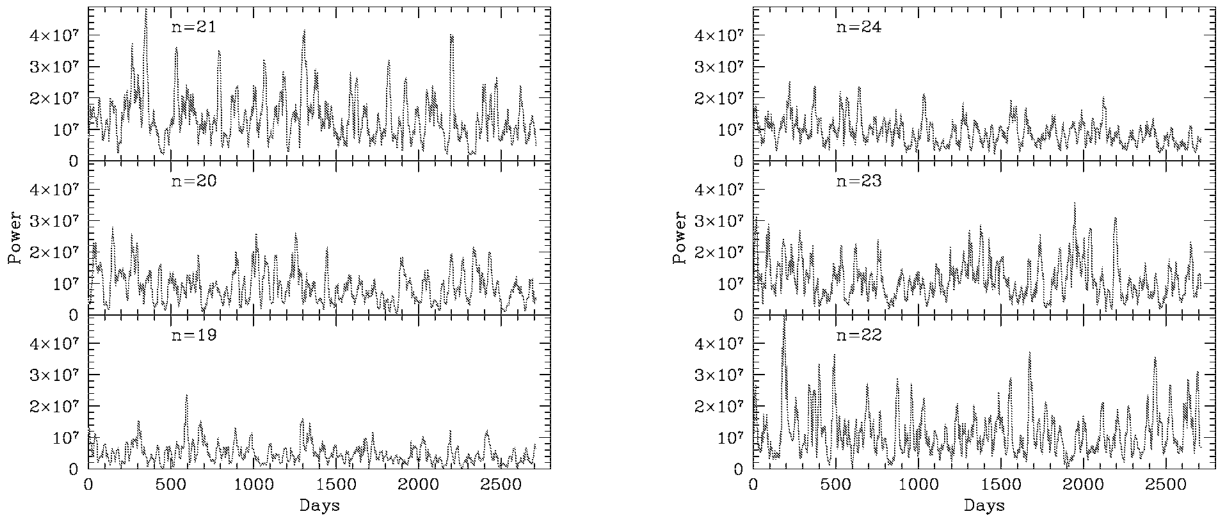

Figure 1. The time sequence of running mean power obtained using a 2736-day long time-series of disk integrated GONG observations for $\ell = 0$, radial modes $n = 19$–24 from using a running window of $T = 23$ days.

3. TEMPORAL VARIABILITY OF FLARE INDEX AND MODE POWER

Temporal changes of various solar activity indices with *FI* during the ascending branch of the current cycle 23 have been reported by Özgüc et al. (2002). They found the monthly mean flare index for this period to be at a much lower level than the previous cycle. Using the discrete Fourier transform on *FI* time series covering 1547 days, they found peaks at 276, 198, 116, 62 and 35 days. By a randomising process to remove aliasing and other spectral leakages, the 116-day periodicity was found at a higher confidence level. Interestingly, the Rieger periodicity of $\approx$ 150–160 days for occurrence of hard flares (Rieger et al. 1984) was found to be absent.

The running mean mode power obtained from GONG data for $\ell = 0$ and $n = 19$–24 over the 2736-day period is shown in Fig. 1. Here we have used a running window of $T = 23$ days for evaluating the mean mode power for all the radial modes as in Gavryusev & Gavryuseva (1999). Considerable amount of fluctuations present in the mode powers are perhaps a result of stochastic excitation of modes. There are also several spikes, i.e., large power pulses, which appear to be quasi-periodic in nature.

In order to check possible periodicities in the mode power variation, we take Fourier transform of the running mean of power (Fig. 1). The results are shown in Fig. 2. It can be seen that there is no clear periodicity, unlike those found for FI by Özgüc et al. (2002), as none of the peaks stands out significantly. There may, however, be hint of some weak periods, such as, 116 day (for n=20), 250 day (for n=21, 22) and 77, 62 day (for n=22). It is to note that out of these, only the 116 day period was found to be present in the *FI* time-series.

In order to improve statistics we take the sum of power in

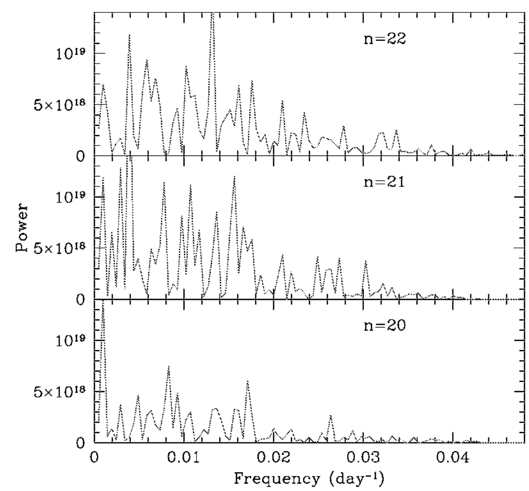

Figure 2. The Fourier transform of the power variation shown in Fig. 1, obtained for $n = 20, 21, 22$.

all modes. The results are shown in Fig. 3, which shows the running mean power as a function of time in the left panel. The right panel shows the power in Fourier transform of the time sequence, which can be used to identify possible periodicities. The weak periods noted for individual radial modes have disappeared.

Fig. 4 shows the histogram obtained for the distribution of the quantity $E_T/\langle E\rangle$ for some typical values of n and $T = 23$ days. This quantity is obtained from the running mean power after normalisation by an average over the entire time span. This distribution resembles with the theoretical model of mode excitation by turbulence, which predicts a random distribution of χ^2-type for the running mean power; decreasing monotonically after reaching the maximum with increasing $E_T/\langle E\rangle$ (Kumar et al. 1988). On the other hand, Gavryusev & Gavryuseva (1999) found that while the left part of the histogram

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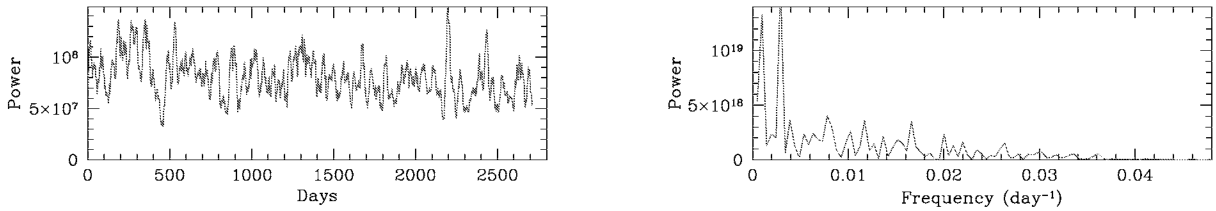

Figure 3. The left panel shows time sequence of running mean power obtained using a 2736-day long time-series of GONG data for $\ell = 0$, summed over all radial modes with n = 16–28 using a running window of T = 23 days. The right panel shows the Fourier transform of the time series.

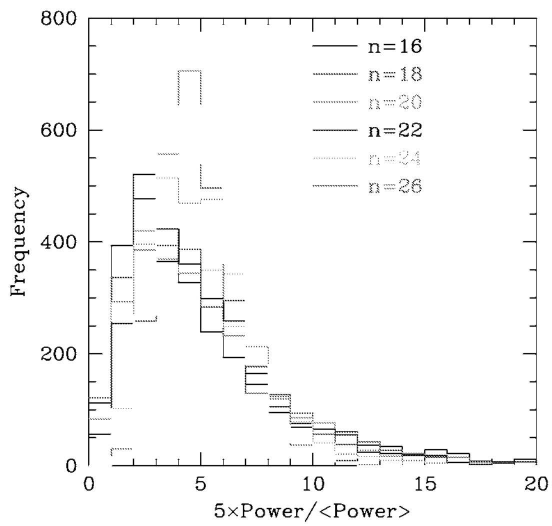

Figure 4. The distribution function of $E_T/\langle E\rangle$ for $\ell = 0$, radial modes $n = 16, 18, 20, 22, 24, 26, 28$ using a running window of T = 23 days.

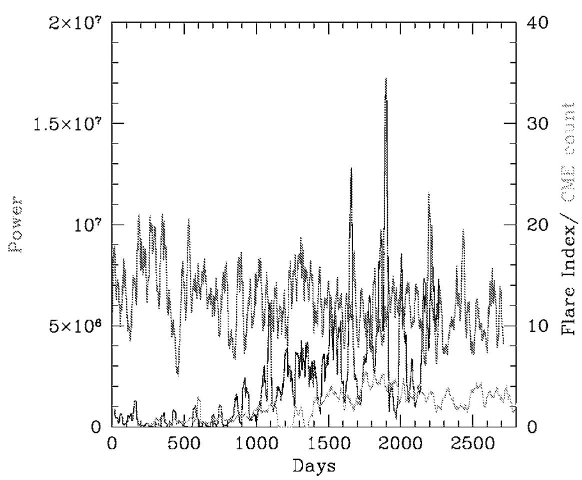

Figure 5. The flare index FI (blue line) and the CME-count (green line) smoothed by the same running window of T = 23 days as used for the p-modes are shown with the overall sum of running mean power of radial modes with n = 16 – 28 (red line). CME-counts and FI are presented in the same scale. The origin of the time-scale is May 1, 1995

resembled the expected χ^2-type distribution, there was a significant feature indicating an excess of events with large power. They had hypothesised that the histogram was a combination of the low power events with χ^2-type statistics and large power events with normal statistics. However, the power distribution obtained here for $n = 16, 18, 20, \ldots, 28$ does not show any significant feature at large power deviating from the χ^2-type distribution.

4. CORRELATION OF FI WITH POWER IN THE MODES

It was first suggested by Wolff (1972) that flares could excite p-modes as a result of mechanical impulse produced by the thermal expansion exerted by a large flare toward solar interior. Later Haber et al. (1988) and Braun & Duvall (1990) reported contradicting results. More recently, Kosovichev & Zharkova (1998, 1999); Donea et al. (1999) and Ambastha et al. (2003) have shown that some large flares may indeed excite the solar oscillations. Therefore, it is expected that disk-integrated flare activity could also excite some solar modes on a global scale.

In order to investigate a possible relationship between disk-integrated flare activity and p-mode power, we compare the temporal changes corresponding to the flare index FI with the power in low-ℓ p-modes. Fig. 5 shows the running mean of FI along with the sum of running mean power of radial modes with n = 16–28. In addition, we also show the corresponding profile for CME counts obtained using the list of LASCO CMEs during the period 1996–2003. The CME counts have been determined by simply counting the daily number of CMEs, as given in the LASCO list without giving any weightage to their energy, as this information is not available. FI, CME counts and p-mode power are all smoothed by the same running window of T = 23 days. No obvious correlation between the FI or CME-count profiles is discernible with the mode power in Fig. 5. The linear correlation coefficients between the running means of FI and power in radial p-modes with n=18–26 are found to be all negative as listed in Table 2. Also listed are the corresponding values obtained for CME-counts, which are also all negative except for n=23. The last column in Table 2 gives the correlation coefficients between the running means of FI (CME-counts) and the net power of ra-

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Table 2. The cross-correlation coefficients between time-series data.

radial order, $n \rightarrow$	18	19	20	21	22	23	24	25	26	Σn
FI	−0.14	−0.17	−0.09	−0.10	−0.16	−0.07	−0.13	−0.005	−0.21	−0.24
CME-Count	−0.21	−0.23	−0.24	−0.20	−0.06	0.10	−0.15	−0.10	−0.13	−0.26

dial modes summed for n=16–28, which are negative too. This result is in contradiction to that found by Gavryusev & Gavryuseva (1999). The large spikes in power are also not well-correlated with the spikes in FI. On the other hand, a reasonably good correlation coefficient of 0.53 is found between FI and CME-Counts.

The mild anticorrelation found between FI (CME counts) and mode power could perhaps be attributed to the magnetic fields associated with the flare producing active regions. A significant anti-correlation between the total power of radial modes $17 \leq n \leq 24$ and the mean solar magnetic field was earlier found by Gavryusev & Gavryuseva (1996, 1997). This is evident from Fig. 5, as one may notice that the mean level of power in p-modes is higher during the solar minimum period; decreasing as it goes towards the ascending phase of Cycle 23. This result conforms with Elsworth et al. (1993), who found using BISON data that the power in the low-ℓ p-modes increased from solar maximum to solar minimum.

5. CONCLUSIONS

We find that the power distribution of low-ℓ modes follows the theoretical χ^2-type distribution with no significant features seen at large-power. This supports the generally accepted mechanism of stochastic excitation of p-modes by turbulence. The power spectrum of the running mean power for radial modes of low-ℓ shows no prominent periodicities. A mild indication of 62, 116 and 250 day periods may be indicative of some quasi-periodicities for individual radial modes, which disappear when sum of powers over these modes is considered. The mean level of running mean power is found to vary; decreasing from solar minimum to ascending phase of solar cycle 23. This is as expected because of increasing level of magnetic fields. A mild anti-correlation between the running means of flare index FI (i.e., solar activity) and mode power is found during the ascending phase of cycle 23. CME-counts are found to be reasonably well-correlated to FI, and show similar mild-anticorrelation with mode power as does the FI.

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