THE SOLAR OSCILLATIONS SPECTRUM AND THE SOLAR CYCLE

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ABSTRACT. During the summer seasons of the years 1977 to 1985 daily velocity measurements of solar global oscillations have been obtained using a resonant scattering spectrometer. After calculating the power spectra of the daily residuals, the mean for each season is found. Several discrete frequency intervals are defined in the spectrum which yield information on the characteristics of the oscillations and noise levels. The mean power in these intervals and the cut-off frequency of the p-mode spectrum, determined for each year, are correlated with the solar activity cycle. Furthermore, several series of 13 contiguous days for each year are analyzed. The frequency and amplitude of the p modes of $l \leq 3$ and $11 \leq n \leq 33$ are determined and their average for these years is found. The frequency differences between modes of the same degree l and between neighbouring modes are found. Their variation over the years is compared with the solar activity cycle.

1. OBSERVATIONS AND ANALYSIS

Measurements of the line of sight velocity of the sun as a star have been carried out at the Observatorio del Teide of the IAC in Izaña (Tenerife) during the summer seasons of 1977 to 1985, with the exception of 1979. In 1983 some fault on the data logging electronics was noticed and therefore the data should be taken with caution. The measurements were made using a resonant scattering spectrophotometer based on potassium built at the University of Birmingham and described in Brookes et al. (1978). A description of the observations and the data used in the present analysis is made in Table I.

In Figure 1 the raw data and the residuals obtained after detrending for the daily variation are shown. The power spectrum of the residuals of individual days is obtained using the FFT technique and a mean of them for each observing season is computed. Six discrete frequency regions are defined for each individual spectrum which contains information on solar oscillations and noise. In these, the mean power

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is calculated and then the average value is found for each observing season (Figure 2).

TABLE I

YEAR	DATE OF OBSERVATION	NUMBER OF DAYS	DAILY MEAN DURATION(h)	13 DAY SERIES	% DATA
1977	12.07 - 25.08	38	9.1	3	35
1978	31.07 - 9.09	25	10.1	2	37
1980	21.07 - 17.08	28	9.6	2	38
1981	29.05 - 25.08	82	10.4	6	44
1982	17.04 - 05.09	123	11.0	9	45
1983	10.05 - 31.08	93	9.9	6	42
1984	17.04 - 20.01	218	9.2	12	42
1985	29.03 - 27.11	169	10.1	10	44

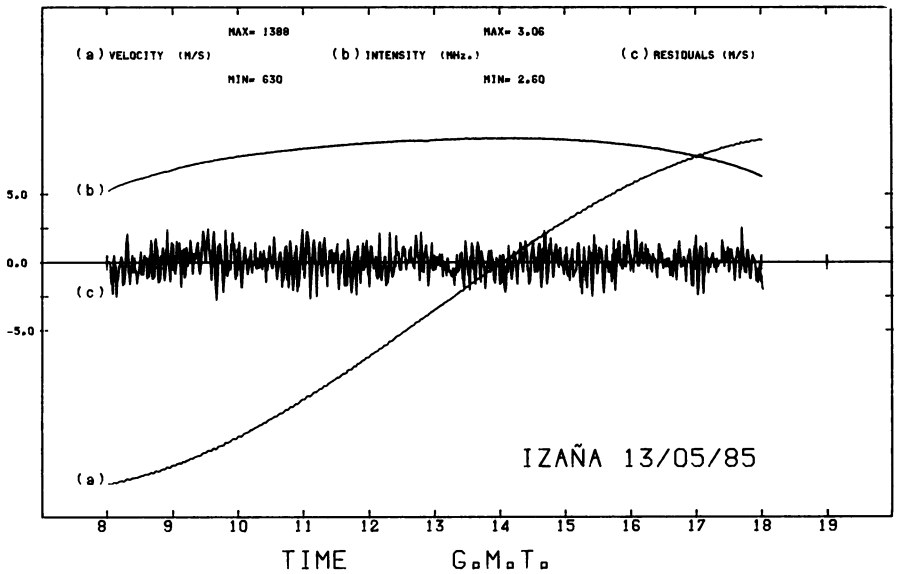

FIGURE 1 This plot shows a typical day of observation. Curve (a) shows the raw velocity data integrated over 42 seconds. Curve (b) shows the transmission through a 15 Å wide filter centred on 7699 Å. Curve (c) is the result of detrending for the daily variation the line of sight velocity data.

Finally, in order to calculate the cutoff frequency of the p mode spectrum, the integrated power is computed for each year and, from it, the cutoff frequency is found (Pallé et al.,1986a).

To identify discrete modes in the p-mode spectrum, series of 13 contiguous days are formed (see Table I) and their power spectra calculated using an iterative sine wave fitting procedure. Peaks are identified in the mean power spectra of each observing season and their frequencies and amplitudes are found. The averages of these parameters, for all the observed years, are shown in Table II. The differences in frequency amongst modes of like l, $\Delta\nu_\ell$, and the ones between adjacent modes $\Delta\nu_{0,1}$, $\Delta\nu_{1,3}$, $\Delta\nu_{0,2}$ are found for each year weighting them

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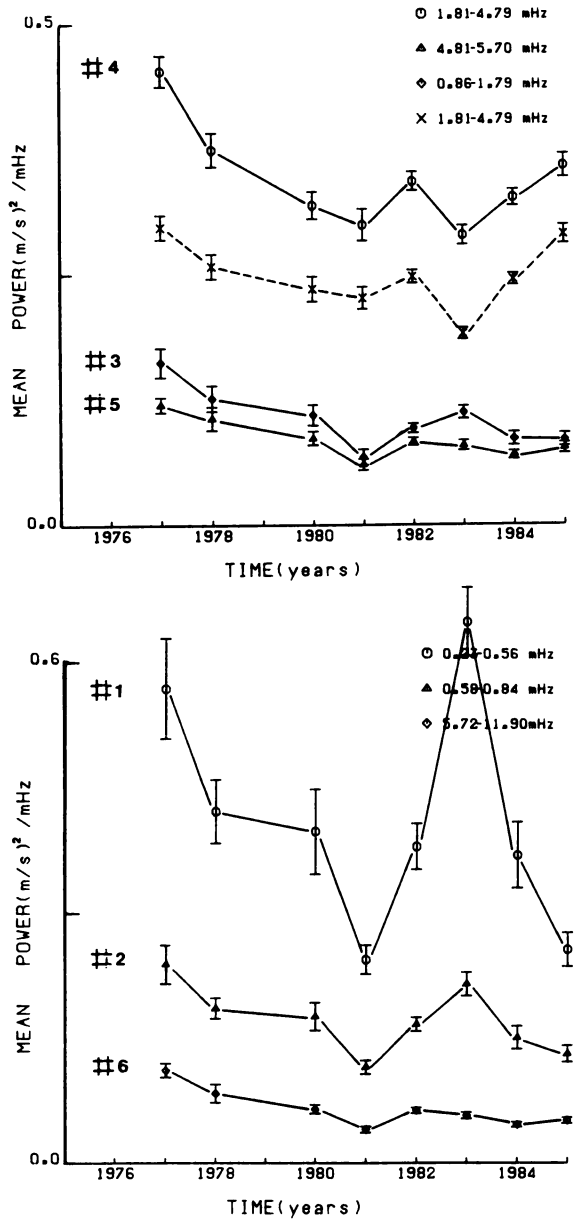

FIGURE 2 In the range from 0.23 to 11.9 mHz we define different frequency intervals which provide information on p and g modes of low n, intermediate frequency noise, the p-mode spectrum and high frequency noise as shown in Table II. The mean power for each of these intervals is calculated and their values are plotted against time in years. The dotted curve is the result of substracting from the mean power at the 5 minute interval (#4) the noise calculated as the mean of the power found at the frequency intervals #3 and #5.

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TABLE II

mean frequency table (1977-1985)

n	l=0	l=1	l=2	l=3
11	.0+/- .0	.0+/- .0	1815.4+/- .1	1868.2+/-1.2
12	1823.6+/- .6	1885.5+/- .4	1947.5+/- .4	2003.4+/- .6
13	1957.3+/- .4	2020.7+/- .4	2084.1+/- .3	2138.7+/- .3
14	2093.5+/- .2	2156.7+/- .4	2218.4+/- .3	2274.7+/- .3
15	2228.6+/- .1	2291.9+/- .2	2352.2+/- .2	2409.4+/- .3
16	2362.5+/- .1	2426.1+/- .2	2486.8+/- .1	2541.9+/- .5
17	2496.6+/- .3	2558.9+/- .2	2620.3+/- .3	2677.4+/- .3
18	2629.6+/- .3	2693.6+/- .3	2754.5+/- .3	2810.9+/- .4
19	2764.4+/- .1	2828.1+/- .2	2890.1+/- .2	2947.9+/- .4
20	2899.3+/- .1	2963.3+/- .2	3024.1+/- .1	3083.5+/- .6
21	3033.8+/- .1	3098.7+/- .1	3160.0+/- .3	3218.5+/- .4
22	3168.6+/- .2	3233.2+/- .3	3296.1+/- .3	3354.4+/- .2
23	3304.1+/- .3	3368.9+/- .1	3431.2+/- .2	3489.5+/- .4
24	3439.8+/- .3	3504.6+/- .2	3567.2+/- .5	3626.1+/- .3
25	3576.3+/- .6	3640.2+/- .4	3703.3+/- .2	3760.9+/- .3
26	3711.5+/- .2	3777.4+/- .7	3837.8+/- .8	3897.6+/- .6
27	3847.4+/-1.0	3914.1+/- .7	3975.5+/- .4	4035.0+/- .7
28	3984.9+/- .3	4052.1+/- .7	4112.9+/- .4	4171.7+/- .7
29	4121.9+/- .4	4189.8+/- .4	4249.3+/- .5	4308.6+/-1.0
30	4257.4+/- .4	4325.6+/- .3	4387.3+/- .4	4443.8+/- .8
31	4394.9+/- .2	4463.6+/- .7	4524.2+/- .4	4583.5+/- .3
32	4532.3+/- .8	4600.8+/- .2	4656.9+/- .8	4717.4+/- .6
33	4668.6+/- .5	4738.6+/- .7	.0+/- .0	.0+/- .0

mean amplitude table (1977-1985) in cm/s

n	l=0	l=1	l=2	l=3
11	.0+/- .0	.0+/- .0	3.1+/- .5	4.1+/- .3
12	4.4+/- .5	3.9+/- .4	3.9+/- .3	3.3+/- .2
13	4.3+/- .5	4.2+/- .3	3.4+/- .4	3.7+/- .4
14	4.1+/- .1	4.3+/- .3	4.3+/- .5	3.9+/- .3
15	5.0+/- .3	5.9+/- .4	5.2+/- .3	4.3+/- .4
16	5.7+/- .4	7.1+/- .5	6.9+/- .4	4.9+/- .4
17	6.4+/- .6	8.9+/- .4	7.7+/- .7	6.2+/- .5
18	7.4+/- .8	9.6+/-1.0	10.2+/-1.0	6.6+/- .4
19	11.6+/-1.2	12.8+/-1.0	11.8+/- .9	8.2+/- .4
20	13.4+/- .6	19.9+/-1.5	14.2+/-1.2	9.4+/-1.2
21	14.6+/-1.4	18.4+/- .9	13.2+/- .9	8.6+/- .4
22	13.7+/-1.2	15.7+/-1.0	11.9+/-1.5	8.1+/- .5
23	13.1+/-1.0	13.5+/- .8	10.8+/-1.3	8.1+/- .8
24	11.1+/- .6	11.4+/- .9	8.1+/- .4	6.0+/- .4
25	8.2+/- .7	7.8+/- .5	7.2+/- .6	5.2+/- .3
26	7.4+/- .6	6.6+/- .4	6.3+/- .6	5.2+/- .3
27	6.1+/- .5	6.1+/- .6	5.7+/- .5	4.6+/- .3
28	5.2+/- .2	5.5+/- .4	5.1+/- .4	4.2+/- .4
29	4.8+/- .4	4.5+/- .4	4.2+/- .3	3.5+/- .4
30	4.4+/- .4	4.1+/- .3	4.2+/- .4	3.1+/- .3
31	4.4+/- .6	3.8+/- .2	3.7+/- .3	3.6+/- .3
32	4.0+/- .4	3.2+/- .4	4.1+/- .4	3.8+/- .5
33	3.5+/- .2	3.4+/- .3	.0+/- .0	.0+/- .0

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by the power of the peaks of all the modes identified (Pallé et al., 1986b), then the mean for each observing season is calculated and when viewed along the observed years they do not show significant variations.

2. CONCLUSIONS

The main findings obtained from the analysis of the line of sight velocity data collected at Izaña (Tenerife) from 1977 to 1985 are:

1) The power of the low l p-modes spectrum seems to vary throughout the years observed (see Figure 2).

2) The cutoff frequency is constant within errors over the years observed (with the exception of 1977 and 1978) and the average value is 5.45 ± 0.06 mHz.

3) From the analysis of the 13 day series the frequencies and amplitudes of the peaks corresponding to modes of $l \leq 3$ and $11 \leq n \leq 33$ are found (see Table II).

4) The differences in frequency $\Delta\nu_\ell = \nu_{n+1,\ell} - \nu_{n,\ell}$ do not show any significant variation along the years and their mean values in μHz are 135.30 ±.15, 135.33 ±.11, 135.46 ± .15, 135.54 ±.16, for l=0,1,2,3 respectively. These numbers show that $\Delta\nu_\ell$ depends on l.

5) Finally, the defined frequency differences $\Delta\nu_{0,1} = \nu_{n,0} - \nu_{n,1}$, $\Delta\nu_{1,3} = \nu_{n,1} - \nu_{n-1,3}$, $\Delta\nu_{0,2} = \nu_{n,0} - \nu_{n-1,2}$ do not vary significantly along the years and their mean values in μHz are 64.57 ±.12, 15.42 ±.12, 9.12 ±.08 respectively.

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REFERENCES

- Brookes,J.R. , Isaak,G.R. , van der Raay,H.B. :1978 . MNRAS,185,1
- Pallé,P.L. , Pérez,J.C. , Régulo,C. , Roca Cortés,T., Issak,G.R. , Mc Leod,C.P. , van der Raay,H.B. :1986a. Astron. & Astroph. (in press)
- Pallé,P.L. , Pérez,J.C. , Régulo,C. , Roca Cortés,T., Issak,G.R. , Mc Leod,C.P. , van der Raay,H.B. :1986b. Astron. & Astroph. (in press)