p Mode Parameters and the Solar Cycle

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Abstract

The properties of solar acoustic oscillations are known to vary with the solar cycle. With 20 years of continuous observations by GONG, we are now in the position to carry out a comparison of the variation of the p mode parameters between the last two solar cycles. We present results of our analyses of the widths, amplitudes, areas (width × amplitude), and background amplitudes of solar p modes, as well as the corresponding physical quantities for modes of harmonic degree $10 \leq l \leq 150$ of the global solar oscillations. We investigate the variation of these parameters for different ranges of mode frequency and harmonic degree. The fractional change in mode widths is largest for modes in the frequency range 2400-3300 μHz, regardless of harmonic degree, with an amplitude of $\sim$10% between solar minimum and maximum. The fractional change in mode amplitude exhibits a peak-to-peak amplitude of $\sim$30% over solar cycle 23. Also, we find hysteresis in mode amplitudes over cycle 23 for some combinations of mode frequencies and harmonic degree. The physical quantities which correspond to the mode parameters (mean square velocity power, total mode energy, mode energy supply rate) are investigated as a function of time for different ranges of harmonic degree. We find that the mode energy supply rate decreased by $\sim$20% over the last 20 years.

Data and methodology

We used the output of the GONG peakfind algorithm, a standard GONG pipeline product, of the first 198 108-day time series in our investigations. We considered all modes with $10 \leq l \leq 150$ for which at least one third of all $(2l+1)$ modes were fitted.
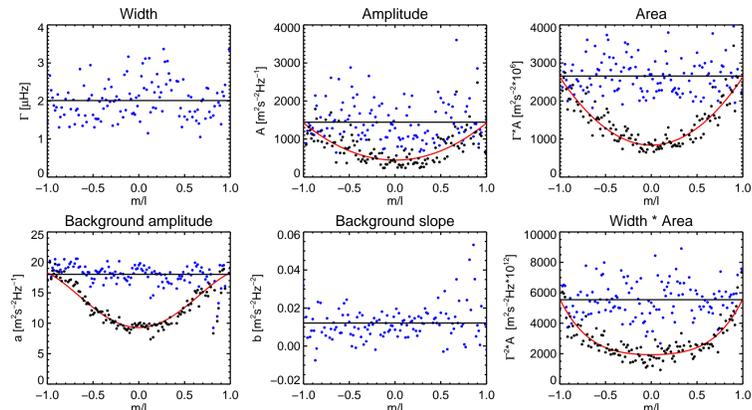

The values of the p mode parameters of each multiplet show different dependencies with m/l. As shown in the figure above for the multiplet $n = 5$, $l = 70$ from the first GONG month, the mode width and the slope of the background do not show a considerable change with m/l, while the other parameters show a clear dependency. This is introduced by the spatial masking of GONG data and a center-to-limb effect in mode velocities. We accounted for this by fitting a $(m/l)^{2k}$ polynomial with $k = 0, 1, 2$ to the data. The mean value of the cleaned data points is taken as the representative value for each multiplet.

Fill factor dependence
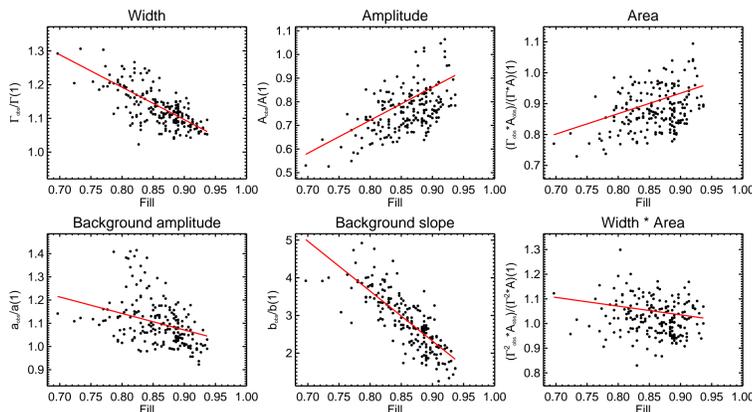
All parameters we investigated show a dependence on the fill factor of the GONG time series. In the figure above, the mode parameters (m-averaged for each GONG month, $n = 5$, $l = 70$, normalized by the intercept at a fill factor of 100%) are shown as a function of fill factor. Evidently, mode widths decrease with increasing fill factor, while mode amplitudes increase with higher fill factor. We accounted for this with a linear regression.

Variation of physical quantities
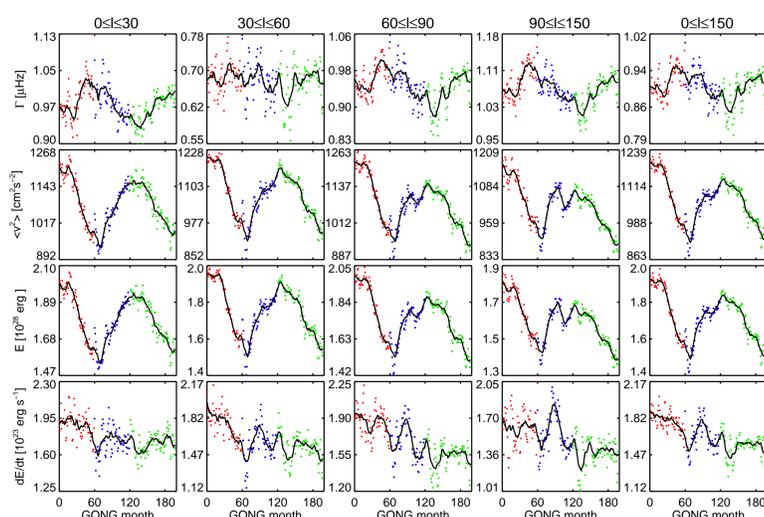
We calculated the physical parameters of mean square velocity power, total mode energy, and mode energy supply rate from the mode parameters [1, and references therein]. In the figure above, the rows display the temporal variation of the physical quantities and rows are different ranges of mode degree. Modes from the following frequency ranges were averaged for the computation of the quantities: 2400-3200 μHz for width, 2950-3350 μHz for velocity, 2950-3350 μHz for energy, 3400-3600 μHz for energy supply rate. Red and blue indicate the ascending and descending phase of cycle 23, respectively. Green indicates the ascending phase of cycle 24.

Mode amplitudes
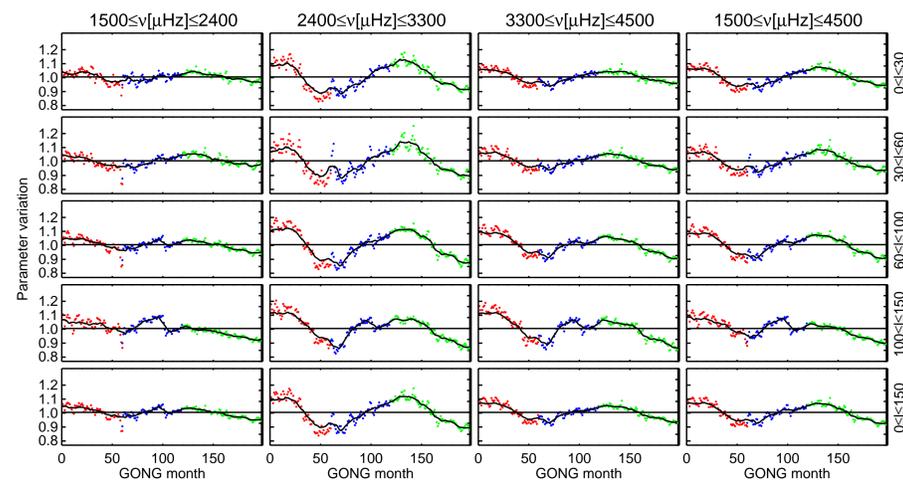
Temporal variation of the mode amplitude, normalized to the mean over all GONG months, for different combinations of mode degree (rows) and mode frequency (columns). For clarity, the black curves show the 10 point boxcar smoothed values (colour coding see box on the bottom left). Mode amplitudes vary by as much as $\sim$ 30% over the course of the solar cycle.
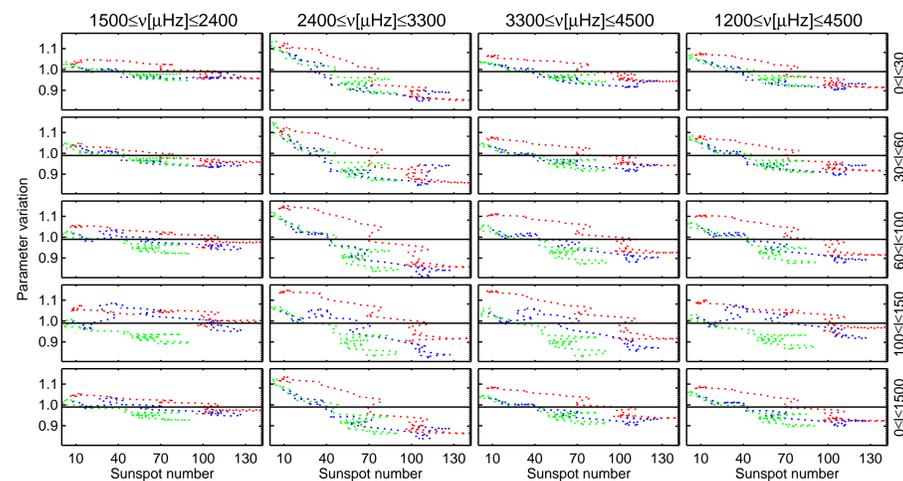
Layout configuration same as for the figure above, but as a function of the sunspot number (Source: WDC-SILSO, Royal Observatory of Belgium, Brussels). Values are 10 point boxcar smoothed.
Mode amplitudes in the intermediate frequency range exhibit hysteresis over cycle 23 (red and blue). This is more pronounced for modes of higher degree.

Summary

We presented results of our investigation of the variation of p mode parameters with the solar cycle. We found that:

- Mode widths are correlated with solar cycle and their variation has an amplitude of up to 10%.

- Amplitudes are anti-correlated with the cycle. A jump in mode amplitudes around GONG month 100 has yet to be explained. It might be due to an increase in background amplitude at the same time.

- The temporal variations of all parameters differ for different combinations of mode degree and mode frequencies.

- Mode amplitudes and areas follow a hysteresis curve over the course of solar cycle 23.

- The energy supply rate decreased over the last 2 cycles. Whether this decrease is of solar origin, just an instrumental effect, or was introduced during data reduction has yet to be investigated.

- The long minimum between cycles 23 and 24 is not clearly reflected in p mode parameters.

References

[1] R. W. Komm, R. Howe, and F. Hill. Width and Energy of Solar p-Modes Observed by Global Oscillation Network Group. Astrophys. J., 543:472–485, November 2000. doi: 10.1086/317101.