Abstract. In the case of spatially-revolved helioseismic data (such as MDI, GONG, HMI), the usual mode-fitting analysis consists of fitting the $2l+1$ individual $m$-spectra of a given multiplet $(n, l)$ either individually or simultaneously. Such fitting methods fail to obtain reliable estimates of the mode parameters (frequency, splitting, ...) when the signal-to-noise ratio (SNR) is low, which makes those methods not suitable when one wants to look at the low-amplitude, long-lived solar p modes in the low-frequency range. Instead, Salabert et al. (2007) developed a new method to extract the mode parameters by adjusting the rotation- and structure-induced frequency shift for each $m$-spectrum to minimize the mode width in the $m$-averaged spectrum (a “collapsogram”). The $m$-averaged spectrum technique, applied to the spatially-resolved GONG and MDI data, appeared to be a powerful tool for low SNR modes in the low-frequency range. Another possibility to increase the SNR is to combine data from different instruments (García et al. 2004a). We present here an adaptation of both techniques: the “collapsograms” applied to a combination of observations from a Sun-as-a-star instrument, GOLF, and a disk-imaged one, GONG.

1. Introduction

After more than 13 years of unprecedented quality helioseismic observations, we have not been able to measure acoustic modes below $\sim 1$ mHz (e.g. Broomhall et al. 2007) or gravity modes. Indeed, only the asymptotic properties of these modes have been uncovered (García et al. 2007, 2008a), but the measurements of individual modes is still a challenge of modern solar physics (e.g. Mathur et al. 2007; Appourchaux these proceedings). It will be impossible to properly determine the structure and dynamic of the solar core without these modes (e.g. García et al. 2008b; Mathur et al. 2008) as well as the high-penetrative, high-order, low-degree p modes (García, Mathur, & Ballot 2008). In order to progress towards lower frequencies, we need to develop new instrumentation — e.g. the GOLF-NG project (Salabert et al. these proceedings), but also to better combine the existent data as well as to improve the analyzing techniques.

As the frequency decreases, the amplitude of the modes decreases while the background level increases. This background noise is a combination of convective noise, instrumental noise, and, in the case of ground-based stations, of
Figure 1. Regions of the power spectrum density (PSD) where the $l = 0$, $n = 5$ (left panels) and $n = 6$ (right panels) are expected. The PSD were obtained with the GOLF 4472-day time series (upper panels) and with the 3620-day (GOLF+GONG) time series (lower panels). The vertical dashed lines indicate the corresponding theoretical frequency from the seismic model (Couvidat, Turck-Chièze & Kosovichev, 2003)

the terrestrial atmosphere. Combining data from different instruments has the advantage to reduce the instrumental noise as well as the convective noise, since each instrument observes at a different height of the solar atmosphere and the convection is not fully correlated (García et al. 2004b).

2. Data sets and methodology

In this work, we use 4472-day time series — from April 11, 1996 to July 8, 2008 — calibrated into velocity (García et al. 2005) of the disk-integrated, Sun-as-a-star GOLF/SoHO instrument (Gabriel et al. 1995), and 3620-day velocity time series — from April 11, 1996 to March 9, 2006 — of the spatially-resolved, ground-based GONG network (Harvey et al. 1996). We average the GOLF observations with the GONG time series from each $|m|$-component ($m = 0$ and $m = \pm 2$) of the spherical harmonic projection of the $l = 2$ mode, both being filtered by a backwards difference filter (BDF). Then, we compute the Fourier transform of each multiplet component with a five times zero padding, correct for the effect of the BDF filter (García & Ballot 2008) and finally average the power spectrum density. The length of the combined series is 3620 days.
3. Power spectra of GOLF and (GOLF+GONG) data sets

The combined power spectrum does not present the daily harmonics thanks to the high duty cycle of the space-based GOLF instrument. Moreover, the leakage from high-degree modes is reduced because they are not present in the GOLF spectra. The amplitude of the $l = 0$ modes increases as they are present in both spectra as well as the overall SNR. For example, the mode $l = 0, n = 5$ has a larger SNR in the combined (GOLF+GONG) data set than in GOLF data alone, even when using 20% shorter time series (see Fig. 1), while the mode $l = 0, n = 6$ has a slightly smaller SNR.

4. Collapsograms applied to the (GOLF+GONG) time series

We applied the collapsogram technique (Salabert et al. 2007) to the $l = 2$ combined (GOLF+GONG) 3620-day time series. Several more low-degree modes in the low-frequency range can be then observed than using the collapsograms applied only to the GONG (or MDI) data, such as the $l = 2, n = 5$ mode (Fig. 2). Moreover, the combination of GOLF with GONG increases the overall SNR, allowing us to measure p modes which would not have a SNR high enough to be measured in GOLF only.
5. Conclusions

This preliminary analysis shows the advantage of combining observations from spatially-resolved helioseismic instruments and disk-integrated, Sun-as-a-star instruments. The noise level in the low-frequency range is reduced and the SNR of the low-degree modes is increased. Moreover, when combining ground-based data with space-based data, there is no signal coming from the daily harmonics. The SNR of the combined data is greater than the SNR of only one instrument even with a longer time series. With the present (MDI, GONG, GOLF, BiSON) and future (HMI, PICARD, GOLF-NG) available helioseismic databases, the combination of observations obtained from spatially-resolved and Sun-as-a-star instruments can be of great interest in the search of the solar low-frequency acoustic and gravity modes.

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