THE EFFECTS OF A NEARLY 100% DUTY CYCLE ON OBSERVATIONS OF SOLAR OSCILLATIONS

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ABSTRACT: Power spectra of window functions with duty cycles between 80% and 99% and with randomly spaced gaps are computed and their effect on observations of solar oscillations are discussed. It is found that for all the cases considered, observations of solar oscillations would not be severely impacted as long as the gap structure is random rather than periodic.

I. Introduction

Currently, the major obstacle to a full helioseismological inversion is the difficulty of resolving and identifying modes in the dense spectrum of solar oscillations. The fact that almost all ground-based observations obtained at a single site are subject to the day/night cycle greatly complicates the task. This cycle produces strong sidelobes centered on each solar frequency, which can overlap and mask other solar frequencies (e.g. Brown 1979). This has proven to be a problem in identifying the splitting of frequencies due to differential rotation (Claverie et al. 1981) and in the identification of long period oscillations (Delache and Scherrer 1983, Bos and Hill 1983). Observations obtained at the South Pole during the Austral summer are free from this cycle but have a maximum duration of only about five days (Grec, Fossat and Pomerantz 1983; Stebbins and Wilson 1983; Harvey, Pomerantz and Duvall 1982). These observations provide power spectra with a frequency resolution of about 2 μHz, substantially higher than the few tenths of a μHz desirable for helioseismology. A network of ground-based stations, or space-based observations from a satellite with a continual view of the Sun, is required to obtain both high frequency resolution and a duty cycle as close to 100% as possible. However, even in these cases a 100% duty cycle will be extremely difficult to achieve. Here, the duty cycle is defined as the fraction of time that the Sun is visible. The purpose of this paper is to investigate the effects of a nearly 100% duty cycle with randomly spaced gaps on the observations of solar oscillations.

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Such duty cycles may be what we can expect to obtain from network or satellite observations.

II. Method

Actual observations result in a time series of velocities that is interrupted during various intervals. This can be represented in the real domain by the product of the actual solar signal and a window function that is 1 when the data is being obtained, and 0 otherwise. In the frequency domain, the observed power spectrum is the convolution of the actual solar spectrum and the spectrum of the window function, neglecting any other instrumental, atmospheric or solar sources of noise. Thus, every real peak in the solar spectrum will be surrounded by an image of the window spectrum. The method used in this study was to simply generate a number of windows with duty cycles of 80% to 99% and then to compute the power spectra of the windows. The gaps in the window function were generated by a number of methods. To simulate the window at a single ground-based site, an ephemeris equation was used to compute the approximate rising and setting times of the Sun at Sacramento Peak Observatory. In addition, a crude model of the weather throughout the year was produced from the author's memory of the seasonal weather patterns. These patterns were basically alternating periods of clear and cloudy weather lasting from 1 to 7 days during the months of November to April, and of clear mornings and cloudy afternoons from May to October. To generate window functions with randomly spaced gaps, the duty cycle D and average length of the gaps, L_g were first specified. This fixes the length of time between gaps, L_b, by

$$L_b = \frac{DL_g}{1-D}$$

Each individual gap had a uniformly distributed random length of between 0.5 L_g and 1.5 L_g and was separated by a uniformly distributed random length between 0.5 L_b and 1.5 L_b. The window was generated with a 1 min time sampling over a total length of 1 year (525,600 samples); thus the power spectrum had a frequency resolution of 31.7 nanoHz.

III. Results

Figure 1 shows the window function resulting from the day/night cycle and the weather at a single ground-based site (SPO). In this and all subsequent figures, the ordinate is the amplitude relative to the central ($\nu = 0$) peak and represents the power of the surrounding window sidelobes relative to any central solar frequency. Figure 1A is the day/night cycle alone, showing the strong periodic structure at 11.57 μHz (1/day) and its harmonics. It is these sidelobes, particularly the first one which has an amplitude of over 60% of the central peak, that cause the severe confusion complicating mode identification. It should be noted that any periodic gap structure will introduce strong sidelobes at the gap frequency and its harmonics. Figure 1B shows the day/night cycle with weather included. The weather adds additional noise at the

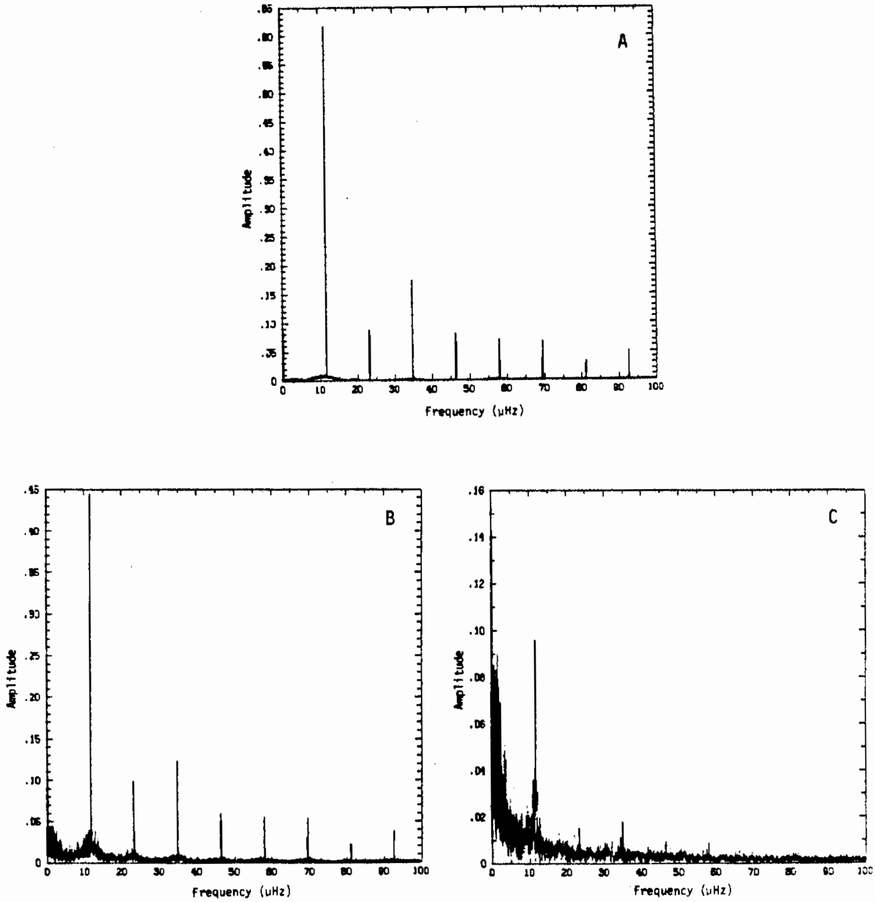

Figure 1: Power spectra of the window function that would result from observations at Sacramento Peak Observatory. A: Day/night cycle throughout year. B: Day/night cycle with approximate weather patterns throughout year superimposed. C: Weather patterns alone. Amplitude is relative to central peak in this and all other figures.

5% level and further reduces the duty cycle. Figure 1C is the transform of the weather alone. It also shows the day/night cycle due to the modelling procedure.

Figure 2 shows the window power spectrum for six different duty cycles of 80, 85, 90, 95, 97 and 99%, all with average gap lengths of 1 hr. Such a gap length might be typical of the observations obtained by a seismology instrument on board a satellite carrrying a number of other instruments with incompatible pointing requirements. The spectra have a dense "grass" structure that peaks at a frequency determined by the average total length of time between gap beginnings ($=L_g/(1-D)$). The amplitude of the peak of noise is quite low, being about 1.5% for the 80% duty cycle and dropping to about 0.2% for the 99% duty cycle. Thus, it appears that all of these duty cycles would be suitable for helioseismology. It should be noted that the 95% duty cycle with 1 hr gaps has its maximum at about 10 µHz, which might affect searchs for rotational splittings of the modes.

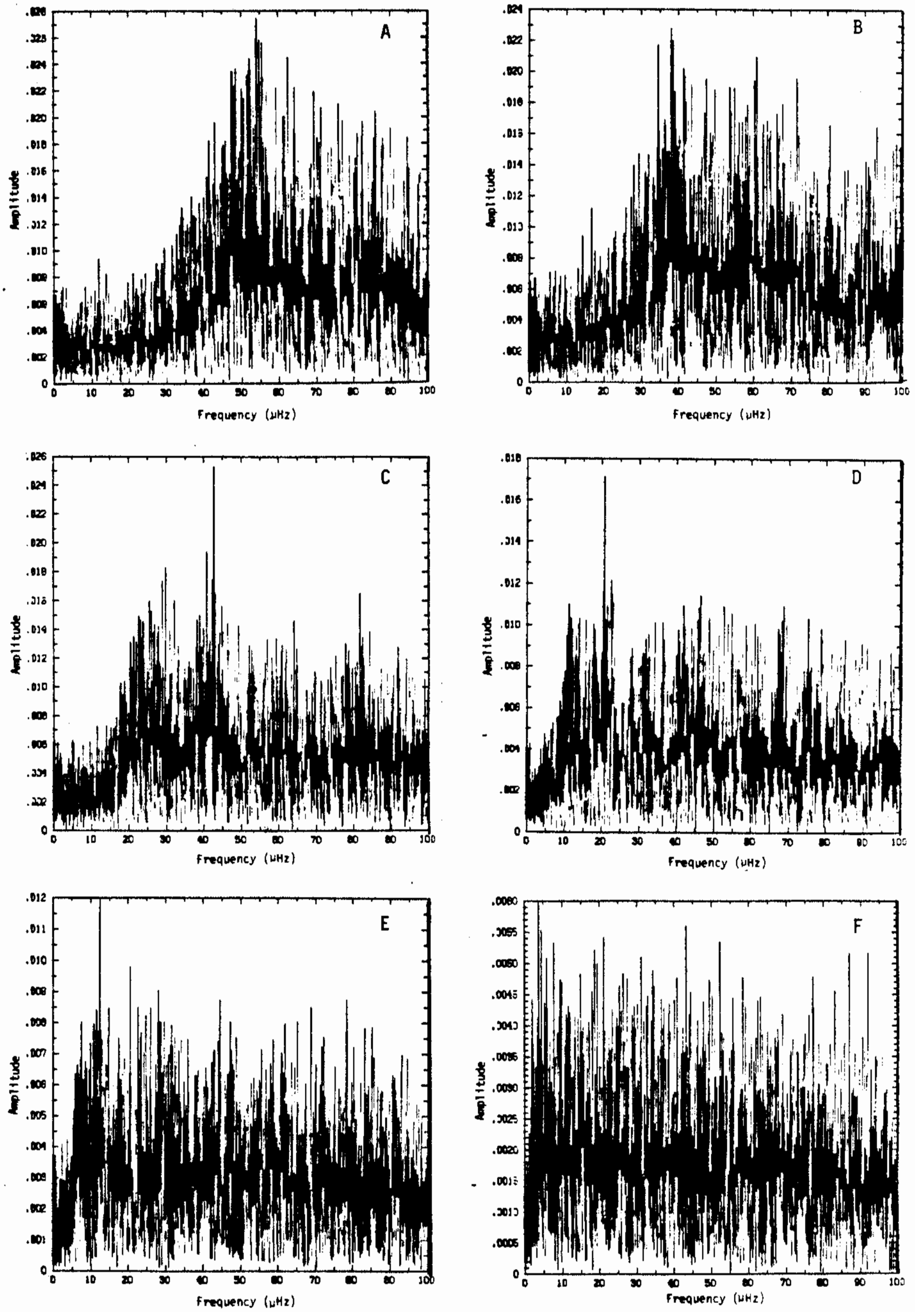

Figure 2: Power spectra of window functions resulting from randomly spaced gaps with an average length L_g = 60 min and with varying duty cycles D. A: D=0.80. B: D=0.85. C: D=0.90. D: D=0.95. E: D=0.97. F: D=0.99.

Figures 3 and 4 show the effect of the average gap length on the window spectrum. Figure 3 illustrates an 80% duty cycle with gap lengths of 6 min (Figure 3A), 60 min (Figure 3B), 600 min (Figure 3C), and 3000 min (Figure 3D). In a space-borne observation context, the short gap length of 6 min might represent data transmission losses, the 600 min gaps might represent minor failures of the TDRS network, and the 3000 min gaps might represent major TDRS failure. Figure 4 illustrates the same gap lengths with a 95% duty cycle. The amplitude of the noise increases as the gap length increases, reaching a maximum of about 10% for the 3000 min case (80% duty cycle). The maximum of the power again varies; for the 95%, 6 min case the maximum occurs at about 138 μHz, which could cause problems when one considers the spacing of the low degree 5 min modes. However, in all cases, it should be noted that the relative power levels of the window functions are quite low, being typically less than 10% of the central power. Thus, probably any of these windows would be suitable for solar oscillation studies.

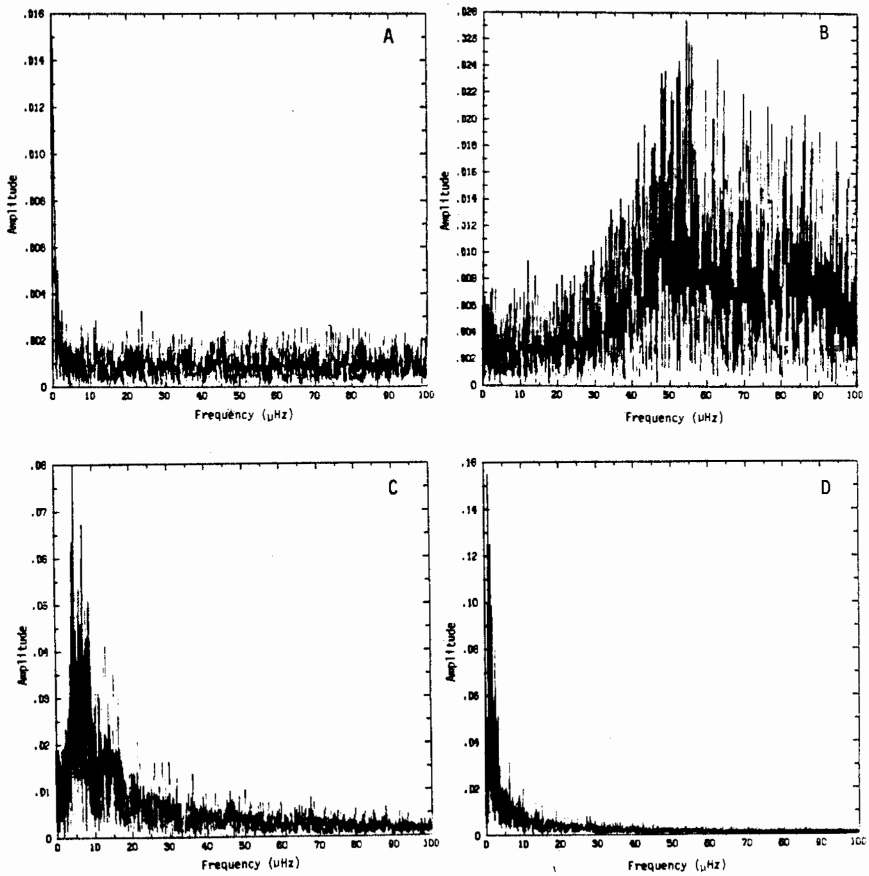

Figure 3: Power spectra of window functions resulting from randomly spaced gaps with a duty cycle D = 0.80 and varying average gap lengths L_g. A: L_g=6 min. B: L_g=60 min. C: L_g=600 min. D: L_g=3000 min.

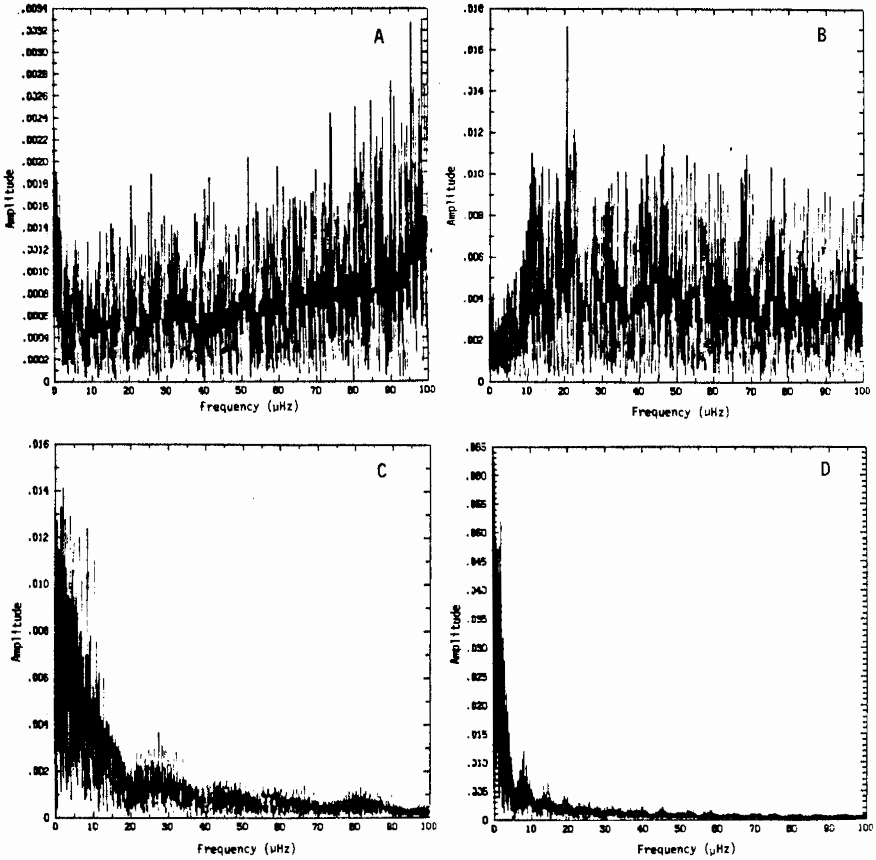

Figure 4: Power spectra of window functions resulting from randomly spaced gaps with a duty cycle D = 0.95 and varying average gap lengths L_g. A: L_g=6 min. B: L_g=60 min. C: L_g=600 min. D: L_g=3000 min.

IV. Conclusions

It is apparent from these power spectra that almost any of the duty cycles and gap lengths considered here would pose little problem to helioseismological inversions, as long as the gaps are randomly distributed in time. The main goal is to avoid periodic gaps of any sort, as these introduce prominent sidelobes surrounding each solar frequency. It is possible to tailor the window by inserting additional gaps in the data, thereby moving the maximum of the window power spectrum away from regions of interest. However, this of course further degrades the duty cycle, and, if one already has a random distribution of gaps, probably would not be warranted. When one considers the performance of either a satellite-borne instrument, or a ground-based network to obtain solar oscillation data, one must compute the power spectrum of the window function to assess the level of confusion generated by any possible sidelobes.

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