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Data Analysis
of the
LPSP Experiment on OSO-8

FINAL REPORT

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1. SUMMARY

The first and statistically most reliable step in the data analysis - the computation of the veritical phase lag between photospheric and chromospheric oscillations - has been completed. Unfortunately, the error associated with this calculated phase lag is so great that the result has no physical significance. Since the subsequent data analysis that was originally planned would have much larger associated errors, it was concluded that the data available is insufficient to allow any meaningful results to be derived. Accordingly, the project has been terminated. The reasons for the failure of the data are discussed. There are two basic reasons for this failure; 1) the very low signal to noise ratio of the raw data, and 2) the small statistical sample that resulted from the very small number of usable orbits.

The final phase of data analysis is described. Finally, some comments and recommendations of a general nature are made concerning this entire contract effort. It is hoped that at least some lessons can be learned from this particular Guest Investigator project, so that future Guest Investigator programs can be pursued more effectively, and with less risk.

2. THE OSO-8, LABORATOIRE DE PHYSIQUE STELLAIR ET PLANETAIRE (LPSP) DATA FROM ORBITS 1330, 1331 AND 1345

Orbits 1330, 1331 and 1345 were the only three orbits from this program where usable data was obtained from the same area on the Sun simultaneously by OSO-8 and Sacramento Peak Observatory (SPO). Accordingly, data analysis concentrated on these three orbits. The hope was that if this analysis was successful, the results would indicate some technique by which conclusions could be drawn from the remaining data despite the fact that the two instruments did not view the same region of the solar surface. This hope was not to be realized.

Data from each of the three prime orbits was extracted from the tapes and reformatted into a time sequence. Due to the low count rate of the LPSP instrument, the time sequences were integrated over the internal raster scan of the LPSP telescope, thereby sacrificing all spatial information on the oscillations in an effort to gain maximum signal-to-noise in the subsequent temporal analysis. Samples of these time sequences from each of these three orbtis are shown in Figure 1. Each of the orbits was programmed slightly differently in accordance with the original intention to acquire a variety of data.

Orbit 1330 emphasized time variations in the profile of the Mg II k line. To increase sensitivity, the wide exit slit was used with the result that the other channels were sacrificed. (In this configuration, the other lines are shifted away from their respective exit slits, and only continuum is observed.) In Figure 1a, the difference between the counts in the blue wing and the counts in the red wing, which is proportional to line of sight velocity, is plotted. The long term drift caused by the orbital motion of the satellite is obvious. Oscillations with a period of three to five minutes are not obvious.

Orbit 1331 emphasized the Lyα profile. As before, the other channels were sacrificed in order to scan the Lyα profile with the wide exit slit. The blue wing-red wing difference is shown in Figure 1b. Despite the integration over x and y and the use of the wide exit slit, the count rate was still so low that the result was almost pure noise.

Orbit 1345 was devoted to a search for rapid oscillations. Therefore the grating was held fixed and the exit slits arranged so that the core of the Mg II h line came through a wide exit slit. This data is shown in Figure 1c. The count rate is indeed high, but rapid oscillations are not obvious.

The power spectra of all the time sequences from the three prime orbits were calculated to search for the presence of oscillatory power. Sample power spectra are shown in Figure 2. The means and linear trends have been subtracted from the data prior to Fourier transformation. Figure 2b, the Lyα and velocity power spectrum is a textbook example of white noise combined with large statistical fluctuations. The Mg II k, velocity and Mg II h intensity power spectra display some oscillatory power in the frequency range of 4 to 10 mHz, in addition to residual low frequency noise. Of all the power spectra, that of the Mg II k velocity data from orbit 1330 (Figure 2a) appeared to display the statistically most significant oscillatory power. Therefore, it was selected for comparison with the ground based data.

3. THE OSO-8/SPO PHASE LAGS

The very first step in the comparison of the OSO-8 data with the SPO data is to calculate the phase lag and therefore the time delay between an oscillation observed in the photosphere (SPO data) and that same oscillation observed in the chromosphere (OSO-8 data). Such an observed phase lag leads directly to an observed phase velocity in this crucial altitude range. The technique for calculating this phase lag was to cross correlate the two data sets as a function of time lag. This cross-correlation is shown in Figure 3. Specifically, this particular pair is orbit 1330, velocity in the photospheric line

Feλ 8468 cross-correlated with velocity in Mg II k. Both time sequences were observed simultaneously at the same 10 x 10 arc sec patch on the sun. It is important to note that of all the possible pairs of data that could be cross-correlated, this particular pair was carefully selected in order to provide the best possible cross-correlation. There appears to be a reasonable cross-correlation for time lags between -500 sec and +500 sec which indicates that the chromospheric velocity oscillation lags the photospheric oscillation by about 140 seconds.

At this point, the critical question is: How accurate is this observed phase lag? To calculate this accuracy, the standard technique of Goodman (1957)* was employed. This technique requires the intermediate calculations of coherence and phase spectra of two fluctuating quantities and furnishes a statistical basis for estimating 80% "confidence limits" (essentially 2σ error bars) of the phase lag at any chosen frequency. These confidence limits are a function of the degree of coherence and the number of statistically independent samples available. For the cross-correlation of Figure 3, the coherence in the frequency range where power exists at all is only 60%, which is very low for such a cross-correlation analysis. The number of statistically independent samples is, of course, one. From this, the 2σ error bars on the 14 second time lag can be calculated: 130 seconds! This means that the phase lag could be anywhere from essentially zero to 270 seconds. Stated physically, the waves in the solar atmosphere could be either standing waves or traveling waves with virtually any physically possible phase velocity! No physical conclusion can be drawn from this phase lag analysis.

*Goodman (1957) Scientific Papers No. 10, Engineering Statistics Laboratory, New York University.

Since this phase lag was calculated from the best pair of time sequences, any further phase lag calculation would be even less meaningful. Likewise, the next expected step in the analysis, the calculation of oscillatory energy flux at different heights in the atmosphere, requires a knowledge of vertical phase velocity at several heights, and would be subject to even greater error than this single, "best", phase lag. The only other result expected from this project, the change in horizontal scale of the oscillations with height, was sacrificed at the start of the analysis when the data was integrated over x and y in order to improve the signal to noise ratio.

We are finally driven to the conclusion that the basic data set is not adequate to derive the simplest conclusion about the height dependence of the oscillations. The project has been terminated.

4. THE SOURCE OF THE MEANINGLESS RESULTS

Why did the data fail so completely to reveal anything about the chromospheric oscillations? There are two fundamental reasons. The most obvious reason is the high noise level that resulted from the low sensitivity of the LPSP instrument. This noise level completely obliterated the Lyα signal (Figures 1b and 2b) and seriously degraded the Mg II data. It is also probable that this noise level is responsible for decreasing the coherence between the Mg II k time sequence, thereby increasing the error in the phase lag to an intolerable level.

The second basic, though less obvious, reason is the low sampling statistics that resulted from the fact that only three orbits worth of usable data were collected. Furthermore, each of these three orbits had been programmed to collect data in a different line, so the results from the three orbits could not be averaged together. How serious was the effect of this low sample? The best idea can be obtained by considering ground based observations of photospheric oscillations, which by now have a very long and well documented history. In nearly all original data records, it can be seen that oscillations are present with significant amplitude about one third of the time. With only three orbits worth of data, this project had, at best, an even chance of seeing any oscillations at all! On top of these odds, the lack of any capability to average over more than one observed set of wave trains probably doomed the analysis effort.

5. GENERAL RECOMMENDATIONS

Despite the fact that nothing was learned scientifically from this project, there are still some important lessons to be learned about how to conduct a Guest Investigator project. To put this question in perspective, it should be remembered that OSO-8 sponsored the most ambitious Guest Investigator program ever attempted by NASA, and that this particular Guest Investigator project involved some of the most sophisticated operational and data analysis techniques ever attempted with any satellite. Therefore, it must be expected that this project pioneered considerable new ground in the utilization of satellites by Guest Investigators. It is therefore important to ask how successful the overall operation was, and what difficulties were encountered that should be avoided in the future.

In retrospect, it is clear that this project was too sophisticated for a Guest Investigator effort. It entailed too many requirements for near-nominal operation of the satellite instrument. In other words, the project was not designed to "degrade gracefully". Since a Guest Investigator has no respoonsibility or authority over the design and operation of a satellite instrument, it would be a mistake for him to design an observing program that requires nominal instrument performance. The "pioneering" experiments should clearly be left to the principal investigator and his team.

One other major recommendation emerges from the experience gained in this contract. There should be much greater communication and cooperation between Guest Investigator and Principal Investigator before, during and after the execution of the Guest Investigator's observing program. The idea that a Guest Investigator can come to a satellite control center, operate the instrument for a few days, then take his data home for analysis, is naive in the extreme. In this particular project alone, there were many specific instances (which will be left undocumented) where the attempt to operate in this "individualistic mode" resulted in inefficient operation of the satellite, degraded data and duplication of effort. The prime example of this inefficiency is probably in the early phase of the data analysis. A significant portion of the funds in this contract was expended writing computer programs to read the satellite data tapes, reformat and calibrate the data, etc. These programs probably were an exact duplication of those written by the P.I. team. A combined programming effort would have been far more cost effective.

From the standpoint of efficiency and quality of data, there appears to be no limit to the desirability of closer P.I.-G.I. cooperation. It seems more effective therefore to organize a rather formal team consisting of the P.I. and all the G.I.s fairly early in the life of a satellite program, with the overall tasks and the individual responsibilities spelled out clearly. The G.I.s should be allowed to become closer members of the "team", and the P.I. should be able to expect greater assistance from the G.I.s as well as significant involvement in the scientific results. Furthermore, as future satellite instruments become even more complicated and sophisticated, it can be expected that this requirement for more coordination and organization will become even more severe.

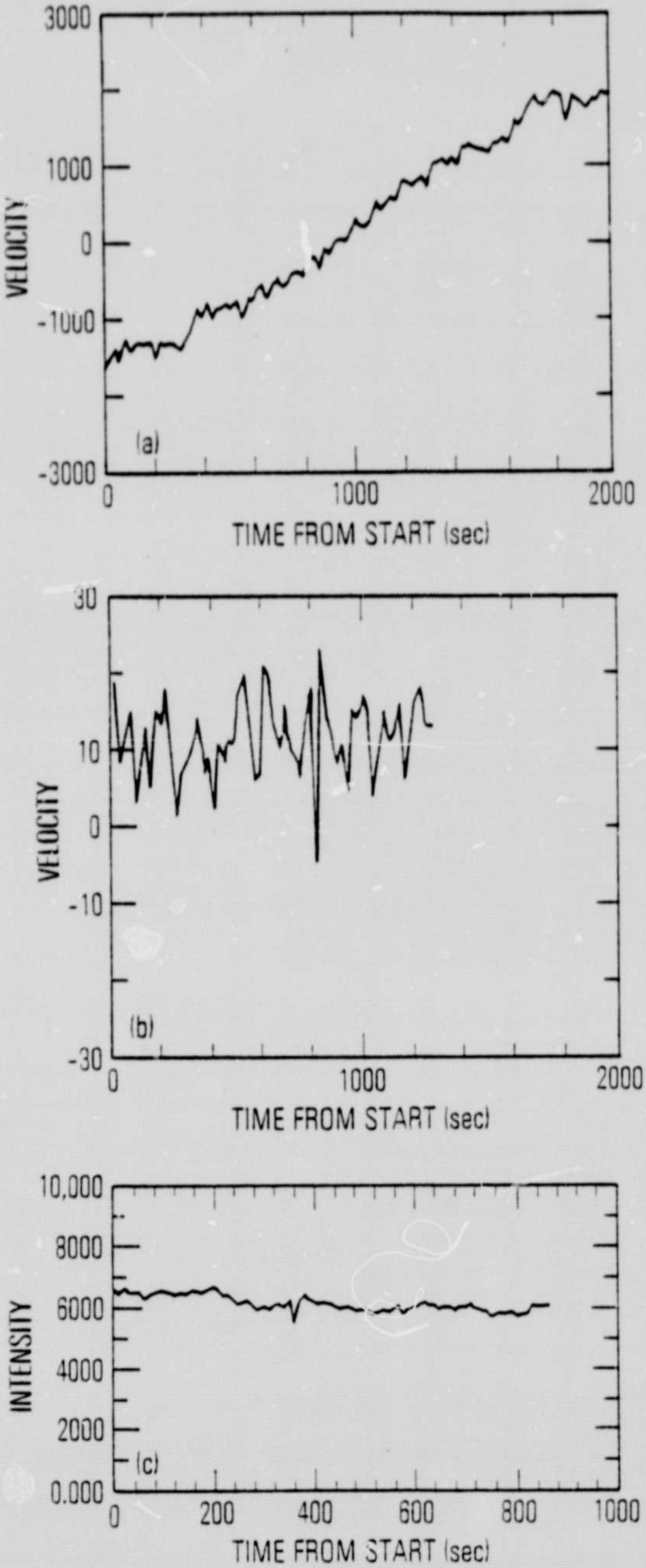
In conclusion, it can be said that this entire project pushed a little too hard in several different directions, and as a result all that was learned were some lessons about how not to push too hard in the future.

Figure Captions

Figure 1. Samples of raw data from each of the three prime orbits. (a) Orbit 1330, velocity measured in the wings of the Mg II k line. The units are the difference between the counts in the blue wing and in the red wing. (b) Orbit 1331, velocity measured in the wings of the Lyα line. The units are the same as in (a). (c) Orbit 1345, intensity of the Mg II h line. Intensity is measured in counts.

Figure 2. Power spectra of the data displayed in Figure 1. The mean and linear trends were removed from the data before the power spectra were calculated. Power is expressed in arbitrary units. Only orbit 1330, (panel a) displays significant oscillatory power. All other power represents either noise or long term drifts.

Figure 3. The cross-correlation between the OSO-8 data (orbit 1330, Mg II k velocity) and the Sacramento Peak Observatory data (Fe λ 8468, velocity) taken simultaneously from the same patch on the sun (10 arc sec x 10 arc sec).



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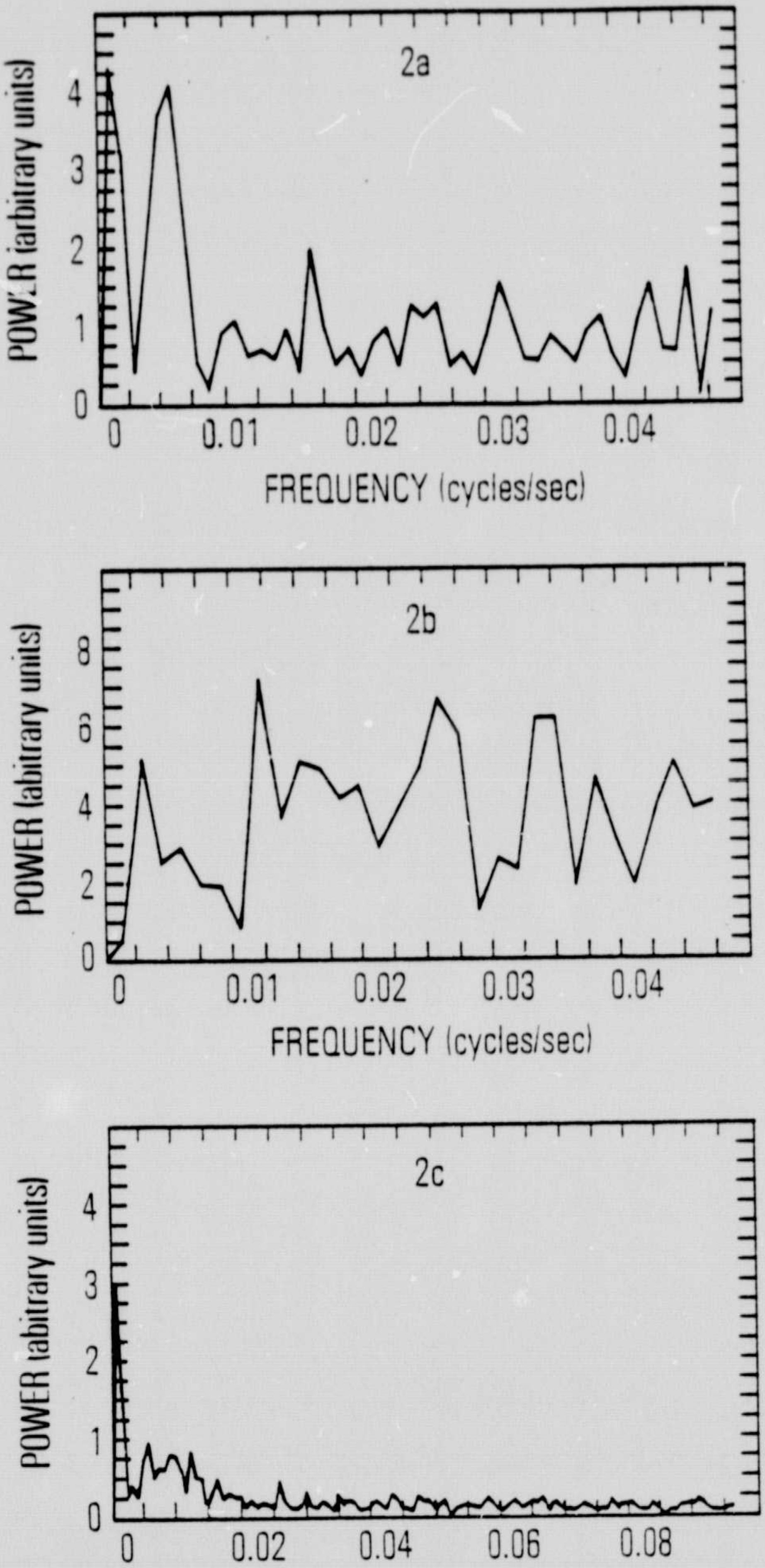
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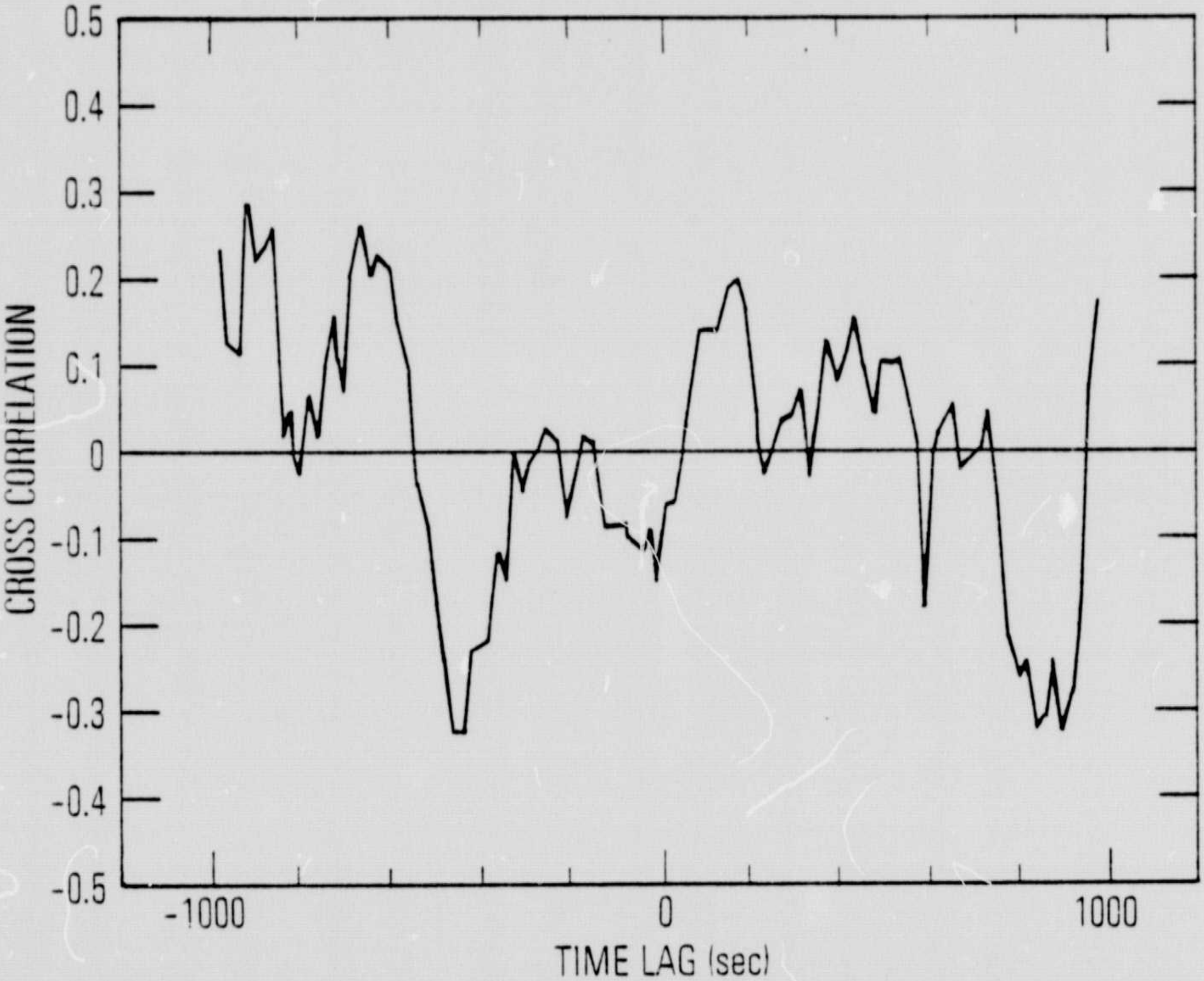

CROSS CORRELATION
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-1000
0
1000
TIME LAG (sec)