Dave Boore's Notes:

IS FILTERING ENOUGH?

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Is low-cut filtering all that is needed in processing strong-motion data to remove low-frequency noise? The answer is "not always" (although in most cases flow-cut filtering seems to be all that is needed). The story is told in the attached plots showing processing of a record from the 2/21/2000 $M_L = 4.5$ Loma Linda, CA, earthquake.

The first two figures appeared in Boore *et al.* (2002). The discussion from the paper appears below. Note that it was primarily concerned with seeing if the quadratic baseline fitting used in Boore *et al.* (2002) was adequate for the Loma Linda record. I will include the text from the paper just below this paragraph. I have redone the figures using acausal filtering (causal filtering was used in the Boore *et al.*, 2002, paper) and added some figures below the first two figures. The story does not change and shows that for the type of "noise" produced by the series of baseline offsets occurring on the Loma Linda record that filtering along is not adequate. This is an important exception to the usual case when filtering alone seems to work well.

Here is the text from Boore *et al.* (2002):

Example from the 02/21/2000 Loma Linda Earthquake

> We now discuss processing of the bottom trace shown earlier in Figure 3 for which the velocity trace suggests a series of small step changes in acceleration. Our motivation is to see how well the "generic" quadratic-fit, filtering approach, or just filtering alone, will work on a record such as this. The comparisons of the derived velocities and displacements are shown in Figures 20a and 20b. Filtering alone, or in combination with removal of a constrained quadratic fit to velocity, gives unrealistic-looking waveforms. This is not surprising in view of the character of the uncorrected velocity, which indicates that a series of four steps occurred in the acceleration. Choosing the times of these steps from visual inspection of the top trace in Figure 20a, we made corrections based on a sequential series of constrained linear lines fit to the velocity traces (this correction could be determined in one step by finding the coefficients of a series of hinged straight line segments). The bottom two traces in Figure 20 show the results of this correction with and without filtering. Subjectively, the bottom trace looks the best, although we have no way of knowing if the oscillations in the displacement trace are real or not. The period of the late oscillation in the bottom trace is about 10 sec, whereas the filter period is 14.3 sec--- thus the oscillation probably is not a filter transient. Note the low amplitude of the peak displacement--- about 0.01 cm.

It is interesting to note that although the velocity waveforms are somewhat different, the peak motions are rather similar (except for the uncorrected velocity shown as the top trace of figure 20a). This is good news, for it means that routine processing can yield peak velocity values that can be used for the construction of ShakeMaps (Wald *et al.*, 1999)---corrections tailored to the data may not be needed. This cannot be said for the peak displacement, however. As shown in Figure 20, the waveforms and the peak displacements are quite different (the traces are plotted with individual scaling). The response spectra for the corrected accelerations are shown in Figure 21. As judged from Figures 20 and 21, the tailored correction based on fitting a series of line segments goes a long ways toward removing the baseline problem, even without filtering. Note that even for such a small earthquake, the digital recording seems to give good information for periods as long as about 10 sec and for displacements as small as 0.01 cm.

REFERENCE

Boore, D.M., C.D. Stephens, and W.B. Joyner (2002). Comments on baseline correction of digital strong-motion data: Examples from the 1999 Hector Mine, California, earthquake, *Bull. Seismol. Soc. Am.* **92**, 1543—1560.

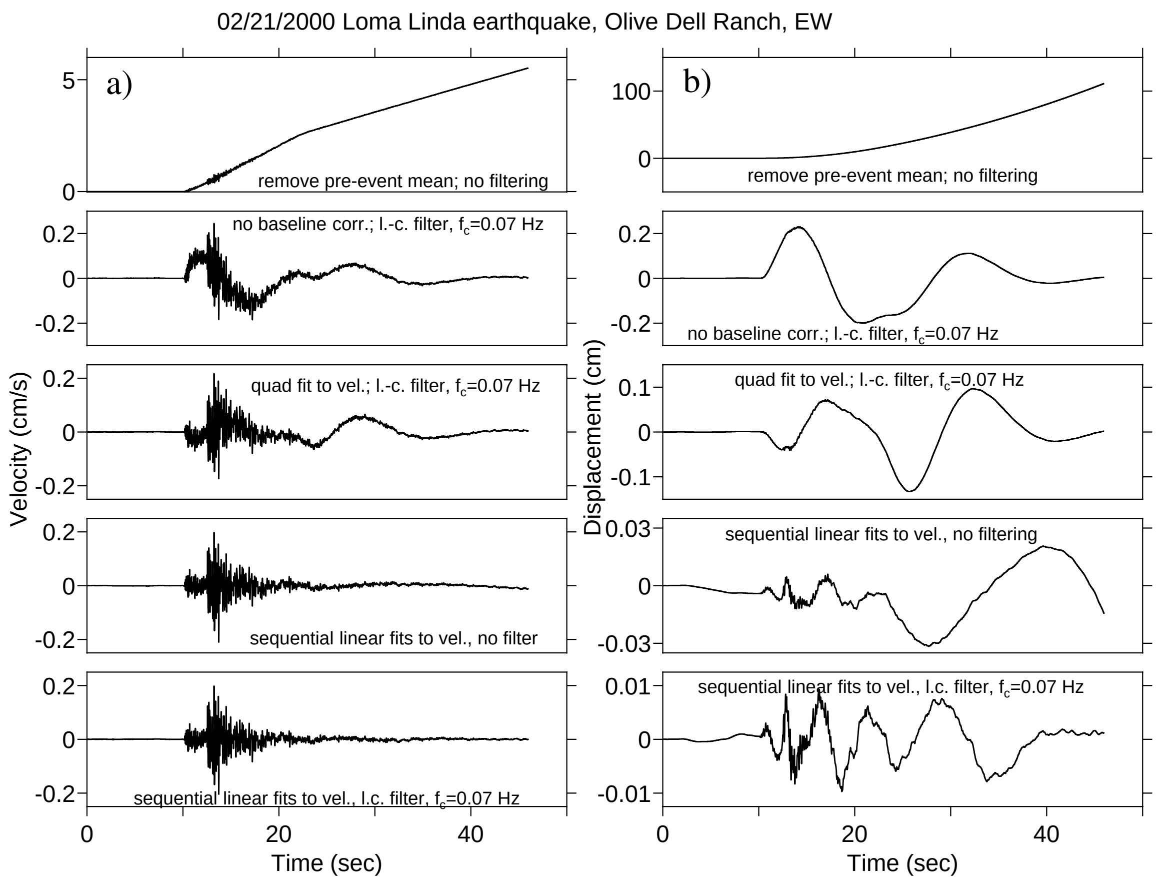

Figure 20 from Boore *et al.* (2002). a) Velocities and b) displacements from various processing schemes applied to the acceleration time series shown in the bottom trace of Figure 3a. The earthquake producing the ground motion was much smaller than the Hector Mine earthquake ($M_L = 4.4$, compared with $\mathbf{M} = 7.1$ for Hector Mine). "l.c." stands for "low-cut".

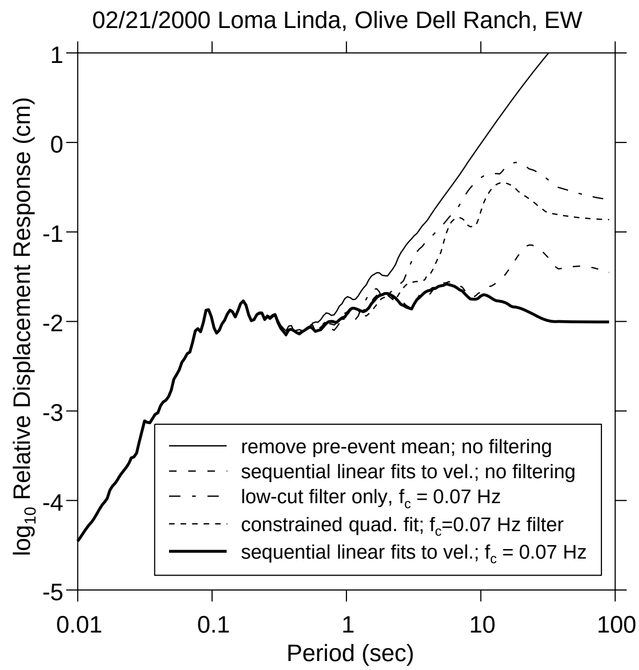

Figure 21 from Boore *et al.* (2002). Five-percent-damped relative-displacement response spectra from the accelerations processed as in the previous figure.

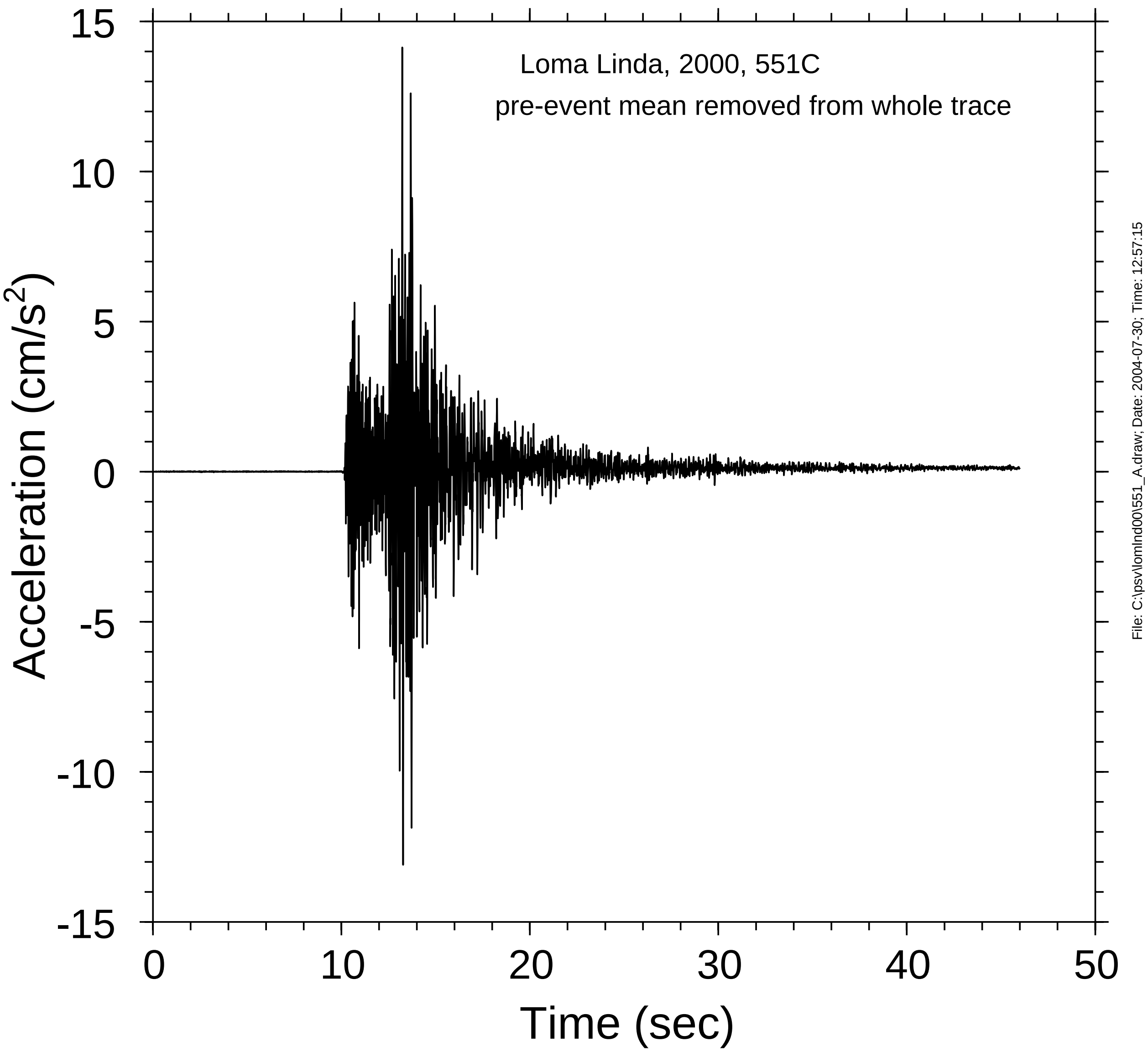

Fig. 1. Acceleration, after removing pre-event mean (this minimal processing was done on all subsequent figures).

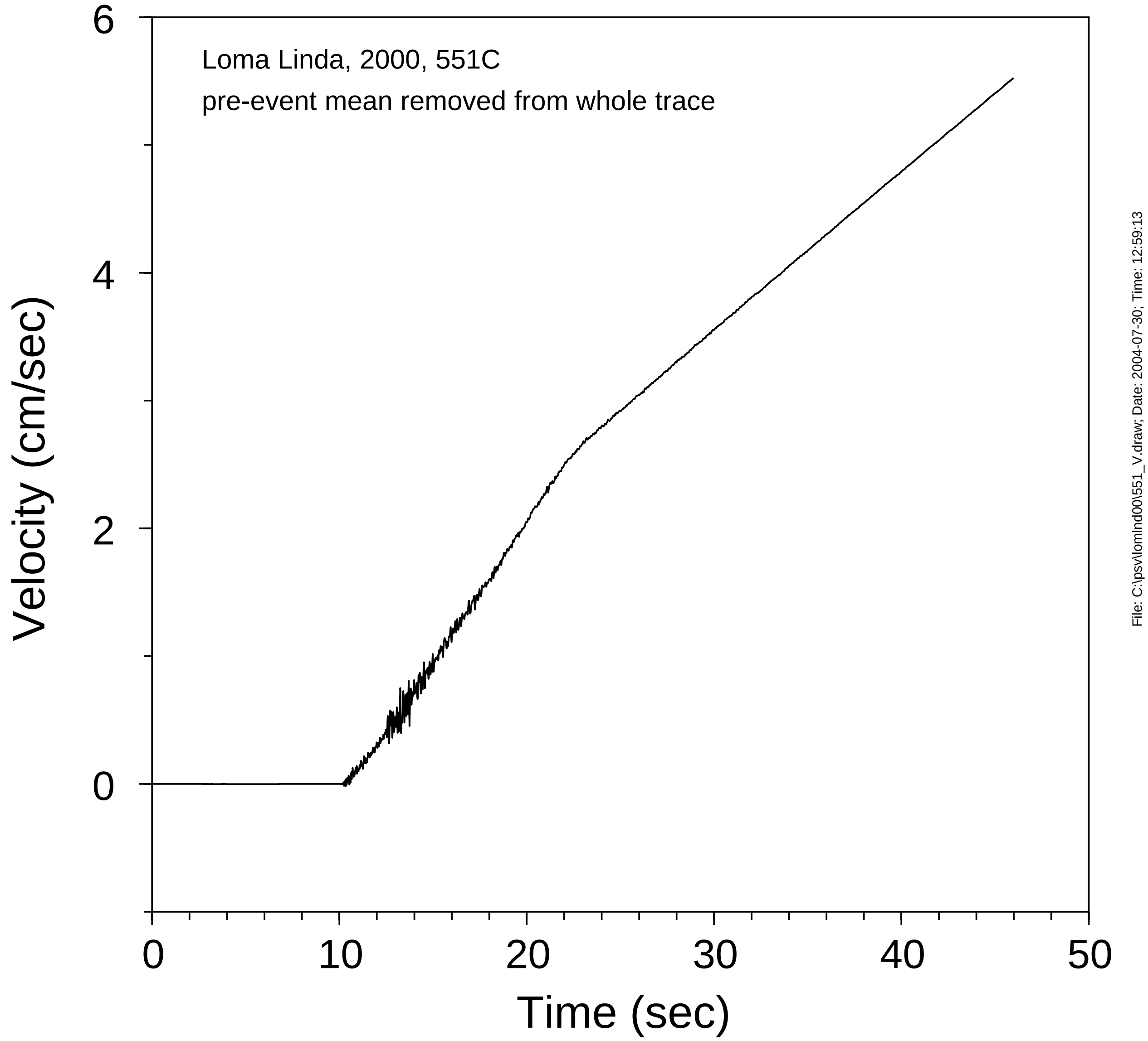

Fig. 2. Velocity. Note appearance suggests a series of steps in the acceleration trace. By using a straightedge, I approximated the baseline drift with 4 line segments.

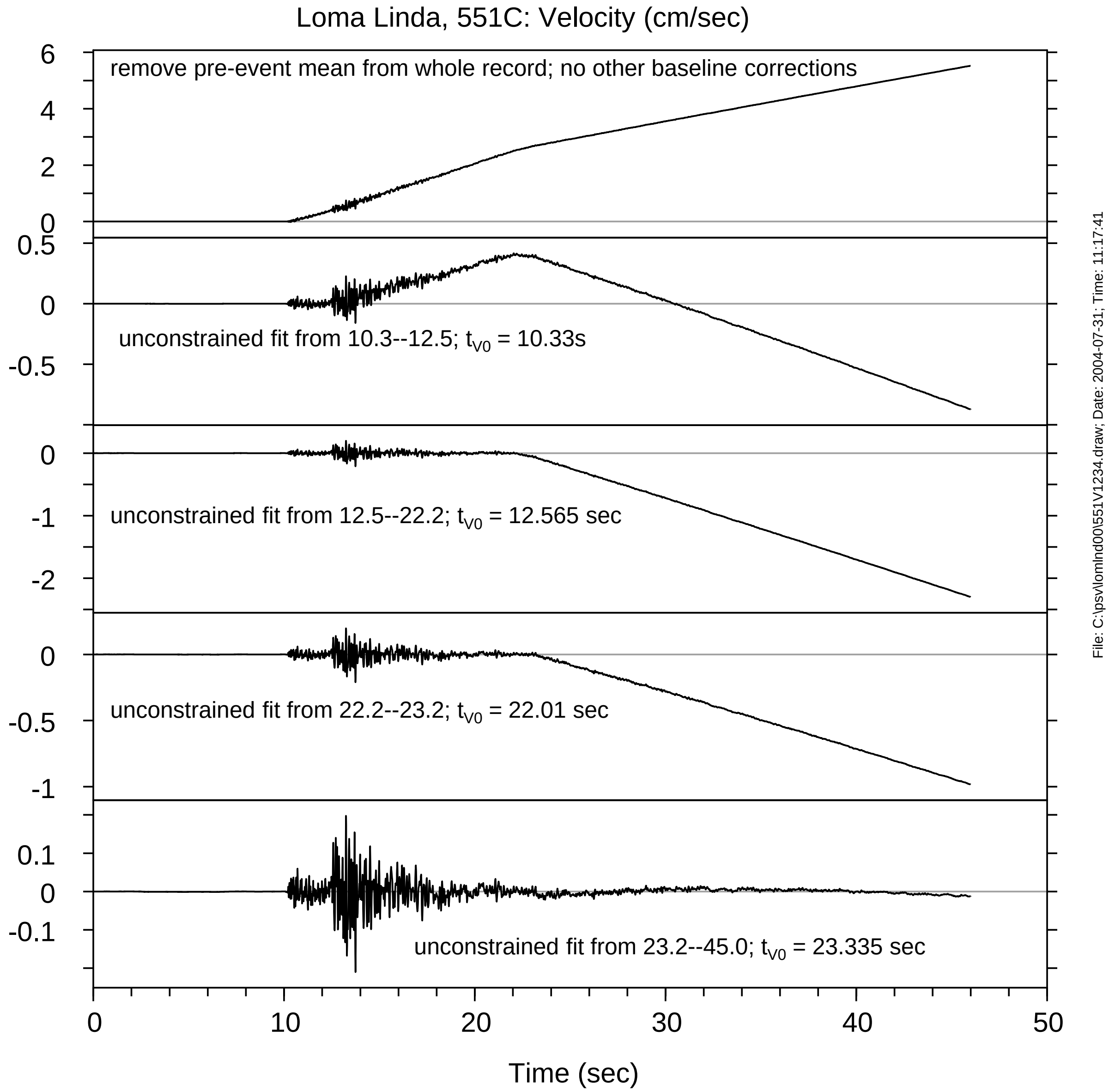

Fig. 3. Iterative correction for the 4 line segments. I did not want to take time to dust off my multisegment program, so I simply processed the acceleration four times.

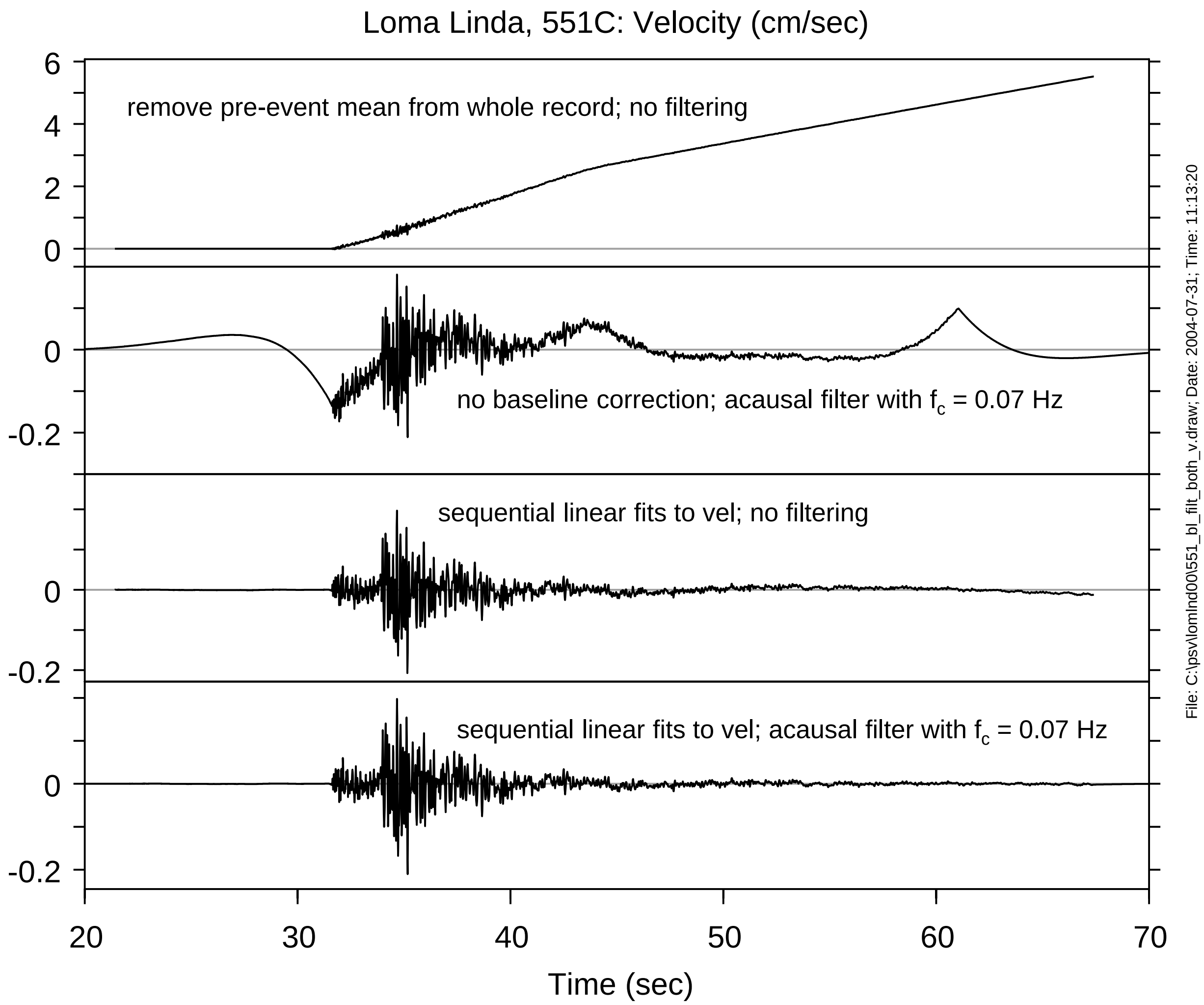

Fig. 4. Velocity for a number of methods of baseline correction and filtering. The 2nd trace from the top shows the result of low-cut filtering with no baseline correction (I chose the corner = 0.07 Hz subjectively). The bottom trace corresponds to the multisegment fits, with low-cut filtering.

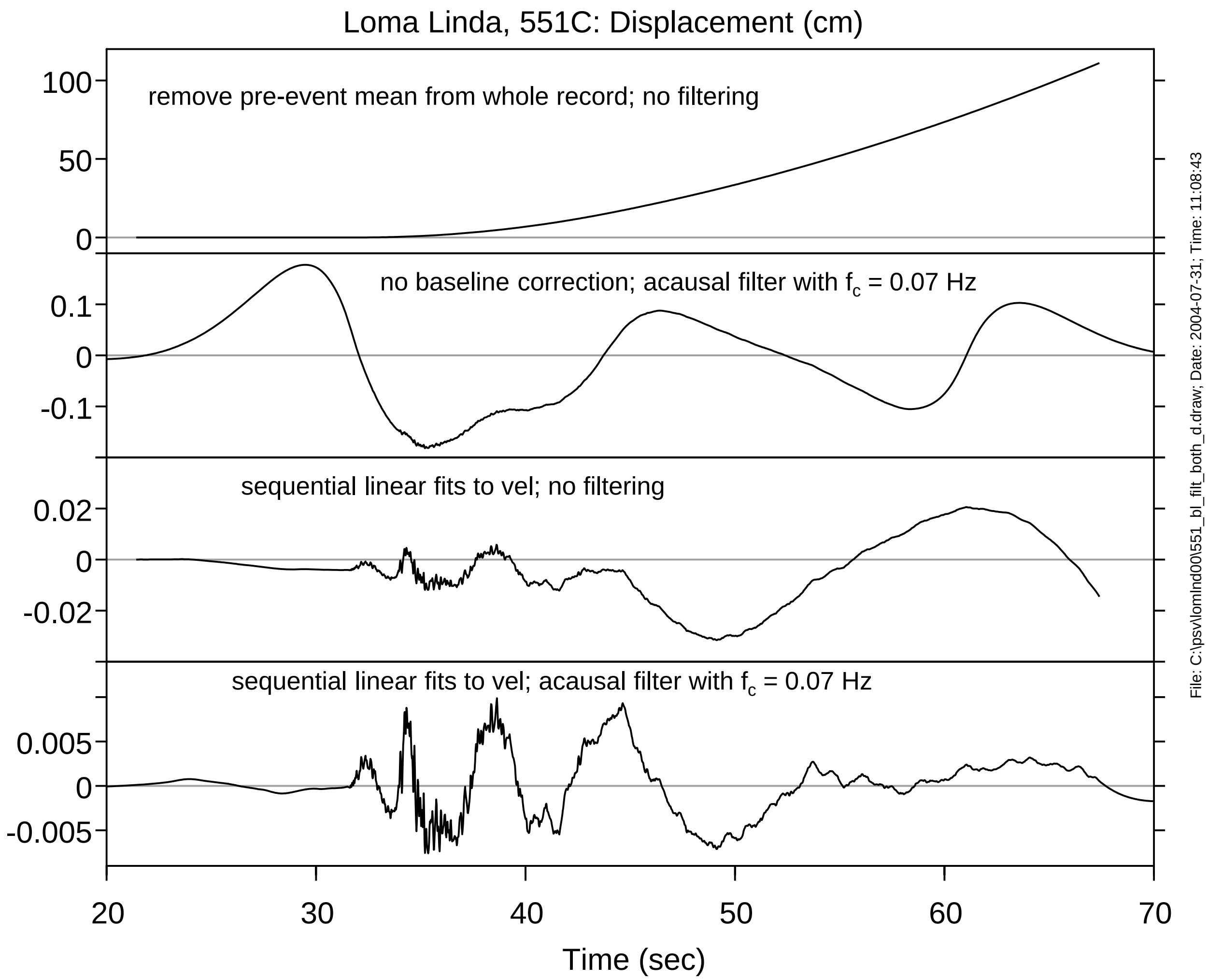

Fig. 5. Displacements for the velocities in the previous figure. Note independent scaling of each trace. Of course, there is no way of knowing what is "truth", but the displacement from the filtered, multisegment-corrected acceleration (bottom trace) doesn't look bad. I am not sure if the approximately 10 sec oscillation in the last half of the record is real or not, but recall that the filter period is 1/0.07 = 14.3 sec, so I do not think the oscillations are a filter transient. Also note the very small amplitudes of the motion--- about 0.01 cm. The low-cut-only processing yields a displacement trace dominated by the filter transient and much larger than the bottom trace.

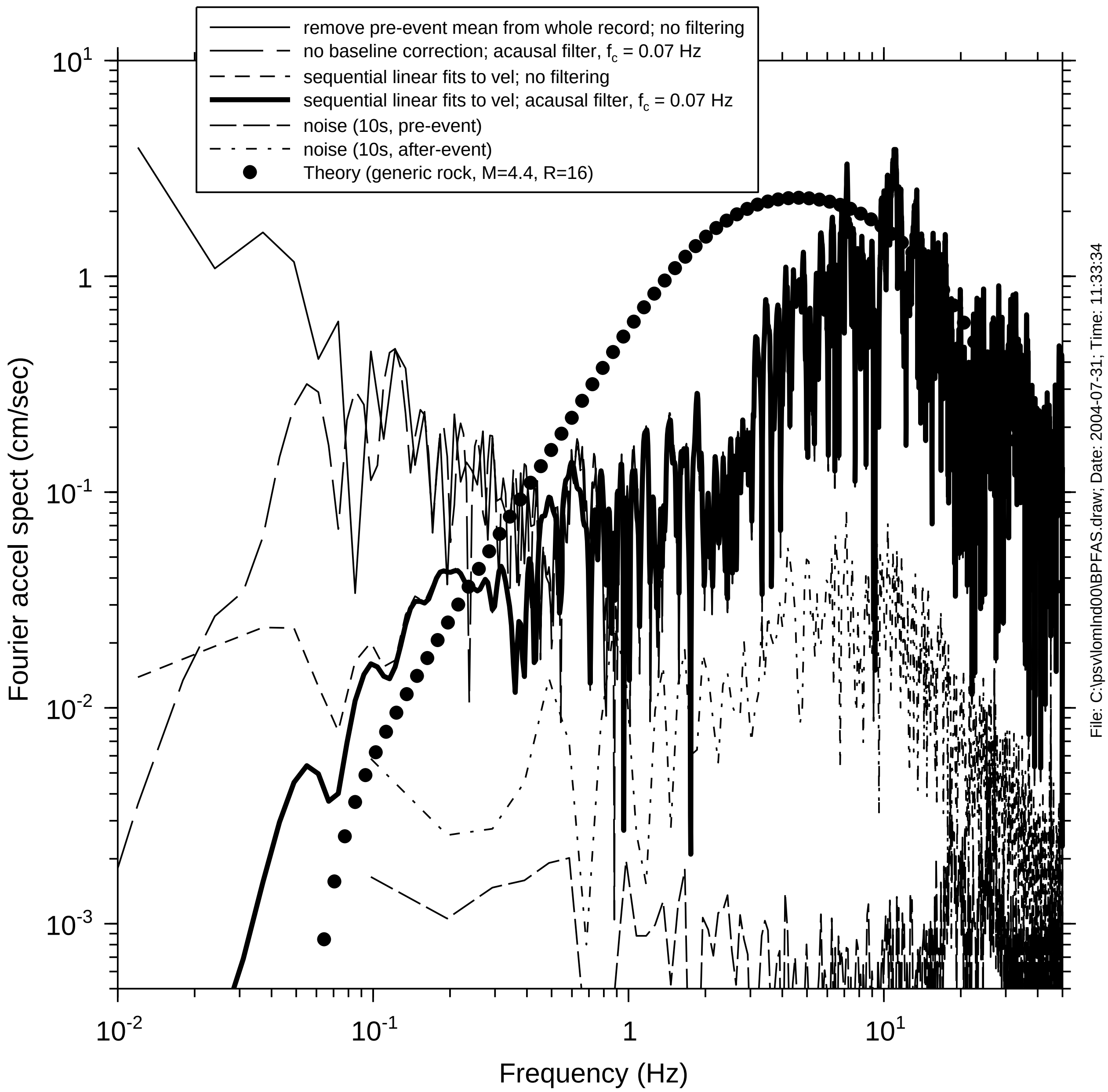

Fig. 6. The Fourier acceleration spectra for the acceleration time series from which the velocities and the displacements shown in the previous two figures were derived, along with the spectra of 2 10-sec noise samples (pre-event and near the end of the record). Also shown is the theoretical spectrum, including low-cut filtering with a 0.07 Hz low-cut filter. Clearly, making the multisegment baseline correction buys a lot (compare the short-dashed line and light solid line)--- it seems that we can obtain reasonable results to 0.1 Hz, where “reasonable” is a subjective judgment based on the appearance of the spectra. The “noise” introduced by the baseline offsets is sufficient that simple filtering by itself is not adequate for this record (this ``noise" is not the same as the pre- and post-event noise whose spectra are shown here; that noise is much less important than the ``signal-generated noise" produced by the baseline offsets).

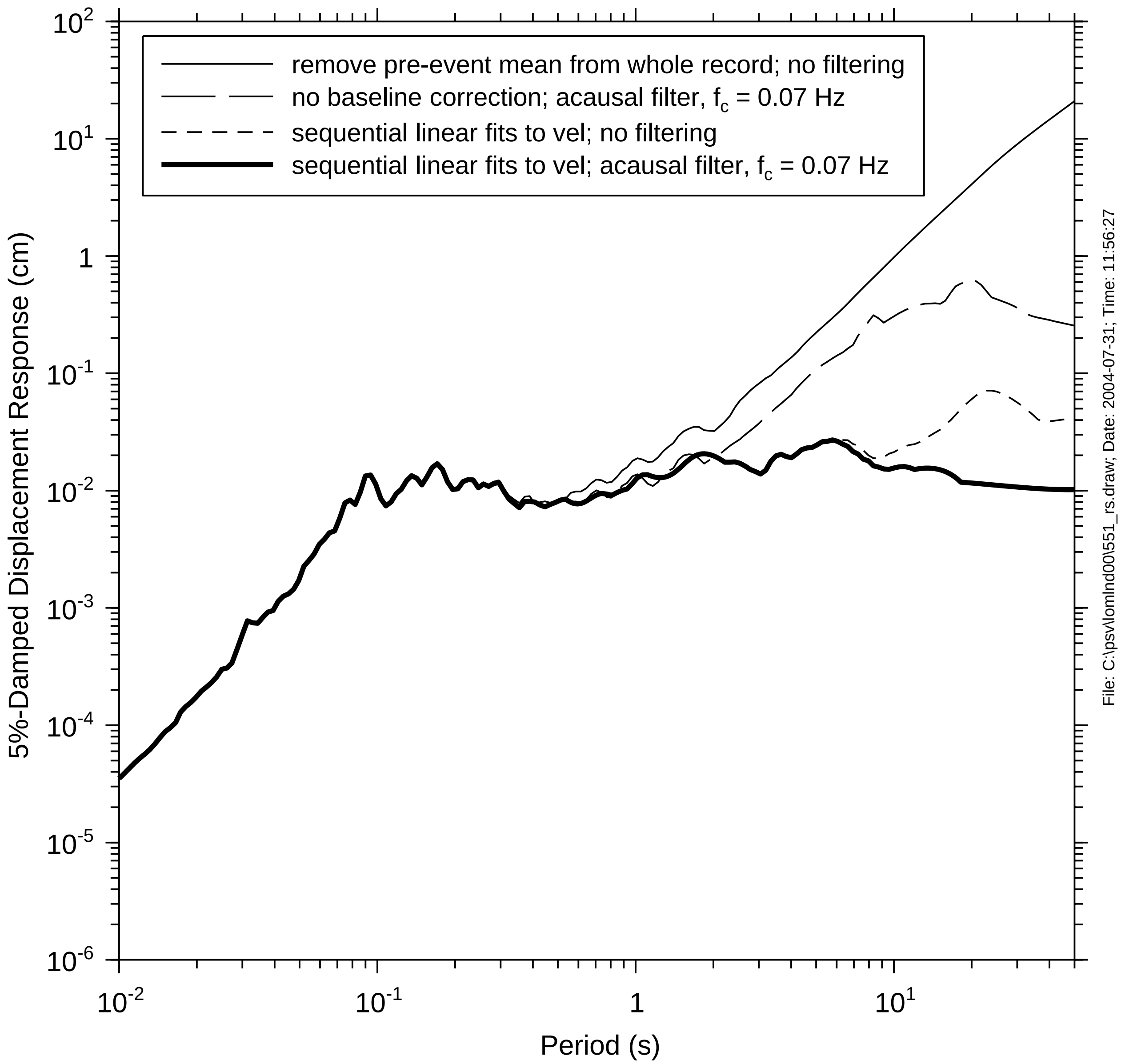

Fig. 7. The response spectra for the acceleration time series processed in several ways. As seen in the Fourier spectra, making the multisegment baseline correction buys a lot (compare the short-dashed line and light solid line)---it seems that we can obtain reasonable results to 0.1 Hz, where "reasonable" is a subjective judgment based on the appearance of the spectra.