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7.8 Time shifts of phase onsets caused by SNR variations

Introduction

In section 7.3 of this report (Kværna, 1996) we described an experiment where quality metrics associated with the AR-AIC onset time estimation method were evaluated by successively reducing the SNR by adding scaled noise samples. The evaluation was done by comparing the AR-AIC onsets estimated on SNR reduced simulated records with the manual time picks of the original high SNR signals (SNR > 100). We were able to derive onset quality metrics that could be used both for selecting the best AR-AIC model as well as for flagging onsets that had a high probability of being incorrect.

Another interesting finding was that we could clearly observe the SNR dependent delay of the automatic AR-AIC phase onsets, see Fig. 7.8.1. In this figure we have divided the onsets into 5 SNR categories. For each category we have computed the median and the inter-quartile range of the time difference between the $AR\text{-}AIC_{F+S}$ onsets and the corresponding reference phase picks. The original 83 phases included in Fig. 7.8.1 are mainly teleseismic P-phases from different events recorded at the GSETT-3 stations, and should thus include a wide variety of signal signatures. From the good correspondence between manual phase picks and automatic AR-AIC onsets found by Kværna (1995), we could also infer that the SNR dependent delay of the phase onsets would also apply to manual phase picks done by an analyst.

We will in the following present in more detail the results for a couple of specific events.

Impulsive signals; Lop Nor nuclear explosion

Teleseismic P-phases from nuclear explosions are usually among the most impulsive signals observable, and we would therefore expect a relatively small time delay when the SNR is reduced. Fig. 7.8.2 shows P-phases recorded at a few of the GSETT-3 stations from the 17 August 1995 Chinese nuclear test at Lop Nor.

In Fig. 7.8.3 we have plotted the corresponding simulated SNR dependent delays for the phase onsets. Notice that for the SNR category 2.8-5 the onset estimation was quite unstable, such that these results should be interpreted with caution. It is, however, interesting to observe that even for the SNR range 20-50, a consistent time delay of 0.2 seconds is found, and for the SNR range 5-10 the delay is increased to 0.5 seconds.

Emergent signals; Yunnan earthquake

This large earthquake located in the Yunnan province of China had an m_b of 6.3 and an M_s of 6.5 (PDE). As seen from the P waveforms of Fig. 7.8.4, the signals are quite complex and emergent, and it is therefore reasonable to expect that the estimated onsets will become strongly delayed when the SNR is reduced. In the PDE bulletin it was noted that analysis of broadband data indicated that the earthquake consisted of 2 events, separated by 1.5 seconds. Although this means that the event is somewhat anomalous, its P-wave characteristics can nevertheless be used to illustrate the class of emergent signals, particularly attributed to larger earthquakes or to signals from certain distance ranges.

For the Yunnan earthquake we have in Fig. 7.8.5 again, for 5 SNR categories, plotted the median and the inter-quartile range of the time difference between the AR-AIC$_{F+S}$ onsets and the corresponding reference phase picks. Compared to the results from the Lop Nor explosion, shown in Fig. 7.8.3, the time delays due to the SNR reduction are substantially larger, approaching 3 seconds at the lowest SNRs.

The effect of bandpass filtering

The AR-AIC onset estimation process includes 2nd order causal Butterworth bandpass filtering of the data in the widest possible so-called "usable" frequency band (Kværna, 1995). The group delay of a Butterworth filter is known to increase with decreasing bandwidth. The "usable" frequency band usually becomes narrower for lower SNR, so that the onset time delays due to filtering are expected to increase with decreasing SNR. In order to investigate the filtering effects on the AR-AIC onset estimates of Figs. 7.8.1, 7.8.3 and 7.8.5, we conducted the following experiment:

- For a set of 130 reference teleseismic P-phases with varying SNR, we ran the AR-AIC$_{F+S}$ method without bandpass filtering. The onset estimates were checked by an analyst, so that erroneous onsets were removed.
- For each of the reference onsets, we ran the AR-AIC$_{F+S}$ method on data filtered respectively in 2 Hz, 1 Hz and 0.5 Hz bandwidths centered on the dominant signal frequency.
- For each of the bandwidths, we plotted the time difference between the AR-AIC$_{F+S}$ onsets on filtered data and AR-AIC$_{F+S}$ onsets on unfiltered data. The results are shown in Figs. 7.8.6a, 7.8.6b and 7.8.6c.

It can be seen that for all bandwidths the effect of bandpass filtering is small, and a maximum time delay approaching 0.1 seconds is observed for the lowest SNR's. The difference in time delay between the 2 Hz bandwidth filter (Fig. 7.8.6a) and the 0.5 Hz bandwidth filter (Fig. 7.8.6c) is also observed to be small. These findings suggest that the results shown in Figs. 7.8.1, 7.8.3 and 7.8.5 are generally representative for the SNR-dependent delays and that only a small fraction of the delays are due to the bandpass filtering.

Implications

For impulsive signals illustrated in Figs. 7.8.2 and 7.8.3, the onset time delay caused by reduced SNR will have relatively little effect on the event locations when locating with an average global model. This is primarily due to the fact that the model uncertainty will be significantly larger than the corresponding uncertainty of the time picks. If we on the other hand are conducting master event or JHD location, the model uncertainty will be significantly reduced, and the picking uncertainty can be the limiting factor of the location precision. In such cases it might be appropriate to correct the timing of the phase onsets with the SNR dependent corrections shown in Fig. 7.8.3, but this needs to be tested in practice.

The implications of using emergent phase onsets in the event location process can be quite severe, especially when including phases with low SNR. As illustrated in Fig.

7.8.5, large time inconsistencies can occur between high and low SNR phases, resulting in erroneous event locations, and/or large travel-time residuals.

The SNR measure itself can also be quite misleading for emergent signals, as the reported SNR is often measured as the maximum SNR within, e.g., 3-5 seconds after the onset, and therefore not being representative for impulsiveness of the actual onset. The envelope onset quality measurements described in section 7.3 of this report, can on the other hand be used to characterize events with emergent phase onsets due to extended source time functions or rupture area. If the event recordings at the stations with the highest SNR are analyzed by the envelope quality measurements, we can in an automatic way describe the event as being of the emergent type, and thereby exercise due care when using low SNR phases in the event location process.

We have also shown that the phase shift of the signal caused by bandpass filtering has relatively small effects on the actual onset estimates. This observation is in contrast to the filter compensation included in the current processing at the IDC, where a 2nd order Butterworth bandpass filter with 2 Hz bandwidth is assumed to introduce a time delay of 0.25 sec for all SNR's. For a 3rd order filter the corresponding number is 0.38 seconds. Based on our results, this is a substanstial overcompensation, and it would actually give better results not to introduce a filter delay compensation at all. We therefore believe that the topic of correcting the phase onsets for the effect of filtering should be revisited carefully, and that there is a strong need to improve the algorithms at the IDC.

T. Kværna

References

Kværna, T., 1995. Automatic onset time estimation based on autoregressive processing. Semiannual Technical Summary, 1 April - 30 September 1995, NORSAR Sci. Rep. No. 1-95/96, Kjeller Norway.

Kværna, T., 1996. Quality assessment of automatic onset times estimated by an autoregressive method. Semiannual Technical Summary, 1 October 1995 - 30 March 1996, NORSAR Sci. Rep. No. 2-95/96, Kjeller Norway.

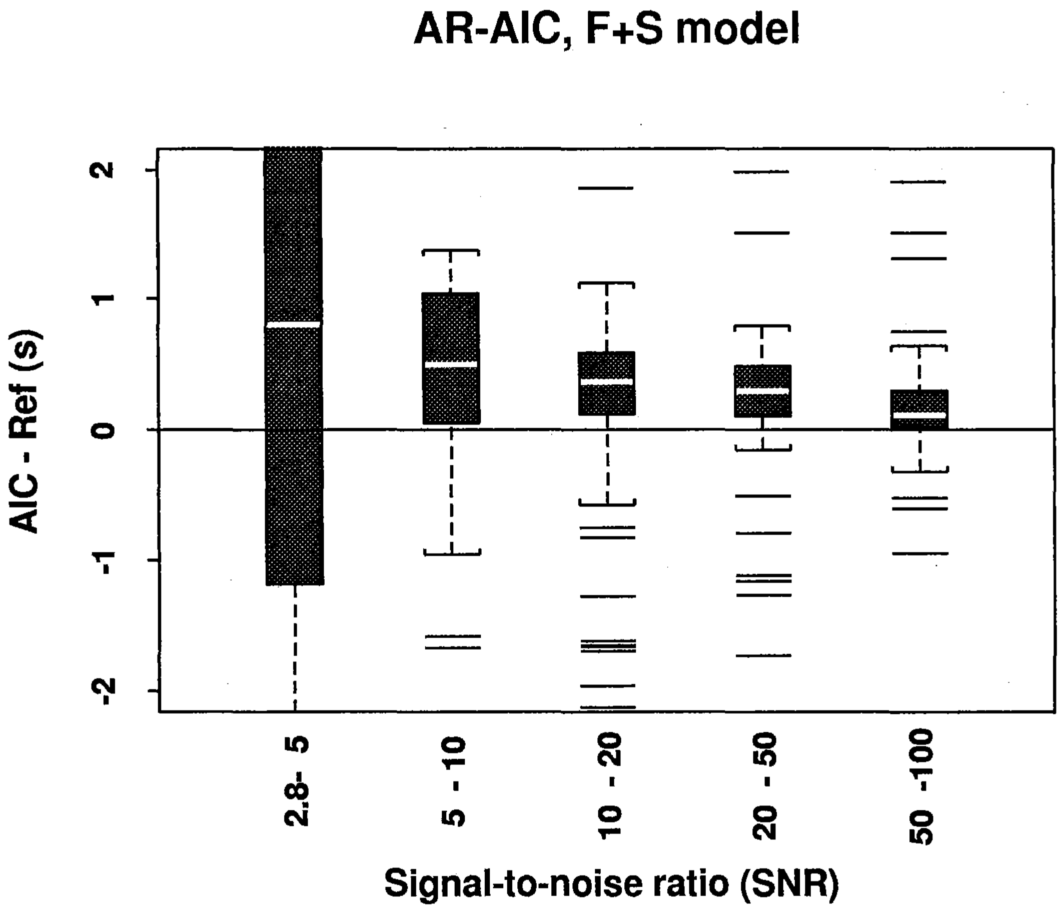


Fig.7.8.1. The database used in this figure consists of 83 P-phases with SNR greater than 100. The observations at the GSETT-3 stations are mainly done at teleseismic distances. For each of the phases, the SNR was successively reduced by adding scaled noise samples, and the AR-AIC method (F+S model) was used to estimate the onsets on the simulated SNR reduced phases. By comparing these AR-AIC onsets to the manual time picks on the original high SNR phases, we could investigate the dependency of the AR-AIC onset estimates on the SNR. In this figure we have divided the onsets into 5 SNR categories. For each category we have computed the median and the inter-quartile range of the time difference between the AR-AIC onsets and the corresponding reference phase picks. The horizontal line in each box is located at the median of the data, and the box itself spans the distance from the first to the third quartile. The whiskers extend to the extreme values of the data or to a distance of 1.5 times the interquartile distance from the center, whichever is the smaller. The lines outside the whiskers represent single observations.

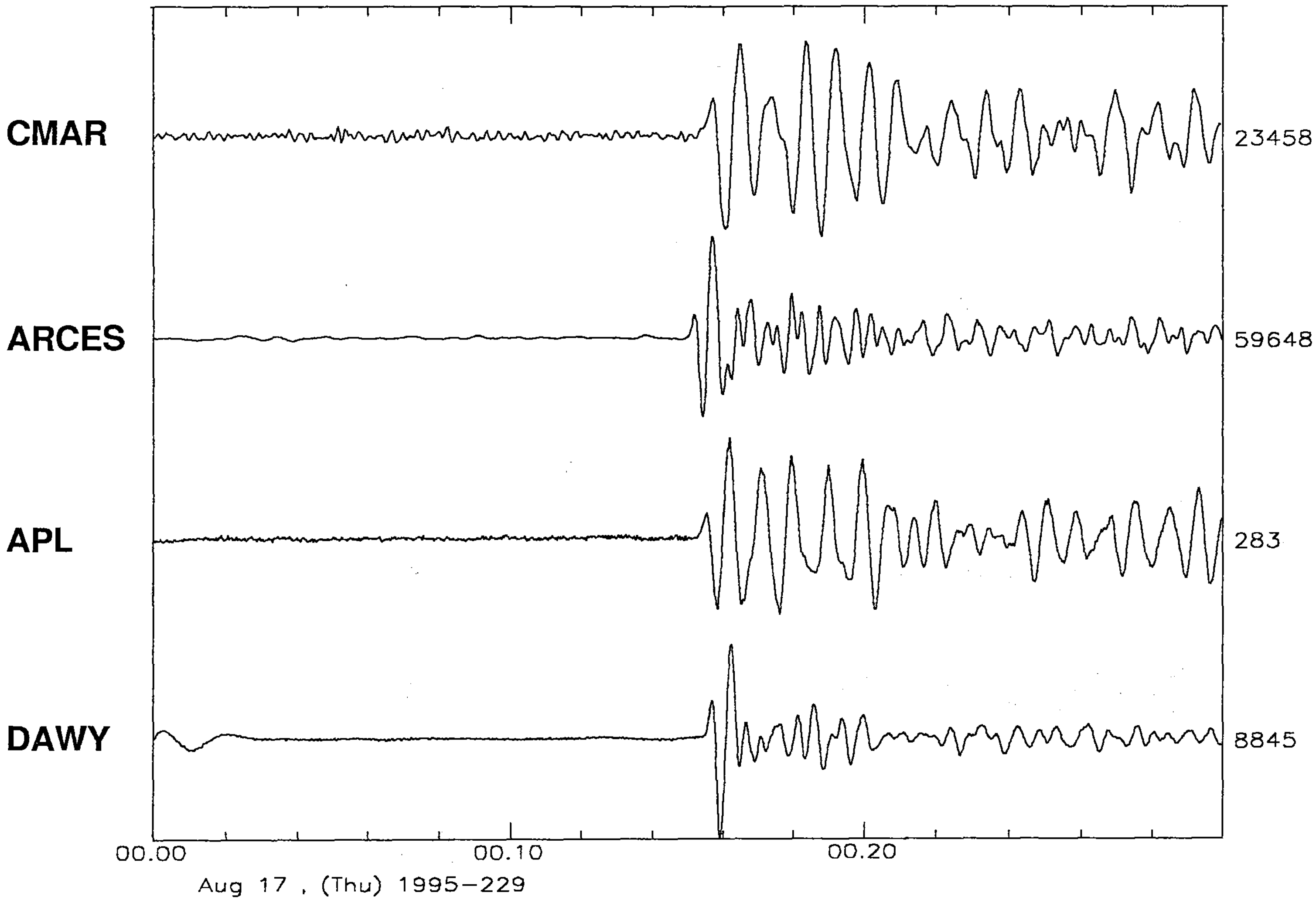


Fig. 7.8.2. P-phases recorded at four of the GSETT-3 stations from the 17 August 1995 Chinese nuclear test at Lop Nor.

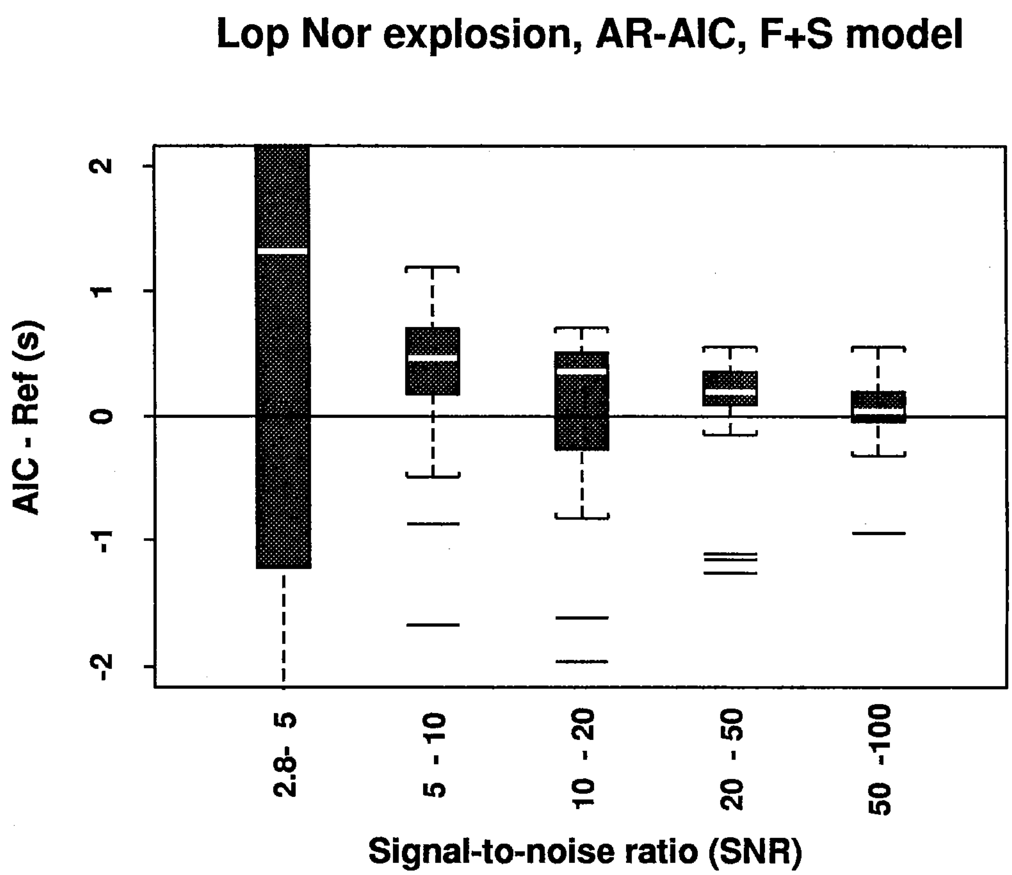


Fig. 7.8.3. Simulated SNR dependent time delays of phase onsets at the GSETT-3 stations from the 17 August 1995 Chinese nuclear test at Lop Nor. For plotting details see the caption of Fig. 7.8.1.

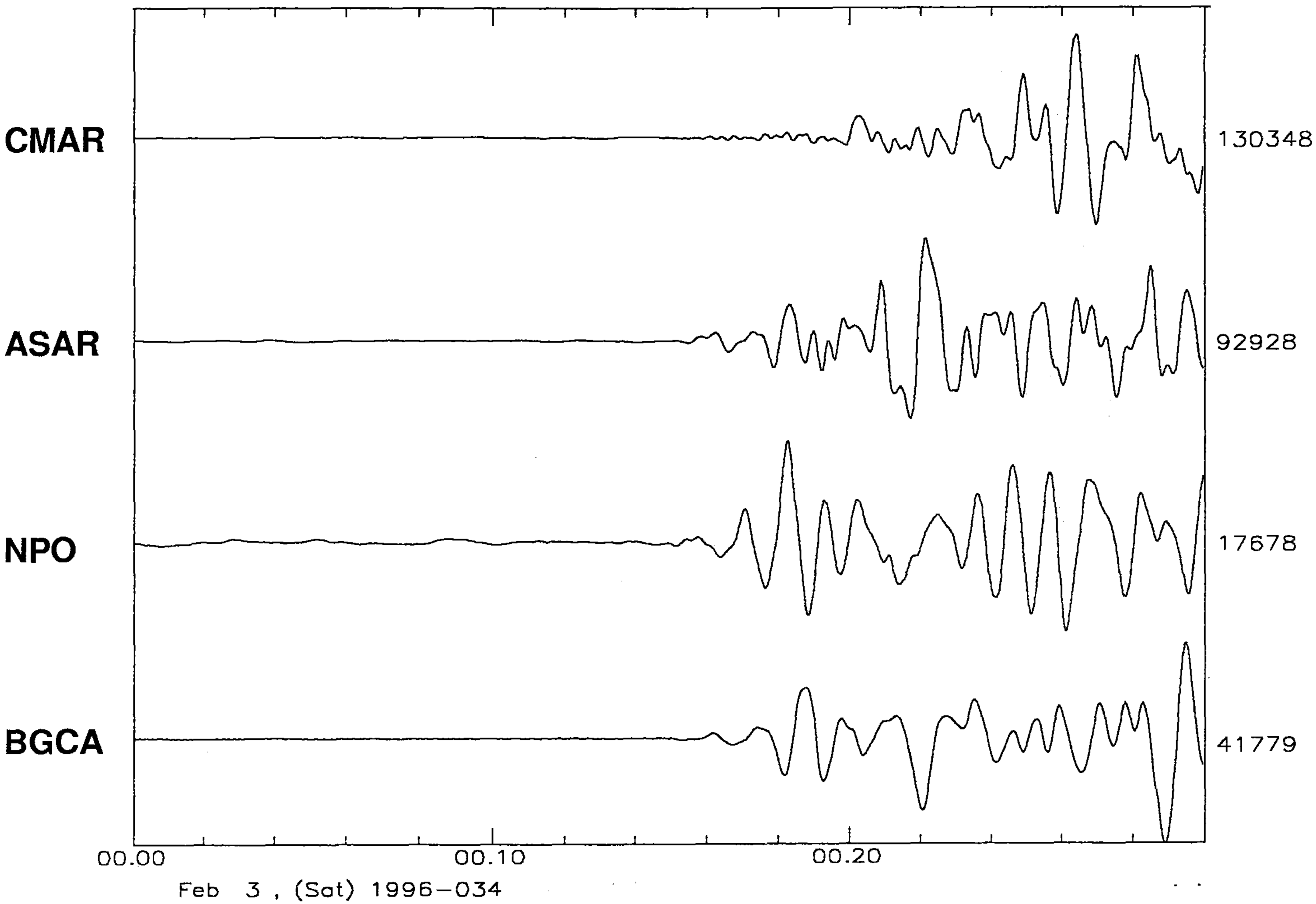


Fig. 7.8.4. P-phases recorded at four of the GSETT-3 stations from the 3 February 1996 Yunnan earthquake.

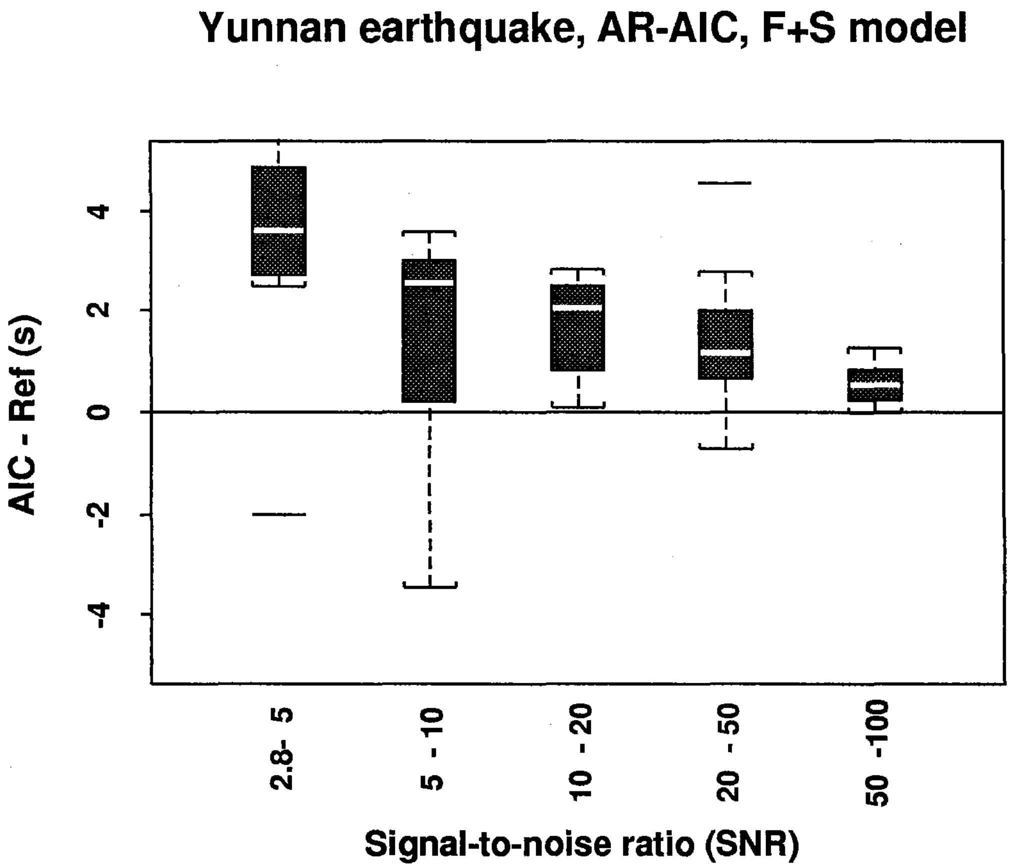
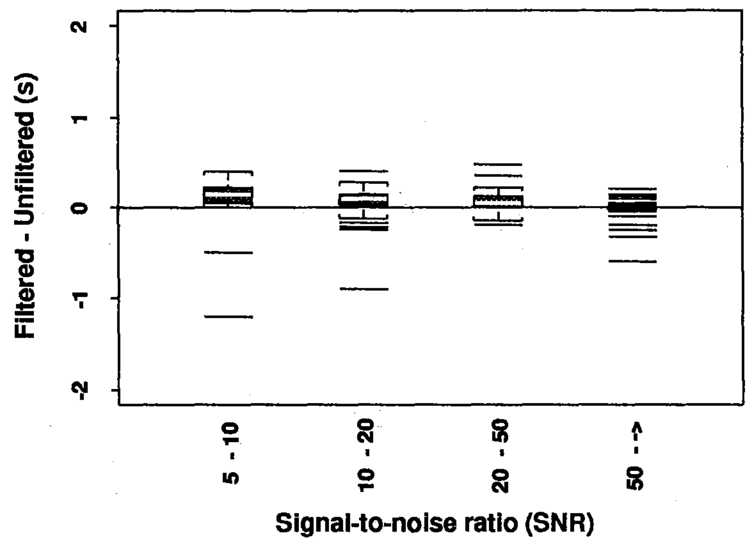


Fig. 7.8.5 Simulated SNR dependent time delays of phase onsets at the GSETT-3 stations from the 3 February 1996 Yunnan earthquake. For plotting details see the caption of Fig. 7.8.1

2 Hz bandwidth, 2nd order Butterworth

a)



1 Hz bandwidth, 2nd order Butterworth

b)

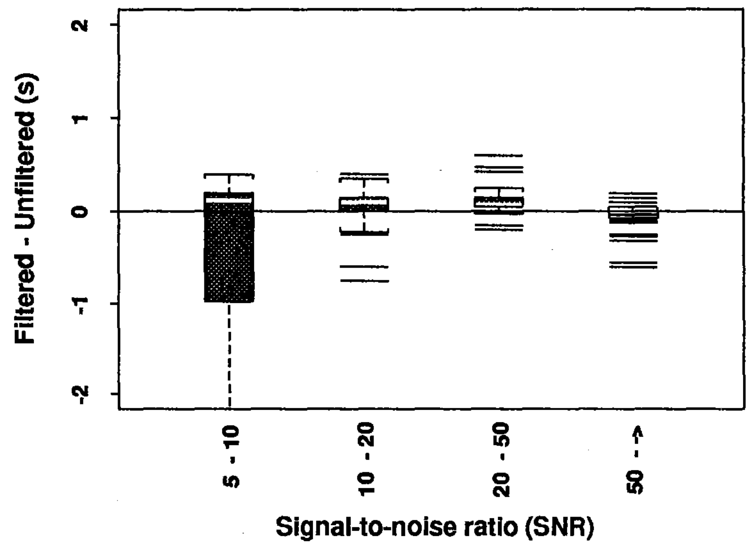


Fig. 7.8.6a-c. The data set used in these figures consists of teleseismic P-phases with varying SNR. For each of the phases, we estimated the AR-AIC$_{F+S}$ onsets on both filtered and unfiltered data, and the time difference between filtered and unfiltered AR-AIC$_{F+S}$ onsets are plotted as boxplots as a function of SNR. For further plotting details see the caption of Fig. 7.8.1. In Fig. 7.8.6a, we have used a causal 2nd order Butterworth filter with 2 Hz bandwidth centered on the dominant signal frequency. In Fig. 7.8.6b the bandwidth was 1 Hz and in Fig. 7.8.6c the bandwidth was 0.5 Hz.

0.5 Hz bandwidth, 2nd order Butterworth

c)