

FLEXWIN : An automated time-window selection algorithm for seismic tomography

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1 Introduction

The **FLEXWIN** algorithm (Maggi et al., 2008) automates the time-window selection problem for seismology. It operates on pairs of observed and synthetic single component seismograms, $d(t)$ and $s(t)$, defining windows that cover as much of a given seismogram as possible, whilst avoiding portions of the waveform that are dominated by noise.

FLEXWIN selects time windows on $s(t)$ within which the waveform contains a distinct energy arrival, then requires an adequate correspondence between $d(t)$ and $s(t)$ waveforms within these windows. This selection paradigm is general, and can be applied to synthetic seismograms regardless of how they have been obtained.

2 Method

FLEXWIN is a configurable data selection process that can be adapted to different tomographic scenarios by tuning a handful of parameters (Table 1). Although the algorithm was designed for use in 3D-3D adjoint tomography, its inherent flexibility should make it useful in many data-selection applications.

Standard tuning parameters:

$T_{0,1}$	band-pass filter corner periods
$r_{P,A}$	signal to noise ratios for whole waveform
$r_0(t)$	signal to noise ratios for a single window
$w_E(t)$	water level on short-term:long-term ratio
$CC_0(t)$	acceptance level for normalized cross-correlation
$\Delta\tau_0(t)$	acceptance level for time lag
$\Delta \ln A_0(t)$	acceptance level for amplitude ratio

Fine tuning parameters:

c_0	for rejection of internal minima
c_1	for rejection of short windows
c_2	for rejection of unclear arrivals
$c_{3a,b}$	for rejection of multiple distinct arrivals
$c_{4a,b}$	for curtailing of windows with emergent starts and/or codas
$w_{CC}, w_{len}, w_{nwin}$	for selection of best non-overlapping window combination

Table 1: Overview of standard tuning parameters, and of fine tuning parameters. Values are defined in a parameter file, and the time dependence of those that depend on time is described by user-defined functions.

2.1 Phase 0

Pre-processing. Observed and synthetic seismograms are band-pass filtered between T_0 and T_1 . We reject seismograms that are dominated by noise (power and amplitude signal-to-noise ratios r_P and r_A). We then construct a short-term long-term average ratio (STA:LTA, $E(t)$) from the envelope of $s(t)$ (Figure 1).

Local maxima in $E(t)$ correspond both in position and in width to the seismic phases in $s(t)$, and local minima in $E(t)$ correspond to the transitions between one phase and the next. We use these correspondences to define time windows.

2.2 Phase A

Definition of preliminary time windows. We take each local maximum in $E(t) > w_E(t)$ as a separate seed maximum at time t_M , and create all possible candidate windows that contain it (Fig-

ure 2a). Window start and end times correspond to local minima in $E(t)$.

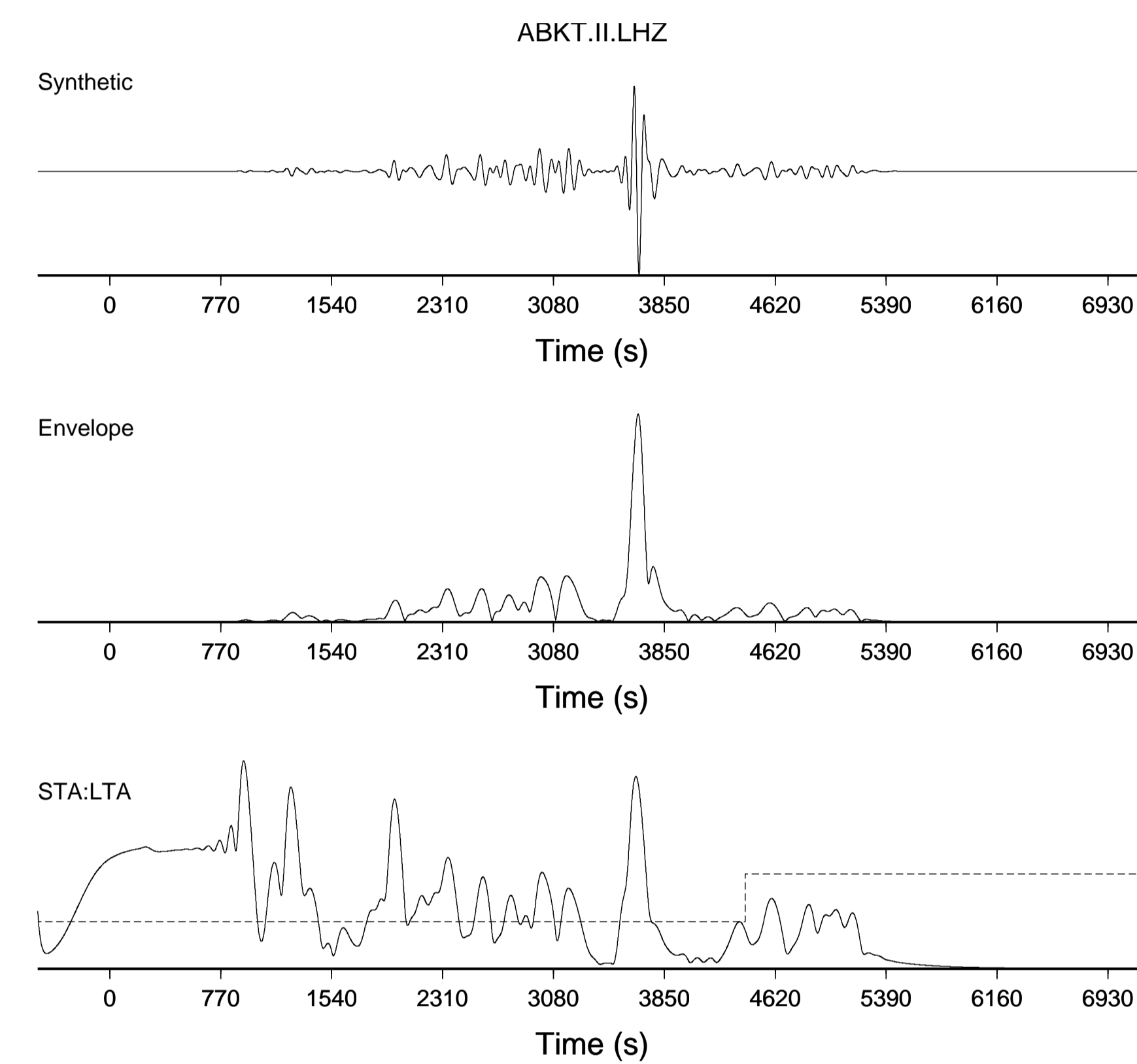


Figure 1: A synthetic seismogram and its corresponding envelope and STA:LTA timeseries.

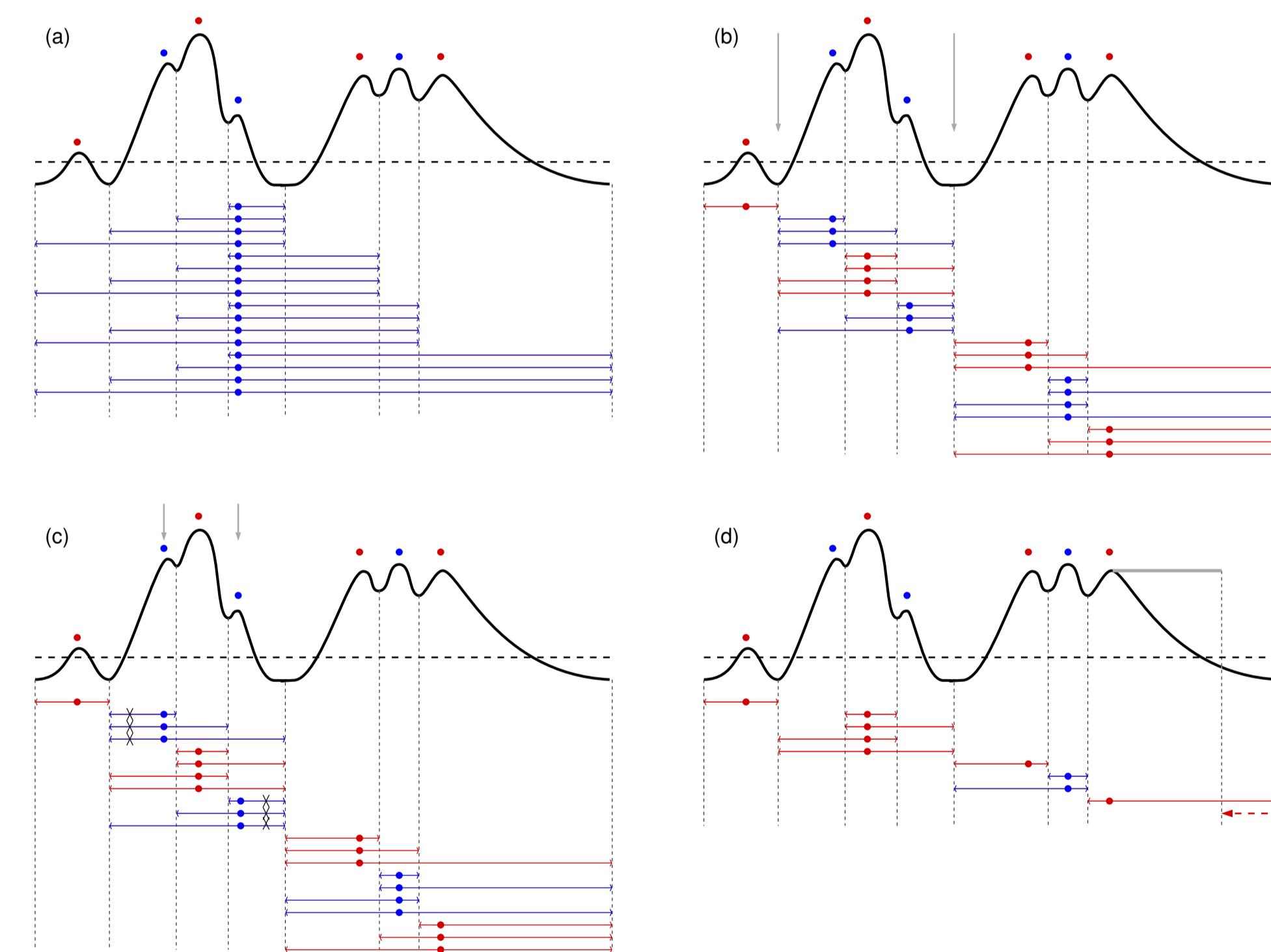


Figure 2: (a) Window creation process. The STA:LTA waveform $E(t)$ (thick line), its water level $w_E(t)$ (dashed line), local maxima (red and blue dots), and windows (two-headed horizontal arrows). (b) Rejection based on the amplitude of the local minima. (c) Rejection based on the prominence of the seed maximum. (d) Shortening of long coda windows.

2.3 Phase B

Rejection of preliminary windows based on $s(t)$ alone. We reject windows based on criteria concerning the shape of the STA:LTA waveform $E(t)$, in order to retain only windows within which $s(t)$ contains well-developed seismic phases or groups of phases.

1. Reject windows that span deep local minima: $E(t) < c_0 w_E(t)$ (Figure 2b).

2. Reject short windows: $\Delta T < c_1 T_0$.

3. Reject windows with subdued seed maxima: $E(t_M)$ rises by less than $c_2 w_E(t)$ above either of its adjacent minima (Figure 2c).

4. Reject windows that contain at least one strong phase arrival that is well separated in time from t_M (Figure 3) : $h/h_M > f(\Delta T/T_0; c_{3a}, c_{3b})$, where

$$f(\Delta T) = \begin{cases} c_{3a} & \Delta T/T_0 \leq c_{3b}, \\ c_{3a} \exp[-(\Delta T/T_0 - c_{3b})^2/c_{3b}^2] & \Delta T/T_0 > c_{3b}. \end{cases}$$

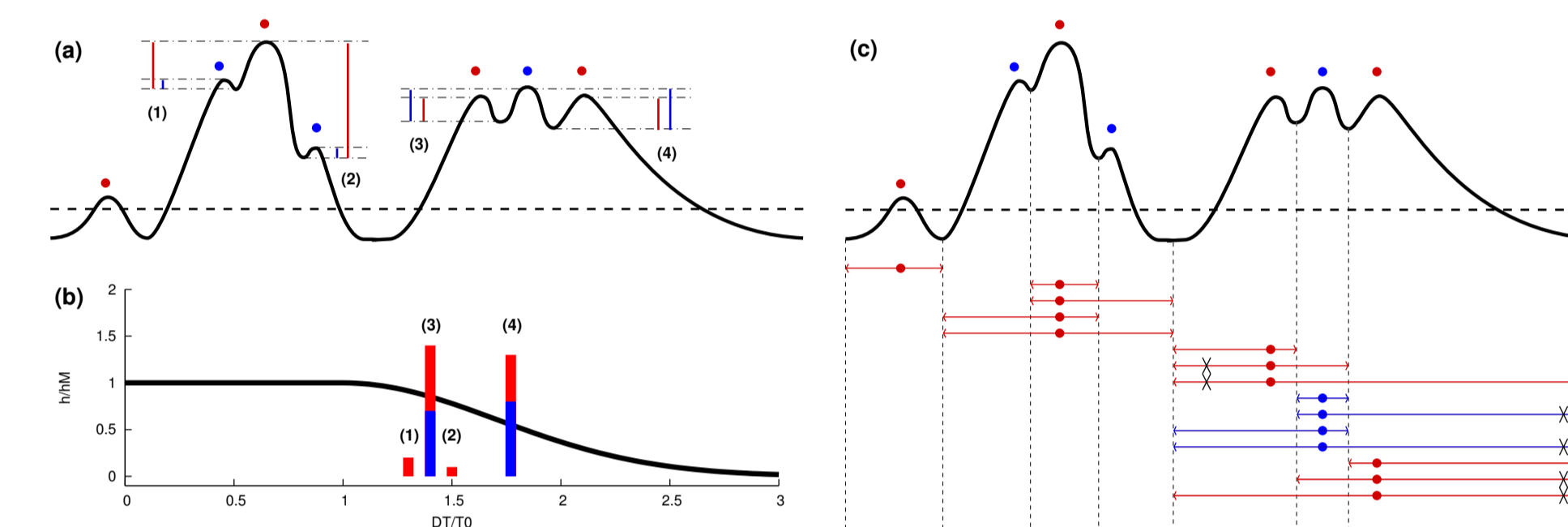


Figure 3: Rejection of candidate windows based on the separation of distinct phases. (a) Heights of pairs of local maxima above their intervening minimum. (b) Vertical bars represent h/h_M for each pair of maxima (vertical bars colored by the seed maximum corresponding to h_M). Bars whose height exceeds the black line represent windows to be rejected. (c) Rejected windows are indicated by black crosses.

Coda details are often poorly matched by synthetics, so we shorten windows on the left if they start earlier than $c_{4a}T_0$ before their first local maximum, and on the right if they end later than $c_{4b}T_0$ after their last local maximum (see Figure 2d).

2.4 Phase C

Rejection of preliminary windows based on the differences between $d(t)$ and $s(t)$.

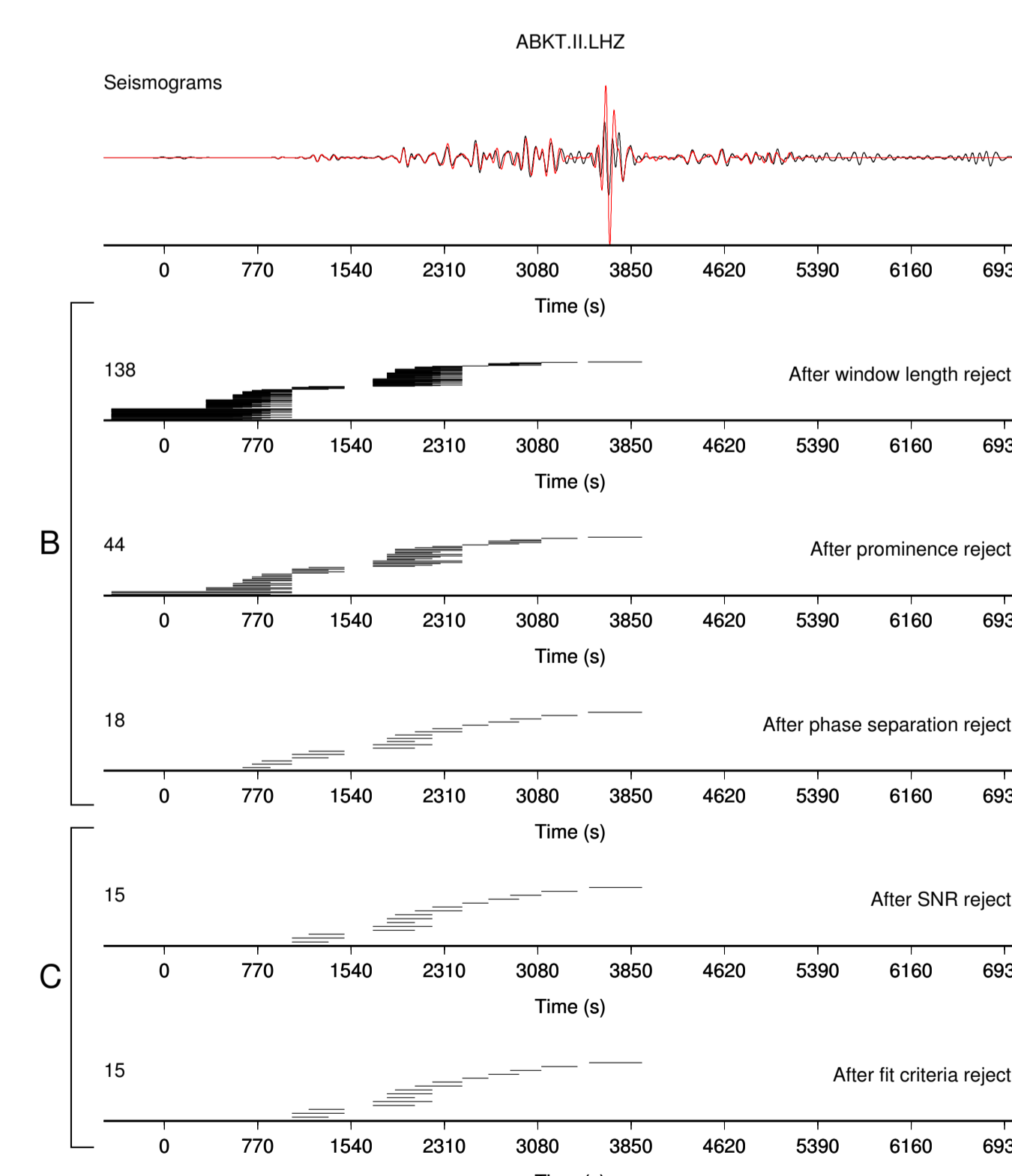


Figure 4: Window rejection applied to real data. Top panel: observed (black) and synthetic (red) seismograms. Subsequent panels: candidate windows at different stages, separated into Phase B (shape based rejection) and Phase C (fit based rejection). Each candidate window is indicated by a black segment. The number of windows at each stage is shown to the left.

We only accept windows in which the observed signal is above the noise level ($r_0(t_M)$), the observed and synthetic signals are reasonably similar in shape ($CC_0(t_M)$), their arrival times differences are small ($\Delta\tau_0(t_M)$), and their amplitudes are broadly compatible ($\Delta \ln A_0(t_M)$).

2.5 Phase D

Overlap resolution. We construct all possible non-overlapping subsets of remaining candidate windows, and score each subset on three criteria: length of seismogram covered by the windows, average cross-correlation value for the windows, and total number of windows.

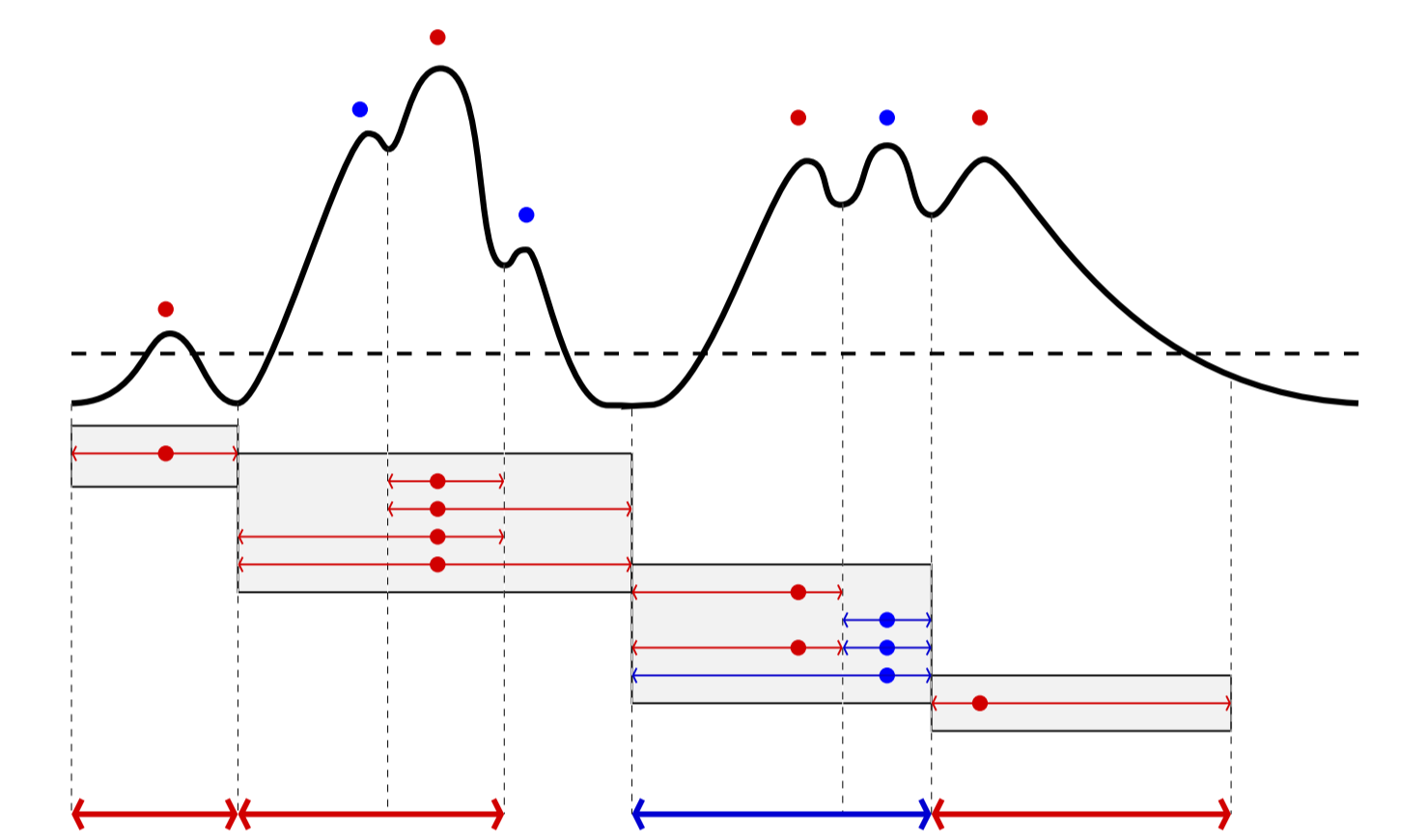


Figure 5: The selection of the best non-overlapping window combinations. Each grey box represents a distinct group of windows. Non-overlapping subsets of windows are shown on separate lines. Only one line from within each group is chosen.

3 Results

Figure 6 shows FLEXWIN results for the seismogram in Figures 1 and 4. Many of the features within the chosen windows correspond to known seismic phases. More examples of window selection using FLEXWIN for different tomographic scenarios (global, regional, local) can be found in Maggi et al. (2008).

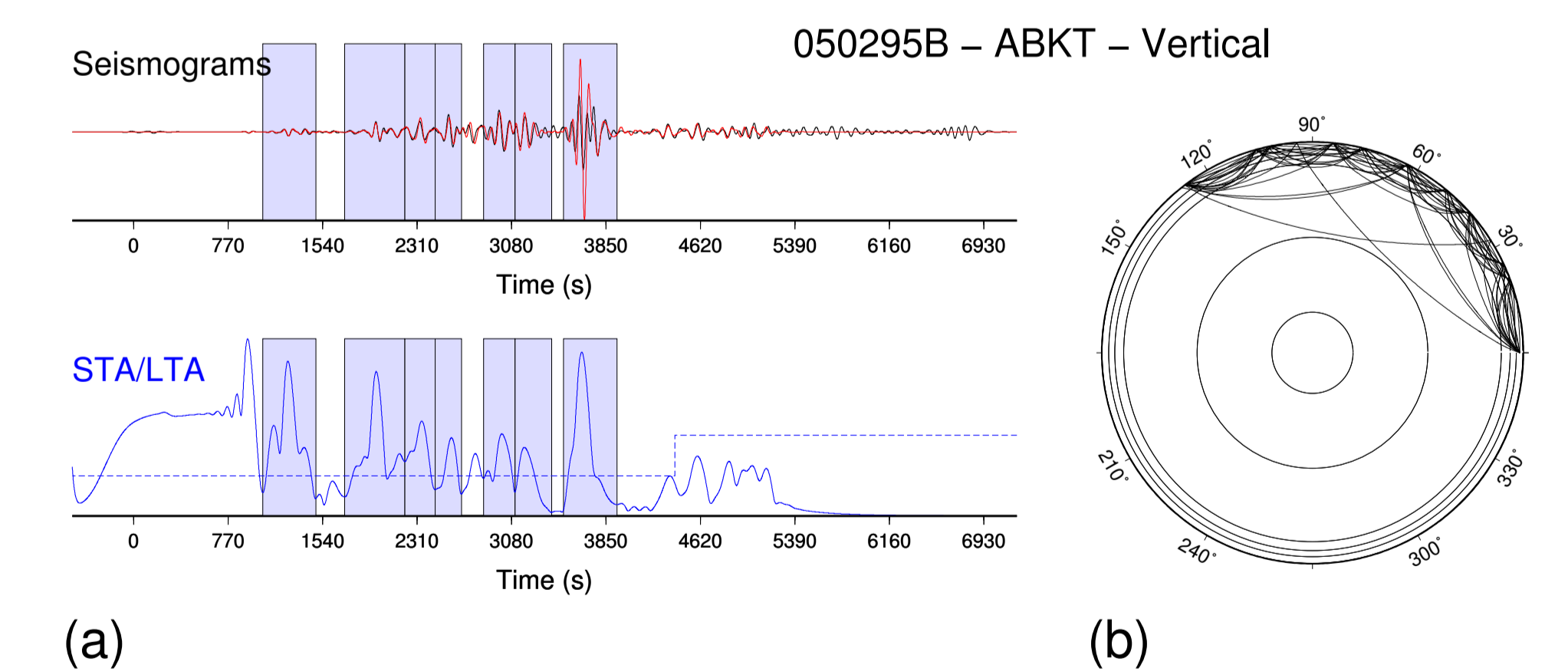


Figure 6: Window selection results. (a) Top: observed and synthetic seismograms (black and red traces); bottom: STA:LTA timeseries $E(t)$. Windows chosen by the algorithm are shown using light blue shading. (b) Ray paths corresponding to the body wave phases present in the data windows.

FLEXWIN is an open-source code available through the Computational Infrastructure for Geodynamics, www.geodynamics.org.

References

A. Maggi, C. Tape, M. Chen, D. Chao, and J. Tromp. An automated time-window selection algorithm for seismic tomography. *Geophys. J. Int.*, 2008. (submitted).