Robust Delineation of Seismic Coda with $k$-Order $\alpha$-Hull

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I. INTRODUCTION

Reconstructing shape of a point cloud is a fundamental problem having applications in a number of fields. In geophysics, studies of seismic coda shape provide Earth’s shells scattering characteristics and temporal changes thought to precede major earthquakes and eruptions. We analyze seismic coda with the developed generalization of classical computational-geometry tool of $\alpha$-hull – $k$-order $\alpha$-hull. This generalization has been recently presented as a new shape reconstruction tool applicable to seismic data (Fig. 1). Here we use $k$-order $\alpha$-hull to quantify PKiKP coda shape yielding estimates of the Earth’s inner core scattering attenuation ($Q$).

II. DATA AND METHOD

We analyzed digital broadband and short-period Z-component seismograms of underground nuclear explosions. There were processed records of seismic arrays KURK, FINES, YKA, ASAR and PDAR that registered Chinese explosions, and data integrated into an array of sources. The latter arrays were formed out of Semipalatinsk Test Sites exposure closely conducted and few years ago, and recorded by a three-component station (BRVK, KEV, COL and LON) – Fig. 2. The analyzed time period of traces spans at least half an hour past the origin time and contains a passage with seismic noise prior to the first arrival of P and arrivals of main seismic phases including PKiKP whose coda (Fig. 3) is to be identified in the tail of the seismogram.

Estimating inner core scattering attenuation involves (i) detecting PKiKP coda, and (ii) fitting the detected PKiKP coda shape with a model curve (Fig. 4). In contrast to P- and S-codas – the ones generated on crust and mantle heterogeneities and routinely observed on three-component records – the inner core scattered coda is unique and detected only on array beams. The inner core scattered energy was built up on array beams by linear summation of moved out individual array traces for the theoretical PKiKP slowness with respect to the standard Earth model of PREM. The PKiKP coda shapes are extracted from beam envelopes estimated via the Hilbert transform. The PKiKP coda is expected to follow the parent phase and usually expressed as a pronounced or vague growth in amplitudes obscured by rapid changes and extreme points (Fig. 4).

Although ambiguous, adjacent averaging is sometimes used to reveal the clear-cut PKiKP coda shape. To avoid ambiguity resulting from uncertain procedure for selecting the smoothing interval, we invoke $k$-order $\alpha$-hull for restoring undisturbed PKiKP coda shape. This includes splitting each envelope into the noise and data parts, training $\alpha$-balls on seismic noise for choosing right $\alpha$ and $k$, and then dragging the balls through the data (Fig. 1).

III. RESULTS

Nine output curves delineate seismic coda and reveal fine structure of the original decay process obscured by intensive oscillations (Fig. 5). The detected PKiKP curves are independent of the parent phase and observable with or without distinct PKiKP waveform in the head. Compared to envelope averaging, $k$-order $\alpha$-hull never distorts the PKiKP coda shape following an intensive spike-like “detached” PKiKP. This allows unambiguous identification of growth and decay phases of PKiKP coda including “smoothly decaying” ones built either due to inner core boundary reverberations or scattering on shells above the inner core following propagation of a strong PKiKP waveform (see ASAR record in Fig. 5). The inner core scattered energy delineated by the output curve can then be quantified using explicit objective criteria, e.g. for measuring coda duration or intensity, one can use the output curve’s maxima, intersection with the noise level or portions of monotonous growth/decay. Moreover, such delineation allows unbiased comparison of time-separated seismic coda when estimating temporal changes in coda characteristics. The measured duration of the PKiKP coda decay phase varies in our dataset between 80 and 250 seconds with no clear dependence on the epicentral distance or intensity of the parent phase. We fit linear function to non-growing passage of the output curve between the first past-PKiiKP maximum and the curve intersection with the noise level or the curve end if the noise is not reaching owing to the record shortness. The relevant Q estimates turned out surprisingly stable making 44±43 for all 9 traces. We show that removing the effect of pre-existing coda is unnecessary, as we found that PKiKP coda essentially generated in nearby regions of the inner core and differently propagated in the outer core, mantle and crust are identical (Fig. 6).

Use noise to “train” the ball – choose $a$ and $k$

Apply to the data

Link between shape modeling and statistics

Generalizing statistical depth $\alpha$-hull, $\alpha$-k-depth contour, etc.

Ongoing work

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Fig. 1. A poster presented by the authors at International Conference on Shape Modeling 2008