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Focal mechanisms of the 2017 North Korean nuclear test and its early collapse event

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1.Introduction

North Korea conducted the sixth underground nuclear test on 3 September 2017. Unlike its previous tests, a rare subsequent collapse event occurred after about 8.5 minutes. As two types of distinctive shallow seismic events, accurate inversion of their focal mechanisms is important for event identification for CTBT.

2.Data and methods

Seismic waveform data at 91 stations in northeast China from Geophysical Institute of Chinese Seismological Bureau, and at 32 regional stations from IRIS were requested and processed (Figure 1).

First, we selected the data of the 45 stations of epicentral distances within ~500 km to do the waveform inversion using the gCAP program. Next, the amplitude ratios of the surface waves of all the stations were used to further examine parameter space with small waveform residual solutions in order to improve the resolution.

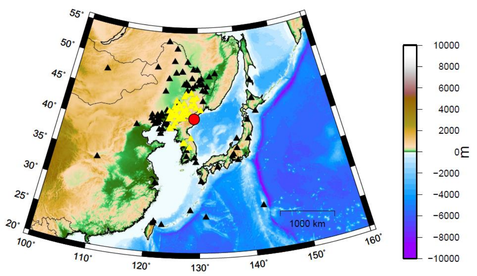

Figure1 The map of Seismograph station (triangles), the 2017 nuclear test and the collapse event(dot) distribution. The epicenter locations of the nuclear test and collapse event are very close. The yellow triangles are the stations used for the waveform inversion, and the black triangles are those stations used to calculate the surface wave amplitude ratios only

3.Inversion results

3.1Waveform inversion

Table1 Moment tensor solutions from the waveform inversion. Moment tensor components are in 10^{16} N.m.

Event	Mxx	Myy	Mzz	Mxy	Mxz	Myz	Mw	Depth(km)	Rms
Explosion	9.00	9.00	15.15	-1.14	-2.43	0.57	5.37	0.5	0.225
Explosion	11.89	11.50	22.03	-0.97	-0.58	-0.78	5.46	1	0.207
Collapse	-0.12	-0.12	0.31	0.04	0.06	0.10	4.23	0.5	0.459
Collapse	0.04	0.01	1.02	0.06	-0.06	0.07	4.51	1	0.445

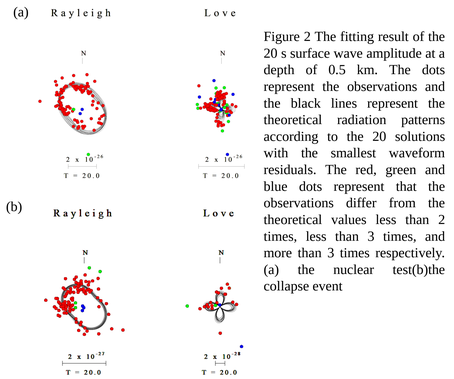

Figure 2 The fitting result of the 20 s surface wave amplitude at a depth of 0.5 km. The dots represent the observations and the black lines represent the theoretical radiation patterns according to the 20 solutions with the smallest waveform residuals. The red, green and blue dots represent that the observations differ from the theoretical values less than 2 times, less than 3 times, and more than 3 times respectively. (a) the nuclear test(b)the collapse event

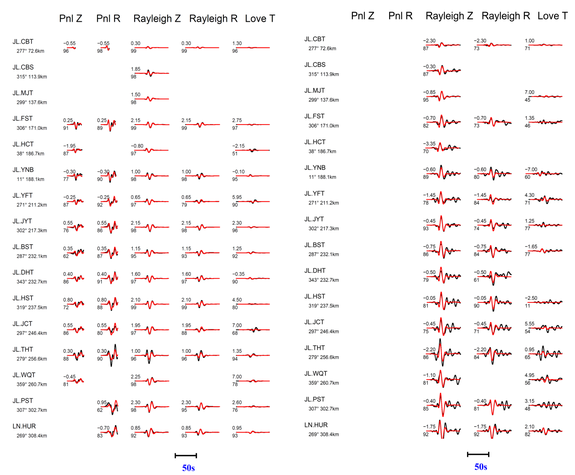

Figure 3 The waveform inversion fitting result of the nuclear test and collapse event at partial stations at a depth of 0.5 km. The black lines are the observed waveforms, and the red lines are the fitted waveforms (a) the nuclear test (b) the collapse event

3.2 Amplitude ratio of the surface waves

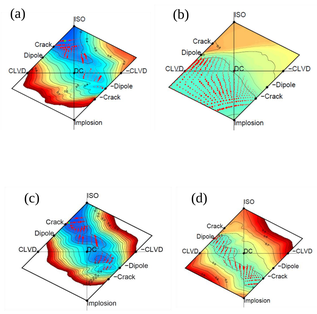

Figure 4 The corresponding amplitude ratio residuals of the solutions with small waveform residuals in different scenarios on the Hudson map. The size of red dots represents the magnitude of the amplitude ratio residual, and the larger the dots, the smaller the amplitude ratio residual. The green dot gives denotes the position of the optimal focal mechanism determined by the combination of waveform inversion and amplitude ratio. (a)the result of Love/Rayleigh wave amplitude ratio of the nuclear test at a depth of 0.5 km source depth. (b)the result of Rayleigh/Rayleigh wave amplitude ratio of the collapse event at a depth of 0.5 km. Same as (a) except the depth is 1 km (d) Same as (b) except the depth is 1 km

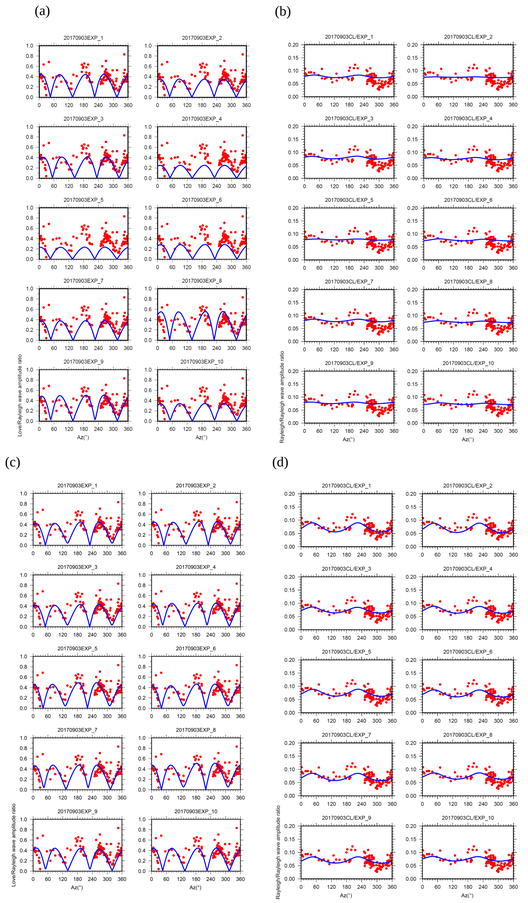

Figure 5 The fitting result of amplitude ratio of the Love/Rayleigh wave of the nuclear test(a) and the Rayleigh/Rayleigh wave of the two events (b) at a depth of 0.5 km. The red dots represent the observations and the blue lines represent the theoretical curves calculated according to the 10 solutions with the smallest waveform residuals. (c) Same as (a), except the theoretical curves calculated according to the 10 solutions with the smallest amplitude ratio residuals (d) Same as (b), except the theoretical curves calculated according to the 10 solutions with the smallest amplitude ratio residuals

4.Discussion and conclusions

We constrain focal mechanism solutions of the 2017 DPRK nuclear test and its collapse event combining with waveform inversion and fitting the amplitude ratios of the surface waves. The nuclear source solutions show high resolution and its optimal solution is close to the Crack source. However, the collapse event source solutions do not show very good resolution and its source type is difficult to be determined. In this case, except for the moment tensor similar to -Crack, the moment tensor containing a positive isotropic component can also explain the observation data well. This may be mainly due to the fact that the Pnl wave of the collapse event are difficult to identify and the long period surface wave are difficult to distinguish all the moment tensor elements for the shallow source, resulting in uncertainty of the inversion results. Therefore, we think that long period surface waves alone does not constrain the focal mechanism of this collapse event to be similar to -Crack or Implosion. Thus, other seismic phases are needed. On the other hand, the focal mechanism of the collapse event may be inherently complex, leading to inconsistent results among the different researchers.

Acknowledgements

Data from regional seismic stations of Northeast China used in this study is provided by the Geophysical Institute of Chinese Seismological Bureau and their availability is still not open. Other data used are from the IRIS Data Management Centre.