Combining Back-Projection and Matched Filter in Detecting Offshore Seismicity: Application to NE Japan Subduction Zone

Tian Feng[1](tianfengseis@g.ucla.edu), Lingsen Meng[1], Hui Huang[1]
Earth, Planetary and Space Sciences, University of California, Los Angeles, CA 90025, USA.

UCLA

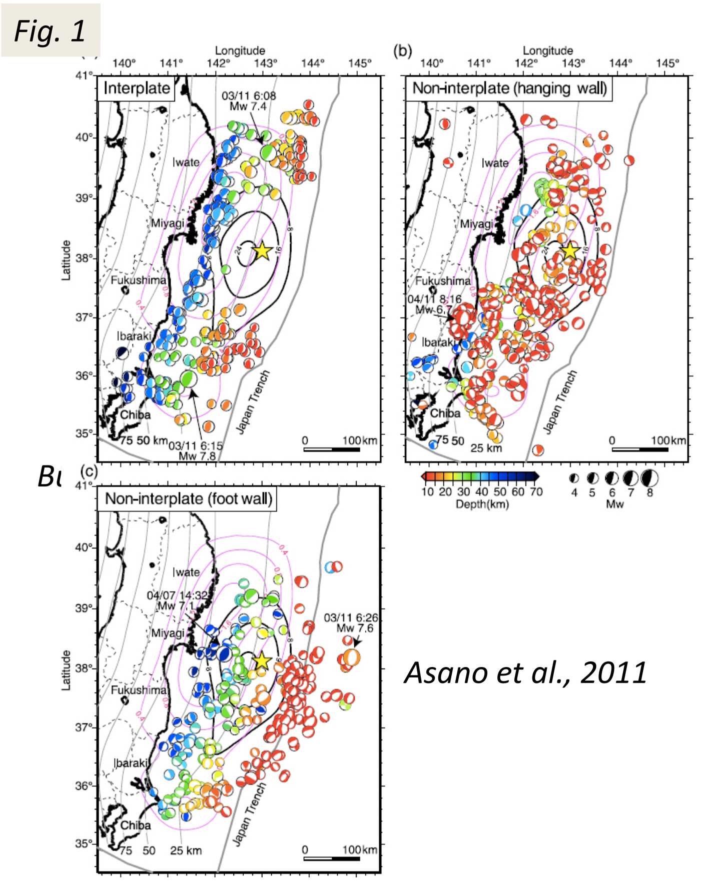
Poster #086

SCEC AN NSF+USGS CENTER

NSF

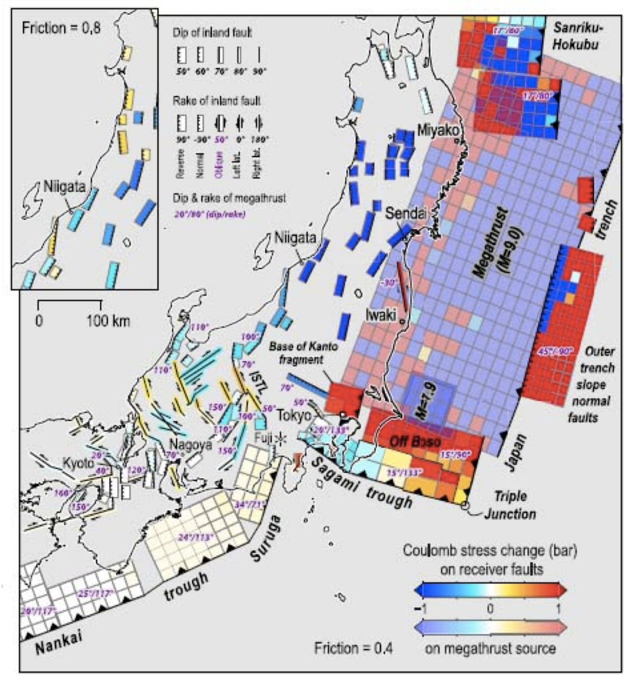
Outer Trench Normal-faults Aftershocks

Fig. 1



Asano et al., 2011

Fig. 2



Toda et al., 2011

In the 2011 Mw 9.0 Tohoku, a significant amount of aftershocks in the foot wall of the major fault are normal-fault events (Fig. 1c), including a Mw 7.6 events at 6:26 of 03/11. Most of these events are concentrated in the outer-rise area, consistent with positive static Coulomb stress changes induced by mainshock rupture (Fig. 2). To understand the relation between normal-fault events and the Coulomb stress change, we need a more complete picture of the early offshore aftershocks. The detection of offshore seismicity in shallow portion of the subduction zones is ineffective due to the large distance from landward instruments. The seismicity at the shallow subduction zone may have important implications on the near-trench deformation, which is related to the shallow slip and tsunami hazard. Here, we propose to improve the capability of detecting offshore events by combing two recently developed techniques: Back-Projection (BP) imaging and match-filter detection (MF). The MF method searches for similar patterns by cross-correlating waveforms of known template events with continuous seismic records. However, the MF method is heavily relying on known earthquake templates, which are obtained from the routine catalogs that lack events in the offshore region. By including BP-detected events as additional templates in the MF detection, we can potentially improve the picture of offshore seismicity.

Detection of Early Aftershocks by Back-Projection Imaging

a) Illustration of the back-projection imaging: The black dots in the center of the rectangular grids indicate the location of testing sources in back projection. The true source location (red star) is connected to the teleseismic receivers (black triangles) through ray theory. The black curves above the receivers denotes the recorded seismograms. In principle, the moveout of the true source locations (red lines) brings the seismograms in phase, thus the stack along the moveout reaches the maximum.

b) The USArray stations (red triangles) used in the BP analysis for imaging the aftershocks within the first week after the 2011 M 9.0 Tohoku-Oki earthquake.

Fig. 3

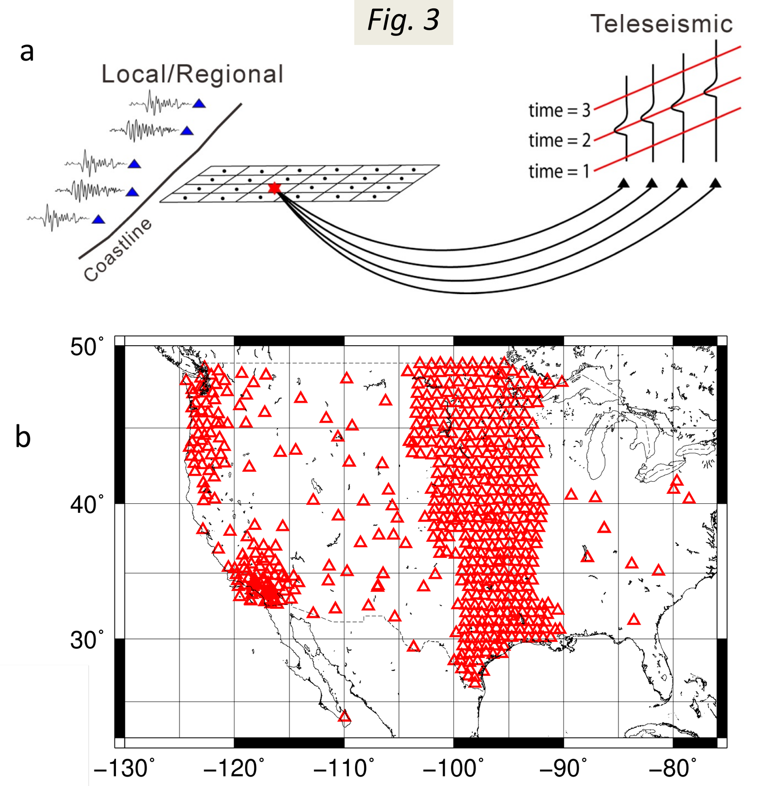
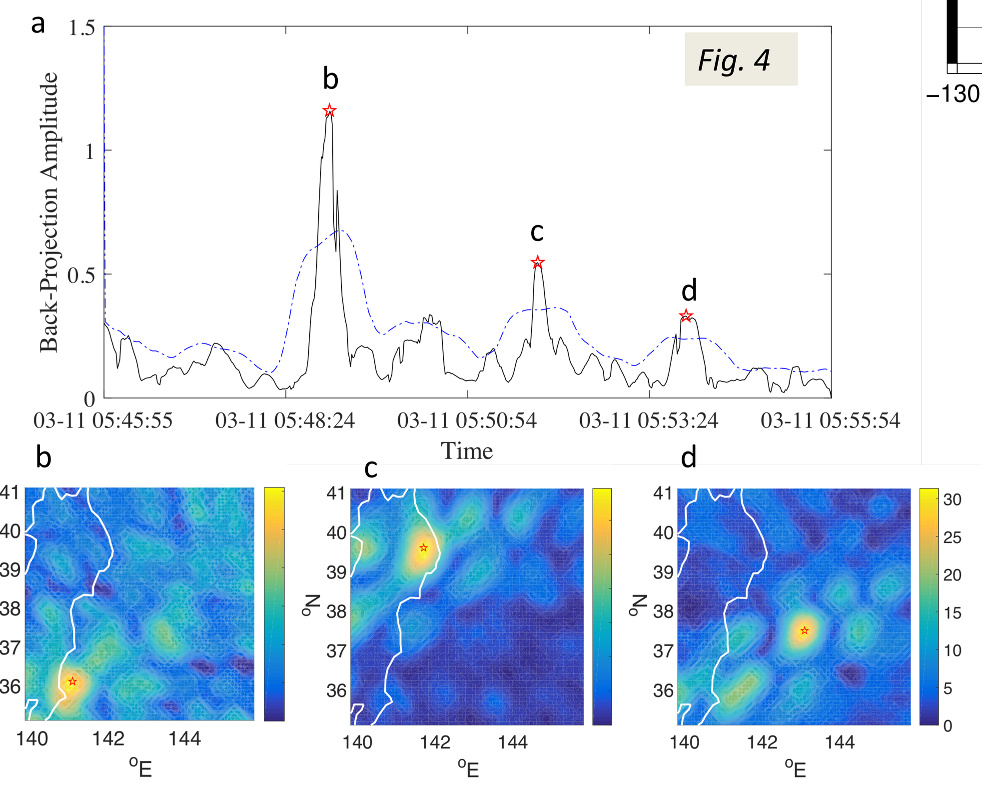


Fig. 4



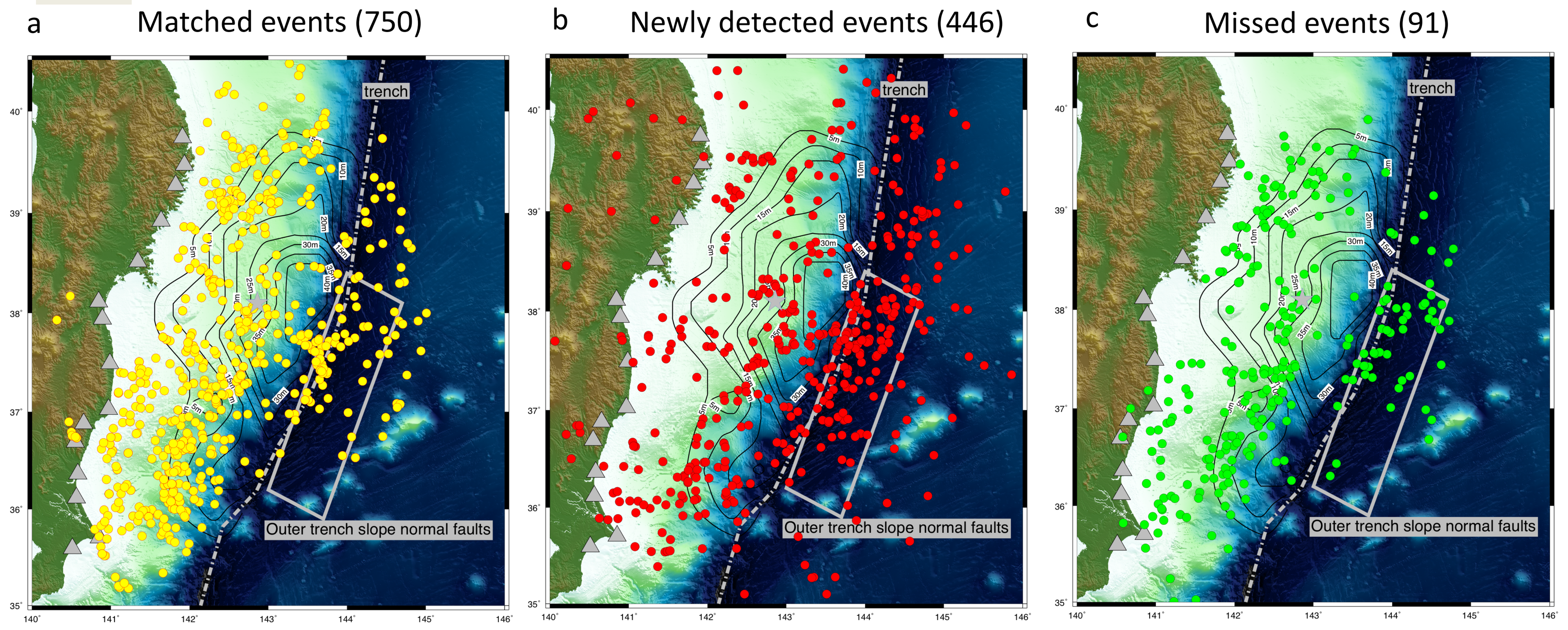
a) Shows the stacked amplitude from beam-forming (black trace) and 3 detected events (b-d). We consider the peak amplitudes (red stars) of each event is larger than 1.5 times of background noise level (blue dash line).

b-d) show the distributions of normalized energy release for the 3 sample events. We consider the BP event epicenters locate at corresponding energy peaks (red stars).

Incorporating BP-imaged Events into MF Templates

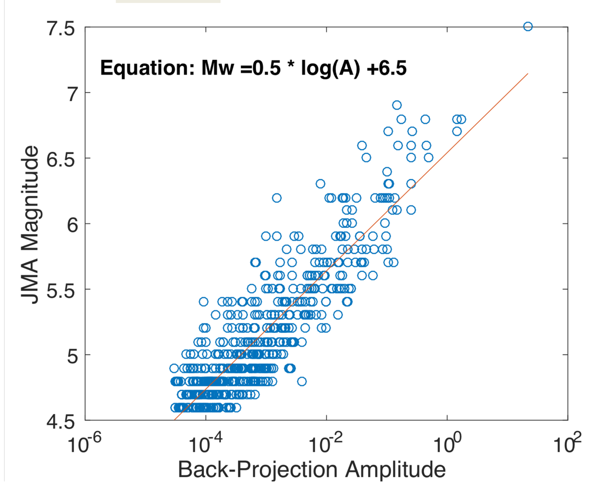
We first perform the BP imaging to one-week continuous vertical waveforms after the mainshock recorded by USArray in teleseismic distance (Fig. 3). The data are filtered at 0.5 - 2 Hz and the processing steps are similar to Kiser and Ishii (2013). As a result, we match 750 Back-Projection detected events with Mw > 4.5 events in Japan Meteorological Agency (JMA) catalog (yellow dots) and detect 446 new events that are not listed in the JMA catalog (red dots), with a significant portion located in the offshore region (Fig. 5). We match an event pair if the time difference are less than 3 min and if the epicenter separations are less than 50 km (Fig. 5a). Since most matched event are located west to the trench and few JMA events are near the trench, we deduce that JMA catalog systematically missed substantial events near the trench. However, those events could be effectively detected by Back-Projection technique (Fig. 5b). On the other hand, BP missed 91 events (green dots) recorded by JMA (Fig. 5c), which might be caused by low coherence between waveforms received by teleseismic stations.

Fig. 5



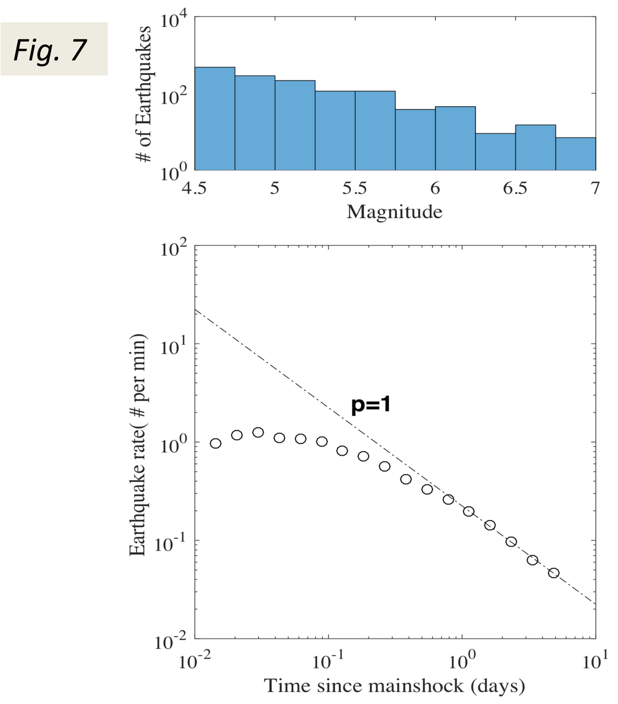
a) Distribution of 750 aftershocks both recorded in JMA (Mw > 4.5) and BP catalog one week after the 2011 Mw 9.0 Tohoku earthquakes, with a great portion near trench (gray dash line) and outer trench slope normal faults (gray box). The 15 near-coast Hi-Net stations (gray triangles) are used for the match-filter.
b) Distribution of 446events only detected by BP.
c) Distribution of 91 events missed by BP.

Fig. 6



We then compare the magnitudes of matched events and their corresponding Back-Projection amplitudes (Fig. 6). We use a equation Mw =0.5*log(A)+6.5 to fit the observations, where Mw is the interpreted event magnitudes and A is observed BP amplitude, which is similar to Kiser and Ishii (2013). The uncertainty of interpreted magnitude is within 0.5.

Fig. 7



We then augment the JMA catalog with our newly detected events (Mw > 4.5). The upper panel of Fig. 7 shows magnitude distribution and the lower panel shows aftershock rates against time since mainshock for newly detected events (red) and events in the JMA catalog (black). Lengliné et al. (2012) corrected aftershock rate by using template matching method and fit the decay rate with 1/t. Even though the augmented catalog fit the Omori Law very well after 12 hours, it still missed significant early events.

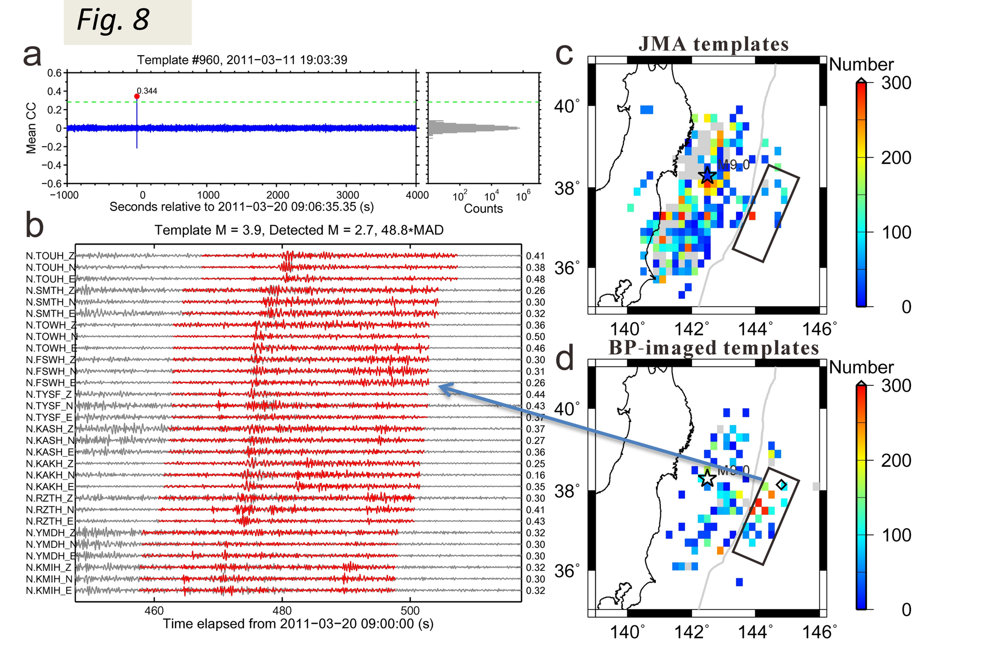
Reference

Asano, Y., Saito, T., Ito, Y., Shiomi, K., Hirose, H., Matsumoto, T., ... & Sekiguchi, S. (2011). Spatial distribution and focal mechanisms of aftershocks of the 2011 off the Pacific coast of Tohoku Earthquake. Earth, planets and space, 63(7), 29.
Kato, A., Obara, K., Igarashi, T., Tsuruoka, H., Nakagawa, S., & Hirata, N. (2012). Propagation of slow slip leading up to the 2011 Mw 9.0 Tohoku-Oki earthquake. Science, 1215141.
Kiser, E., & Ishii, M. (2013). Hidden aftershocks of the 2011 Mw 9.0 Tohoku, Japan earthquake imaged with the backprojection method. Journal of Geophysical Research: Solid Earth, 118(10), 5564-5576.
Lengliné, O., Enescu, B., Peng, Z., & Shiomi, K. (2012). Decay and expansion of the early aftershock activity following the 2011, Mw9. 0 Tohoku earthquake. Geophysical research letters, 39(18).
Toda, S., Lin, J., & Stein, R. S. (2011). Using the 2011 M w 9.0 off the Pacific coast of Tohoku Earthquake to test the Coulomb stress triggering hypothesis and to calculate faults brought closer to failure. Earth, planets and space, 63(7), 39.

Matched-Filter Detection of Aftershocks

We combine the BP-imaged catalog with the JMA catalog and visually check the waveforms of events at 15 coastal Hi-Net stations. Among the combined catalog, 662 events are selected as templates since they have relatively clear waveforms at the time window around the theoretical S arrival times. Under the threshold of 9 times the median absolute deviation (MAD) of each day, there are a total of 49924 newly detected events within 60 days after the mainshock. Among these new events, 8402 events (~17%) are detected by the BP-imaged templates. It shows a significant amount of newly detected seismicity in the offshore region, especially in the areas around the trench. This demonstrates that the offshore seismicity will be improved a lot by incorporating the BP-imaged events into the template dataset in the MF detection.

Fig. 8

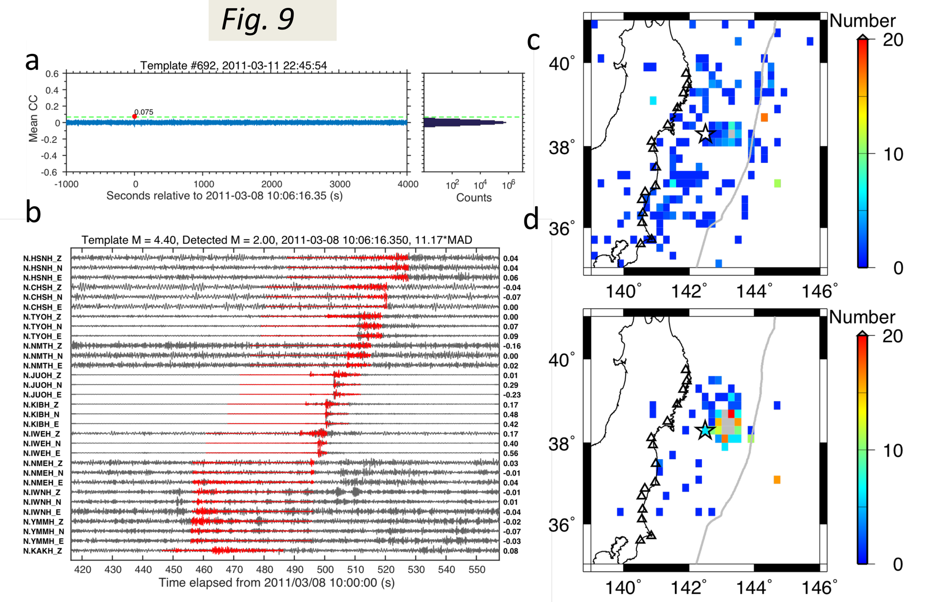


(a) and (b) show an example of the MF detection with the template from BP imaging, which is located in the outer rise but not listed in the JMA catalog (diamond in (d)).

(c) shows the density (0.2*0.2 deg.) of the 41522 newly detected events by 545 templates from the JMA catalog. (d) shows the density of the 8402 new events detected by 117 templates from the BP-imaged catalog.

Matched-Filter Detection of Foreshocks

Fig. 9

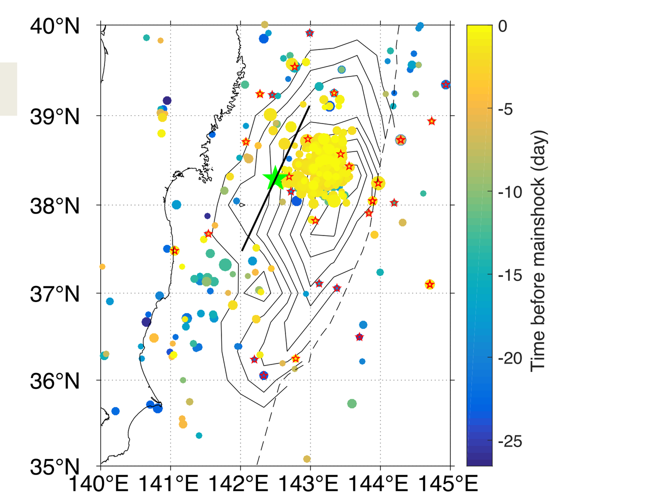


(a) and (b) are similar to Fig.8

(c) shows the density (0.2*0.2 deg.) of the 270 foreshocks (Mw > 2.5) from 02/13 to 03/09, before the largest foreshock (Mw 7.3).

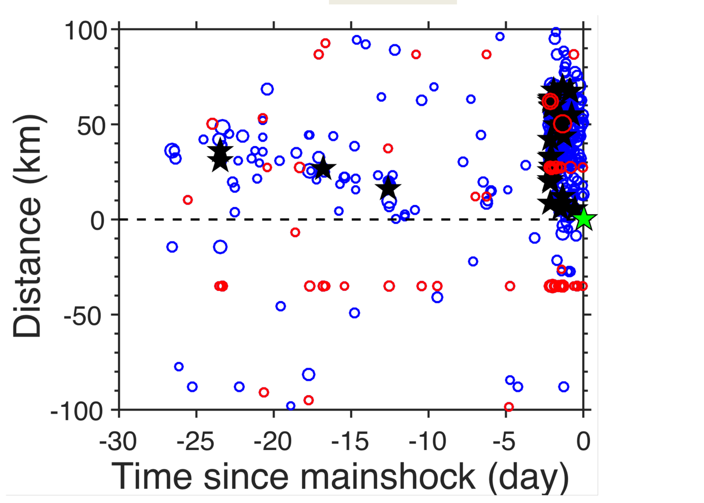
(d) shows the density of the 491 foreshocks from 03/09 to 03/11, after the largest foreshock and before the mainshock.

Fig. 10



Shows the spatiotemporal distribution of 729 foreshocks (Mw > 2.5) from 02/13 to 03/11, in which 94 are newly detected events by BP templates (Red stars). Black contours represent the coseismic slip of the mainshock.

Fig. 11



Shows foreshocks migration along the strike direction of the mainshock (positive= NE), including newly detected events based on BP template (red circles), mainshock (green star), and large events with magnitude larger than 6 (black stars). We find the similar foreshock migration pattern as Kato et al., 2012.

Summary and Outlook

We combine the Back Projection (BP) imaging and match-filter detection (MF) techniques to improve the capability of detecting offshore events. BP imaging could find plenty of new early aftershocks near the trench in addition to the JMA catalog. We combine the BP-imaged catalog with the JMA catalog to form a template dataset input for the MF detection. We find a total of 49924 newly detected events within 60 days after the mainshock. Among these new events, 8402 events (~17%) are detected by the BP-imaged templates. A significant amount (~ 80%) of newly detected seismicity are located in the offshore region, especially in the outer trench slope normal fault. We also detected 94 additional foreshocks by the BP-imaged templates from 02/13 to 03/11 and find the similar foreshock migration pattern as Kato et al., 2012. The new events are located in the periphery of the mainshock coseismic slip zone. This demonstrates that the picture of offshore seismicity can be improved by incorporating the BP-imaged events into the template dataset in the MF detection. In our future work, we plan to relocate the newly detected events. This work is supported by EAR-1723192.