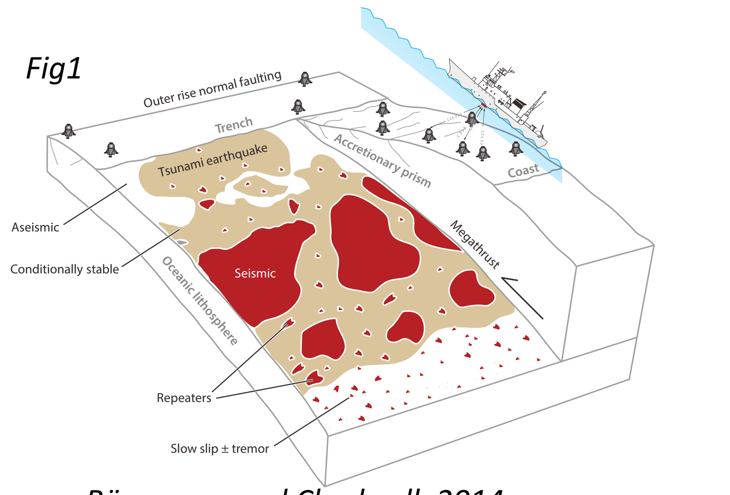
Detecting Small Offshore Earthquakes with Back-Projection Imaging and Match-filter Method

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.

Offshore Deformation in Subduction Zones

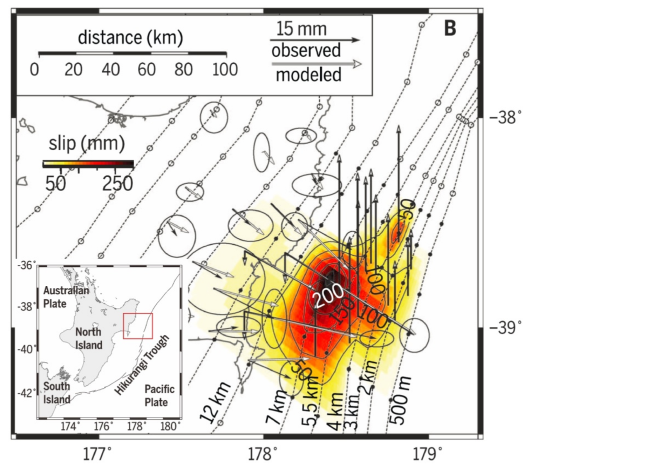
Fig1



Bürgmann and Chadwell, 2014

Sketch of the subduction megathrust zone. Red regions represent the rupture zones of large and small earthquakes. Tan-colored areas are inferred to be conditionally stable and are expected to slip aseismically.

Fig2



Modified from Wallace et al., 2016

The slow-slip episodes in September and October 2014 observed in the Hikurangi subduction zone, New Zealand. distribution inverted from onshore and offshore surface displacements. The dashed lines show the depth contours to the subduction interface.

Slow slip has close connections not only slow earthquakes but also with regular earthquakes, which may have important implications on the physical processes related to earthquake triggering and the nucleation of megathrust earthquakes. Most megathrust earthquakes rupture the plate-boundary fault with a large portion of coseismic slip located offshore or even reaching the trench (Fig. 1). Therefore, to understand the relation of slow slip with the megathrust rupture, we need to well characterize the offshore slow slip. 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 deformation there, which is related to the shallow slip and tsunami hazard. To better understand the offshore seismicity and slow slip around recent megathrust earthquakes, 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).

Detection of Early Aftershocks by Back-Projection Imaging

A) Integration of 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 day after the 2011 M 9.0 Tohoku-Oki earthquake. C) shows the stacked amplitude from beam-forming (red trace) with blue dots marking the picks when events are detected (BP events).

Fig3

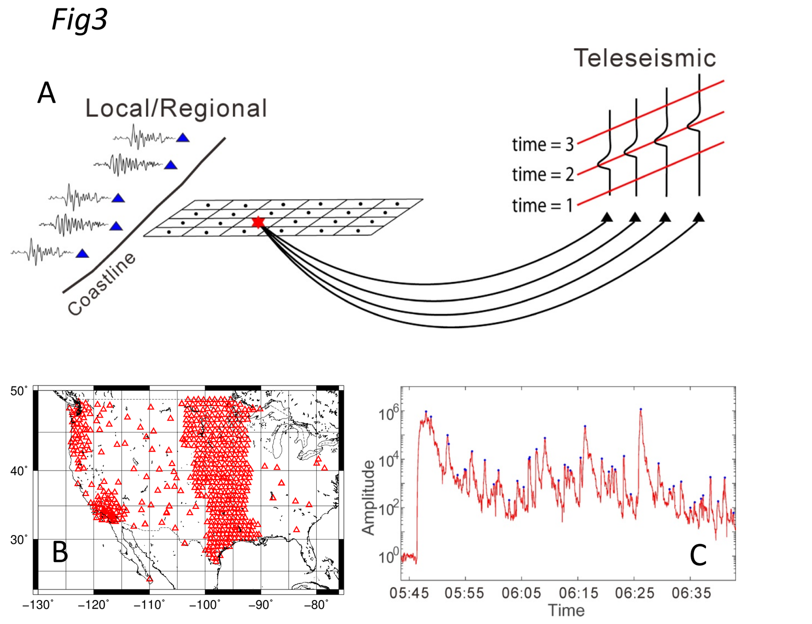
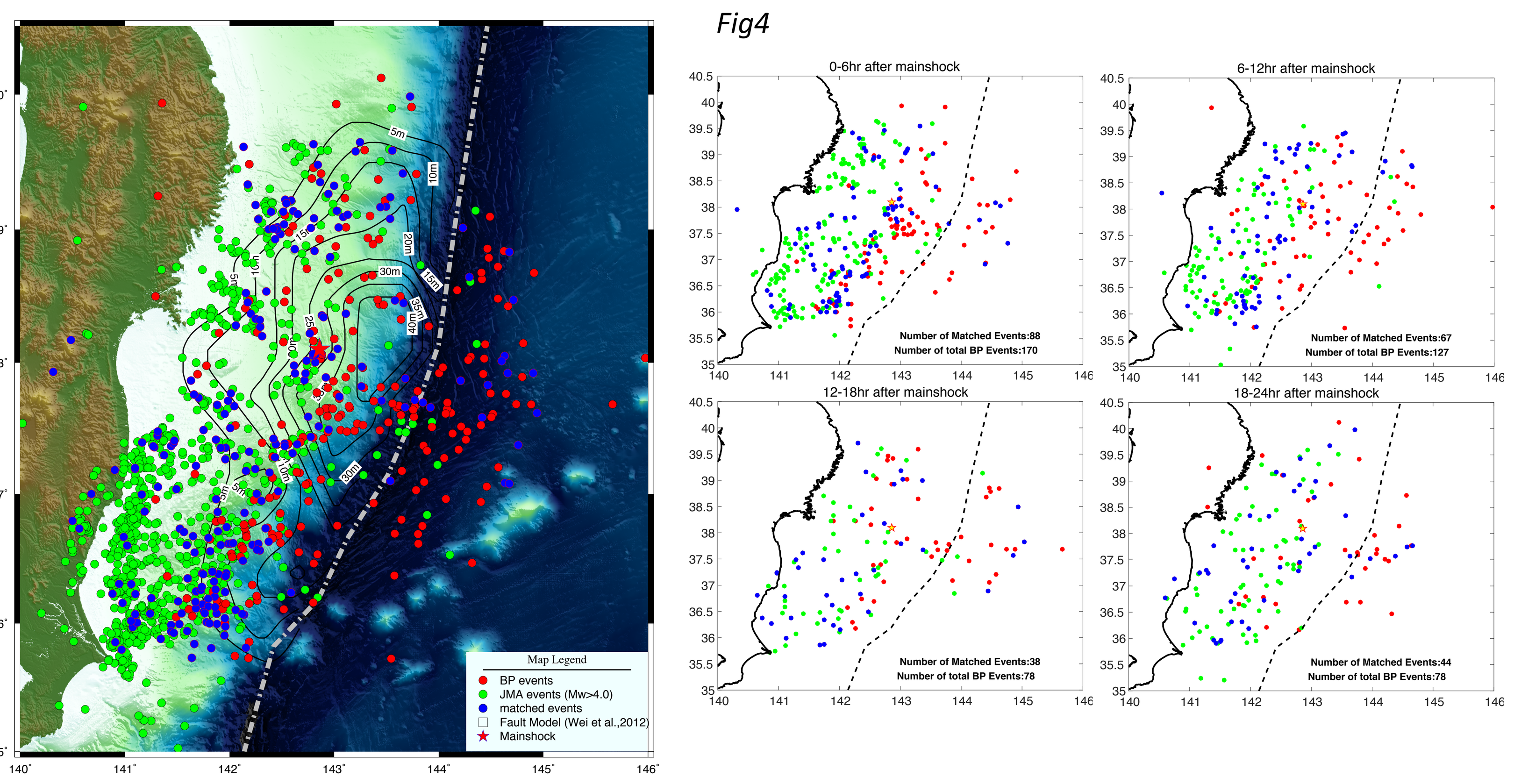


Fig4



We first perform the BP imaging to the first 24 hours of continuous vertical waveforms recorded by USArray in teleseismic distance (Fig. 4). 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 237 Back-Projection detected events with Japan Meteorological Agency (JMA) catalog (blue dots) and detect 216 new events that are not listed in the JMA catalog (red dots), with a significant portion located in the offshore region. We match the event pairs with origin time difference less than 30s and epicenter seperation less than 30km. From the evidence that most matched event located west to the trench and few JMA events located near the trench, we could deduce that JMA catalog systematically missed plenty of events near the trench. However, those events could be effectively detected by Back-Projection technique.

Slowness Correction

One concern in the BP imaging is the accuracy of the imaged aftershock locations. Due to the heterogeneity of the Earth interior, we introduce a slowness error term into the traditional BP equation to further account for the 3D path effect on the travel time calculation (Meng et al.,GRL, 2016). This physics-based slowness correction successfully mitigates the source location discrepancies among the arrays in 2015 Gorkha earthquake (Fig. 5).

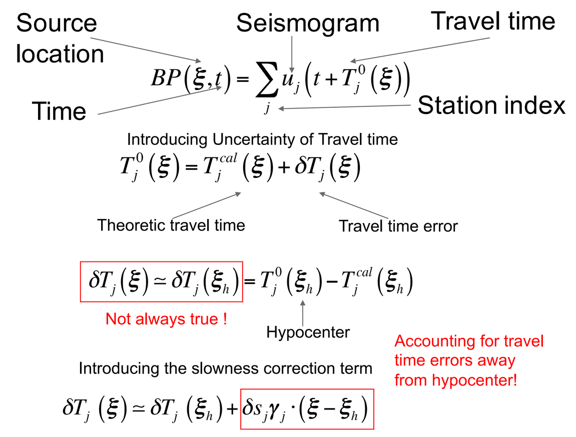
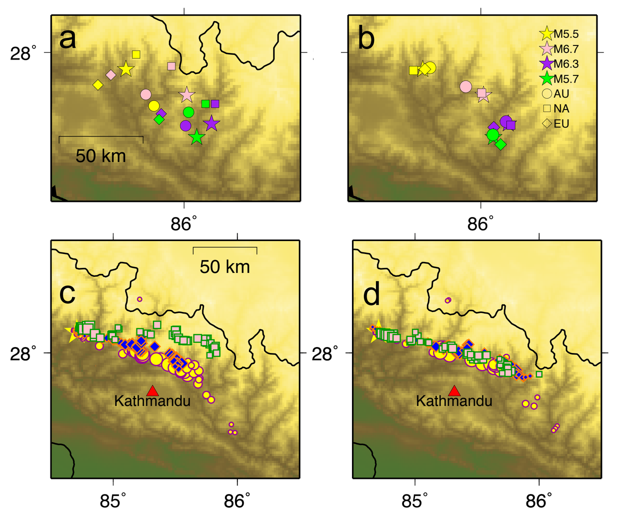


Fig5 **2015 Gorkha earthquake**



Meng et al.,GRL, 2016

The back projections with slowness correction. (a and b) Aftershock locations inferred from back projection with catalog location before (a) and after (b) slowness correction. The stars show NEIC catalog locations of four moderate size (M5 ~ 7) aftershocks, with colors corresponding to four aftershocks. The symbols (circle, square, and diamond) denote apparent back projection locations imaged by the AU, NA, and EU arrays. (c and d) The main shock back projections of different arrays before (c) and after (d) correction.

In this project, we used 173 matched aftershocks to do the slowness correction (Fig. 6). The travel time from JMA location to teleseismic station is t_{JMA} and The travel time from BP location to teleseismic station is t_{BP}. We attribute travel time difference between t_{JMA} and t_{BP} to slowness term. We assume a uniform slowness across the Tohoku area, thus we used a plane to fit the travel time difference (Fig. 7).

Fig6

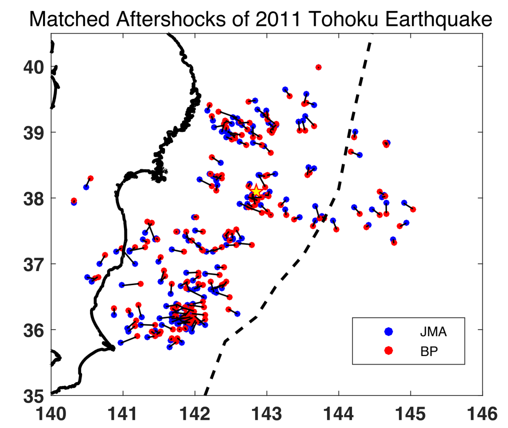
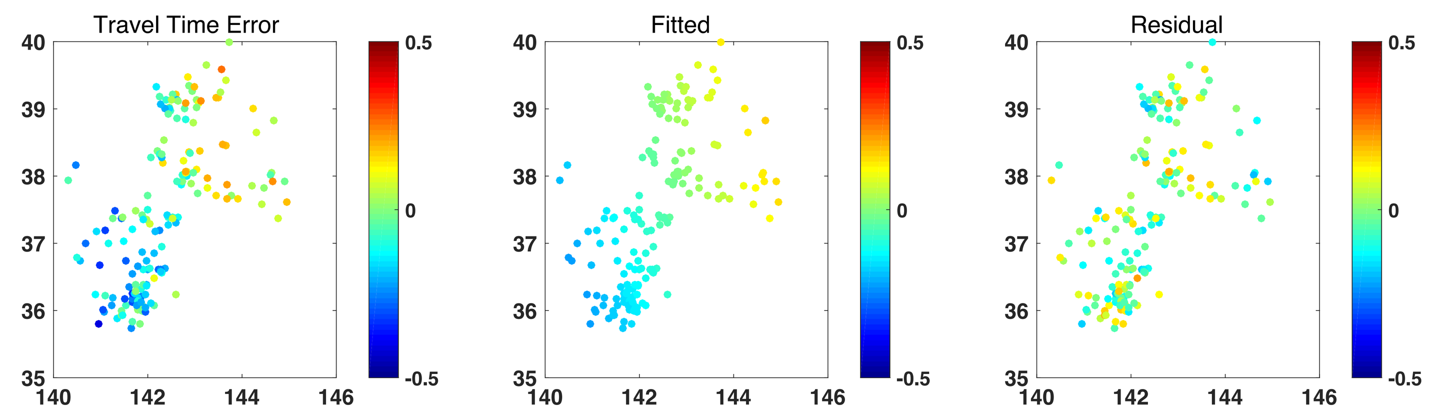
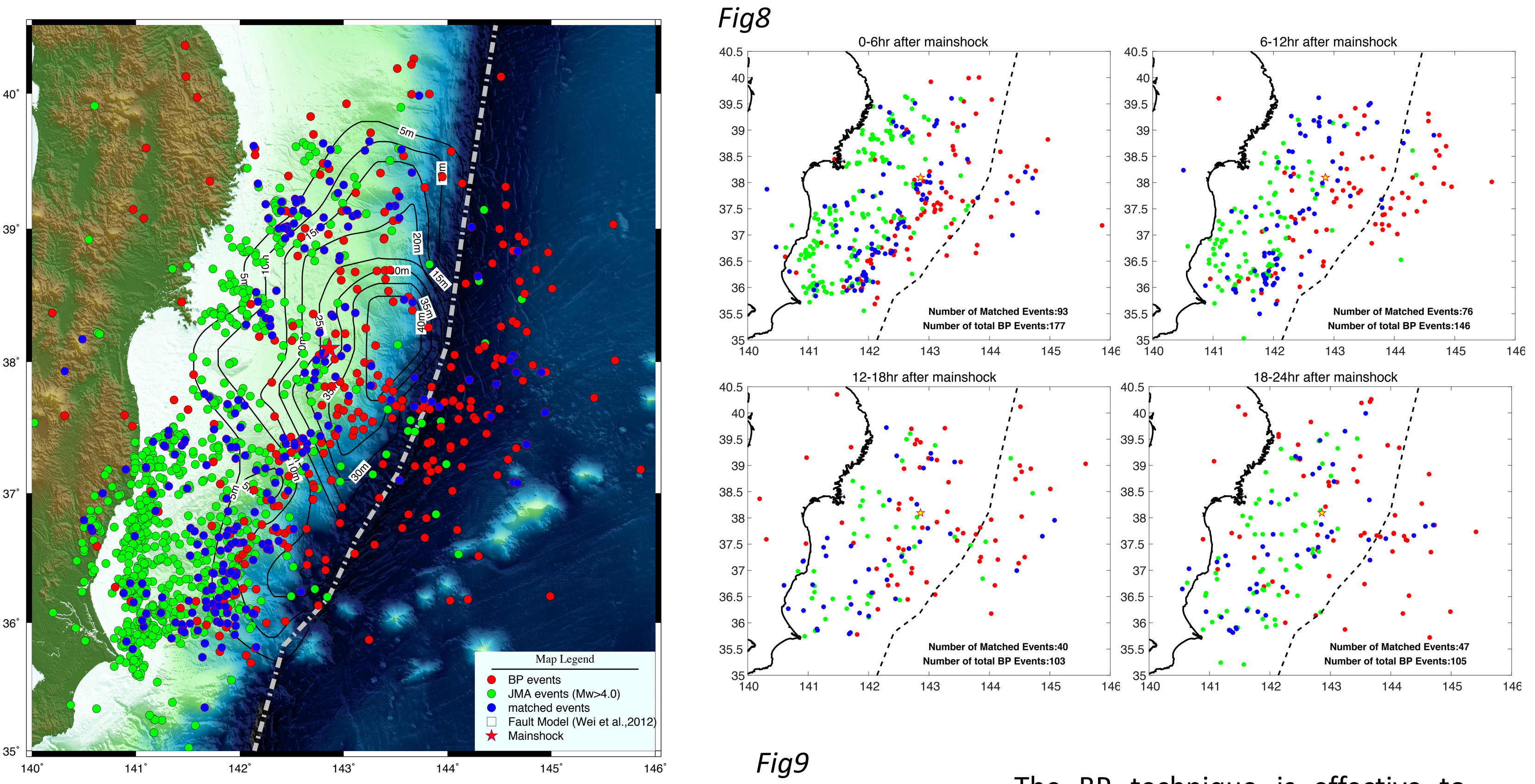


Fig7



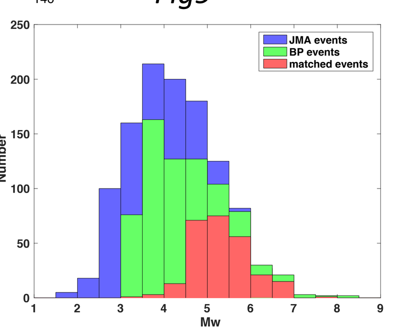
Station:TA.U35A-Pawnee,OK,USA

Fig8



After slowness calibration, we could detect 78 (about 17%) more BP events and match 19 (about 8%) more aftershocks (Fig. 8). And Most of the new detected events locate near the trench, which could be important potential template for the following match-filter.

Fig9

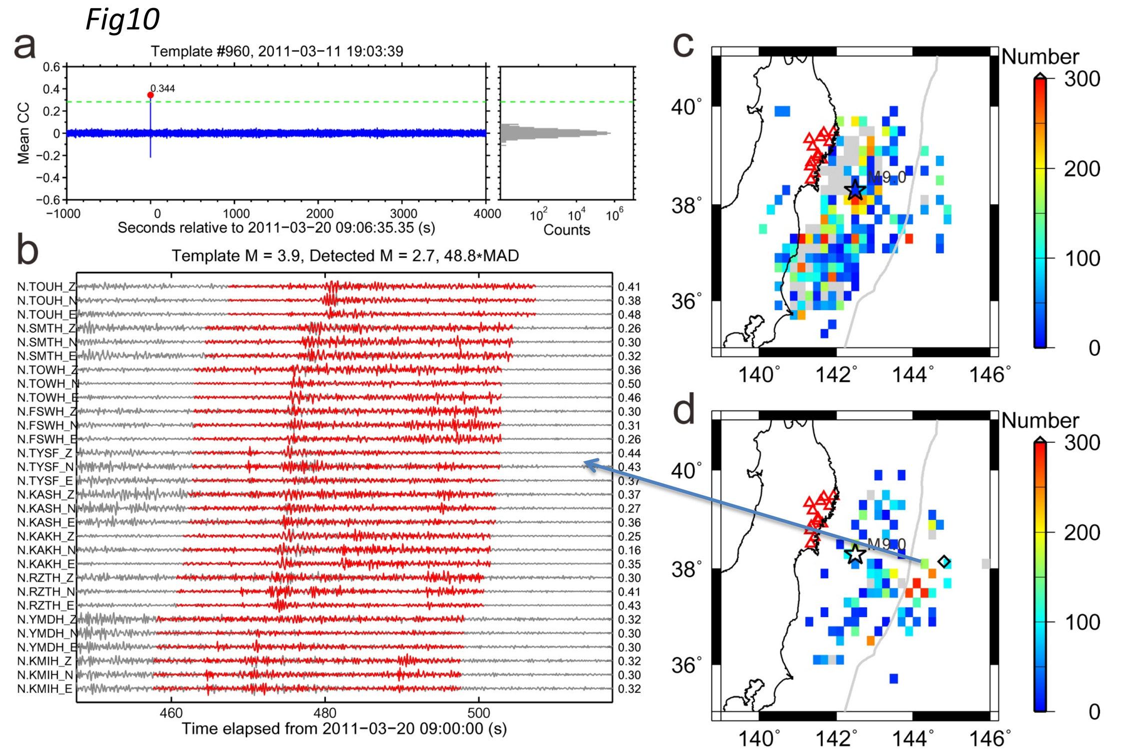


The BP technique is effective to detect most of large events (Mw > 6.0) in the JMA catalog but ineffective to detect earthquakes smaller than Mw 3.0. The BP imaging detects a lot more events in the magnitude range of 3-7.

Matched-Filter Detection and Repeating Earthquakes

We combine the BP-imaged catalog with the JMA catalog and visually check the waveforms of events at 13 coastal Hi-Net stations. Among the combined catalog, 662 events are selected as templates as 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.

Fig10



(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.

Fig11

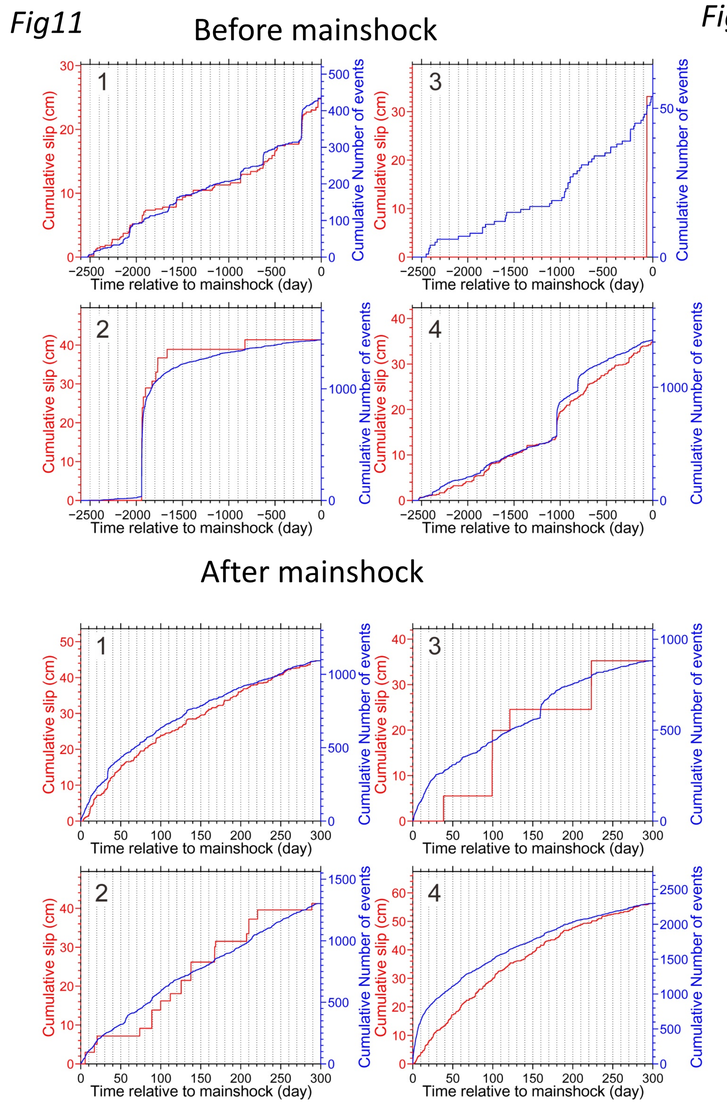
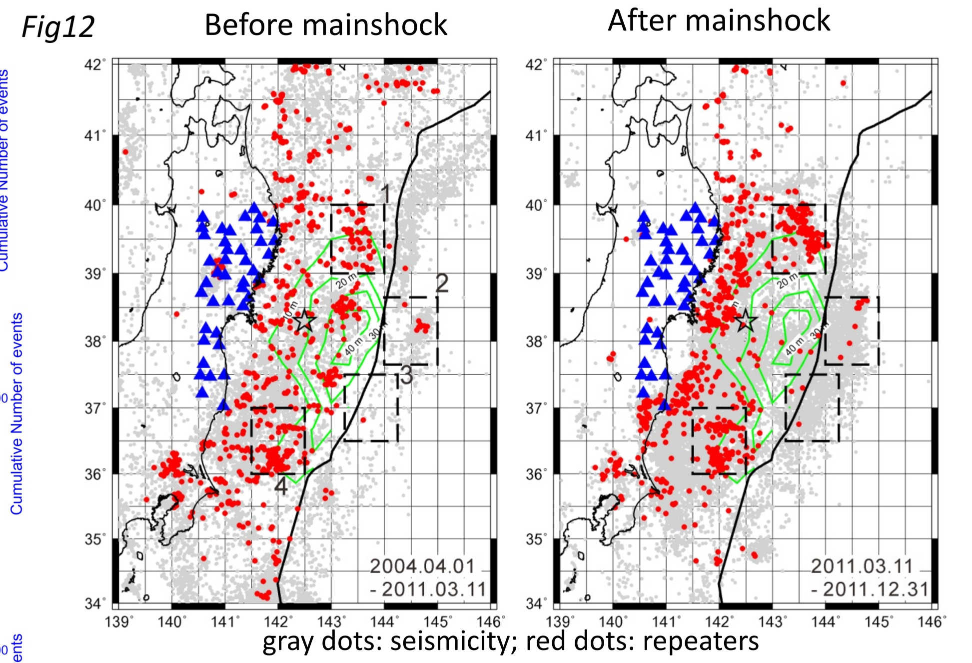


Fig12



gray dots: seismicity; red dots: repeaters

The combined BP-imaged and JMA events will be used to detect events in a long time period both before and after the mainshock. Then repeating earthquakes will be extracted to image possible aseismic-slip episodes. As a preliminary test, we inspect the seismicity and aseismic-slip rates based on the JMA catalog within different parts around the principal coseismic slip zone of the Mw 9.0 mainshock. The occurrence of repeaters in the up-dip region (e.g. region 2 & 3) reveals possible aseismic transients both before and after the mainshock. The pattern will be improved after scanning for missing events among continuous data by the new template dataset.

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. In this project, we introduce the slowness correction to improve the accuracy of imaged aftershock locations. After slowness correction, we could find and match more events with the JMA catalog. We combine the BP-imaged catalog with the JMA catalog to form a template dataset input into the MF detection. 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. In our future work, we plan to enhance the seismicity and aseismic-slip rates by MF detections with the new templates. The slip mode, partitioning and rheological parameters will be investigated along different parts of the megathrust.

Reference

Bürgmann R, Chadwell D. Seafloor geodesy[J]. Annual Review of Earth and Planetary Sciences, 2014, 42: 509-534.
Huang H, Meng L, Plasencia M, et al. Matched-filter detection of the missing pre-mainshock events and aftershocks in the 2015 Gorkha, Nepal earthquake sequence[J]. Tectonophysics, 2016.
Meng L, Zhang A, Yagi Y. Improving back projection imaging with a novel physics-based aftershock calibration approach: A case study of the 2015 Gorkha earthquake[J]. Geophysical Research Letters, 2016, 43(2): 628-636.
Wallace L M, Webb S C, Ito Y, et al. Slow slip near the trench at the Hikurangi subduction zone, New Zealand[J]. Science, 2016, 352(6286): 701-704.