A trial extraction of crustal deformation from seafloor hydraulic pressure gauges to estimate interplate coupling for subduction plate boundaries

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ABSTRACT

To estimate seismic plate coupling and crustal deformation near the trench such as Nankai Trough, we perform a trial simulation of earthquake, applying a rate- and state dependent friction law on the plate boundary and assuming a megathrust earthquake and slow earthquakes occurring in numerous small asperities. Our simulation suggests that the observed activity of the shallow slow earthquakes locally around the fault segmentation boundary between the source regions of the Tonankai and Nankai megathrust earthquakes may be due to weak coupling between the two segments, while quiescence of the shallow slow earthquake around the segmentation boundary between the Tonankai and Tokai megathrust earthquakes may indicate strong plate coupling between the two segments. To evaluate these characteristics quantitatively, we also estimate leveling change at seafloor due to shallow VLFE swarms. Since the levelling change is expected to be so local as to be incoherent, removal of the moving-averaged data from the data stacked by four nearby observation point in the same node may be useful to detect the short-term local levelling change. In the future, we have to extract the crustal deformation component by separating other components such as instrumental drift and oceanic changes in order to consider coherent change among the same science node.

KEY WORDS: Nankai Trough, subduction plate boundary, megathrust earthquake cycle simulation, levelling change near the trench

INTRODUCTION

Slow earthquake (Ide et al. 2007) is thought to occur in the frictional transition zone between seismogenic and stable sliding zones (e.g., Schwartz and Rokosky 2007), which means that slow earthquake should occur in the shallower transition zone near the trench. Recently, broadband seafloor seismometers near the trench (Sugioka et al. 2012) and dense inland networks of highly sensitive seismic stations (Matsuzawa et al. 2015) have enabled detection of the slow earthquakes in shallower part of the plate boundaries.

However, there is a gap of characteristic activity between the shallower and deeper slow earthquakes. After the 2011 Tohoku earthquake, Matsuzawa et al. (2015) reported that shallower VLFEs became active locally off the Fukushima, Ibaraki and Iwate prefectures but have been inactive off Miyagi prefecture. In addition, shallower VLFEs appears not to migrate for long distances along the strike direction but to occur in isolation there, which is different behavior from obsrevational results for the Nankai Trough in the down-dip range of the seismogenic zone (Obara and Sekine 2009).

Ariyoshi et al. (2014a) have pointed out the locality of VLFEs off Tohoku region may be explained by the effect of strong plate coupling around the source area of 2011 Tohoku earthquake rather than by the inhomogeneity of frictional properties in the shallower part of the transition zone along strike direction (Matsuzawa et al. 2015).

In this study, we try to estimate plate coupling around the source regions of megathrust earthquakes on the basis of VLFE activity and the detectability of crustal deformation by hydraulic pressure gauge and repeating earthquake acitivity.

NUMERICAL SIMULATION OF VLFEs

Ariyoshi et al. (2014a, 2014b) performed numerical simulation of shallower VLFEs under a megathrust earthquake cycle. Their simulation results are summarized as follows:

(i) When the down-dip limit of an interplate earthquake or a frictional transition zone is as deep as 30 km, deep VLFEs occur repeatedly and migrate for long distances along the strike direction. This is because the free-surface effect that amplifies the stress shadow is significant only in the shallow part.

(ii) For a megathrust earthquake in which the coseismic slip penetrates to the trench, interplate coupling in the postseismic stage will be strong in the region from the central part of the source region to the shallower part toward the trench, which will cause the shallow VLF after-events to be quiescent or to occur infrequently in isolation.

(iii) On the outer rim, shallow VLF after-events will be reactivated with migration earlier than they will be in the center because of locally weak interplate coupling.

These results suggest that we may try to estimate seismic plate coupling on the basis of VLFE activity. Since VLFE is expected to cause crustal deformation, hydraulic pressure gauge may be useful to detect VLFEs. In the next section, we discuss the detectability of VLFEs by seafloor hydraulic pressure gauges.

DISCUSSIONS

Following the 2004 Sumatra-Andaman Earthquake, the Japanese government has established the DONET along the Nankai Trough. In the Tonankai district, *M*8-class (*M* 8.1 to 8.5) megathrust earthquakes will probably occur in the near future; DONET-I has now operated since August 2011. DONET-I is located above the source region of the 1944 Tonankai earthquake. Delivering seismic and hydraulic pressure data in real time, DONET is also expected to monitor the state of parameters such as seismicity and crustal deformation around a Tonankai earthquake by responding to its pre-seismic change.

Since the hydraulic pressure on the seafloor is expressed as integration of weight density dependent on temperature and salinity from the ocean surface to the bottom, the raw data of the pressure gauge is composed of crustal deformation and oceanic fluctuation due to marine current (e.g., Nagano et al. 2013) and ENSO scale changes of ocean temperature such as El Nino and La Nina (e.g., Hasegawa et al. 2013) in addition to instrumental drift (e.g., Matsumoto et al. 2013).

Figure 1 shows overview of our plan to analyze ocean bottom pressure at DONET by integral study of seismology, geodesy, ocean technology and meteorology. Repeating earthquake analysis (e.g., Uchida et al. 2013; Igarashi 2010) and tilt estimated by accelerators (e.g., Obara et al. 2004) help us to detect crustal deformation in addition to levelling change at seafloor.

In summary, it is imoportant for us to integrate the analysis of hydraulic pressure data by collaborating between seismologist, geologist, meteorologist and tsunami engineer in order to extract crustal deformation as well as oceanic change with removal of the instrumental drift. This collaboration will bring about more robust data for both the two geo-signal components, which reveals the crustal deformation near the trench due to VLFEs and oceanic warming significantly.

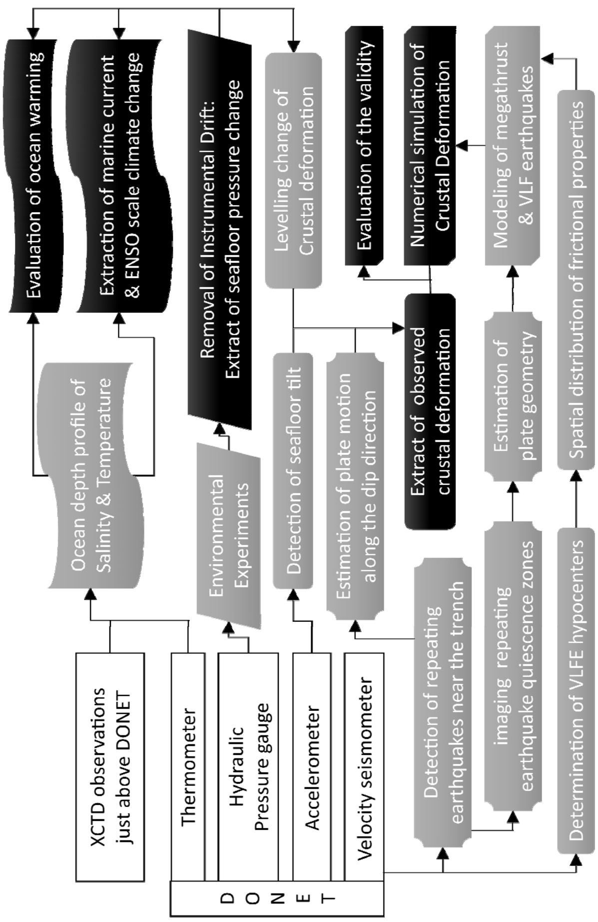

Figure 1. Overview of integral study in order to extract crustal deformation component of hydraulic pressure change.

ACKNOWLEDGEMENTS

This study was also partly supported by the DONET project from MEXT, the research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai trough region from MEXT, and JSPS KAKENHI Grant Numbers 15H04228 and 26000002.

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