

Accretionary prism deformation and fluid migration caused by slow earthquakes in the Nankai subduction zone

Summary:

Tonegawa et al. discusses the connection between tremors (slow earthquakes) and the fluid migration in the Nankai subduction zone (Japan). The focus lies on changes in the seismic velocity and correlation coefficient at the subduction zone by combining a temporally installed OBS network and a permanently installed cabled OBS network. The study period contains a series of slow earthquakes starting in the northwestern part and moving southeast ward. The correlation coefficients (cc) show a similar movement whereas the dv/v remains stable in the northwest. Both measurements (dv/v and cc) are used to monitor the subsurface (structure and properties). It is interpreted that the step-like drop in dv/v and the temporally drop of the cc point toward aspect rotation of cracks and fluid migration.

General Comments:

Generally, the present preprint is close to the published paper Tonegawa et al. 2022. To me, it has to be clear which are the differences between the two publications (data, method, and findings). It has to be immediately clear what we learn by including the temporally OBS network. Further, section 3.4 “Spatial mapping of velocity change and seismic scattering coefficient” is very similar to Tonegawa et al. 2022. Instead of repeating all this, just focus on the new parts and refer to Tonegawa et al. 2022 for the rest.

Throughout the manuscript, the terms “tremor, slow eq, slow slip event, VLFE” seem sometimes to be used interchangeable. Please introduce all of them carefully by explicitly mentioning the difference between them and further, use them carefully. As a non-expert on this topic, I found it difficult to follow and I believe the manuscript would benefit from a clearer distinction between these terms.

The understandability mainly in the Introduction and Discussion can be improved by slightly restructuring the sections.

- E.g. l32-44: You start introducing the Nankai subduction zone and the different types of seismic (and aseismic) events). Then you move toward the different types of observations and at the end, it feels like you finish the introduction of the Nankai subduction zone from the event perspective.

- E.g. l55-63: You talk about the Nankai subduction zone twice, once about the central part and the second time about the western part. In between you talk about the Hikurangi subduction zone.
- E.g. l131-134: A sentence about the CCFs between OBS and DONET followed by a sentence about DONET clocks and then again, a sentence about CCFs between OBS and DONET. L150-152 is again about the station pairs. This should be said in l131 and following.
- E.g. l194: First sentence about stations and following sentence is talking about tremor activity.
- E.g. l314-317: Sentence explaining mechanism followed by sentence about special occurrence followed by sentence about observation of mechanism in data. The middle sentence separates a logical thought.

Be consistent in using the term OBS. Sometimes it is used for the temporally deployed OBS network but sometimes it is also used for cabled sensors. It is clear to me that both are OBS but to improve readability I would not talk from OBS in connection with the cabled array and instead just use the station name or node name.

If I understand correctly, there are data from the temporally installed OBS from September 2019 until May 2021. I would appreciate to see the whole (or at least longer) dv/v and CC time-series (Fig. 4, 5, 6).

The terms north, south, east and west, all are used but I think you are mainly talking about two regions, the one around KMD and MRD. If this is correct, I would choose either east-west or maybe north-south but avoid using both.

Line Comments:

Introduction:

L 15: “heterogeneous structures (correlation coefficient, CC)”, more is not needed in the abstract

L17: spatial or temporal pattern? Please specify

L26: “(1) the seismic velocity”

L42: “Nankai Trough, they are approximately 1–5 years” to “Nankai Trough between 1 to 5 years”

L44: add citation after first sentence

L65-66: I would avoid the term OBS in connection with DONET since you call the temporal network OBS. Maybe just write “Using the continuous record of the Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET, Fig. 1) ...”

L68: Change the comma to a point “... subduction zone. Tonegawa et ...”

L71: “However, the time after the slow...”

L73: I don’t know the term “seismic structure”, therefore I would replace it with “subsurface structure”

L74-76: “In this study, we include the temporary OBS deployments into the existing DONET deployment to cover the gap between DONET1 and DONET2 and estimate temporal changes in the subsurface structure using ambient noise correlation techniques. Additionally, we investigate the connection between fluids and the occurrence of slow earthquakes.”

L76-78: This sentence is not needed. I hope that you choose a period with slow eq. to study them. Please make sure that after deleting this sentence, you connect the sentence before and after (e.g. do not take first about slow eq. and then about tremor)

L78-80: “The tremor activity started on December 5, 2020, peaked on December 11 and 28 and faded by early February 2021 (Fig. 1b).”

L80-84: Not needed, everything already mentioned

Data:

L96: “We used the continuous vertical component records from 49 DONET stations.”

L96-98: In Figure 1 it looks more like the tremors occur in the northern part of the network.

L102-104: “To fill the gap, 15 OBSs with short-period sensors (1Hz) were deployed between September 2019 and May 2021. 10 OBSs were used for two subarrays. In this study, we used 2 OBSs located at the center of the two subarrays. In total 7 OBSs were used.”

Methods:

L106-110: This is not needed

L112-121: “We calculated cross-correlation functions (CCFs) from ambient noise records following established methods (e.g. Campillo and Paul, 2003; Shapiro et al., 2005; Breguier et al., 2007). To suppress energetic signals, such as those from earthquakes, we applied lognormal-shaped functions (Tonegawa et al., 2020; 2022). A bandpass filter of

0.5–2.0 Hz combined with spectral whitening was used. In the chosen frequency band, the ambient seismic noise is dominated by acoustic-coupled Rayleigh (ACR) waves. These waves propagate through the ocean and the entire accretionary prism in this region with 1.3–1.5 km/s (Tonegawa et al., 2015). CCFs were computed using 600-second time windows, and a 30-day moving average was obtained by stacking daily CCFs for each station pair. If the duration affected by the lognormal-shaped function was less than 70% of the 30-day period, the corresponding CCF was discarded. Additionally, reference CCFs for each station pair were generated by stacking CCFs over the entire observation period. In the CCFs, direct ACR wave propagation between station pairs appears at early lag times, while scattered waves are observed in the coda (Fig. 2)."

L141: It seems like you have an example for this symmetrical shift. Add such an example figure to the Supplement and add a reference. If figure 2.b shows this asymmetry, add a clear statement to the figure caption and add a reference to figure 2.b.

L142: “– 20 – 20 s” looks like there are two minus signs. I would replace the second one with the symbol used in “2-s” so that it is clearer. (Also e.g. l163)

L143-145: I cannot follow. This sentence starts with CFs and ends with CCFs.

L145-147: "If, within a given time window, the cross-correlation coefficients of the CCFs exceed 0.9 for more than 85% of the observation period, the window is considered to contain coherent signals throughout the period. The delay times of these CCFs are then interpreted as clock deviations."

L163: $dv/v = - dt/t$ should be introduced in the sentence before. Possible reference: Poupinet et al., 1984 (Monitoring velocity variations in the crust using earthquake doublets: An application to the Calaveras Fault, California)

L163-165: I do not understand this sentence.

L174: What do you think is the reason that MRE-OBS is below 70%?

L193-194: Why southern part? The figures 5 and 6 show variations in the northeast.

L195-200: I would like to see more periods (earlier and later). Further, I think it is a bit problematic to use 30 d data and show periods with an increment of just 10 days. To me this is too much overlap. If 30 d data used to get stable results, reduce the number of periods between November 25 2020, and January 20 2021.

L200-230: To me these formulas do not have to be in the main text since they have been published already in Tonegawa et al., 2022. Move them to the supplement. The last paragraph with information about the parameters can still be part of the main text if preferred.

Results:

L235-240: Very clear and interesting. To me, the key message is that some station clocks can be interpolated linearly and some not but table 1 does not support this finding. Therefore, I suggest moving the table to the supplement. Further, the clock of station SHM3 could also be interpreted as slightly periodic instead of linear.

L246-248: Also include the DONET2 nodes in these sentences to support the last sentence.

L251-254: I cannot see the time offset in CC time series for OBSs (Fig 4.d). You are analyzing the spatio-temporal scattering changes later (Fig 6) so you don't have to say anything about the CC values and their spatio-temporal evolution here.

L254: This is confusing because here you use the term OBS for the cable array.

L567: Is it also consistent with other nodes shown in supplement figure?

L262-264: Correct but the weaker (less energy) tremors are also located at the same spot. The energy rates are not used to support your findings.

L264: I'm not sure if the CC reductions "merged" or if the strong one from the eastern part moved and the weaker one in the western part disappeared. I think your time resolution is not high enough to distinguish the two options.

Discussion:

L284-285: By expanding the study period it would become clearer how strong the dv/v reduction and the tremor occurrence really correlate and if there is something like healing after the tremor series.

L291: You stacked over 30 d, can you make a statement about 10 d?

L299: I would call it a step-like drop.

L302: Drop "In addition"

L304: Which episode do you mean? Drop "Furthermore"

L308-311: Are these the cracks shown in Fig. 8a? If so, add a reference.

L311-314: Is this shown in one of the subplots in Fig 8? Might be helpful.

L314: Does this mean you expect a slight increase of dv/v after the slow eq but not back to the original level? Do you see this?

L317: I do not understand what is meant by “this mechanism” because you explain the spatial distribution in the sentence before and not a mechanism. I think what you mean is that the step-like drop with almost no healing supports the crack thesis. If so, I the sentence beforehand discussing the spatial occurrence of the dv/v drop should not split the mechanism and the observed drop (sentence before and after).

L318-333: This is introduction and too much background for a discussion. The amount of background information should be shortened and more closely connected to your new findings. Further, make clear what the new findings about tremor location and fluid migration are compared to Tonegawa et al 2022.

L336-345: Concept is clear and supported by references. But to me it is not clear how this new analysis supports this concept. (I think this does not have to be added here and you can leave this last paragraph how it is but make this clear in the two antecedent paragraphs.)

L308-345: I understand that dv/v is linked with cracks and CC with fluids. For the increased pore pressure, you need this impermeable clay sheets (to trap fluids). How are these two things (cracks and high pore pressure) linked? Intuitively I would think that more cracks (dv/v) drop lead to a pressure decrease and not increase. I find this very interesting but I cannot completely follow here.

Conclusion

L355-356: “We present the temporal variations in dv/v and CC in the Nankai subduction zone associated with the slow earthquake activity that began at the end of 2020.”

Figure Comments:

Figure 1:

- add a and b and replace top and bottom
- (a) legend for seismic network
- Label the Nankai Trough with 0 km
- Remove station names and numbers and add figure like Tonegawa et al. 2022 Fig 1 to Supplement
- Add (thicker) black edge color for stations used in this study
- (inserted map of Japan) color ocean blue or land brown and change plate boundaries to orange (like in (a))
- (b) I would remove the vertical black lines marking the end of the month
- Caption:
 - o DONET1 and DONET2 are circles and squares vs temp. OBS are triangles
 - o Time format: Please double check the time format and keep it consistent (December 1st 2020 is not the same as December 1, 2020)
 - o “The histogram represents the number of tremors per day whereas the red line shows the cumulative number of tremors between December 1, 2020 and February 5, 2021. Tremor locations are represented in (a).”

Figure 2:

- Caption:
 - o Time format
 - o “CCFs for XX station pairs stacked between START-DATE and END-DATE (1 year). The two lines represent a propagation velocity of 1.5 km/s.”
 - o (b) add the time frame for stacking

Figure 3:

- (a) Nankai Trough (0 km) + 10 km orange (like Fig. 1 a)
- (a) Add legend explaining red, yellow and pink markers therefore remove “The symbols are the same as those in Fig. 1.”
- (b) Cut off the uppermost 100 days (600-700 seems to be empty)
- (b) Make black dots transparent that density of points becomes visible
- (b) “The estimated clock deviations at SHM7c represented by the black dots. The red line marks the median value and right respectively left cyan line indicate the first respectively third quartiles.”

Figure 4:

- OBS is not the same as temporally deployed OBS
- The y-axis do not make sense since you plot the station pair with offset.

Figure 5:

- Color bar can be larger

- Use the same shapes for the different arrays as in Figure 1 and 2 (circles, triangles, squares)
- Would be interesting to expand this analysis in time (backward and forward)
 - o Maybe the subsurface needs just more time to “relax” after the slow eq. activity
- I know that sometimes stacking over long time periods is necessary to acquire stable dv/v results. But here, to me there is too much time overlap between the different periods. If there is no way to shorten the stacking period, the number of presented periods should be reduced to avoid that much overlap.
- You write in L174 that you could not use the node MRE but MRE stations are plotted on the map. Just plot the stations used to generate the dv/v anomaly or make the unused stations transparent.

Figure 6:

- No extra color bar is needed for the first Period
- See comments Figure 5

Figure 7:

- Not sure why energy rates are plotted. I don't see a correlation between energy rates and scattering coeff.
- Color bar can be larger
- Use the same shapes for the different arrays as in Figure 1 and 2 (circles, triangles, squares) → if tremors are black, use same colors for stations as in Figure 1 and 2
- Unclear why figure (b) appears twice. Upper plot is sufficient.

Figure 8:

- What is the difference between e.g. (c) Period 2 and 3 when there are (no) pink arrows pointing upward?
- Slow eq vs. tremor
- Just use a,b,c,.. and remove the left vs right