The Non-volcanic tremor observation in Northern Cascadia

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3/22
Reference


Introduction

• Non-volcanic tremor (NVT) was originally identified in the subduction zone southwest of Japan. [Obara, 2002 ]
• NVT represents seismic signal observed away from volcanic regions with long durations, no clear body wave arrivals, and spectra depleted in high-frequency energy compared with regular earthquakes of similar amplitude.

[Brudzinski et al., 2010]
Introduction

- **Episodic tremor and slip (ETS)**
  - It is empirically defined as “repeated, transient ground motions at a plate margin, roughly opposite to the direction of longer-term interseismic deformation, accompanied by low-frequency emergent, semicontinuous seismic signals.”

[Patricia et al., 2004]

[Patricia et al., 2004]
Analysis

- **Tremor Activity Monitoring System (TAMS)**
  - The original objective of TAMS is to recognize waveform patterns associated with tremor signals in a timely manner by systematically examining seismic waveforms recorded at contiguous stations.

**Moving Average (MA)**

A simple calculation that smoothes the data and makes it easier to spot trends.

**Scintillation Index (SI)**

The square root of the normalized variance of the intensity of the signal.

\[
\mu_{|y|} = \left( \sum_{j=i-\left(\frac{N-1}{2}\right)}^{j=i+\left(\frac{N-1}{2}\right)} |y(j)| \right) / N
\]

\[
SI_i = \sqrt{\left( \mu_{|y|}^2 - \mu_{|y|}^2 \right) / \mu_{|y|}^2}
\]
Analysis

[Kao et al., 2007]
Source Scanning Algorithm (SSA)

Brightness function:
The ‘brightness’ of a point ($\eta$) at time ($\tau$) is calculated by summing the normalized amplitudes from all stations at the predicted arrival times.

$$br(\eta, \tau) = \frac{1}{N} \sum_{n=1}^{N} |u_n (\tau + t_{\eta n})|$$
Analysis

- The SSA results for the Earthquake sample in Cascadia.
Analysis

- The SSA results for the tremor sample in SW Japan.

[Shelly et al., 2006]
Result

- TAMS Daily Summaries for Vancouver Island

(after 20 day low-pass filter)
Northern Cascadia ETS Between 19970101 and 20071231

Result

GPS E-Component at NTKA

GPS E-Component at ALBH

447 ± 43 (day)
Result

• Source distribution

Table 3. Average Nearness Between Different Types of Seismic Events in Northern Cascadia

<table>
<thead>
<tr>
<th>Types</th>
<th>A–A'</th>
<th>B–B'</th>
<th>C–C'</th>
<th>D–D'</th>
<th>E–E'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tremor–Tremor</td>
<td>1.2</td>
<td>0.7</td>
<td>0.8</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Tremor–Crustal Earthquake</td>
<td>6.6</td>
<td>9.9</td>
<td>9.0</td>
<td>11.7</td>
<td>17.5</td>
</tr>
<tr>
<td>Tremor–Intraslab Earthquake</td>
<td>13.8</td>
<td>14.4</td>
<td>16.9</td>
<td>16.4</td>
<td>17.4</td>
</tr>
<tr>
<td>Crustal Earthquake–Crustal Earthquake</td>
<td>0.9</td>
<td>1.3</td>
<td>1.7</td>
<td>4.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Intraslab Earthquake–Intraslab Earthquake</td>
<td>2.1</td>
<td>2.9</td>
<td>1.8</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Discussion

✓ Significance of the Tremor gap

✓ 1. The lack of tremors is equivalent to the lack of mechanisms to release accumulated stress, so the two earthquakes occurred.

✓ 2. The occurrence of two large earthquakes in the relatively recent past could have significantly reduced crustal stress and/or fluid pore pressure, thereby inhibiting tremor activity in this region for some period of time.

➢ The different spatial relationship in the two regions might imply that the physical processes responsible for forming a tremor gap are not necessarily the same.

[Obara and Hirose, 2006]
Discussion

- **Along strike migration (For the six A class episodes)**
  - **Steady**
  - **Halt**
    - staying in a particular place for a certain period of time
  - **Jump**
    - the tremor clusters reappears in different places
Discussion

- Along strike migration

Average velocity of each episodic is about 7-12 km/day.
Discussion

The Rapidly Reverse Pattern of the Tremor Migration

A new feature of tremor organization — streak-like clusters of tremor that propagate rapidly back from the front of the advancing tremor through the region that has already experienced tremor, termed Rapid Tremor Reversals (RTR).
Discussion

- The Rapidly Reverse Pattern of the Tremor Migration

- The slip and tremor fronts are roughly coincident, the RTR regions have already been ruptured in ETS.

- Fluid pressure waves may propagate back along the previously ruptured plate interface more rapidly than they can advance.

Tidal influence?
The definition of **streaks** as the rapid tremor migration that shows reasonable continuity in space and time, lasts at least 10 minutes, and propagates paralleled the slip more than 10 km horizontally.
Discussion

- Characterization of the different migration type

![Graphs showing migration patterns and velocities](image)

- Many minutes
- 7-12 km/day
- 200 km/day
Discussion

Possible mechanisms of tremor occurrence

Kao’s model

An increase in fluid pressure results in a decrease in effective normal stress on fractures allowing for strain energy release at low shear stresses. These resulting strain releases need not be limited to the subduction interface.

[Kao et al., 2006]

[McCausland et al., 2010]
Discussion

- Possible mechanisms of tremor occurrence
  - For the existence of the Rapid Tremor Reversals and Tremor Streak.

- Non-volcanic tremors and slow slip events occur simultaneously (ETS) in the transition zone from locked to aseismic.
Discussion

- Possible mechanisms of tremor occurrence
  - For the existence of the **Rapid Tremor Reversals**.
  - The common features of each episodic, particularly the tendency to propagate mainly northwestward, suggest the influence of permanent aspects of the plate interface. [Houston et al., 2011]
Discussion

- Possible mechanisms of tremor occurrence
  - For the existence of the **Tremor Streak**.
    - It has long been known that fault surface exposures show prominent linear striations (corrugations/mullions and ridge-groove structures) with their long-axis parallel to the slip direction.

[Image of diagrams with equations and annotations]

[Ref: Ghosh et al., 2010]
Conclusion

1) The mechanical/rheological conditions that facilitate the occurrence of ETS tremors and discourage the occurrence of ordinary earthquakes, and vice versa.

2) In order to reconcile the slow propagation of ETS processes with the seismic speeds of stress transfer, a slowly propagating disturbance such as a creep wave or fluid diffusion front must be involved.

3) Whether the tremors distribute in a large volume or only occur at the interface, the tremor observation still provides a new insights into structural interpretation and modelling.
Thanks for your attention!