Constraining the depth of the time-lapse change in seismic velocity after the 2011 Tohoku earthquake, Japan

Kaoru Sawazaki¹,³, Hisanori Kimura¹, Naoki Uchida², Ryota Takagi², and Roel Snieder³

¹: National Research Institute for Earth Science and Disaster Prevention (NIED)
²: Tohoku University
³: Colorado School of Mines
2011 Tohoku earthquake ($M_w 9.0$)

Koketsu et al. (2011)
Area of velocity change

- KiK-net (strong motion seismograph network)
- Hi-net (High sensitivity seismograph network)

100m-80km

\[ \text{crustal deformation} \]

\[ \text{fault rupture} \]

\[ \text{repeating earthquake} \]
Methods and Targets

Methods
• 0-100m depth: deconvolution analysis (KiK-net)
• 100m-80km depth: repeating earthquakes (Hi-net)

Targets
• S-wave velocity \((V_S)\)
• P-wave velocity \((V_P)\)
• S-wave splitting
Deconvolution analysis

\[ D(\omega) = \frac{u_1(\omega)^* u_2(\omega)}{|u_1(\omega)|^2} \]

\( V_P: \) Z comp.  
\( V_S: \) Horizontal comps.

Snieder and Safak (2006)
S-wave splitting

\[
\frac{V_S(\phi)}{\overline{V}_{S,\text{Bef}}} = \frac{\overline{V}_S}{\overline{V}_{S,\text{Bef}}} + \frac{A}{\overline{V}_{S,\text{Bef}}} \cos[2(\phi - \psi)]
\]

- normalized anisotropy coefficient \( \approx \gamma_s^{(s)}/2 \)
- azimuth of maximum \( V_S \)

Nakata and Snieder (2012)
Data

• ▲: KiK-net stations
• period: 2008/11-2012/3
• hypocentral depth: > 40km
• bandpass filter: 1-10Hz
Temporal changes in $V_P$ and $V_S$

2008/11/1-2011/3/11

2011/3/11-2012/3/11

$V_P / V_{P, Bef}$

$V_S / V_{S, Bef}$

Normalized velocity

Lapse time (month)
Temporal change in S-wave splitting

- Winter
  - BefSS VV
  - BefSVA

Normalized Vs

Anisotropy coefficient

2008/11/1-2011/3/11

2011/3/11-2012/3/11

Lapse time (month)
Correlation with dynamic strain

\[ \mathcal{E} = \frac{v_{\text{particle}}}{V_{S30}} \]
Map of $V_s$ change

- 0–1 months
- 1–3 months
- 3–6 months
- 6–12 months

Normalized $V_s$
Summary of deconvolution analysis

1. $V_P$ and S-wave splitting do not show systematic change

2. $V_S$ decreases by 6%

3. $V_S$ reduction correlates with dynamic strain $\varepsilon$ when $\varepsilon > 5 \times 10^{-4}$

4. $V_S$ recovers continuously for 1 year
Repeating earthquake analysis

- : before
- : after

Lapse time (s)
Repeating earthquake analysis

Poupinet et al. (1984)
Data

- ▲: Hi-net stations
- period: 2003/6-2011/8
- hypocentral depth: 8-80km
- bandpass filter: 1-4Hz
Temporal change in $V_S$

![Graph showing temporal change in $V_S$]
Temporal change in $V_S$

- 0-100m depth
- 100m-80km depth

Normalized $V_S$

Lapse time (year)

Lapse time (month)

0-100m depth

100m-80km depth
Comparison to slip distribution

Koketsu et al. (2011)

1-3 months

Deconvolution

Repeating earthquake

Koketsu et al. (2011)
Depth dependence of velocity change

- 0-100m depth: 
  $V_S$ decreases by 6%, correlates with dynamic strain of strong motion

- 100m-80km depth: 
  $V_S$ decreases by 0.4%, may correlate with coseismic slip
Future works

- $V_P$ and S-wave splitting change at 100m-80km depth
- Physical interpretation
Acknowledgments

- NIED
- Tohoku University
- CWP
- Japan Society for Promotion of Science (JSPS)