In this presentation file, we mainly showed published data.

Continuous source system and distributed acoustic sensing for reservoir to crust monitoring

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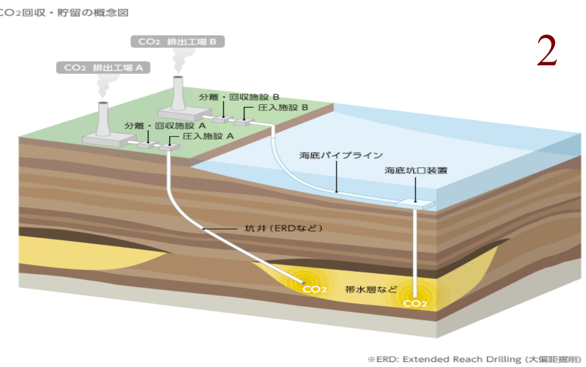
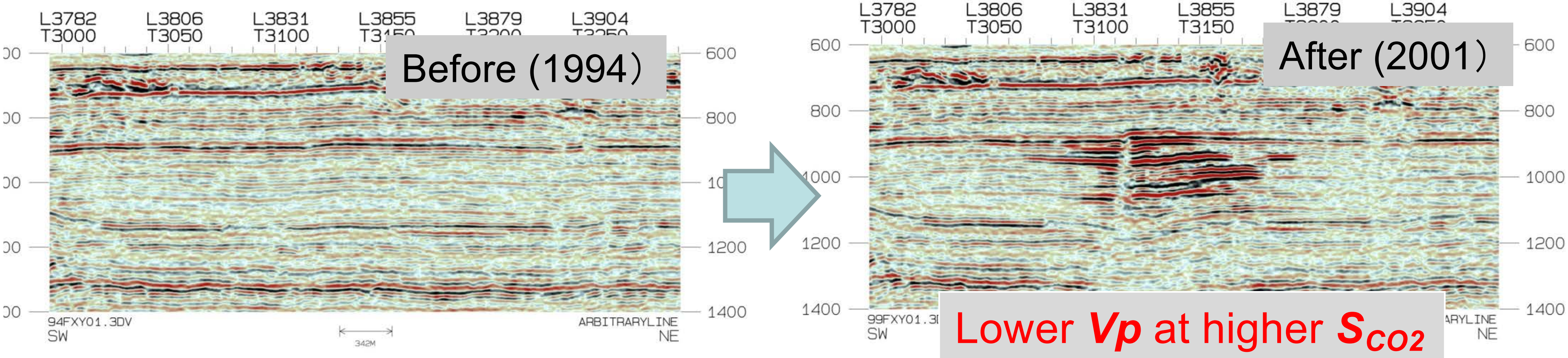
Monitoring in CO_2 geological storage



Common approach in CO_2 storage:
Time-lapse seismic monitoring

Sleipner CCS project (Arts et al. 2008)



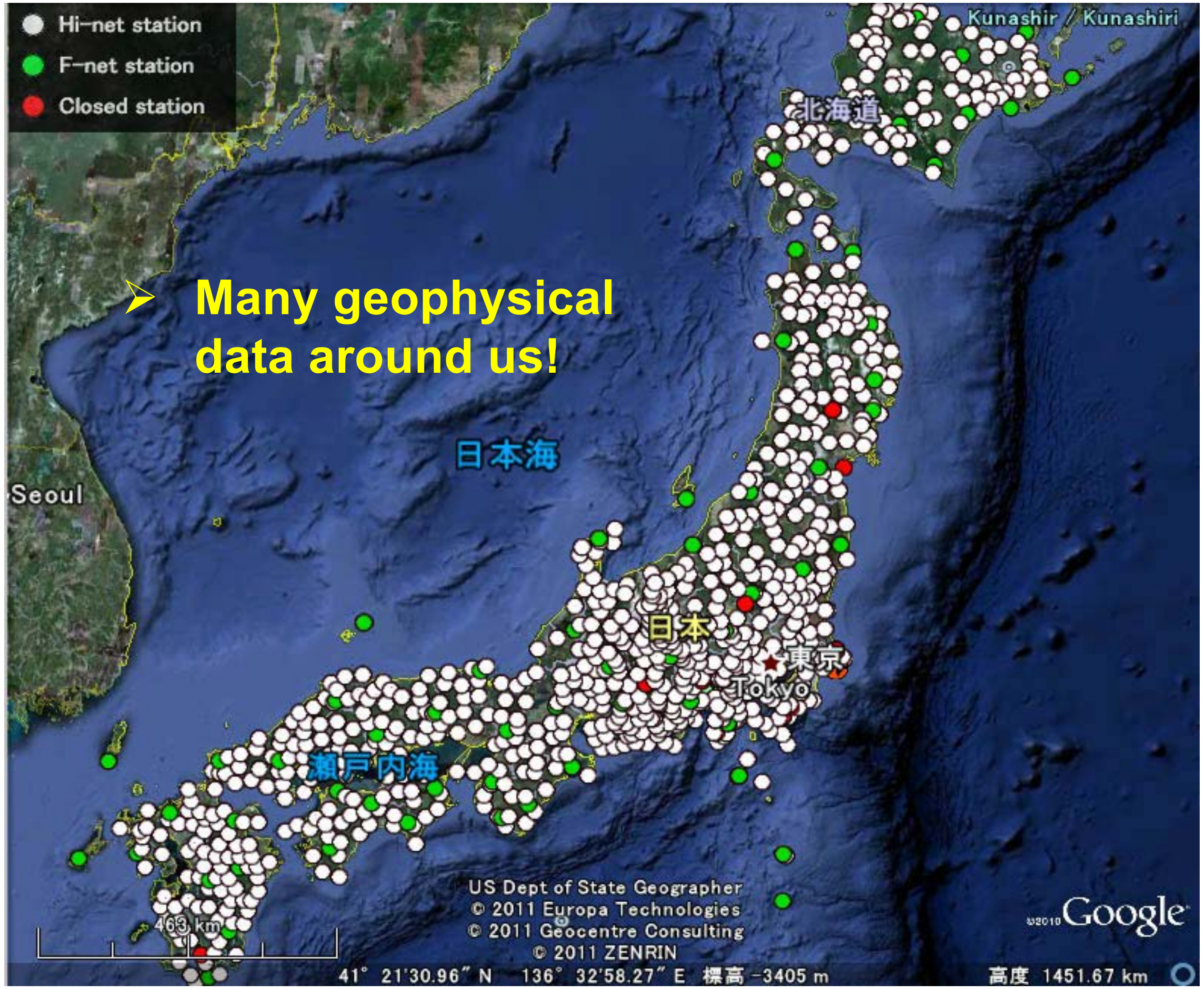
High cost → Longer time interval for data acquisition

Develop continuous monitoring system using (1) ambient noise and (2) continuous and controlled source system

- **Low cost**
- **Continuous**

Ambient noise is recorded at many seismometers

- Firstly, we use ambient noise (big data) for geophysical imaging and monitoring

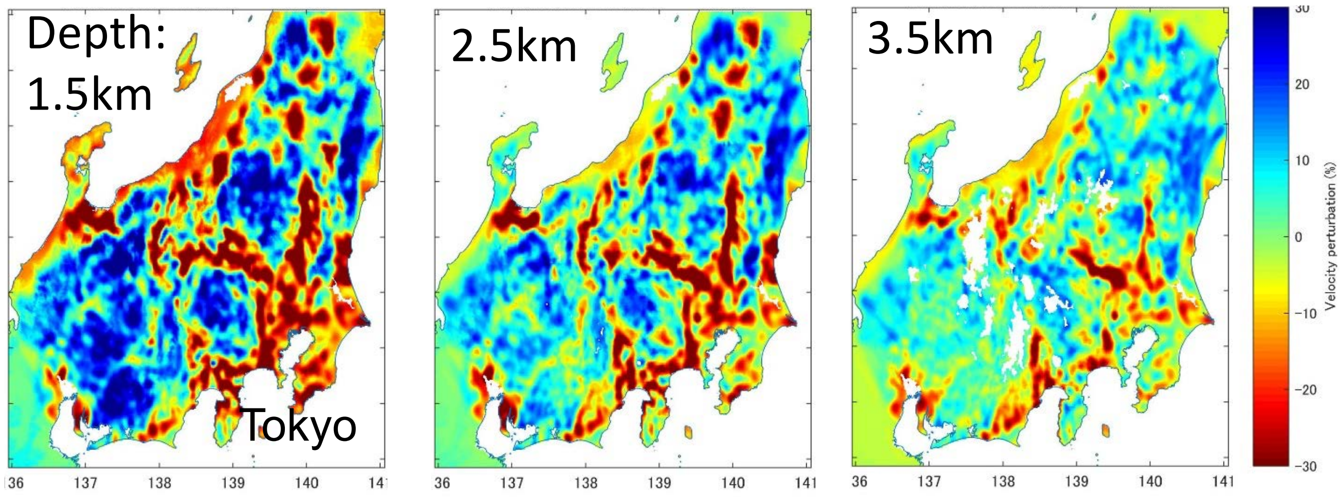


Seismometer locations

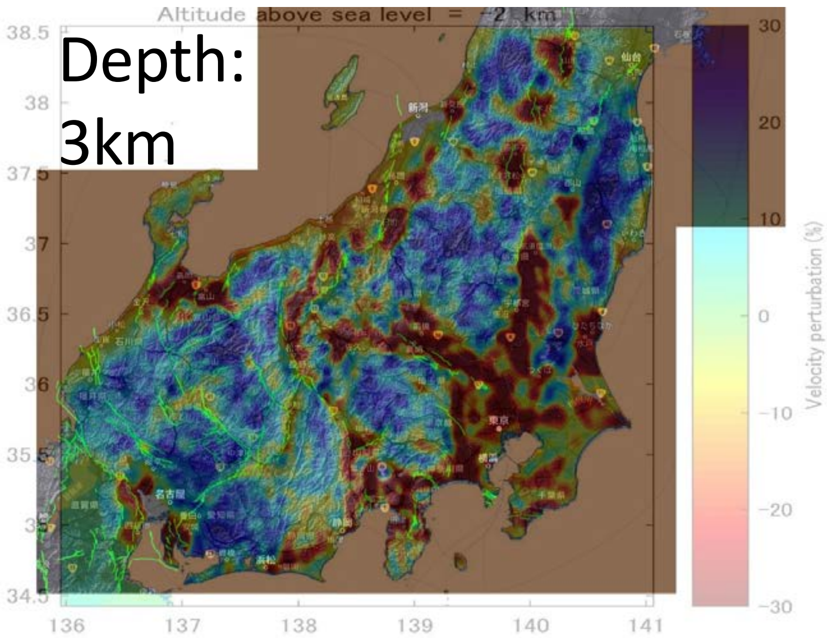
NIED

S-wave velocity by applying seismic interferometry to ambient noise

Surface wave analysis (Zero-crossing method)



H. Nimiya, T. Ikeda, and T. Tsuji, Three-dimensional S-wave velocity structure of central Japan estimated by surface-wave tomography using ambient noise, JGR Solid Earth, doi:10.1029/2019JB019043, 2020.



High-resolution geologic model of large-scale Japanese Island

- Velocity anomaly agrees with faults and volcanoes

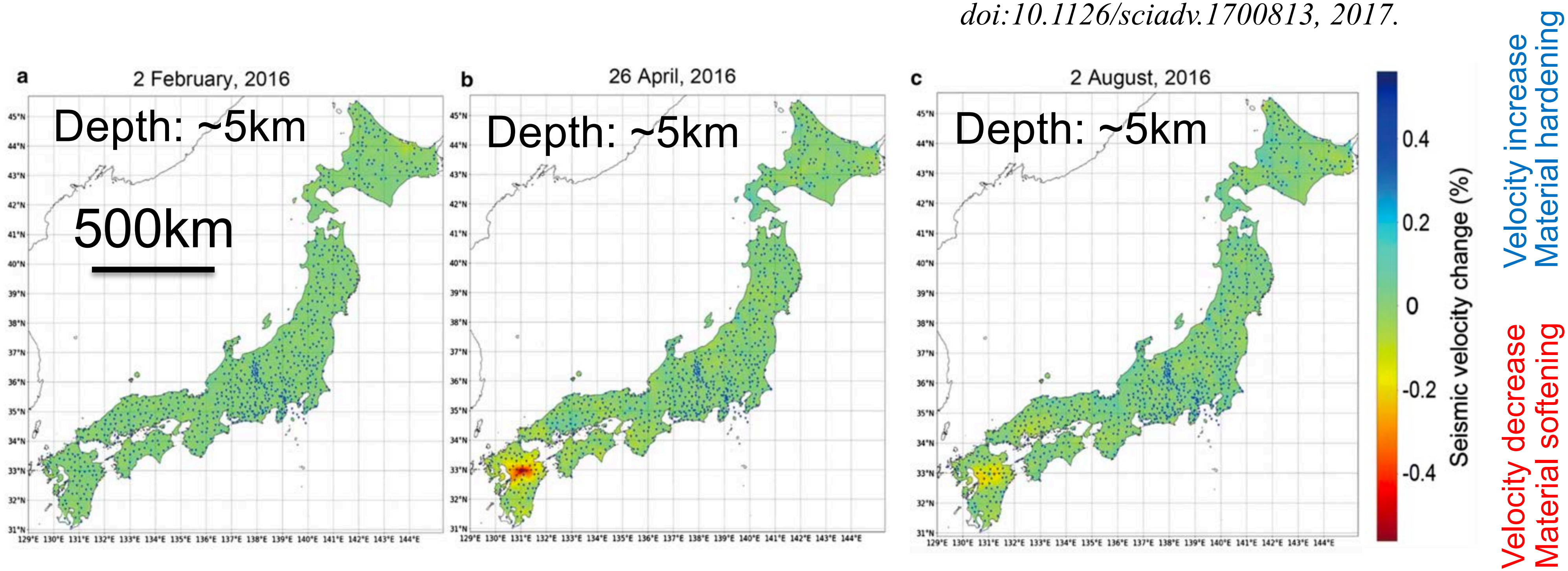
- If we estimate temporal variation of the S-wave velocity, we may monitor dynamic behaviors of Japanese Island!

Continuous monitoring of whole Japanese Island using ambient noise

Spatio-temporal S-wave velocity variation during the 2016 Kumamoto earthquake by applying seismic interferometry to ambient noise

- Velocity decrease due to earthquake rupture
- Velocity increase after Aso volcano

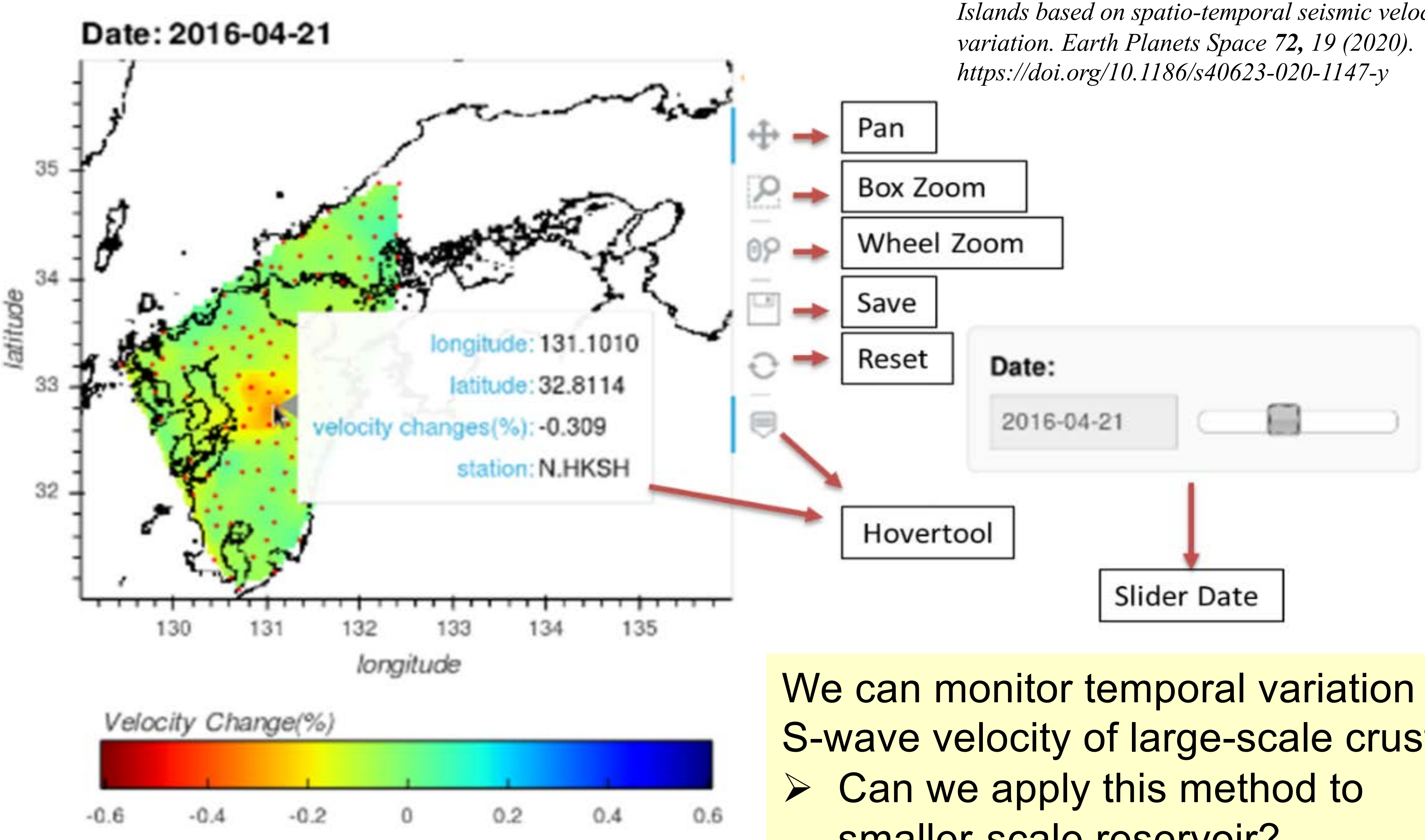
H. Nimiya, T. Ikeda, and T. Tsuji, Spatial and temporal seismic velocity changes on Kyushu Island during the 2016 Kumamoto earthquake, Science Advances, 3(11), e1700813, doi:10.1126/sciadv.1700813, 2017.



The velocity variation could reflect pore pressure variation in the crust

Open the monitoring results (only Kyushu area) to public

Hutapea, F.L., Tsuji, T. & Ikeda, T.
Real-time crustal monitoring system of Japanese Islands based on spatio-temporal seismic velocity variation. Earth Planets Space 72, 19 (2020).
https://doi.org/10.1186/s40623-020-1147-y



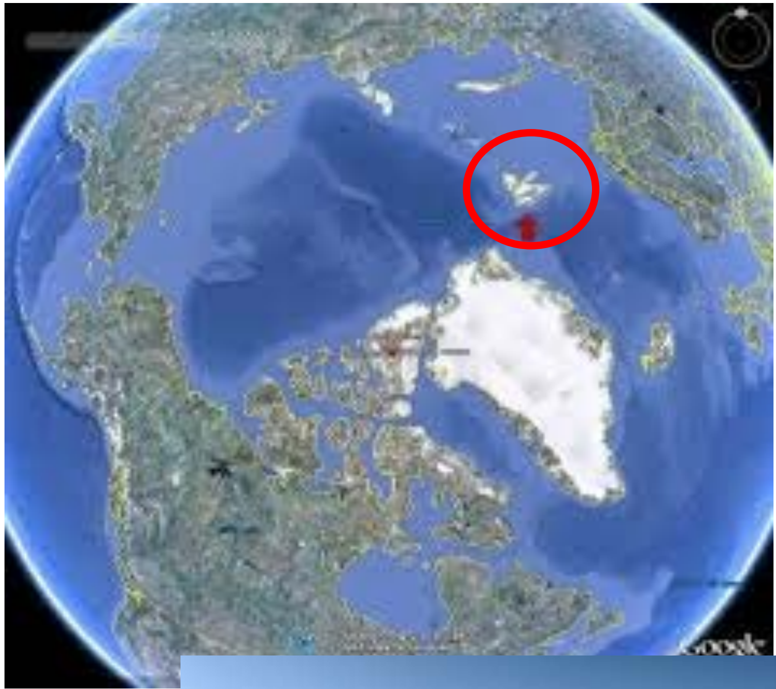
We can monitor temporal variation of S-wave velocity of large-scale crust

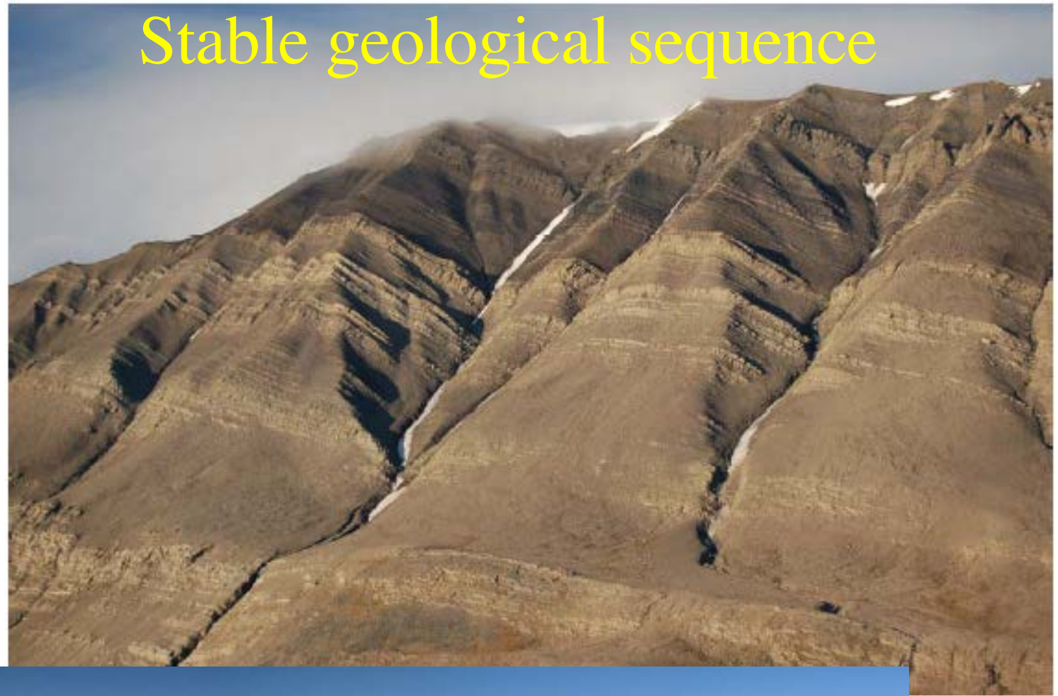
- ➢ Can we apply this method to smaller-scale reservoir?

Apply to fluid injection experiments in Spitsbergen, Norway

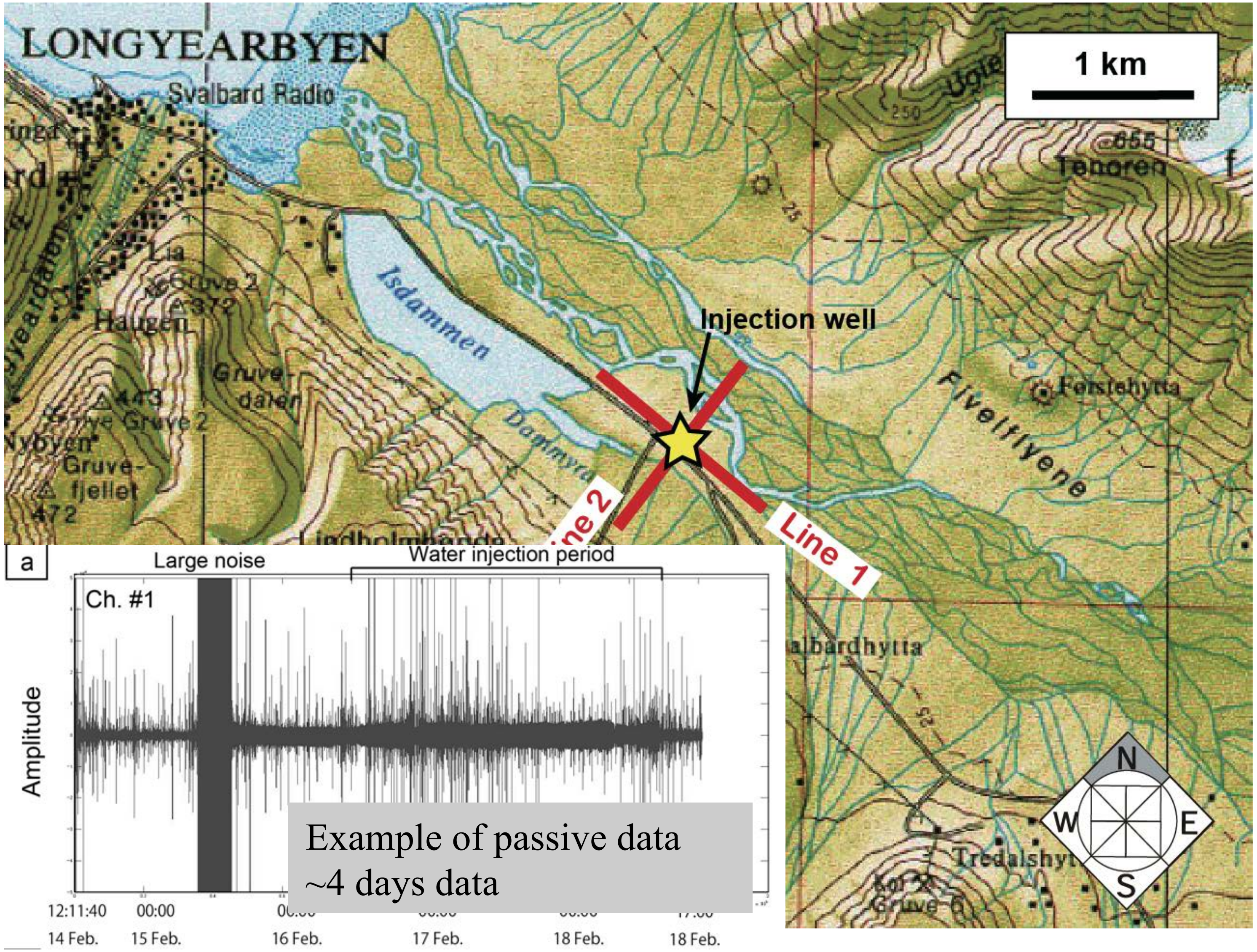
Use ambient noise data recorded by high-density seismic array

- Try to make time-lapse profile using ambient noise





Ambient noise data during fluid injection experiment



- 48 channels (1.2 km) for each line
  - Active-source seismic data
  - Passive seismic data

Shot gather retrieved from ambient noise

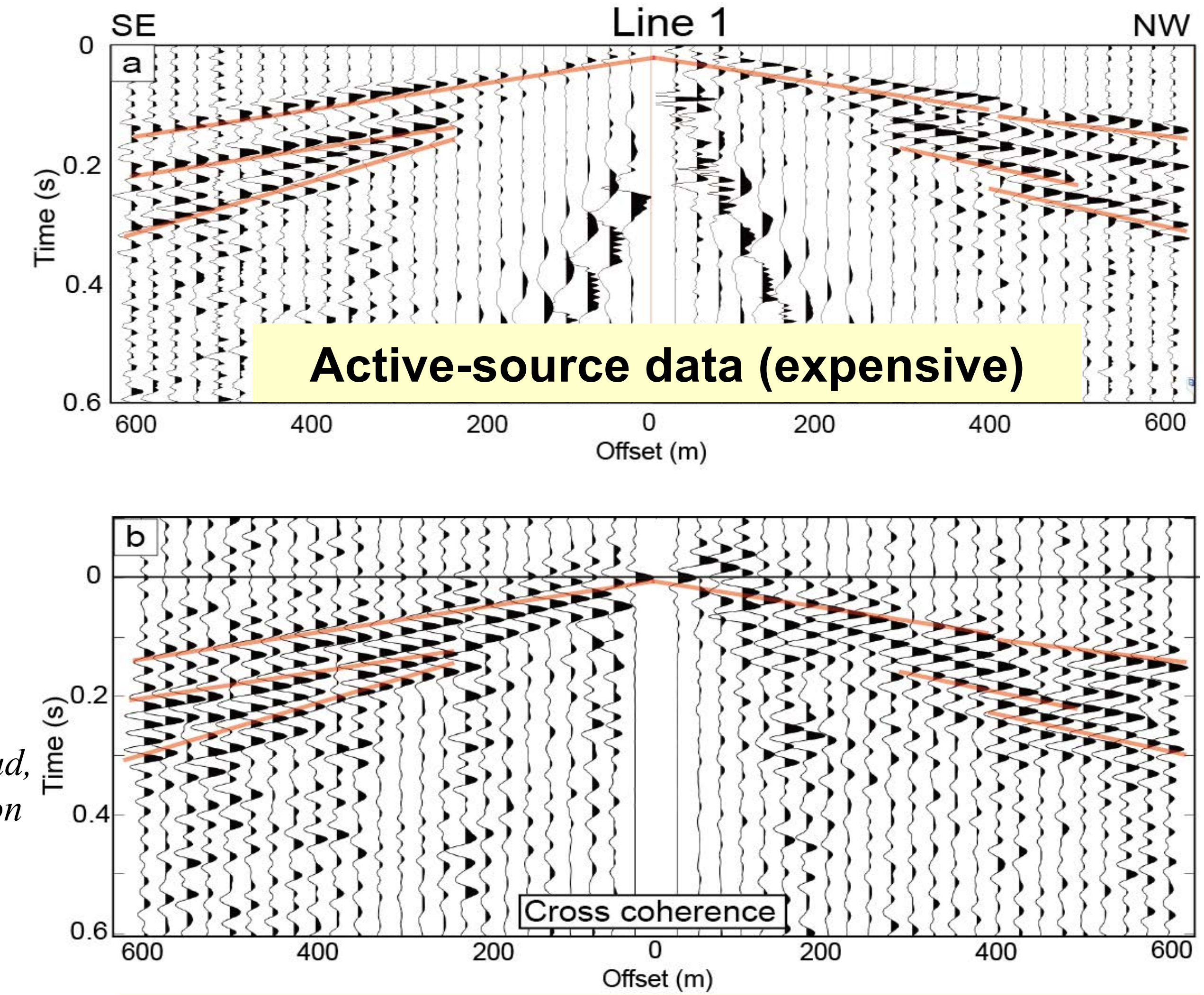
■ Retrieve shot gather using seismic interferometry

Shot gathers derived from seismic interferometry are well consistent with active-source data

- •Direct P-wave (~3300 m/s)
- •Reflection

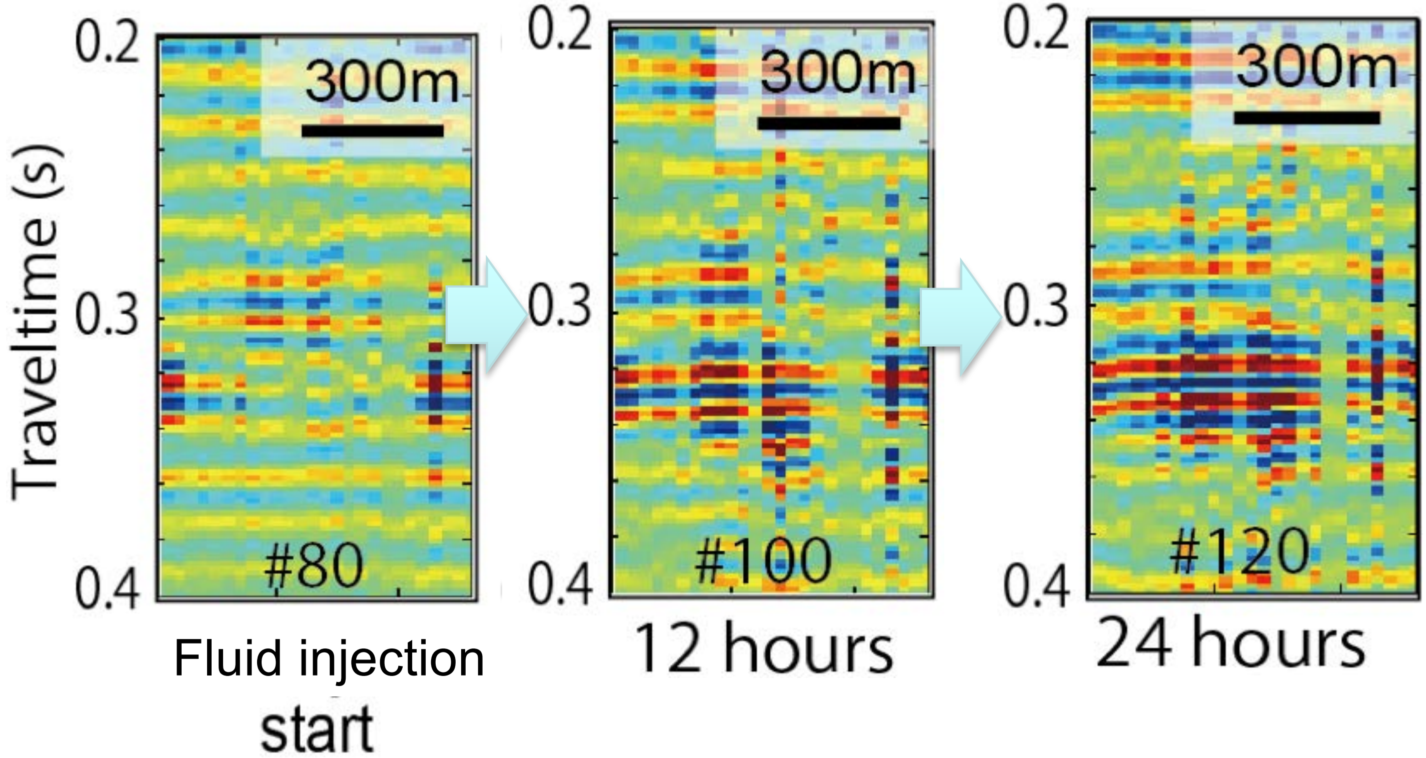
➢ Since the ambient noise were acquired in longer-term, we continuously obtain the shot gather.

T. Tsuji, T. Ikeda, T.A. Johansen, and B.O. Ruud, Using seismic noise derived from fluid injection well for continuous reservoir monitoring, Interpretation, 4(4), SQ1-SQ11, doi: 10.1190/INT-2016-0019.1, 2016.

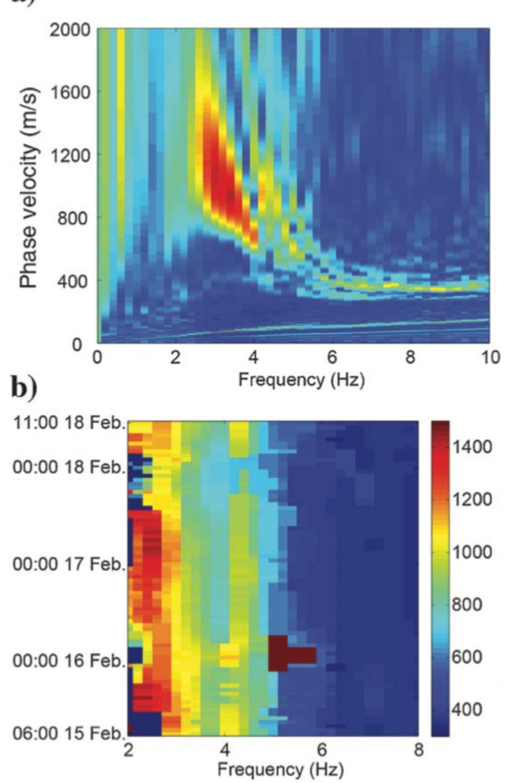


Seismic interferometry for ambient noise (cheap and continuous data)

Time-lapse reflection profiles derived from ambient noise data



Dispersion curve is also time variant



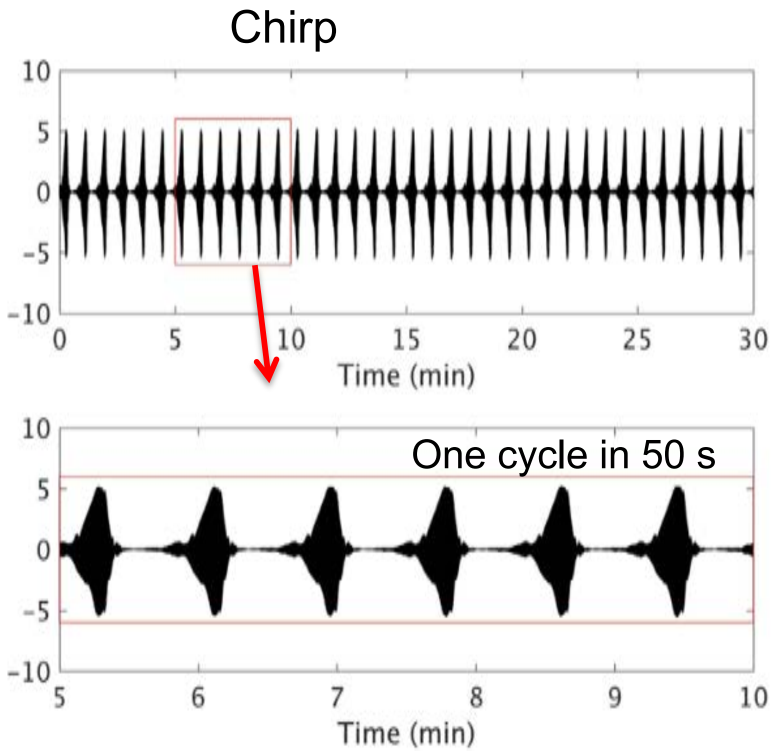
Time variation of source function (e.g., frequency component, localized source) influences to the results …

- To accurately monitor smaller-scale reservoir, the source should be more stable

T. Tsuji, T. Ikeda, T.A. Johansen, and B.O. Ruud, Using seismic noise derived from fluid injection well for continuous reservoir monitoring, Interpretation, 4(4), SQ1-SQ11, doi: 10.1190/INT-2016-0019.1, 2016.

Develop small-size continuous monitoring system for accurate monitoring of small-scale reservoir (e.g., geothermal reservoir)

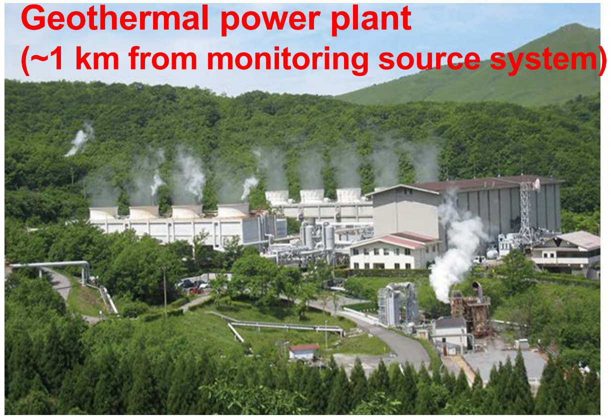
Size: ~1m

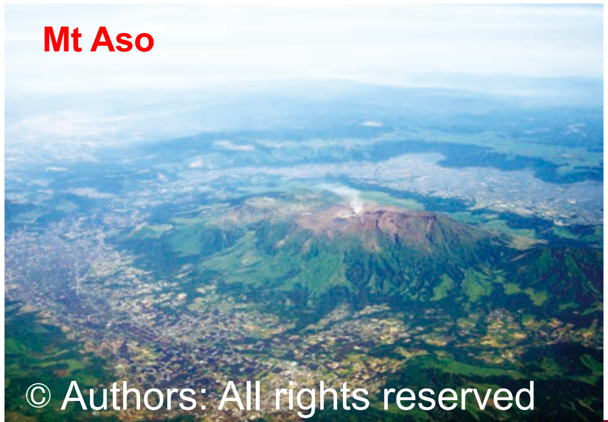


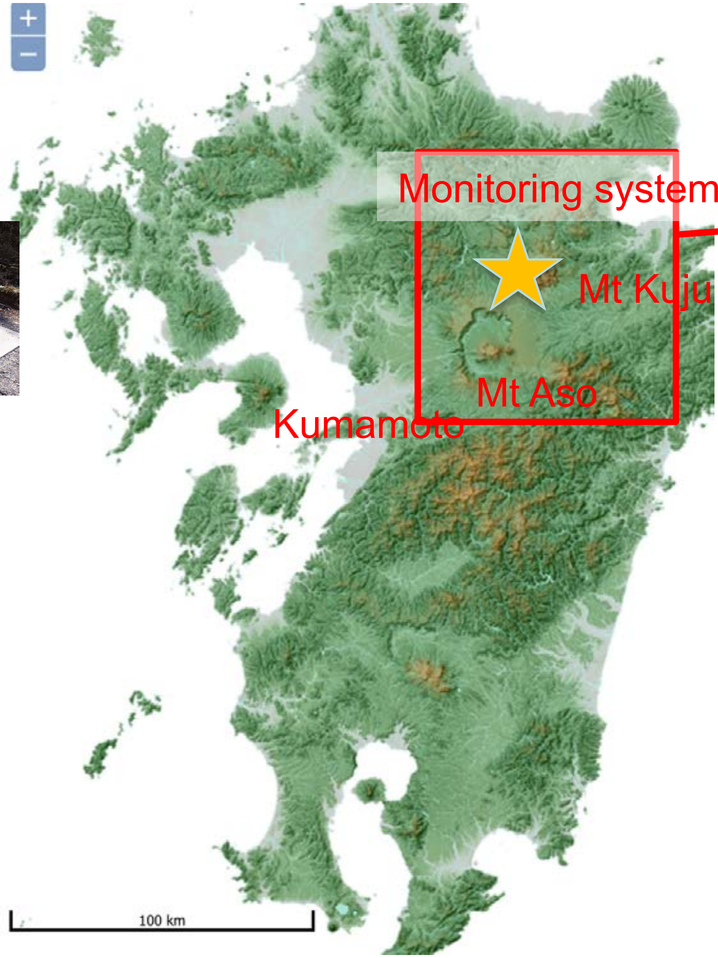
- Continuously generate the vibration (sweep)
- Improve S/N by stacking the longer-term signal

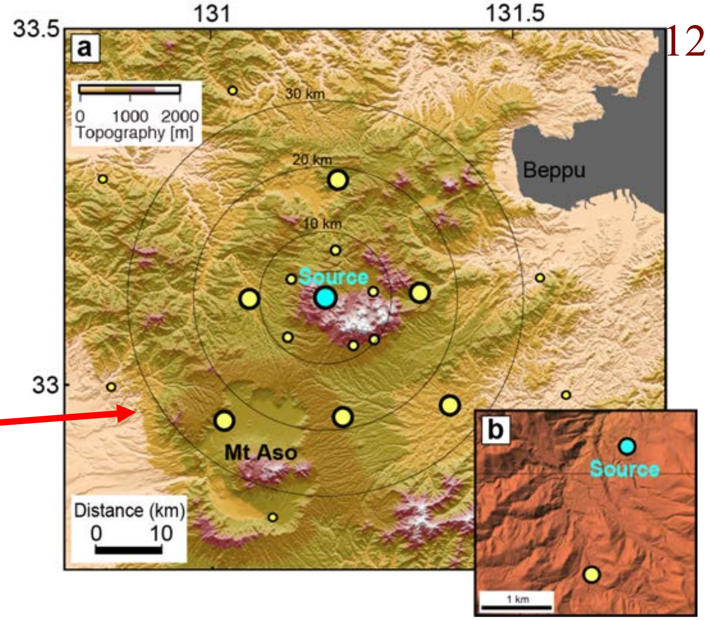
- Larger system was developed in seismology (lower frequency)
  - Optimized for monitoring of shallower reservoir (~1km depth)
    - Smaller system
    - Generate higher frequency (<30Hz)

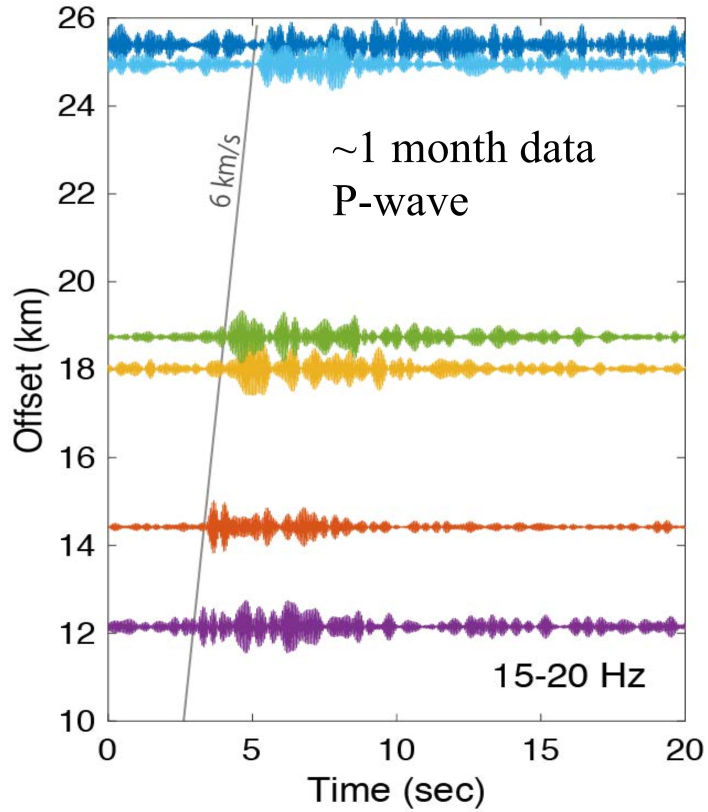
Deploy our monitoring source system in Kuju geothermal field









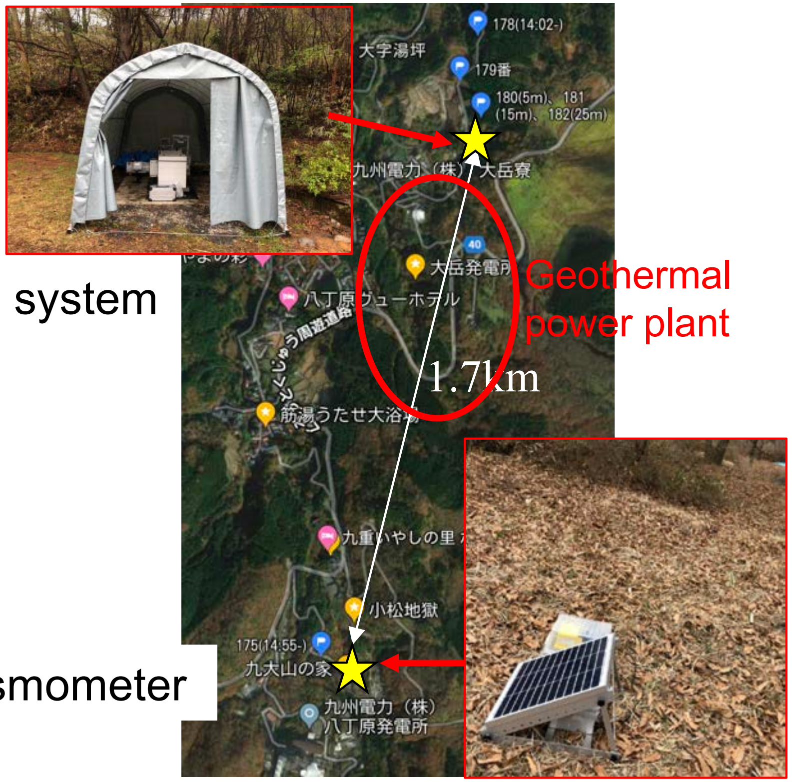


Monitor the geothermal fields and volcanoes

Monitoring results of the geothermal field (smaller-scale target)

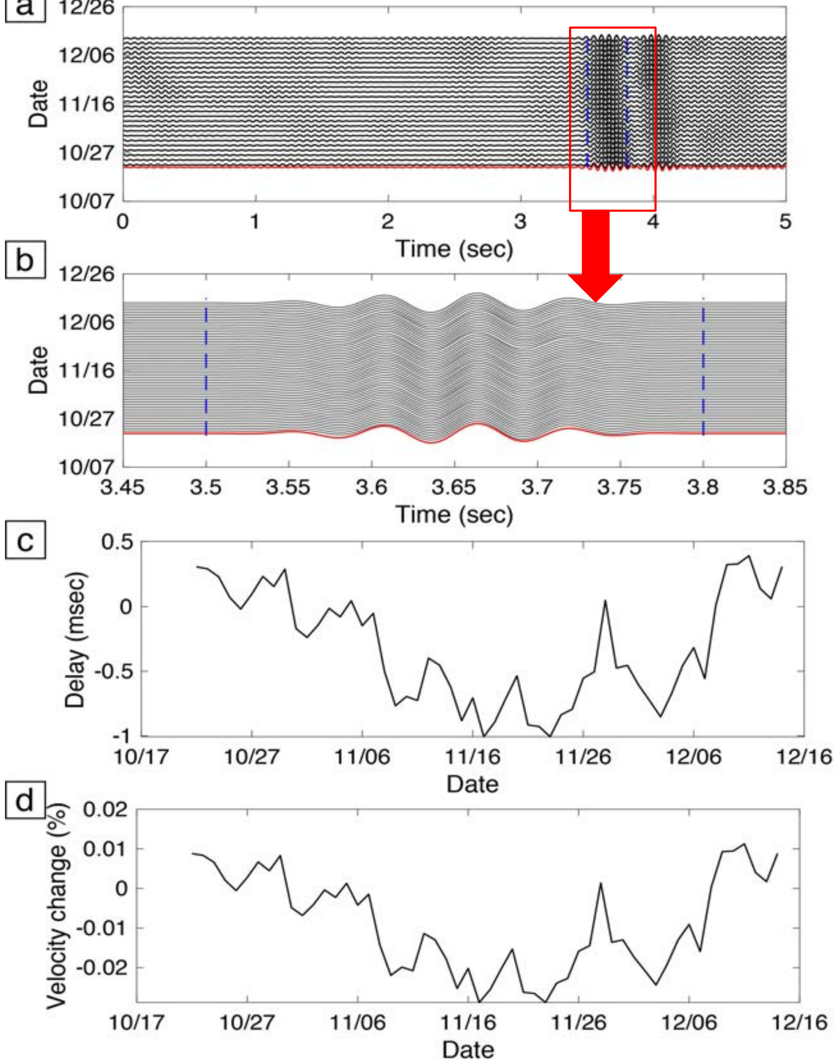
- Estimate temporal velocity variation between the source and seismometer (distance: ~1.7 km)
- Succeeded to estimate Vp variation in accuracy of ~0.01%
  - Since *Vp* is ~5000 m/s, we can detect <1 m/s *Vp* variation

Source system



Seismometer

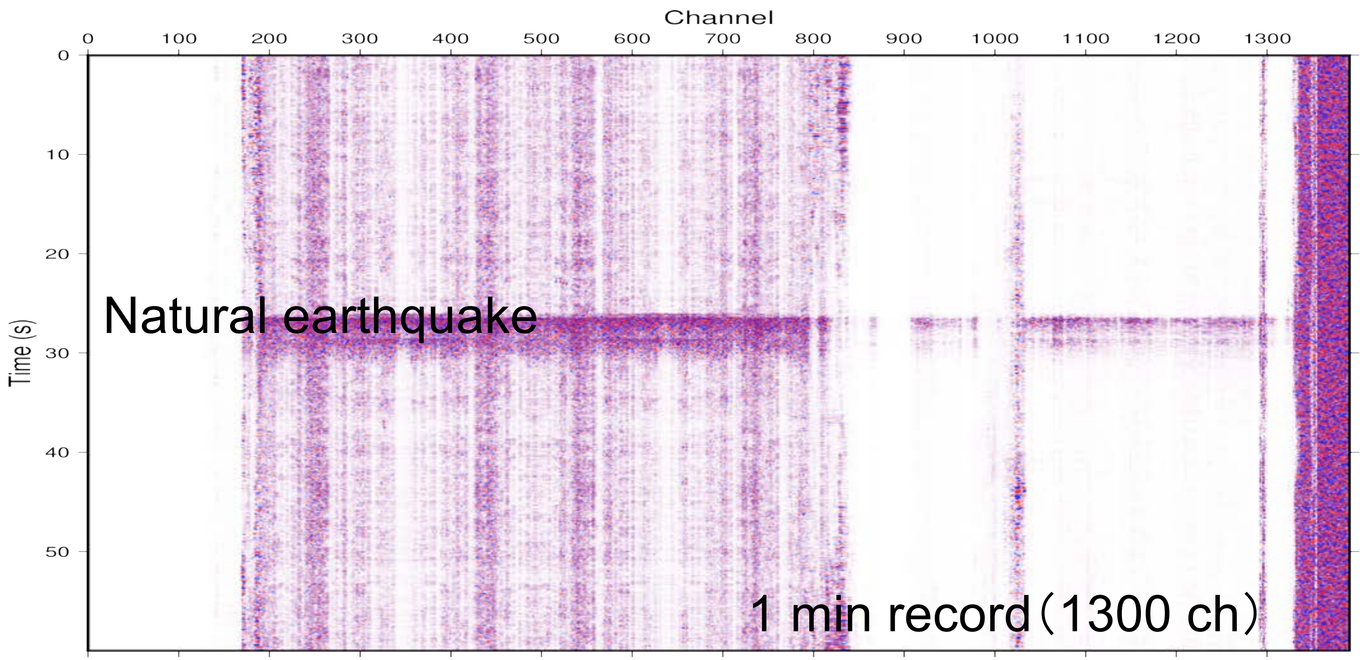
Display P-wave arrival per day

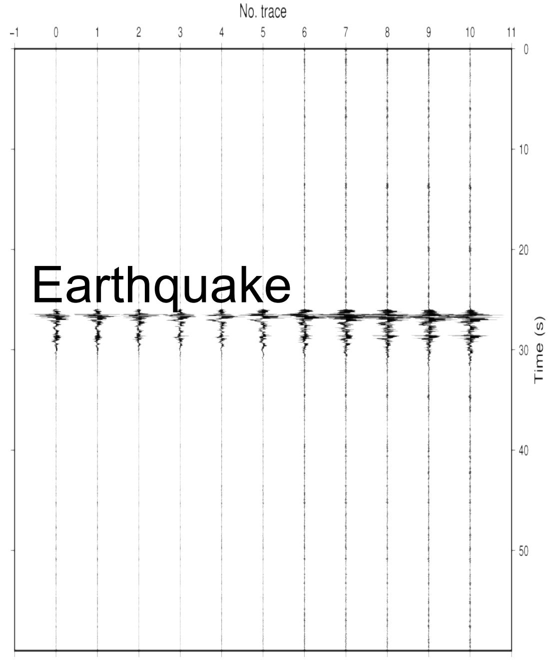


P-wave velocity variation between source and one seismometer

Distributed acoustic sensing DAS

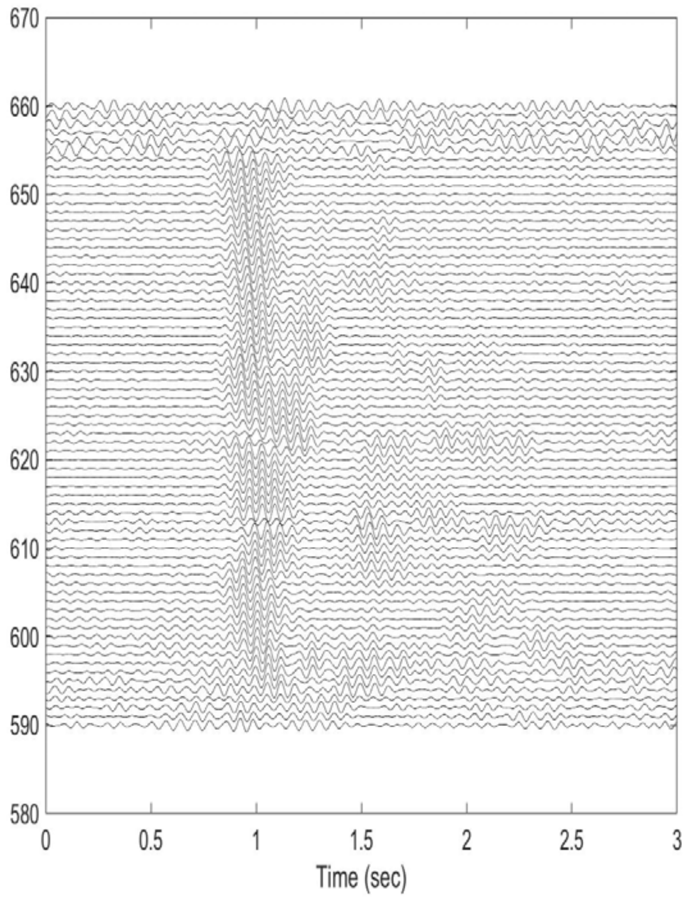
- Deploy fiber optical cable in the geothermal field at 1.7 km from continuous monitoring source system
  - Cable length : ~1300 m
  - Data size: >300 MB/min



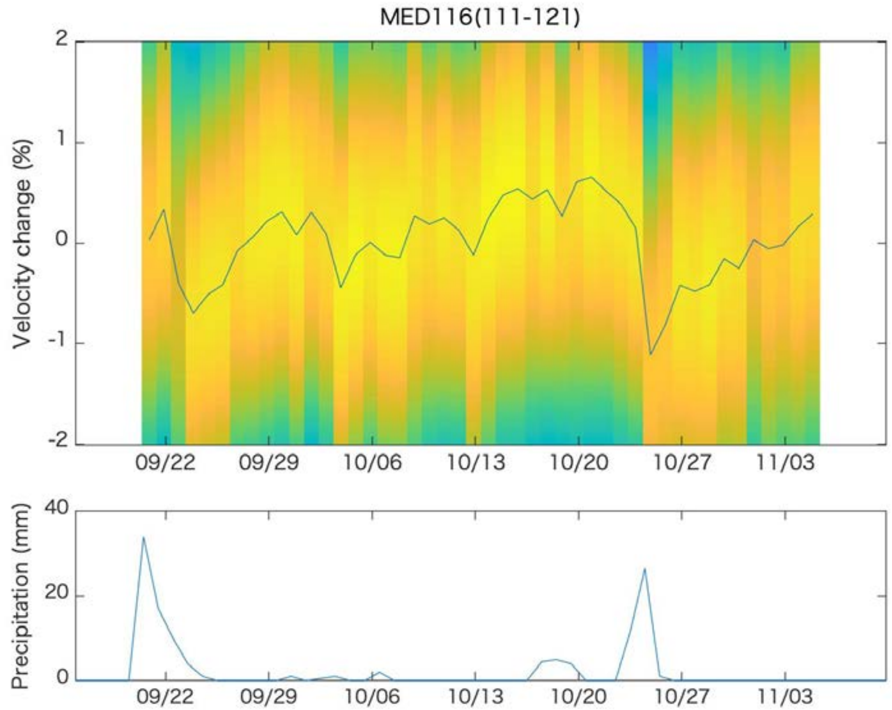


Monitoring both using continuous monitoring source and DAS

Transfer functions between the source system and DAS



Velocity variation derived both from continuous source and DAS



- By using both continuous source and DAS, we are able to monitor wide area with lower cost.

Summary

- Develop continuous monitoring system using (1) ambient noise, and (2) continuous monitoring source system and DAS

(1) Ambient noise

- Monitor large-scale crust (real time monitoring is realized)
- But, it is difficult to monitor smaller-scale reservoir because of temporal source variation

(2) Continuous monitoring source system and DAS

- Succeeded to monitor smaller-scale reservoir in high accuracy