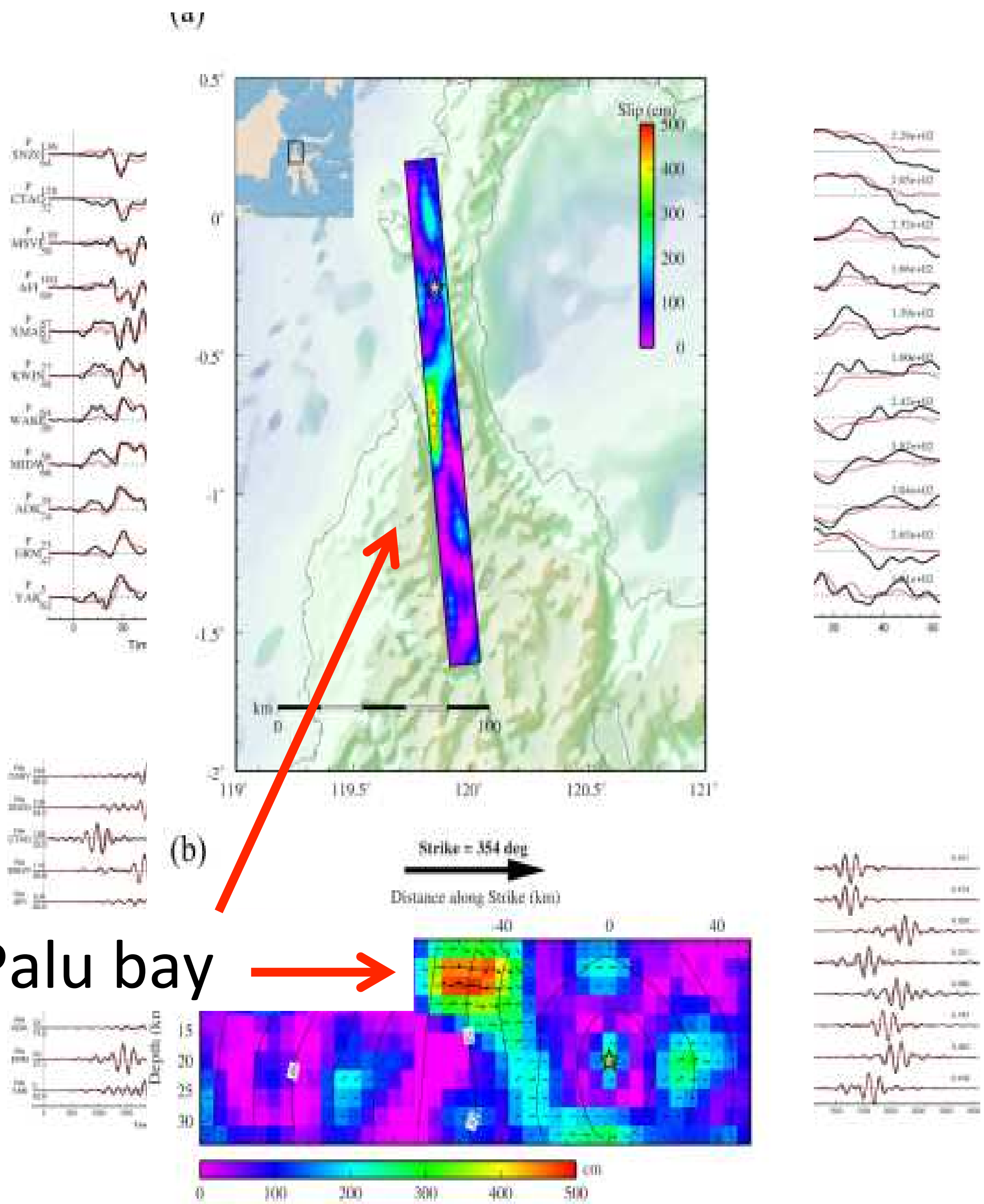
Tsunami Induced by the Strike-Slip Fault of the 2018 Palu Earthquake, Sulawesi Island, Indonesia, Earthquake

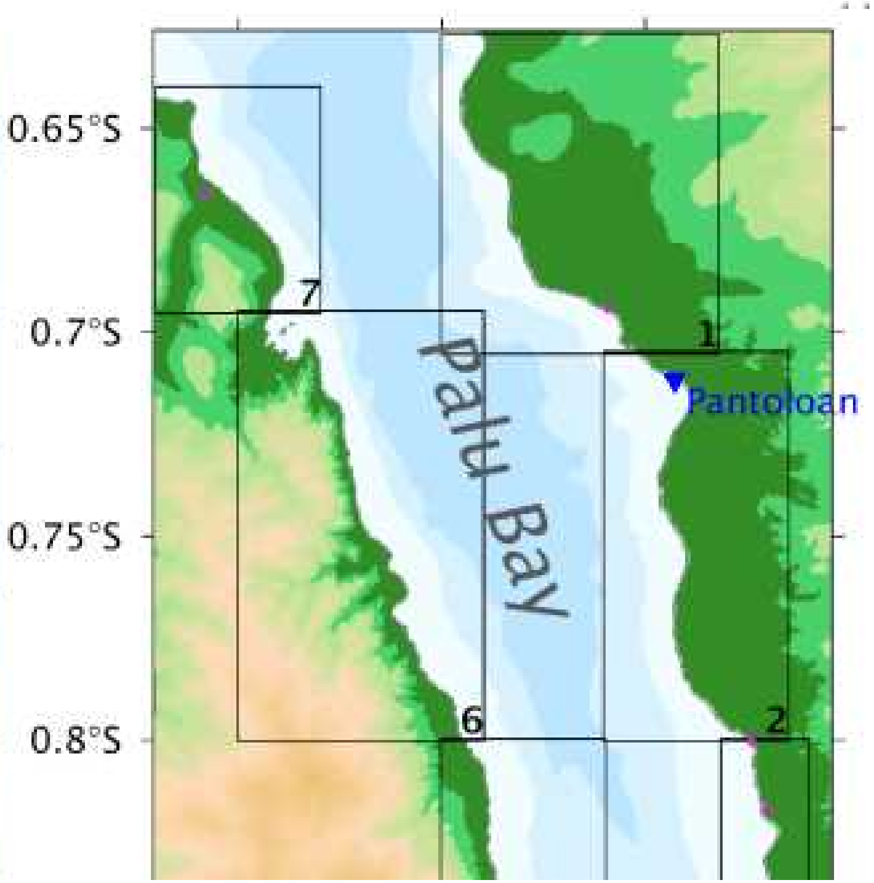
Tung-Cheng Ho, Kenji Satake, Shingo Watada, Ming-Che Hsieh, Ray Y. Chuang, Yosuke Aoki, Iyan E. Mulia, Aditya Riadi Gusman, Chih-Heng Lu

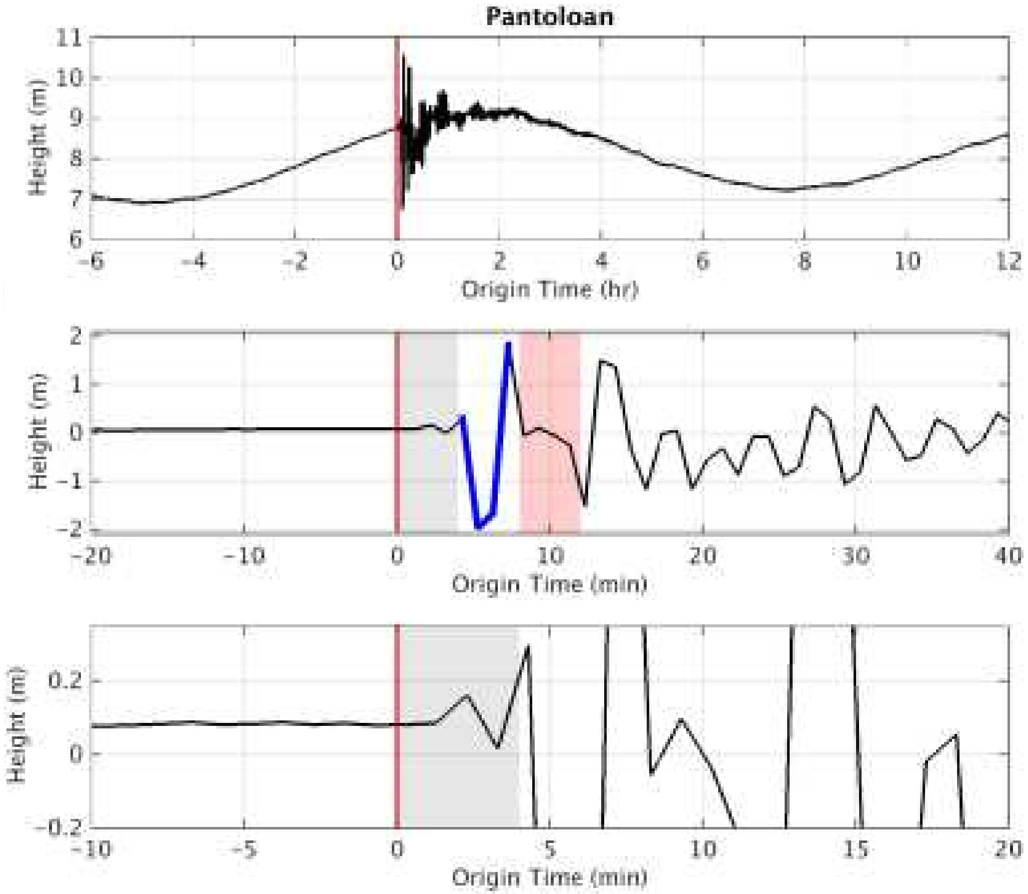
Telseismic waveforms



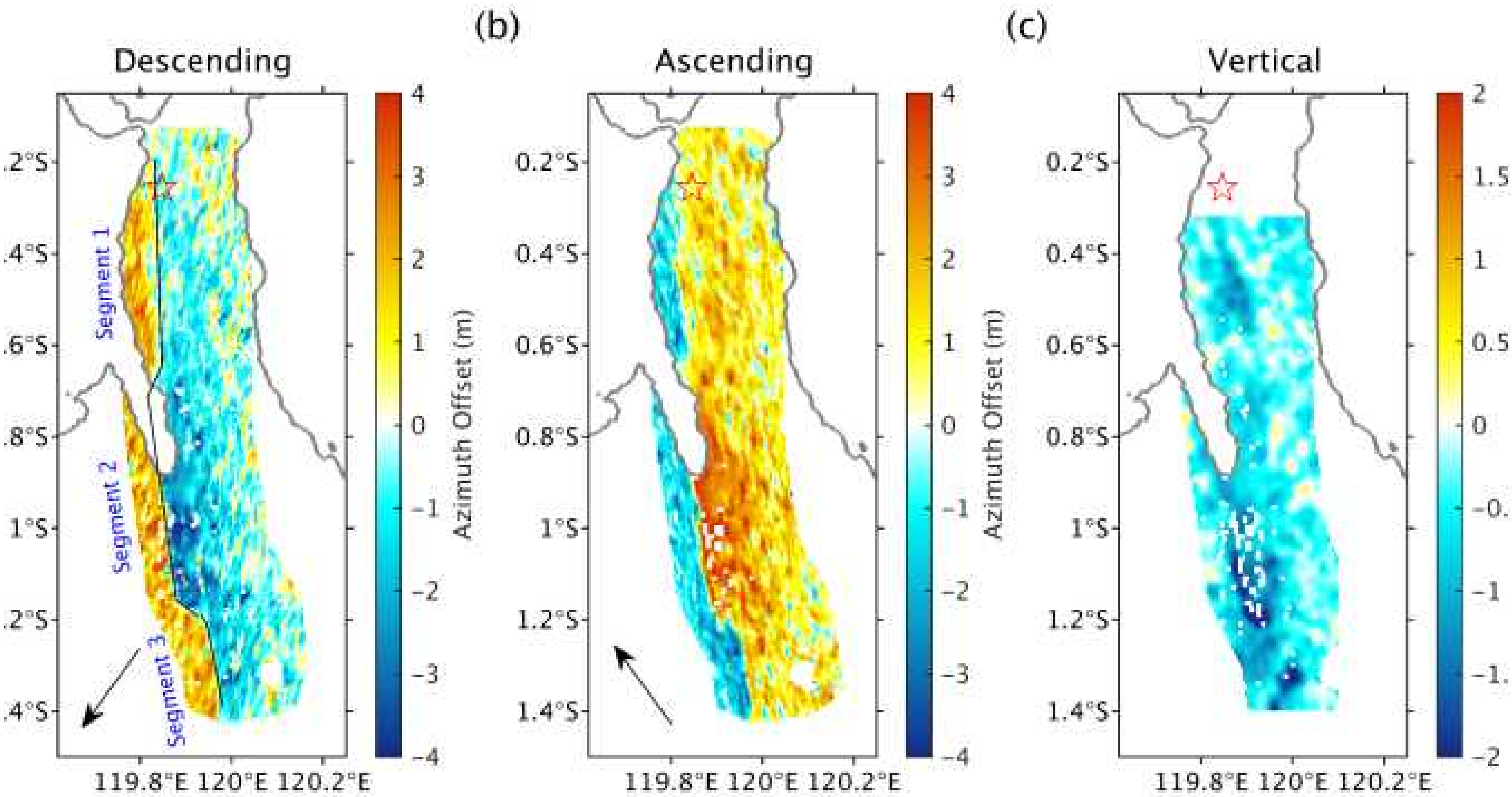
Large slip near the Palu bay

Tide gauge record in Palu bay

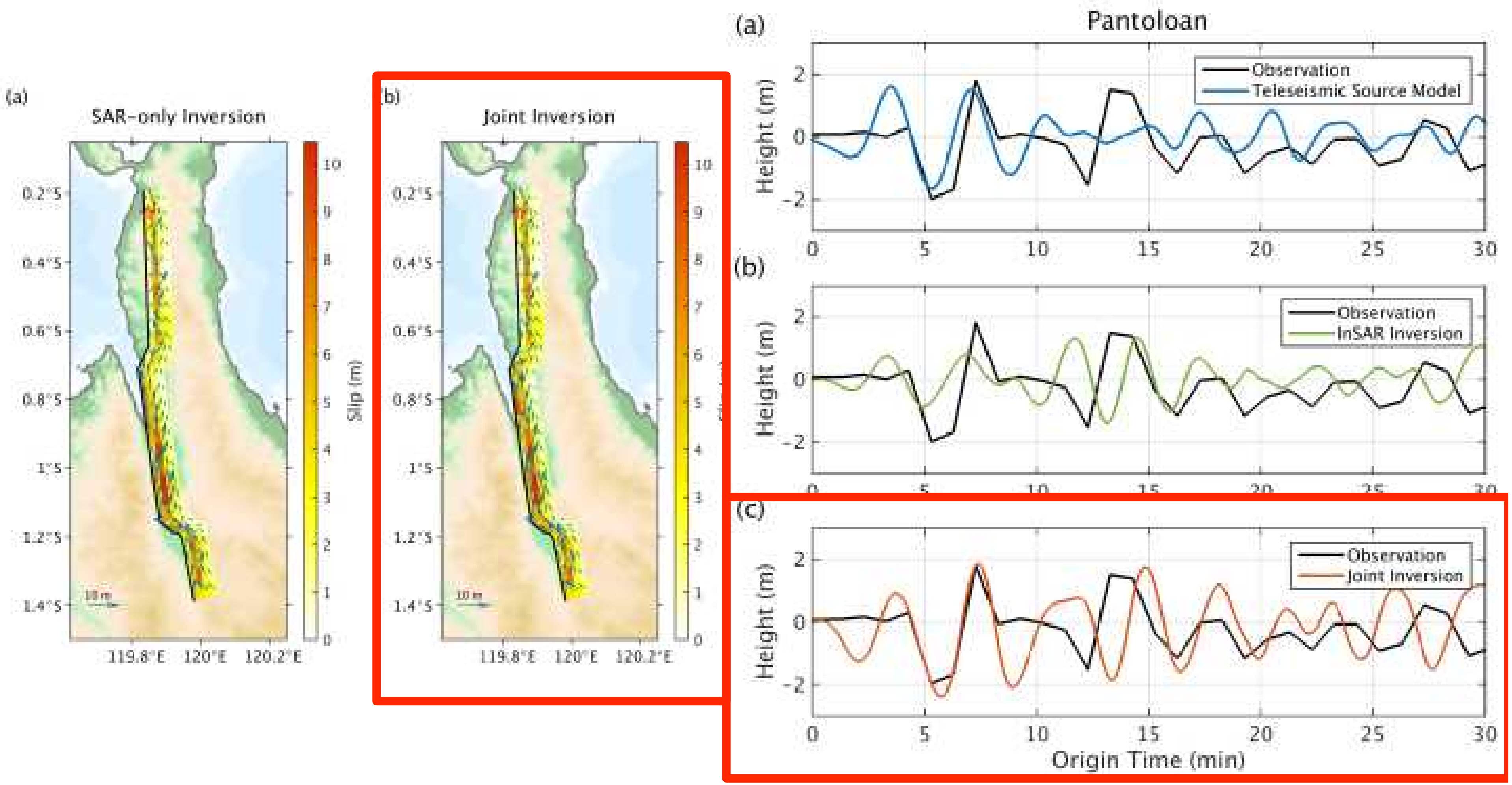




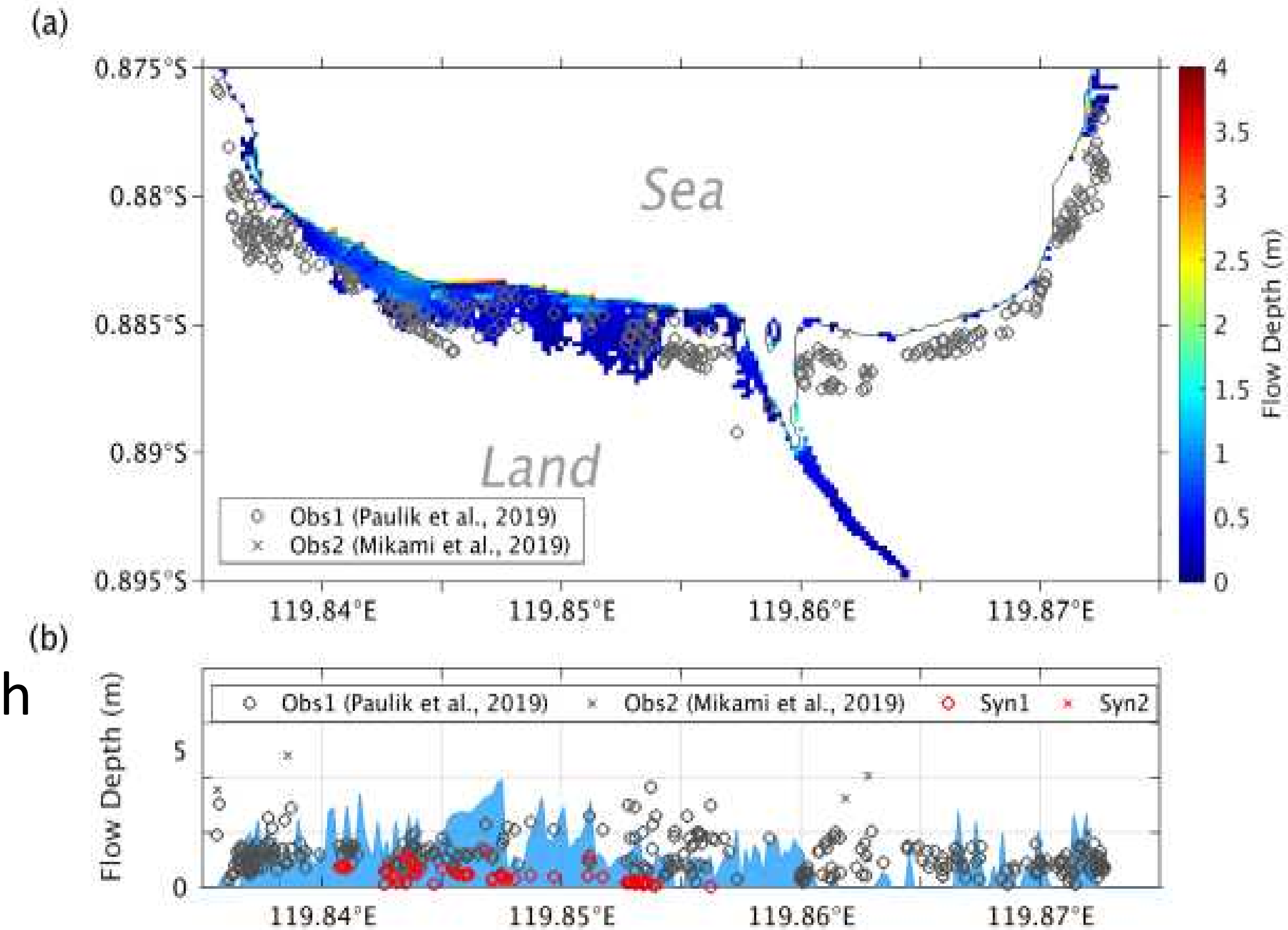
InSAR data (Sentinel-1)



Joint Inversion of Tsunami & InSAR



Inundation measurements and model predictions

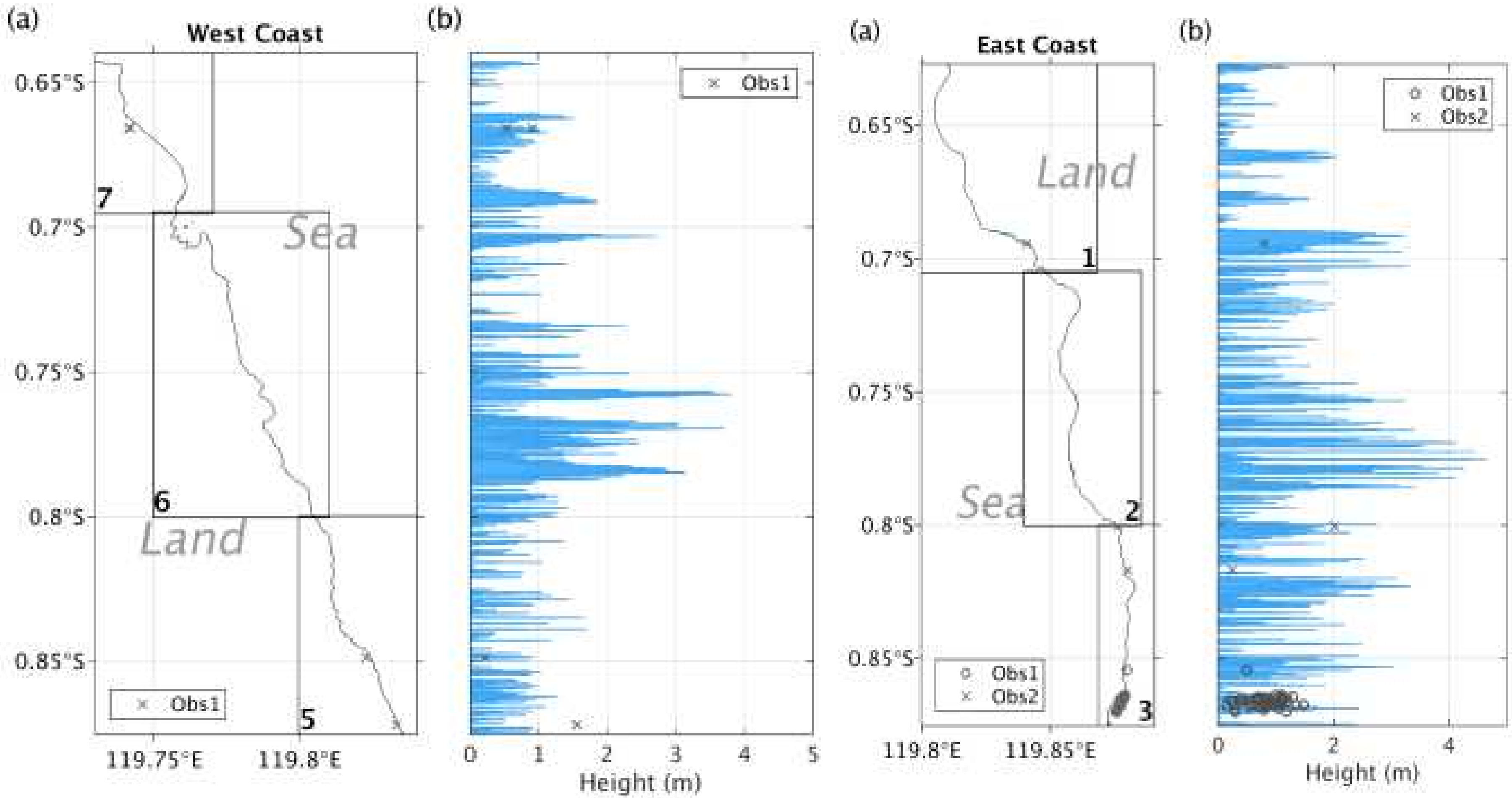


Flow depth

measured

predicted

Inundation measurements and model predictions



Conclusion

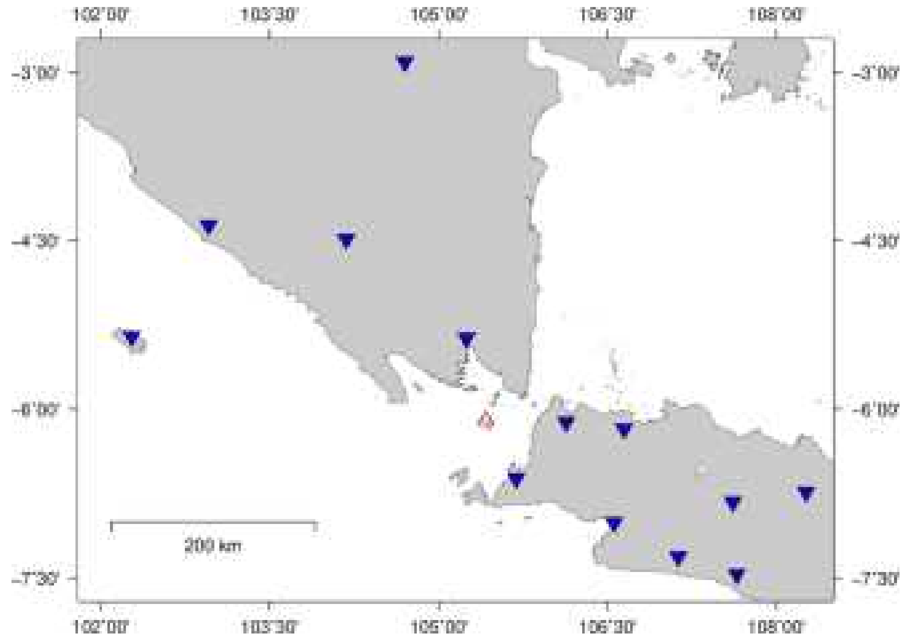
- Tsunami analyses based on a teleseismic source study hint that the leading tsunami at Pantoloan directly came from the fault slip.
- We reveal the fault mechanism for the offshore and onshore area utilizing tsunami and SAR data.
- Our analysis implies additional tsunami sources to account for the large inundations.

Generation Mechanism of the 2018 Sunda Strait Tsunami

Shingo Watada, Masumi Yamada, Iyan Mulia,
Tomokazu Kobayashi, Hiroshi Yarai,
Karyono Karyono, Aditiya Arif

Indonesia Sunda Strait

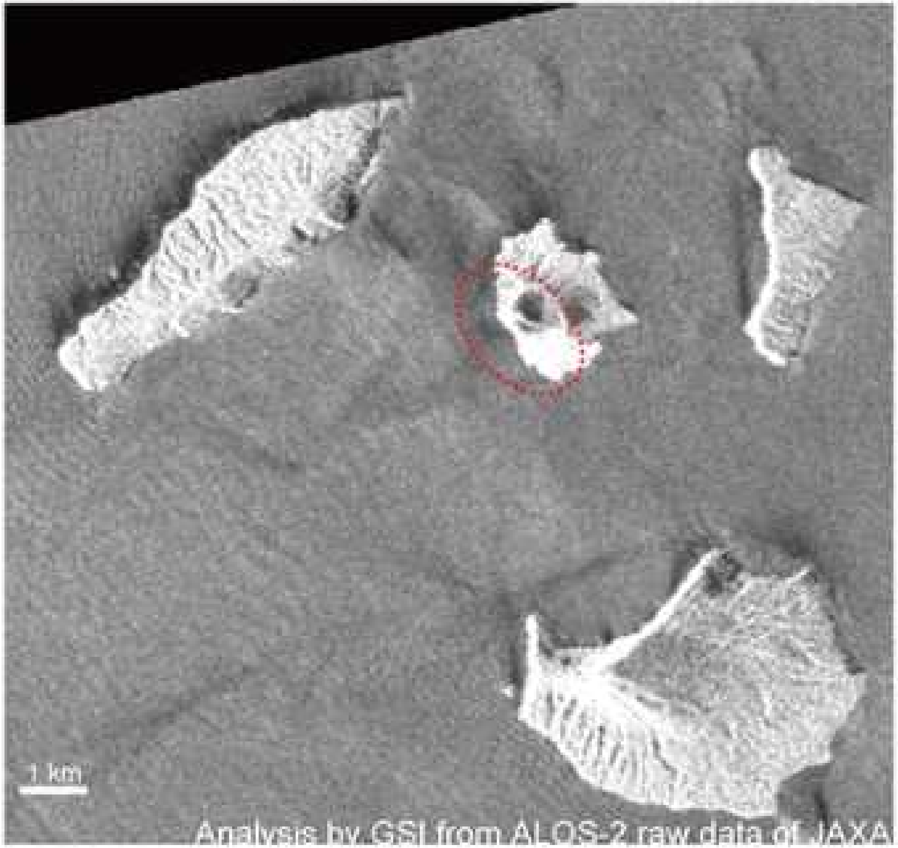
GSI home page



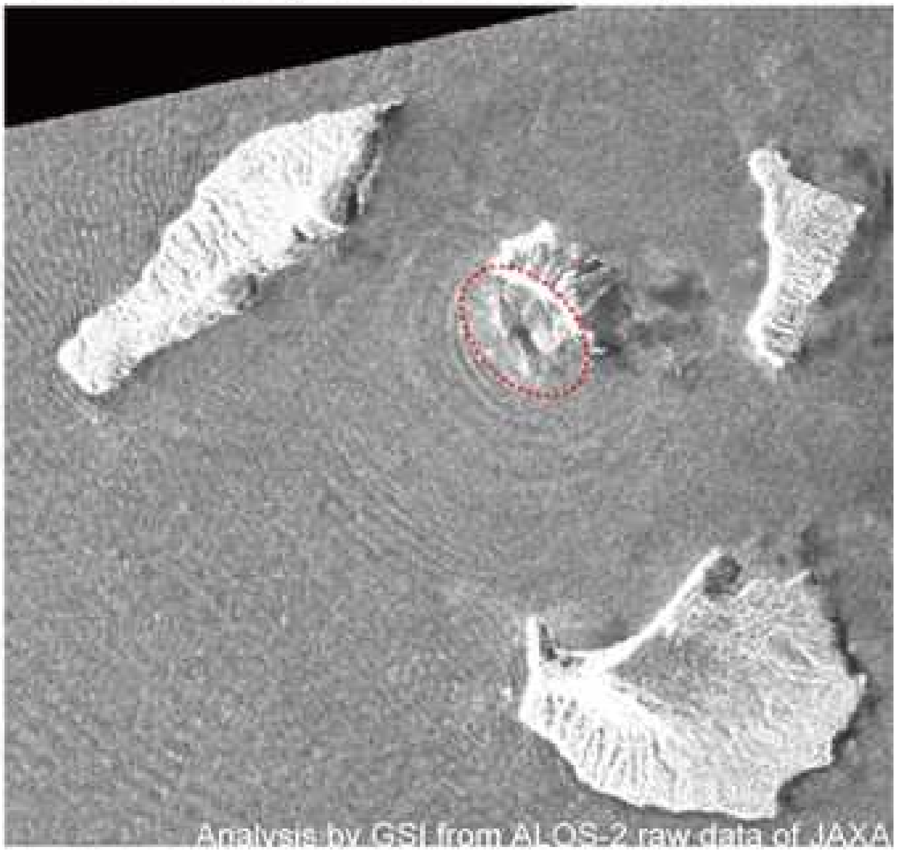
Anak Krakatau

Indonesia Sunda Strait

噴 火 前 2018/08/20
(Before Eruption Aug. 20, 2018)



噴 火 後 2018/12/24
(After Eruption Dec. 24, 2018)



SAR images from GSI home page

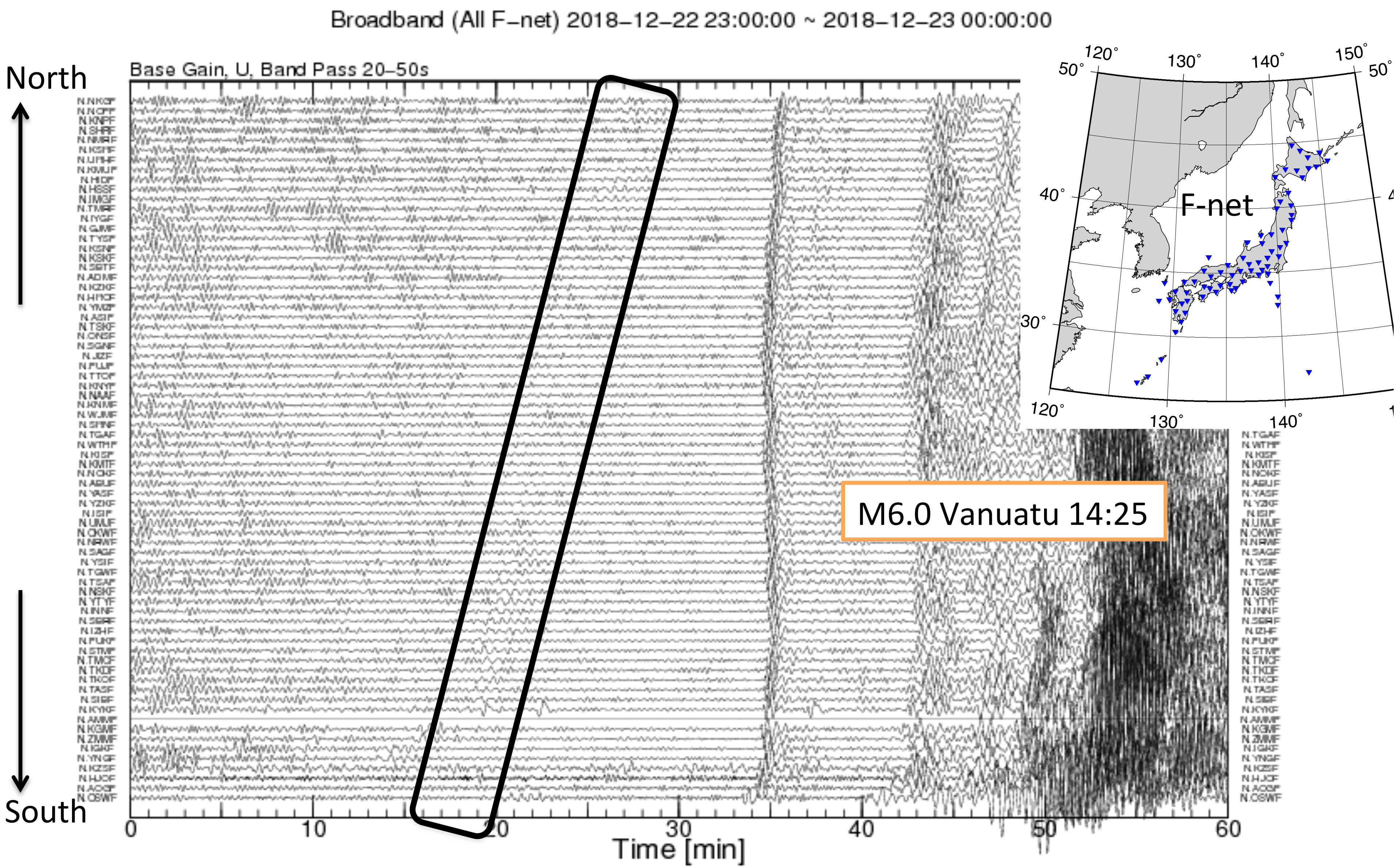
1883 Krakatau eruption

Anak Krakatau

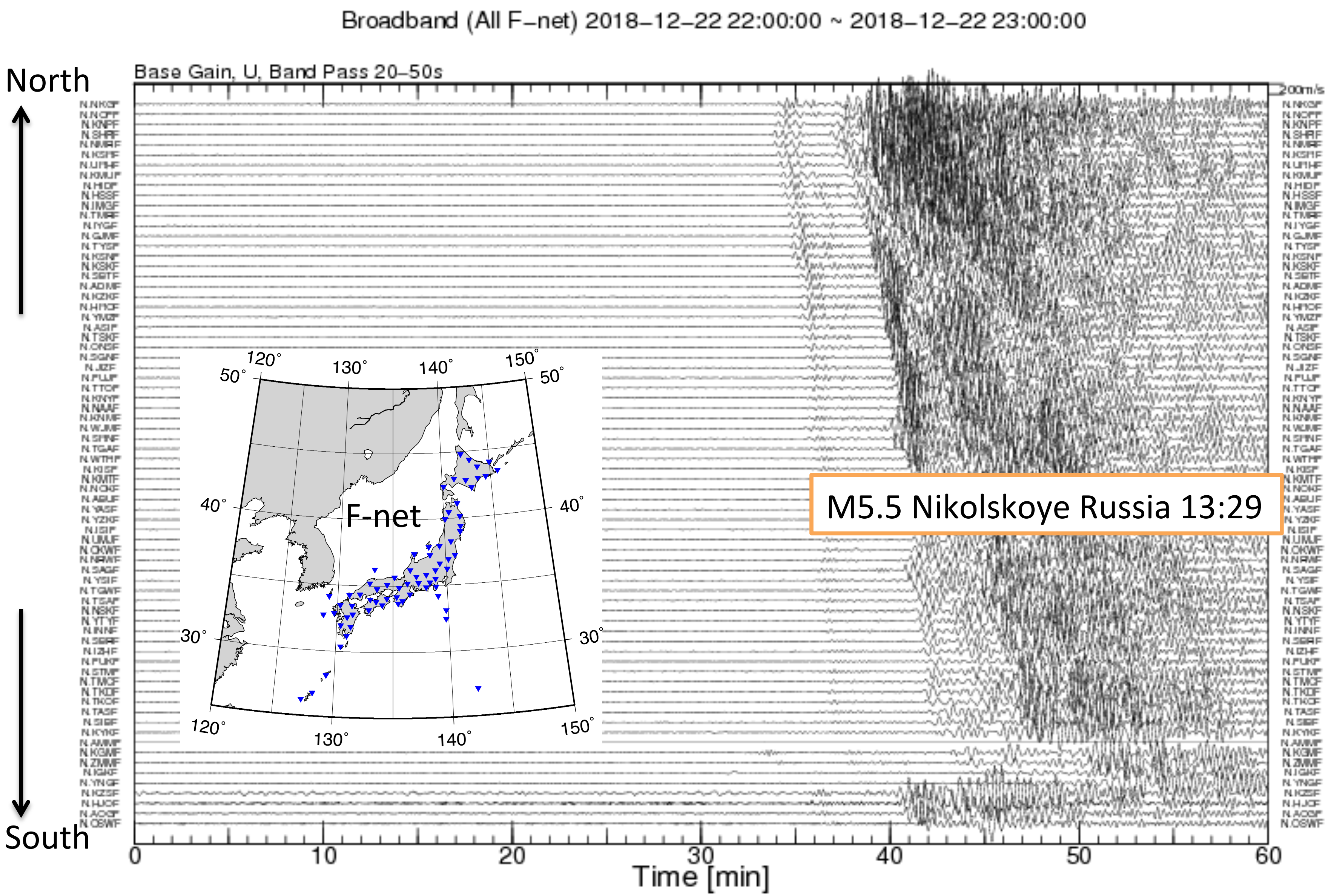
H450m disappeared
Tsunami, air waves

Symons ed. (1888) Eruption of Krakatoa and subsequent phenomena

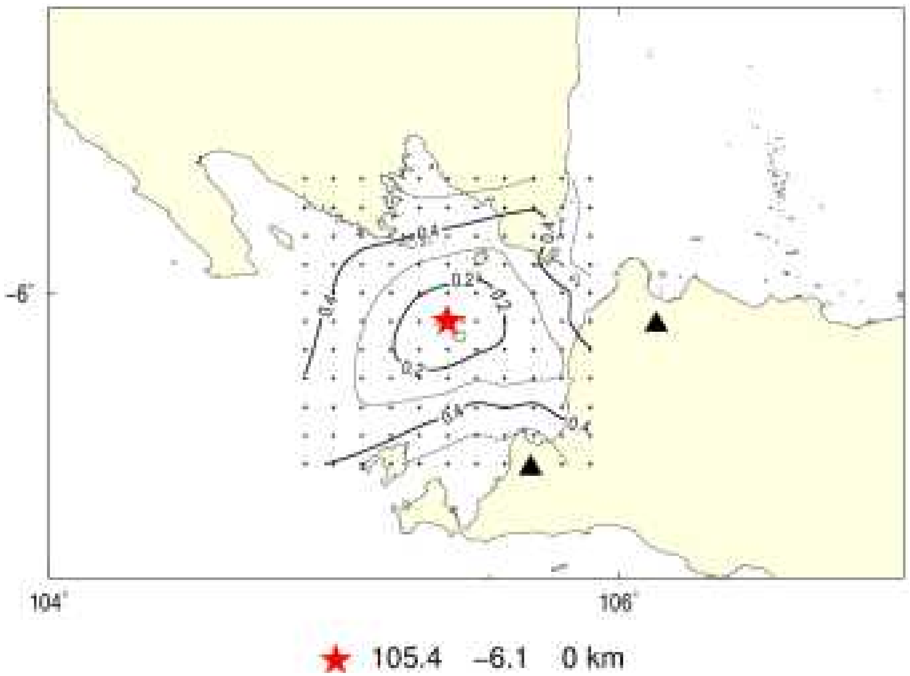
Seismic waveforms F-net in Japan



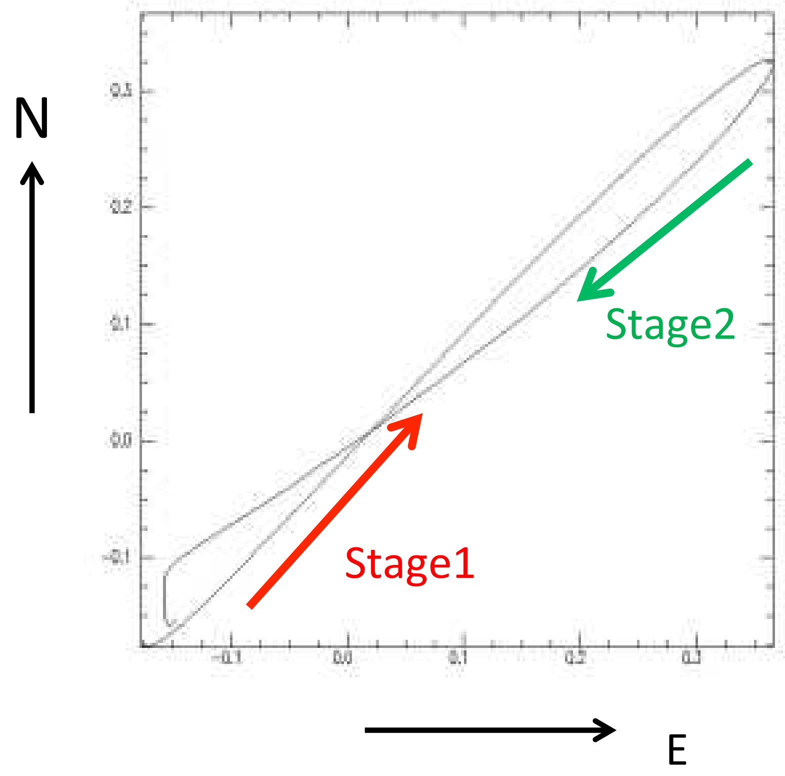
Seismic waveforms F-net in Japan

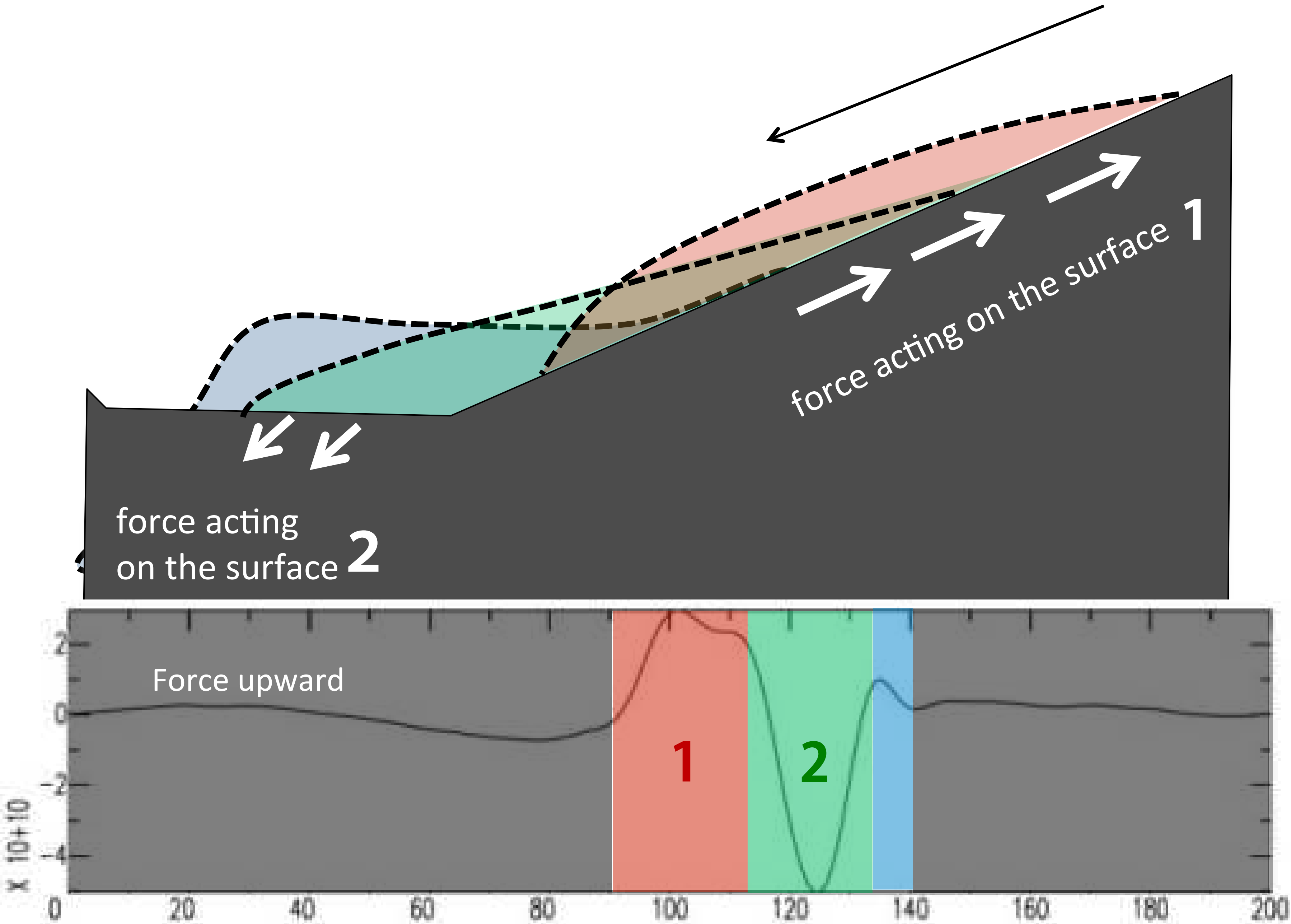


Force model location

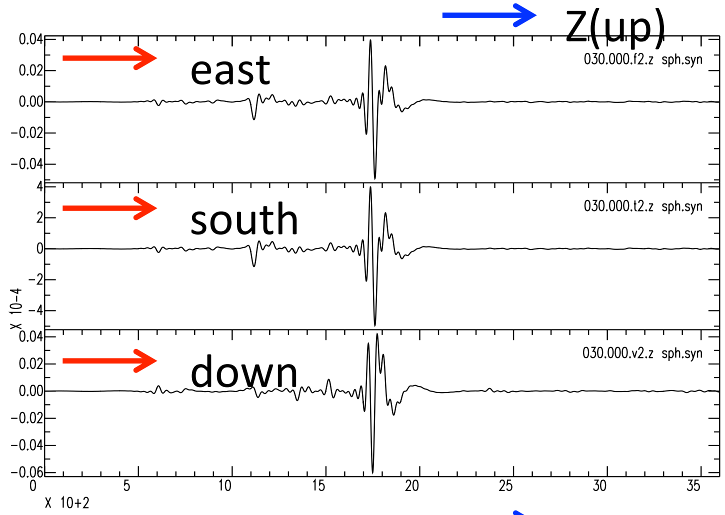


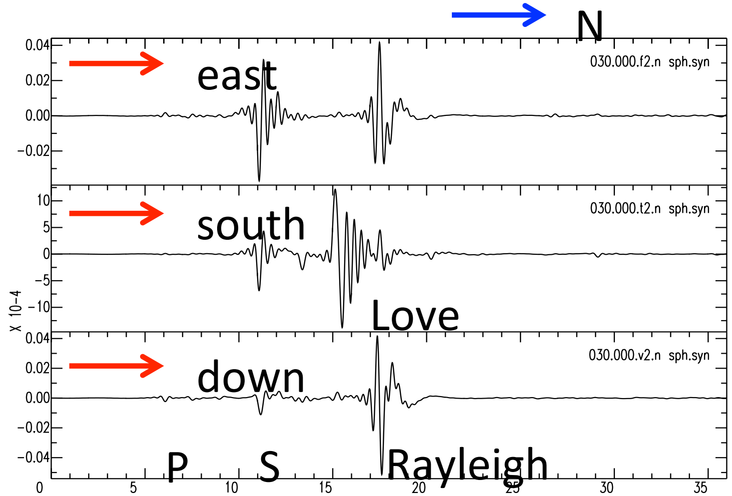
Horizontal Plane

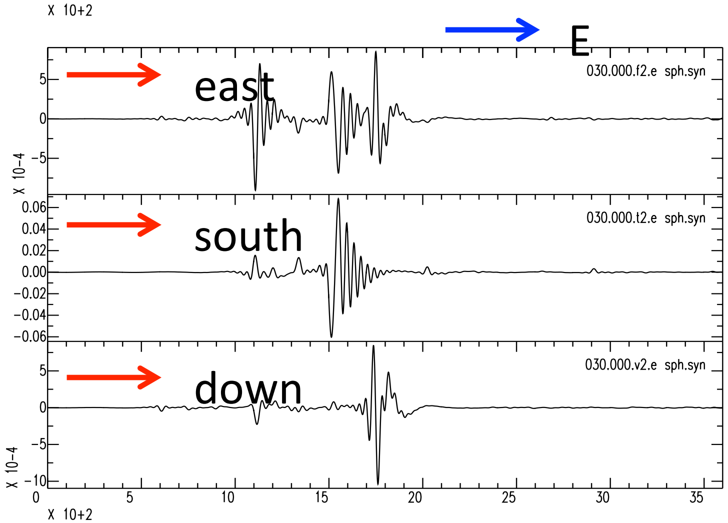



force acting on the surface 1
force acting
on the surface 2
Force upward
1
2
x 10+10
0
20
40
60
80
100
120
140
160
180
200
2
0
-2
-4

Green's function G(t) for a point force source

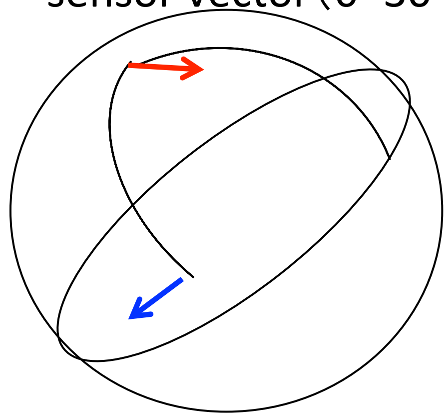




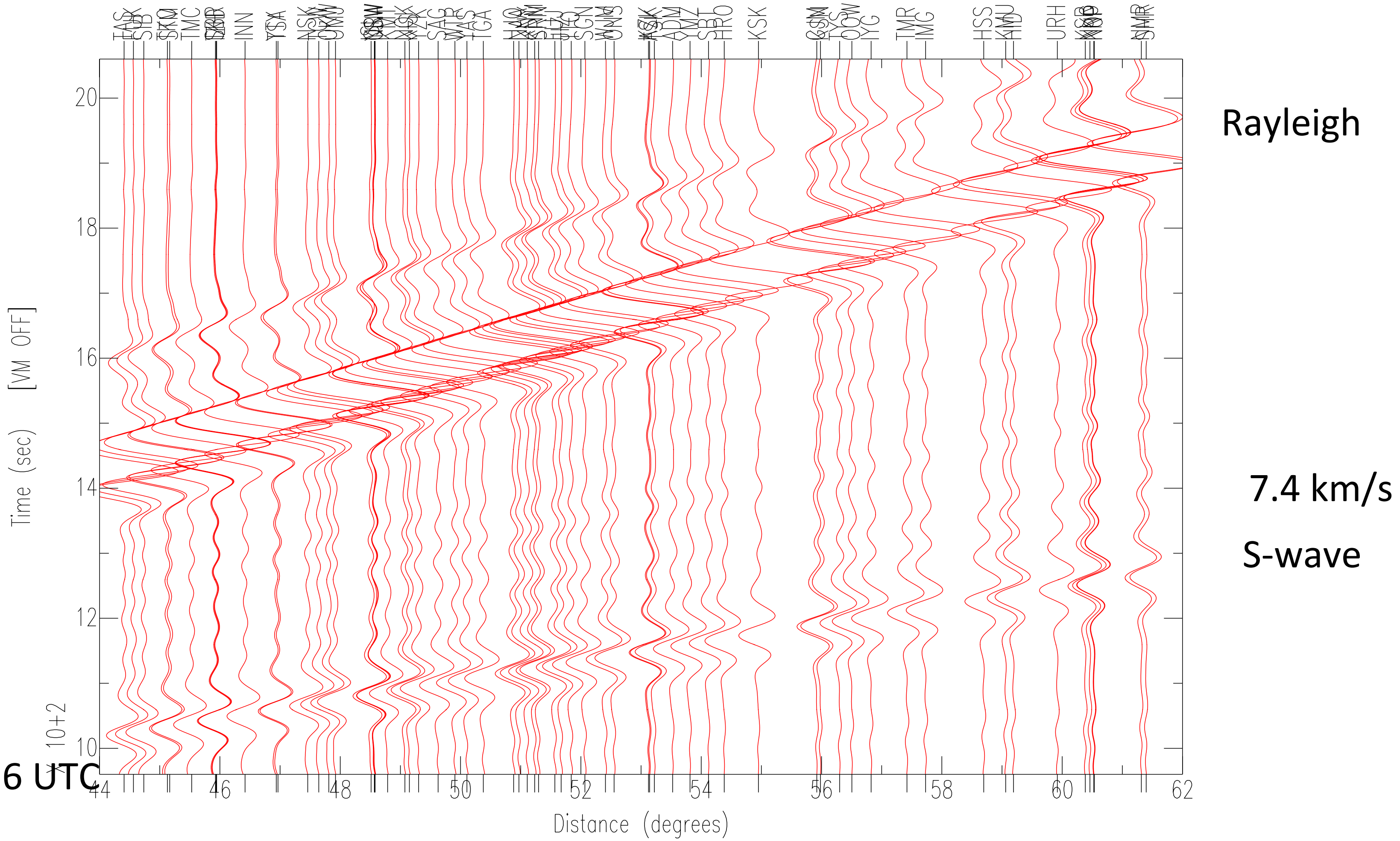


force vector (θ=89°, ϕ=90°)

sensor vector（θ=30°, ϕ=0°)

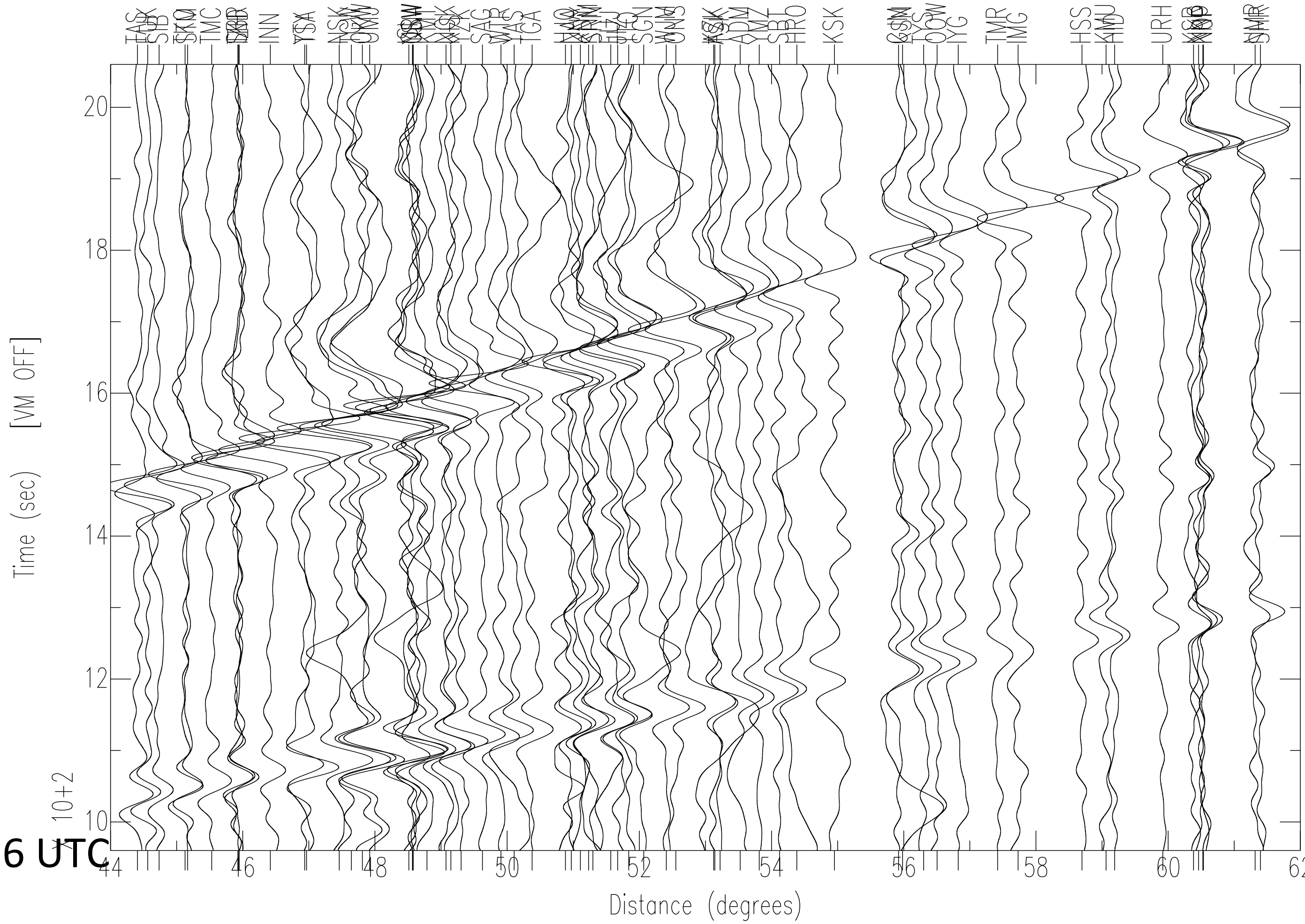


Synthetics in Japan (F-net) ∫G(t-τ)f(τ)dτ



2018/12/22 Broadband Fnet velocity Z bp 64-256 s

Observed Seismic waves in Japan (F-net)



Rayleigh

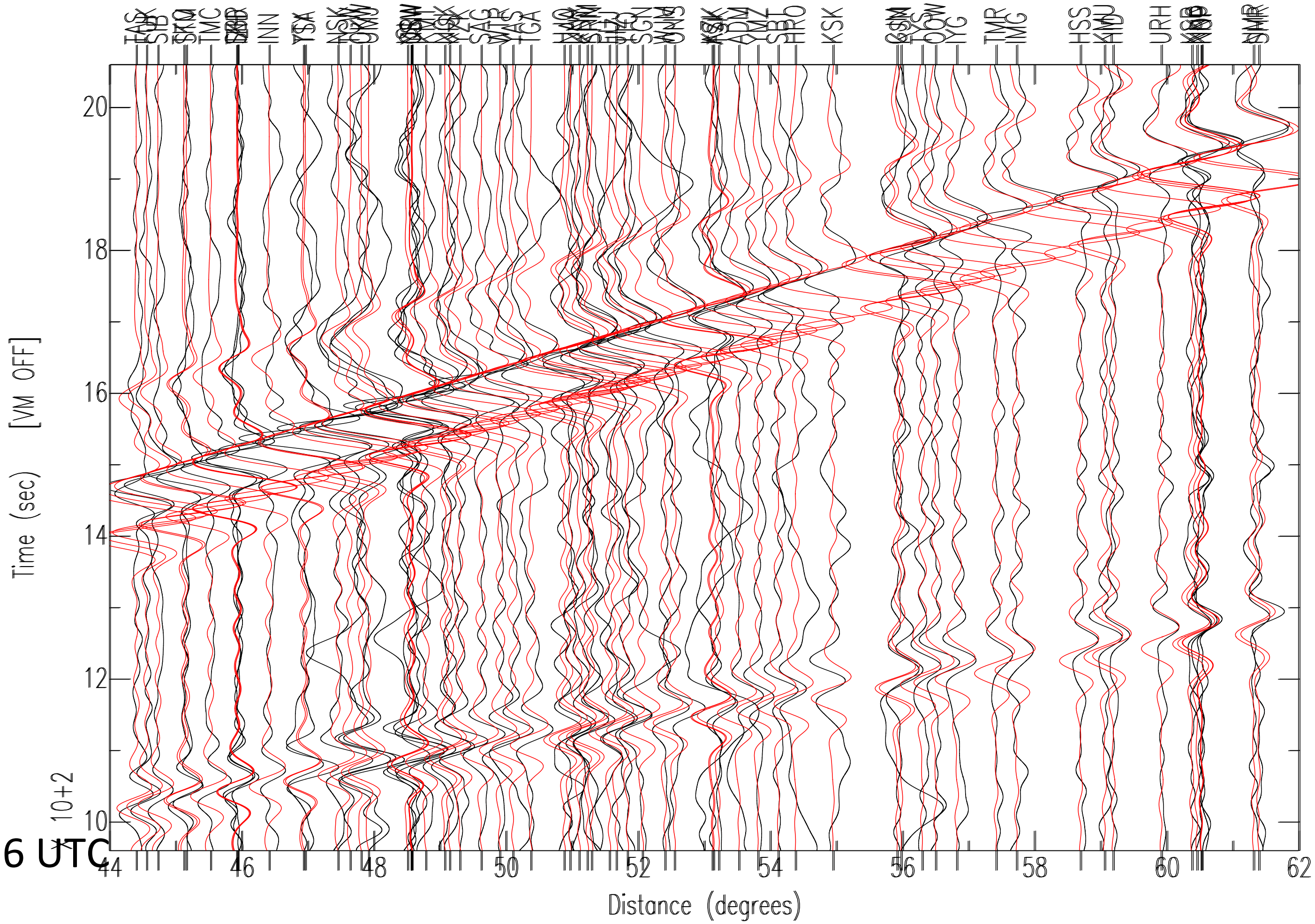
7.4 km/s

S-wave

T_0=13:56 UTC

2018/12/22 Broadband Fnet velocity Z bp 64-256 s

Seismic waves in Japan (F-net)



Rayleigh

7.4 km/s

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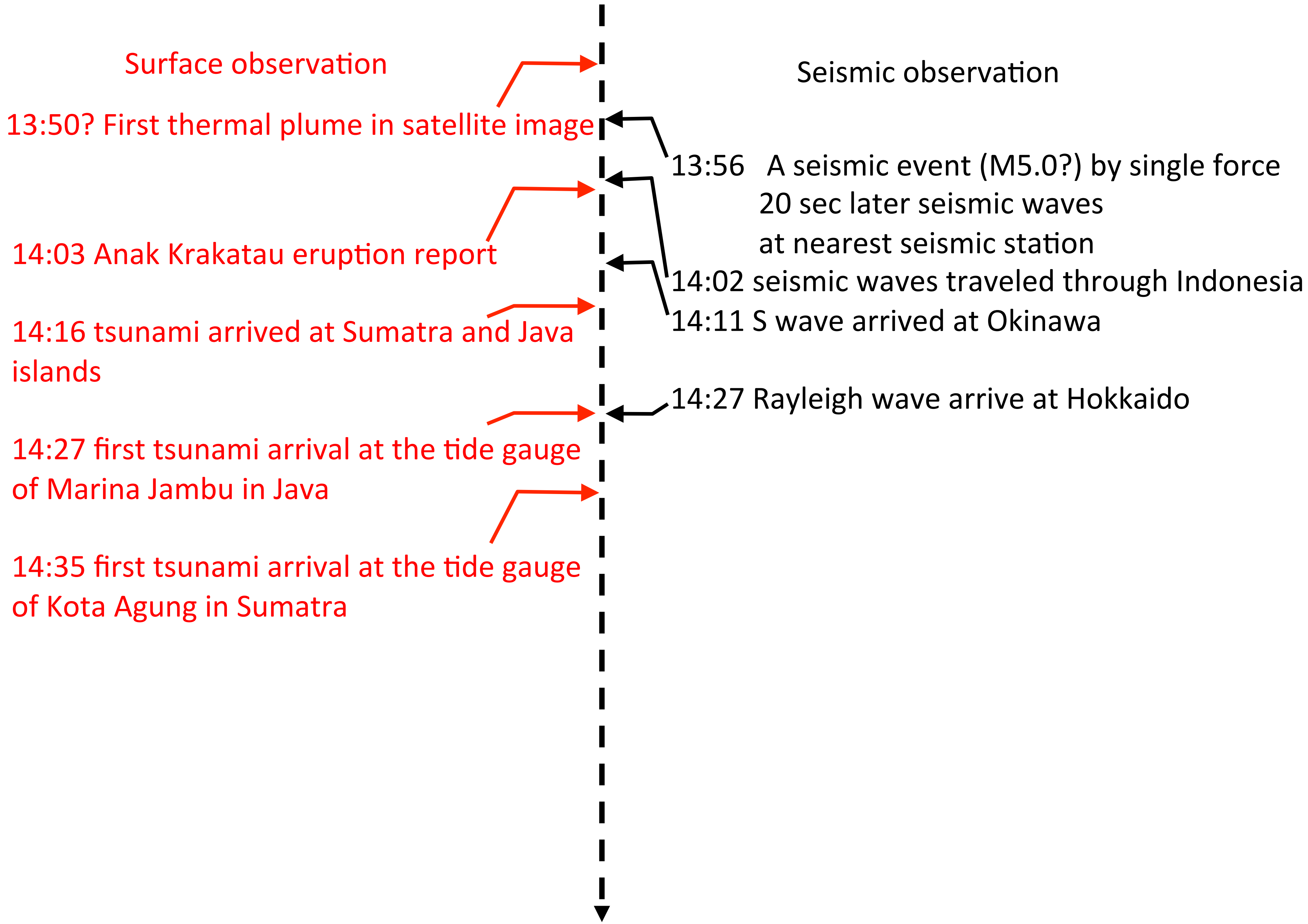
T_0=13:56 UTC

2018/12/22 Broadband Fnet velocity Z bp 64-256 s


Surface observation
13:50? First thermal plume in satellite image
14:03 Anak Krakatau eruption report
14:16 tsunami arrived at Sumatra and Java islands
14:27 first tsunami arrival at the tide gauge of Marina Jambu in Java
14:35 first tsunami arrival at the tide gauge of Kota Agung in Sumatra
Seismic observation
13:56 A seismic event (M5.0?) by single force
20 sec later seismic waves at nearest seismic station
14:02 seismic waves traveled through Indonesia
14:11 S wave arrived at Okinawa
14:27 Rayleigh wave arrive at Hokkaido

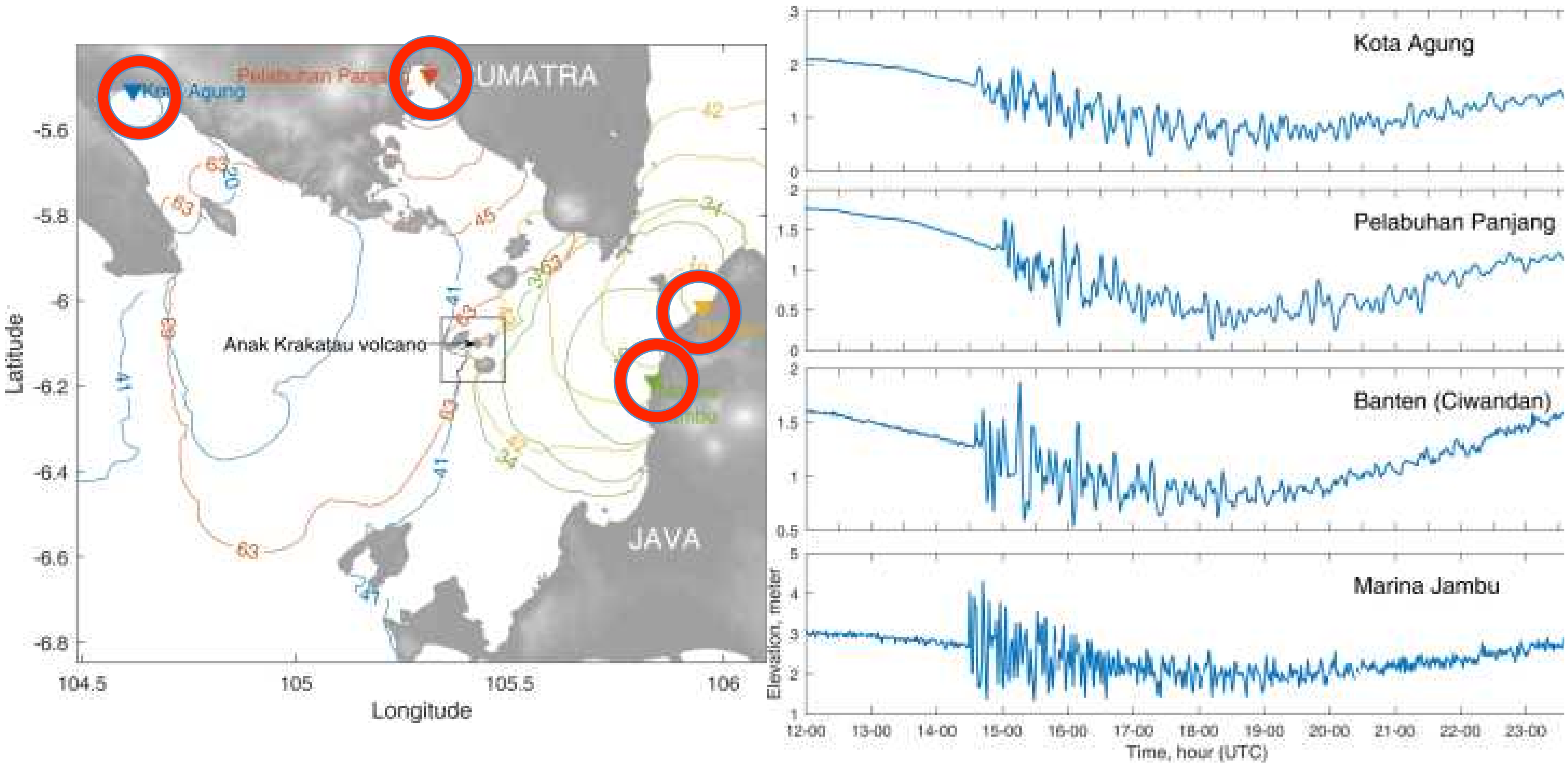
Seismic waves from Anak Krakatau

- Low-frequency (20-100 s) seismic waves are radiated during the edifice collapse of Anak Krakatau.
- Landslide tsunami is modeled by two-layer tsunami simulation. Seismic and tsunami analyses suggest a mass (volume ~0.2km^3) motion in 100 sec or less toward SW.
- A (submarine) landslide coeval with the seismic wave radiation and the volcanic eruption, generated a tsunami that hit the coast of Java and Sumatra islands.
- Monitoring the seismic activity at low frequency bands, the collapse of the volcano island can be detected before tsunamis hit populated area.

Simulation of the 22 December 2018 tsunami due to the flank failure of Anak Krakatau Volcano and recommendation for future observing systems

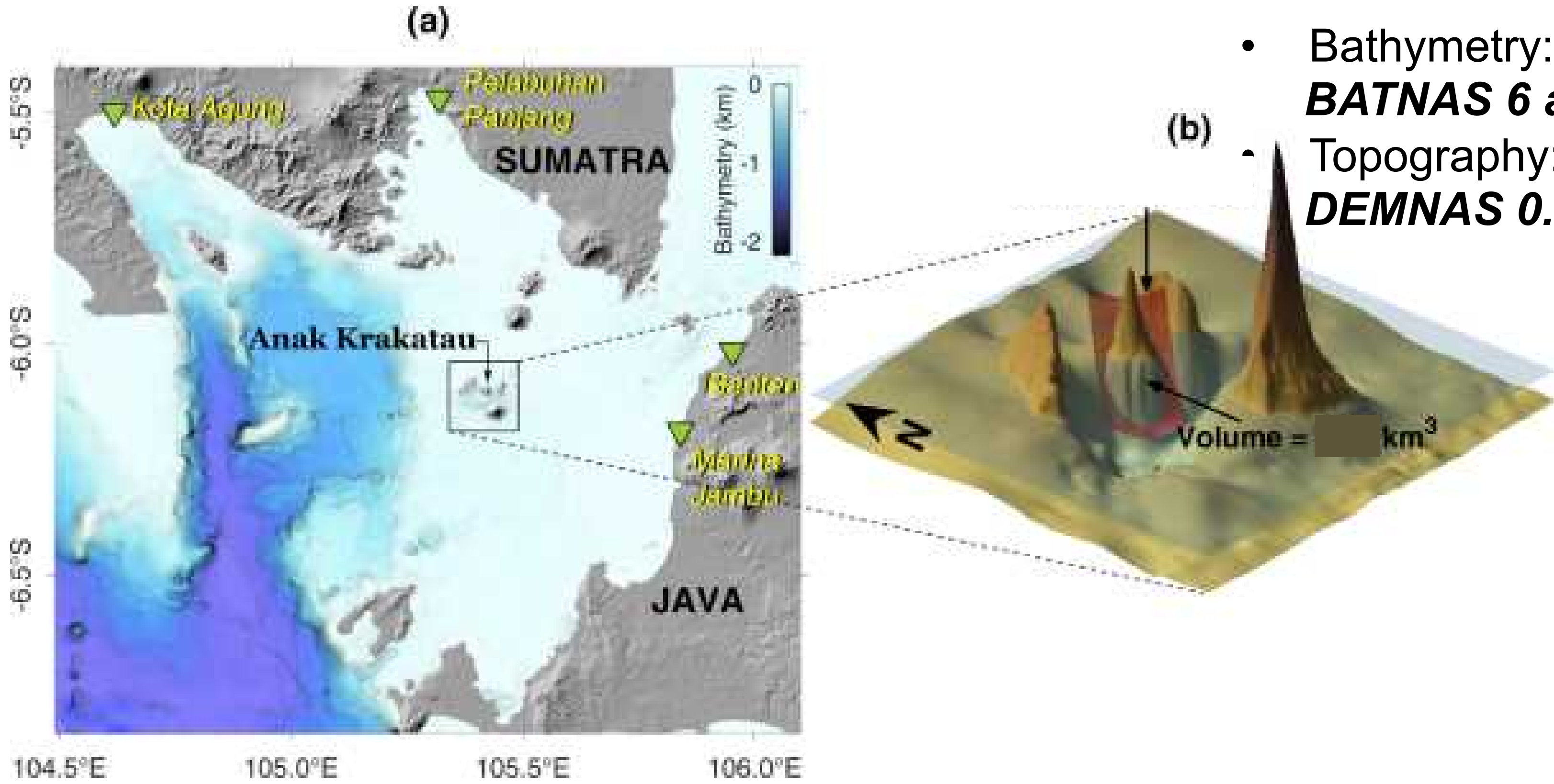
Iyan Mulia, Shingo Watada, Masumi Yamada,
Karyono Karyono, Aditiya Arif

Back-propagated travel time from four tide gauges



National Bathymetry of Indonesia (BATNAS) 6 arc-min

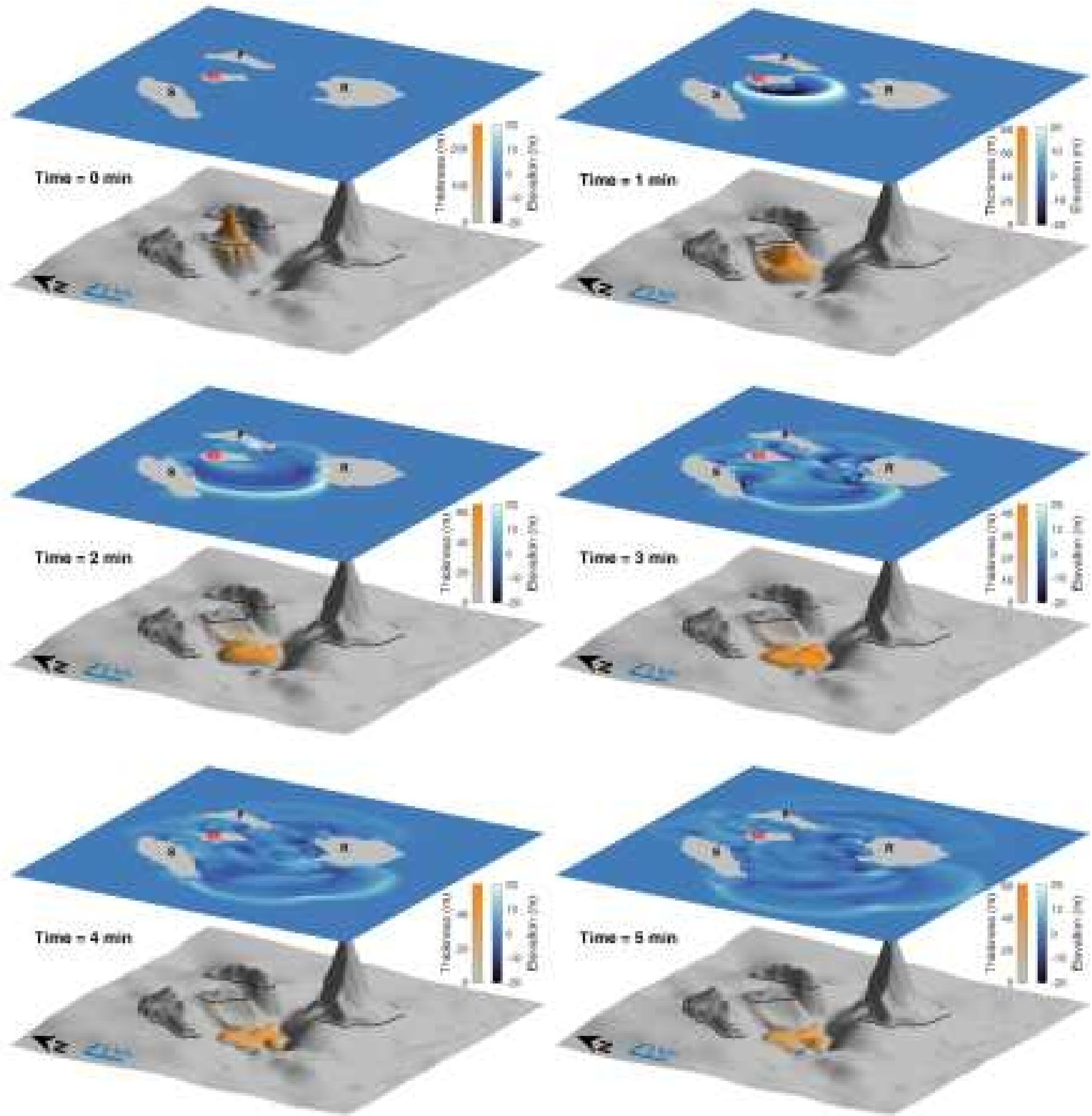
Landslide + tsunami generation model



- Bathymetry: ***BATNAS 6 arc-sec***
- Topography: ***DEMNAS 0.27 arc-sec***

NHWAVE (3D) grid size (3 arc sec)

Landslide + tsunami generation model

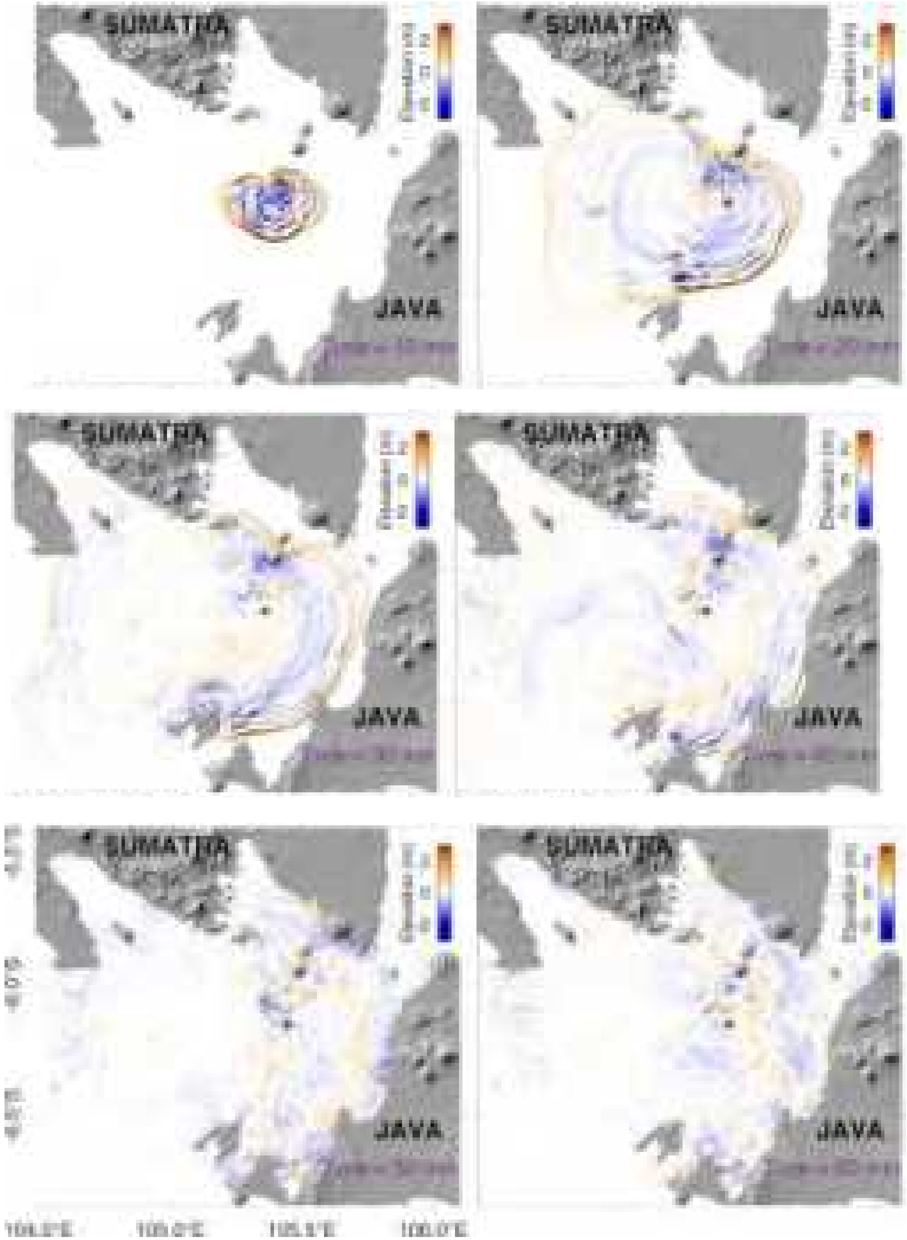


- **NHWAVE (3D)**
- **Two-layer model**

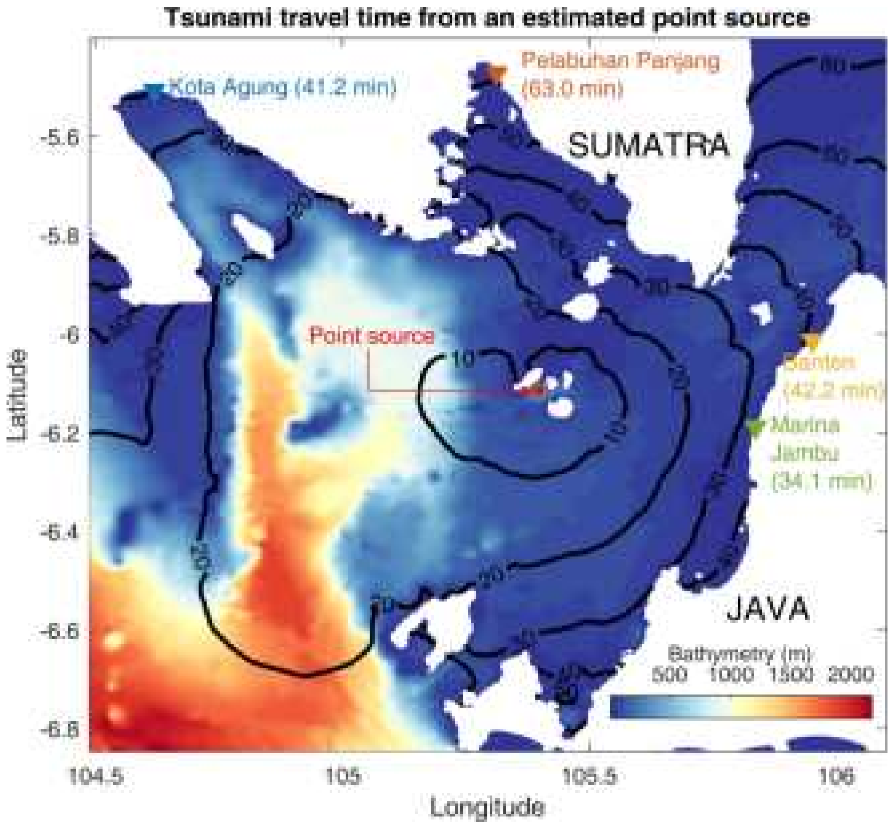
Tsunami propagation model

FUNWAVE (2D)
grid size (6 arc sec)

- Initial condition from NHWAVE(3D) at 5 min.
- Nonlinear + dispersive.
- Total simulation = 2 h.



Tsunami source origin time estimation



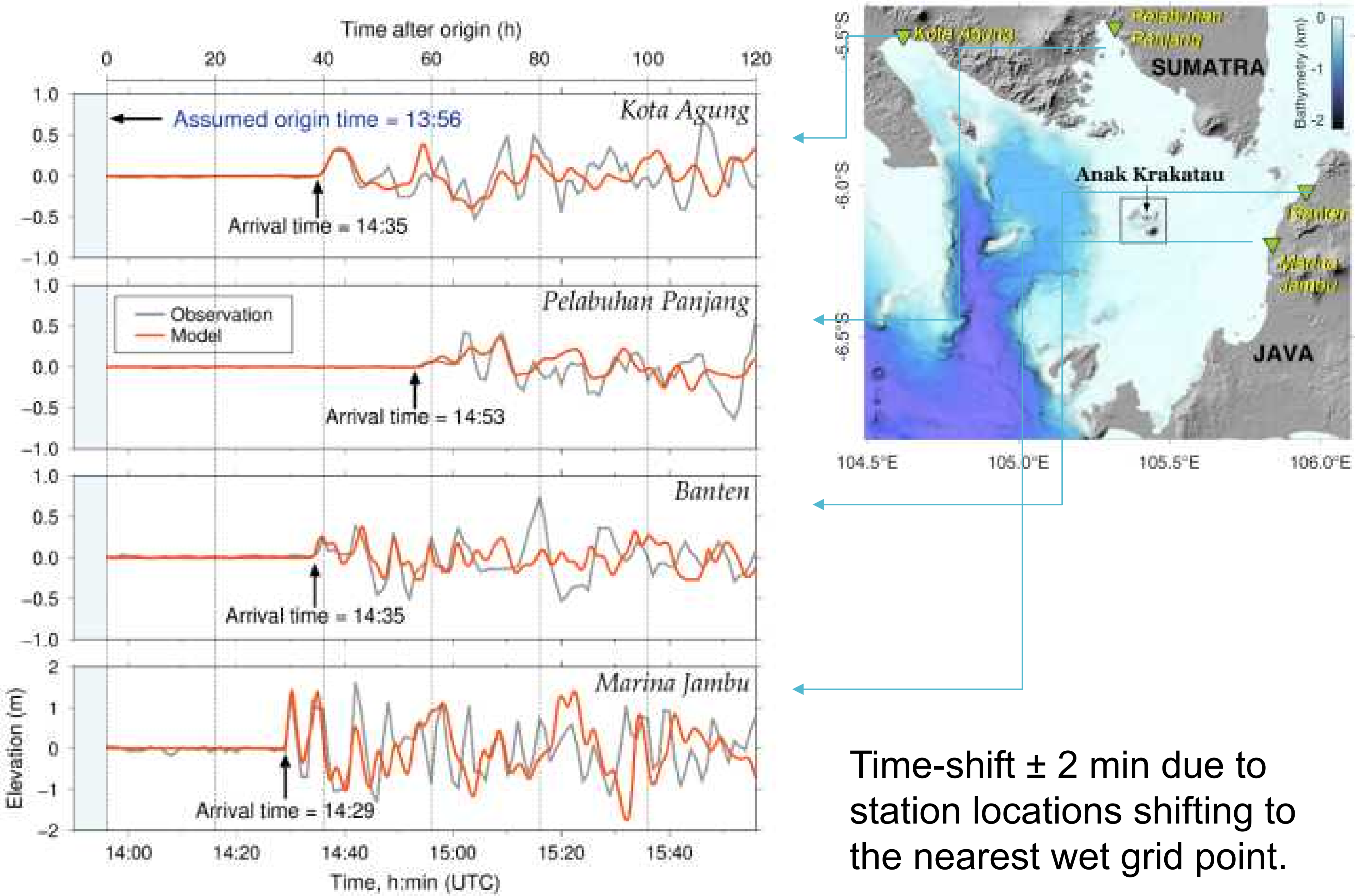
Point source

Station	Arrival time (UTC)	Travel time (min)	Calculated origin time (UTC)
Kota Agung	14:35:00	41.2	13:53:48
Pelabuhan Panjang	14:53:00	63	13:50:00
Banten	14:35:00	42.2	13:51:48
Marina Jambu	14:29:00	34.1	13:54:54
		Average	13:54:28

Modified travel time

Station	Arrival time (UTC)	Travel time (min)	Calculated origin time (UTC)
Kota Agung	14:35:00	39	13:56:00
Pelabuhan Panjang	14:53:00	57	13:56:00
Banten	14:35:00	39	13:56:00
Marina Jambu	14:29:00	33	13:56:00
		Average	13:56:00

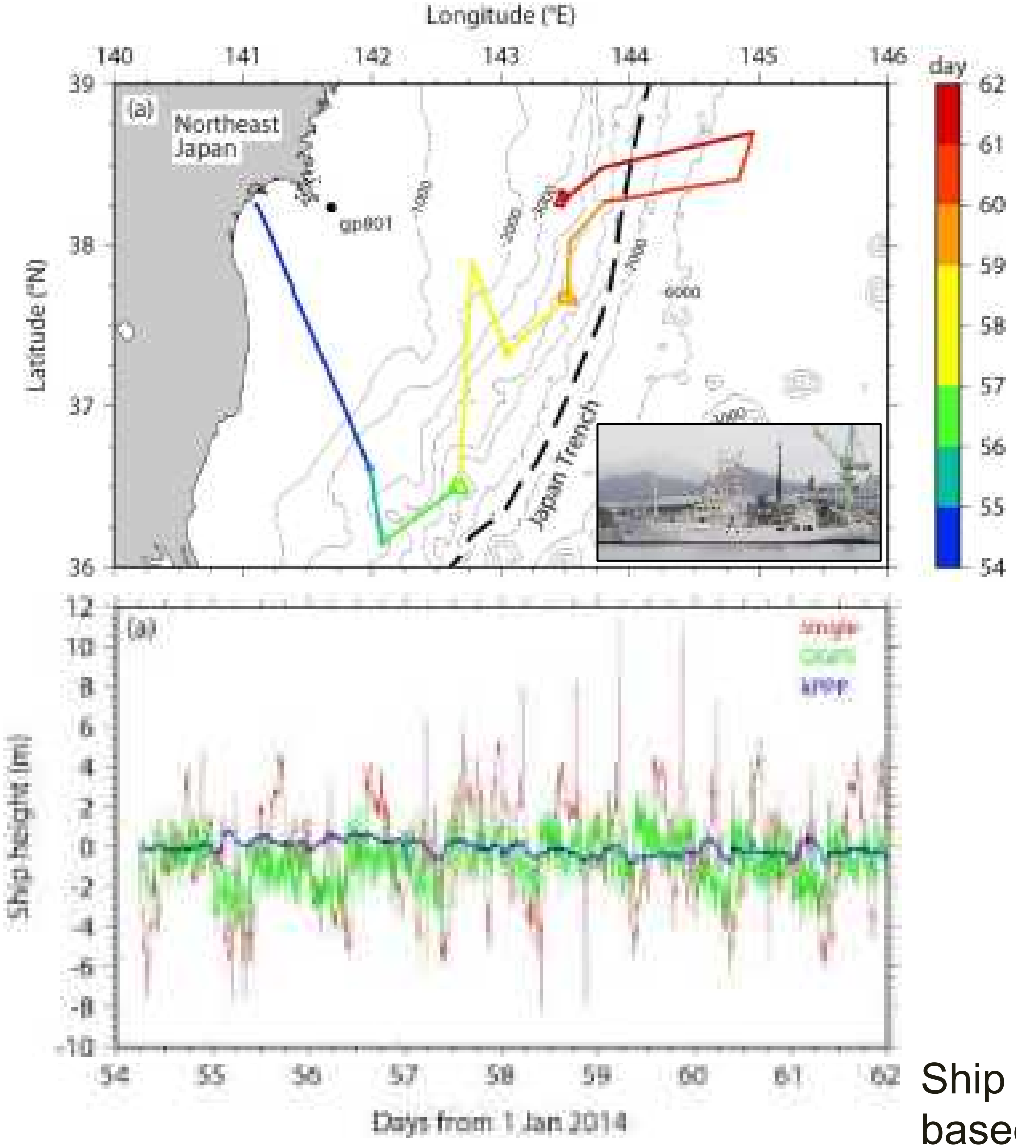
Observation vs simulation

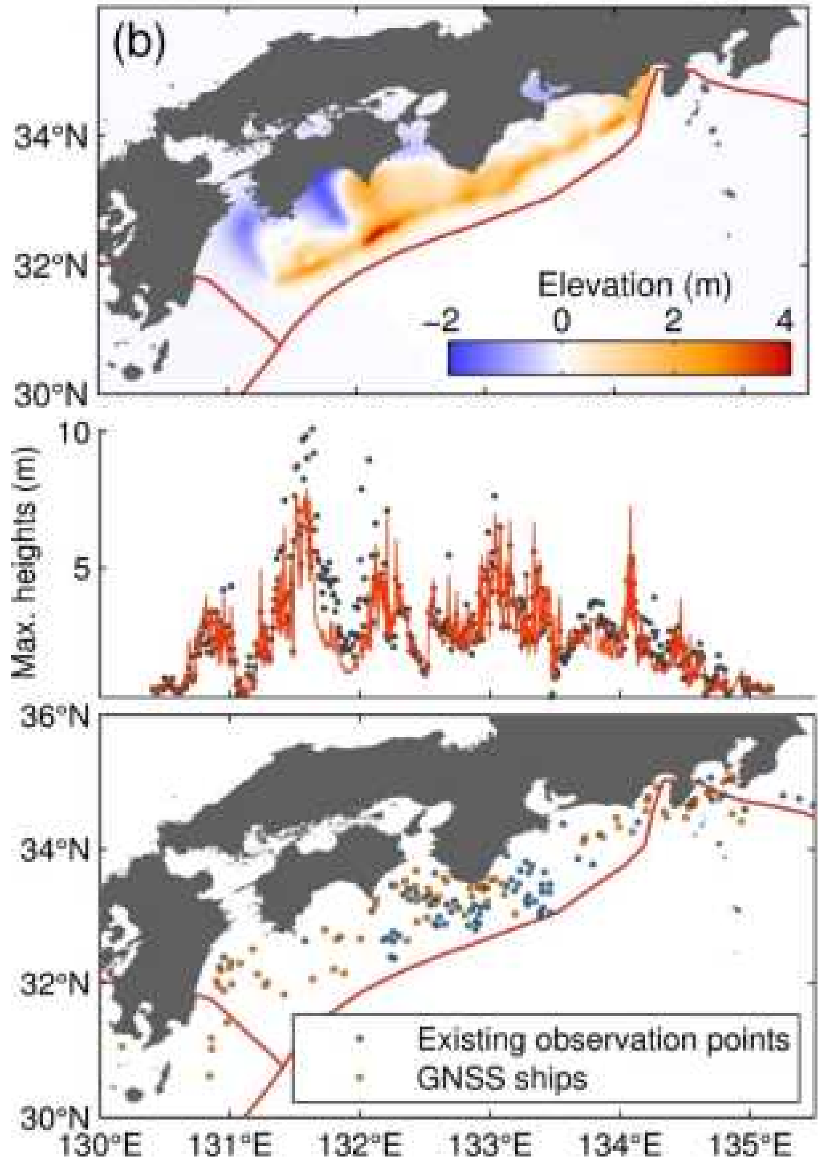


Time-shift ± 2 min due to station locations shifting to the nearest wet grid point.

Recommended observing systems

Ship height positioning

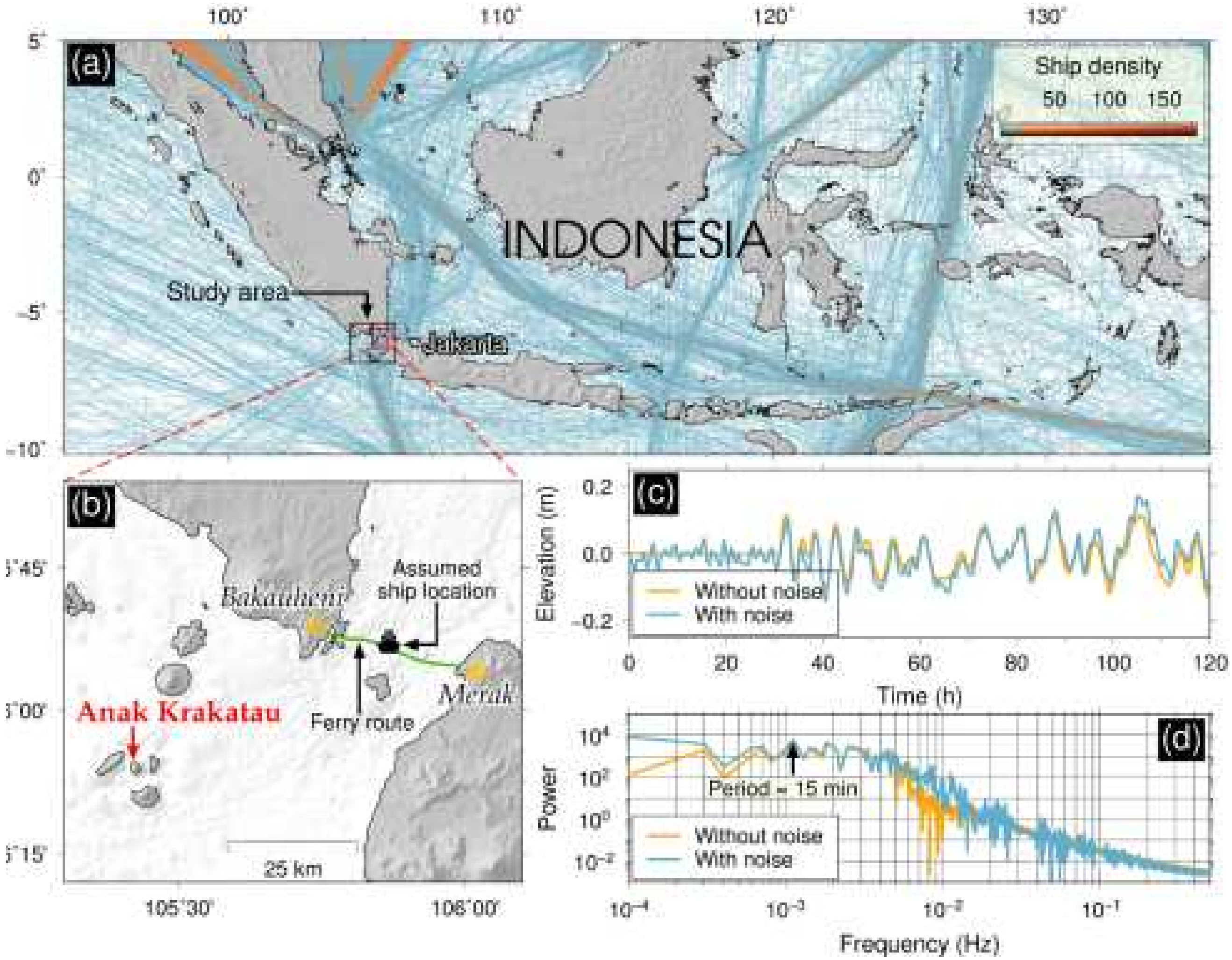




Ship locations (tanker = 28, cargo ship = 64) are based on the data on January 1, 2015, 20:00

Recommended observing systems

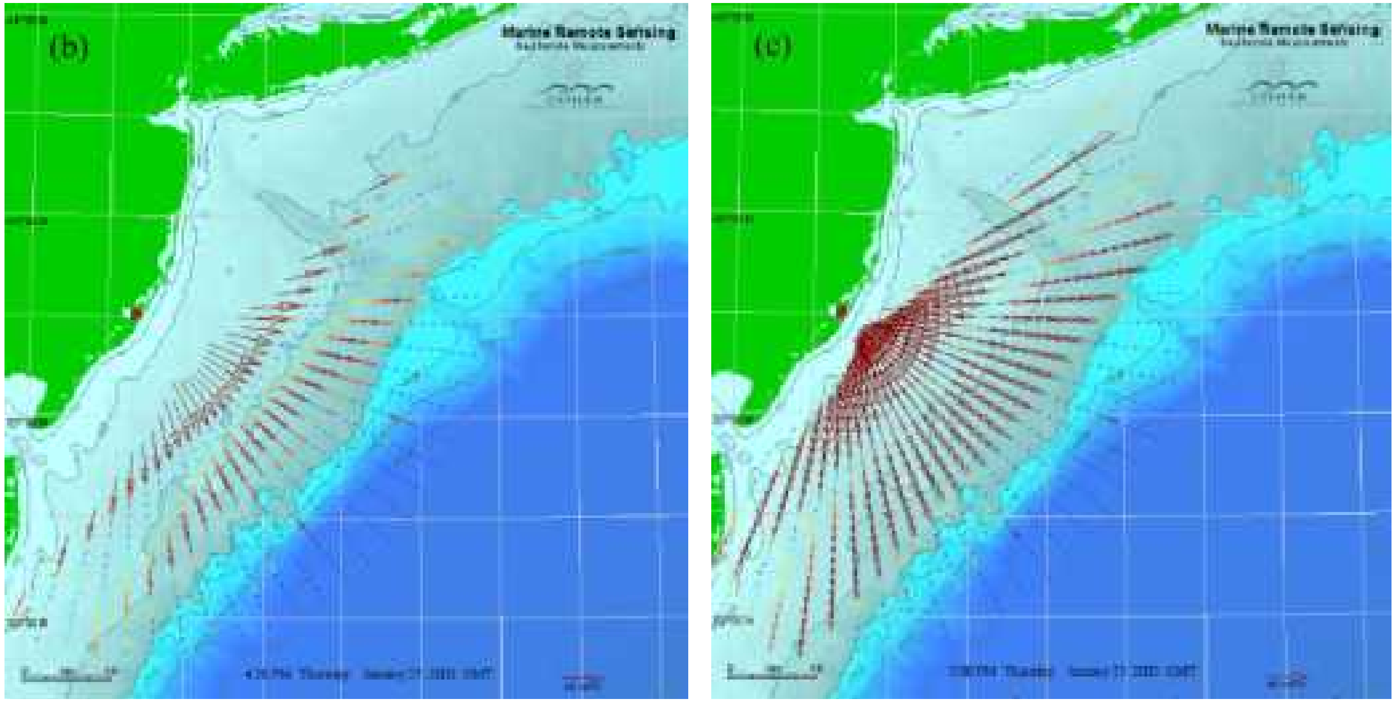
Ship height positioning



Commercial shipping activity (2004-2005) United Nations Environment Programme (UNEP, 2019)

Recommended observing systems

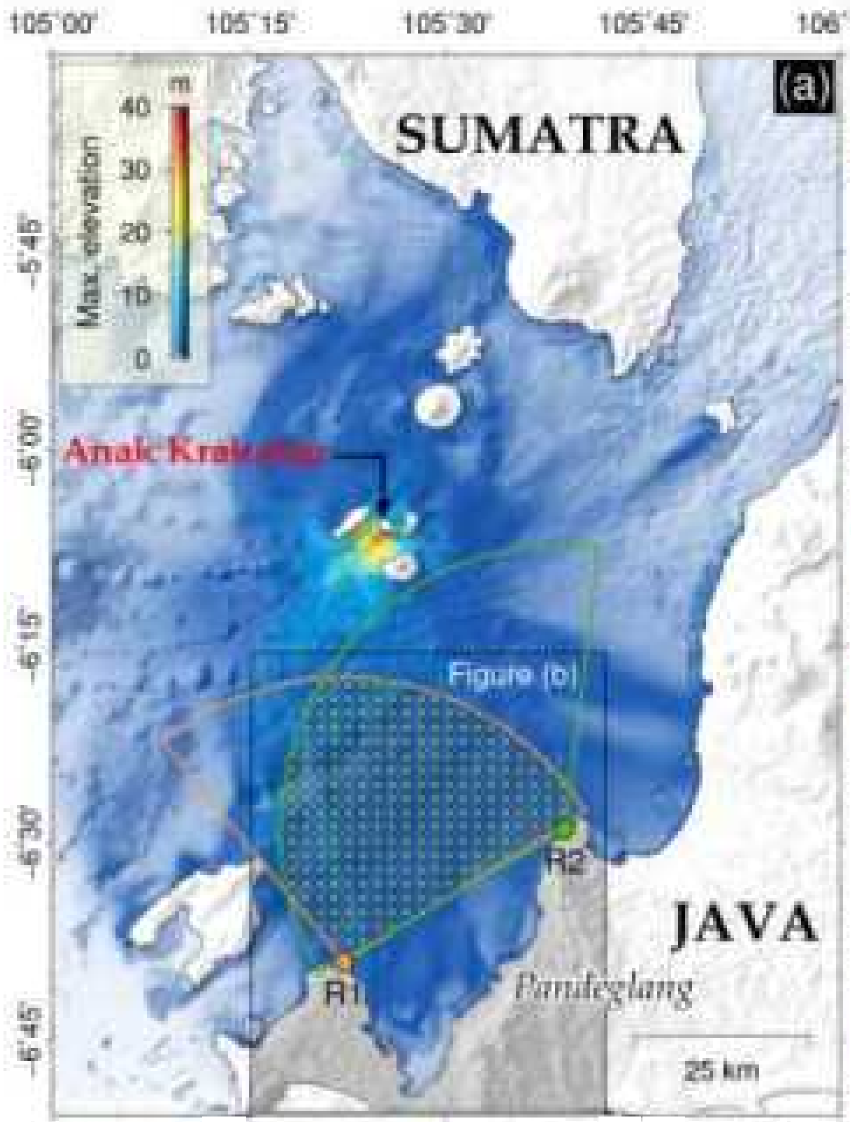
Oceanographic high-frequency radar



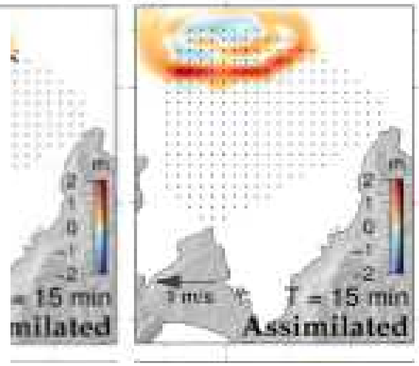
- Can monitor ocean surface currents to distances of up to 200 km.
- Detection probability depends on the water depth (< 200 m) (Lipa et al., 2011, 2012; Ogata et al., 2018).
- More than one radar is required to generate current maps.

Recommended observing systems

Oceanographic high-frequency radar



Velocity **Elevation**



- Spatial resolution 2 km x 2 km. Lipa et al. (2011) used 0.5 km x 0.5 km
- Temporal resolution 1 min. Hinata et al.

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Mitsubishi Electric Develops Enhanced Tsunami Detection Te

Will contribute to earlier and more accurate detection of tsunamis and facilitate time

Conclusions

- The 22 December 2018 Sunda Strait tsunami was caused by the southwest flank collapse of the Anak Krakatau Volcano.
- Tsunami data assimilation and observing systems based on ship height positioning and oceanographic radars are suitable for the region.

Future works

- Update the bathymetry data for more accurate tsunami simulations.