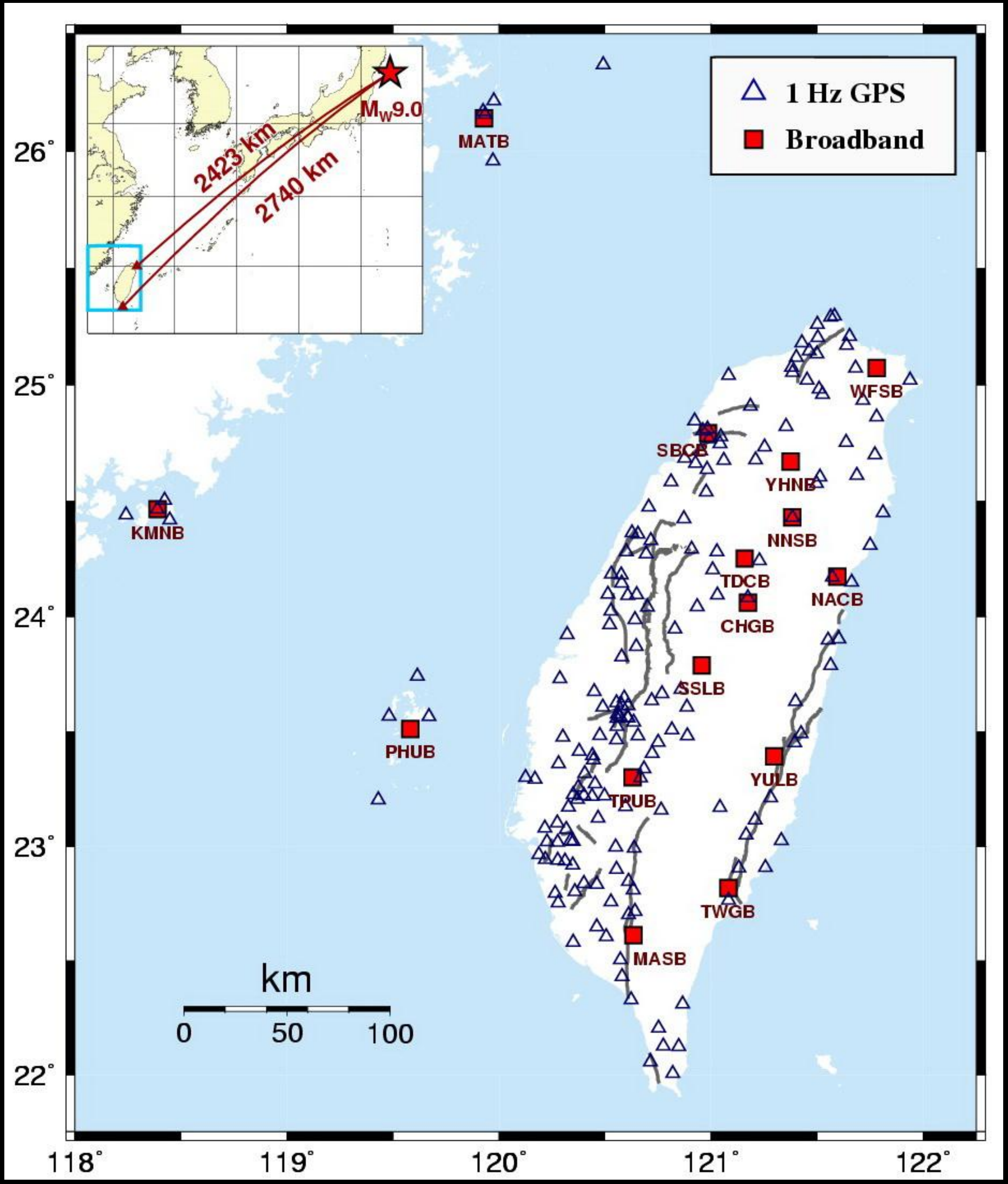
Precision of Surface Wave Displacement Seismograms From the 2011 M_W 9.0 Tohoku, Japan Earthquake Recorded by a Dense High-rate GPS Network in Taiwan

Huang-Kai Hung, Ruey-Juin Rau*

Department of Earth Sciences, National Cheng Kung University, Tainan, Taiwan

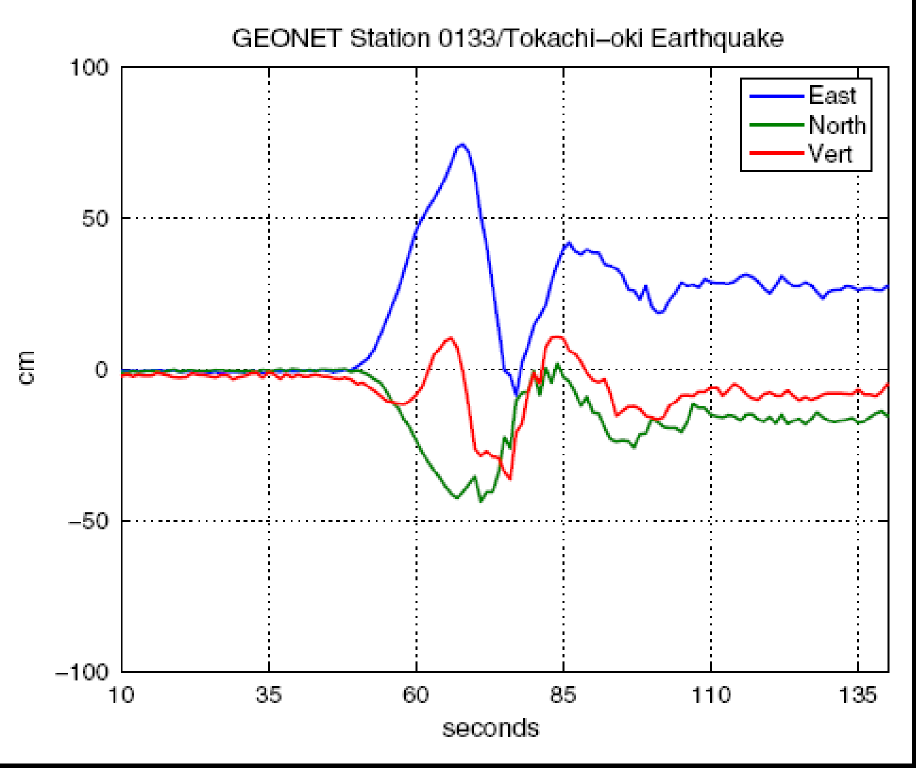
Purposes

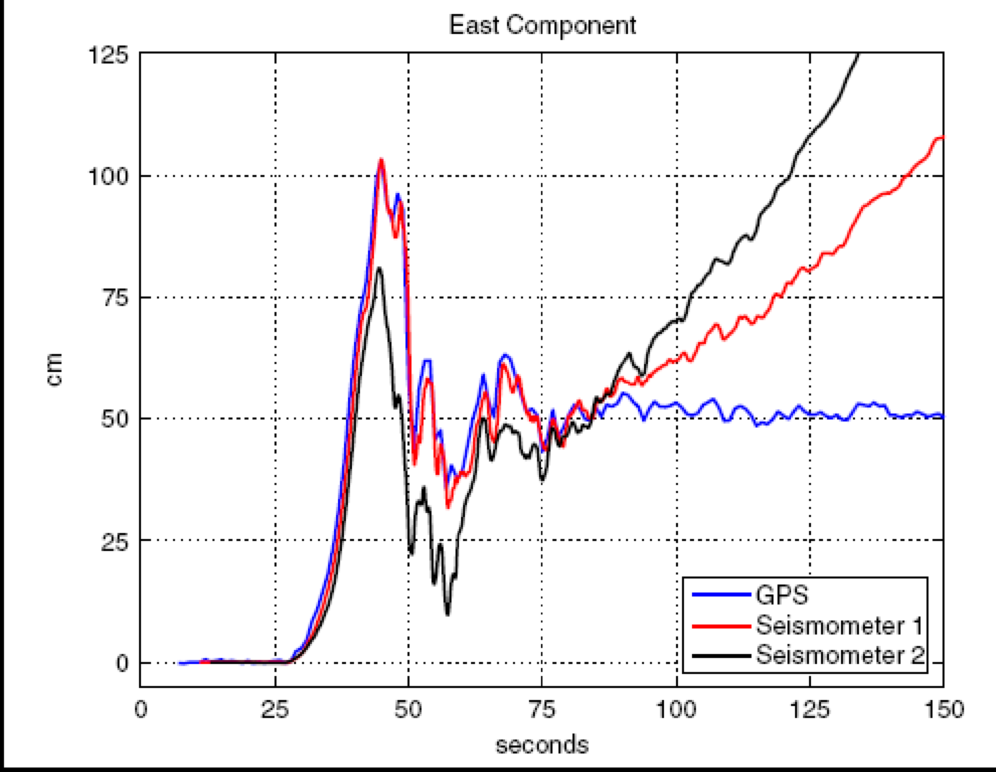
- Demonstrate the capability of high-rate GPS in measuring surface wave displacements.
- Differences in seismograms between high-rate GPS and broad band seismometer.
- Tohoku earthquake induced surface wave observed in Taiwan.



GPS Seismology

GPS as a *strong motion* instrument



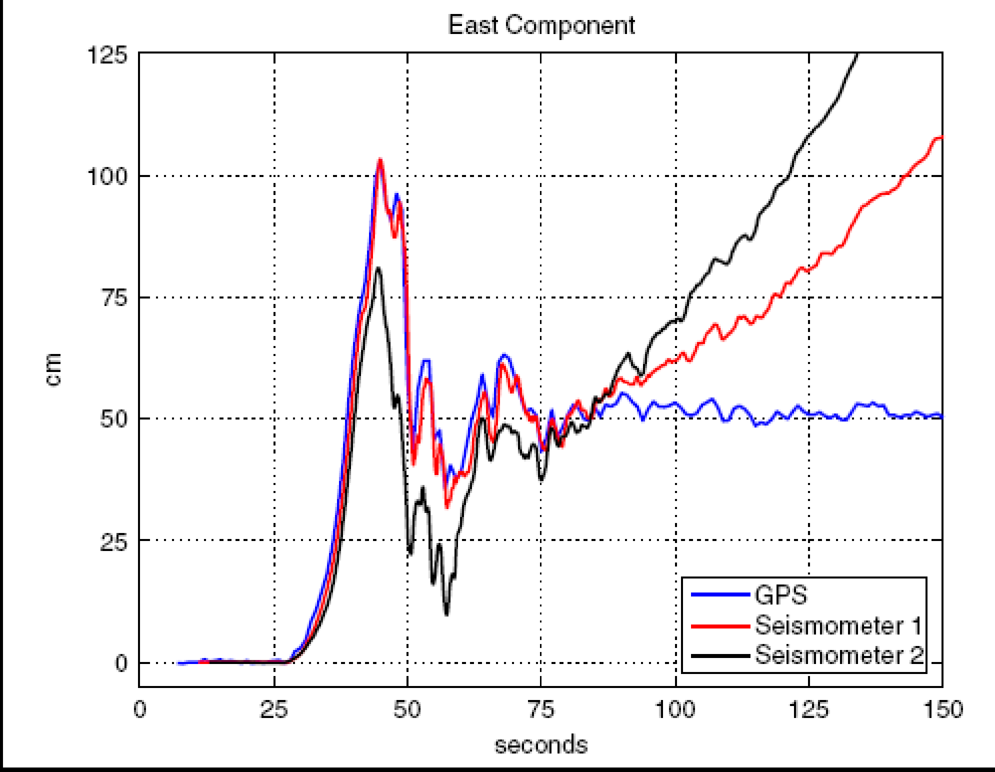


Miyazaki *et al*., 2004; Larson, 2009

GPS Seismology

GPS as a *strong motion* instrument

1. High rate GPS is an extra sensor
2. No clipping
3. Strong motion
4. No more double integrating acceleration
5. Static offset displacement
6. Direct link between coseismic and postseismic

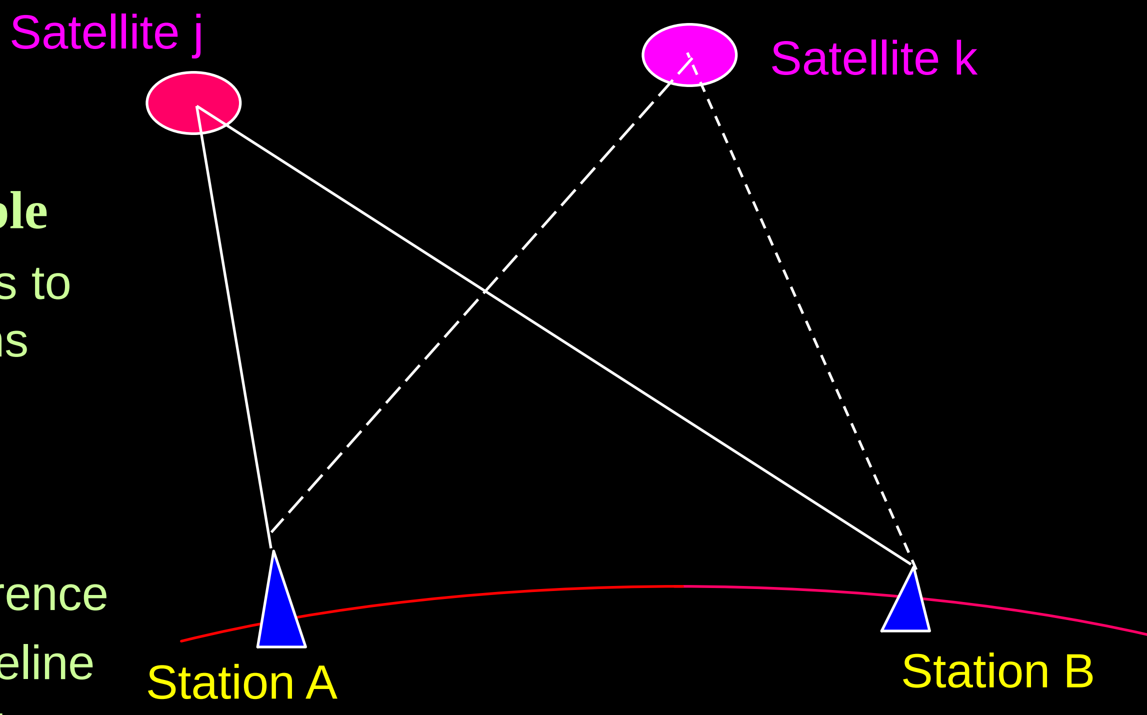


Miyazaki *et al*., 2004; Larson, 2009

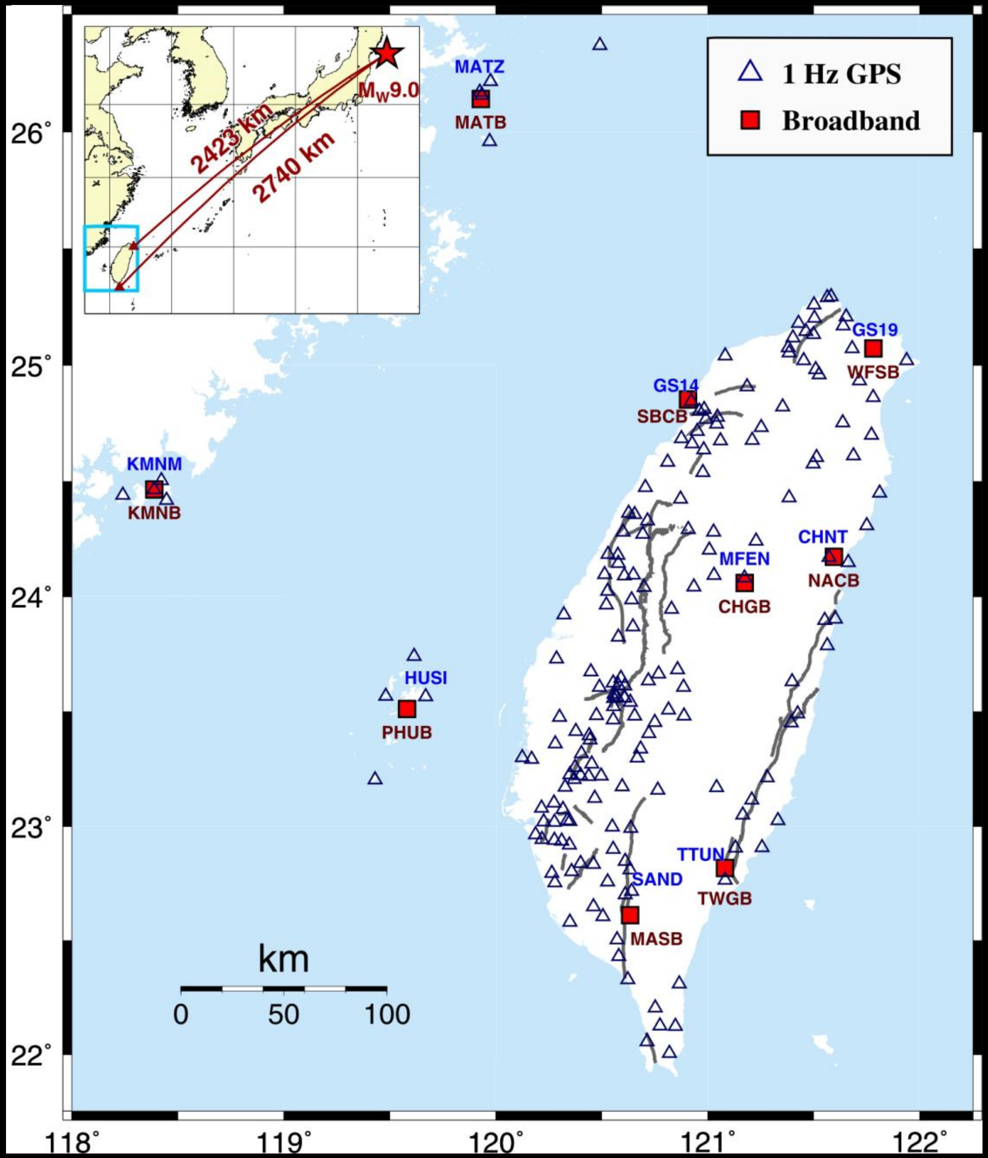
High rate GPS processing

- **Undifferenced observable**
  - Estimate both receiver and satellite clocks
  - Precise Point Positioning – Fix prior satellite clocks and estimate only receiver clocks
  - Few parameters

- **Double-differenced observable**
  - Undifferenced observations to two satellites at two stations
  - Form two between-station differences and then double-difference
  - Common clock terms difference
  - More precise for short-baseline relative motion, but depends on base station



High rate GPS & BB seismic data



- *High-rate continuous GPS (183)*

  CWB, CGS, NLSC, NCCU

  1-Hz, 7-11 March, 2011

- *Broadband seismometers (15)*
  BATS, 20-Hz

- 9 co-located pairs for comparison

High-rate GPS processing

- Precise Point Positioning (PPP) *(Zumberge et al., 1997)*

  1. GPStools software (GT) *(Takasu, 2006)*
  2. Satellite clock error file: CODE 5 sec *(Bock et al, 2008)*

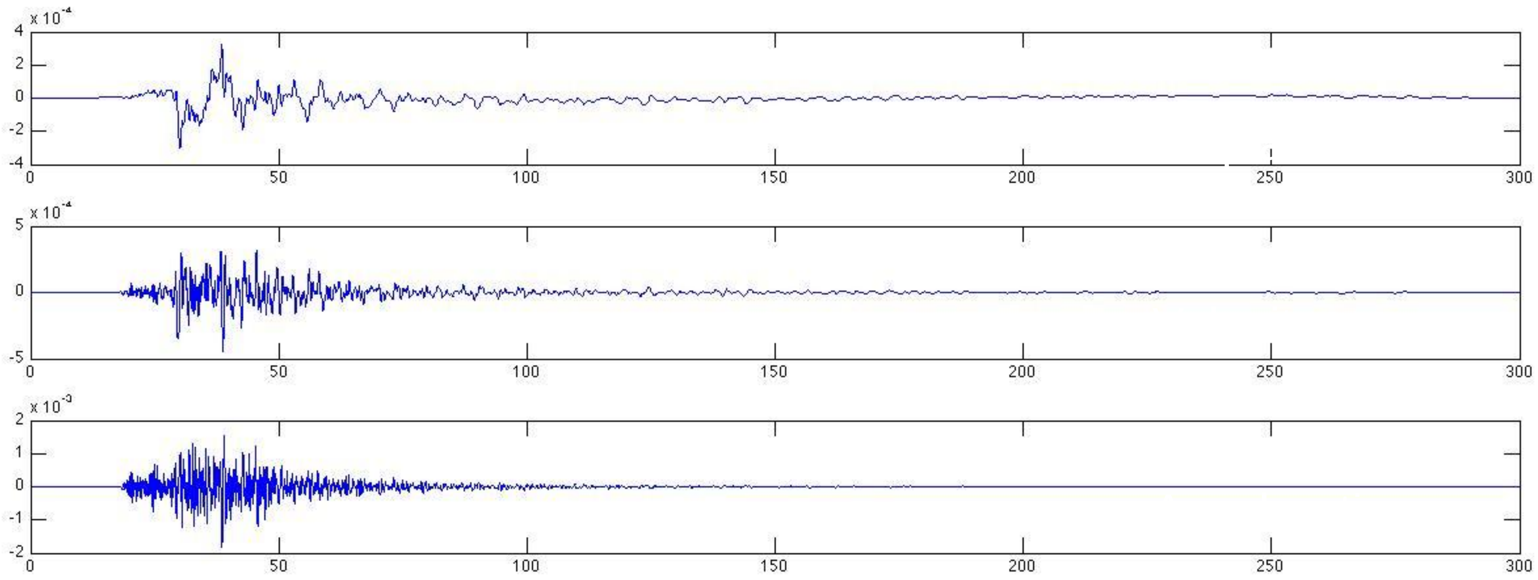
- Modified Sidereal Filtering (MSF) *(Choi et al., 2004)*

  1. Estimate optimal repeat times of the GPS satellite orbits *(Agnew and Larson, 2007)*
  2. Deriving MSF time series *(Nicolaidis, 2002)*
  3. Obtaining residual time series after subtracting MSF

Broadband seismometers

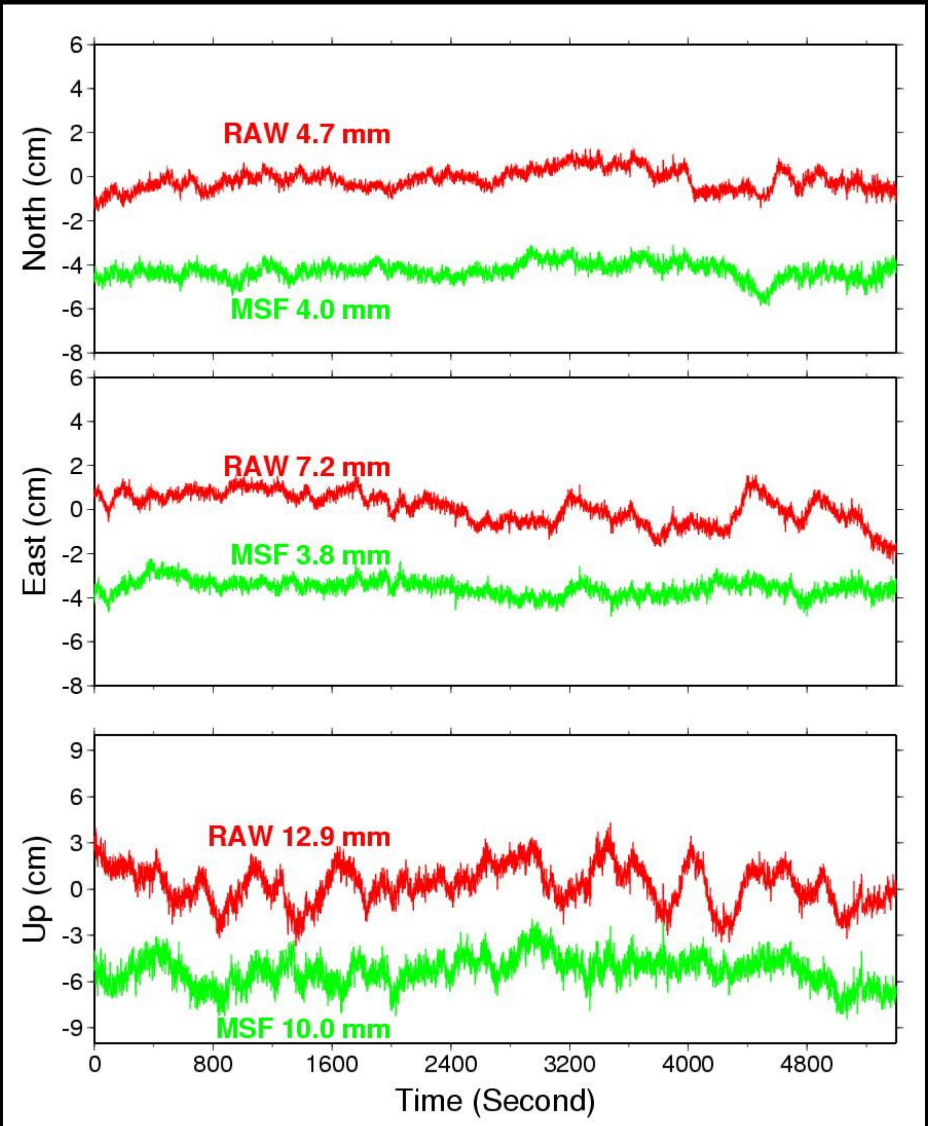
(VELOCITY → DISPLACEMENT) (Bilich et al., 2008)

- Remove the mean and linear trend
- Taper the ends
- Remove the instrument response
- Data integration
- Apply a 200-sec high-pass filter

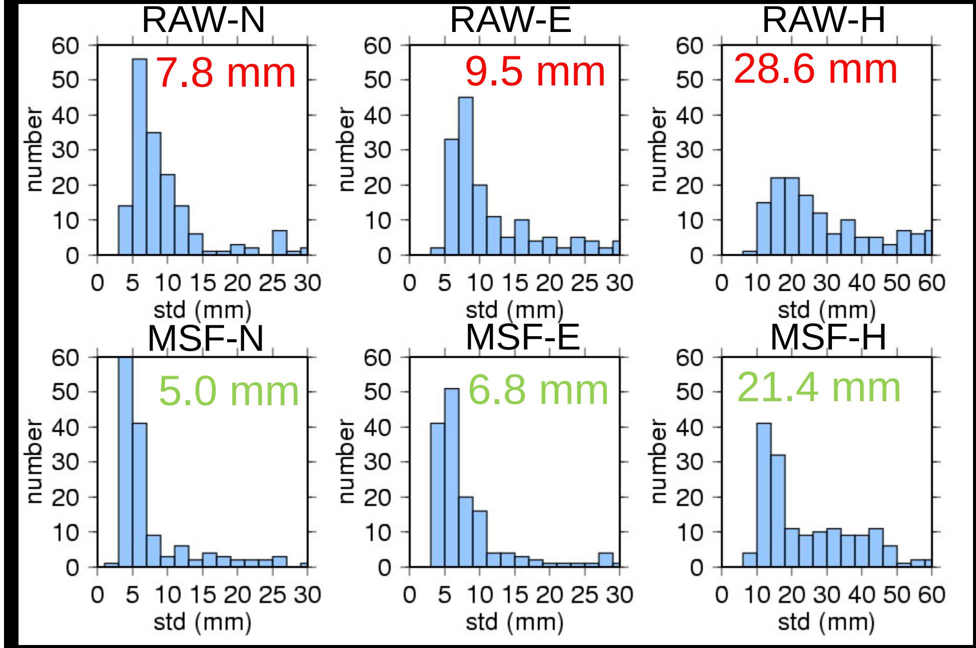


Precision of high-rate GPS

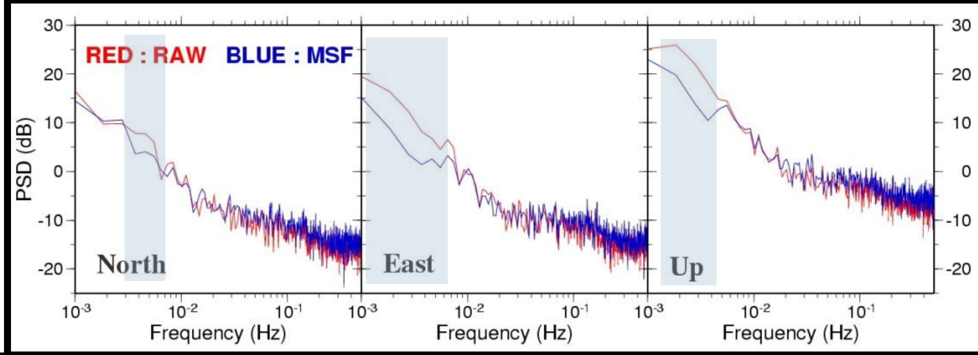
MFEN, 04:00:00-05:29:59, 5400 epoch



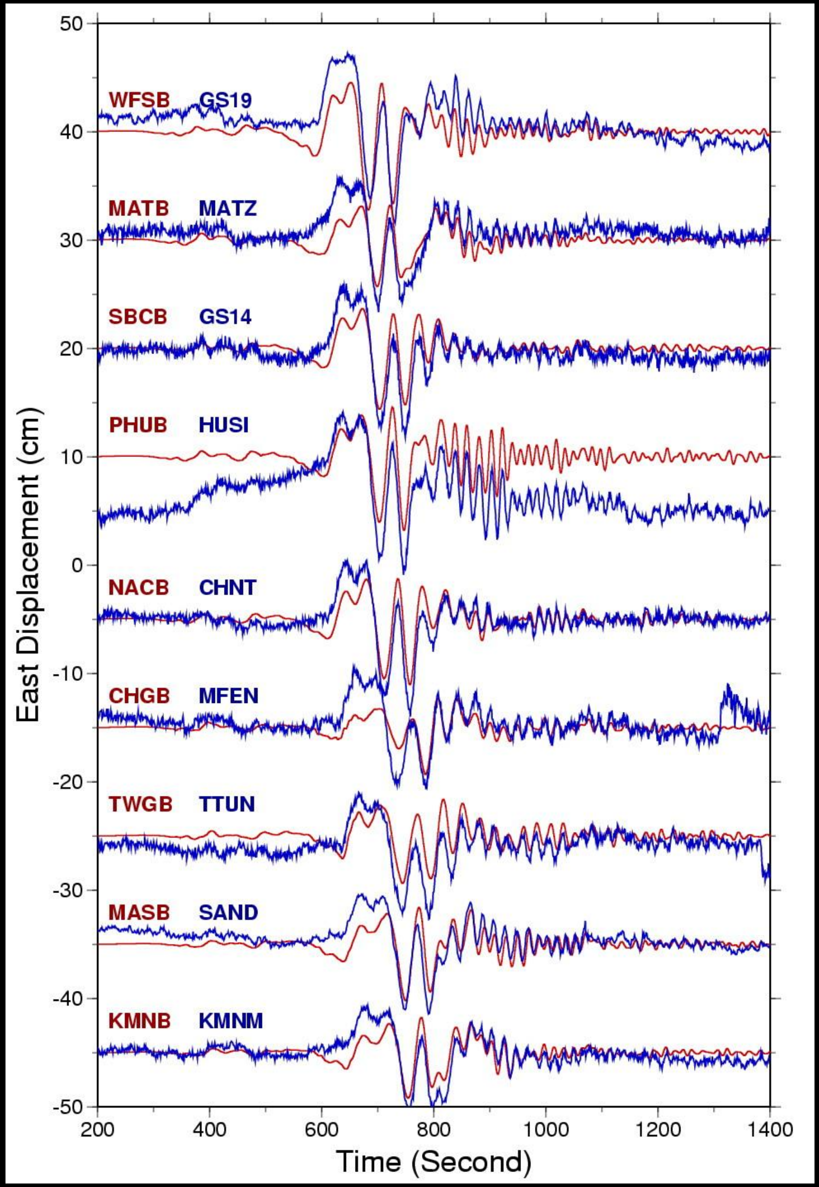
statistics in 183 CGPS data

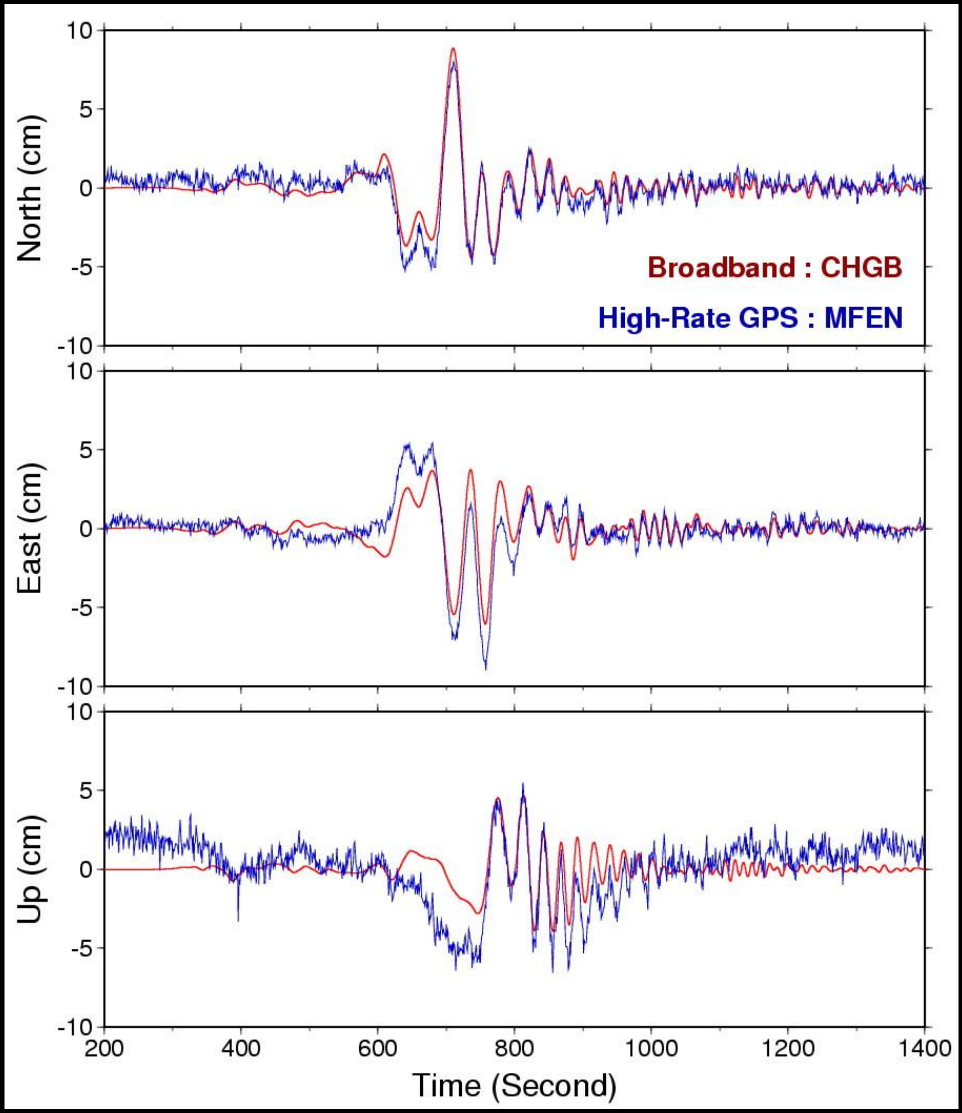


Spectral analysis

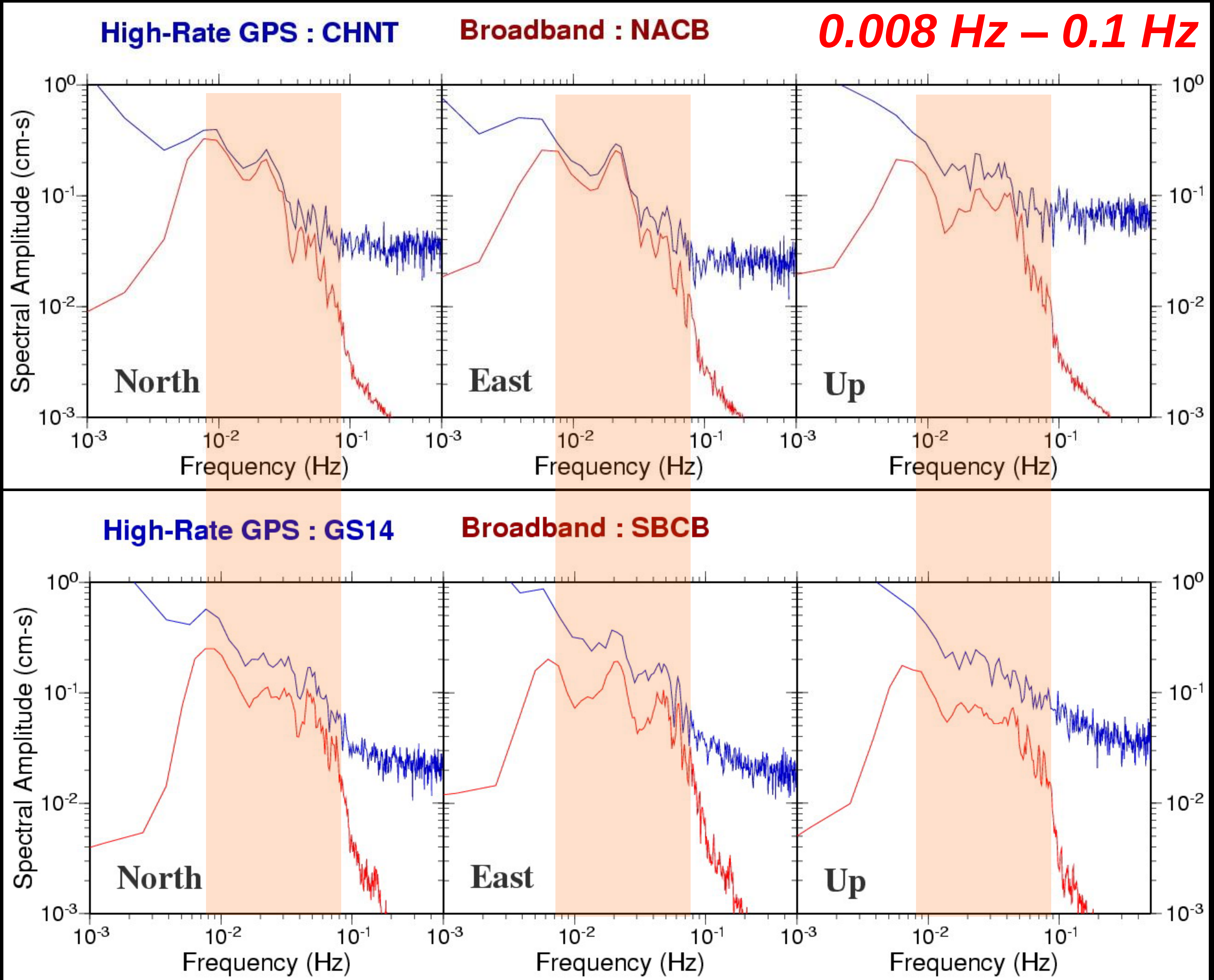


High-rate GPS and BB seismometers

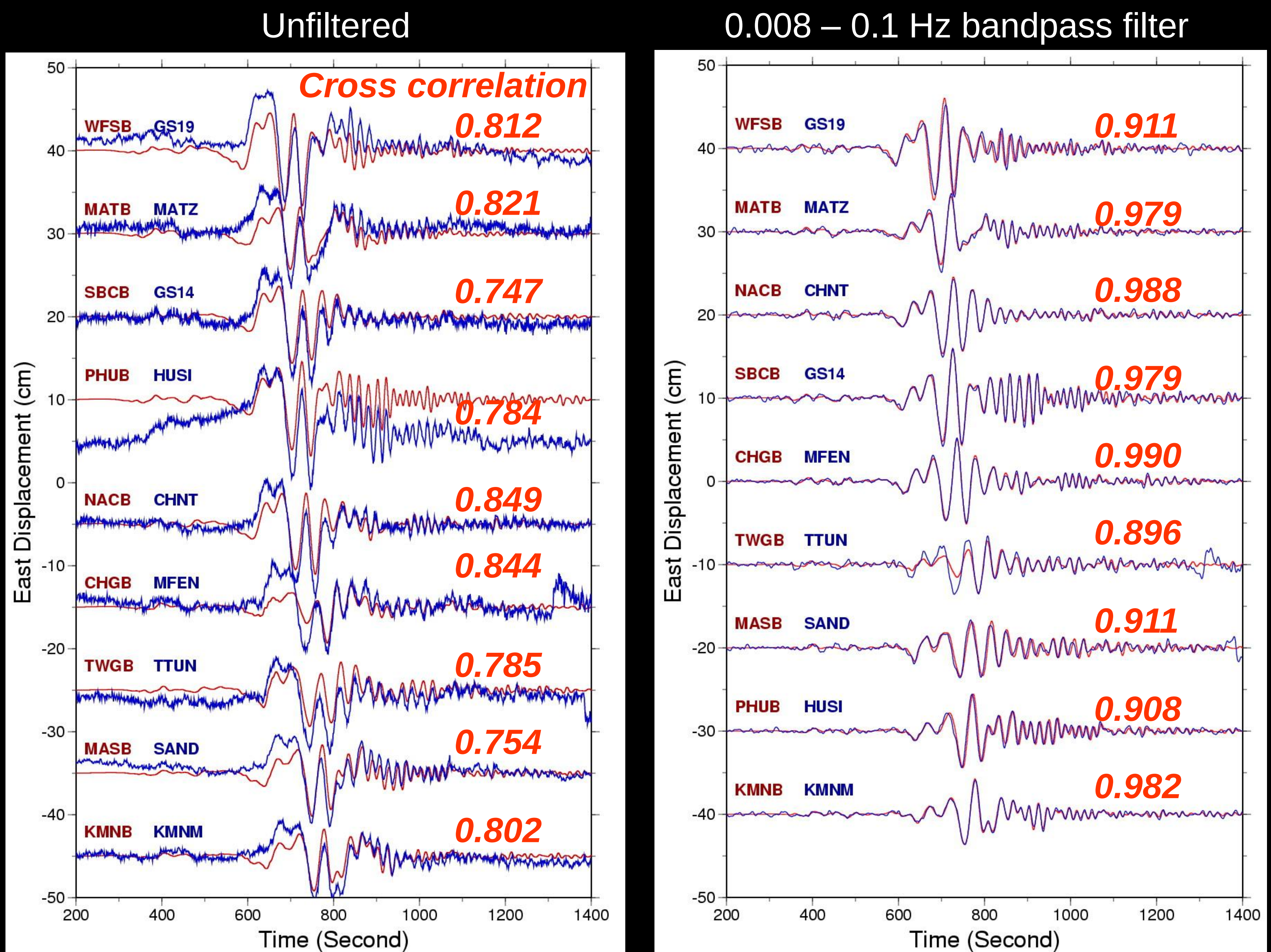




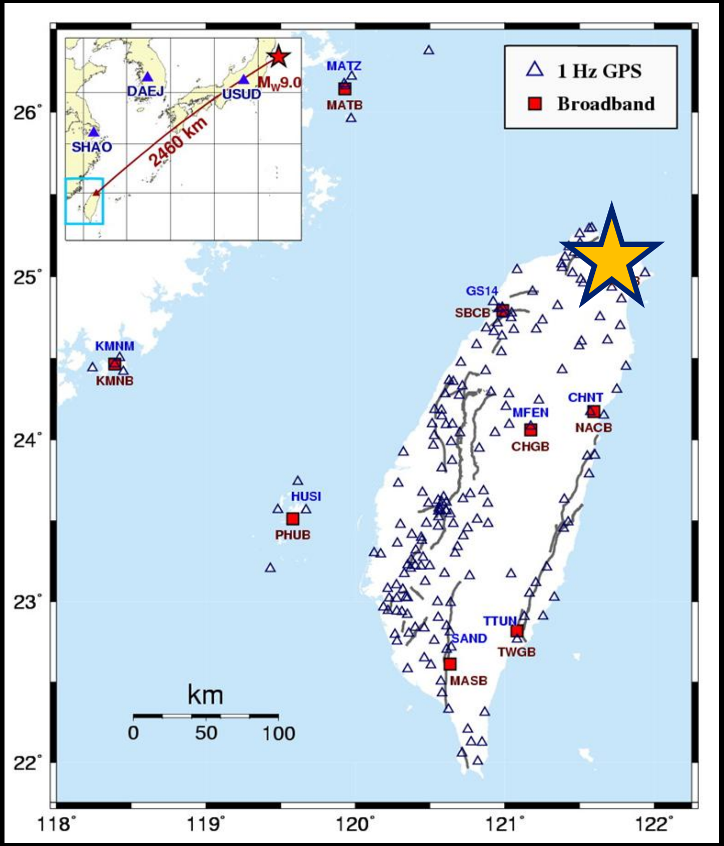
Spectral analysis

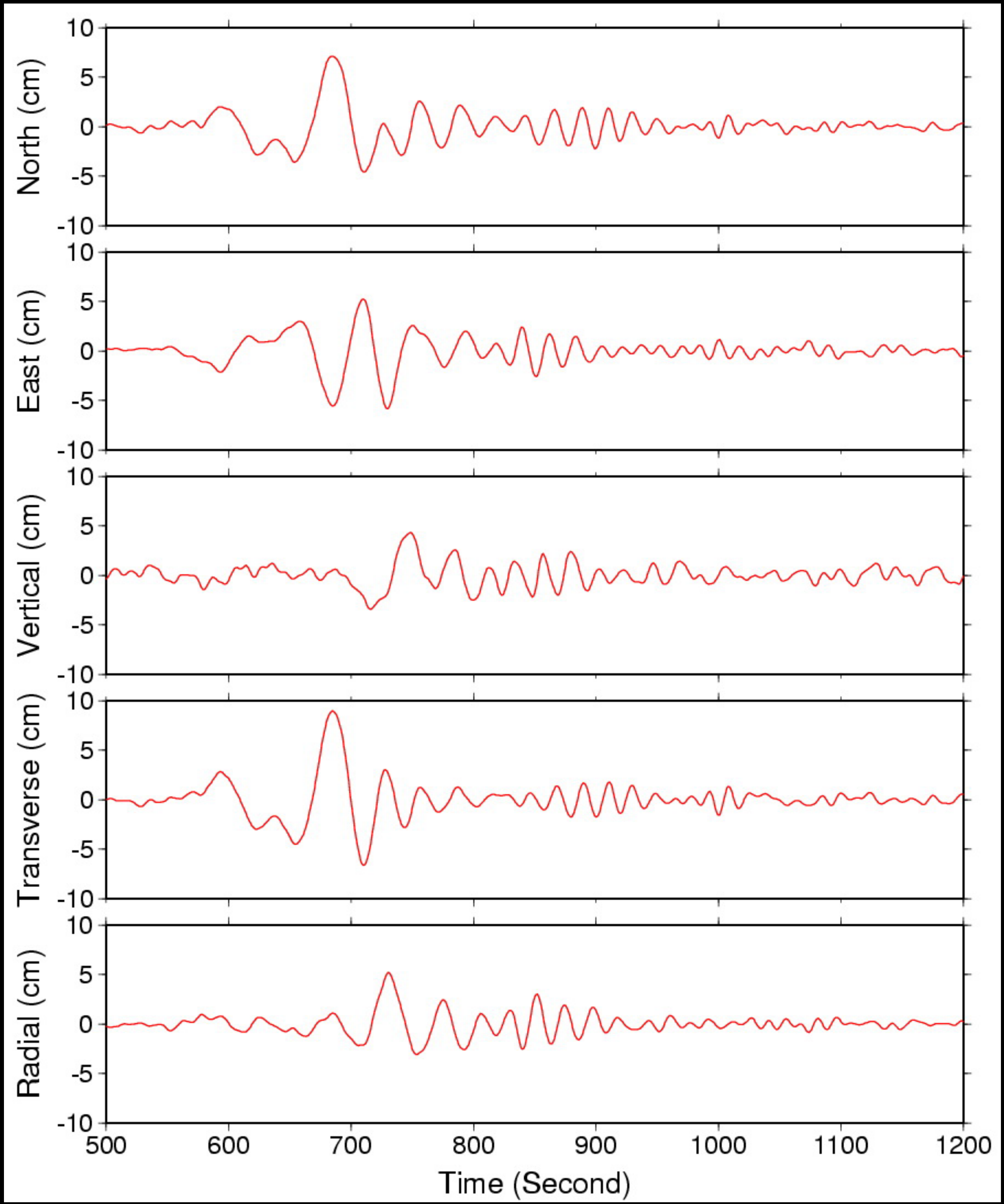


Comparison between high-rate GPS and broadband data



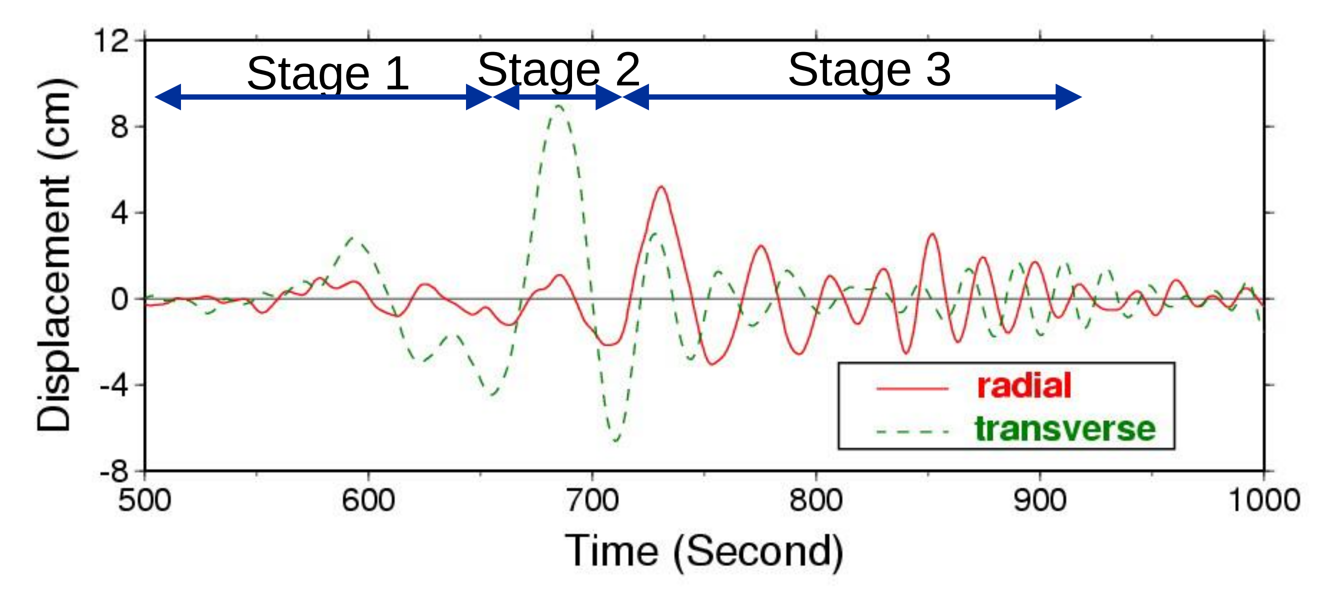
CGPS SITE: GS19



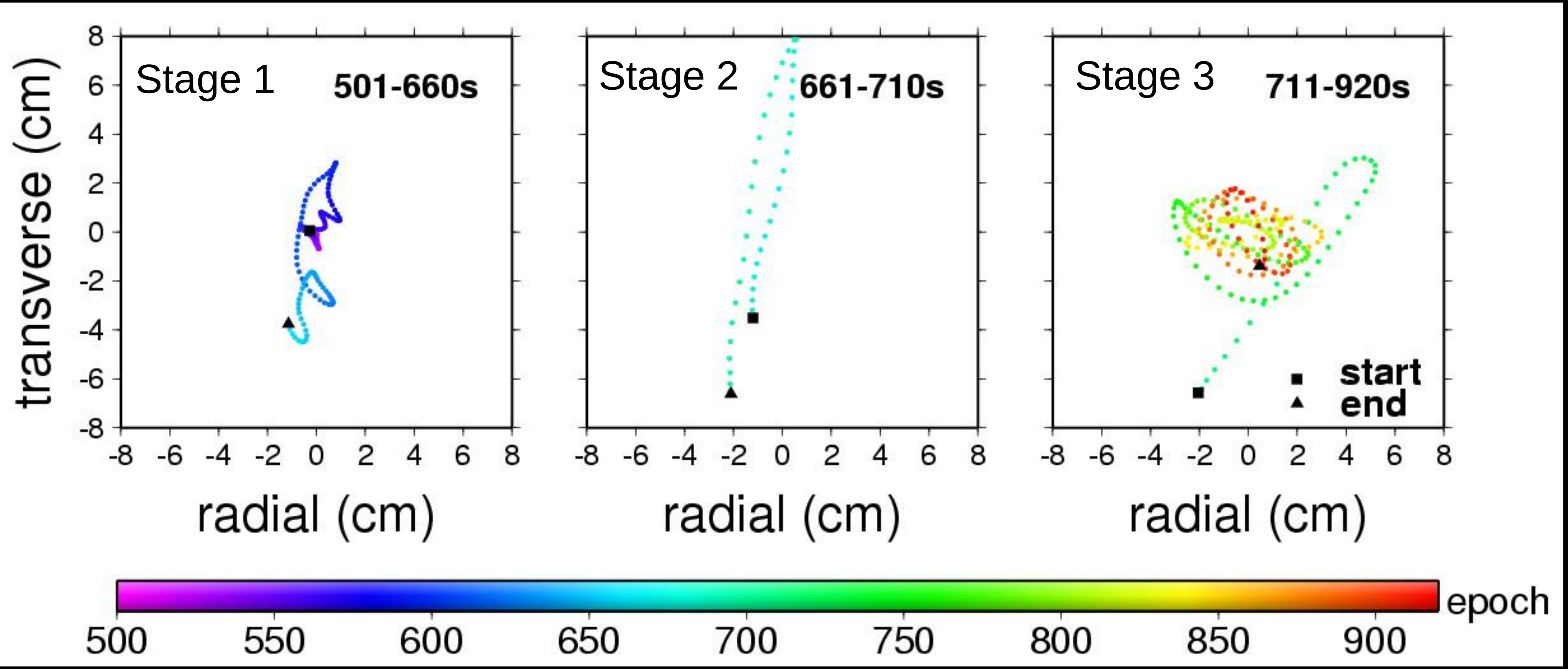


Surface waves excited by Tohoku earthquake

Love waves

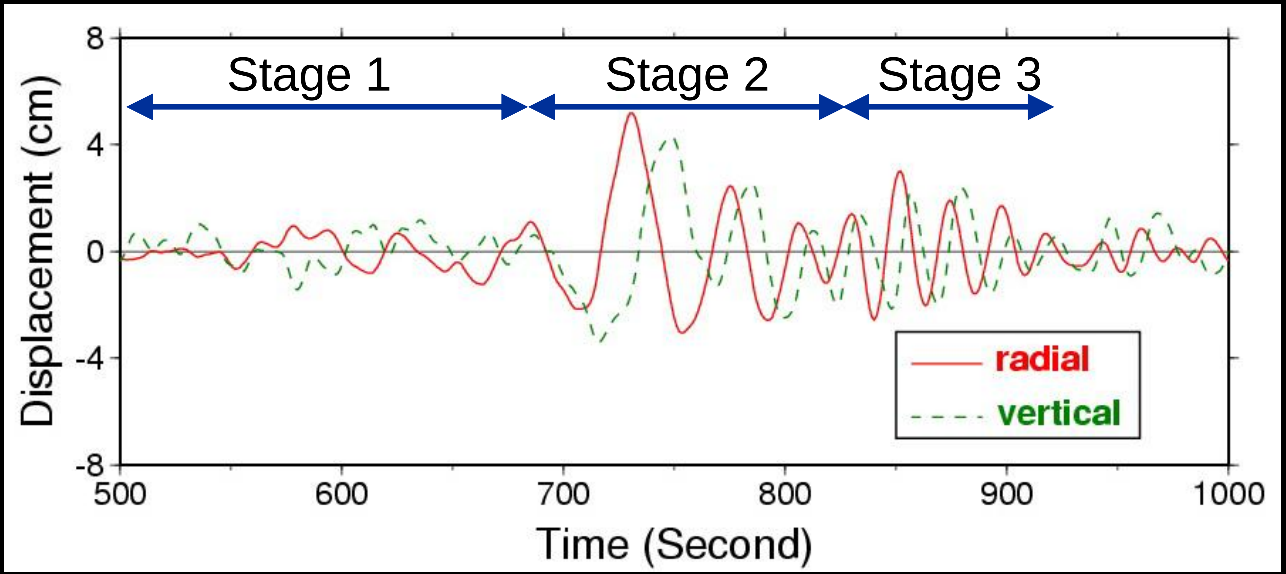


Particle motion

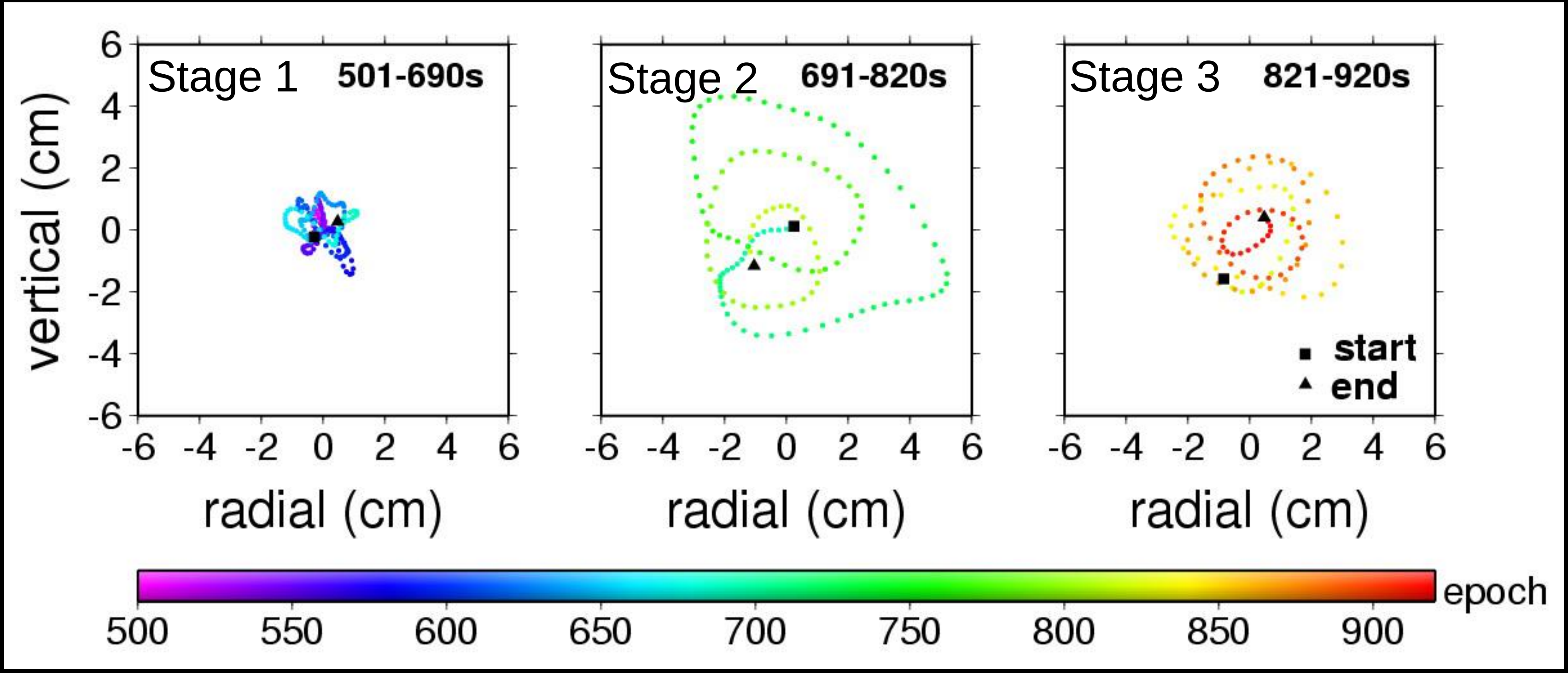


Surface waves excited by Tohoku earthquake

Rayleigh waves

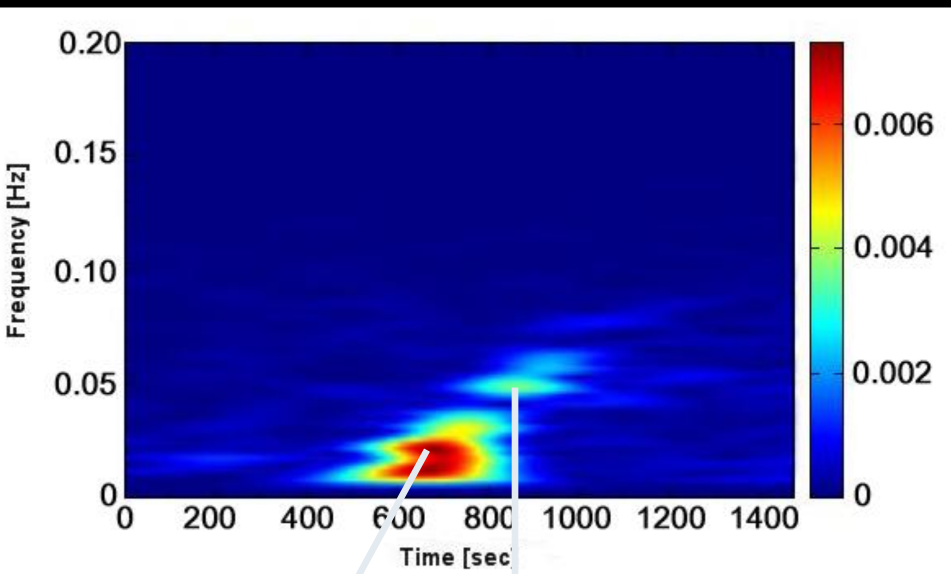


Particle motion

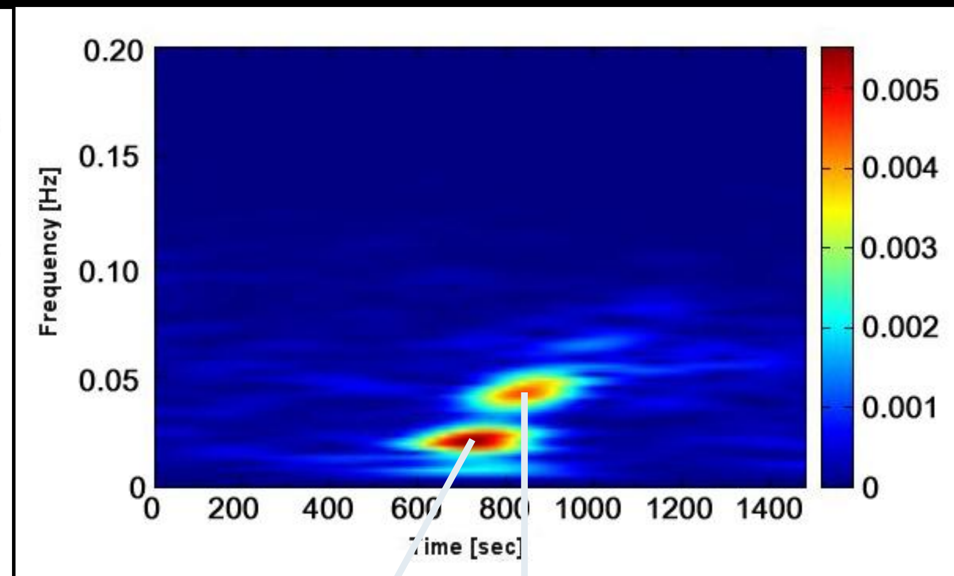


Time-frequency relationships of surface waves from Tohoku earthquake

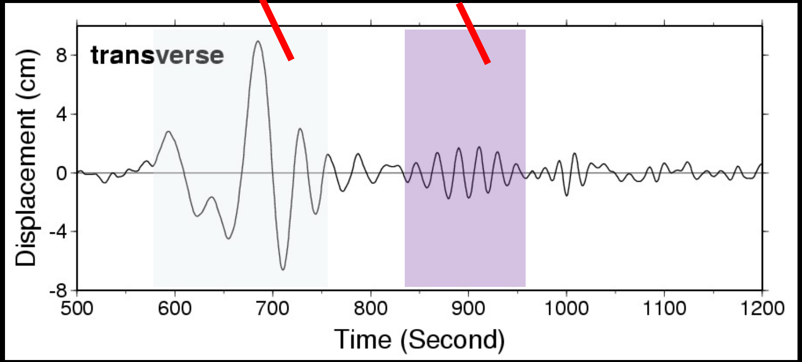
Love wave - transverse



Rayleigh wave - radial



0.02 Hz 0.05 Hz



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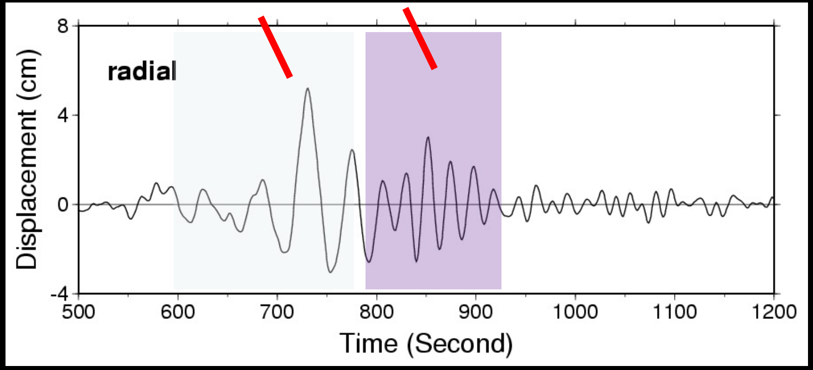
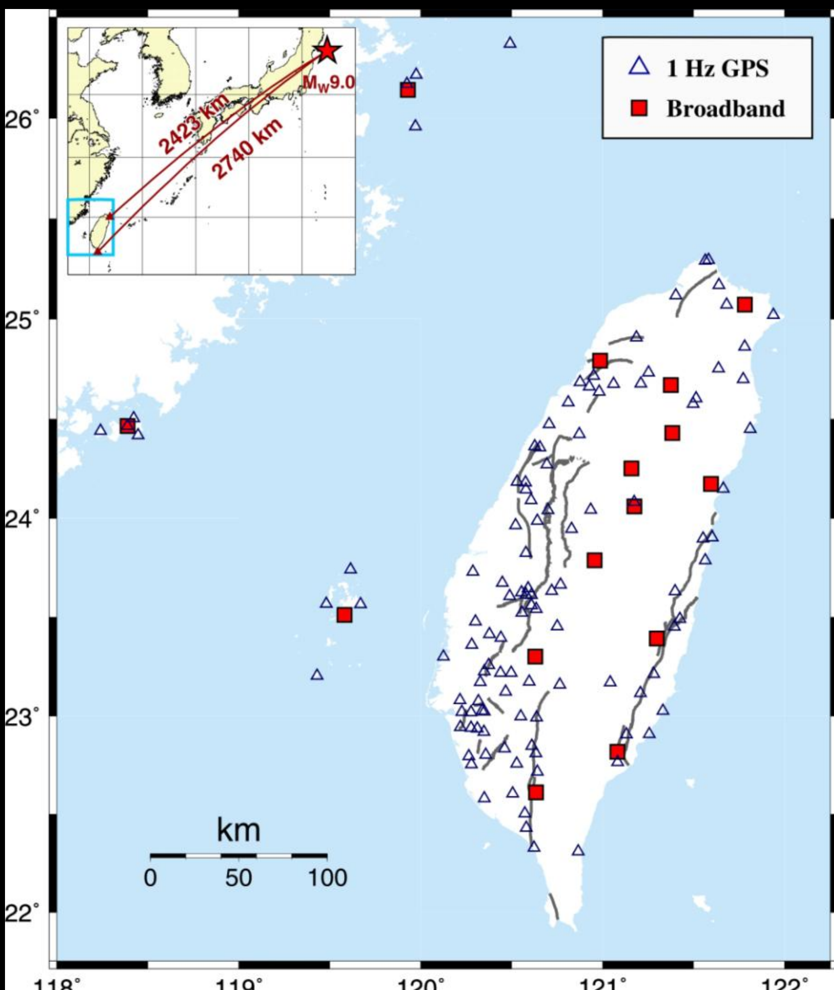
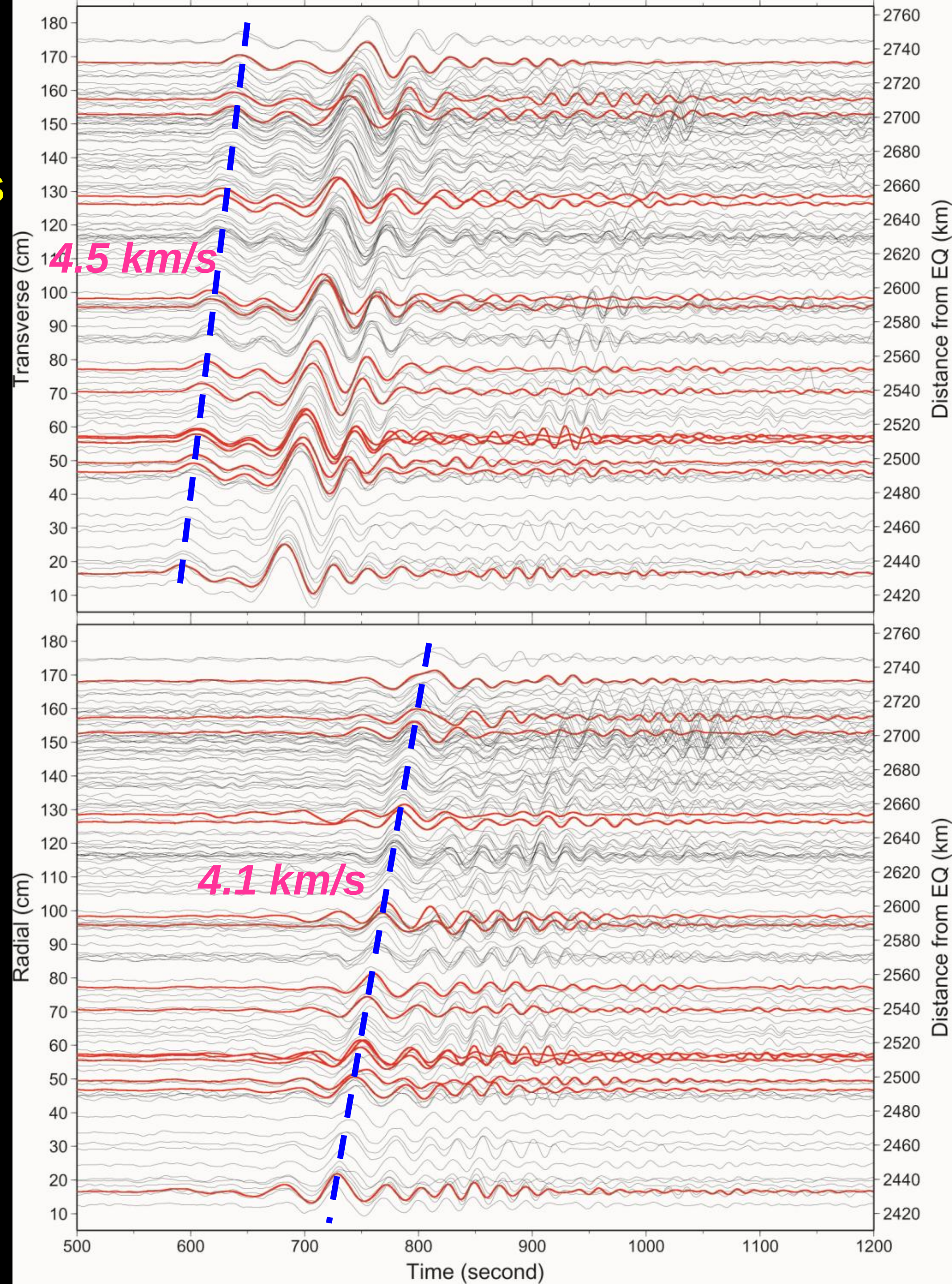
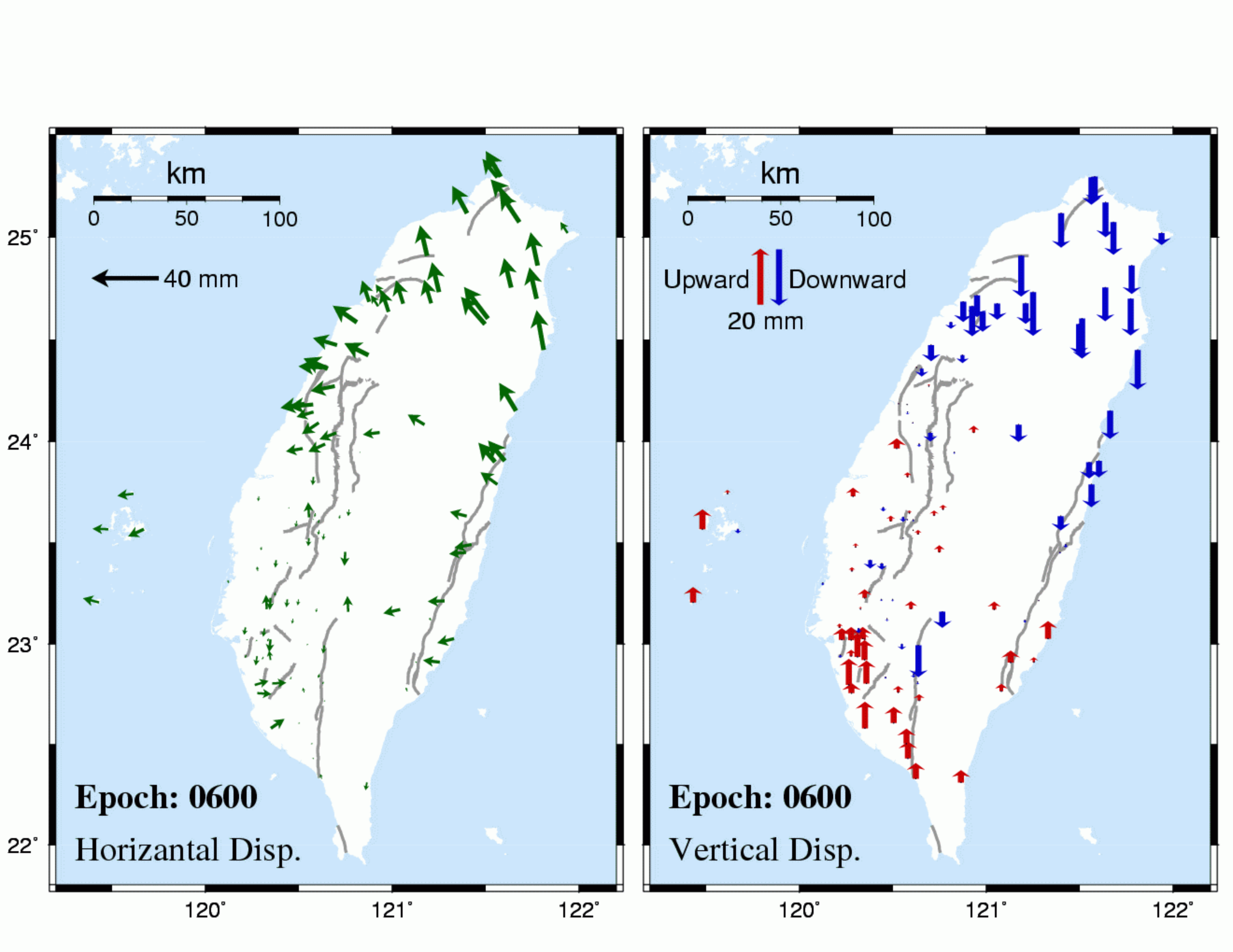


Surface waves derived from 115 CGPS and 15 BB seismic stations



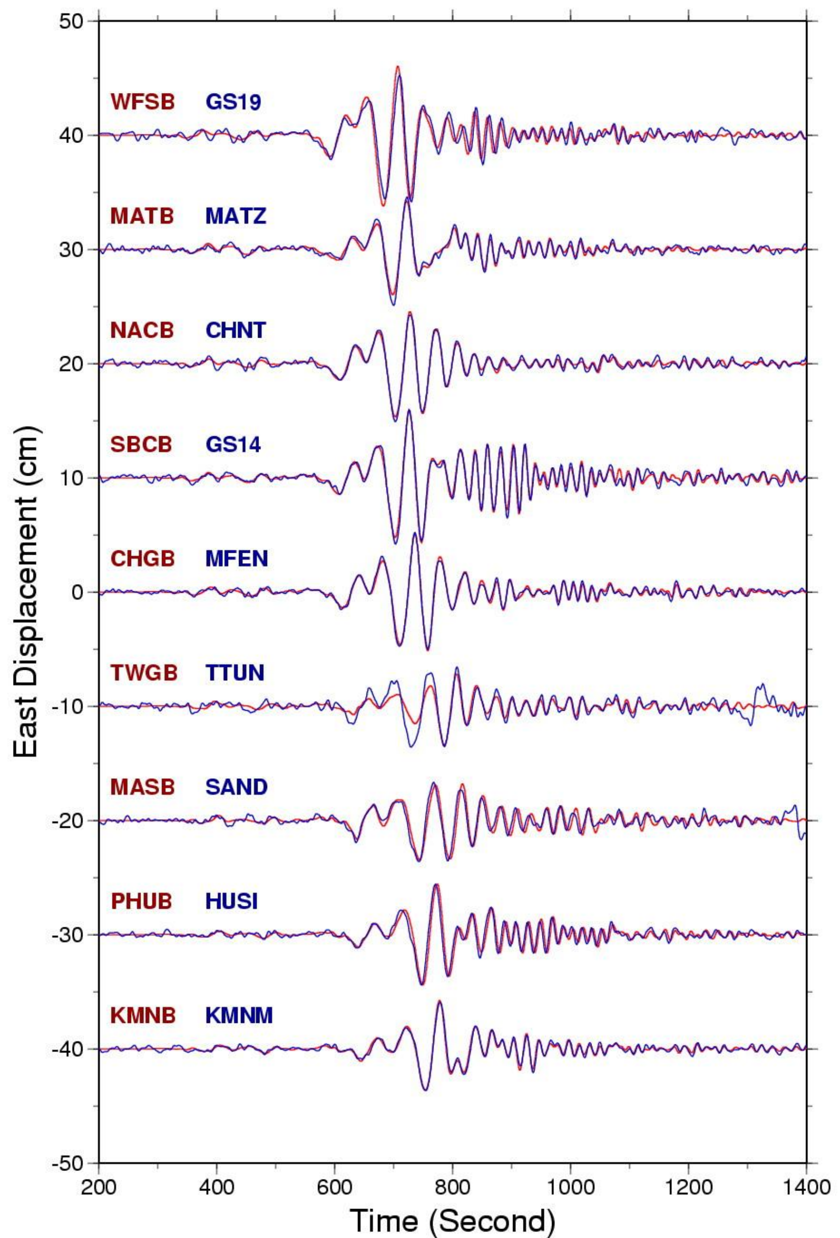


Surface wave deformation field in Taiwan



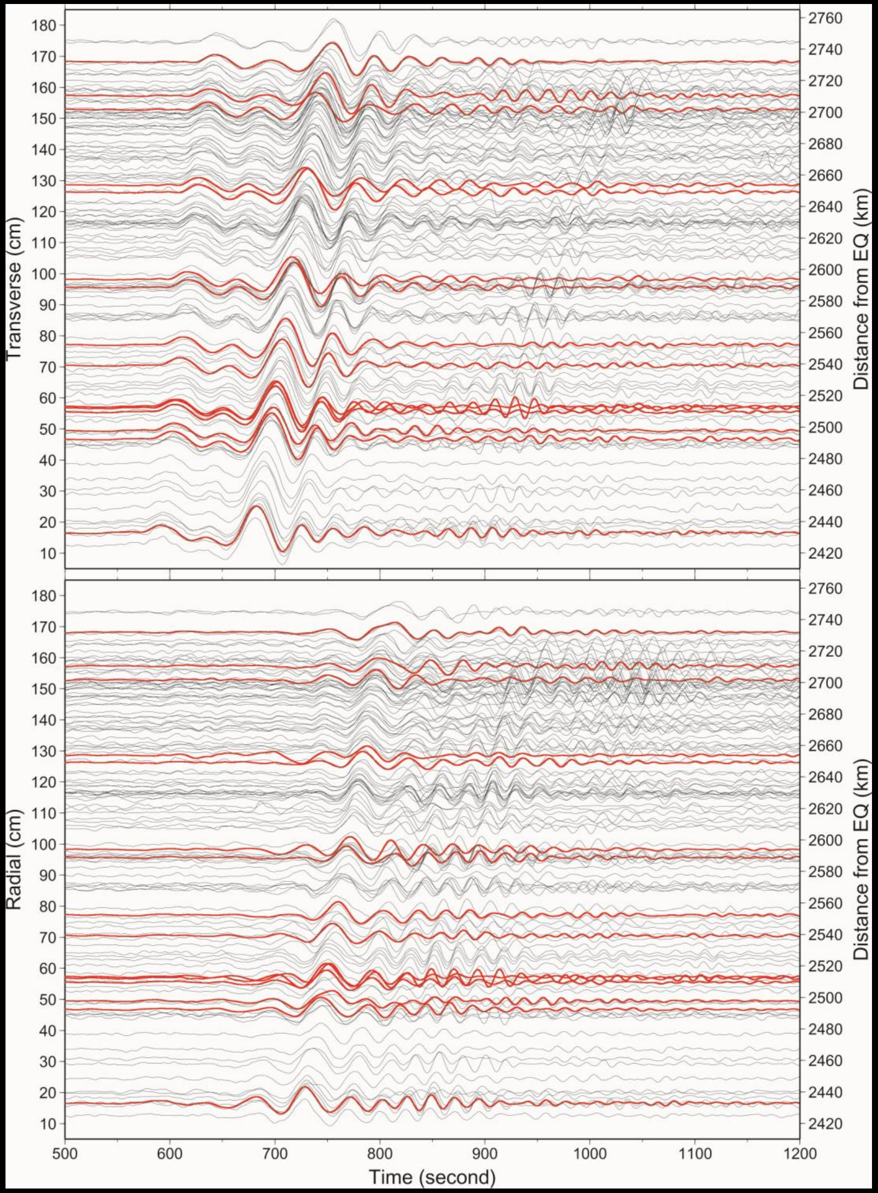
Summary (1)

- Precisions of high-rate GPS are 5.9 mm and 21.4 mm in the horizontal and the vertical components, respectively.
- High consistencies are observed between high-rate GPS and BB seismometer surface waves, and the cross correlation coefficients are 0.95 and 0.85 in the horizontal and vertical components, respectively, after 0.008 – 0.1 Hz band-pass filter.



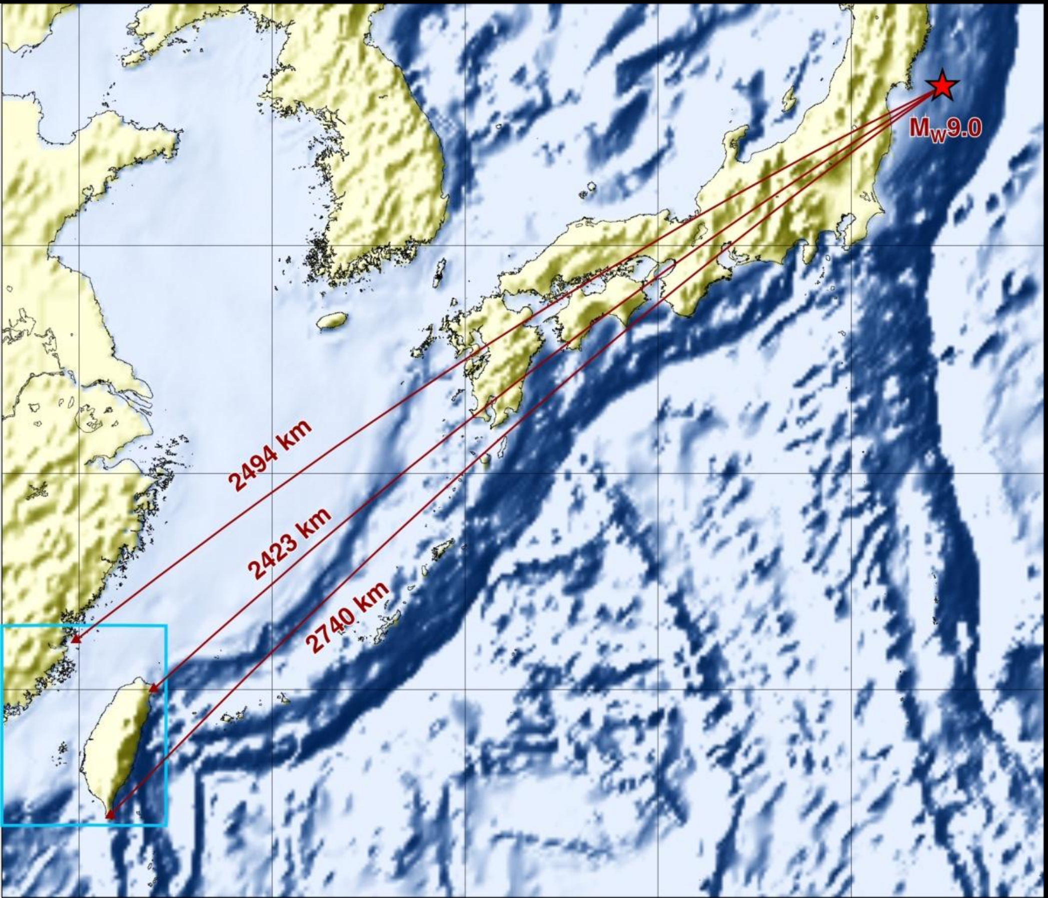
Summary (2)

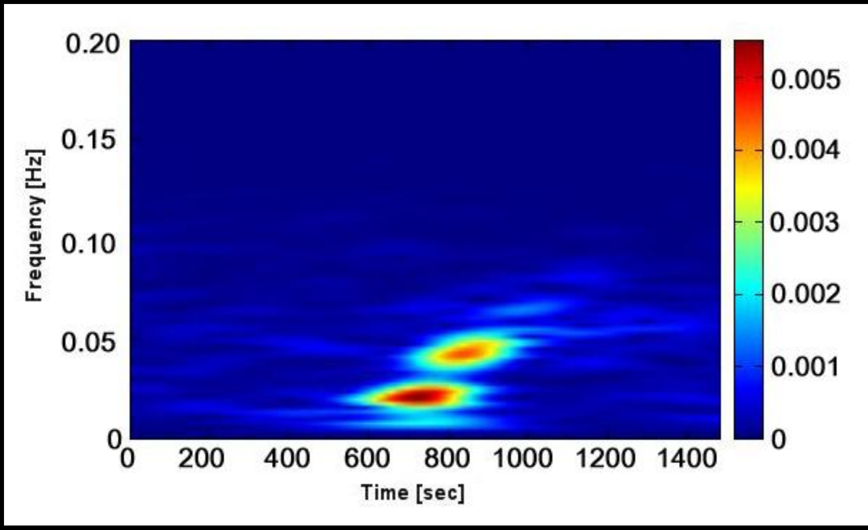
- In addition to BB stations, densely-spaced GPS show coherent surface wave motions with the presences of significant later multiple arrivals.
- Demonstrate the use of high-rate GPS for BB seismometers.

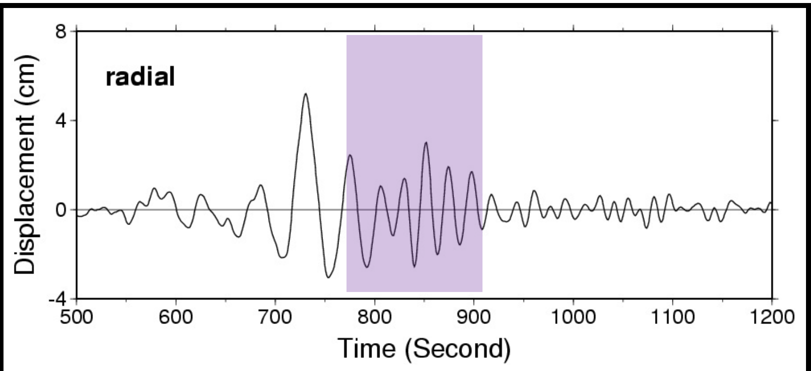


Summary (3)

- Surface waves of 20 s period indicate great circle path of continental-oceanic transition.







Strain field