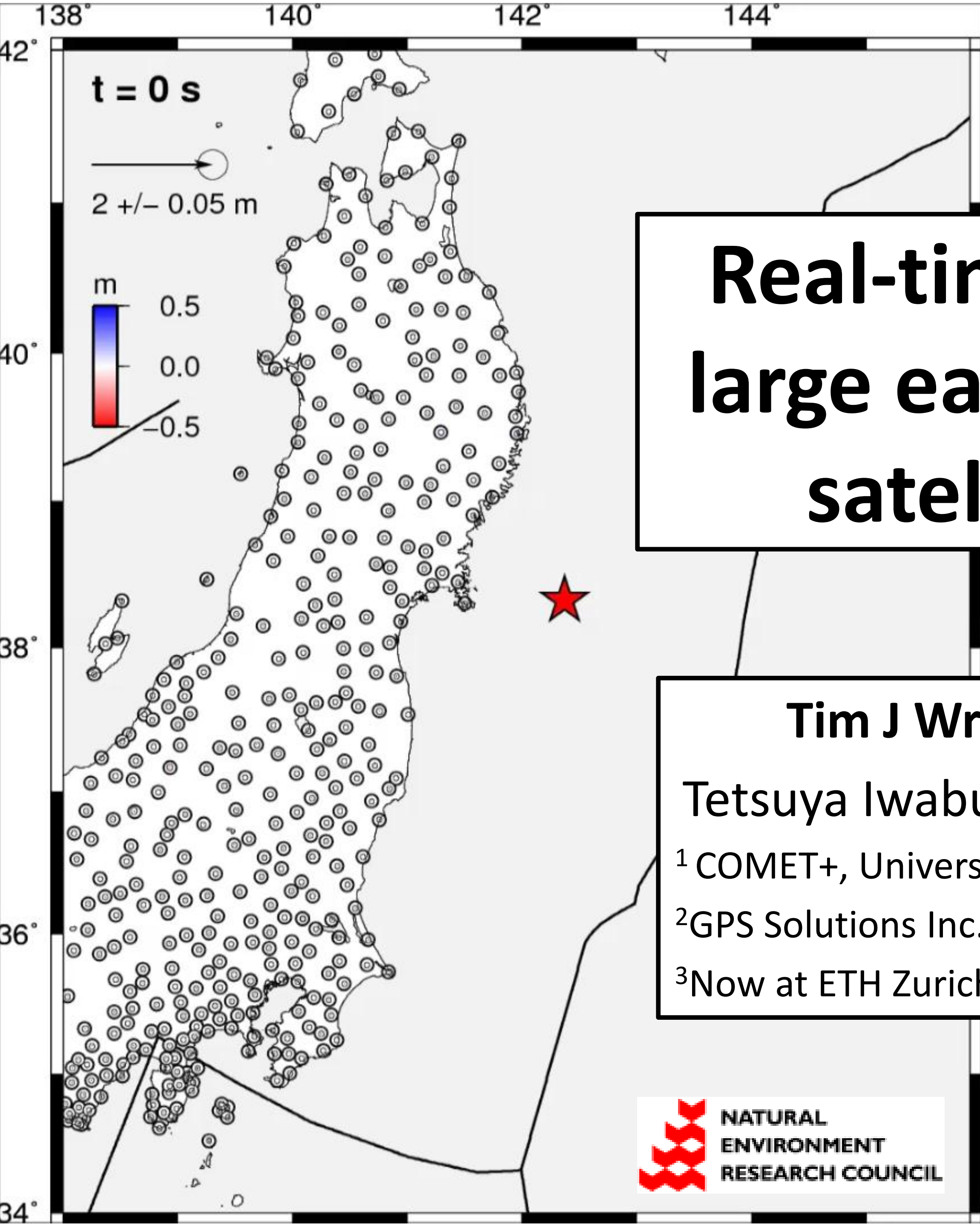

Real-time response to large earthquakes with satellite geodesy

Tim J Wright[1], Mark Hildyard[1],
Tetsuya Iwabuchi[2], and Nicolas Houlié[1,3]
[1] COMET+, University of Leeds, UK;
[2]GPS Solutions Inc., Boulder, Colorado, US;
[3]Now at ETH Zurich, Switzerland

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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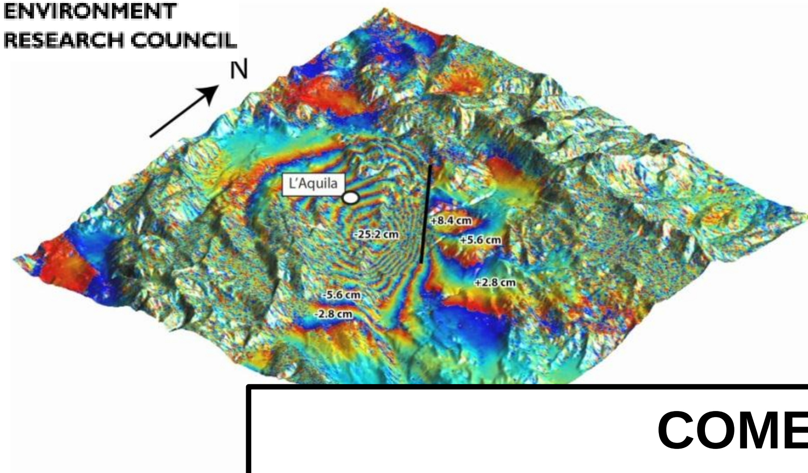
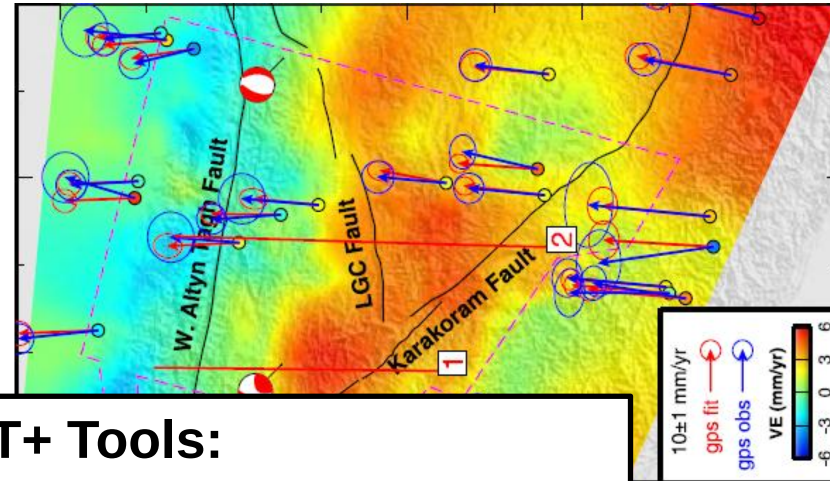
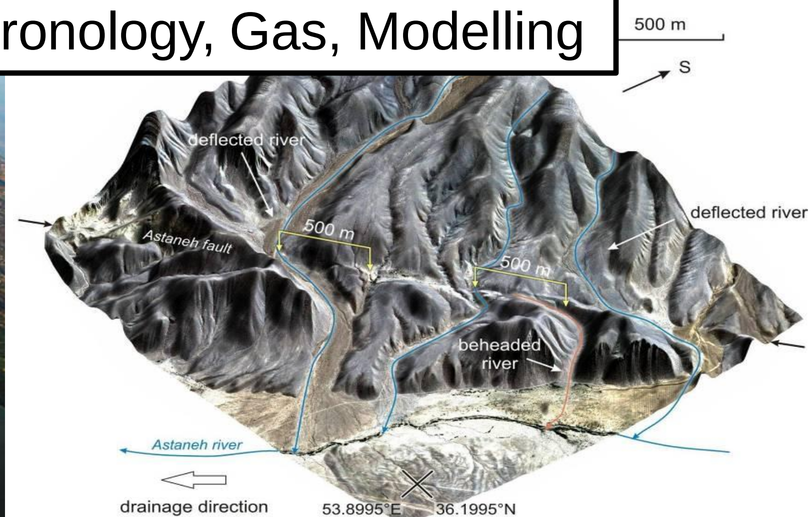




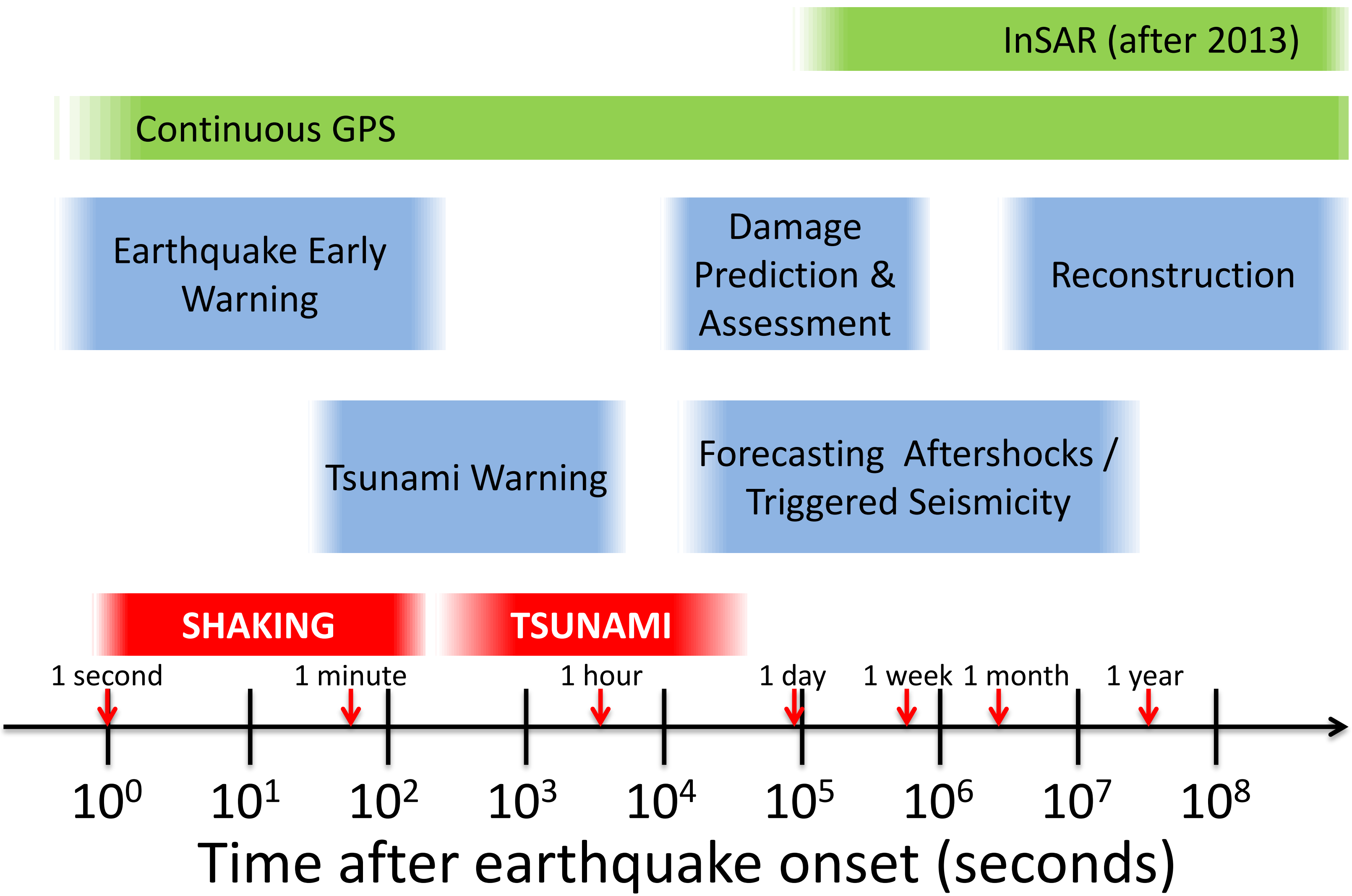
COMET+ Tools:
InSAR, GPS, Seismology, Geology, Geomorphology, Geochronology, Gas, Modelling



http://comet.nerc.ac.uk

Interdisciplinary partnership between Universities of Leeds, Oxford, Cambridge, UCL, Reading, Bristol and Glasgow to exploit Earth Observation data for Geohazards

What is "rapid response"?



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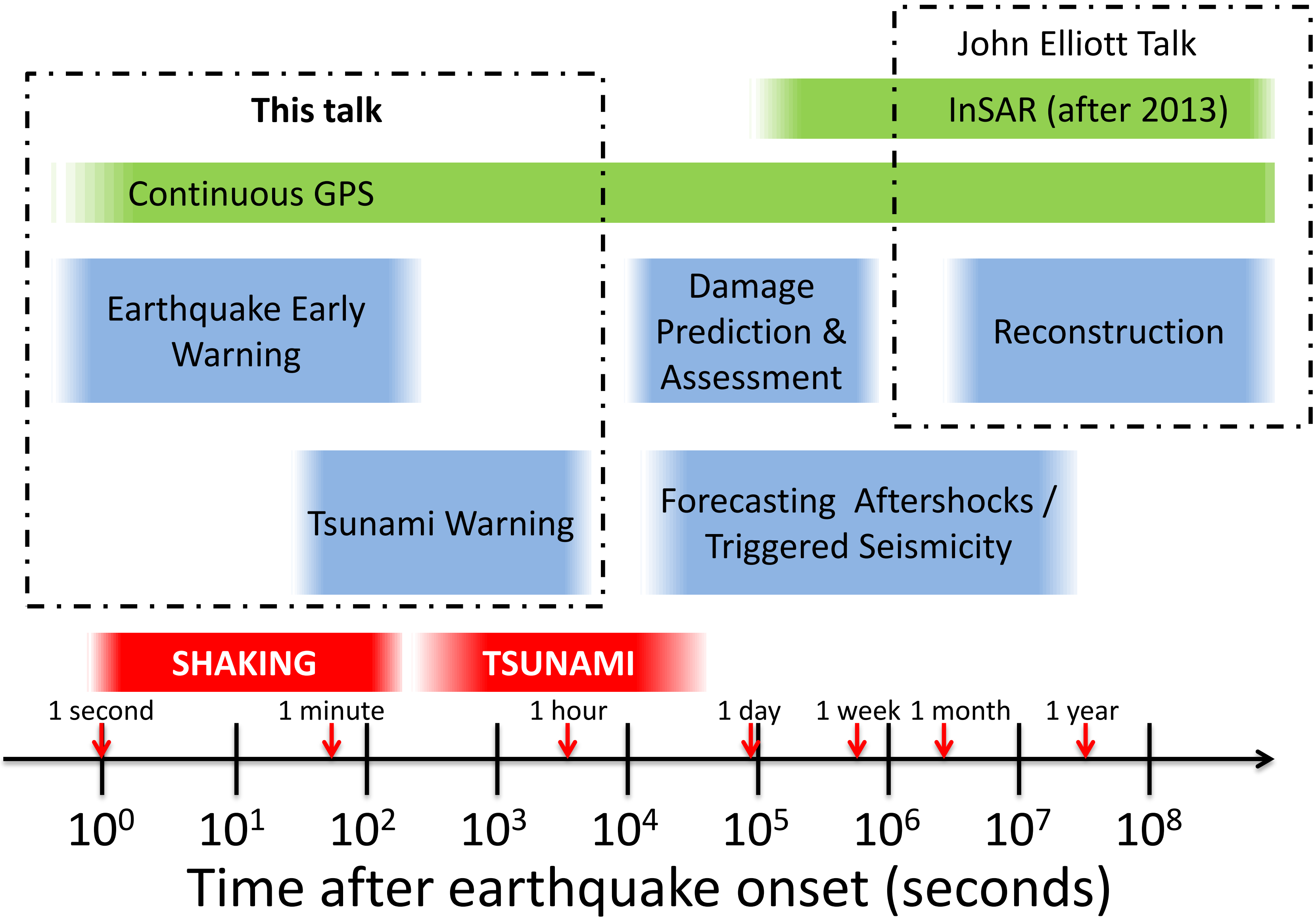

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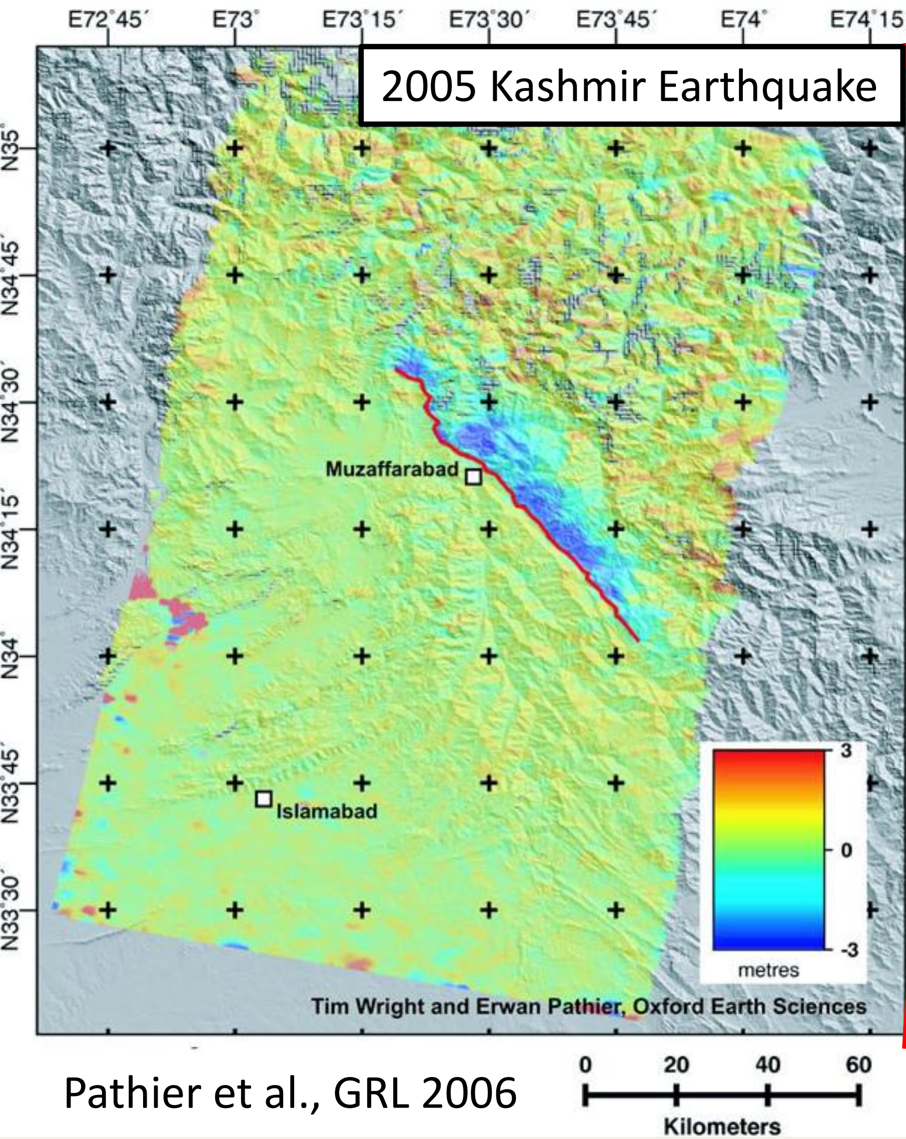
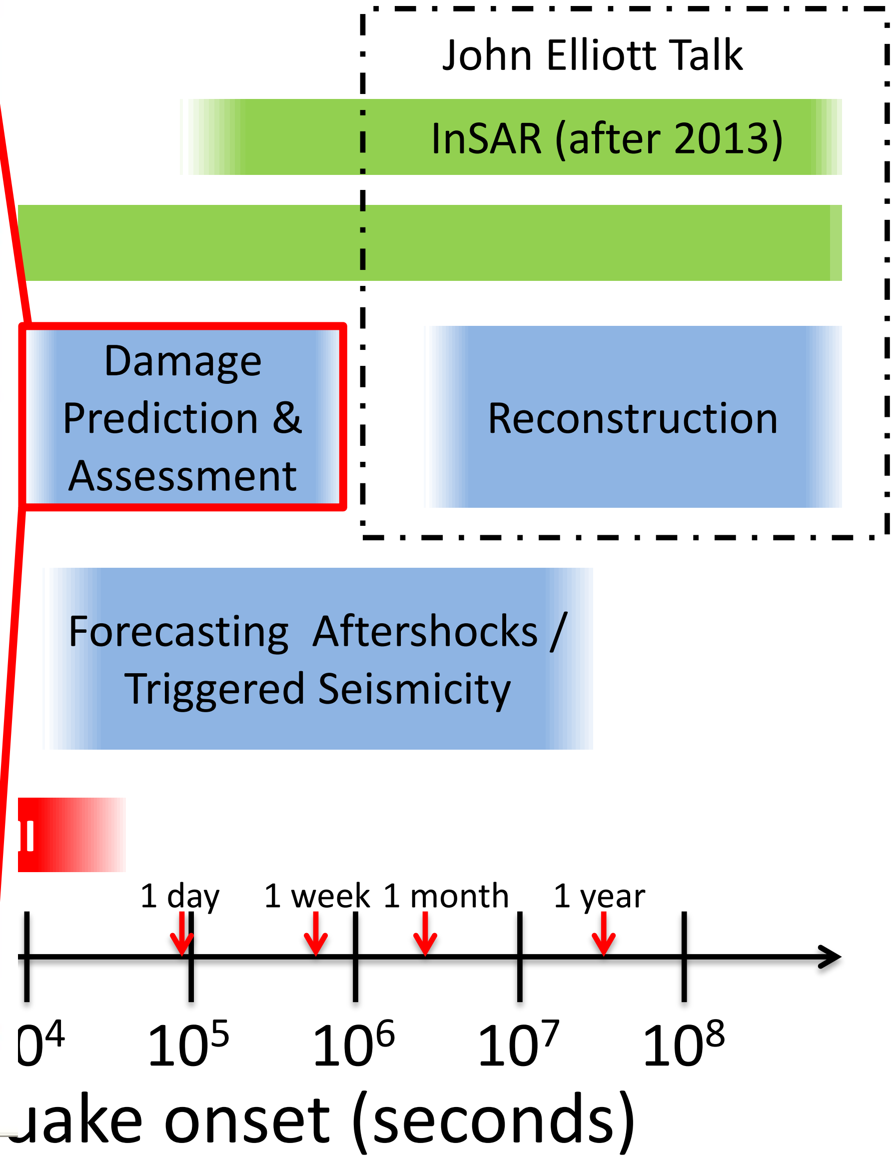


Pathier et al., GRL 2006



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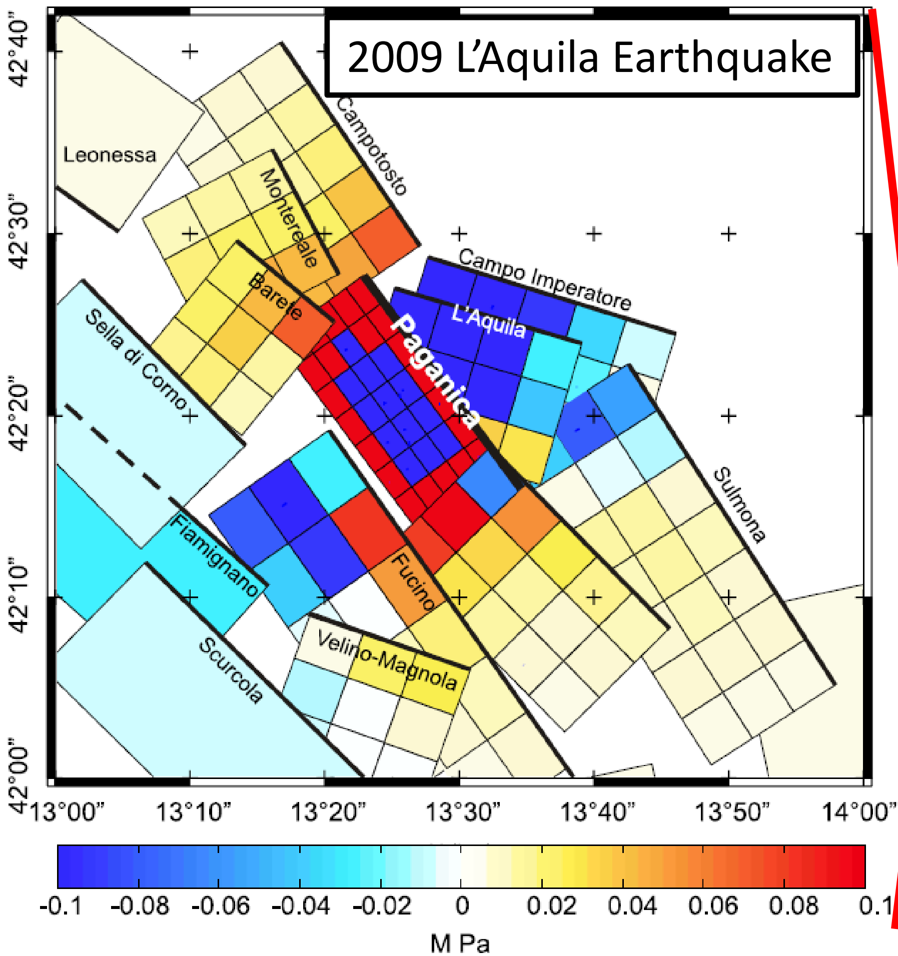
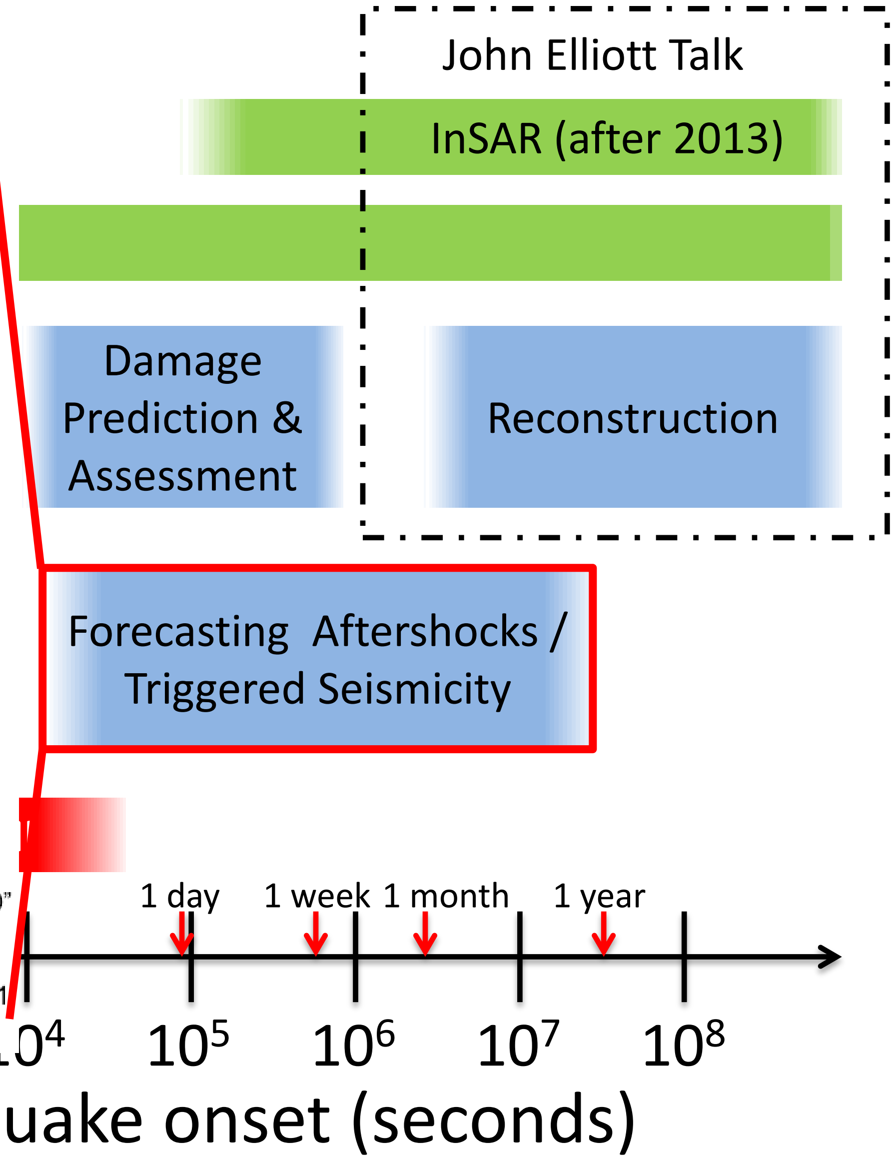


Walters et al., GRL 2009



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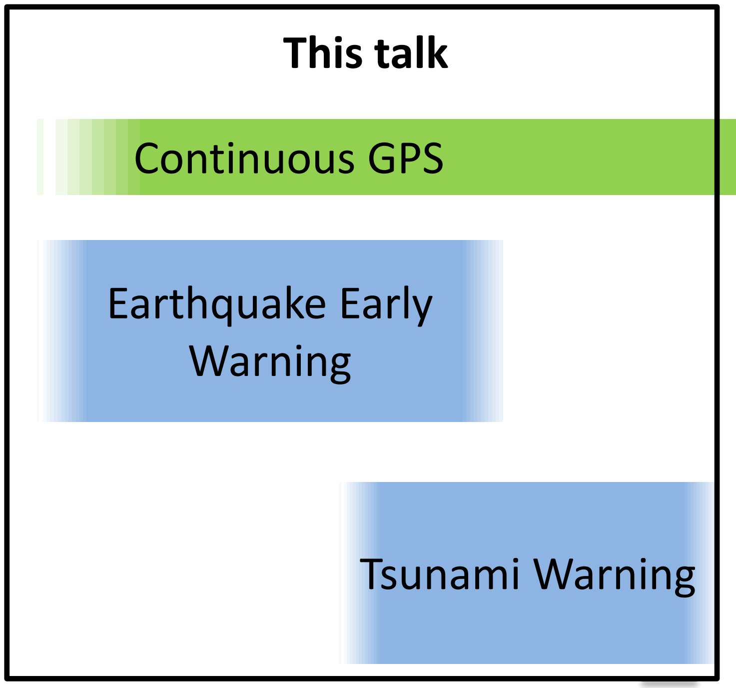
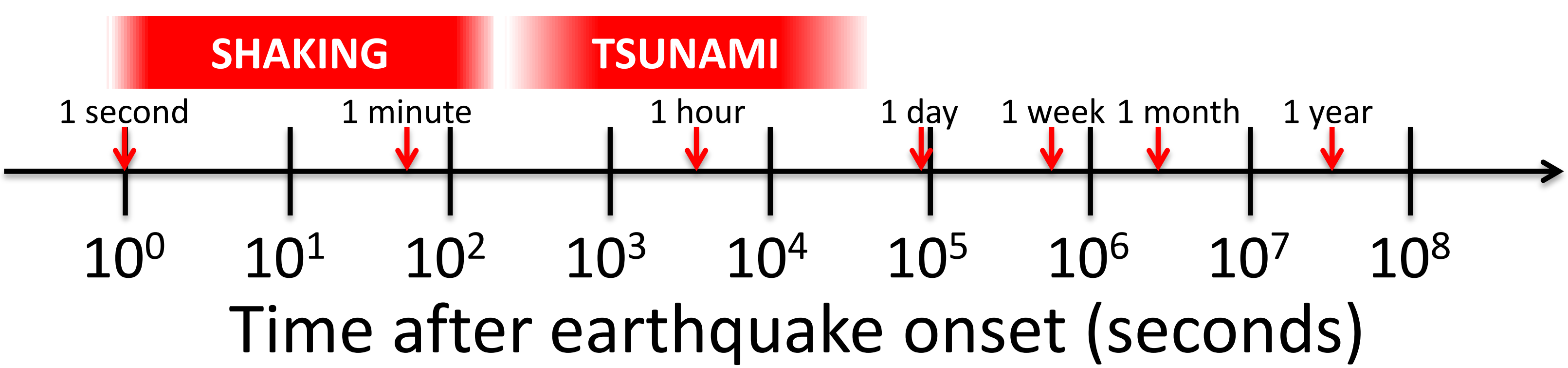
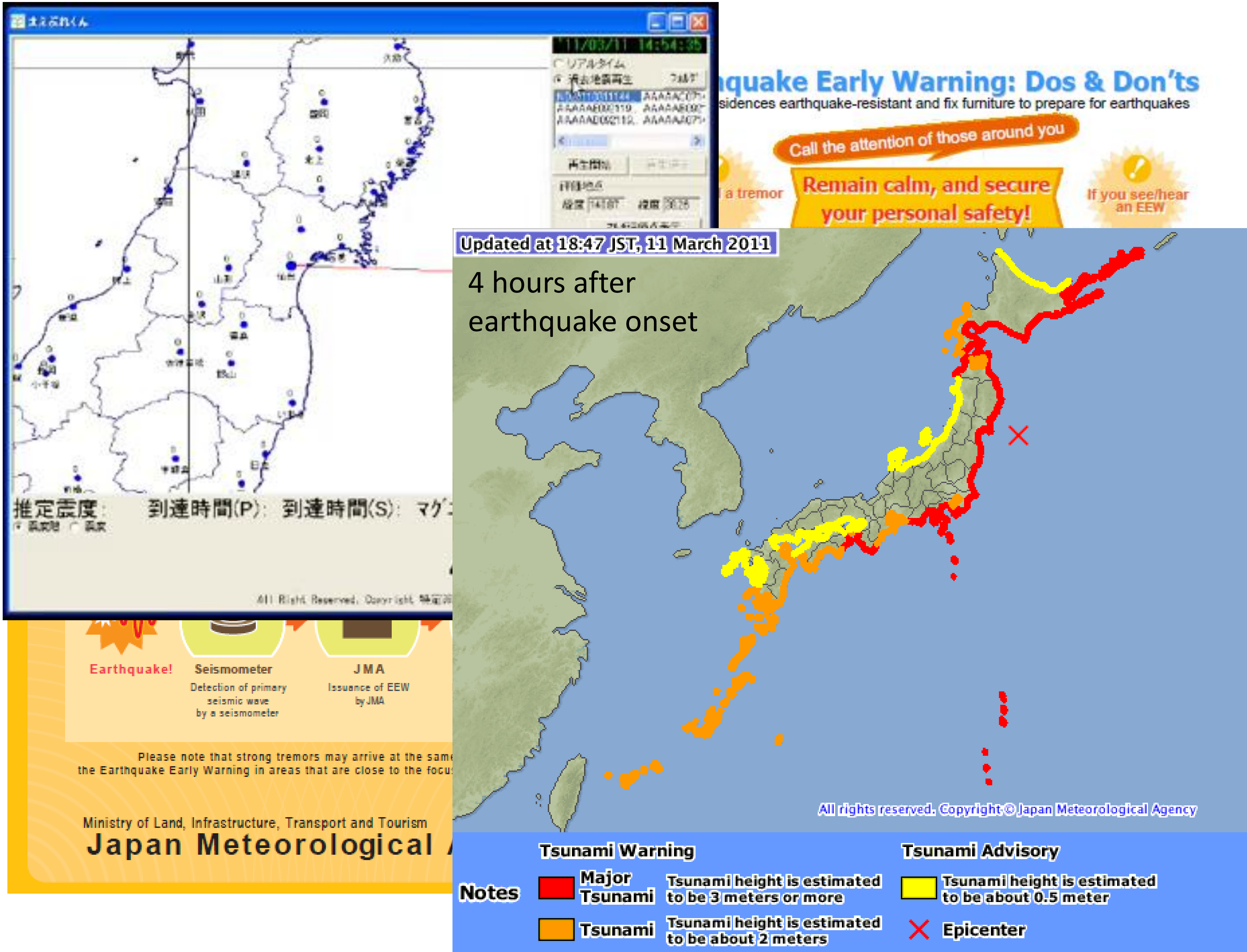


Outline

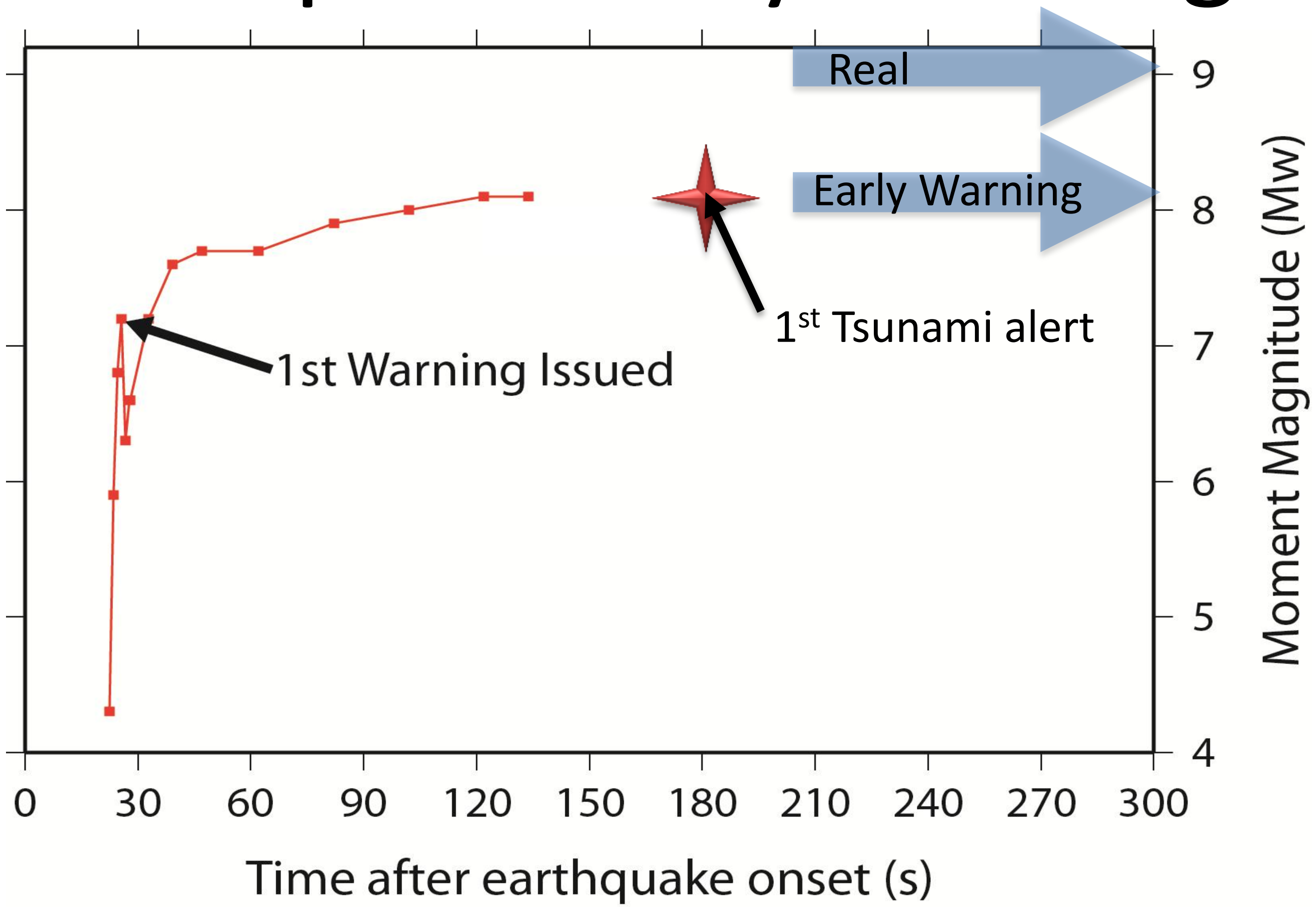
1. Why do we need geodesy for EEW?
2. Previous Work
3. Real-time PPP processing of GPS *(+ Tetsuya Iwabuchi's talk)*
4. Rapid, simple modelling
5. Results from 2011 Tohoku-Oki Earthquake
6. Results from 2003 Tokachi-Oki Earthquake
7. Summary and Recommendations



4 hours after earthquake onset

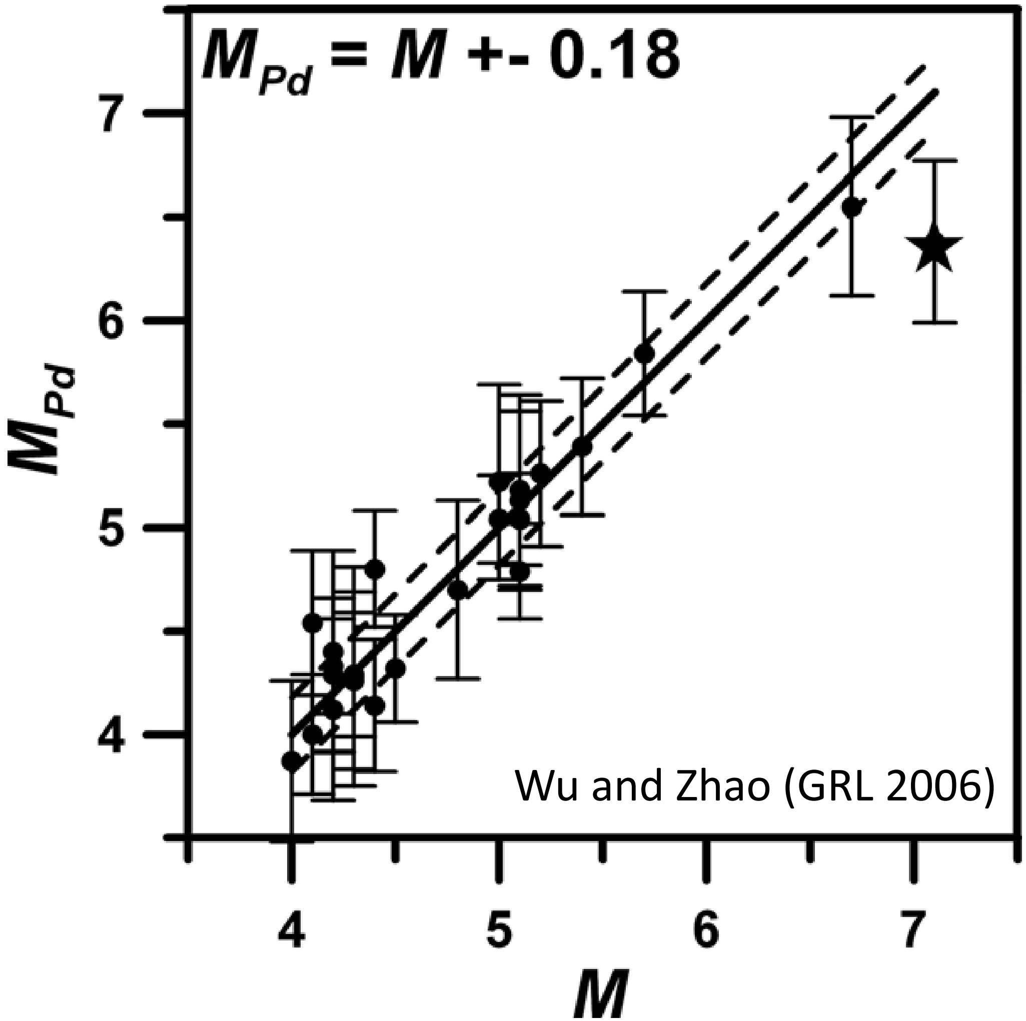


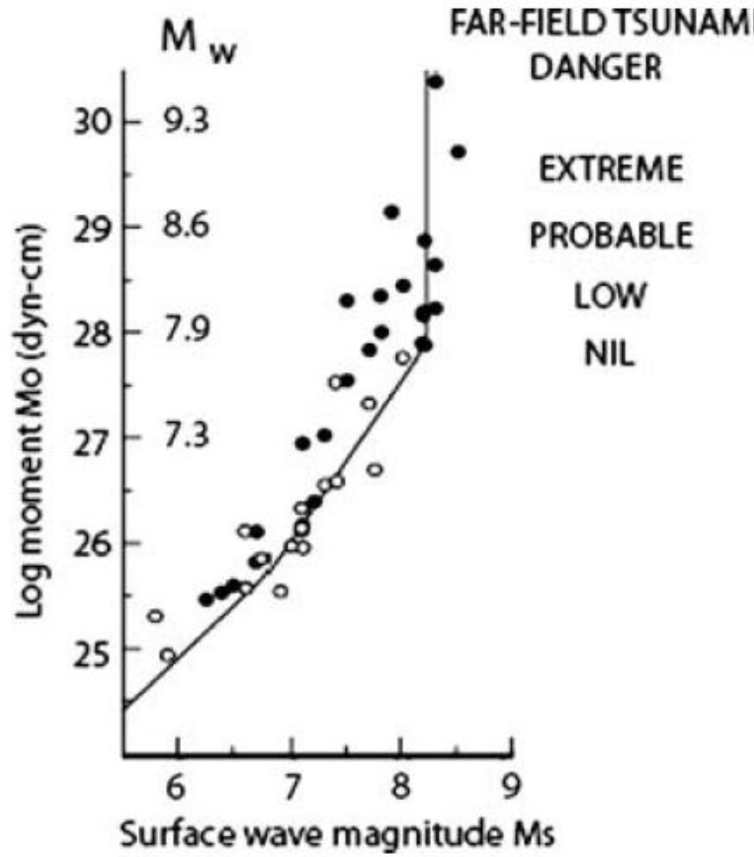
Earthquake Early Warning



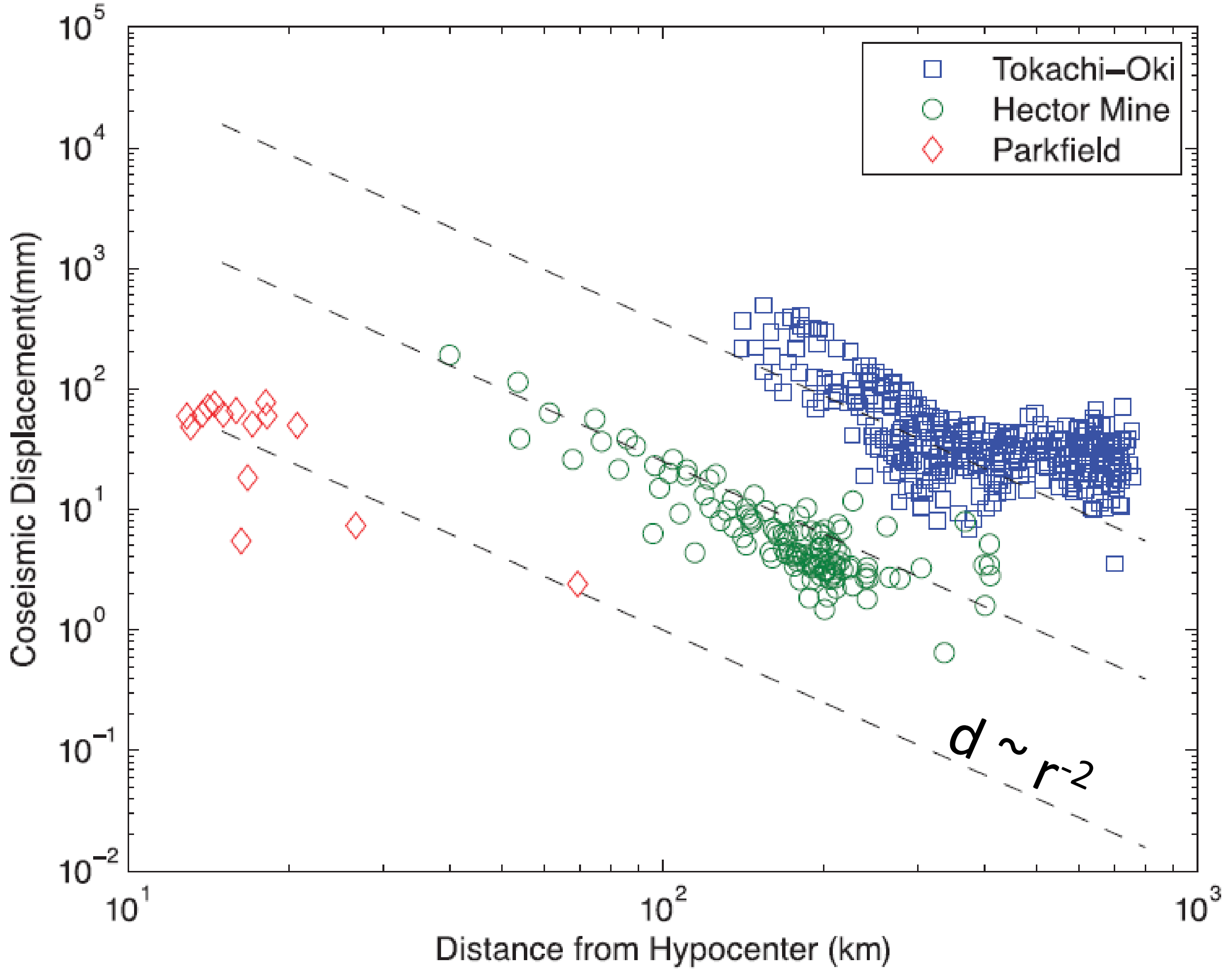
- The earthquake and tsunami warnings issued by JMA for the Tohoku-Oki earthquake saved thousands of lives.
- But the warning significantly underestimated the earthquake magnitude.

Saturation of magnitude estimates from seismology for large earthquakes



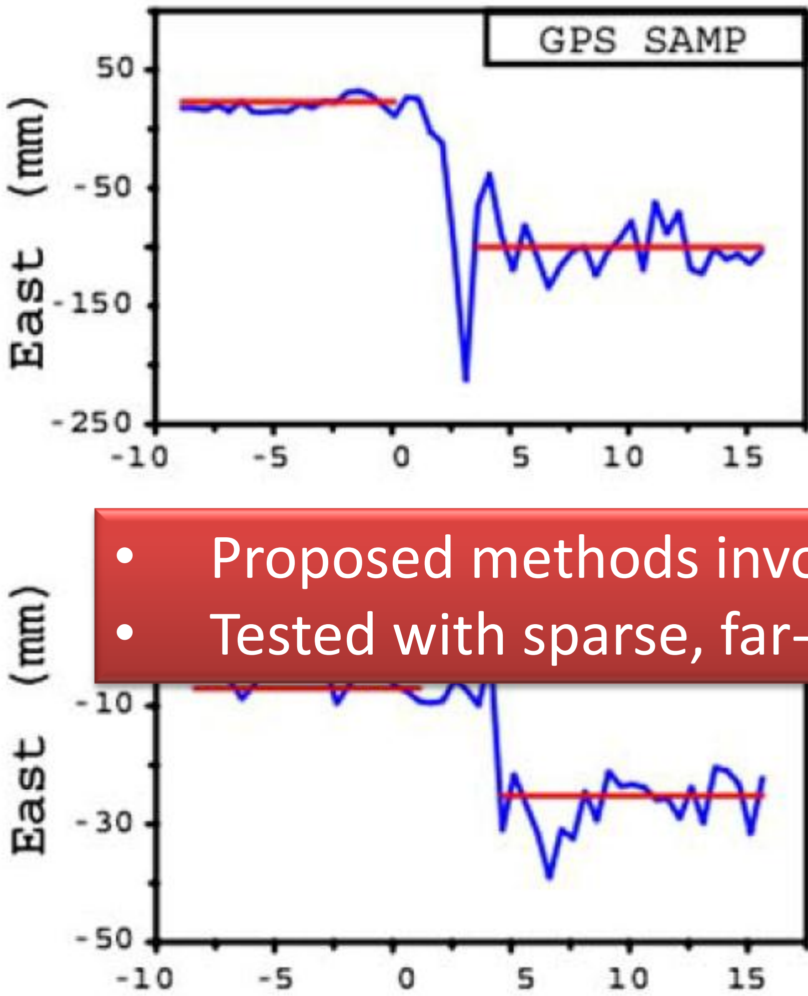


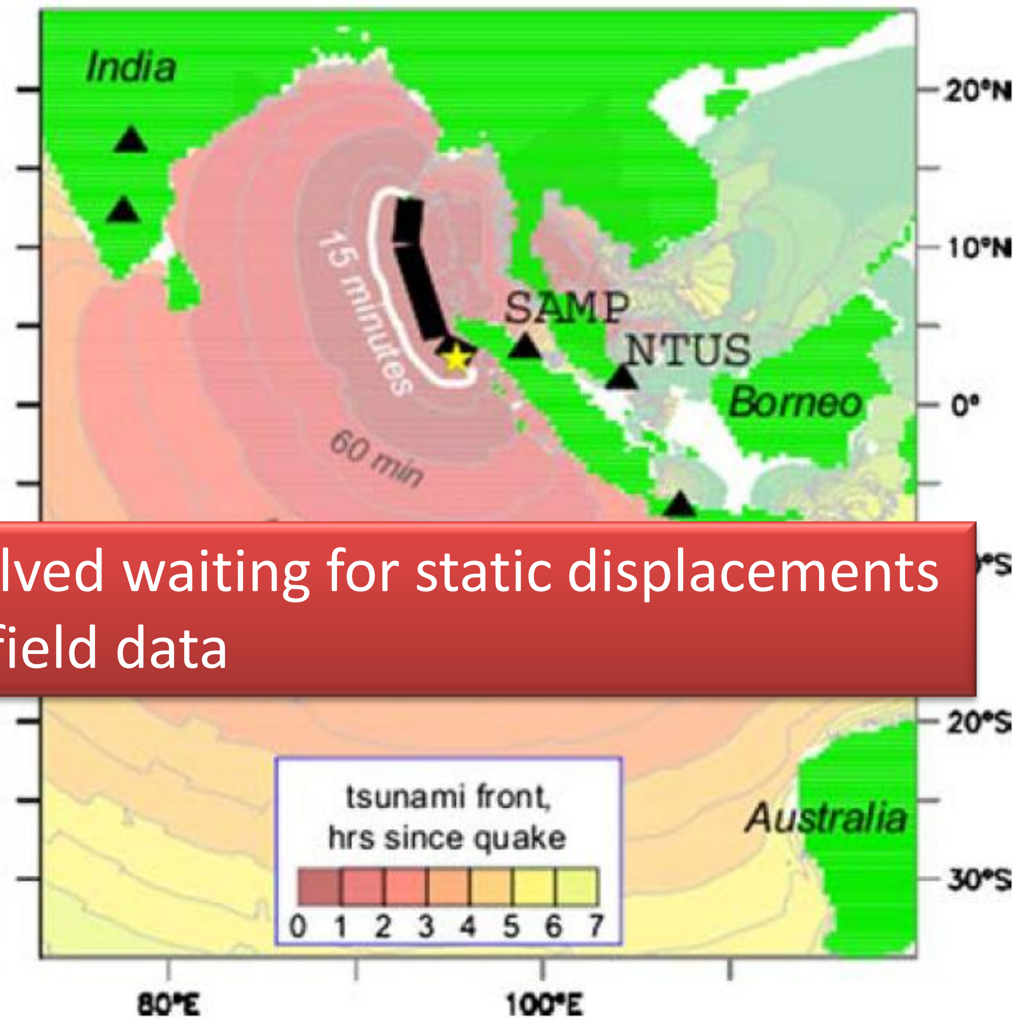
Previous work promoting use of GPS for Earthquake or Tsunami Warning



Crowell et al. (SRL 2009)

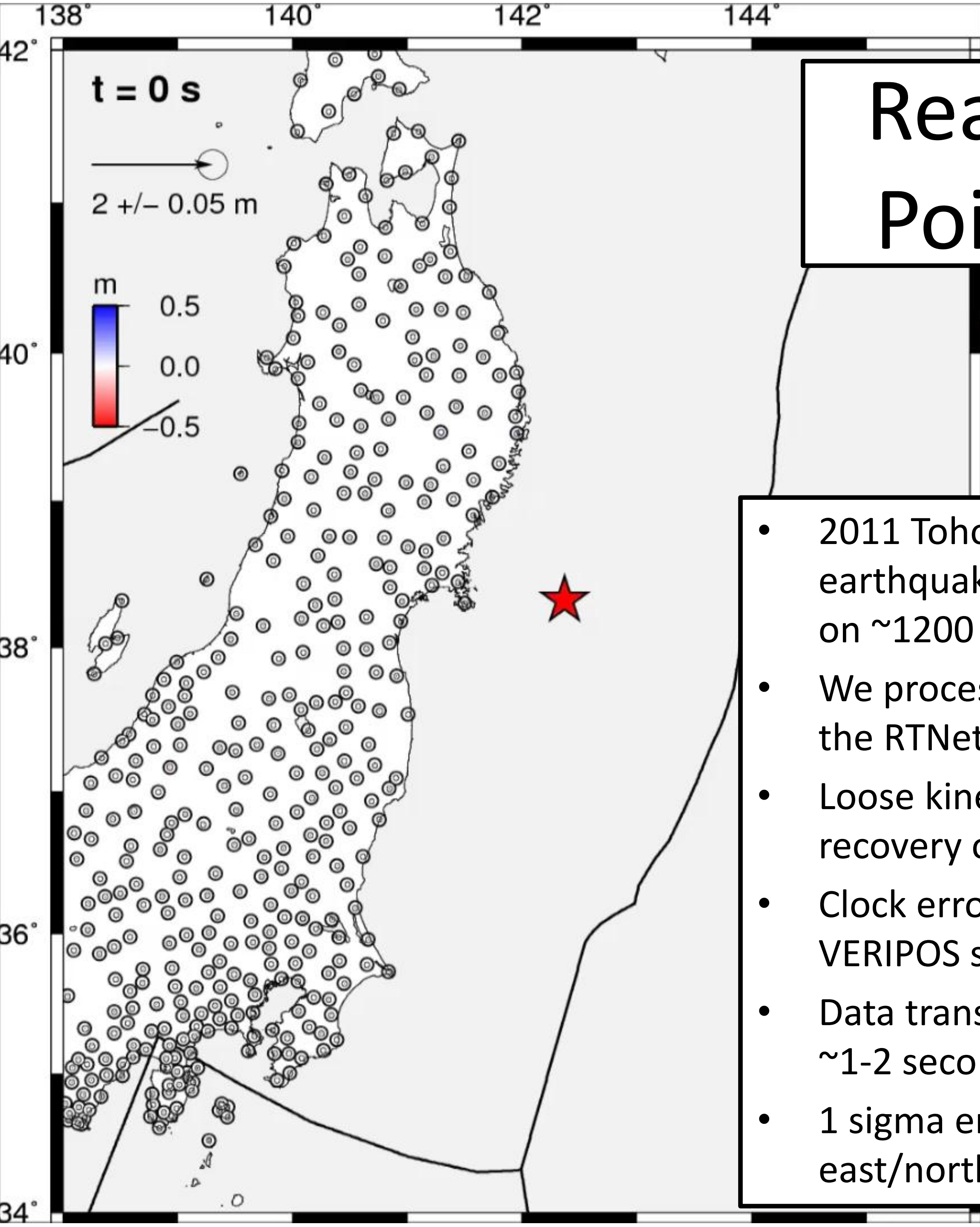
Previous work promoting use of GPS for Earthquake or Tsunami Warning





- Proposed methods involved waiting for static displacements
- Tested with sparse, far-field data

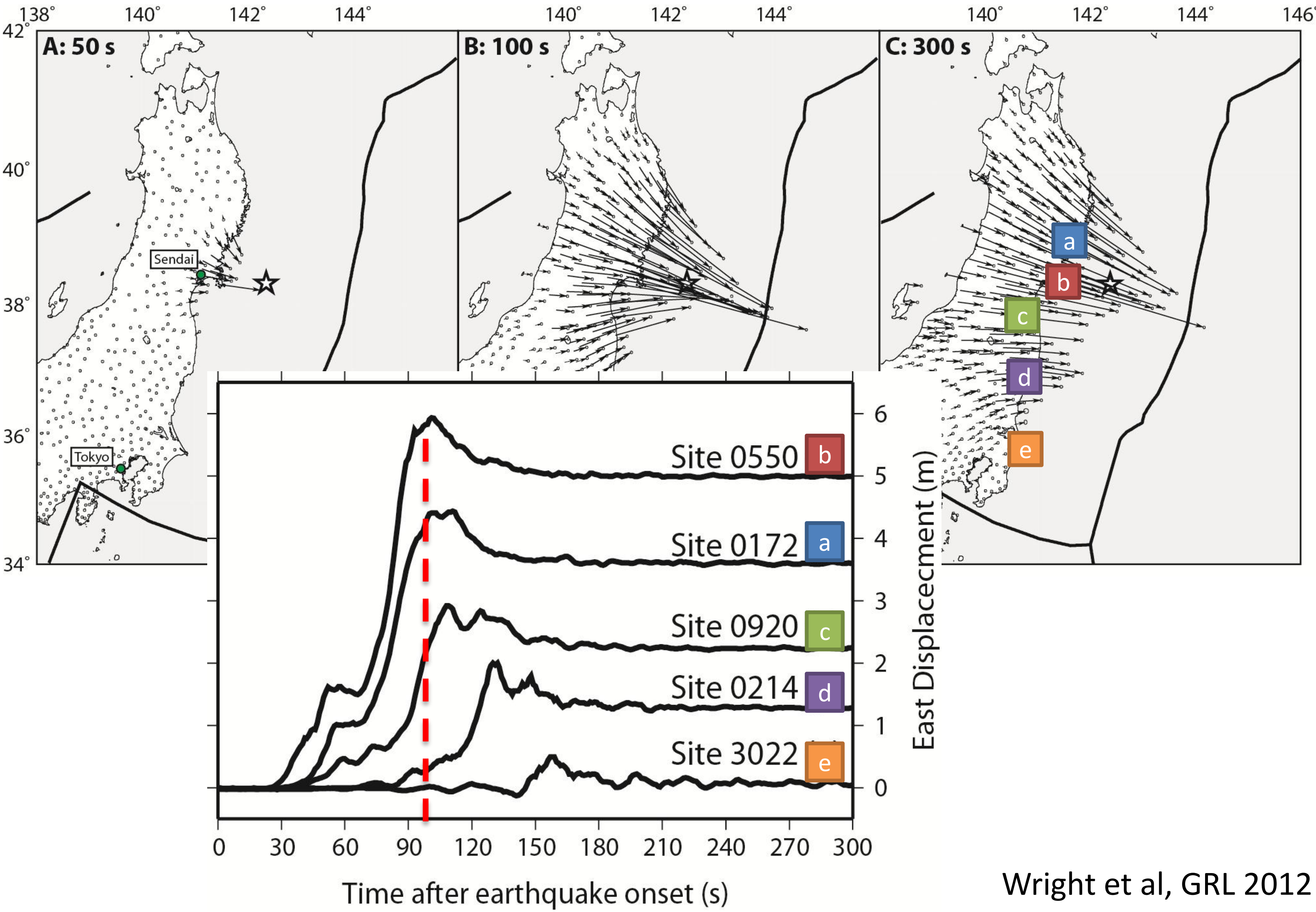
Blewitt et al. (GRL 2006, J. Geod. 2009)



Real-time Precise Point Positioning

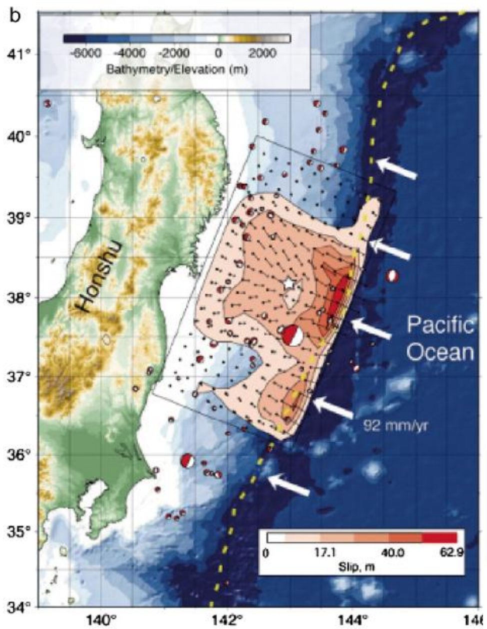
- 2011 Tohoku-Oki event is best recorded great earthquake in history - deformation recorded on ~1200 GEONET cGPS sites.
- We process in real-time mode using PPP with the RTNet software (Iwabuchi talk).
- Loose kinematic constraints (100 m/s) allow recovery of motions.
- Clock errors and orbits correction using VERIPOS service.
- Data transmission and processing would take ~1-2 seconds.
- 1 sigma errors ~2.7/4.2/12.2 cm in east/north/up components.

Displacement History in Tohoku-Oki Earthquake

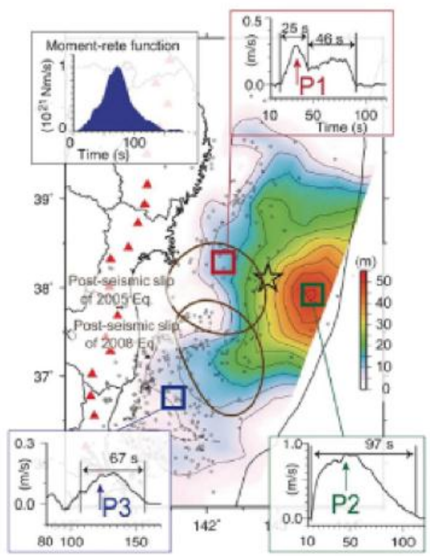


Wright et al, GRL 2012

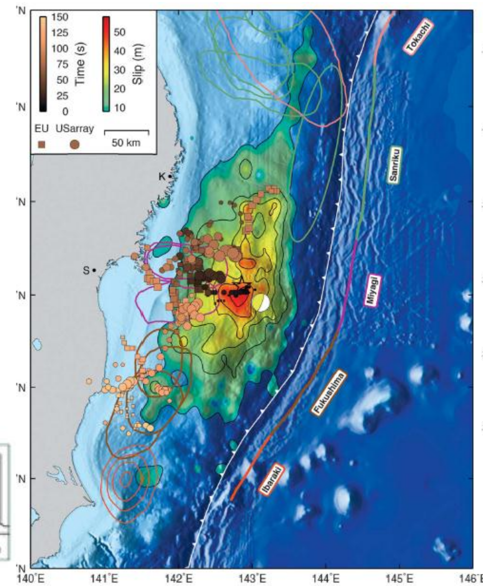
Slip Distributions from Geodesy (+seismology + tsunami modelling +…)



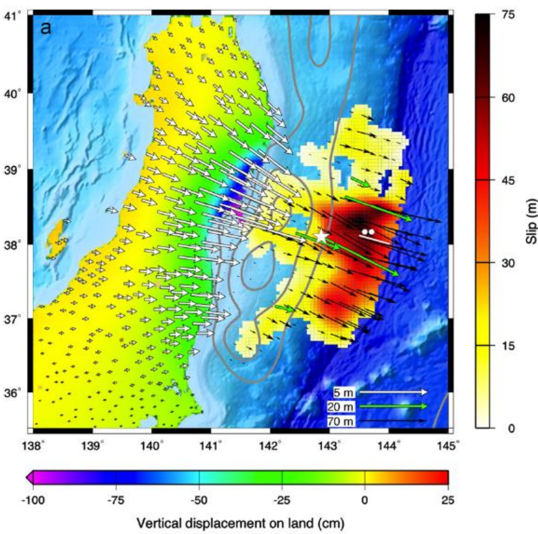
Lay et al, 2011



Yagi and Fukahata, 2011



Simons et al, 2011

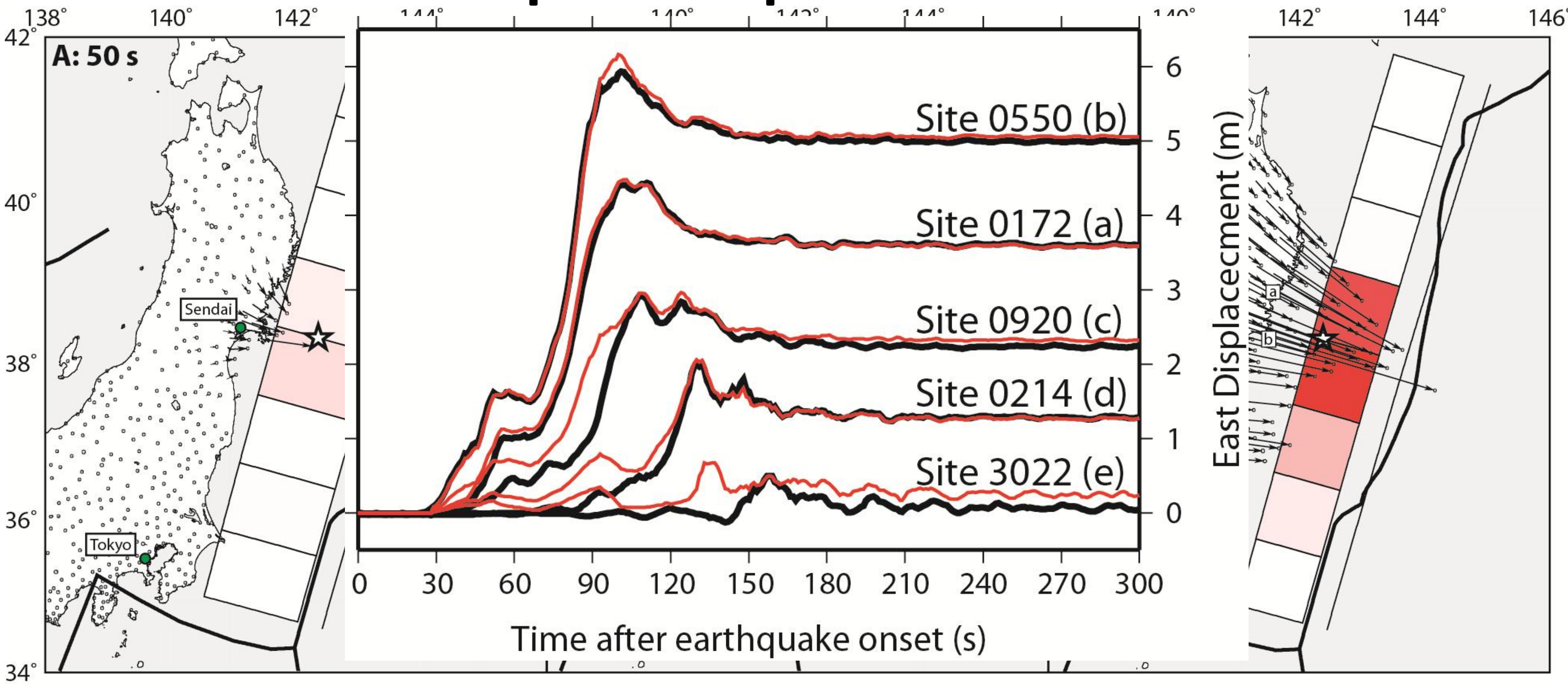


Hooper et al., 2012

These slip models are important for understanding earthquake physics and future hazard.

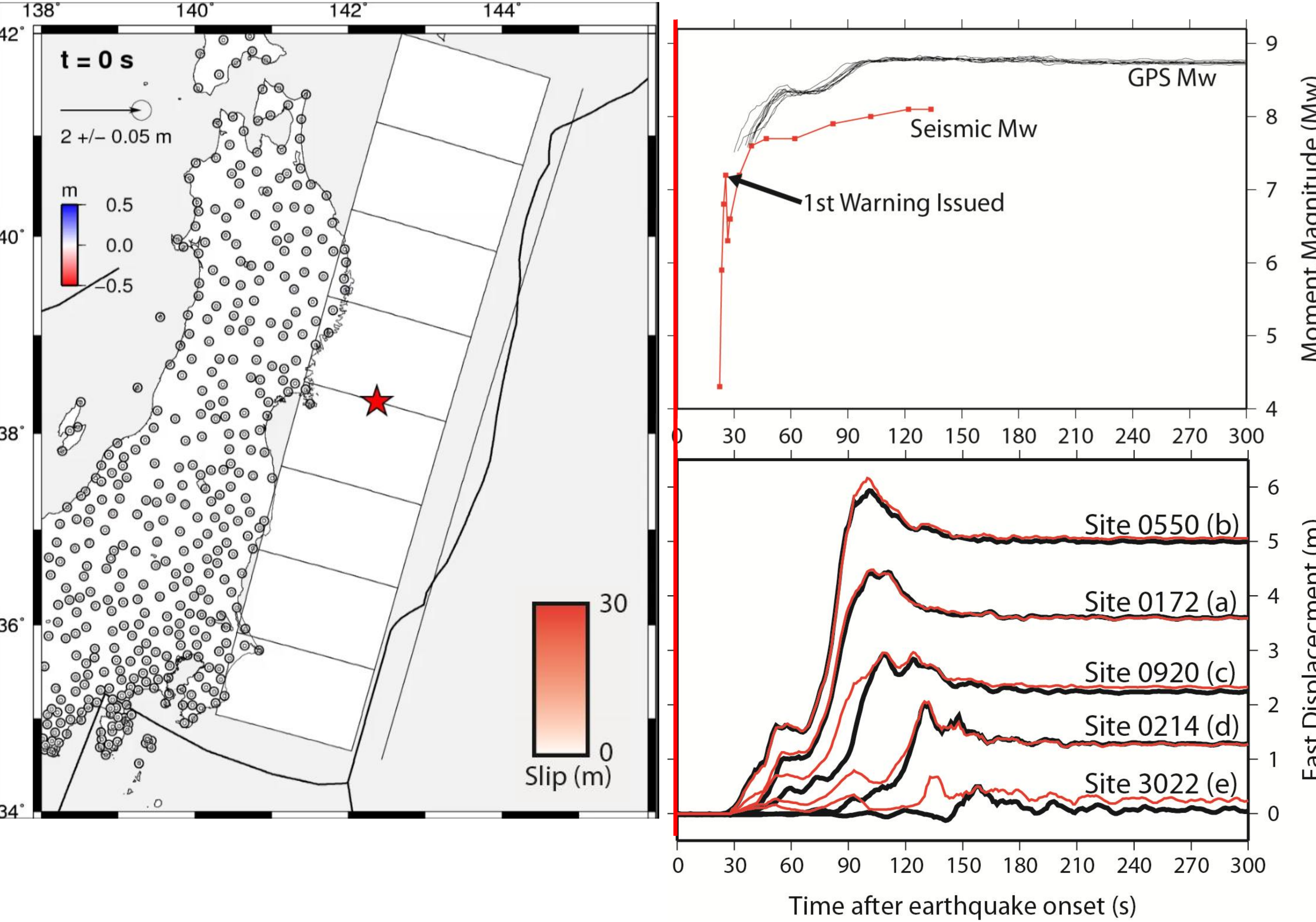
There is no need for this complexity for EEW.

Simple slip inversion



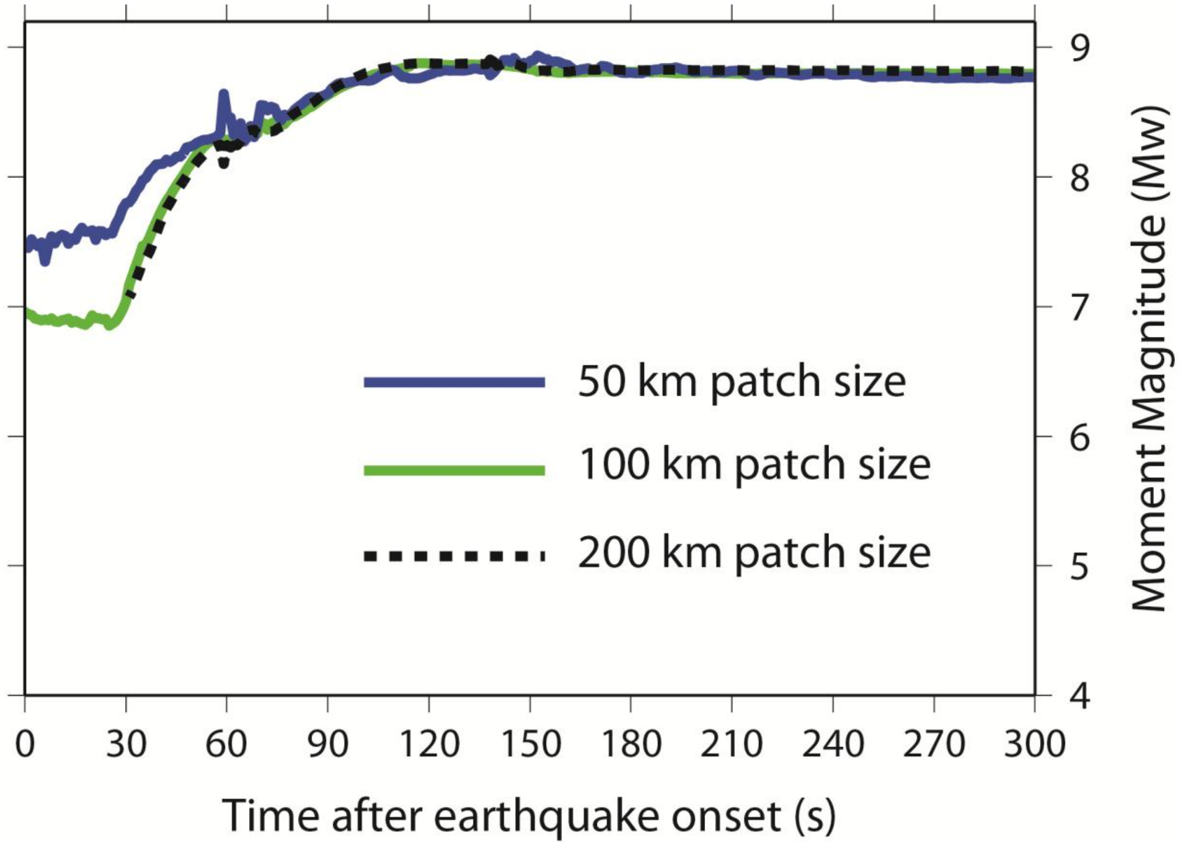
- **Assume instantaneous displacements are final static displacements**
- Uniform slip on 100 km sections of pre-defined subduction interface.
- No resolution from geodesy near the trench, so fix upper limit of faulting.
- Allow depth extent to vary (non-linear inversion).
- Use subset of 10 GPS sites; 8 cm displacement “trigger”.
- Inversion runs in less than a second on a single processor.

Wright et al, GRL 2012



138°
140°
142°
144°
42°
40°
38°
36°
34°
t = 0 s
2 +/– 0.05 m
m
0.5
0.0
–0.5
30
0
Slip (m)
GPS Mw
Seismic Mw
1st Warning Issued
Moment Magnitude (Mw)
Site 0550 (b)
Site 0172 (a)
Site 0920 (c)
Site 0214 (d)
Site 3022 (e)
East Displacement (m)
0 30 60 90 120 150 180 210 240 270 300
Time after earthquake onset (s)

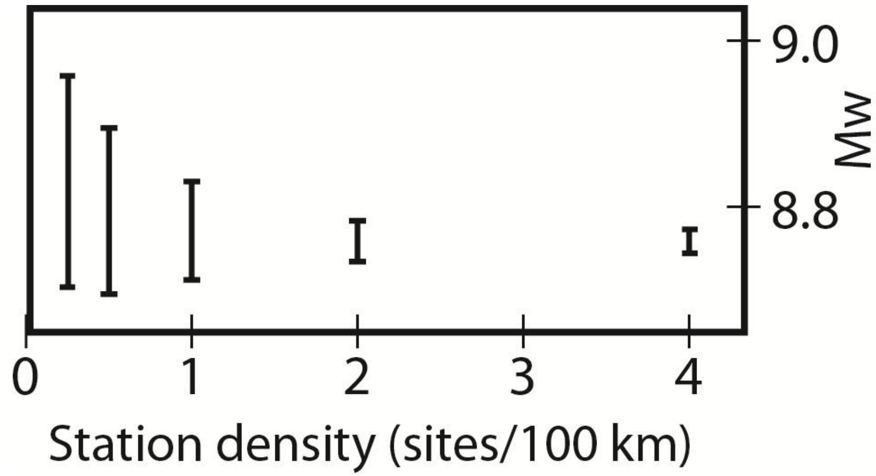
Influence of patch sizes



- 50 km patches are noisier than 100 km station spacing
- 200 km patches less sensitive to station noise (fewer false alarms) but later detection.

Wright et al, GRL 2012

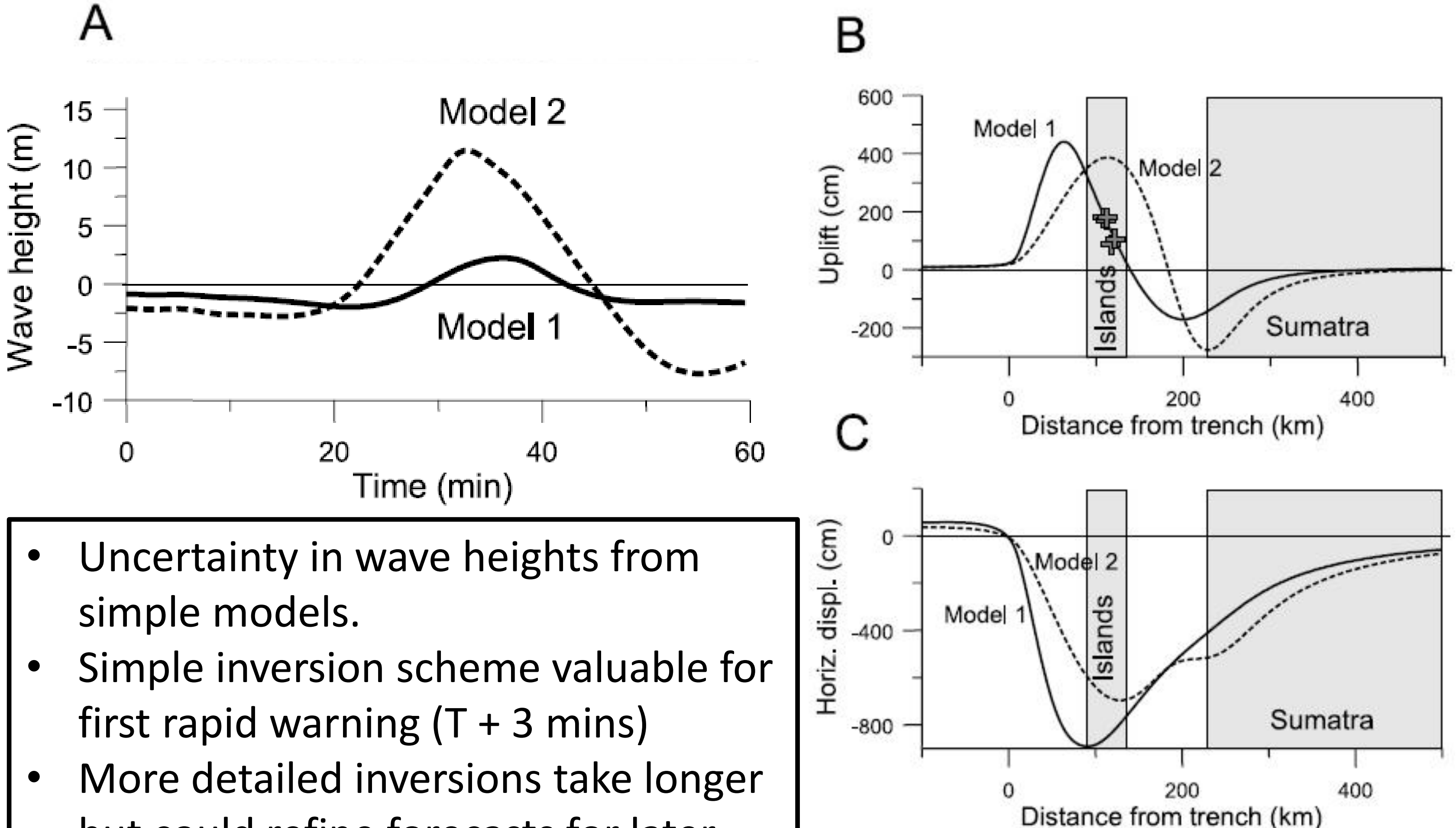
How many GPS sites are needed?



- GEONET allows us to test different station configurations
- For each station density, we looked at 50 randomly chosen configurations.
- Fewer than 1 site / 100 km needed, but more sites ensures robustness against station failures or outliers.

Wright et al, GRL 2012

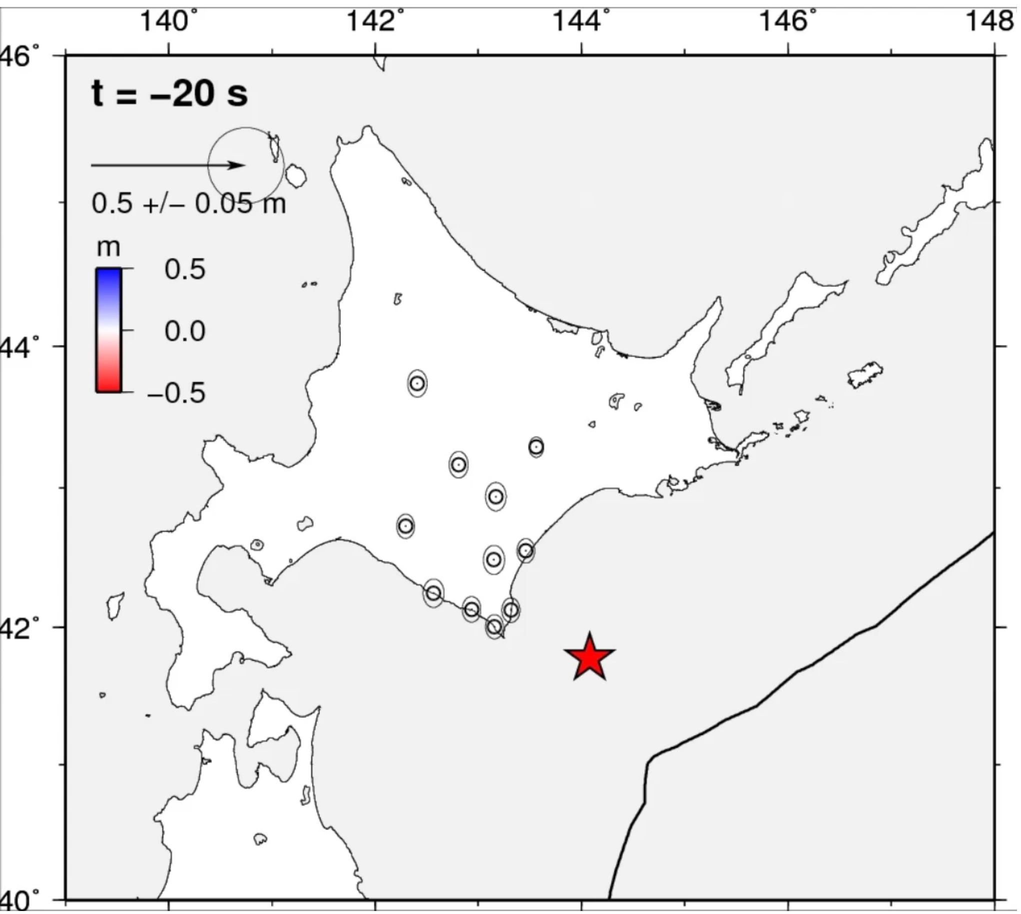
Can this be applied to Tsunami Forecast?

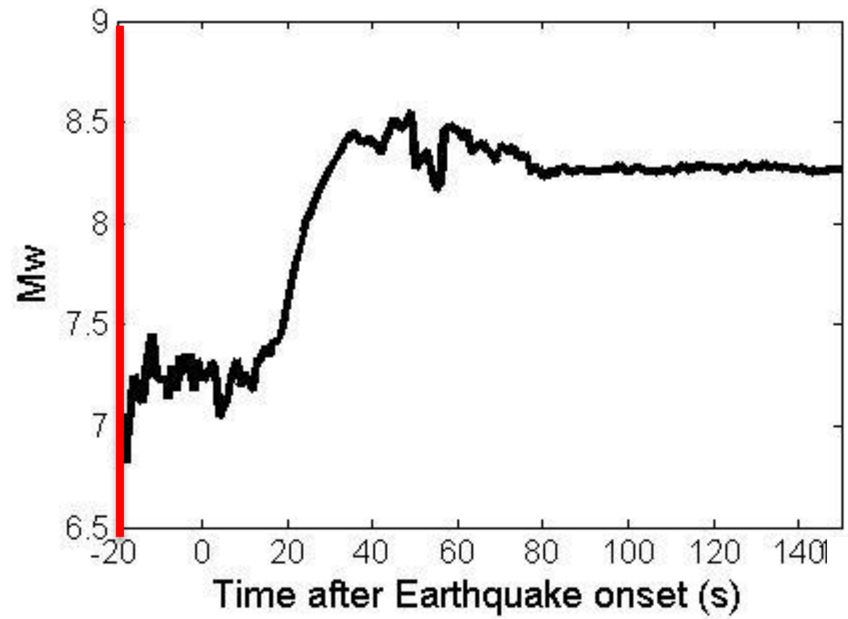


- Uncertainty in wave heights from simple models.
- Simple inversion scheme valuable for first rapid warning (T + 3 mins)
- More detailed inversions take longer but could refine forecasts for later times.

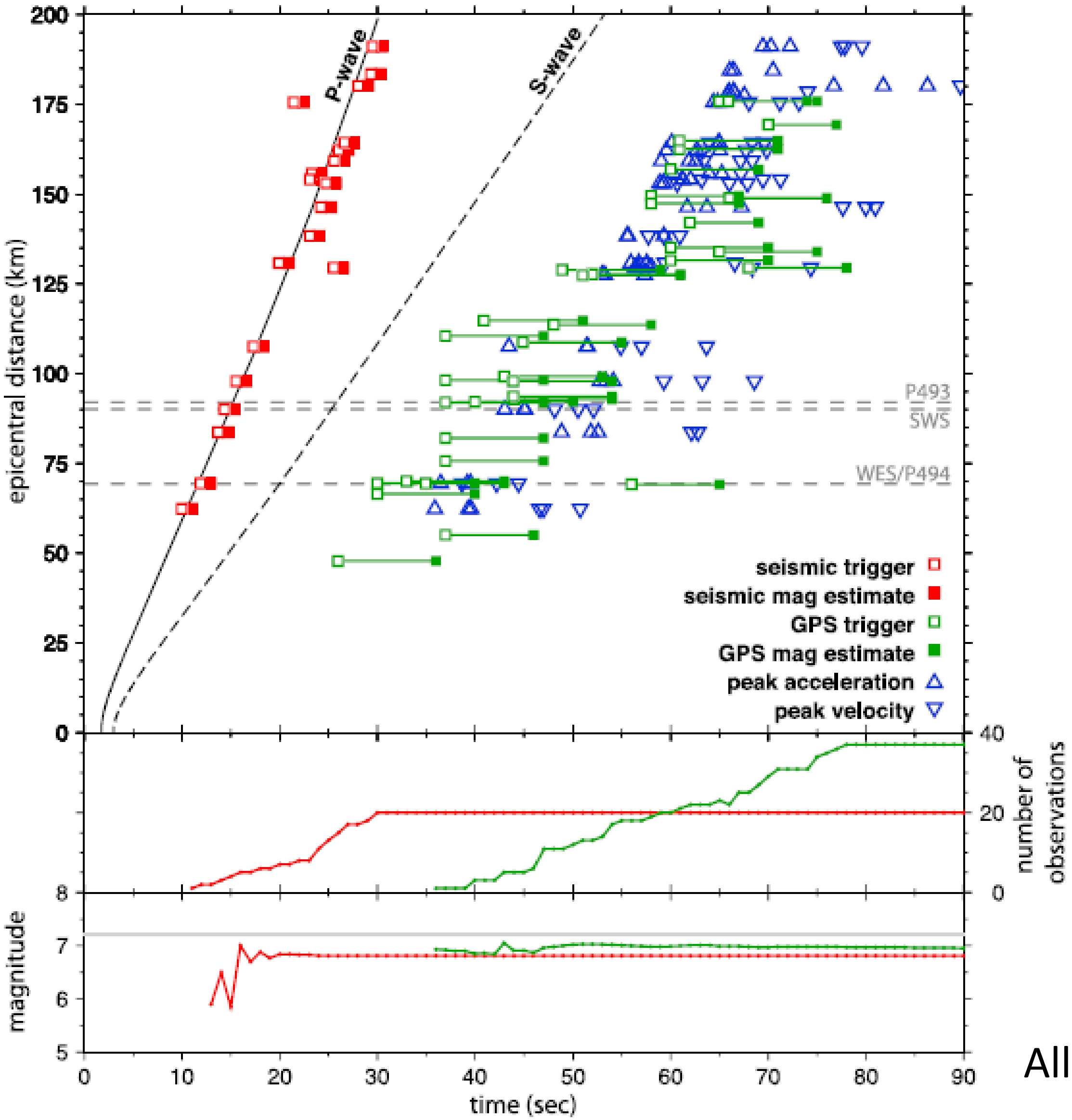
Sobolev et al., JGR 2007

2003 Tokachi-Oki Earthquake (Mw 8.3)





Timing of GPS EEW



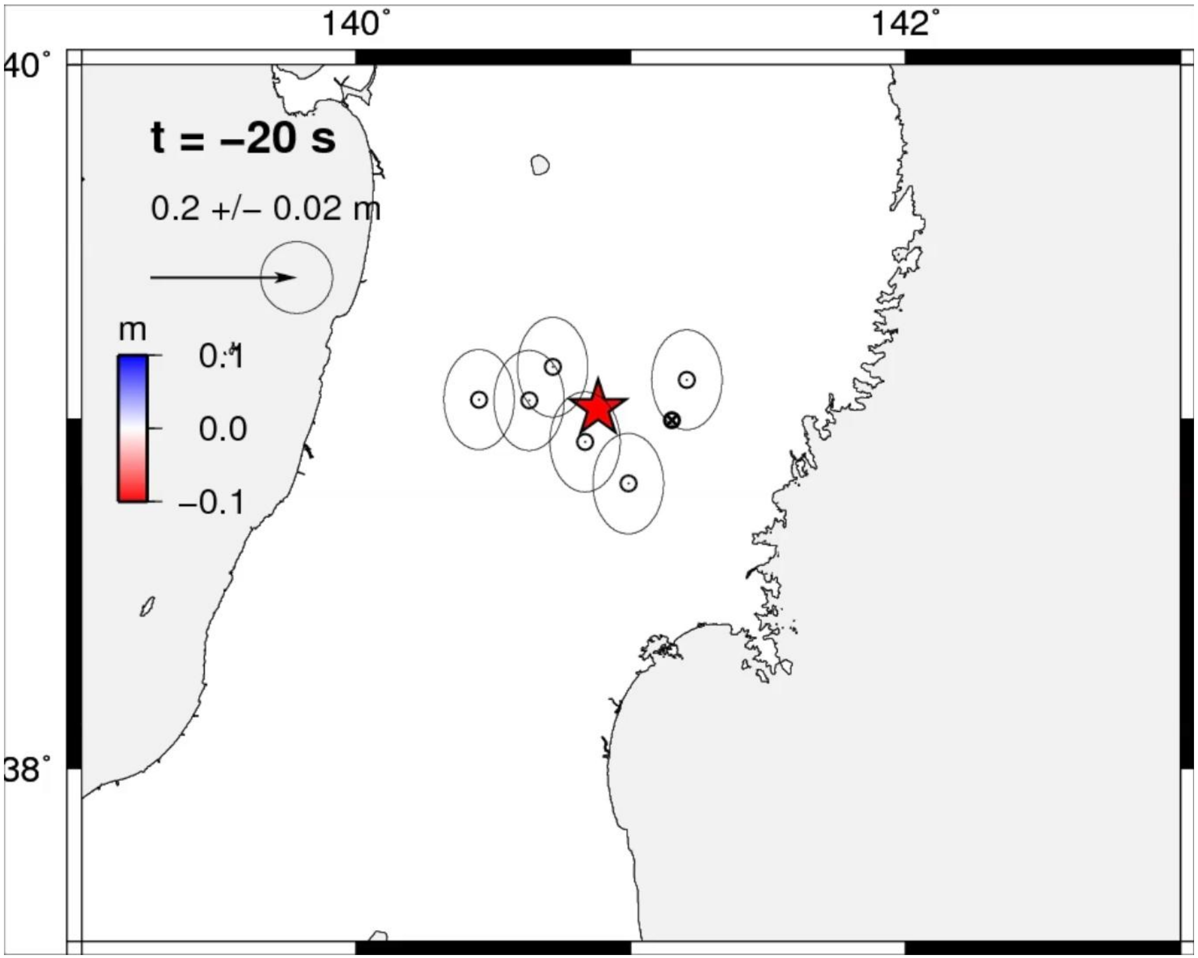
- Seismic EEW are faster
- Displacements reach peak with surface waves not P-waves

Allen and Ziv , GRL 2011

Unresolved issues

- Fault geometry – what happens if the quake is not on the expected rupture plane (e.g. outer rise earthquakes)?
- What about earthquakes on unknown faults?
- Do these methods work with smaller earthquakes?
- Can seismic and geodetic methods be combined for an optimum system?

2008 Iwate-Miyagi earthuake (M_w~6.8; Shallow Thrust Fault)



Conclusions & Recommendations

- Geodesy has an important role in the response phase to earthquakes, on time scales from minutes to years.
- The exceptional geodetic instrumentation in Japan has enabled tests of earthquake early warning methods that use continuous GPS.
- GPS magnitude estimates do not saturate.
- GPS can and should be processed in real time; results could be integrated with the existing seismic EEW system.

Symposium on Leading International Cooperative Research of Integrated Disaster Science on Evolving Natural Hazards

One, two and three dimensional wave propagation inside vertical arrays: which influence on the Green’s functions and spectral ratios?

F. De Martin, S. Matsushima and H. Kawase

Geoscience for a sustainable Earth
brgm

DPRI-KU

Introduction

One-dimensional (1D) wave propagation is a natural approach to study data from buried seismic sources recorded by vertical arrays

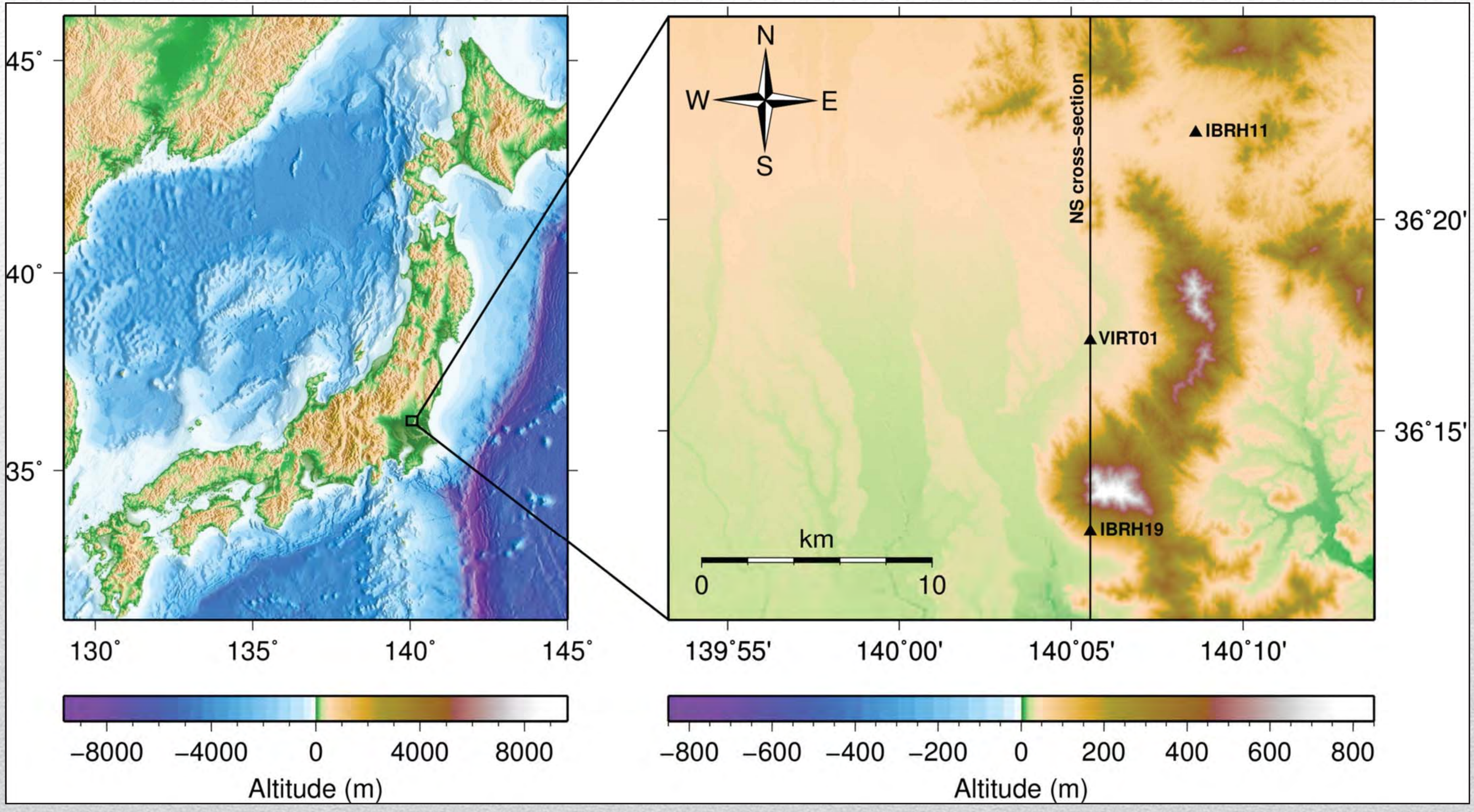
Medium
=
Stack of welded homogeneous isotropic horizontal layers overlying a homogeneous half-space

Wave
=
Plane P, SV or SH waves

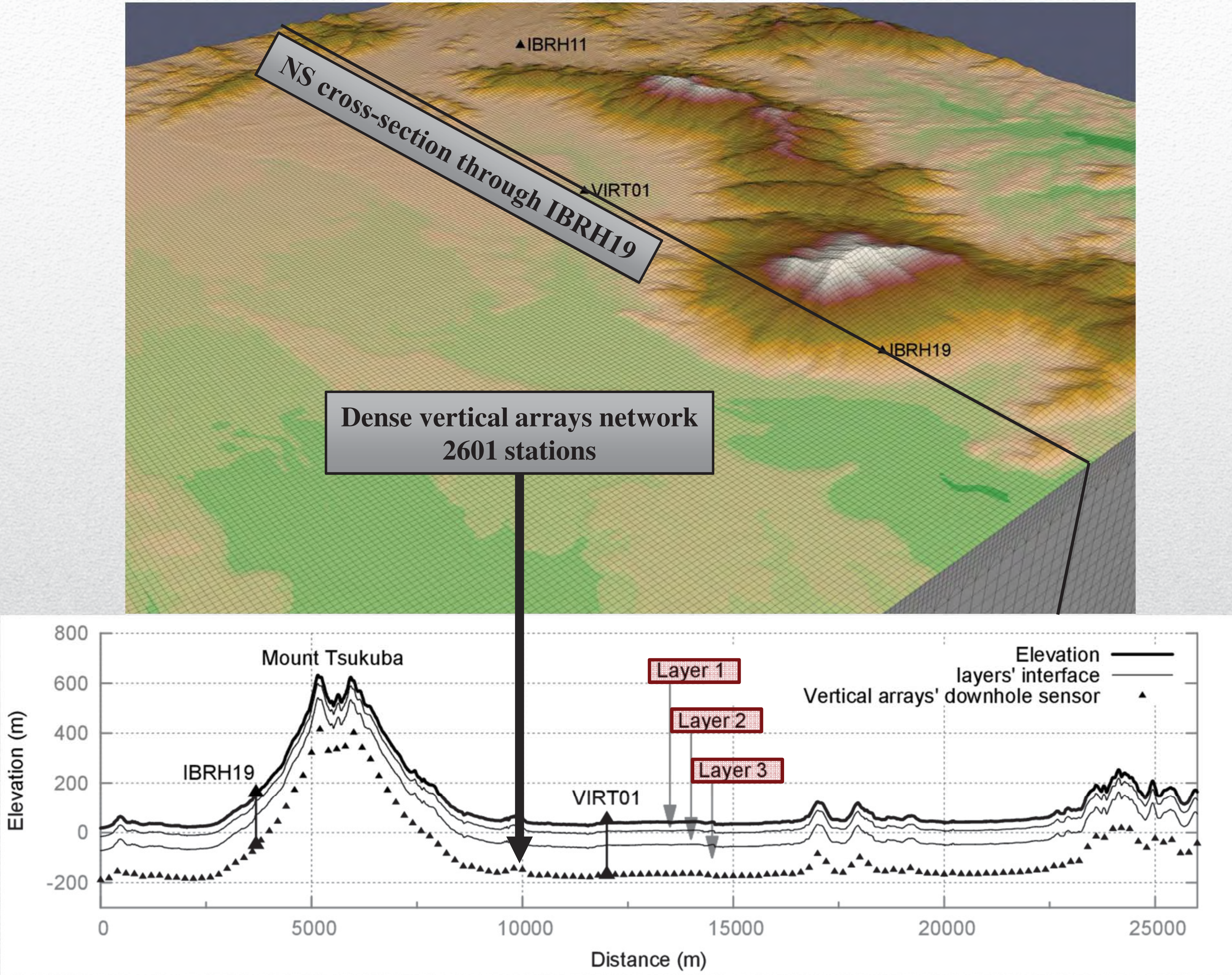
What is the influence of non-horizontal layering on the Green's functions and spectral ratios ?

Perform 1D, 2D and 3D elastic linear wave propagation with the spectral-element method code EFISPEC (http://efispec.free.fr)

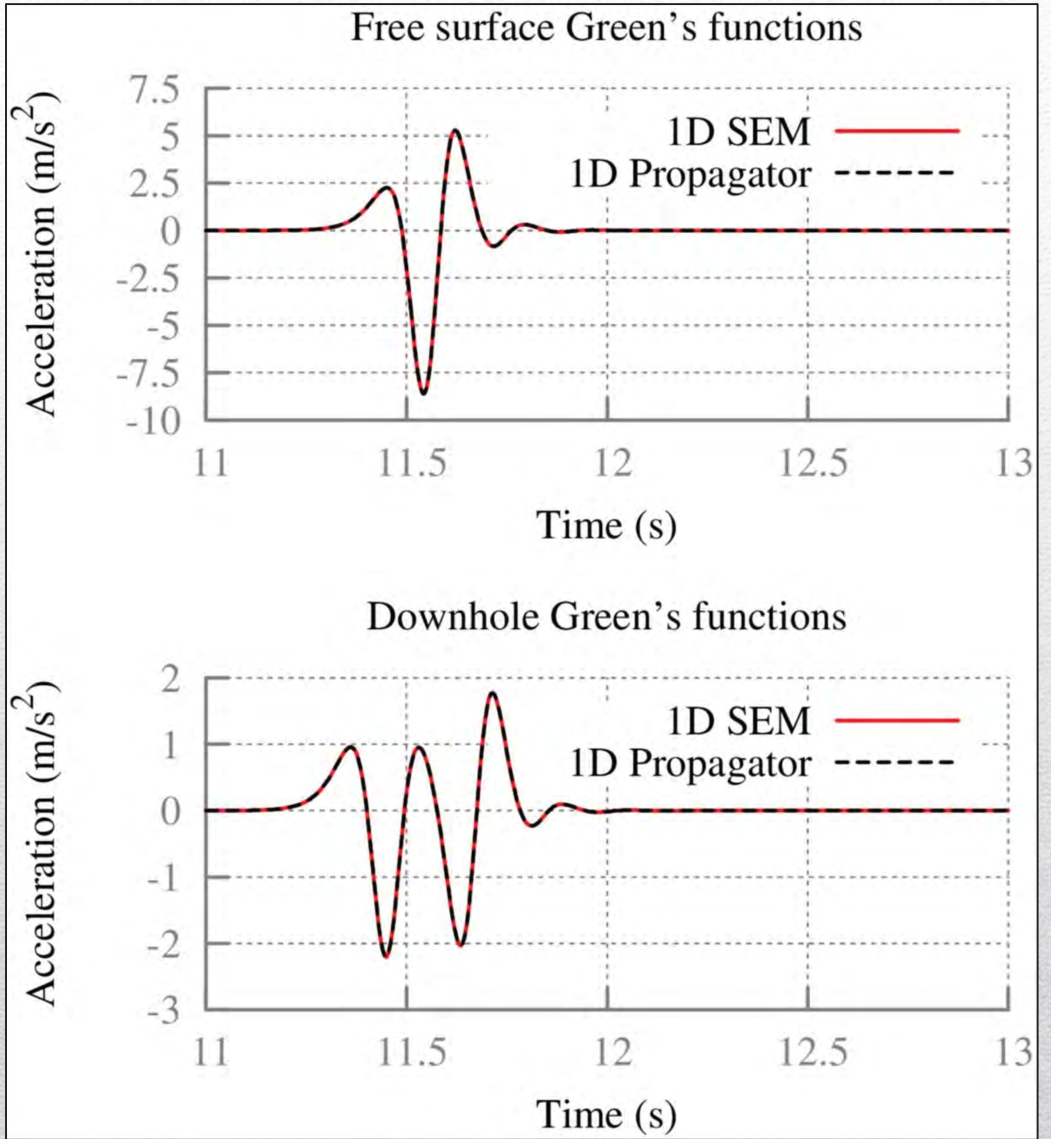
Area of study



Definition of the models



Verification of the spectral-element method code



SEM

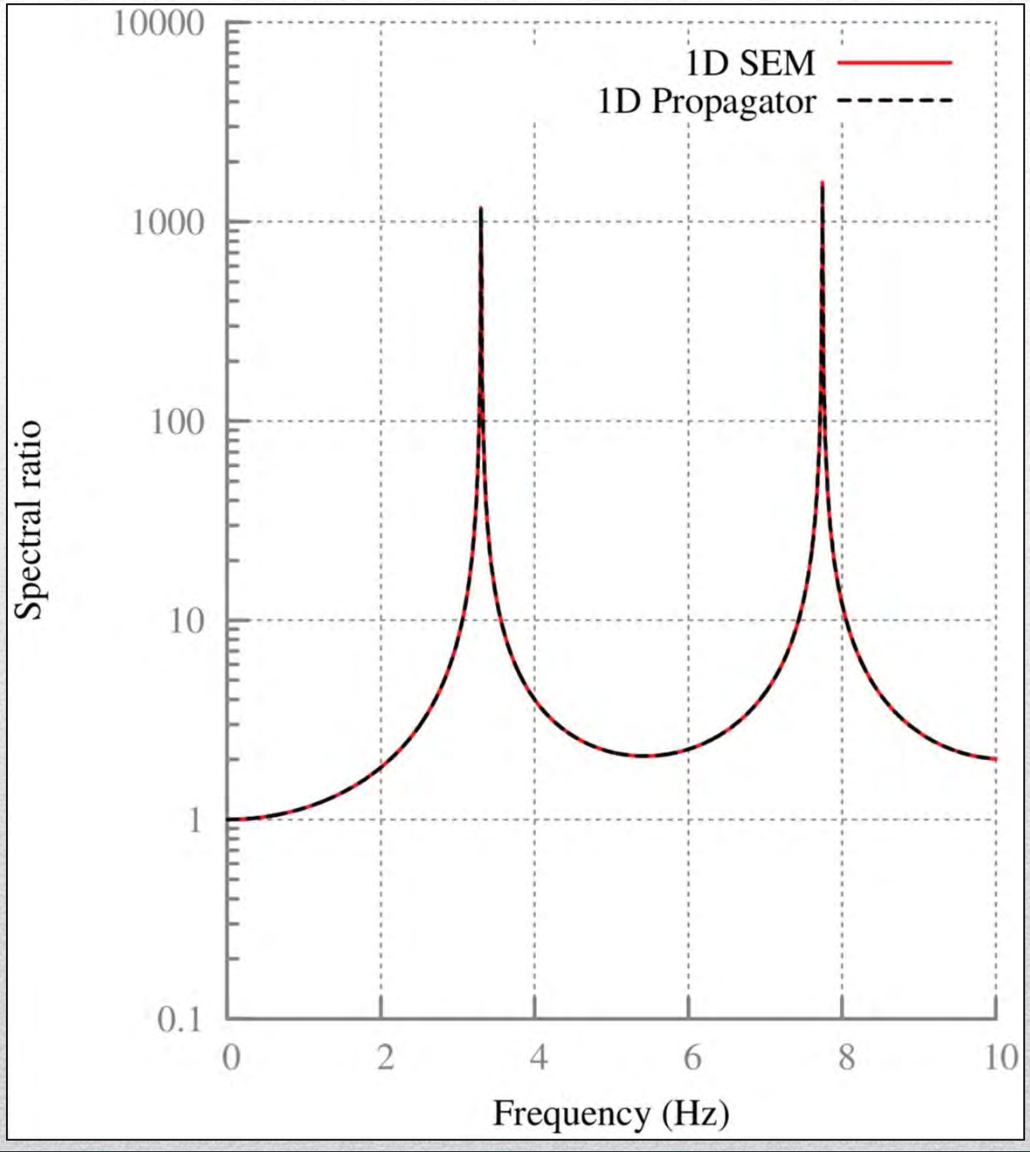
Green's function computed directly in the time domain

PROPAGATOR MATRIX METHOD

Computation of the transfer function in the frequency domain

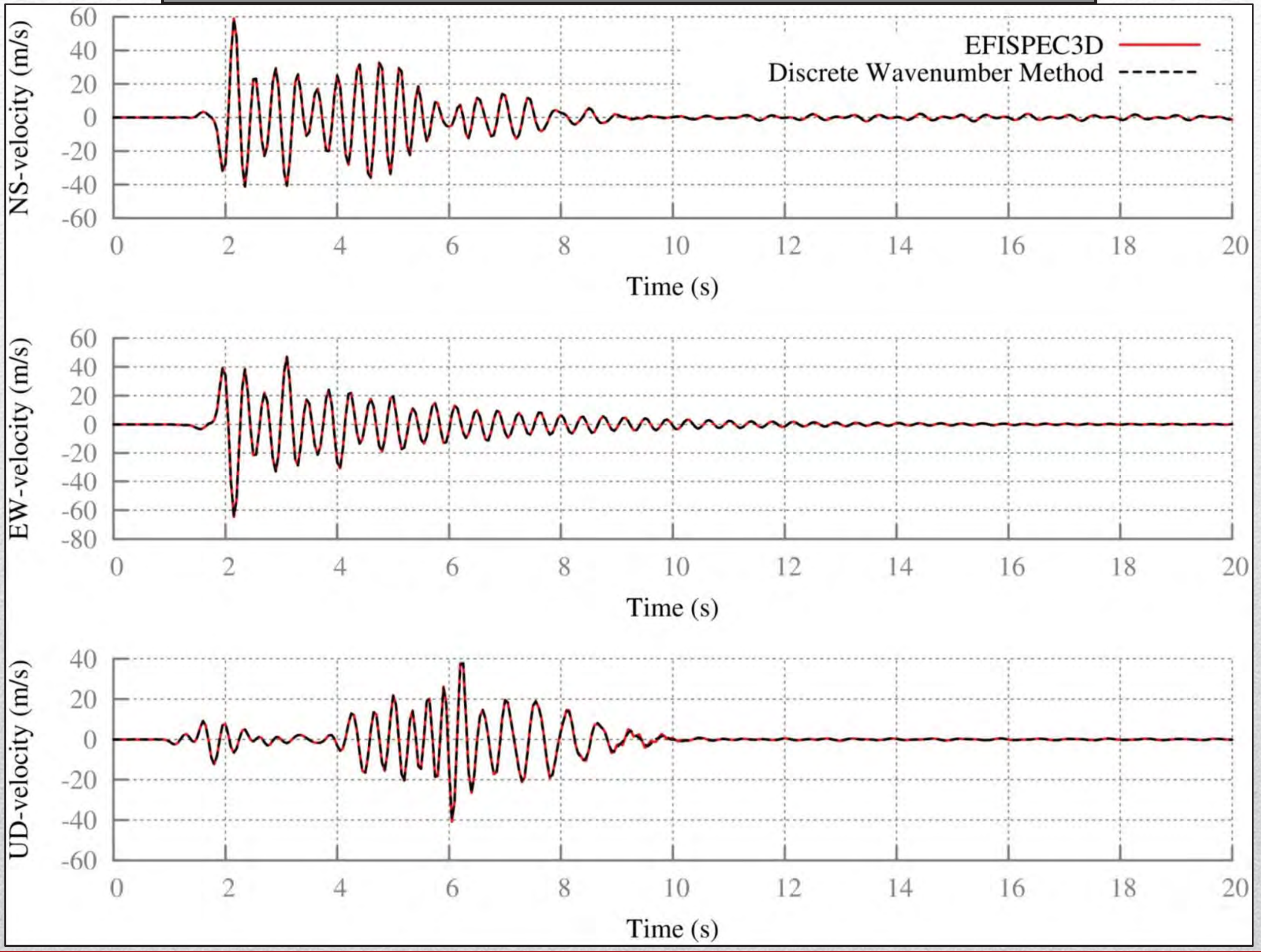
Back to time domain by inverse FFT

Verification of the spectral-element method code

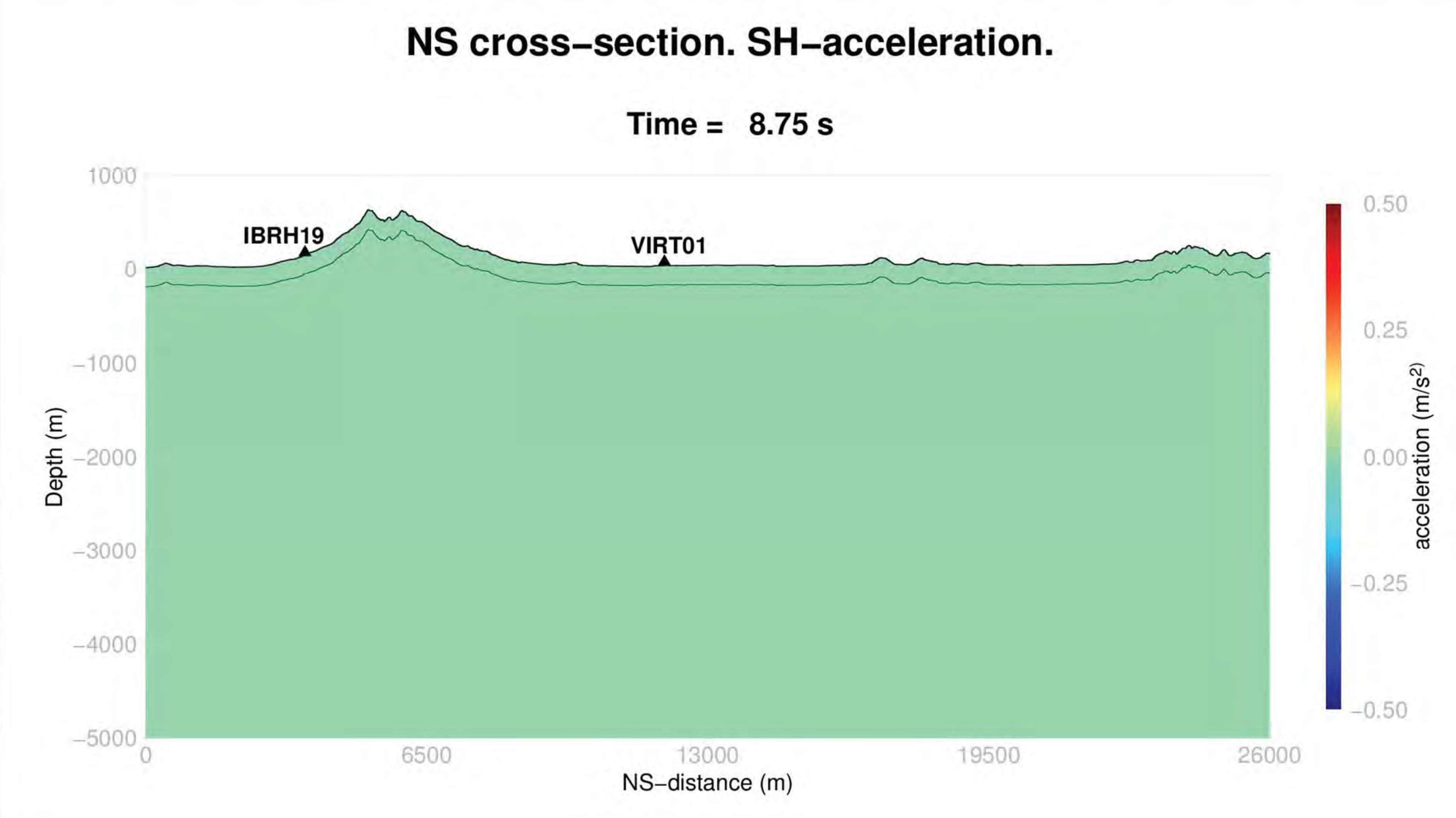


Verification of the spectral-element method code

E2VP2 : CAN2

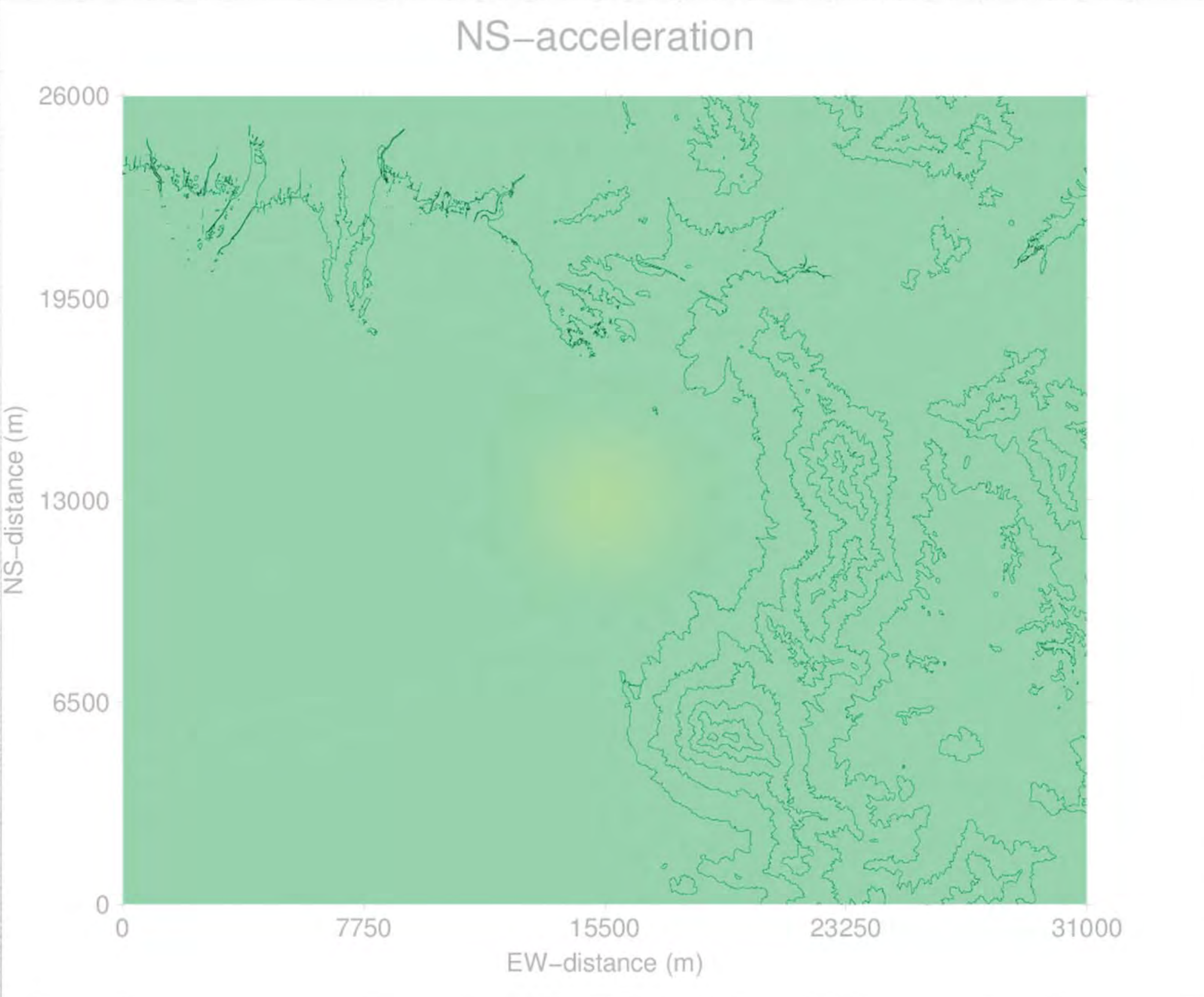


2D Green's functions



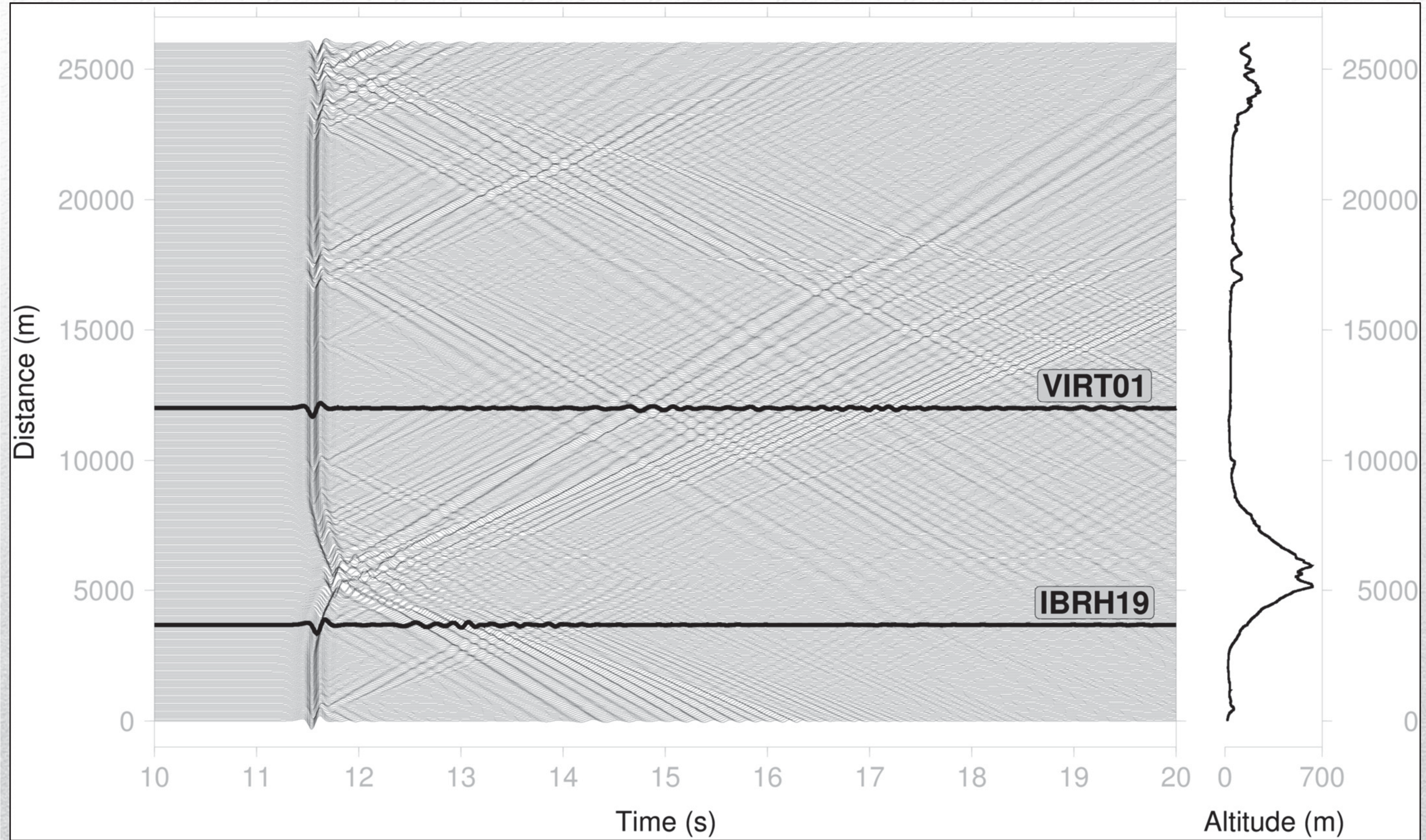
2D simulation by spectral-element method valid in [0.05 - 10] Hz

3D Green's functions

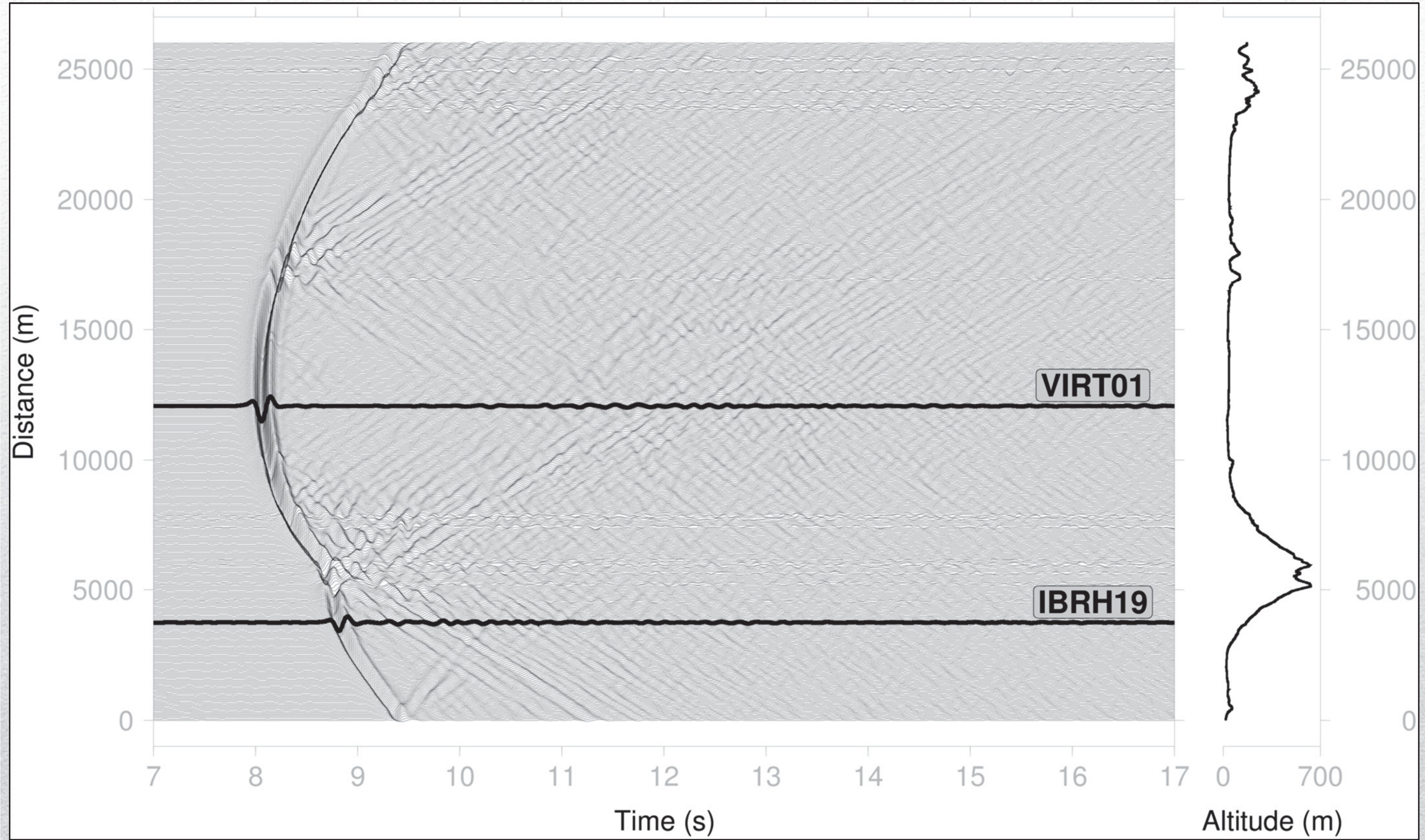


3D simulation by spectral-element method valid in [0.05 - 10] Hz

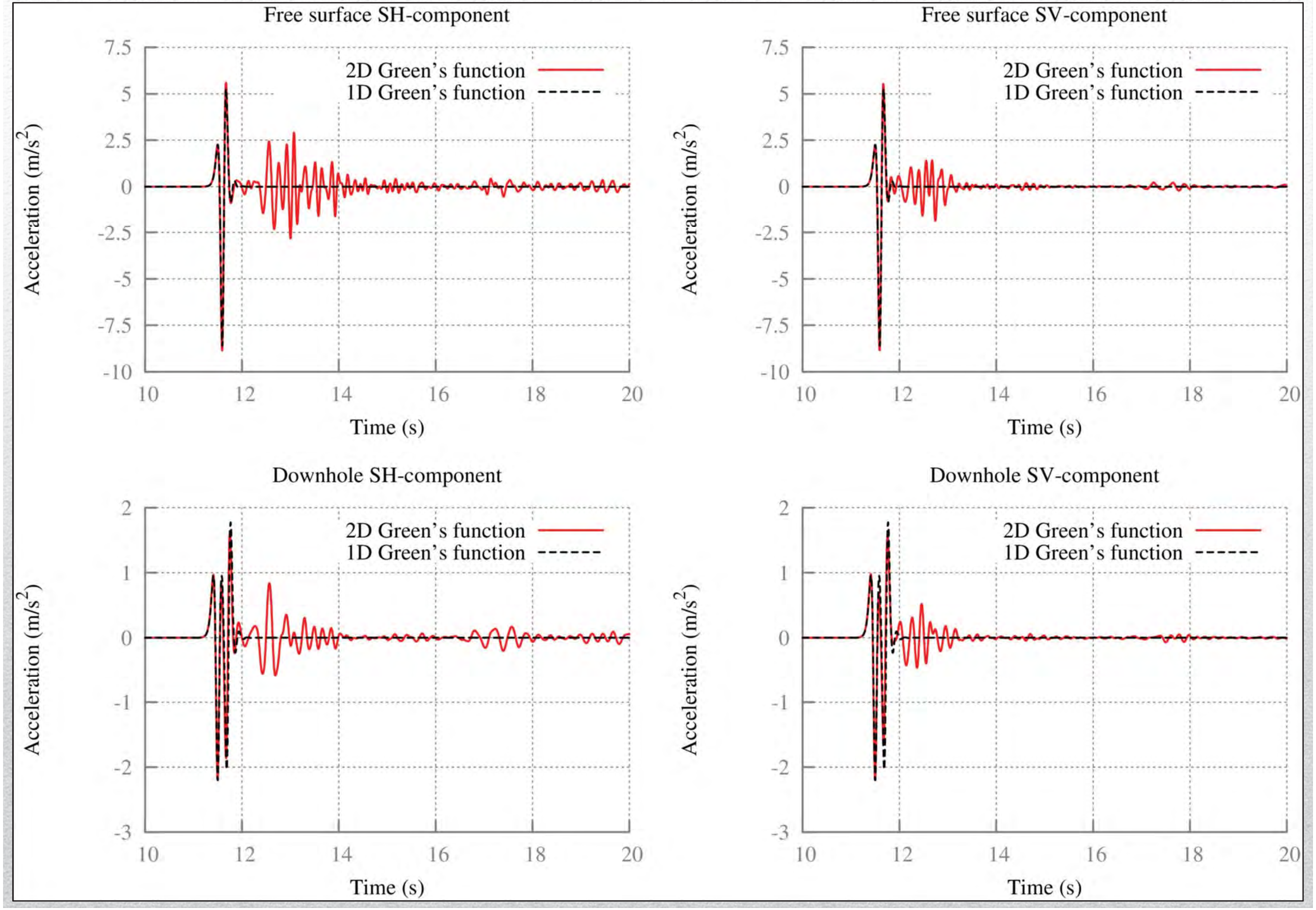
2D Green's functions : 2601 stations



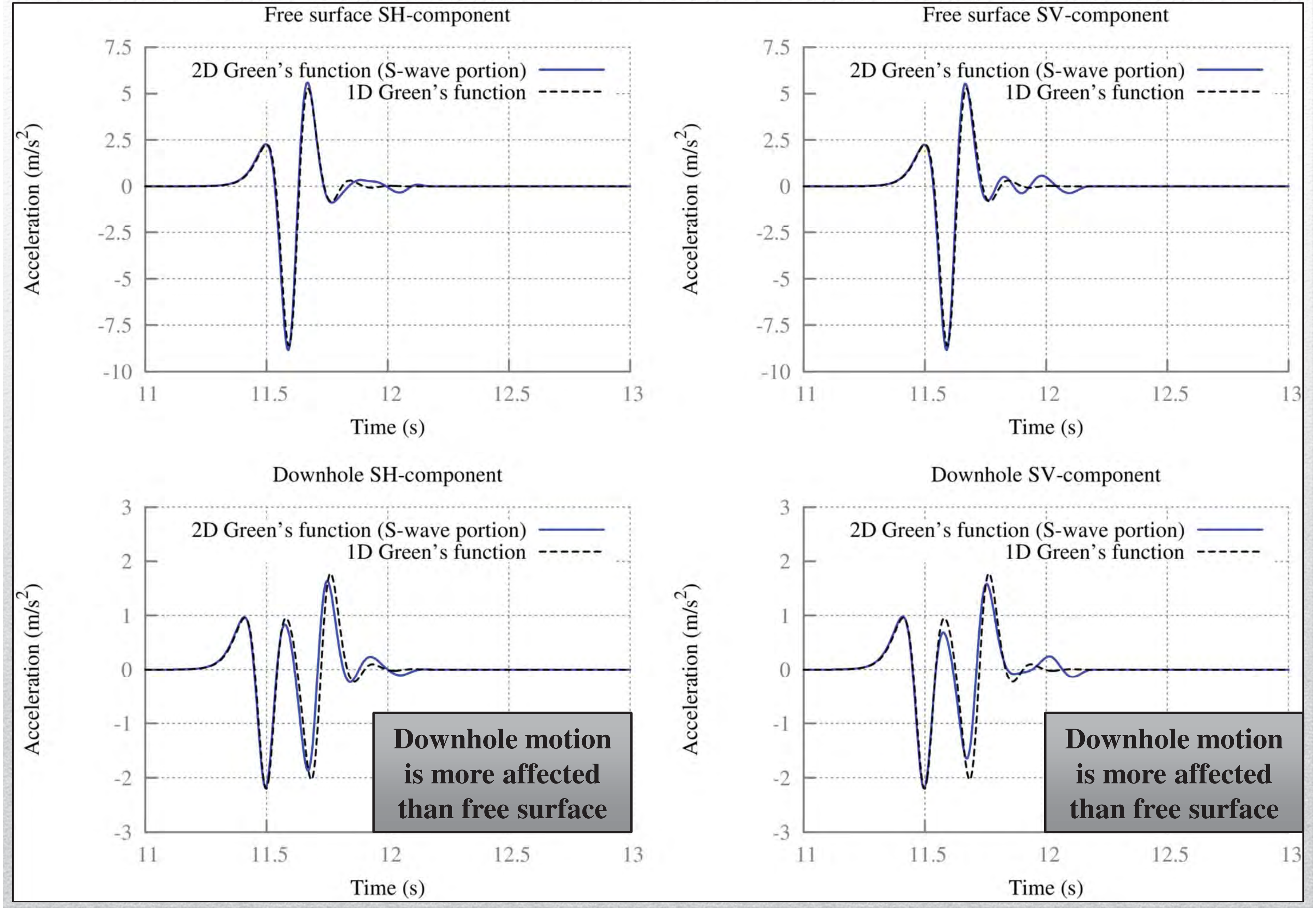
3D Green's functions : 2601 stations



2D Green's functions : IBRH19



2D Green's functions : IBRH19



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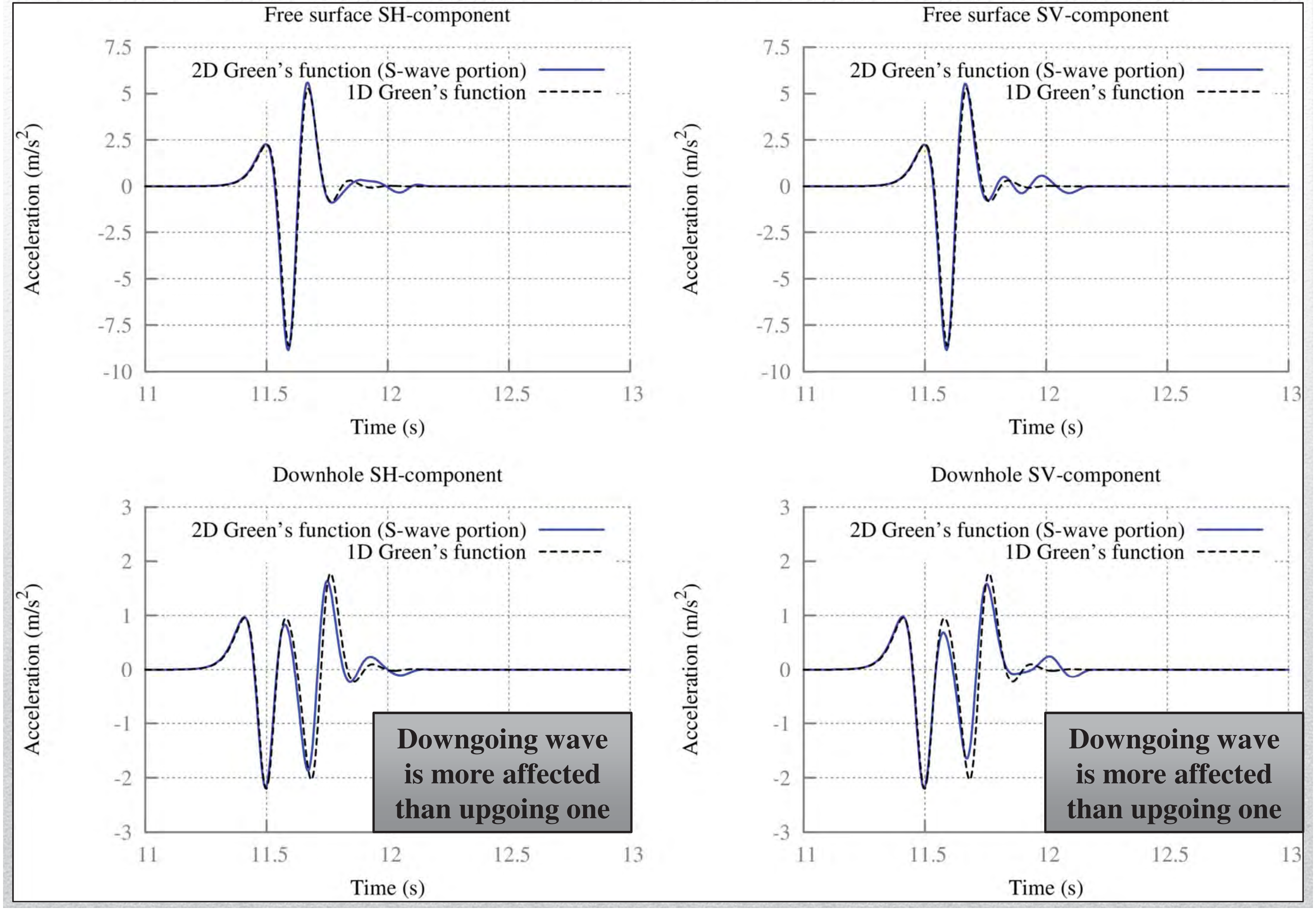
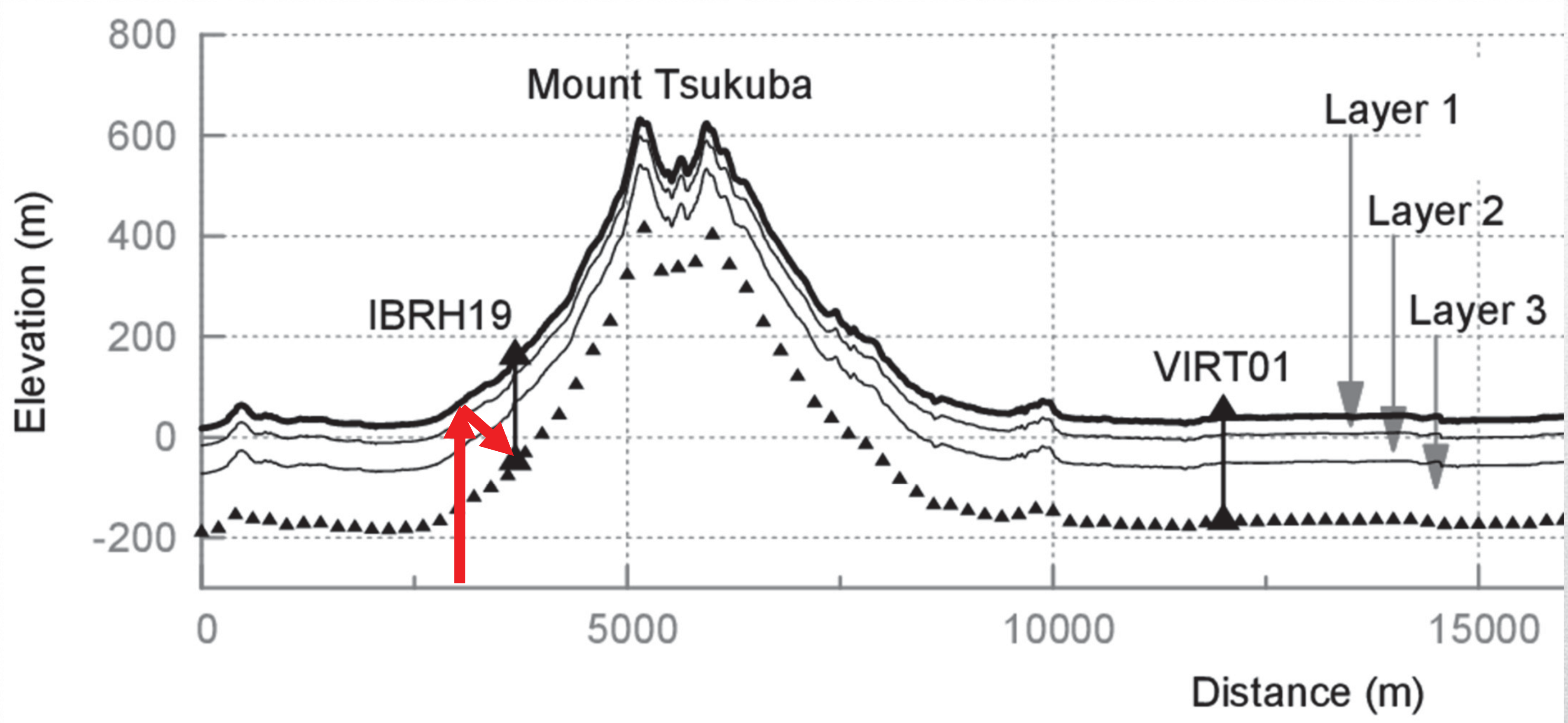
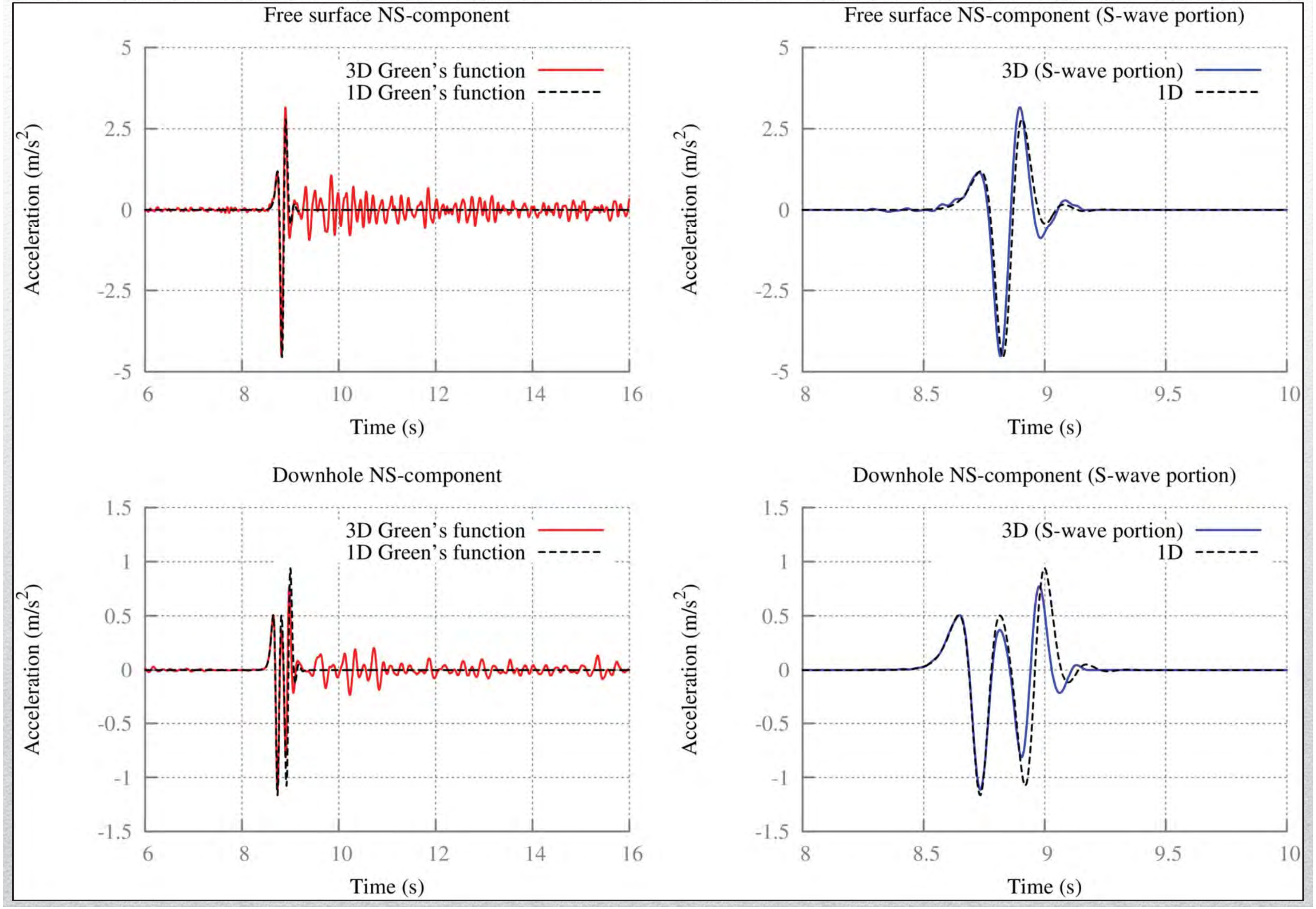


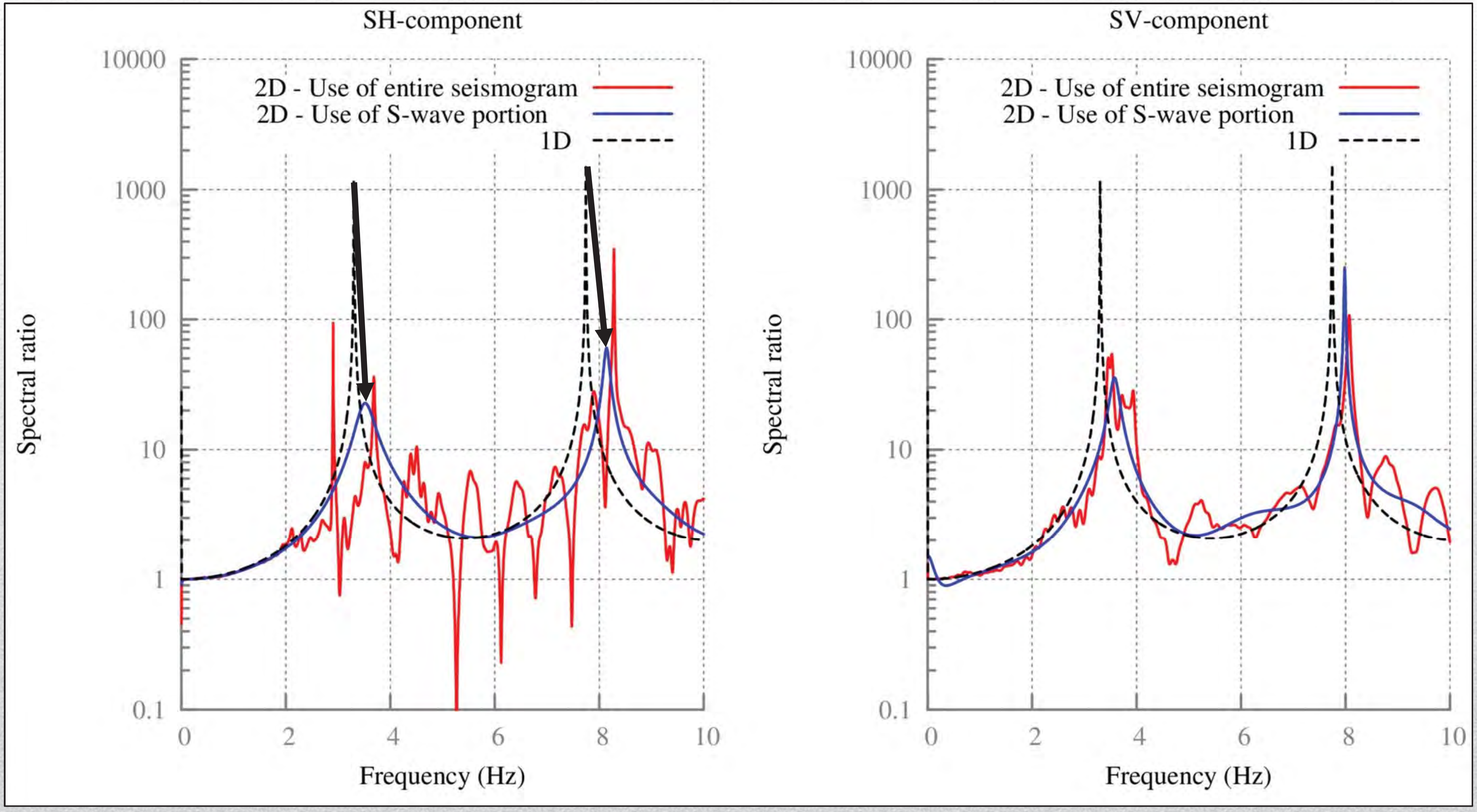
2D Green's functions : IBRH19



3D Green's functions : IBRH19



2D Green's functions



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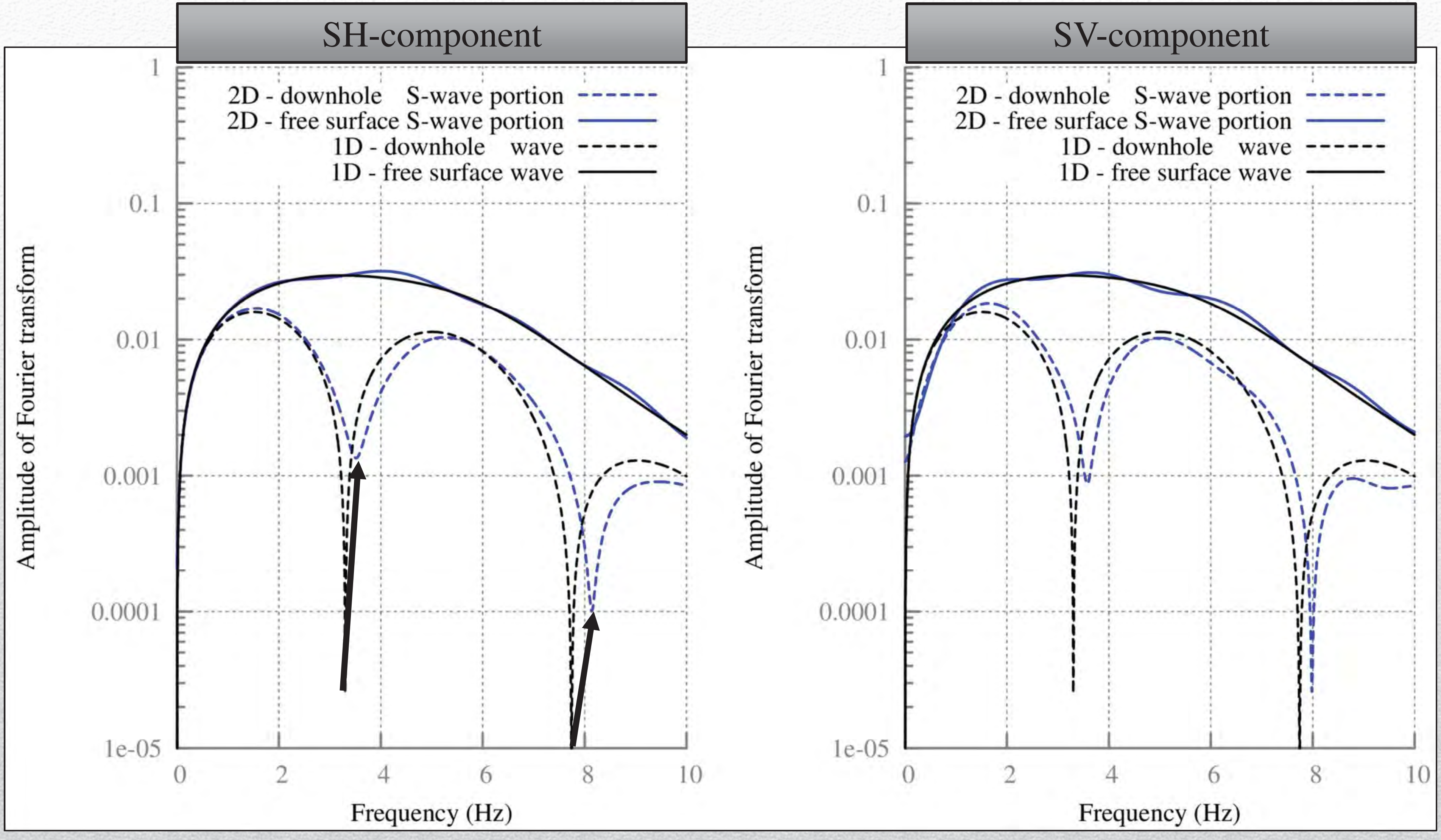

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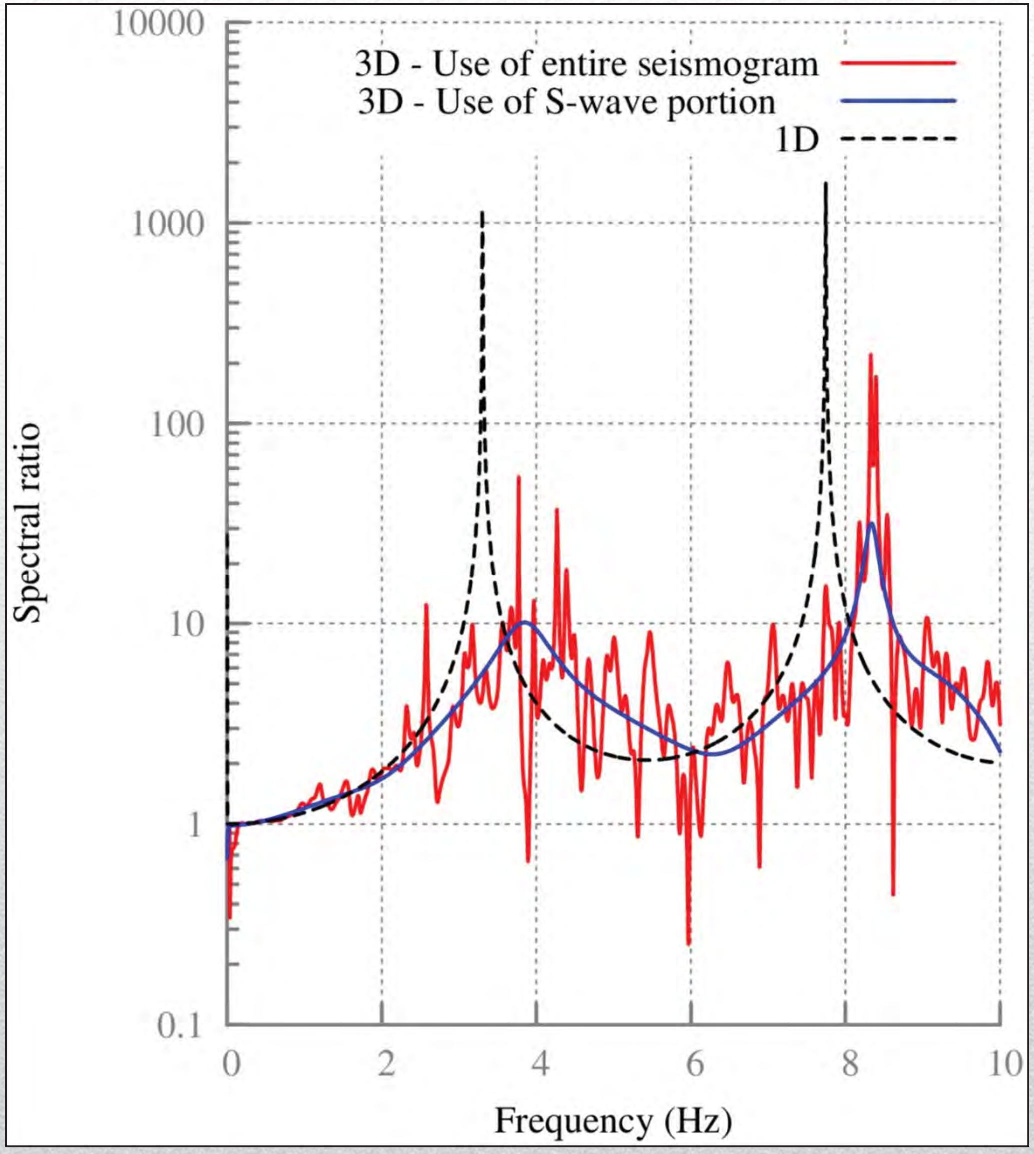
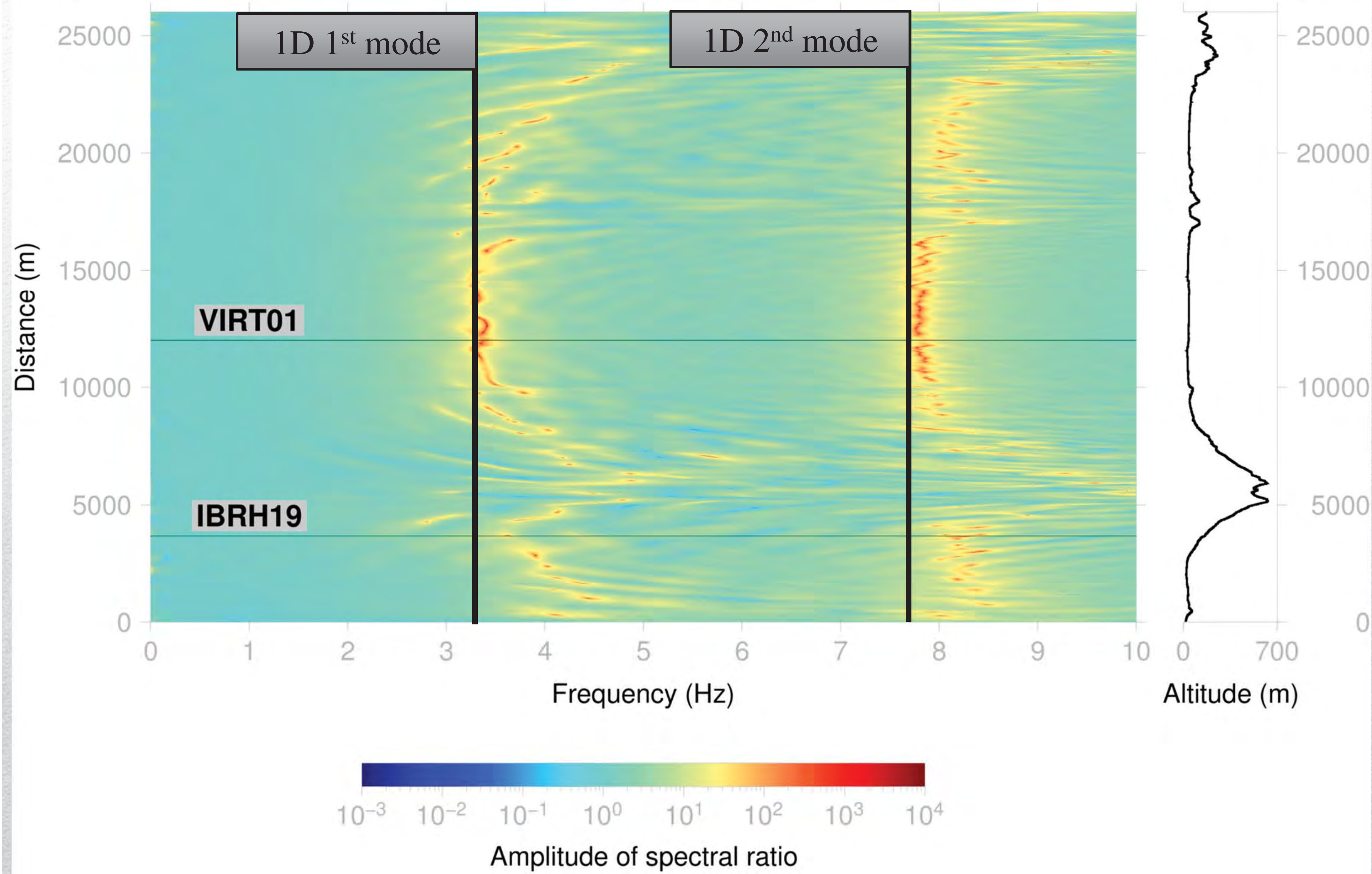


3D Green's functions : 2601 stations



Conclusions and Perspectives

- **Influence of geometrical effects (non-horizontal layering) is not negligible**

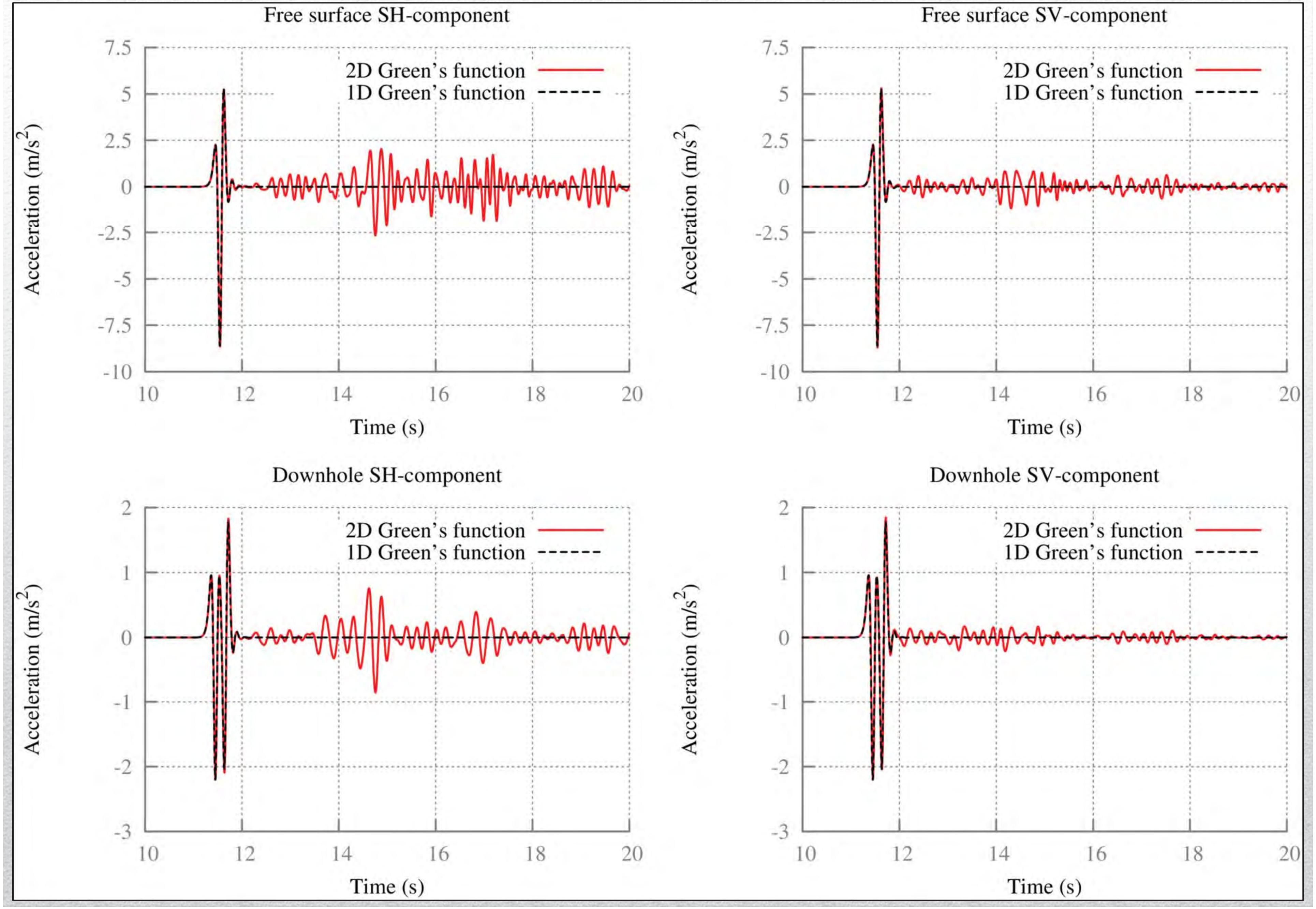
- **Both free surface and downhole waves are influenced by geometrical effects**
  - The downhole motion is more affected than the free surface motion
    - The downgoing wave is more affected than the upgoing wave

- **Inversions of borehole's records based on 1D theory should be treated with care**
  - Spectral ratio is a very sensitive physical variable
  - Geometrical effects lead to a shift of natural frequencies and to a decrease of the amplitude of a spectral ratio
  - So far, quality factors inverted from 1D theory may be underestimated

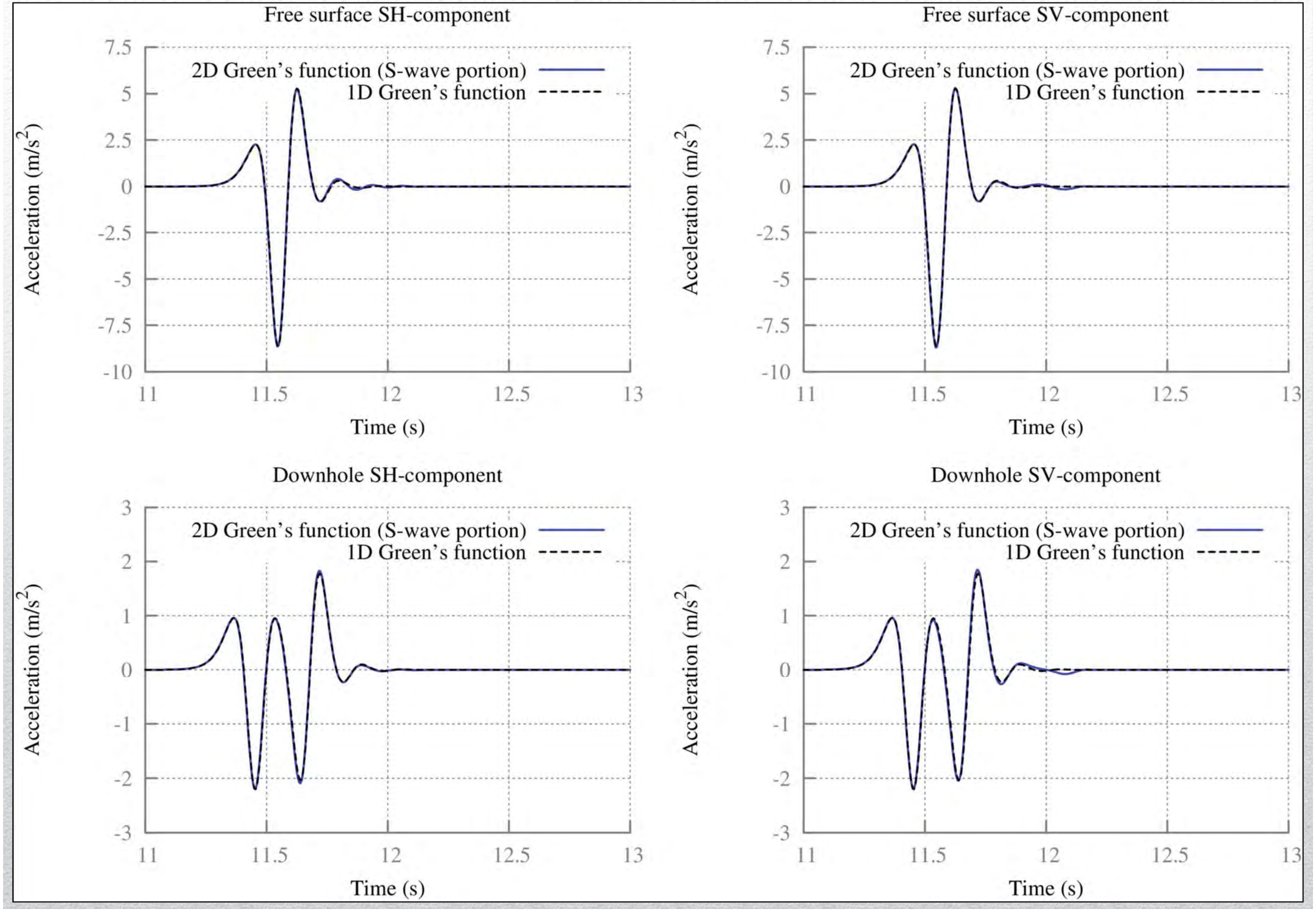
- **Research work with DPRI will go on**
  - March 13th 2013 → Signature of DPRI-BRGM Memorandum of Understanding
    → 5 new years of collaboration

THANK YOU

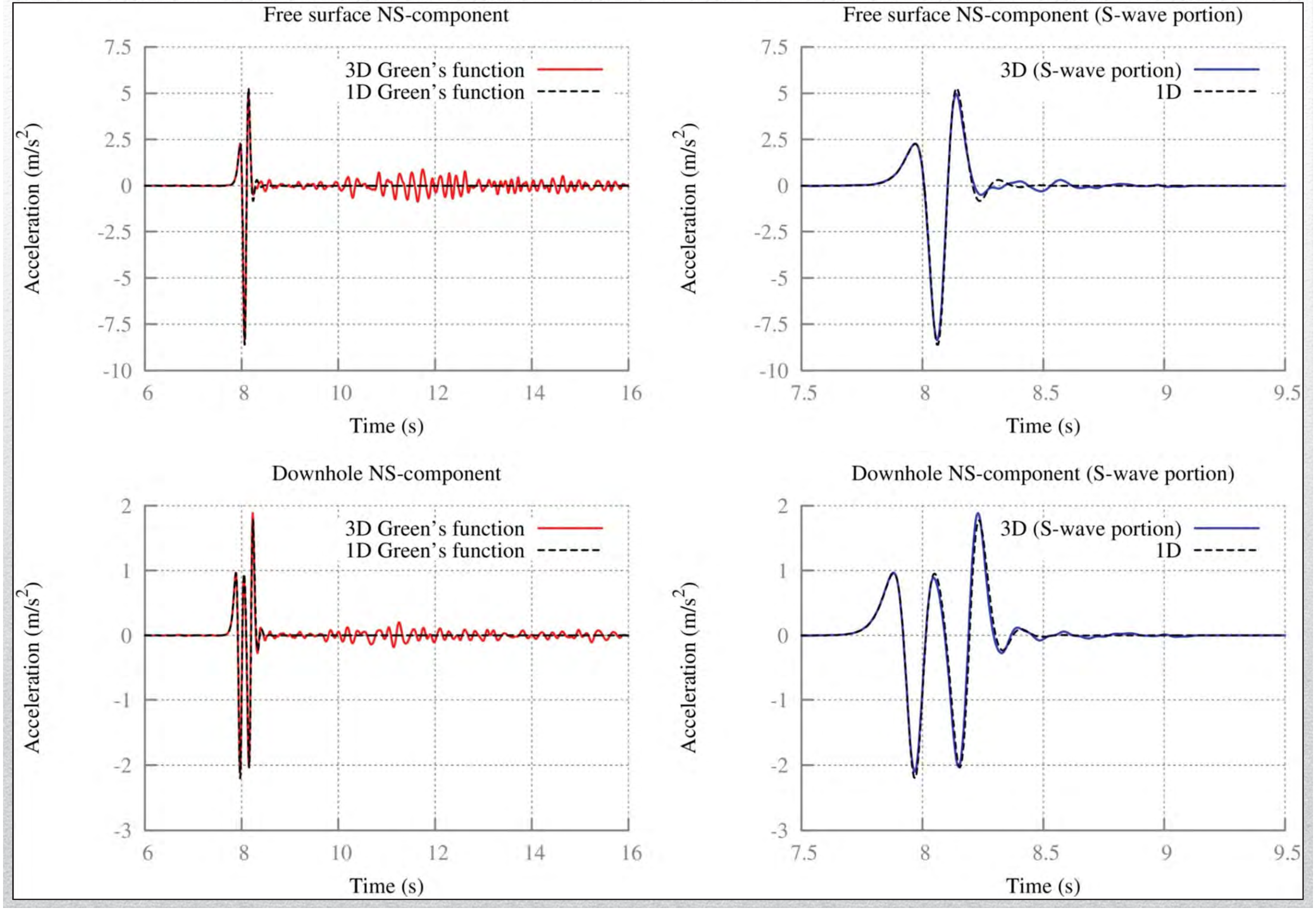
2D Green's functions : VIRT01



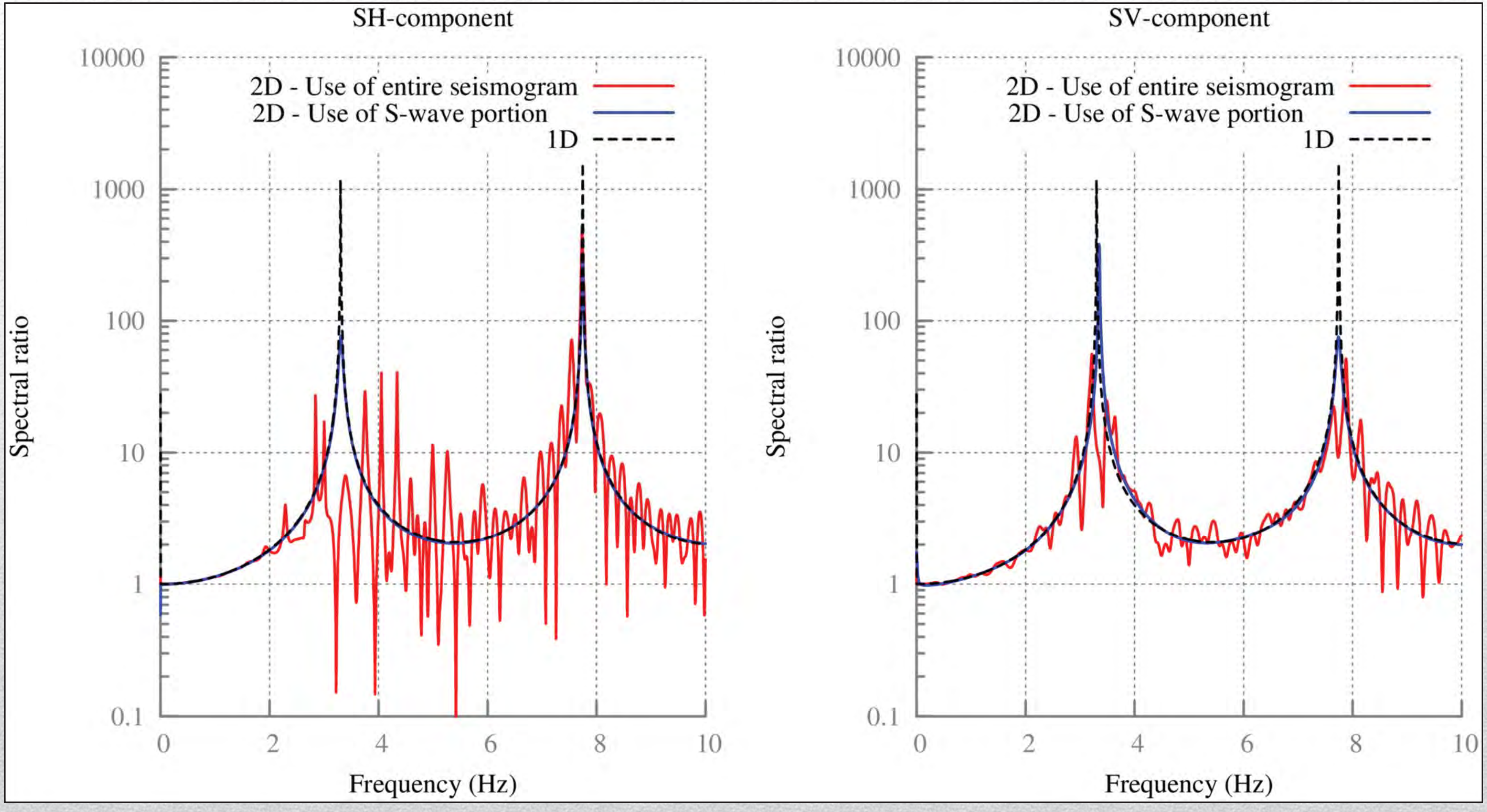
2D Green's functions : VIRT01



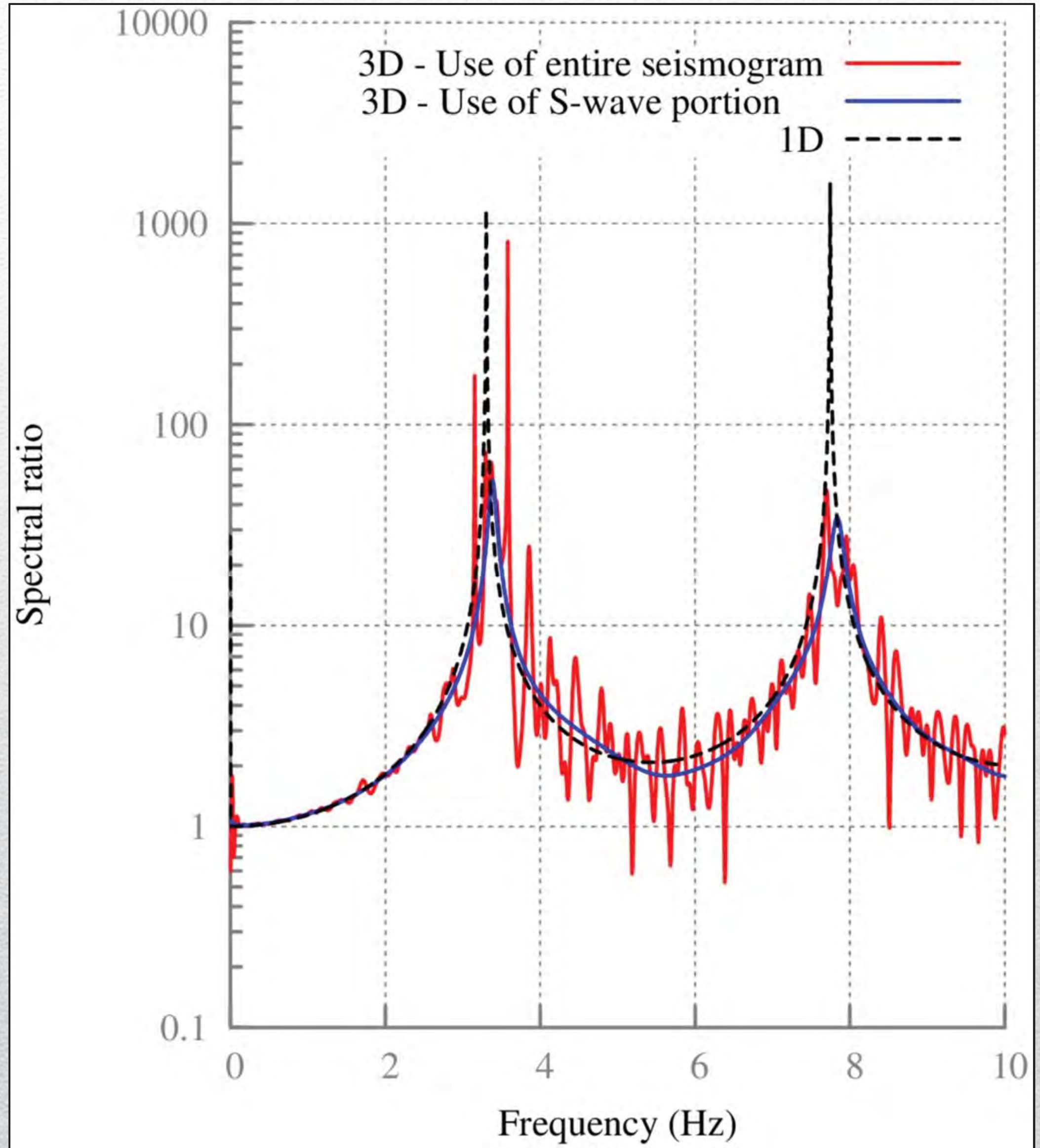
3D Green's functions : VIRT01



2D Green's functions : VIRT01



3D Green's functions : VIRT01



Comparison of temperature change in urban areas between different geographical conditions

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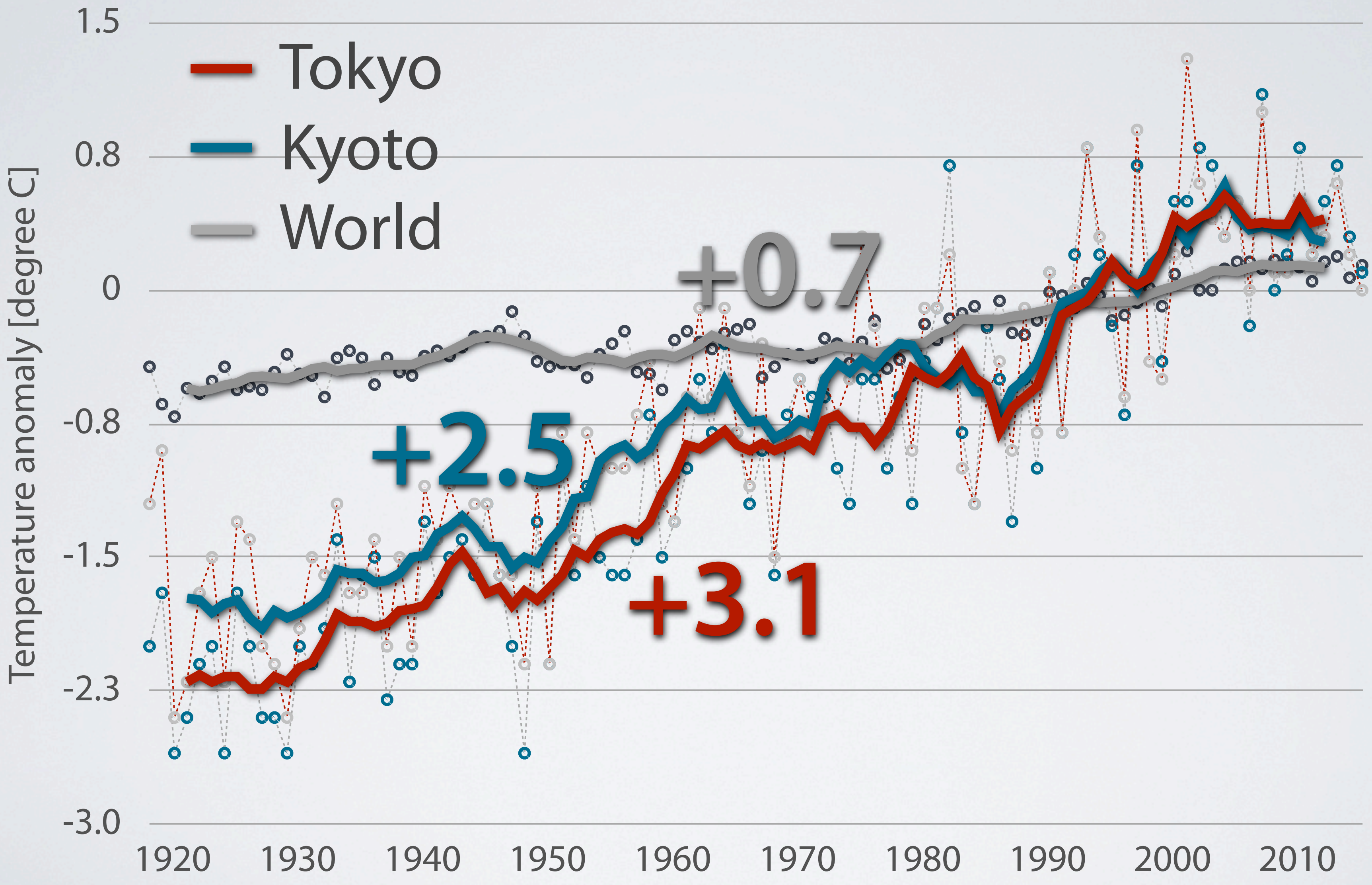
11 March 2013

Temperature trend



Problems caused by urban warming

Natural disasters

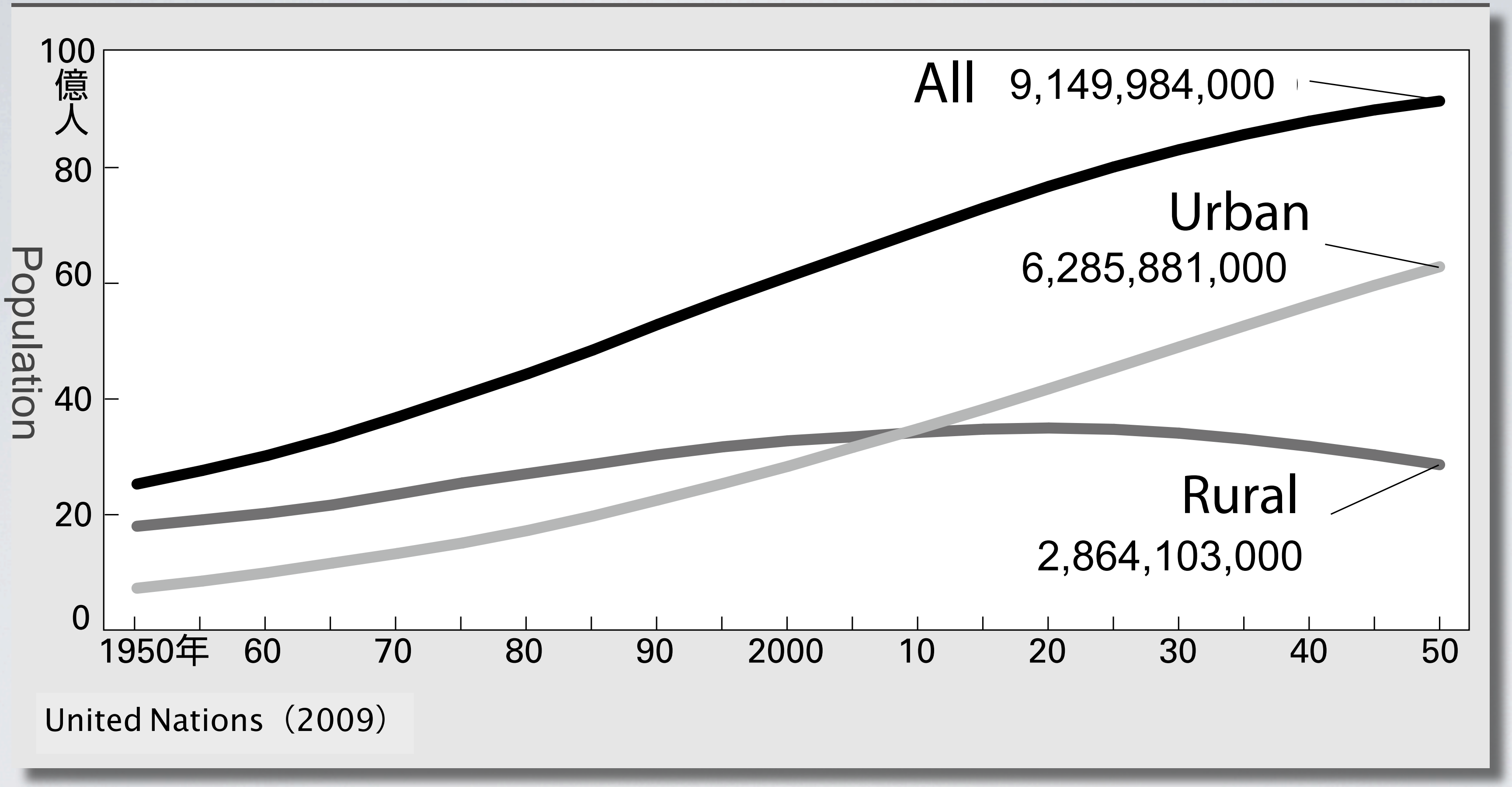
- ✓ Heavy rain
- ✓ Severe floods

Damage on health

- ✓ Heat stress / Heat stroke
- ✓ Disturbance in sleep
- ✓ Air pollution etc...

Other

- ✓ Increase of energy consumption



70% of population of the world will live in urban areas in 2050.
The present problems will grow and influence the lives of many people.

NRI NEWS

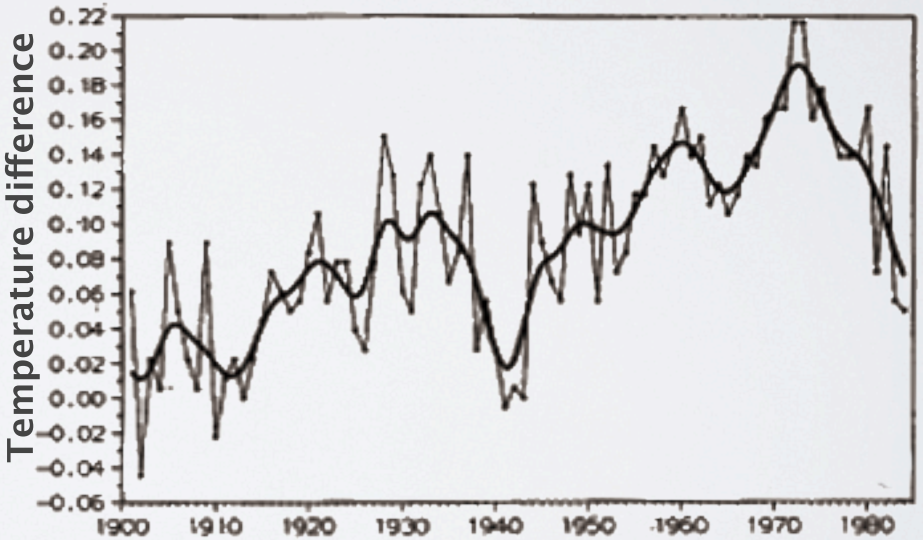
Measurement urban warming

Heat island intensity: $\Delta T = T_{urban} - T_{rural}$

Hypothesis

- ✓ NOT urbanized and natural climate in rural sites
- ✓ Same geography (topography, water bodies, ..)

(Karl et al. 1988, Park et al. 1994, Fujibe 1995)



Time series of the average urban minus rural temperature difference in U.S. (Karl et al. 1988)

Geographical effect

One of the main difficulties to estimate urban warming is the geographical setting.

The magnitude of heat island may depend more on the local terrain than on the urban complex.

(Chandler 1964, Landsberg 1981)

Individuality of urban climate

Urban factors
- Land-use change
- High buildings
- Anthropogenic heat

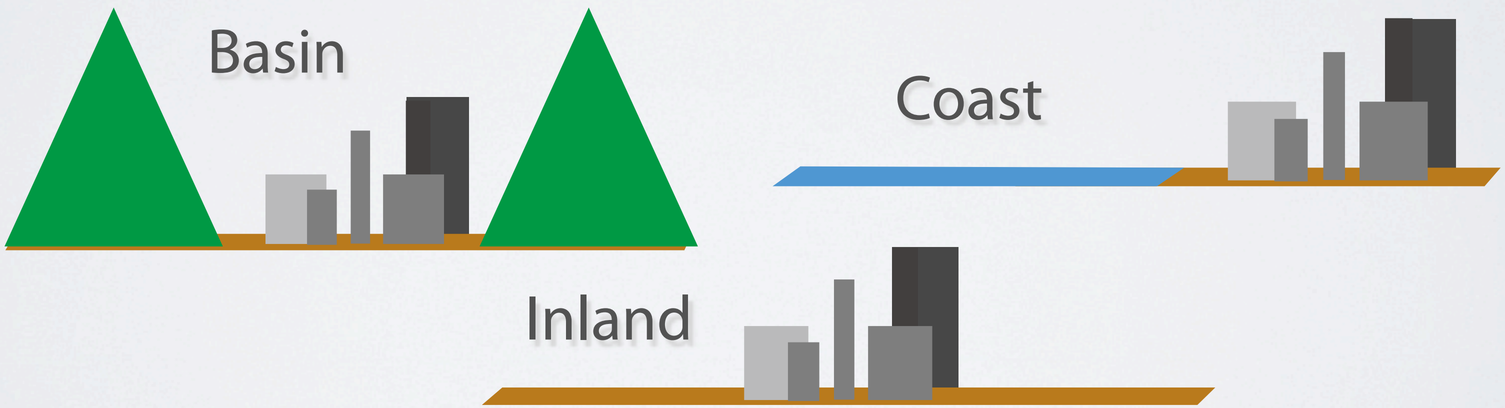
Geographical factors
- Terrain
- Relief
- Distance from coasts

Oke 1973
Goldreich 1984

Purpose

Comparing the geographical effects on urban warming has been insufficient, and the magnitude of the effect is unclear.

To reveal the difference of geographical effects, relationship between the temperature rising rate and urban surface coverage were compared between different geographical conditions.



Data and Methods

Temperature rising rate

Data	Observation data by the Japan Meteorological Agency
Methods	Trend estimated by principal component analysis

Urban surface coverage

Data	Digital national land information
Methods	Coverage index: $U(r) = \dfrac{\sum_g \exp[-(r_g/r)^2]u(g)A}{\pi r^2}$

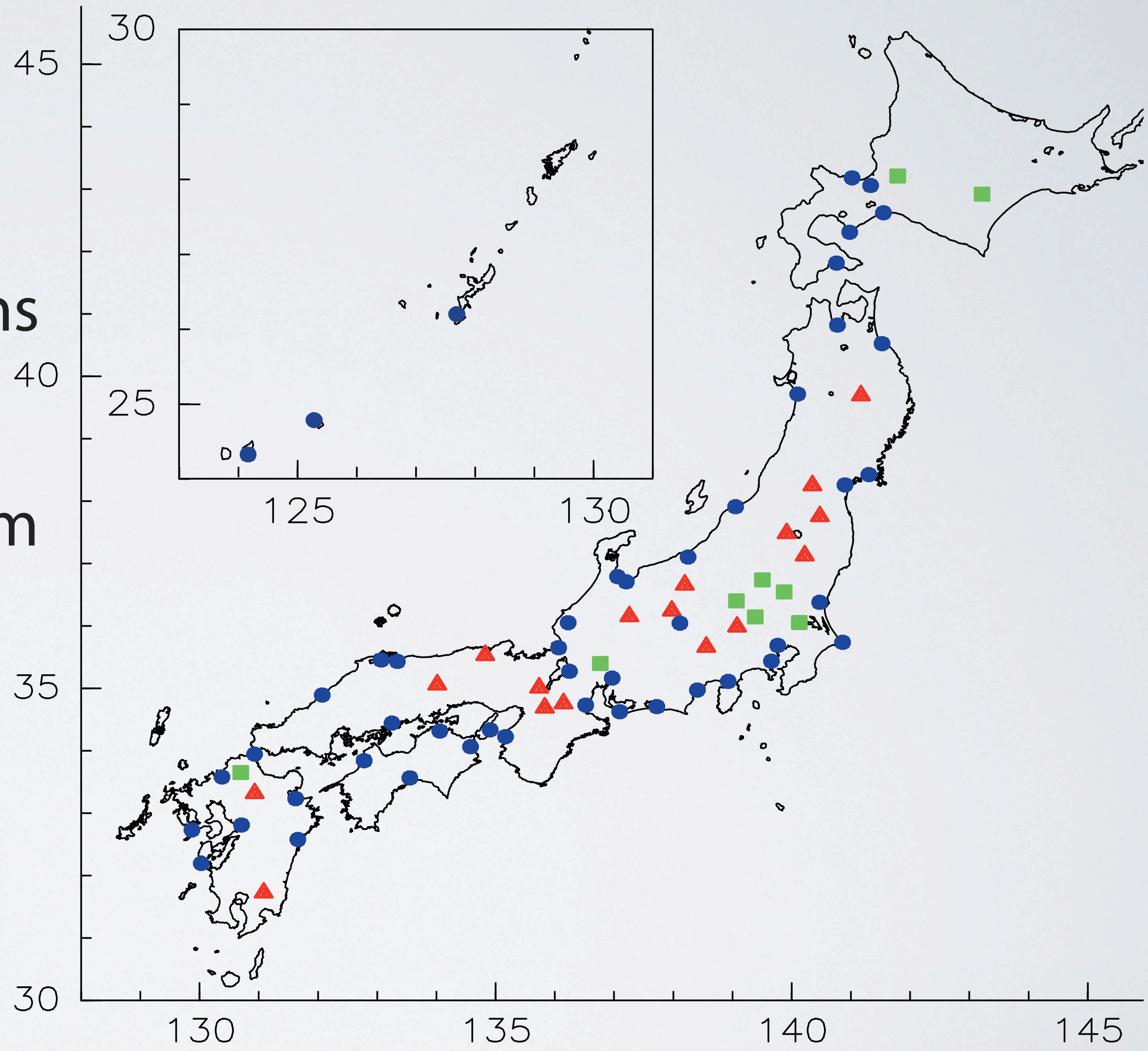
Park et al. 1994
Fujibe 2009

Geographical conditions

▲ Basin
surrounded by mountains

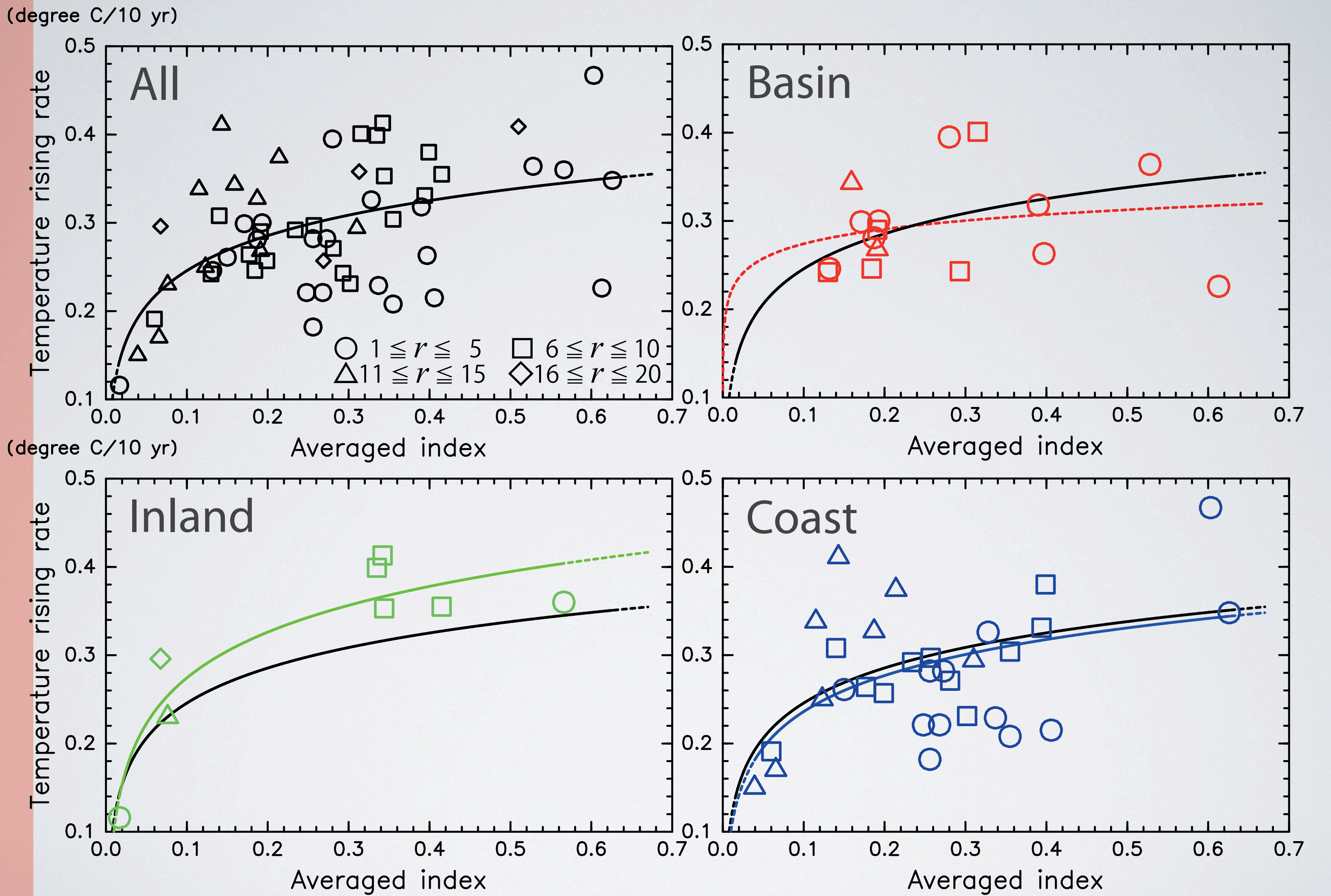
■ Inland
situated more than 20 km
from a coastline

● Coast
situated within 20 km
of a coastline



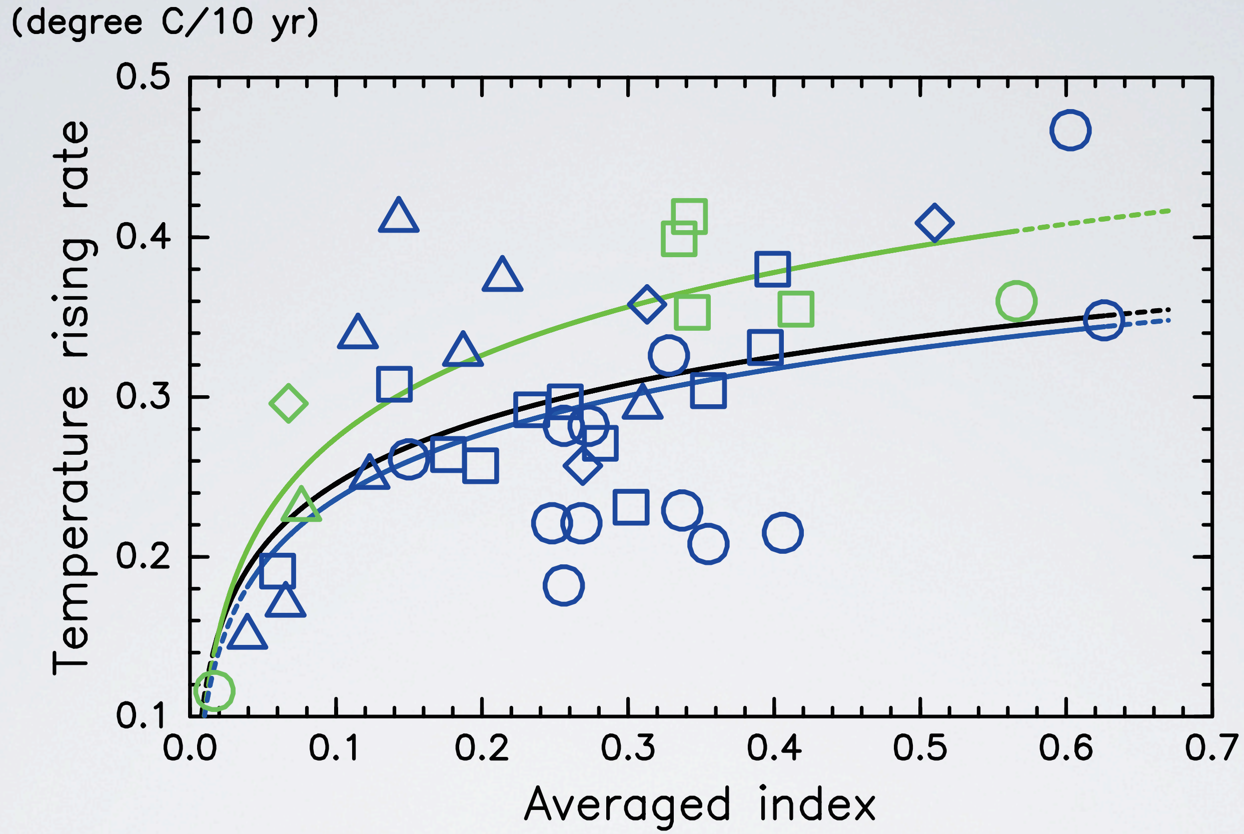
Results

(Focusing on mean temperature)

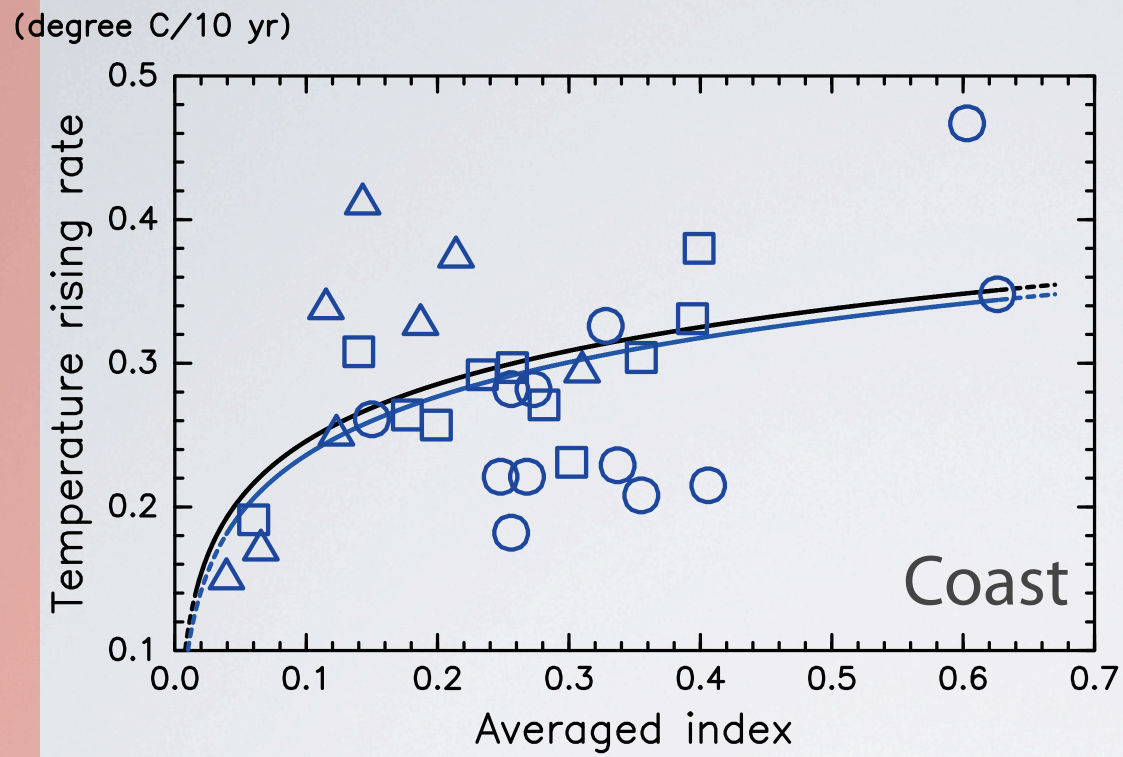


Temperature rising rate and averaged index

Mean Temp.



If the sites are occupied by the same area of urban surface, the temperature rises higher at inland sites than at coastal sites.



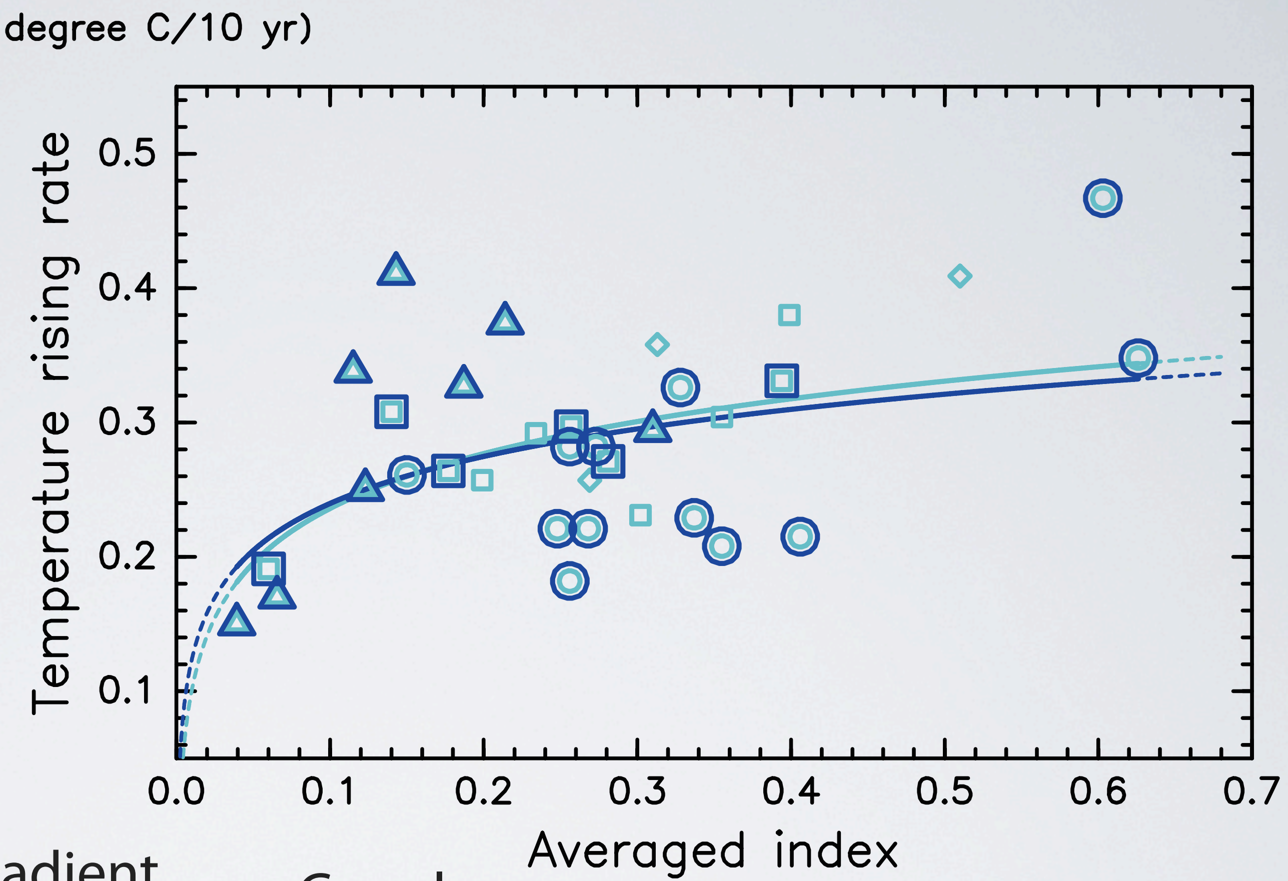
Local circulation may influence coastal sites.

Is the distance from the coast an important factor?

Correlation between the rising rate and the distance

Correlation was the strongest for the sites <u>within 7 km of the coast</u>.

For coastal sites

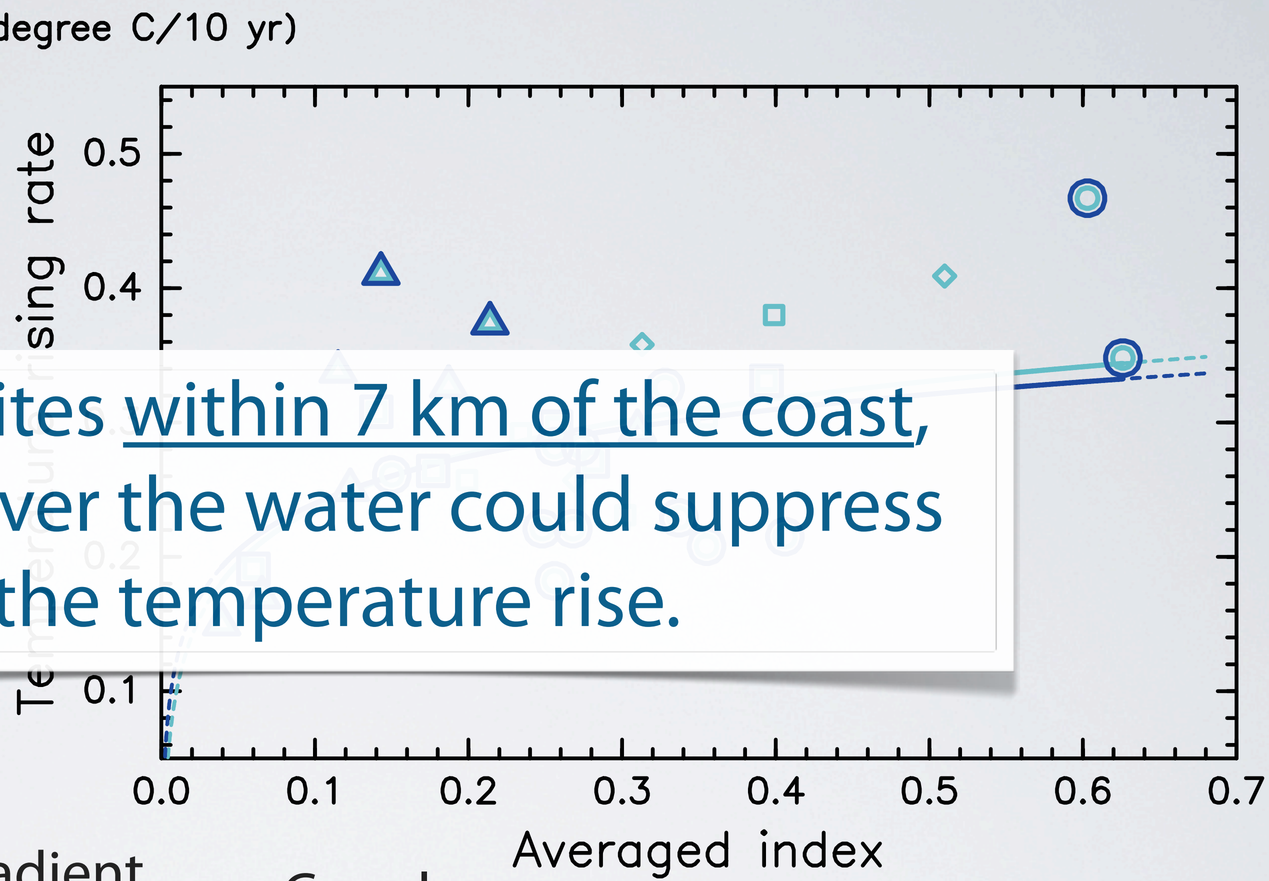


Site	Gradient [×10⁻² degree/log(index)]	Correl.
All ≦ 20 km (34)	5.9	0.49
Inlands ≦ 7 km (26)	5.1	0.45

at 5% significance level

Mean Temp.

For
coastal sites



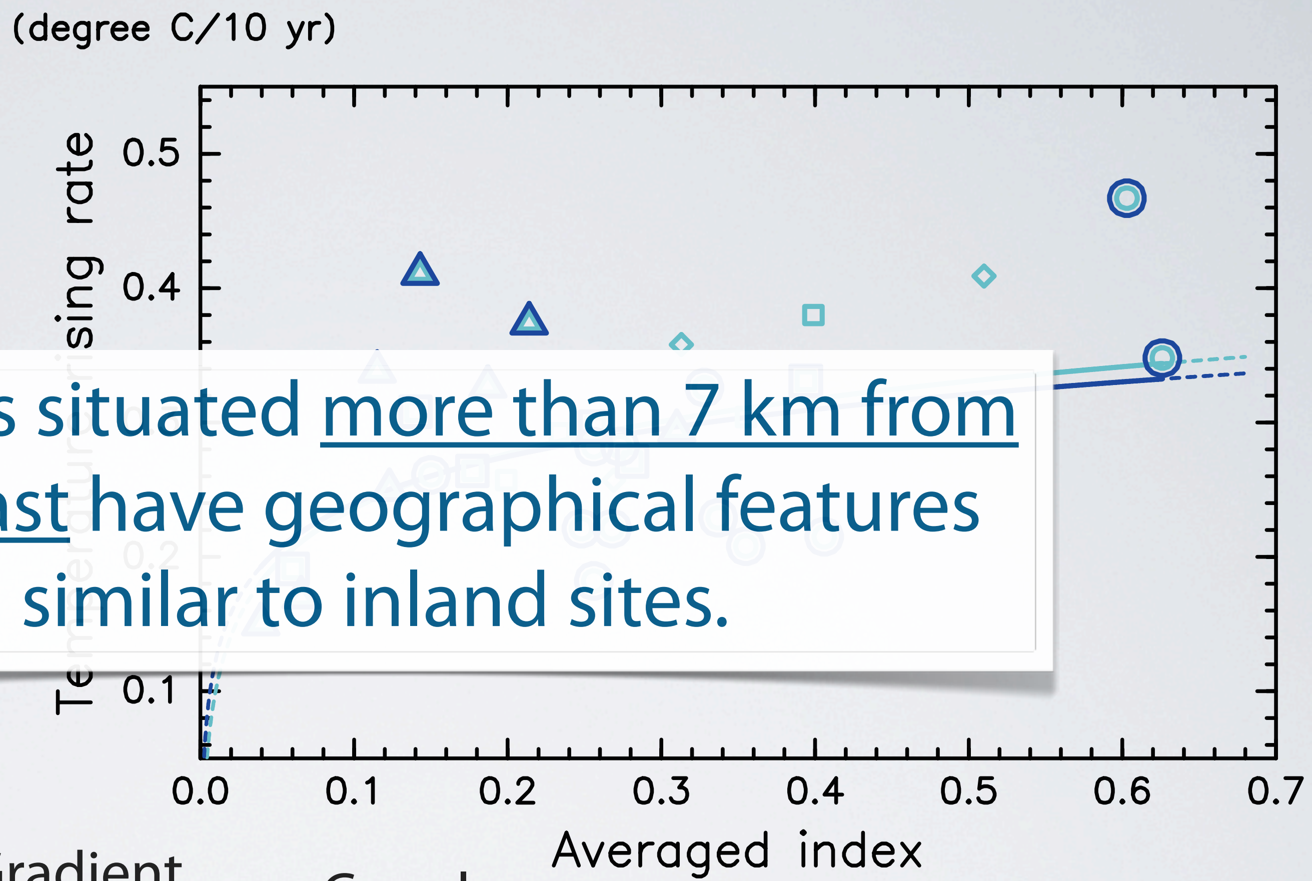
At the sites <u>within 7 km of the coast</u>, the air over the water could suppress the temperature rise.

Site	Gradient [×10^{-2} degree/log(index)]	Correl.
All ≦ 20 km (34)	5.9	0.49
Inlands ≦ 7 km (26)	5.1	0.45

at 5% significance level

Mean Temp.

For
coastal sites



The sites situated more than 7 km from the coast have geographical features similar to inland sites.

Site	Gradient [×10^{-2} degree/log(index)]	Correl.
All ≦ 20 km (34)	5.9	0.49
Inlands ≦ 7 km (26)	5.1	0.45

at 5% significance level

Mean Temp.

Conclusion

To reveal the difference of geographical effects, relationship between the temperature rising rate and urban surface coverage were compared between different geographical conditions.

- ✓ Significant positive correlations were shown for inland and coastal sites. The gradient is higher for the inlands than coasts.
- ✓ The sites situated within 7 km of the coast, could be influenced by the air over the water to suppress the temperature rise.
- ✓ The sites situated more than 7 km, are considered to have geographical features similar to those of the inlands.

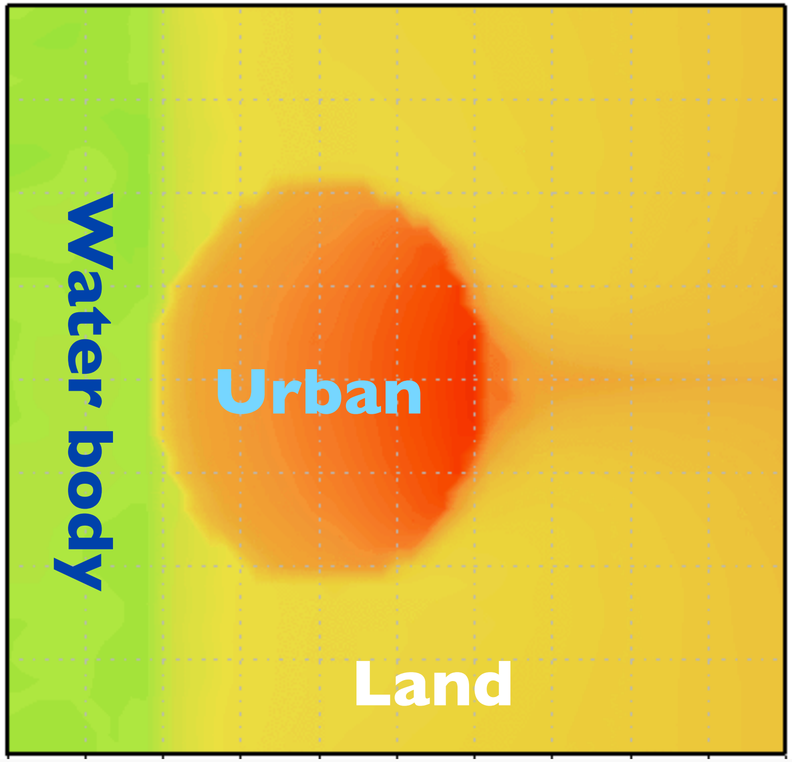
Future plans

Represent urban climate under various geographical conditions
using a regional atmospheric model

- ✓ Reveal the mechanisms
- ✓ Make general expression
  for urban climate with geographical conditions

Result example

Daily variation of surface air temperature



Thank you for your attention.

Feel free to contact me
if you have any questions or comments.

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