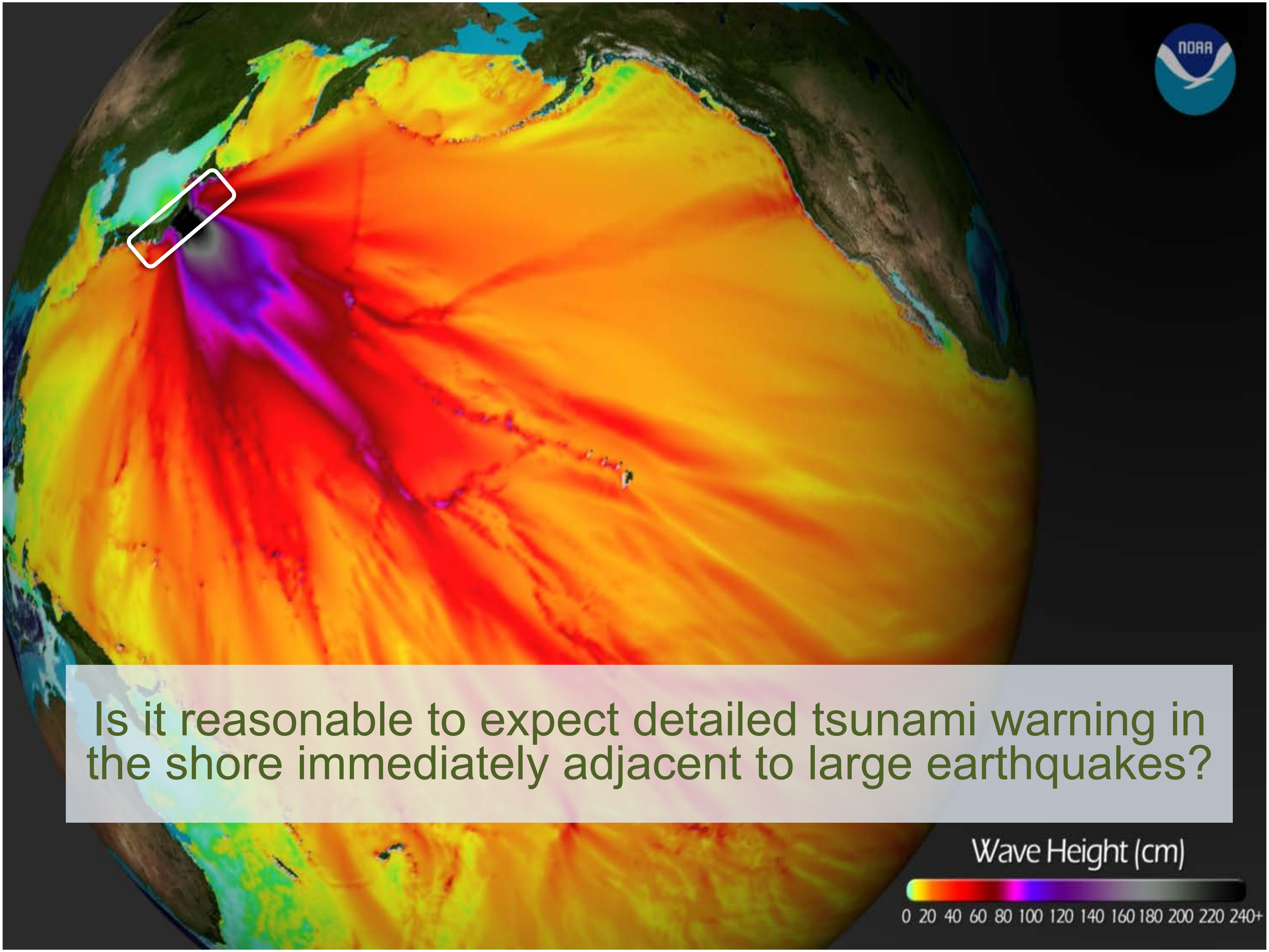
GPS and Tsunami Early Warning

Diego Melgar



Is it reasonable to expect detailed tsunami warning in the shore immediately adjacent to large earthquakes?

The Early Warning System in Japan

THE NEW TSUNAMI WARNING SYSTEM OF THE JAPAN METEROLOGICAL AGENCY

Hidee Tatehata
Earthquake and Tsunami Observation Division
Seismological and Volcanological Department
Japan Meterological Agency

Science of Tsunami Hazards, 1998

distance is close to make this approximation formula applicable, then the wave heights can be represented as f(x0) and f(x1). When another tsunami occurs at the hypocenter (x) where divided with k:(1-k), tsunami height f(x) will be estimated easily with this approximation formula. It is easy to expand this approximation theory into the X-Y coordinates as is clear from the Fig.3. In the same way, the wave heights or tsunami arrival times of any tsunamis generated in the four hypocenters can be estimated with the next approximation formula:

$$f(x,y)=(1-l)\{(1-k)f(x_0,y_0)+k\ f(x_1,y_0)\}+l\{(1-k)\ f(x_0,y_1)+k\ f(x_1,y_1)\}.$$

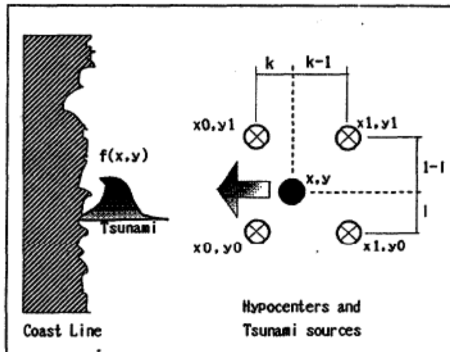


Fig.3 The concept of the interpolation theory on 2 dimensional coordinates.

As an expansion of this theory, the approximation formula does not include only any hypocenters but also magnitude, fault depth and etc. But it is needless to say that a great number of the tsunami simulations are required to make precise forecast for all of the earthquakes and generated tsunamis around Japan like as shown in schematic Fig.4. A white circle denotes a hypocenter for the tsunami simulation.

Specifically, many tsunami simulation output files are fulfilled as in Fig.5. A white circle means a data file related to the tsunami heights for the entire coast in Japan.

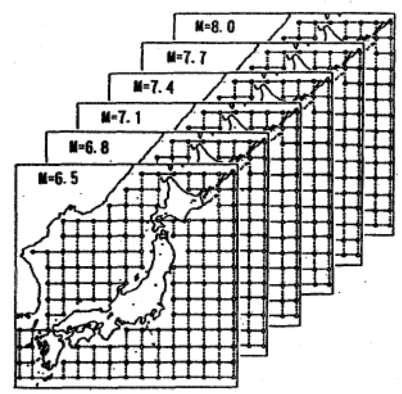
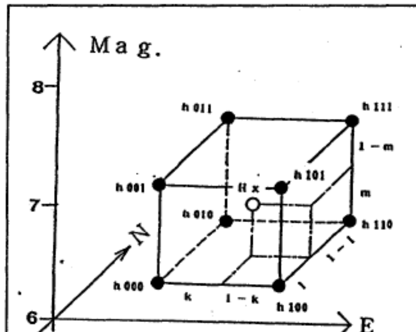


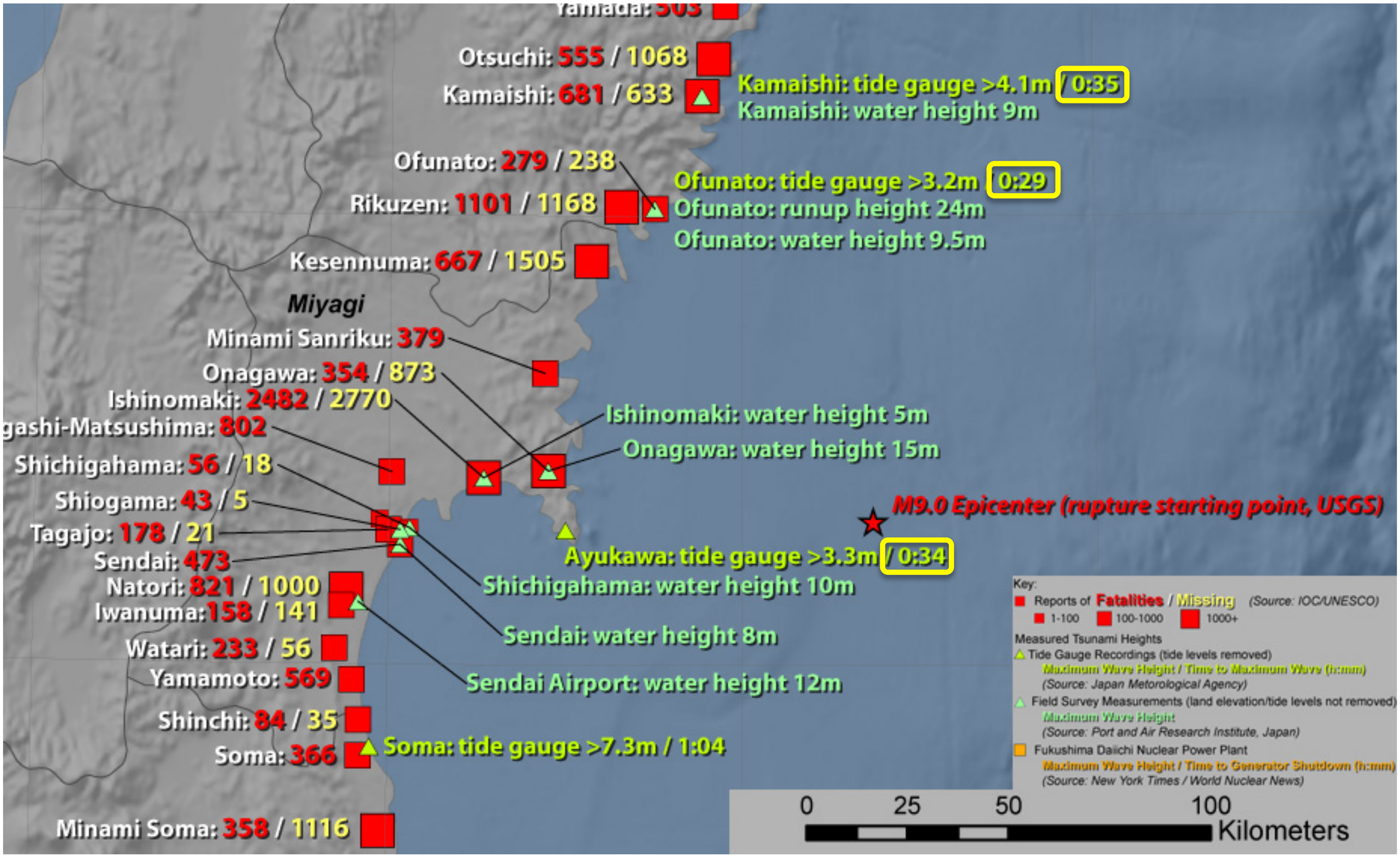
Fig.4 The structure of the data base for the tsunami forecast that are composed of many results of numerical simulations about various source parameters



$$Hx=[(1-l)\{(1-k)h000+kh100\}+l\{(1-k)h010+kh110\}]^{1-m}\ [(1-l)\{(1-k)h001+kh100\}+l\{(1-k)h010+kh111\}]^{m}$$

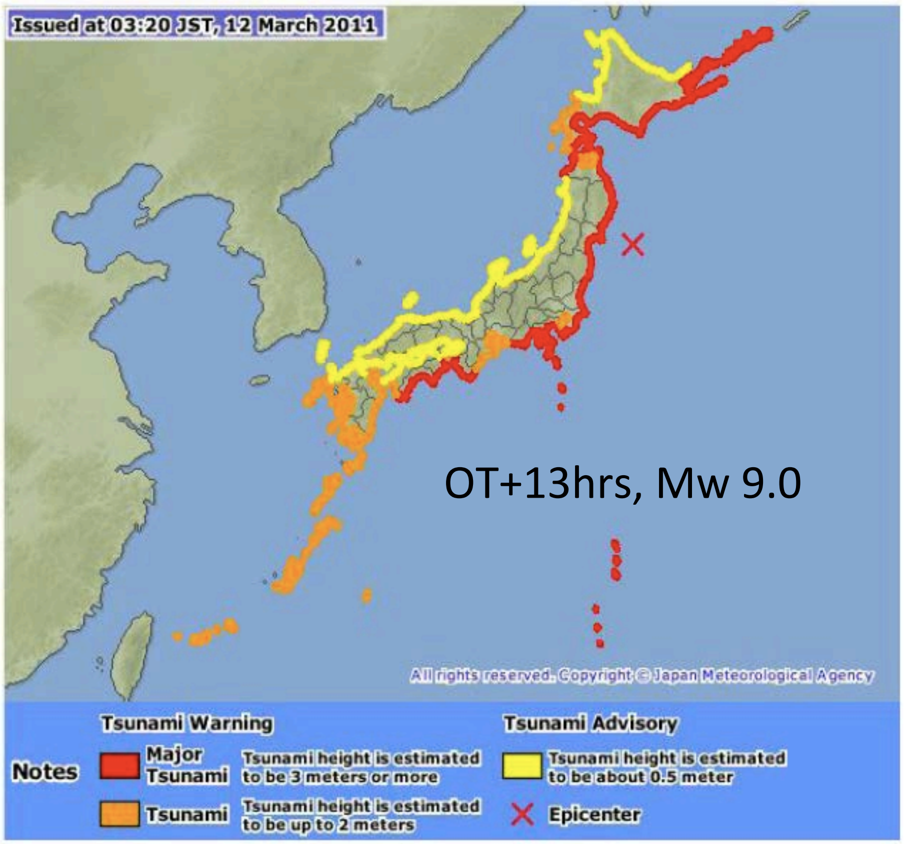
Fig.5 Illustration of the interpolation method presented with a geometrical diagram and an algebraic equation. Without any complicated numerical simulation, we can obtain a convenient approximation when an earthquake or a tsunami occurs.

Near-Field Tsunami Warning: The M9 2011 Tohoku-oki Event



Source: NGDC

Operational Near Source Tsunami Warning Times

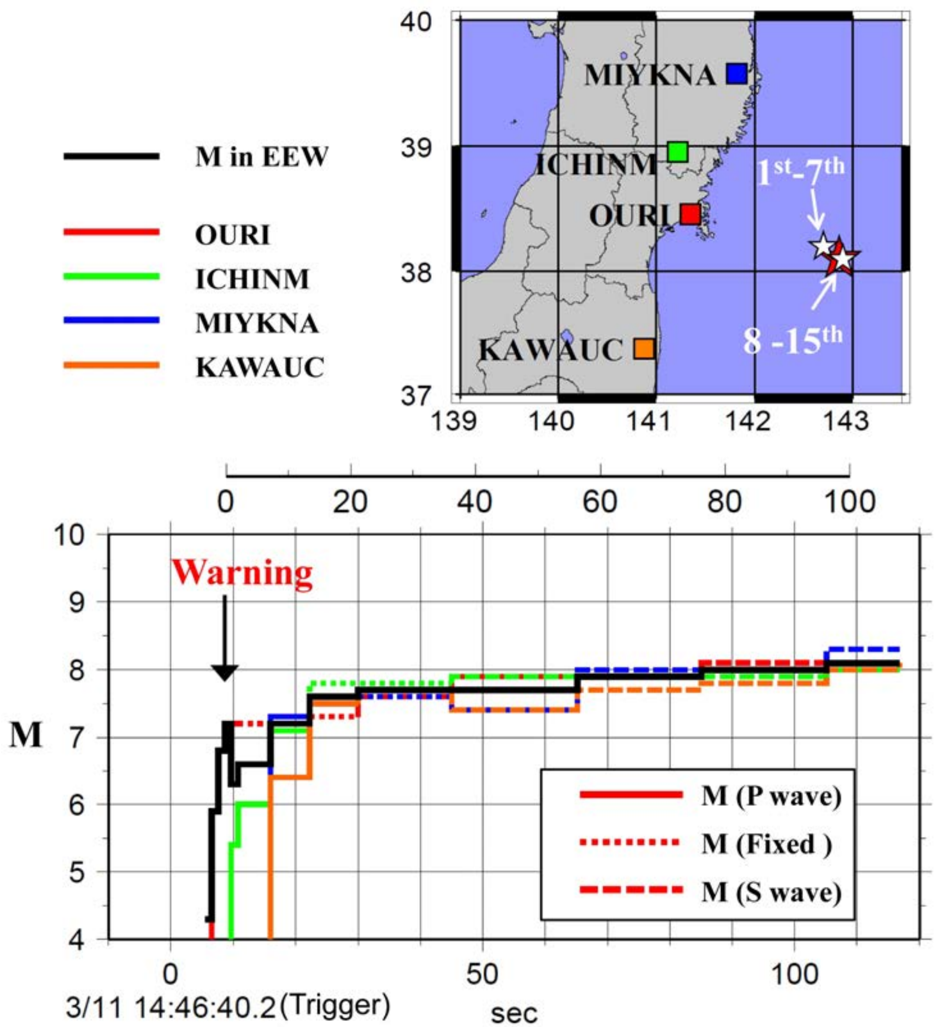


Ozaki, EPS , 2011

Warning updates at:

- OT+28mins
- OT+44mins
- OT+82mins
- OT+240mins
- OT+423mins
- OT+480mins
- OT+740mins

Why Were Early Magnitude Estimates so low?



Hoshiba et al, EPS , 2011

- The EQ source characterization system relies strictly on seismic stations.
- No GPS or off-shore wave gauge information is used.
- Magnitude saturation.

Seismic Sensors

- Two basic kinds, weak-motion and **strong**-motion.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

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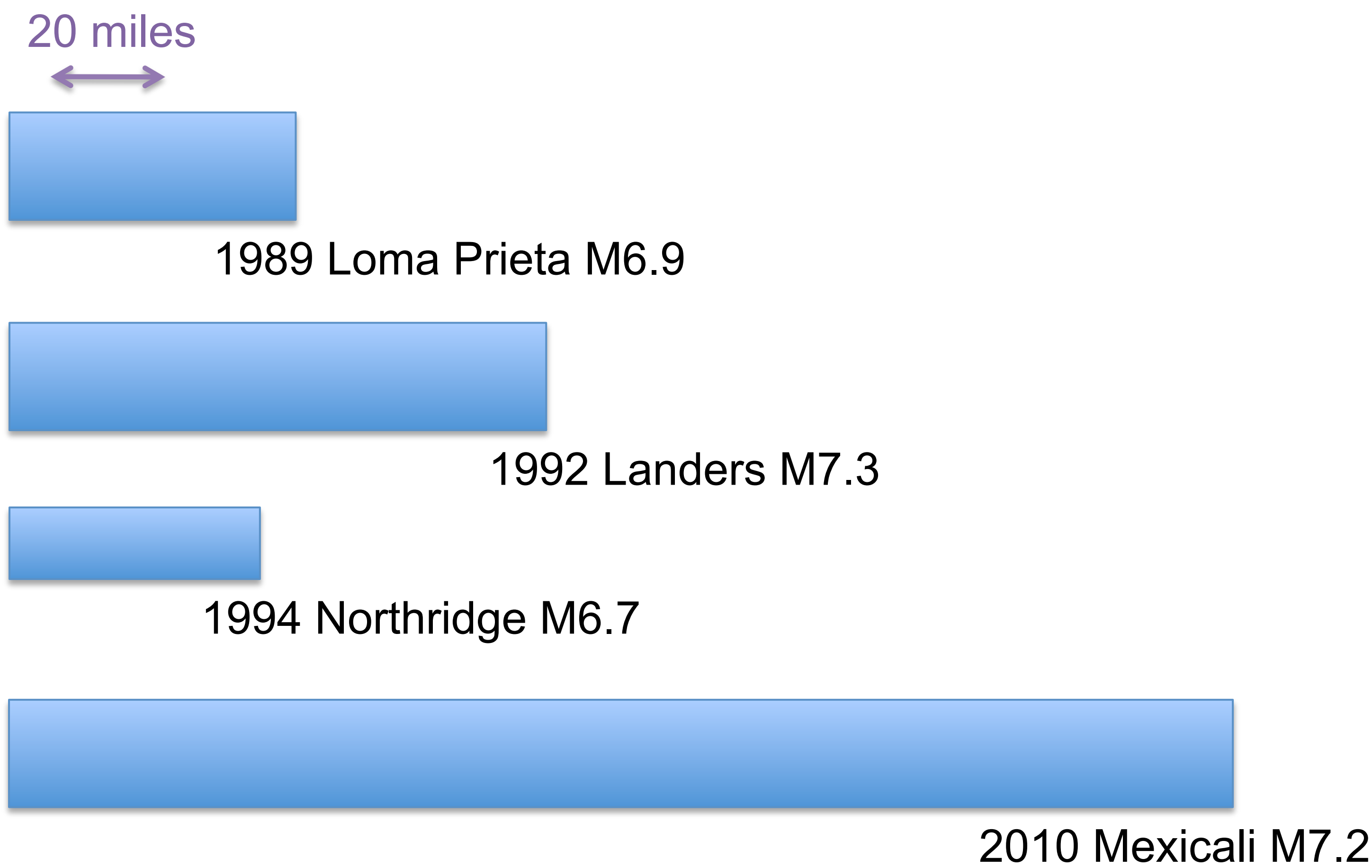
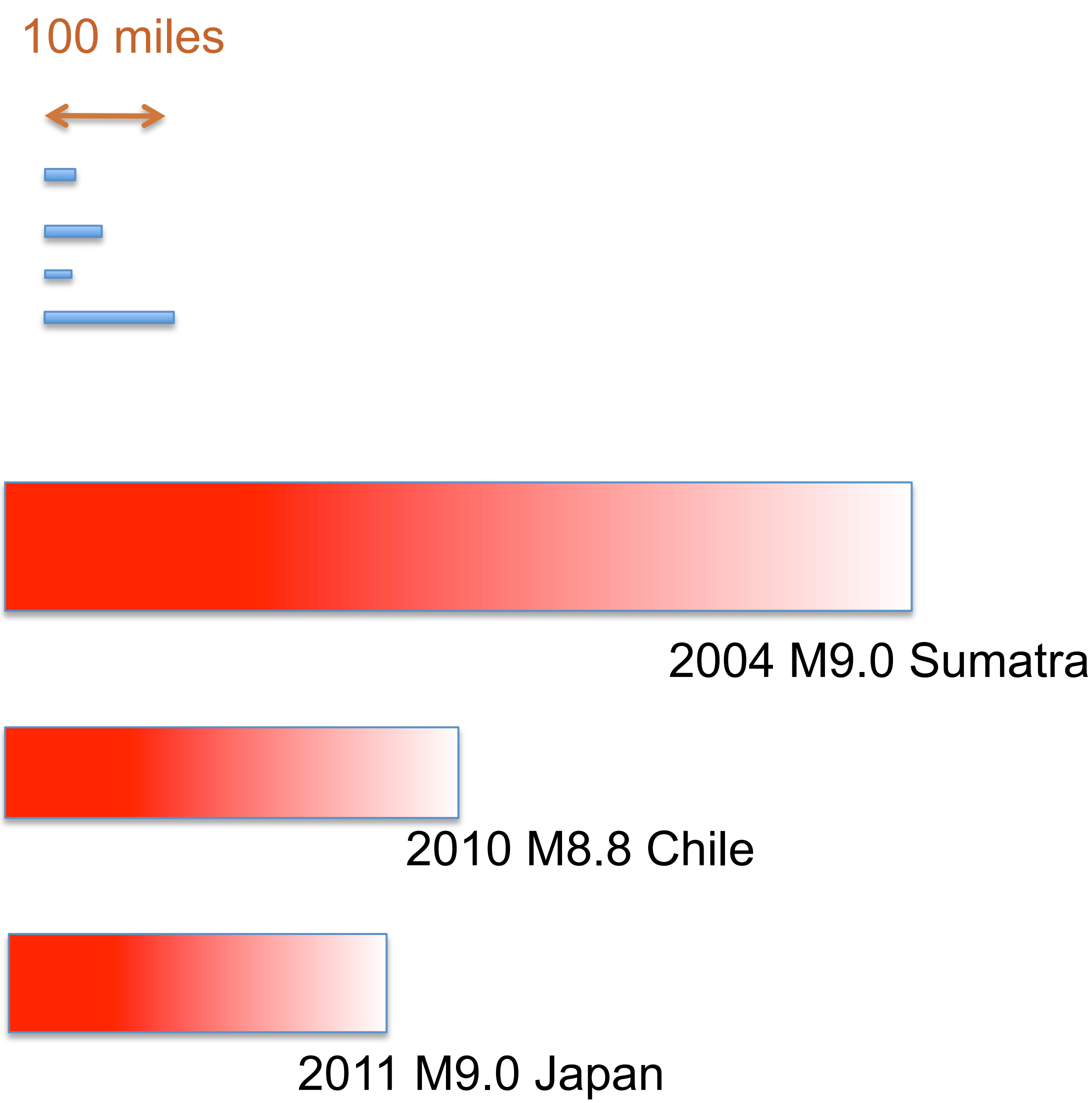
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

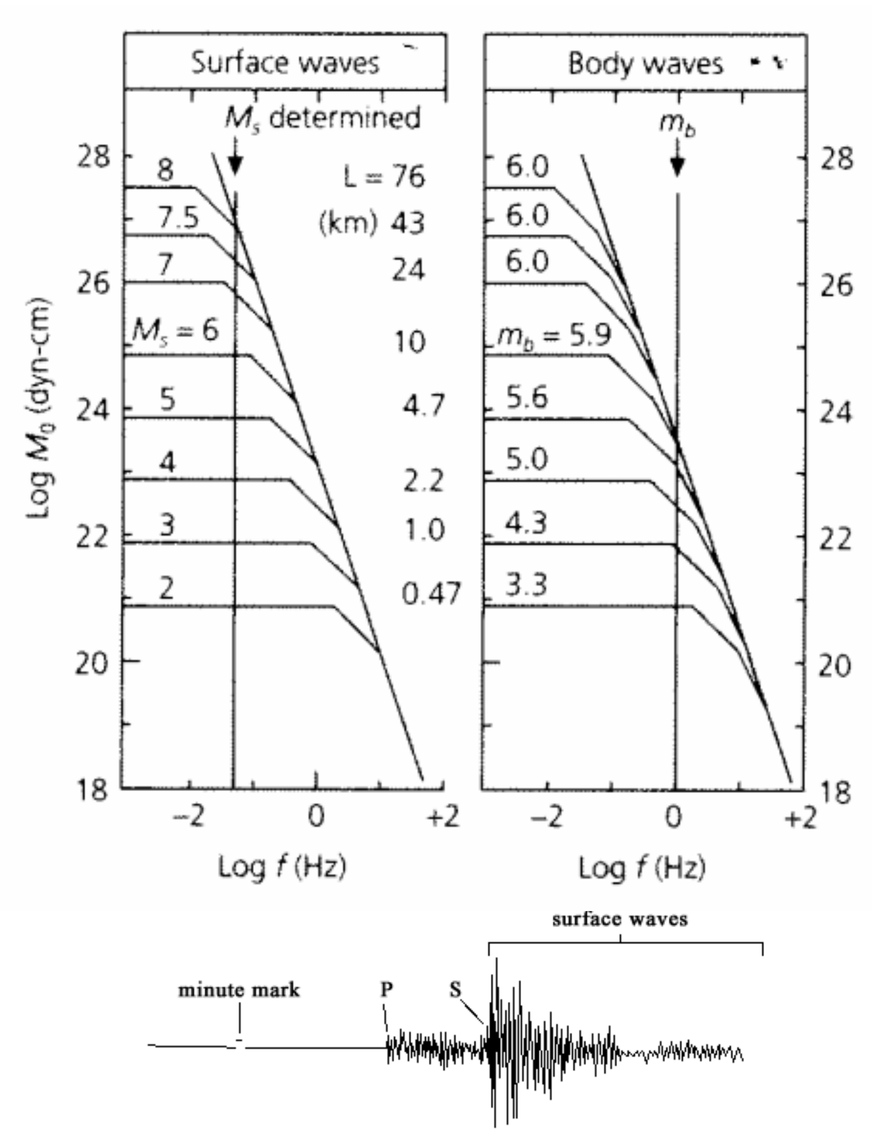
Why does Magnitude Saturate or Just how big are big earthquakes?



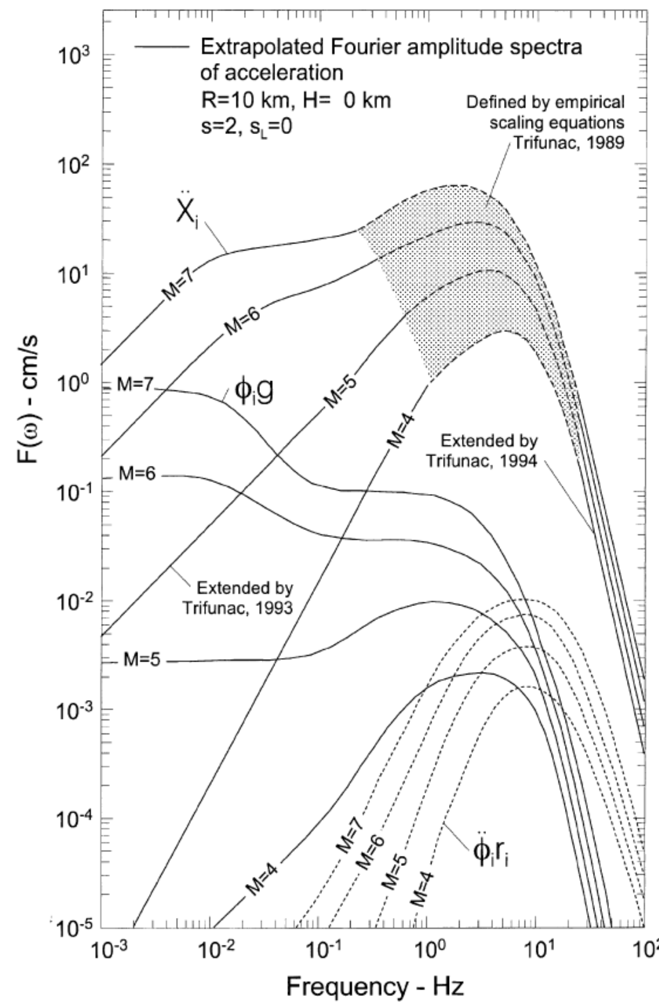
Just how big are big earthquakes?



Consequences for metrology

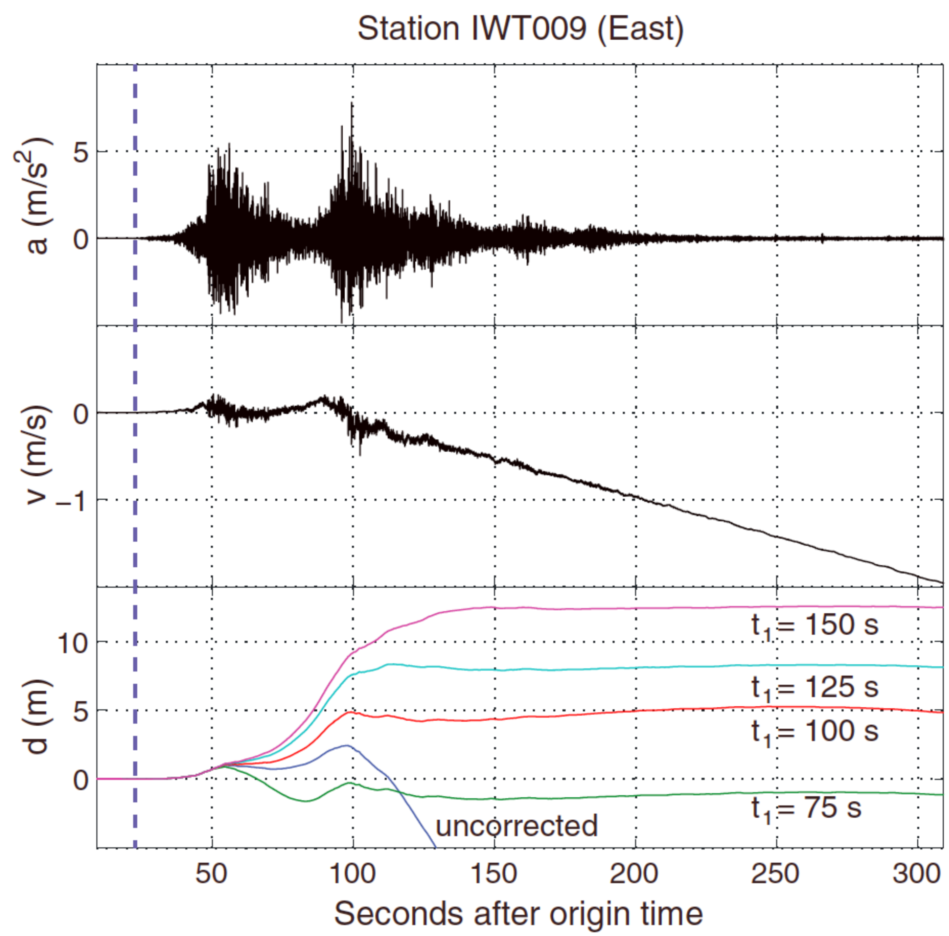


Stein & Wyssession, 2003

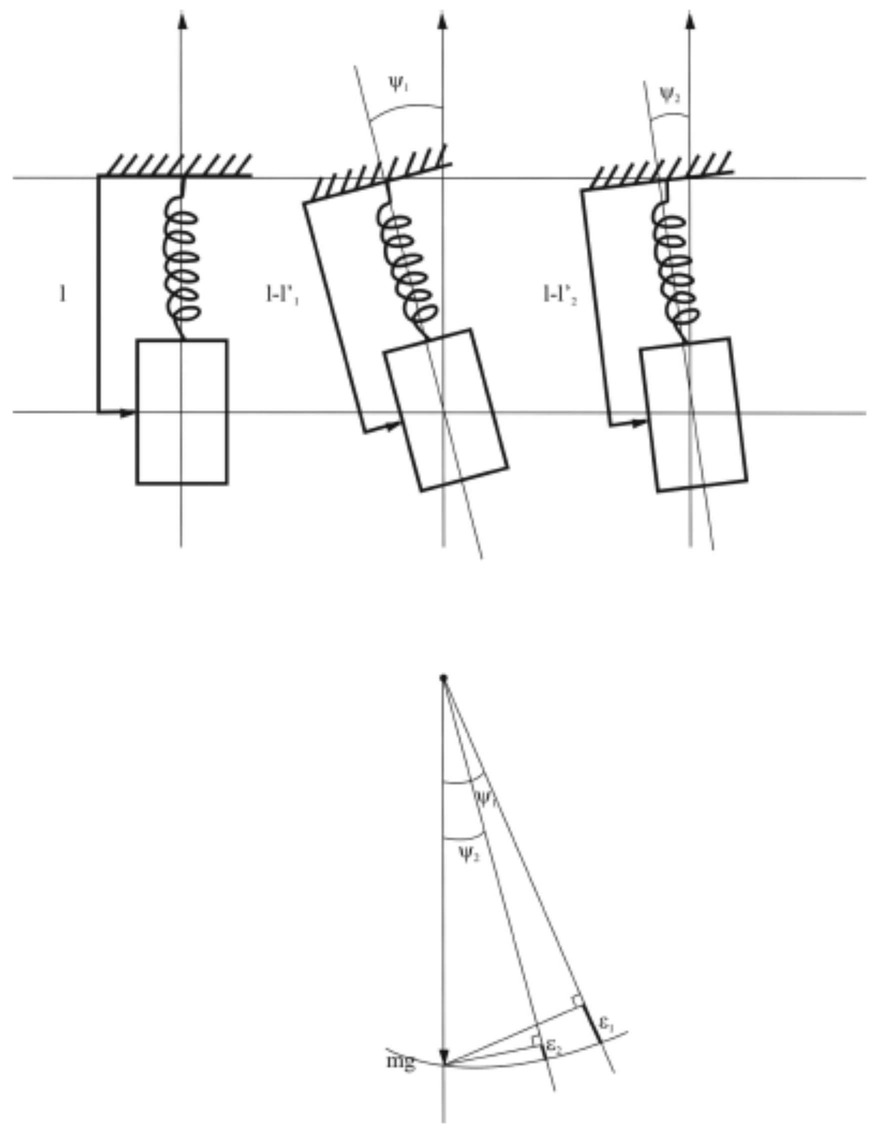


Trifunac & Todorovska, 2001, BSSA

Pesky rotations

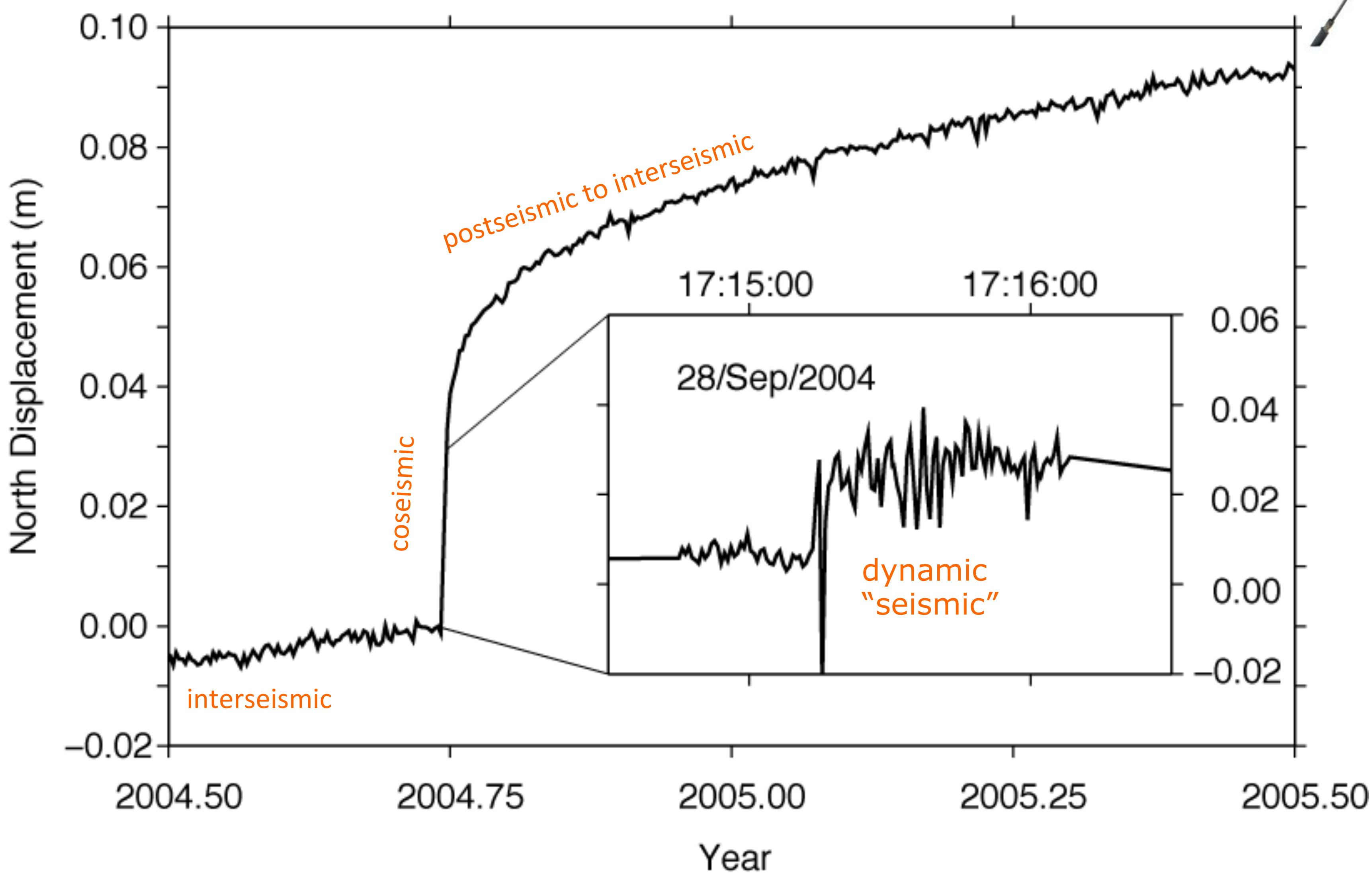


Melgar et al., 2013, JGR



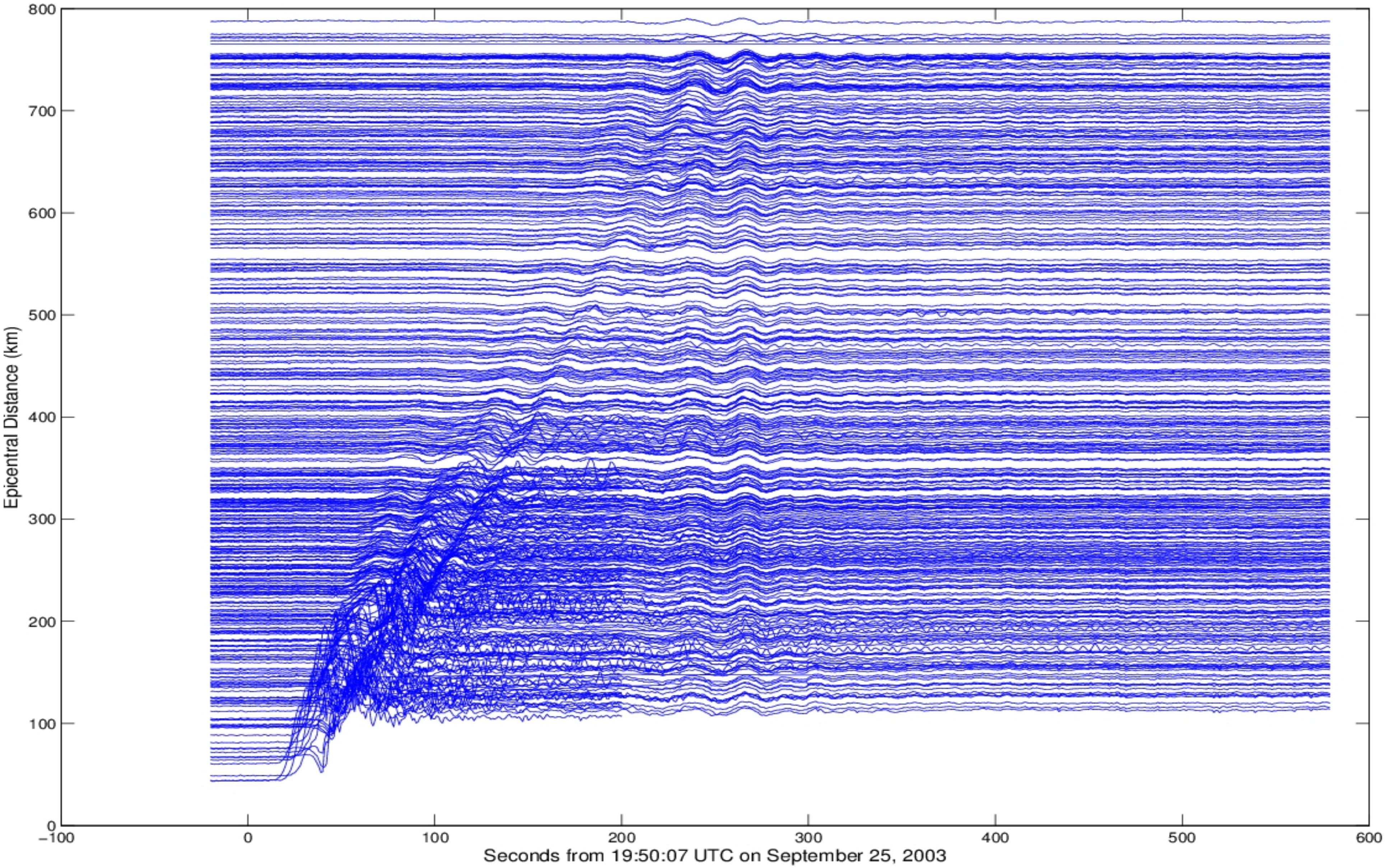
Pillet & Virieux, 2007

Earthquake Cycle Deformations Recorded with GPS



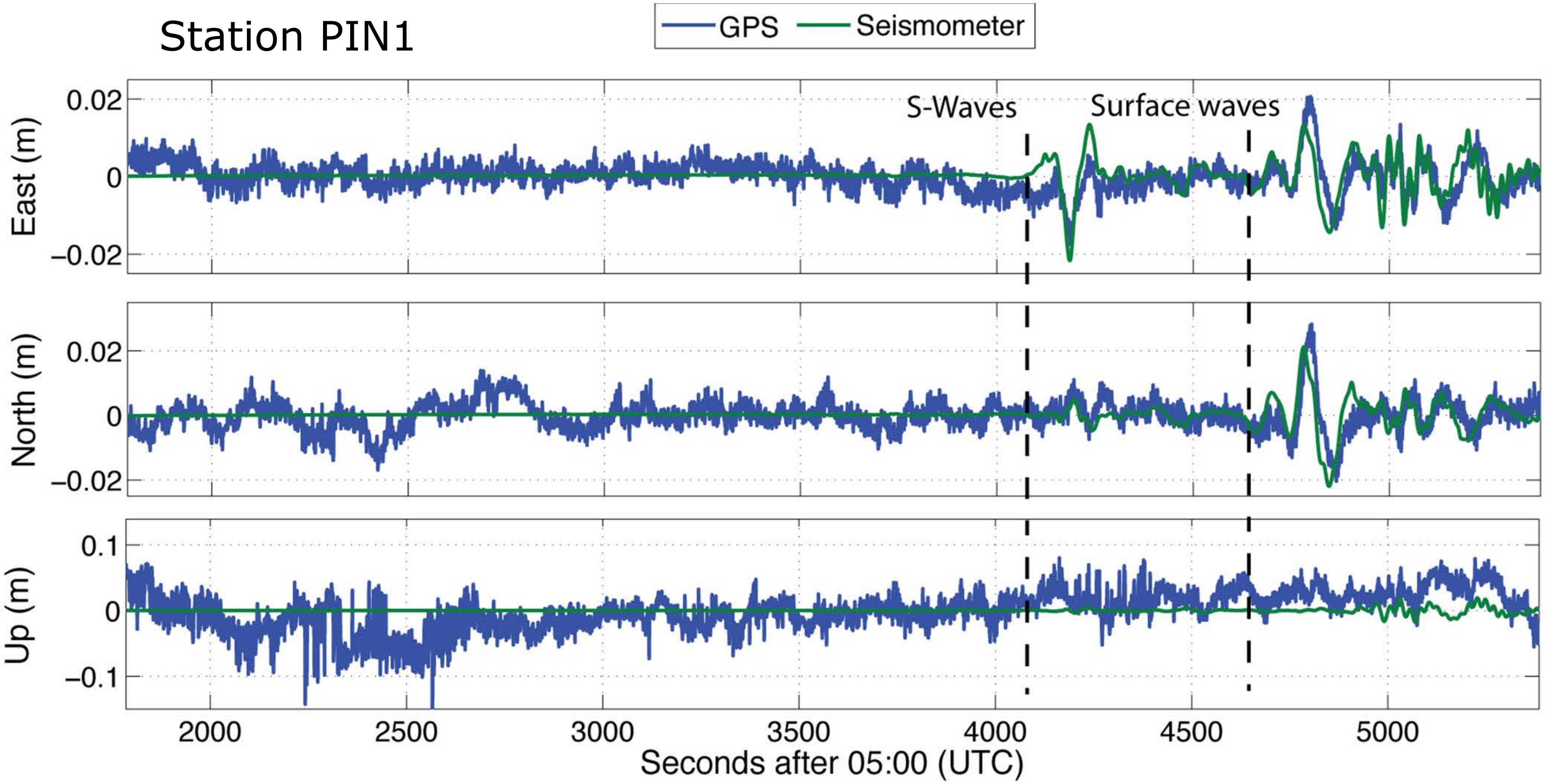
Bock et al., BSSA, 2011

A regional example, the Mw 8.3 Tokachi-oki event



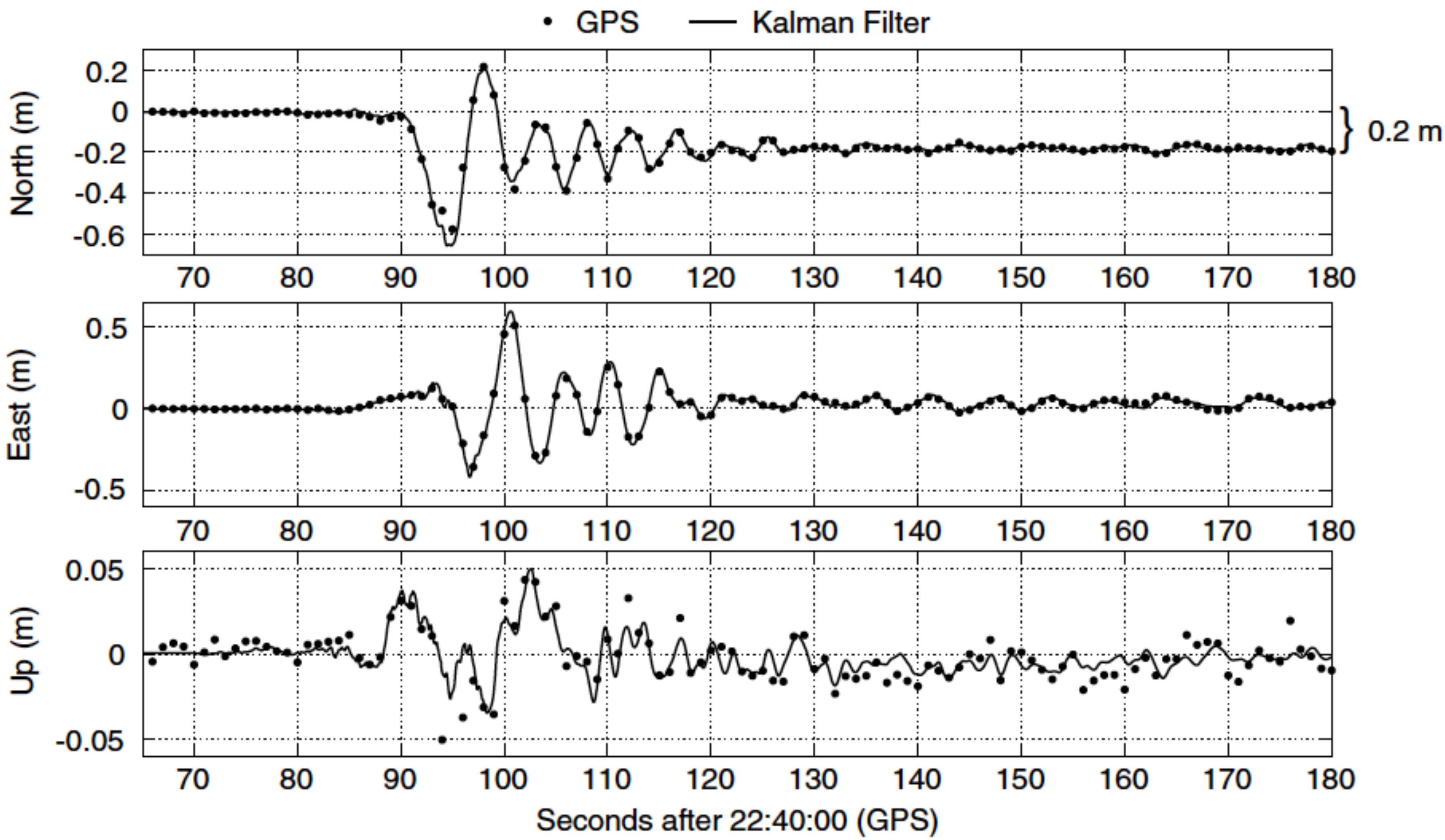
Unpublished

Teleseismic Data Example: Tohoku-oki EQ from California



Unpublished

One step Further: Seismogeodesy



\+

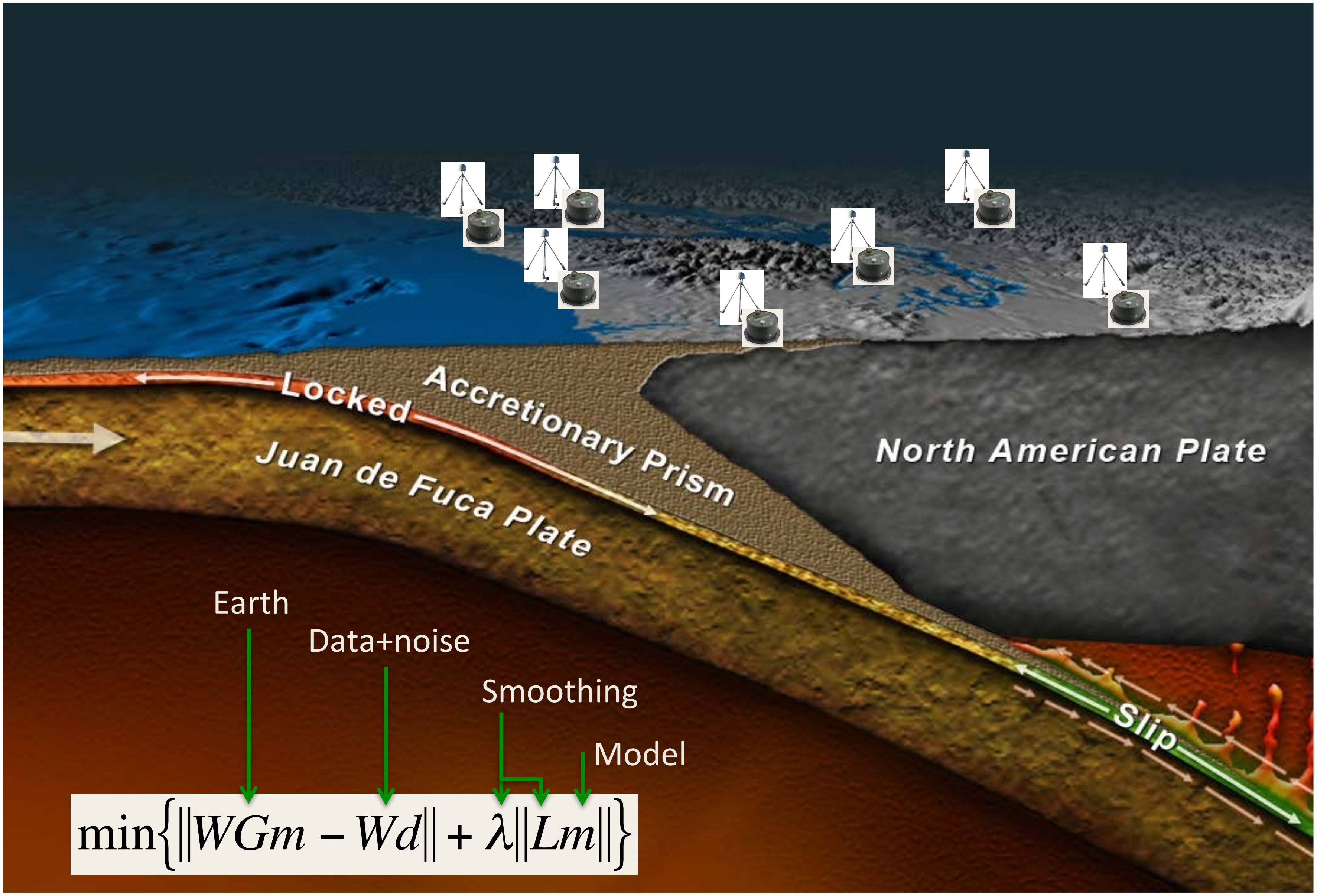
= 100Hz

1Hz

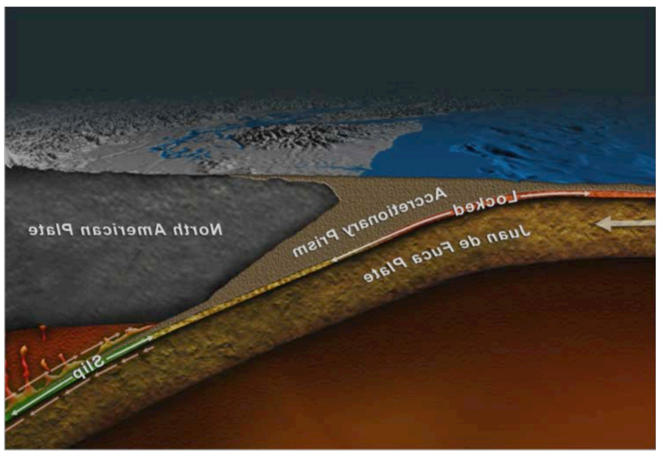
100Hz

Bock et al., 2011, BSSA
Melgar et al., 2013, JGR

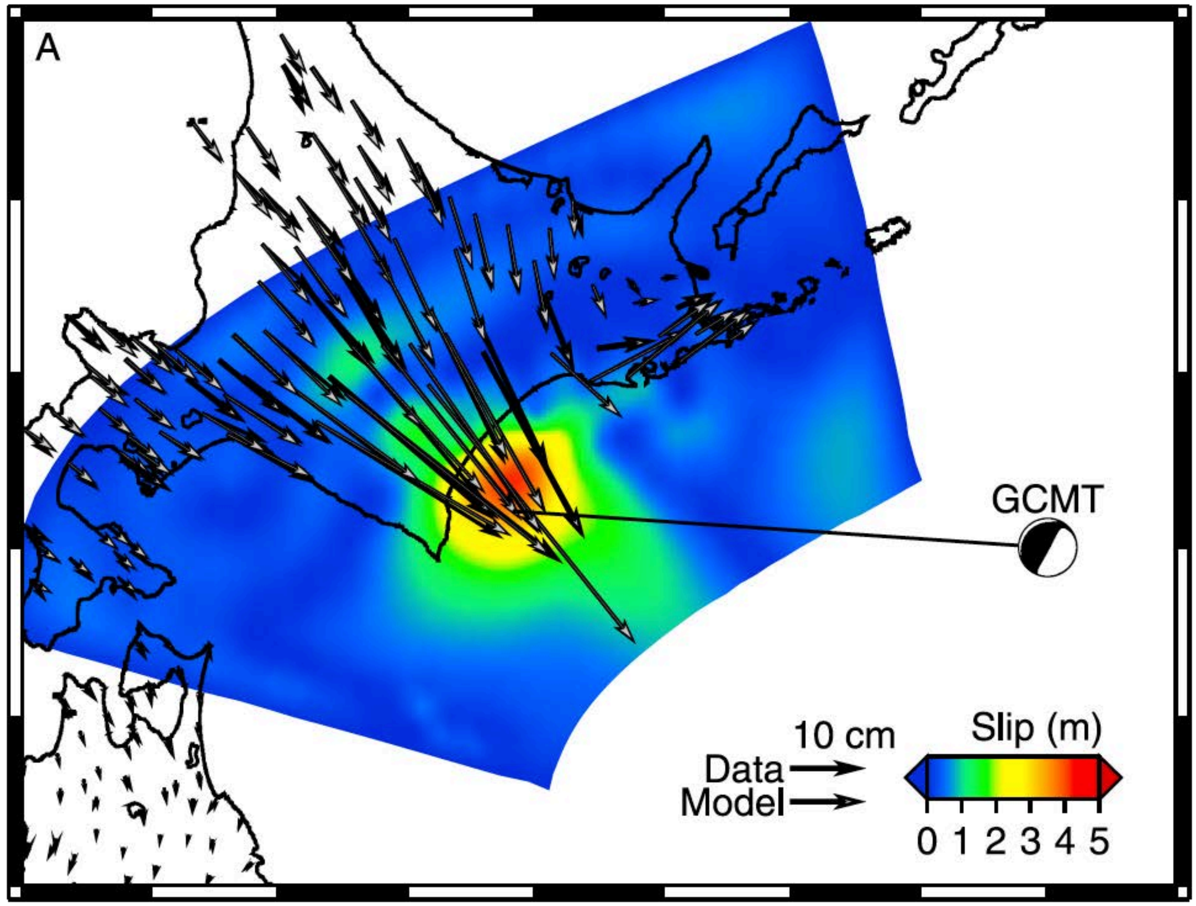
How do we Model the EQ Source?



Slip Inversions



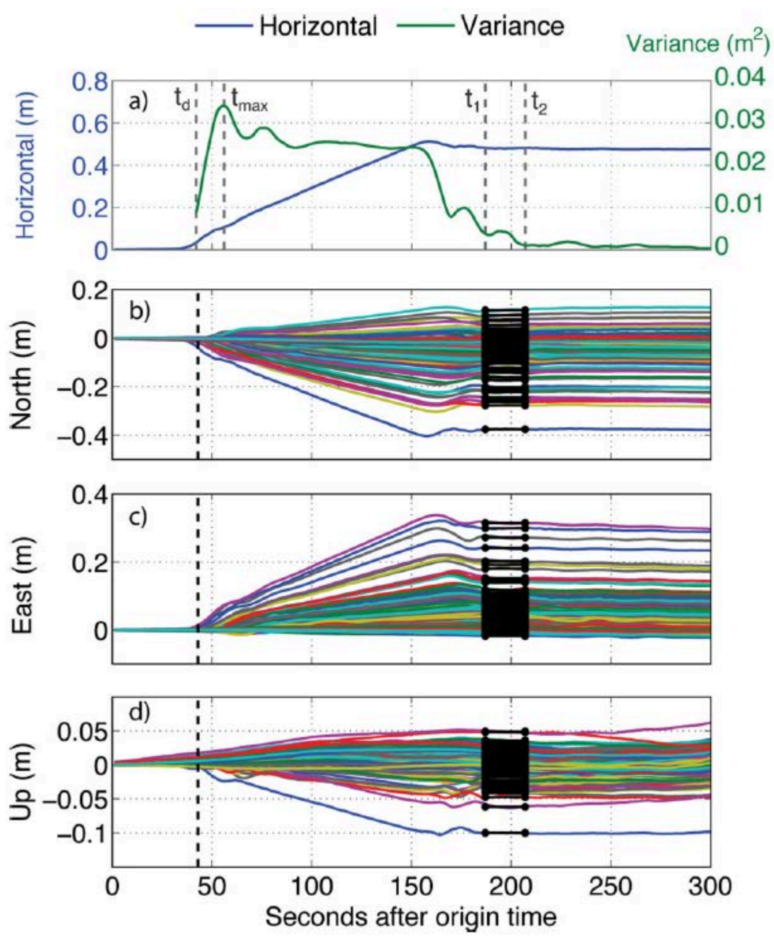
Mw 8.3 2003 Tokachi-oki



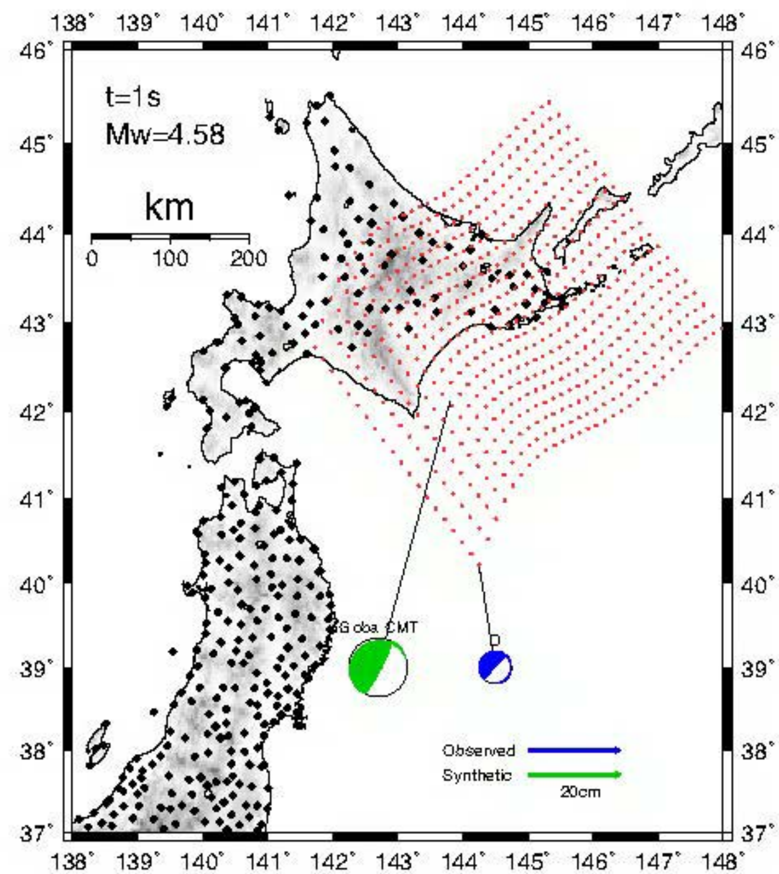
Crowell et al., 2012, GRL

Beachballs!

- Computing the moment tensor discriminates between types of earthquakes

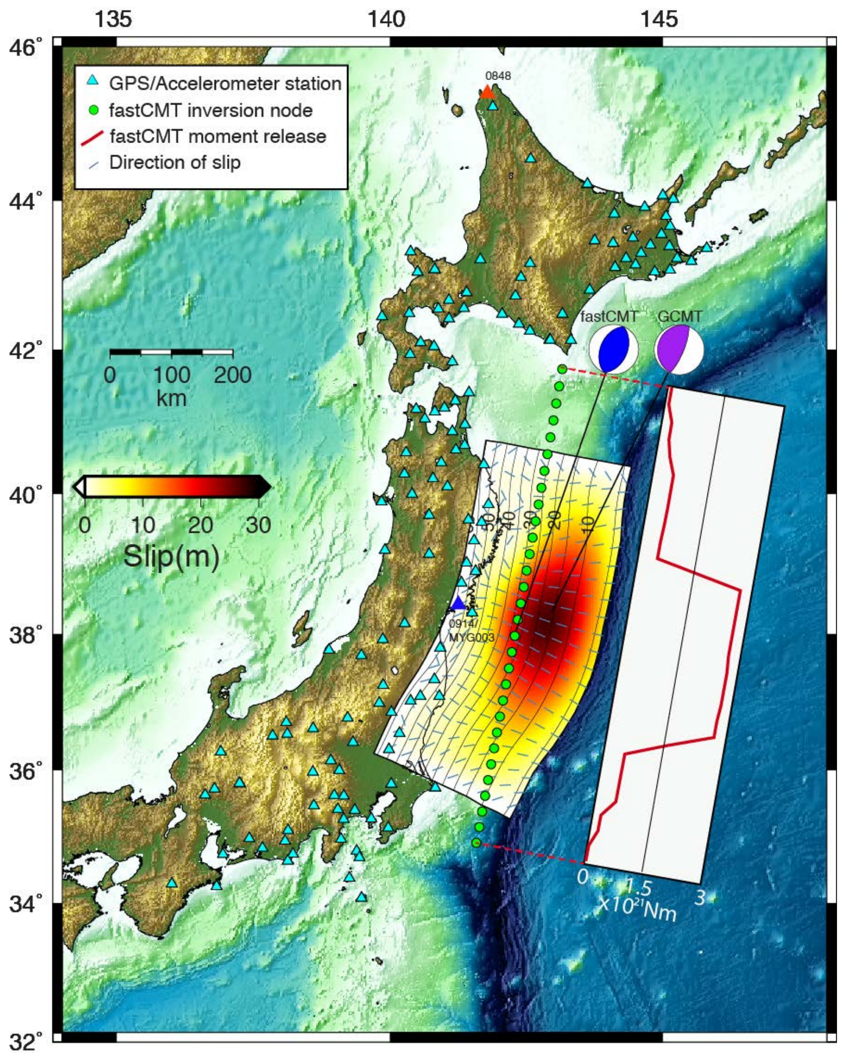


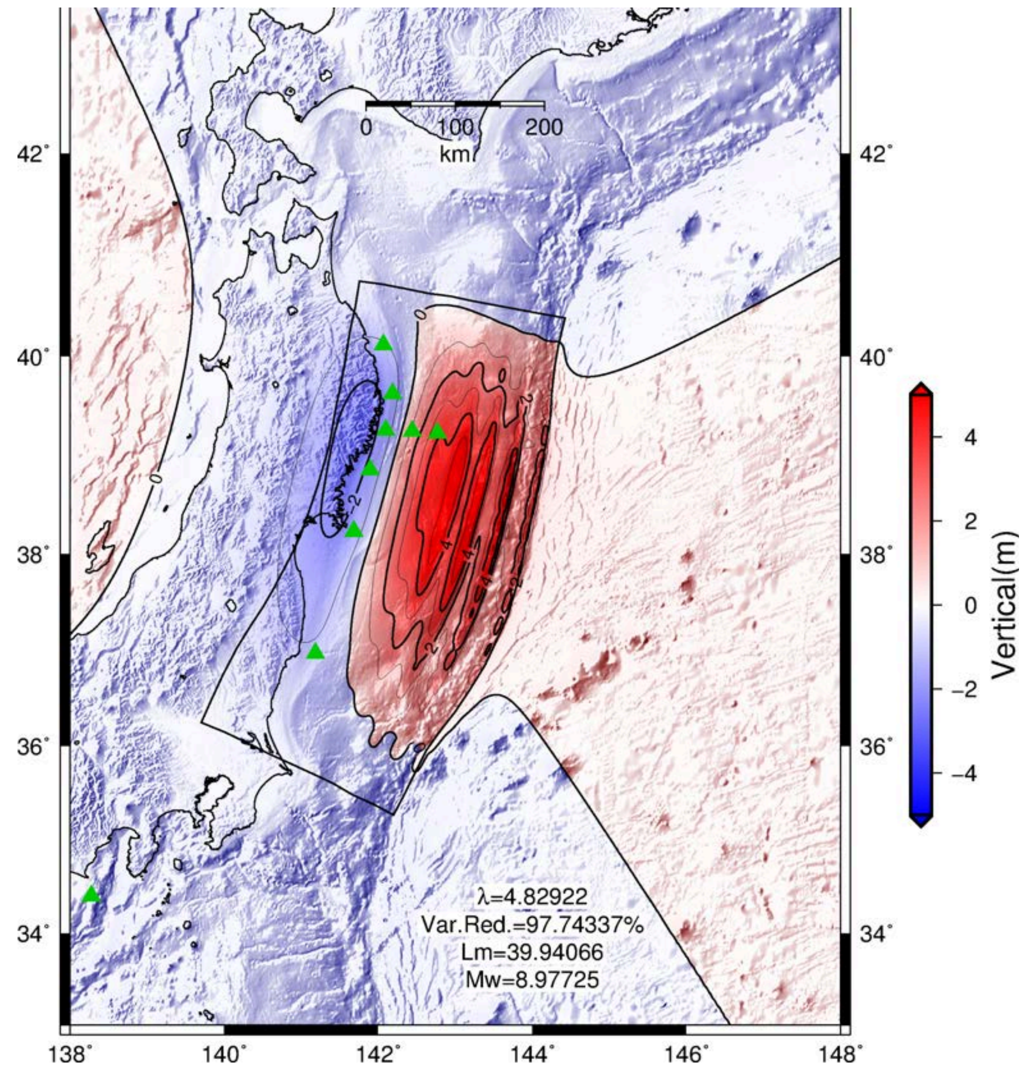
2003 Mw 8.3 Tokachi-oki



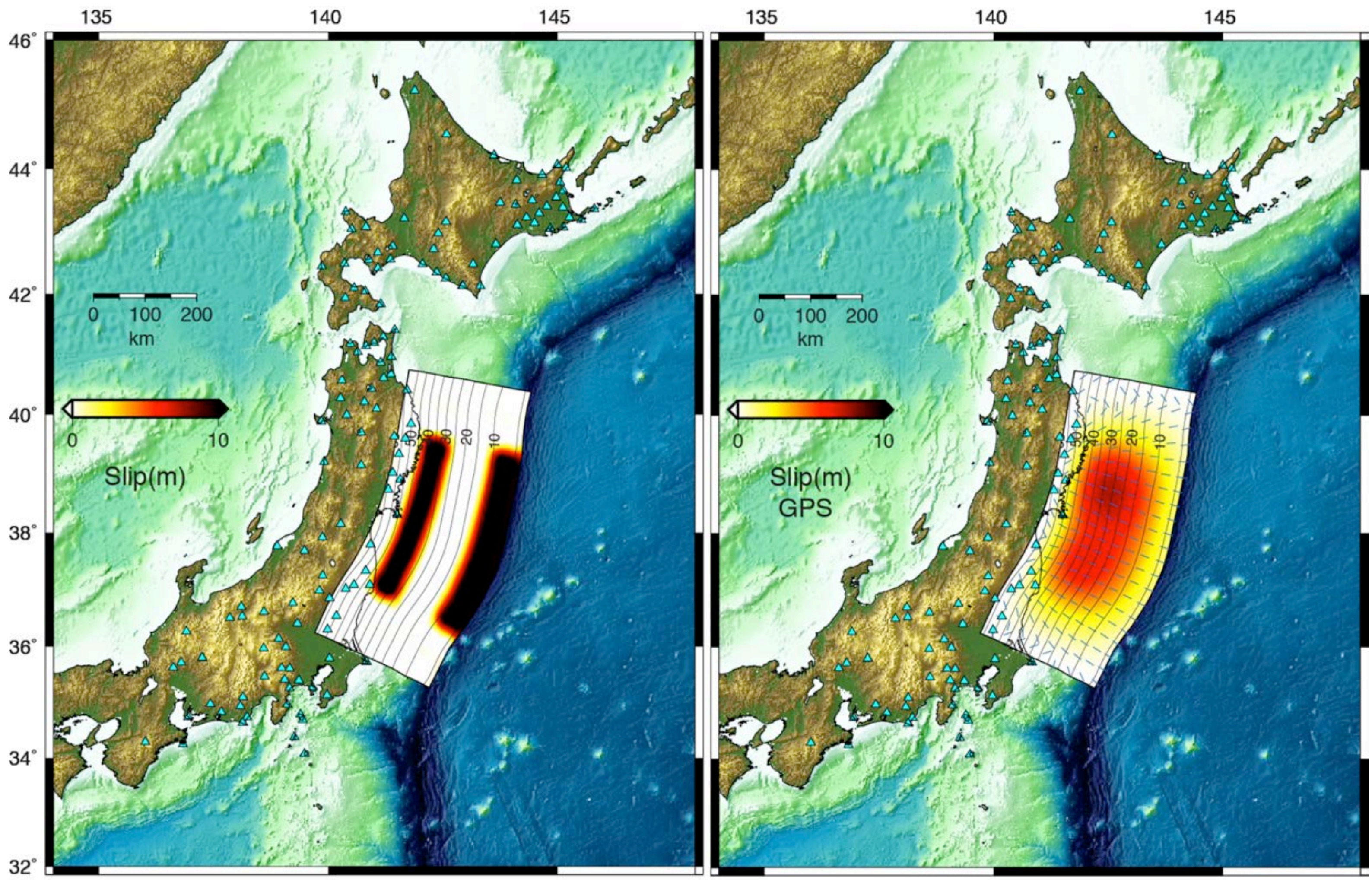
Melgar et al., 2012, GJI

It is Feasible to Compute Rapid Source Models





Can this be Used to Rapidly Estimate a Tsunami Model?



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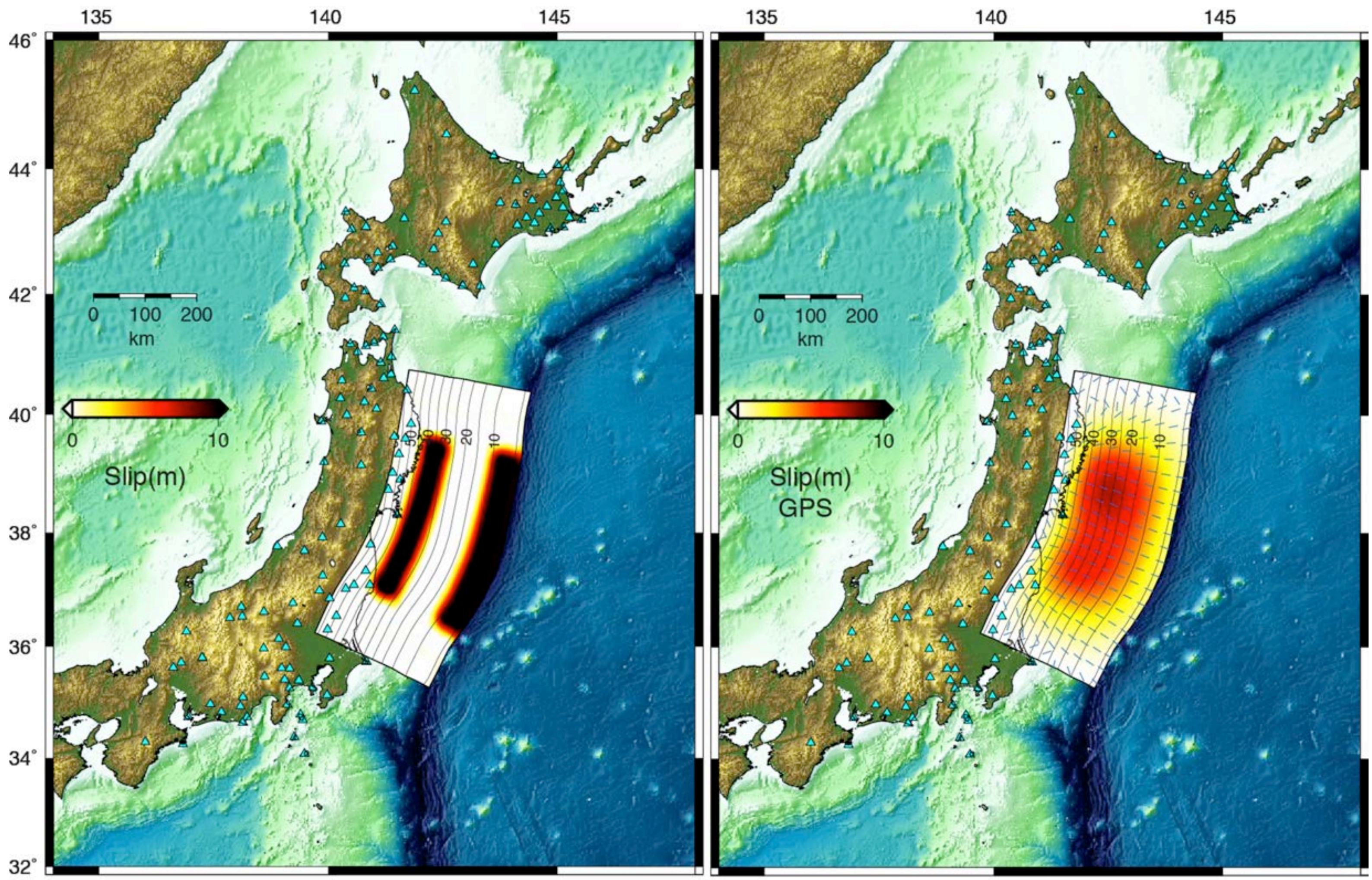
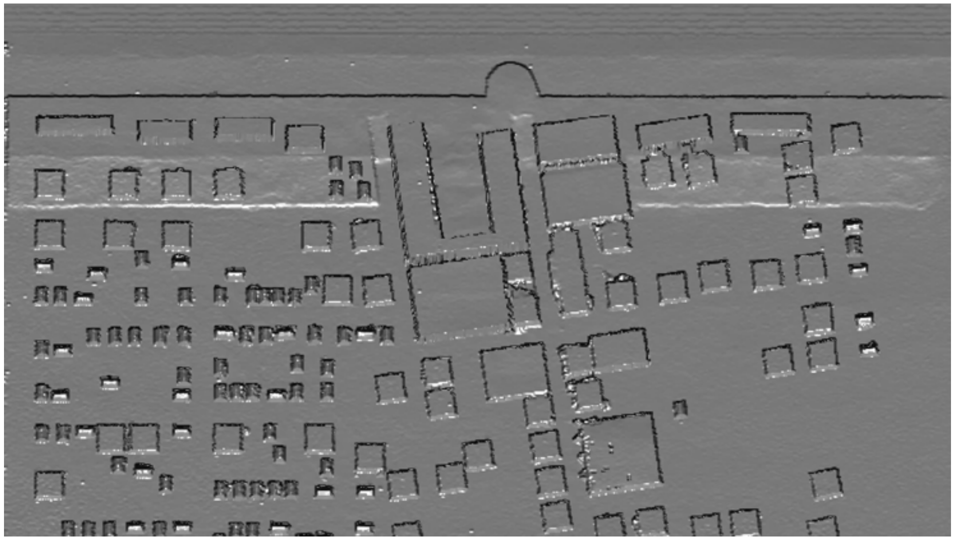
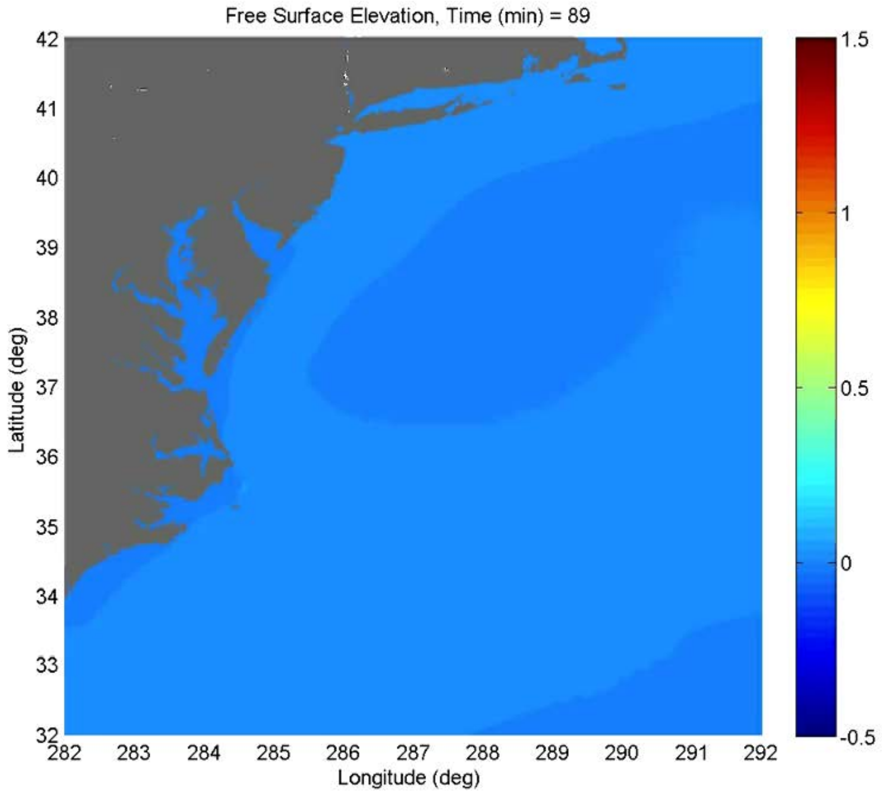


The State of Tsunami Modeling



COULWAVE
Patrick Lynett (USC)
Phillip Liu (Cornell)



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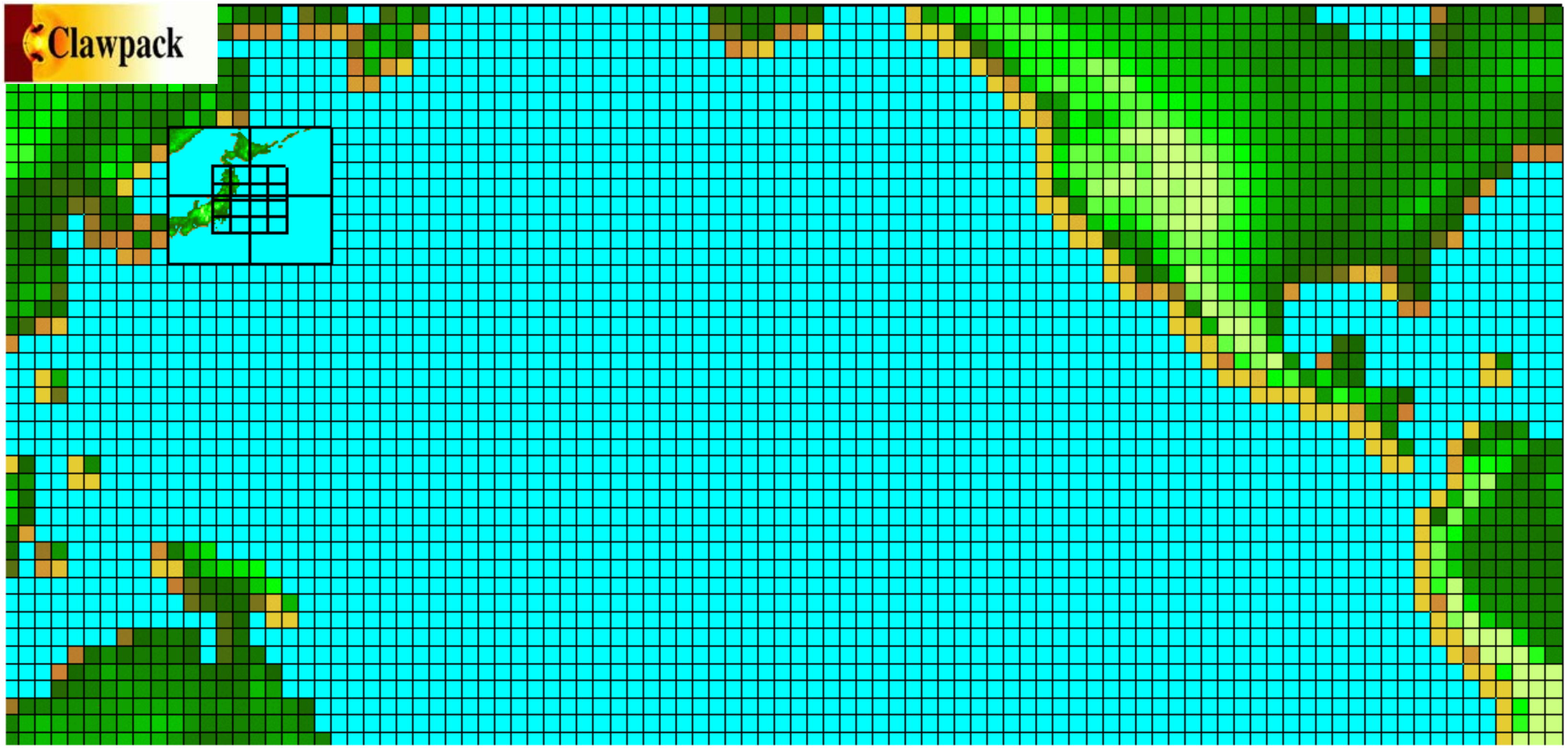


Clawpack – Geoclaw
Randal LeVeque et al. (UW)

David George, USGS

Modeling with Geoclaw

Validation of the GeoClaw Model

NTHMP MMS Tsunami Inundation Model Validation Workshop

GeoClaw Tsunami Modeling Group, University of Washington.

Frank I. González, Randall J. LeVeque, Paul Chamberlain, Bryant Hirai, Jonathan Varkovitzky
and David L. George (USGS)

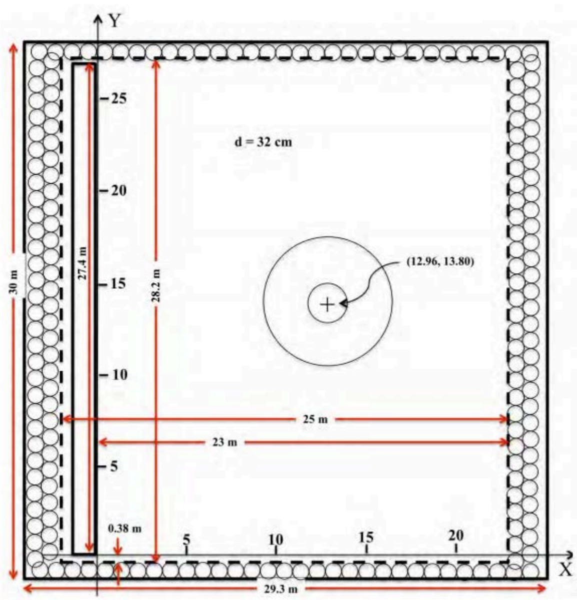
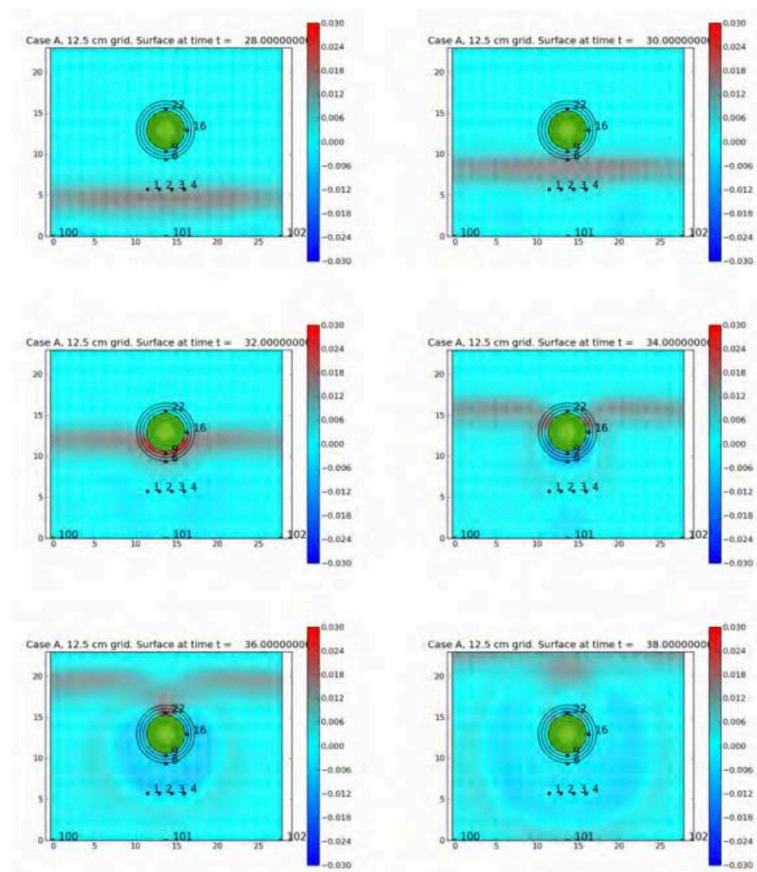
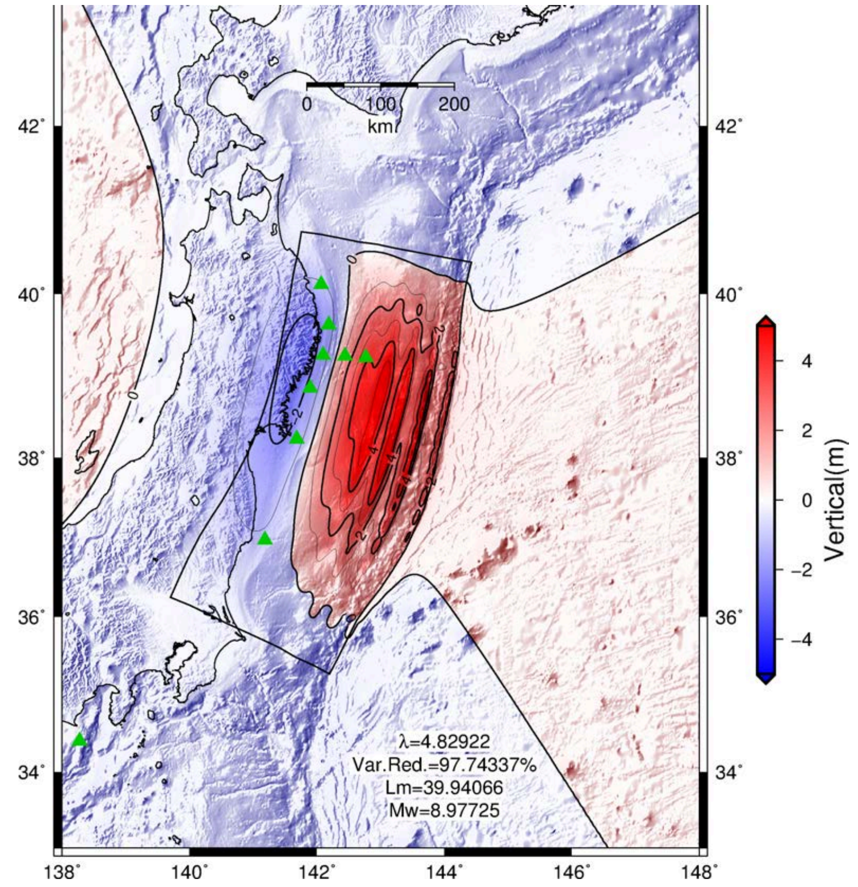


Figure 3.6.1: Basin geometry and coordinate system. Solid lines represent approximate basin and wavemaker vertical surfaces. Circles along walls and dashed lines represent rolls of wave absorbing material. Note the gaps of approximately 0.38 m between each end of the wavemaker and the adjacent wall. Gage positions are given in Figure 3.6.2.



How do we Judge Whether a Simulation is Good?

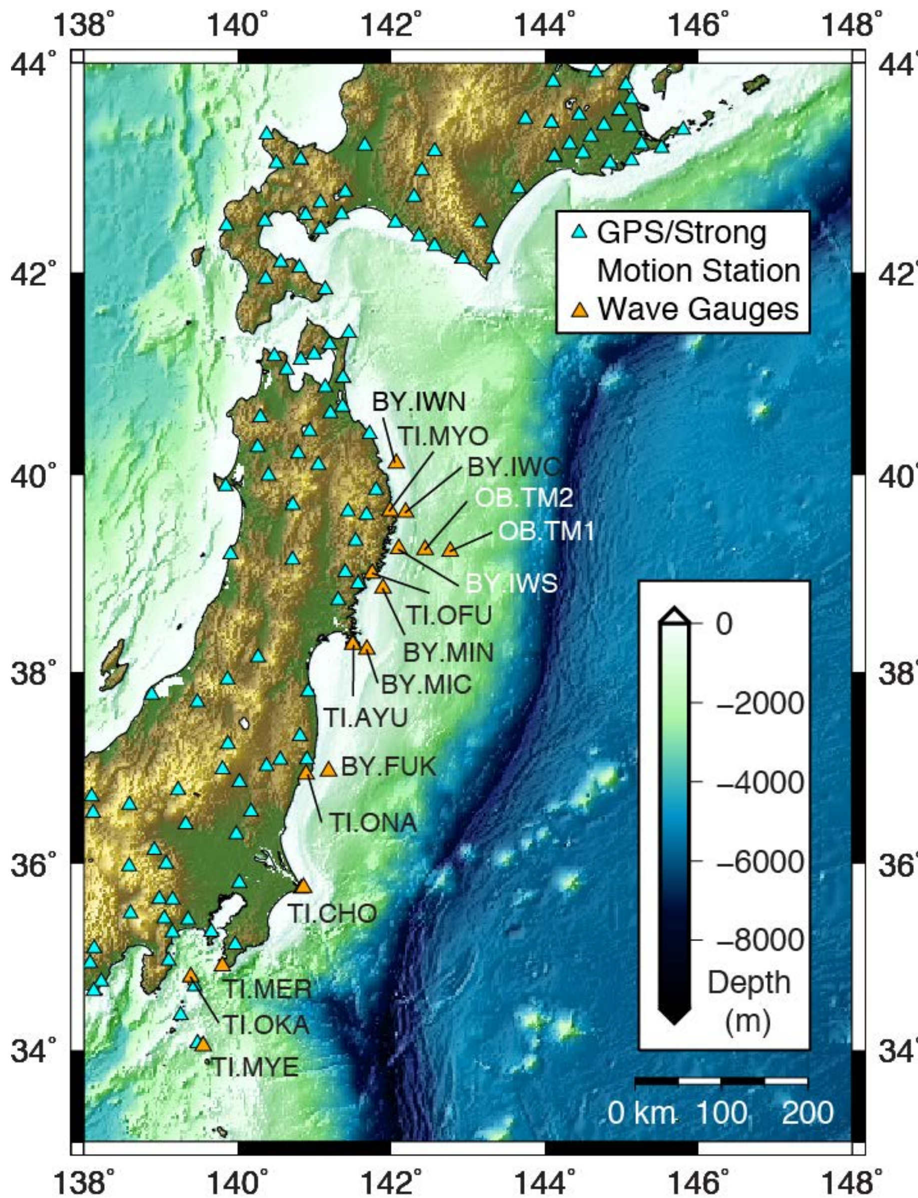
- Good (or at least decent) fits to wave gauges.
- Good prediction of inundation amplitude (survey points).
- Tohoku-oki has a wealth of these types of data



How do we Judge Whether a Simulation is Good?

3 types of wave gauges

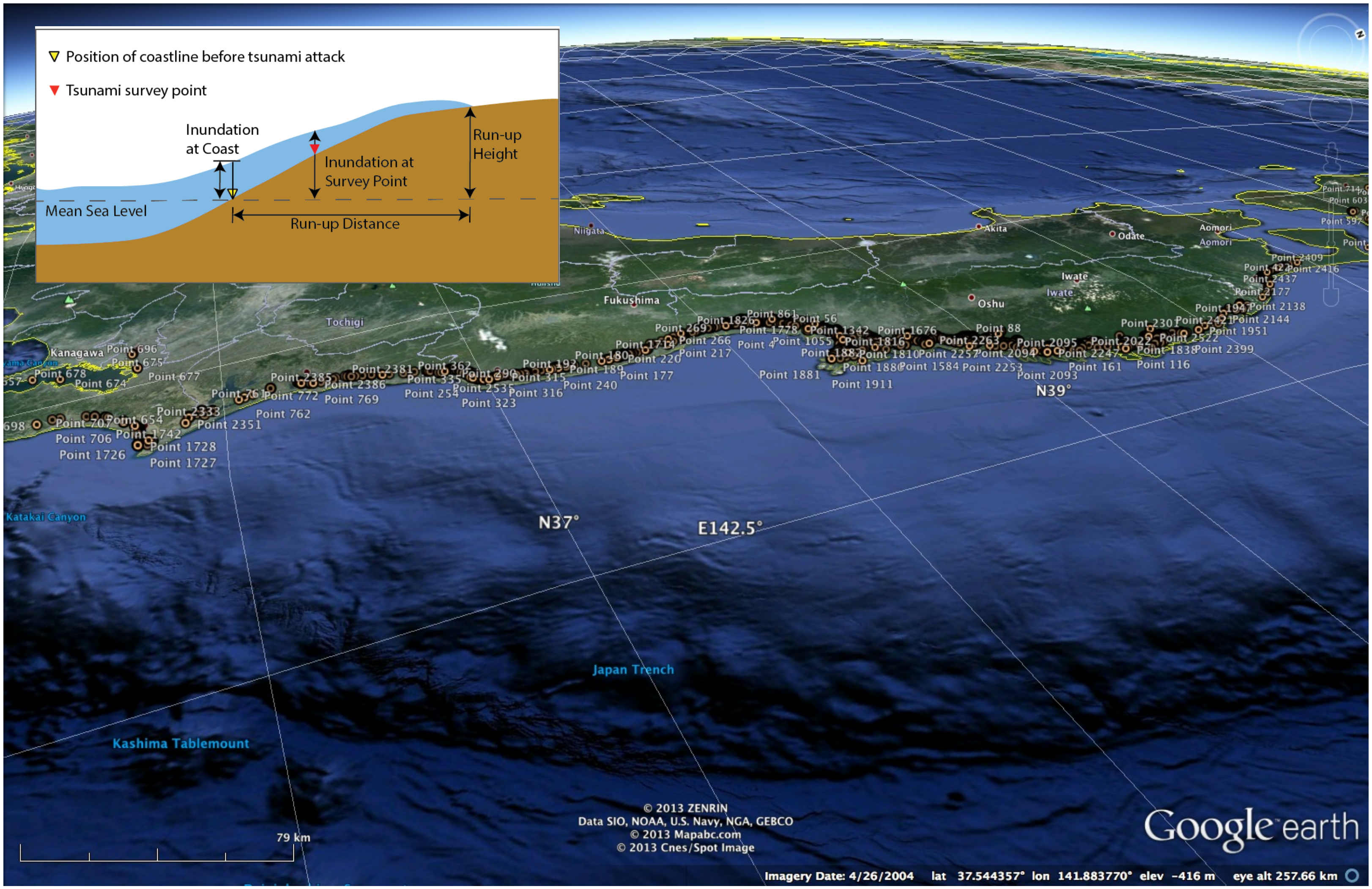
- Ocean bottom pressure (OB)
- GPS buoys (BY)
- Tide gauges (TI)



Melgar & Bock, *in review*, JGR

How do we Judge Whether a Simulation is Good?

- 2000+ inundation amplitude survey points (Mori et al, 2012)



How do we Judge Whether a Simulation is Good?

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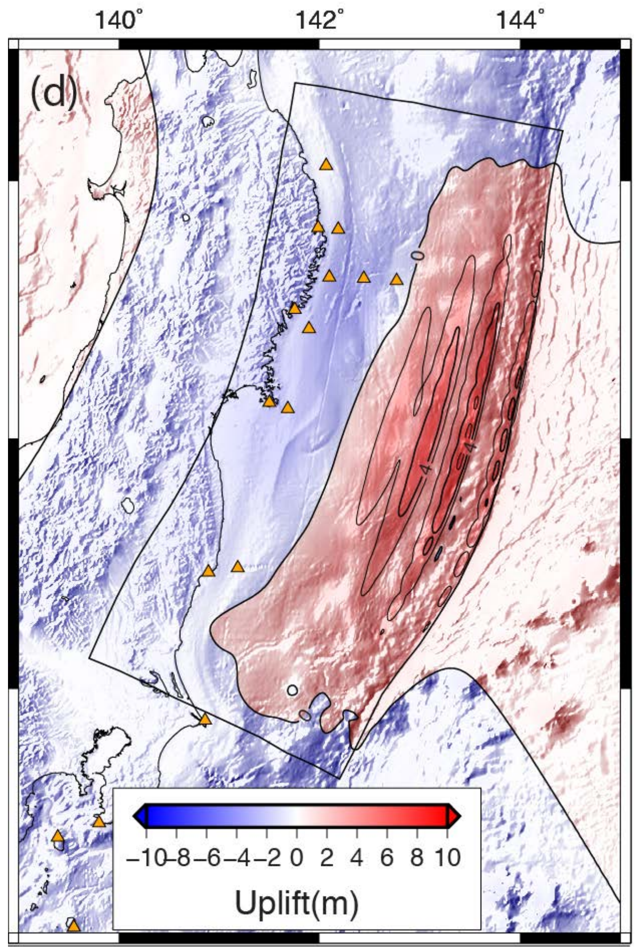
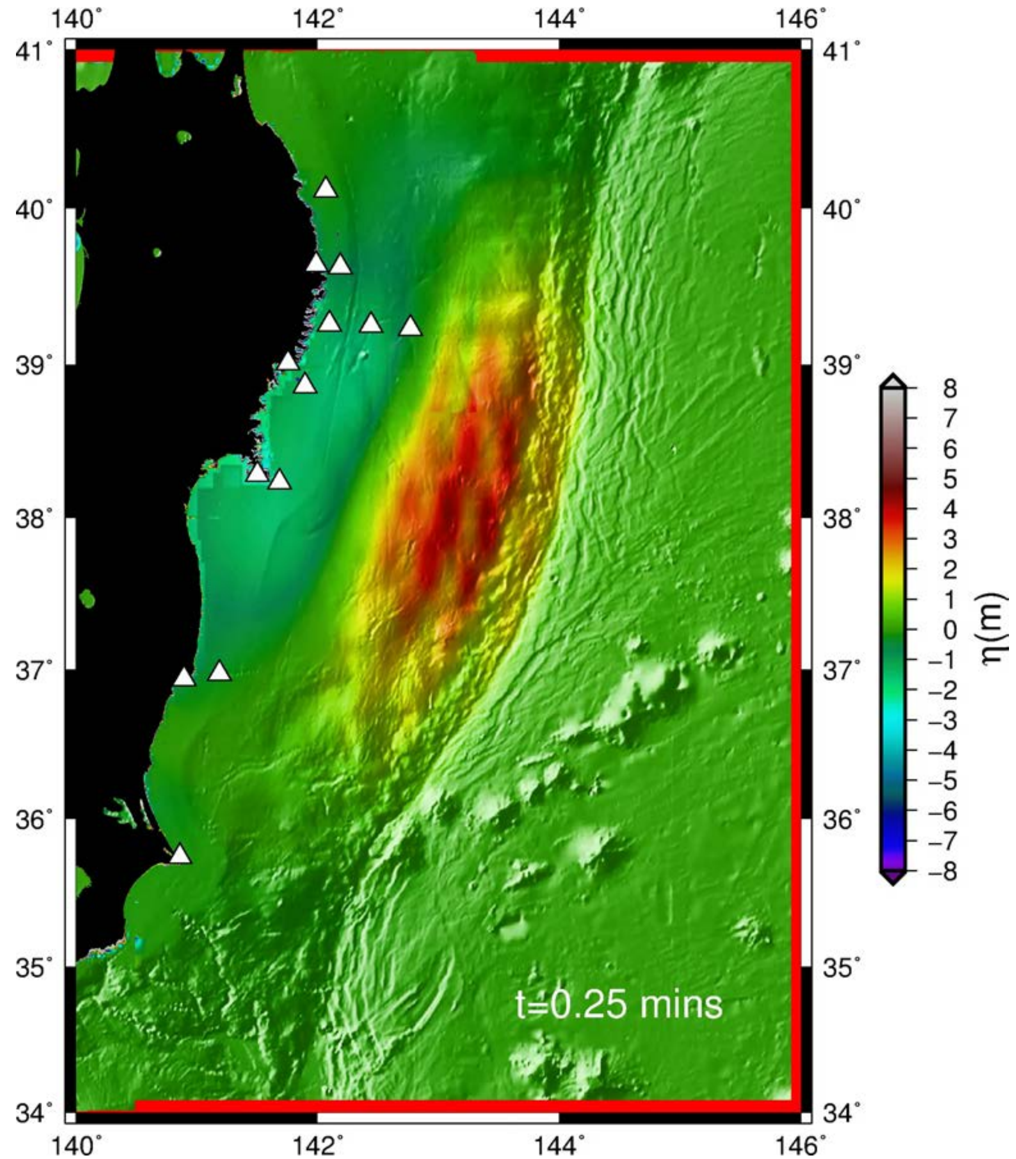
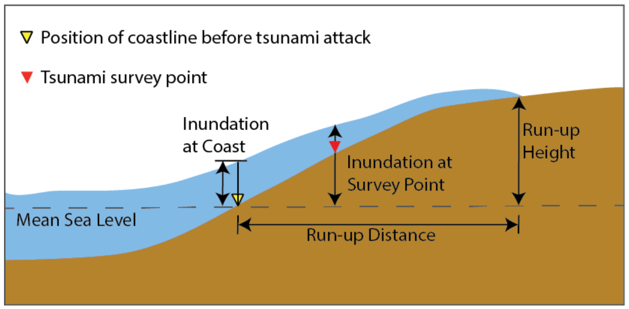
Simulation Results with Land Observations

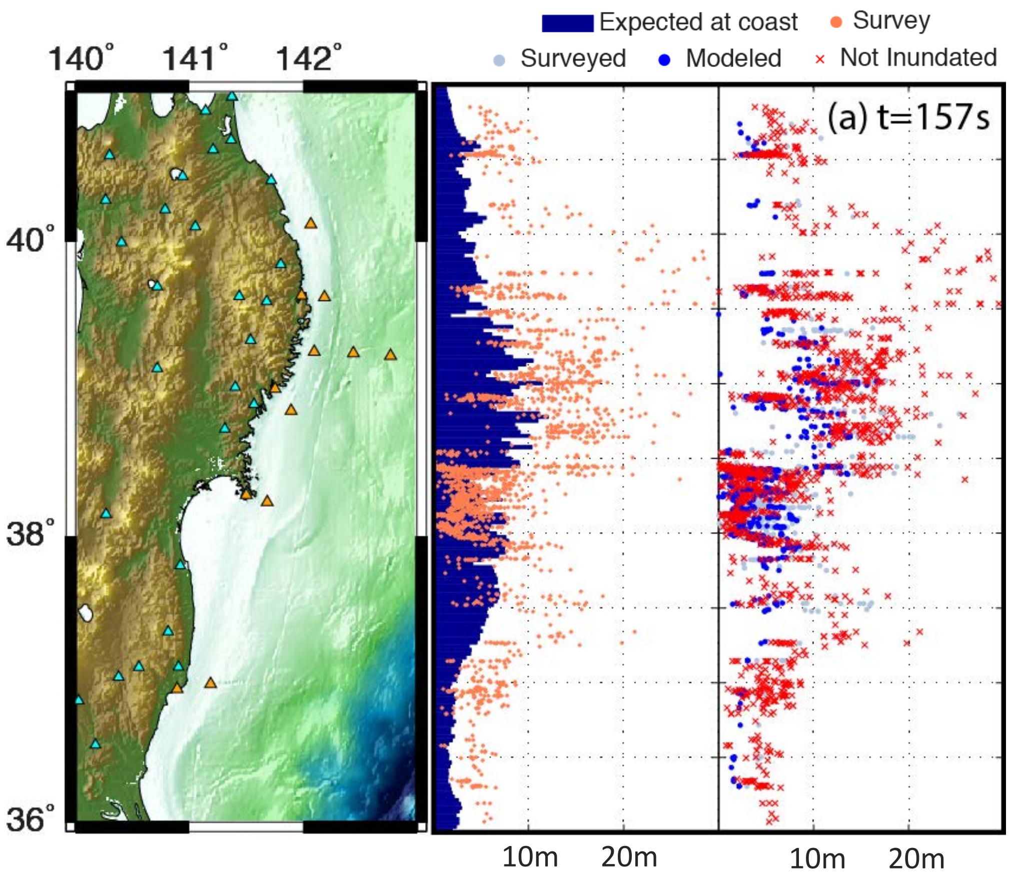




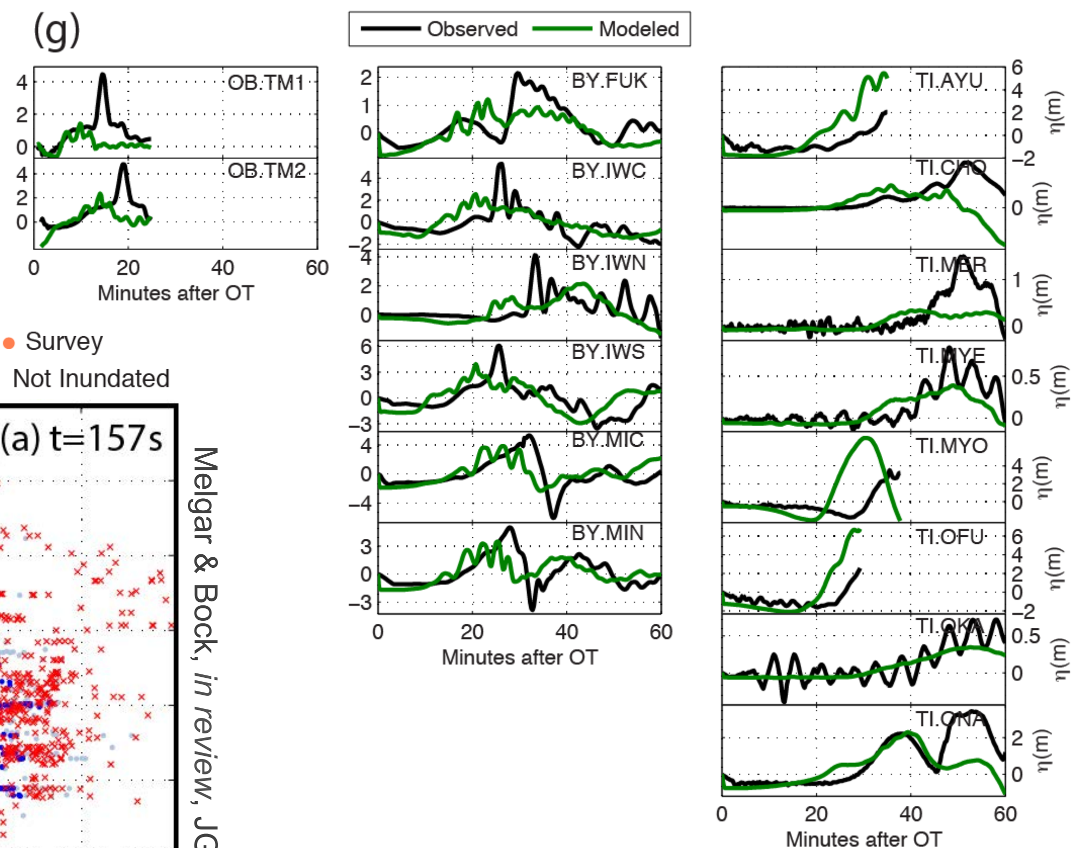
Melgar & Bock, *in review*, JGR

Land-based Forecast Results



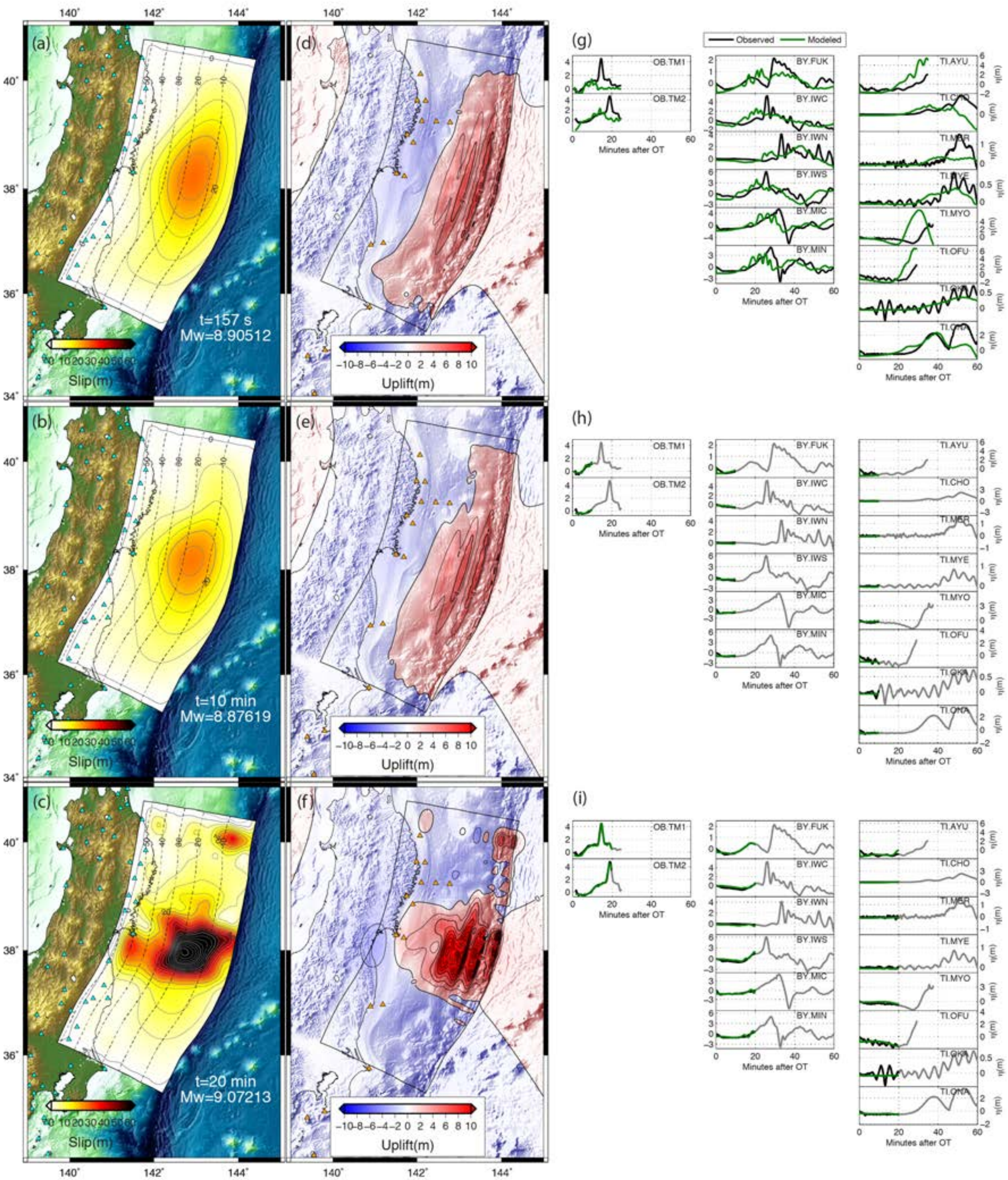


Melgar & Bock, in review, JGR



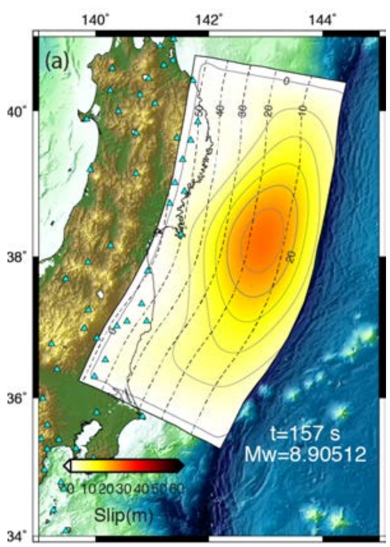
<u>Inundated 956/2250 survey points</u>

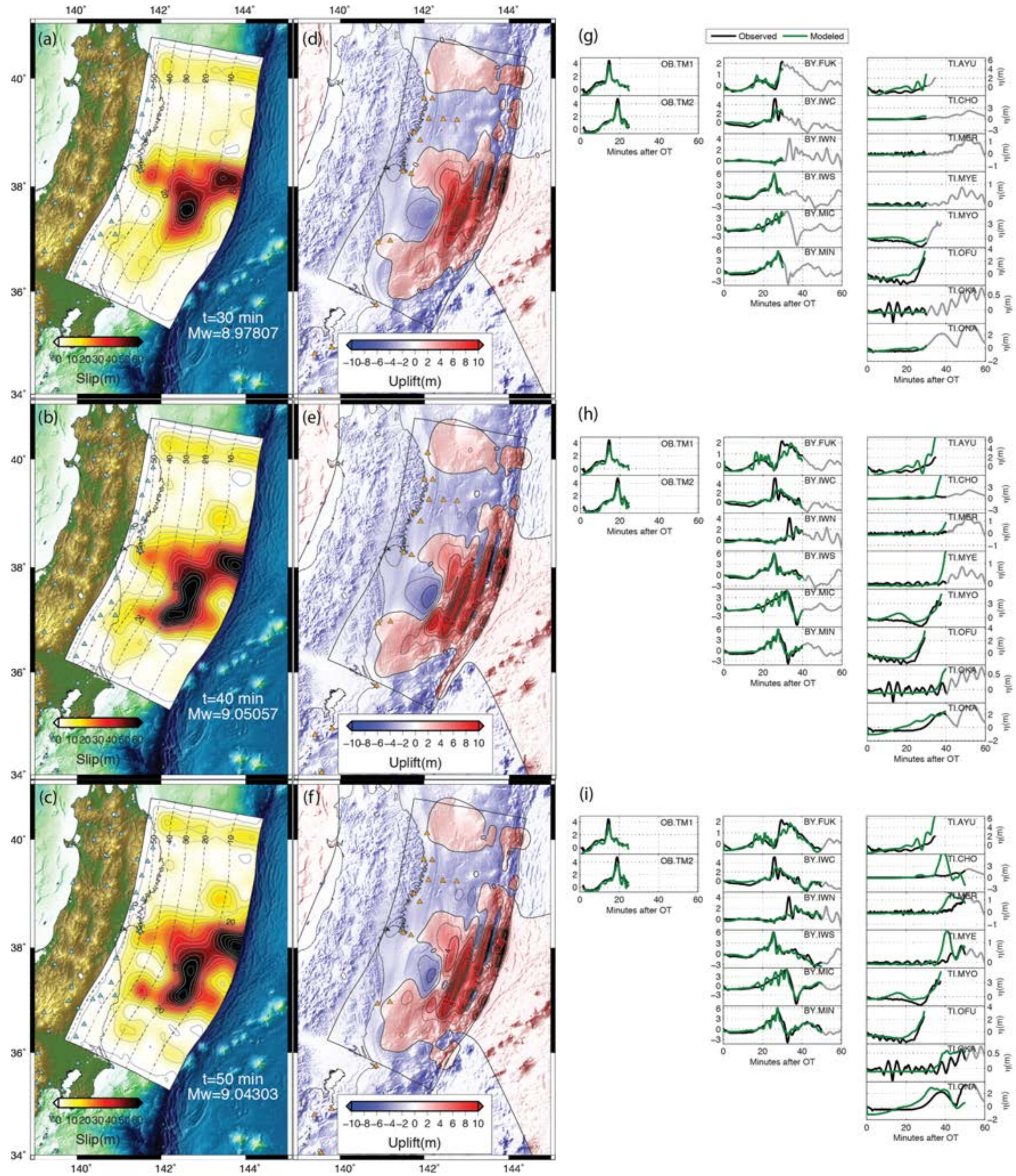
Joint Inversion Results



Melgar & Bock, *in review*, JGR

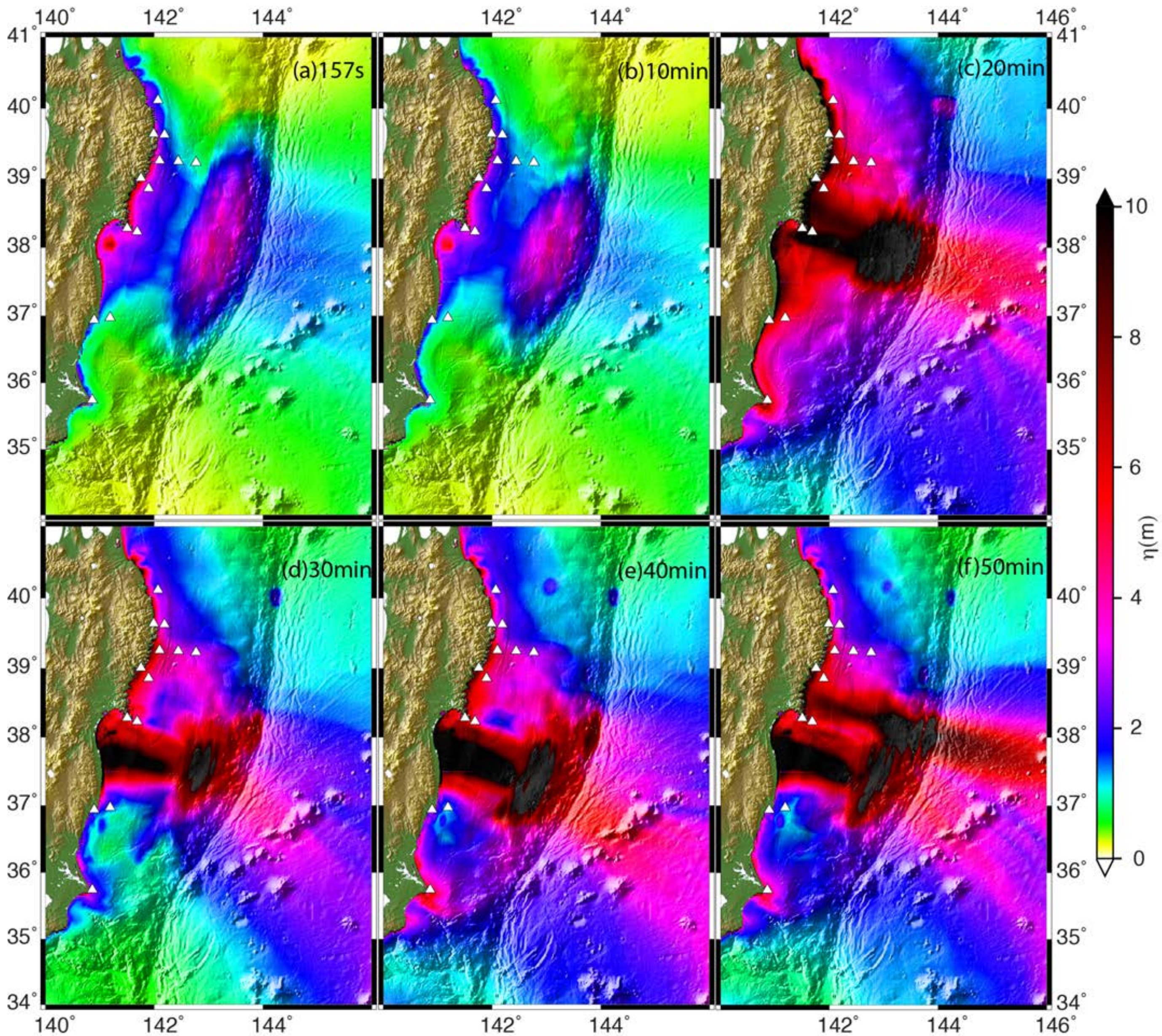
Joint Inversion Results





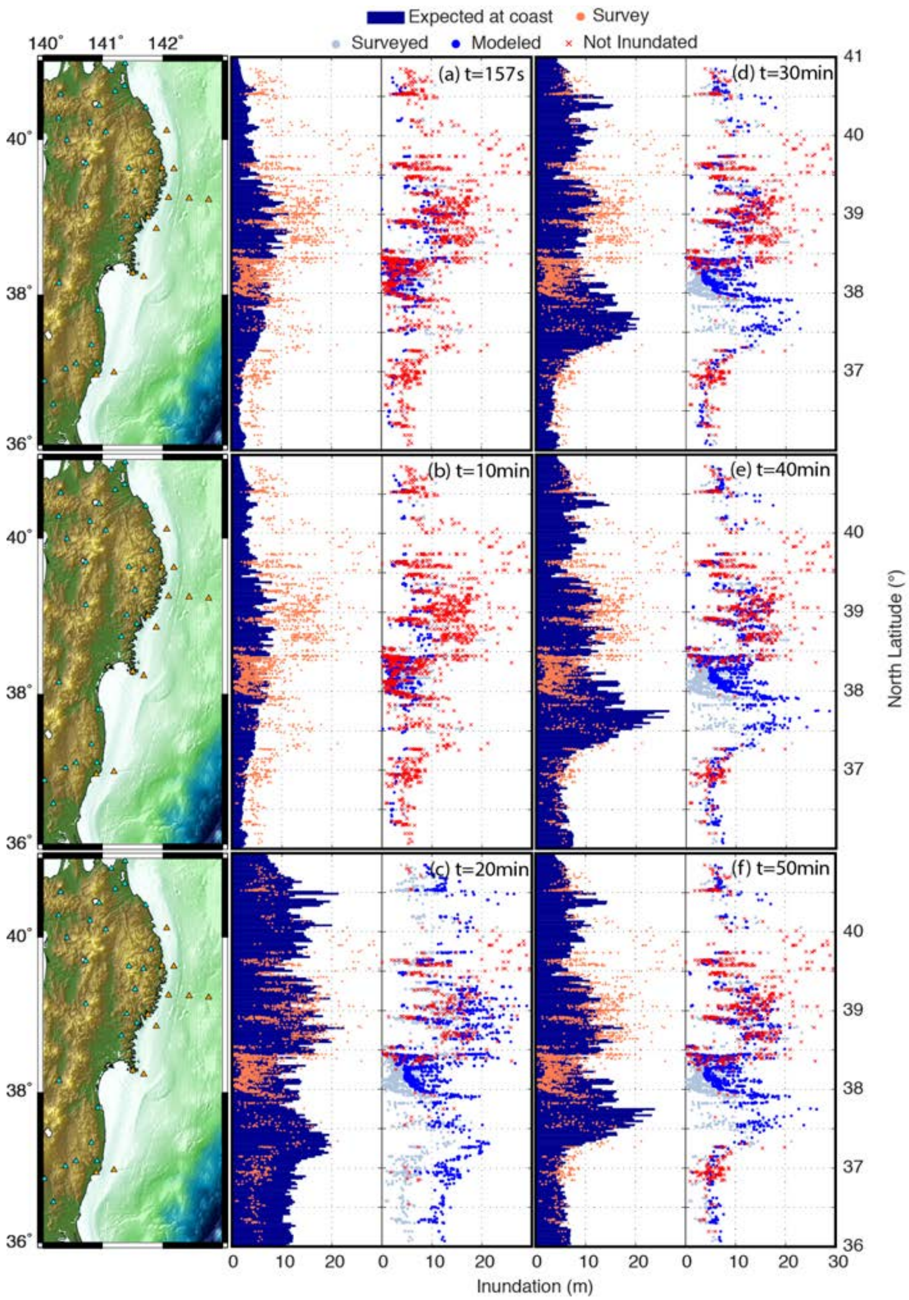
Melgar & Bock, *in review*, JGR

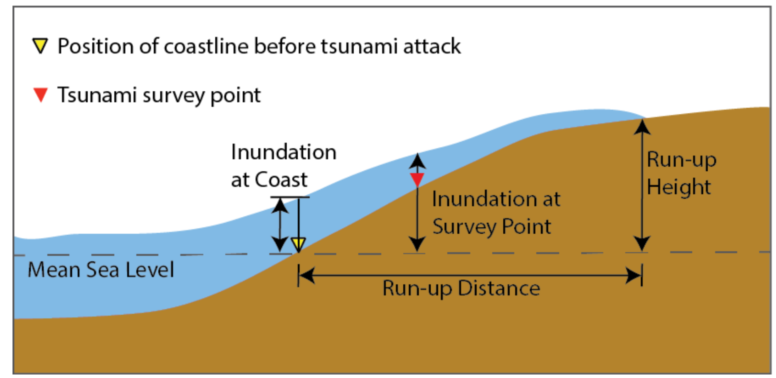
Predicted Tsunami Intensities



Melgar & Bock, *in review*, JGR

Predicted Tsunami Intensities





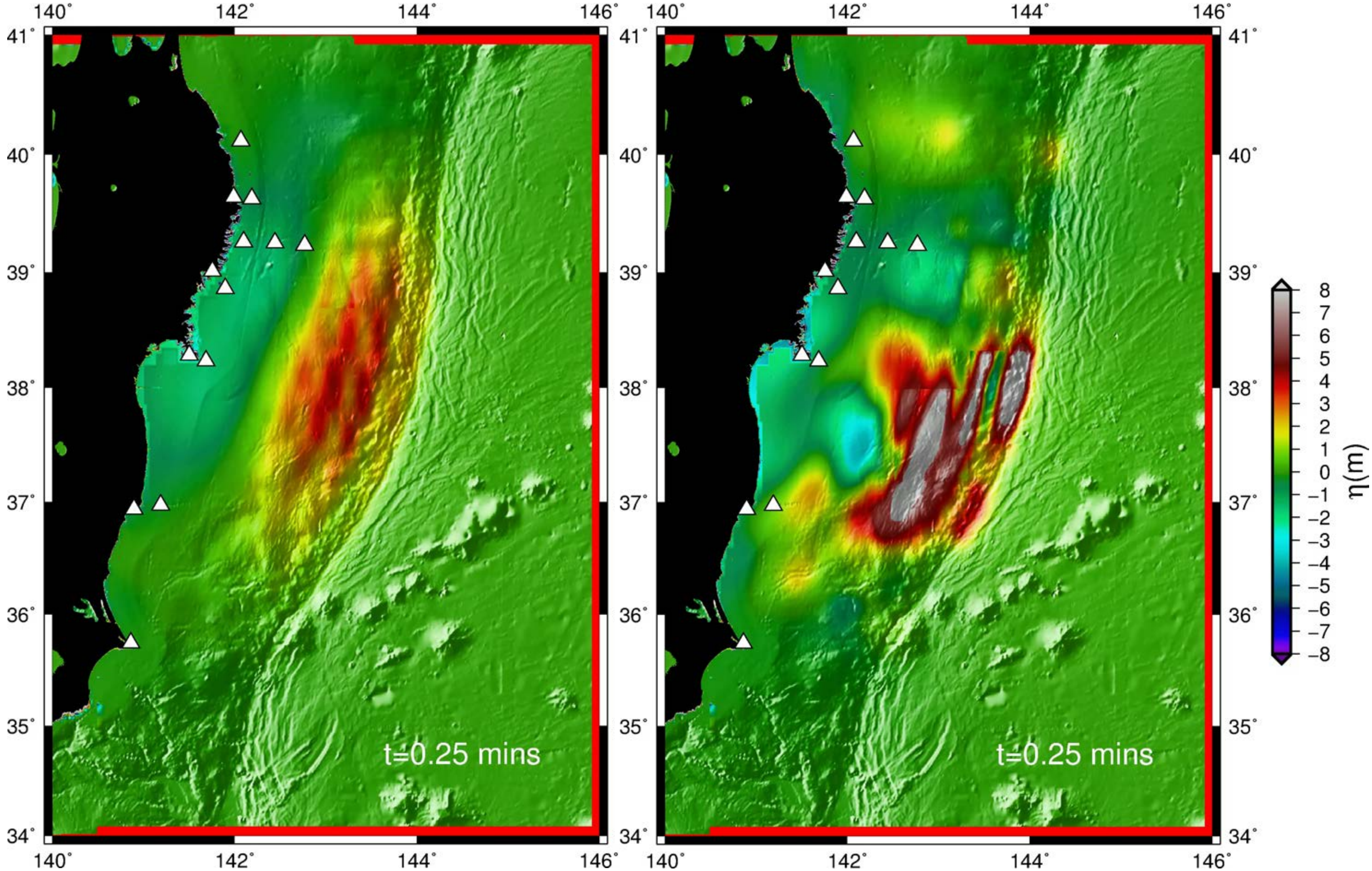
Time after OT	Wave Gauge RMS (m)	Survey Var. Red. (%)	# of Survey Points Inundated
157 s	1.42	85	956/2250
10 min	0.26	79	905/2250
20 min	0.24	60	1913/2250
30 min	0.55	73	1538/2250
40 min	0.87	65	1604/2250
50 min	0.85	78	1611/2250

Melgar & Bock, *in review*, JGR

On the Importance of Offshore Data

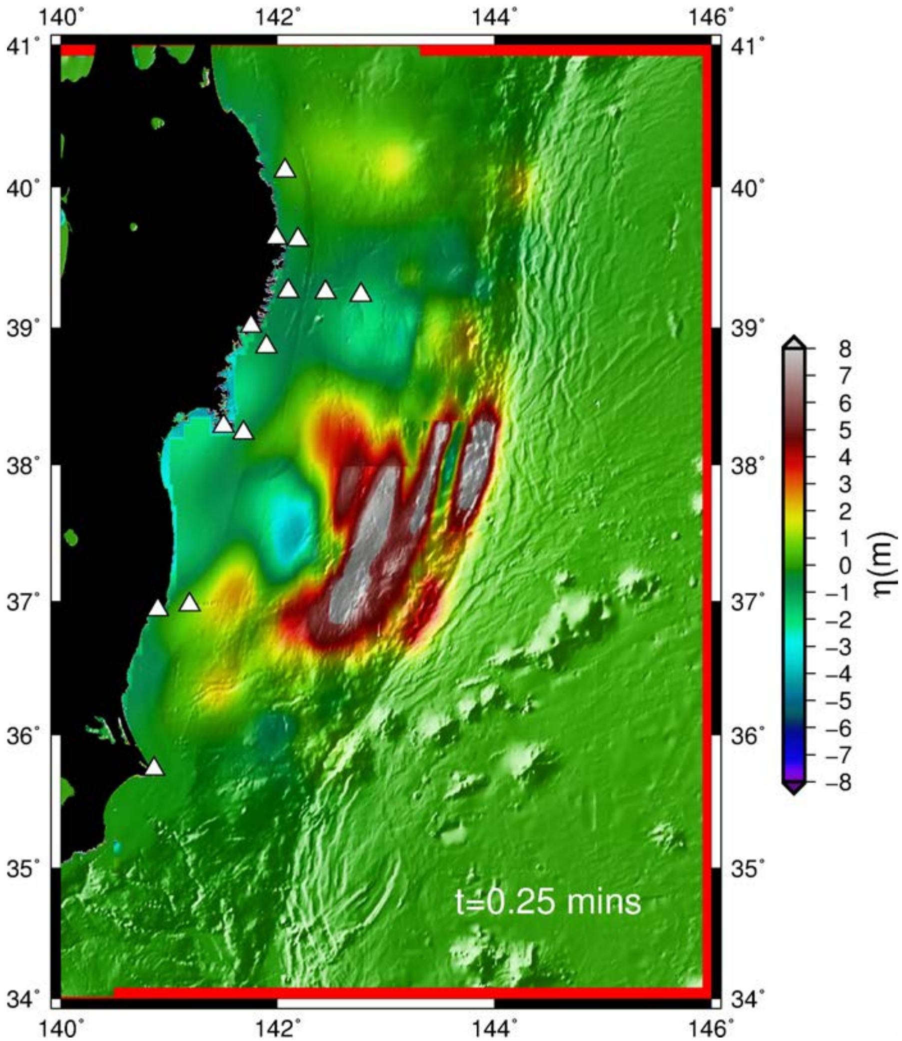
Land-based inversion

Joint inversion



Conclusions

- It is reasonable to expect more complete forecasts of tsunami propagation
- Land based forecasts are fast but limited
- Ocean-based data illuminates tsunami complexity
- Need to relax some physical assumptions
- Improvements needed in modeling/inversion techniques
- What do you do with this information?




冨嶽三十六景
東海道江尻
田子の浦略圖