Operational GNSS-based Tsunami Warning in the US and an AI Future

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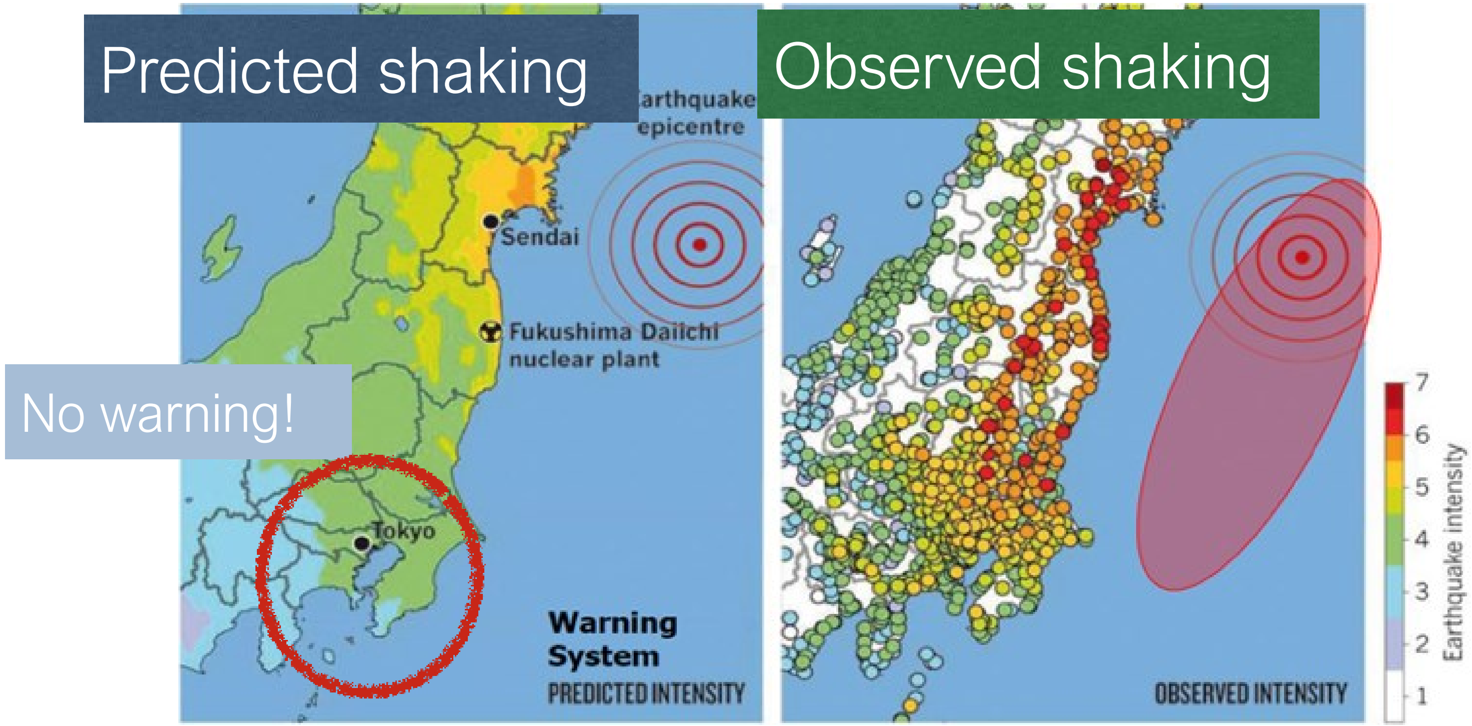
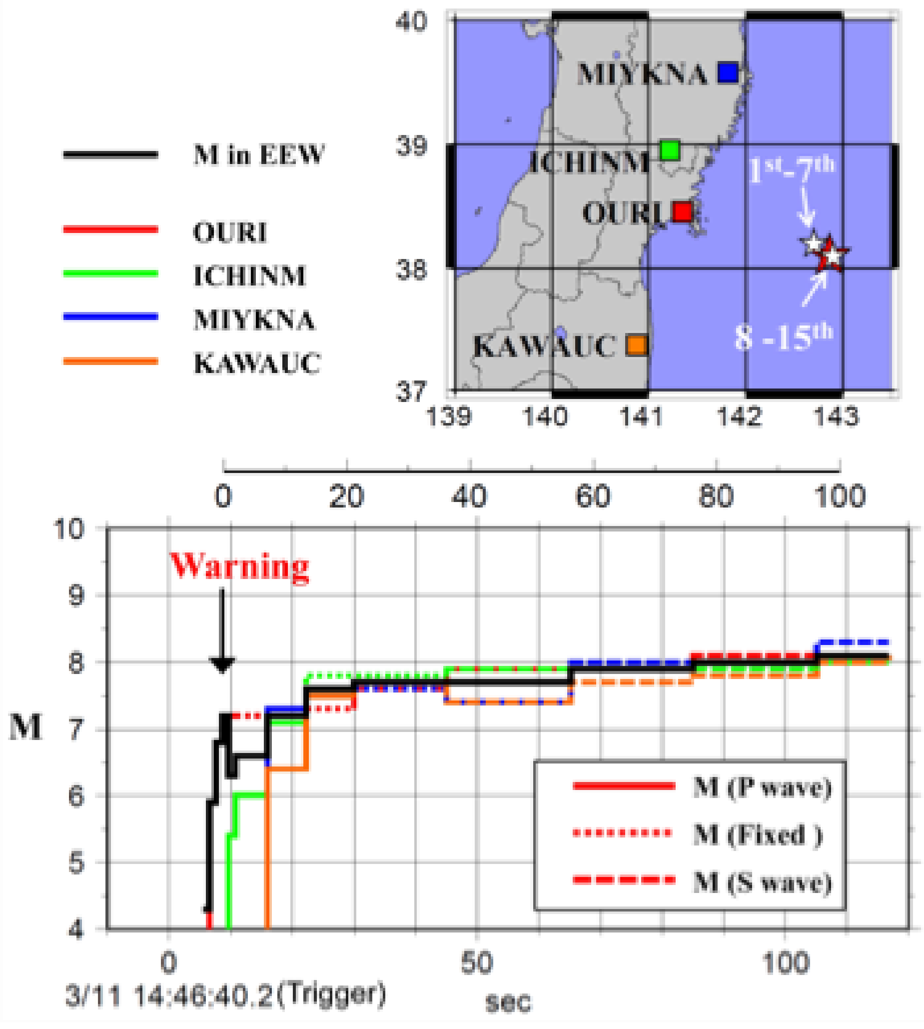
Motivation: Large Magnitude Events Can Be Difficult

- Earthquakes with M>7.5 are very challenging for seismic-only systems
- Magnitude saturation means the shaking/tsunami alert will not cover as wide an area as necessary
- One solution is to use GPS as part of the system as well.





Hoshiba et al. (2012)

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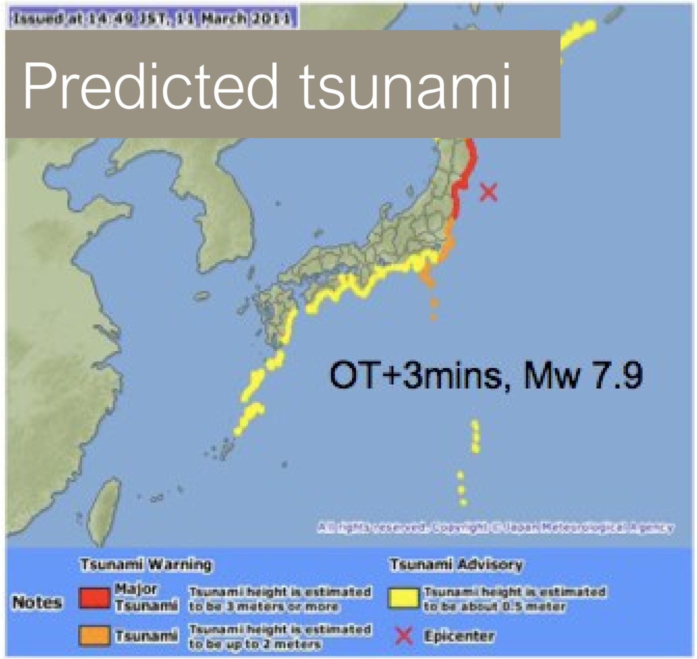
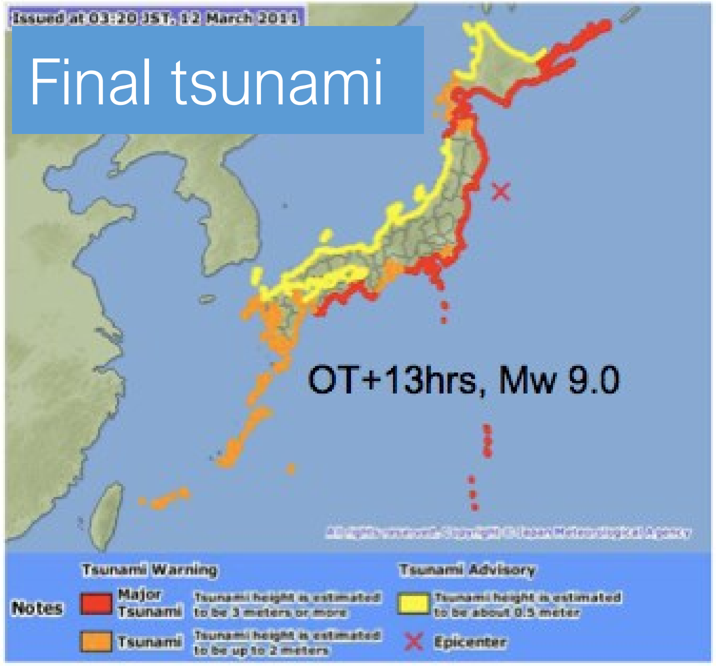
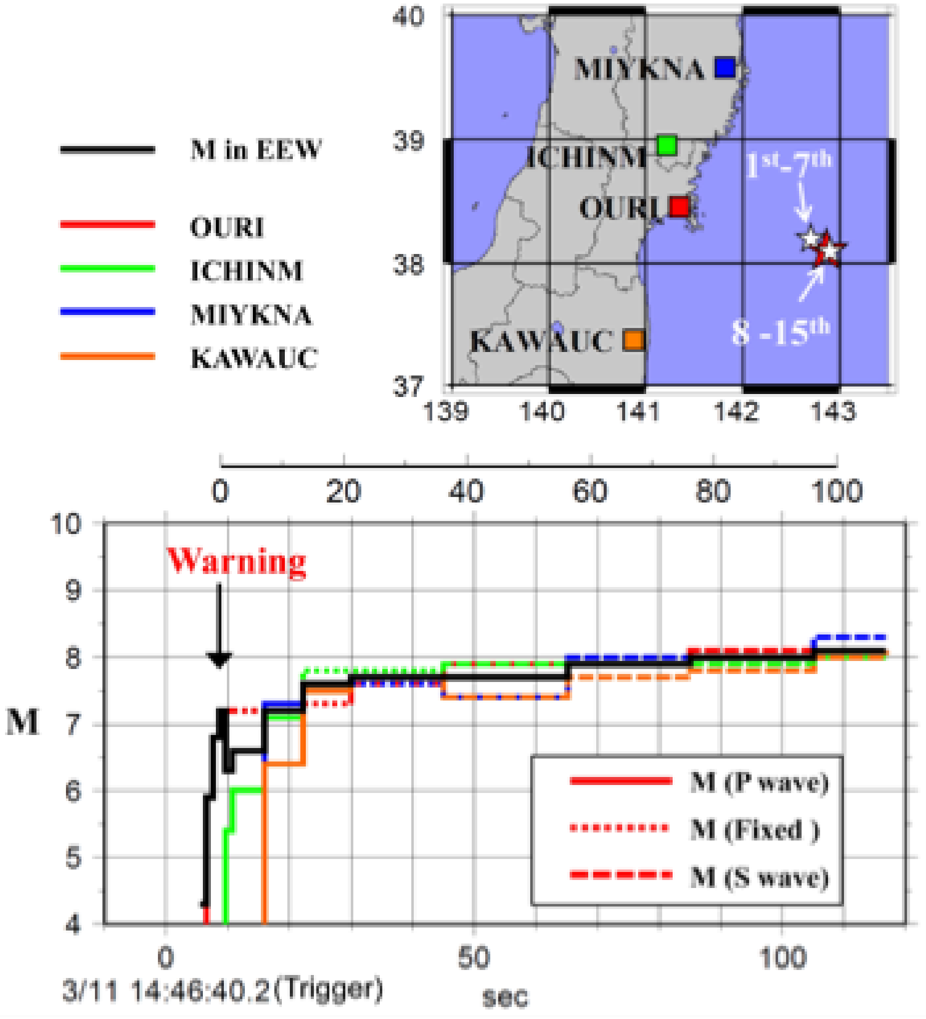






Hoshiba et al. (2012)

How are we using GNSS data operationally

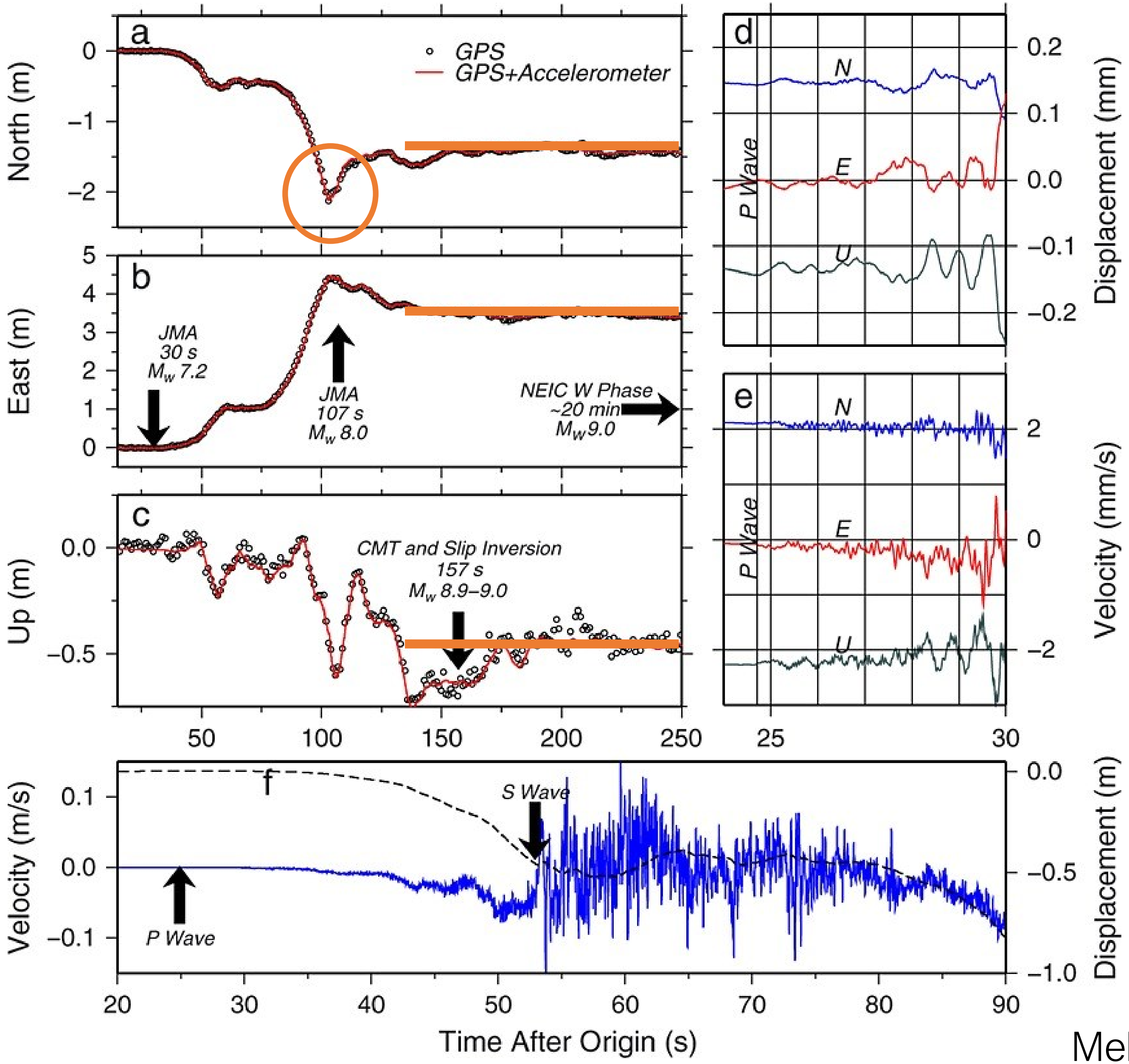
Current RT-GNSS positions available on PNSN server this morning
1420 stations with 5-day data buffer, latency ~2 s

USGS NEIC: We have built server-side tools for the NEIC to access and manipulate the data on the left and model earthquakes. Plan to add this information to event overview pages. Event based and single station queries, PGD analysis, W-phase, finite fault inversions.

ShakeAlert: GFAST PGD magnitude module is being incorporated, should be operational in < 1 year.

NOAA TWCs: GFAST is being added to SIFT to merge the geodetic slip estimates to tsunami inundation in the near-field. Four-year NASA Disasters project.

How do we apply this information?



Peak ground displacements: magnitude

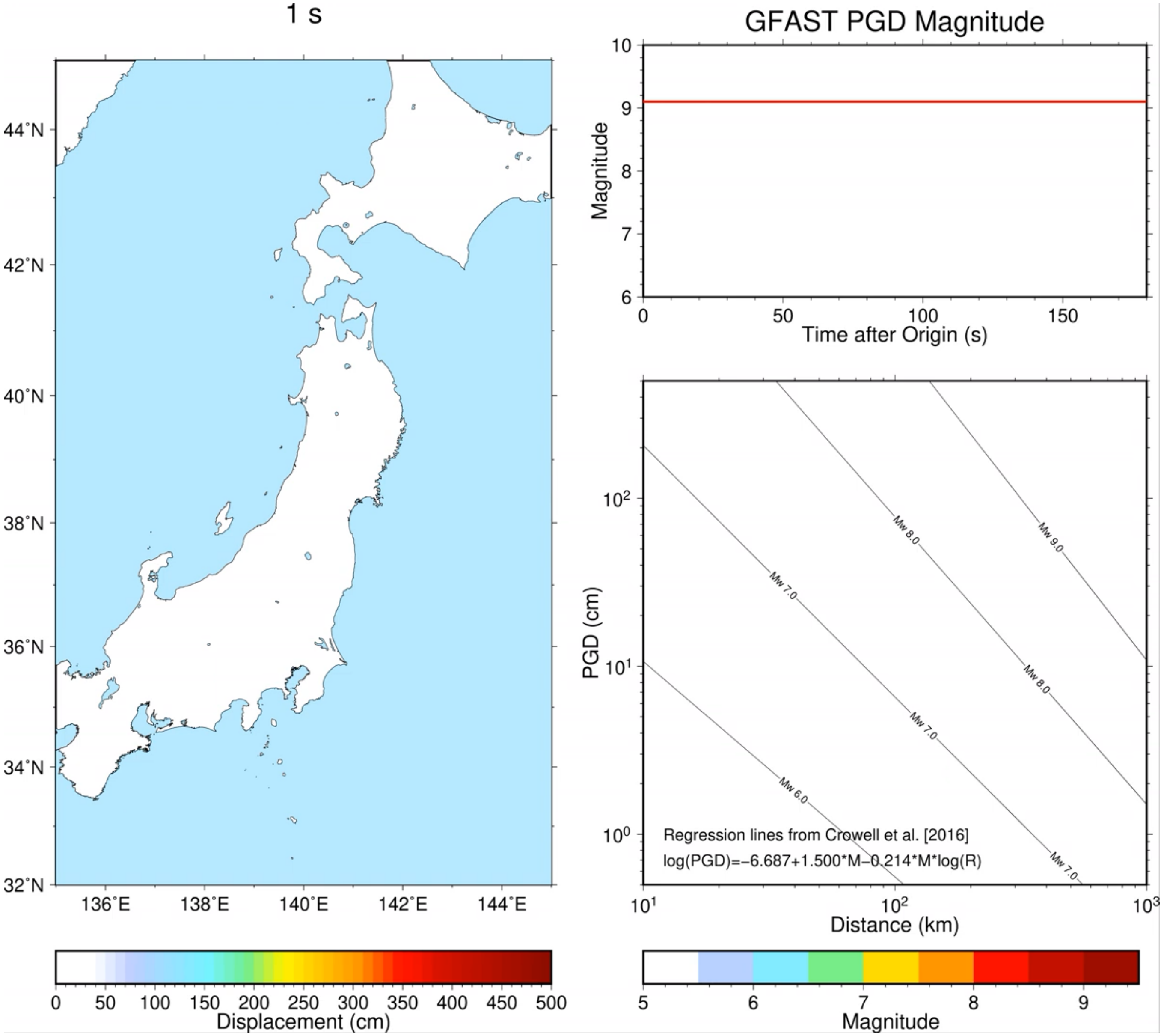
Coseismic offsets: CMT, slip inversion, magnitude

Impact Modeling:

Ground Motions
Tsunami Inundation

Melgar et al. (2013)

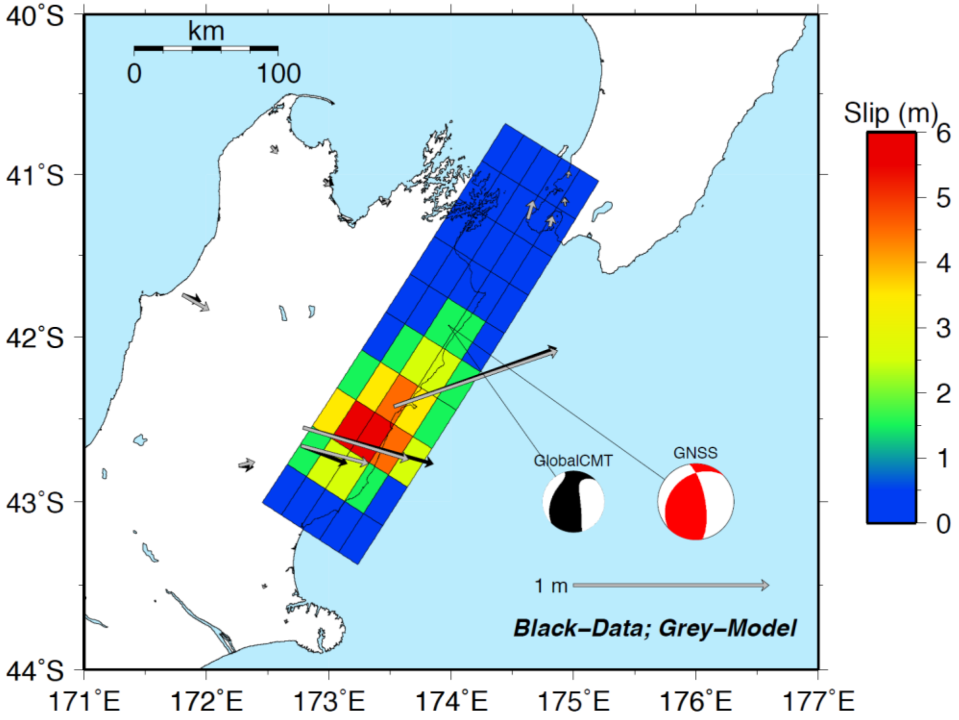
How do we apply this information currently?



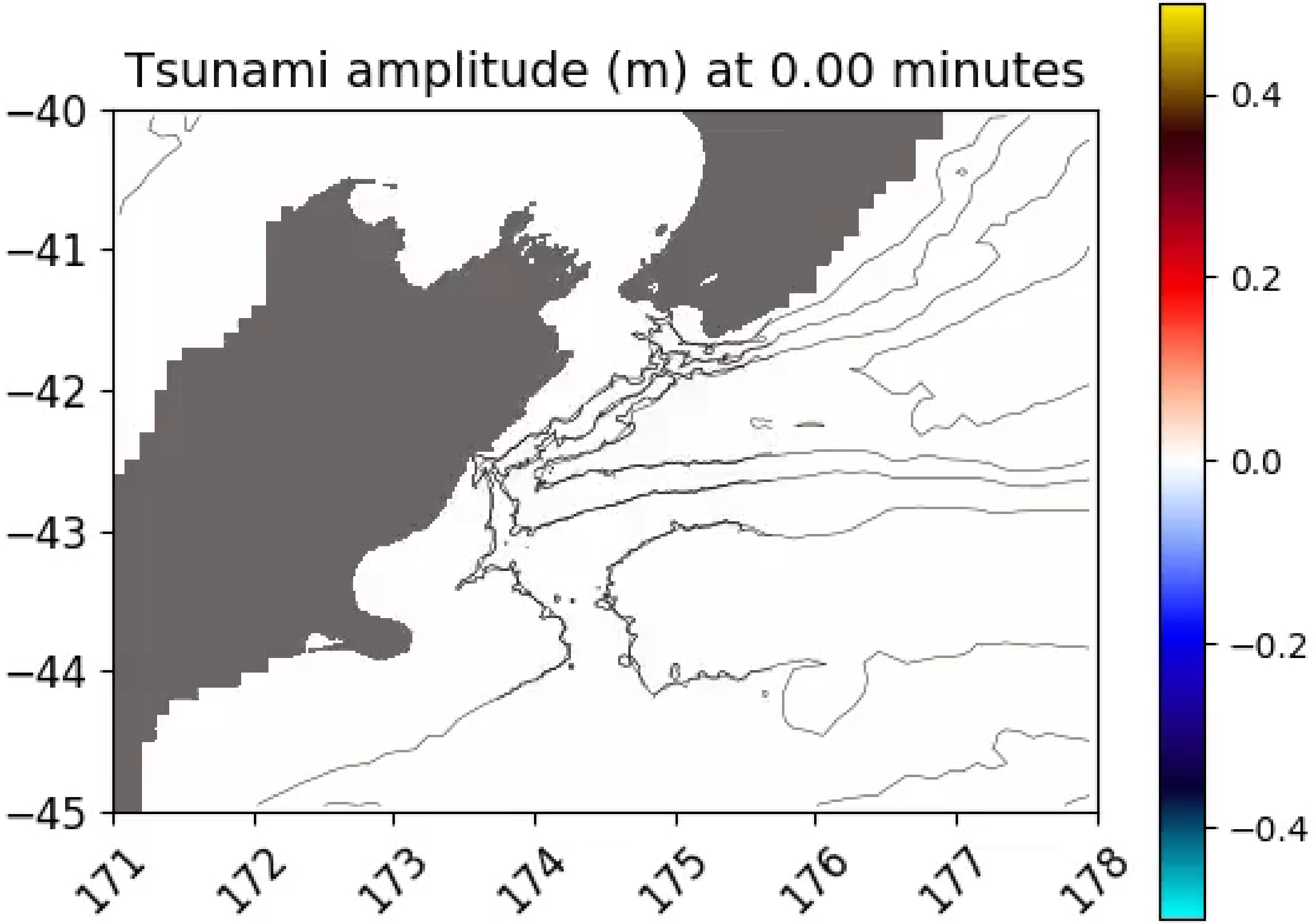
When 4 stations are available, a magnitude and source is estimated by G-FAST

This estimate is fed into tsunami propagation codes, which will then inform a watchstander of the tsunamigenic potential of an earthquake

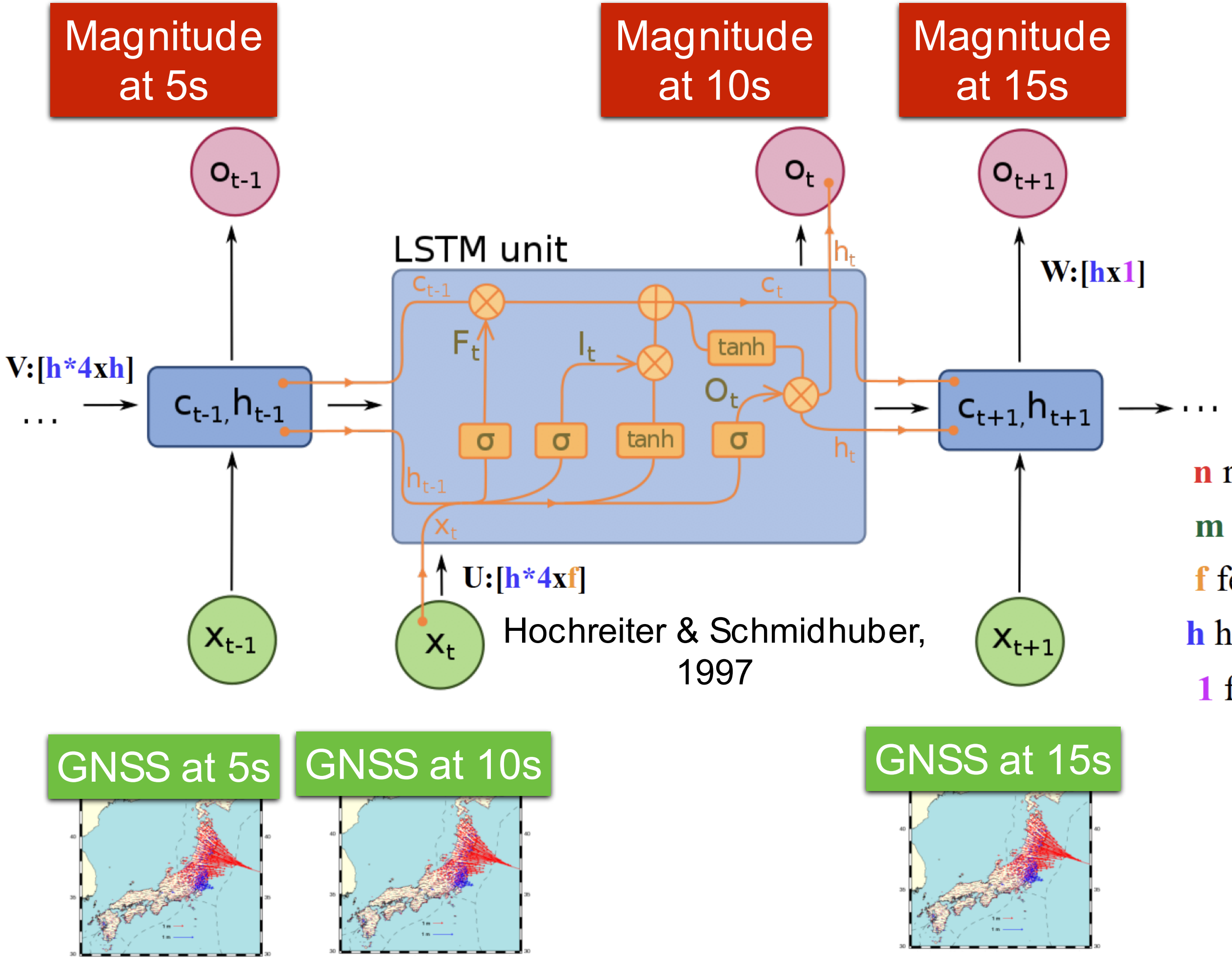
From G-FAST Finite Fault to Tsunami Prediction



Input Model at 3 minutes



Recurent Neural Networks



X:[nxmxf]

O:[nxm]

U:[h*4xf]

V:[h*4xh]

W:[hx1]

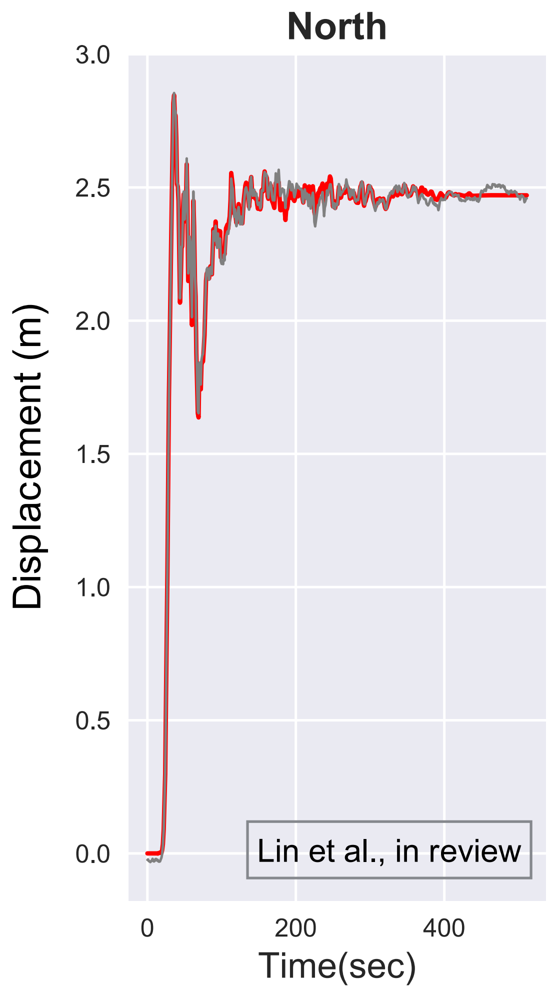
n rupture scenarios

m time sample points (updates ever 5s)

f features (number stations + station on/off)

h hidden units

1 final output (i.e. M_w) for each time



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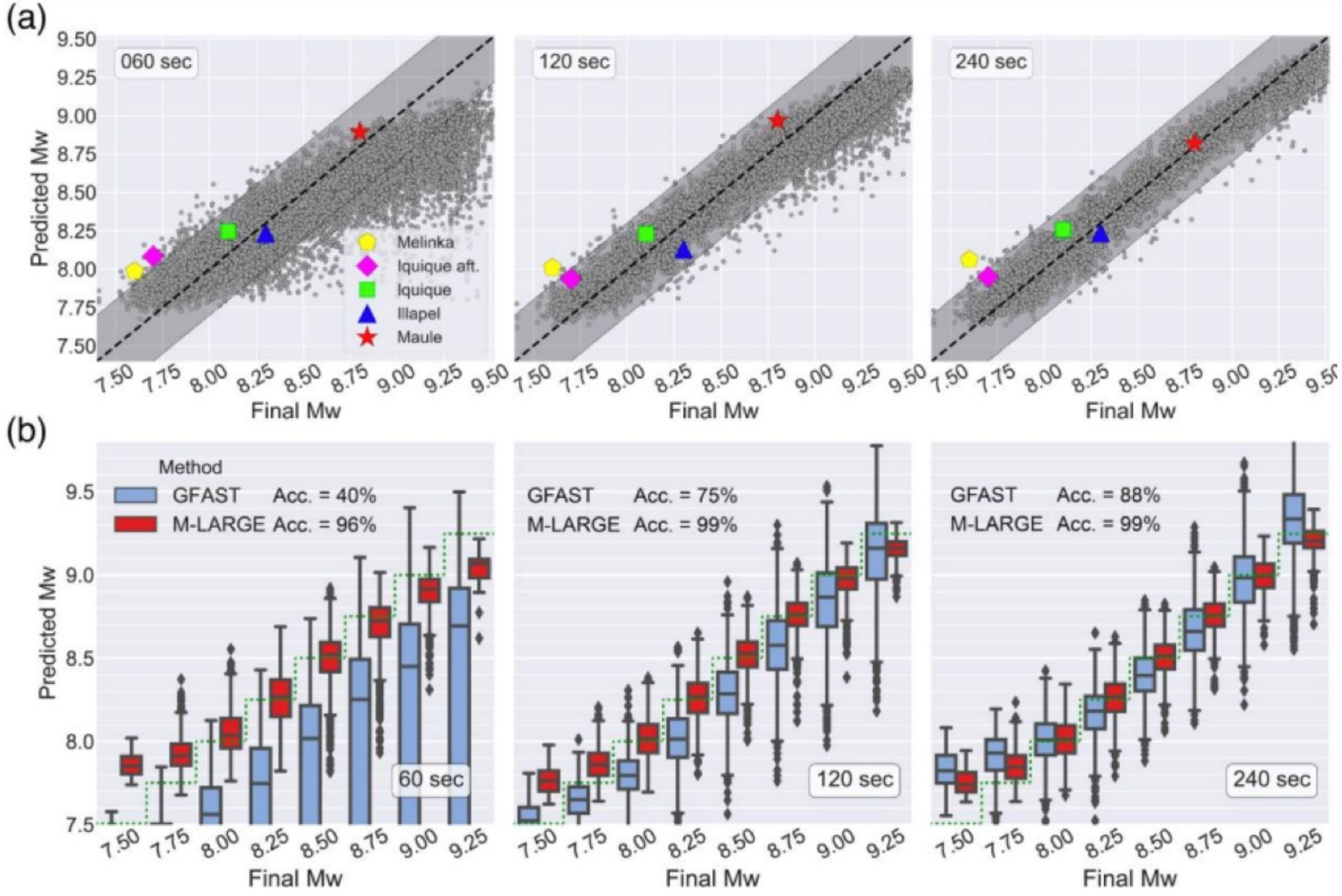
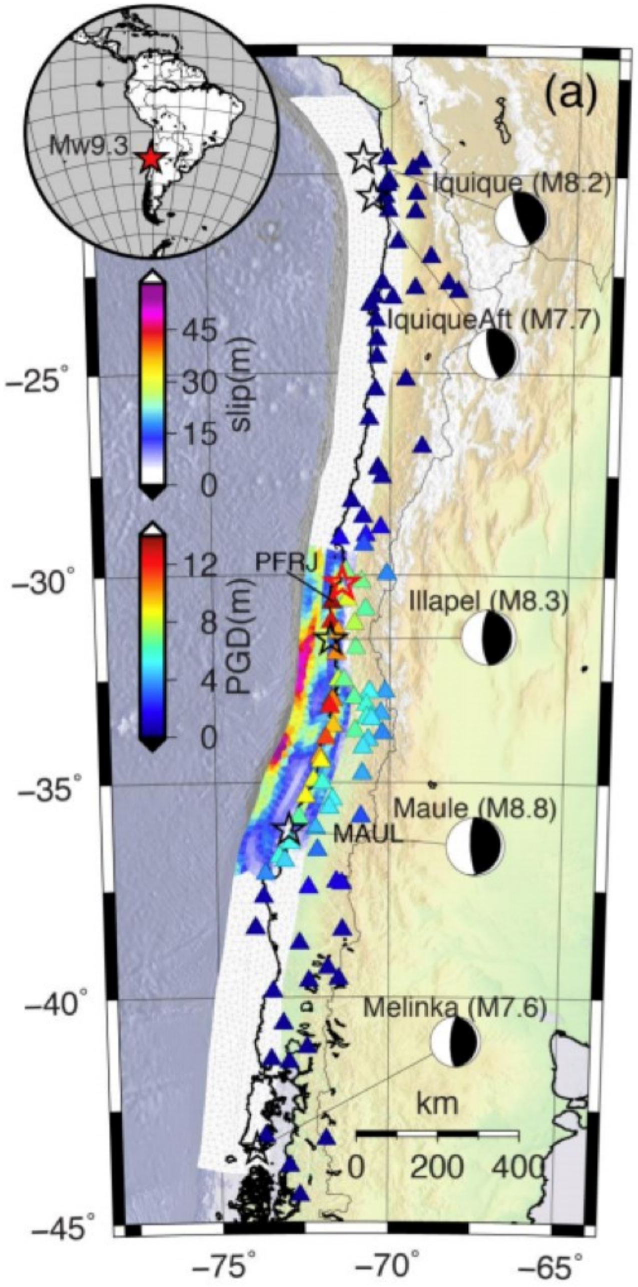
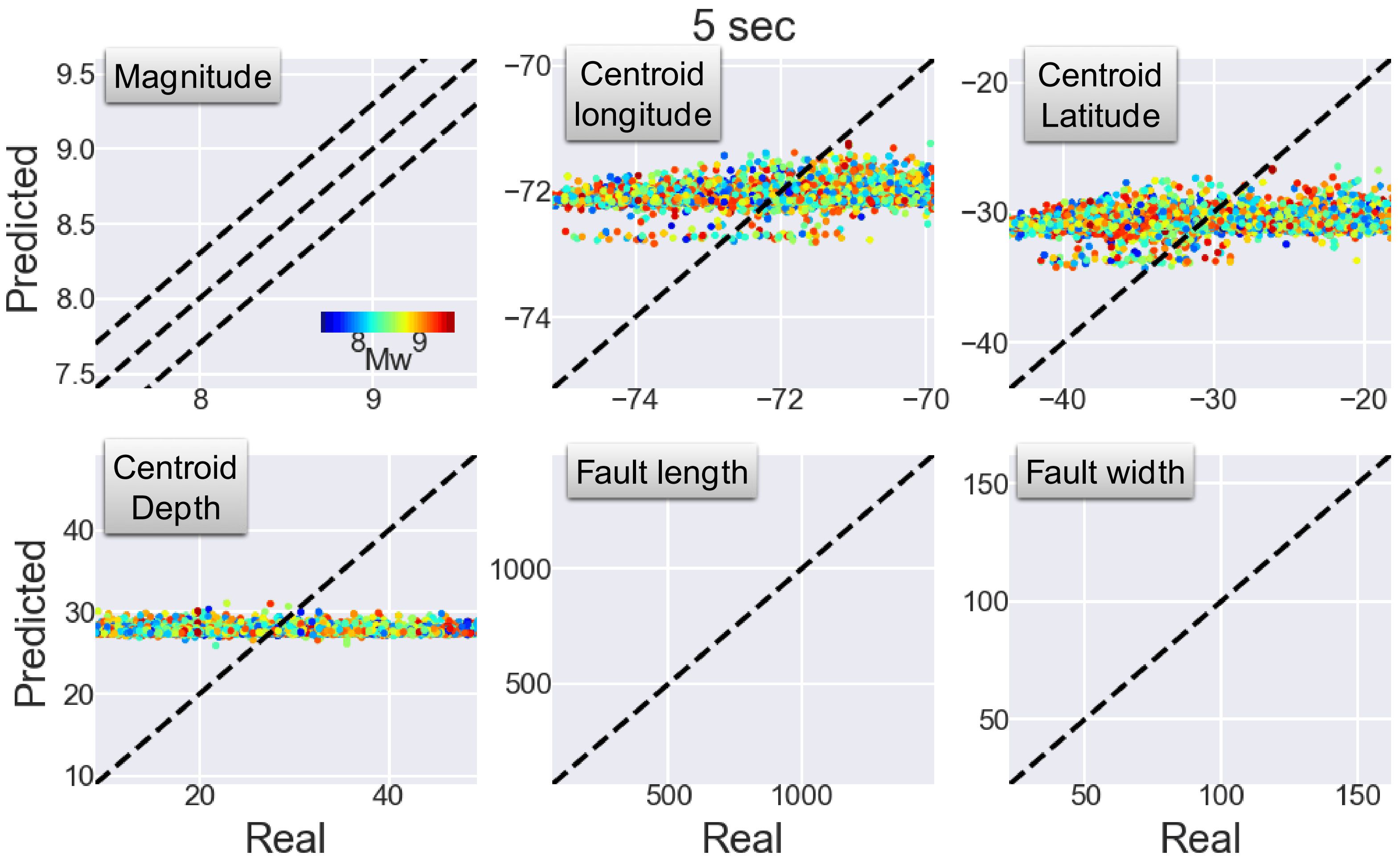
Using RNN to Predict Final Magnitude

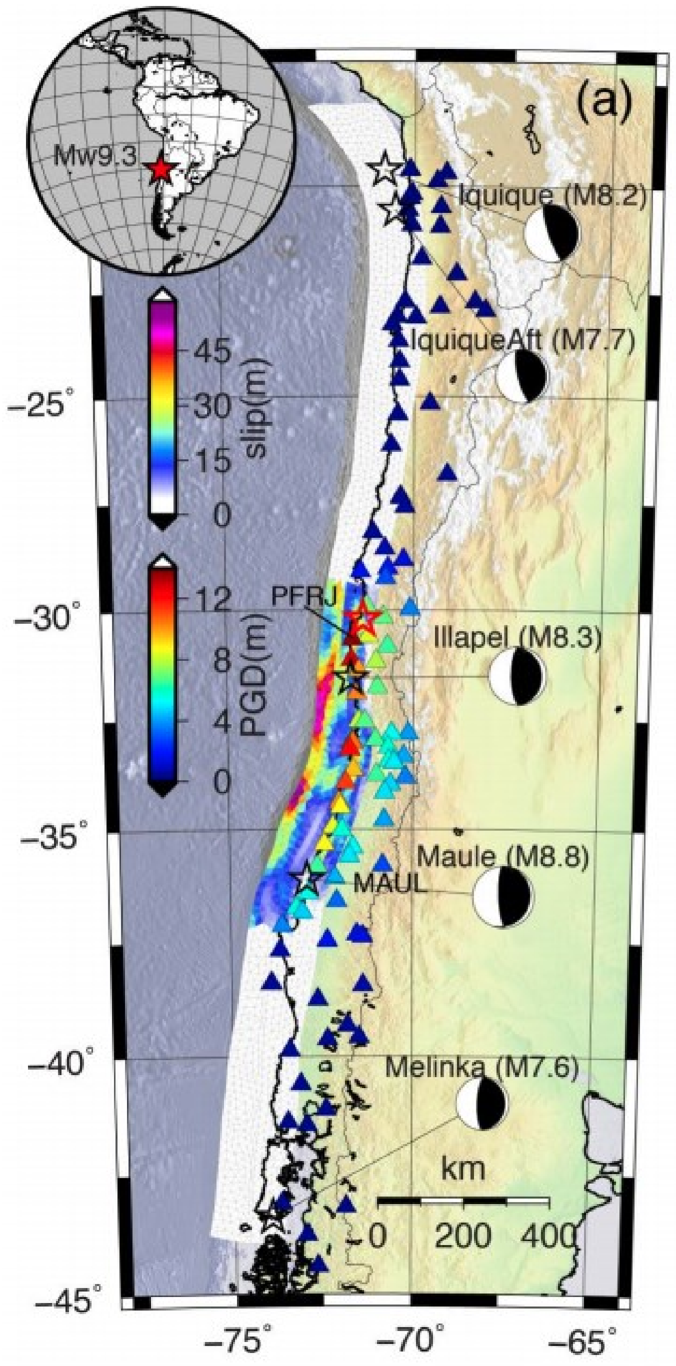




Where to next? M-LARGE 2.0

- Predict the extent of faulting (the rupture polygon)
- This is the most important thing for forecasting shaking in real-time





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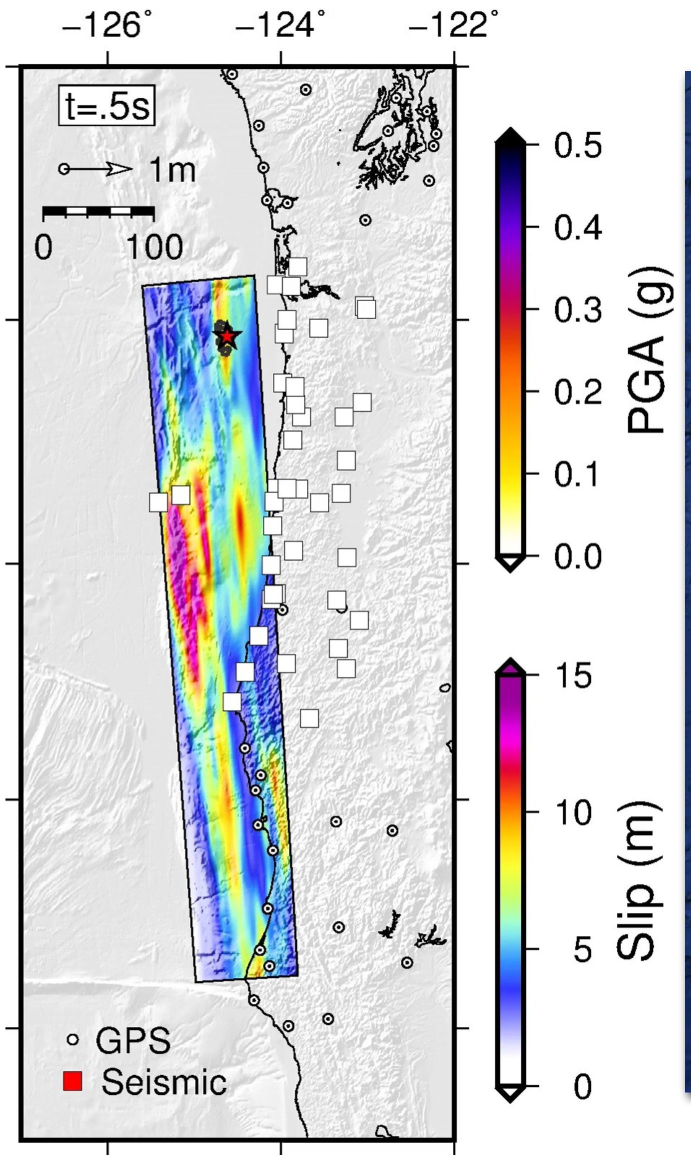
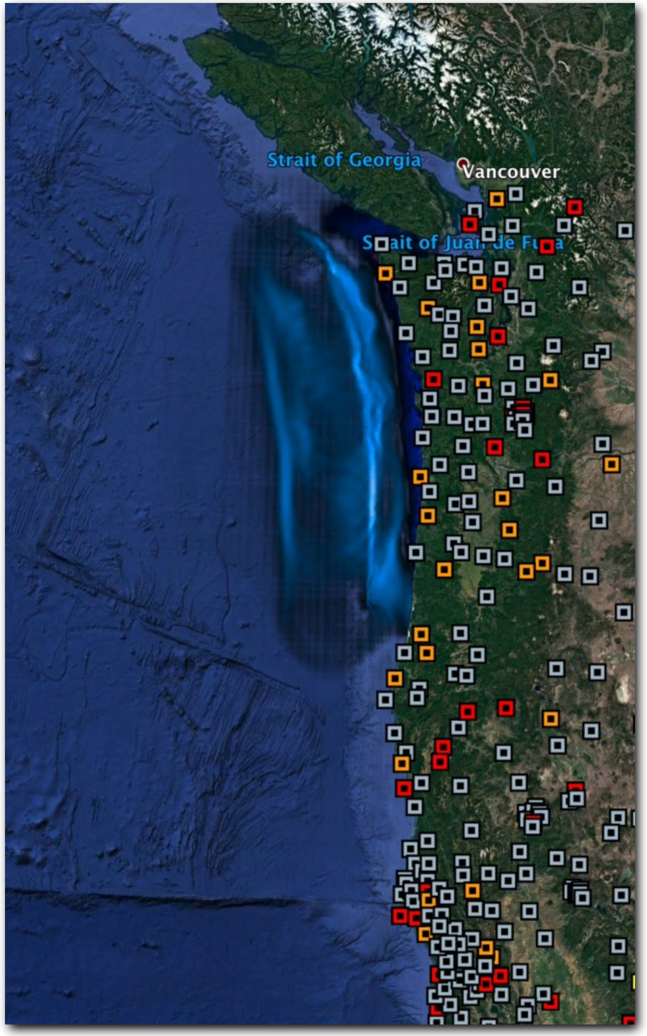
Where to next: Who cares about the earthquake?

- Who cares about the earthquake?
  - The GNSS data encodes (most of) the potential earthquake and tsunami hazards
  - From the crustal deformation patterns predict shakemaps the tsunami amplitudes at the coast **without characterizing the earthquake**





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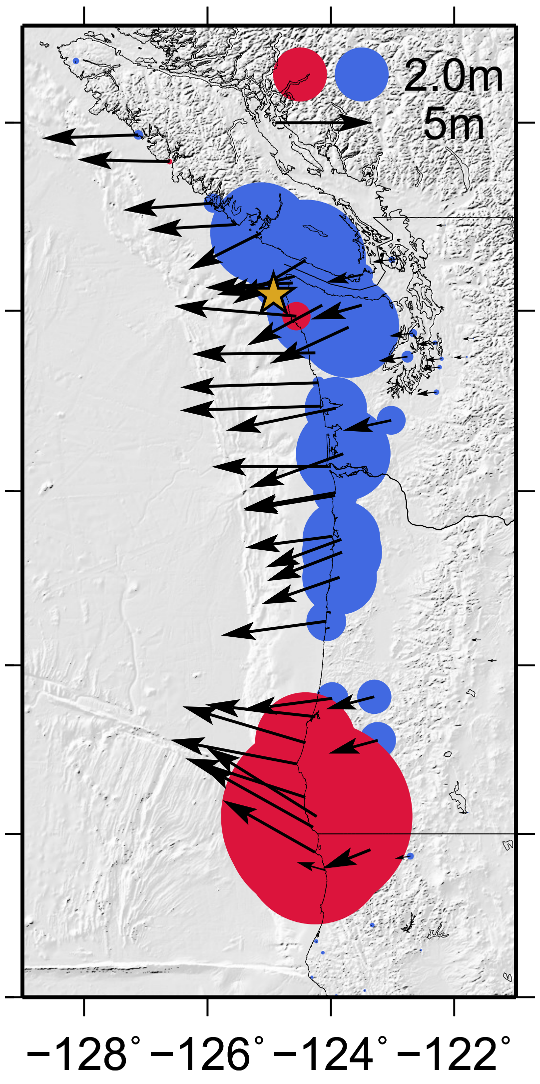

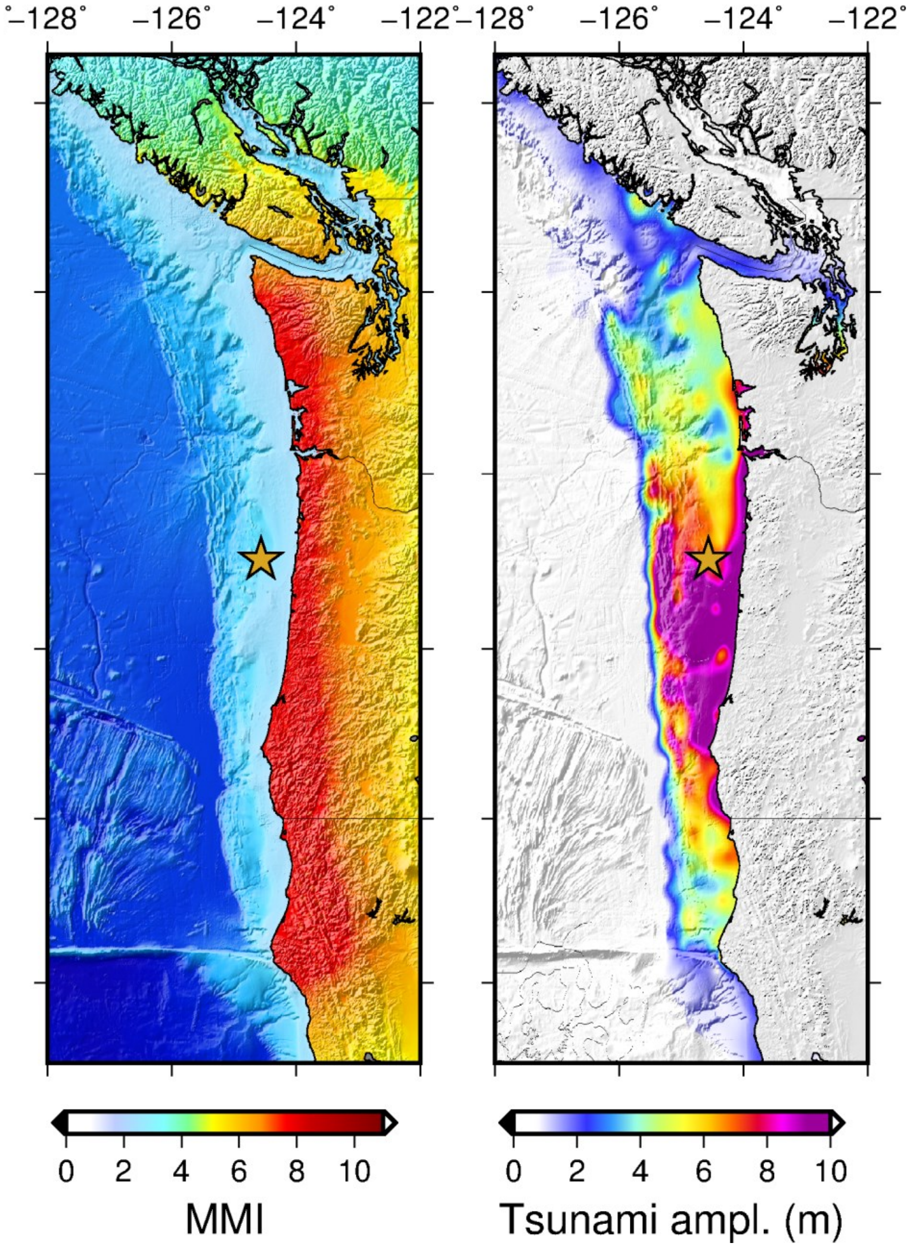

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Conclusions

- GNSS-based earthquake and tsunami early warning is currently in the production phase at USGS and prototype phase at NOAA
- Our current method relies upon traditional techniques, i.e., use a physics-based approach to invert for the earthquake rupture using the displacements recorded.
- ML approaches can help in most aspects of early warning, from the data processing, to the source inference, to the impact modeling.
- The framework exists to test ML approaches within G-FAST without disrupting the existing modeling modules.