Local tsunami warning for Cascadia: The challenges ahead

Diego Melgar
University of Oregon

NASA

NOAA

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

NATIONAL WEATHER SERVICE

Pacific Tsunami Warning Center

National Tsunami Warning Center

CWU Central Washington University

UNIVERSITY OF OREGON

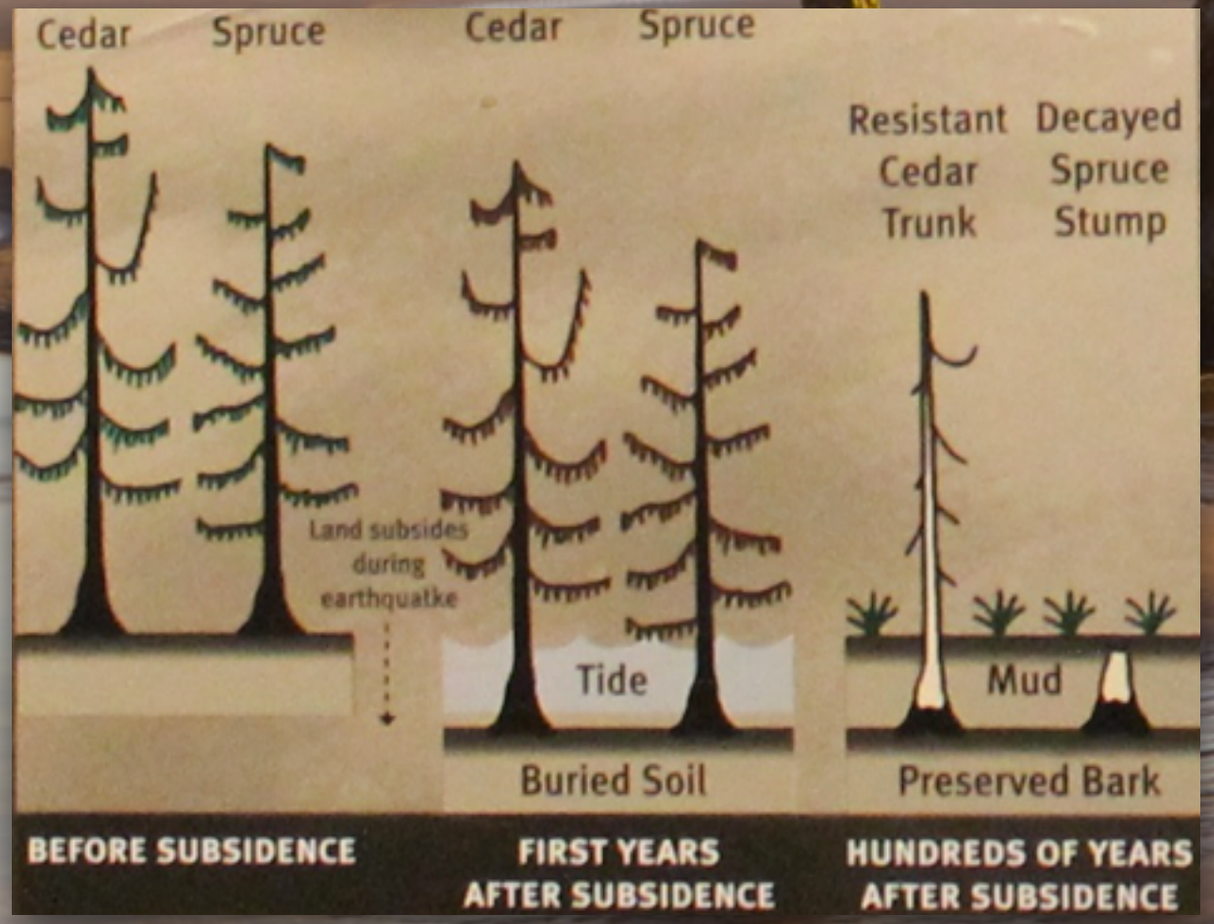
UNIVERSITY of WASHINGTON

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Neskowin Ghost Forest, OR

Large (M9) events roughly every 300 years

Last one (~M9) on January 26th, 1700



The Cascadia Subduction Zone

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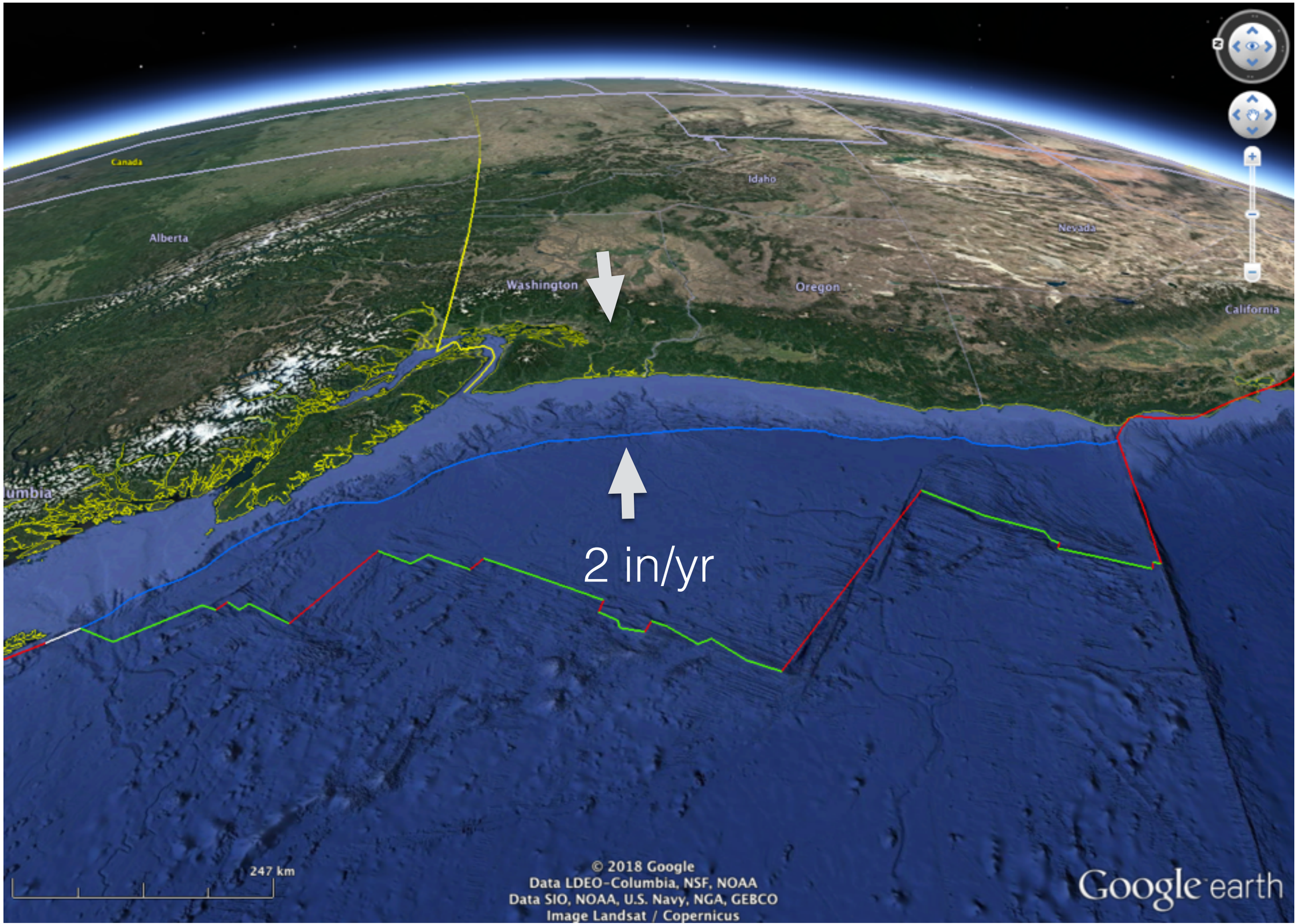

The Cascadia Subduction Zone

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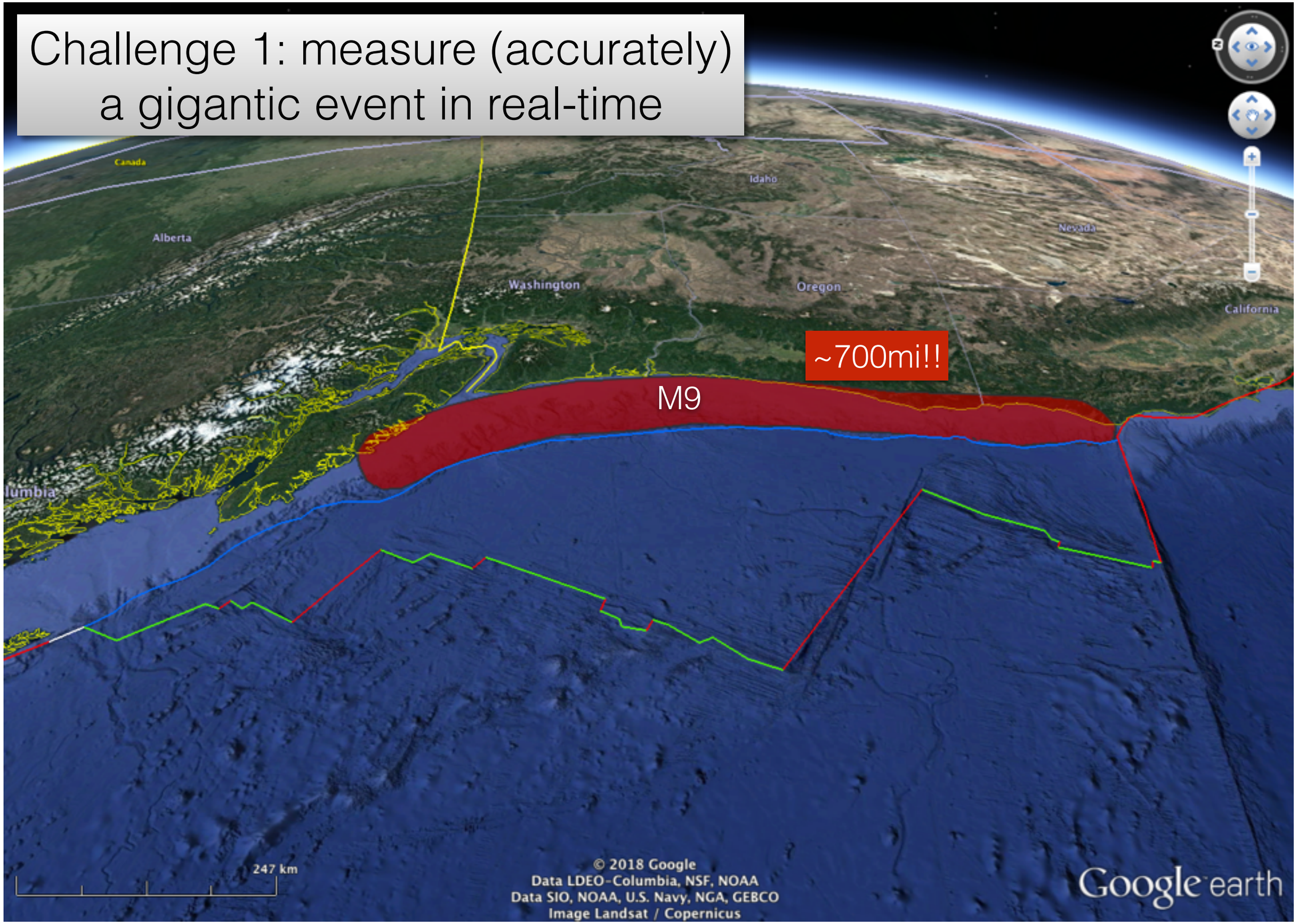
Challenge 1: measure (accurately) a gigantic event in real-time



The Cascadia Subduction Zone

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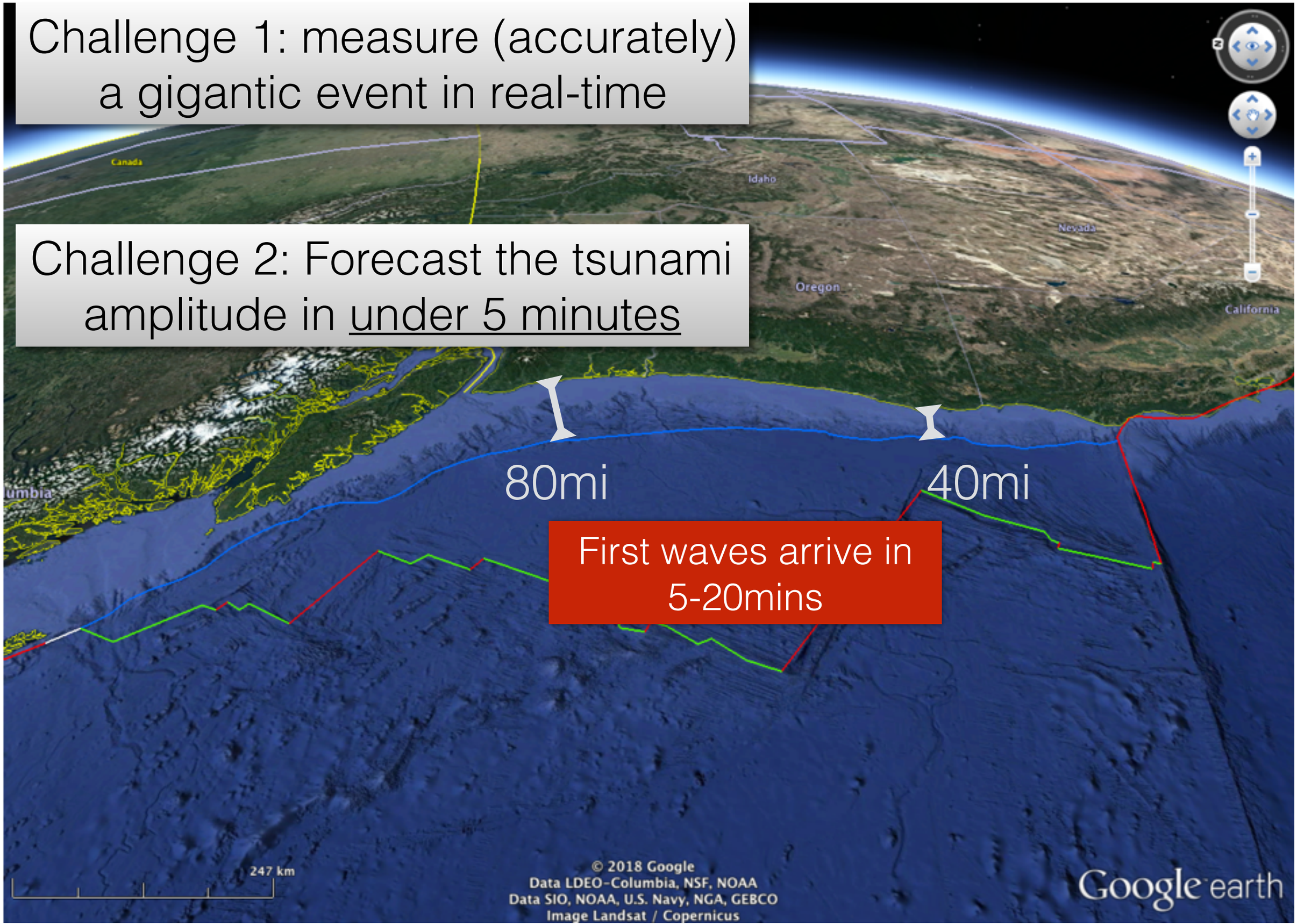
Challenge 1: measure (accurately) a gigantic event in real-time

Challenge 2: Forecast the tsunami amplitude in <u>under 5 minutes</u>



The Cascadia Subduction Zone

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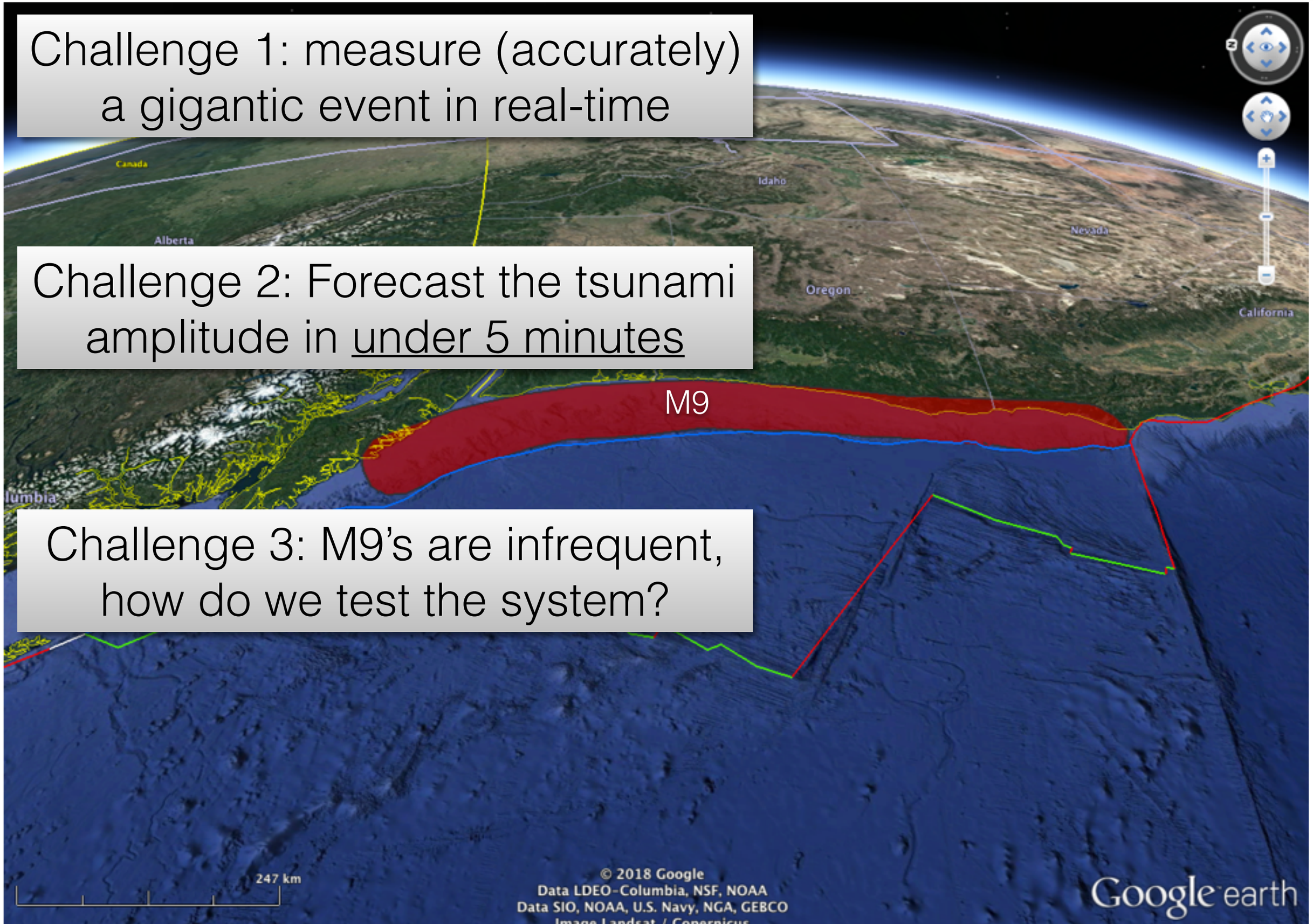


Local warning

Minutes of lead time

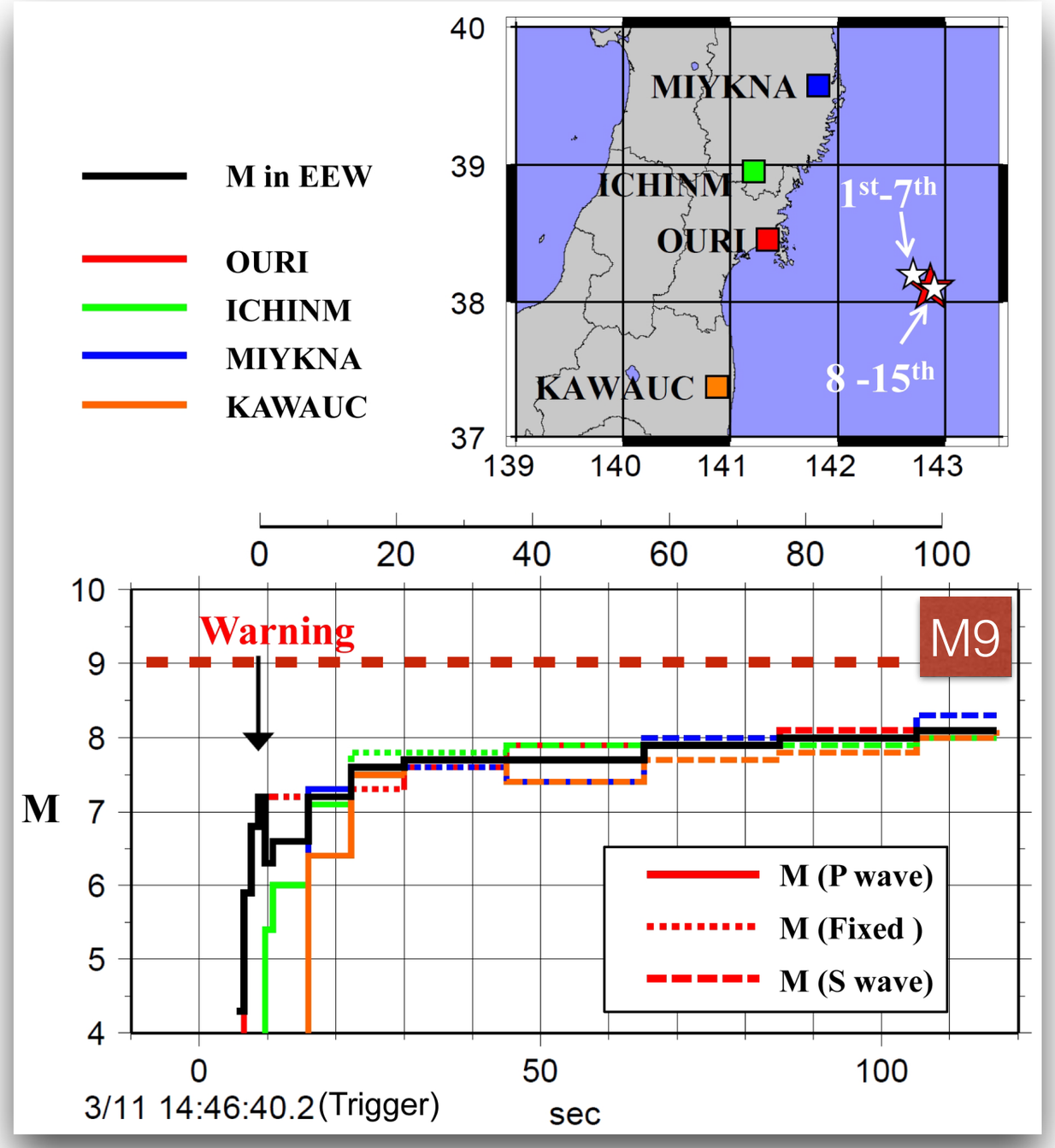
Global Warning
Hours of lead time

Japan is the only country in the world with a purpose built operational local warning system

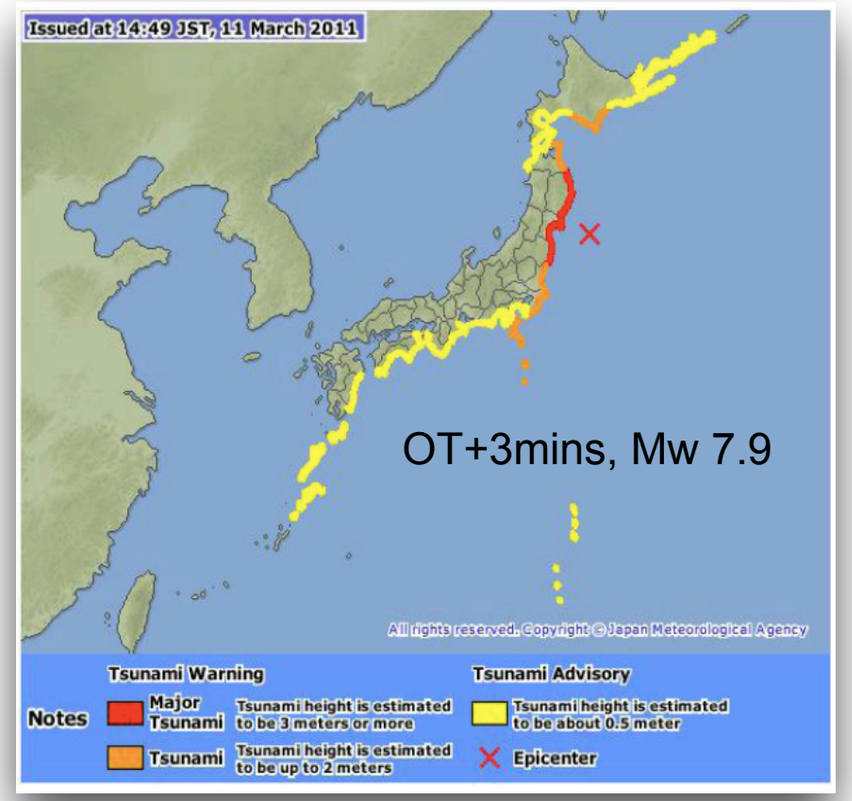
Wave Height (cm)

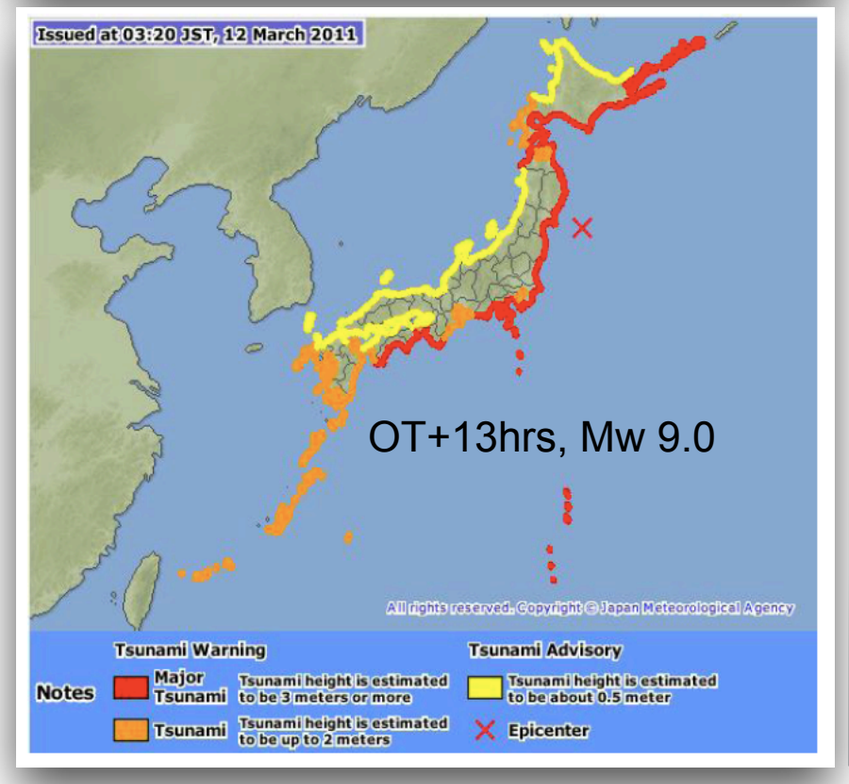
0 20 40 60 80 100 120 140 160 180 200 220 240+

Local Warning in Practice: The Tohoku Experience



Hoshiba et al, 2011, EPS





Ozaki et al, 2011, EPS

Fault Areas of some California earthquakes

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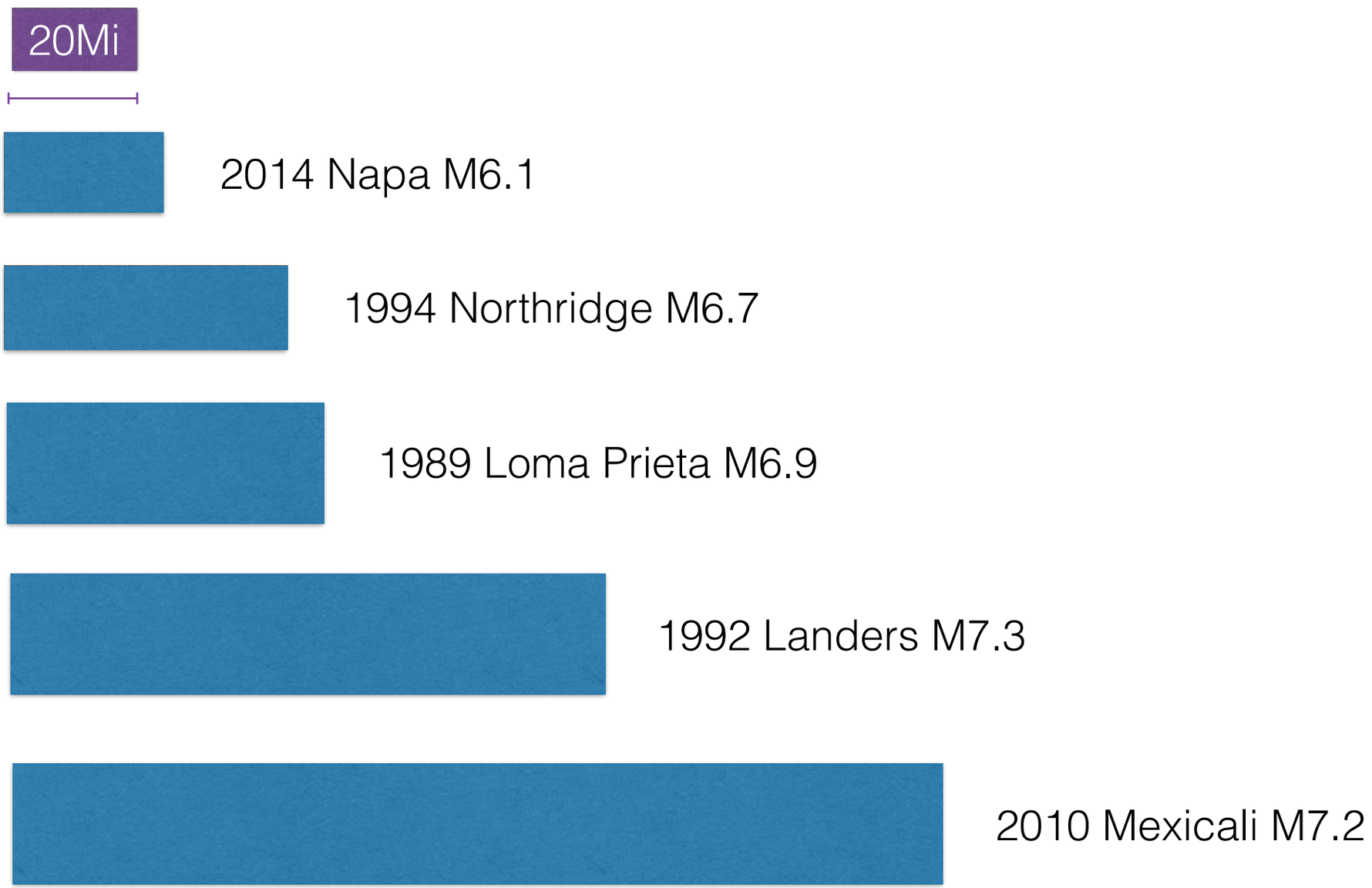
- Rapid determination of an earthquakes size and rupture characteristic is tricky.



Fault Areas of large earthquakes

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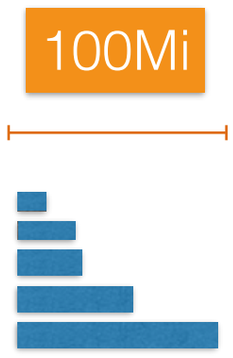
- Rapid determination of an earthquakes size and rupture characteristic is tricky.



2010 M8.8 Chile

2011 M9.0 Japan

2004 M9.2 Sumatra

Seismometers have a really hard time measuring things this big

So we use high precision GPS

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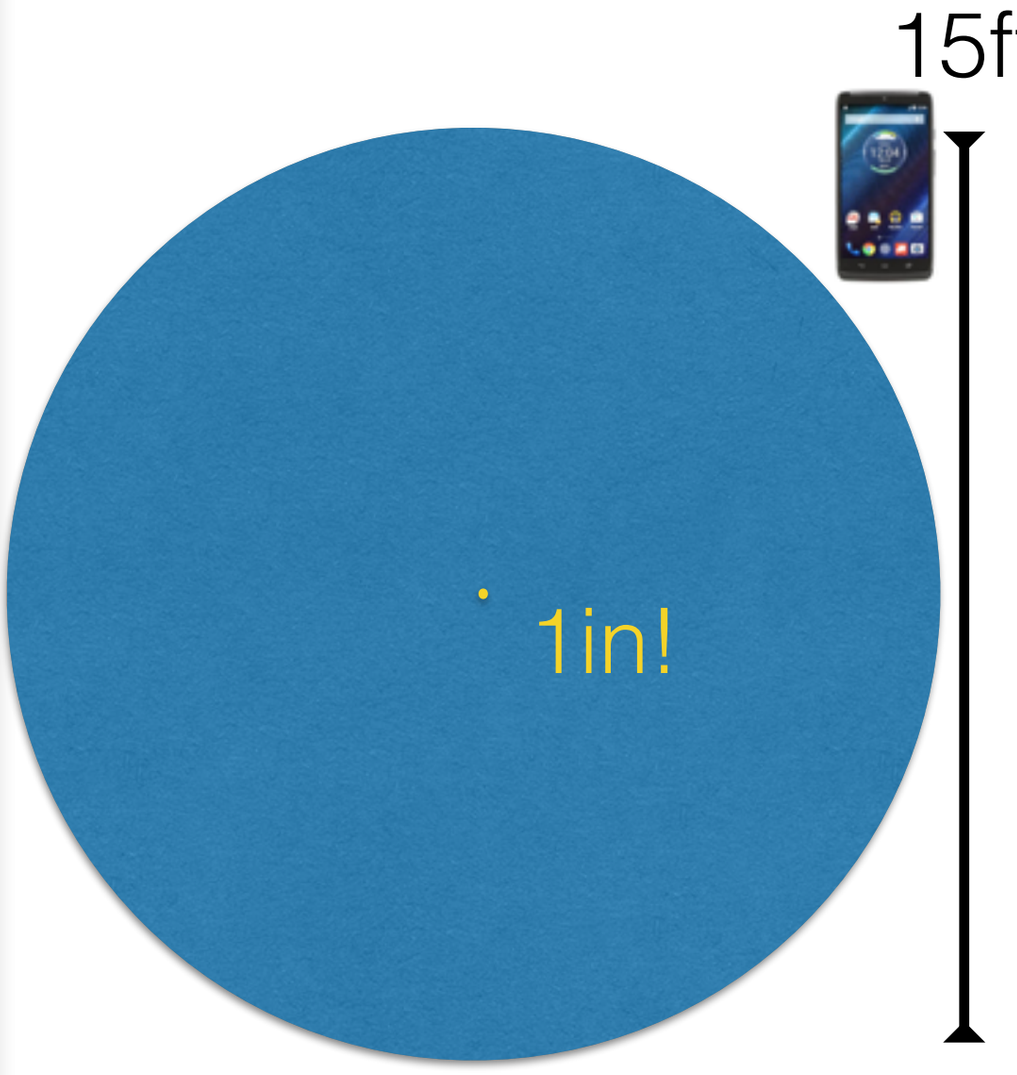

EI GPS is the best sensor for very large EQs

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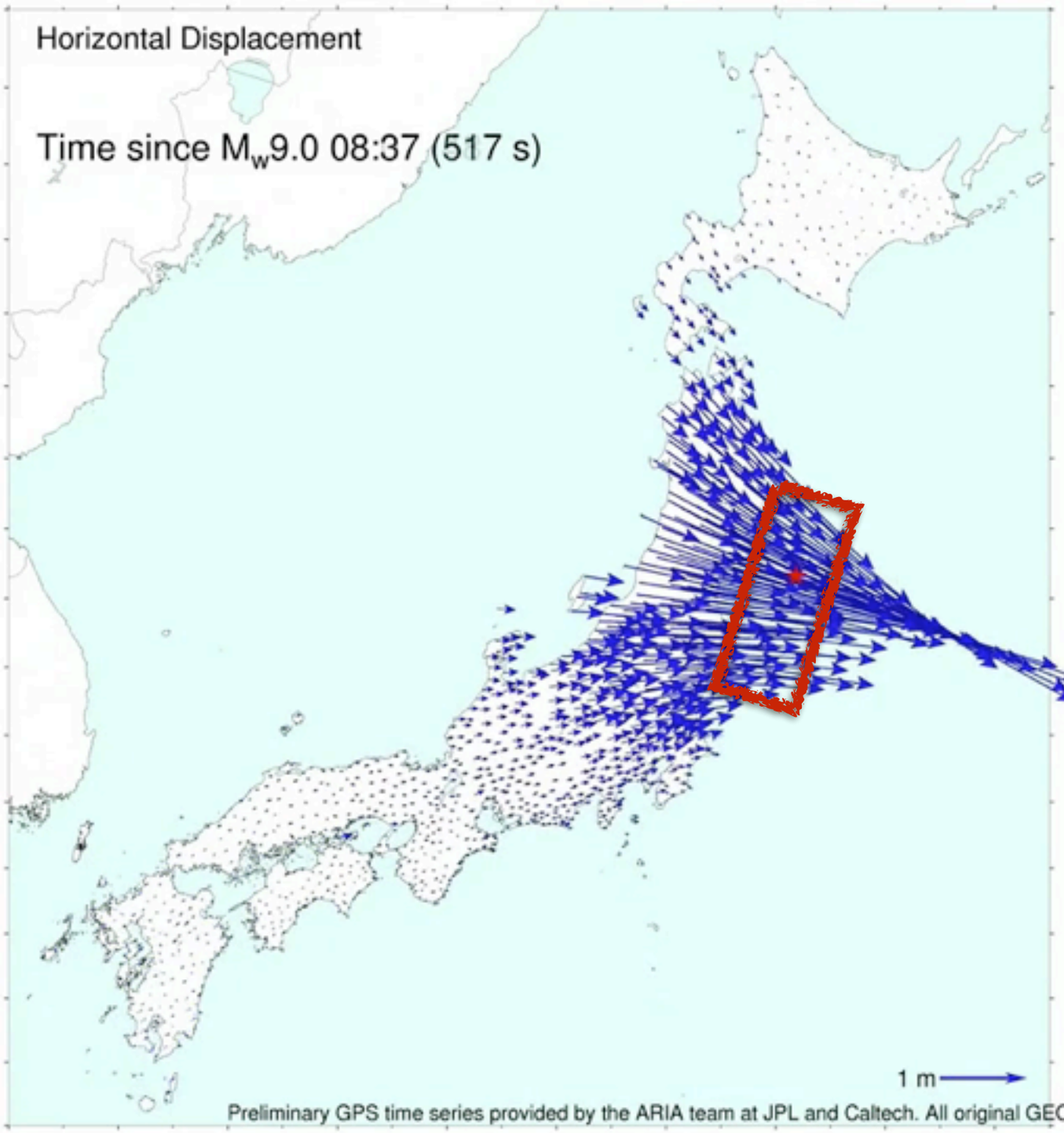
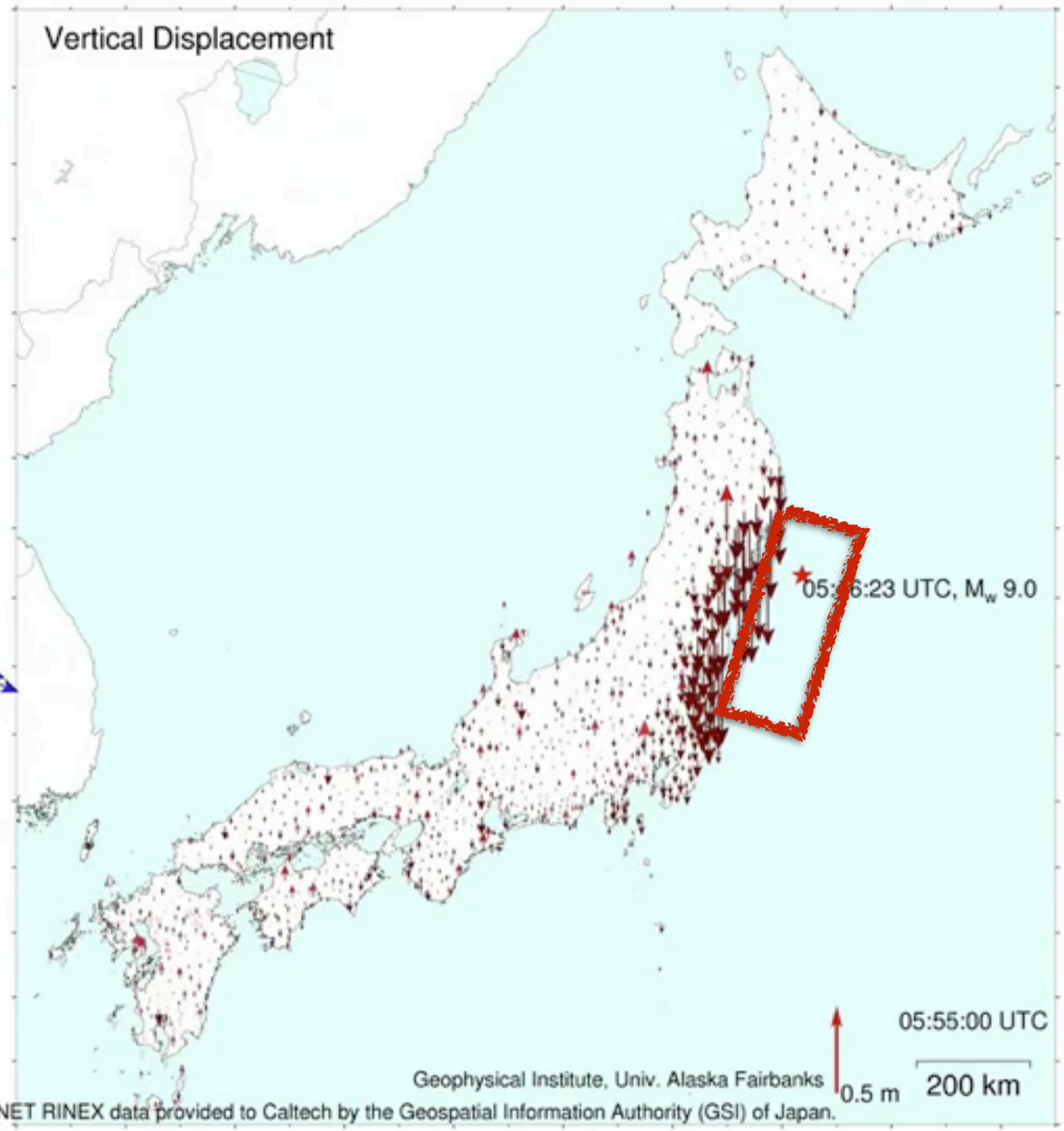
2011 M9 Tohoku-oki



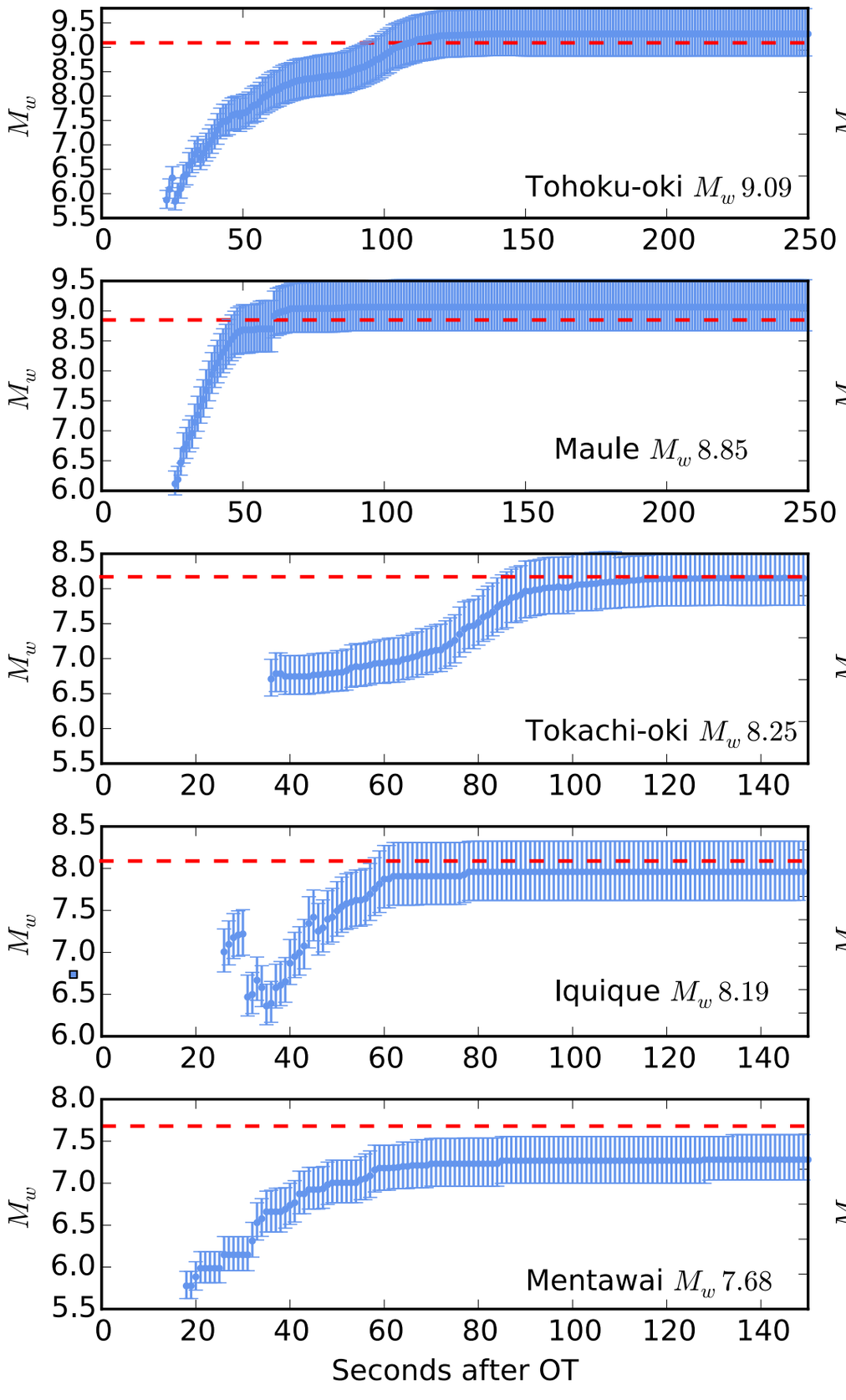


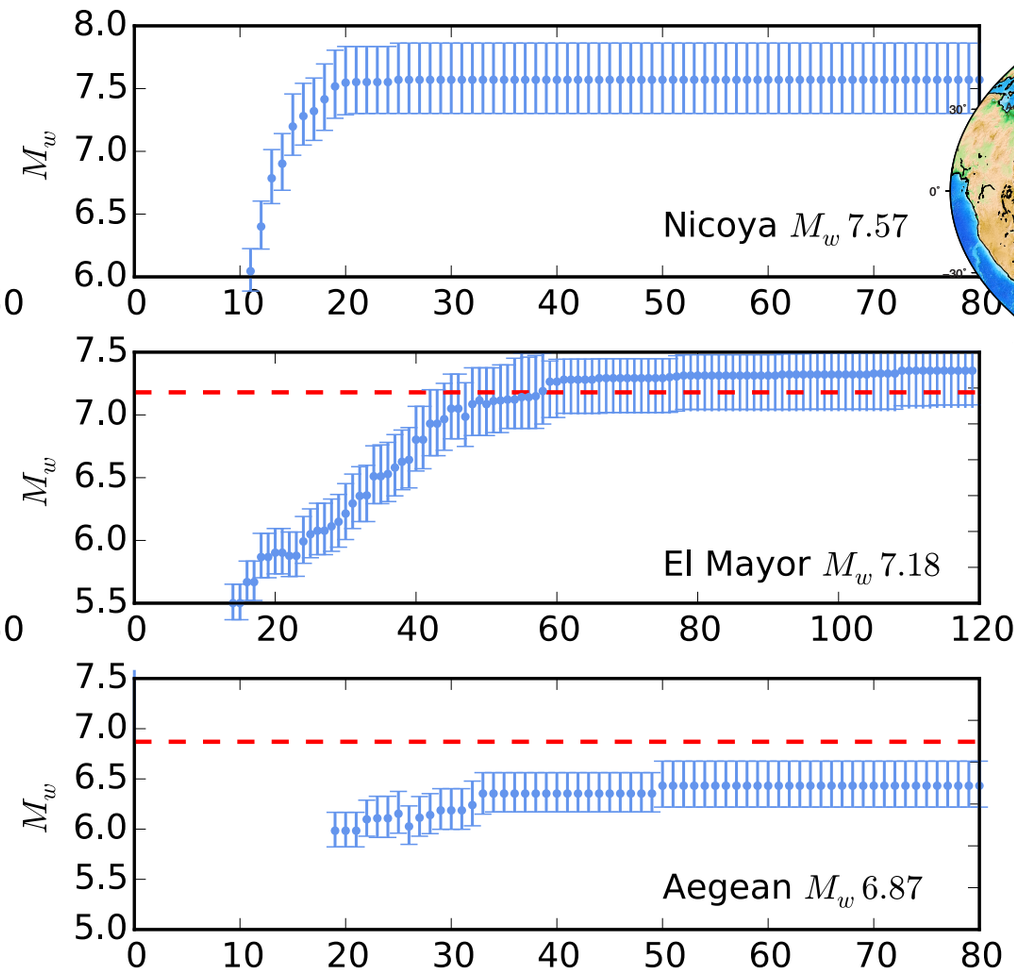
Geophysical Institute, Univ. Alaska Fairbanks

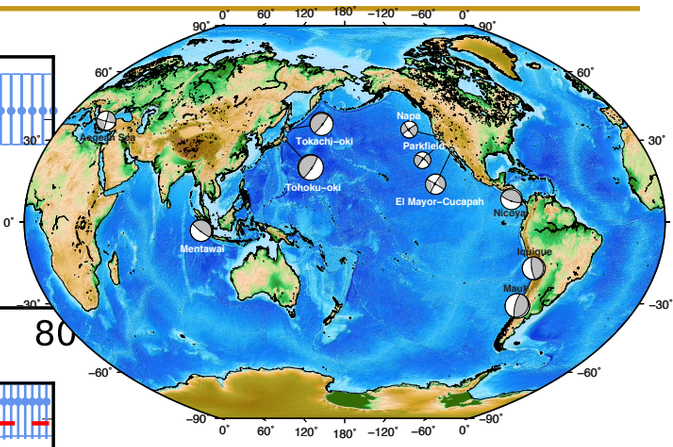
Preliminary GPS time series provided by the ARIA team at JPL and Caltech. All original GEONET RINEX data provided to Caltech by the Geospatial Information Authority (GSI) of Japan.

Grapenthin et al., 2012

We know it works

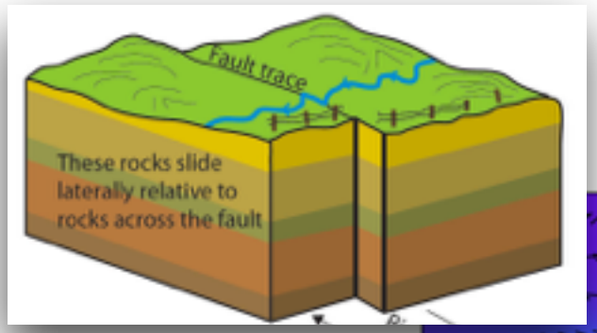




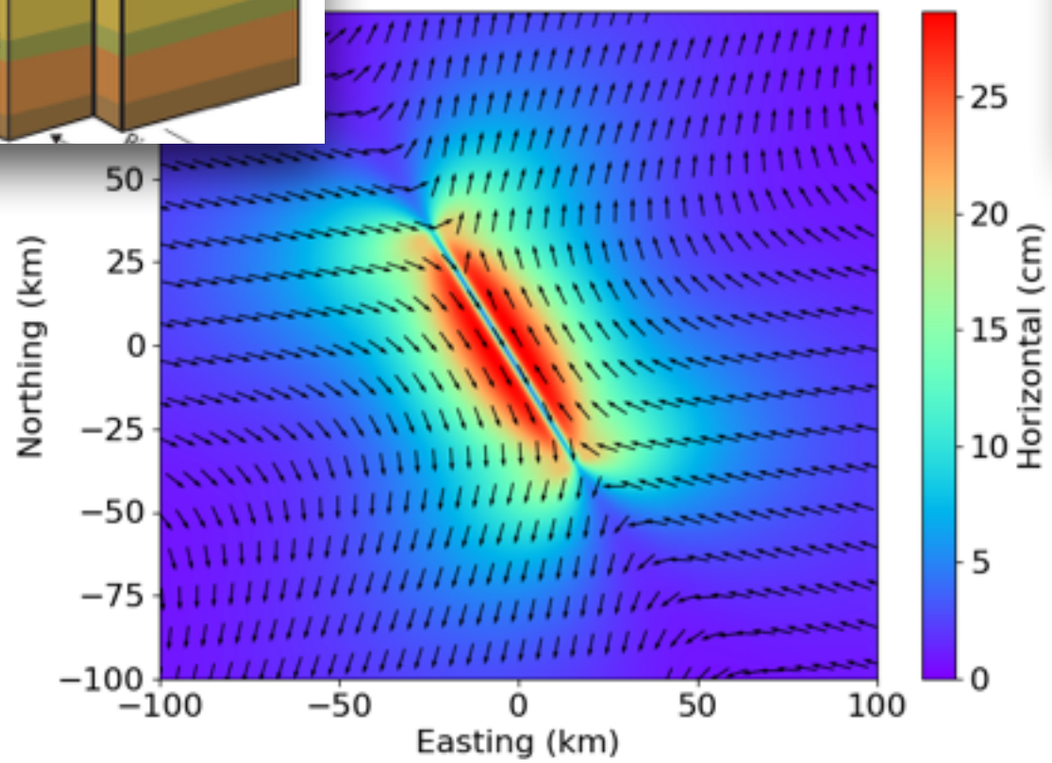


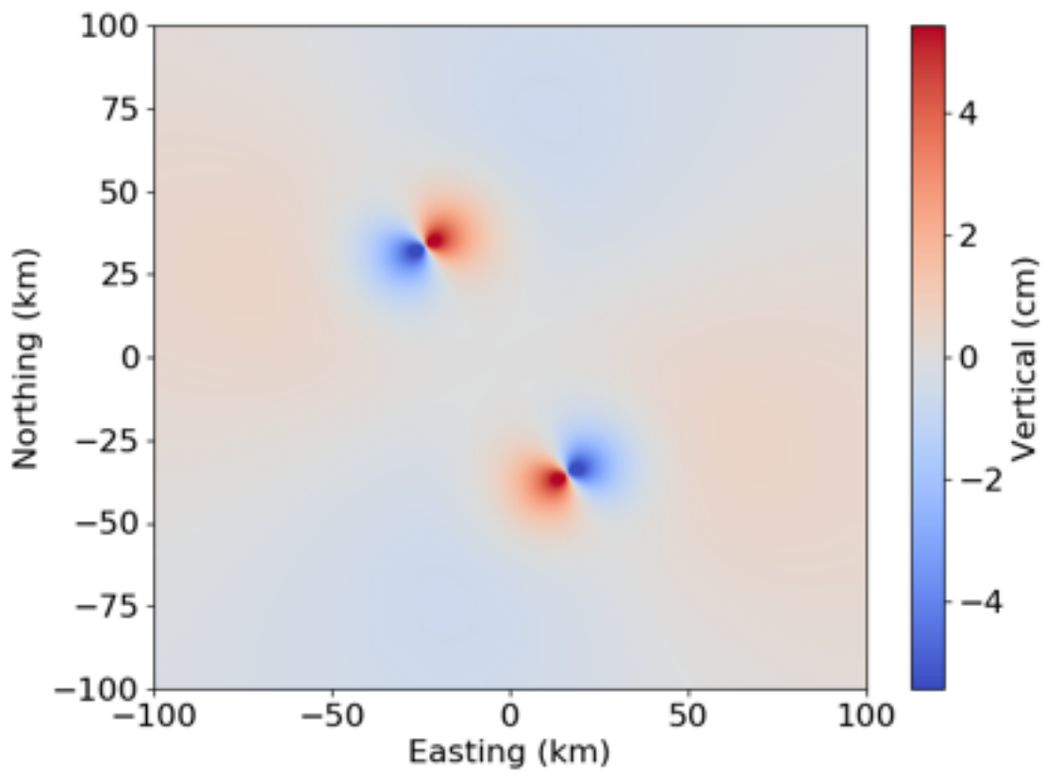
Melgar et al., 2015

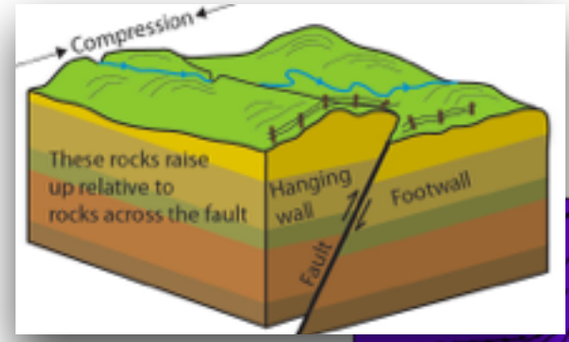
GPS also discriminates the "type" of earthquake



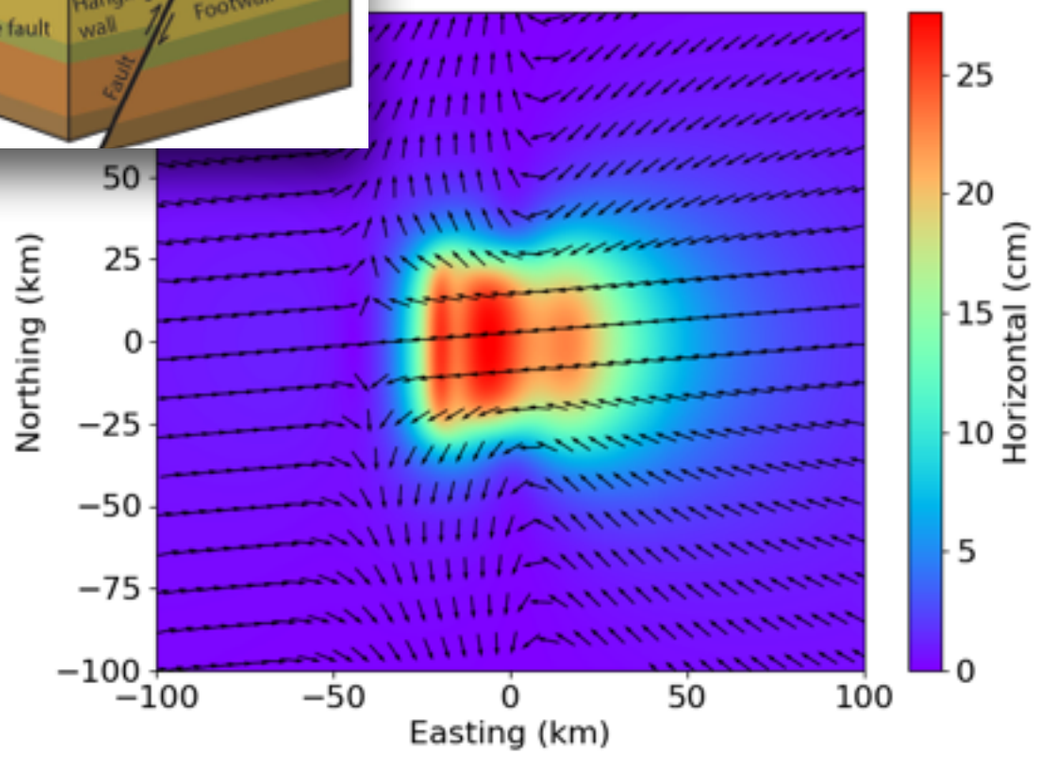
M7 strike-slip

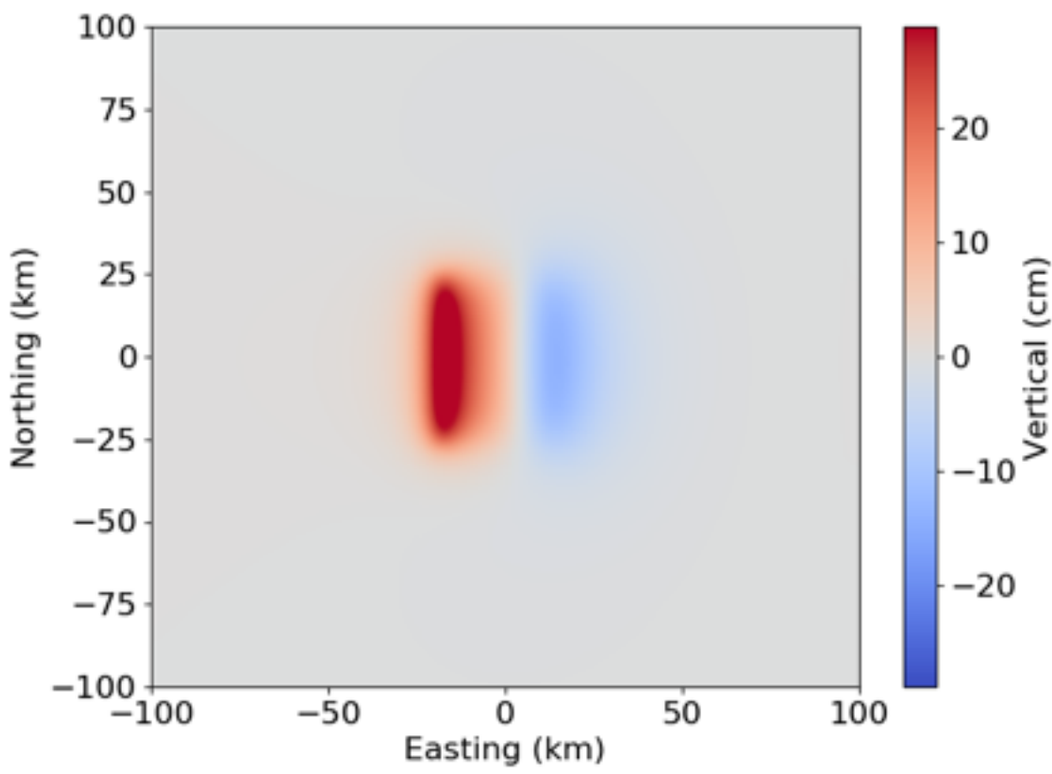






M7 Thrust





These happen in the real world

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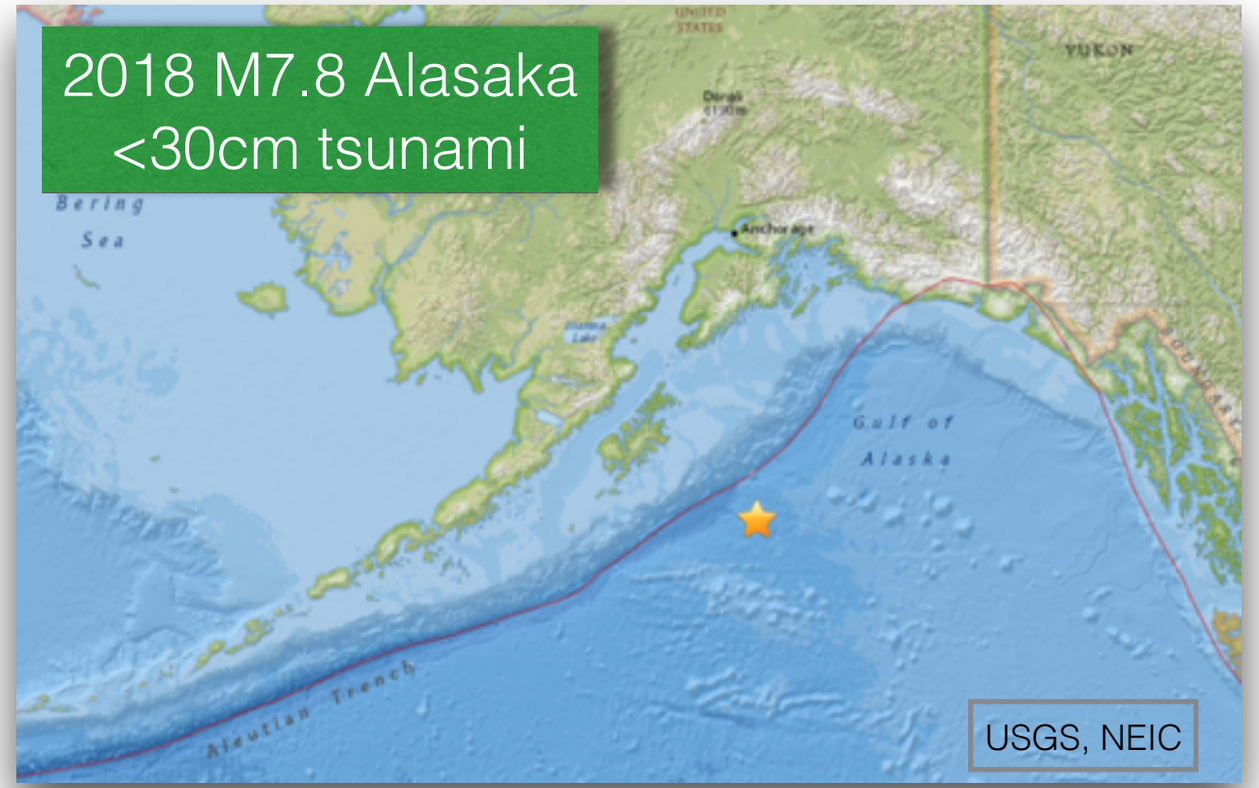

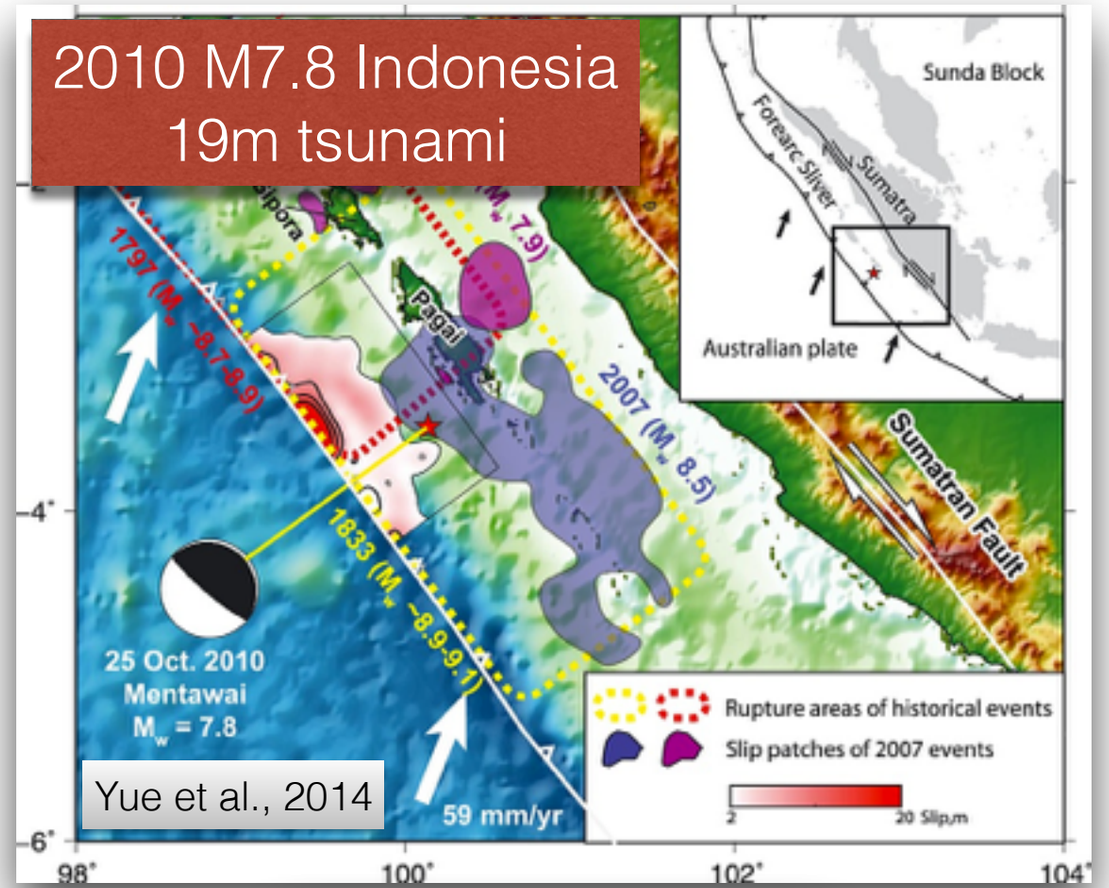

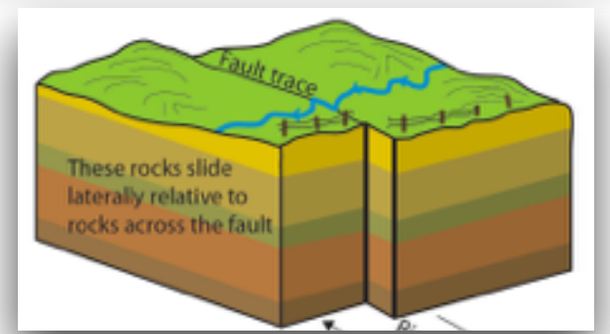

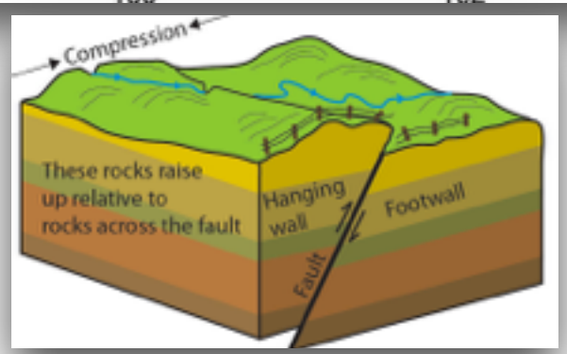

GPS in the western US

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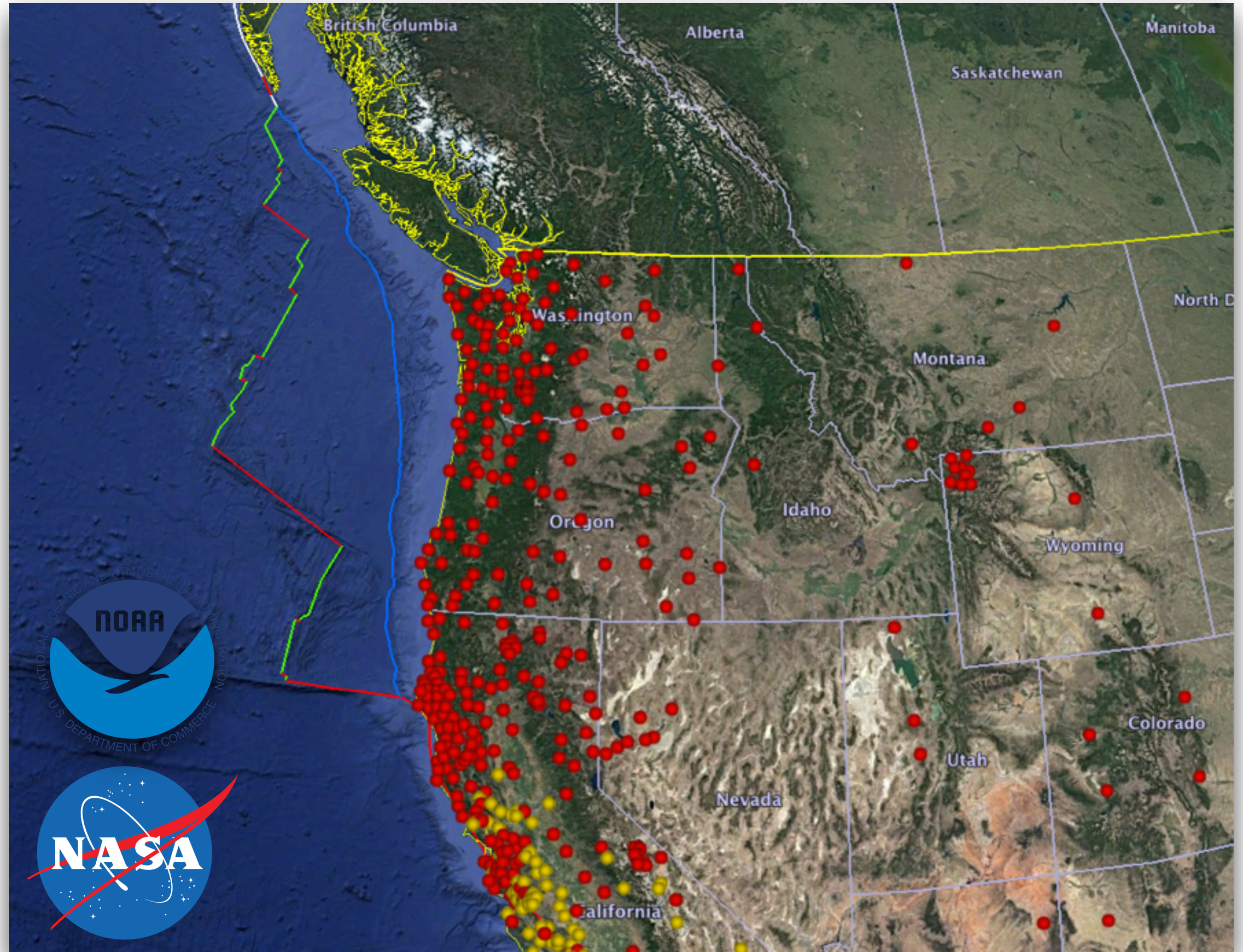

The Cascadia Subduction Zone

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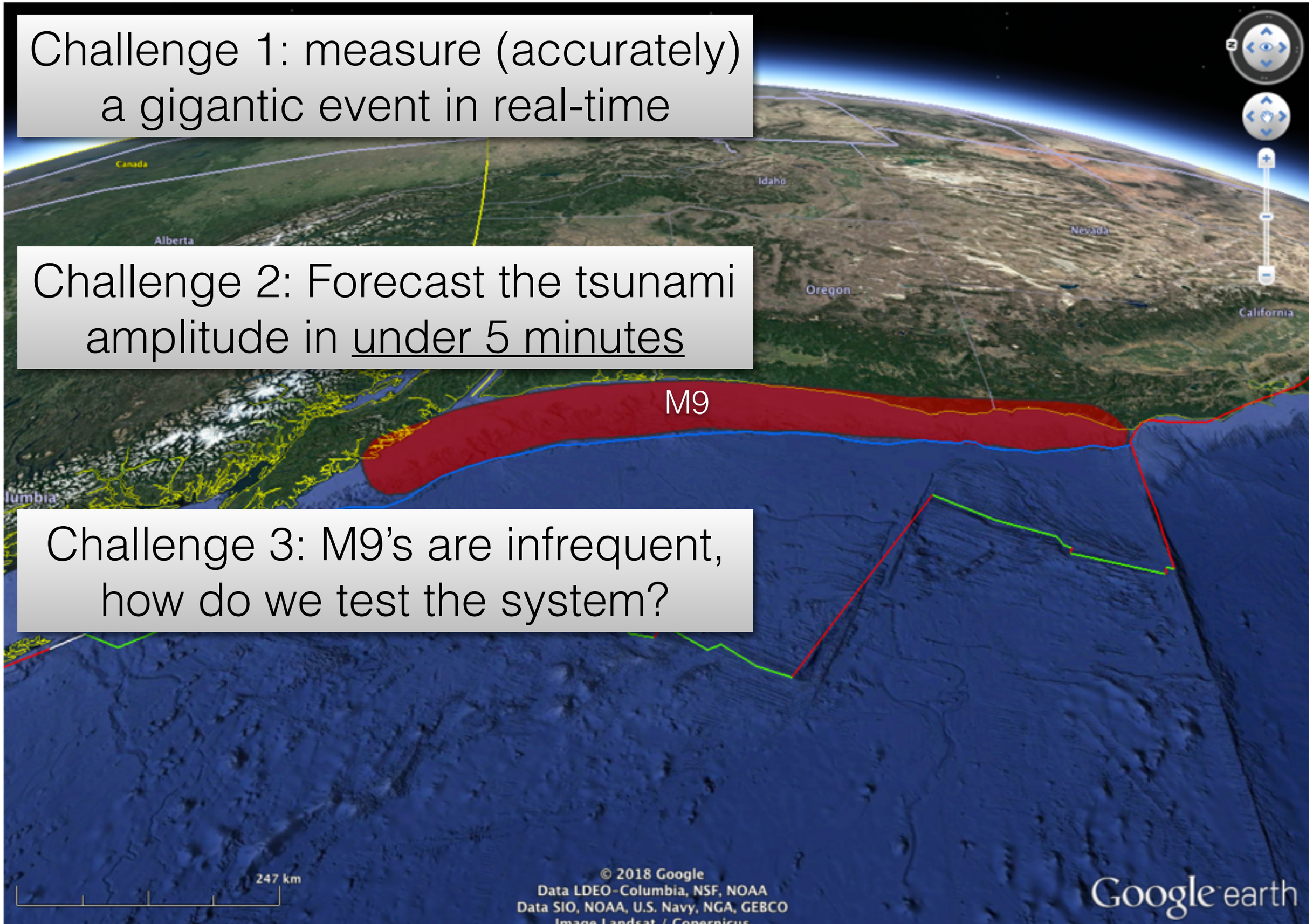

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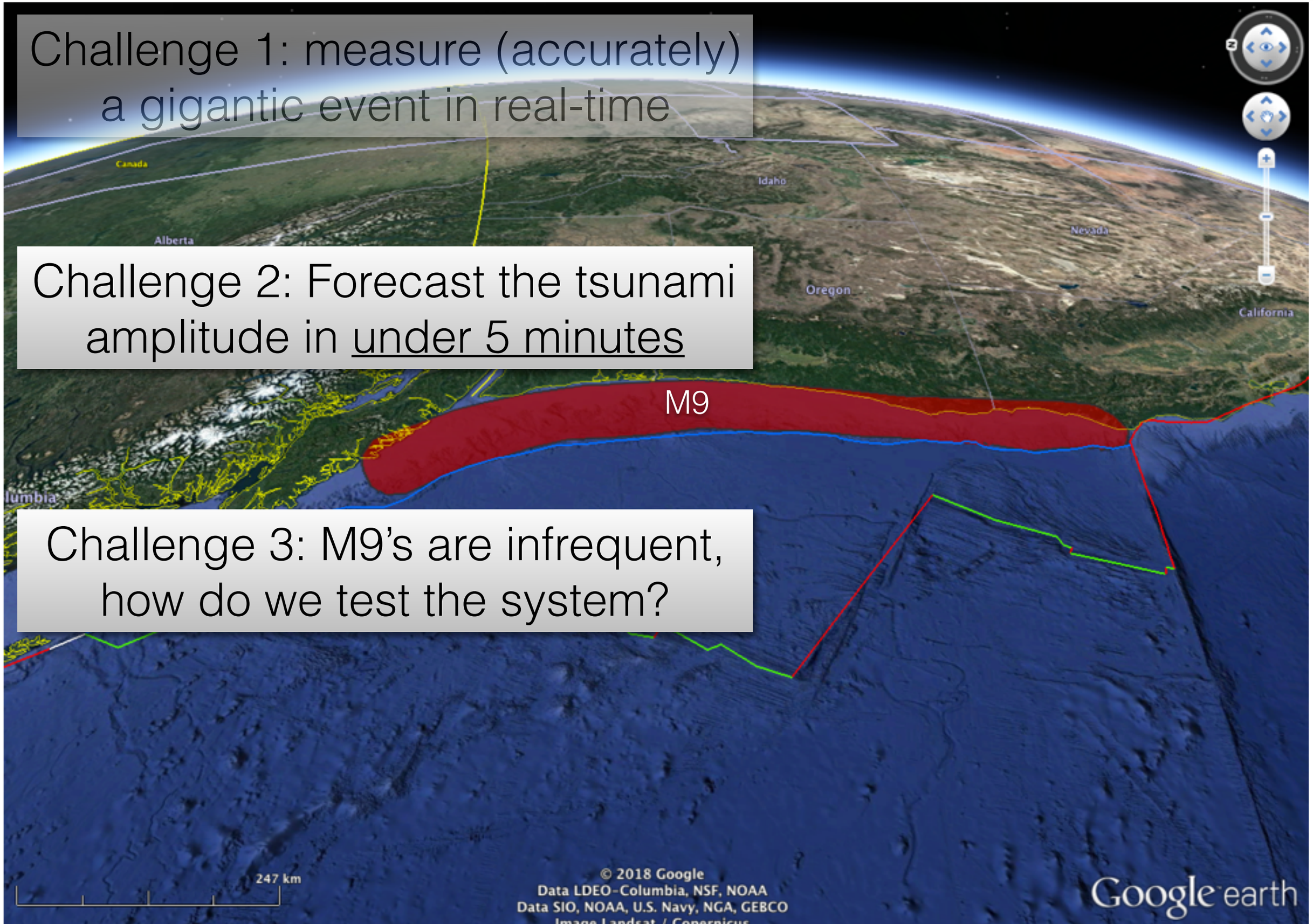

How good are the rapid intensity models?

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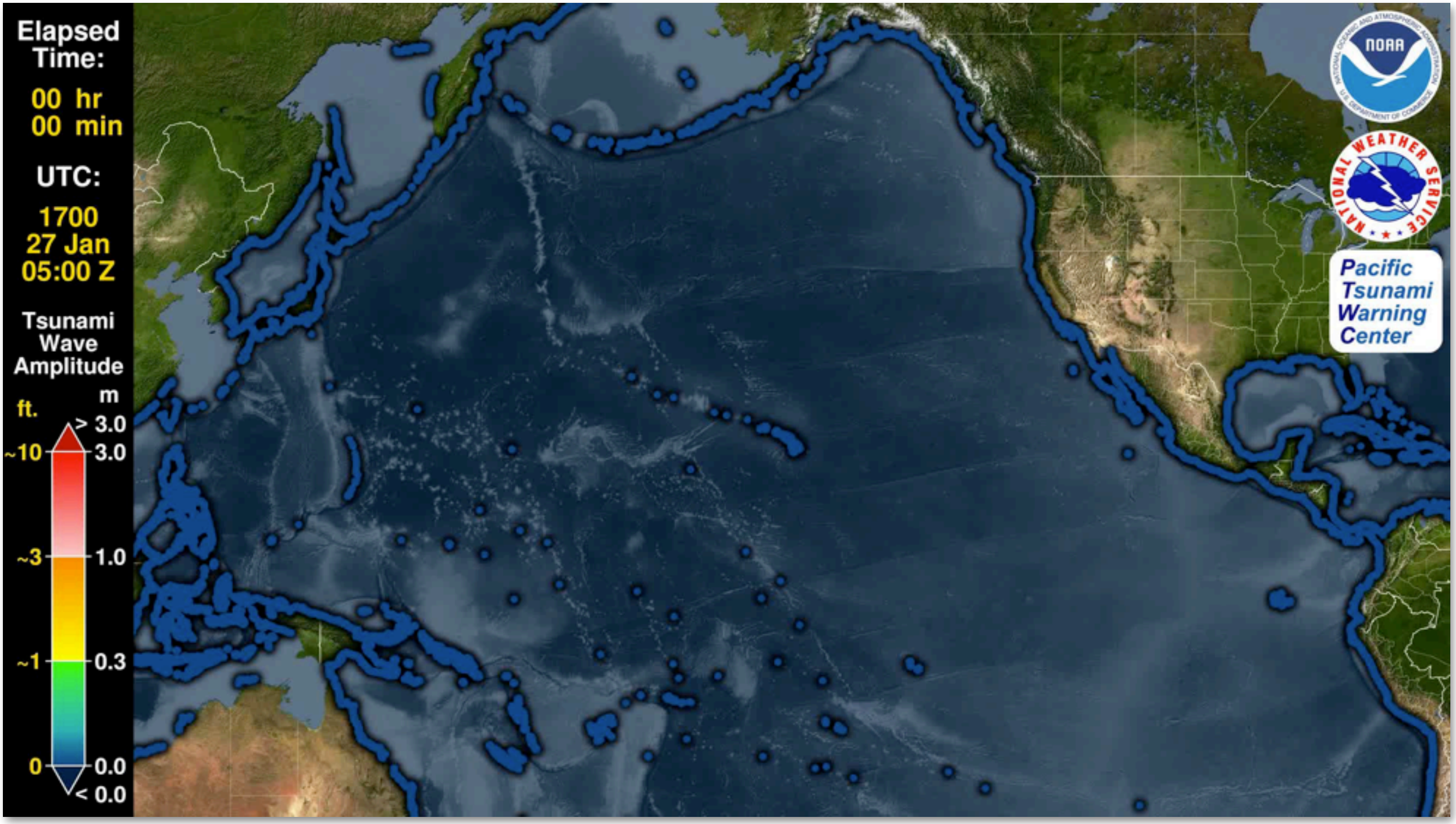

Nathan Becker & Dailin Wang PTWC, NOAA

How good are the rapid intensity models?

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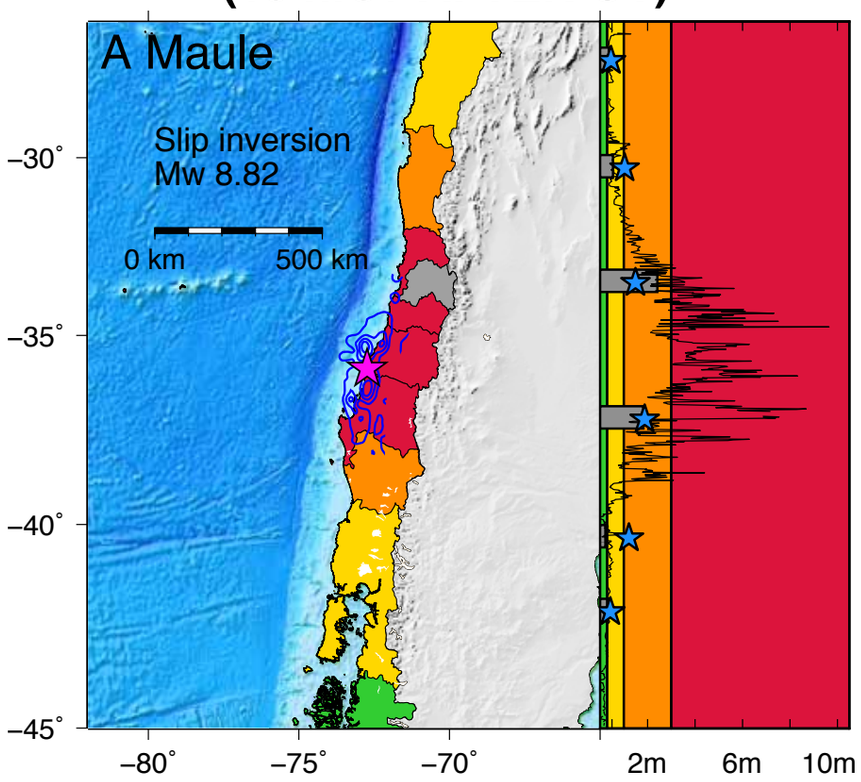
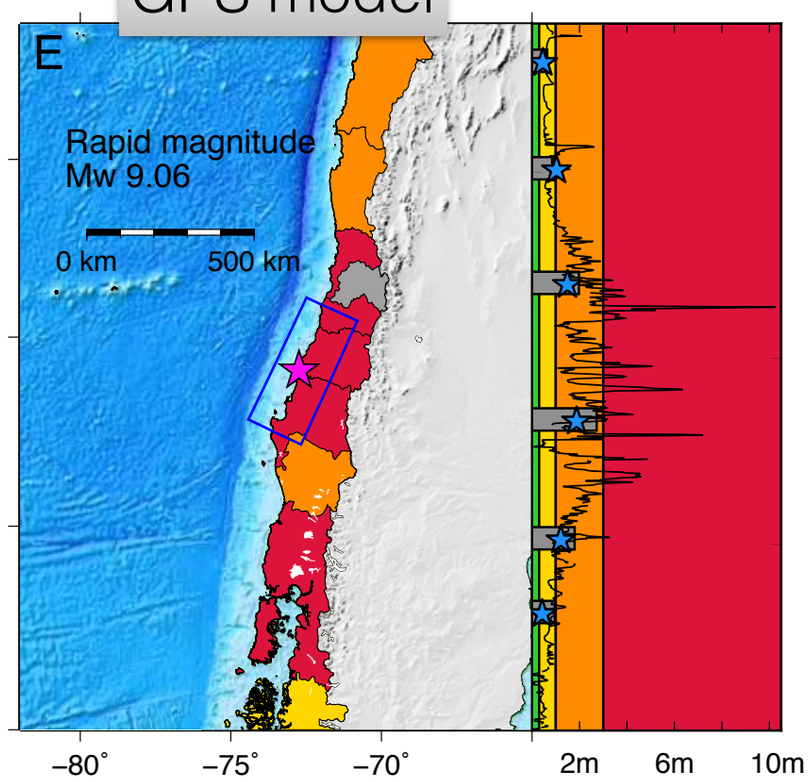
NON REAL-TIME
(15 hrs+ AFTER OT)



GPS model

2-3 mins AFTER OT



- ★ Tide gauge observed maximum amplitude
- ▬ Tide gauge predicted maximum amplitude
- — Coast predicted maximum amplitude
- ★ Event hypocenter
- — Modeled earthquake rupture area

Tsunami warning level
(Expected maximum amplitude)

- >3m
- 1–3m
- 0.3–1m
- < 0.3m

Melgar et al., GRL, 2016

How good are the rapid intensity models?

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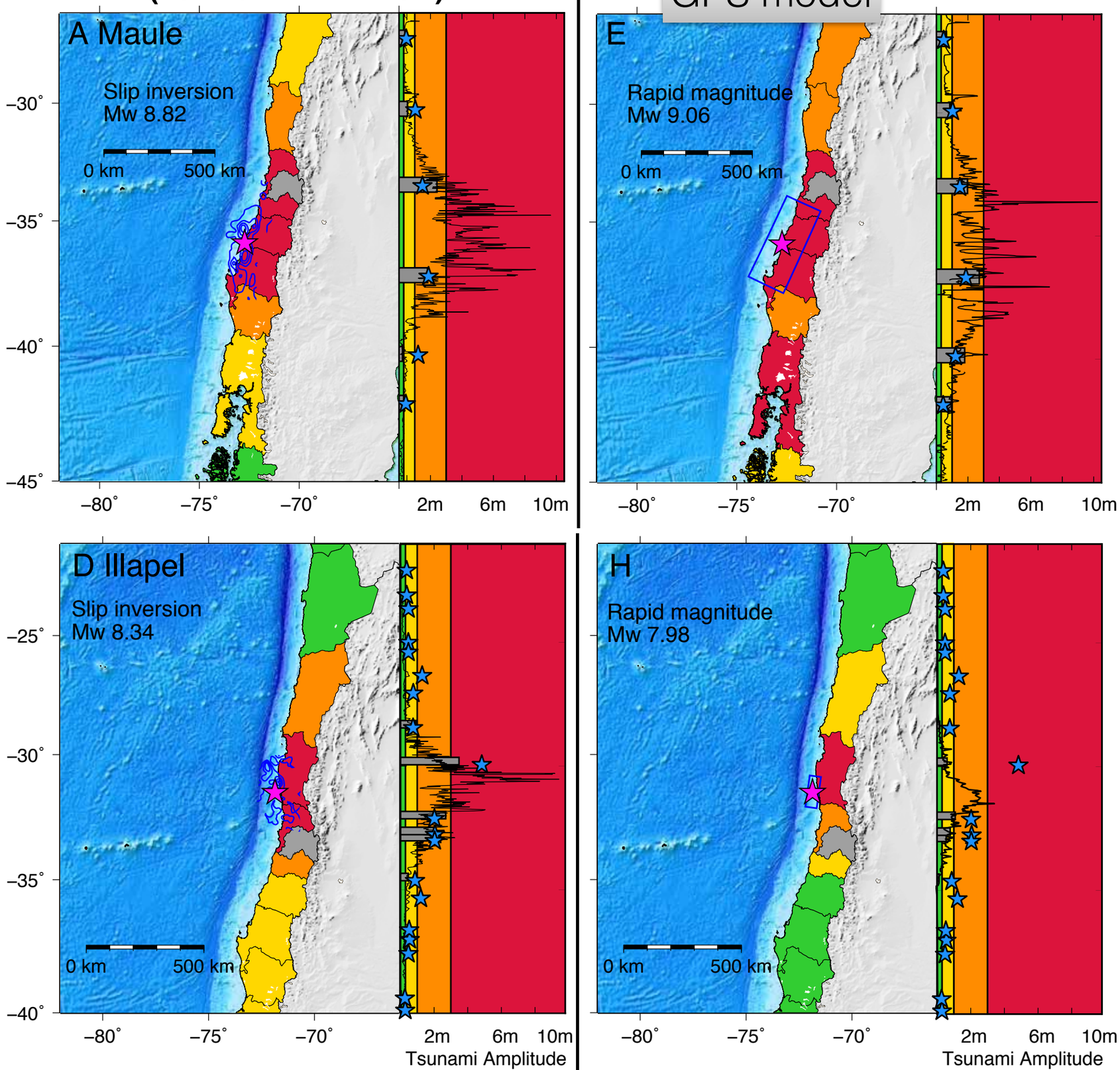
NON REAL-TIME
(15 hrs+ AFTER OT)

2-3 mins AFTER OT

GPS model



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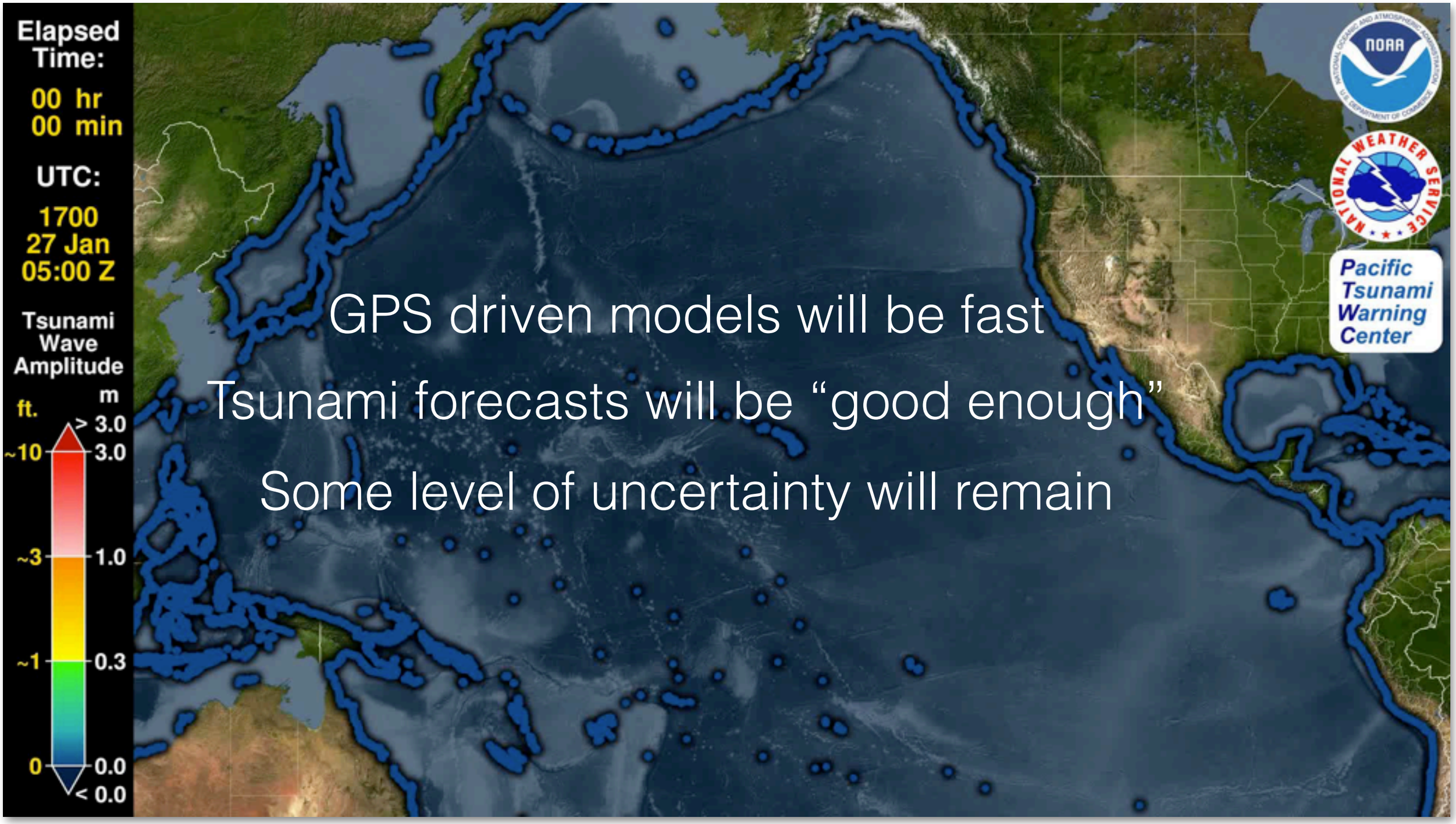

Nathan Becker & Dailin Wang PTWC, NOAA

The Cascadia Subduction Zone

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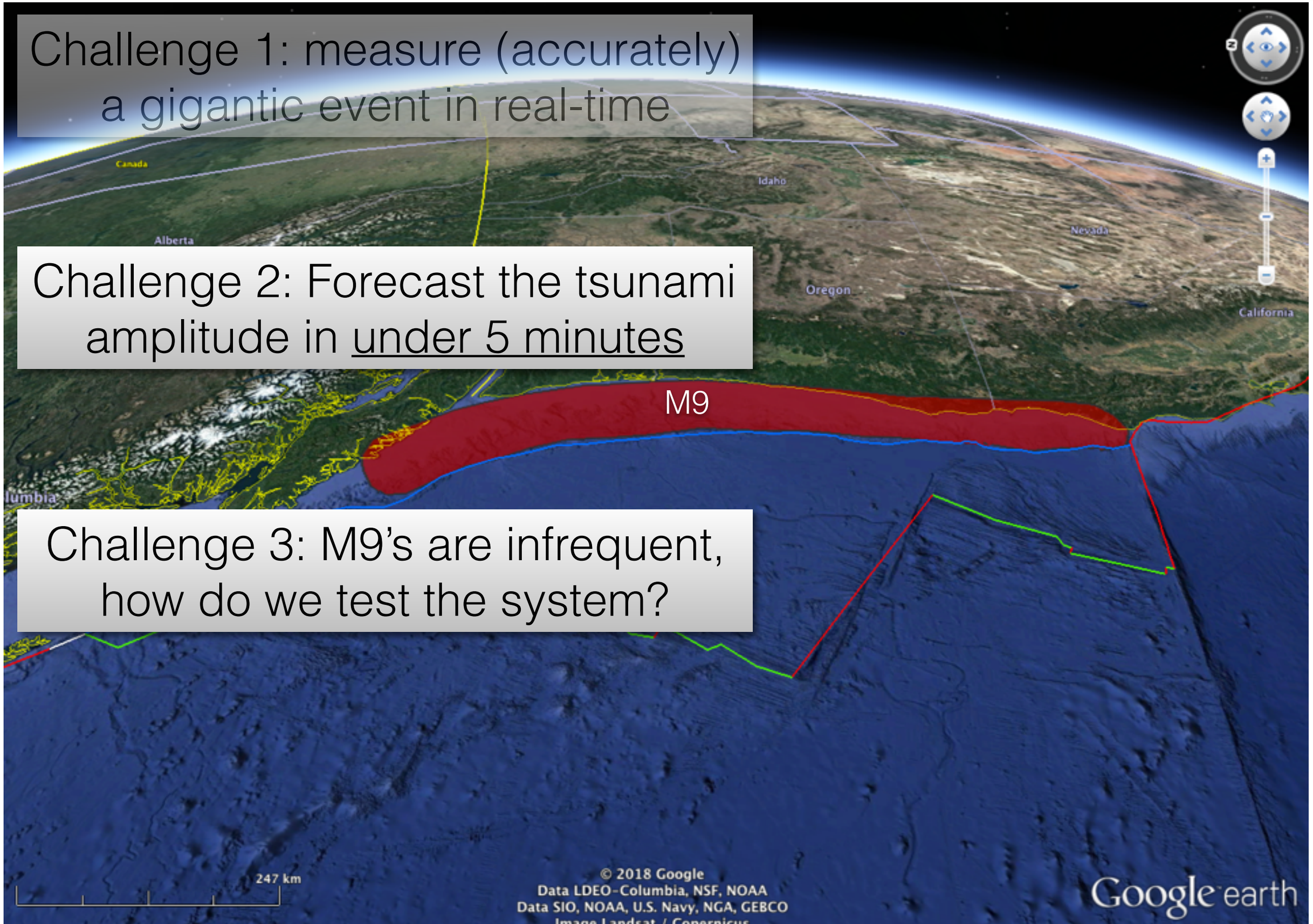

The Cascadia Subduction Zone

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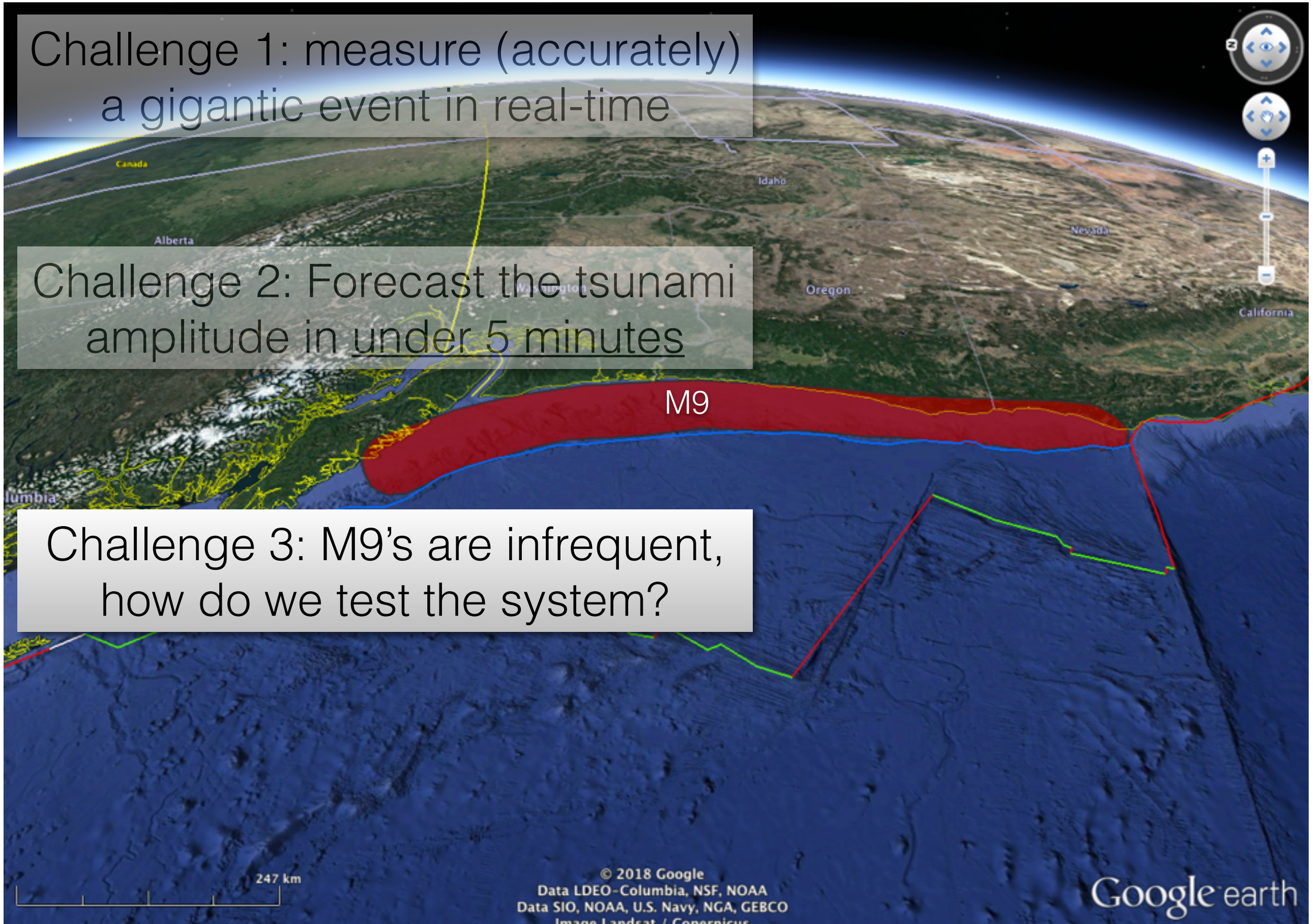

How do we test the systems?

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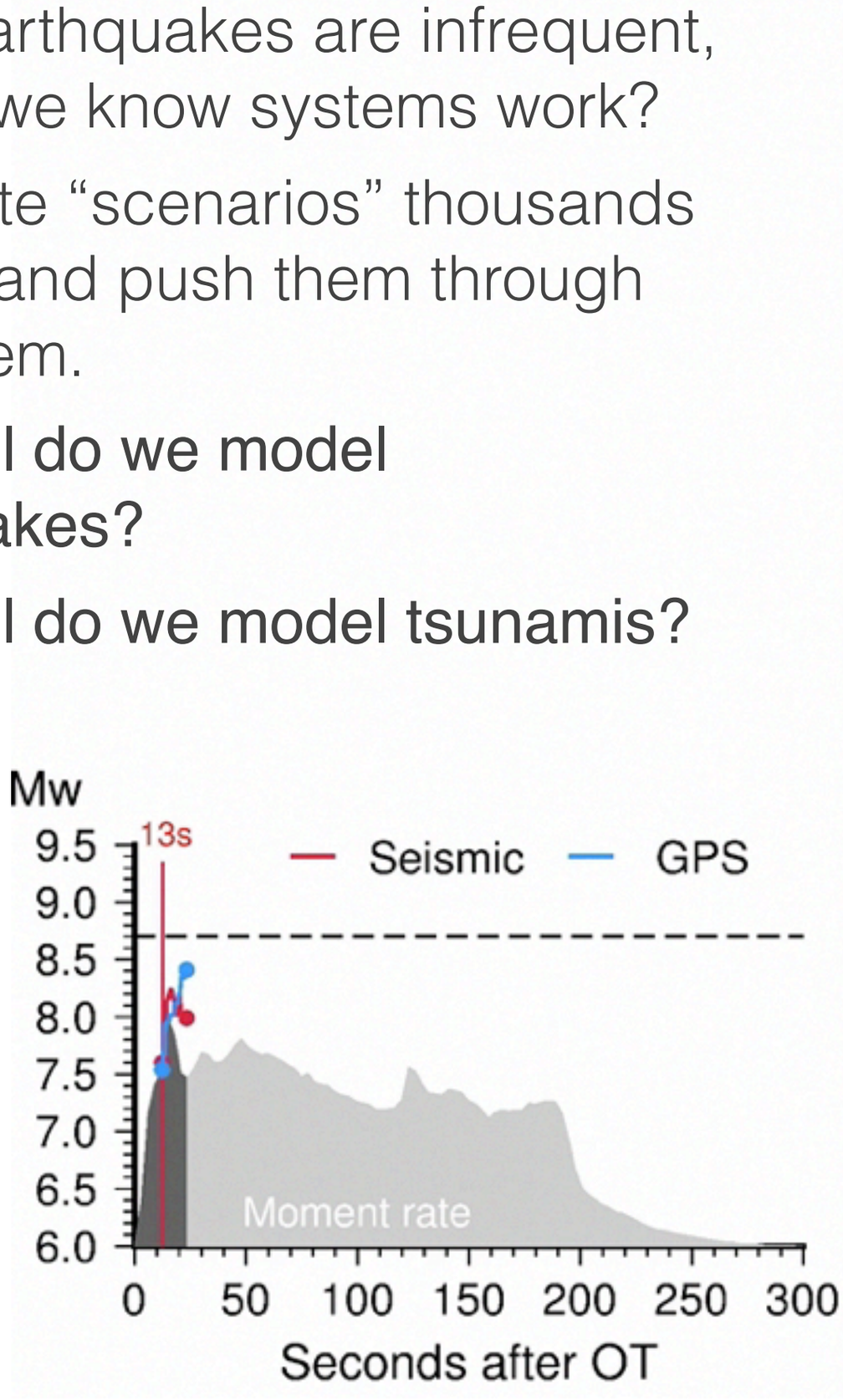
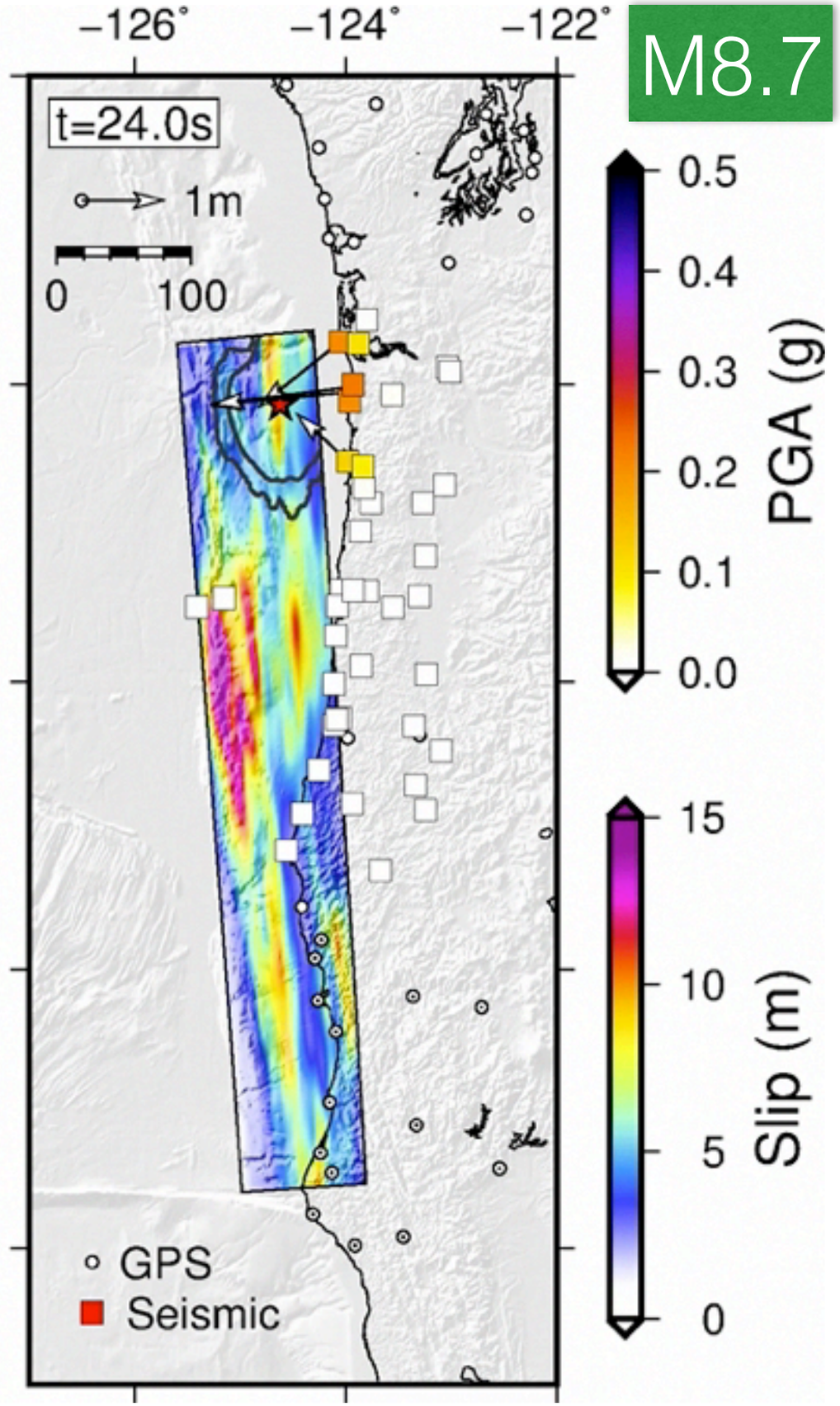
- Large earthquakes are infrequent, how do we know systems work?
- We create “scenarios” thousands of them and push them through the system.
- How well do we model earthquakes?
- How well do we model tsunamis?





Ruhl et al., GRL, 2017

Scenarios in Cascadia

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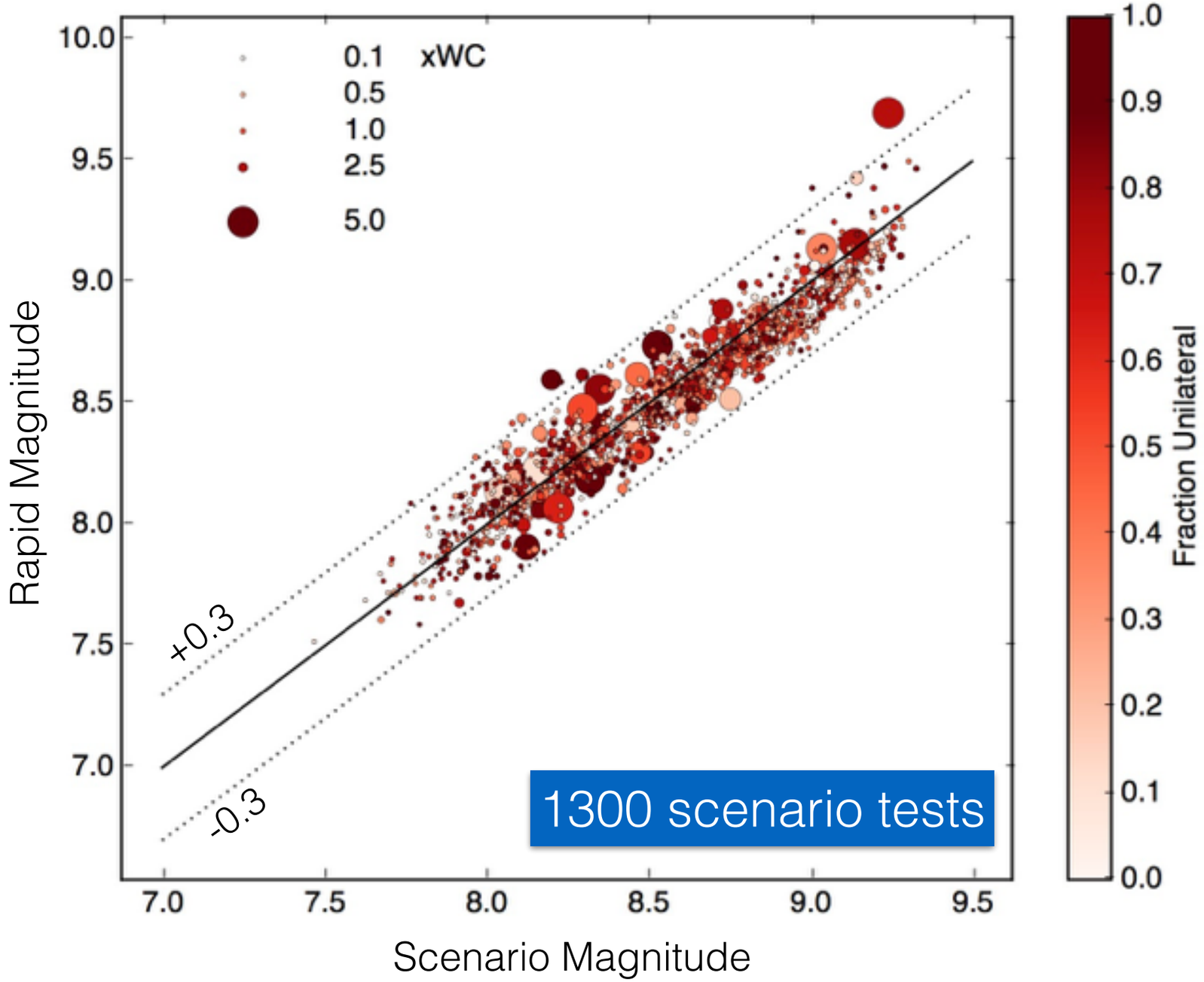

Ruhl et al., GRL, 2017

The Cascadia Subduction Zone

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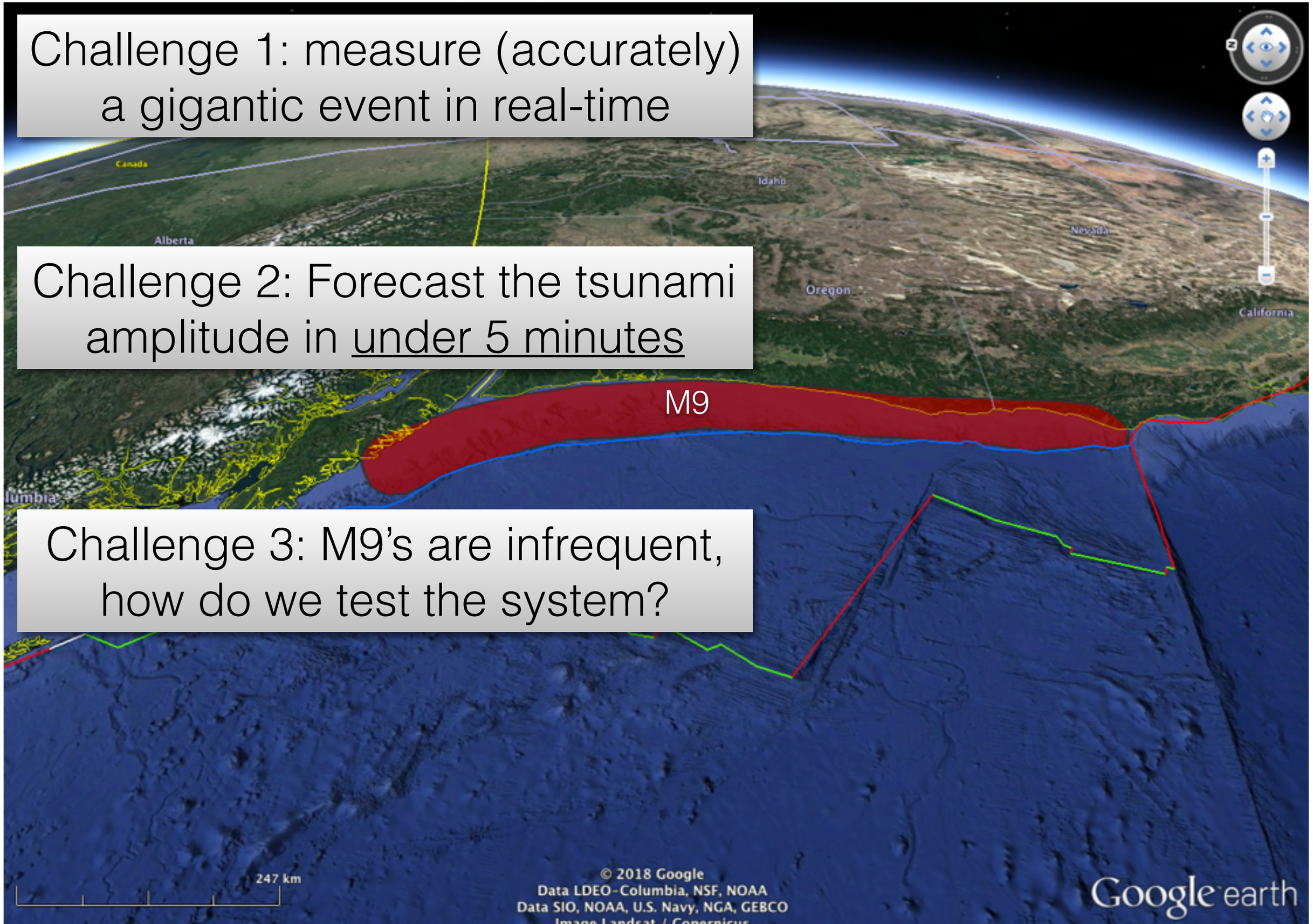

So how are we doing?

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- The outlook is overall positive, with continued effort warning for a Cascadia M9 earthquake in under 5 minutes will be possible.
- The key components, GPS and tsunami modeling, are there.
- We are now on the road from research to operations.
- Testing the operational environment will be important as well.
- Are we done?

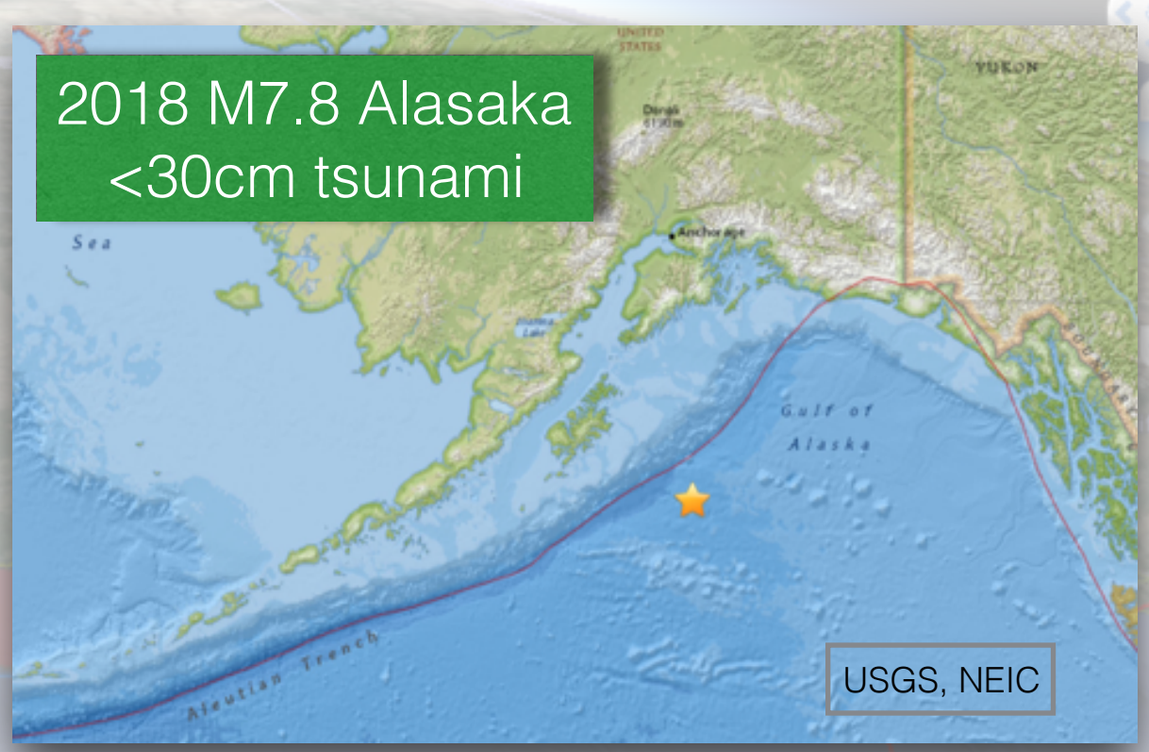
So how are we doing?

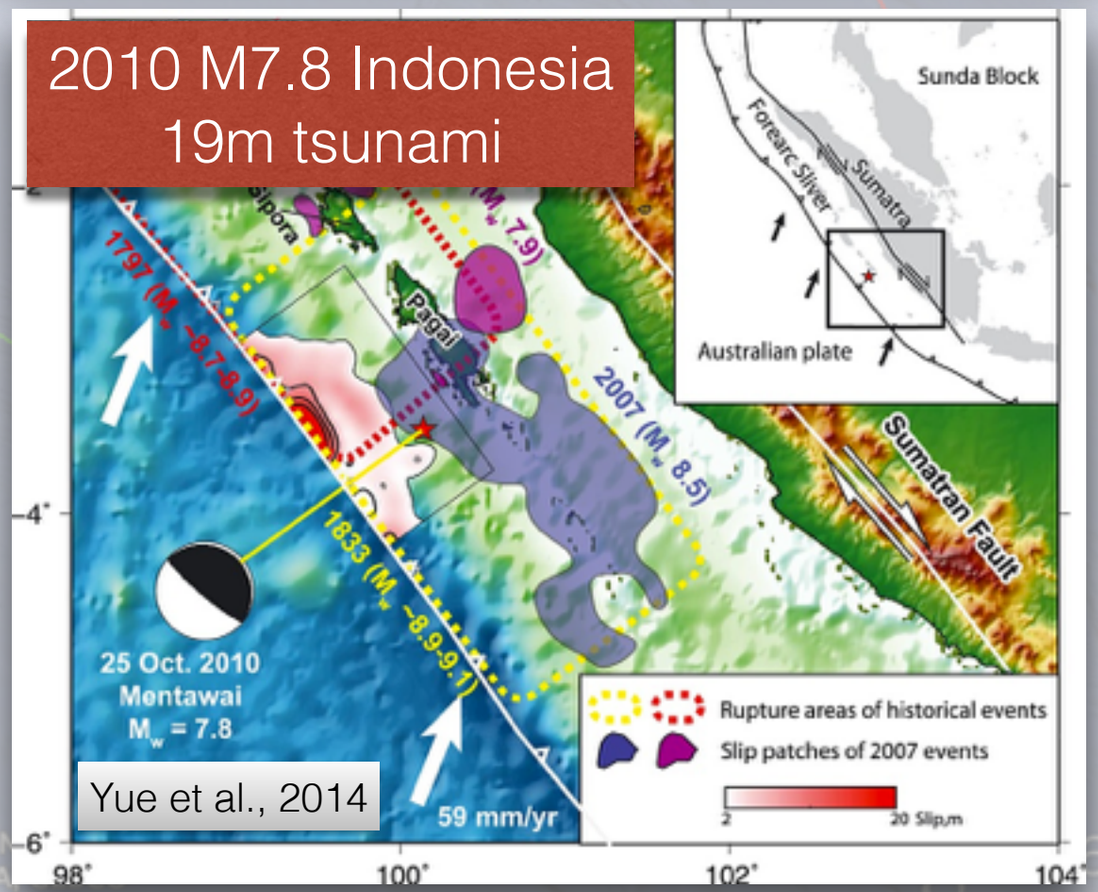
- Earthquakes and tsunamis are complex

- What I've described here is indirect warning, we measure the earthquake not the tsunami

- Indirect warning is inherently uncertain

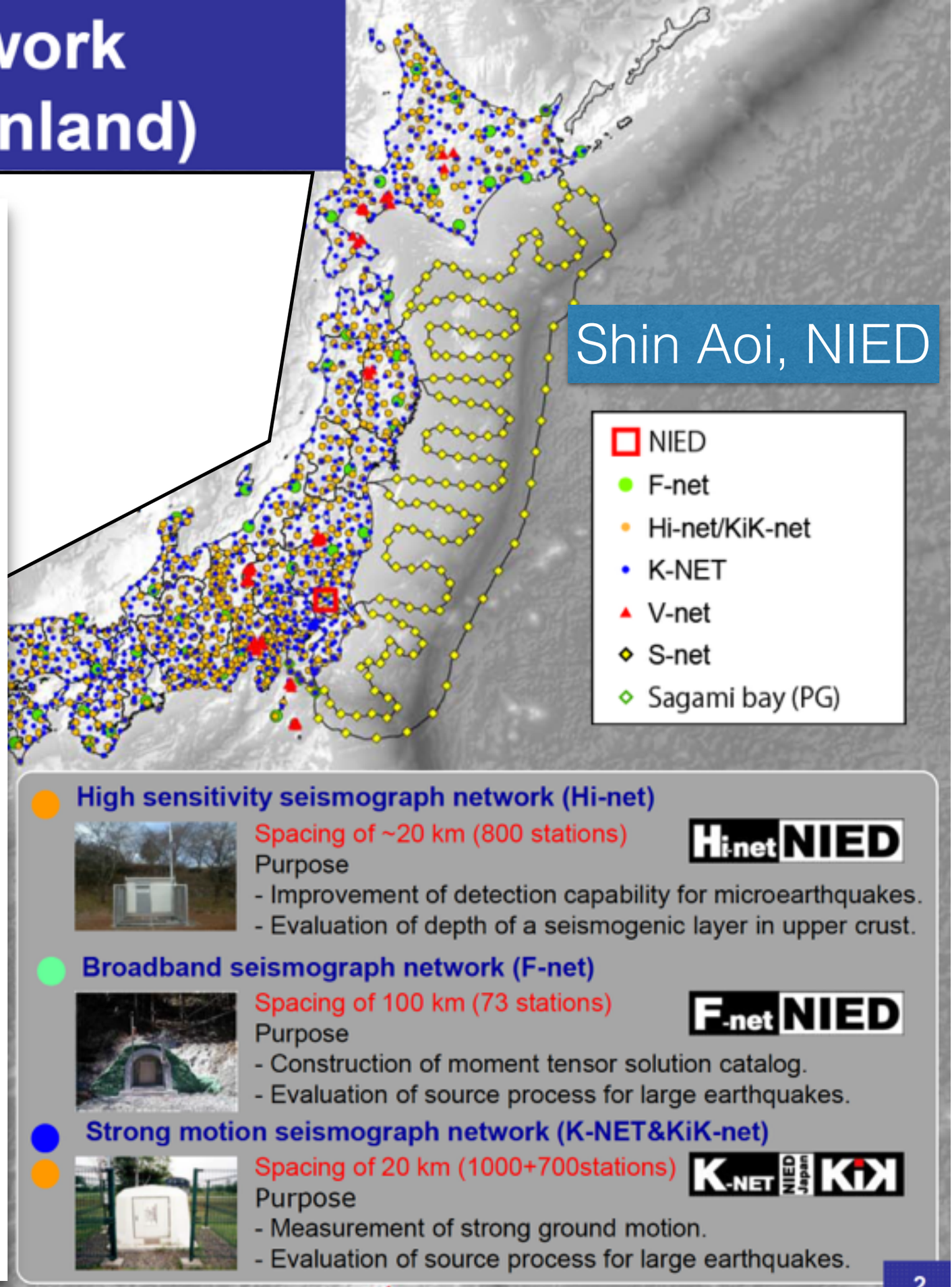
- What are the new technologies?





Seismograph Network Operated by NIED (Inland)

- Real-time cabled sensors
- Will directly measure the tsunami
- The fastest most reliable way to issue accurate local warnings
- It is also useful for basic science
- It's costly, ~$500M buildout and $5M/yr operations



A real-time ocean bottom network

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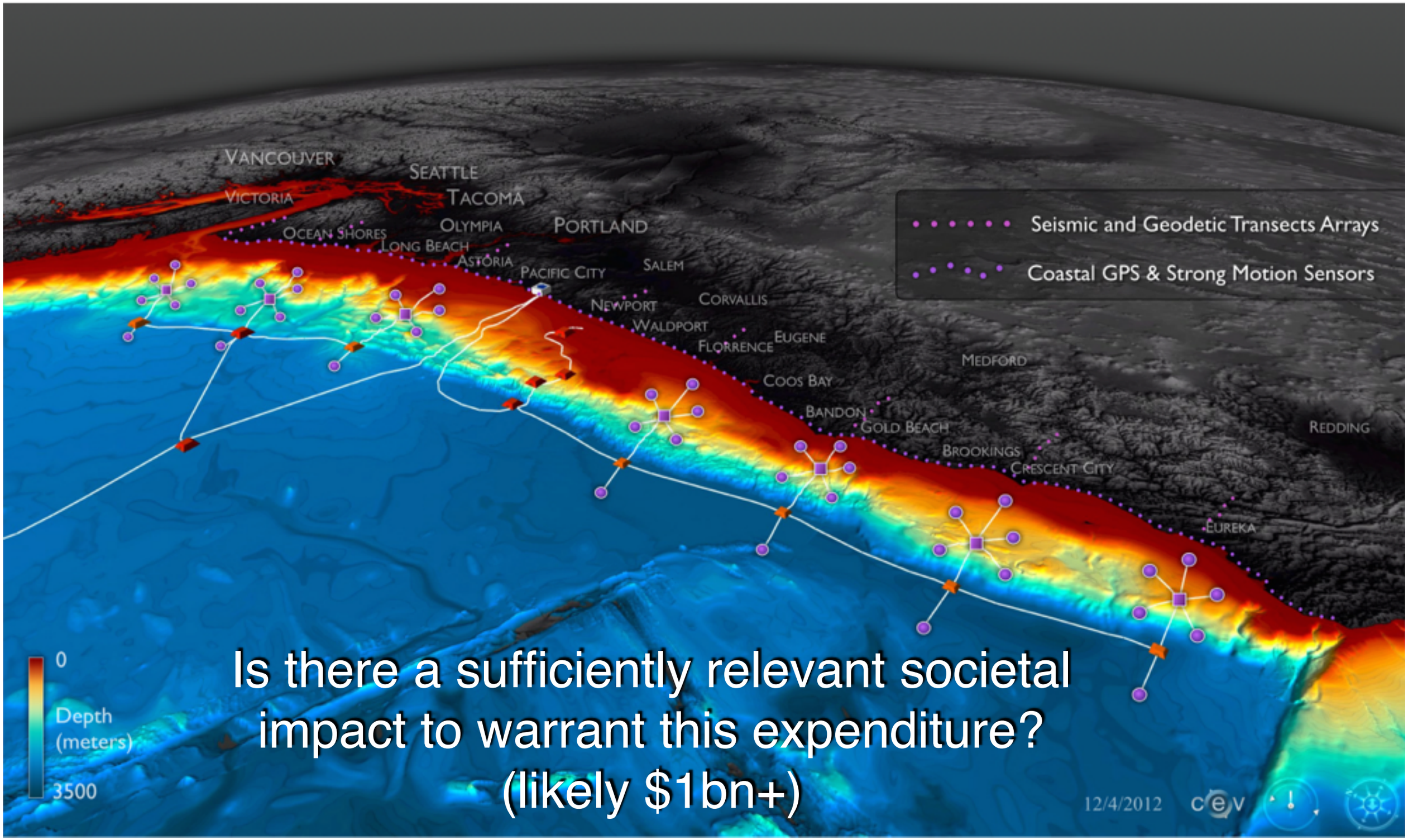
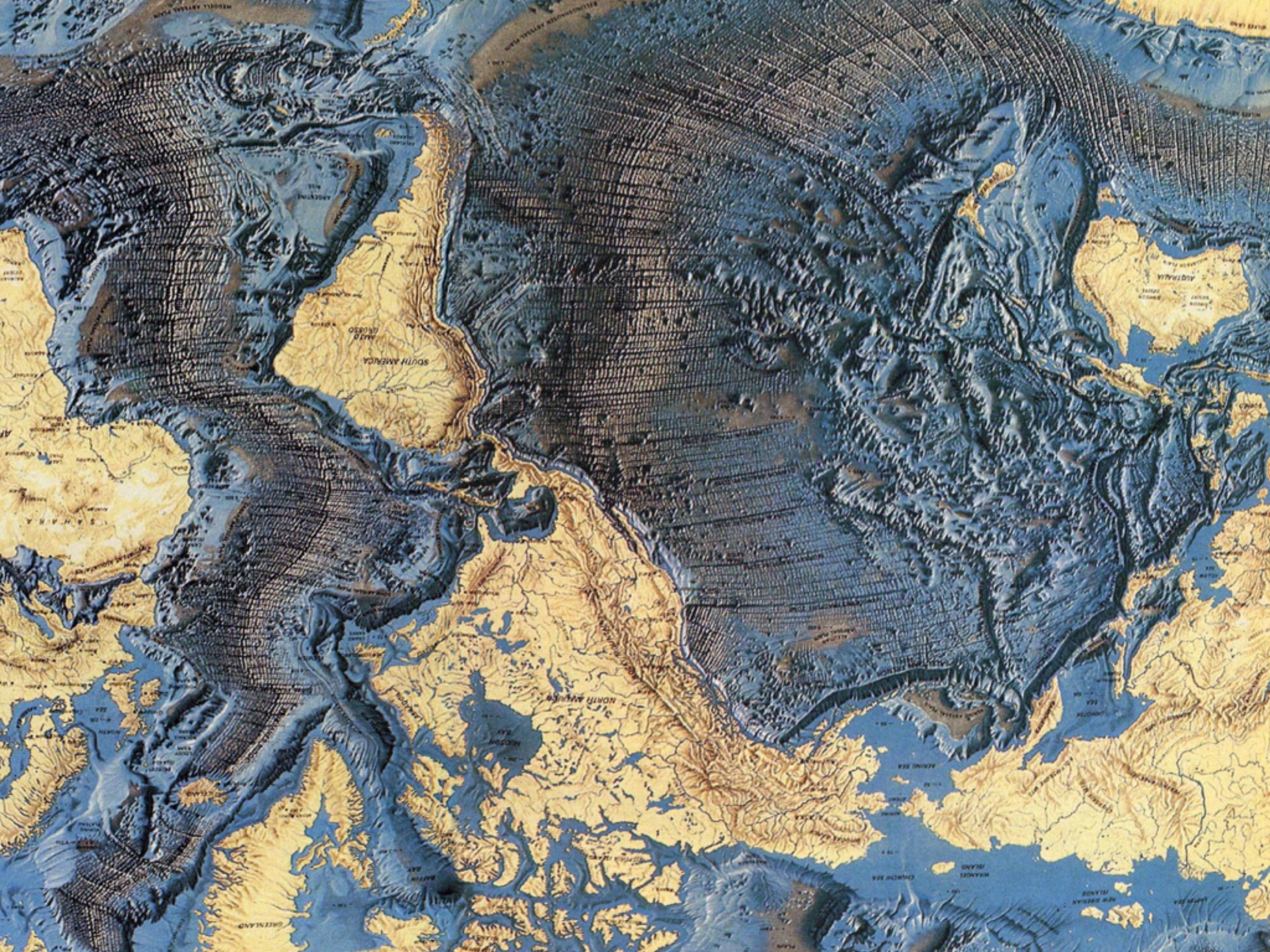


Is there a sufficiently relevant societal impact to warrant this expenditure? (likely $1bn+)

Wilcock et al., 2016, SZO white paper


SOUTH AMERICA
AUSTRALIA
NORTH AMERICA
HUDSON BAY
BAFFIN BAY
GREENLAND
ICELAND
ARCTIC OCEAN
CHUKCHI SEA
BERING SEA
NEW GUINEA ISLANDS
MEANDI ISLAND

How good are the rapid intensity models?

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An example: The 2004 Indonesia Tsunami

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Motion of the seafloor

It takes 10 minutes!

An example: The 2004 Indonesia Tsunami

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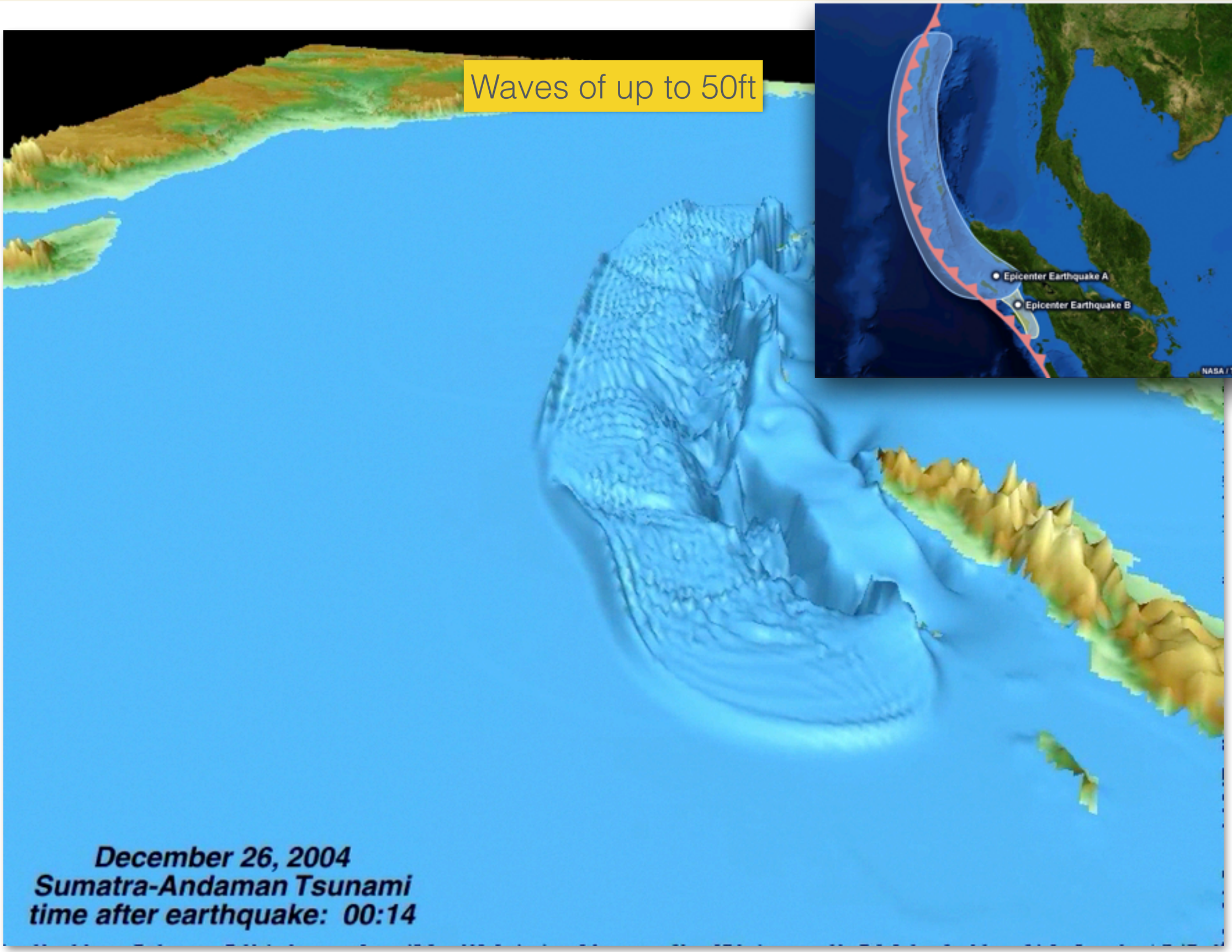

A tsunami's speed

Depth (ft)	Speed (mi/hr)	
15,000	**500**	Deep ocean
3000	**222**	Continental shelf
1500	**158**	Continental shelf
300	**70**	Coast

When does the tsunami arrive?

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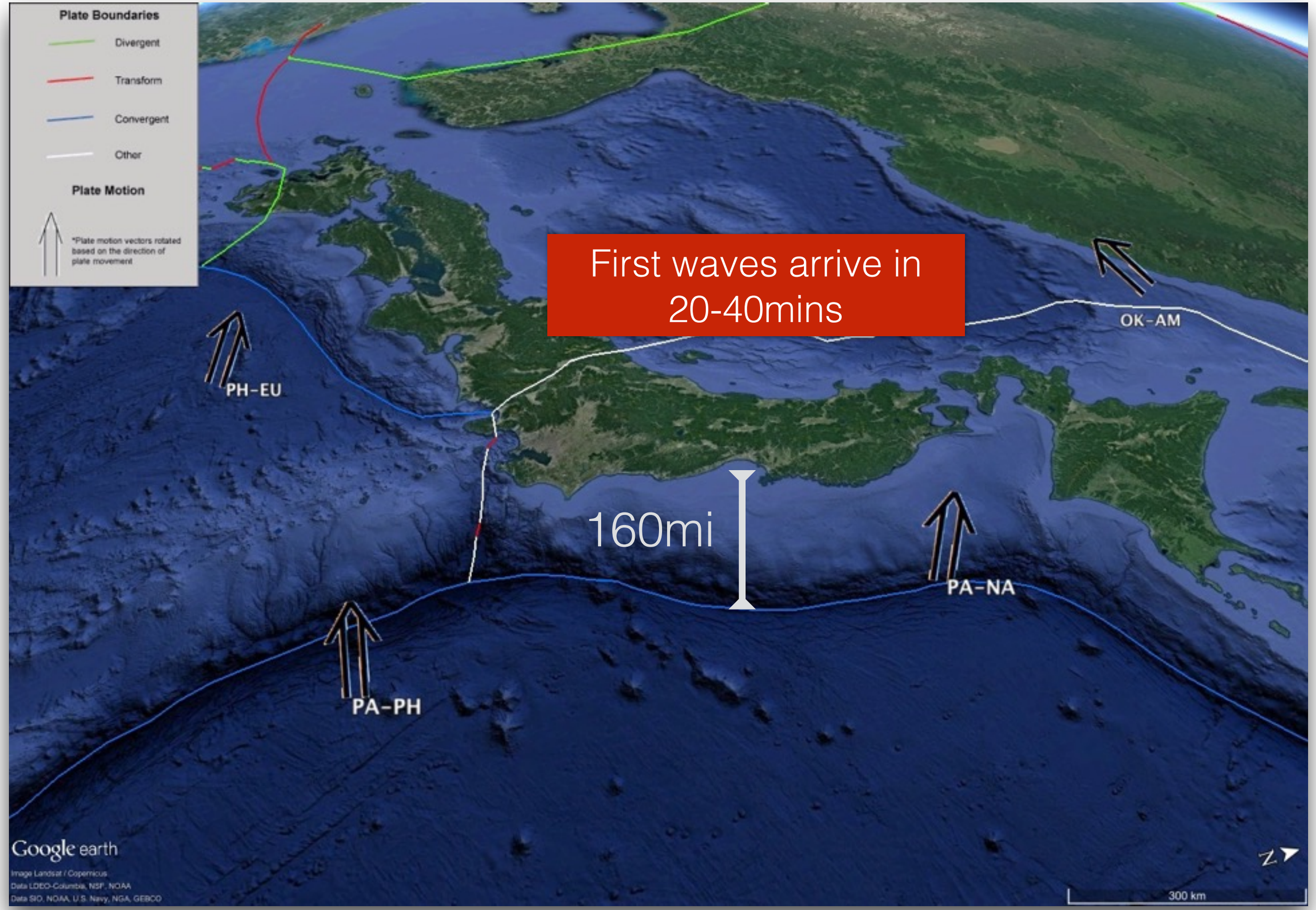

When does the tsunami arrive?

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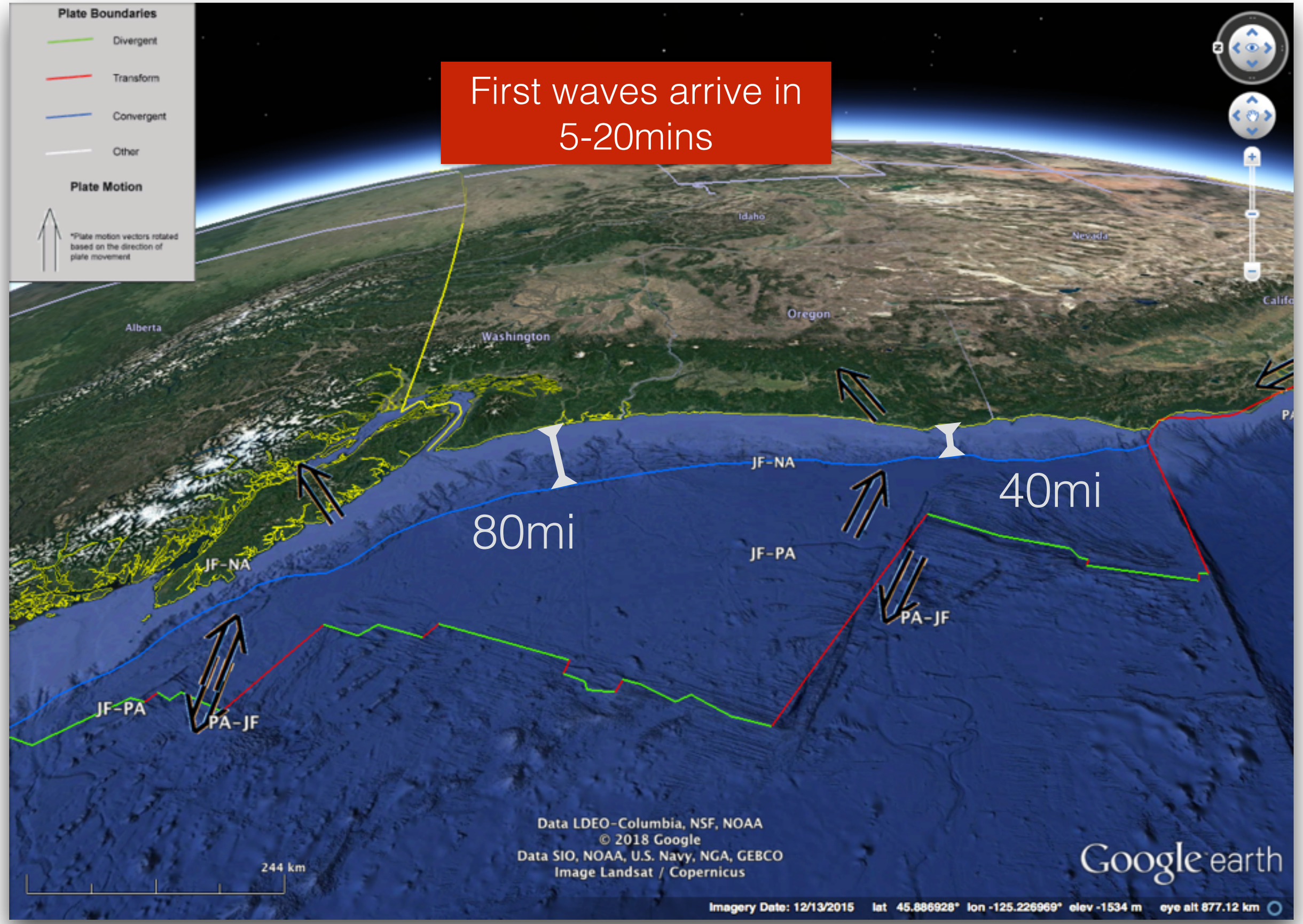

Second line of defense, buoys!

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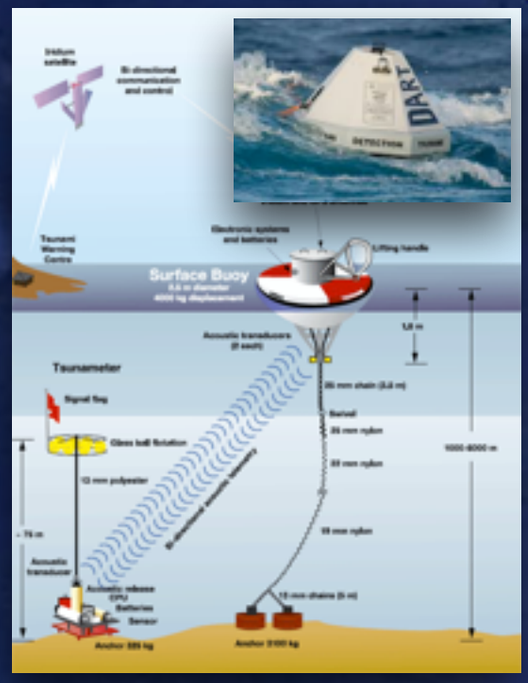
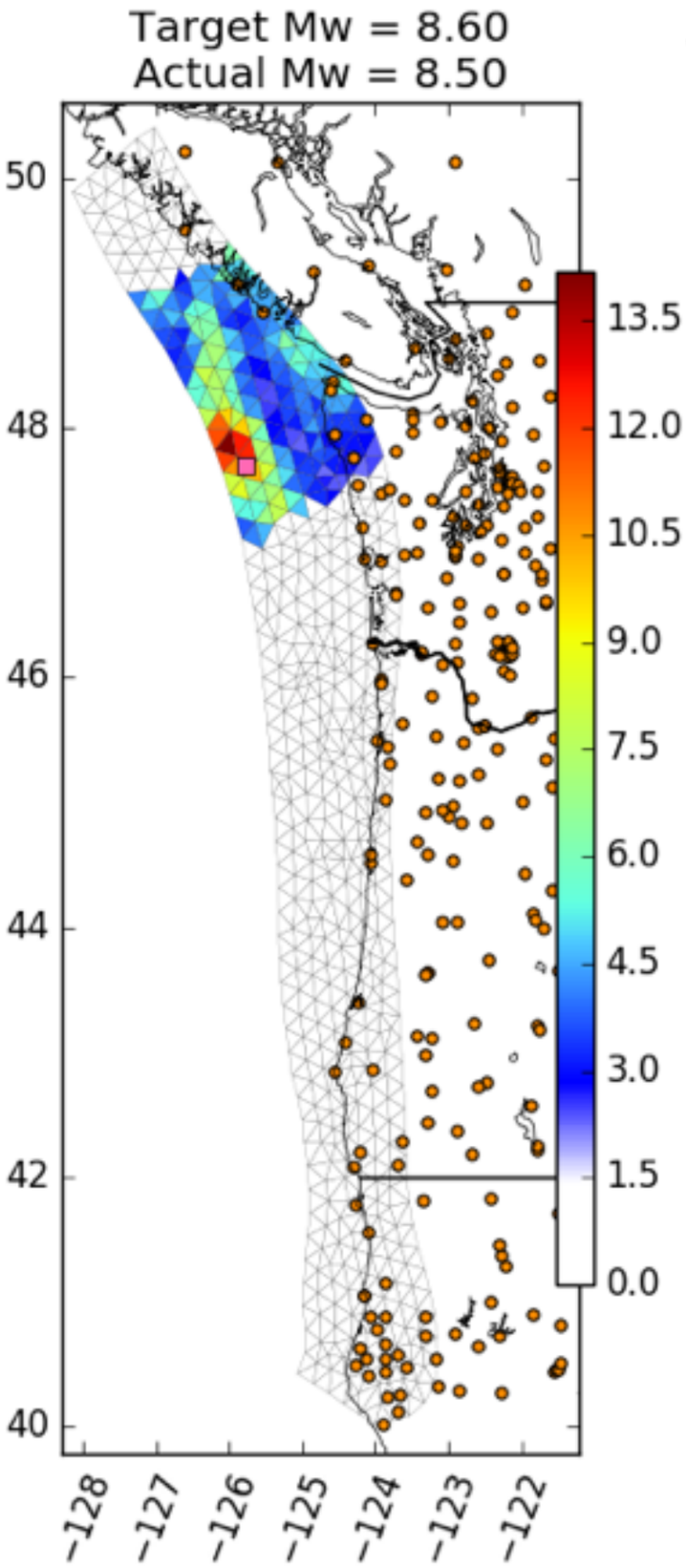
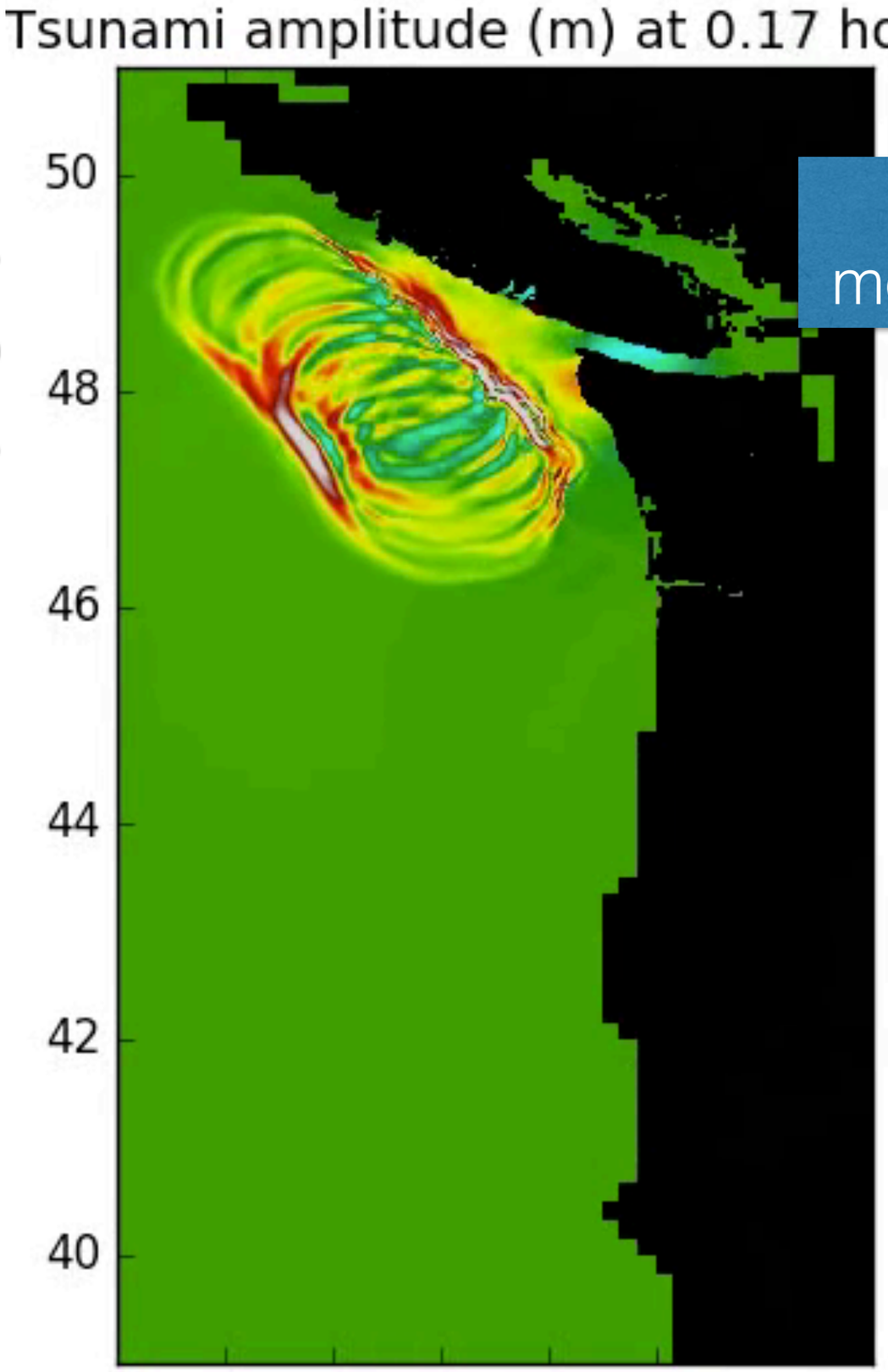
Buoys measure the actual tsunami

Very precise but it might be too late for those closest to the earthquake



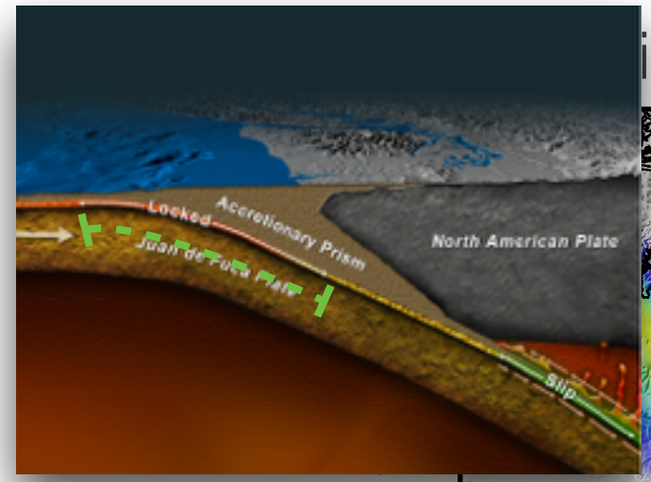
How do we test the systems?





How well do we model the tsunami?

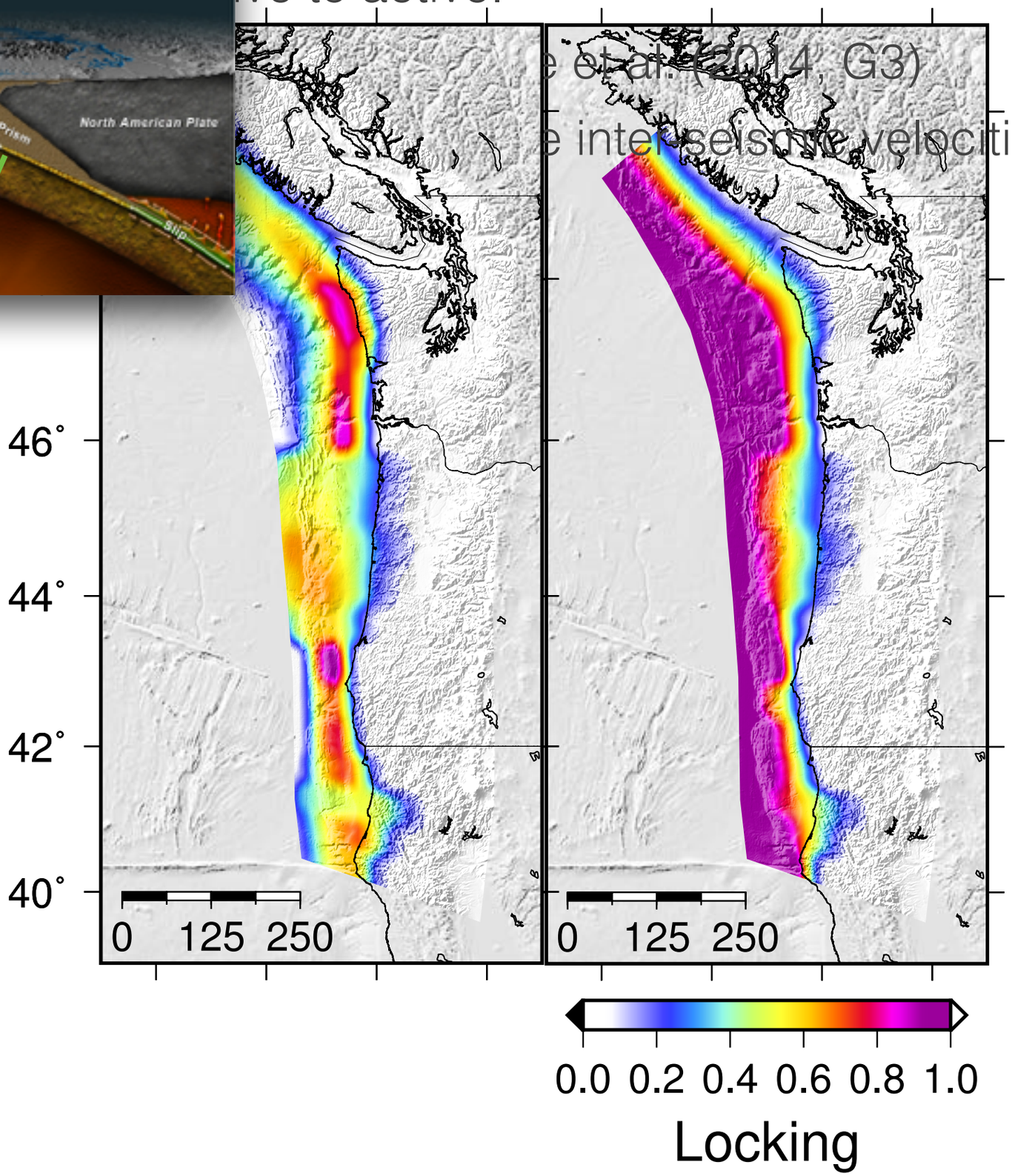
Can we map out the shallow megathrust?



ive to active.

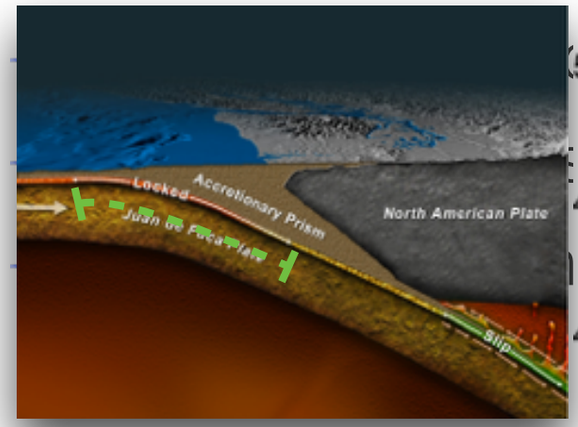
e et al. (2014, G3)

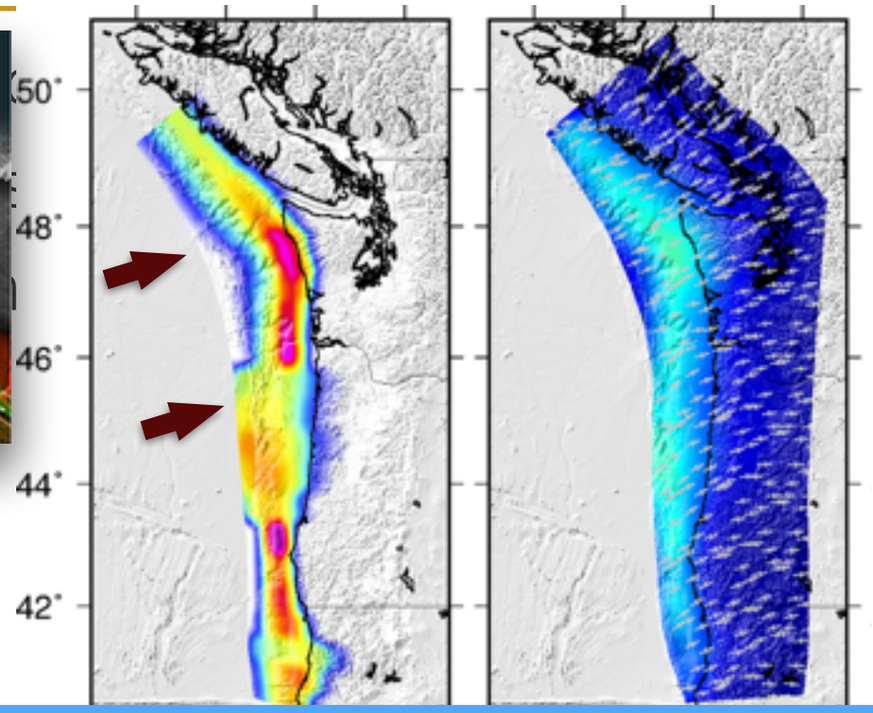
e inter-seismic velocities



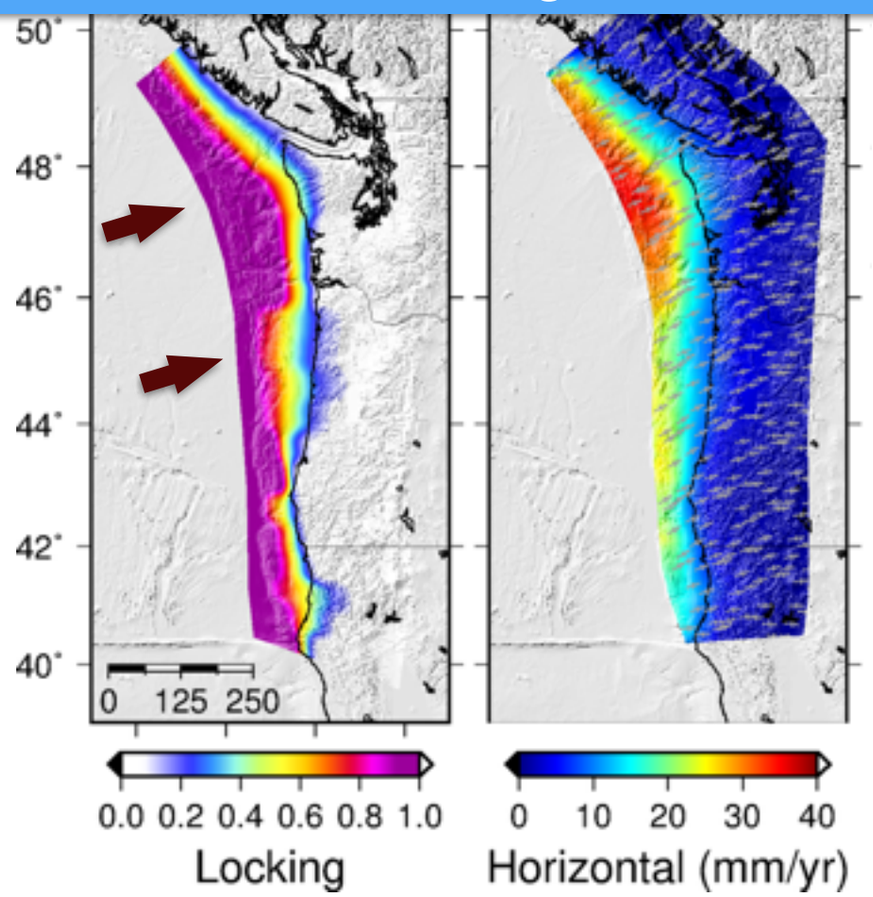
Melgar et al., in prep

Can we map out the shallow megathrust?



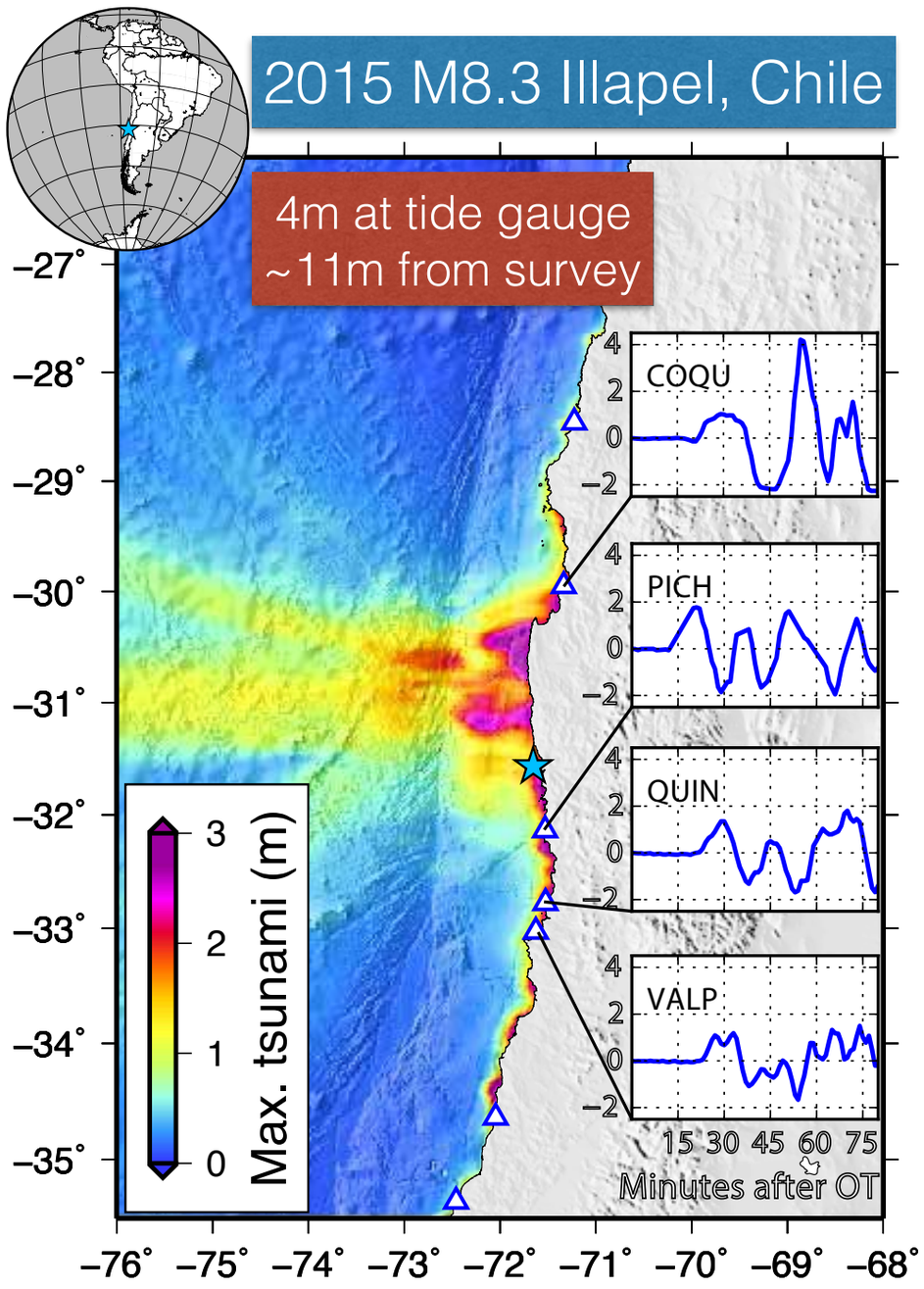


How do we imagine heterogeneity of the shallow megathrust?



Melgar et al., in prep

The timeline for warnings



Event origin 22:54 UTC

B

:

5min: PTWC bulletin #1
M=7.9 , Tsunami ampl.=N/A

5min: CSN W-phase M=8.1

8min: SNAM tsunami bulletin #1
M=7.9 , Tsunami ampl.=N/A

10min

14min: Tsunami first arrival at PICH tide gauge

16min: ***ONEMI issues evacuation order for all coastal regions of Chile***

19min: SNAM tsunami bulletin #2
M=7.9 , Tsunami arrival times

20min

20min: NEIC W-Phase, M=8.3
CSN W-phase update, M=8.4

20min: First maximum at PICH tide gauge

30min

31min: First maximum at VALP and QUIN tide gauges

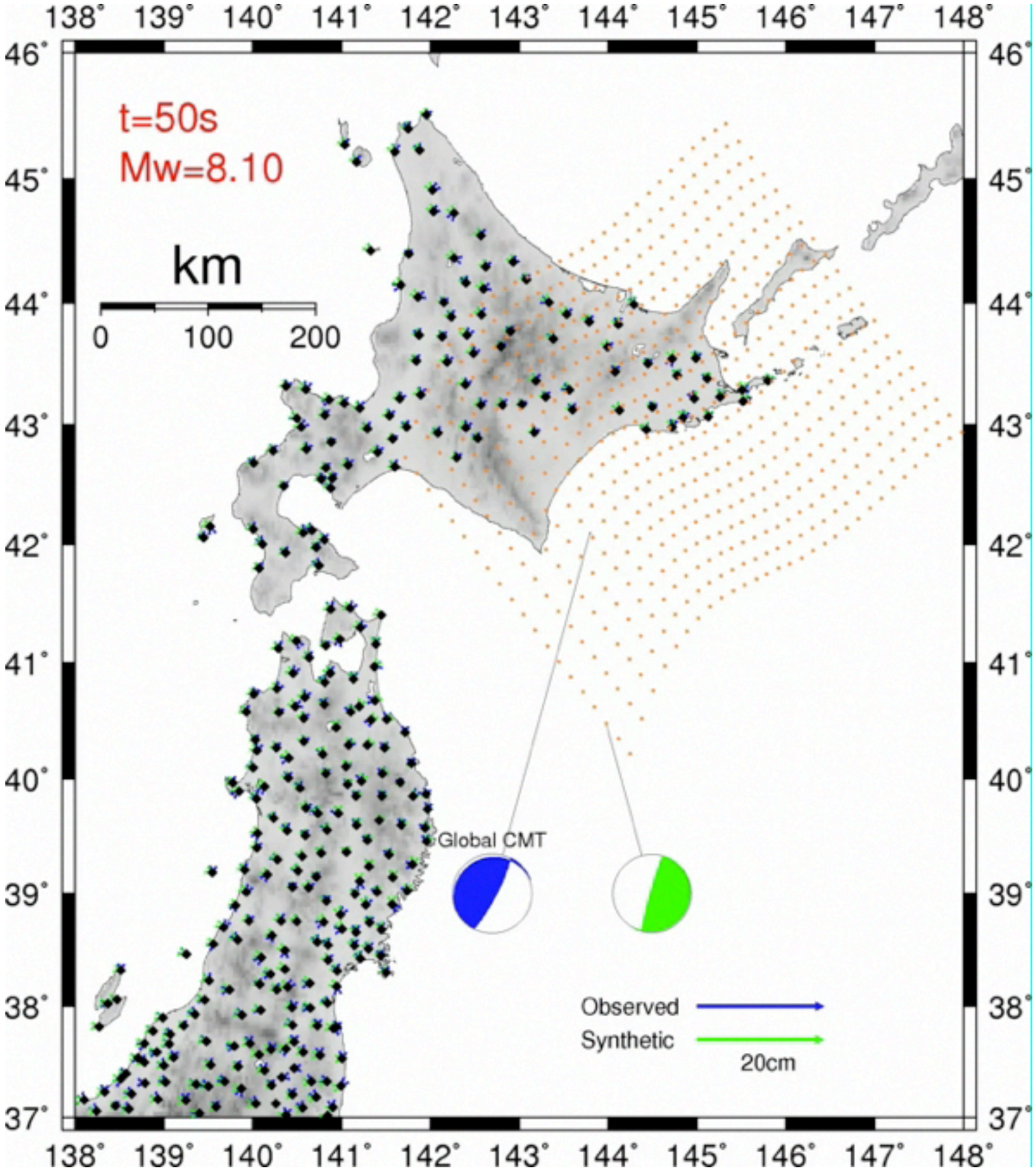
31min: PTWC bulelting #2
M=8.3 , Tsunami ampl. = 3m possible for all Chile

Tsunami warning centers have the operational goal to issue warnings in 20-30 minutes

Melgar et al., GRL, 2016

A real-time test

- M8.3 Tokachi-oki Japan earthquake



Melgar et al., 2011