UNESCO-IOC / NOAA ITIC Training Program in Hawaii (ITP-TEWS Hawaii)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
15-26 September 2025, Honolulu, Hawaii

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Intergovernmental Oceanographic Commission

Real-Time Earthquake detection and Fast Source Characterization: Determining Fault Mechanisms, Using GNSS/GPS to constrain co-seismic deformation

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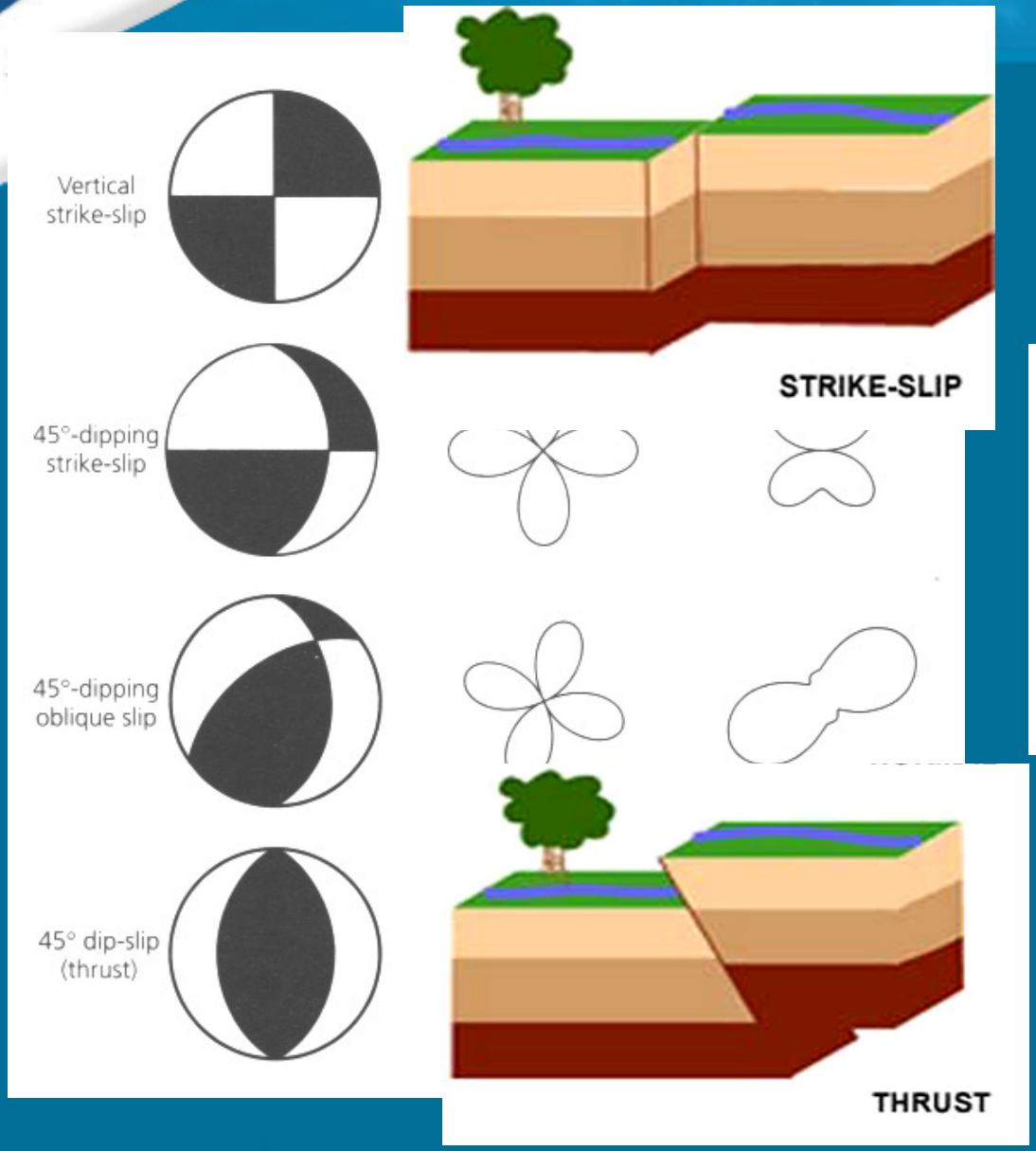
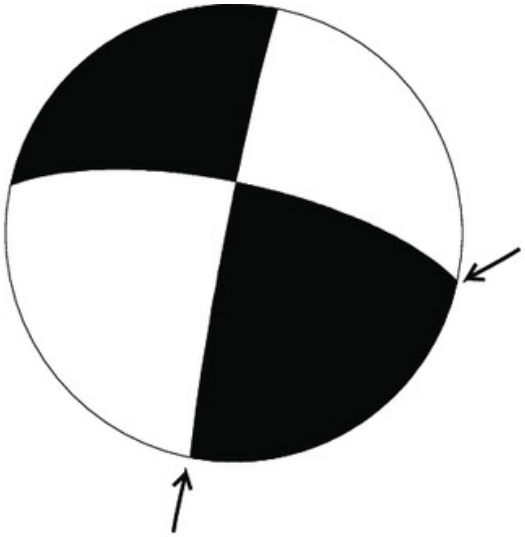
Pacific Community
Communauté du Pacifique

Focal Mechanism: Geometry of Faulting



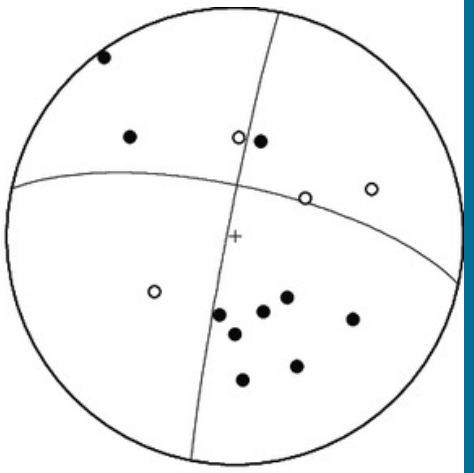
Once we know the geometry of faulting and the Mw we can compute the sea-floor displacement and then generate a forecast.

Focal Mechanism: Geometry of Faulting



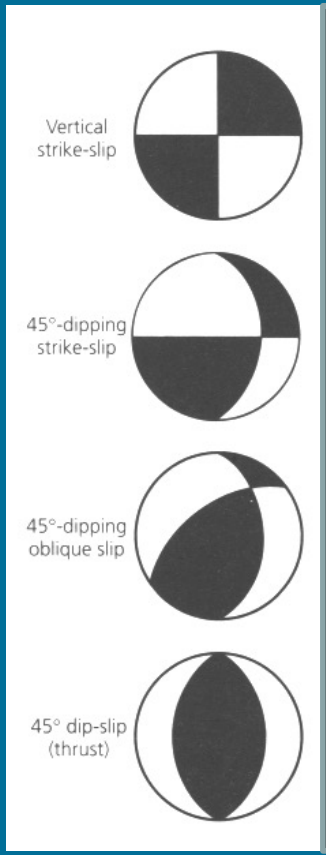
First nodal plane:
- strike: 282°,
- dip: 72°,
- slip: 3°.

Second nodal plane:
- strike: 191°,
- dip: 87°,
- slip: 162°.



Centroid Moment Tensor (CMT)

- The CMT characterizes the geometry of the earthquake and can be used to compute the surface deformation.
- Fits shape and amplitude of seismic waves to synthetics to model moment tensor and energy released.
- Usually based on longer period and very slow surface waves. CMT required ~90 minutes of wait until there was enough data to compute.



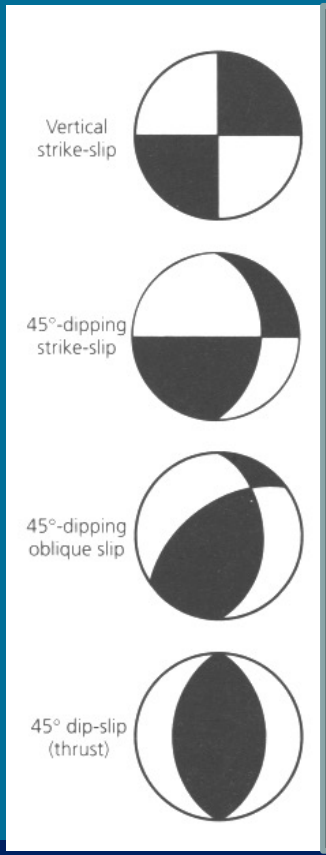
Strike-Slip
Pure horizontal motion

Oblique, motion has horizontal and vertical components

Thrust
Pure Vertical Motion

Centroid Moment Tensor (CMT)

- **Problem with using CMT for tsunami hazard:**
  => It took too long.
- **That changed with the introduction of the W-phase CMT by Kanamori and Rivera in 2008. W-phase travels several times faster than surface waves.**



Strike-Slip
Pure horizontal motion

Oblique, motion has horizontal and vertical components

Thrust
Pure Vertical Motion

W-phase CMT method gives both the fault geometry and an authoritative magnitude 5-25 minutes after the earthquake. It is the primary reason why PTWC can now quickly issue a reliable forecast.

Centroid Moment Tensor (CMT)

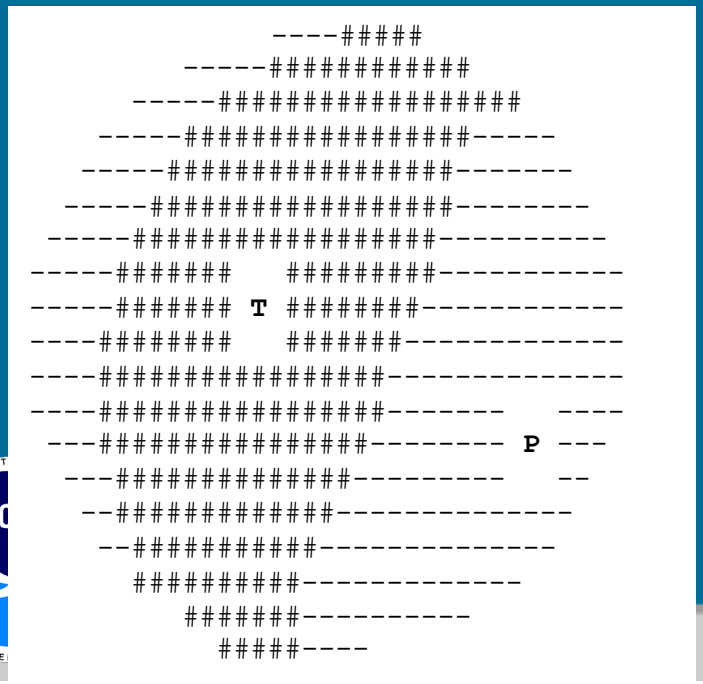
- Characterizes the geometry of faulting
- Gives the seismic Moment (Energy Released) μAD
- Can be used to compute surface deformation
- Fits shape/amplitude of waves to synthetic seismograms
- Usually based on longer period and very slow surface waves, so often requires around 90 minutes to compute

Wphase (WCMT) Inversion

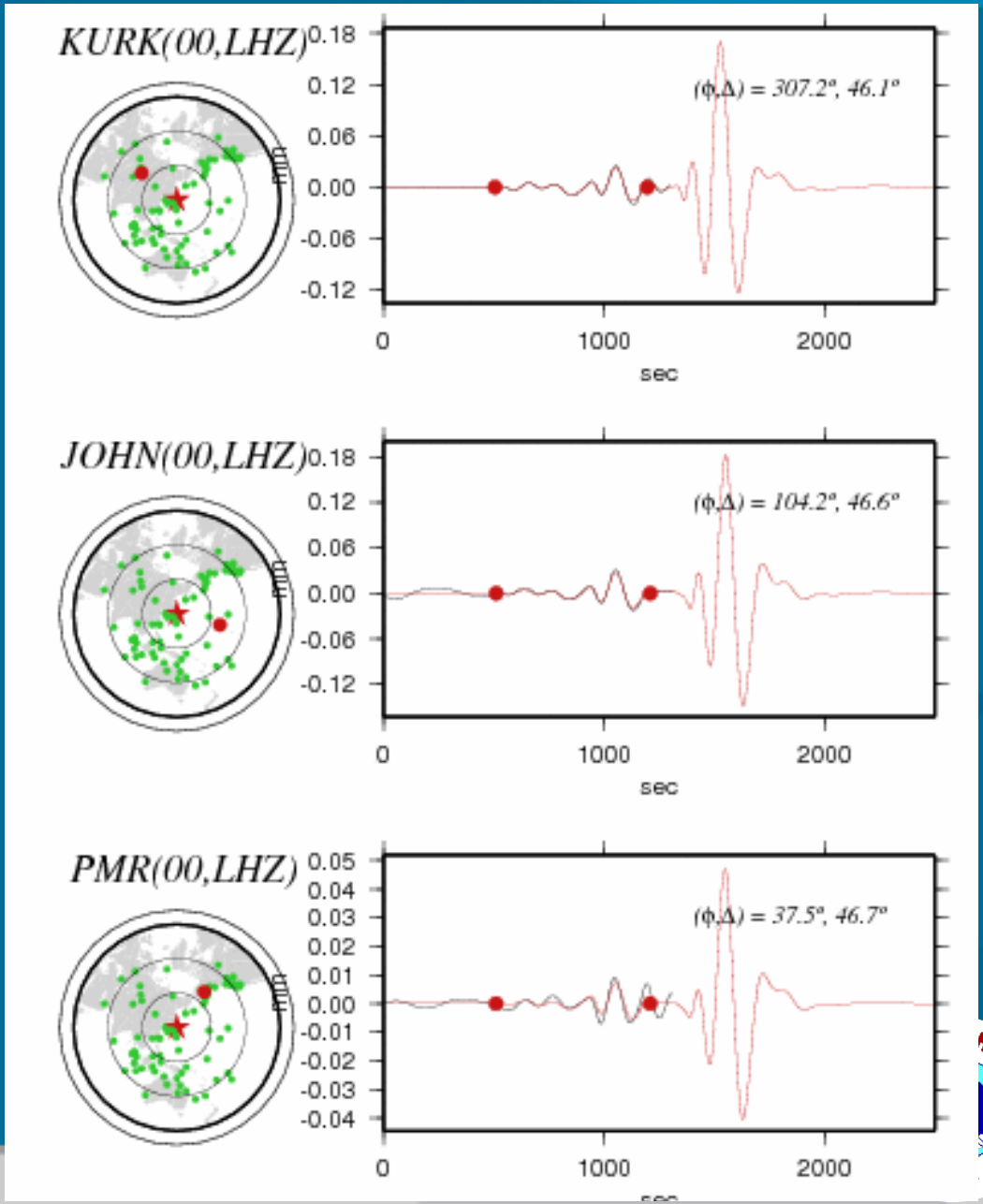
Kanamori and Rivera, 2008

The Wphase is a complex seismic wave that travels with a speed between that of the P & S waves.

Much faster than the Surface waves.



Japan, 2011 Mw=9.1



Wphase Inversion

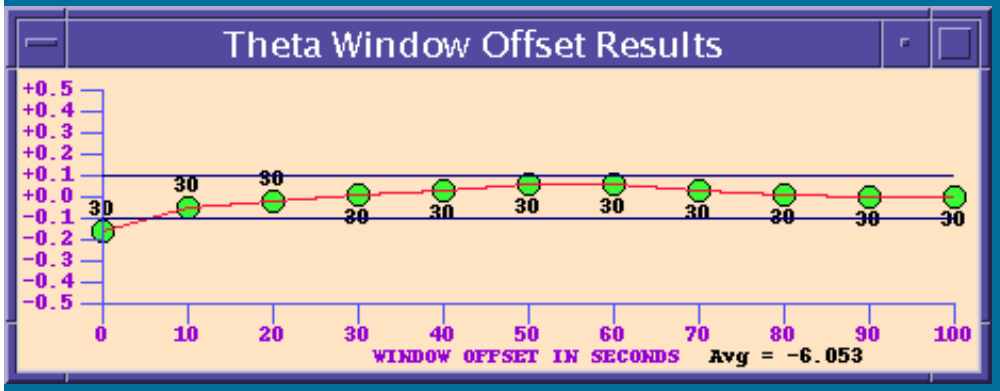
Focal Mechanism

Best Double Couple: Mw = 7.35
NP1: Strike=189 ; Dip=22.3514 ; Slip= 66
NP2: Strike= 35 ; Dip=69.7468 ; Slip=100

$\text{Theta} = \log_{10} (Er / M_o)$

E_r is the energy carried by high frequency P-waves and Mo is the seismic Moment. Basically Theta is the ratio of the energy Contained by high frequency P-waves to the Energy released by the earthquake.

Extended Theta can elucidate Complex Events



This is a slow, or tsunami earthquake!

Energy Discriminant

EXIT | 01:05:19 09/02 | Mw: 7.20

STA	STATUS	ETA	THETA
HIA	PEND	00:00	-----
KDAK	DONE	-----	-6.23
	DONE	-----	-5.32
	DONE	-----	-5.37
	DONE	-----	-6.37
	PEND	00:00	-----
	PEND	00:00	-----
	DONE	-----	-5.81
	DONE	-----	-5.86
	PEND	00:00	-----
	DONE	-----	-5.86
	PEND	00:00	-----
	DONE	-----	-5.94
	DONE	-----	-6.06
	DONE	-----	-6.14
COLA	DONE	-----	-5.74
SNCC	PEND	00:00	-----
PKD	DONE	-----	-6.03
CRAG	DONE	-----	-6.06
WDC	DONE	-----	-6.00
YBH	DONE	-----	-6.10
ORV	DONE	-----	-6.30
CMB	DONE	-----	-6.18
OSI	PEND	00:00	-----
COR	DONE	-----	-5.94
	GAP	NA	-----
	DONE	-----	-6.09
	PEND	00:00	-----
KCC	DONE	-----	REM
ISA	PEND	00:00	-----

FINISHED | Mean Theta is: -5.83(43) | PRINT

The CMT has it's limitations

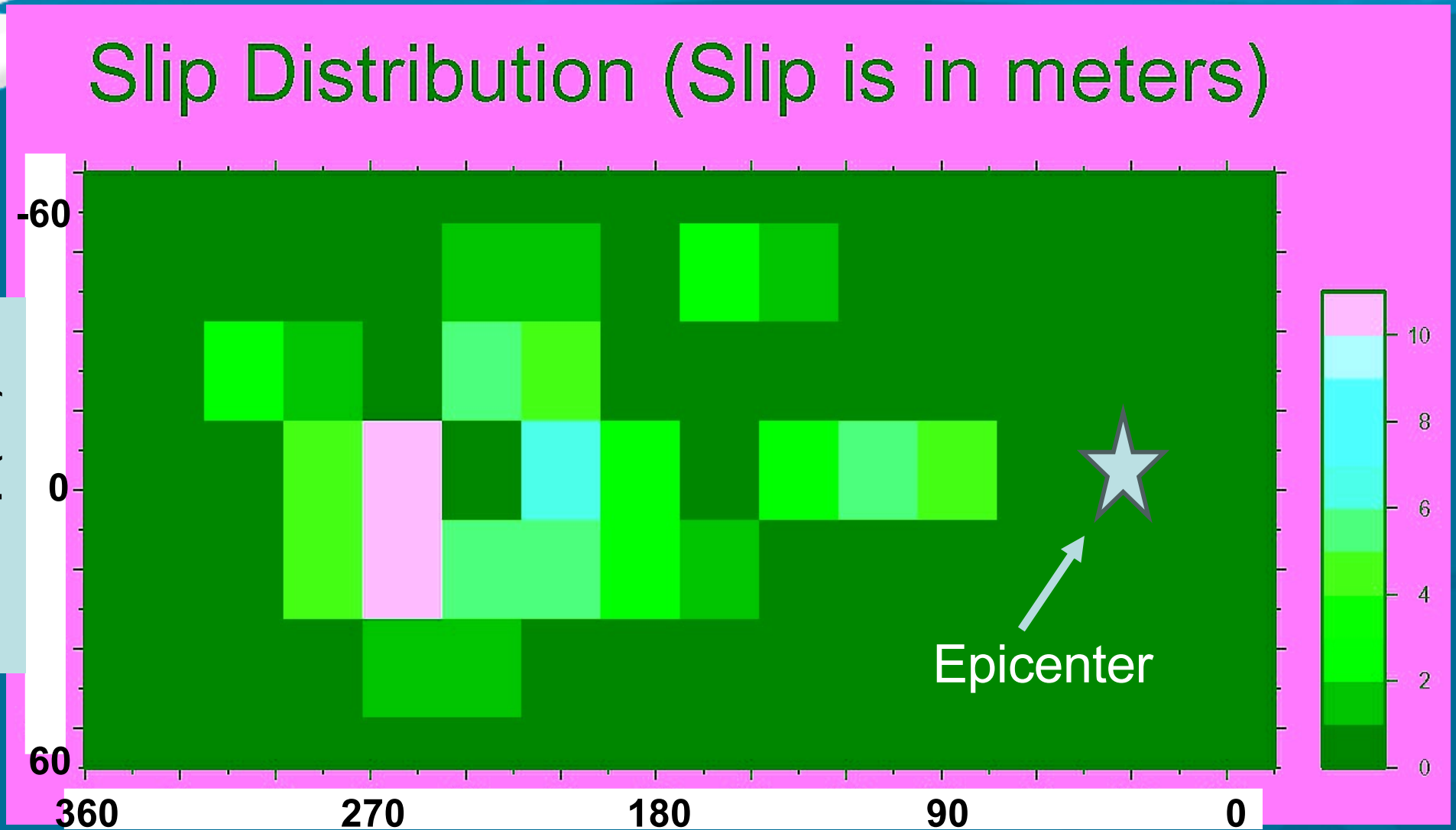
It tells you what the geometry of the fault is, but doesn't give the slip distribution along the fault.

Using scaling relationships, we can estimate the size of the fault based and then assume a homogenous slip distribution based on the seismic moment

However.. We can do better.. FINITE FAULT

Peru 2001

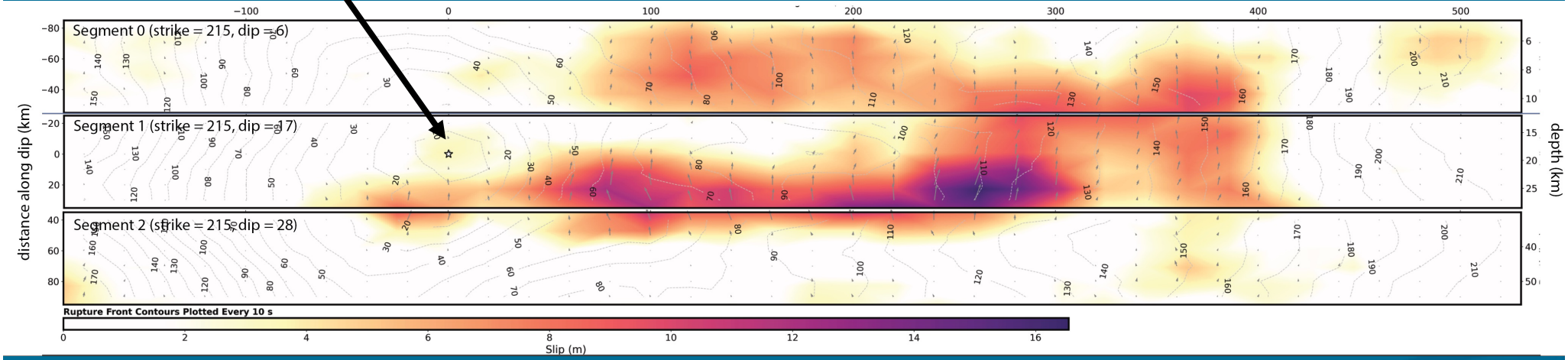
Inversion of teleseismic P-waves



Weinstein and Lundgren, 2008

Kamchatka Mw 8.8 Finite Fault USGS

HYPOCENTER



Maximum Slip 17-18m, Propagation from North to South

Inversion used P, S and surface waves

Finite Fault gives timing of slip as well

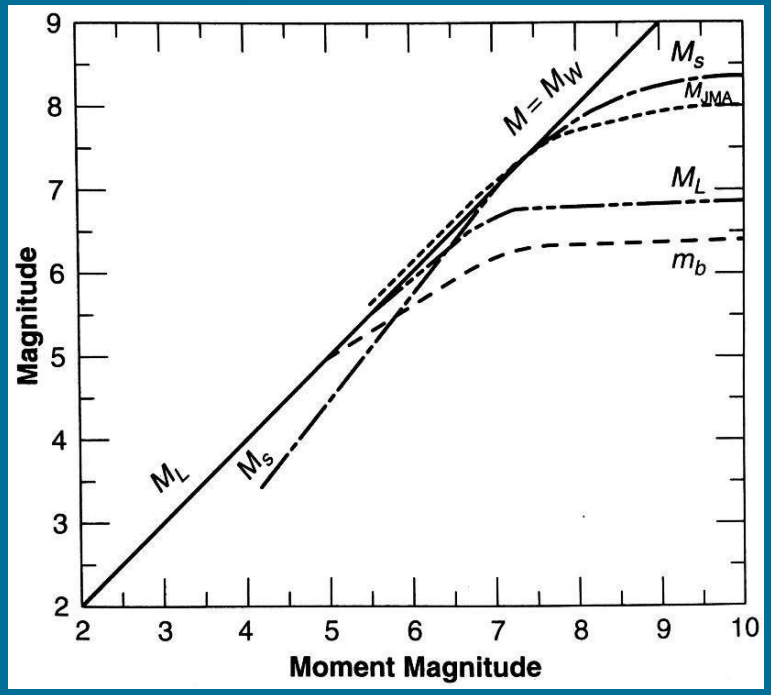
Seismogeodetic Data

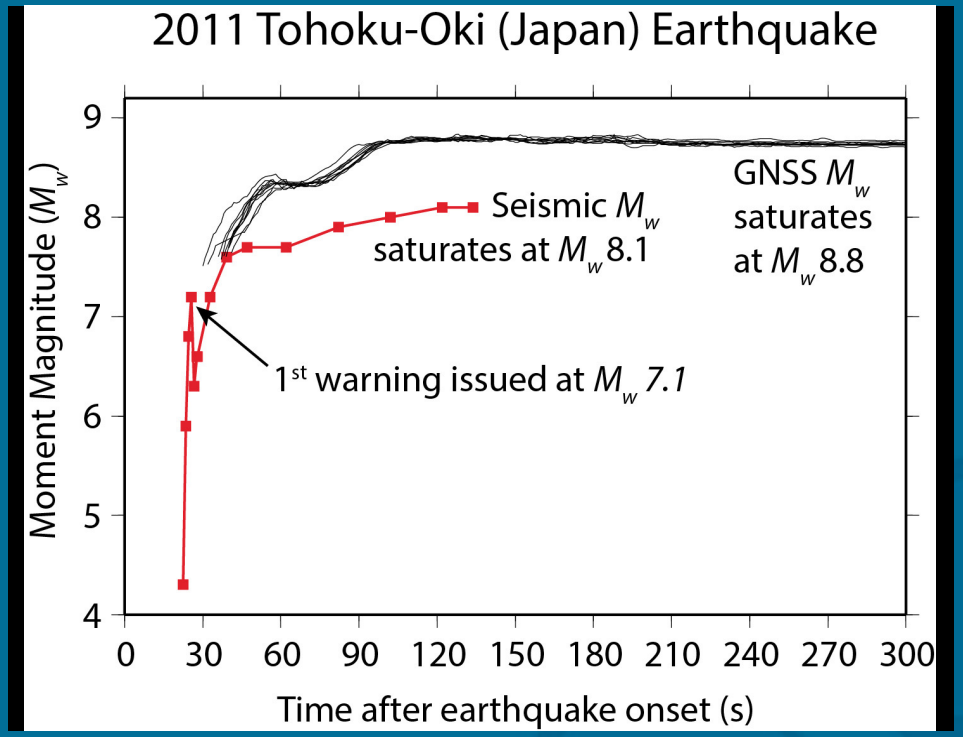
⇒ Combine Accelerometer Data with GNSS Data

⇒ Gives the *ultimate seismogram*
It never “clips”, and therefore can be used to assess earthquake magnitude even in the nearfield of great earthquakes

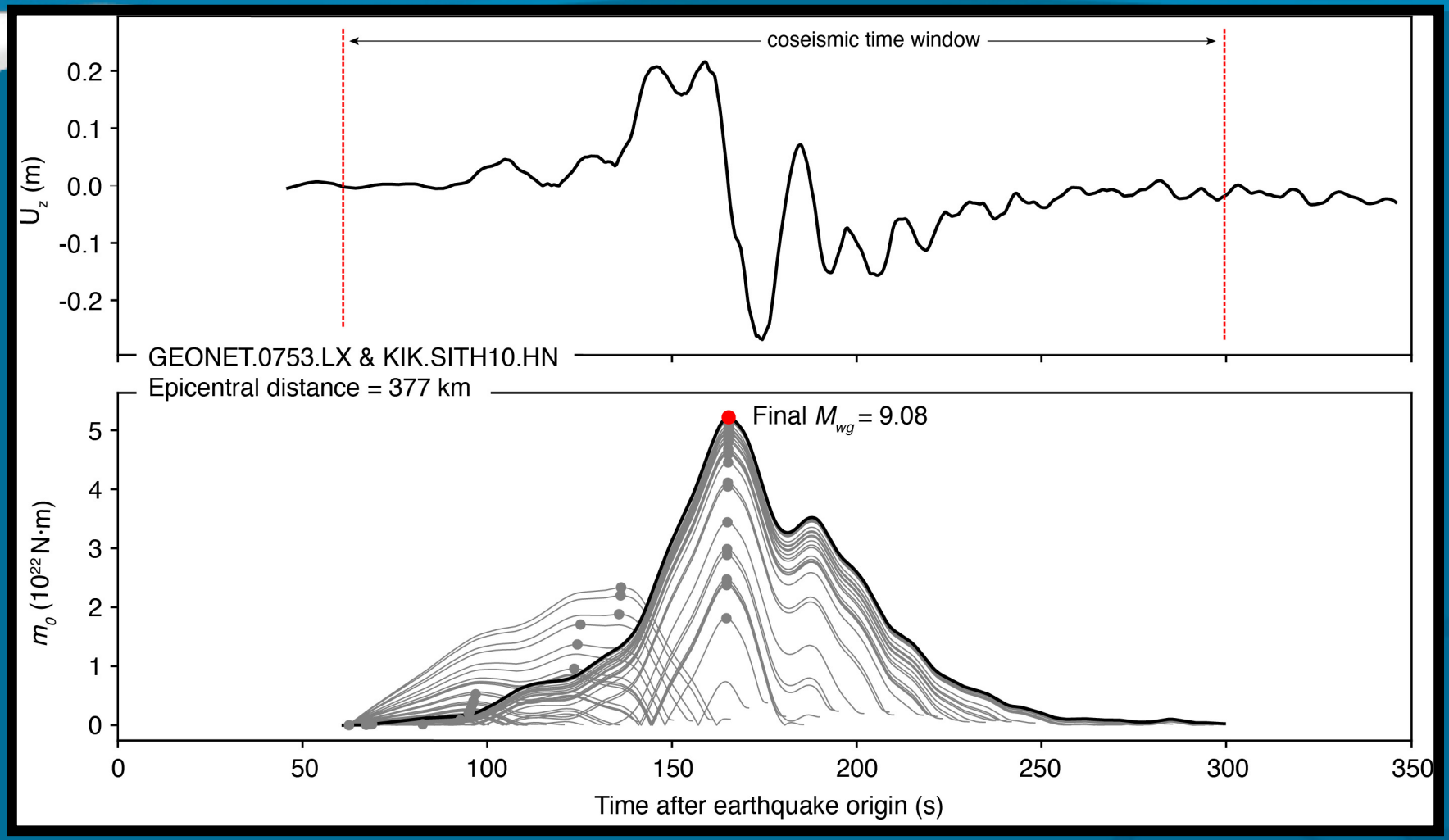
⇒ Can yield the magnitude of great earthquakes in ~3mins

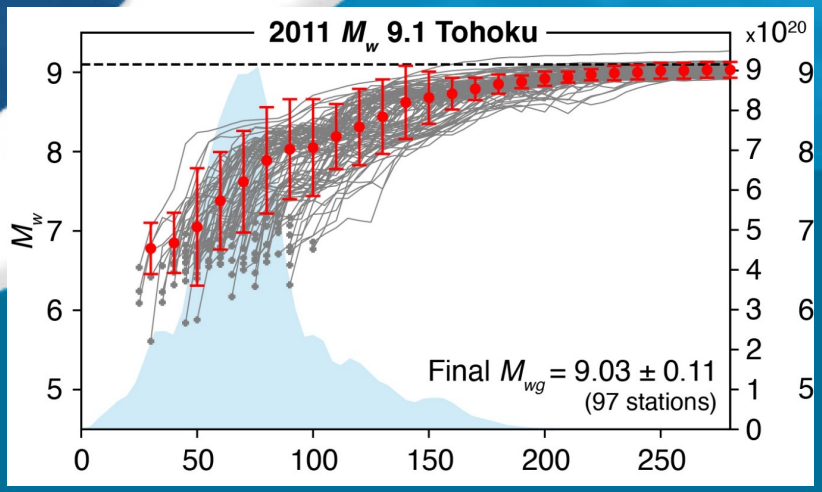
The future of rapid and accurate earthquake magnitude estimation and tsunami warning will include high-rate GNSS/GPS data



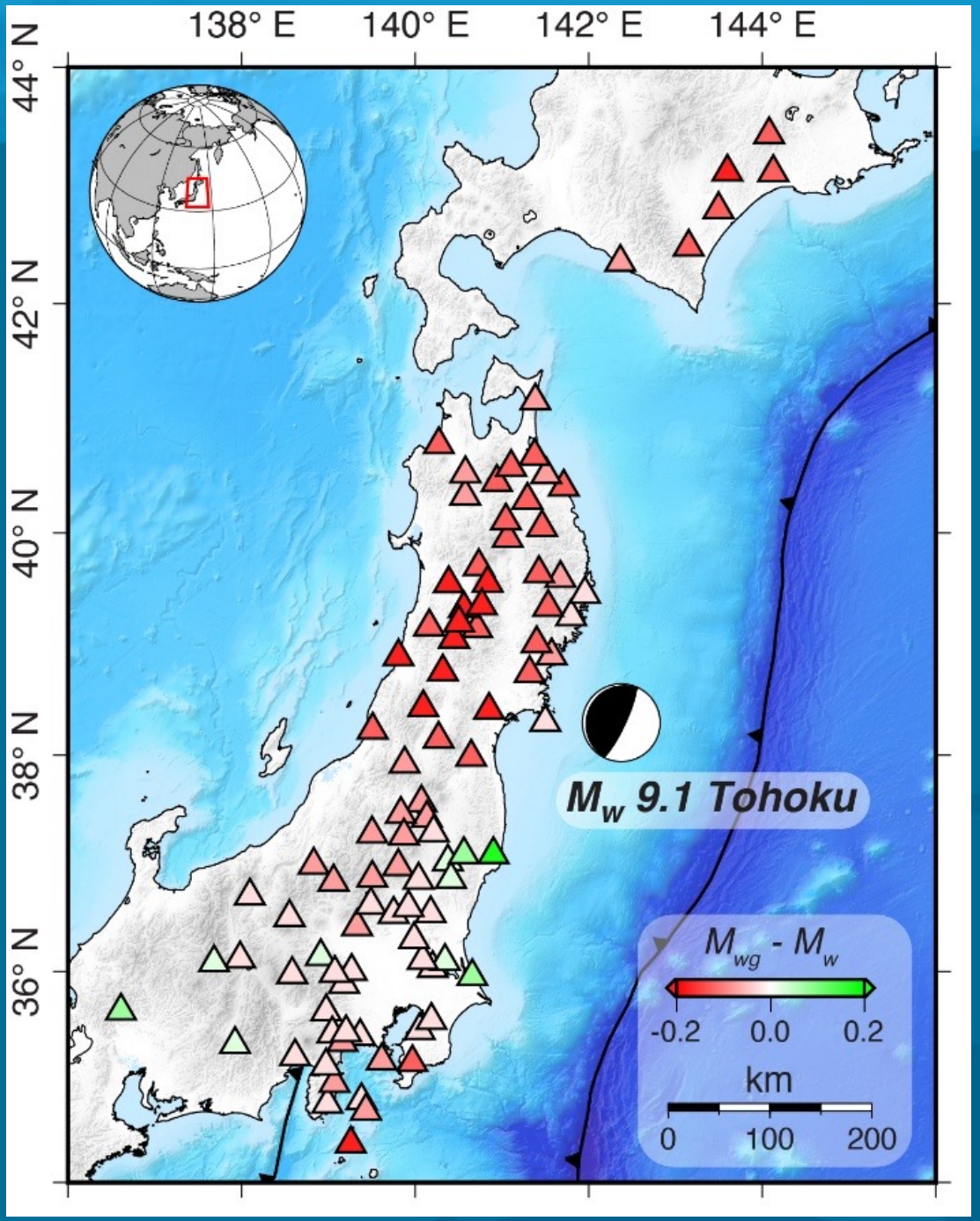


Seismogeodetic displacements & derived moment function during the 2011 M_w 9.1 Tohoku earthquake





- GNSS/GPS data provide direct measurements of surface displacement
- Fast & accurate, M_w 1-3 mins. after rupture initiation
- No saturation, can handle earthquakes with complex source time functions
- Working to incorporate in TWC operations…stay tuned



Thank You

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