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Seismological Constraints on Fault-Slip Source Models and Rupture Characteristics of Global Large Earthquakes (Mw ≥ 7.5) and Associated Tsunamis

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07 May 2020 @ 14:00-15:45

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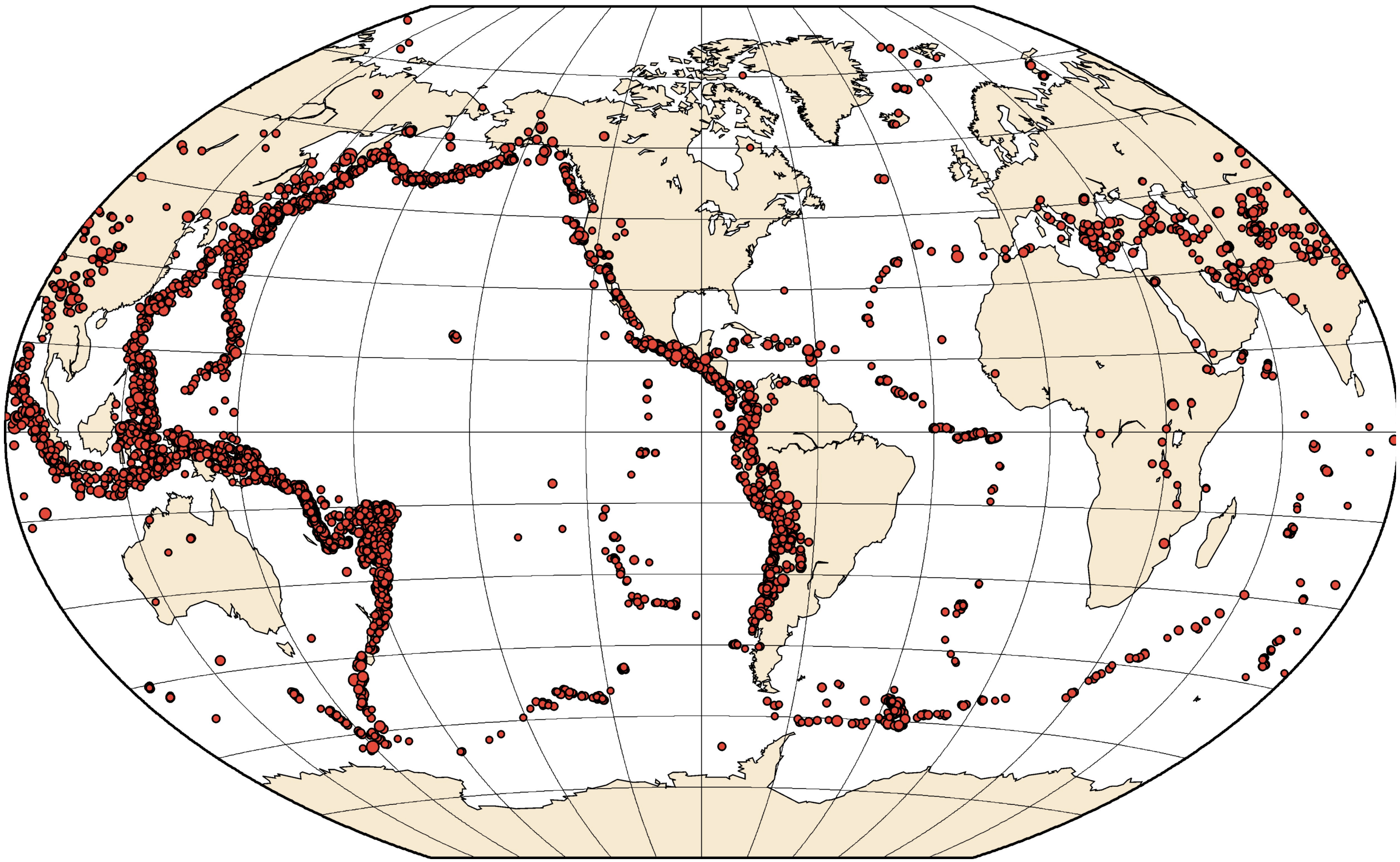
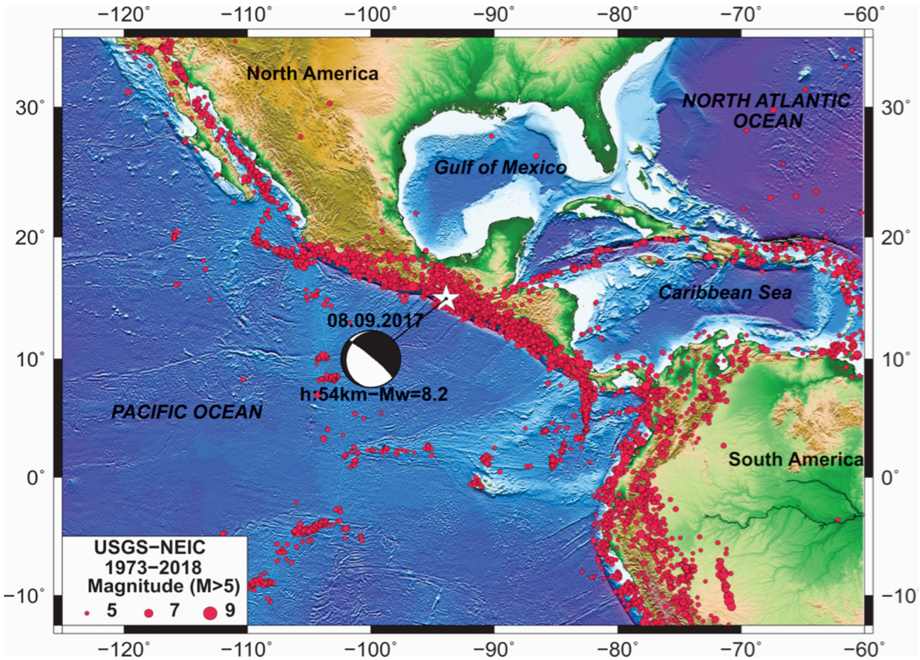
Earthquake distribution on the Earth (M > 6.0; USGS-NEIC)



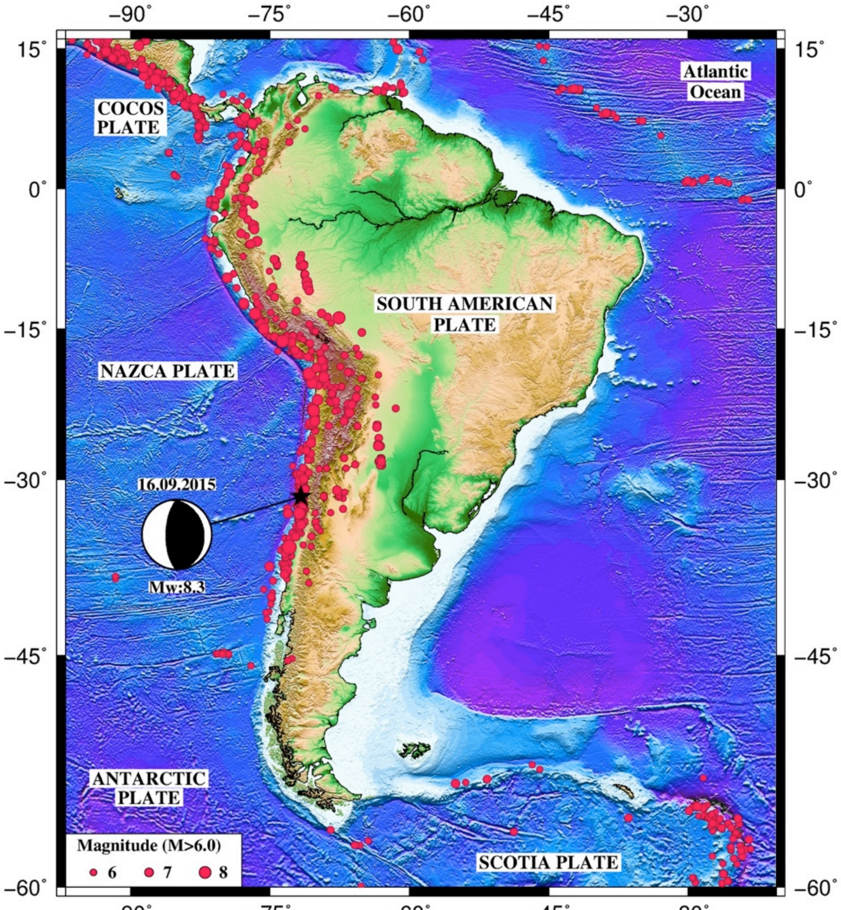
On a global scale, many destructive and tsunami-generating earthquakes ($M_w \geq 7.5$) cause widespread devastation, economic and human life loss due to the active plate interactions along the major subduction zones.

Global Examples:
Destructive Tsunamigenic Mega Earthquakes ($M_w > 8.0$)

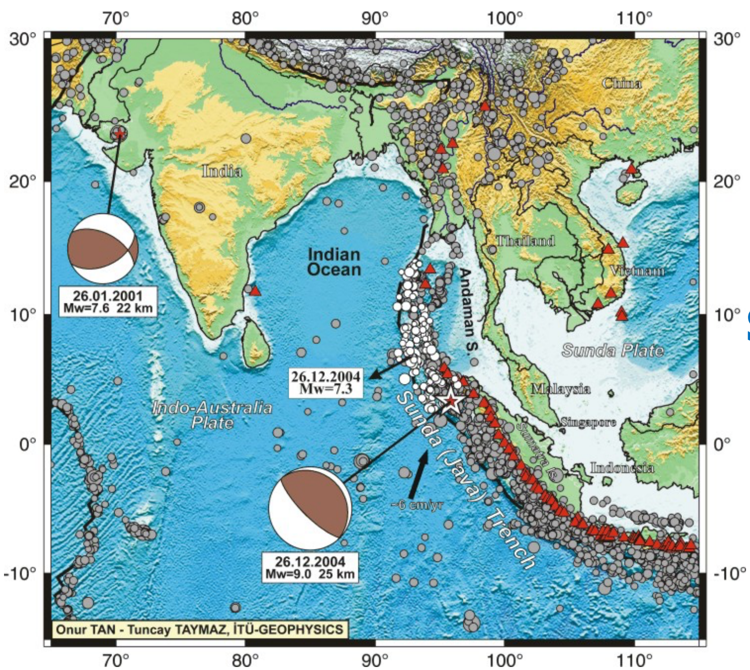
Middle America Trench



Peru-Chile Subduction Zone



Sumatra Subduction Zone

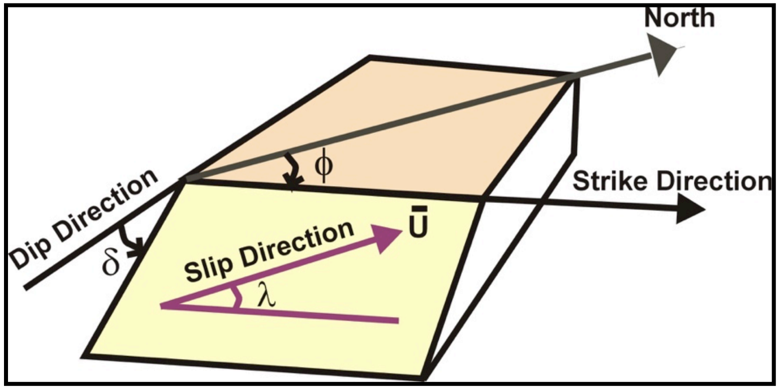


METHODS – SOURCE MECHANISMS

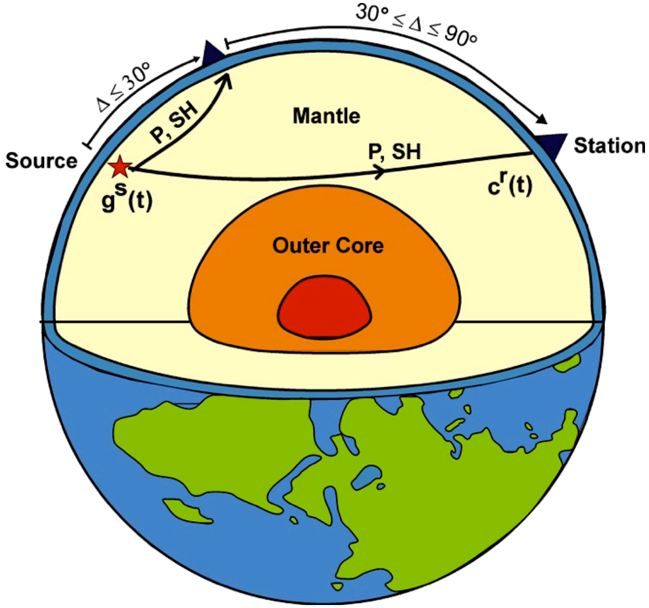
- Teleseismic Distance (30° ≤ Δ ≤ 90°)
- Green's function

↓

- Fault parameters (*ϕ, δ and λ*)
- Source Time Function (STF)
- Focal Depth (*h*)
- Seismic Moment (Mo)



Aki and Richards (1980)



$$G(t) = c^r(t) * m(t) * g^s(t)$$

$$m(t) = g * a(t,t^*) * \delta(t-tm)$$

$c^r(t)$ = Crustal effects under the receiver

$g^s(t)$ = Crustal effects under the source

$m(t)$ = Mantle effect

g = Geometrical spreading

$a(t,t^*)$ = Anelastic attenuation

Langston and Helmberger, 1975; Nabelek, 1984 ; McCaffrey and Nabelek, 1987; Nelson et al., 1987; Fredrich et al.,1988; Molnar and Lyon-Caen, 1989; Taymaz et al., 1990, 1991a,b; Priestley et al., 1994; Foster and Jackson, 1998; Berberian et al., 1999 ; Maggi et al., 2000; Jackson et al., 2002.

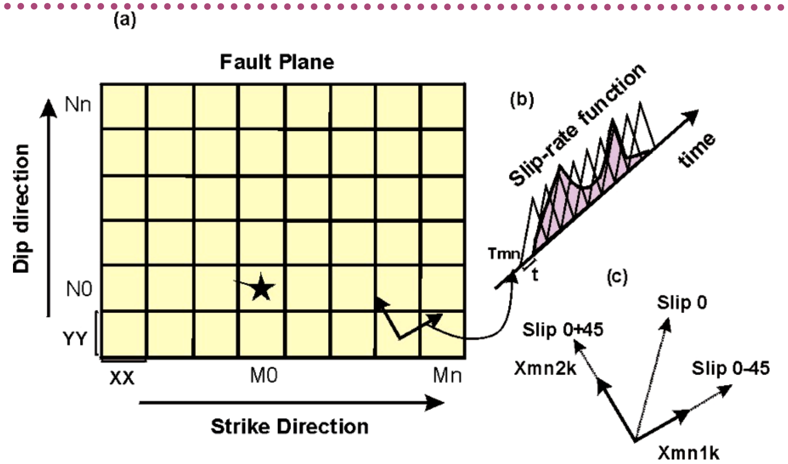
Models of Spatio-Temporal Slip Distribution and Rupture History

To obtain spatio-temporal slip model, an inversion algorithm of Yagi et al. (2012) is used.

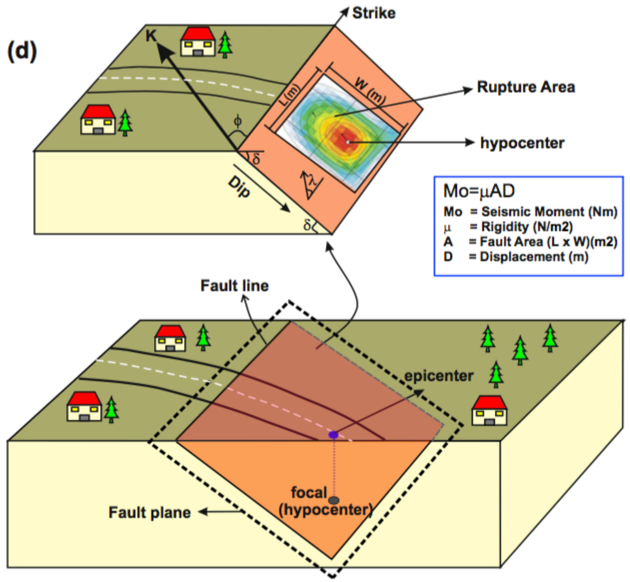
Teleseismic

broad-band P- body waves

- Fault area (length, width)
- Source Time Function (STF)
- Displacement (D)
- Slip distribution on the fault plane
- Stress drop



Yagi and Kikuchi (2000); Yagi et al. (2012)



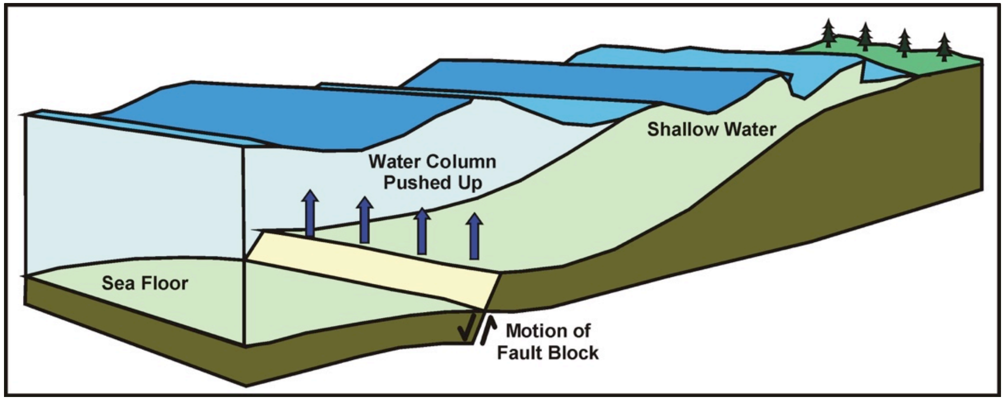
Yolsal-Çevikbilen and Taymaz (2012)

Tsunami Waves

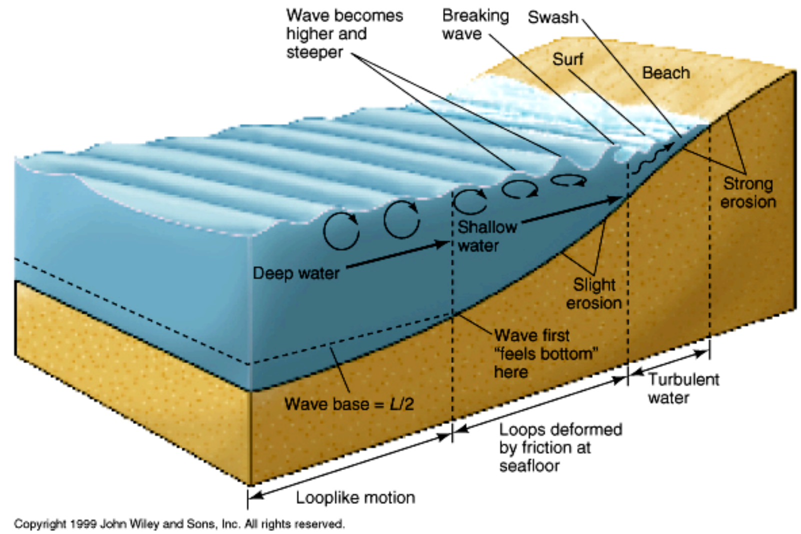
A tsunami is a series of ocean waves generated in a body of water by an impulsive disturbance that displaces the water.

- **Long period and long wavelength**
- **Water depth / wavelength is small**

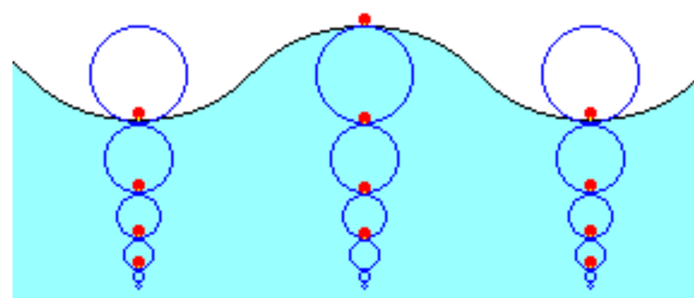
→ **Tsunami waves are called as shallow water** ***(Imamura, 1995).***



(http://earth.geol.ksu.edu/sgao/g100/plots)



They are primarily associated with the big oceanic earthquakes having shallow focal depths and dip - slip mechanisms (M > 6.5; Bryant, 1991), but there may be other causes.



Wave propagation speed (V):
(Langrange equation)

$$V = \sqrt{g \times h}$$

g: gravity constant (9.81 m /sec^2)
h: water depth (m)

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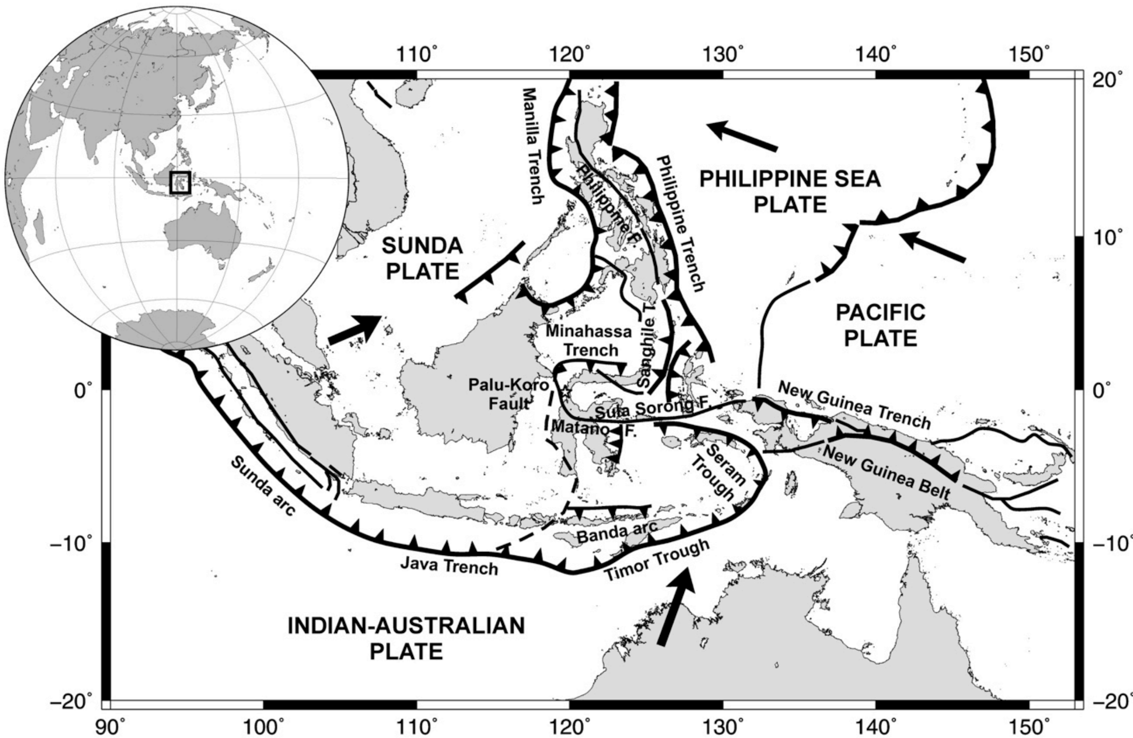
Pure and Applied Geophysics

AN EXAMPLE OF GLOBAL LARGE EARTHQUAKES (M_w >7.5)

Source Characteristics of the 28 September 2018 M_w 7.5 Palu-Sulawesi, Indonesia (SE Asia) Earthquake Based on Inversion of Teleseismic Bodywaves

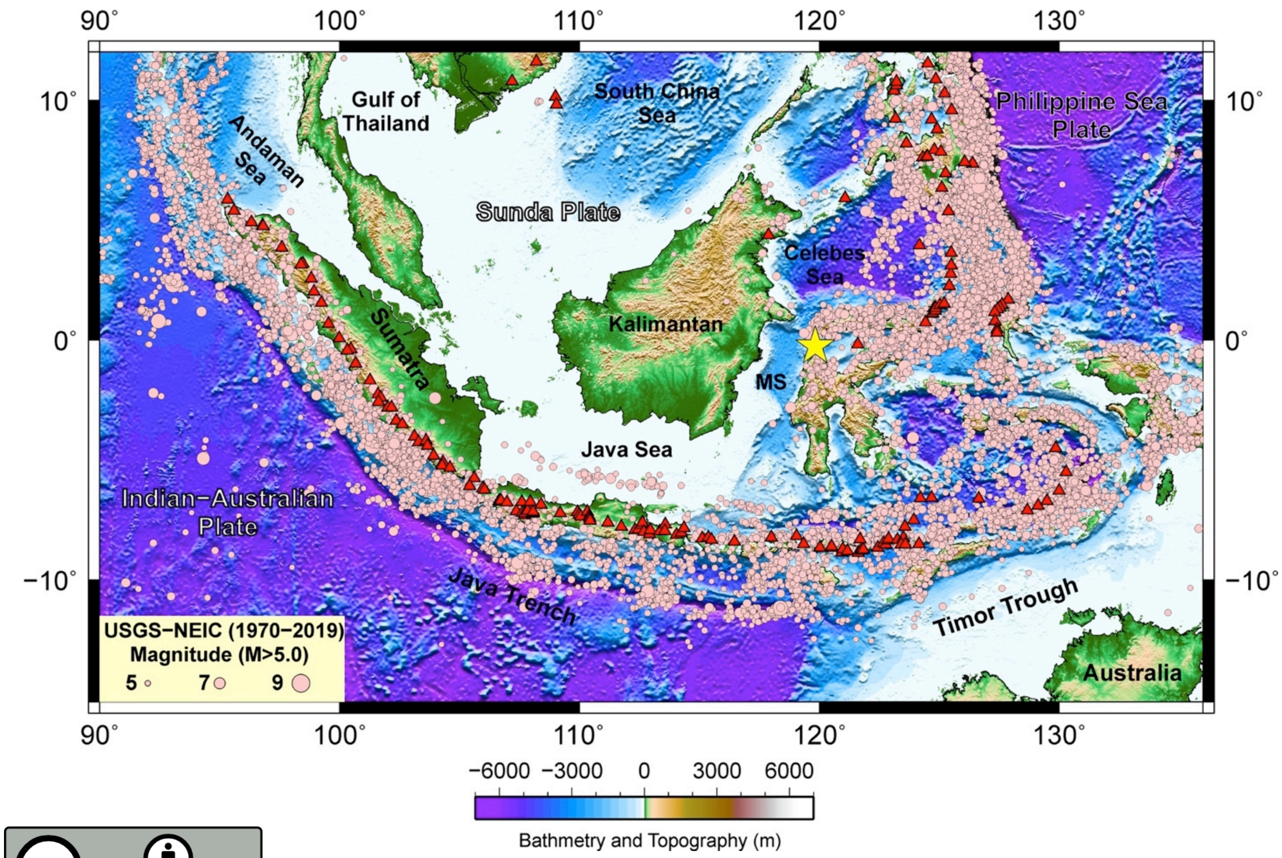
Seda Yolsal-Çevikbilen[1] and Tuncay Taymaz[1]



re-drawn from Socquet et al. 2006). The faults are reported by Hamilton (1979)

28 September 2018 Palu-Sulawesi (Indonesia) Earthquake (M_w 7.5)

Active tectonics of the Sulawesi region is governed by relative motions between several micro plates that interact due to the broad convergences of the **Australian, Sunda, Pacific and Philippine Sea** plates.

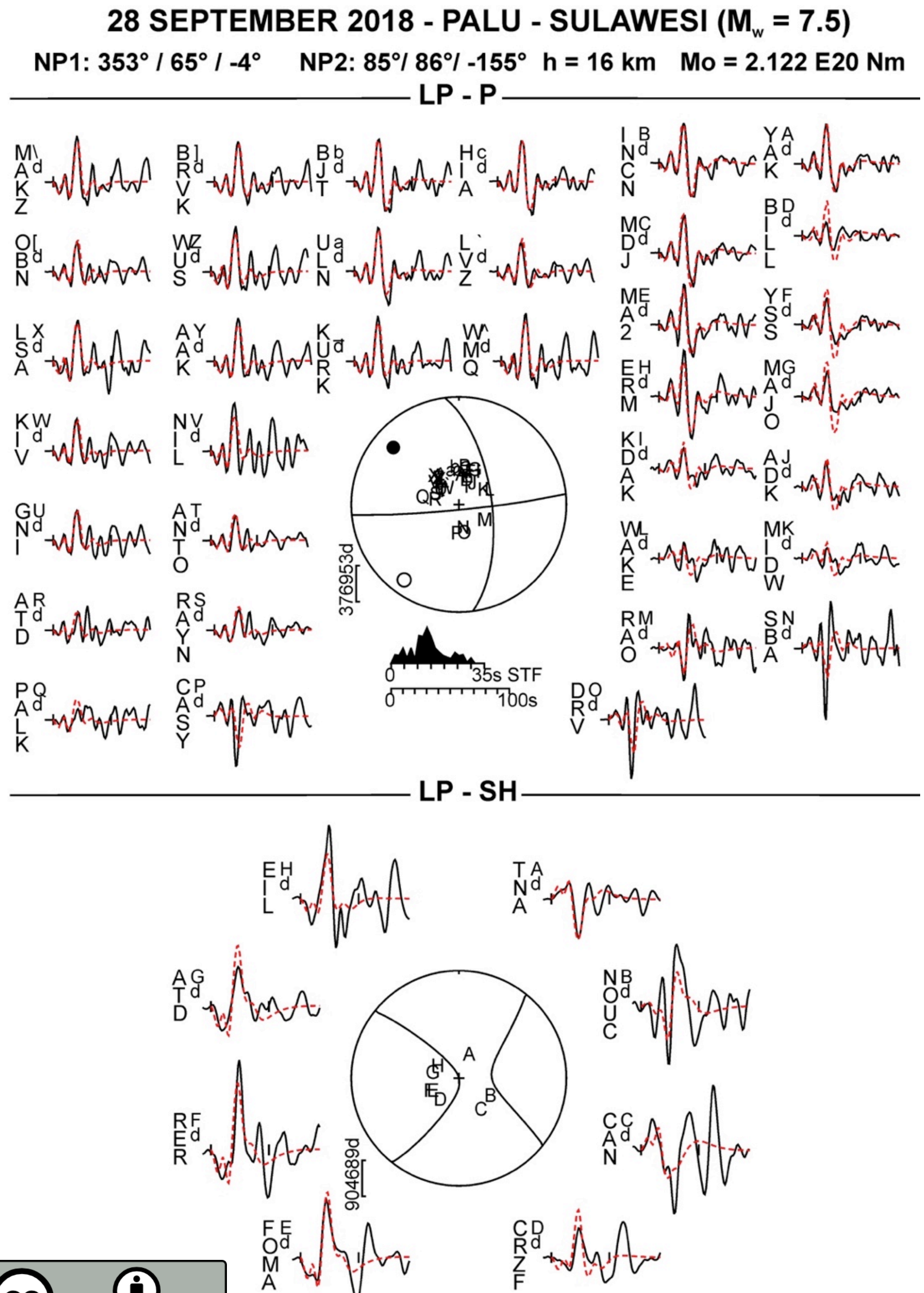


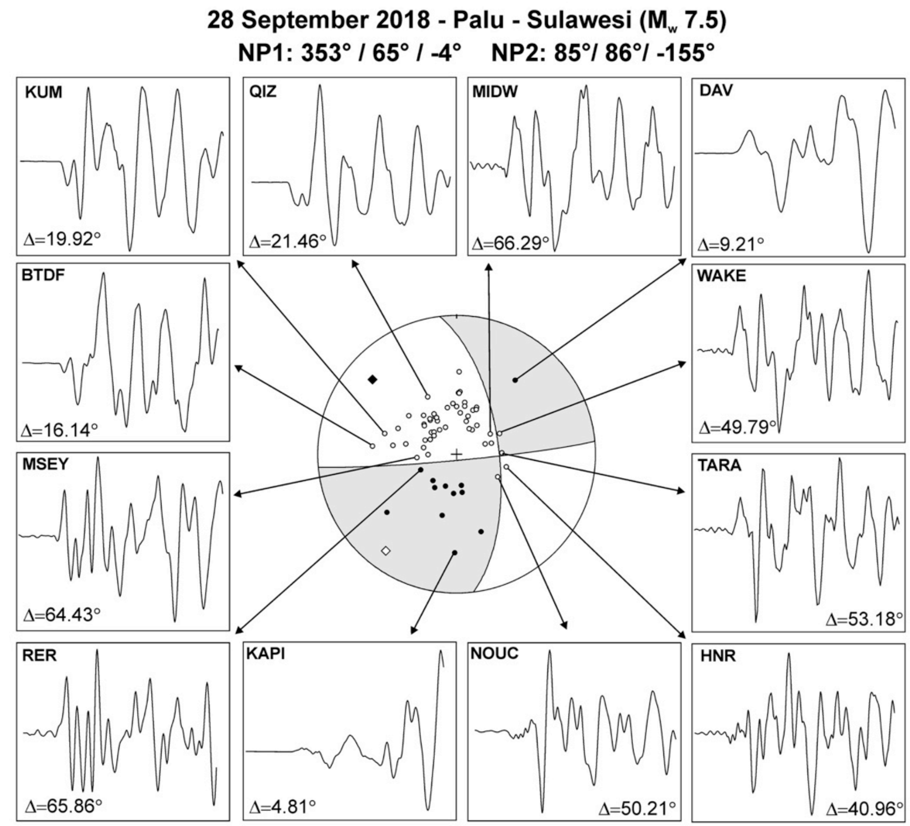
A latest large strike-slip earthquake **(M_w 7.5)** hit the eastern part of Indonesia on **the September 28, 2018** by producing astonishing tsunami waves up to 8–10 m at the coastal plains of Palu Gulf on the Sulawesi Island (Muhari et al., 2018; Hui et al., 2018) .

It is correlated with the *NW–SE trending left-lateral Palu-Koro strike-slip fault* in central Sulawesi.

Seismological and geodetic studies (Okuwaki et al. 2018; Bao et al. 2019; Socquet et al. 2019; Fang et al. 2019) showed super shear earthquake characteristics for the 2018 Palu (M_w 7.5) earthquake.

Yolsal-Çevikbilen, S. and Taymaz, T., 2019. Source Characteristics of the 28 September 2018 Mw 7.5 Palu-Sulawesi, Indonesia (SE Asia) Earthquake Based on Inversion of Teleseismic Bodywaves, **Pure and Applied Geophysics**, Topical collection, https://doi.org/10.1007/s00024-019-02294-1.





Inversion results indicated a strike-slip faulting mechanism with a small amount of dip-slip component at a shallow focal depth succeeding a super-shear rupture velocity of V_r: 4.1 km/sec

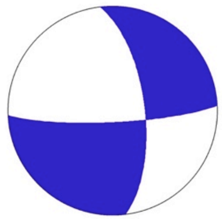
Yolsal-Çevikbilen and Taymaz (2019)

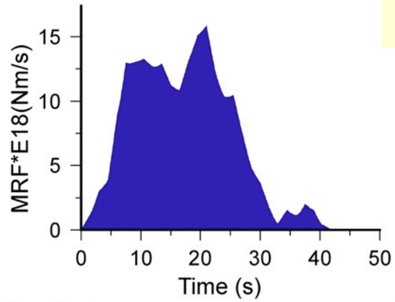
28 September 2018 - Palu - Sulawesi (M_w 7.6)

NP1: 353°/65°/-10° NP2: 87°/81°/-155°

Seismic Moment (Mo) = 2.981 x 10^{20} Nm

Focal Depth = 16 km Vr_{max} = 4.10 (km/sec)





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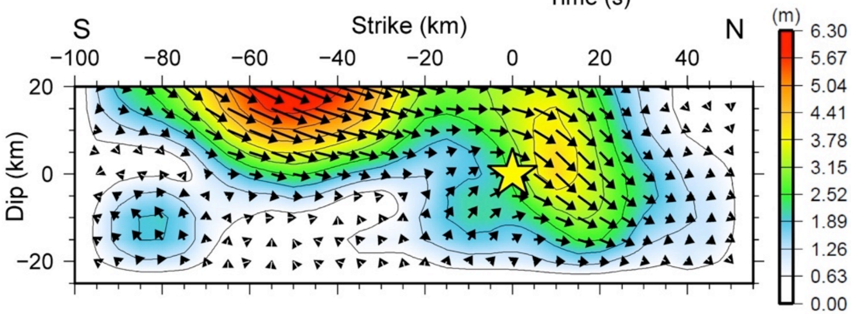
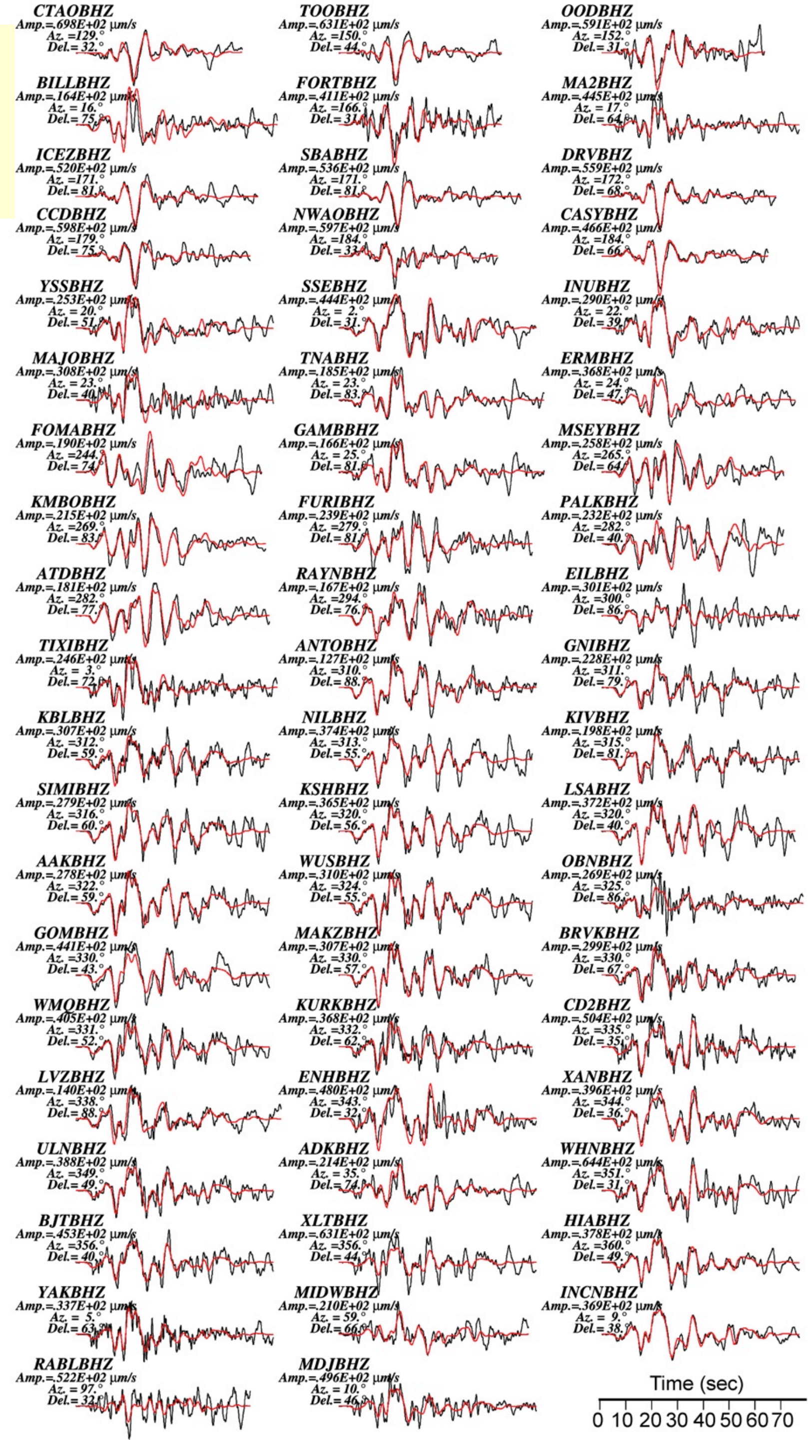
Broad-Band P-Waveforms





The rupture initiated from the hypocenter, then it propagated towards southward and eventually reached the surface.

Fault length x Fault width = 150 km x 45 km

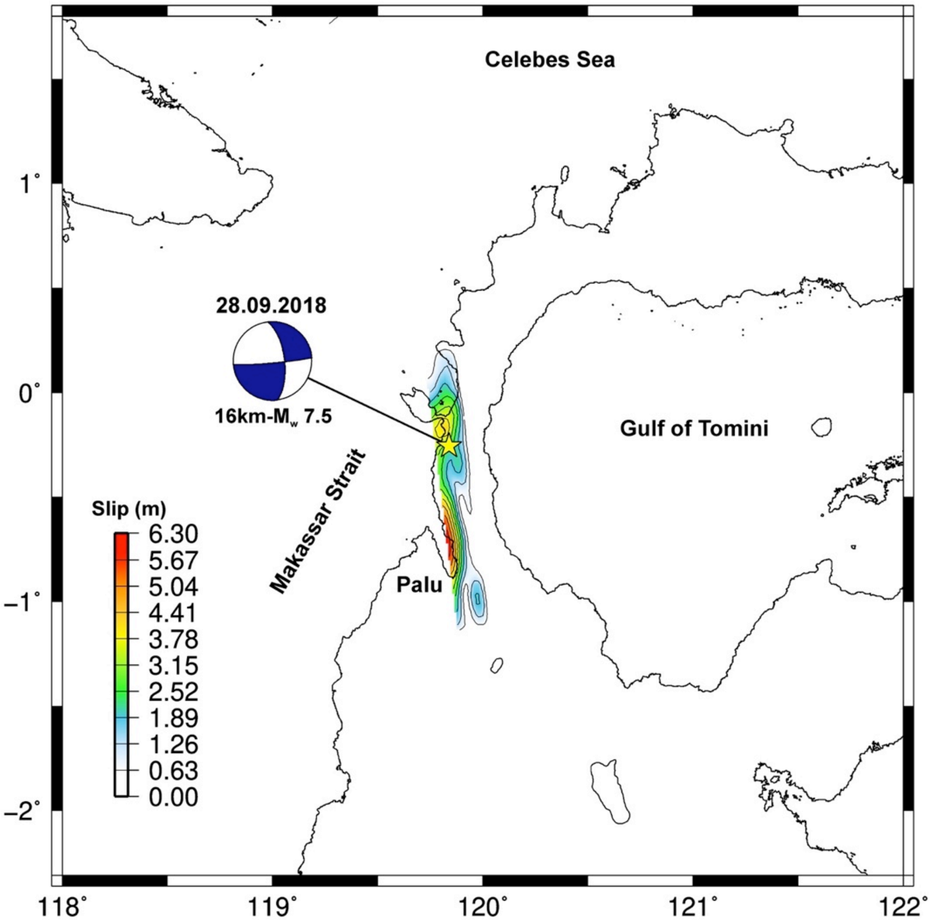
D_{max}: 6.3 m D_{av}: 1.5 m

A total source duration is obtained to be about 40 s with the most of seismic energy released at 10 s and 25 s.

There are two slip-patches of 2.0–4.0 m at north of the fault plane near the hypocenter, and 5.0–6.3 m at south near Palu city.

Yolsal-Çevikbilen and Taymaz (2019)

28 September 2018 Palu-Sulawesi (Indonesia) Earthquake (M_w 7.5)



The maximum displacement of 6.3 m occurred in an area close to the Palu city at south of the fault plane, which is very well matched with the observed damage and destruction occurred during the earthquake.

This oblique shear that also revealed from the slip inversion could be partially responsible for the unexpected tsunami generation along the left-lateral Palu-Koro Fault.

Yolsal-Çevikbilen and Taymaz (2019)

Pure Appl. Geophys. 176 (2019), 2995–3033

https://doi.org/10.1007/s00024-018-1996-5

Pure and Applied Geophysics

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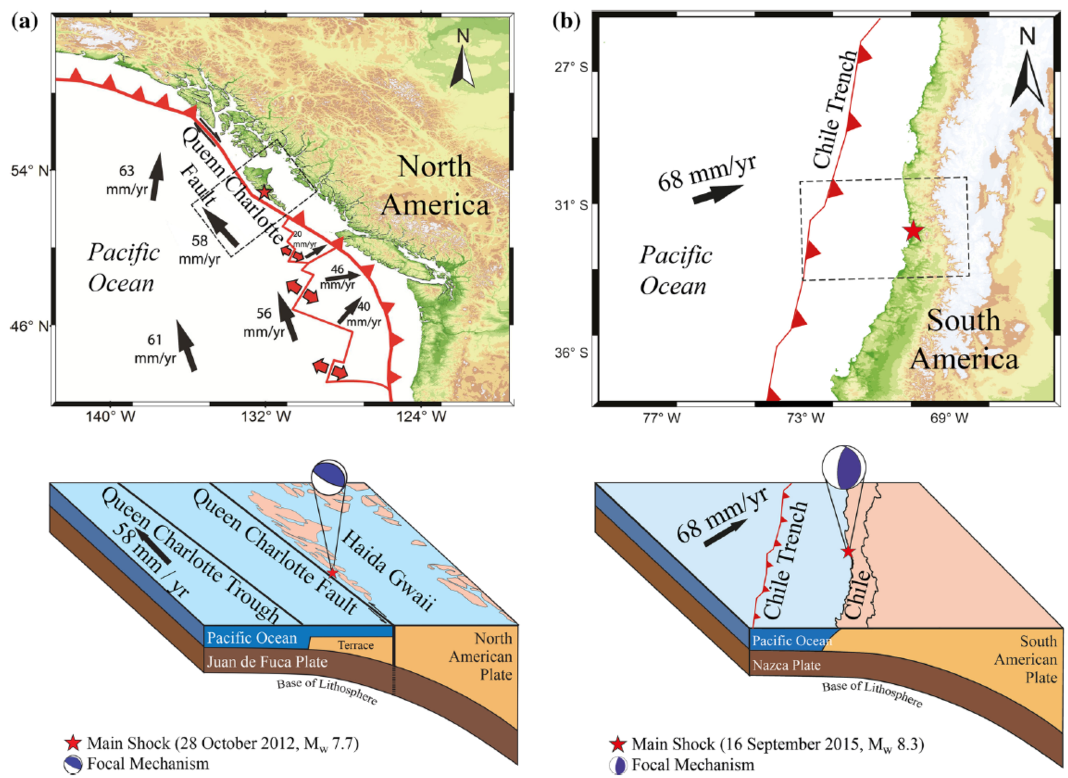
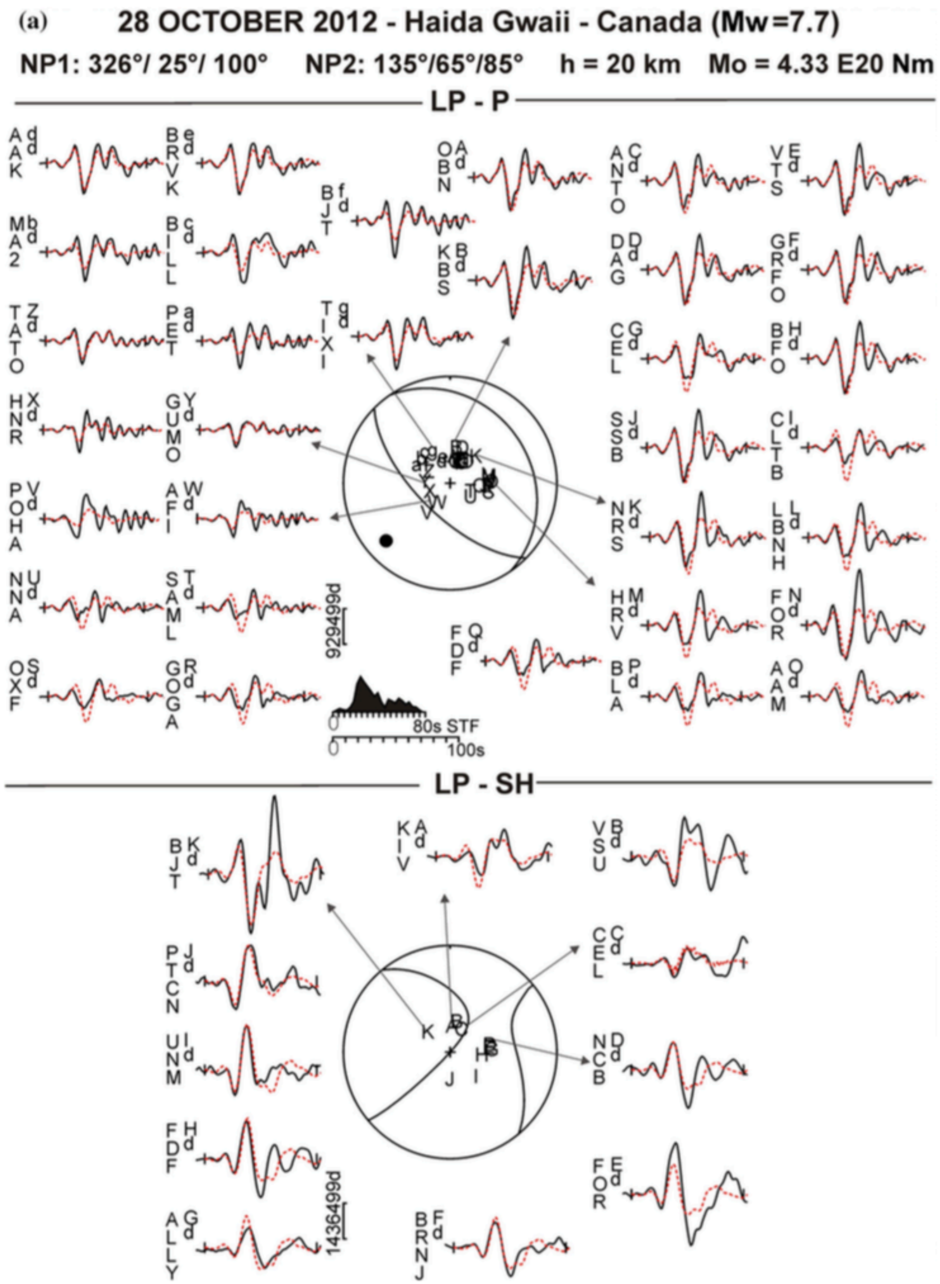
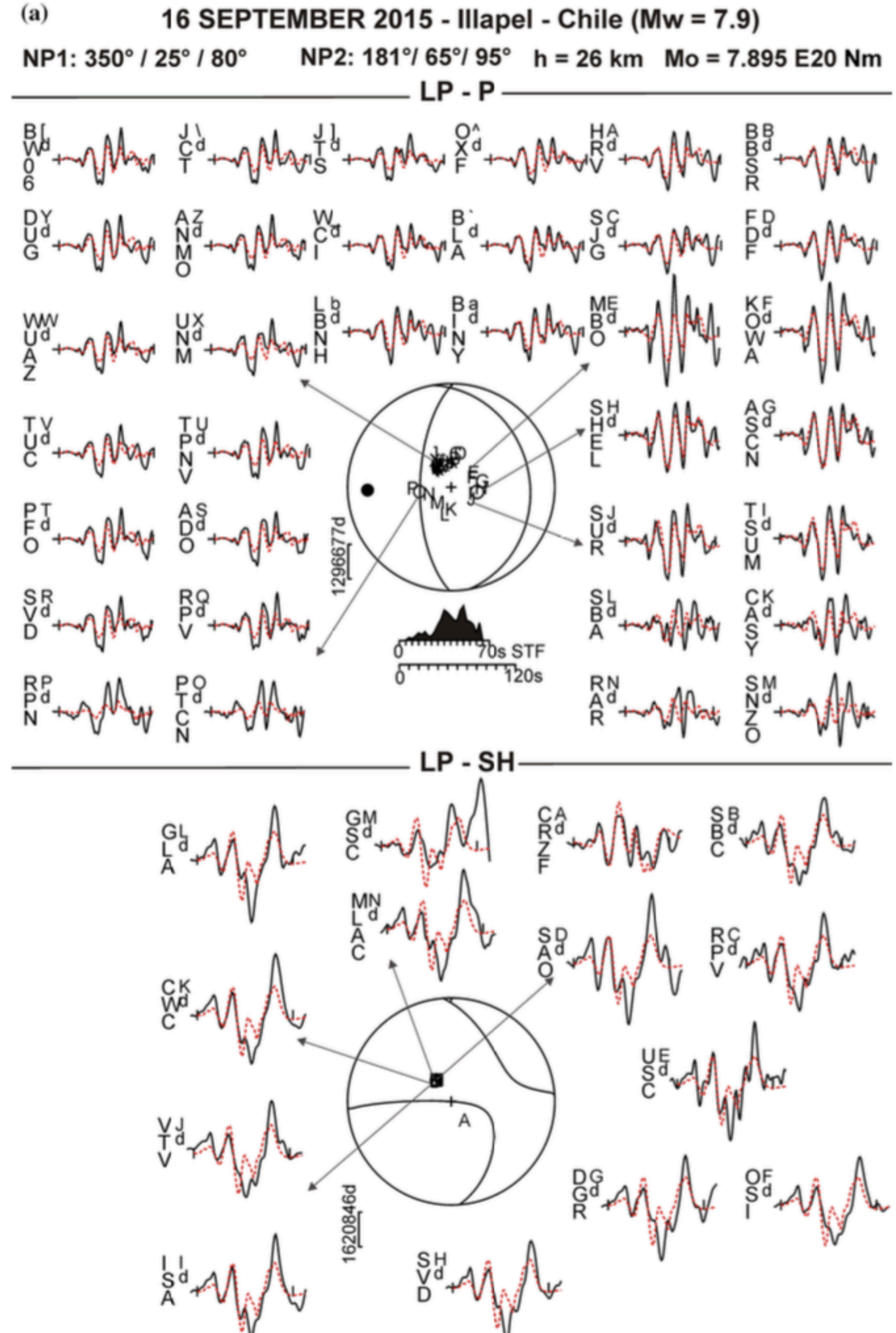
EXAMPLES OF GLOBAL LARGE EARTHQUAKES (M_w >7.5)

Source Models of the 2012 Haida Gwaii (Canada) and 2015 Illapel (Chile) Earthquakes and Numerical Simulations of Related Tsunamis

Seda Yolsal-Çevikbilen,[1] Ergin Ulutaş,[2] and Tuncay Taymaz[1]







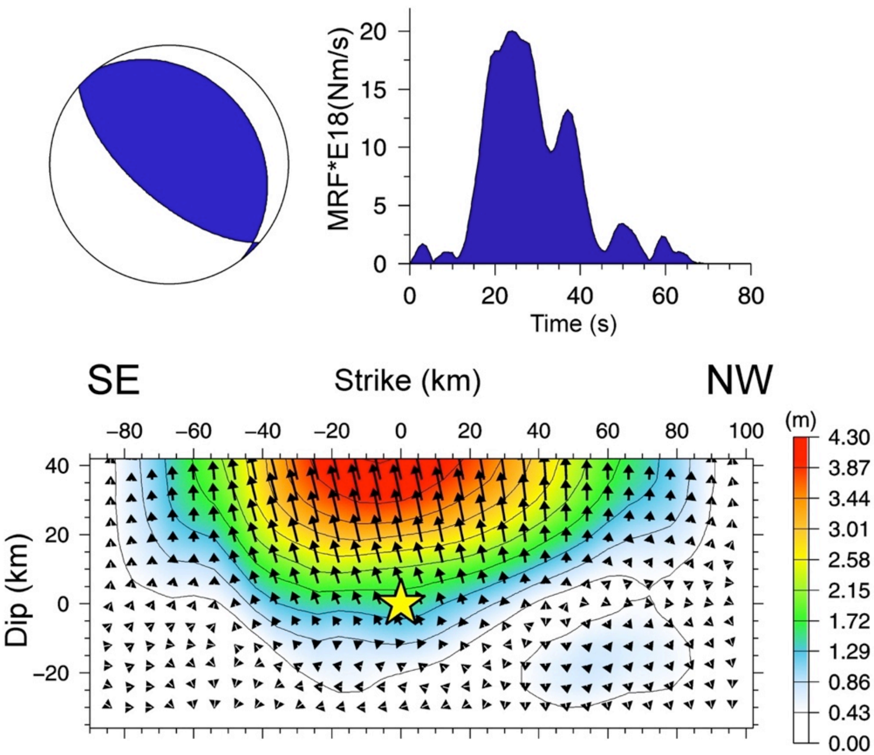
Yolsal-Çevikbilen, Ulutaş and Taymaz (2019)

28 October 2012 Haida Gwaii (M_w: 7.7)

NP1: 323°/25°/101° NP2: 131°/65°/85°

Focal Depth: 20 km

Seismic Moment (Nm): 4.082 x 10^{20} Nm



The fault plane is divided into 31 x 13 sub-faults with dimensions of 6 x 6 km^2

Fault length x Fault Width: 160 km x 60 km

D_{max}: 4.3 m D_{av}: 1.41 m

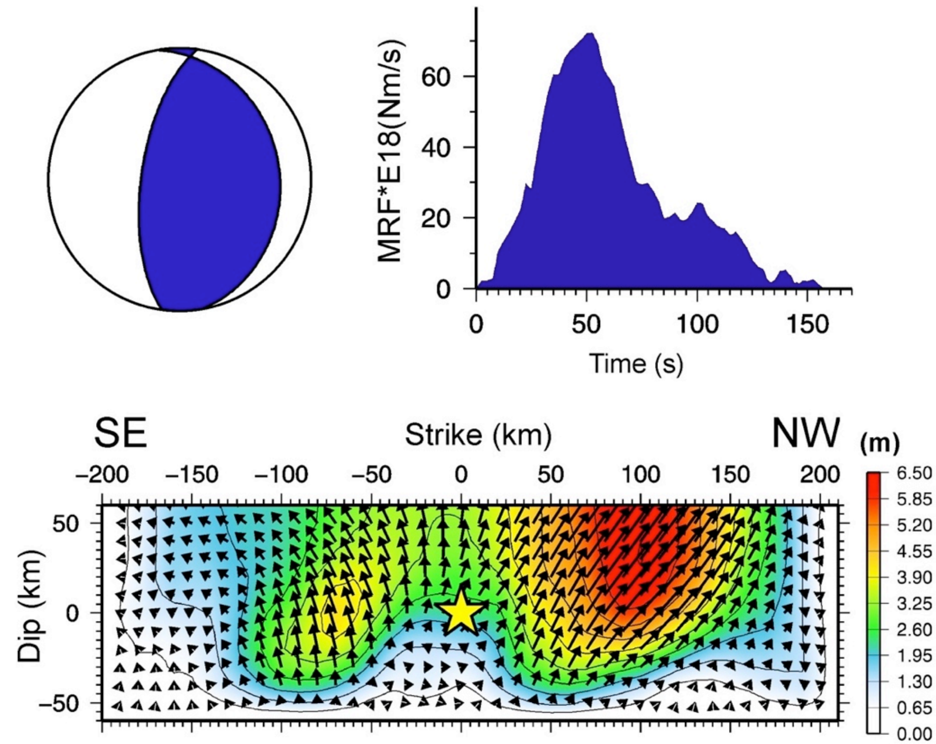
Source duration: 50-60 sec

16 September 2015 - Illapel (Chile) M_w: 8.3

NP1: 350°/25°/74° NP2: 188°/66°/97°

Focal Depth: 26 km

Seismic Moment (Nm): 4.06 x 10^{21} Nm



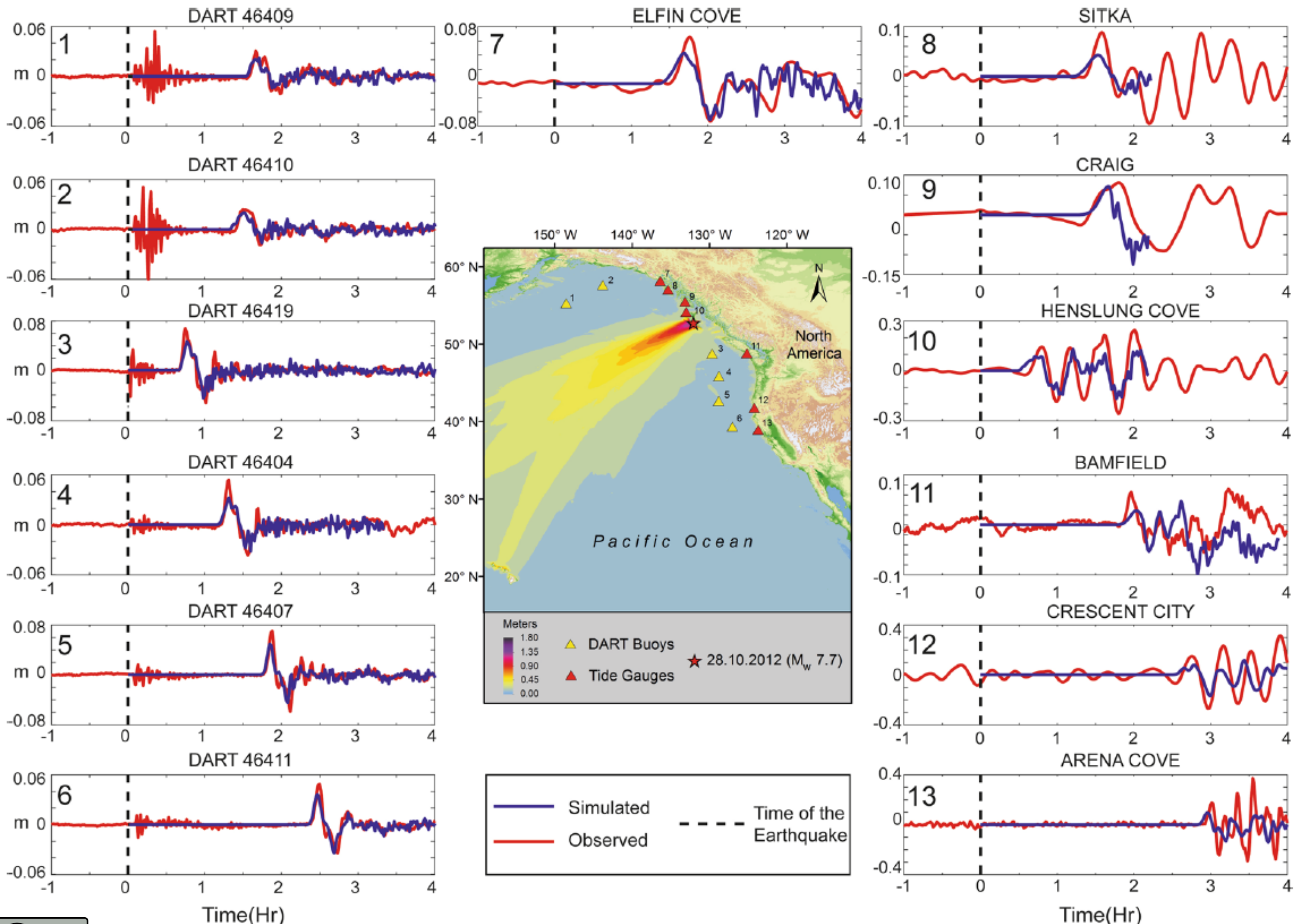
The fault plane is divided into 40 x 12 sub-faults with dimensions of 10 x 10 km^2

Fault length x Fault Width: 350 km x 100 km

D_{max}: 6.5m D_{av}: 3.86 m

Source duration: 150 sec

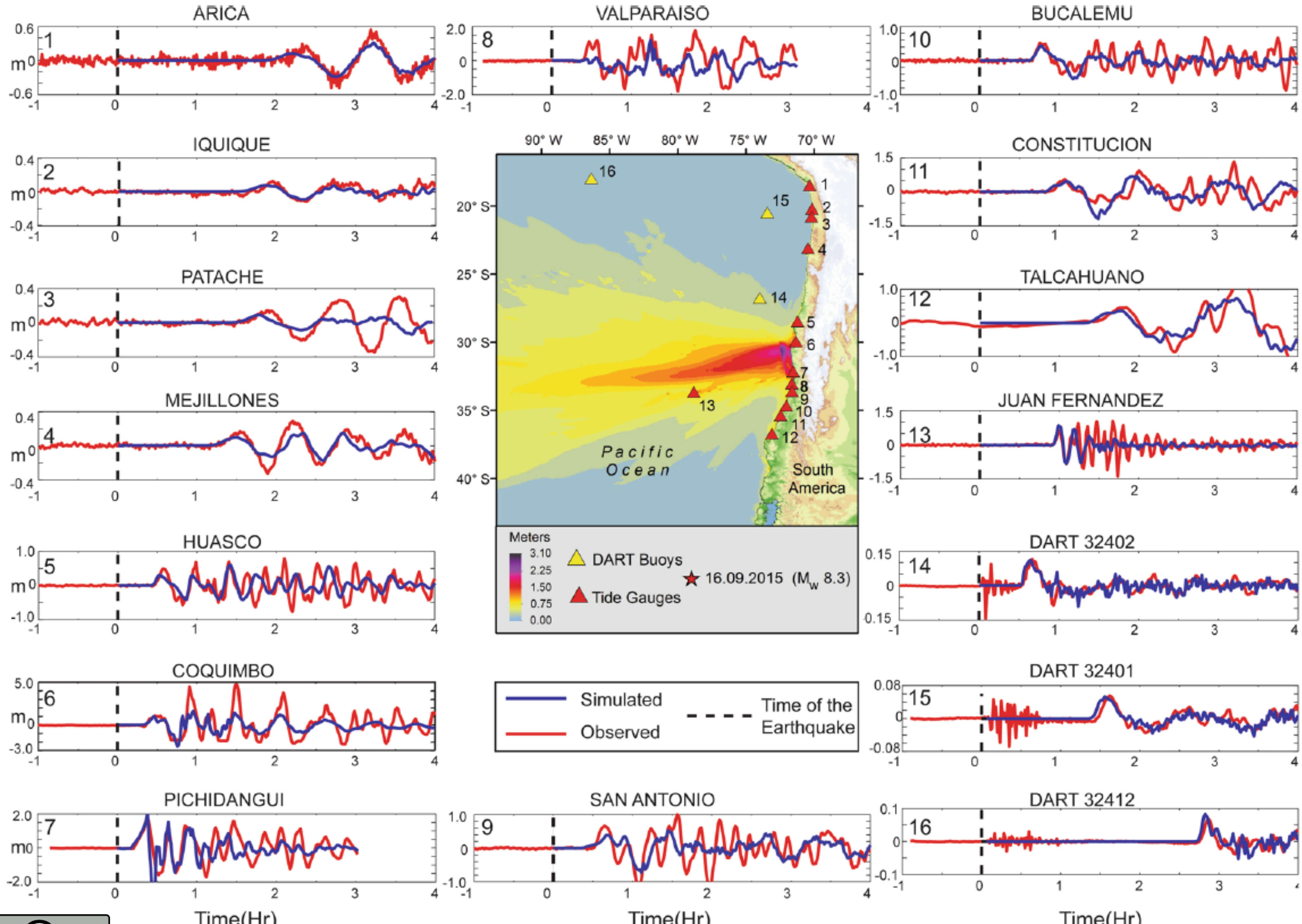
28 OCTOBER 2012 HAIDA GWAII (CANADA) EARTHQUAKE AND TSUNAMI (Mw 7.7)



With non-uniform slip model

Yolsal-Çevikbilen, Ulutaş and Taymaz (2019)

16 SEPTEMBER 2015 ILLAPEL (CHILE) EARTHQUAKE AND TSUNAMI (Mw 8.3)

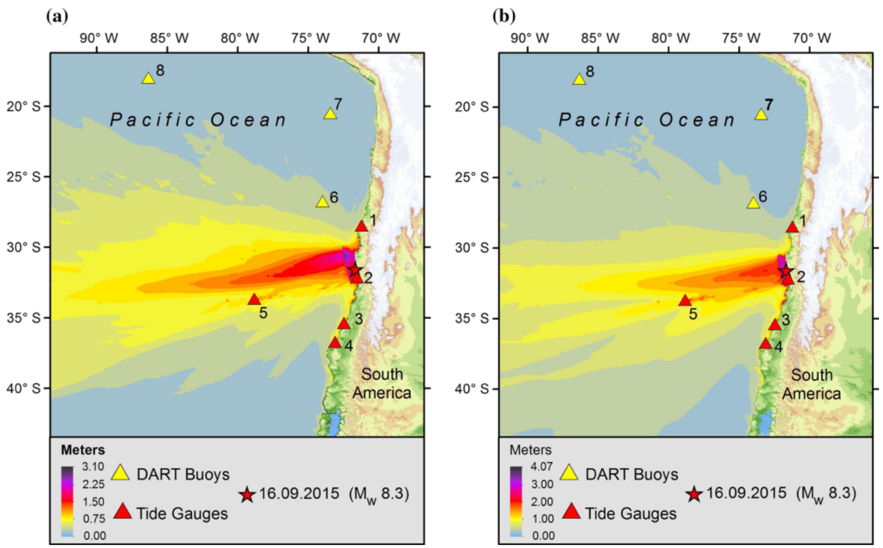


With non-uniform slip model

Yolsal-Çevikbilen, Ulutaş and Taymaz (2019)

16 SEPTEMBER 2015 ILLAPEL (CHILE) EARTHQUAKE AND TSUNAMI (Mw 8.3)

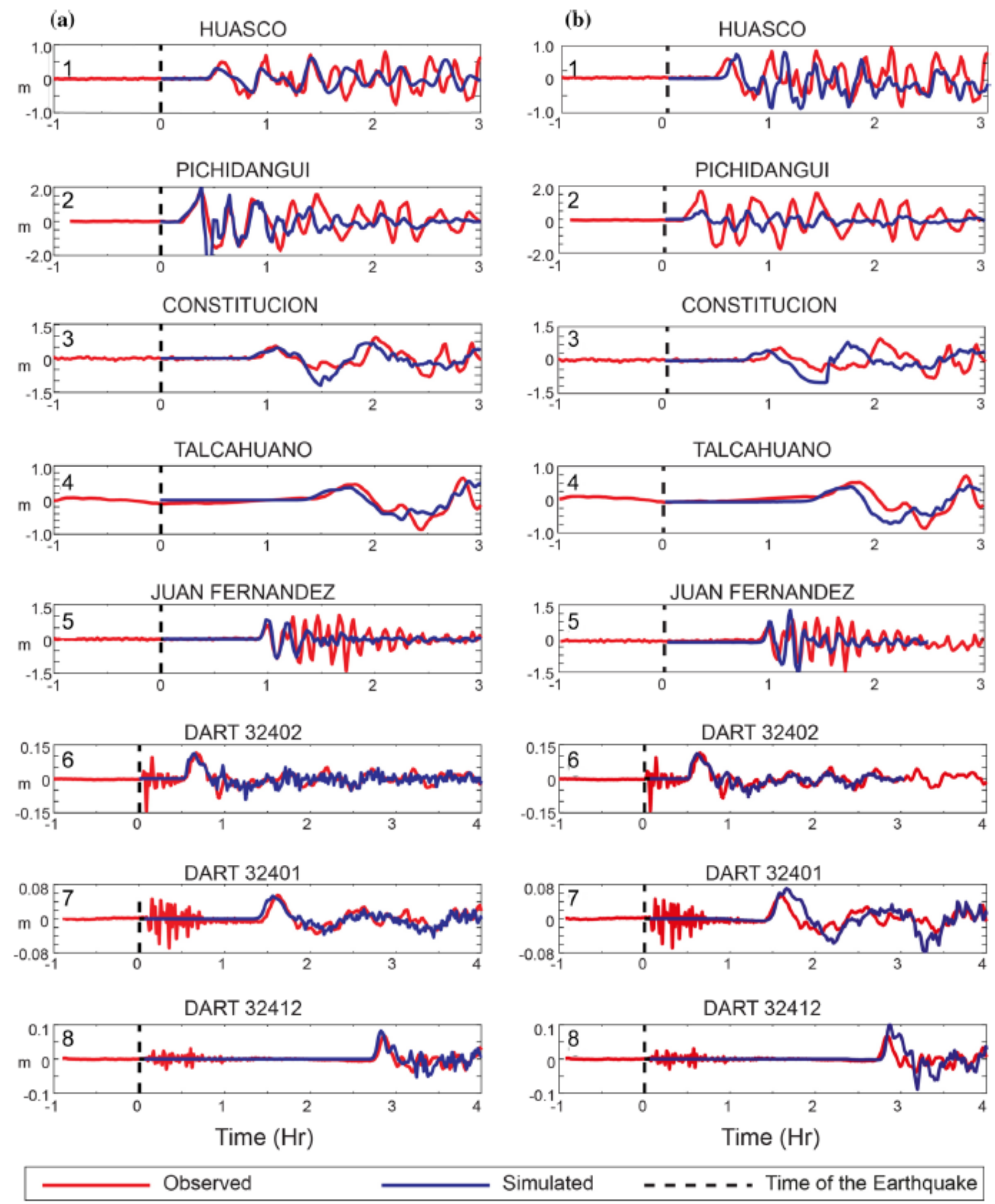
COMPARISON OF TSUNAMI MODELLING RESULTS BASED ON UNIFORM AND NON-UNIFORM SLIP DISTRIBUTION MODELS



(a)
Tsunami wave propagation based on non-uniform slip model

(b)
Tsunami wave propagation based on uniform slip model

non-uniform slip model **uniform slip model**



Yolsal-Çevikbilen, Ulutaş and Taymaz (2019)

CONCLUSIONS

- Understanding the complex behaviour of earthquake source evolution provides principal knowledge in terms of estimating input parameters of tsunami studies (e.g., faulting geometry, focal depth and seismic moment release).
- The importance and necessity of seismological parameters and a high-resolution bathymetry data in tsunami simulations, and the major effects of tectonic structures developed under the complex tectonic evolution on earthquake source parameters and tsunami wave characteristics are evidently emphasised.
- We observed that mathematical tsunami simulations based on heterogeneous slip distribution model of earthquakes give more detailed and precise estimations of synthetic tsunami waves, which are quite compatible with the real-time DART and tide-gauge records.

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