

del Código Madelo Sismica para América Latina y El Garibe

# Simulación de tsunamis y aplicación de inteligencia artificial

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Pontificia Universidad Católica de Chile

San Salvador, El Salvador 9 de octubre de 2025

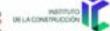
www.codigomodelosismico.org















#### Itinerario



- Fuentes sísmicas
- Acoplamiento mecánico entre placas
- Modelos físicos de ciclo sísmico
- Escenarios sismo-tsunami generados con fuente sísmica



Necesidad de cuantificar inundaciones de olas de tsunami y medidas de intensidad, e.g. altura máxima, velocidad, momentum, runup, etc.



Terremoto Mw9.0 de Tohoku 2011



Necesidad de cuantificar inundaciones de olas de tsunami y medidas de intensidad, e.g. altura máxima, velocidad, momentum, runup, etc.





Cilia et al. (2021)

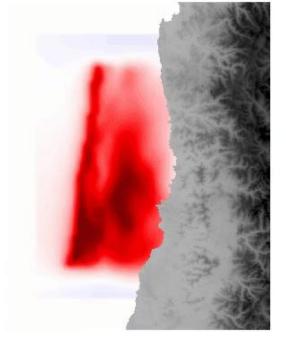
Terremoto Mw7.5 de Palu 2018

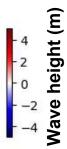


1. La disponibilidad de datos observacionales de inundación por tsunami es limitada.



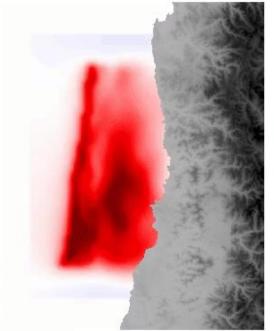
- 1. La disponibilidad de datos observacionales de inundación por tsunami es limitada.
- 2. Escenarios de inundación por tsunami pueden ser generados mediante simulaciones numéricas; sin embargo, estos procesos son computacionalmento costosos.







- 1. La disponibilidad de datos observacionales de inundación por tsunami es limitada.
- 2. Escenarios de inundación por tsunami pueden ser generados mediante simulaciones numéricas; sin embargo, estos procesos son computacionalmento costosos.
- 3. El uso de redes neuronales puede simplificar el proceso de la creación de las simulaciones.



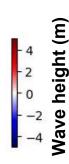
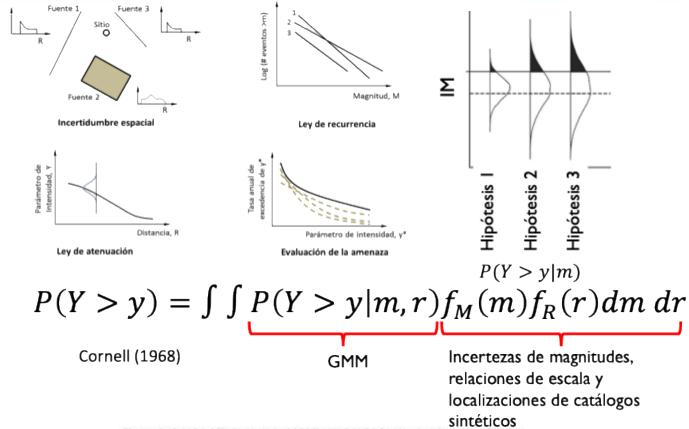


Fig 2. Simulación de inundación por tsunami

#### Amenaza sismo-tsunami





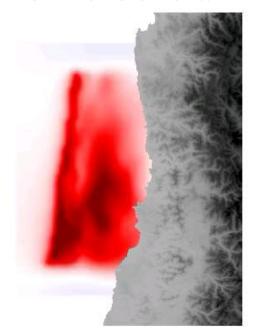
8º Jornado de la Comisión Permanente del Código Módelo Sismico para América Latino y El Caribe

#### Amenaza de tsunami



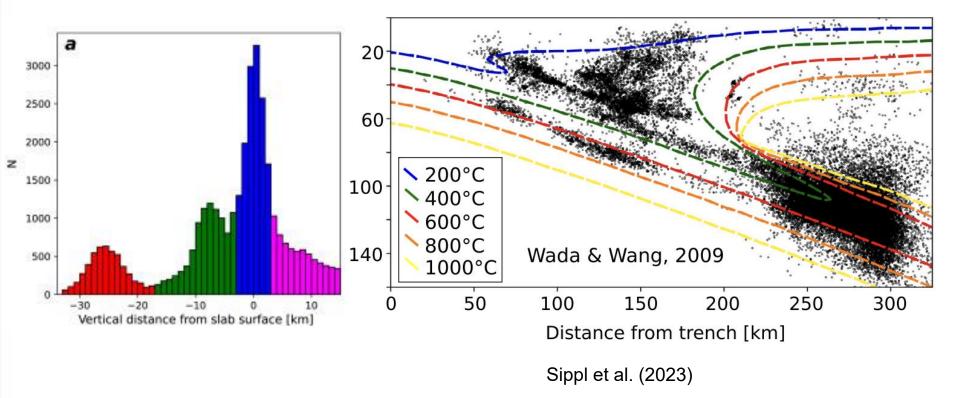


#### **Chile Central**



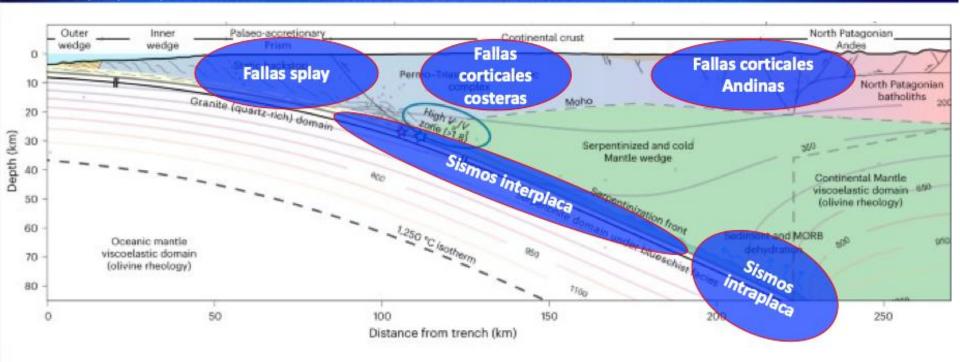
tura de ola (m)





#### Itinerario

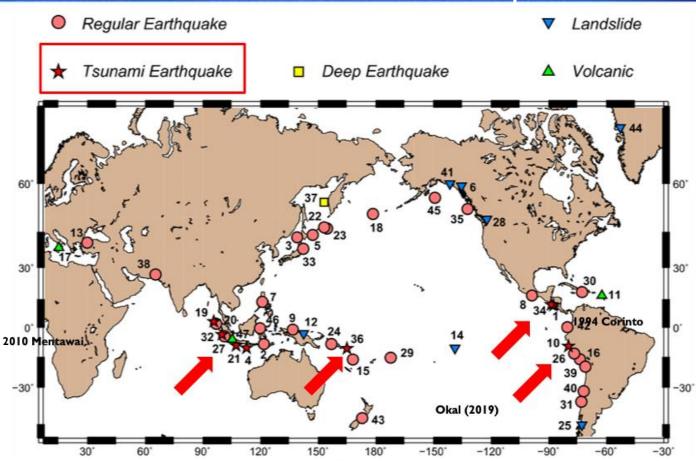




Julve et al., 2023

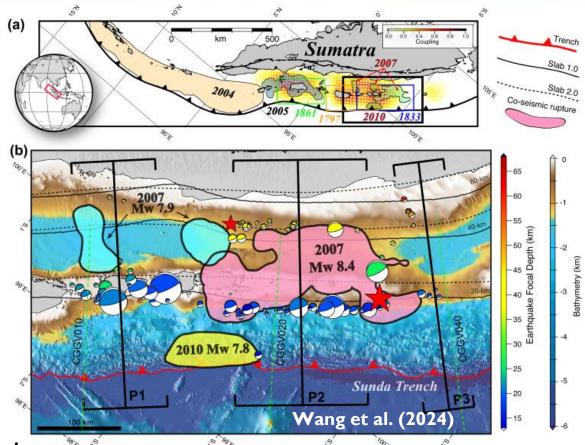


#### Terremotos tsunami o "Tsunami earthquakes"



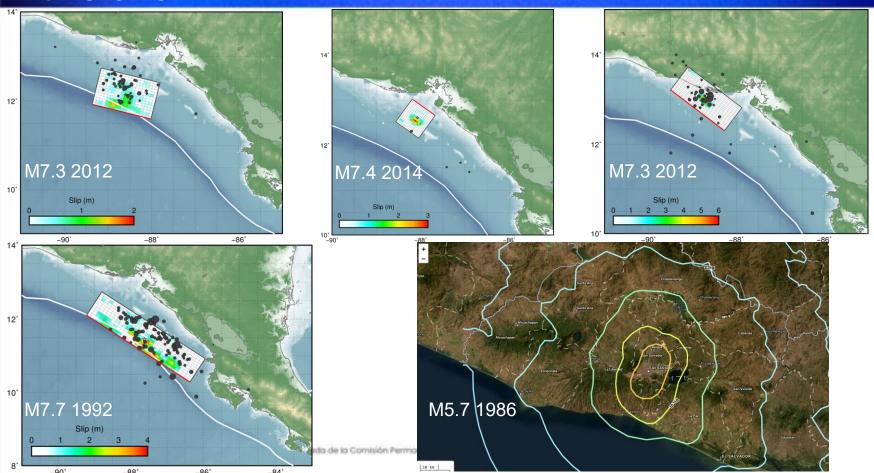






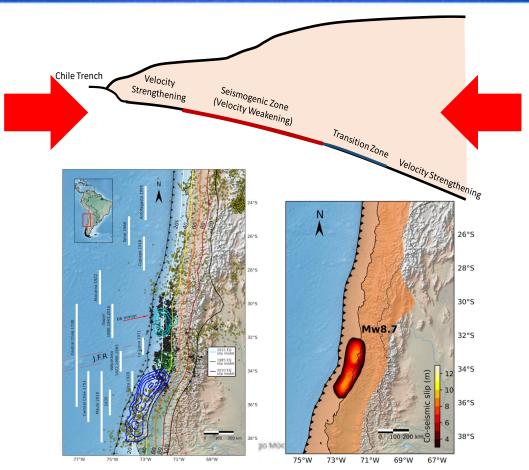
# Itinerario





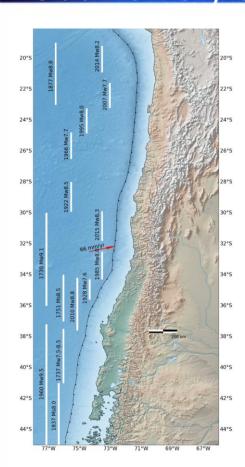
## Acoplamiento sísmico

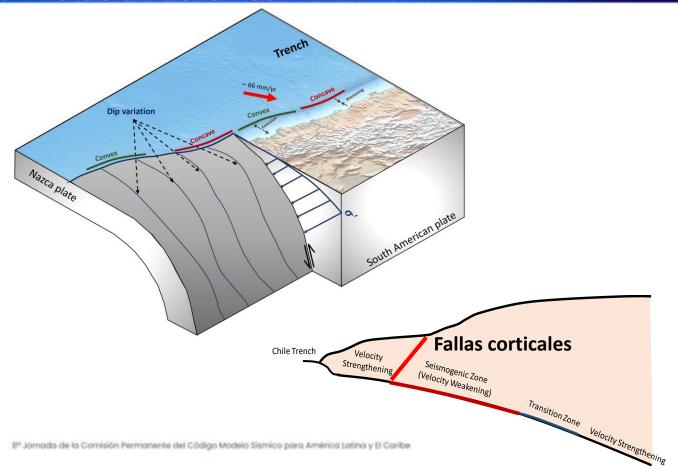




## Geometría y sismicidad histórica

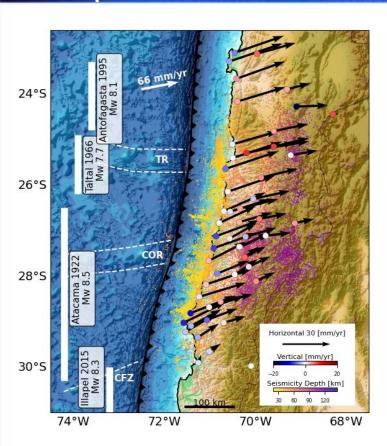


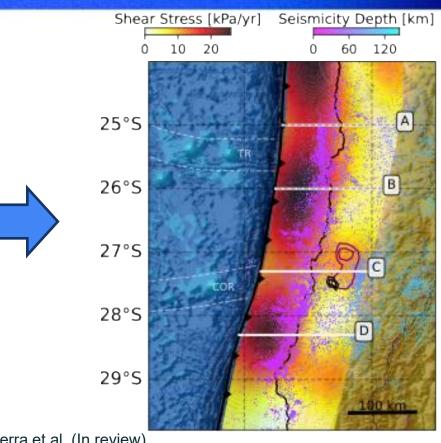




## Acoplamiento sísmico



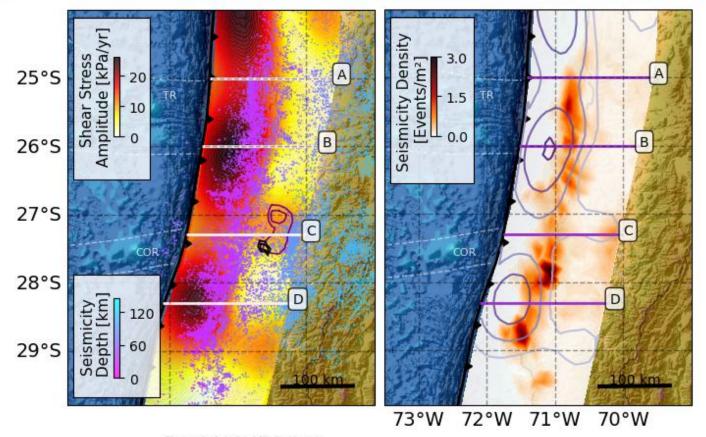




Becerra et al. (In review)

#### Acoplamiento sísmico

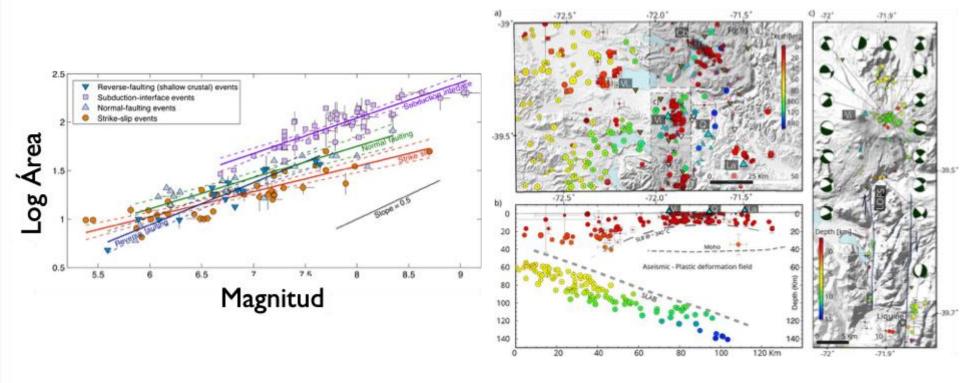




8º Jórnado de la Comisión Permanente del Codigo Modelo Sismico para America Latina y El Caribe

#### Leyes de escala de terremotos



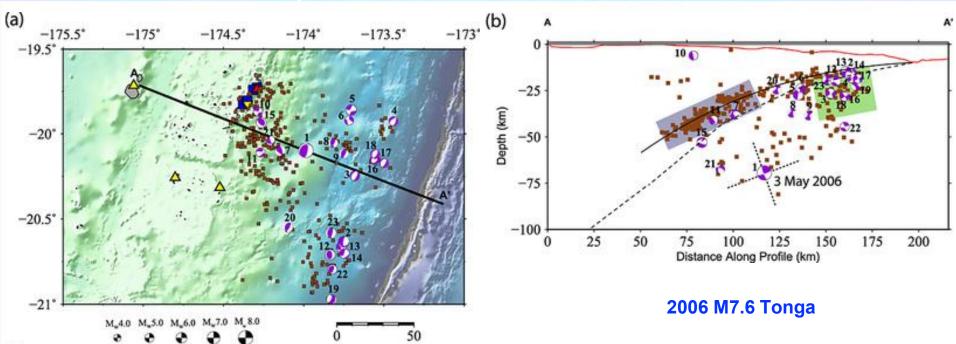


Thingbaijam et al., 2017

Siefeld et al., 2019

## Terremotos intraplaca

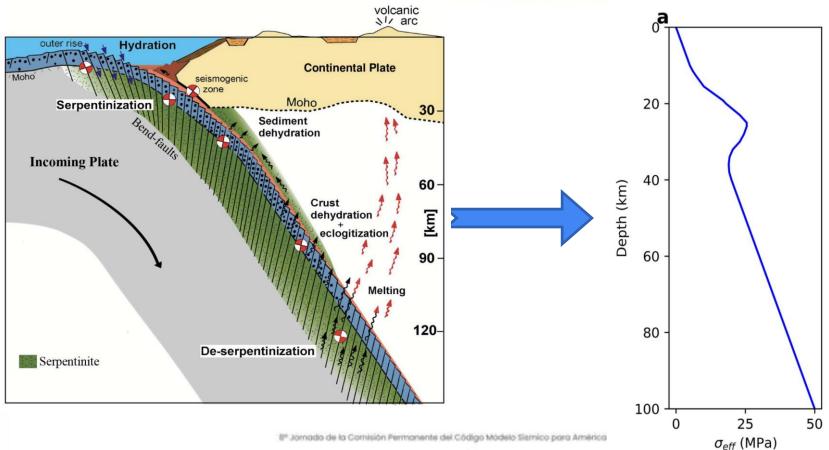




Meng et al. (2015)

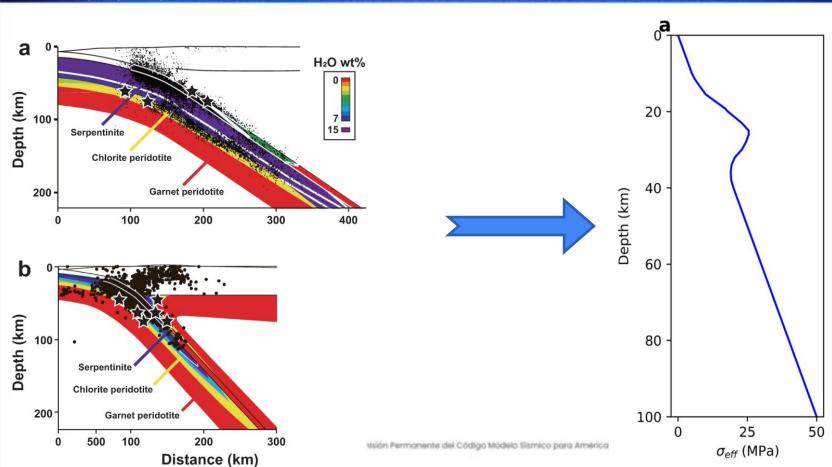
#### <u>Itinerario</u>





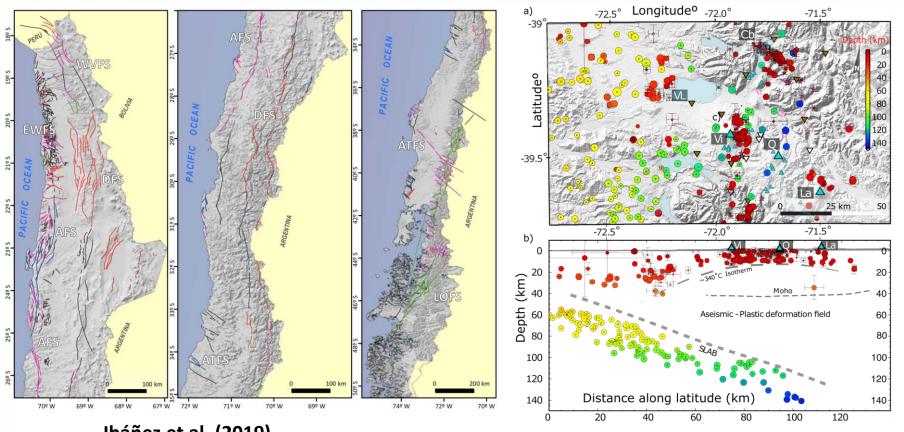
## Itinerario





## Fallas corticales

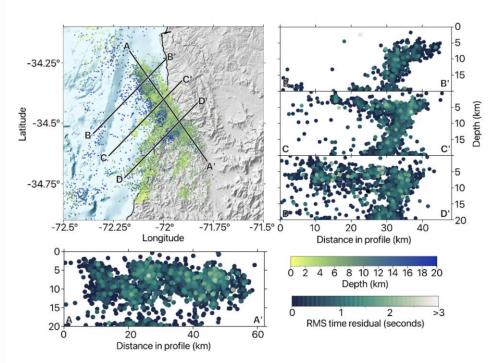




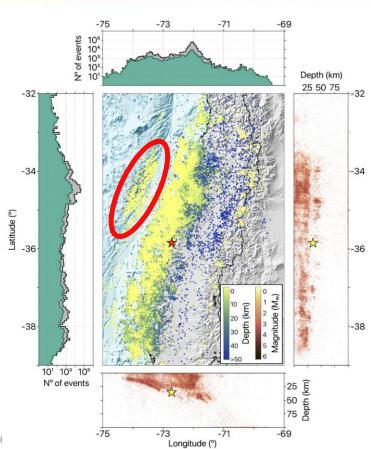
Ibáñez et al. (2019) Tr Jornado de la Comisión Permanente del Código Modelo Siemico para América Latina y El Caribe Siefeld et al. (2019)

#### Fallas corticales

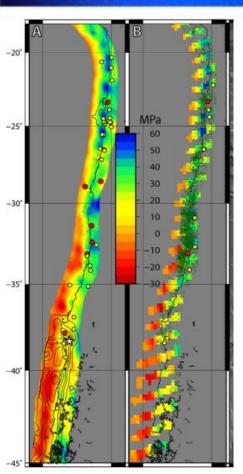


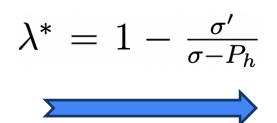


Flores-Allende et al. (2025)

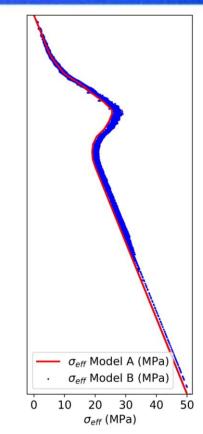


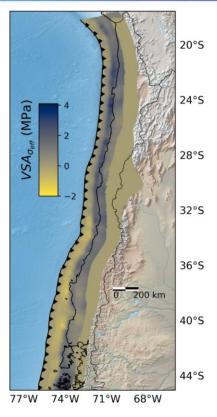






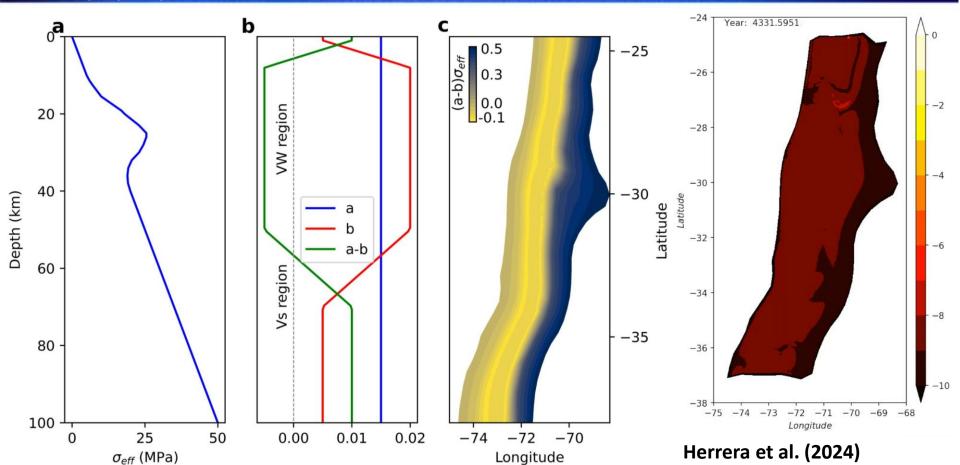
 $P_f$ : Presión de poros  $P_H$ : Presión hidroestática  $P_l$ : Presión Litoestática





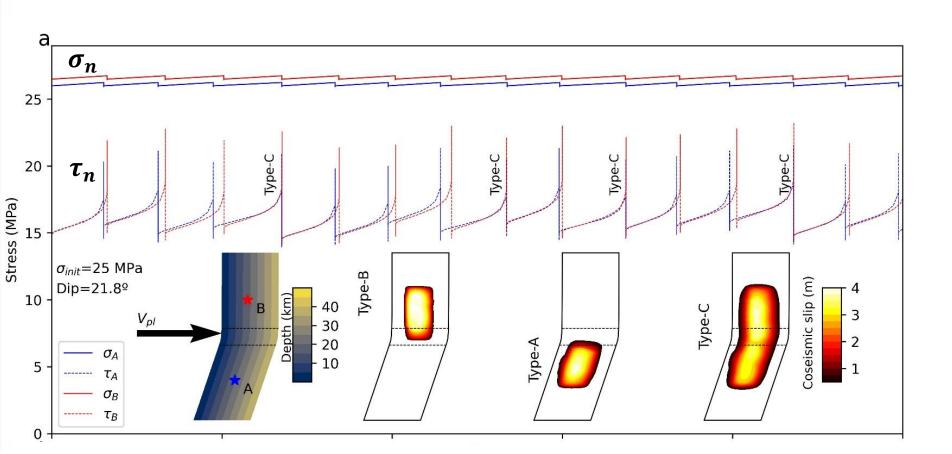
#### <u>Itinerario</u>





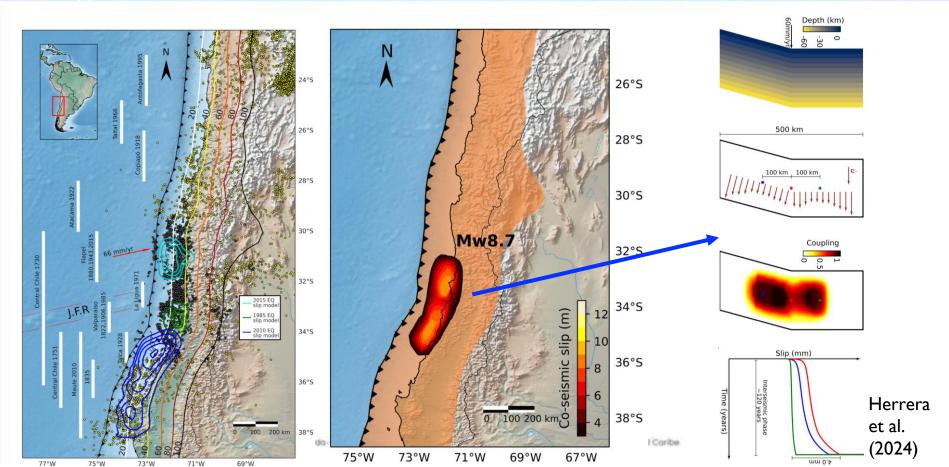
#### Ciclo sísmico sintético: "Toy model"





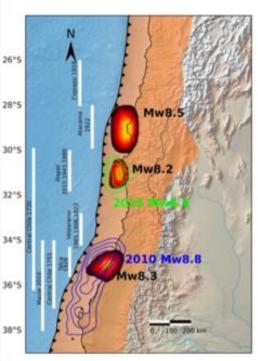
#### Segmentación sísmica

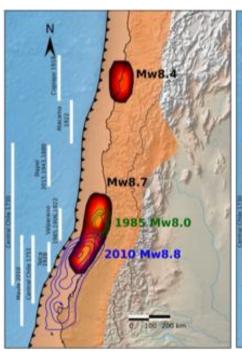


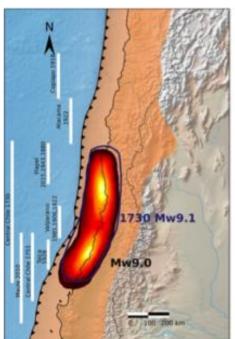


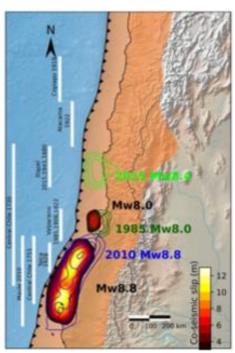
## Rupturas sintéticas







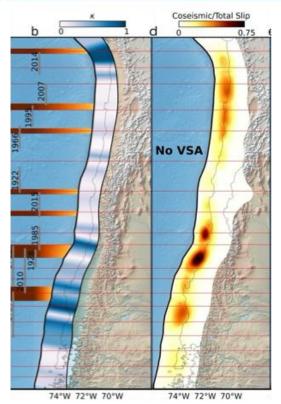




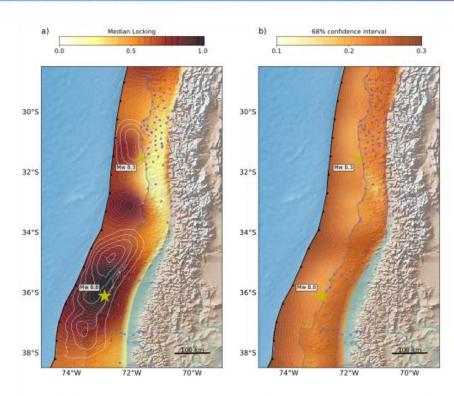
Herrera et al. (2024)

#### Acoplamiento + Ciclo sísmico sintético





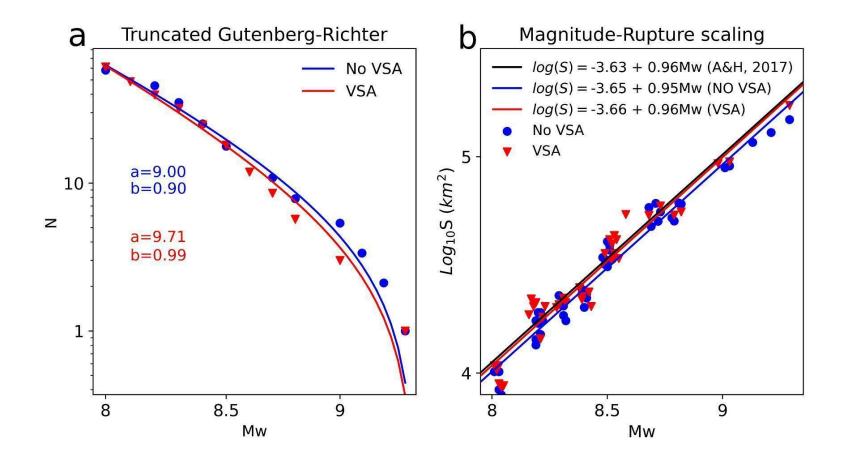
**Numerically inferred coupling** 



GPS inferred coupling, (Bercerra et al., 2022)

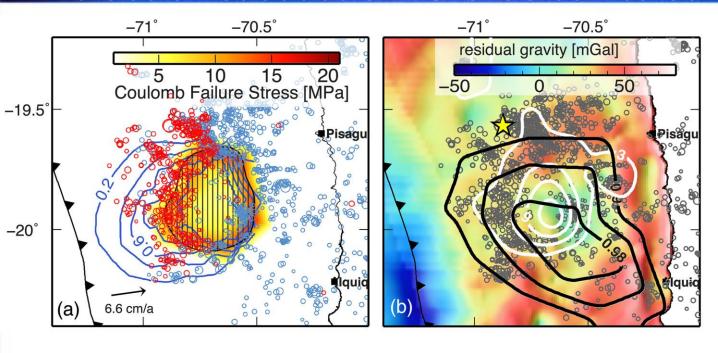


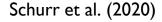


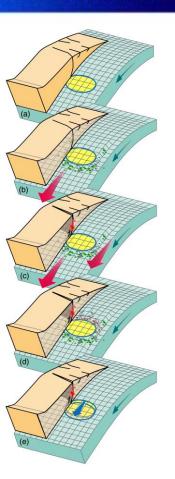




## Interacción subducción vs fallas corticales

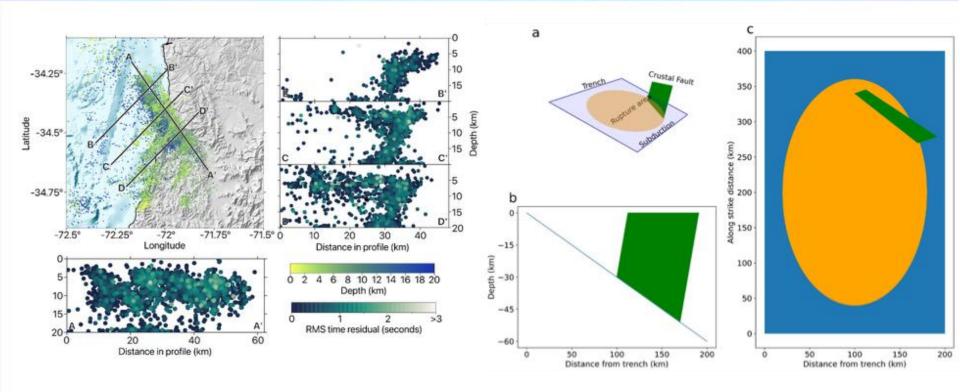






#### <u>Itinerario</u>



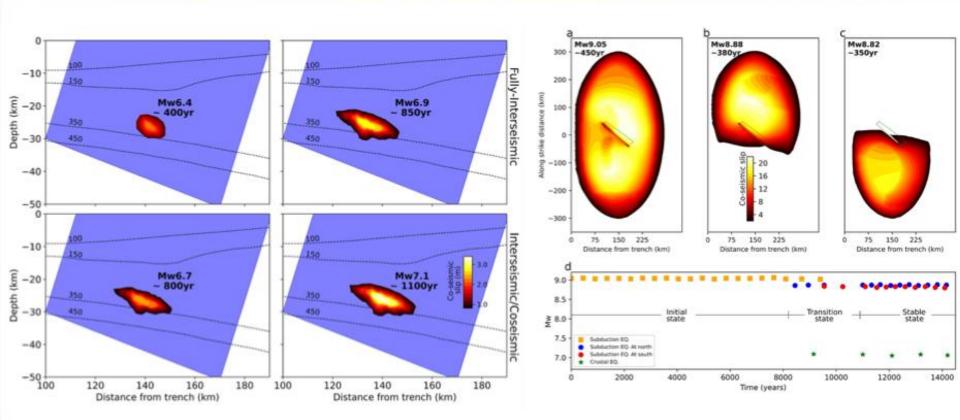


Flores-Allende et al. (2025)

Herrera et al. (in preparation)

#### **Itinerario**





## Modelos propagación de ondas de tsunami

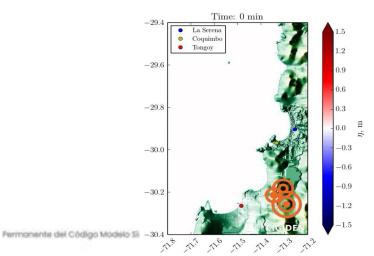




Videos de Alenjandro Urrutia

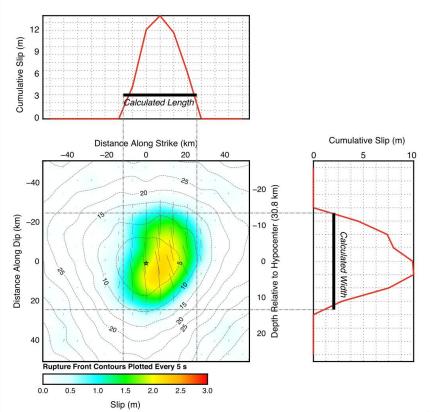
Time: 1 min





#### Leyes de escalamiento de fuente sísmica



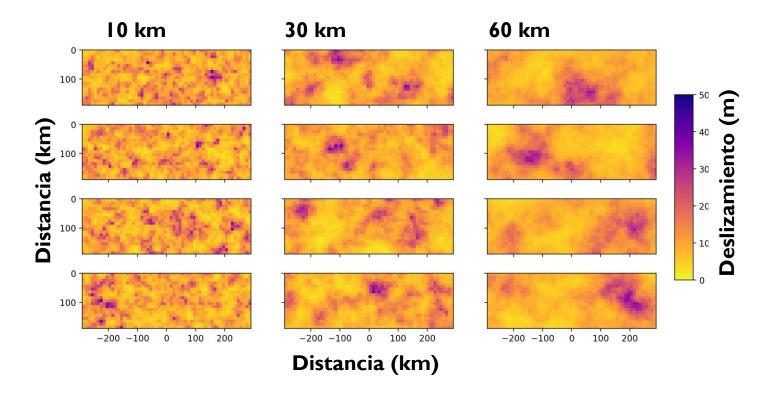




$$\log L = -2.90 + 0.63 \cdot M_{\rm w}$$
$$\log W = -0.86 + 0.35 \cdot M_{\rm w}$$

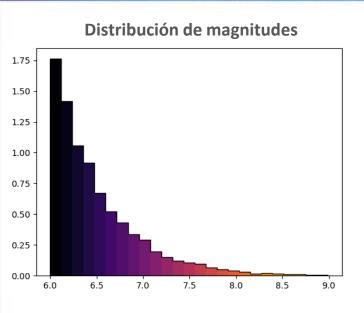
# Itinerario





## Cálculo de amenaza sismo-tsunami conjunto





**Ubicación espacial** 

**Deslizamiento** 

Alzamiento/subsidencia

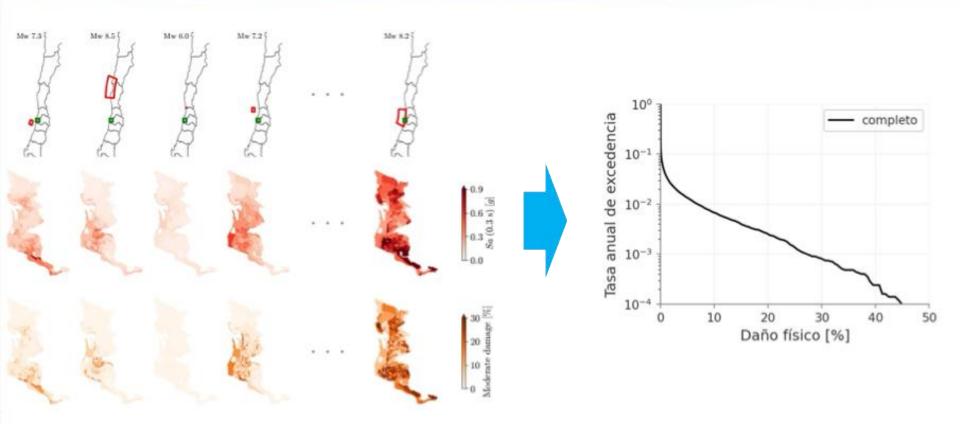
Poulos et al. (2019)

8º Jornado de la Comisión Permonente del Código Modelo Sismico

Crempien et al. (2020) Hayes et al. (2018) Okada (1985)

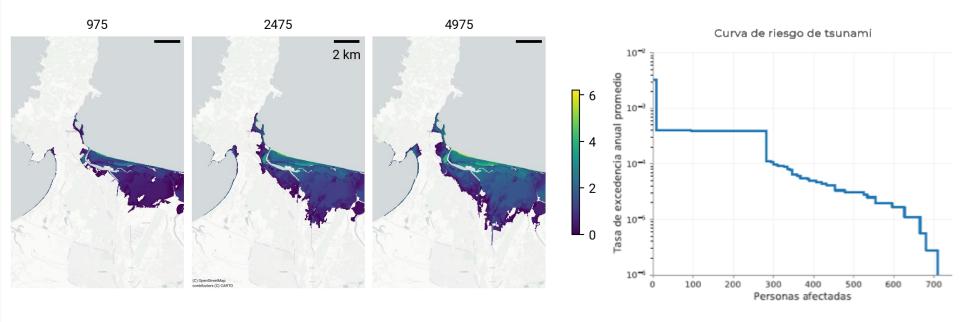
# Cálculo de amenaza sismo-tsunami conjunto



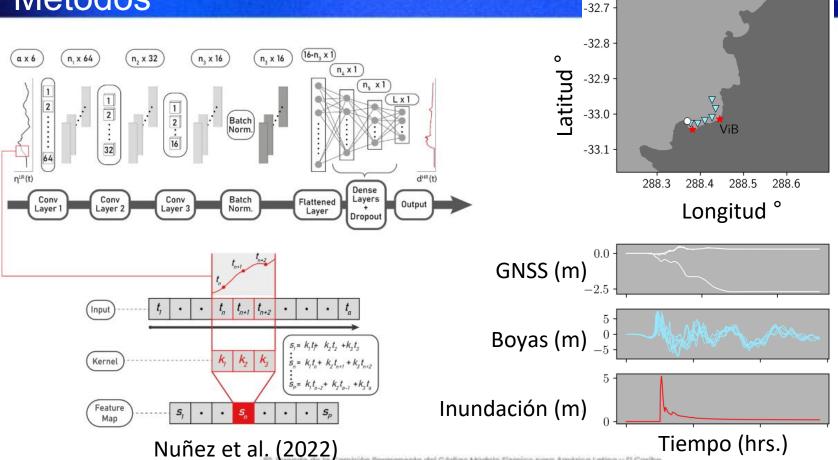








#### Métodos

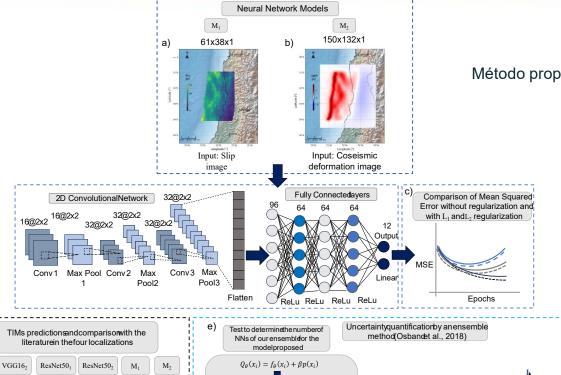


## Métodos

d)

VGG16<sub>1</sub>





 $Q_{\theta}(x_i) = Model(x_i) + \beta Model_{No trainable}(x_i)$ 

 $P(\theta|D) = \frac{1}{K} \sum_{k=1}^{K} Q_{\theta}^{k}$ Varying K by 10, 20, 30, 50, 100
and 200 NNs

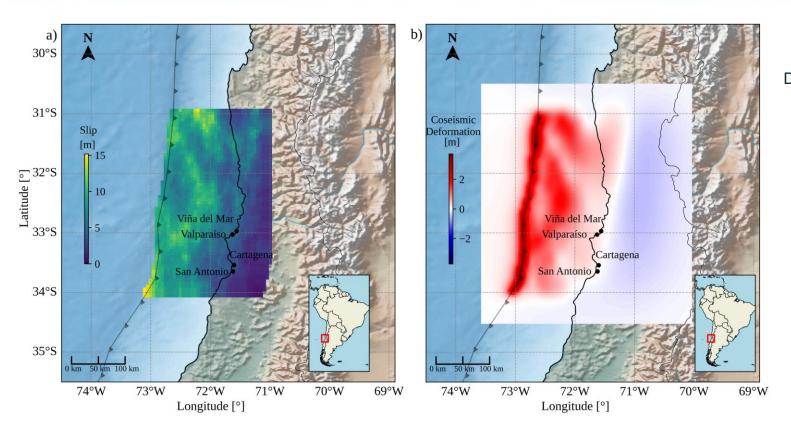
Comparisonof MSE

and SDfor an increasingnumberof NNs

Método propuesto, Buenrostro et al. (In review)

#### Datos de entrenamiento

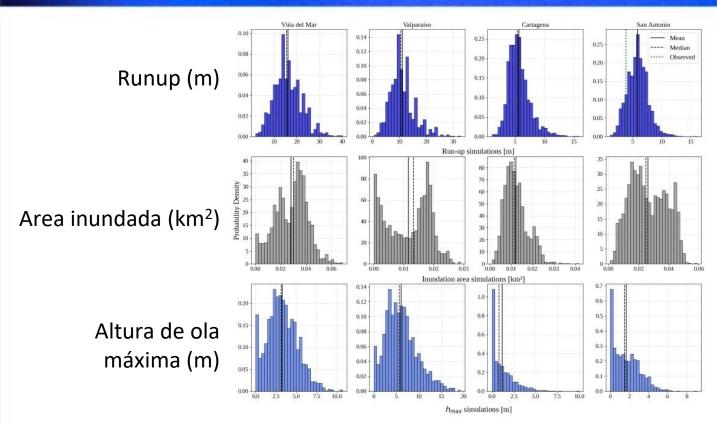




Datos de entrada: 1800 imágenes

#### Datos de entrenamiento

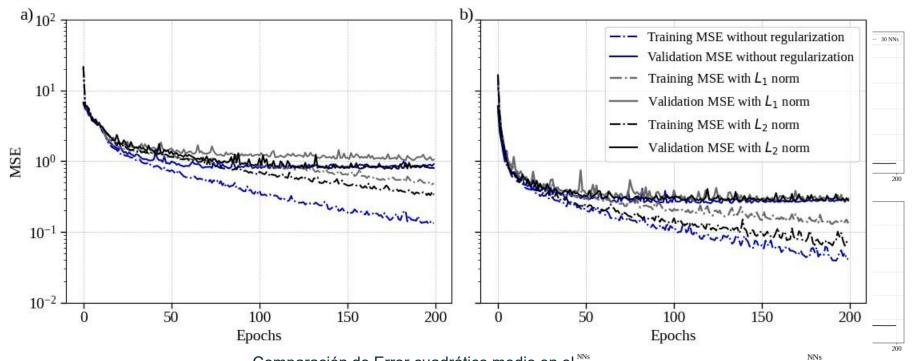




Datos de salida: 1800 simulaciones por cada locación por cada medida de intensidad

## Cuantificación de incertidumbre

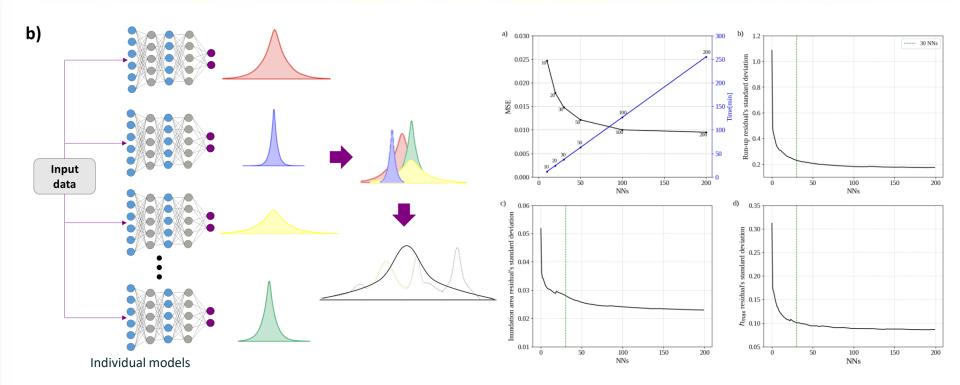




Comparación de Error cuadrático medio en el <sup>NNs</sup> entrenamiento de las redes neuronales propuestas para: a) modelo 1, b) modelo 2

# Cuantificación de incertidumbre

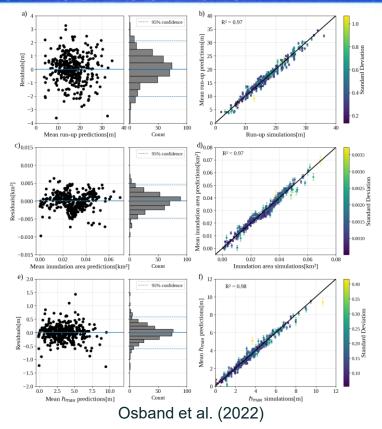




Osband et al. (2022)

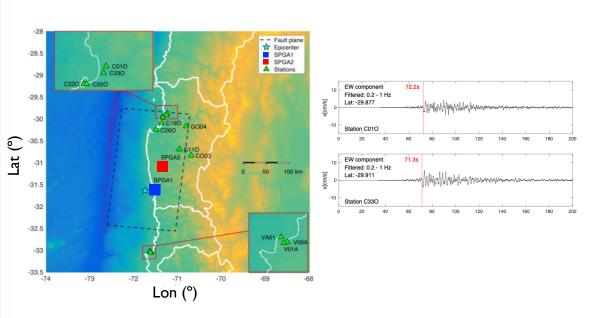


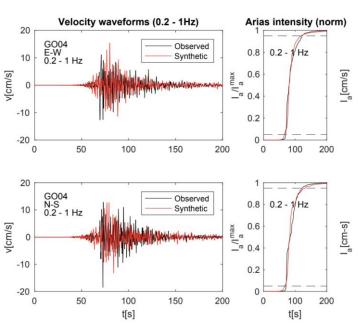




## Escenarios sísmicos



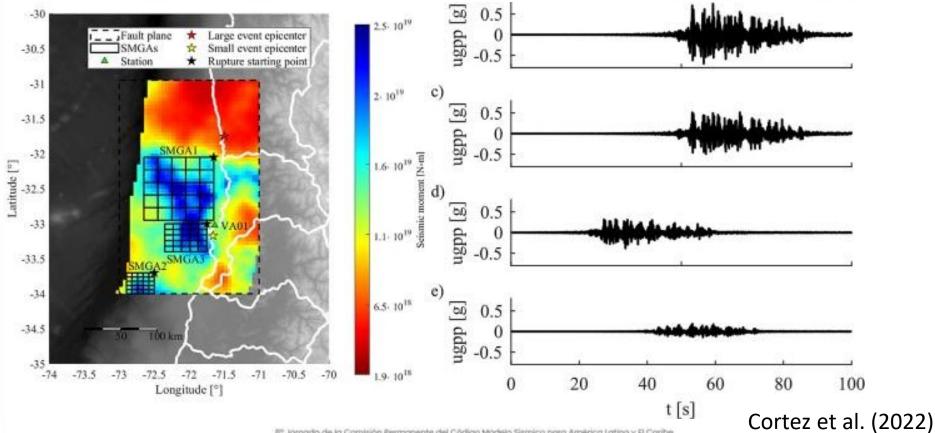




Fernández et al. (2022)

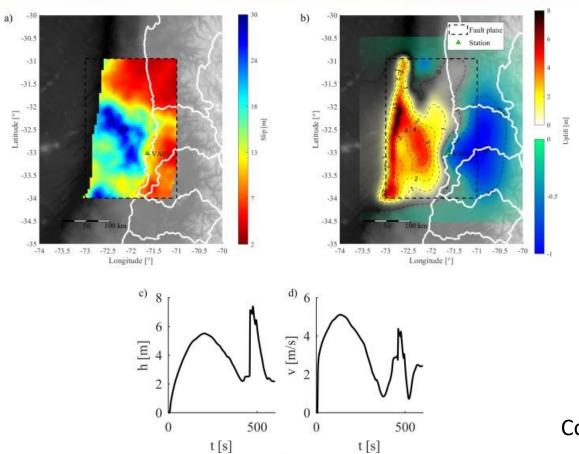
## Escenarios sísmicos





# Escenarios sismo-tsunami





Cortez et al. (2022)



