XXXVIII Simposio Nacional de Prevención de Desastres

Ciencia e Ingeniería para proteger vidas ante terremotos y tsunamis

Sistema automatizado para la generación en tiempo real de reportes técnicos de pronóstico ante tsunamis integrando simulaciones numéricas y plataforma web

Ing. Carlos Francisco Dávila de la Cruz

A. Quesquén, J. Salinas, J. Palacios, L. Tinco, F. Garcia, J. Cueva, L. Marquez y M. Estrada

Lima, 26 de mayo de 2026

1. Introducción

al Sistema de Alerta Temprana ante Tsunamis

Sismo

INSTITUCIONES DEL SNAT*

Componente sísmico (**IGP**) → IGP – INSTITUTO GEOFÍSICO DEL PERÚ

Información del sismo:
- Latitud
- Longitud
- Magnitud

t_1 = 4 min

Componente oceanográfico (**DIHIDRONAV**) → Marina de Guerra del Perú – Dirección de Hidrografía y Navegación

Información del tsunami:
- Nivel de alerta
- Tiempo de arribo
- Altura de tsunami

t_2 = 8 min

Componente de atención al riesgo (**INDECI**) → Instituto Nacional de Defensa Civil – Perú

Toma de medidas:
- Evacuación
- COEN
- Boletín informativo

El nivel de alerta se activa para todo el litoral peruano

(1) No es factible realizar simulaciones de tsunamis en **tiempo real** que brinden: $T_{arribo} + H_{tsunami}$ (4 min)

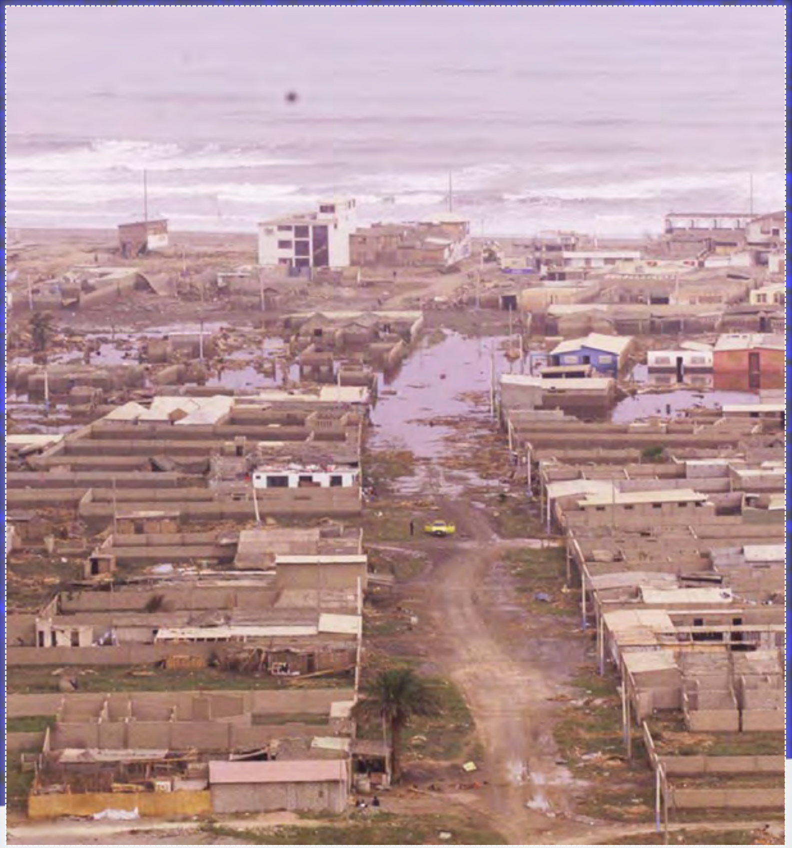
(2) Los **niveles de alerta** están en función de la magnitud (M_w), ubicación y profundidad del sismo

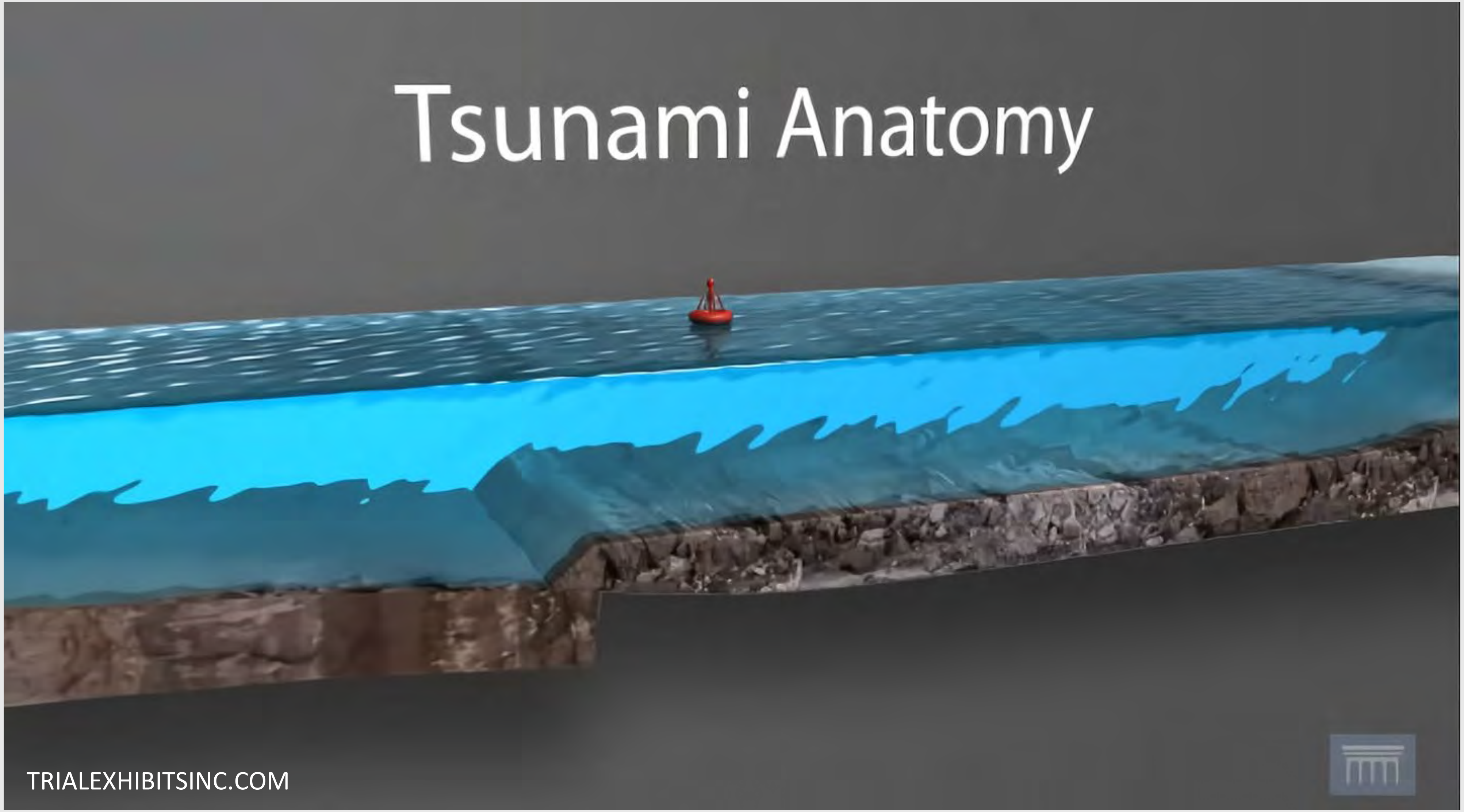
(3) No se emiten niveles de alerta **diferenciados** para cada unidad administrativa del litoral

*__Dirección de Hidrografía y Navegación (2013).__ Tsunamis en Perú (1° ed.). Marina de Guerra del Perú.

2. Amenaza

ante tsunami con el modelo TUNAMI-N2




Tsunami Anatomy
TRIALEXHIBITSINC.COM

TEORÍA DE AGUAS SOMERAS*

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \qquad (2.50)$$

} Conservación de masa

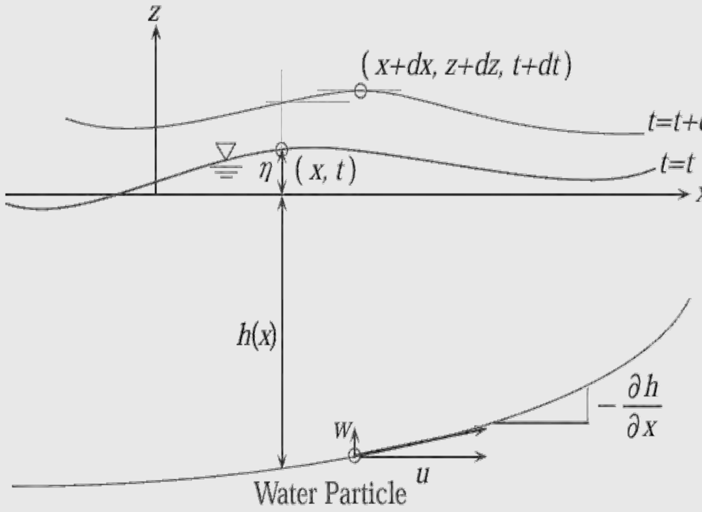
$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) = -gD\frac{\partial \eta}{\partial x} - \frac{gn^2}{D^{7/3}} M\sqrt{M^2+N^2} \qquad (2.51)$$

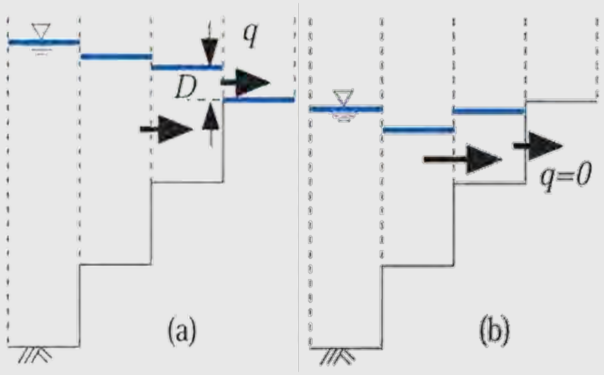
$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) = -gD\frac{\partial \eta}{\partial y} - \frac{gn^2}{D^{7/3}} N\sqrt{M^2+N^2} \qquad (2.52)$$

} Conservación de momento

Método de diferencia central

$$\eta_{i,j}^{k+1} = \eta_{i,j}^{k} + \frac{\Delta t}{\Delta x}\left(M_{i+1/2,j}^{k+1/2} - M_{i-1/2,j}^{k+1/2}\right) + \frac{\Delta t}{\Delta y}\left(N_{i,j+1/2}^{k+1/2} - N_{i,j-1/2}^{k+1/2}\right) \qquad (3.42)$$

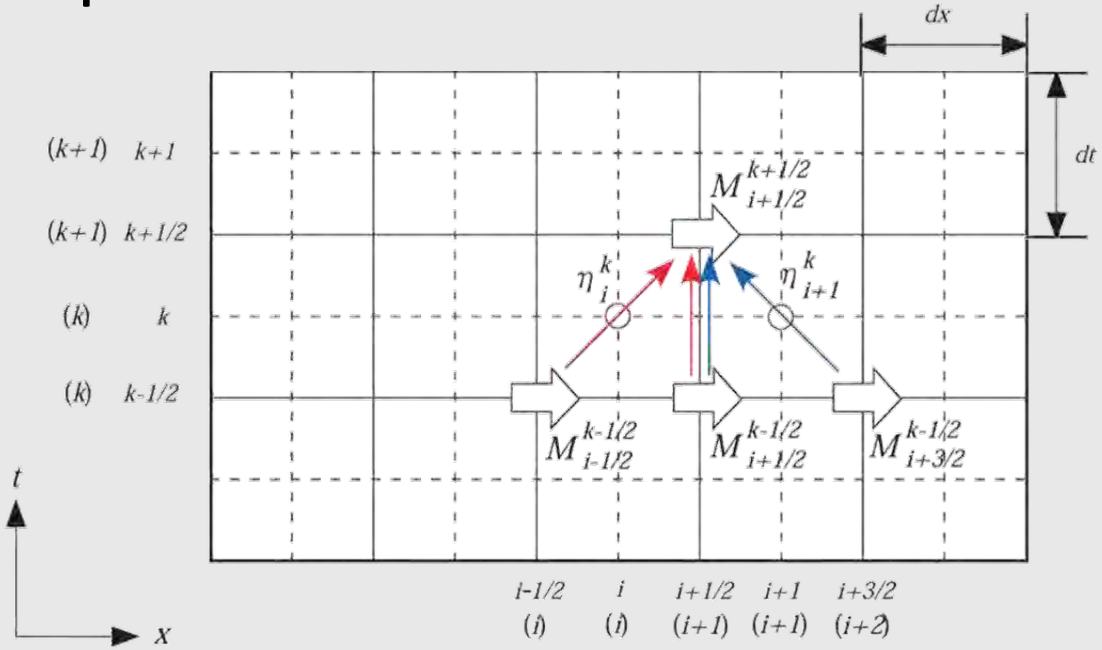




$D = h + \eta \;>\; 0$: Grilla sumergida

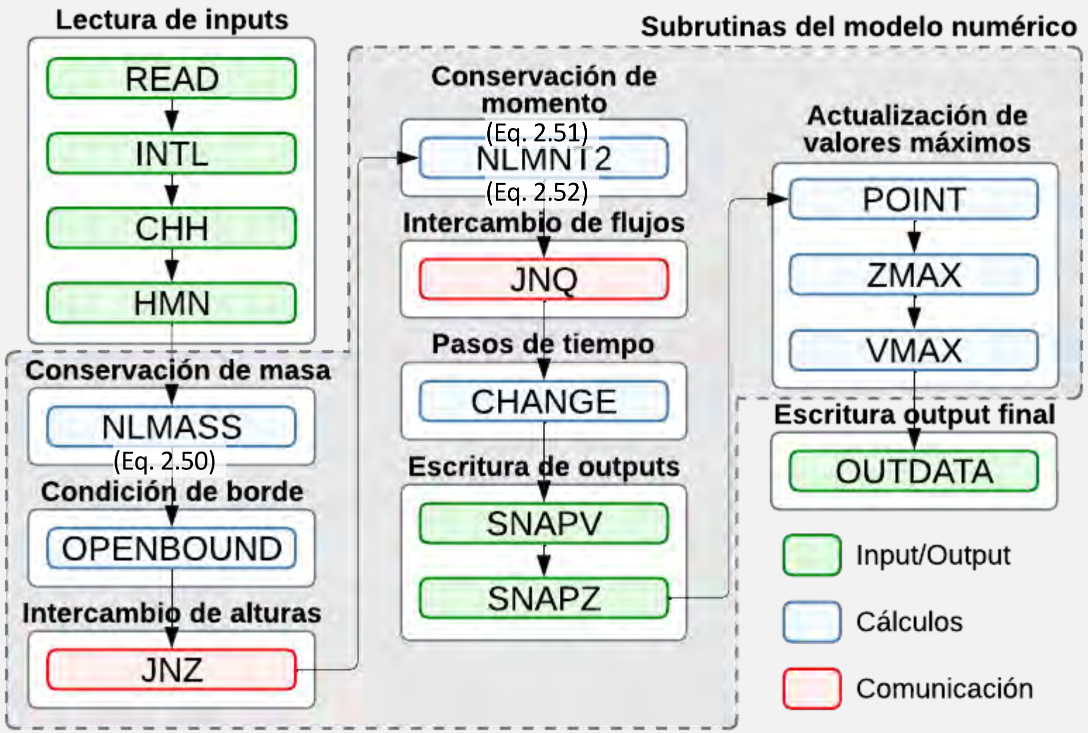
$\qquad\qquad\;\; \leq\; 0$: Grilla seca

Esquema de salto de rana escalonado

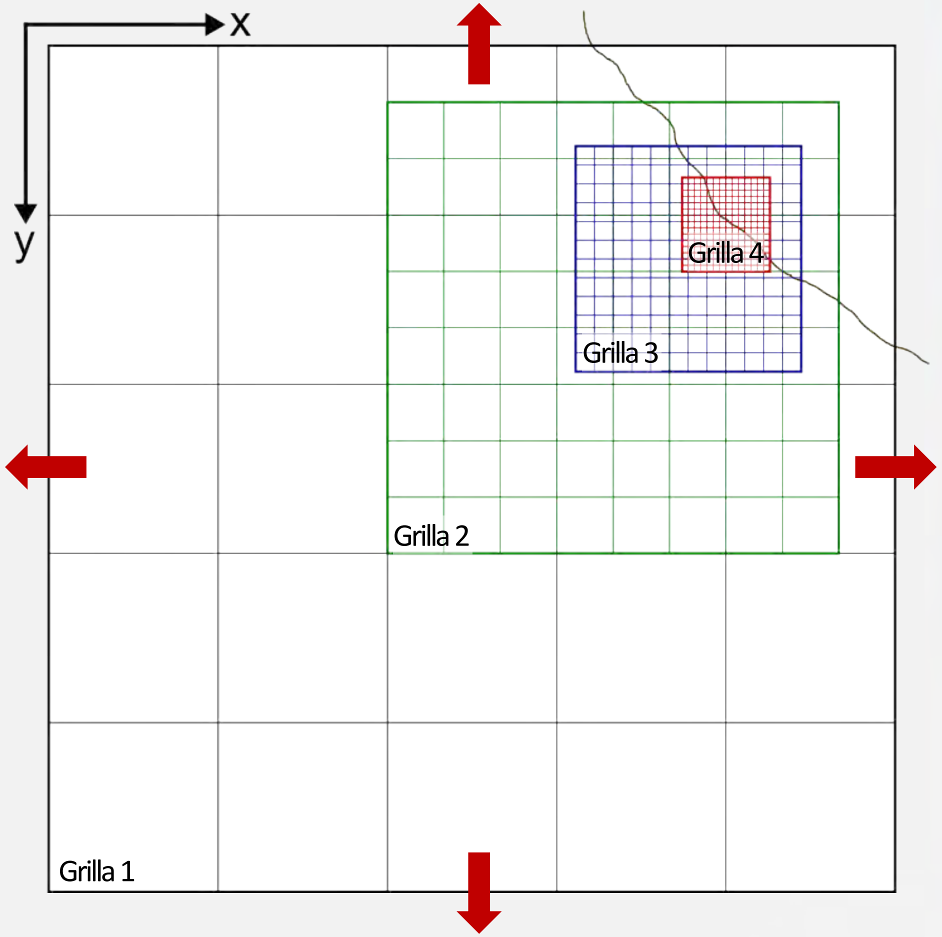


*S. Koshimura (2013). TUNAMI-CODE Tohoku Unviersity's Numerical Analysis Model for Investigation of Tsunami.

Modelo TUNAMI-N2*



Sistema de grillas anidadas



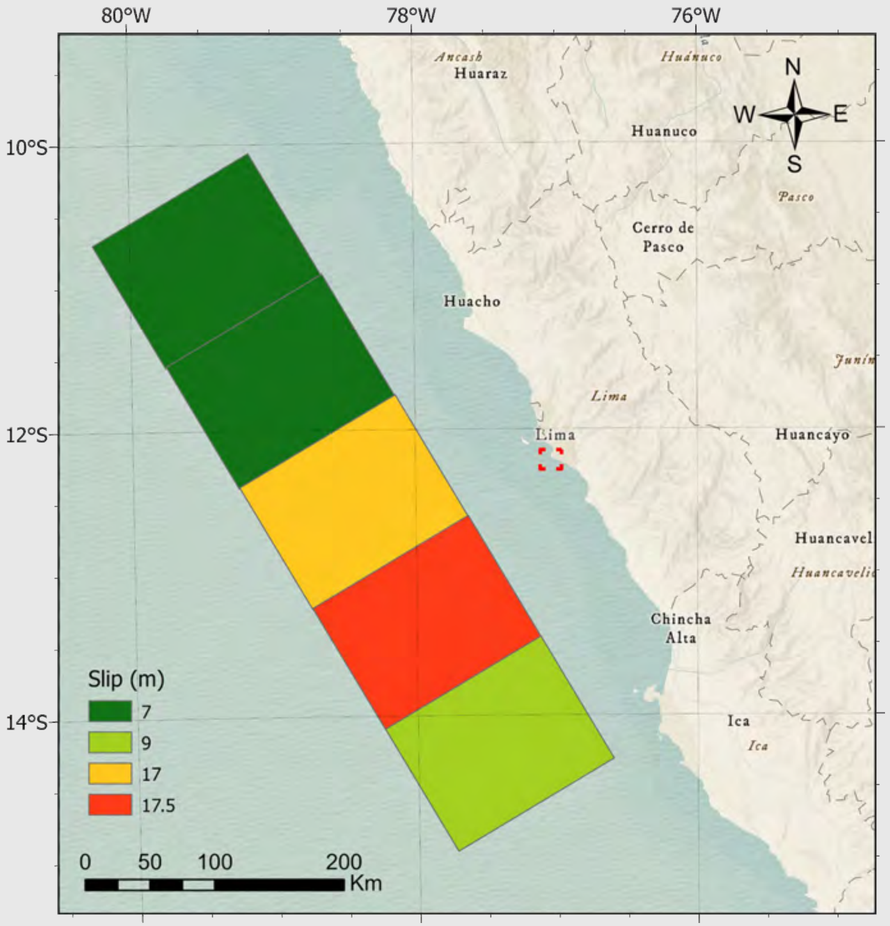
Condición de Courant-Friedrichs-Lewy (CFL)

$$\Delta t \leq \frac{\Delta x}{\sqrt{2gh_{max}}}$$

Condición de frontera abierta

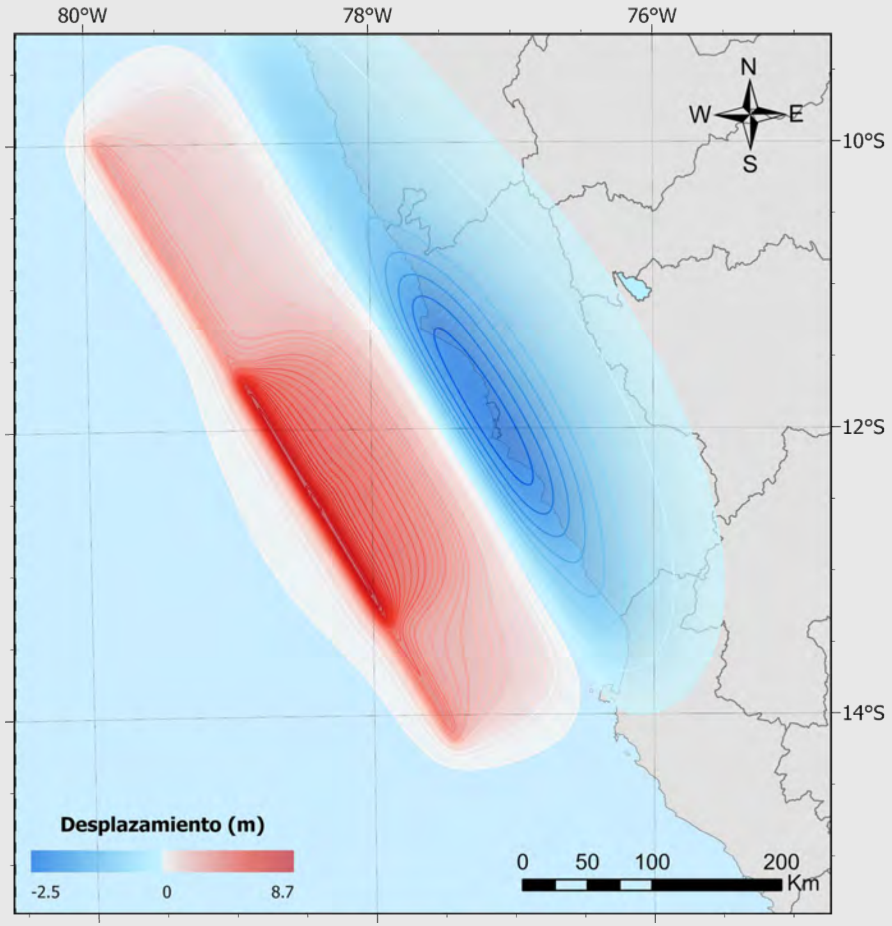
$$Fr = \pm \frac{|\vec{U}|}{\sqrt{gh}}$$

***S. Koshimura (2013).** TUNAMI-CODE Tohoku Unviersity's Numerical Analysis Model for Investigation of Tsunami.



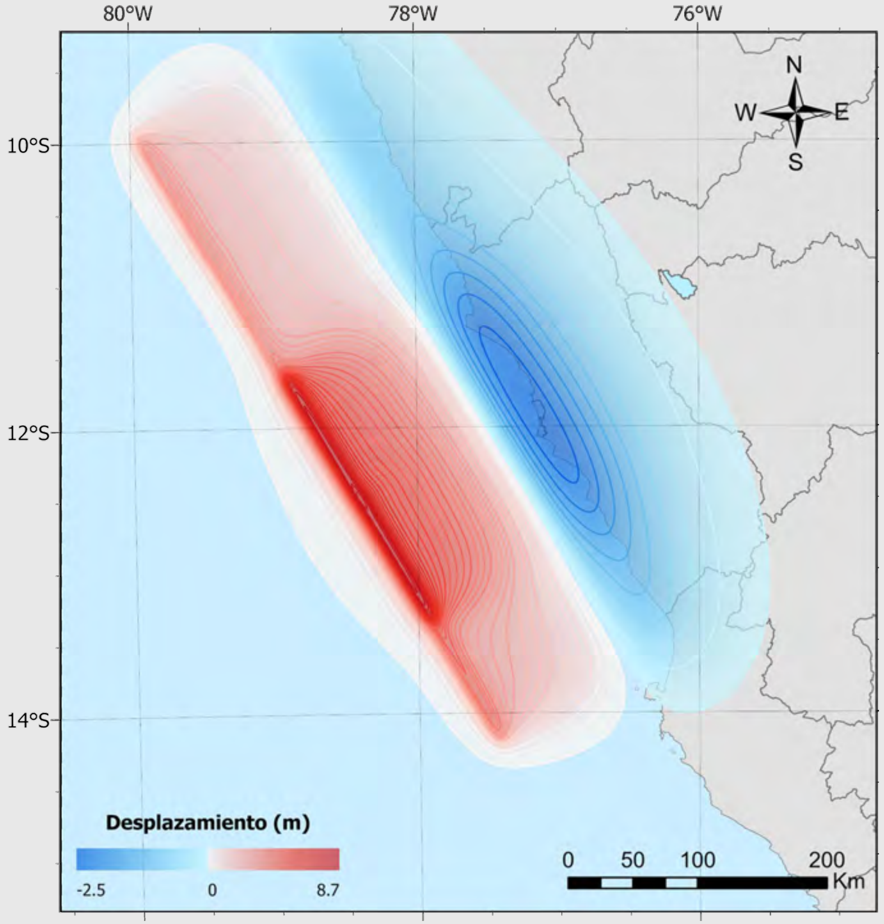
ESCENARIO SÍSMICO

Sismo histórico de 1746 (Jimenez et al., 2013).



DEFORMACIÓN INICIAL

Modelo de dislocación rectangular (Okada, 1985).



DEFORMACIÓN INICIAL

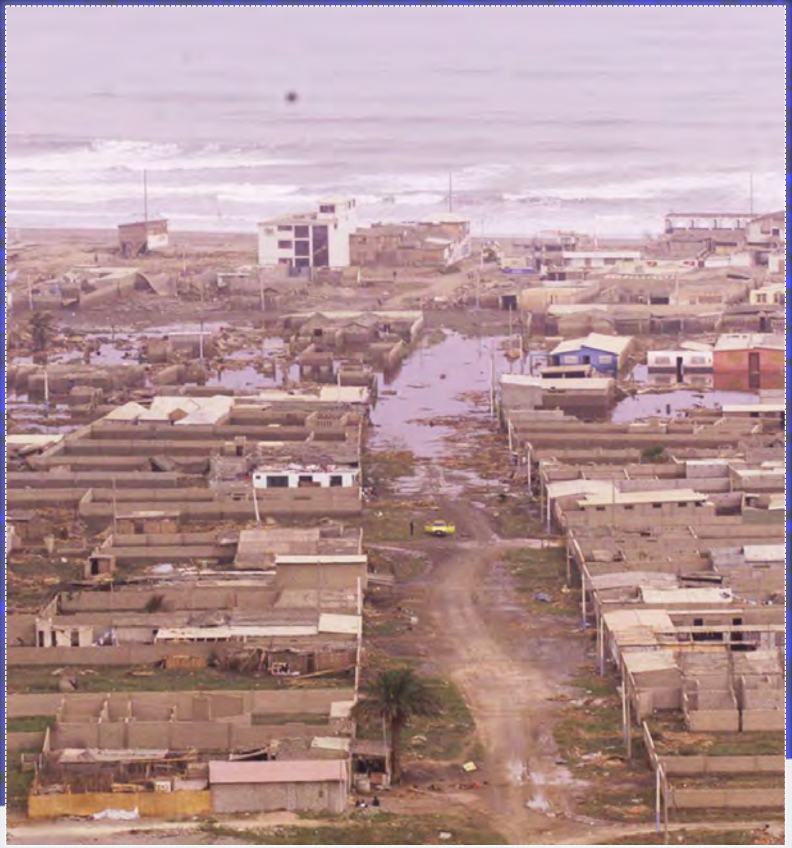
Modelo de dislocación rectangular (Okada, 1985).

SIMULACIÓN DE TSUNAMI

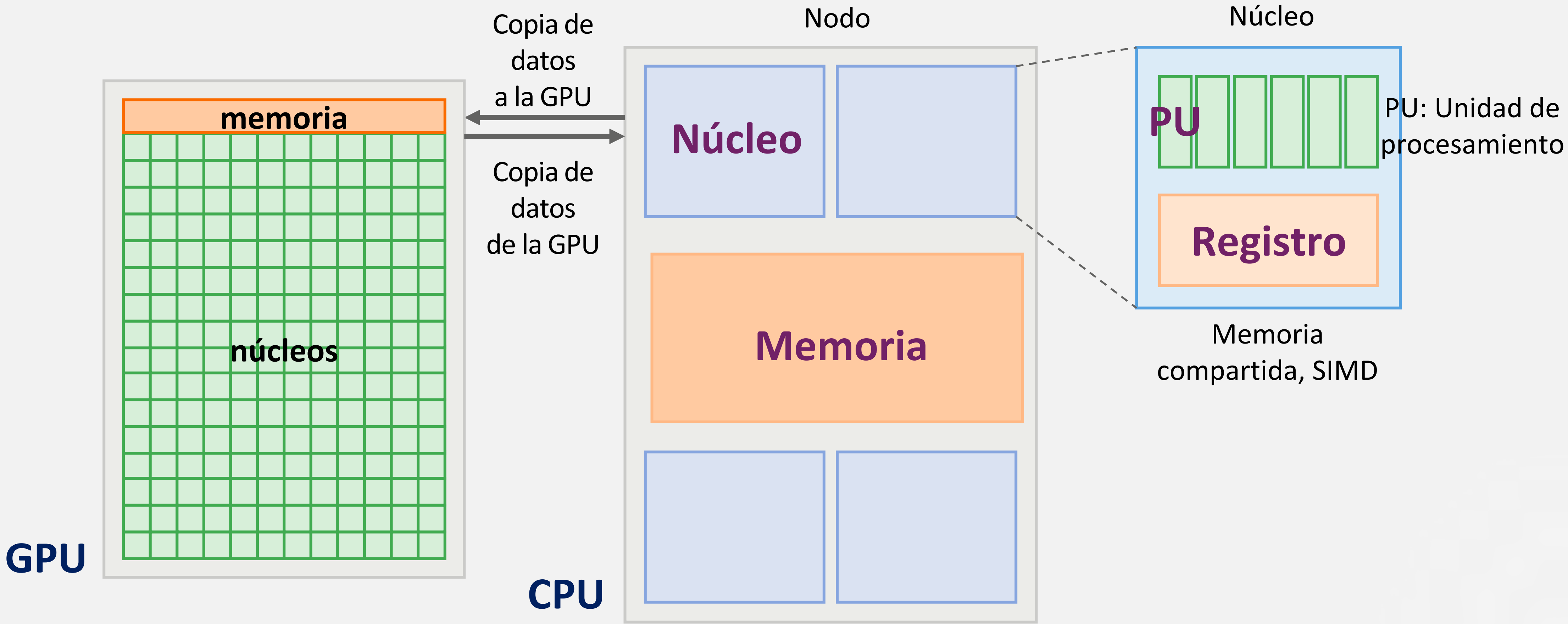
Costa Verde.

3. Computación

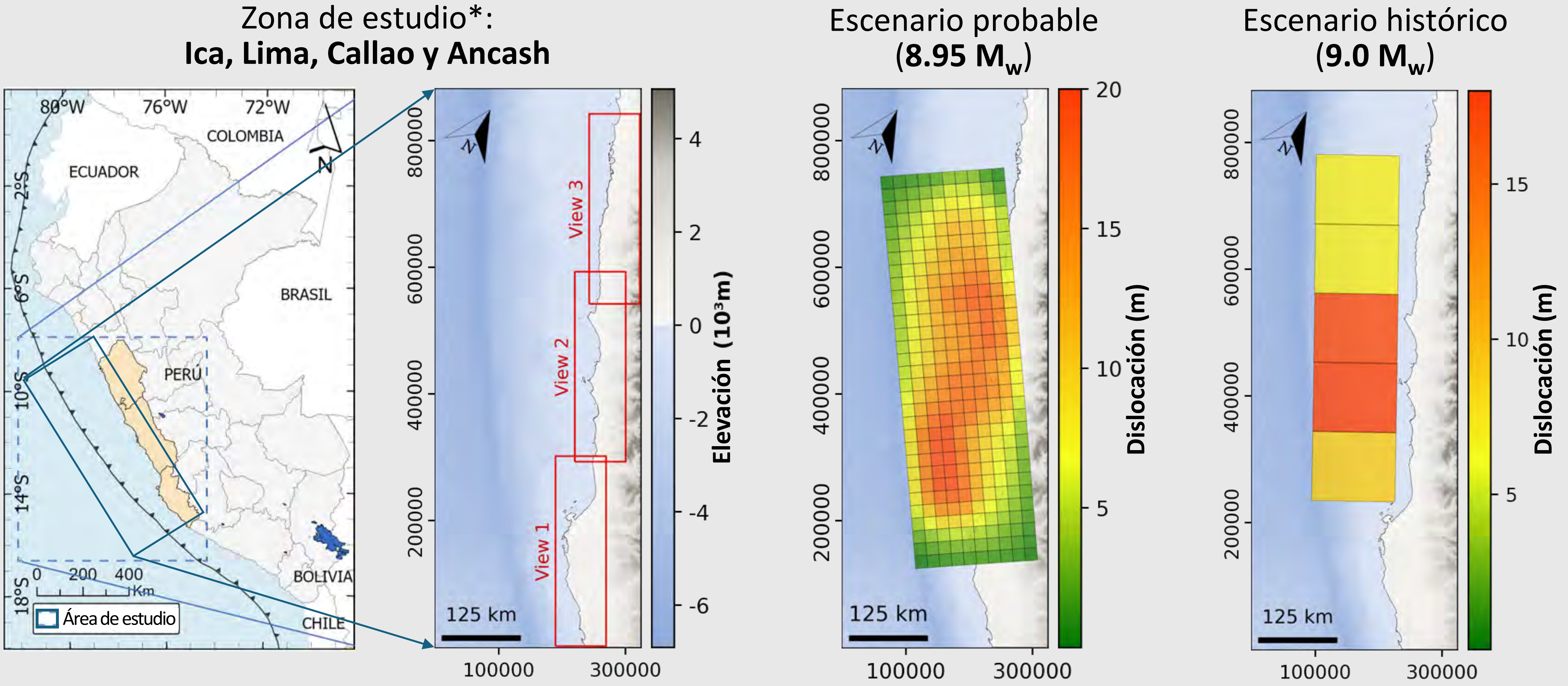
con paralelización de procesos en GPUs



COMPUTACIÓN PARALELA



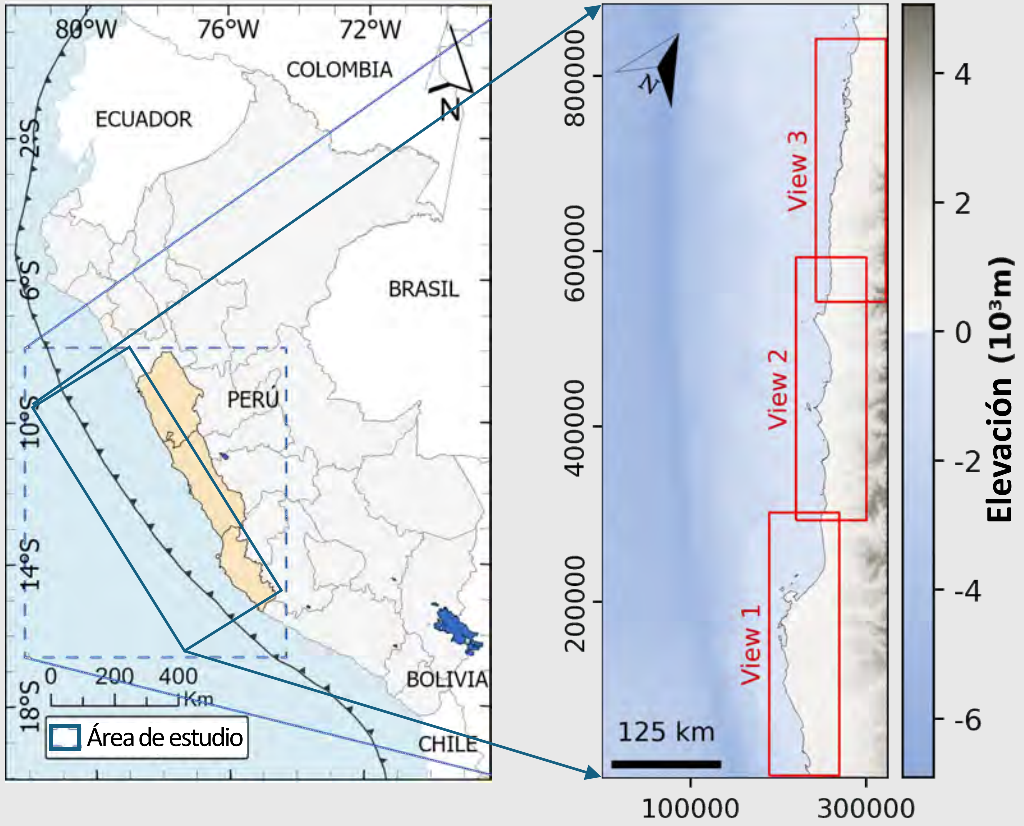
SIMULACIÓN DE TSUNAMI EN LA ZONA CENTRAL DEL PERÚ*

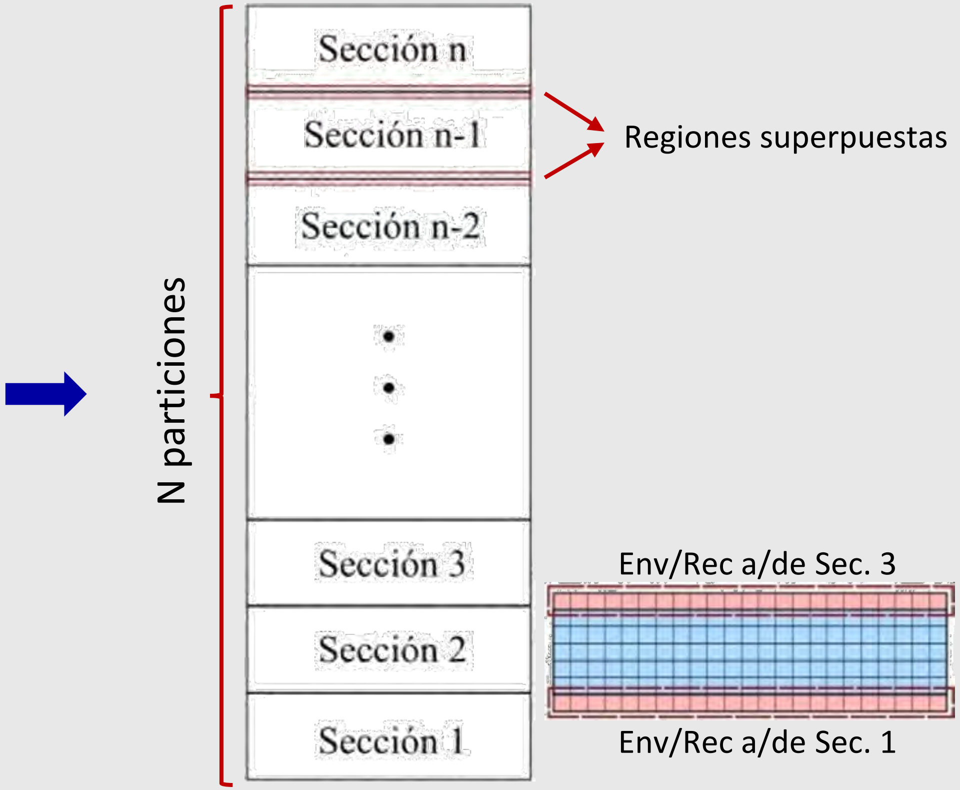


*F. García et al. (2025). Parallel Computing Approach for Rapid Estimation of Tsunami Hazard and Population Exposure in Peru. Journal of Disaster Research, 20(6), 912–921.

PARALELISMO DE MEMORIA DISTRIBUIDA (MPI)*

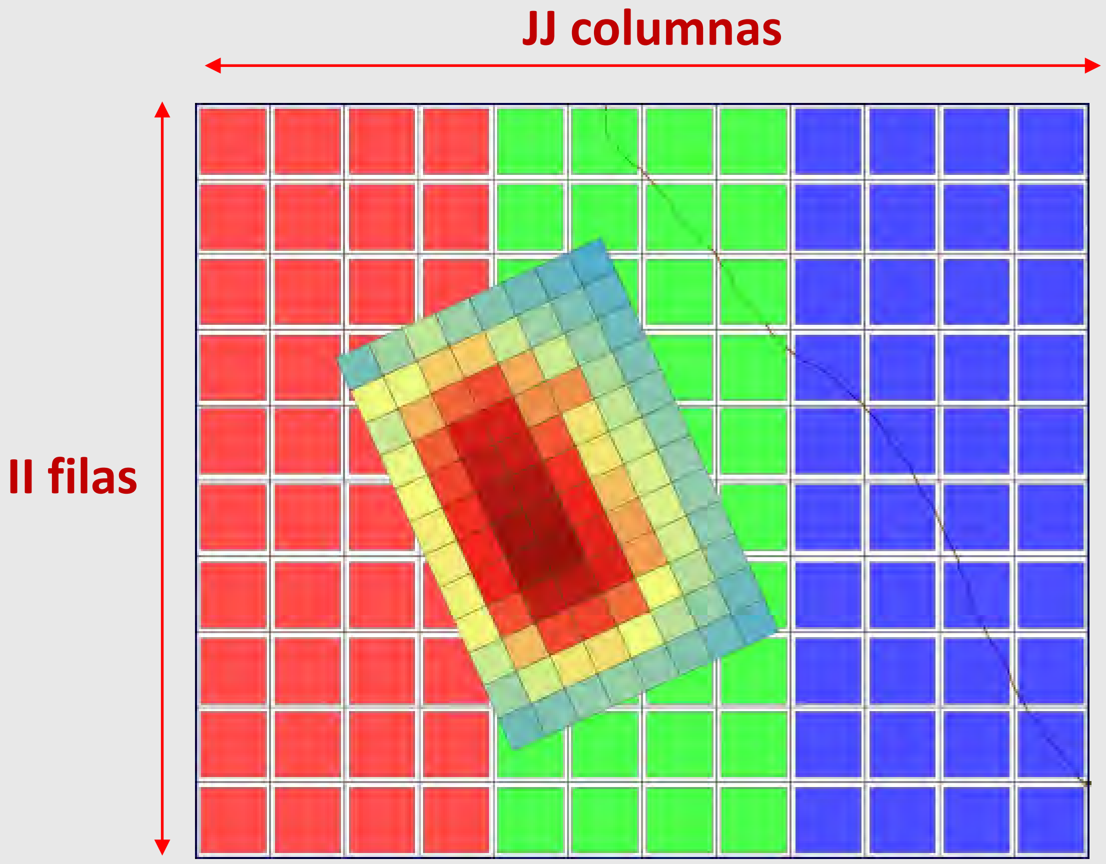
Zona de estudio:
Ica, Lima, Callao y Ancash





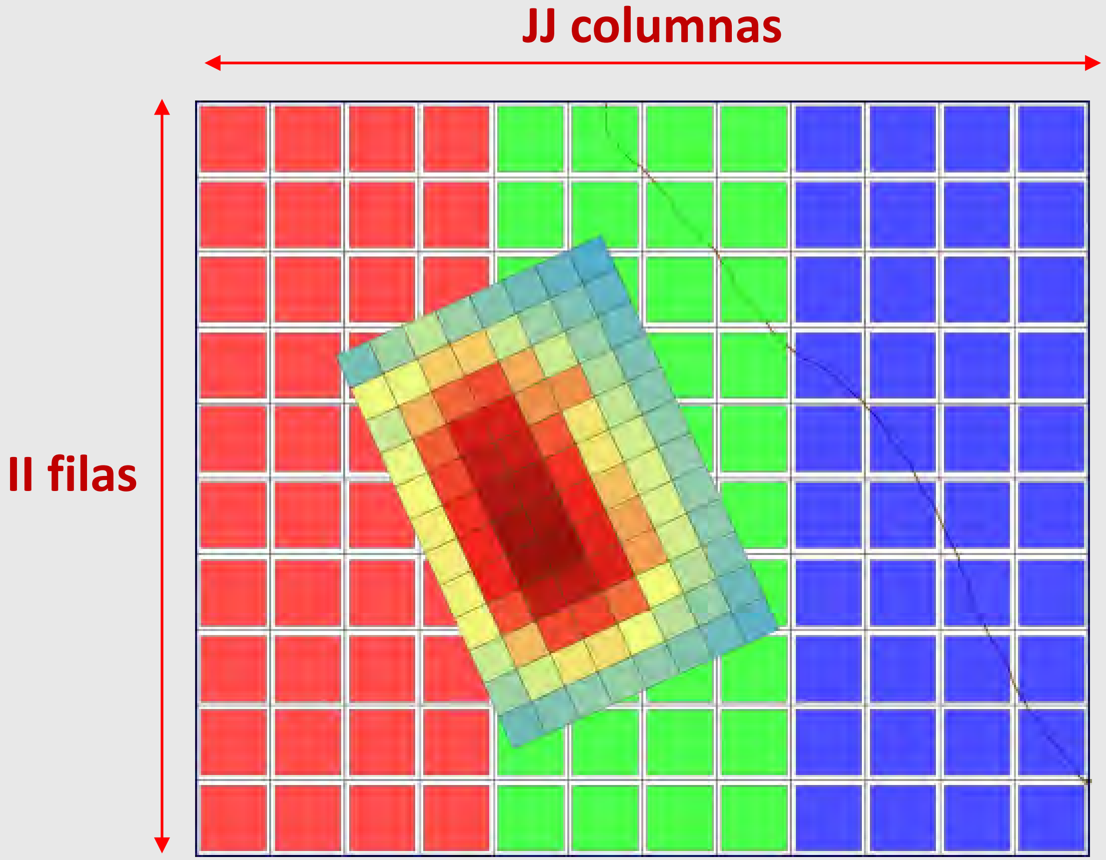
***F. García et al. (2025).** Parallel Computing Approach for Rapid Estimation of Tsunami Hazard and Population Exposure in Peru. Journal of Disaster Research, 20(6), 912–921.

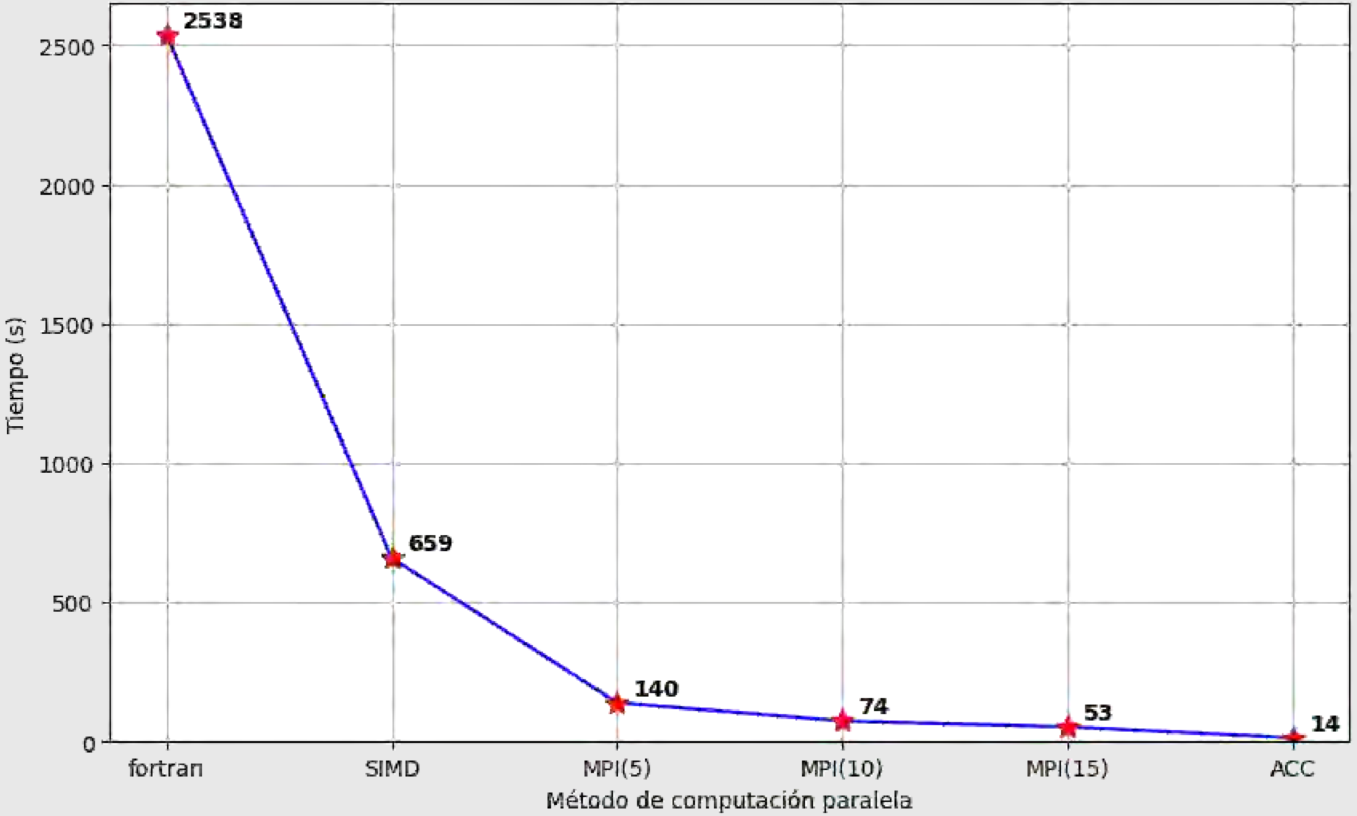
COMPUTACIÓN ACELERADA POR GPUs CON OPENACC



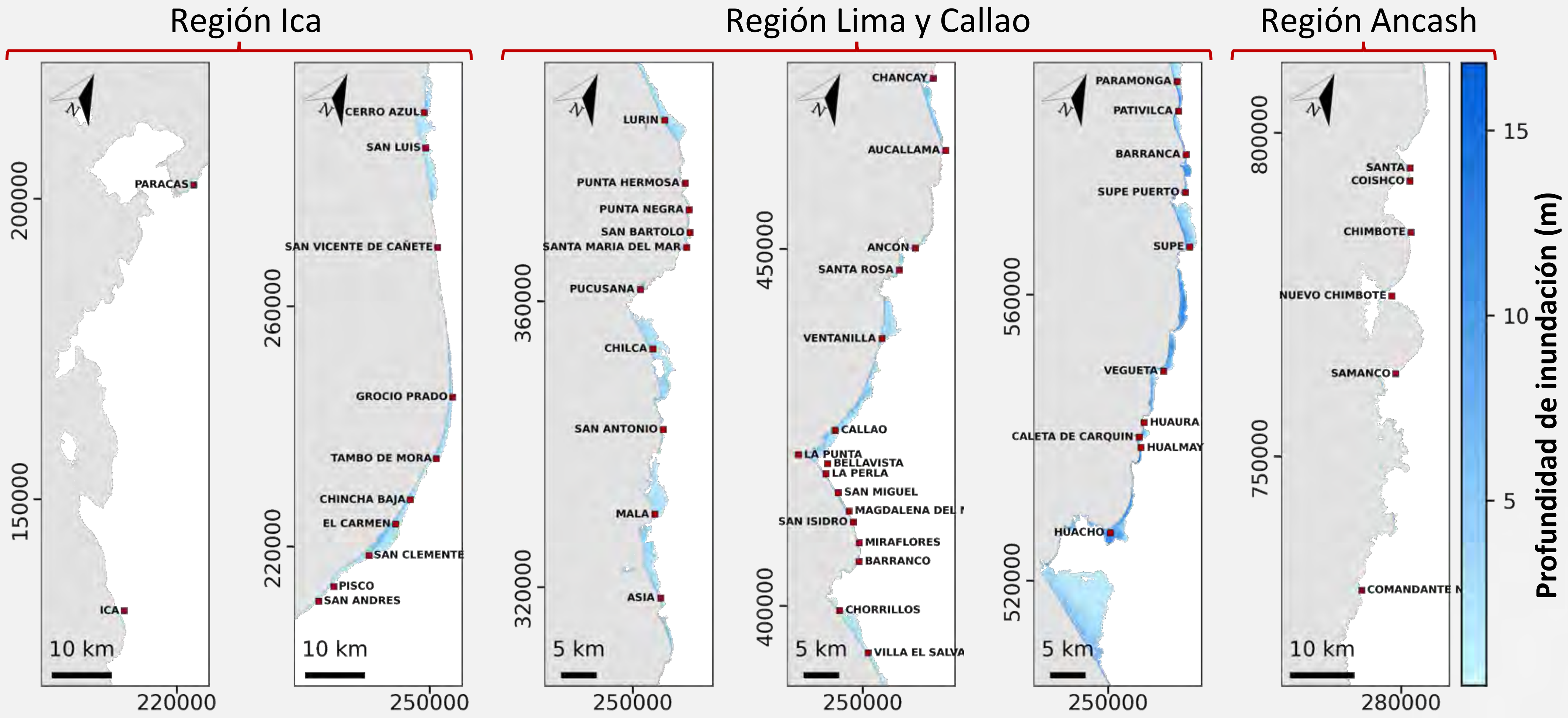

```
include "mpif.h"
! ...
open(1,file='./fault.txt ', action='read' )
! ...
!$acc data copyin(...) copyout(Z)
DO N = 1, NP
    ! ...
    !$acc parallel loop present(Z)
    DO I = 1, II
        DO J = 1, JJ'
            ! ...
            Z(I,J) = Z(I,J) + UZST + UZDP
            ! ...
        END DO
    END DO
    !$acc end parallel loop
END DO
!$acc end data
! ...
open(2,file='./deforms_#rank.txt', action='write' )
```

COMPUTACIÓN ACELERADA POR GPUs CON OPENACC





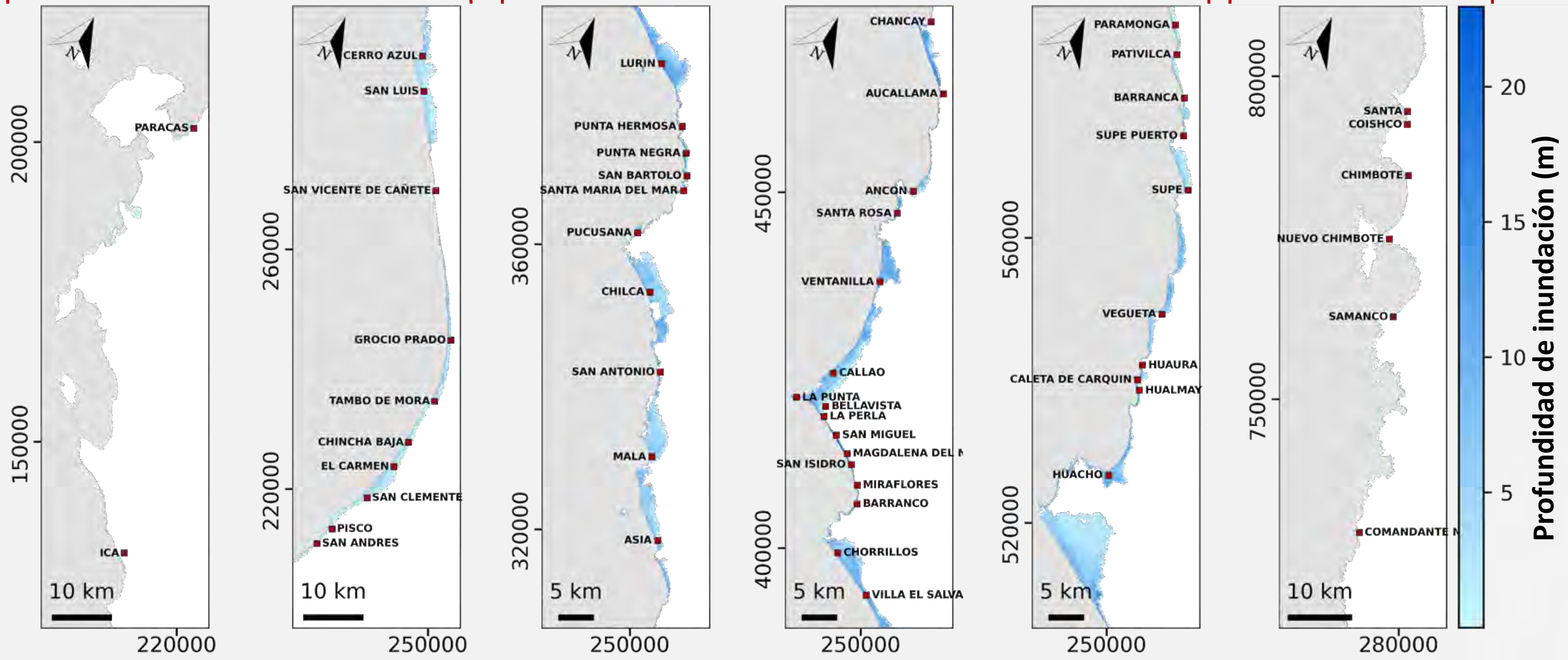
ÁREAS DE INUNDACIÓN (escenario probable 8.95 M_w)*



*F. García et al. (2025). Parallel Computing Approach for Rapid Estimation of Tsunami Hazard and Population Exposure in Peru. Journal of Disaster Research, 20(6), 912–921.

ÁREAS DE INUNDACIÓN (escenario histórico 9.0 M_w)*

Región Ica | Región Lima y Callao | Región Ancash



*F. García et al. (2025). Parallel Computing Approach for Rapid Estimation of Tsunami Hazard and Population Exposure in Peru. Journal of Disaster Research, 20(6), 912–921.

4. Reporte web

de pronóstico ante tsunamis

BOLETÍN INFORMATIVO DE ALERTA DE TSUNAMI
N° 001-2025-INDECI/COEN
Ley N°29664 (SINAGERD) - R.M. N°173-2015- PCM/Numeral 5.2.2.2

COEN
MÓDULO DE MONITOREO Y ANÁLISIS

ALERTA DE TSUNAMI (ACTUALIZACIÓN)

SE COMUNICA A LA POBLACIÓN EN GENERAL QUE EL SISMO OCURRIDO A **119 km al Este Sur Este de Petropavlovsk-Kamchatsky, Russia,** GENERA **ALERTA DE TSUNAMI** EN EL LITORAL PERUANO, Y SE ESTIMA QUE LAS PRIMERAS OLAS ARRIBEN EN EL **PUERTO LA CRUZ** A LAS 10:09 H.

ESTIMACIÓN DE TIEMPO DE ARRIBO Y ALTURA DE OLAS

Puerto	Fecha	Hora de arribo	Amplitud de marea (condiciones del mar)	Altura de ola TSDHN (modelo teórico)	Altura proyectada (real estimada)
La Cruz	30/07/2025	10:09	0.56	0.44	**1.00**
Talara	30/07/2025	10:12	1.18	1.13	**2.31**
Paita	30/07/2025	10:16	1.16	0.35	**1.51**
Pimentel	30/07/2025	10:34	0.80	0.28	**1.08**
Salaverry	30/07/2025	10:48	0.81	0.42	**1.23**
Chimbote	30/07/2025	10:56	0.86	0.42	**1.28**
Huarmey	30/07/2025	11:05	0.66	0.60	**1.26**
Huacho	30/07/2025	11:15	0.62	0.54	**1.16**
Callao	30/07/2025	11:23	0.75	0.52	**1.27**
Cerro Azul	30/07/2025	11:33	0.69	0.56	**1.25**
Pisco	30/07/2025	11:40	0.68	0.69	**1.37**
San Juan	30/07/2025	11:56	0.70	0.45	**1.15**
Atico	30/07/2025	12:09	0.75	0.28	**1.03**
Matarani	30/07/2025	12:21	0.79	0.33	**1.12**
Ilo	30/07/2025	12:30	0.84	0.37	**1.21**

PARÁMETROS SÍSMICOS

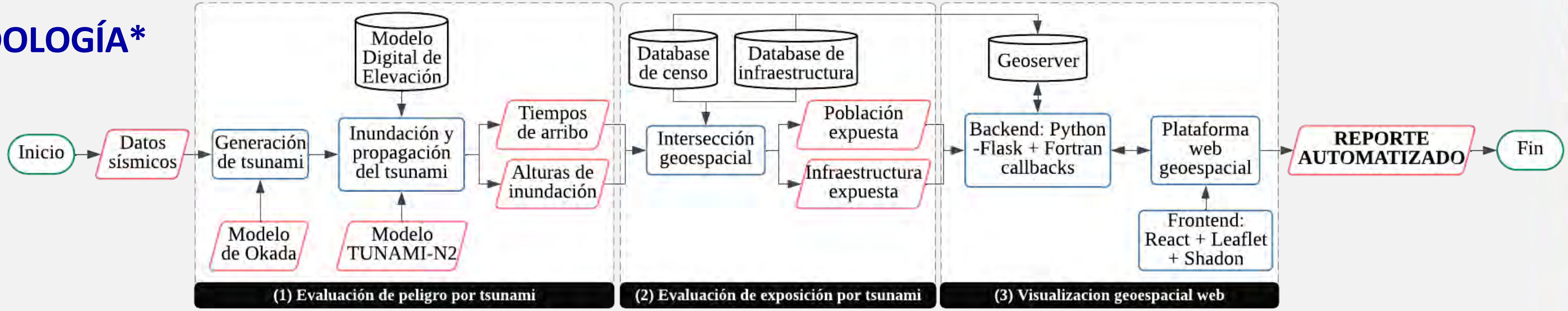
Fecha en Perú	29-07-2025
Hora en Perú	18:24:52
Magnitud	8.8
Intensidad	
Epicentro (Ubicación geográfica)	119 km ESE of Petropavlovsk-Kamchatsky, Russia
Latitud (°)	52.53° N
Longitud (°)	160.165° E
Profundidad (km)	20.7
Fuente	USGS
Fecha UTC	29-07-2025
Hora UTC	23:24:52

FUENTE: DIHIDRONAV – Dirección de Hidrografía y Navegación, Marina de Guerra del Perú

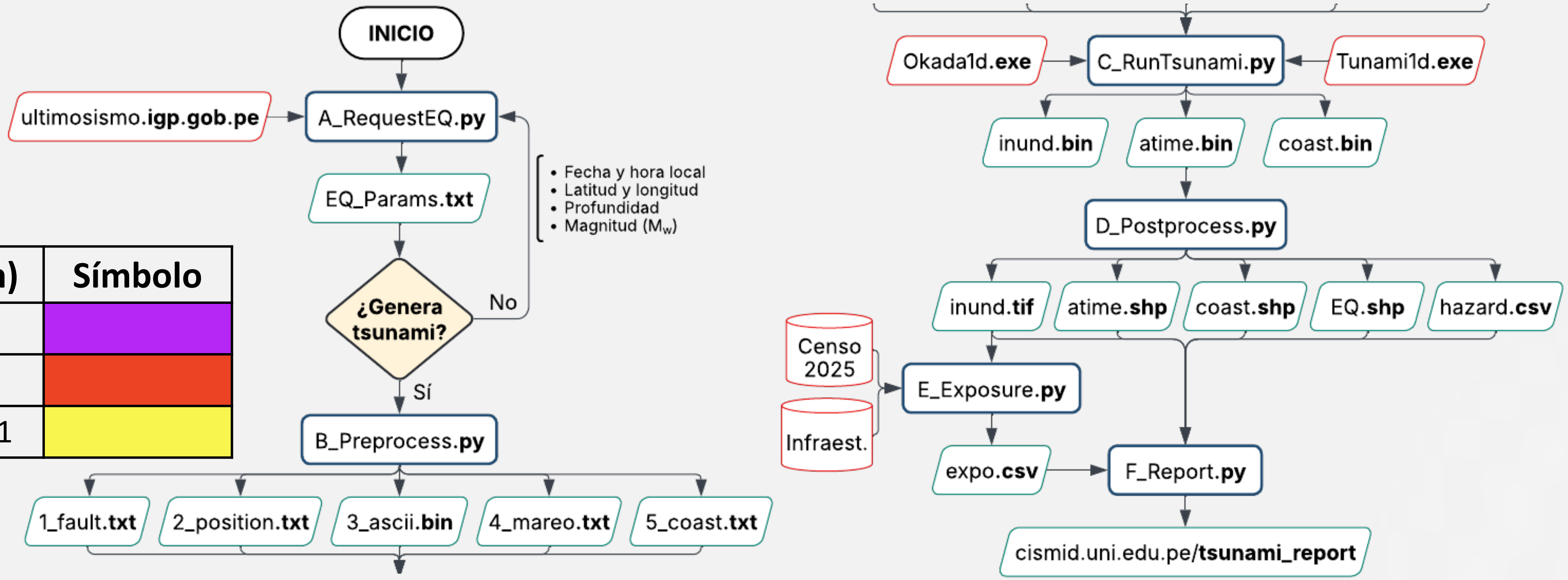
CÓDIGO DE COLORES DE LOS AVISOS

INFORMACIÓN	ALERTA	ALARMA	CANCELACIÓN
Peligro detectado, no reúne las condiciones para generar un tsunami o se intensifica vigilancia.	Probabilidad de ocurrencia de tsunami.	Ocurrencia inminente de tsunami.	Se cancelan los estados de alerta y alarma de Tsunami.

METODOLOGÍA*



FLUJO DE TRABAJO



Nivel	Altura (m)	Símbolo
Alarma	$3 < h$	
Alerta	$1 < h \leq 3$	
Precaución	$0.2 < h \leq 1$	

*C. Dávila et al. (2026). Automated Tsunami Hazard and Exposure Reporting Using Numerical Simulations and WebGIS Visualization. Environmental and Earth Sciences Proceedings, 41(1), 6.

REPORTE WEB AUTOMATIZADO*

***C. Dávila et al. (2026).** Automated Tsunami Hazard and Exposure Reporting Using Numerical Simulations and WebGIS Visualization. Environmental and Earth Sciences Proceedings, 41(1), 6.

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Paper:

Parallel Computing Approach for Rapid Estimation of Tsunami Hazard and Population Exposure in Peru

Fernando Garcia[*,**], Miguel Estrada[*,**,†], Julian Palacios[**], Carlos Davila[*,**], Angel Quesquen[*,**], Jorge Morales[***], Bruno Adriano[***], Erick Mas[***], and Shunichi Koshimura[***]

[*]GeoGiRD Research Group, Facultad de Ingeniería Civil, Universidad Nacional de Ingeniería (UNI)
Av. Tupac Amaru 1150, Rimac, Lima 15333, Peru

[**]Geomatics Laboratory, Centro Peruano Japonés de Investigaciones Sísmicas y Mitigación de Desastres
Lima, Peru

[***]International Research Institute of Disaster Science, Tohoku University
Sendai, Japan

[†]Corresponding author

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Published: December 1, 2025

Keywords: tsunami simulation, population exposure, numerical modeling, parallel computing, HPC

Abstract

Peru faces a significant tsunami hazard due to its location along the Pacific Ring of Fire. Historical megathrust earthquakes and their resulting tsunamis have caused severe damage, highlighting the need for improved warning systems. This study investigates potential tsunami impacts along the central Peruvian coast—including the regions of Ica, Callao, Lima, and Ancash—using numerical simulations. To enable rapid and efficient simulations, we developed gWave-CPU, a parallelized version of the TUNAMI-N2 model created at Tohoku University. Using 90-m-resolution topographic and bathymetric data in combination with census data, we assessed population exposure under two seismic scenarios: a plausible event based on interseismic coupling and a historical scenario simulating the 1746 tsunami. Under the historical scenario, the exposed population was estimated at 320,128, with the highest concentrations in Callao and Lima. Numerical simulations of four hours of tsunami propagation and inundation were conducted using our parallelized implementation, reducing computation time to 68 minutes—a 26.3-fold speedup compared to the conventional model. The results demonstrate that tsunami inundation and population exposure in this region can be efficiently estimated using the proposed approach, providing a valuable contribution to tsunami hazard assessment, management, and emergency preparedness along Peru's central coast.

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Automated Tsunami Hazard and Exposure Reporting Using Numerical Simulations and WebGIS Visualization †

by Carlos Davila [1,2], Angel Quesquen [1,2], Jhianpiere Salinas [2], Julian Palacios [3], Luz Tinco [4], Fernando Garcia [1,2], Jean Cueva [2], Lorena Marquez [4] and Miguel Estrada [1,2,*]

1 GeoGiRD Research Group, Facultad de Ingenieria Civil, Universidad Nacional de Ingenieria, Av. Tupac Amaru 210, Lima 15333, Peru
2 Centro Peruano Japones de Investigaciones Sismicas y Mitigacion de Desastres, Av. Tupac Amaru 1150, Lima 15333, Peru
3 Earthquake Research Institute, The University of Tokyo, Tokyo 113-0032, Japan
4 Dirección de Hidrografía y Navegación, Jr. Roca 118, Callao 07021, Peru
* Author to whom correspondence should be addressed.
† Presented at the 1st International Online Conference on Marine Science and Engineering, 24–26 November 2025; Available online: https://sciforum.net/event/IOCMSE2025.

Environ. Earth Sci. Proc. **2026**, *41*(1), 6; https://doi.org/10.3390/eesp2026041006

Published: 18 May 2026

(This article belongs to the Proceedings of The 1st International Online Conference on Marine Science and Engineering (IOCMSE 2025))

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Abstract

The availability of tsunami hazard and exposure information is crucial to support effective emergency response in coastal areas. This study presents an automated framework that integrates tsunami numerical simulation, geospatial exposure analysis, and WebGIS-based visualization to generate standardized hazard and exposure reports for decision support. Using a parallel implementation of the TUNAMI-N2 model, a 6-h tsunami simulation for the Peruvian coast can be completed in ~45 min, with hazard and exposure reports automatically published on a WebGIS platform within ~3 min. Application to the historical 1746 Lima tsunami demonstrates the system's capability to quantify hazard and exposure for operational decision-making.

Keywords: tsunami hazard; tsunami exposure; numerical simulation; WebGIS; automated system

Gracias

cdaviladelacruz@uni.edu.pe