IHCantabria

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I+D+i para un desarrollo sostenible

TSUNAMI HAZARD MAPS AS A SUPPORT TO STABLISH EMERGENCY AND PREPARATION PLANS AT THE SPANISH REGIONAL SCALE.

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Tsunami Risk in Spain.
A far hazard?

Spanish Coast

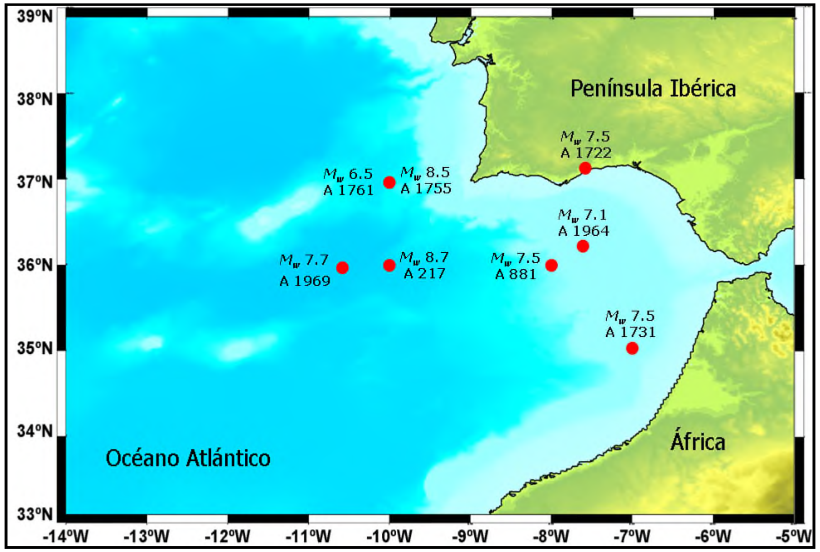
ulf of Cadi:

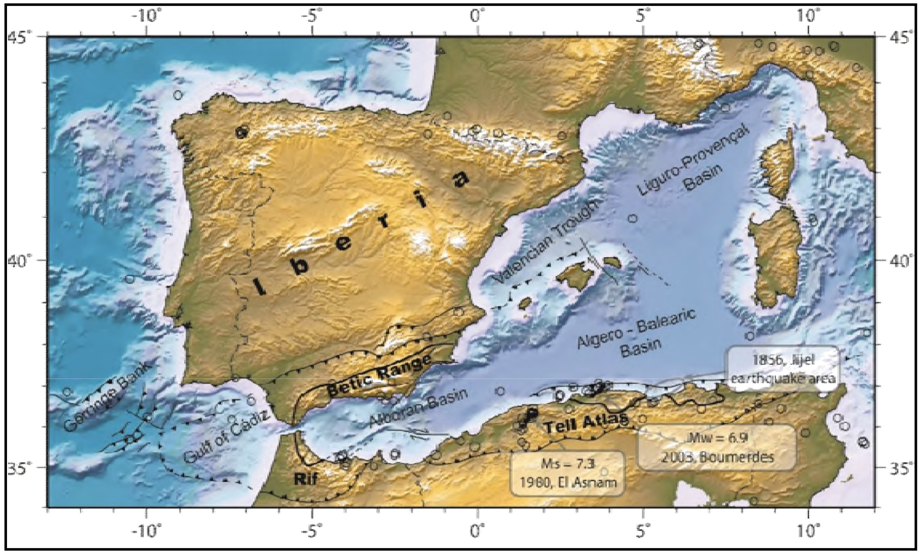
- Tsunamis: low frequency and high magnitude
- Catastrophic flooding
- Huge impact on population

editerranean Coas:

- Tsunamis higher frequency y lower magnitude
- They can cause floodings and damages also inside ports and harbours
- Damages in low coastal areas and beaches

Tsunami hazard on the spanish coast



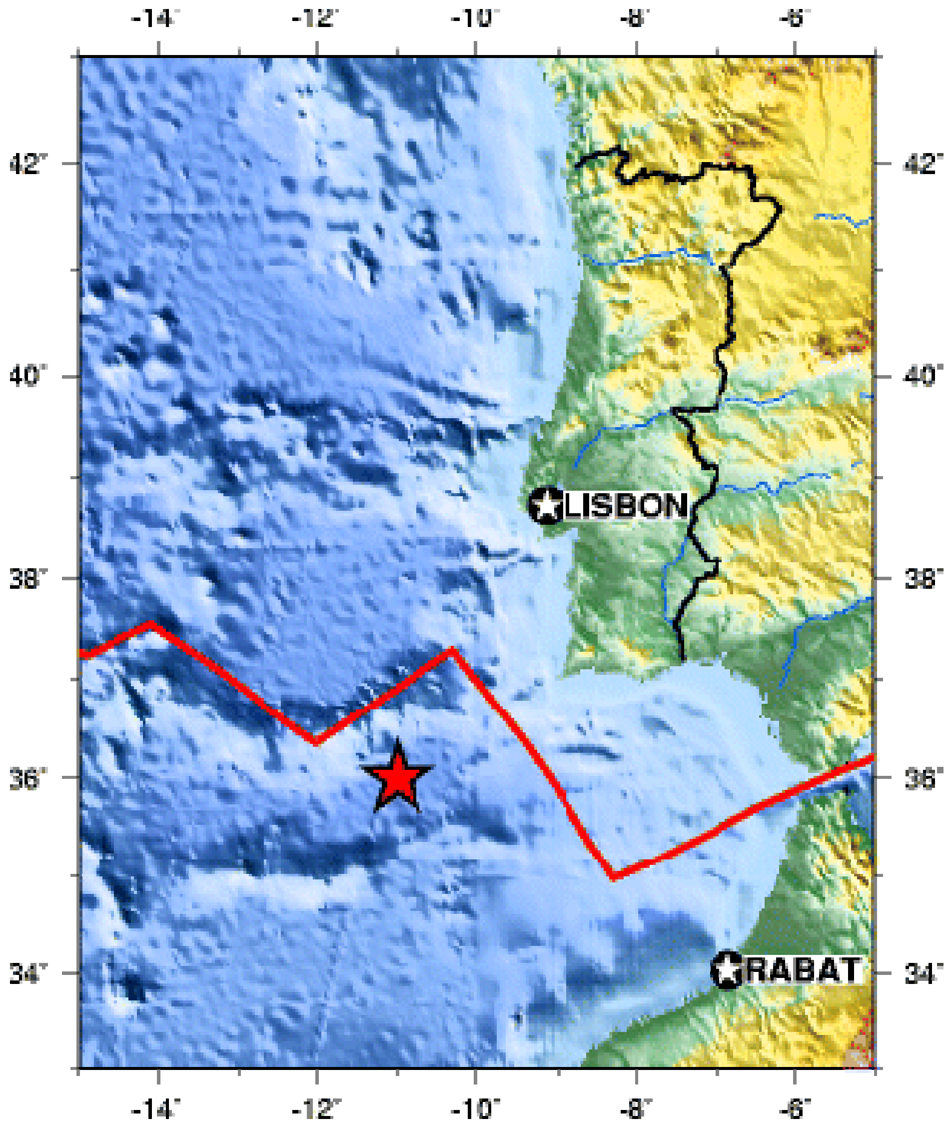


Gulf of Cádiz

Balearic Islands

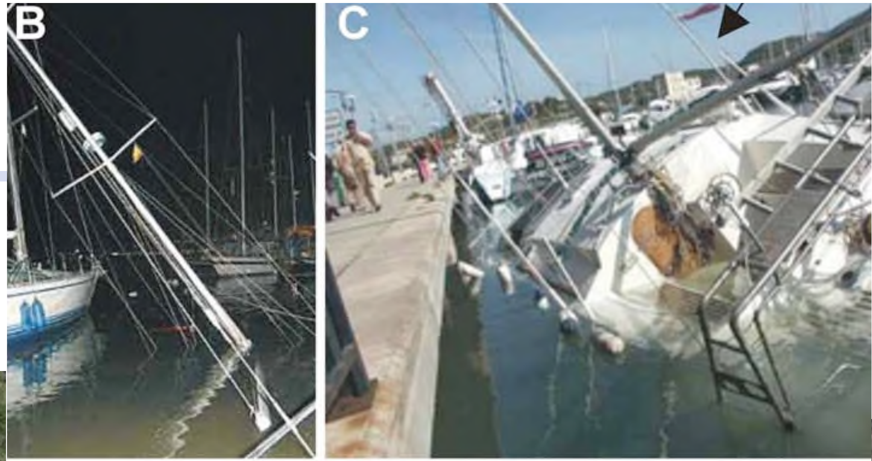
- 1st of November 1755, *Ms* 8.5 – Tsunami de Lisboa – 10,000 casualties en España
- 21st of May 2003, *Ms* 6.9 – Tsunami Boummerdes (low áreas floodings and damages in ports)

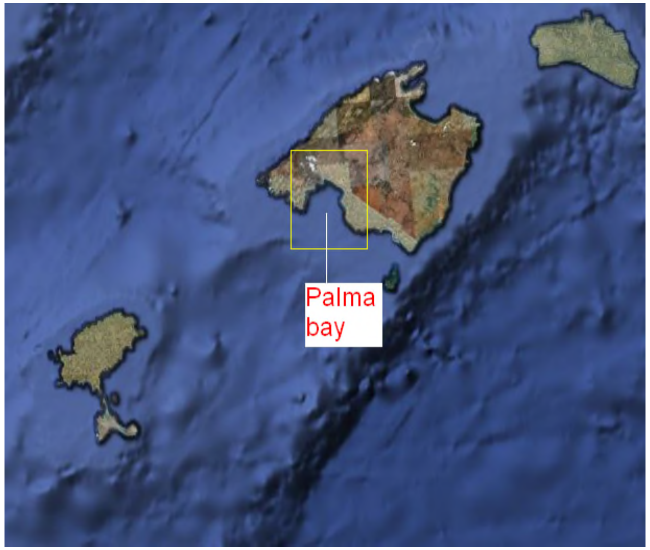
Lisbon, 1755



1755 Lisbon, Portugal Earthquake

Tsunami Algeria (2003)

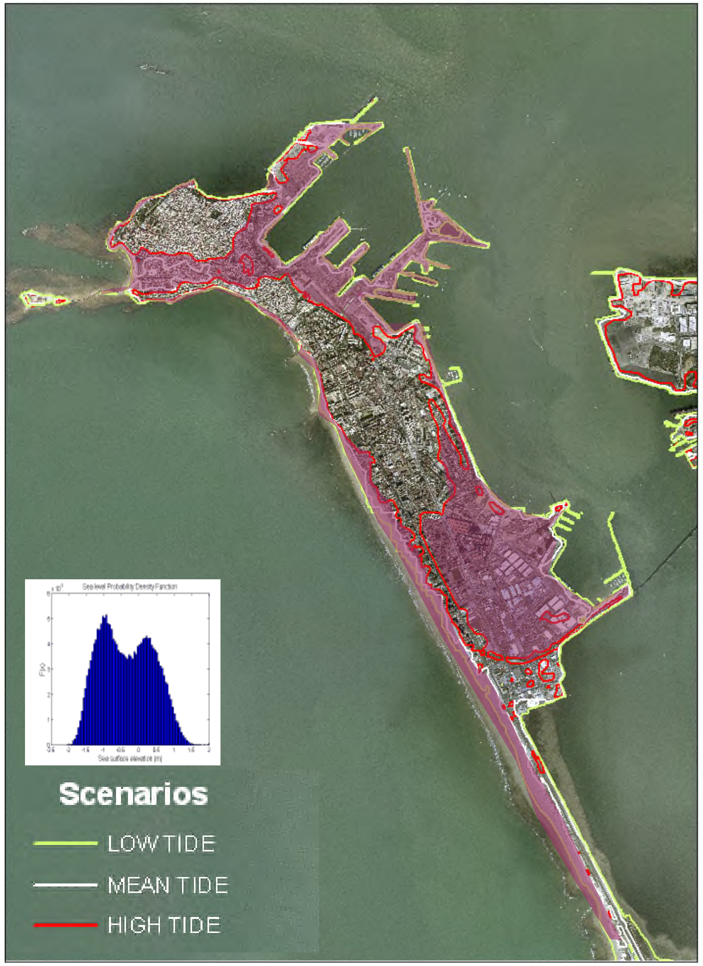


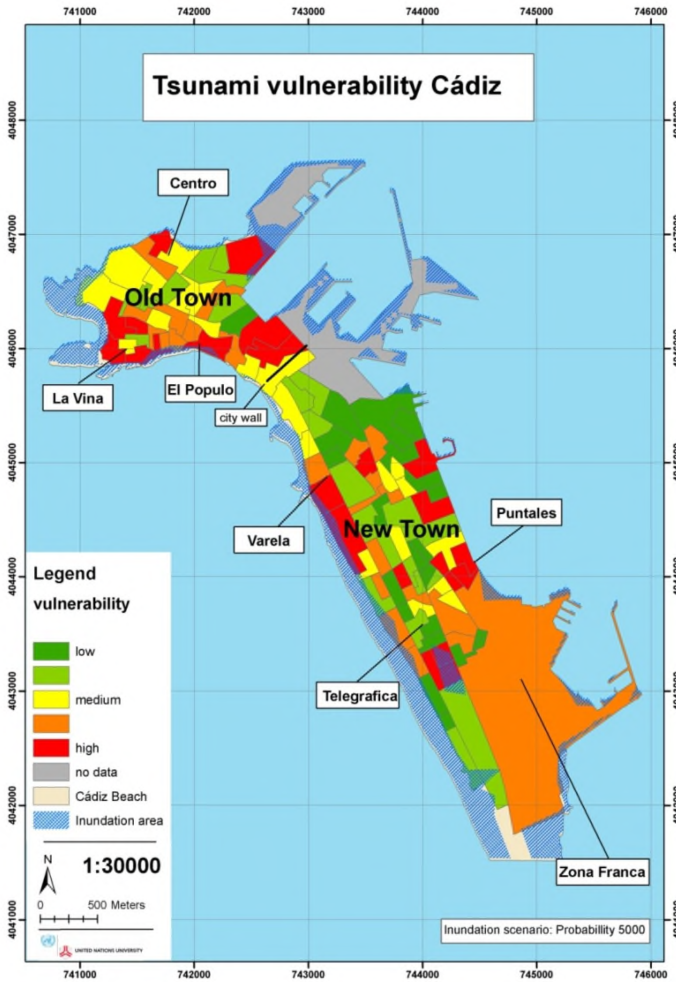


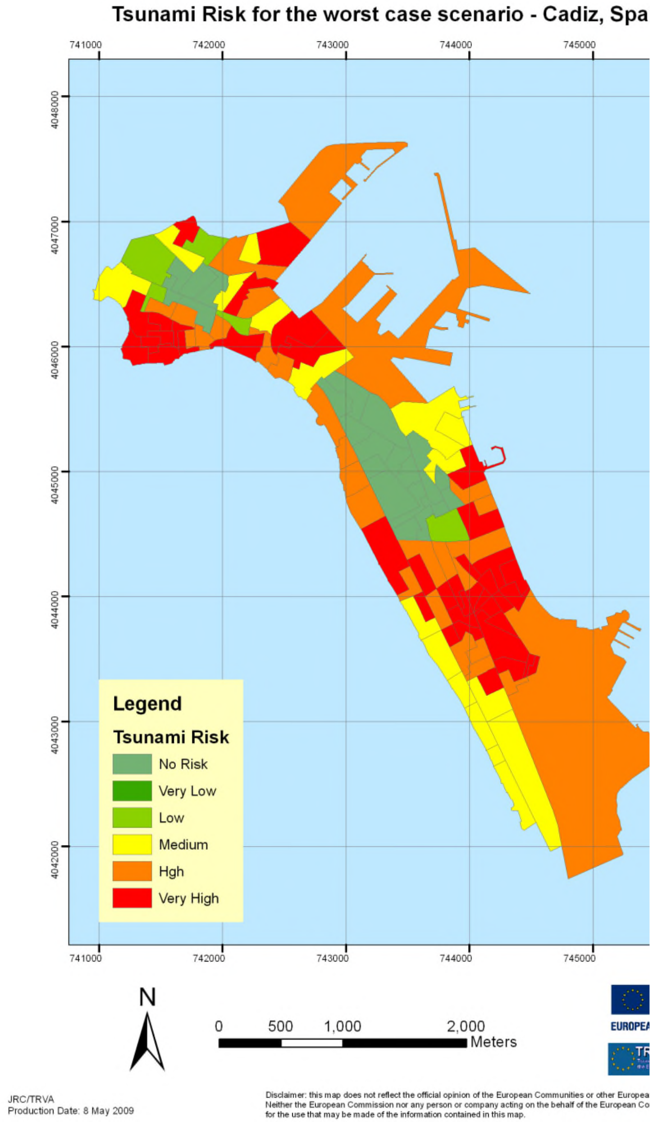
- The tsunami induced by the 21 May 2003 Boumerdès-Zemmouri (Algeria) earthquake (Mw=6.9) did not generated important inundations damages or fatalities in the western Mediterranean area.
- However, damages and economic losses were reported in some harbors (broken mooring lines, sunken boats, displaced moorings, etc.) in some harbours in the Balearic Islands as in Palma de Majorca.

sunami Hazard assessment in Spain has been based on Local research initiatives supported by research EU Projects

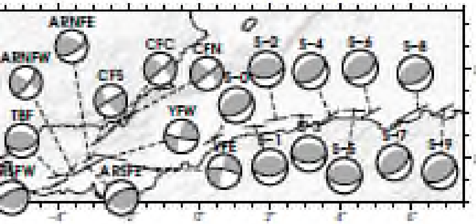
TRANSFER
Tsunami Risk ANd Strategies For the European Region

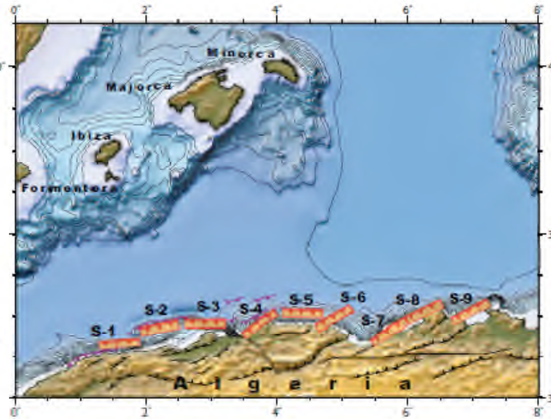




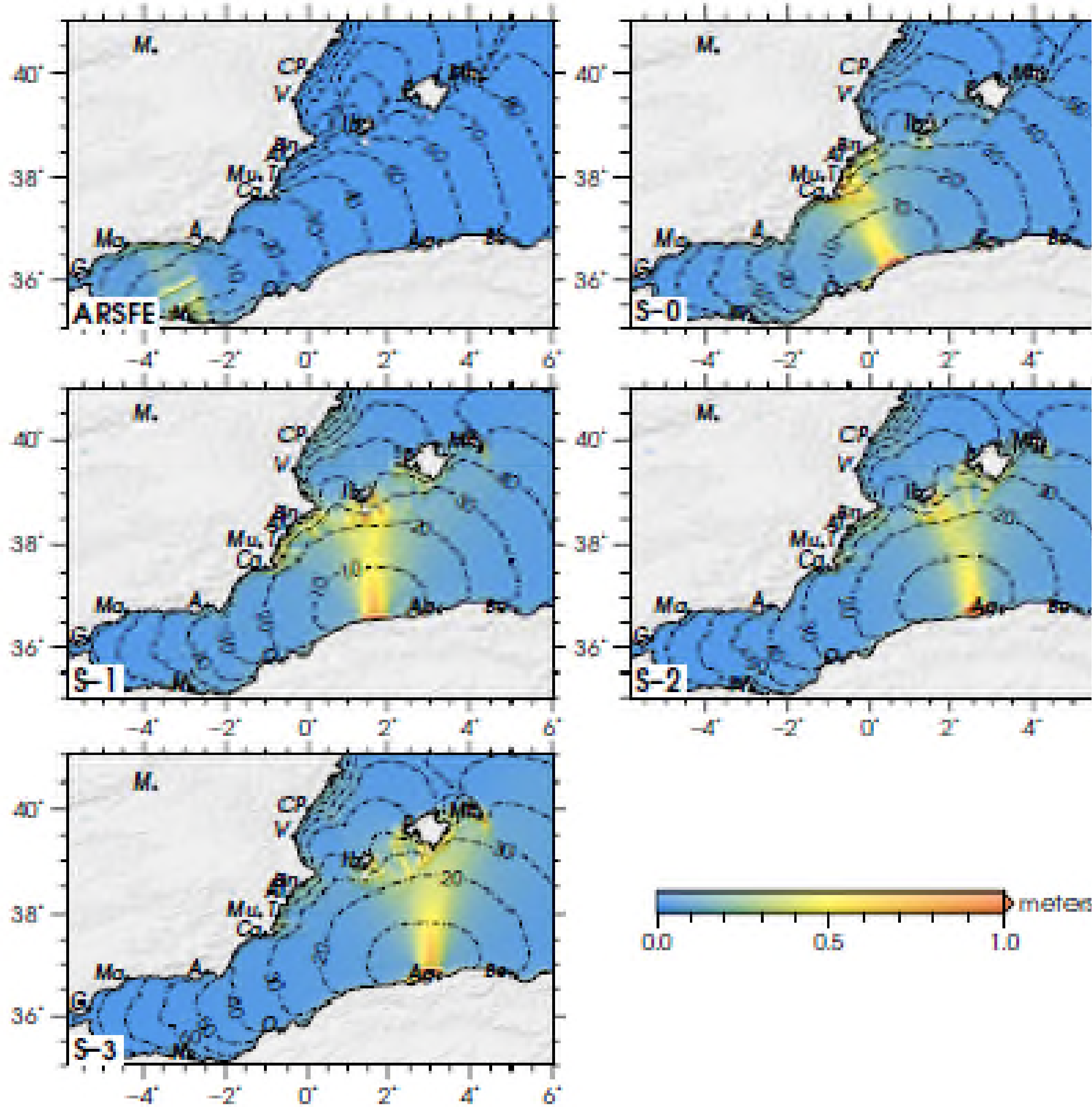


Western Mediterranean seismotectonic sources

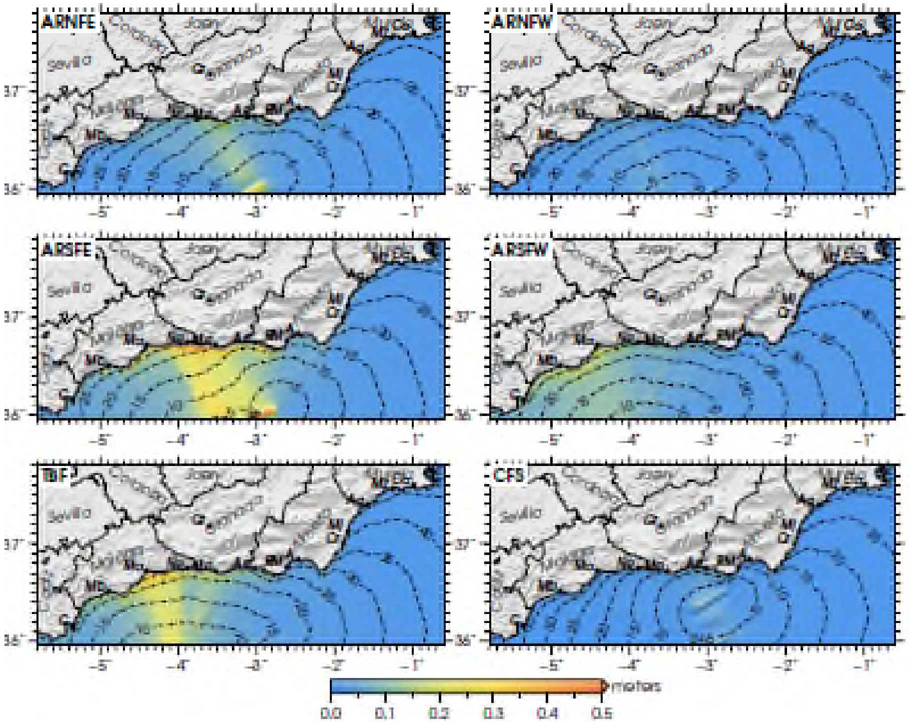




Mediterranean spanish coast



Alboran Sea



2015 WE HAVE A BASIC CIVIL PROTECTION DIRECTIVE AGAINST THE RISK OF TSUN

BOLETÍN OFICIAL DEL ESTADO

Núm. 279 Sábado 21 de noviembre de 2015 Sec. I. Pág. 109769

I. DISPOSICIONES GENERALES

MINISTERIO DEL INTERIOR

12570 *Real Decreto 1053/2015, de 20 de noviembre, por el que se aprueba la Directriz básica de planificación de protección civil ante el riesgo de maremotos.*

- Includes tsunamis as a risk to be planned by Civil protection
- It sets the minimum requirements to be satisfied
- 3 levels of planning are considered:

  Level 1) National
  Level 2) Regional (CCAA) – Coastal Communities (States/Provinces)
  Level 3) Local (municipalities)

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Level 1) National plan

Source: National Spanish Civil protection

- Tsunami Hazard cartography at National scale has been provided. The objective of this Map is to determine communities/provinces that must carri the 2nd level.
- **As a result all the coastal comunnuties/provinces must carry out the level 2 study, except two: Canta and Basque Country.**
- **This National scale Cartography is just applicable ONLY to national scale:**
  - Resolution is not enough to tackle regional or local analyses.
  - The only variable is wave height, i.e. it does n include topography or coastal flooding.

Level 2) Regional plann

The objectives of each Community/Province are (chapter 5):

- To classify the coastal municipalities of its territory based on the tsunami hazard
- To establish directives to elaborate the acting planning at local scale
- To collaborate with local authorities in the preparedness of the arrangements and the necessary means t the potentially affected population

One of the main results of this level 2 (Community/Province scale) is that:

It must be defined which municipalities must carry out level 3 (local) studies.

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Level 3) LOCAL plan

Local Scale acting plans:

- Municipalities must cover:
  - A tsunami risk analisys (Risk= Hazard x Vulnerability) in a local scale with a cartography developed at an adequate scale.
  - An evacuation plan, routes and safe locations to take in evacuated people
  - The means to spread the alerts.

- This planning must detail precisely the alert system and evacuation plans depending on geographic areas (using a cartography elaborated with an adequate scale)

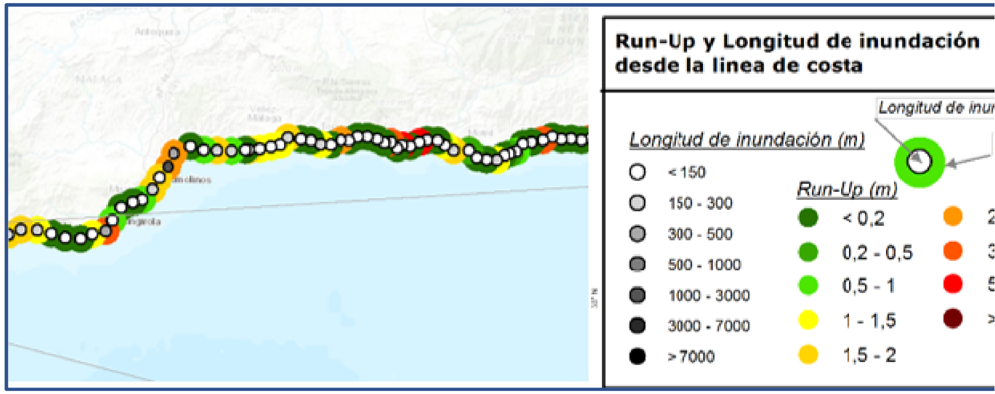
- The local scale acting plans will be approved by each municipality relevant authorities and the corresponding Civil Protection regional commission.

Available Tsunami Hazard Maps in Sp

- Level 1) National already done
- Level 2) Regional (under ellaboration):

From IHCantabria we are developing a hazard cartography :

- With higher resolution
- Flooding calculations
- The establishment of a methodology applicable to the whole country



In order to provide to each coastal community/province:

- Identification of the most affected coastal areas
- Determination of the municipalities that must tackle a local scale study (level 3), including risk assessment

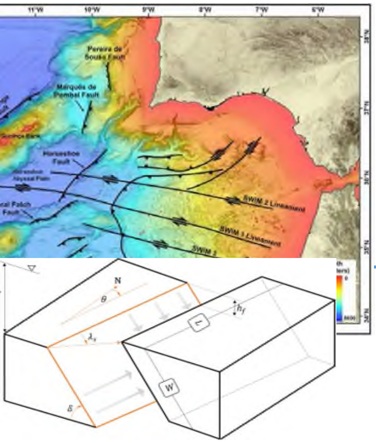
LEVEL 2 COMMUNITY SCALE MAPS

as a support to

establish acting planning

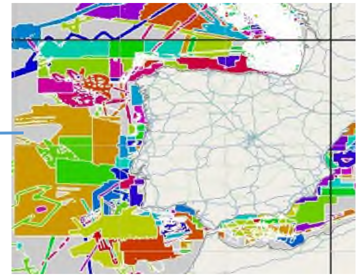
Methodology

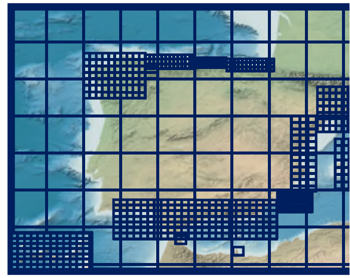
Methodology



Seismotectonic characterization

Topo-bathymetry reconstruction





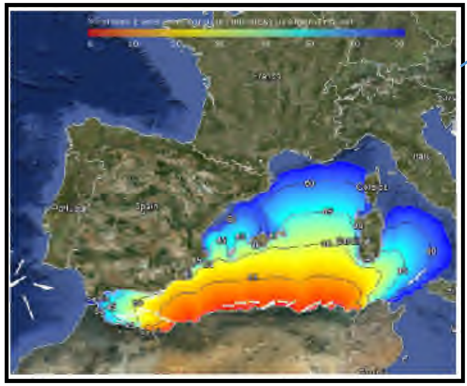
$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left\{\frac{P^2}{H}\right\}+\frac{\partial}{\partial y}\left\{\frac{PQ}{H}\right\}+gH\frac{\partial \eta}{\partial x}+F_x=0$$

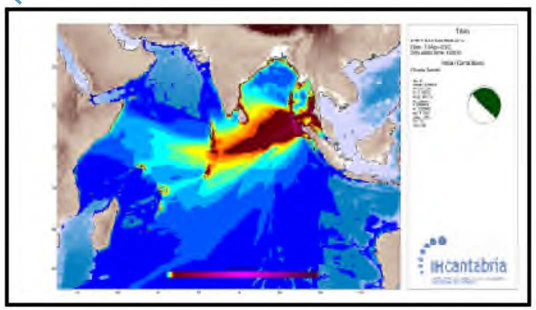
$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left\{\frac{PQ}{H}\right\}+\frac{\partial}{\partial y}\left\{\frac{Q^2}{H}\right\}+gH\frac{\partial \eta}{\partial y}+F_y=0$$

$$\frac{\partial \eta}{\partial t}+\left\{\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}\right\}=-\frac{\partial h}{\partial t}$$

Numerical model

MAPS

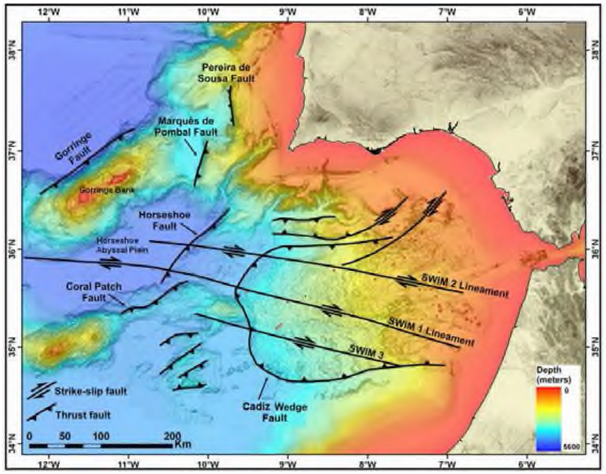




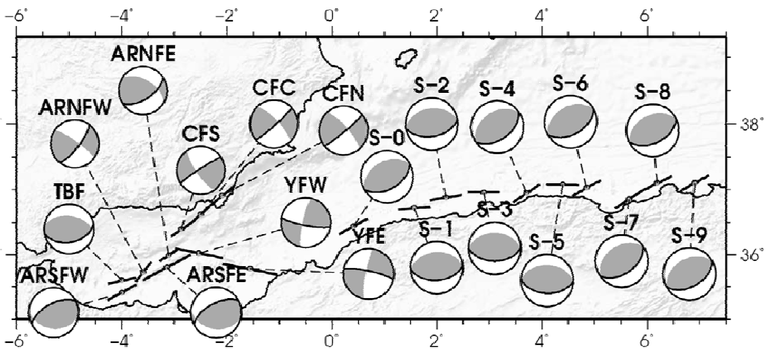
Methodology

Sources characterization

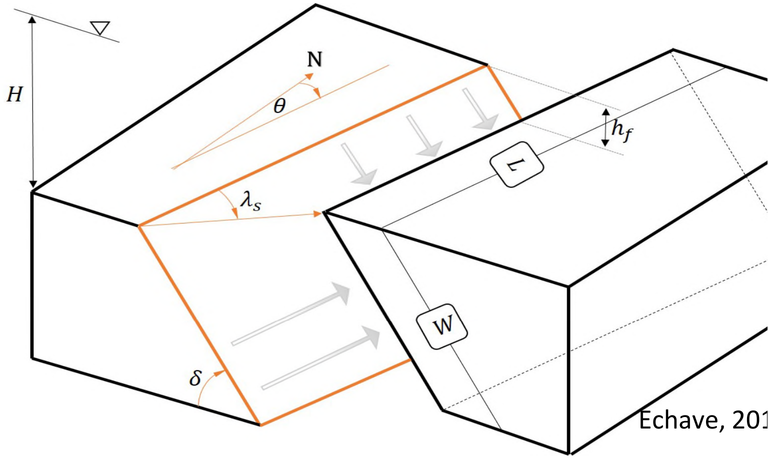
Atlantic Ocean



Mediterranean Sea



- Proyect TRANSFER
- Proyect ASTARTE
- Proyect TSUMAPS
- JRC Database
  - Portugal
  - Italia
  - Spain
- Álvarez-Gómez et al, 2011

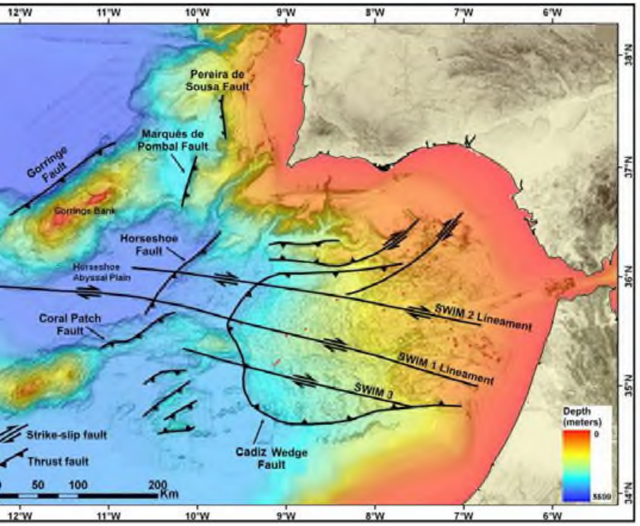


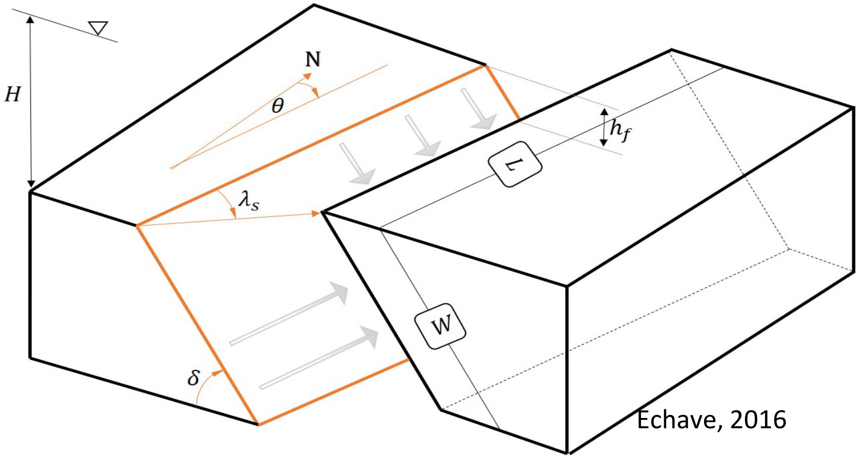
Focal Mechanism→Okada mode
Strike θ , dip δ, rake λ, length L,
width W, Focal depth H, epicente
longitude and latitude

Atlantic Ocean

Methodology

Sources characterization





Echave, 2016

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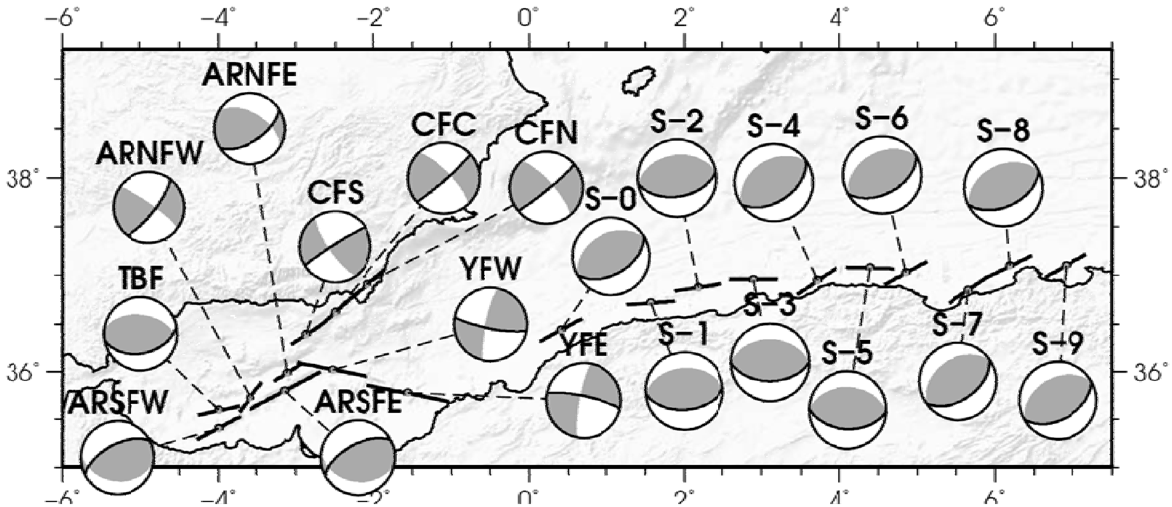
FUENTE	Ref	LENGTH (m)	WIDTH (m)	FOC DEPTH	LAT EP (°)	LONG EP (°)	STRIKE (°)	DIP (°)	RAKE (°)	SLIP (m)	Mw
HSF +CP I +CP II	HSF	165000	70000	5000	35.796	-9.913	42,1	35	90	15	8,5+7+7= 8,6
	CP I	60000	61660	15480	35.398	-11.318	315	30	90	1,68	
	CP I	60000	61660	15480	35.415	-10.743	315	30	90	1,68	
HS + MP	HSF	165000	70000	5000	35.796	-9.913	42,1	35	90	15	8,5 + 8,25= 8,75
	MP	110000	70000	5000	36.656	-10.203	20,1	35	90	8	
GF	GF	200000	50000	1000	37.415	-19.085	82	88	160	11	8,3
CWF	CWF	170000	200000	5000	34,53	-9.121	349	5	90	20	8,75
GBF	GBF	200000	80000	5000	36.283	-11.351	53	35	90	10	8,5

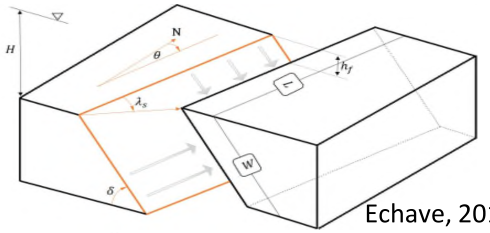
Methodology

Sources characterization

Mediterranean Sea



Source	source trace tips x1	y1	x2	y2	km top	km bottom	km length	km width	° dip	° strike	° rake	M_W	slip
Alboran													
ARNFE	−3.283	35.900	−2.938	36.079	0	11	37	12.7	60	57	45	6.71	1.02
ARNFW	−3.742	35.575	−3.437	35.894	0	11	45	11.4	75	38	10	6.74	1.07
ARSFE	−2.686	36.001	−3.596	35.606	0	11	93	12.7	60	242	70	7.1	1.56
ARSFW	−3.720	35.536	−4.280	35.289	0	11	58	12.7	60	242	70	6.91	1.32
TBF	−4.266	35.550	−3.734	35.642	0	11	49	15.56	45	78	75	6.92	1.34
CFS	−2.667	36.495	−3.064	36.288	0	11	42	11.04	85	237	15	6.7	1.01
CFC	−2.673	36.495	−2.326	36.748	0	11	42	11.04	85	48	15	6.7	1.01
CFN	−2.324	36.751	−1.858	37.059	0	11	54	11.04	85	50	15	6.81	1.16
CFC + CFN	–	–	–	–	0	11	96	11.04	–	–	–	7.08	1.57
CFS + CFC + CFN	–	–	–	–	0	11	138	11.04	–	–	–	7.24	1.9
YFE	−2.987	36.098	−2.082	35.952	0	10	83	10.15	80	101	170	6.96	1.39
YFW	−1.038	35.690	−2.090	35.862	0	10	97	10.15	80	282	−170	7.03	1.51
North Algeria													
S-0	0.135	36.317	0.678	36.557	0.5	13	55	16	50	61	90	7.3	4
S-1	1.262	36.700	1.881	36.738	0.5	13	55	16	50	86	90	7.3	4
S-2	1.869	36.842	2.480	36.919	0.5	13	55	16	50	81	90	7.3	4
S-3	2.583	36.961	3.204	36.962	0.5	13	55	16	50	90	90	7.3	4
S-4	3.449	36.809	3.964	37.084	0.5	13	55	16	50	56	90	7.3	4
S-5	4.082	37.085	4.703	37.071	0.5	13	55	16	50	92	90	7.3	4
S-6	4.576	36.905	5.119	37.146	0.5	13	55	16	50	61	90	7.3	4
S-7	5.400	36.713	5.916	36.988	0.5	13	55	16	50	56	90	7.3	4
S-8	5.916	36.988	6.472	37.207	0.5	13	55	16	50	64	90	7.3	4
S-9	6.637	36.981	7.180	37.221	0.5	13	55	16	50	61	90	7.3	4



Echave, 2016

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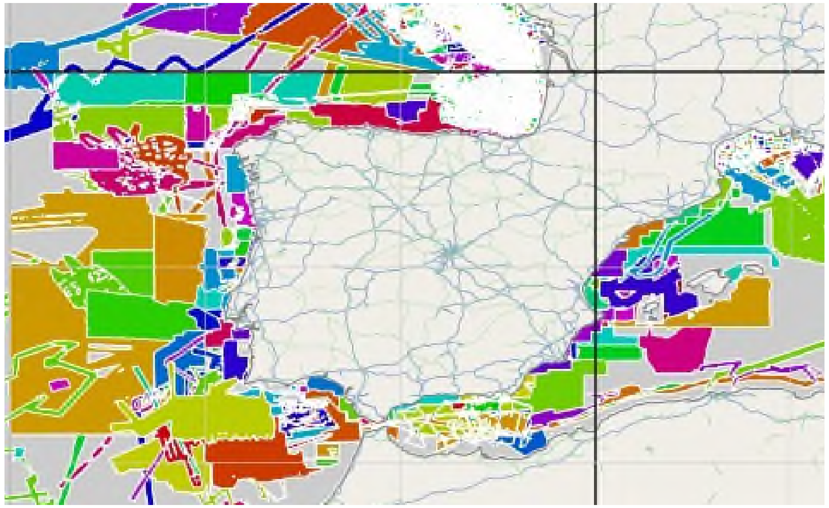
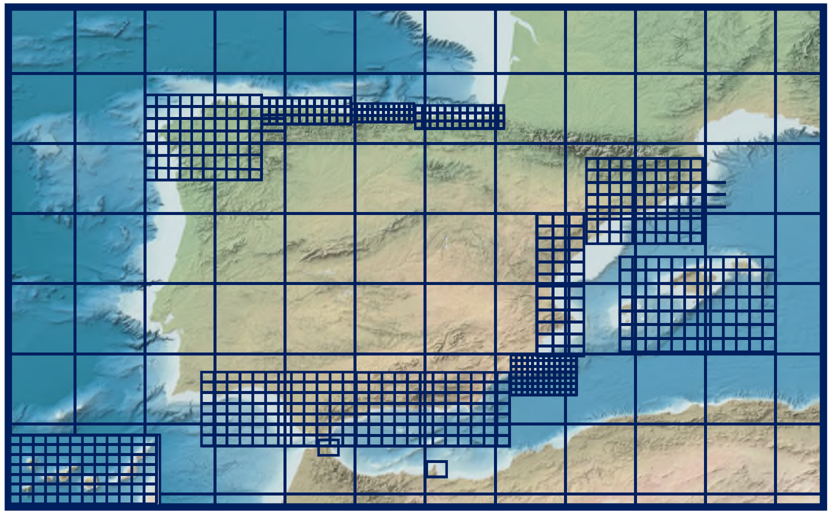
- Álvarez-Gómez et al,

Methodology

Topobathymetric reconstruction

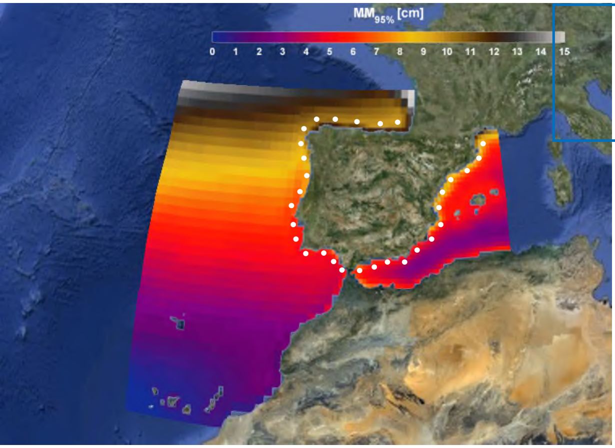


- ❑ Nautical charts Digitization
- ❑ Already existing bathymetric campaigns
- ❑ DTM (Δx=5m) - IGN
- ❑ EMODNET (Δx=200m)
- ❑ GEBCO (Δx=926m)



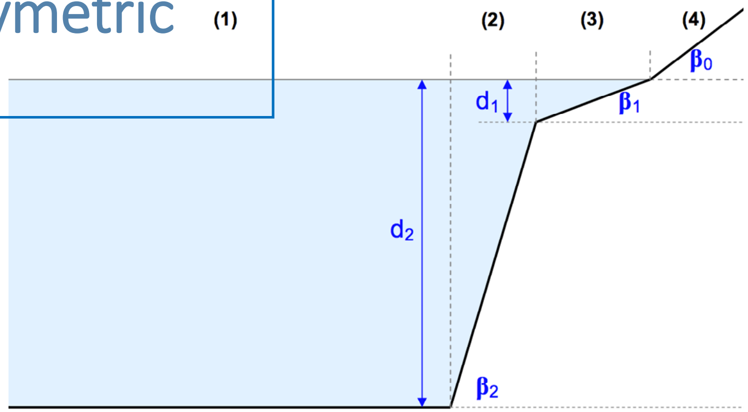
<u>Topobathymetric Grids</u>

- ❑ National Grid(Δx=926m)
- ❑ Regional grids (Δx=150m)
- ❑ Several grids per region
- ❑ Including Tide



Based on the topo-bathymetric reconstruction

To flood all Spanish coast at high resolution, we divided the coast in topo-bathymetric profiles



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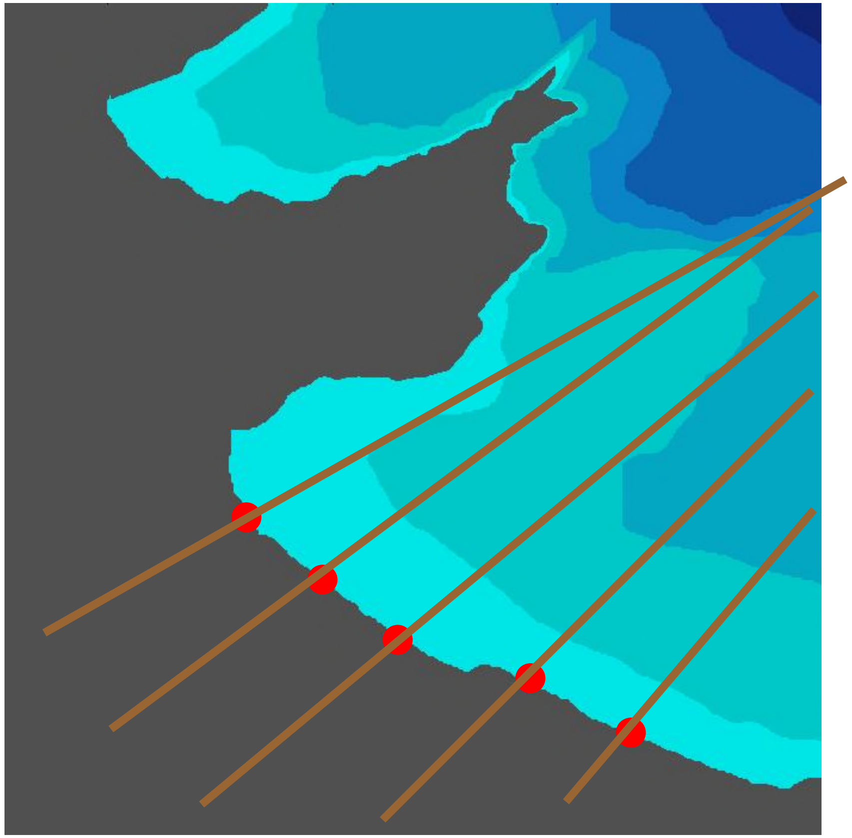
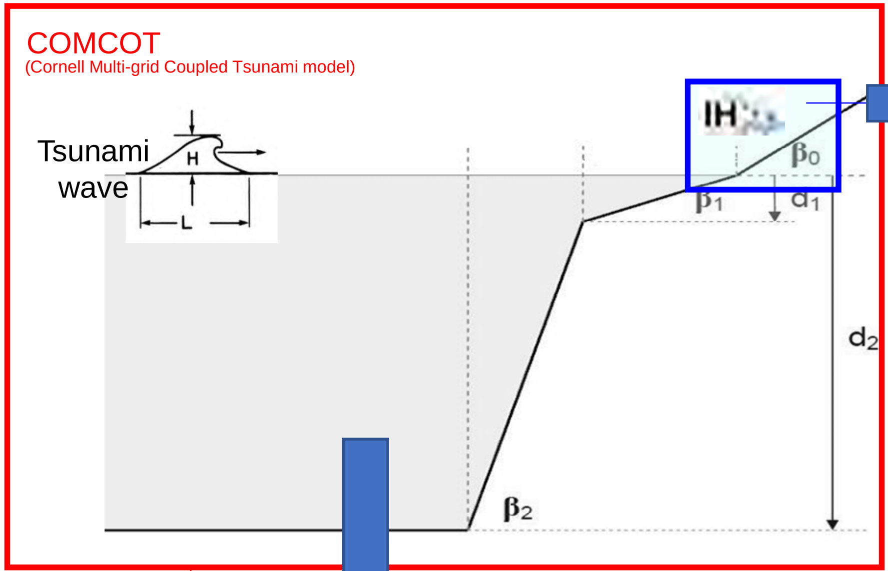
Synolakis:

o construct coastal topo-bathymetric profiles along the country

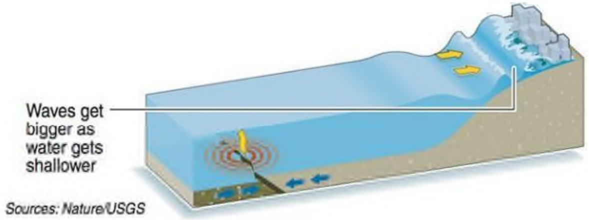
(Dx~300m) O(7000 profiles)

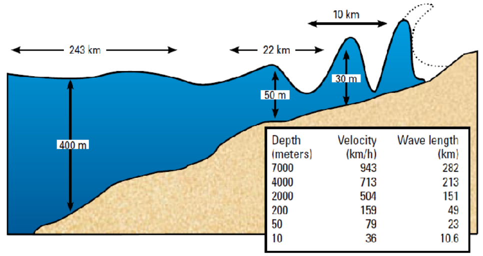




IH 2VOF

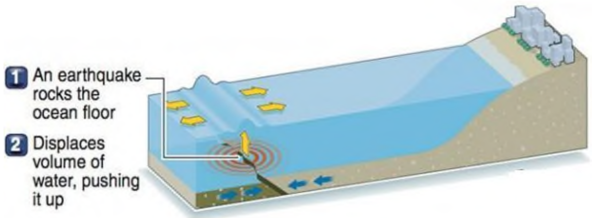
- 2DV model
- RANS equations
  (Reynolds Average Navier-Stokes)
- Waves breaking simulation
  (undular bores, fission processes, dispersive effects,…)



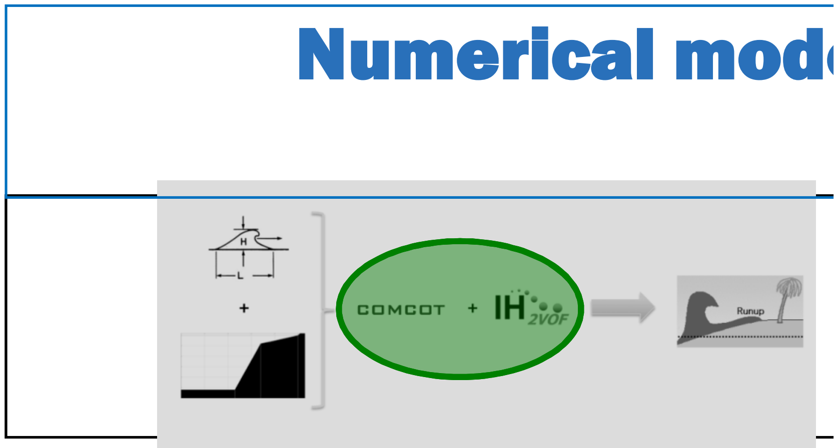


COMCOT
Cornell Multi-grid Coupled Tsunami Model

- 2DH model
- NLSWE
- Suitable for propagating long waves

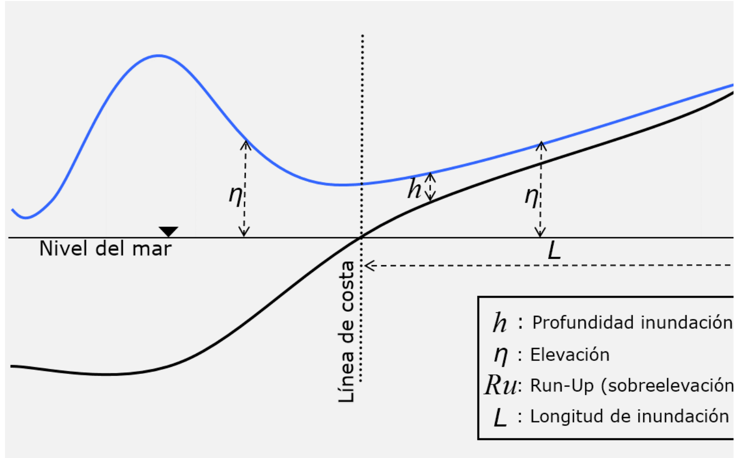


COMCOT
+ IH 2VOF



Methodology

Numerical model



Numerical Model
COMCOT C3

Olabarrieta et al, 2011

- IT solves NLSWE
- Linear and non-lineal (flooding)
- Nesting grids to reach better resolutions
- Finite differences scheme
- Okada's model
- Widely Validated
- Internationally used

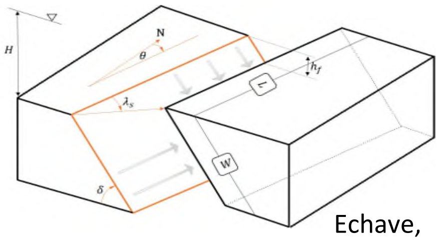
Mass conservation equation:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial x}=0$$

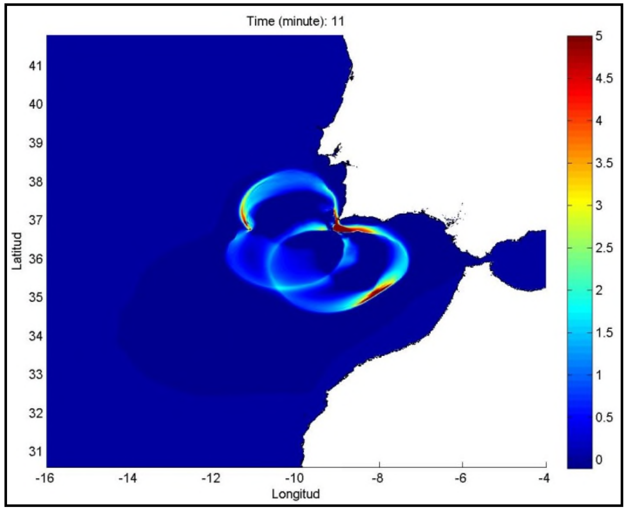
Momentum conservation equations:

$$\frac{\partial P}{\partial t}+\frac{\partial P^2}{\partial x}+\frac{\partial PQ}{\partial y}+gH\frac{\partial \zeta}{\partial x}+\tau_x H-fQ=0$$

$$\frac{\partial P}{\partial t}+\frac{\partial PQ}{\partial x}+\frac{\partial Q^2}{\partial y}+gH\frac{\partial \zeta}{\partial y}+\tau_y H-fP=0$$



Echave, 2016



Results:

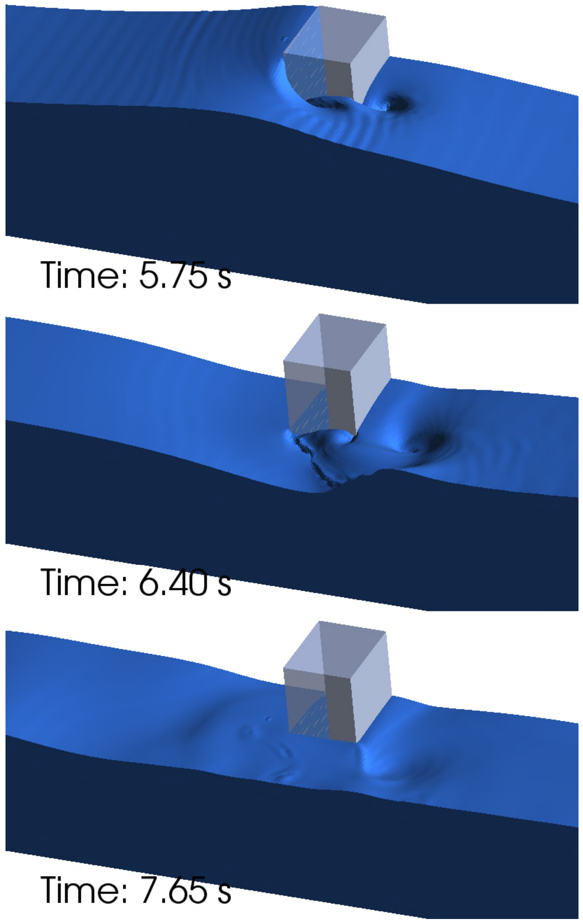
- Depth
- Wave amplitude
- Velocity
- Drag force(u*h)

IH 2VOF

Good simulation of Tsunami flooding inland

- Navier-Stokes solvers (CFD):
  - IH-2VOF: 2DV
  - IH-3VOF: 3D
  - IH-FOAM: 3D

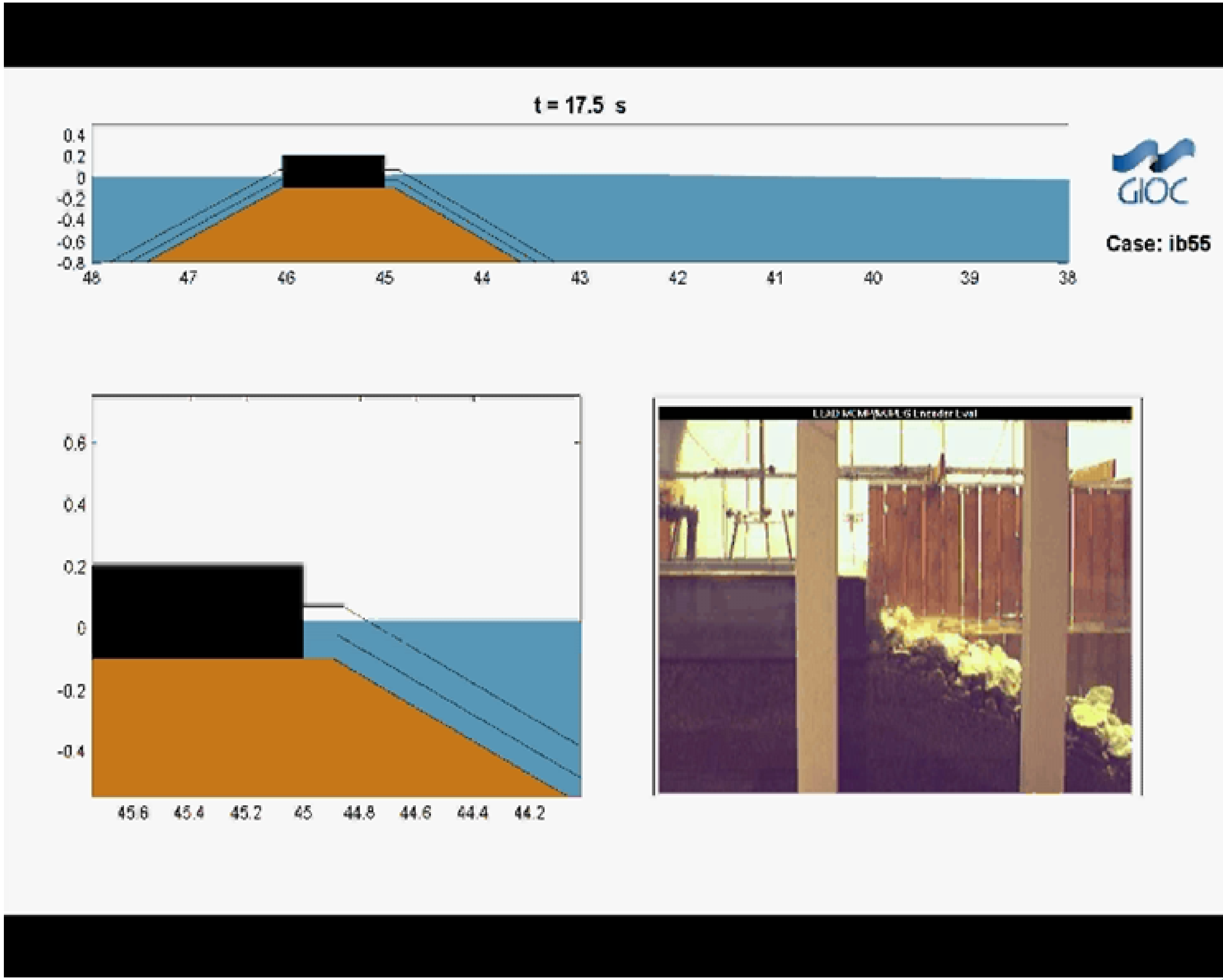
- Wave-structure interaction
- Coastal flooding



- **Good simulation of Tsunami flooding inland (undular bores, fission processes, dispersive effects,…)**
- **Limited for large domains due to high computational costs**

IH 2VOF

[LAB-IH -2Vof](LAB-IH -2Vof)



Results: LEVEL 2 COMMUNITY SCALE MAPS

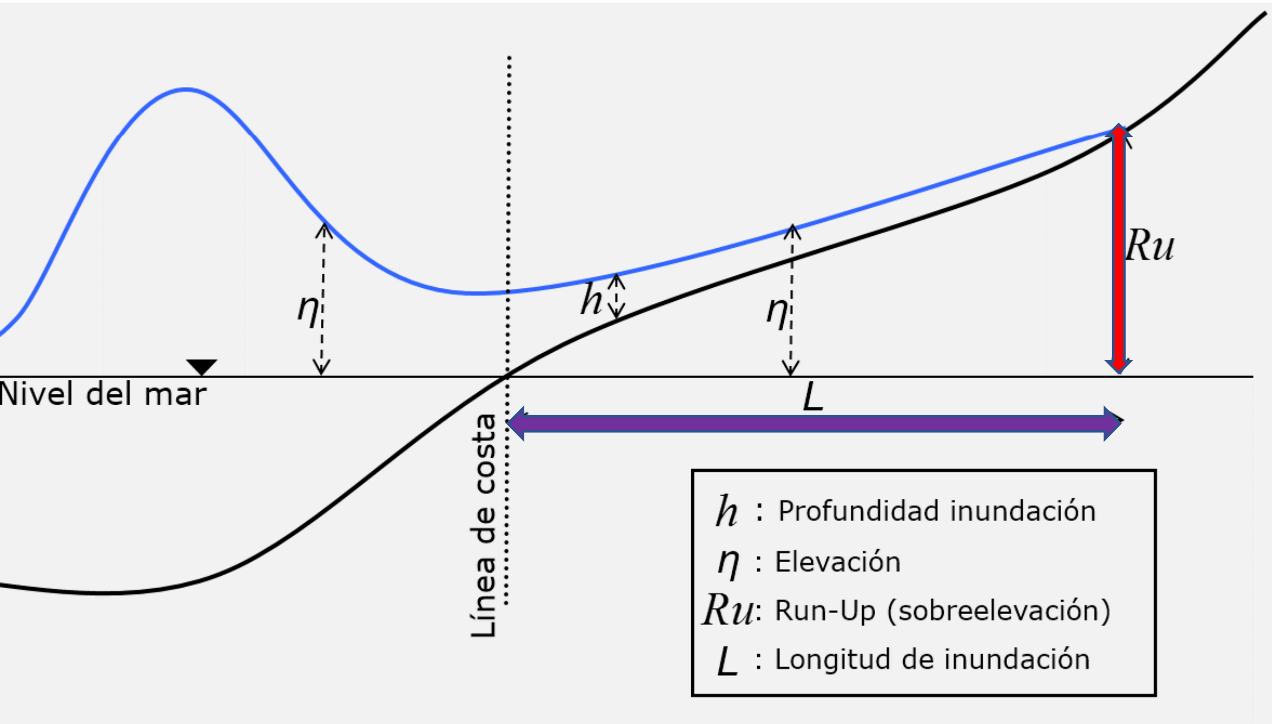
Variables to be represented in maps

1) Tsunami Hazard Map

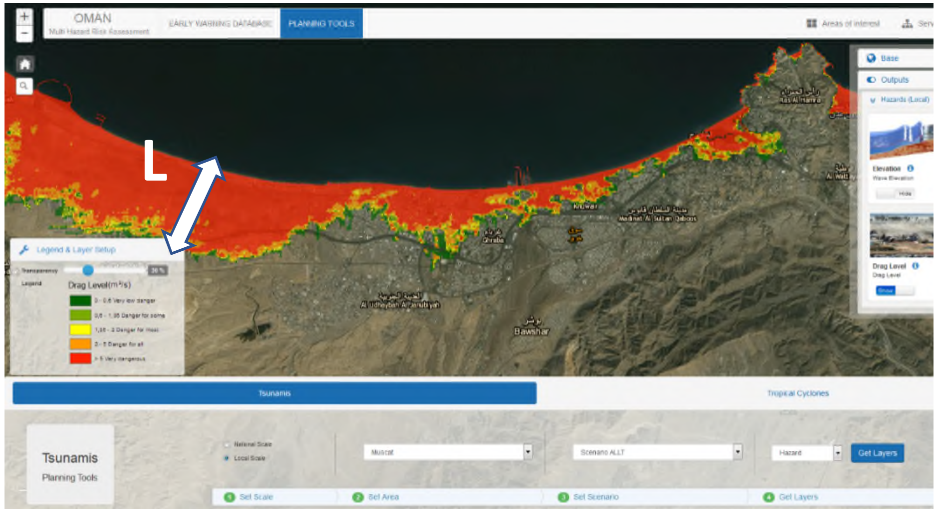
Resultados

Level2) regional scale maps

- Just wave height values are not enough to characterize the affection of a tsunami, because the characteristics of the coastal are that heads the tsunami must be taken into account. This is achieved by combining the wave height with the **run-up** and the **inundation length**.



Run-up definition and flooding length in one profile

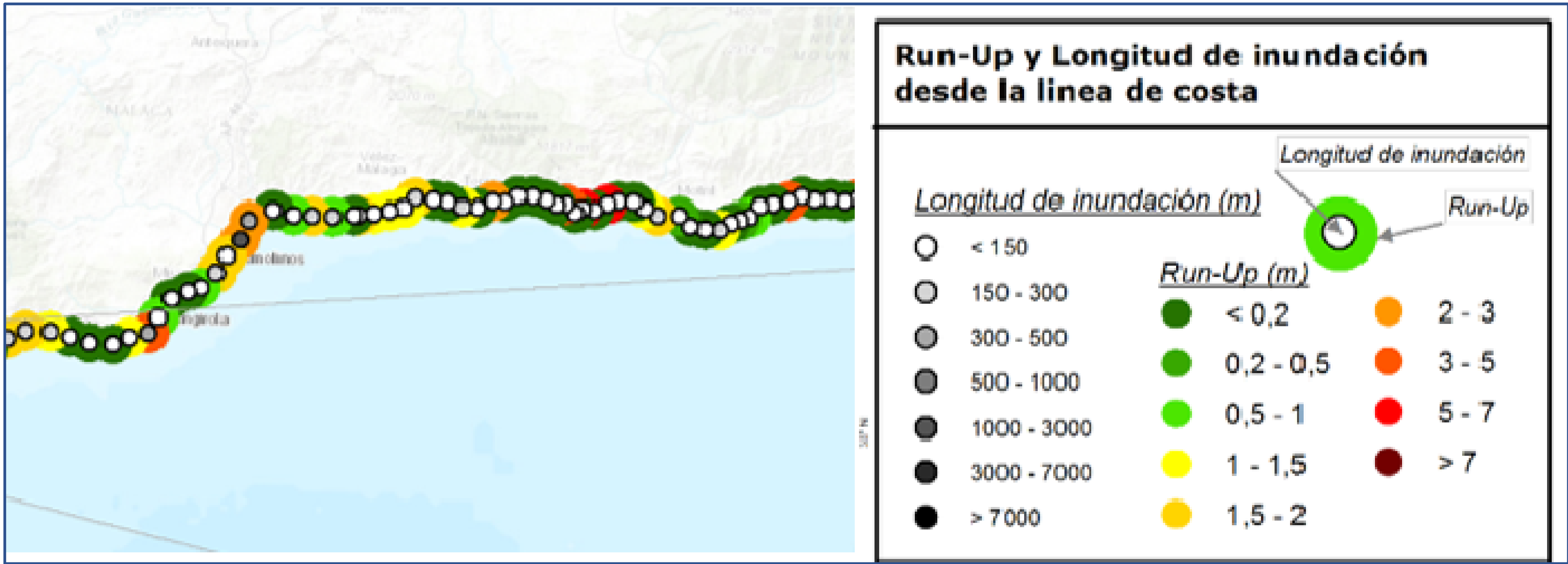


Horizontal Inundation length definition

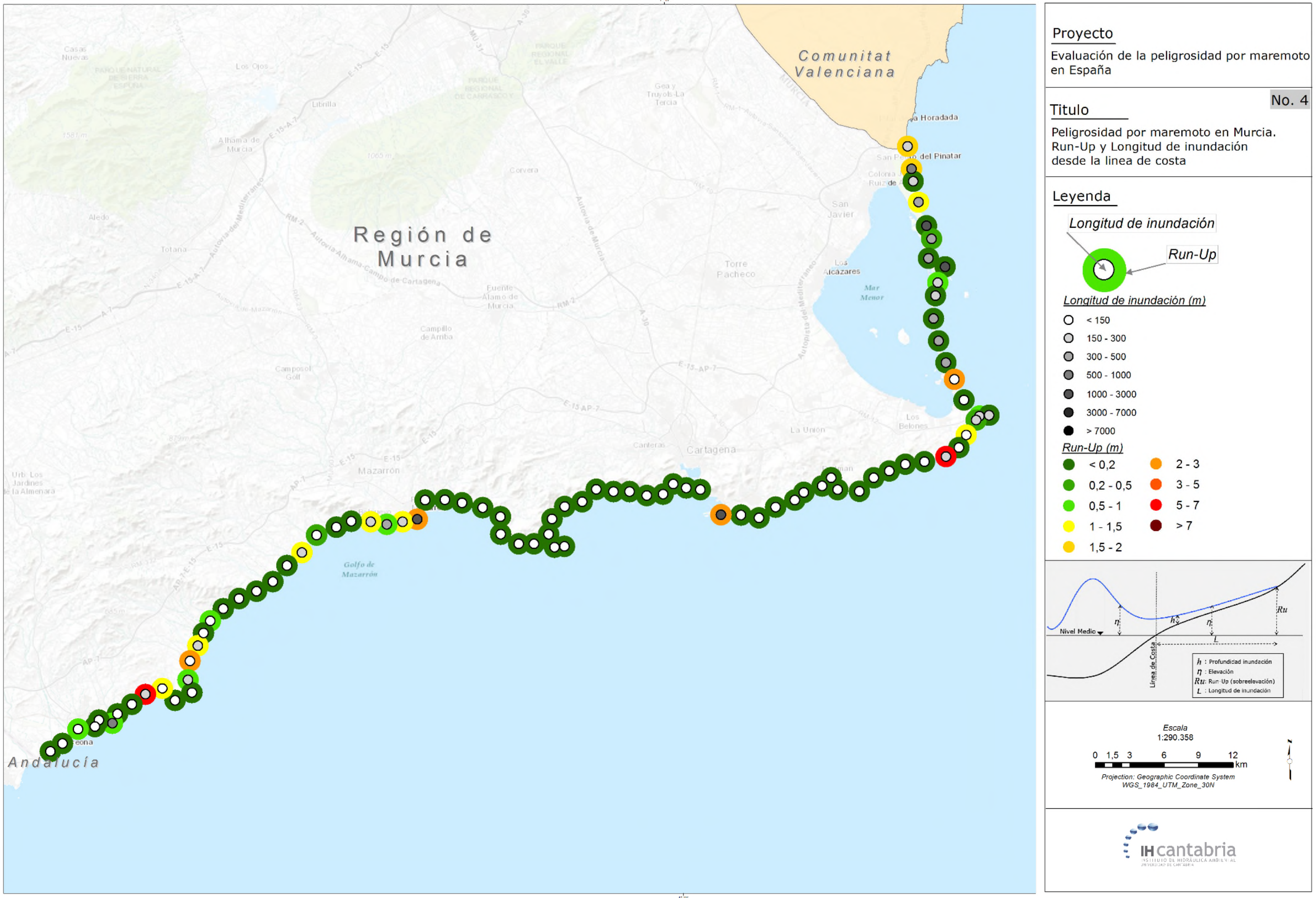
1) Tsunami Hazard Map

Level 2) regional scale maps

- Representation of the run-up and inundation length in one single map
  - **Run-up** or maximum topographic elevation reached by the tsunami during its inundation process
  - **Inundation length from the coastline**



1) Tsunami Hazard Map

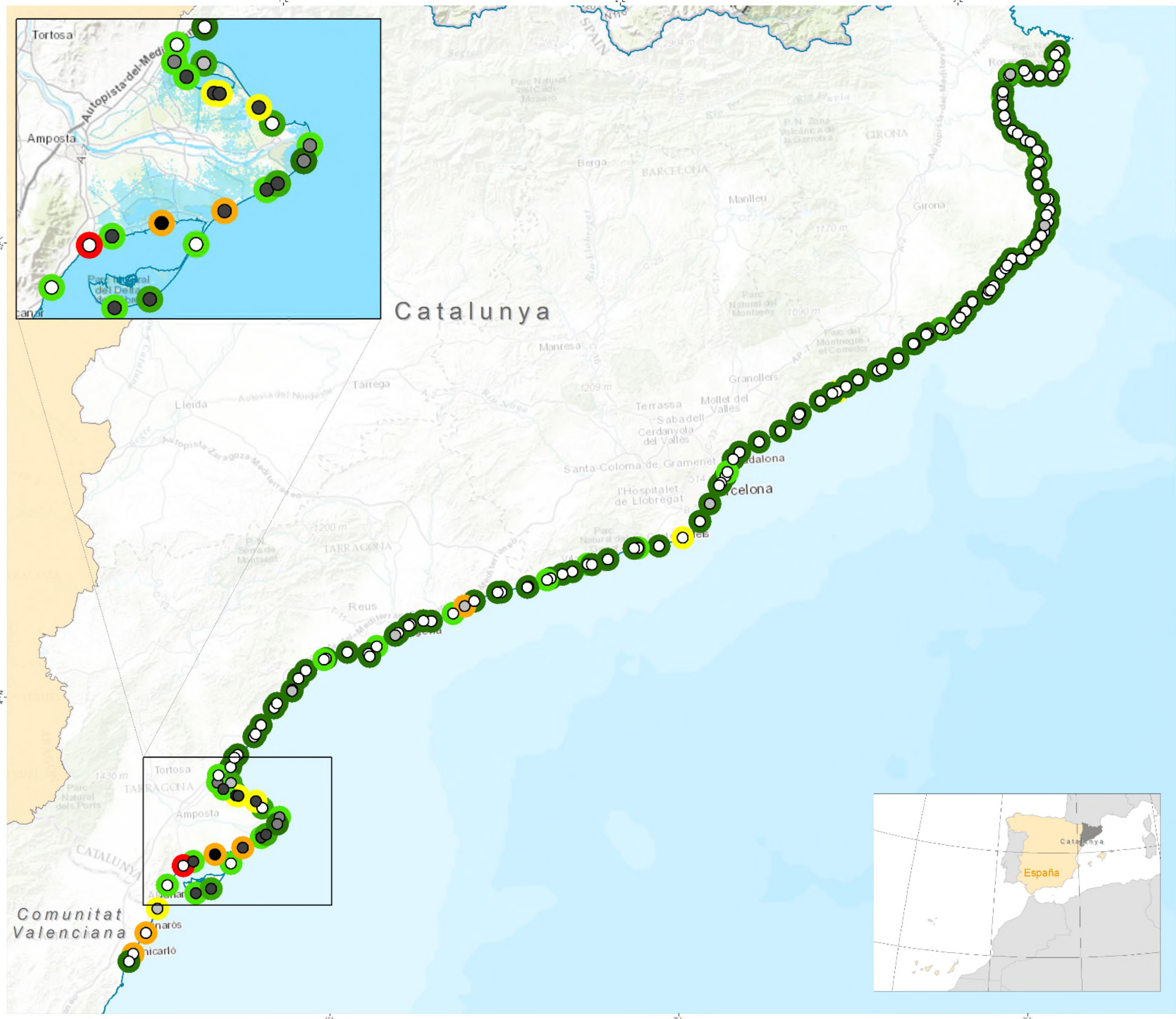


Maps

Región de Mu

Mapas

Cata



Proyecto

Evaluación de la peligrosidad por maremoto en España

No. 12

Titulo

Peligrosidad por maremoto en Cataluña
Run-Up y Longitud de inundación
desde la linea de costa

Legenda

Longitud de inundación

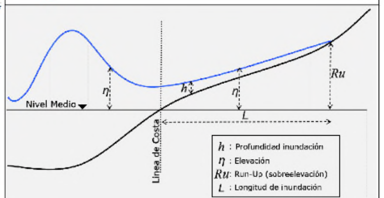
Run-Up

Longitud de inundación (m)

- < 200
- 200 - 500
- 500 - 1500
- 1500 - 5000
- > 5000

Run-Up (m)

- < 0,05
- 0,05 - 0,1
- 0,1 - 0,3
- 0,3 - 0,5
- 0,5 - 0,7
- > 0,7



Escala
1:925.259

0 5 10 20 30 40 km

Projection: Geographic Coordinate System
WGS_1984_UTM_Zone_30N

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ve| 2) regional scale maps:

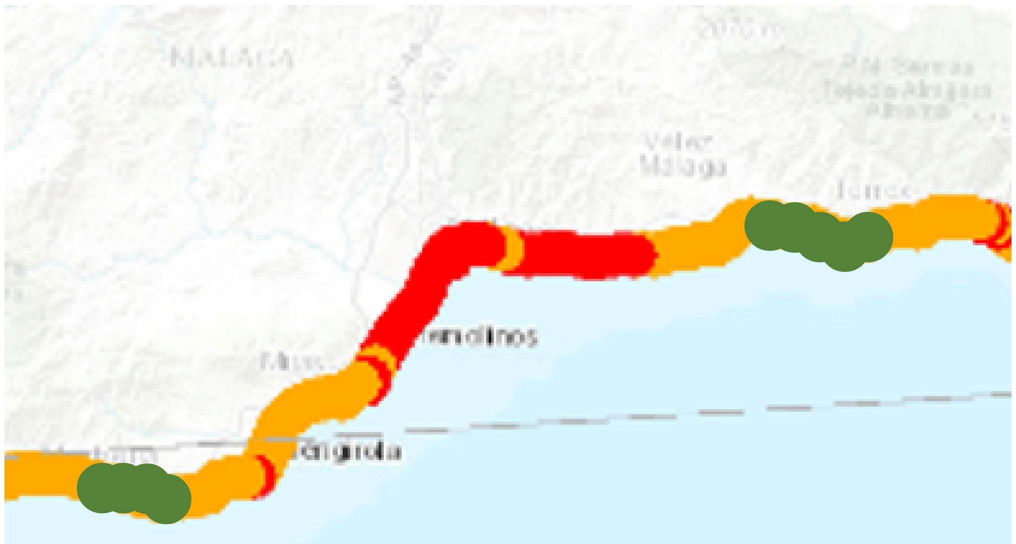
Maps

) Community Map of the Emergency Planning Level at Local Sca

- **Municipalities in RED** when there is flooding inland: **It requires: 1) High resolution risk assessment, 2) Evacuation plans, y 3) Mitigation measures implementation**.

- **Municipalities in YELLOW Beach Flooding:** It requires emergency planning and evacuation of beaches

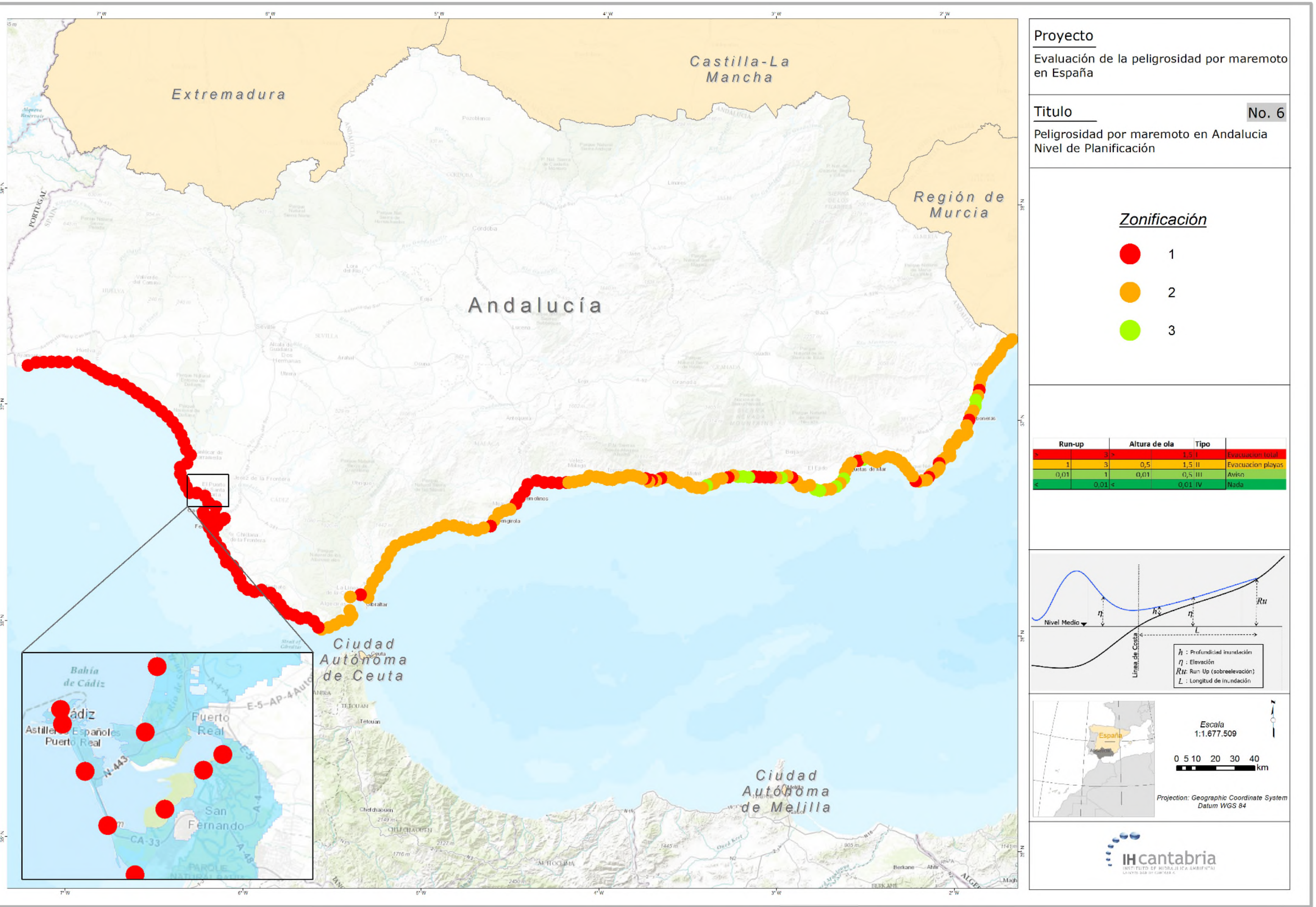
- **Municipalities in GREEN No flooding:** It requires **to plan the emergency in ports and harbors** about the actions to be carried out in case of tsunami wave arriving



Red	Warning for coastal areas Risk planning of prone flooding area Evacuation plan Mitigation measures
Yellow	Beach area warning Evacuation plan for beaches Mitigation measures
Green	Harbors and ports warnings Mitigation measures

Maps

Zonificación nive planeamient Andal



Run-up		Altura de ola		Tipo	
>	3	>	1,5	I	Evacuacion total
1	3	0,5	1,5	II	Evacuacion playas
0,01	1	0,01	0,5	III	Aviso
<	0,01	<	0,01	IV	Nada

Level 3 Municipality Scale

Local scale tsunami planning:
Risk calculation and assessment

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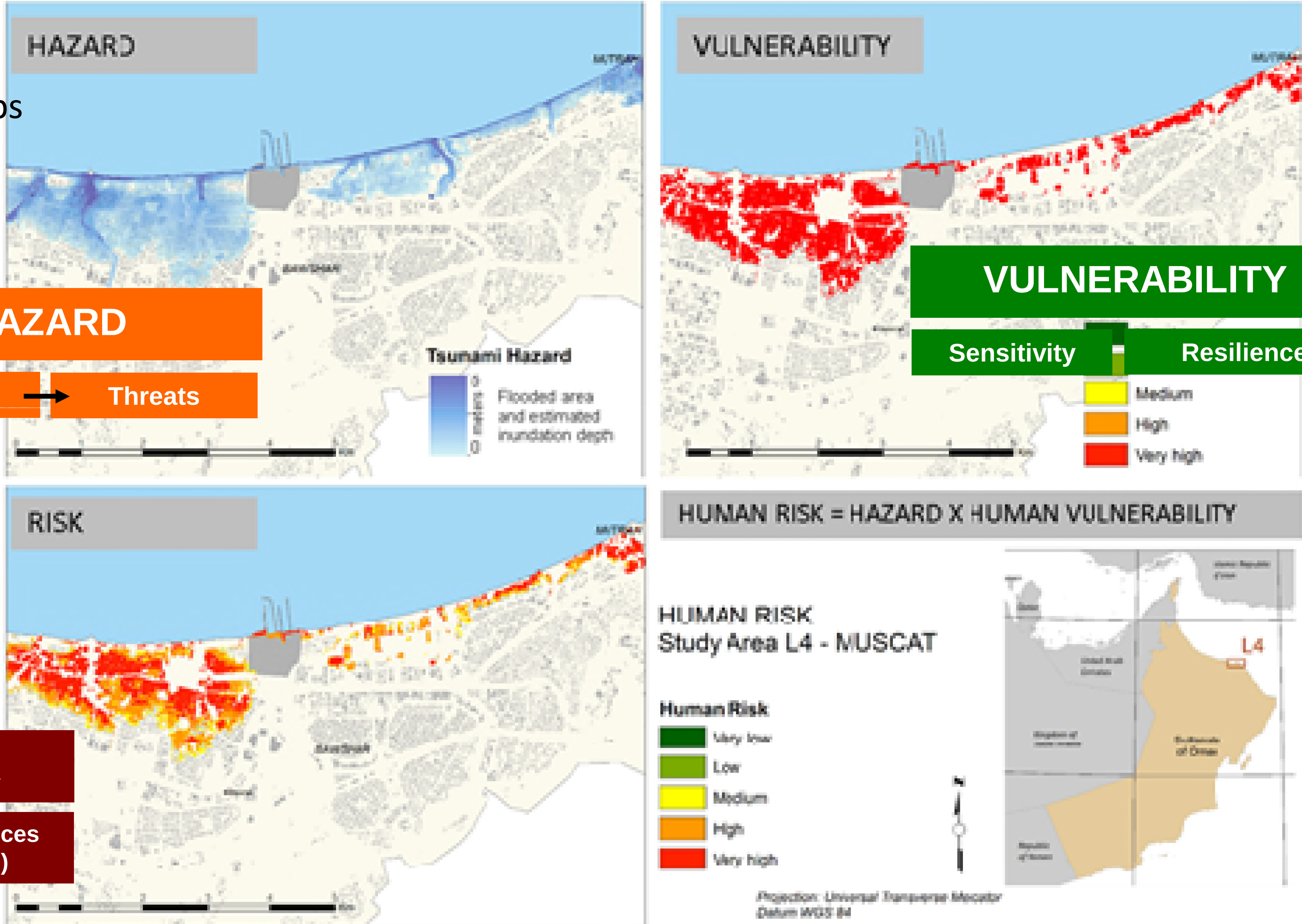
Local Risk Maps (Municipality Scale)

Conceptual Frame

RISK (Impacts) **=** **HAZARD** (Dynamics → Threats) **x** **EXPOSURE** **x** **VULNERABILITY** (Sensitivity, Resilience)

RISK = HAZARD x EXPOSURE x VULNERABILITY

igh resolution maps
x=30-50m



Dimension
- -Human
- -Socioecon
- -Infrastruct
- -Environme

HAZARD

Dynamics → Threats

VULNERABILITY

Sensitivity | Resilience

Mitigation measures and plans

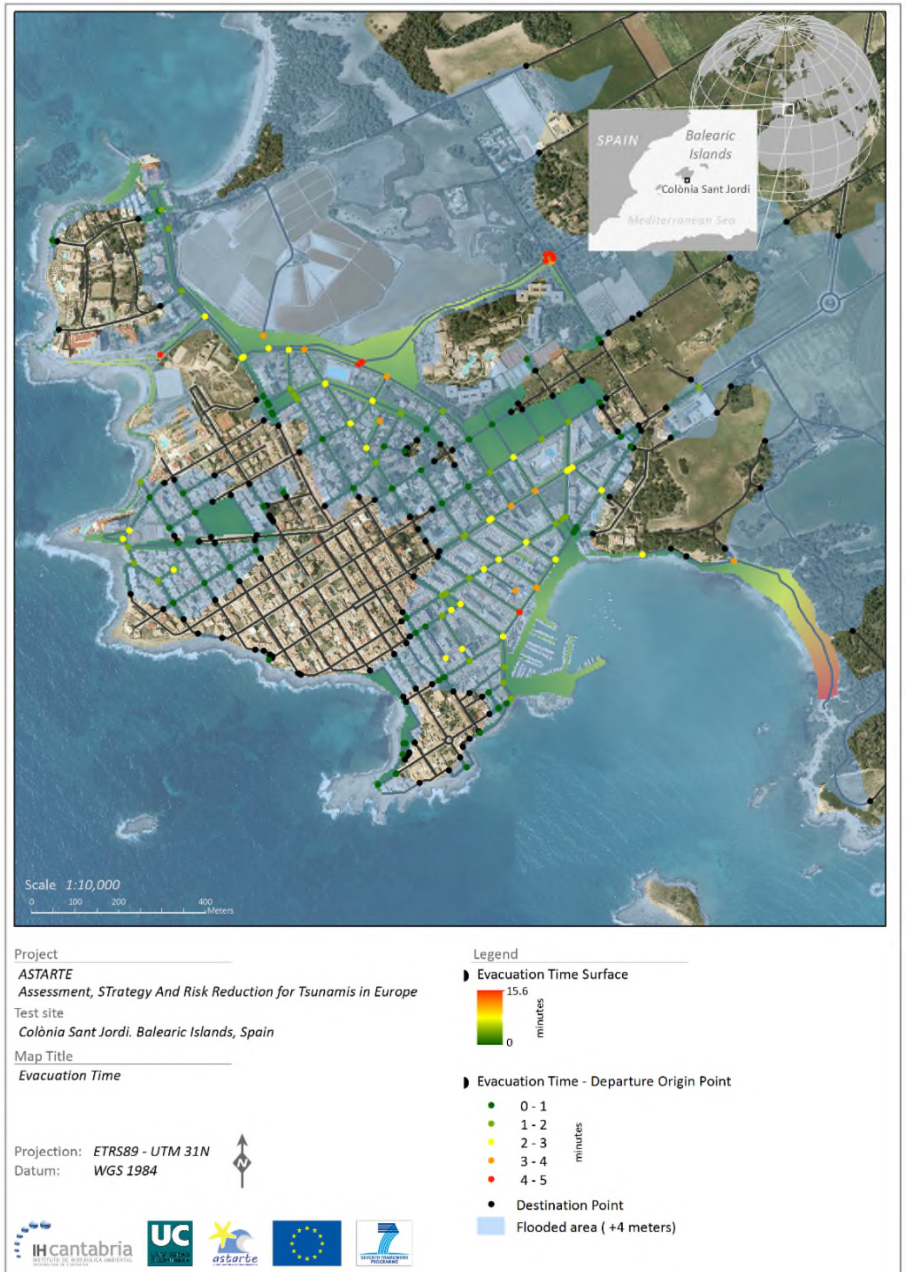
RISK

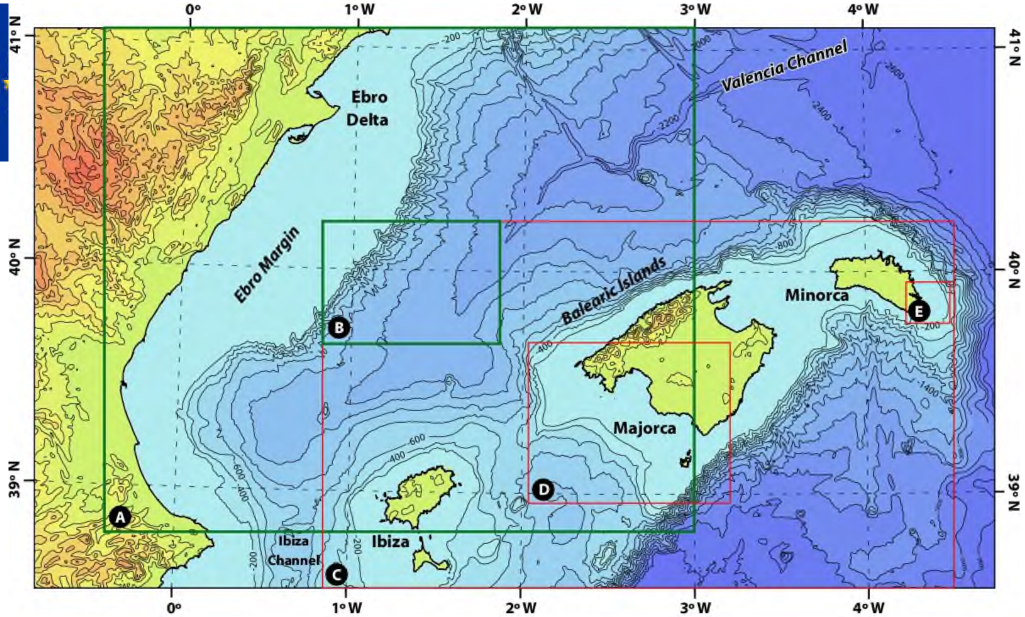
Consequences (Impacts)

Maps Level 3) local scale risk studies

RISK REDUCTION MEASURES PROPOSAL

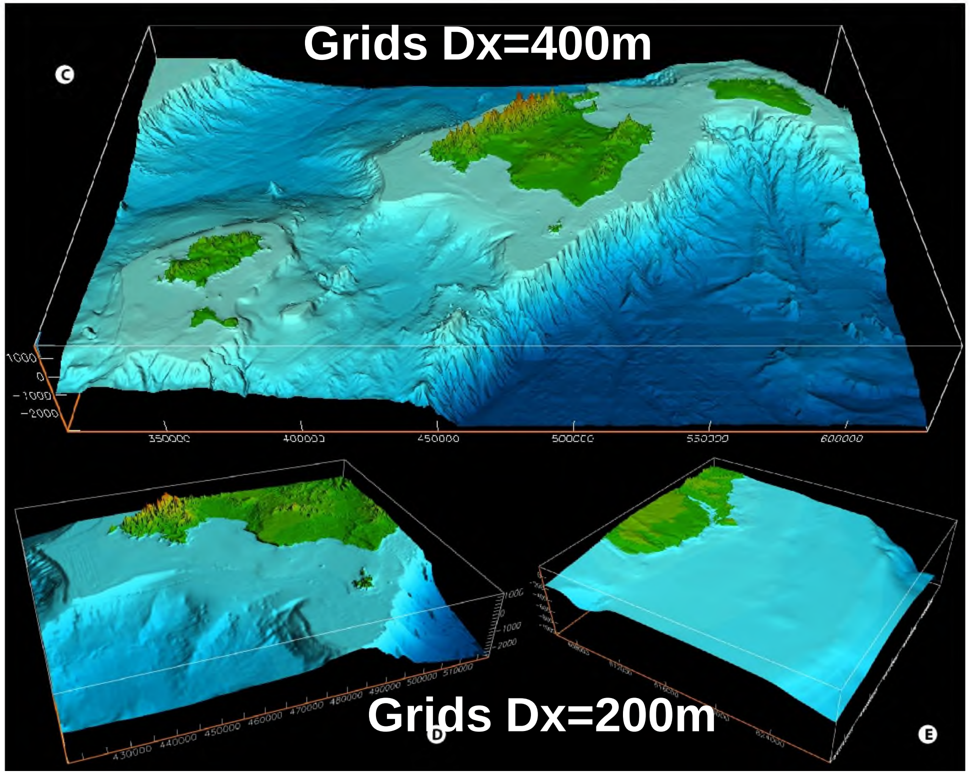
E.g. Evacuation plans



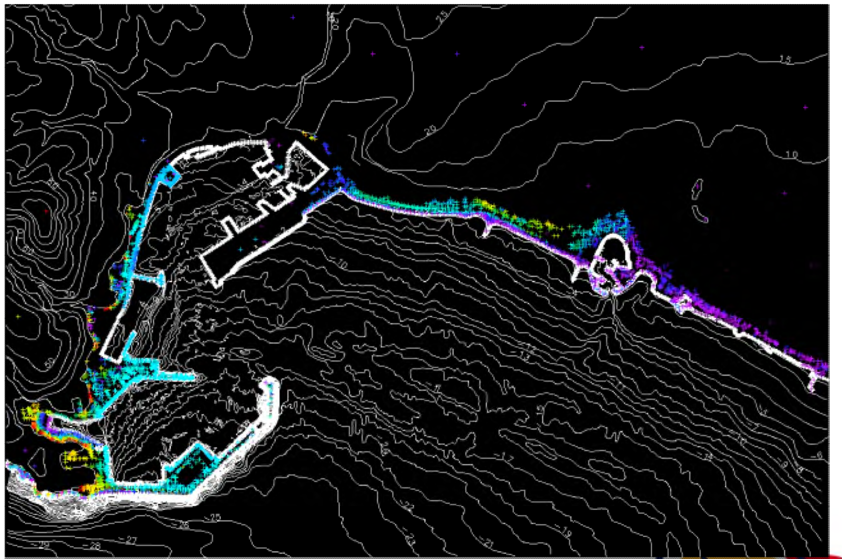


It requires:

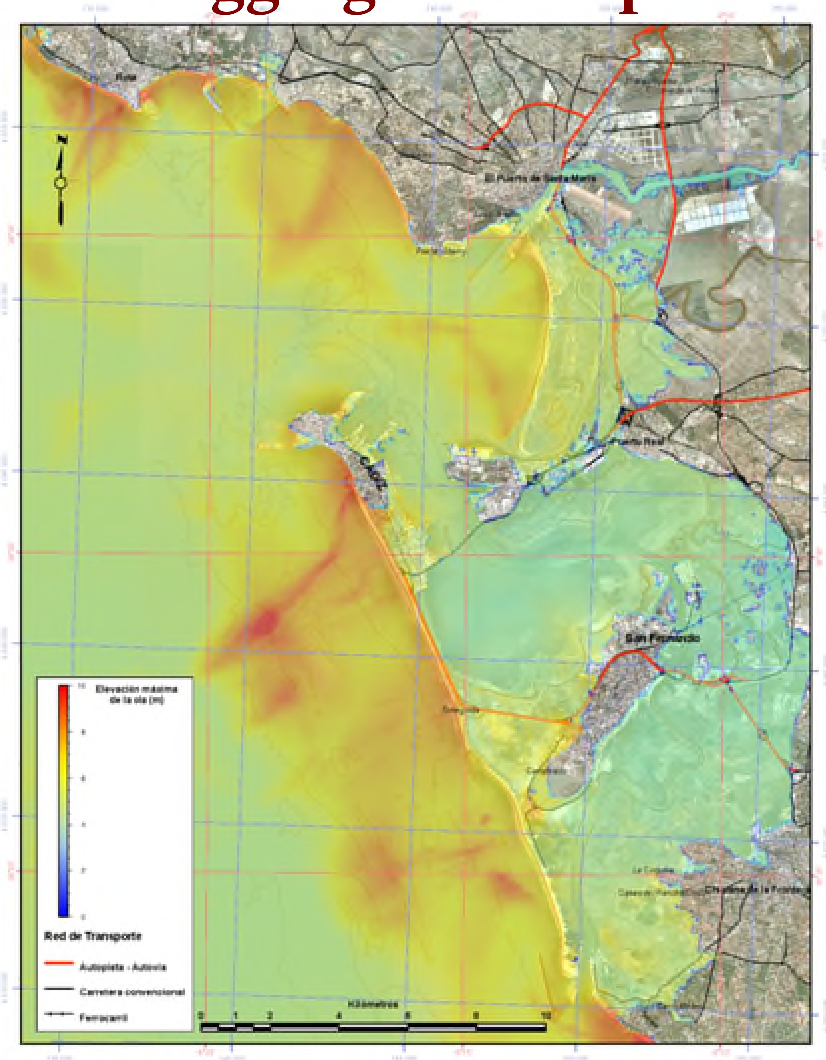
Topobathymetric reconstructio



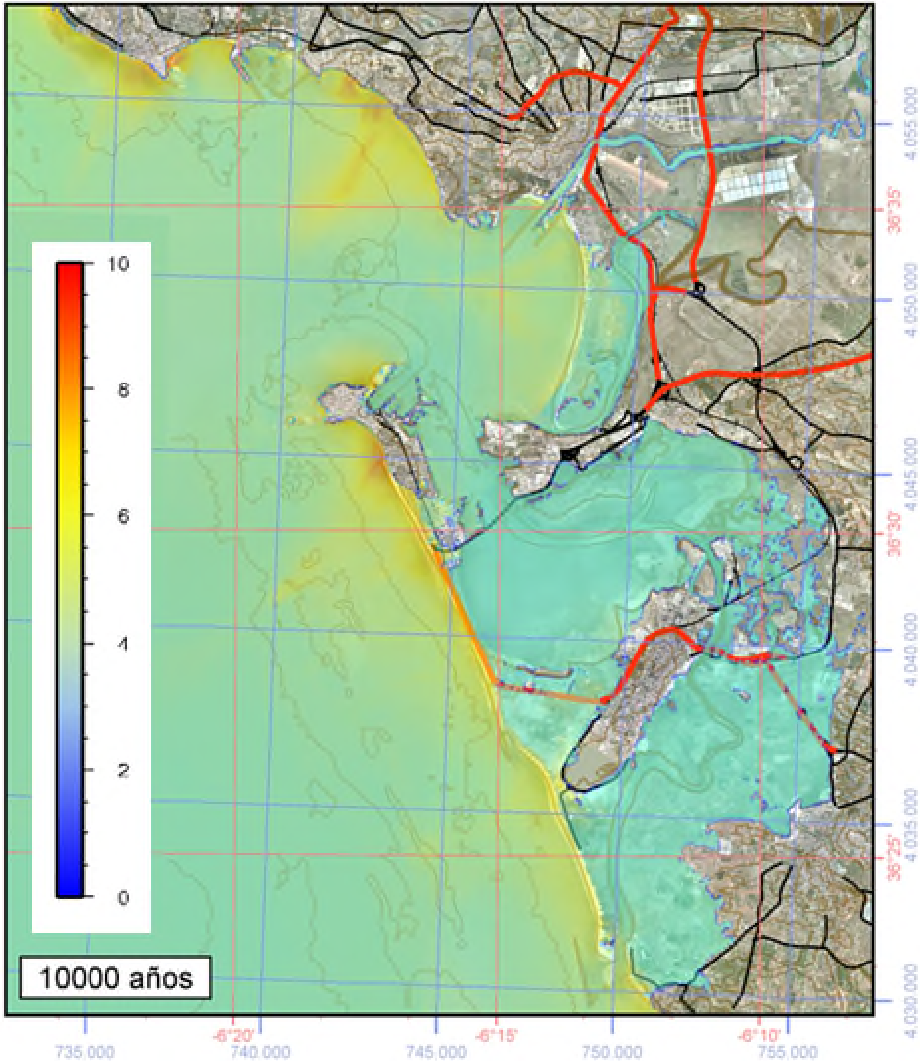
Grids Dx=30-50m



Deterministic Map
Aggregated Map

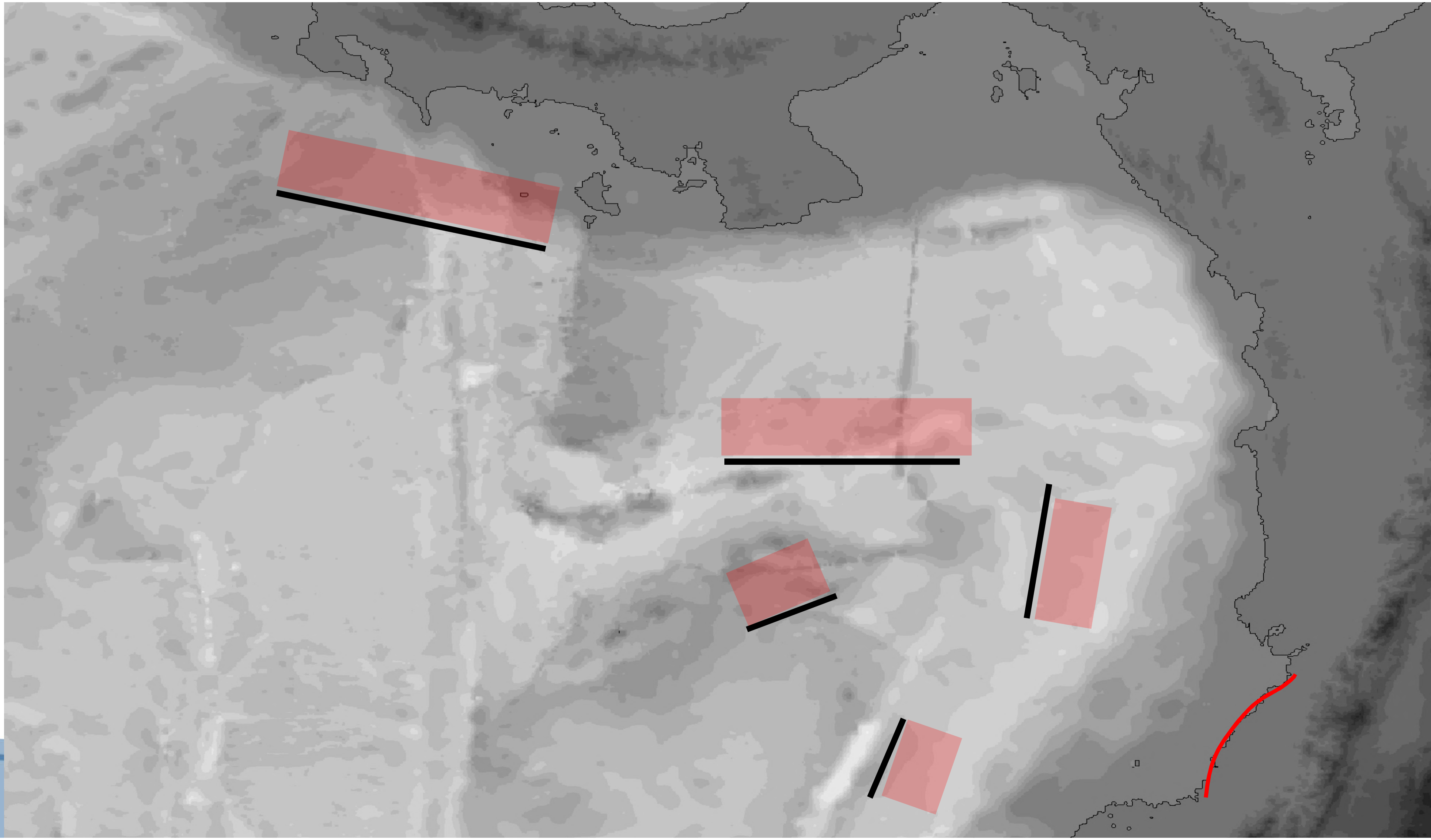


Probabilistic Map
Tr=10.000 years

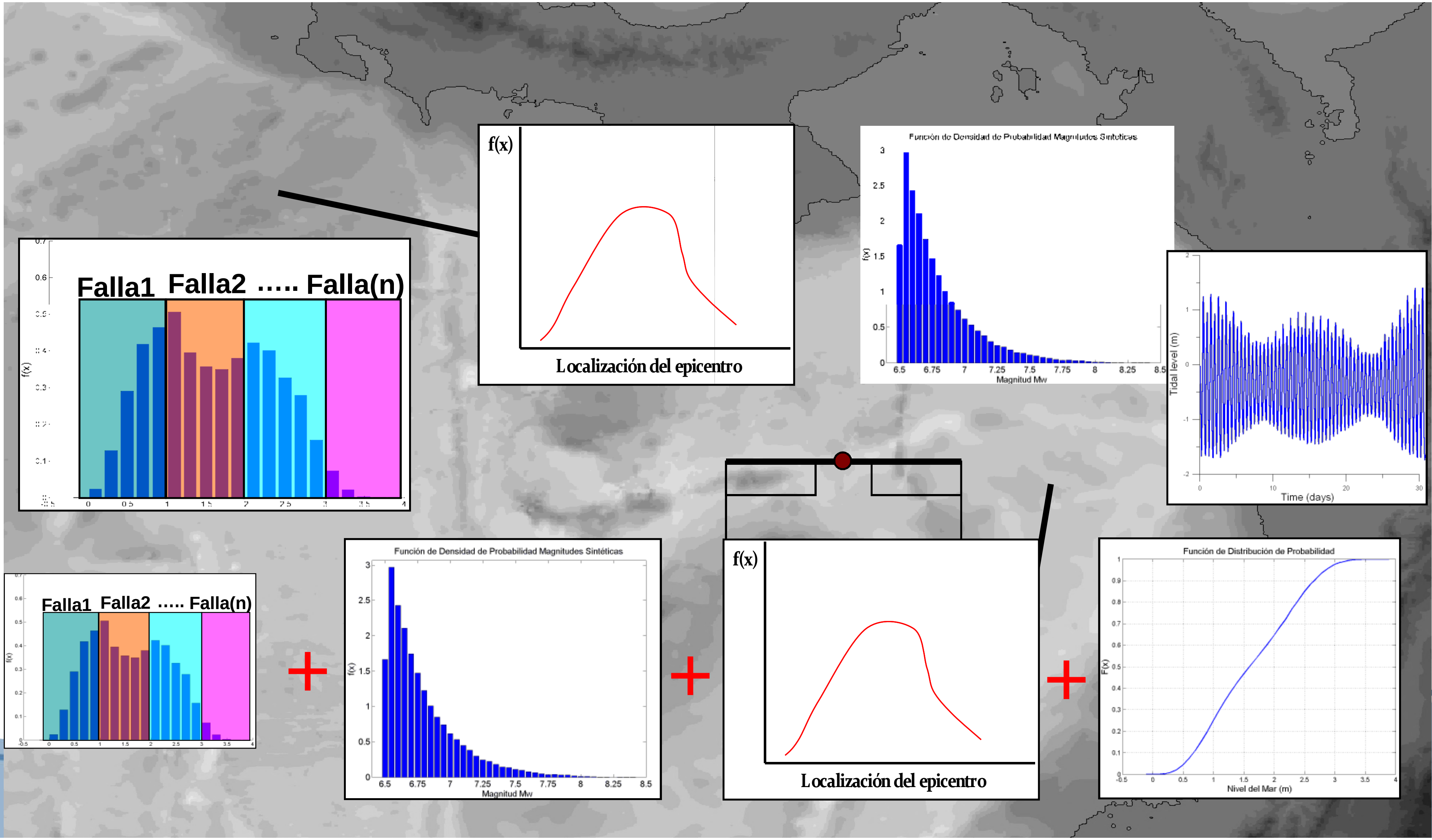


Deterministic approach

(Aggregated maps of Worst Credible Cases)



Probabilistic approach (4 variables)

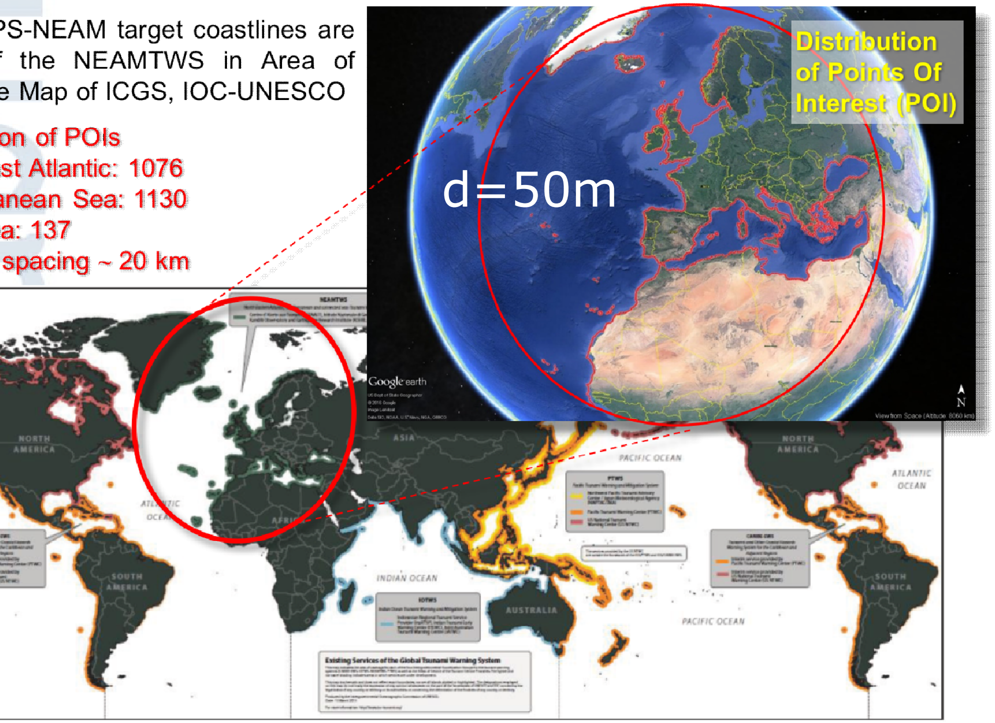


Probabilistic TSUnami Hazard MAPS for the NEAM Region

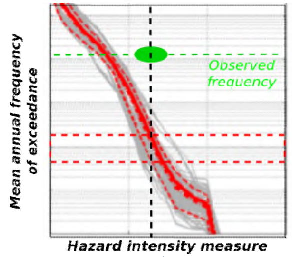
coastlines (NEAMTWS)

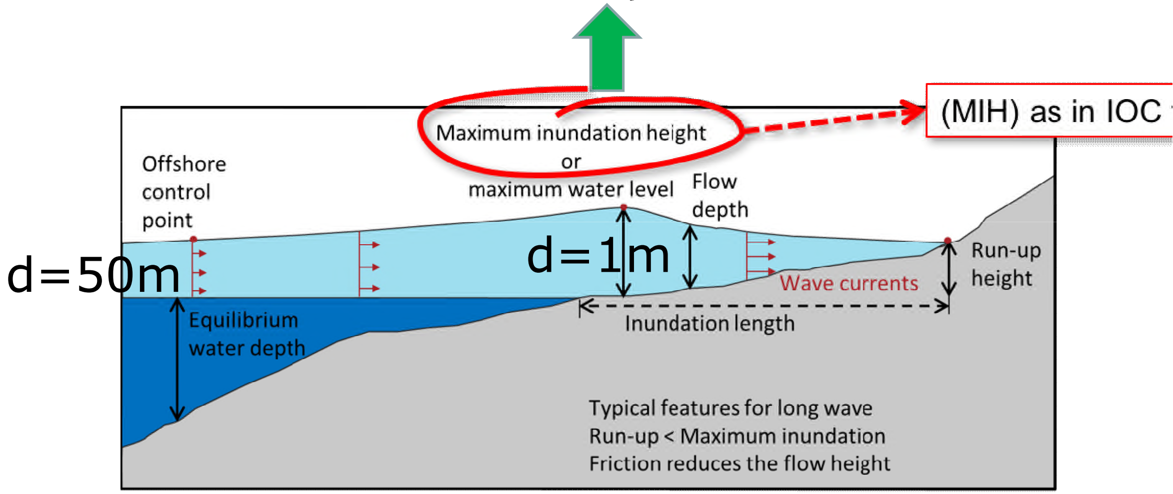
PS-NEAM target coastlines are f the NEAMTWS in Area of e Map of ICGS, IOC-UNESCO

on of POIs
st Atlantic: 1076
anean Sea: 1130
a: 137
spacing ~ 20 km



p on Tsunamis and Other Hazards Related to Sea-Level Warning and Mitigation Systems (TOWS-WG)
g Morioka, Japan 12–13 March 2015





n the future is necessary to stablish a methodology and numerical to Hysea model) to obtain probabilistic flooding maps including the ncertainties, starting with the input in depth=50m

Conclusions

Conclusions

- **The Basic Directive of November 2015 sets 3 levels of Tsunami planning: Level 1: National, Level 2: Regional (CCAA) y Level 3: Local (municipal).**
- The national scale map defined that **all coastal Communities/Provinces must tackle the level 2 analysis except Cantabria and Basque Country**.
- **The existing National cartography does not have resolution enough, neither data onshore to be used in the level 2, for the identification of municipalities that must to carried out local risk assessment at level 3.**
- **IHC proposes to elaborate a medium level cartography, including coastal flooding calculation** to make easier each region decision on **which municipalities must afford a level 3** and set the **"level 3 emergency planning".**

Conclusions

- There are methodologies already developed and applied worldwide to elaborate **local tsunami risk maps** together with evacuation plans.

- **Maps that would allow the municipalities to set and implement mitigation measures in a unified way.**

- **Probabilistic maps require a huge computational effort, and their application is not easy for the local managers.**

- On the other hand, **deterministic maps provide the worst potential situations in a municipality, being a practical tool to implement the mitigation and preparation measures, including evacuation maps and identifying safe areas.**

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Recommendations

- To elaborate the level 2 community/province cartography, **allowing the identification of most affected areas and municipalities.**

- **To avoid a Frankenstein local risk maps**: The LOCAL risk cartography should be elaborated at the same time on each region and municipality in order **to develop the maps following a unified criteria**: the same methodology to elaborate the tsunami hazard, vulnerability and risk maps, the same seism tectonic sources and focal parameters, same bathymetry, scales and resolutions, vulnerability dimensions, etc. **This will make it easier to plan and implement preparation and mitigation measures.**

- **This will facilitate the community authorities, because they are responsible of approving the local scale acting plans.**

- **At this state, it is recommendable deterministic maps over probabilistic maps.**

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I+D+i para un desarrollo sostenible

TSUNAMI HAZARD MAPS AS A SUPPORT TO STABLISH EMERGENCY AND PREPARATION PLANS AT THE SPANISH REGIONAL SCALE.

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