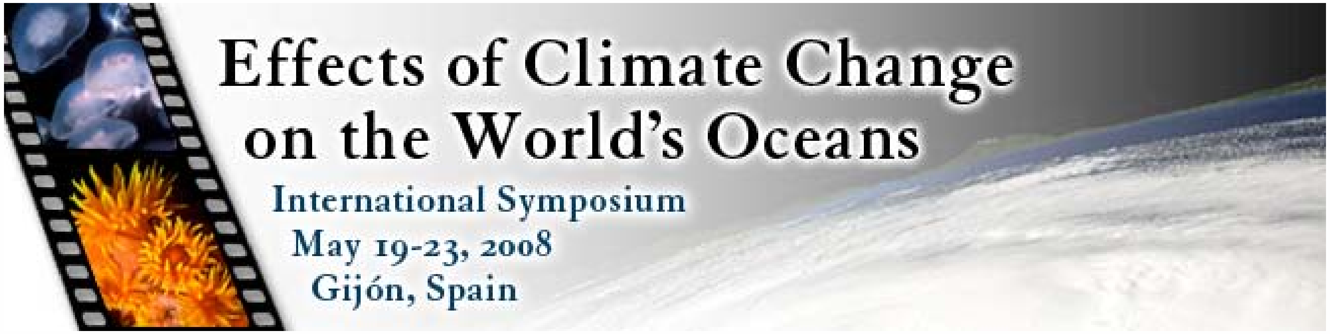


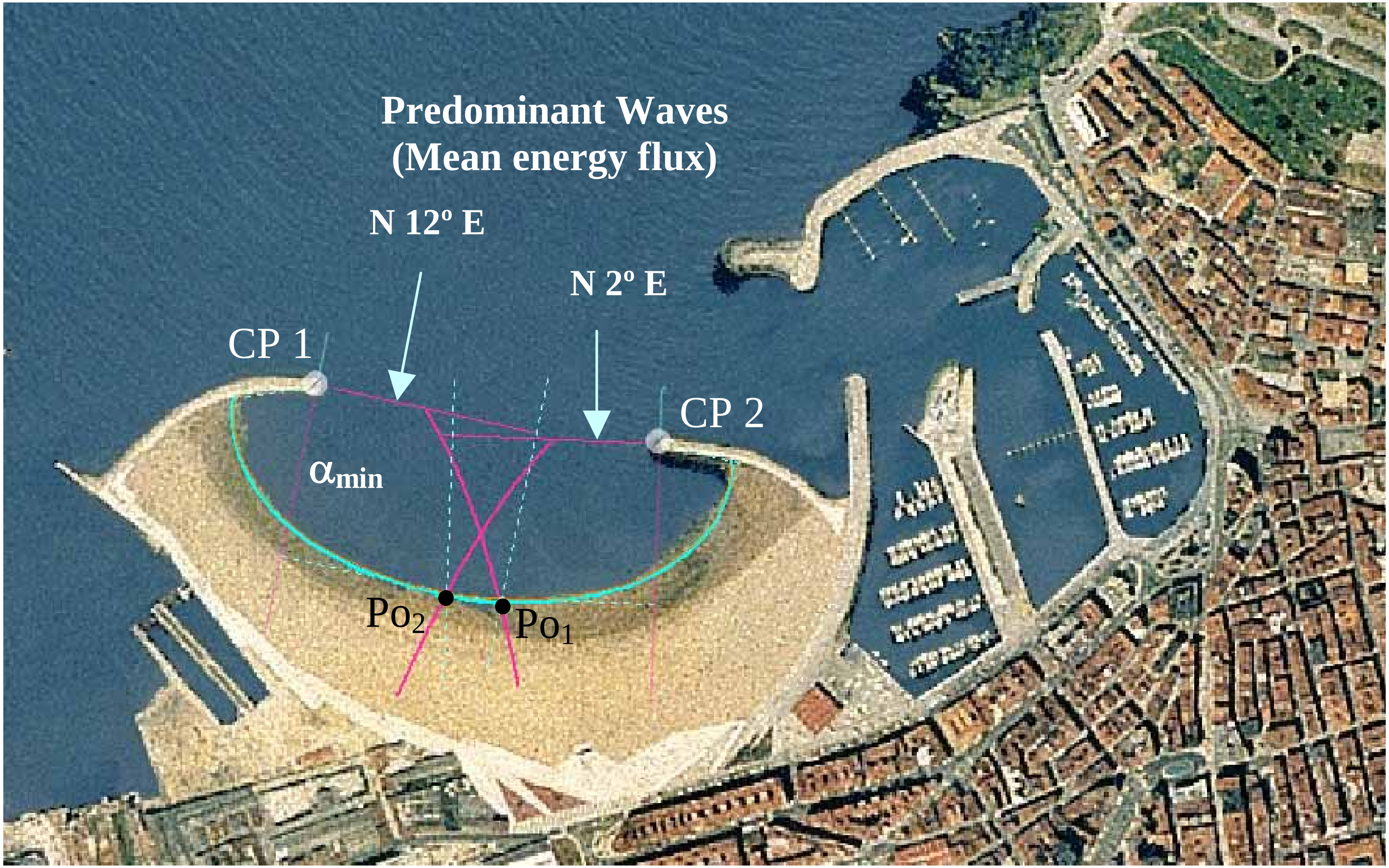
A methodology to evaluate the impacts of climate change in a coastal system

Fernando J. Mendez, Inigo J. Losada, Raul Medina,
Maitane Olabarrieta, Melisa Menendez, Paula Camus

Environmental Hydraulic Institute, IH Cantabria, Universidad de Cantabria
mendezf@unican.es

Which is the shape of the equilibrium planform of this beach?

We need to define the local wave climate: long-term distribution



How many hours in a year the agitation inside the harbor is higher than 30 cm?

We need to define the local wave climate: long-term distribution

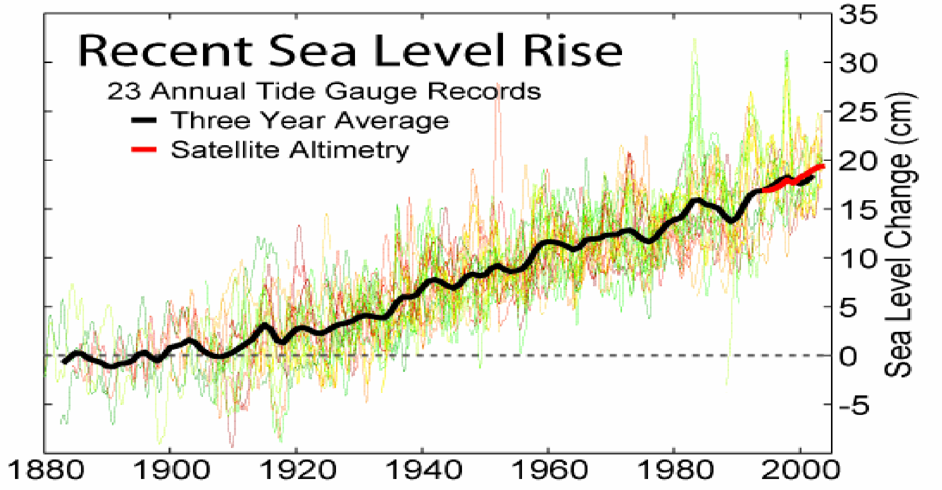
What should be the size of the blocks of this rubblemound breakwater?

We need to define the local wave climate: long-term extreme value distribution

How frequent does the breaching of this beach take place?

We need to define the local wave climate: long-term extreme value distribution

We are aware of recent trends of sea level…



Is Wave Climate being affected by Climate Change ?

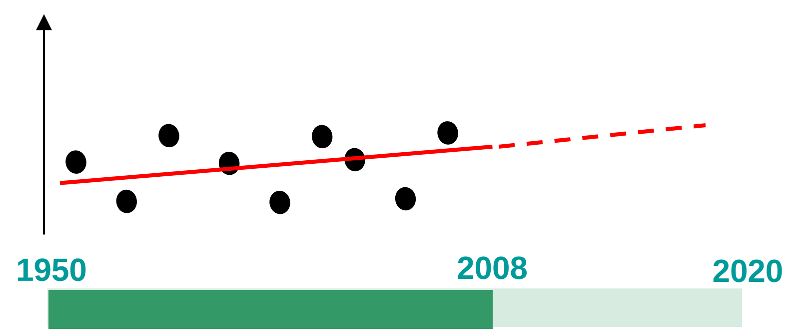
Objective: Evaluation of Climate Change Impact on coastal areas

Analysis and evaluation of climate change impacts on beaches, estuaries, lagoons, deltas and dune morphodynamics; coastal erosion; flooding risk assessment and impacts on the functionality and stability of coastal infrastructures

To take into account

- **Sea level rise**
- **Wave climate trends**: long-term distribution and extreme value distribution: Hs, W, θ, SS

Historical analysis of long-term trends



Outline

1. Introduction
2. Methodology to obtain regional vulnerability indices
3. Methodology to assess detailed studies
4. Conclusions

2. Methodology to obtain regional vulnerability indices

"Effects of the climate change on the spanish coast"(2002-2004)

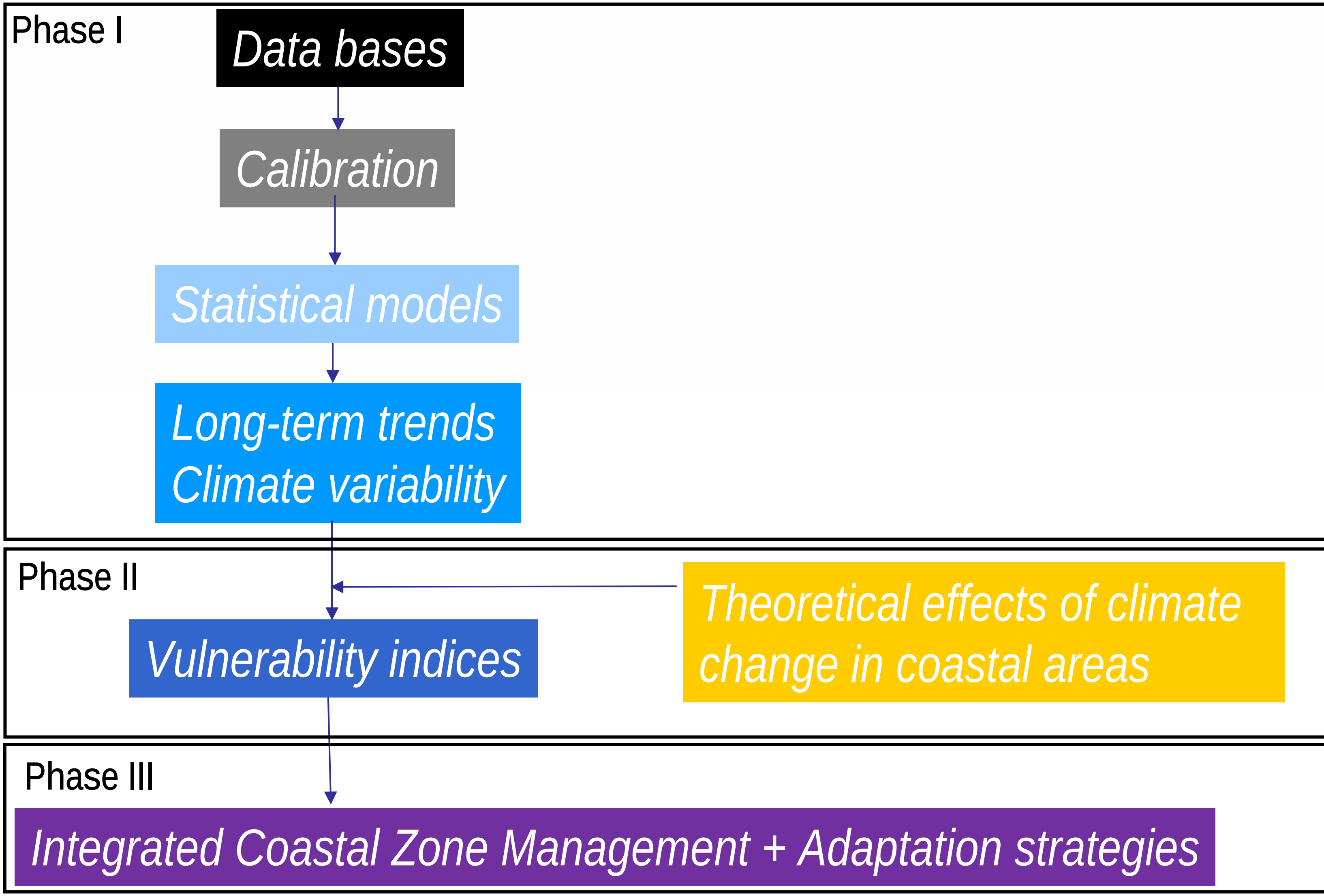
Funded by the Spanish Agency of Climate Change
(Ministerio de Medio Ambiente, SPAIN)

Phase I: To evaluate wave climate and sea level changes along the littoral

Phase II: To evaluate changes in the coast: beaches, ports, estuaries,…

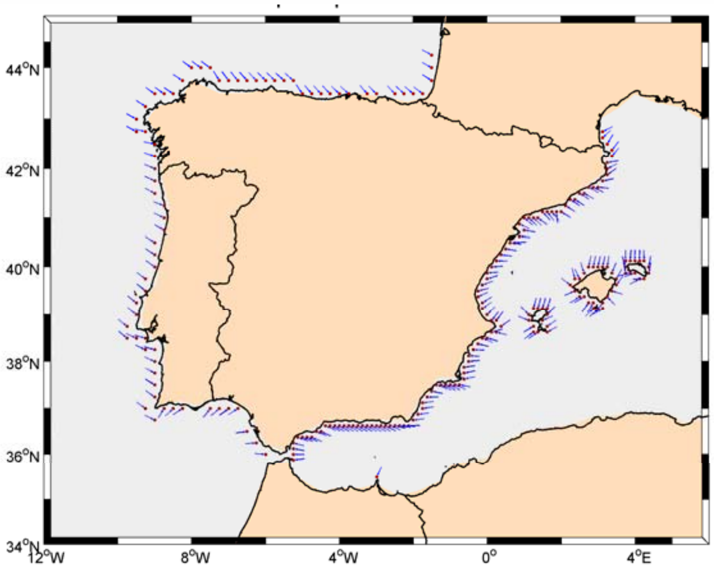
Phase III: To establish strategies

2. Methodology to obtain regional vulnerability indices



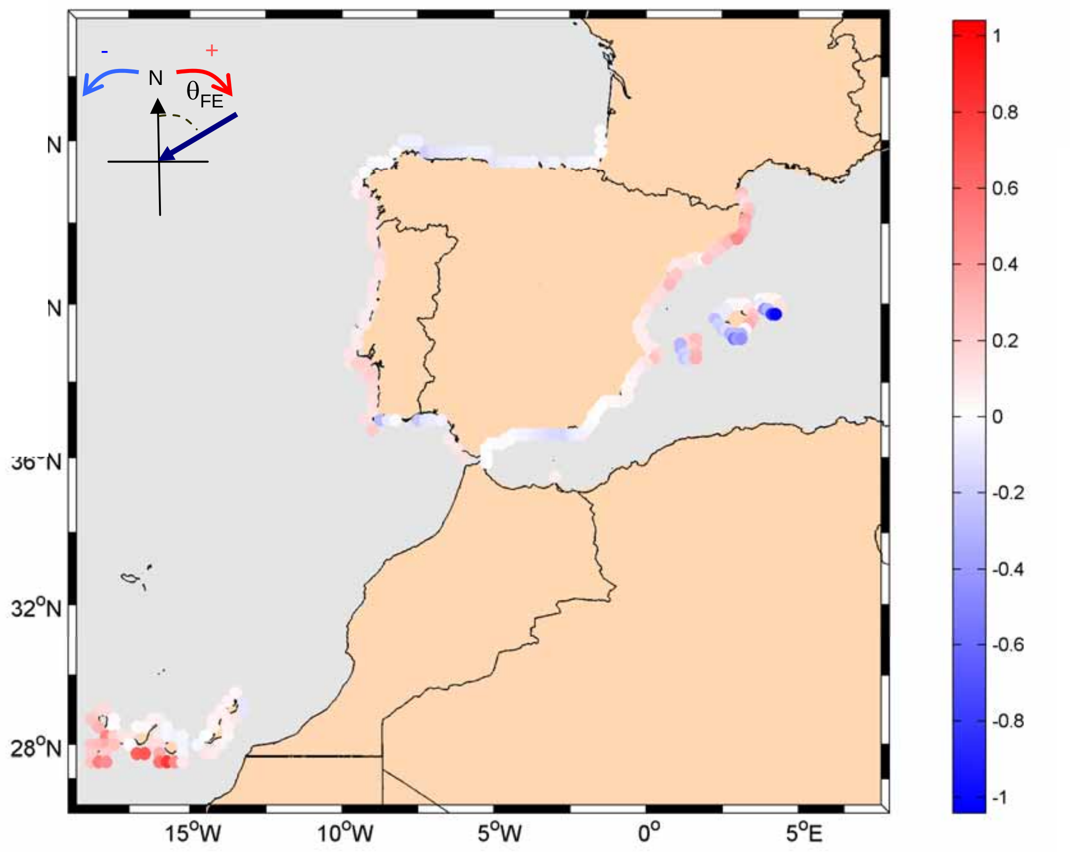
2. Methodology to obtain regional vulnerability indices

Average Direction of mean energy flux

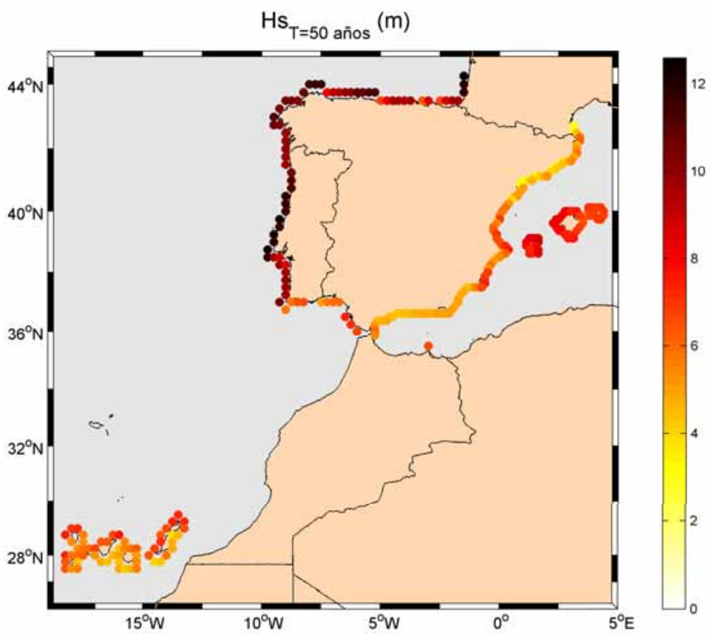


Long-term trend of Direction of mean energy flux

$\Delta\theta_{FE}$ (°/year)



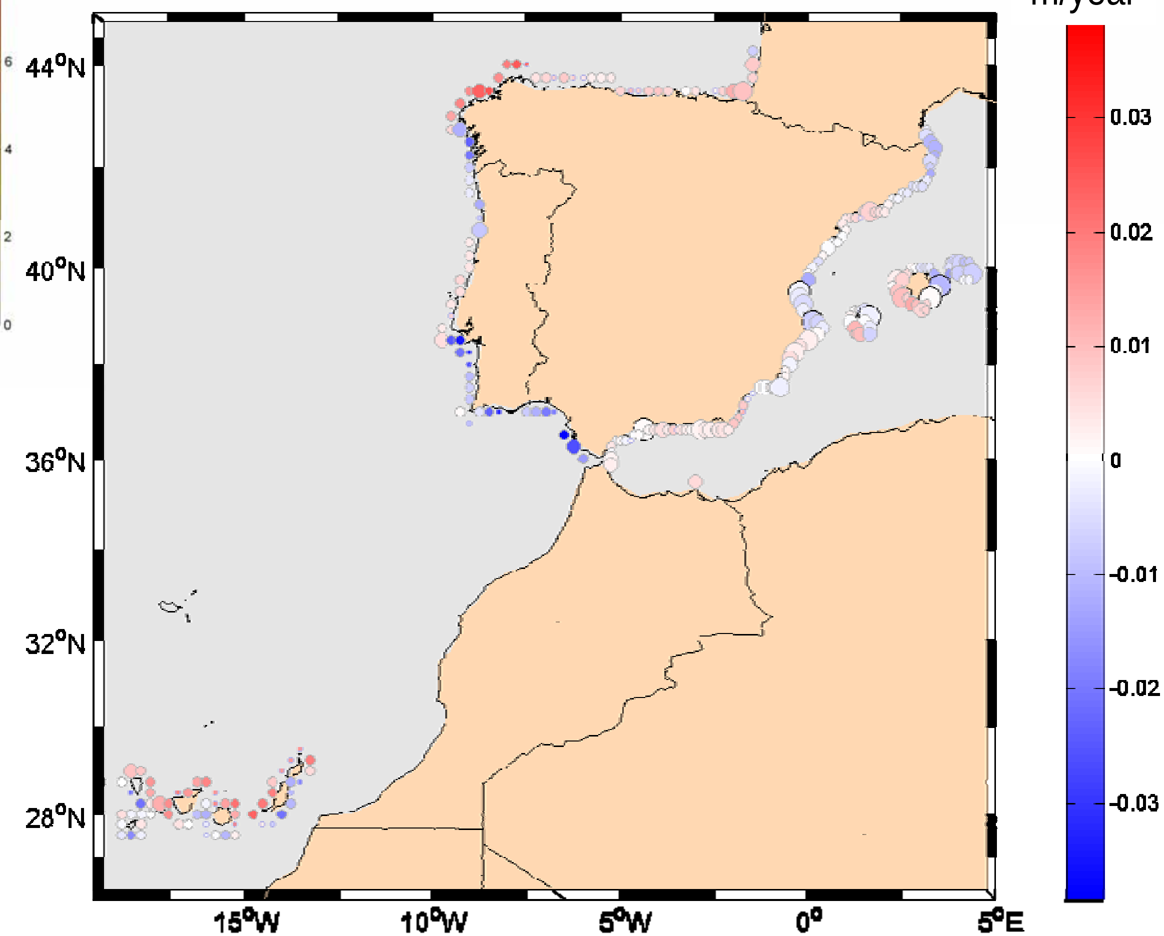
2. Methodology to obtain regional vulnerability indices



H

Long-term trend in SWH exceeded once every 50 years

δH



2. Methodology to obtain regional vulnerability indices

$$W = kH^3$$

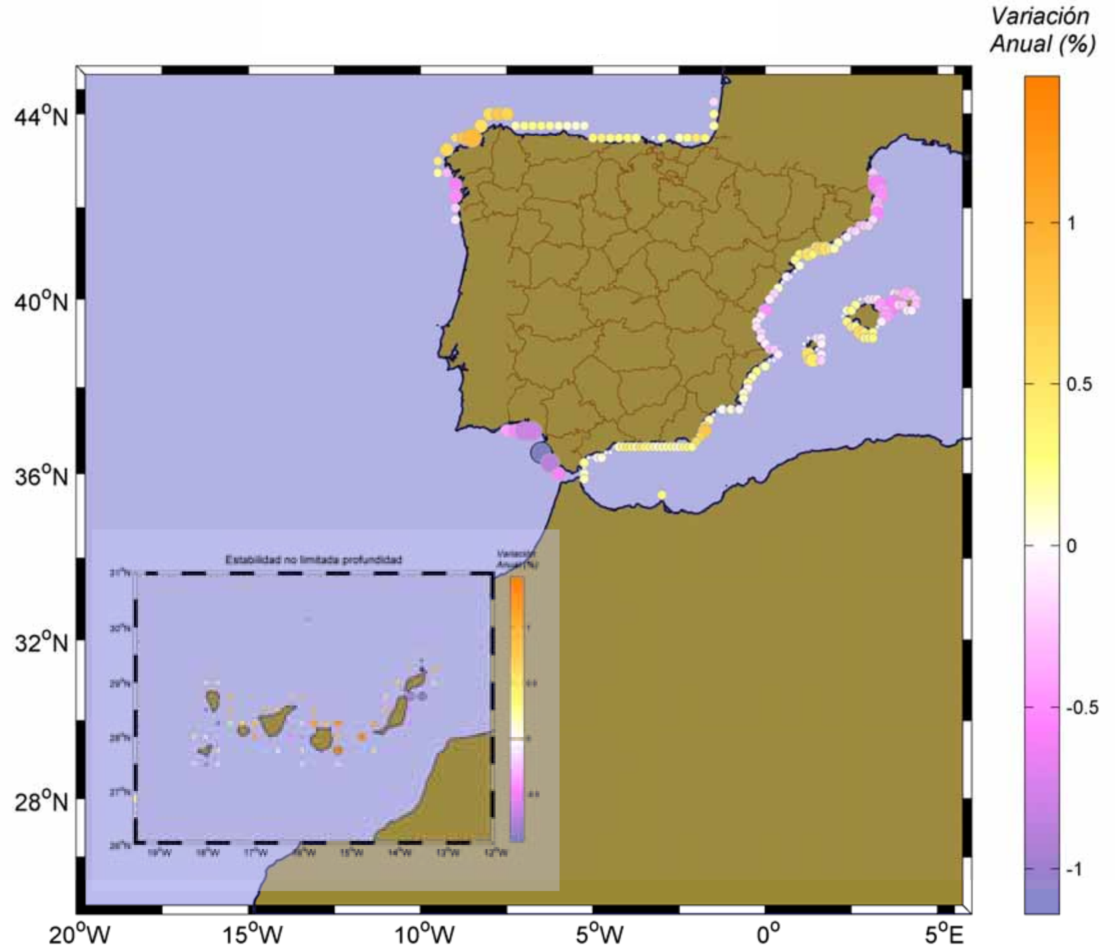
$$\delta W = 3kH^2 \delta H$$

$$\frac{\delta W}{W} = 3\frac{\delta H}{H}$$

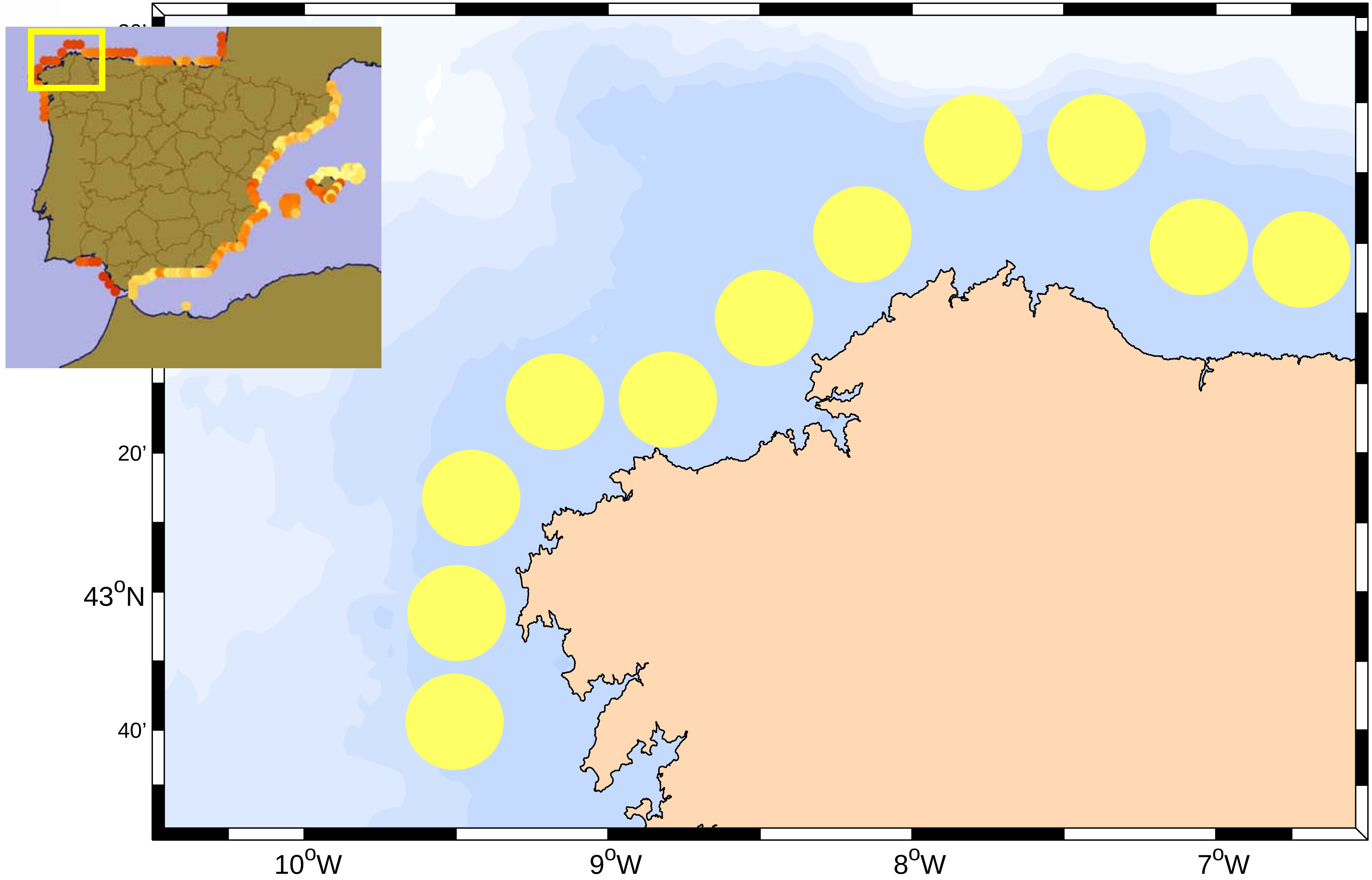
REPRESENTATIVE DATA (2050)		
Galician North Coast and Canarian North coast	Mediterranean coast	Cadiz Gulf
↑ 40 %	-10/10 %	↓ 40 %

Non depth-limited wave!

Rubble-mound block sizes variation



Regional vulnerability indices….. usually in deep water



Outline

1. Introduction
2. Methodology to obtain regional vulnerability indices
3. Methodology to assess detailed studies
4. Conclusions

3. Methodology to assess detailed studies

3. Methodology to assess detailed studies

Data bases

Calibration

Statistical models

Long-term trends
Climate variability

Vulnerability indices

Integrated Coastal Zone Management + Adaptation strategies

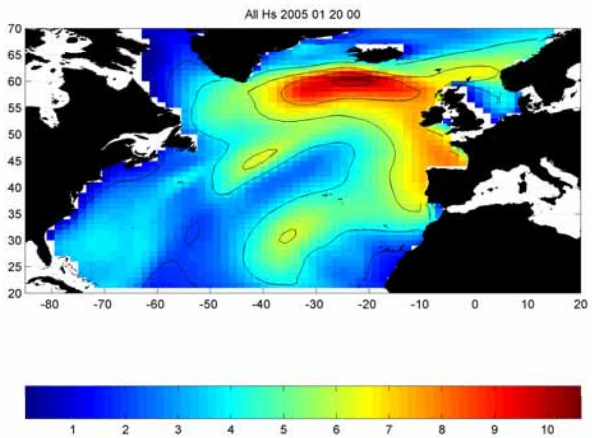
Dynamic downscaling
Wave propagation models
Spatial scale ~ O(m)

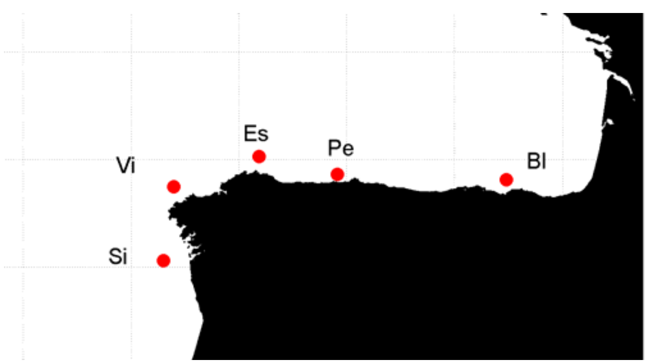
Statistical downscaling
Classification algorithms
Time scale (1 hour)

Theoretical effects of climate change in coastal areas

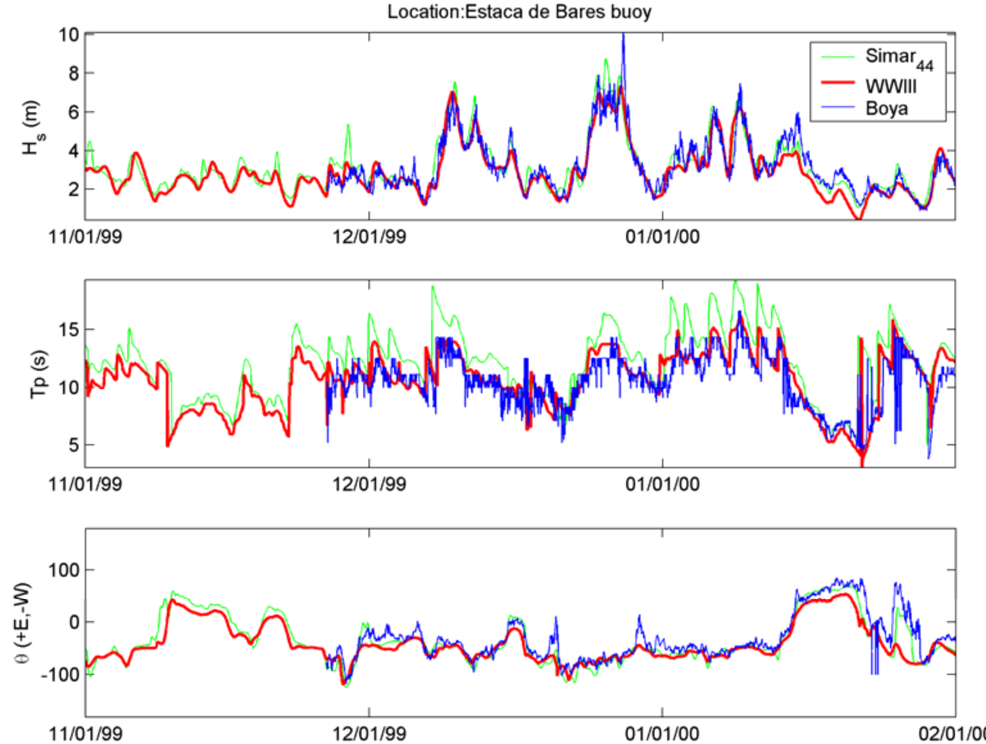
3. Methodology to assess detailed studies

Update of wave reanalysis data



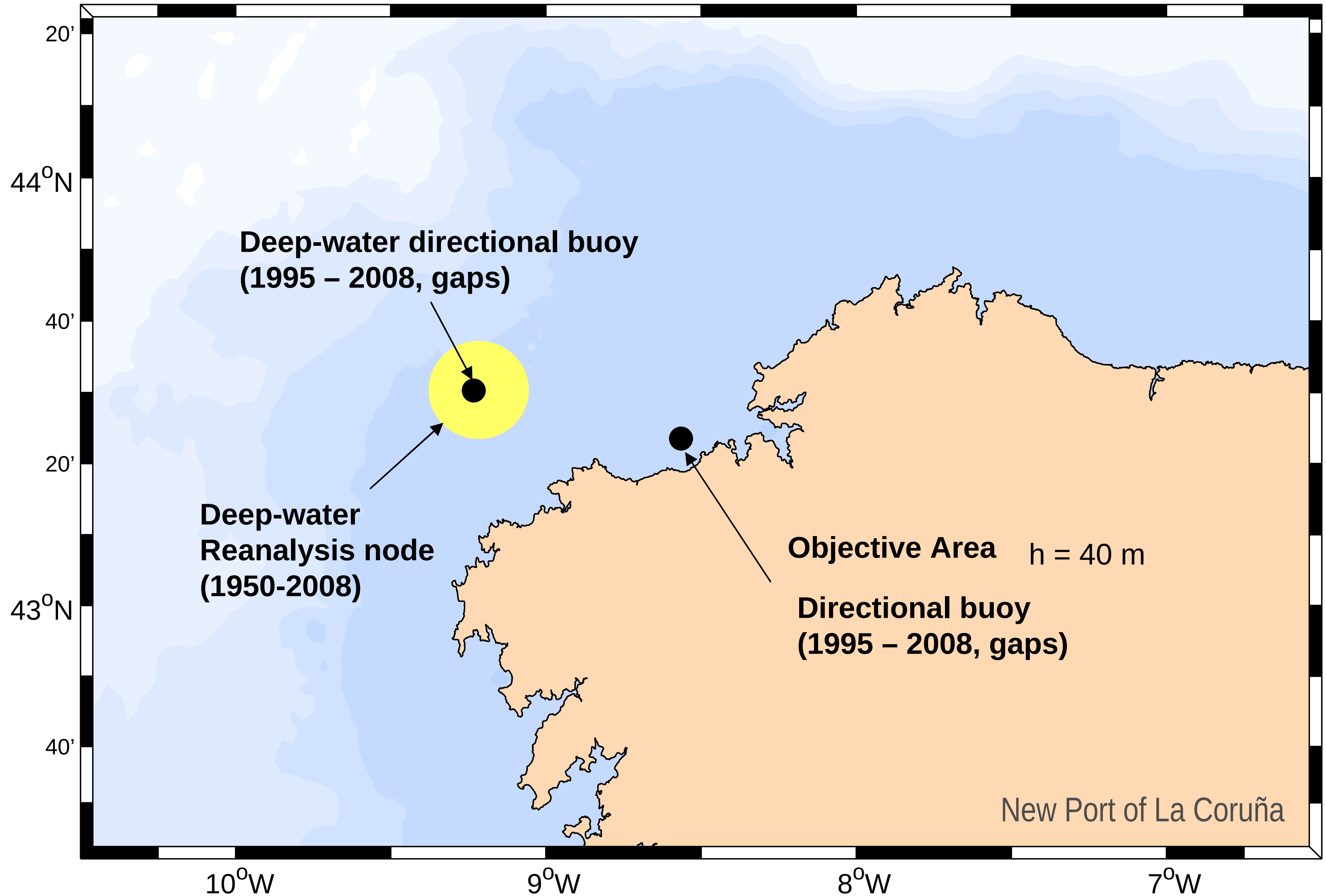


$$H_s, T_p, \theta_m$$

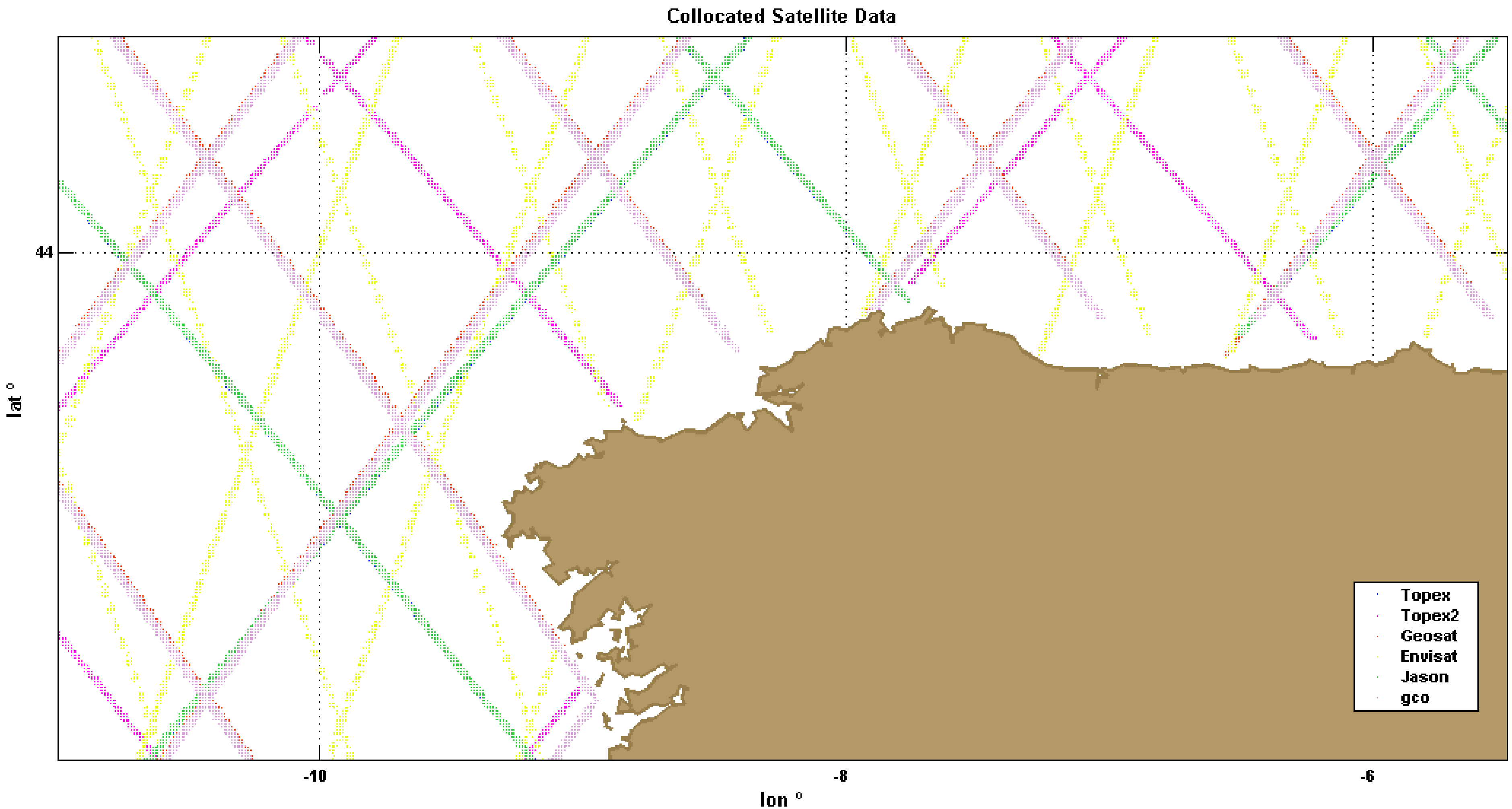


Forcing: NCEP/NCAR winds and ice coverage
WaveWatch-III Version 2.22

3. Methodology to assess detailed studies

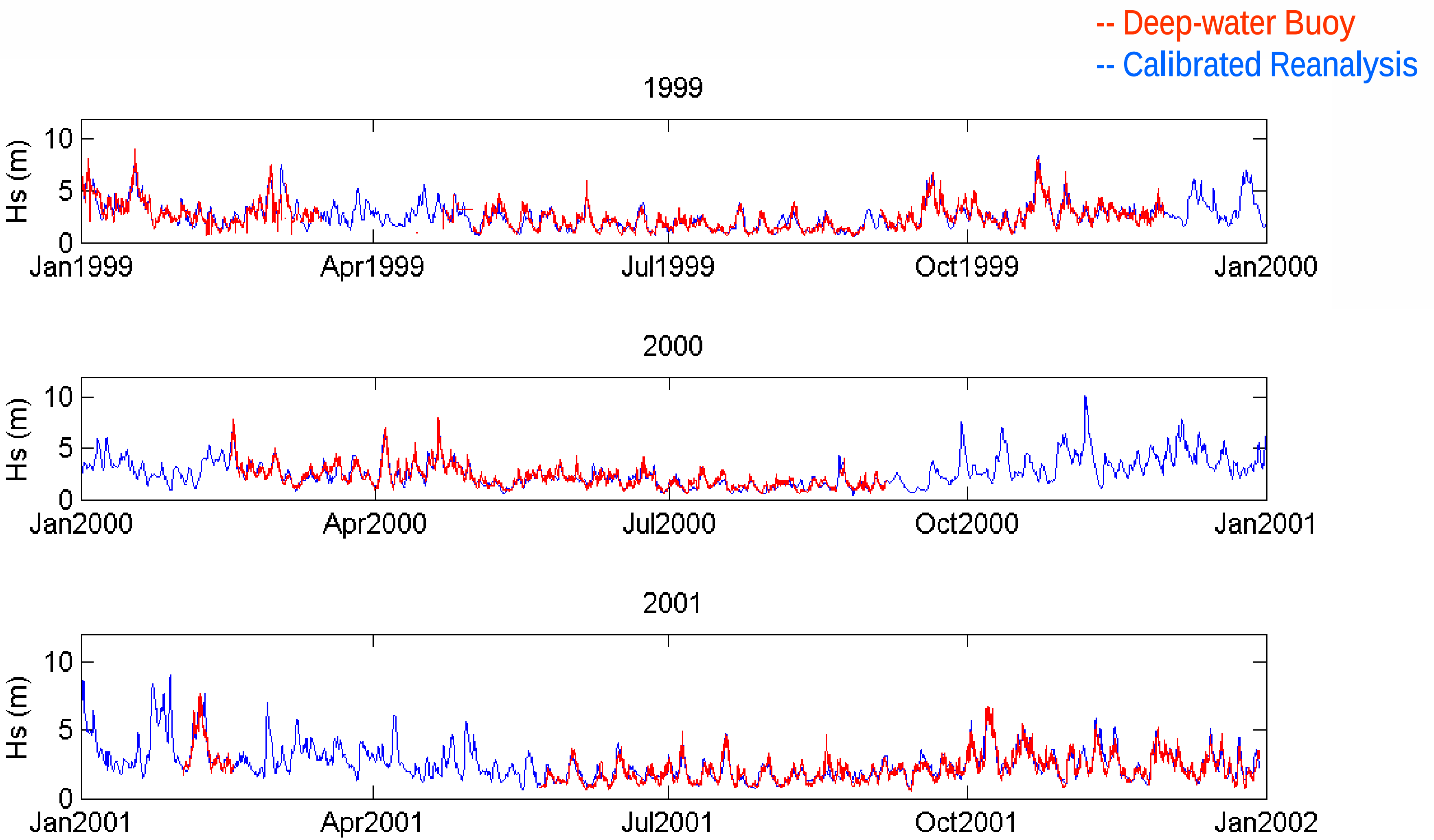


3. Methodology to assess detailed studies

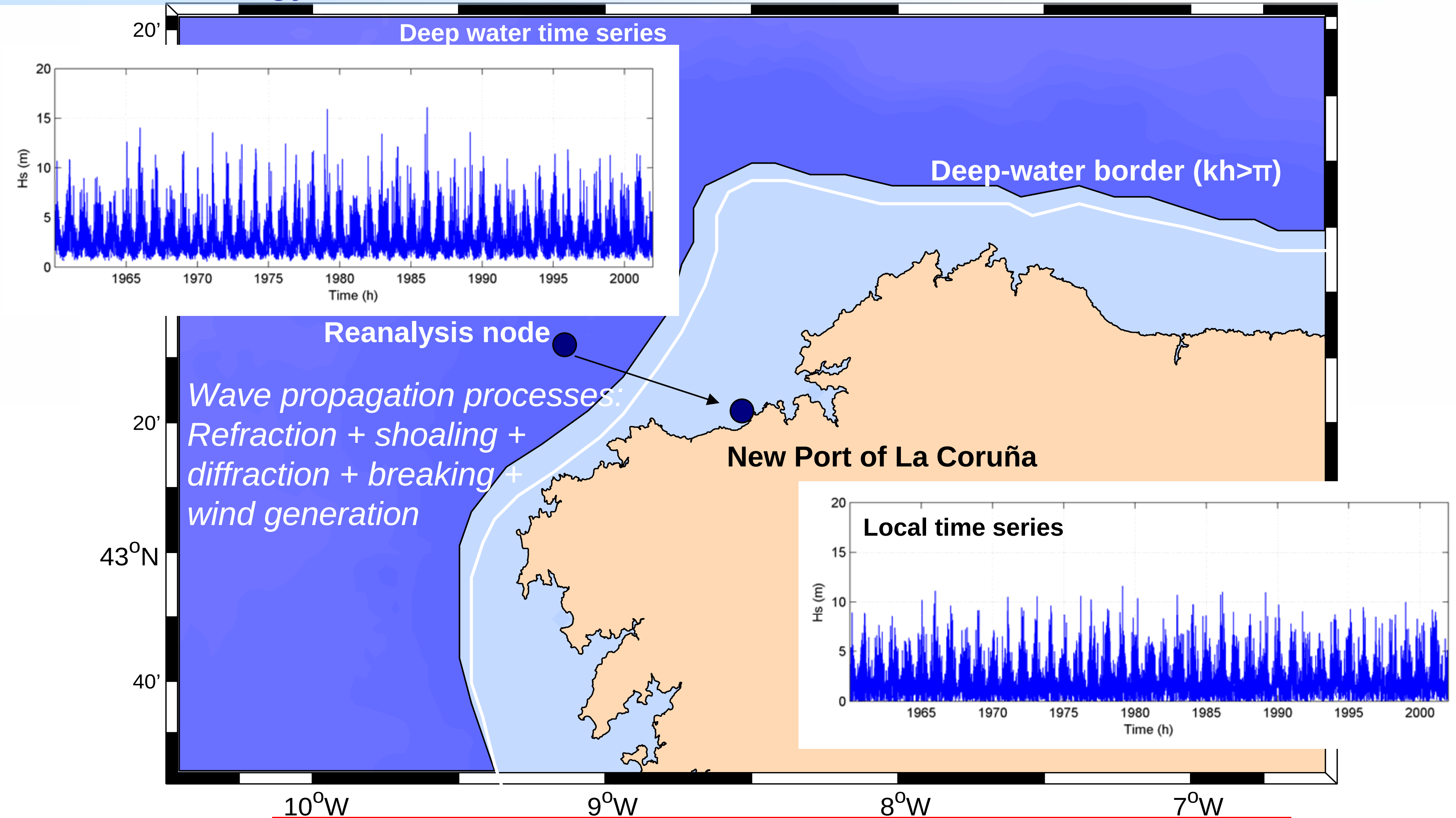


3. Methodology to assess detailed studies

Calibration of wave reanalysis data bases (Tomas et al, 2008, CSR)



3. Methodology to assess detailed studies

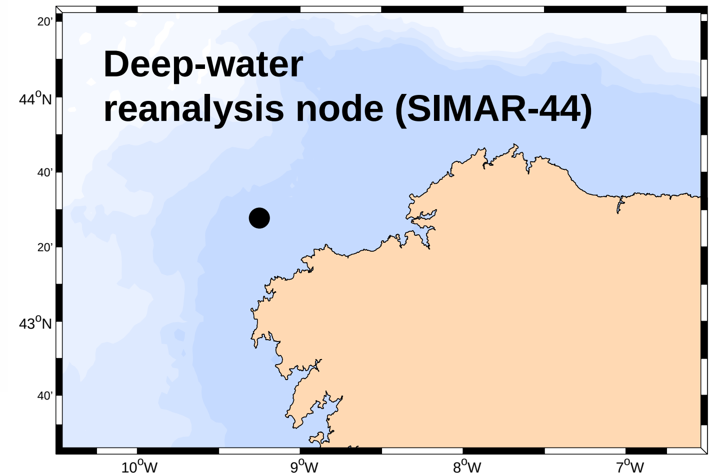


44 years x 8766 sea states (hours)/year = 385.704 propagations !!

3. Methodology to assess detailed studies

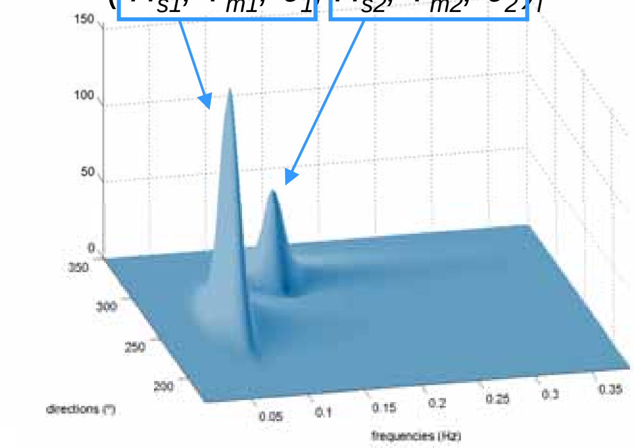
Classification: *Self Organizing Maps*

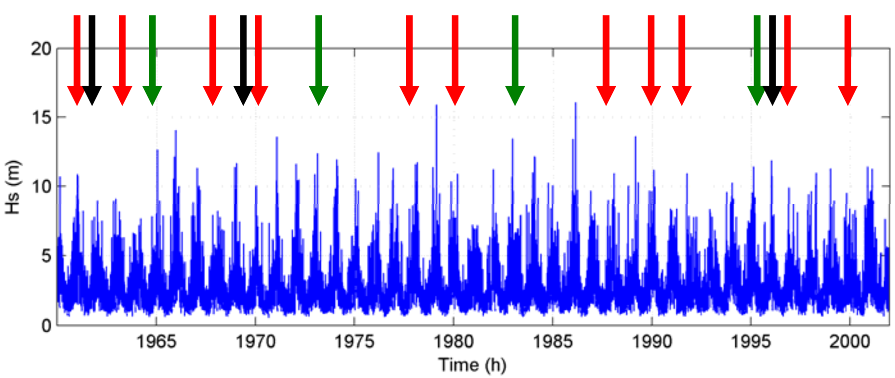
Kohonen (2001)

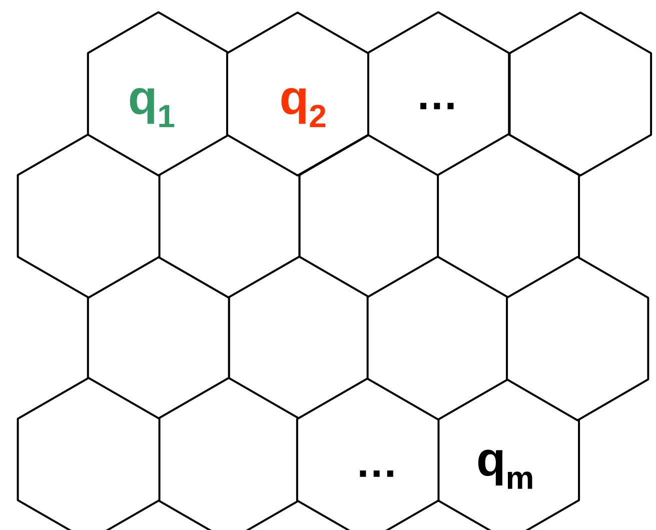


Each sea state:

$$(H_{s1},\ T_{m1},\ \theta_1,\ H_{s2},\ T_{m2},\ \theta_2)_i$$



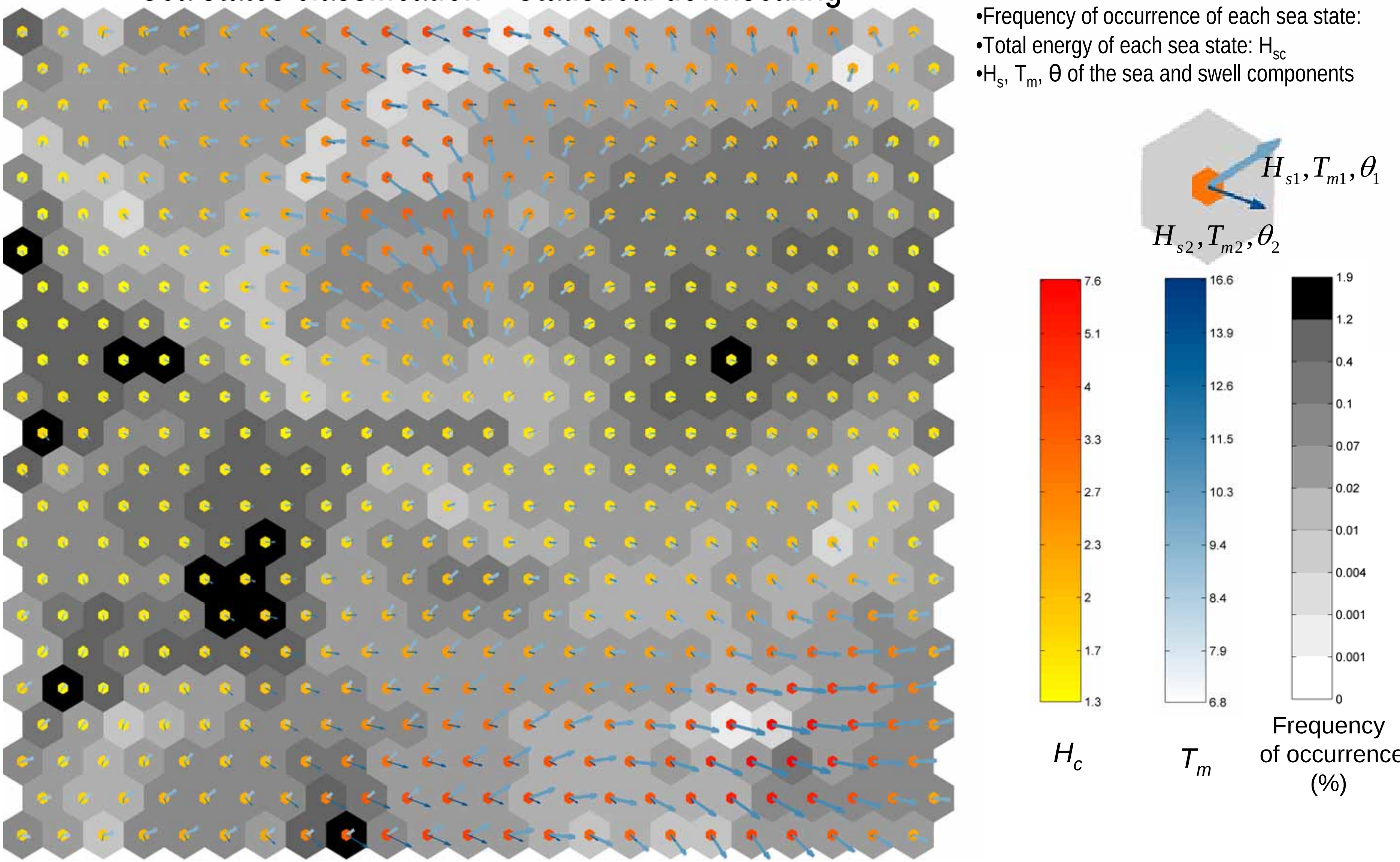




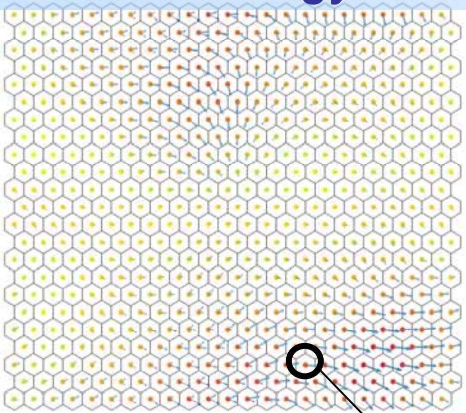
3. Methodology to assess detailed studies. *Self Organizing Maps*

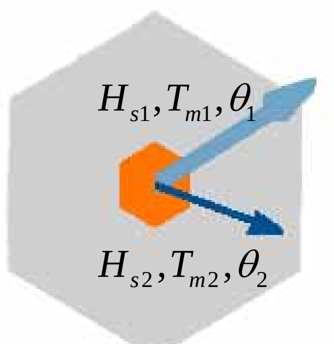
Sea states classification = Statistical downscaling

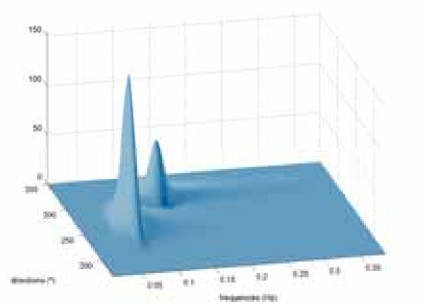
- Frequency of occurrence of each sea state:
- Total energy of each sea state: H_{sc}
- H_s, T_m, θ of the sea and swell components



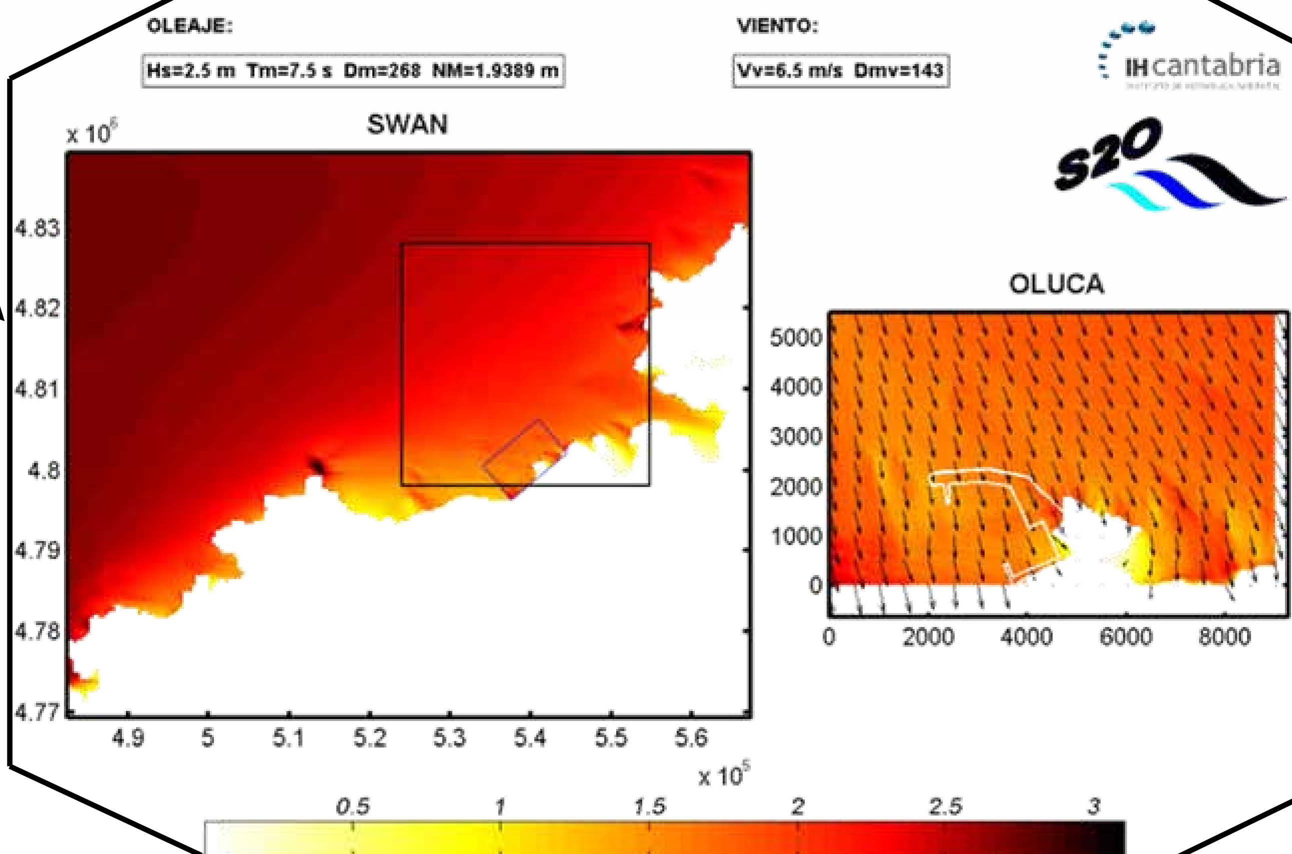
3. Methodology to assess detailed studies.

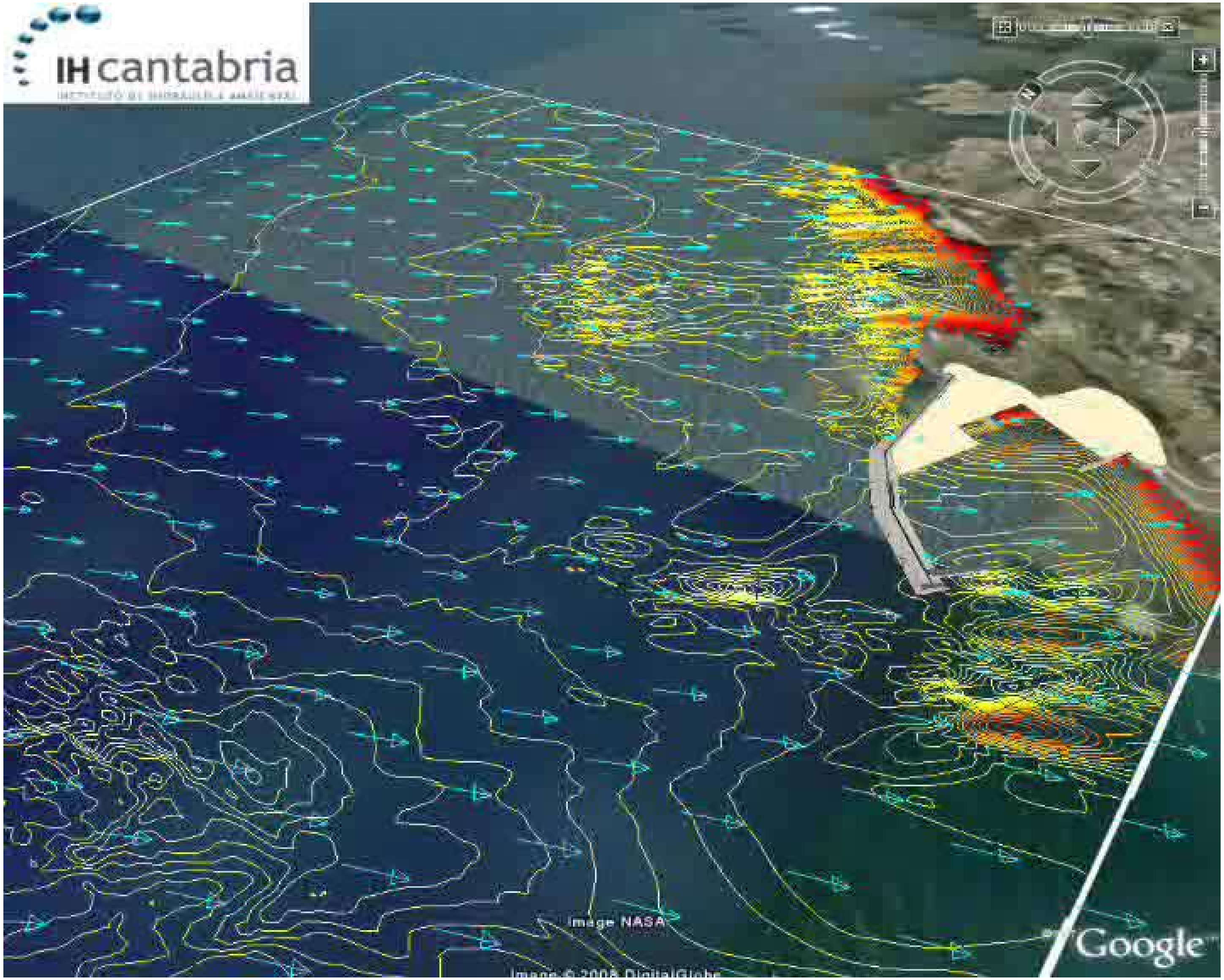






Wave propagation = Dynamic downscaling

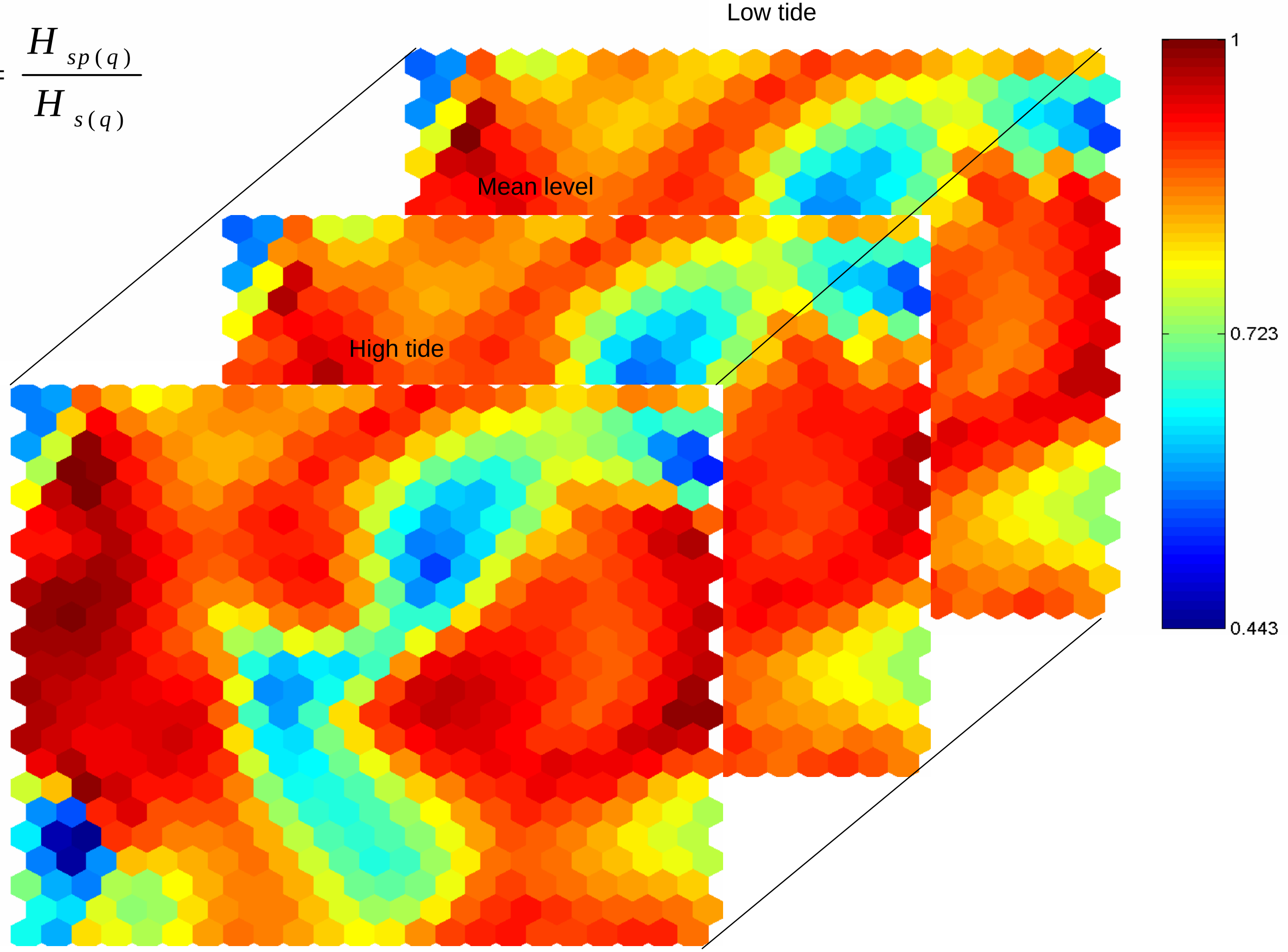



IH cantabria
Image NASA
Image © 2008 DigitalGlobe
Google

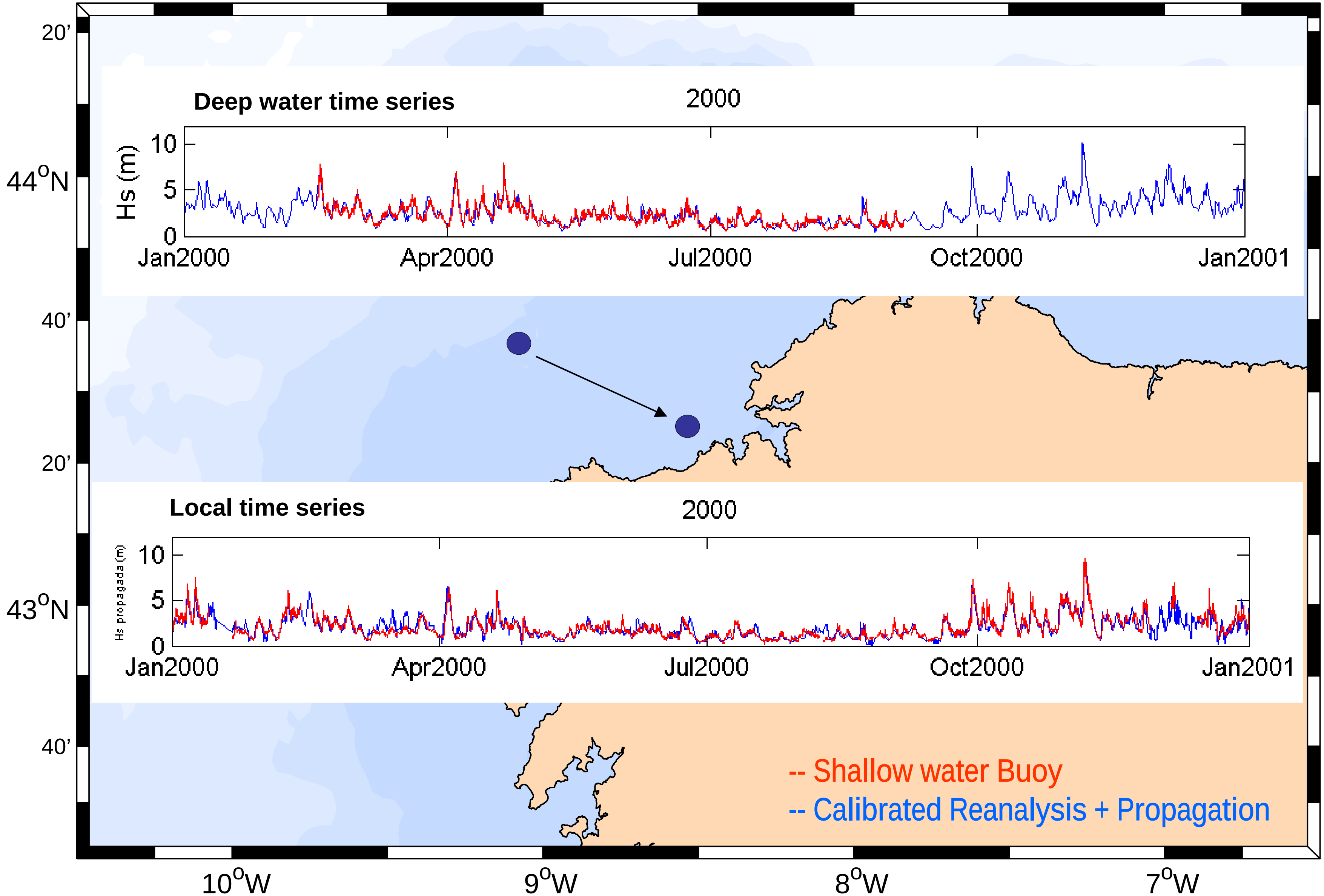
3. Methodology to assess detailed studies

Propagation Coefficients

$$K_{hp(q)} = \frac{H_{sp(q)}}{H_{s(q)}}$$



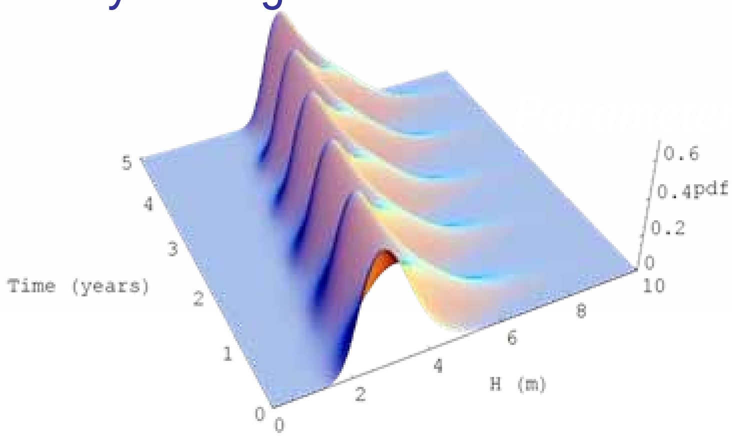
3. Methodology to assess detailed studies



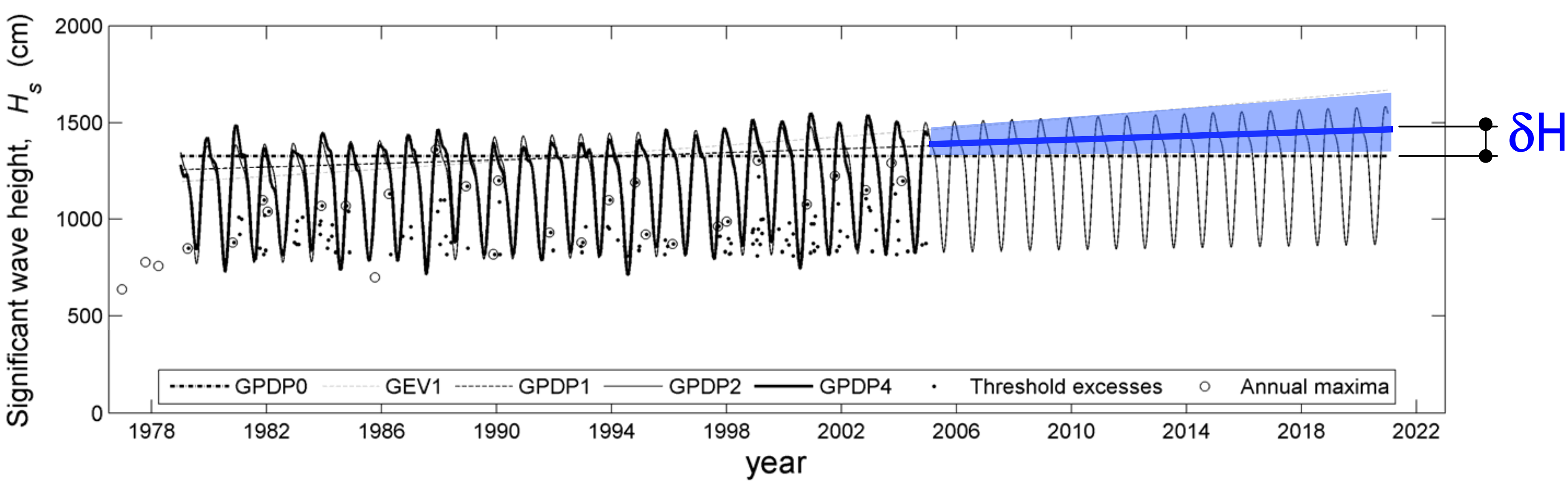
3. Methodology to assess detailed studies

Regression model (Menendez et al, this session; Mendez et al, 2006 JGR)

Seasonality + Long-term Trends

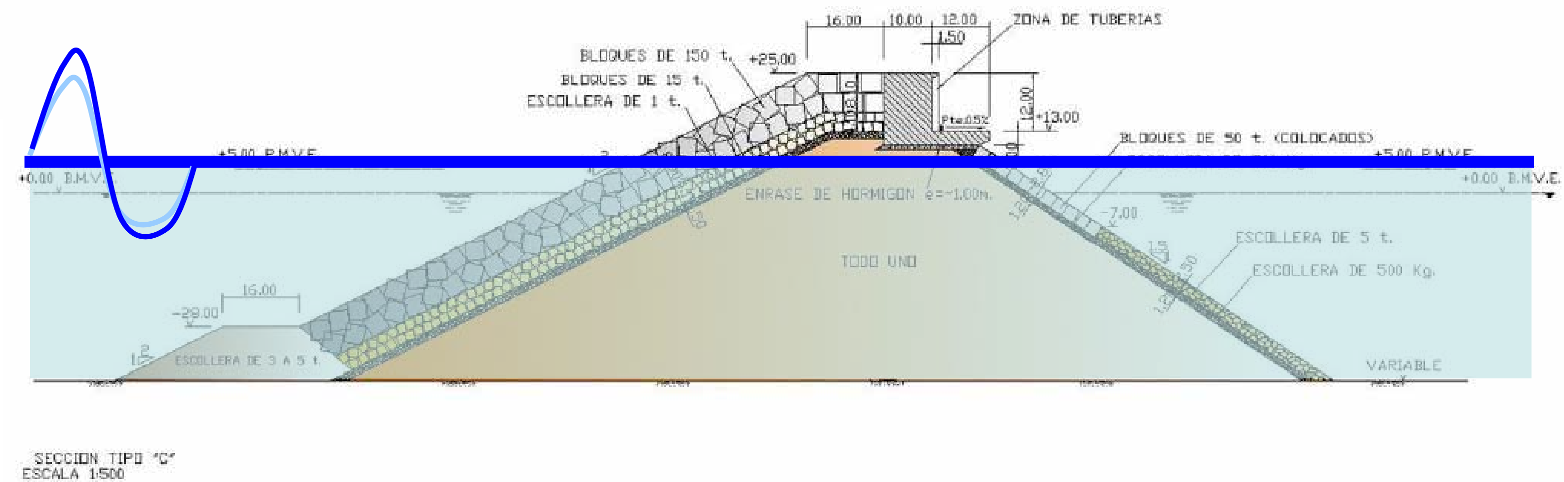


$$\begin{cases} \mu(t) = \left[\beta_0 + \beta_1 \cos(2\pi t) + \beta_2 \sin(2\pi t)\right] e^{\beta_{LT} \cdot t} \\ \psi(t) = \alpha_0 + \alpha_1 \cos(2\pi t) + \alpha_2 \sin(2\pi t) \\ \xi_0 \end{cases}$$



3. Methodology to assess detailed studies

Example of Adaptation

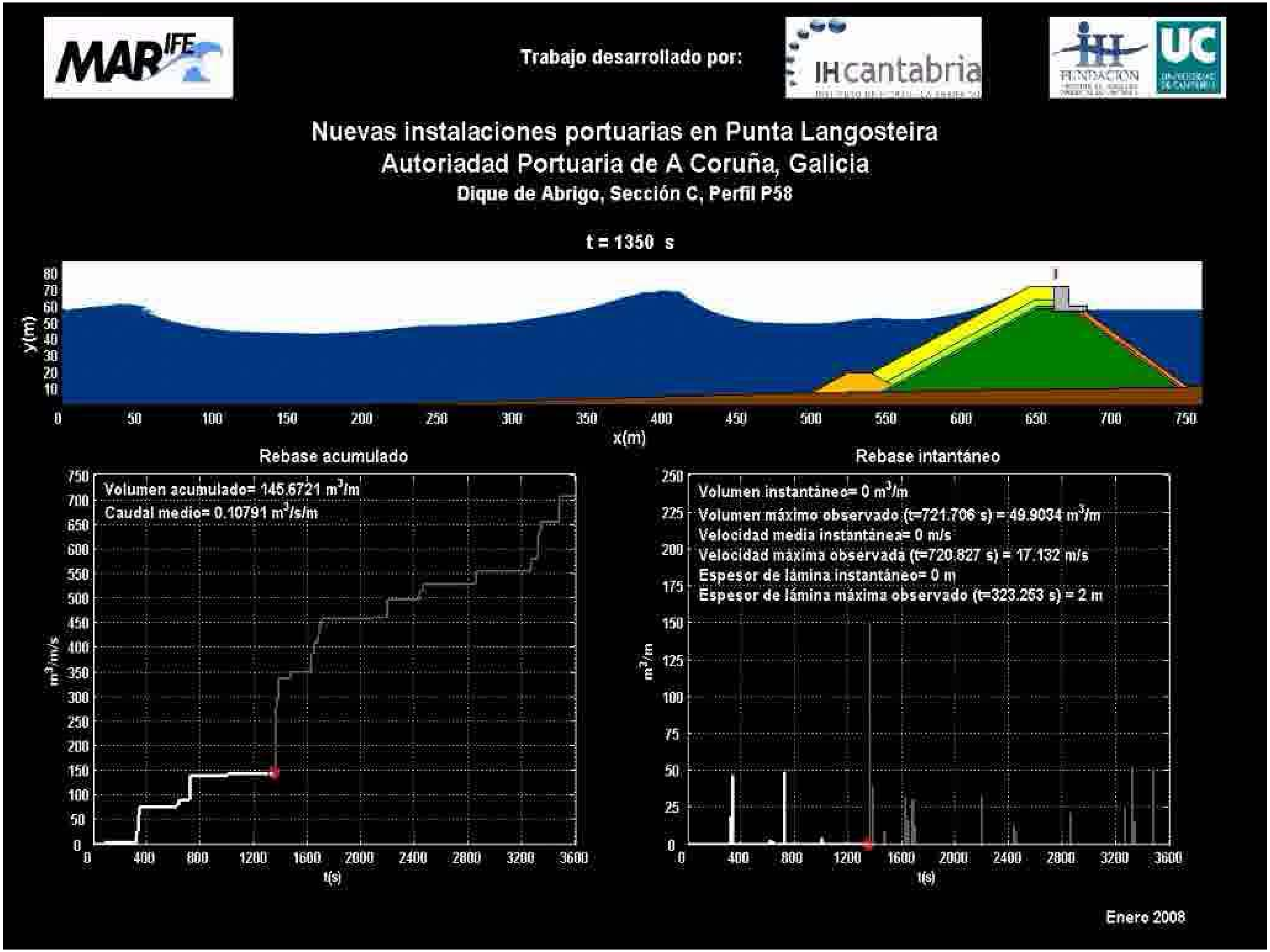


Example: Sea level rise at 2050 δη=15 cm

+ increase of storminess at 2050 (wave height δH=80 cm)

3. Methodology to assess detailed studies

High Resolution Numerical Model

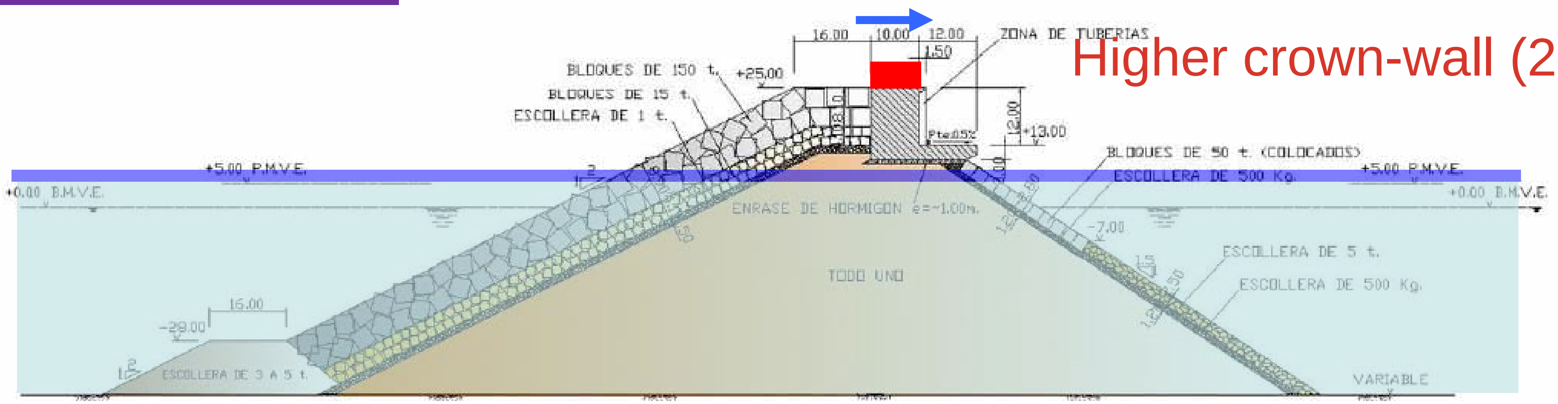


3. Methodology to assess detailed studies

Example of Adaptation

Increase of overtopping

Higher crown-wall (2 m)



<u>Objective</u>: reestablish operations, reliability and security current conditions
<u>Action</u>: higher crown wall

4. Conclusions

- Impact assessment of climate change on coastal areas depends directly on changes on atmospheric and ocean forcings

- The effect of these forcings on coastal areas is highly dependent on local characteristics

- The main agent considered during the last decades has been sea level rise. Wave climate, storm surges, winds and currents have also to be considered

- High resolution information is required to address impact assessment and adaptation measures

- We propose a combination of dynamic, statistical downscaling and time-dependent statistical models

A methodology to evaluate the impacts of climate change in a coastal system

Fernando J. Mendez, Inigo J. Losada, Raul Medina,
Maitane Olabarrieta, Melisa Menendez, Paula Camus

Environmental Hydraulic Institute, IH Cantabria, Universidad de Cantabria
mendezf@unican.es

SOM

Data

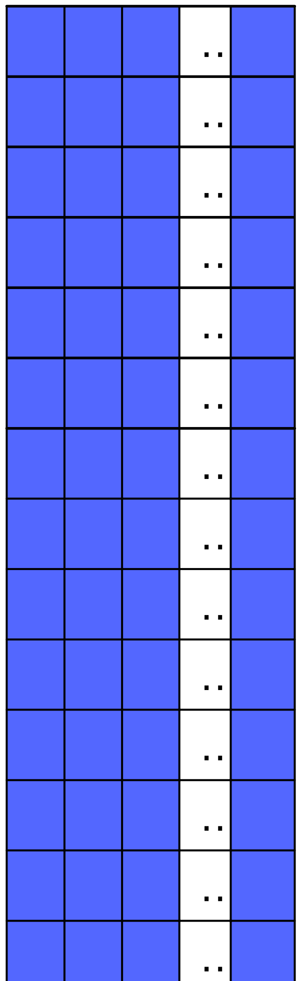
$\mathbf{x_1}=(x_1, x_2, x_3, \ldots, x_n)_1$

$\mathbf{x_2}=(x_1, x_2, x_3, \ldots, x_n)_2$

$\mathbf{x_i}=(x_1, x_2, x_3, \ldots, x_n)_i$

$\mathbf{x_P}=(x_1, x_2, x_3, \ldots, x_n)_P$

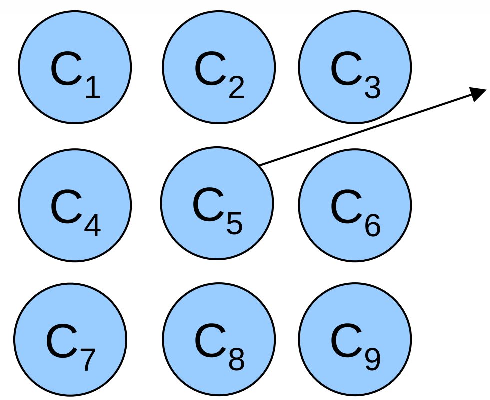
Data vector



Training algorithm

$$\sum_{k=1,\ldots,M} d(C_k) = \sum_{k=1,\ldots,M} \sum_{x_i \in C_k} \left\| x_i - v_k \right\|^2$$

M=9



$c_5=(2,2)$

$v_5=(v_{51},\ldots,v_{5n})$

Scheme of 3x3 two-dimensional self-organizing map

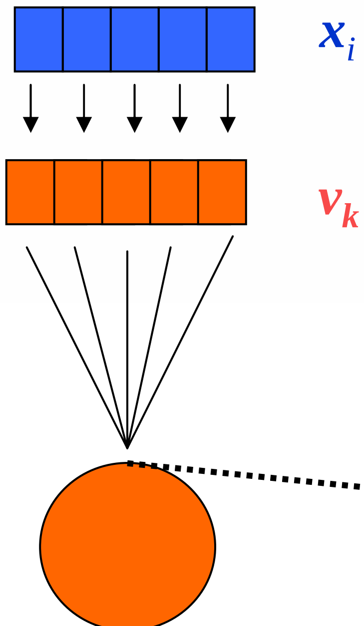
SOM

Data Vector

$\boldsymbol{x_i}=(x_1, x_2, x_3, \ldots, x_n)_i$

Reference Vector

$\boldsymbol{v_k}=(v_1, v_2, v_3, \ldots, v_n)_k$

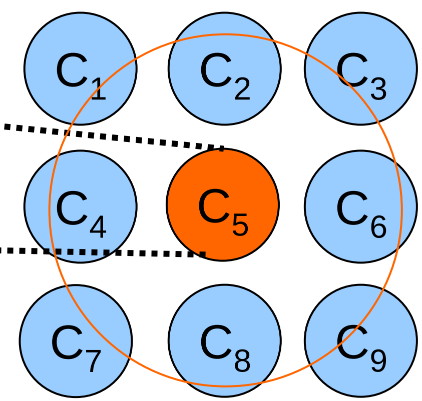


Winner centroid:

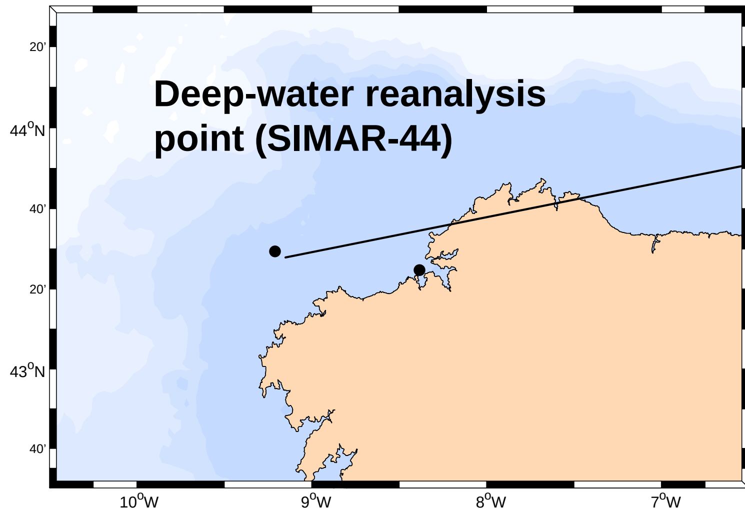
$$\left\| v_{w(i)} - x_i \right\| = \min_k \left\{ \left\| v_k - x_i \right\|, k=1,\ldots,M \right\}$$

Adjustment of the winner centroid and its neighbours

$$v_k = v_k + \alpha h(\omega(i),k)\left(x_i - v_k\right), k=1,\ldots,M$$



Unimodal characterization



Data

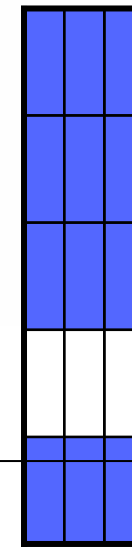
$\boldsymbol{x_1}=(H_s,\ T_m,\ \theta)_1$ →

$\boldsymbol{x_2}=(H_s,\ T_m,\ \theta)_2$ →

$\boldsymbol{x_P}=(H_s,\ T_m,\ \theta)_P$ →

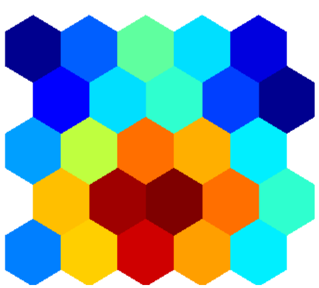
$P \sim 400000$

Data vector

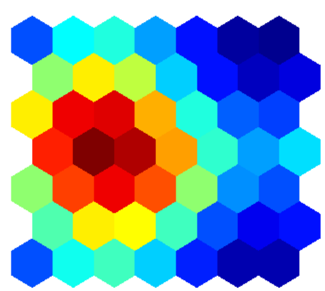


SOM **Sizes: k = [25 49 100 196 324 400 529 625]**

25

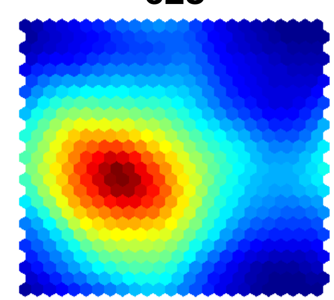


49

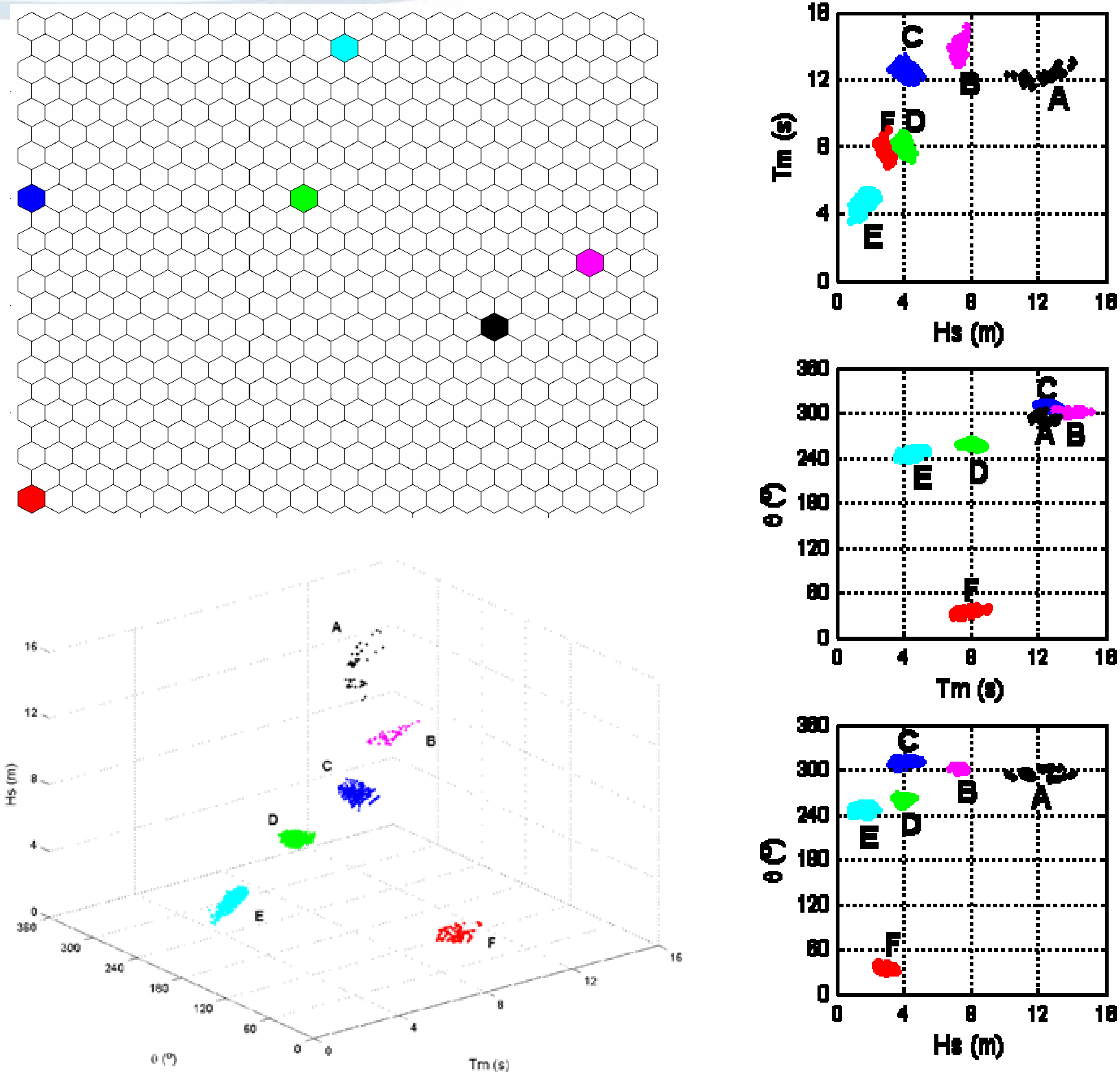


…

625

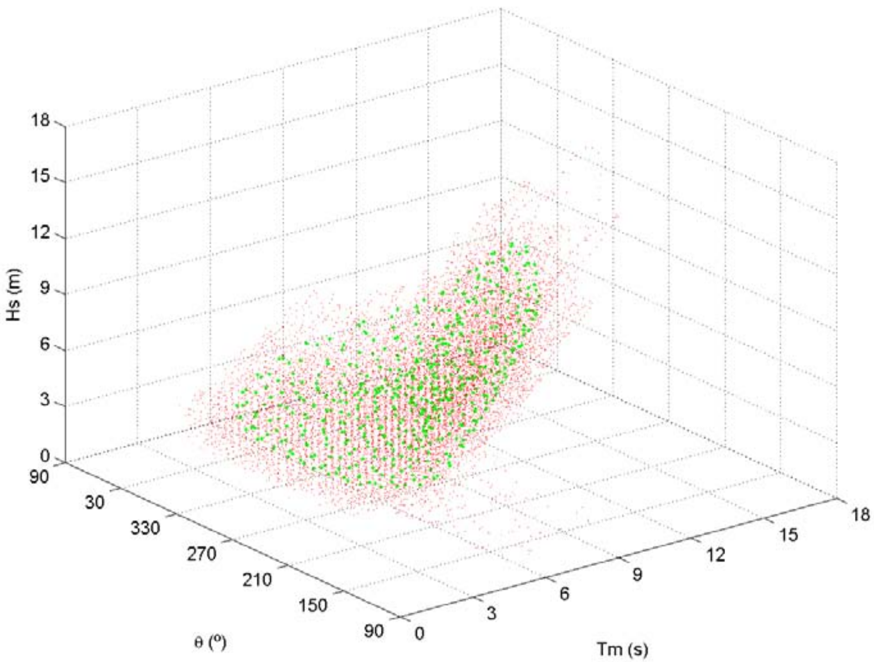


5. Clasificación de estados de mar

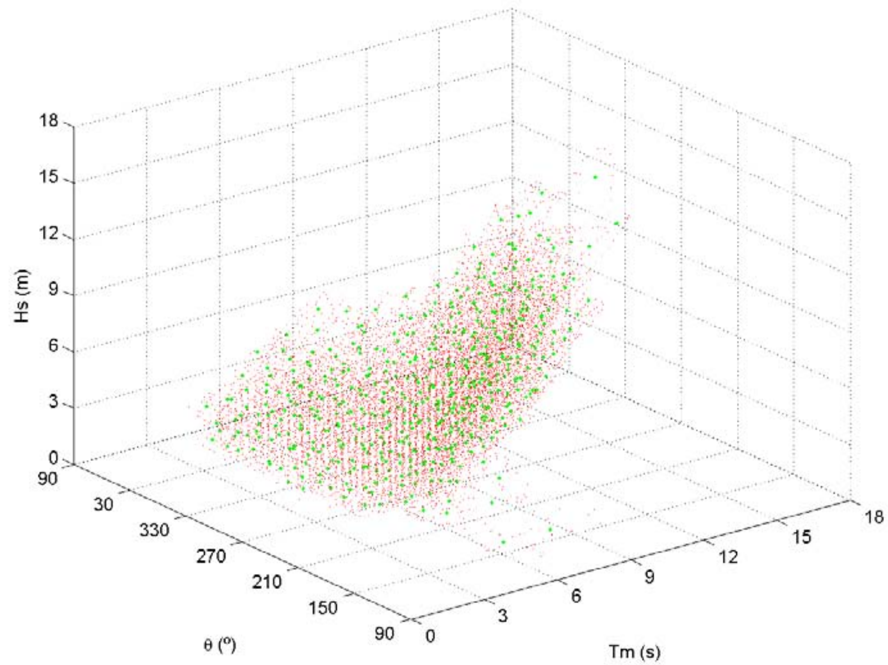


5. Clasificación de estados de mar

Redes neuronales autoorganizativas



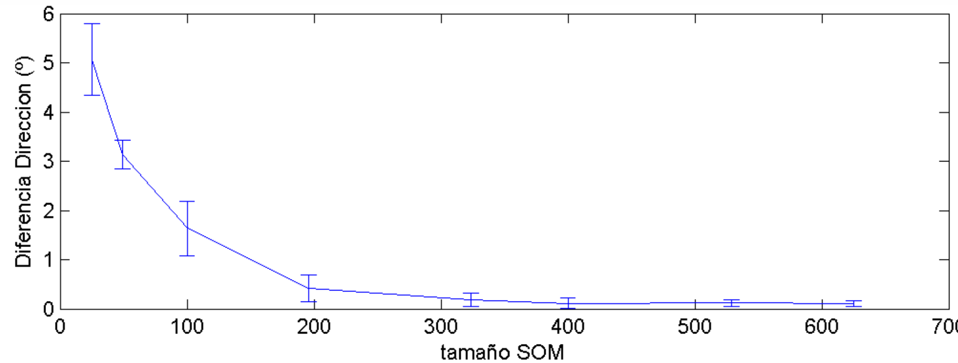
Clasificación mediante K-medias



Unimodal characterization

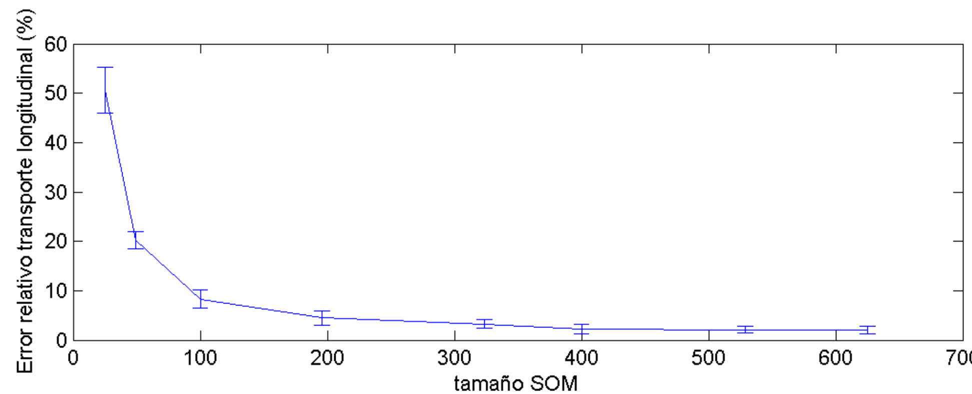
Mean energy flux direction Error

$$\Delta\theta = \theta_{FE_{retroanálisis}} - \theta_{FE_{centroides}}$$



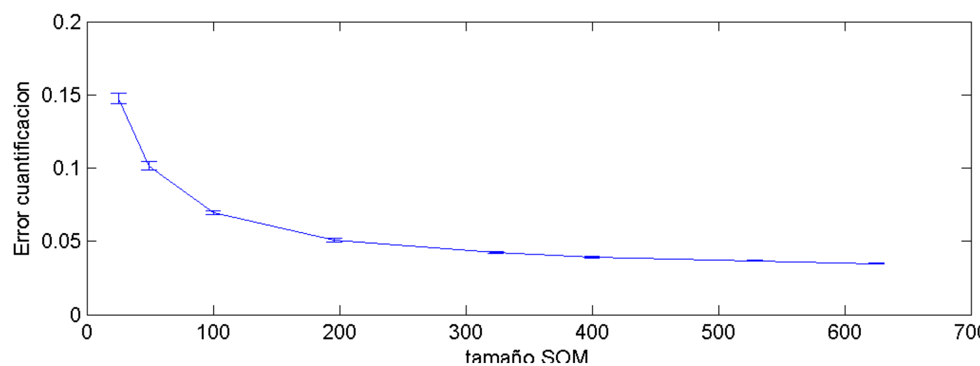
Longitudinal transport relative Error

$$E_Q(\%) = \frac{(Q_{retroanálisis} - Q_{centroides})}{Q_{retroanálisis}} \cdot 100$$

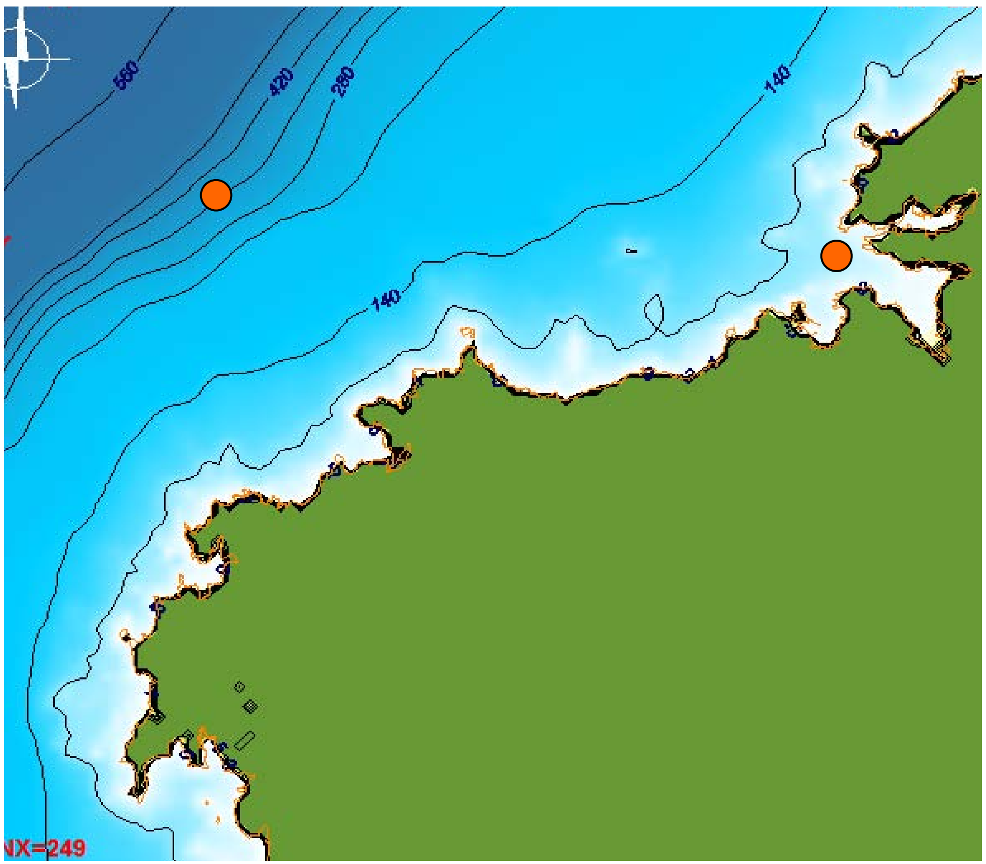


Quantification Error

$$E = \frac{\sum_{k=1,\dots,M} d(C_k)}{P} = \frac{\sum_{k=1,\dots,M} \sum_{x_i \in C_k} \left\| x_i - v_k \right\|}{P}$$



Unimodal characterization



Reanalysis data: P~400000

$$\theta_{FE_{reanalysis}} = arctg\left[\frac{\sum_{i=1}^{P} H_{si}^2 \cdot T_{mi} \cdot sen(\theta_i)}{\sum_{i=1}^{q} H_{si}^2 \cdot T_{mi} \cdot \cos(\theta_i)}\right]$$

$$Q_{reanalysis} = \sum_{i=1}^{P} H_{si}^2 \cdot T_{mi}^{1.5} \cdot \left(sen\vartheta_i\right)^{0.6}$$

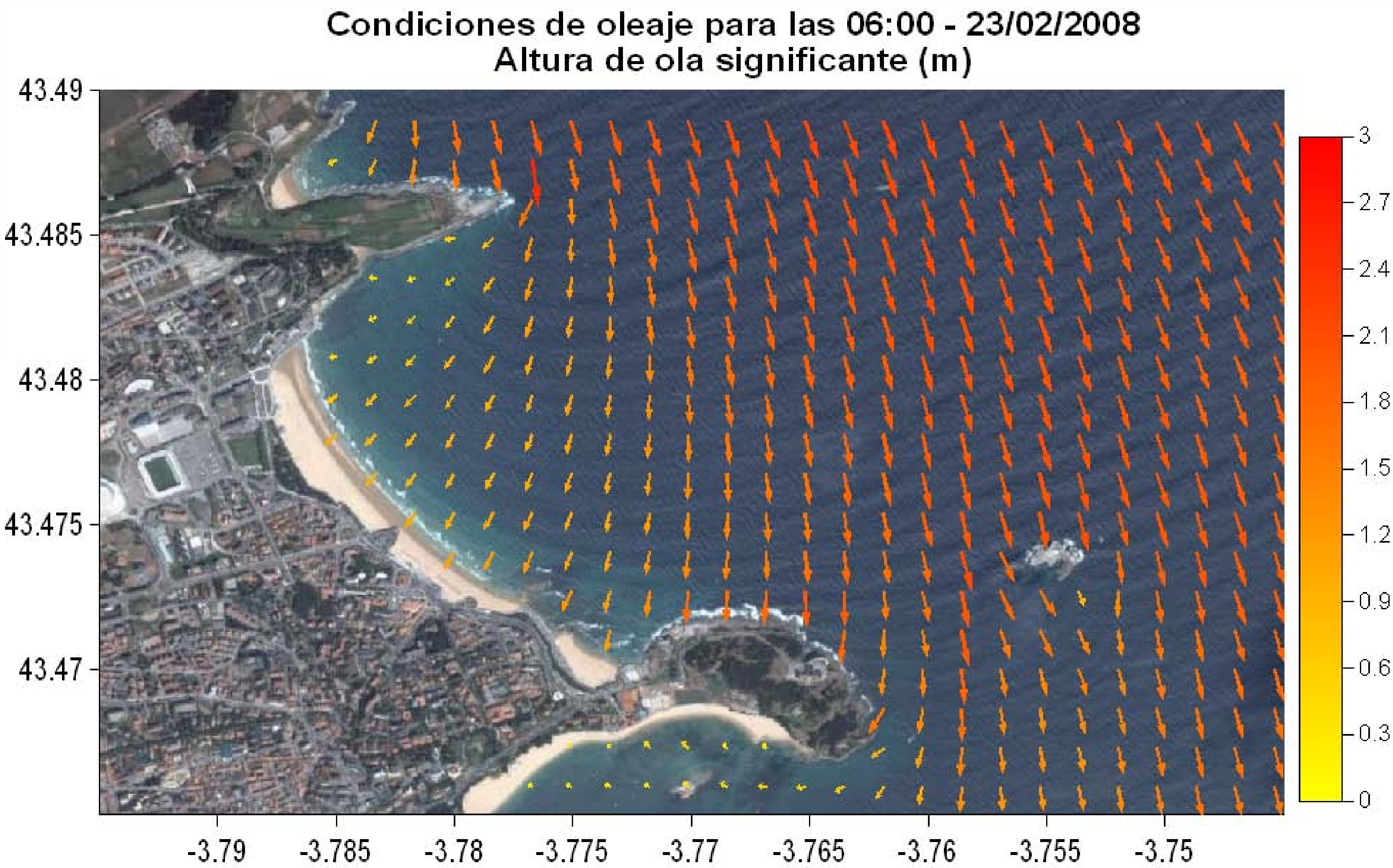
Clusters SOM: M = 25,49, …, 625

$$\theta_{FE_{centroids}} = arctg\left[\frac{\sum_{i=1}^{M} H_{si}^2 \cdot T_{mi} \cdot sen(\theta_i)\, f_i}{\sum_{i=1}^{M} H_{si}^2 \cdot T_{mi} \cdot \cos(\theta_i)\, f_i}\right]$$

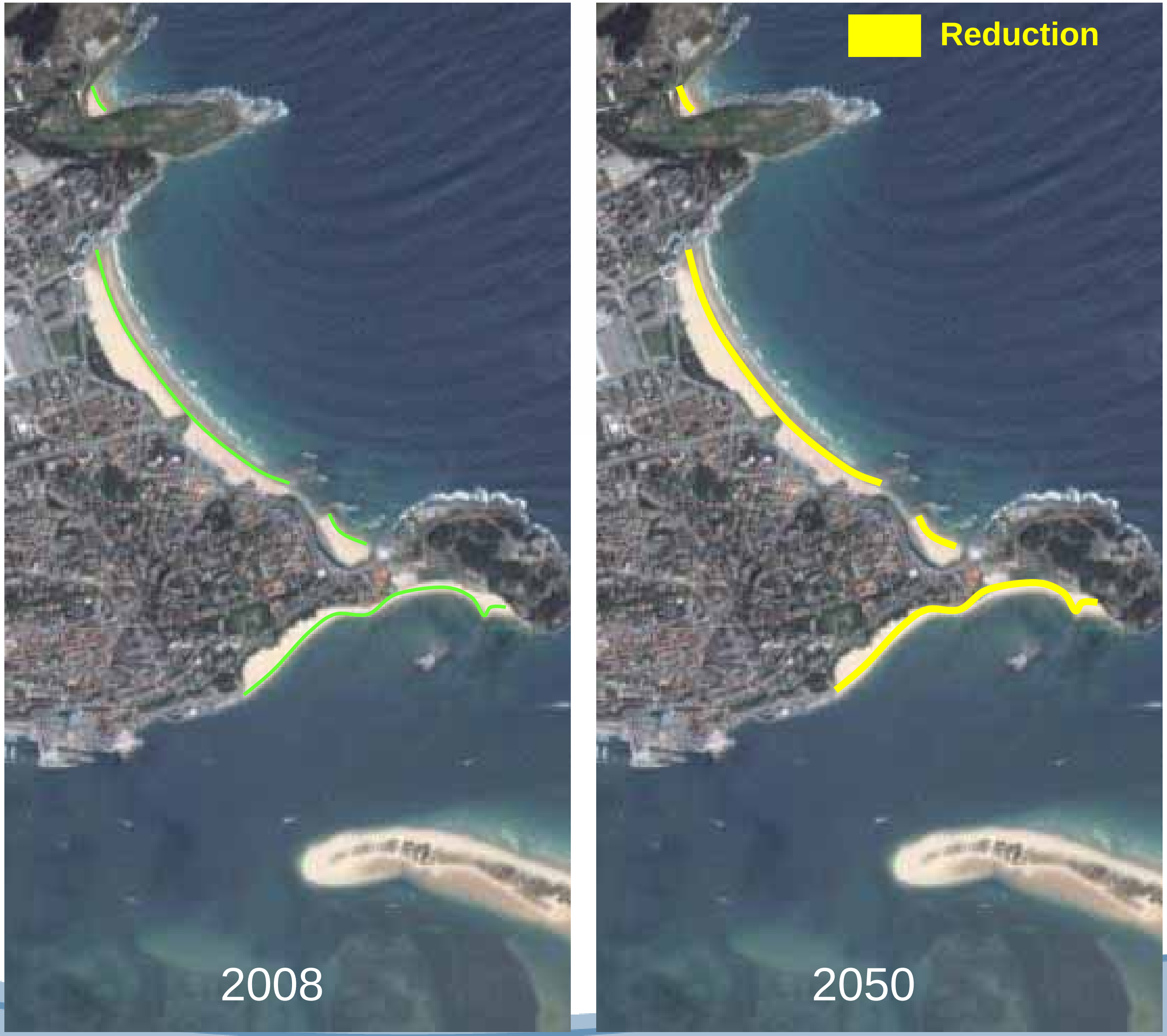
$$Q_{centroids} = \sum_{i=1}^{M} H_{si}^2 \cdot T_{mi}^{1.5} \cdot \left(sen\vartheta_i\right)^{0.6} \cdot f_i$$

4. Methodology to assess detailed studies

4. Methodology to assess detailed studies



4. Methodology to assess detailed studies Adaptation



Shoreline retreat at 2050 = 8 m

Impact: Reduction of 30% occupational Area

Objective: reestablish current situation

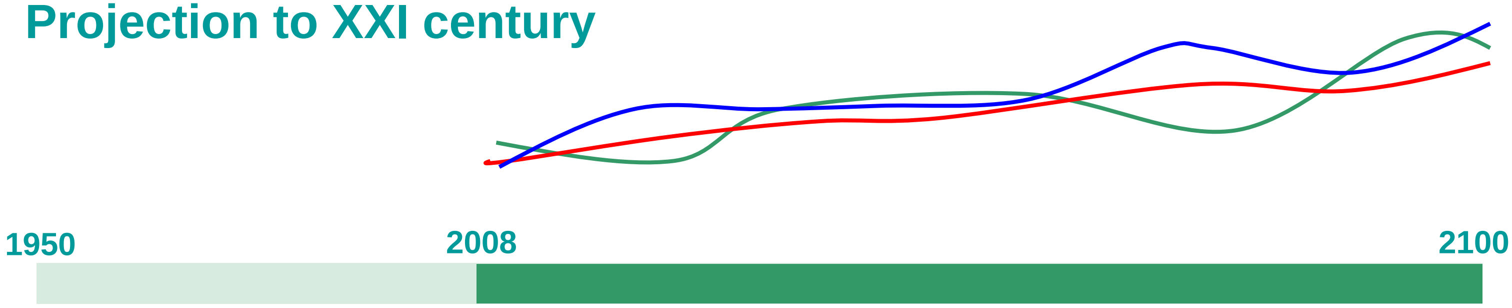
Action: Beach nourishment

8 m x 2500 m x 10 m
Sand 10€/m³
2 M€

5. Projection of Coastal Dynamics to the XXI century

Historical analysis of long-term trends

Projection to XXI century

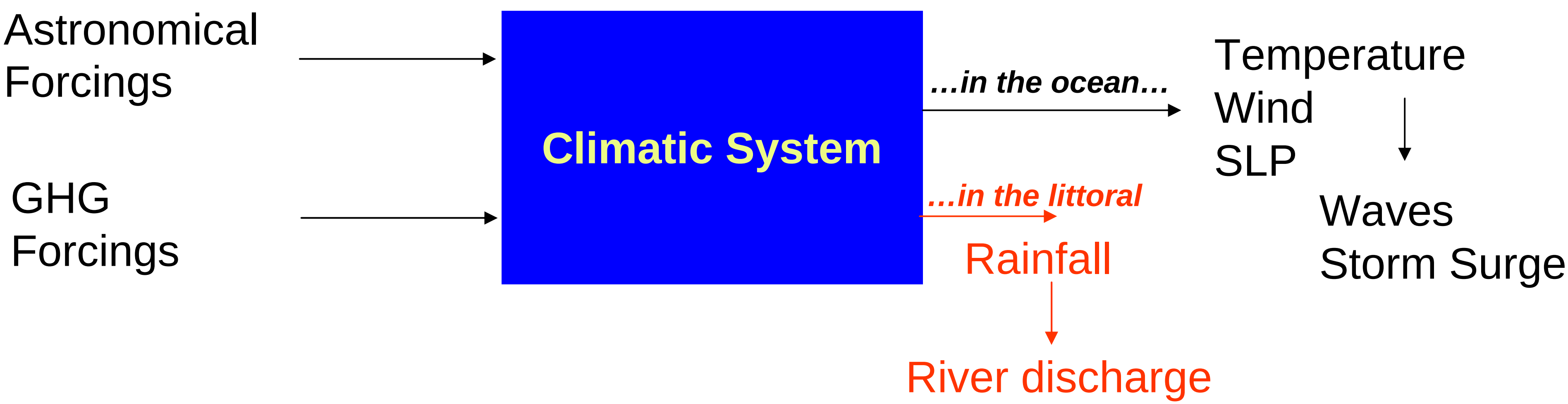


5. Projection of Coastal Dynamics to the XXI century

Wind waves and Storm surge ?

River discharge?

(AOGCM - **Atmosphere-Ocean General Circulation Model**)

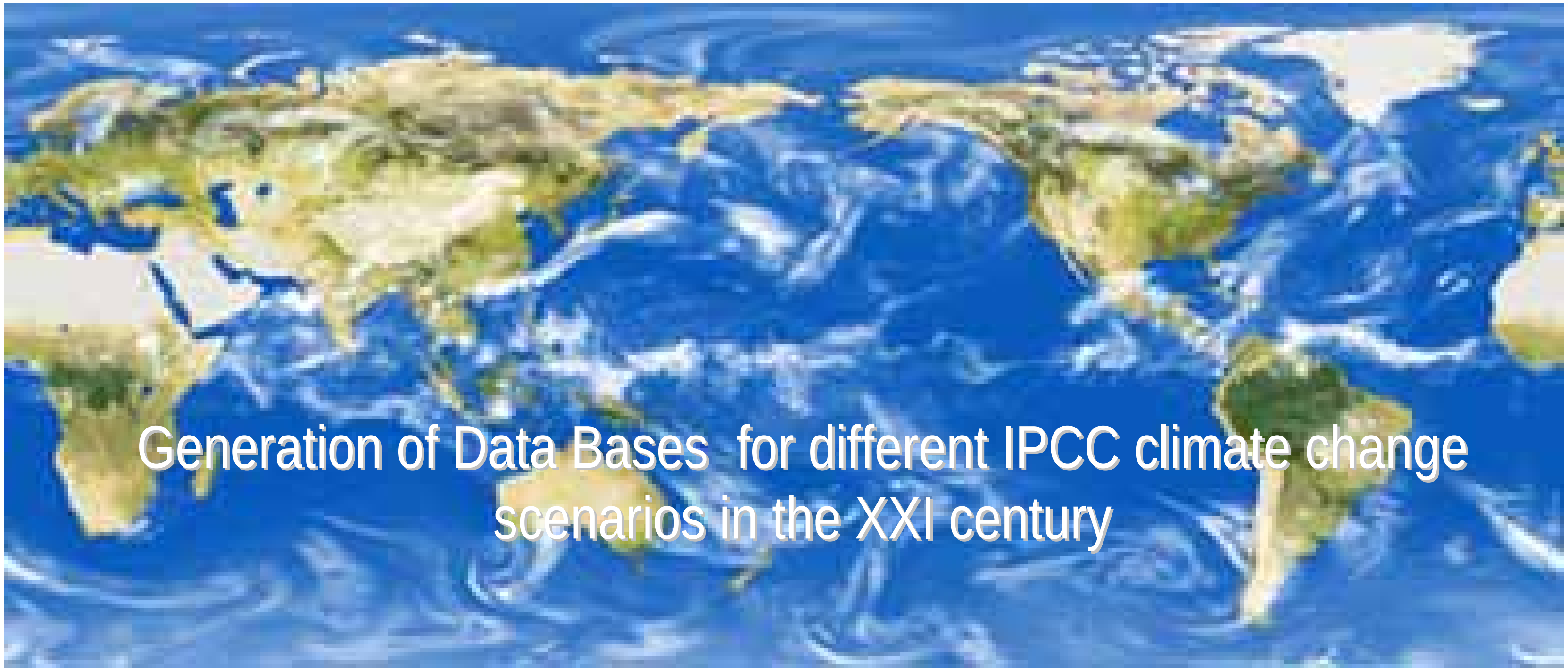


5. Projection of Coastal Dynamics to the XXI century

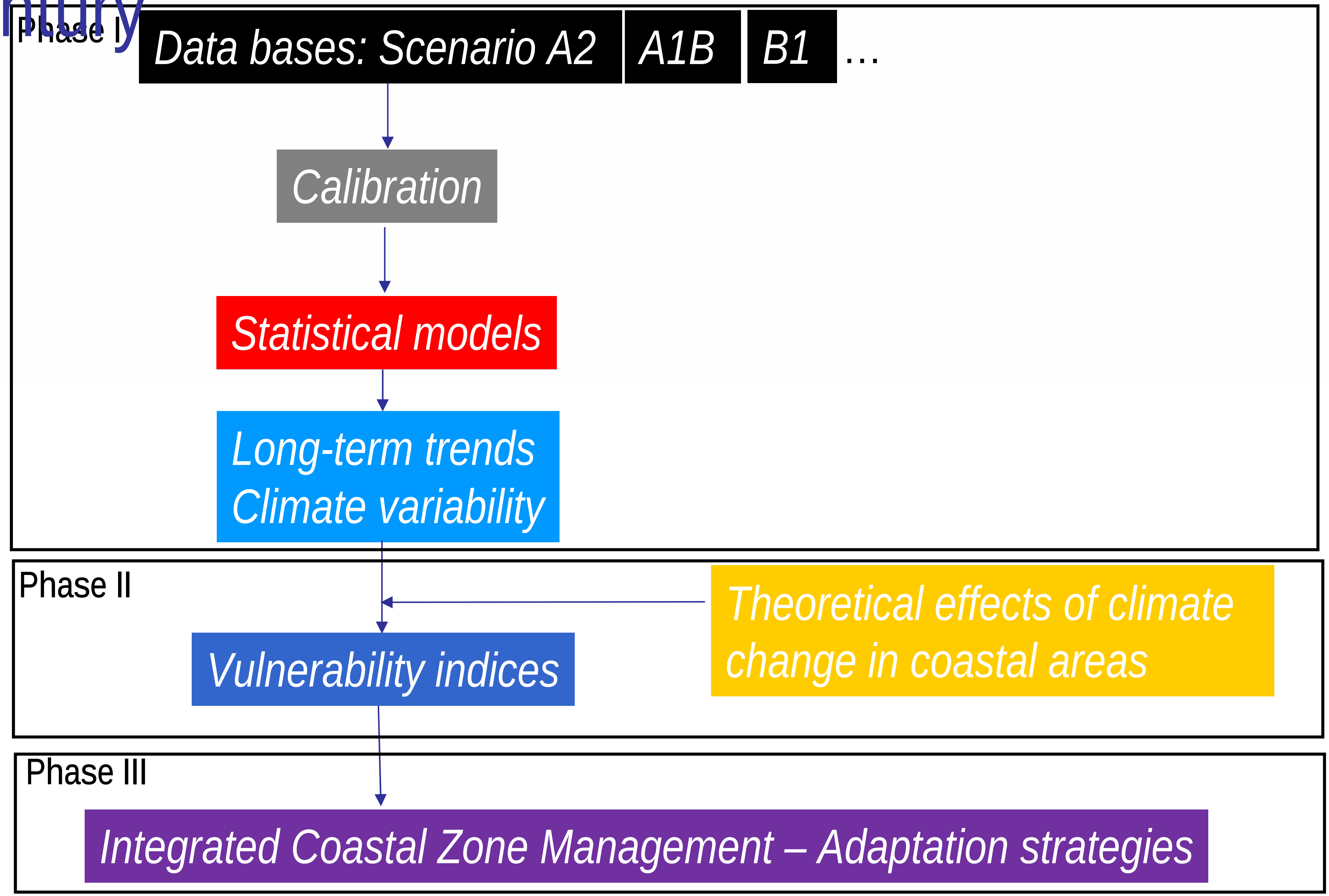
1950 2007 2100

6-hourly SLP data bases available

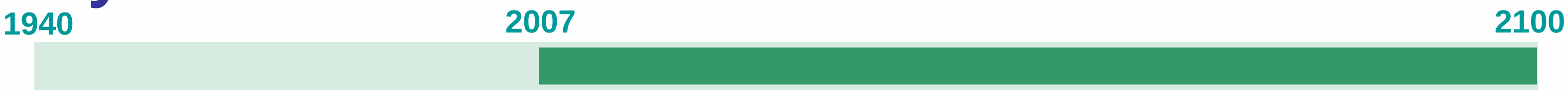
CCSM-NCAR (Community Climate System Model - National Center for Atmospheric Research, USA)
CNRM-MeteoFrance (Centre National de Recherches Meteorologiques, Francia)
CERA, World Data Center for Climate (Max-Planck-Institute for Meteorology, Alemania)
CGCM 3.1 (Environment Canada)



5. Projection of Coastal Dynamics to the XXI century



5. Projection of Coastal Dynamics to the XXI century

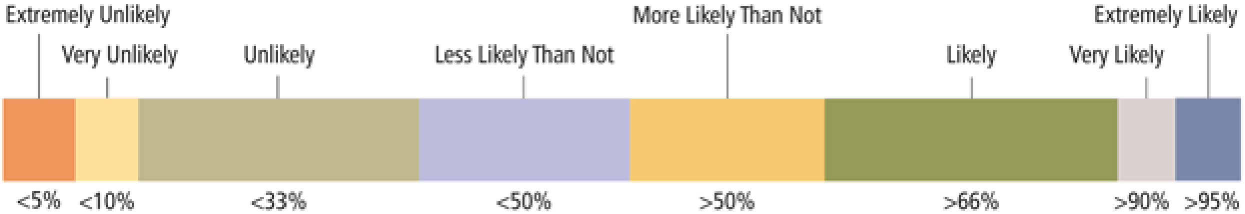


To take into account:

Hurricane projections in the XXI century (statistical and dynamic downscaling)

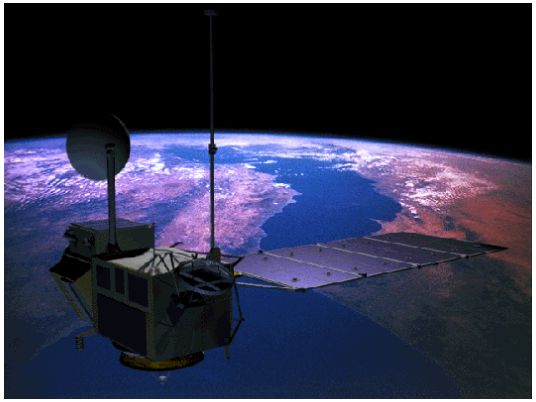
For each scenario…
- Different models
- Different ensembles

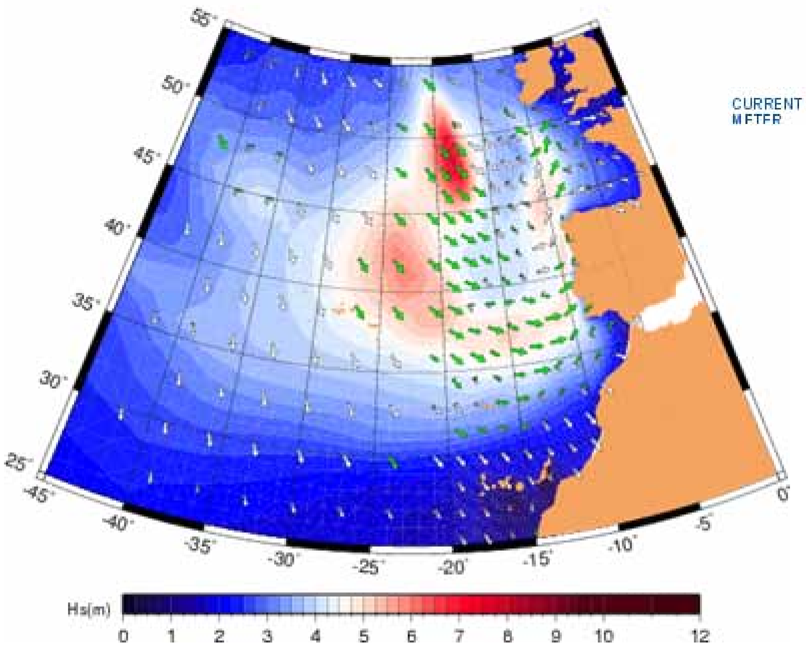
Probabilistic approach… ensemble projections

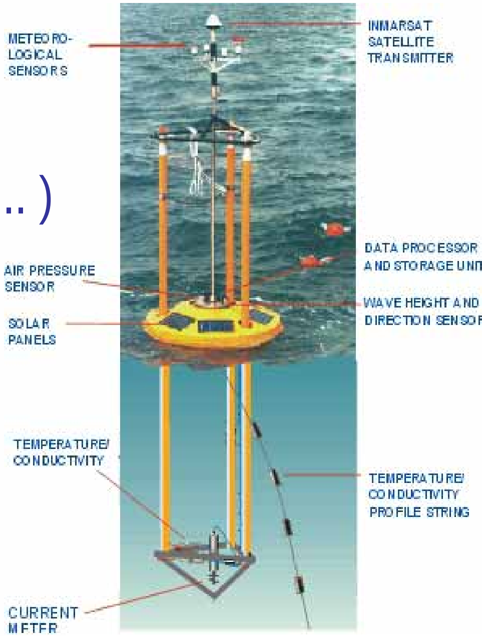


1. Data bases: atmosphere, ocean and hydrology

- Instrumental (buoys, radar, tidal/rainfall gauges, flow measurements,..)
- Visual data (ships)
- Hindcast data (WWWIII / WAM models)
- Satellite data (altimeters)



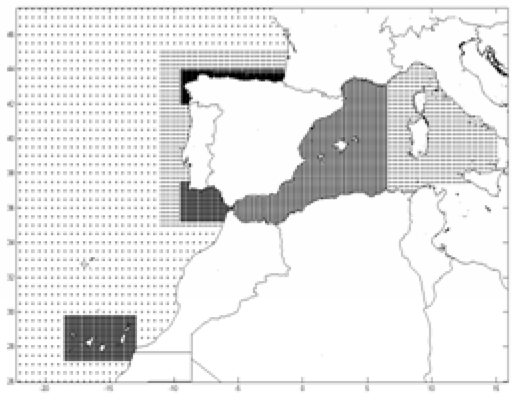




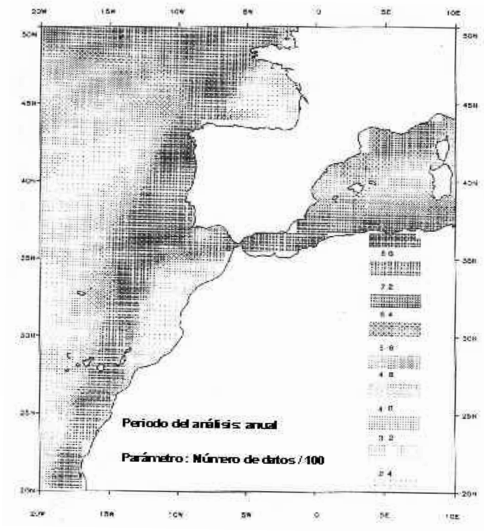
1. Data bases: atmosphere, ocean and hydrology

Summing up..

Numerical model



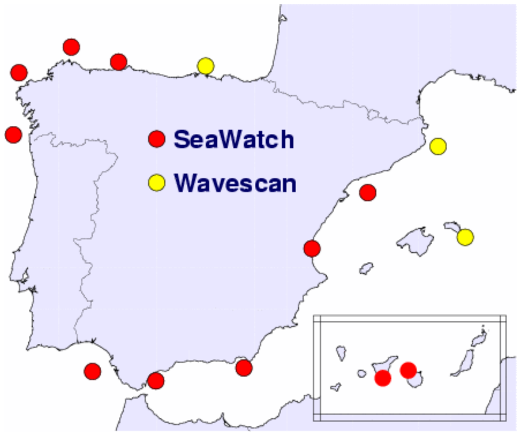
Visual data



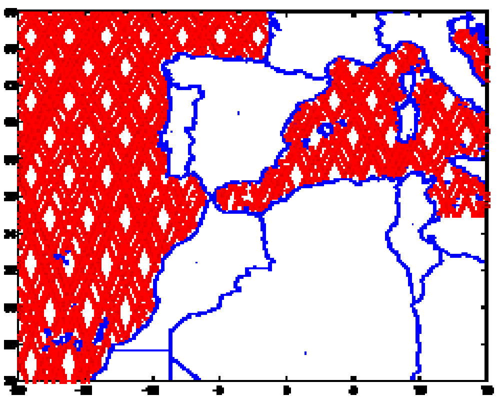
Good qualitatively
Good directional information
Sparse in space
Long records
Extreme values are not adequate

buoys

Good quantitatively
Shallow water buoys affected by propagation
Sparse in space and time, gaps
Short records (in general)



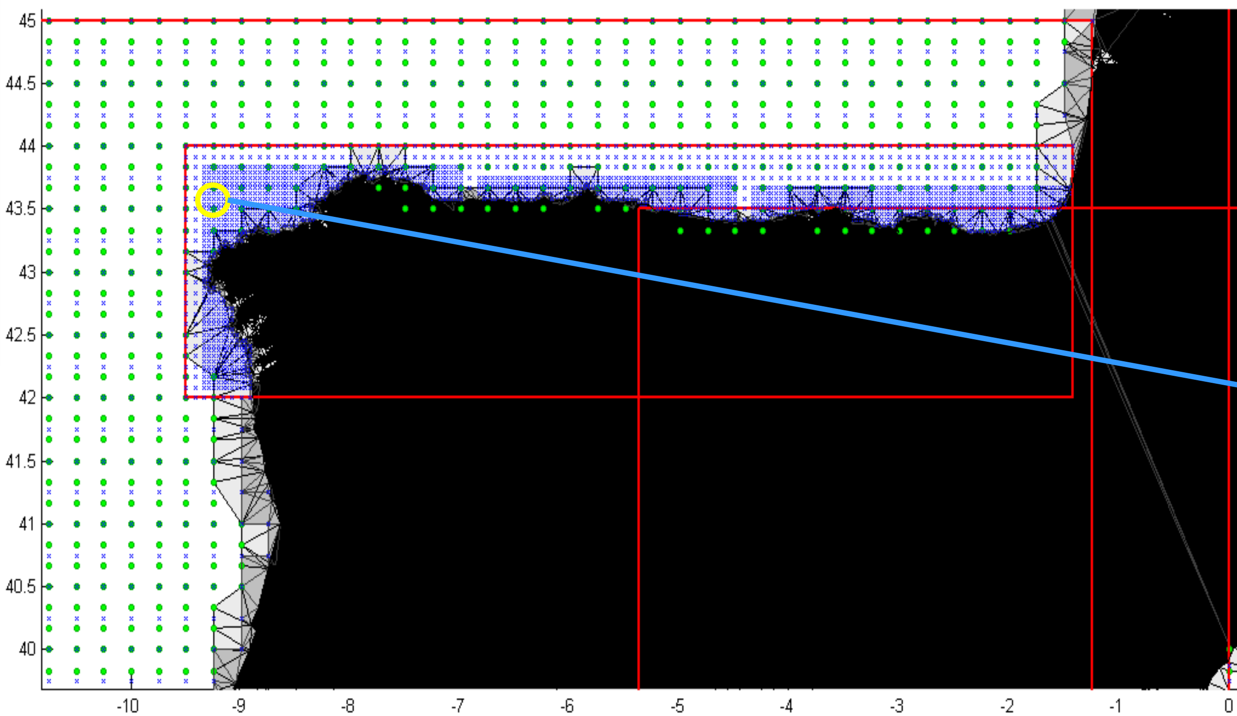
Satellite

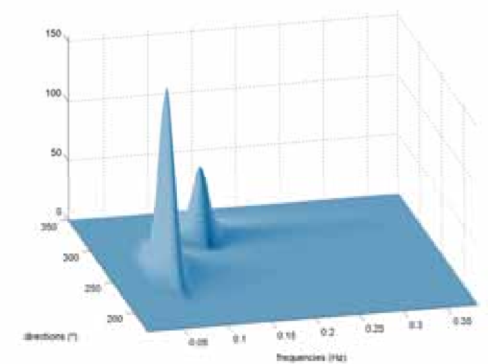


Good quantitatively
Sparse in time
Well-spatially distributed
Short records (10 years)

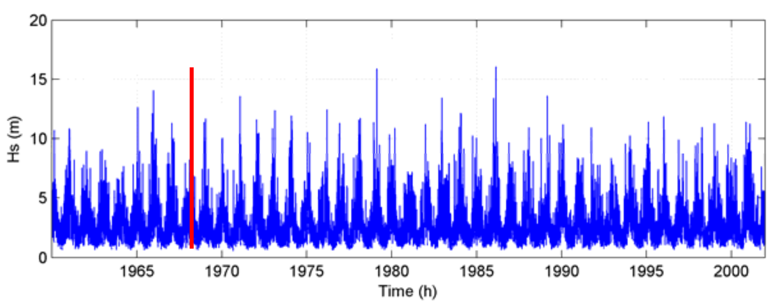
3. Methodology to assess detailed studies

WAVE REANALYSIS DATA SIMAR – 44 DATA BASE





each sea state



Definition of the sea state:

1. H_s, T_p, θ
2. H_{s1}, T_{m1}, θ_1, H_{s2}, T_{m2}, θ_2