PIANC French Section

PIANC Mediterranean Days

and Conference «Port of the future» by Cerema

25 to 27 october 2023 in Sete France

Applications of Machine Learning techniques to assist the design, construction and operation of port infrastructures.

Antonio Tomás, David Lucio, Eva Romano, Gabriel Díaz-Hernández, Javier L. Lara, Iñigo J. Losada.

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This communication presents the results of some applications developed by IHCantabria, based on the use of **Machine Learning techniques** to enhance the design, construction, and operation of port infrastructures, such as:

1) An **early warning system** to support the construction of the Port of Açu (Brazil), providing daily safe and realistic working conditions in advance (to build, transport and anchor concrete caissons and to build concrete caisson crests for different layouts).

2) Projection of **climate change** hazards on 122 Ports of Galicia (Spain), in a high-resolution downscalling framework dealing with multi-model and multi-scenario climate projections.

3) Advanced characterization of the **towing service** of the Port of Santander (Spain), predicting the number and power of tugboats required for general cargo operations.

4) Prediction of the **operability of the berthed vessels** at Las Palmas Port (Spain), to forecast the levels of safety and efficiency of port operations.

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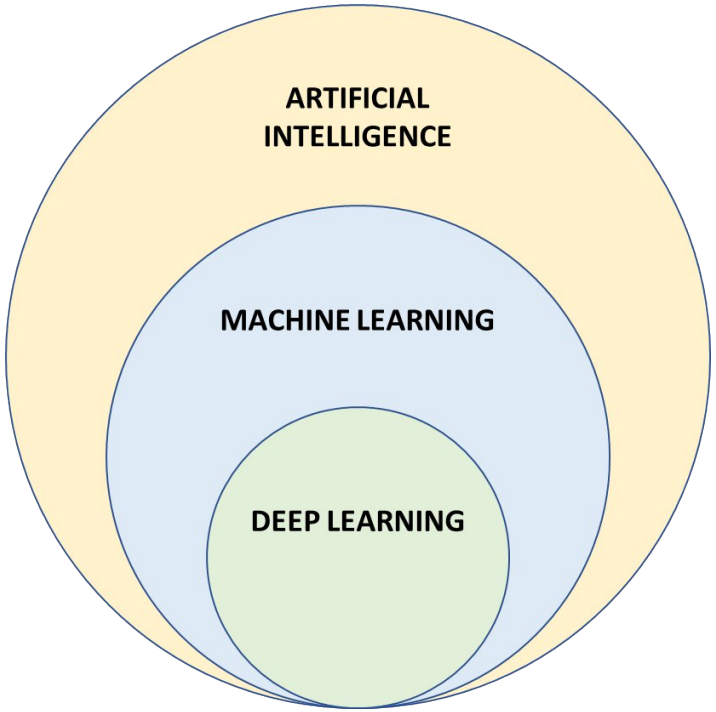
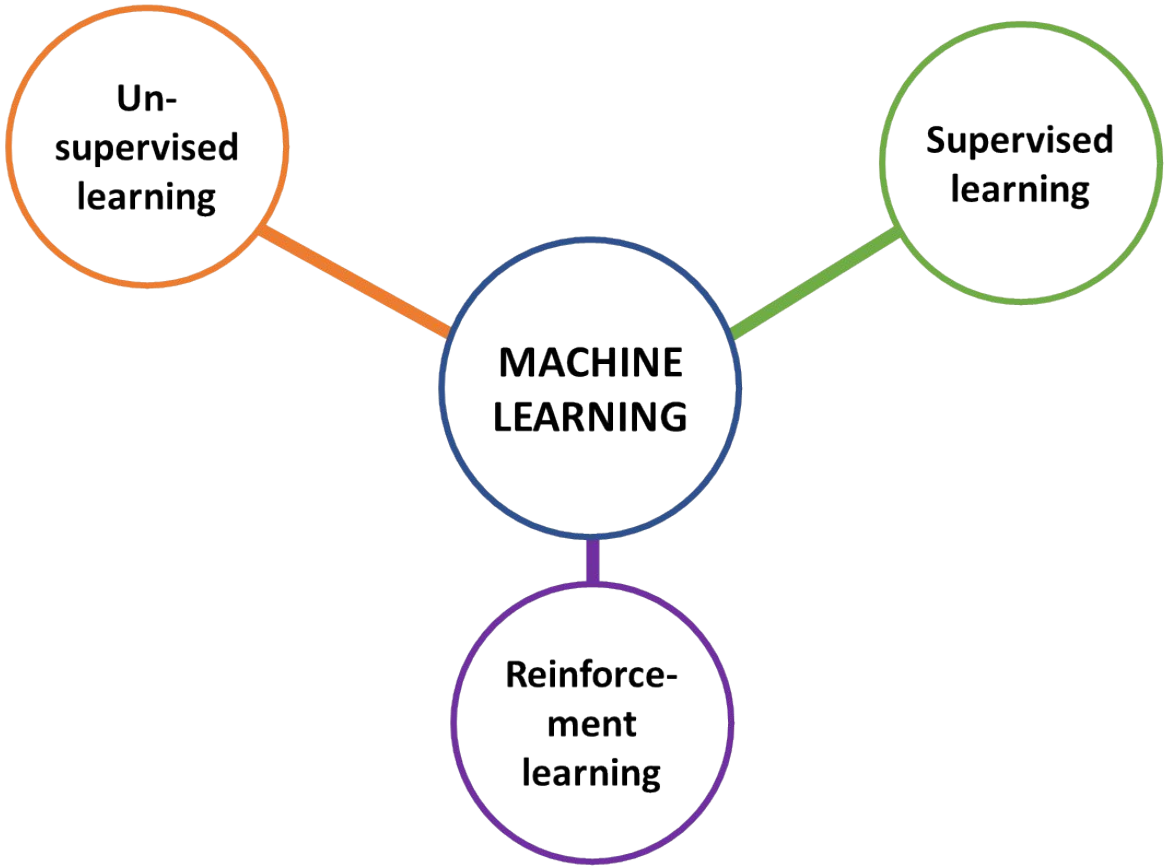
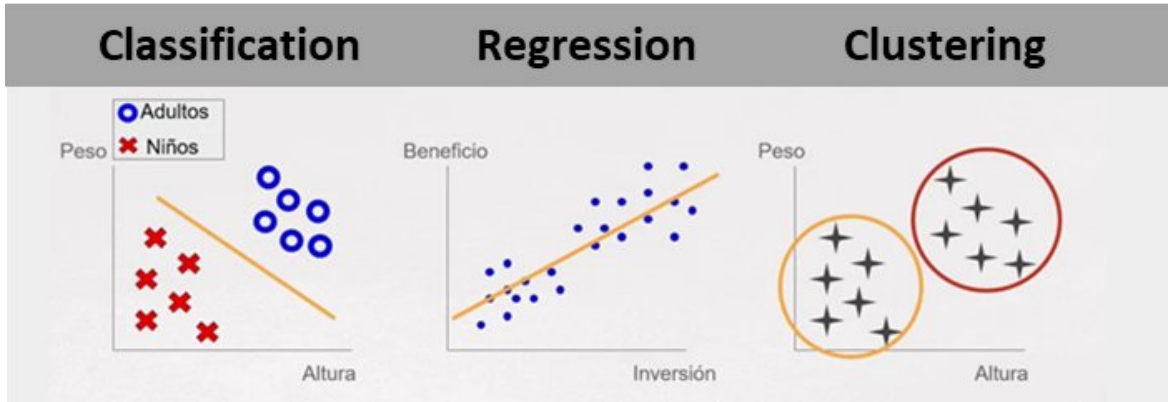

ARTIFICIAL INTELLIGENCE
MACHINE LEARNING
DEEP LEARNING


Un-supervised learning
Supervised learning
MACHINE LEARNING
Reinforce-ment learning

- MACHINE LEARNING
  - Un-supervised learning
    - Dimension-al reduction
      - Principal Component Analysis
    - Clustering
      - K-means
      - Hierarchical clustering
  - Supervised learning
    - Regression
      - Regression analysis
      - Bayesian models
    - Classifica-tion
      - Suppor Vector Machines
      - K-nearest neighbors
      - Decision trees
  - Reinforce-ment learning



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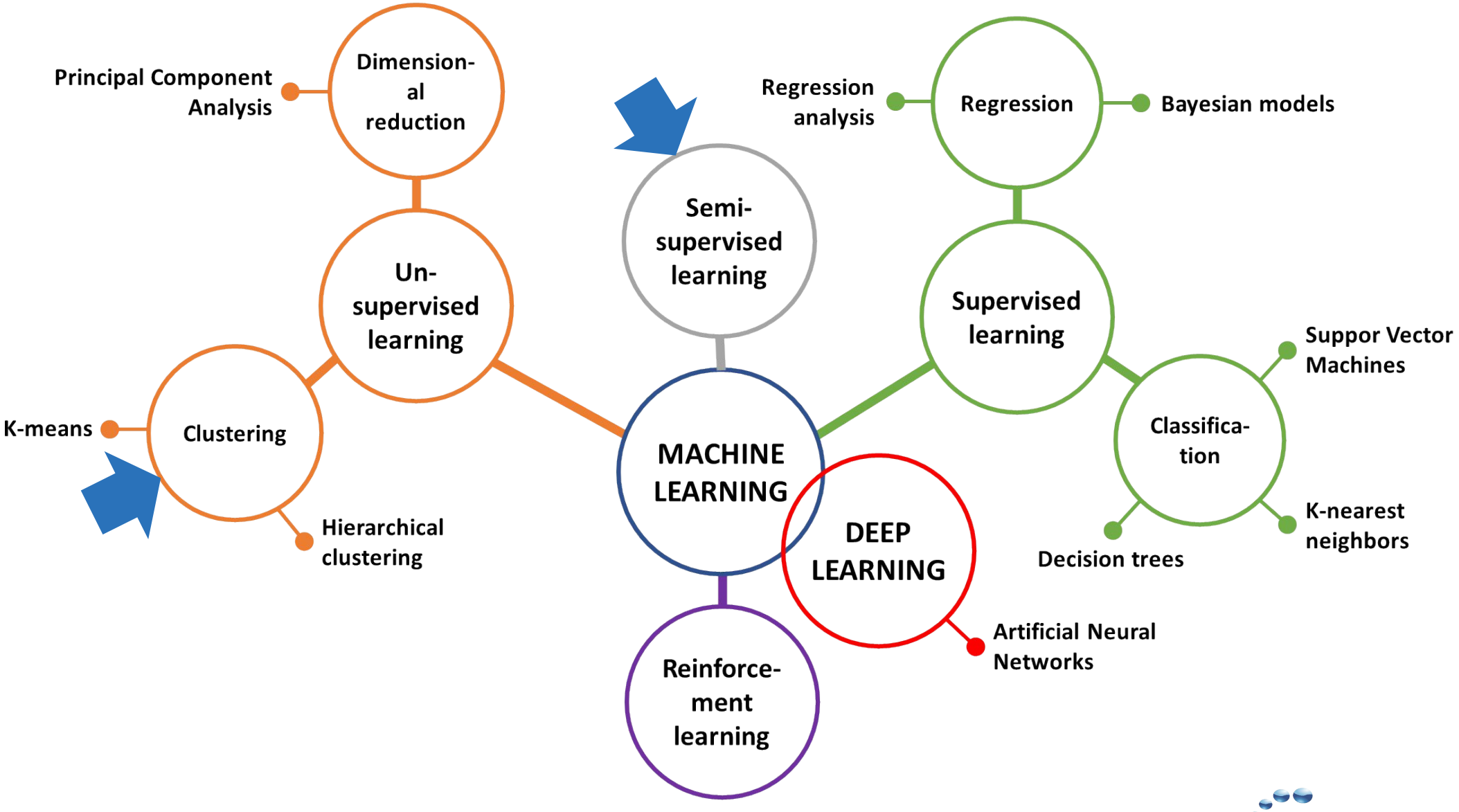
MACHINE LEARNING
Un-supervised learning
Dimension-al reduction
Principal Component Analysis
Clustering
K-means
Hierarchical clustering
Semi-supervised learning
Reinforce-ment learning
Supervised learning
Regression
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Bayesian models
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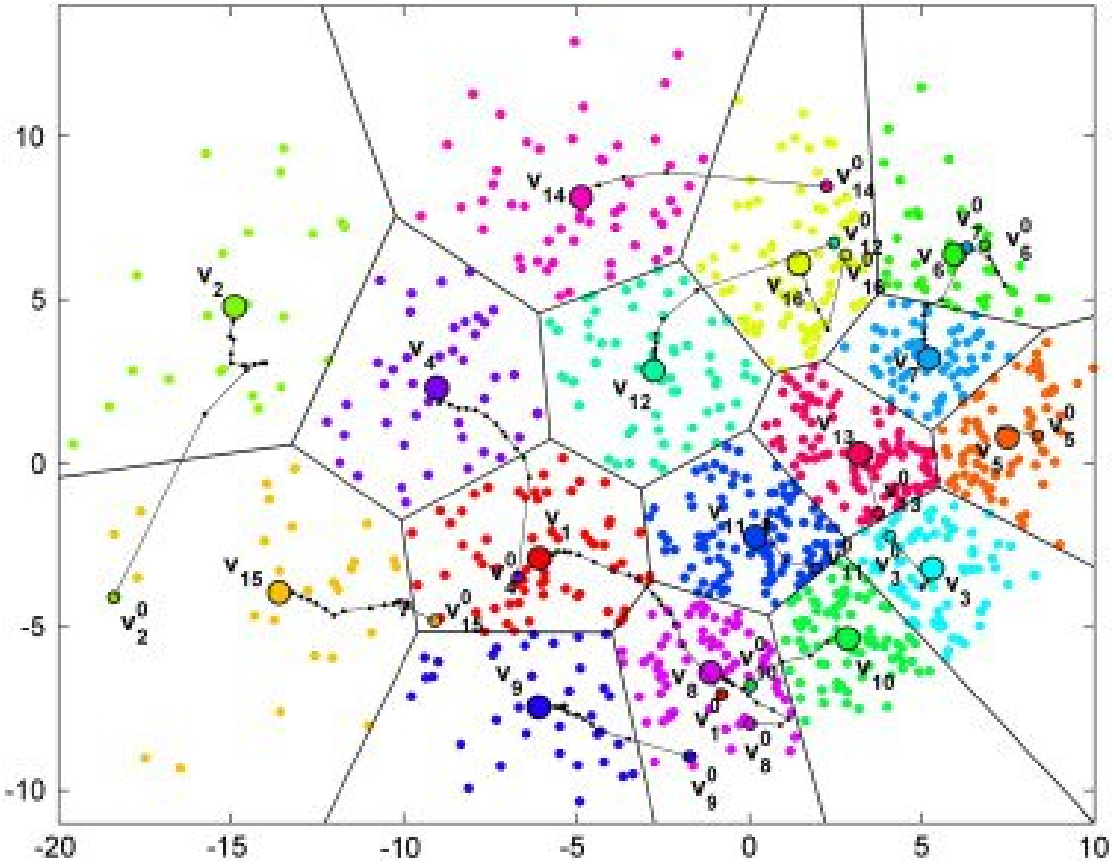
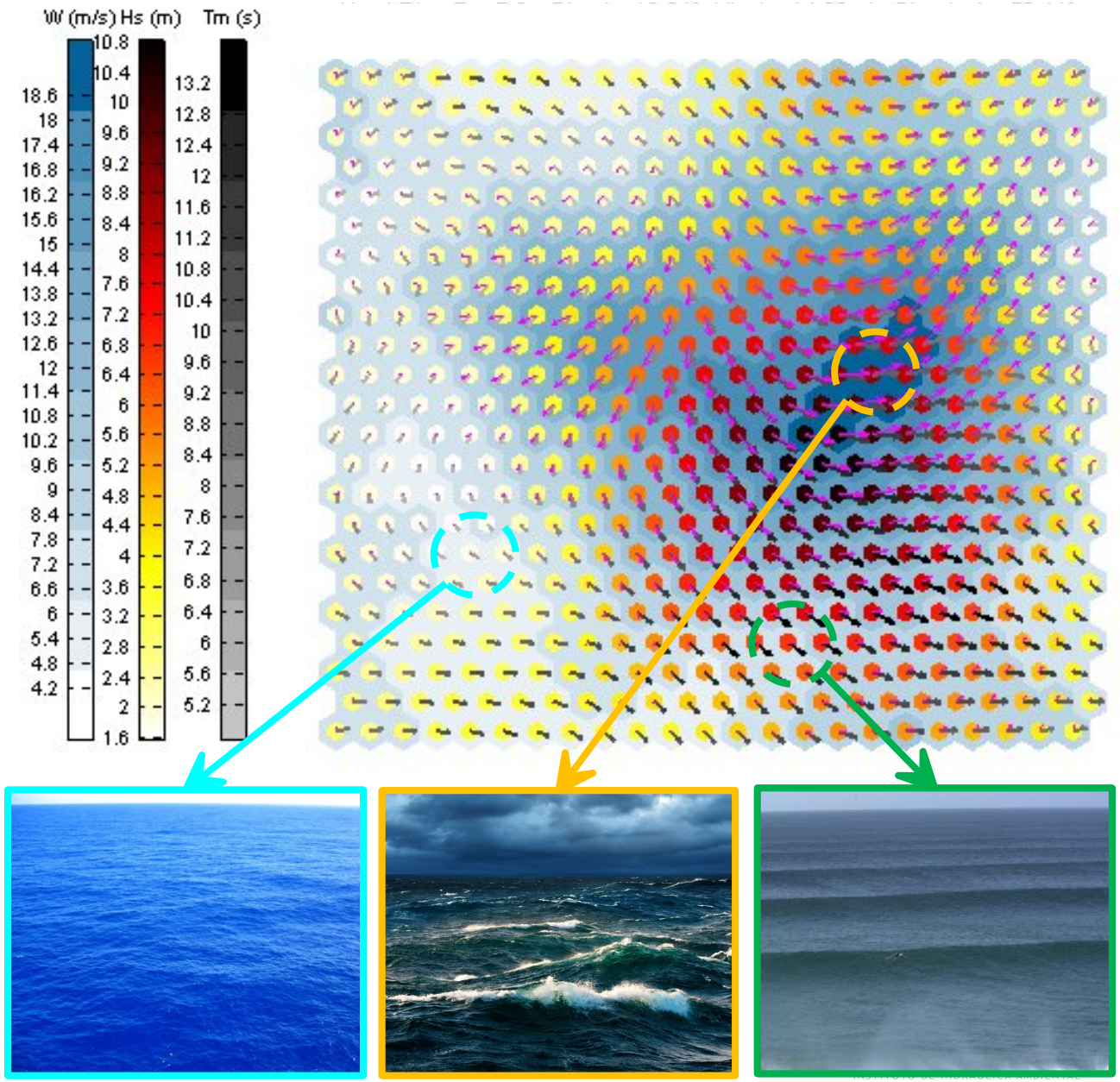
Suppor Vector Machines
K-nearest neighbors
Decision trees
DEEP LEARNING
Artificial Neural Networks

K-means concept (clustering):



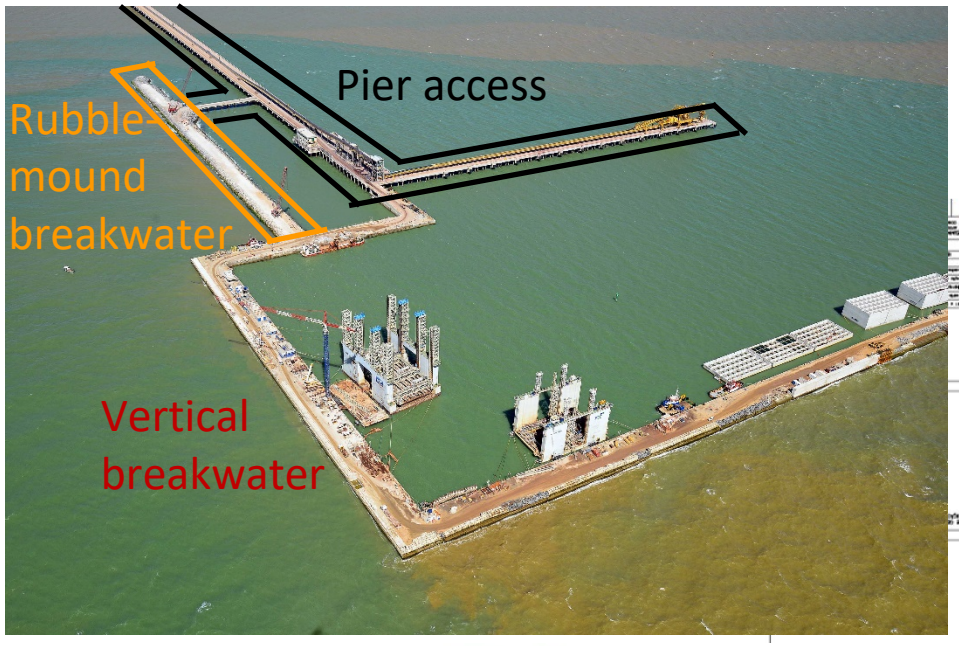
Camus, P.; Mendez, F.J.; Medina R.; Cofiño A.S. (2011). Analysis of clustering and selection algorithms for the study of multivariate wave climate. Coastal Engineering Vol. 58 (6), 453-462. https://doi.org/10.1016/j.coastaleng.2011.02.003.



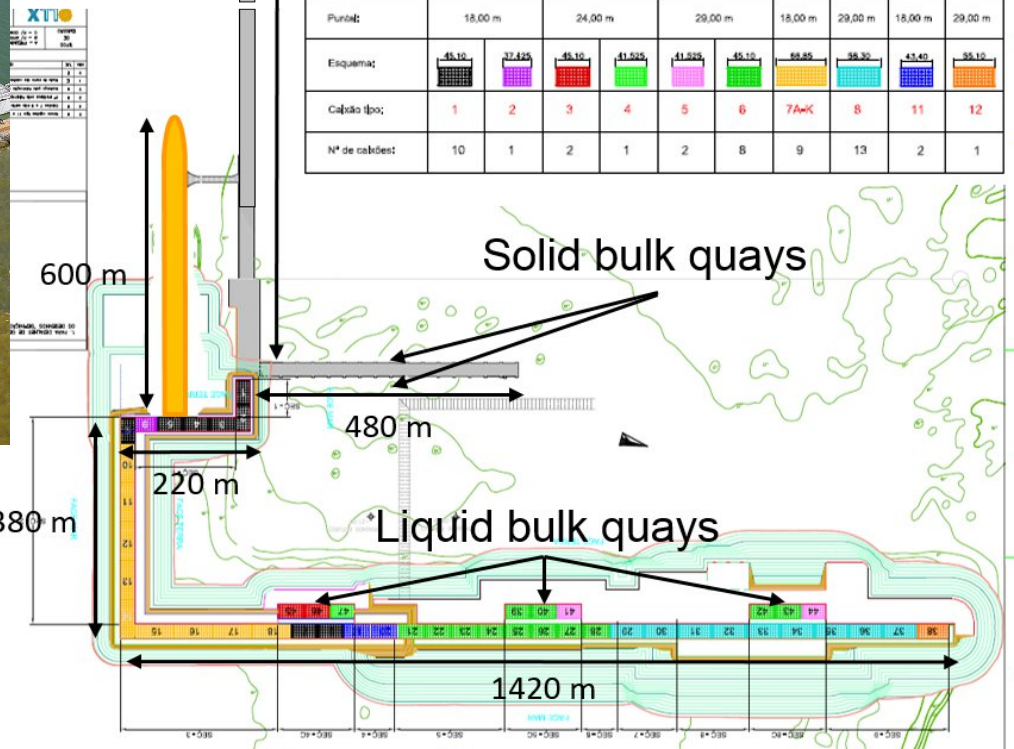
An early warning system to support the construction of the Port of Açu (Brazil):

TX-1 Açu Port Construction (Brazil)

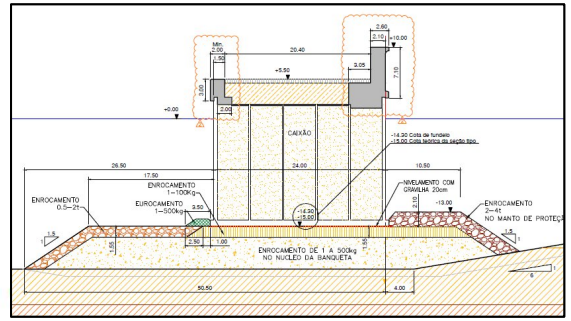
Works include the construction of a breakwater, composed by a 600 m long rubble-mound breakwater (Core-loc 10T) and a 2.100 m long vertical breakwater (47 reinforced concrete vertical caissons), crested at +10 m.

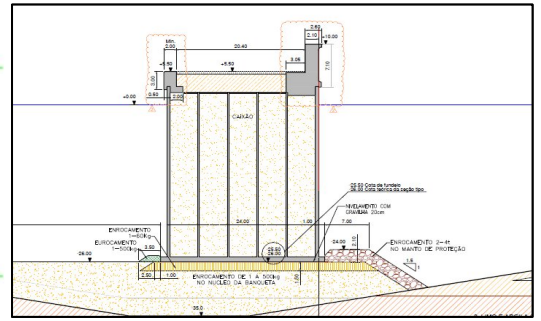


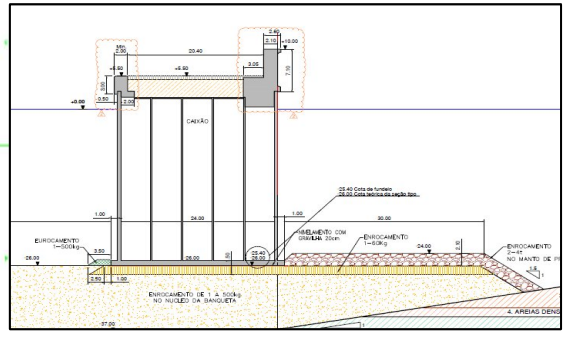
47 (38+9) reinforced concrete caissons with lengths between 37 and 66.85 m, a beam of 24 m and depths between 18 and 29 m.



Puntal:	18,00 m		24,00 m		29,00 m		18,00 m	29,00 m	18,00 m	29,00 m
Esquema:	45,10	37,425	45,10	41,525	41,525	45,10	66,85	56,30	41,40	55,10
Caixão tipo:	1	2	3	4	5	6	7A+K	8	11	12
Nº de caixões:	10	1	2	1	2	8	9	13	2	1







TX 1 AÇU

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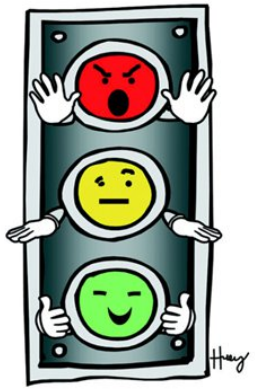
An early warning system to support the construction of the Port of Açu (Brazil):

The problem:

The system should provide daily **safe and realistic working conditions** in advance (**one week forecast**)

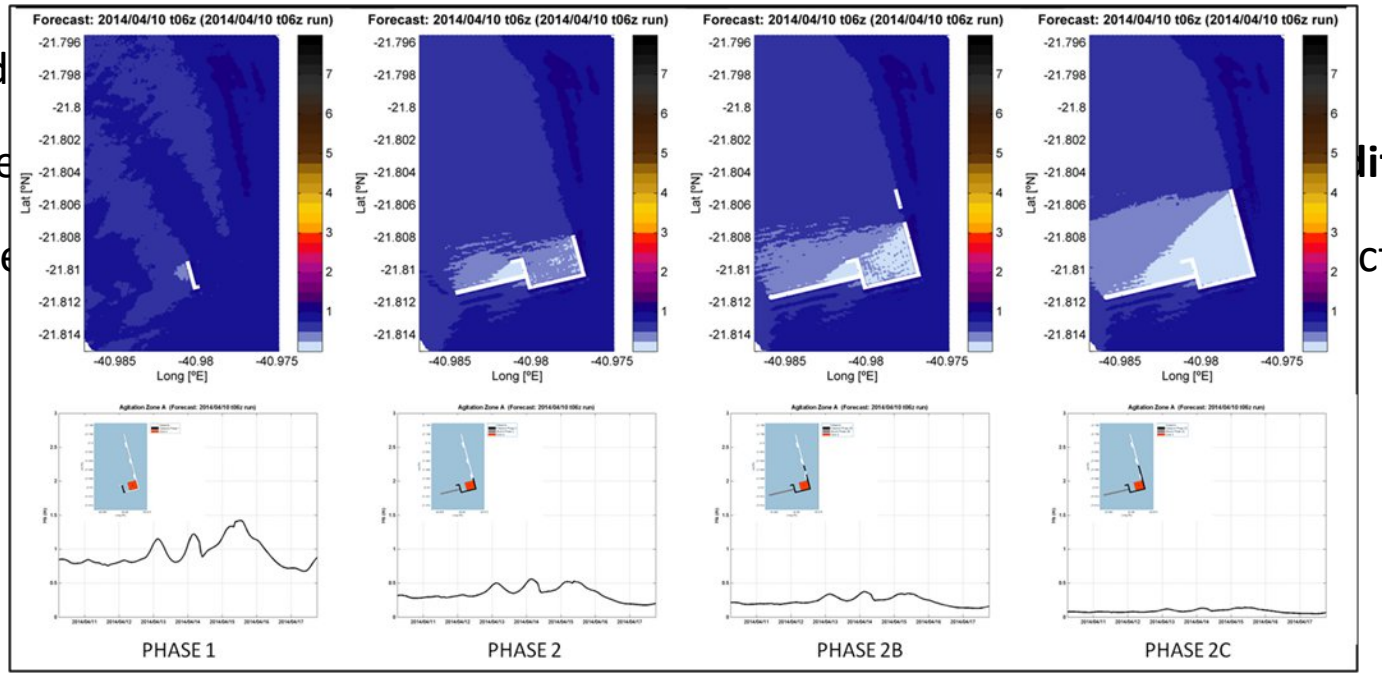
- **to transport the concrete caissons from Río de Janeiro to the port of Açu,**
- **to build the concrete caissons,**
- **to anchor the concrete caissons**
- **to build the concrete caisson crests (superstructure).**



The system should

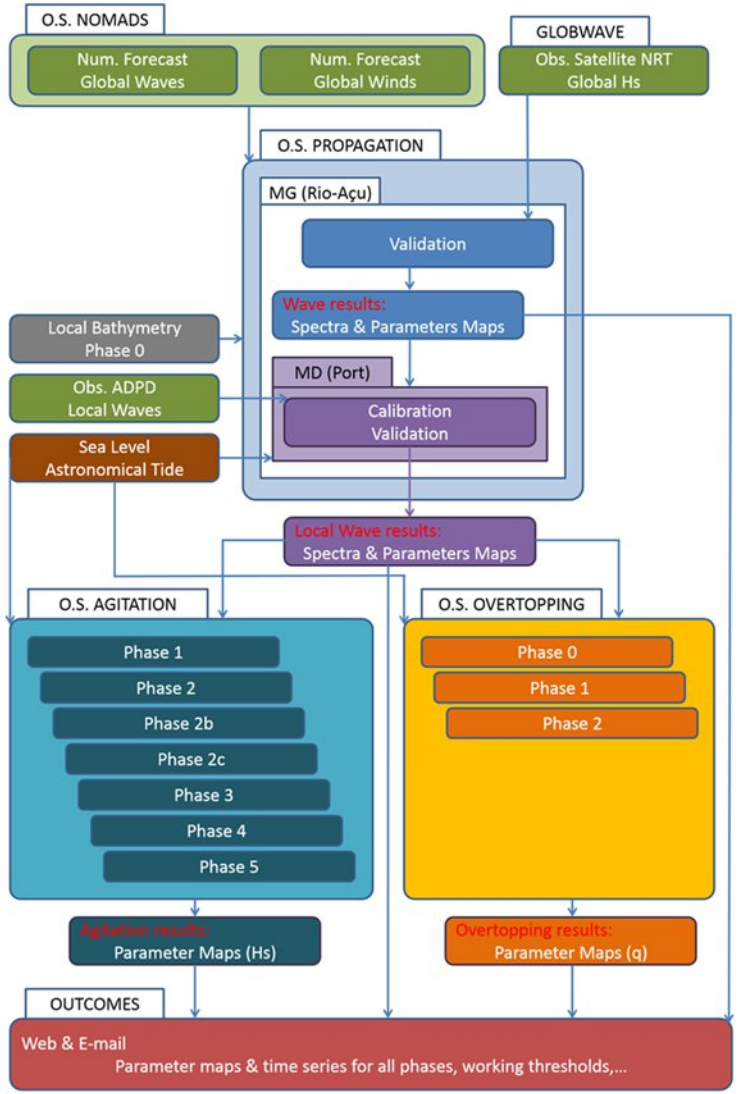
Results should give **different areas of the port**.

Results should take ction stage.



An early warning system to support the construction of the Port of Açu (Brazil):

Results:



All the modules are integrated in a
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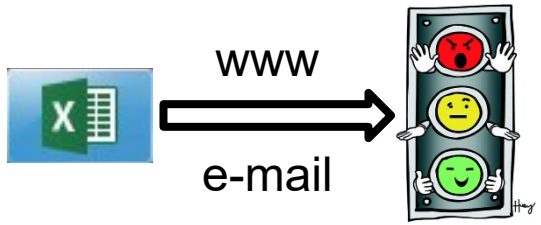
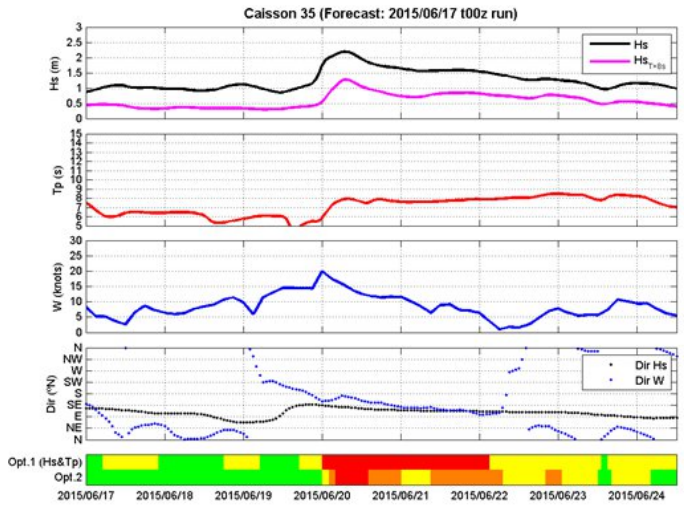
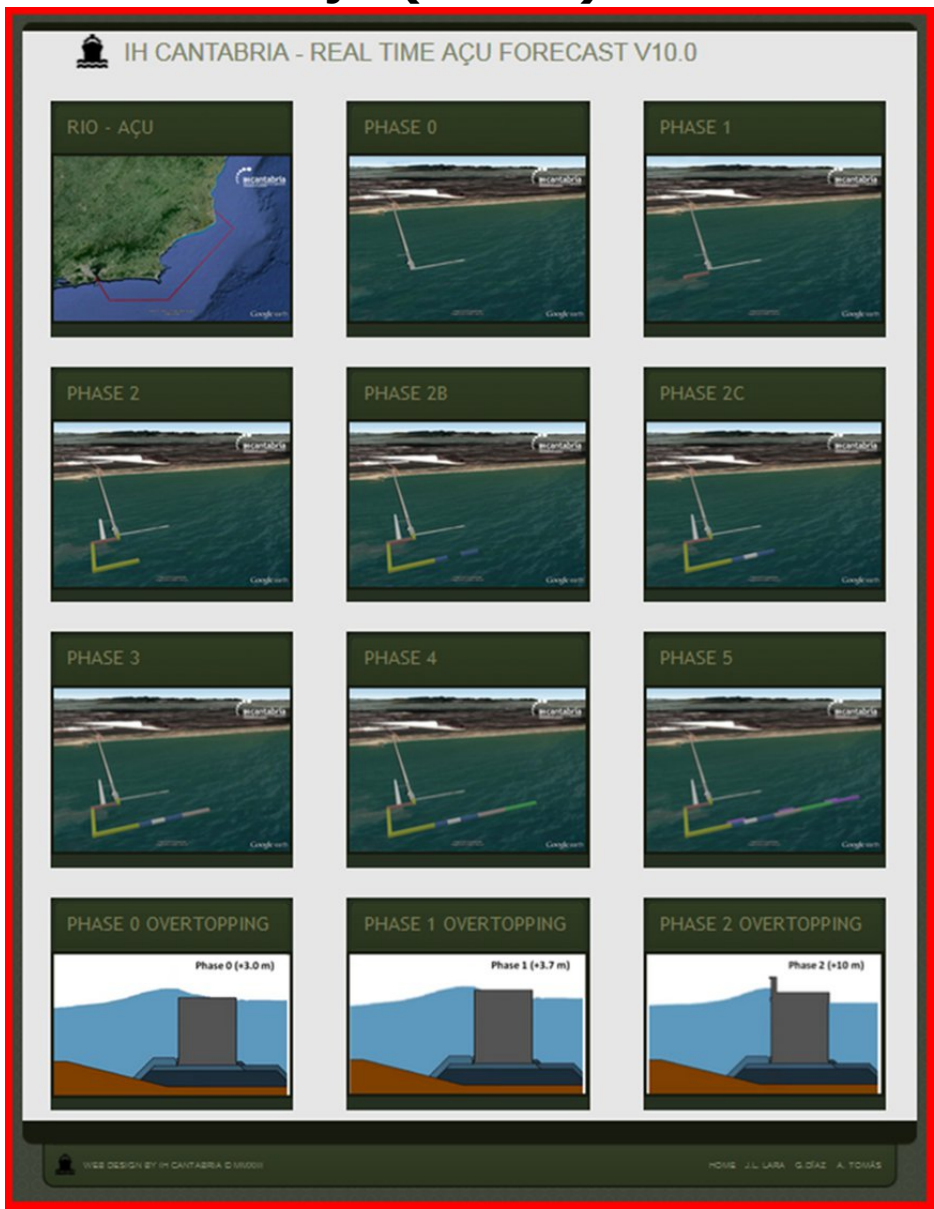




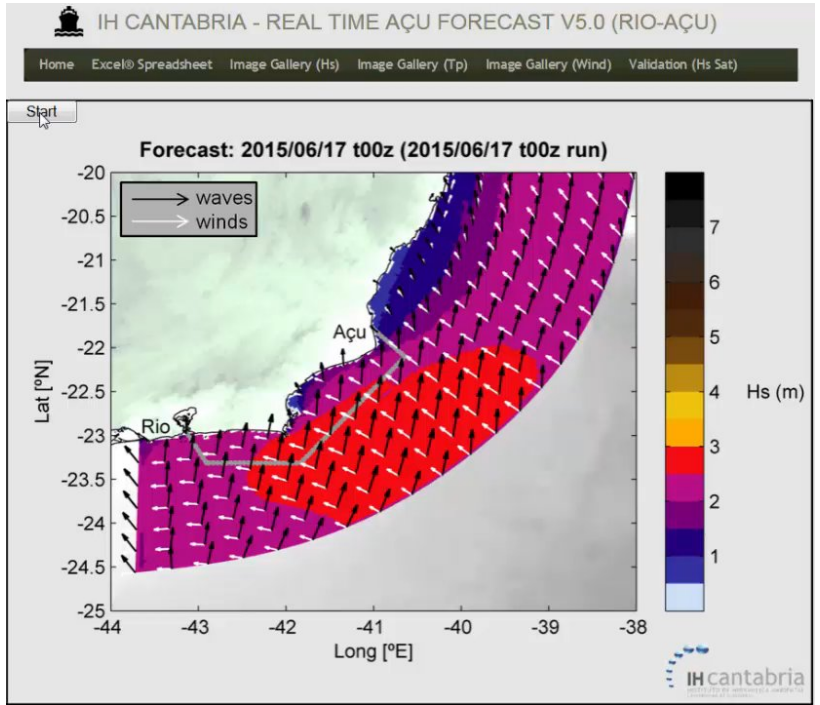


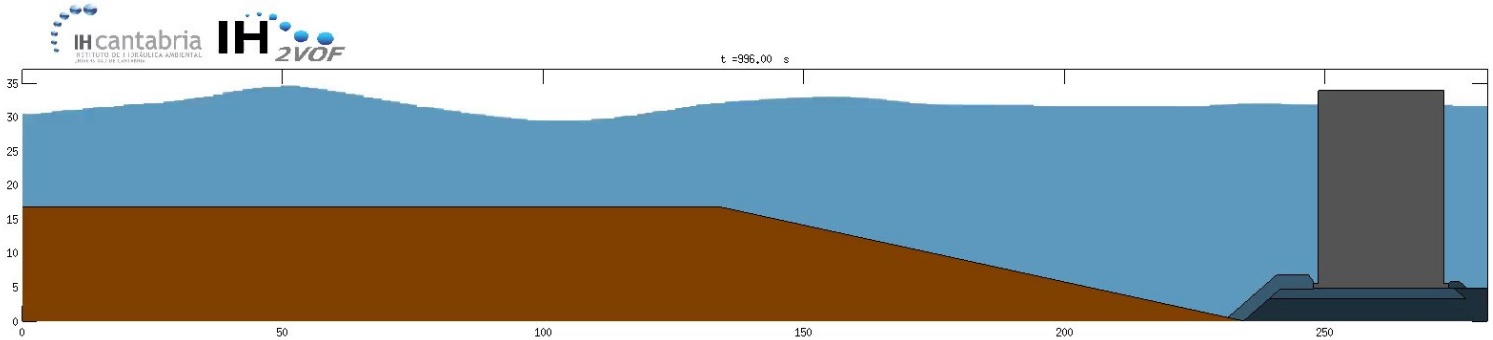
An early warning system to support the construction of the Port of Açu (Brazil):

The Challenge

Methodology based on dynamic downscalling:

The computation time of numerical models through dynamic runtimes are not feasible with an adequate update of the operational system (2 - 4 times per day).





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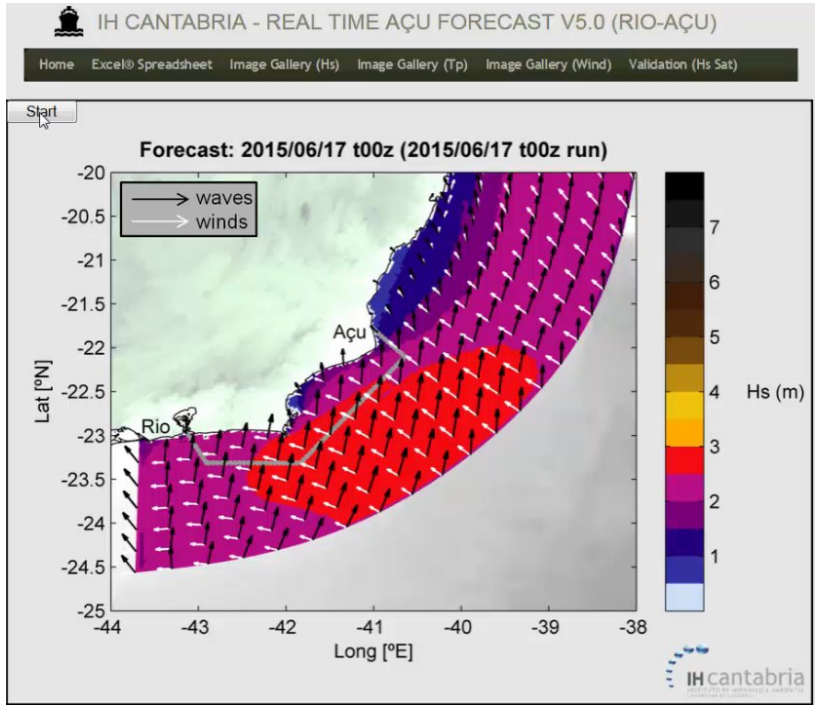
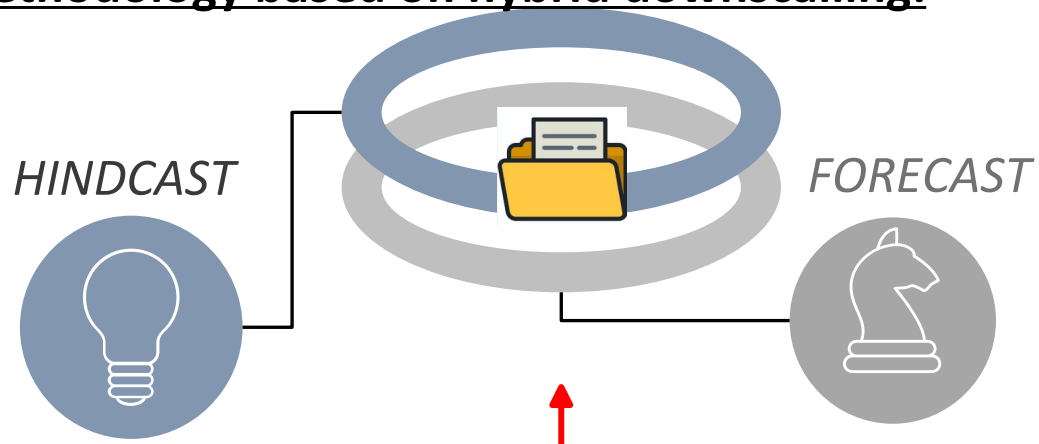
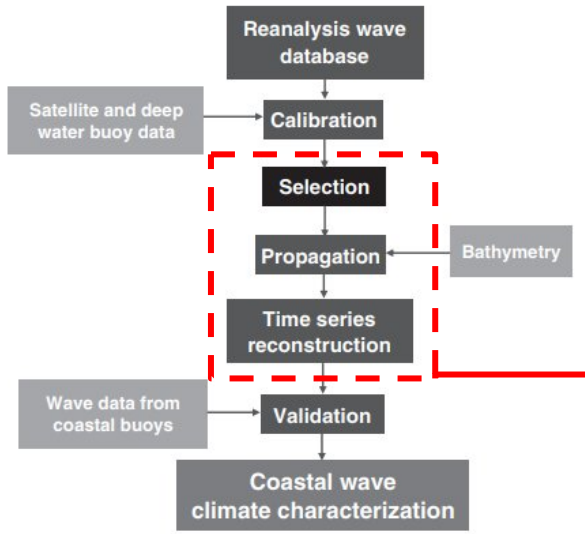


The Solution

Methodology based on hybrid downscalling:





Camus, P.; Mendez, F.J.; Medina R..; Tomás, A.; Izaguirre, C.; (2013) High resolution downscaled ocean waves (DOW) reanalysis in coastal areas. Coastal Engineering, 72, 56-68. https://doi.org/10.1016/j.coastaleng.2012.09.002

AI (clustering)

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Projection of Climate Change hazards on 122 Ports of Galicia (Spain):

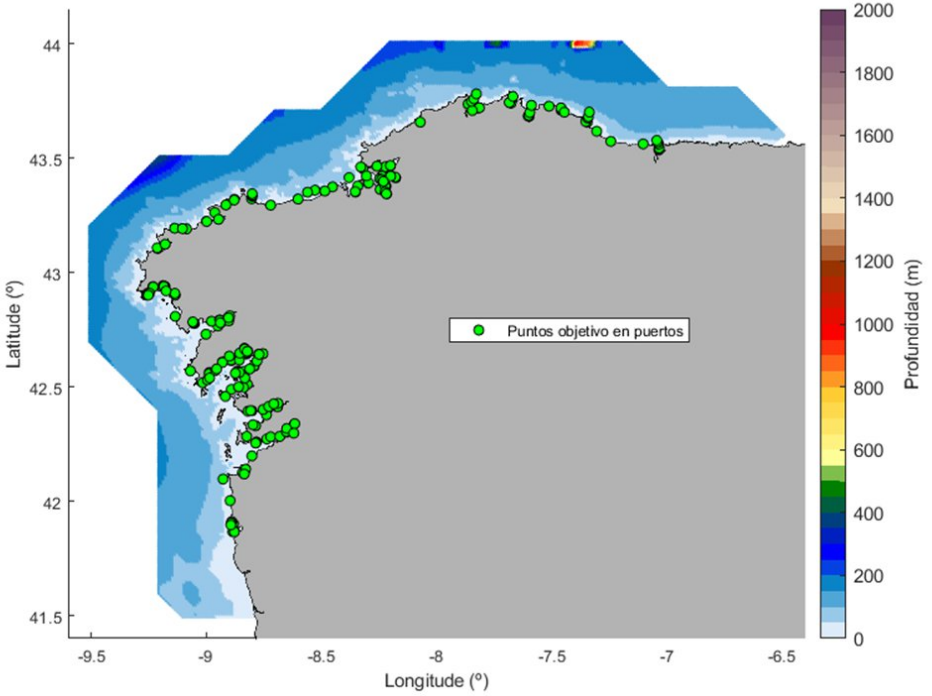
In the framework of "Climate Change adaptation plans for ports managed by the public body Portos de Galicia" a hybrid downscaling approach is applied to propagate offshore wave dynamics to every regional port. The challenge is including climate change effects (changes on waves and sea-levels taking place at the same time) into a highly-efficient wave propagation strategy due to the extensive volume of climate data involve. In this context, we suggest expanding this hybrid downscaling approach to encompass a multi-model and multi-scenario analysis.

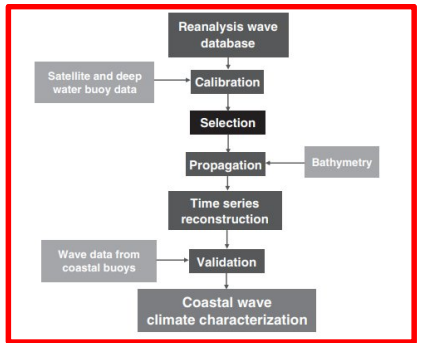
The Challenge

Wave propagation of hourly hindcast wave series (1985-2019) and Climate Projections to 122 ports.

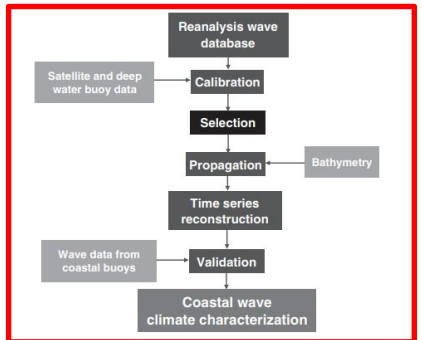
Climate projections from 4 climate models for the reference period (1985-2005) and for two future trajectories of greenhouse gas emissions associated with climate change (scenarios RCP4.5 and RCP8.5) in the short-medium term (2026-2045) and in the long term (2081-2100).

Wave propagation, to each of the 122 ports, of approximately 20 time series of 20 years each.





… 2000 times …



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Portos de Galicia

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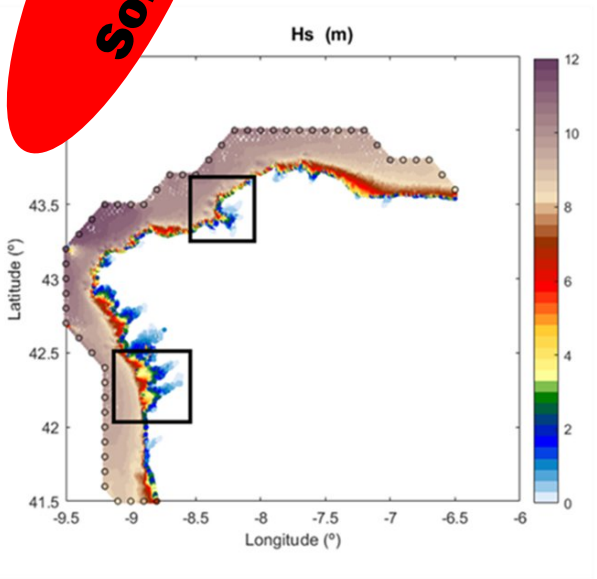
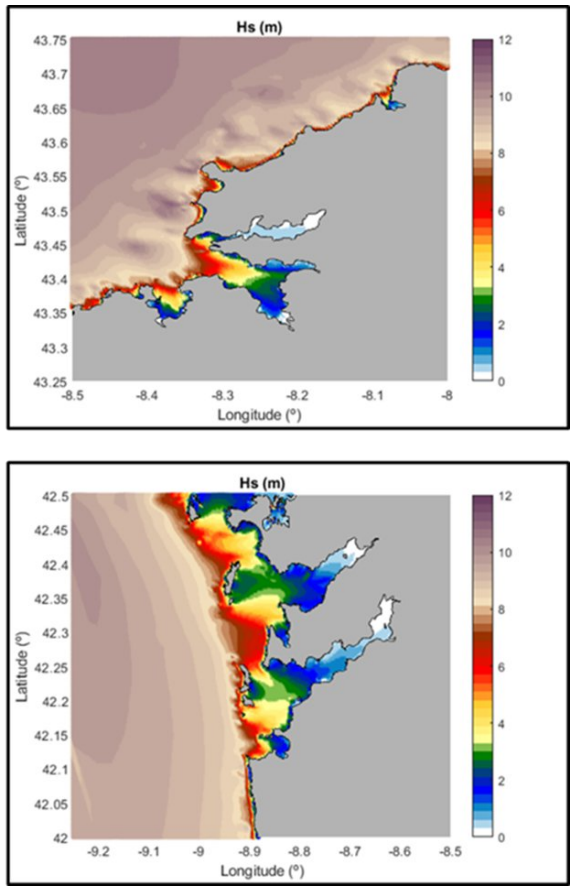
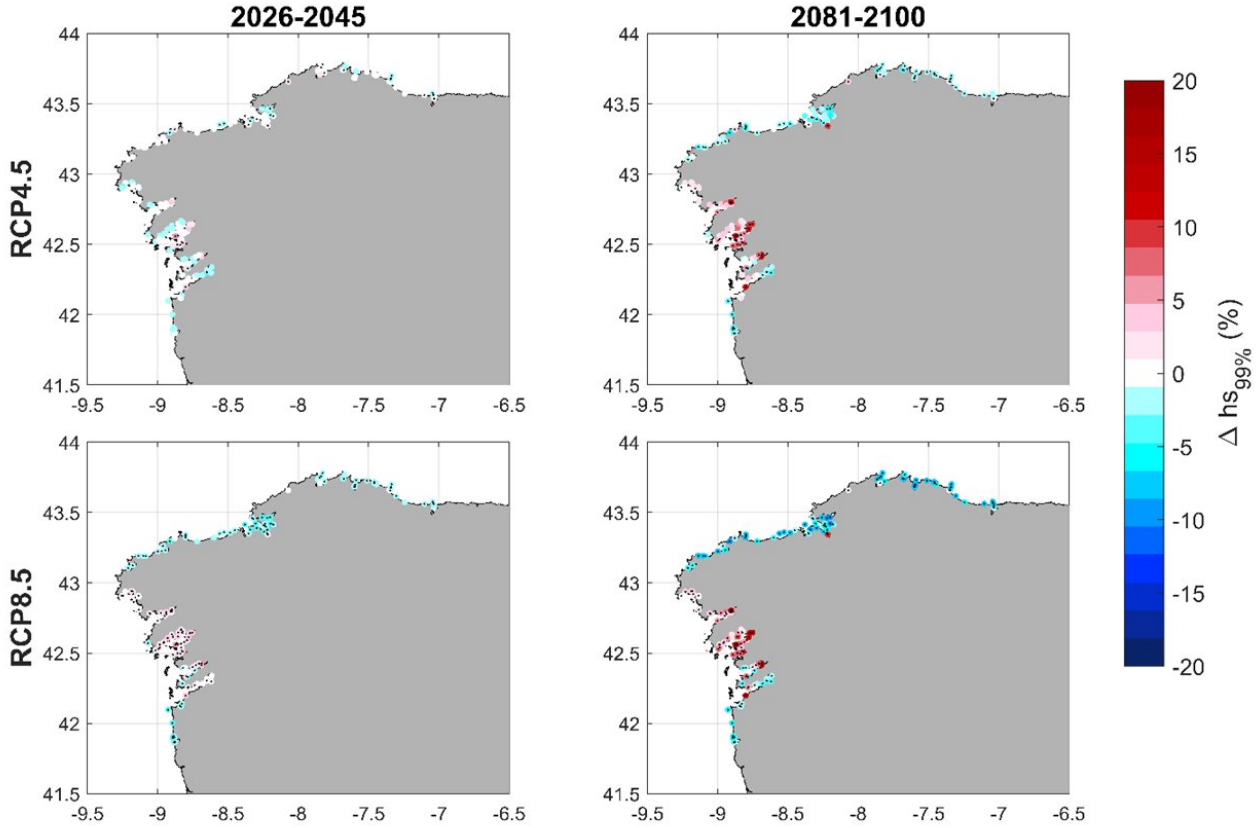
Projection of Climate Change hazards on 122 Ports of Galicia (Spain):

The Solution

All hourly wave series of Hindcast and Climate Projections are correctly propagated to the 122 ports based on only 1000 numerical simulations with a new **clustering-based methodology**







Camus, P., Tomás, A., Díaz-Hernández, G., Rodríguez, B., Izaguirre, C., Losada, I.J. (2019) Probabilistic assessment of port operation downtimes under climate change. Coastal Engineering, 147, 12-24. https://doi.org/10.1016/j.coastaleng.2019.01.007

Advanced characterization of the towing service of the Port of Santander (Spain):

The dimensioning of the port towing service requires defining (1) the number of tugboats and (2) their pulling capacity. In general, it is subjectively defined only based on the historical experience of the port's needs, considering the usual type of vessels, as well as the prevailing weather conditions. In this sense, there is not a technical methodology for selecting the suitable number of tugboats and their related pulling capacity.

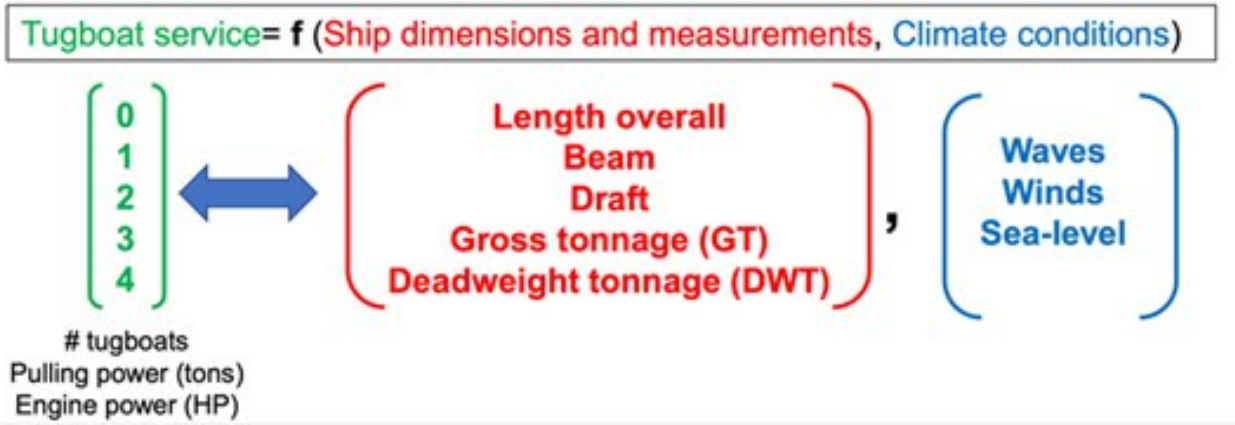
The Challenge

Here, a new approach based on **machine learning techniques** is presented to analyze such port service on The State-owned Spanish Port System. In particular, The Port of Santander located in the Cantabrian Sea, is taken as an example to analyze such port towing service for General Cargo vessels, both for the **current climatic** **tion and vessel traffic demand** and **under different combinations of climate change and future fleets**.

These works were developed in the framework of the “Application of Machine Learning technology for the design of towage operations in a port” funded by the Government of Cantabria.

Advanced characterization of the towing service of the Port of Santander (Spain):

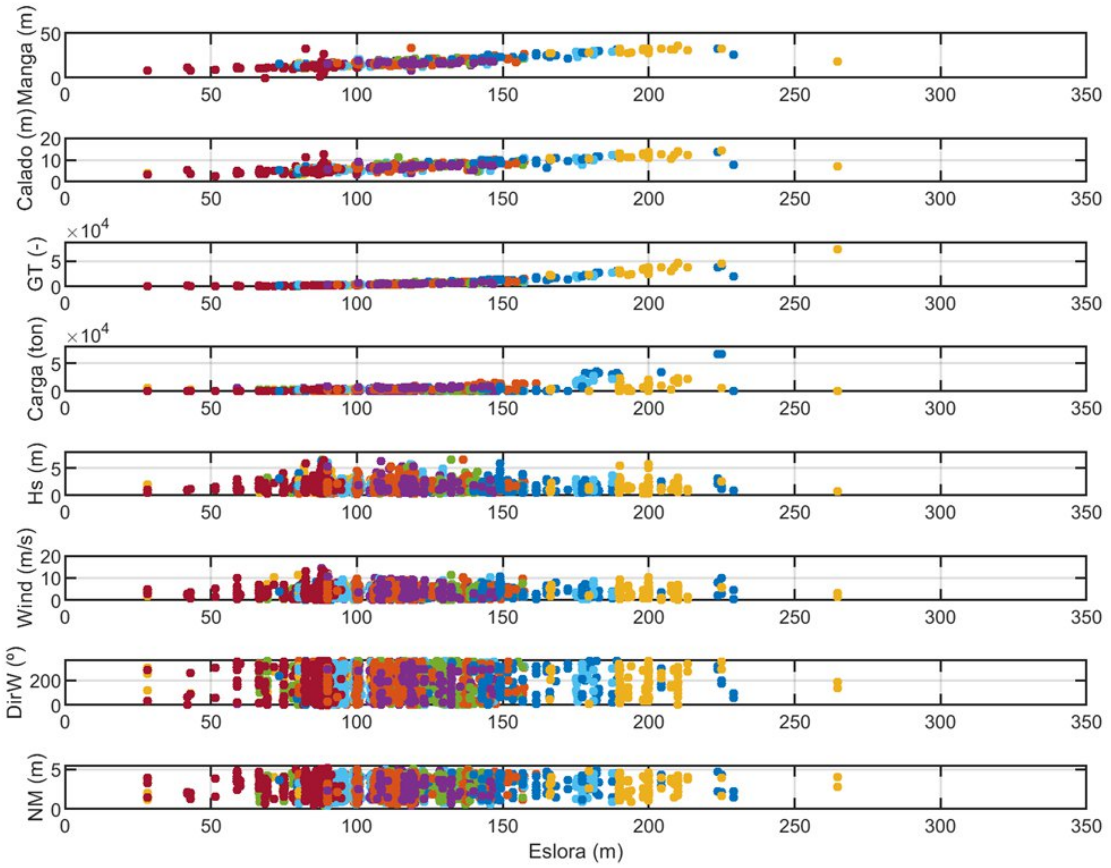
The objective is to build a new predictive tool for the towing service (number of tugboats to be used for port entry/exit, required pulling and engine power) for the GENERAL CARGO typology according to the individual ship characteristics (Length overall, beam, draft, gross tonnage and deadweight tonnage) and the particular weather conditions (waves, winds and sea-level) in the operation.



The Solution

The **k-means algorithm** was applied to identify 25 9-dimensional homogeneous clusters using the **regression guide technique**:

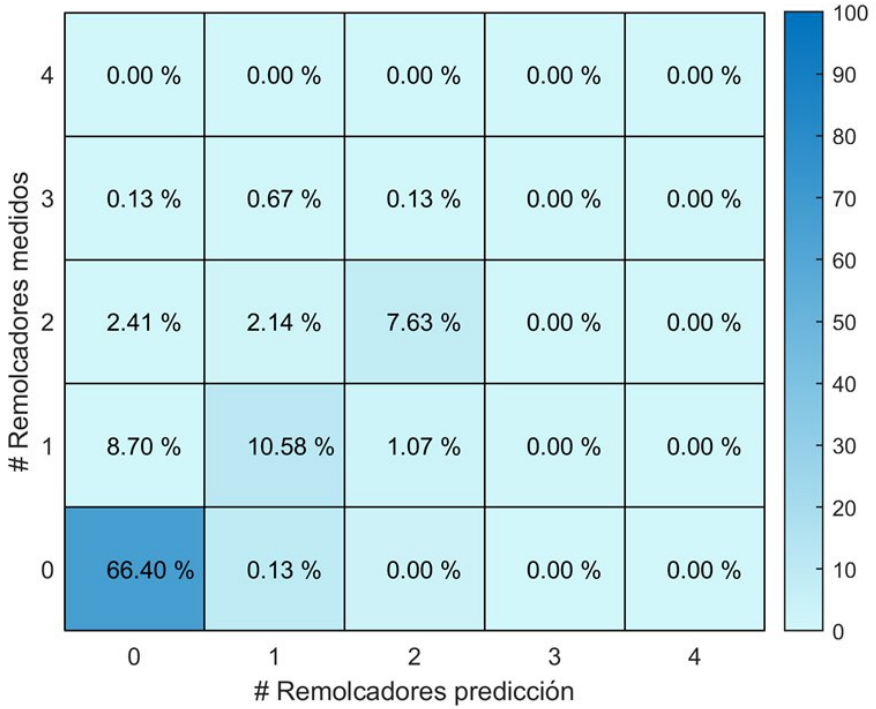
Camus, P., Rueda, A., Méndez, F.J., Losada, I.J., (2016). An atmospheric-to-marine synoptic classification for statistical downscaling marine climate. Ocean Dyn., 66, 1589–1601. https://doi.org/10.1007/s10236-016-1004-5

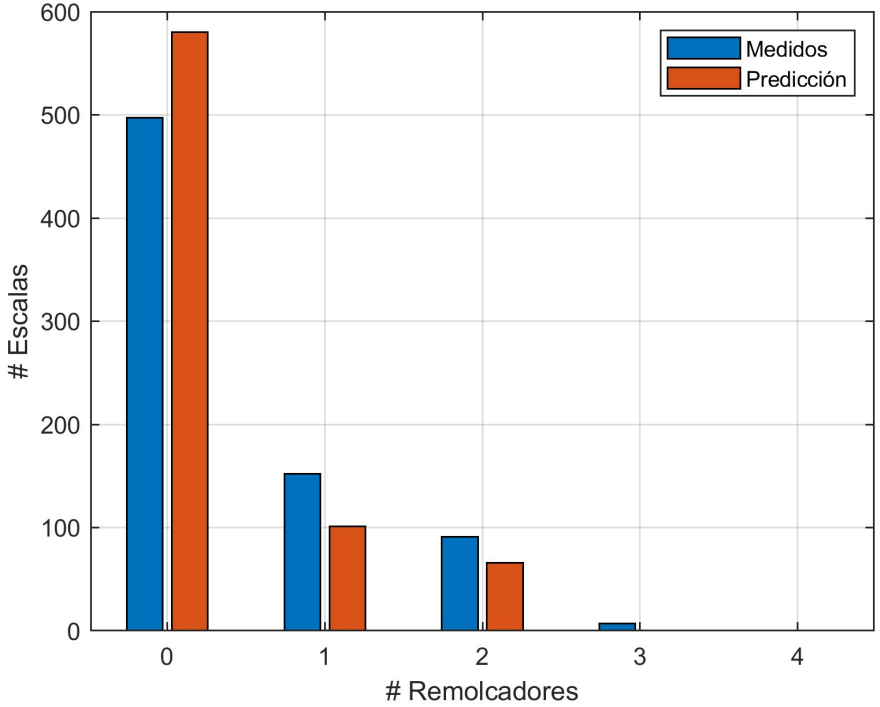


Advanced characterization of the towing service of the Port of Santander (Spain):

The tool was trained with the database corresponding to the period **2015-2018** (4453 scales) and validated (tested) with the database corresponding to the year **2019** (747 scales), all provided by the Port of Santander.

The success rate was higher than a **85%,** although other relevant variables such as the state of conservation of the ship or port pilot knowledge are not included into the tool.





Advanced characterization of the towing service of the Port of Santander (Spain):

The tool was also used to analyze port towing service (for General Cargo vessels) under different combinations of **climate change** (Sea Level Rise) and **future fleets** (optimistic, neutral and pessimistic):

Tugboat service= f (Ship dimensions and measurements, Climate conditions)

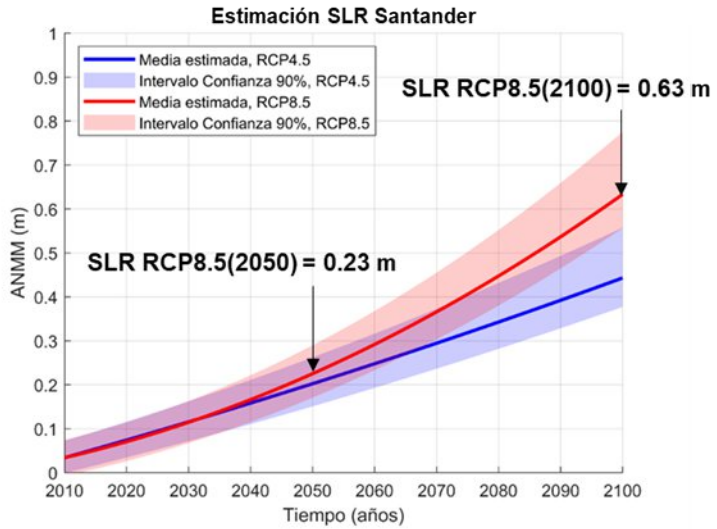
0
1
2
3
4

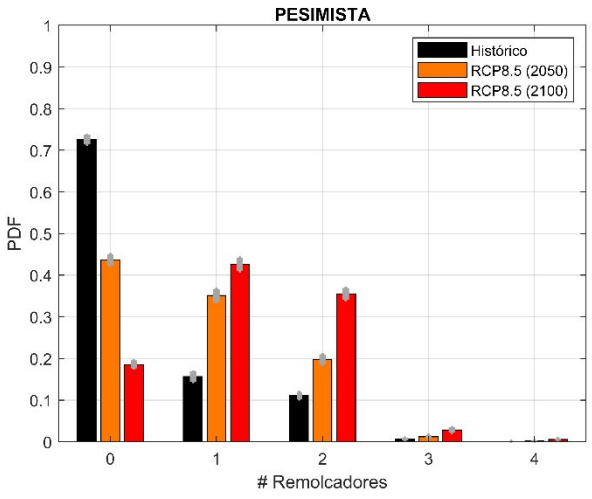
tugboats
Pulling power (tons)
Engine power (HP)

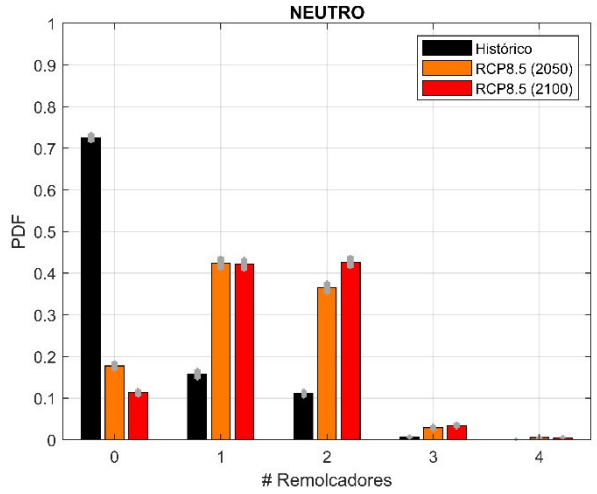
Length overall
Beam
Draft
Gross tonnage (GT)
Deadweight tonnage (DWT)

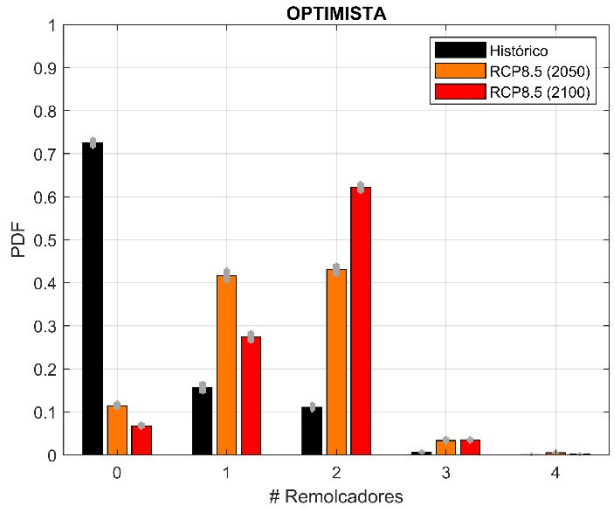
,

Waves
Winds
Sea-level







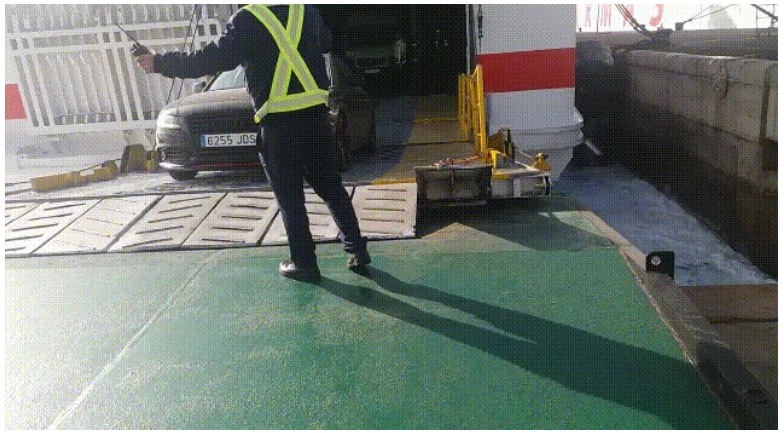


Prediction of the operability of the berthed vessels at the Las Palmas Port (Spain):

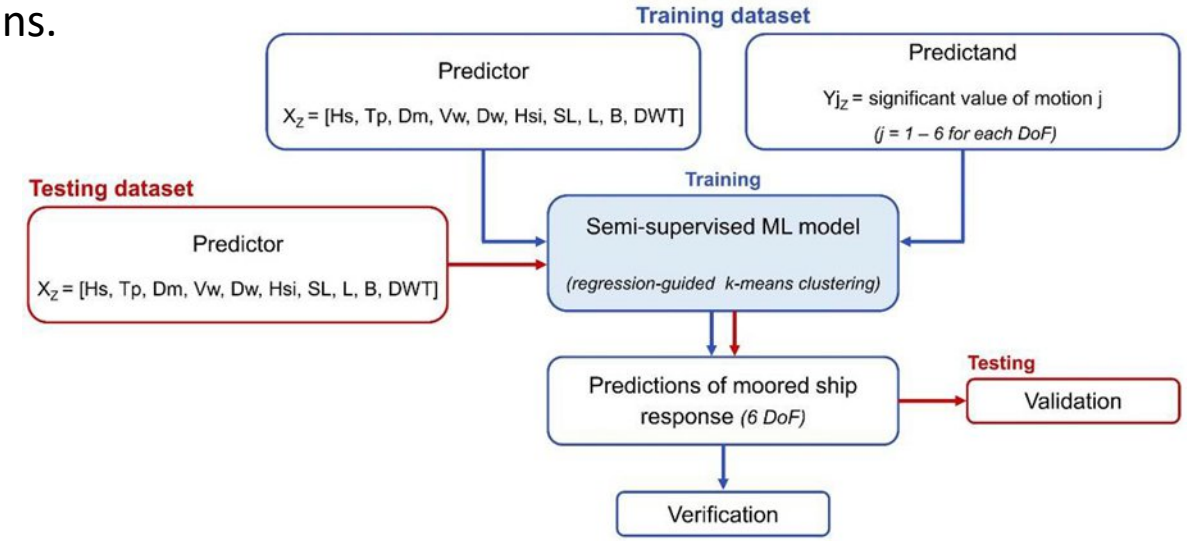
The main objective of this system is to develop a predictive tool for the **safety and efficiency levels of port operations** based on specific information for each berth (met-ocean predictions, planning of ship calls and expected operations), that make up the knowlodge base of the project.

The Challenge

To this end, a "**port-agnostic**" methodology is developed, based on the advanced exploitation of the knowledge base to dynamically adjust the **predictive tool for port operations**, applicable to different time horizons.



The methodology is based on an inference model based on **semi-supervised Machine Learning** techniques developed for predicting moored ship motions.



Prediction of the operability of the berthed vessels at the Las Palmas Port (Spain):

The methodology (1) has been validated with the instrumental databases available (2) in the outer harbour of A Coruña:

The highest performance of the proposed prediction model is demonstrated from a comparative analysis of different Artificial Intelligence techniques. **In addition, the simplicity and robustness should be pointed out, compared to other more complex techniques, such as ANN.**

Training

		Surge		Sway		Heave		Roll		Pitch		Yaw	
		R^2	RMSE (m)	R^2	RMSE (m)	R^2	RMSE (m)	R^2	RMSE (°)	R^2	RMSE (°)	R^2	RMSE (°)
Supervised ML	Multiple linear regression [1]	0.82	0.20	0.72	0.19	0.90	0.05	0.73	0.39	0.70	0.21	0.79	0.31
	Gradient Boosting [2]	0.86	0.11	0.92	0.04	0.92	0.03	0.91	0.11	0.98	0.04	0.95	0.06
Unsupervised ML	K-means [1]	0.89	0.15	0.75	0.17	0.94	0.04	0.78	0.34	0.84	0.14	0.78	0.32
Semi-supervised ML	Regression-Guided K-means [1]	0.88	0.15	0.77	0.16	0.90	0.05	0.80	0.32	0.85	0.13	0.81	0.30
Deep Learning	Artificial Neural Networks [2]	0.99	0.03	0.99	0.02	0.95	0.05	0.99	0.06	0.98	0.02	0.98	0.01
	Range	2.3 m		2.5 m		0.9 m		4.3°		2.8°		4.8°	

Testing

		Surge		Sway		Heave		Roll		Pitch		Yaw	
		R^2	RMSE (m)	R^2	RMSE (m)	R^2	RMSE (m)	R^2	RMSE (°)	R^2	RMSE (°)	R^2	RMSE (°)
Supervised ML	Multiple linear regression [1]	0.51	0.23	0.50	0.15	0.55	0.08	0.47	1.06	0.35	0.19	0.17	0.37
	Gradient Boosting [2]	-	0.39	-	0.11	-	0.09	-	1.04	-	0.24	-	0.28
Unsupervised ML	K-means [1]	0.43	0.17	0.48	0.14	0.52	0.14	0.50	0.89	0.66	0.10	0.55	0.17
Semi-supervised ML	Regression-Guided K-means [1]	0.65	0.07	0.53	0.13	0.53	0.11	0.51	0.90	0.72	0.08	0.58	0.15
Deep Learning	Artificial Neural Networks [2]	-	0.10	-	0.15	-	0.12	-	0.90	-	0.11	-	0.15

1 Romano-Moreno, E., Tomás, A., Diaz-Hernandez, G., Lara, J.L., Molina, R., García Valdecasas, J. (2022) A Semi-Supervised Machine Learning Model to Forecast Movements of Moored Vessels. J. Mar. Sci. Eng. 2022, 10, 1125. https://doi.org/10.3390/jmse10081125.

2 Alvarellos, A. aalvarell/ship-movement-dataset: Outer Port of Punta Langosteira ship movement dataset (Version v1.0.0). Github 2021.

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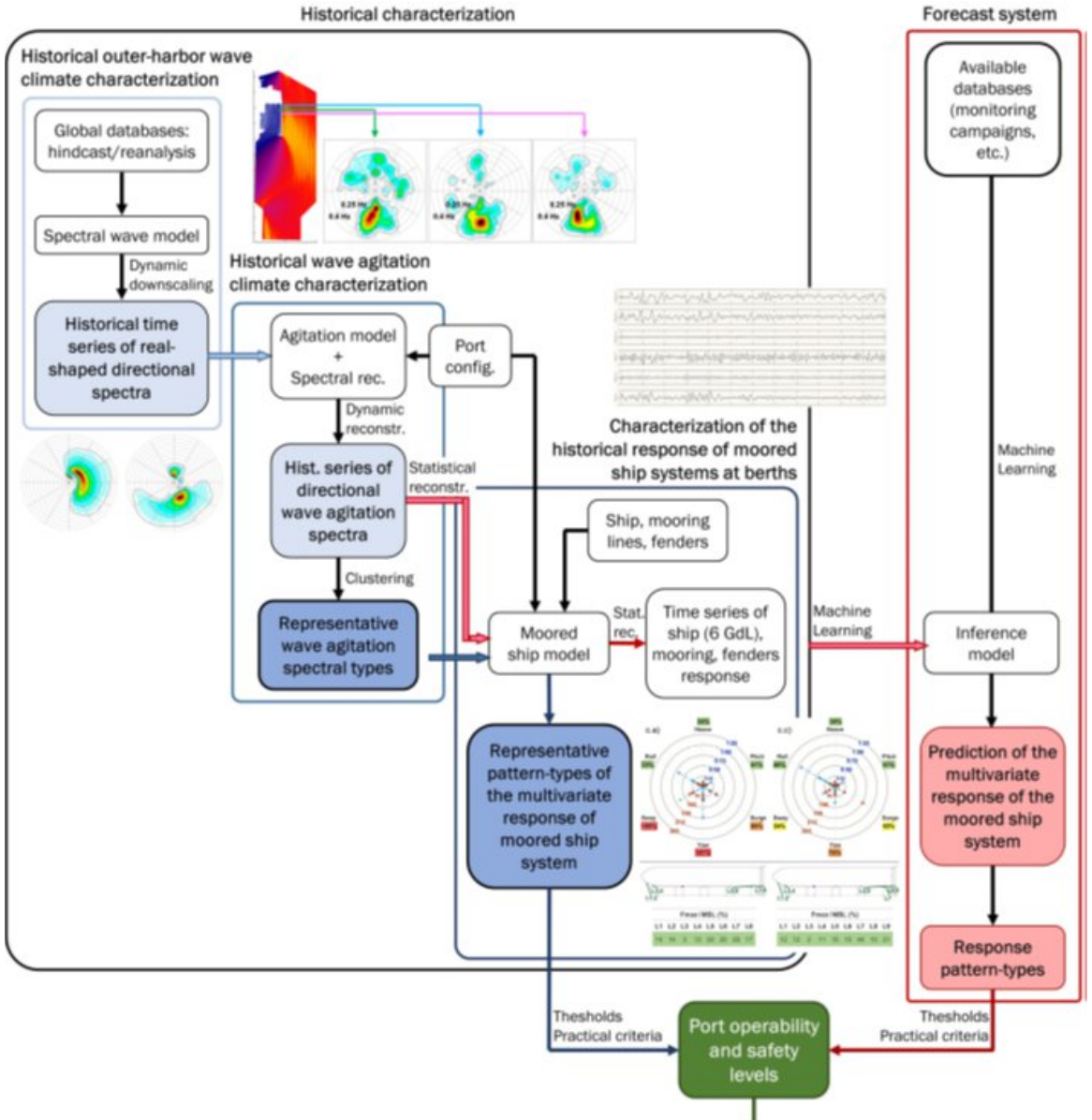
Prediction of the operability of the berthed vessels at the Las Palmas Port (Spain):

A numerical-statistical methodology is developed for a **multi-process and multivariate characterization** of port operability, allowing a complete understanding and accurate assessment of downtimes.

A detailed description of the main sea-side processes is provided, allowing to relate the forcing agents with the corresponding system response, taking into account the site-specific characteristics, and all this finally linked to **operability and safety levels at berths**.

The Solution

The coupling scheme of the predictive tool (forecast system) is based on the historical characterization through the definition of **wave agitation spectral types** which are stablished by using **machine learning** techniques.



Romano-Moreno, E., Diaz-Hernandez, G., Tomás, A., Lara, J.L. (2023) Multivariate assessment of port operability and downtime based on the wave-induced response of moored ships at berths. Ocean Engineering, 283. ISSN 0029-8018. https://doi.org/10.1016/j.oceaneng.2023.115053.

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- Thanks to the applications of machine learning techniques, several projects, methodologies and tools were developed by IHCantabria to assist the **design, construction and operation of port infrastructures.**
- **Operational systems** help the construction managers to optimize exploitation and construction costs and to achieve the individual deadlines of every activity related with the different tasks along the harbor, exposed to the met-ocean variables, and interacting with the unfinished harbor structures.
- A novel climate hybrid modelling of wave events in a coastal site under different **climate change scenarios** is developed to downscale multi-model and multi-scenario offshore high-resolution climate change projections to local scale for evaluating climate change-induced impacts on ports.
- A novel methodology has been developed for the characterization and modeling of the **port towing service** by applying machine learning techniques. Specifically, the applied technique allows to answer what are the towing service requirements, in terms of number of tugboats; required pulling and engine power; for a port scale arriving or leaving the port depending on the particular characteristics of the vessel and the weather conditions.
- Important advances have been achieved for efficient and safe port operations thanks to the developed of a comprehensive characterization of **port operability prediction** of the berthed vessels.

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I+D+i para un desarrollo sostenible

Applications of Machine Learning techniques to assist the design, construction and operation of port infrastructures.

Antonio Tomás, David Lucio, Eva Romano, Gabriel Díaz-Hernández, Javier L. Lara, Iñigo J. Losada.

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