LABORATORY OF HARBOUR WORKS

NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF CIVIL ENGINEERING
DEPARTMENT OF WATER RESOURCES & ENVIRONMENTAL ENGINEERING
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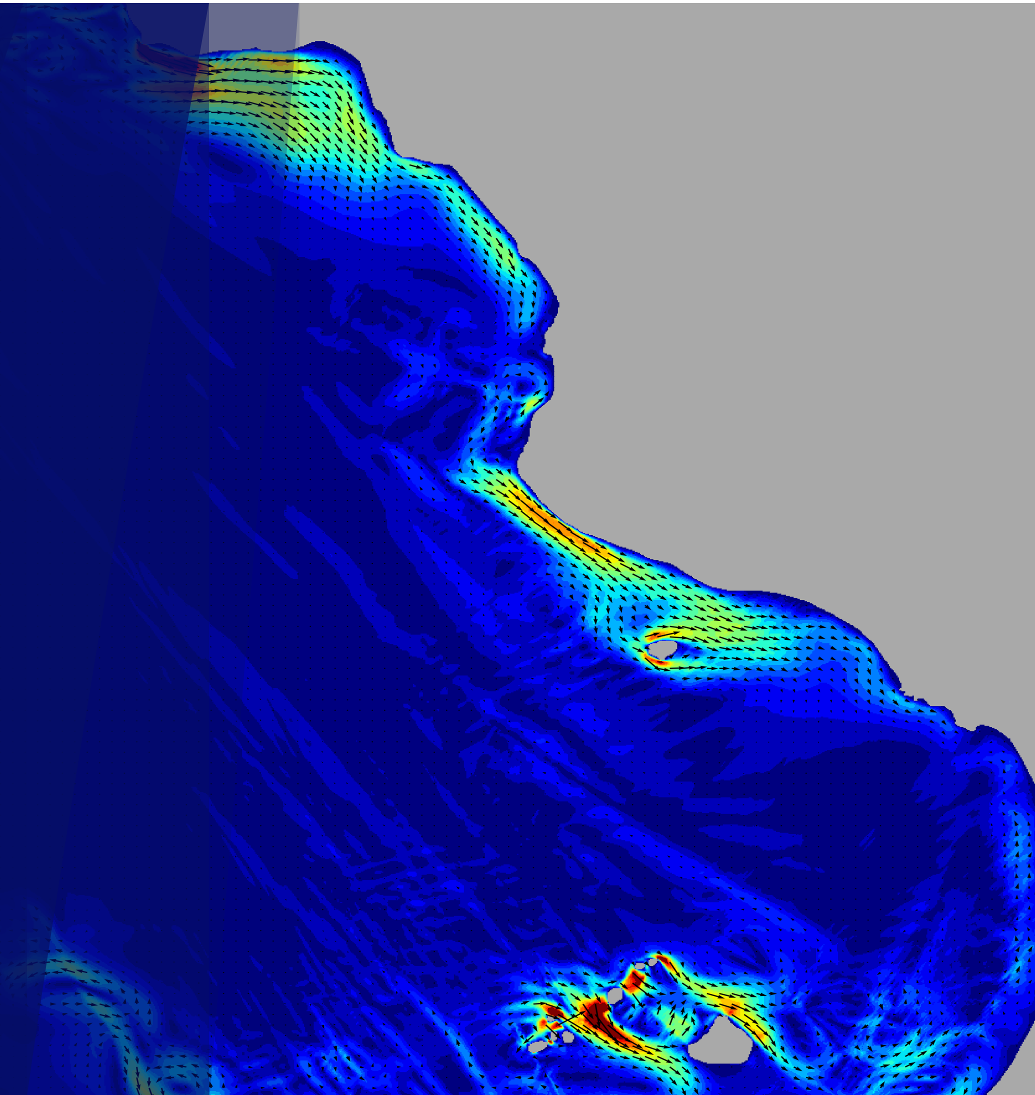
Representative Waves for Estimating Annually Averaged Sedimentation and Erosion Trends in Sandy Coastal Areas using Numerical Models and Artificial Neural Networks



M. Diamanta, Undergraduate Student
M. Chondros, Assistant Professor

Outline

1. Research Framework
2. Proposed Methodological Approach
3. Case study
4. Findings and Conclusions

Research Framework:

Problem Definition

Existing Solutions

Objective

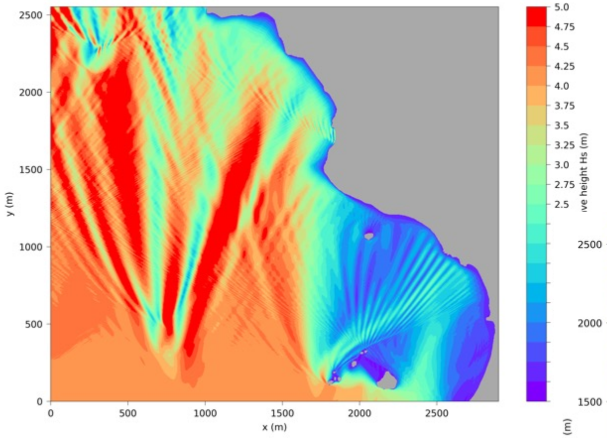
Tools and Methods

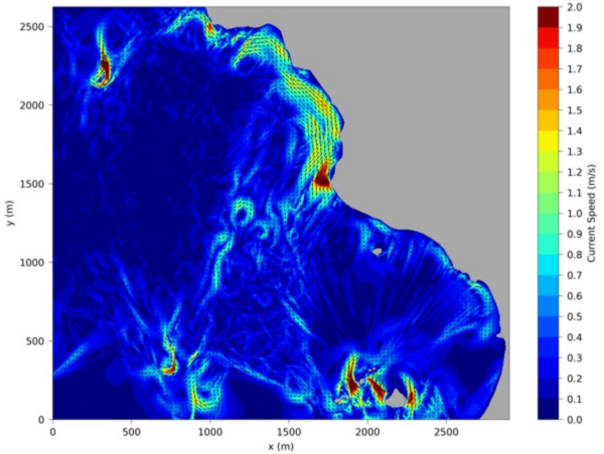
Problem Definition

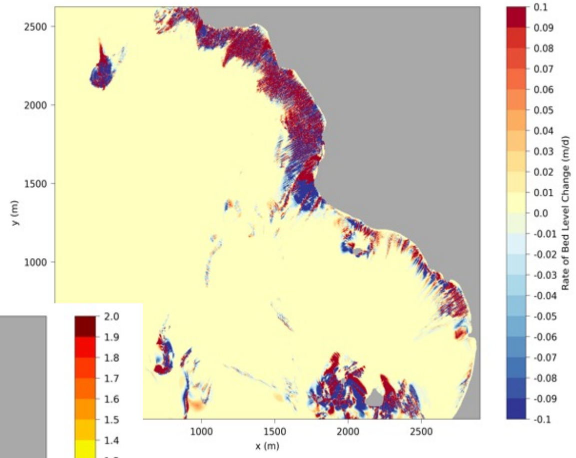
Process based numerical models

+ Valuable tool for simulating coastal bed morphology

− Increased Computational Effort and Processing Capacity Requirements







- Coastal engineering studies typically require multiple simulations to fully investigate the complex processes that take place in coastal areas
- Additional simulations to optimize the design of coastal protection
- Climate change scenarios.

→ **Increased Computational Resources and Simulation Run Times**

Existing Solutions

1

ISE Modelling
Initial Sedimentation/Erosion

(de Vriend, 1993; Roelvink and Reniers, 2012)

- Reduces model complexity by assuming an initial bed morphology, that is not updated after each computational time-step.
- Simulation of each distinct incident wave scenario and integration of the results based on the frequency of occurrence.

2

Wave Climate Schematization

- Reduction of wave input data for the numerical models.
- Binning methods: division of wave climate into directional and wave height bins, containing an equal amount of proxy (i.e. sediment transport potential, energy flux)

➢ Energy Flux Method
➢ *CERC Method*
➢ Pick-up rate Method *(Papadimitriou et al. 2019)*
➢ *Opti-routine Method (Roelvink and Reniers, 2012)*

Benchmark Wave Schematization Methods

Classical Approach

- Division of the full wave climate into fixed directional and wave height bins. The mean values of the offshore wave parameters (Hs,Tp,MWD) in each bin make up the distinct incident wave scenarios.
- Simulations are conducted for each scenario.
- The results are then integrated based on the frequency of occurance to derive the full coastal morphodynamic profile.

8-10 Simulation Scenarios per Direction

Chondros et al. (2022)

Sediment transport potential

$$w_i = f_i Q_i = f_i \frac{0.149}{(\rho_s - \rho)(1-p)} H_{sbi}^{2.75} T_{pi}^{0.89} m_{bi}^{0.86} d_{50i}^{0.69} \sin^{0.5}(2a_{bi})$$

Equivalent Wave Characteristics

$$H_e = \frac{\sum_{i=1}^{N_{Dir}} (w_i H_{soi})}{\sum_{i=1}^{N_{Dir}} (w_i)} \qquad T_{pe} = \frac{\sum_{i=1}^{N_{Dir}} (w_i T_{pi})}{\sum_{i=1}^{N_{Dir}} (w_i)} \qquad MWD_e = \frac{\sum_{i=1}^{N_{Dir}} (w_i MWD_i)}{\sum_{i=1}^{N_{Dir}} (w_i)}$$

$$Q_e f_e = \sum_{i=1}^{N_{Dir}} (f_i Q_i)$$

One Simulation Scenario per Direction

Objective

Reduction of number of simulation scenarios required to **predict the evolution of coastal bed morphology** in order to **accelerate** simulation processes, while increasing the **accuracy** of the results.

Reduced Computational Effort
One representative wave per direction

Improved Accuracy
Utilization of Artificial Neural Network

Tool for Researchers
Efficient and effective simulation of wave processes in coastal environments

Tools and Methods

scientia maris

Simulating Sea Water Environments

Artificial Neural Network

Numerical Models

Proposed Methodology

Proposed Methodology

Artificial Neural Network (ANN) Programming and training

Determining the Equivalent Waves and Conducting Simulations

Proposed Methodology

Artificial Neural Network (ANN) Programming and training

Determining the Equivalent Waves and Conducting Simulations

1

Training Scenarios for the ANN

Selection of characteristic parameter pairs

(Hs, Tp, MWD)

2

Computing the target outputs

Carrying out simulations for an idealized shore scenario of uniform bottom slope

3

Developing and Training the ANN

Using the collected input and target datasets and investigating the optimal architecture

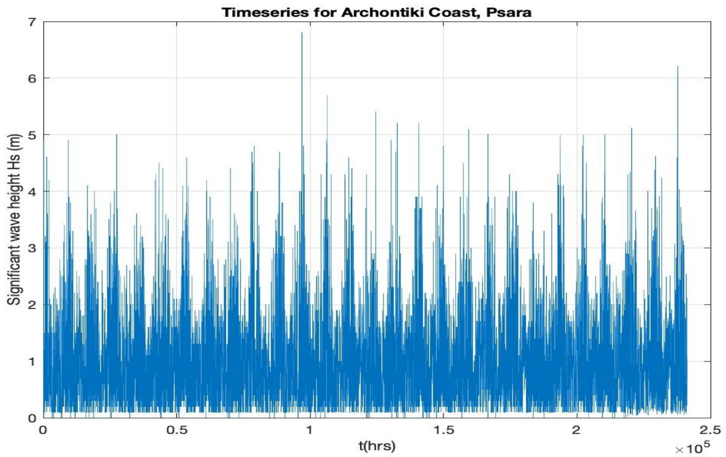
Proposed Methodology

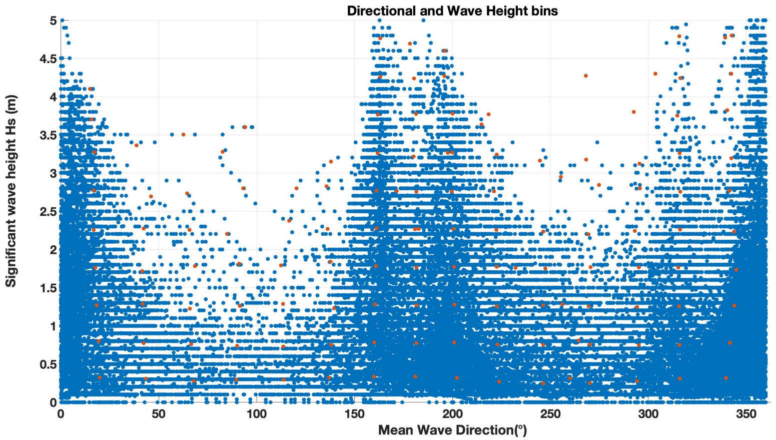
Artificial Neural Network (ANN) Programming and training

Determining the Equivalent Waves and Conducting Simulations

1. Dividing The Multivariate Climate

- Time series of offshore wave characteristics obtained from open databases, are divided into equally spaced directional and wave height bins.
- Mean values of characteristic parameters (Hs, Tp, MWD) and frequency of occurrence are calculated for each sector.





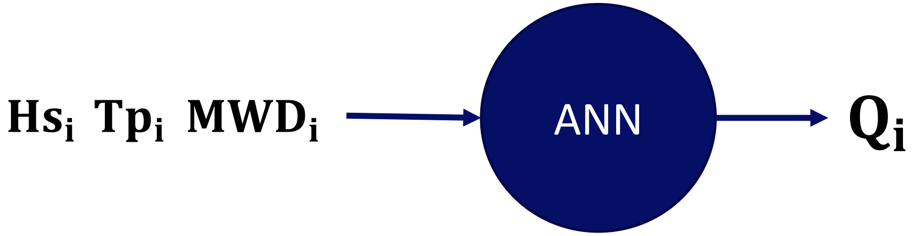
Proposed Methodology

Artificial Neural Network (ANN) Programming and training

Determining the Equivalent Waves and Conducting Simulations

2. ANN Processing

- Input values: Normalized means for each directional/wave height sector
- Output values: Longshore sediment transport rate Q (m3/s)



Proposed Methodology

Artificial Neural Network (ANN) Programming and training

Determining the Equivalent Waves and Conducting Simulations

3. Representative Waves Calculation

Equivalent waves characteristics based on the formulas developed by Chondros et al. (2022):

$$H_e = \frac{\sum_{i=1}^{N_{Dir}} (w_i H_{soi})}{\sum_{i=1}^{N_{Dir}} (w_i)} \qquad T_{pe} = \frac{\sum_{i=1}^{N_{Dir}} (w_i T_{pi})}{\sum_{i=1}^{N_{Dir}} (w_i)} \qquad MWD_e = \frac{\sum_{i=1}^{N_{Dir}} (w_i MWD_i)}{\sum_{i=1}^{N_{Dir}} (w_i)}$$

Weights are calculated based on the Sediment Transport potential (Qi), produced by the ANN's processing:

$$w_i = f_i Q_i$$

Proposed Methodology

Artificial Neural Network (ANN) Programming and training

Determining the Equivalent Waves and Conducting Simulations

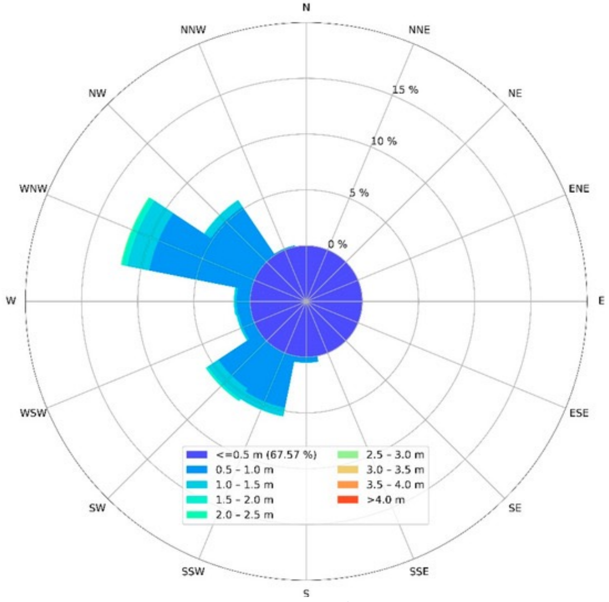
4. Numerical Model Simulations

- Simulations are carried out for each of the representative sea state scennarios.
- Integration of results to derive the full sedimentation/erosion profile of the coastal area.

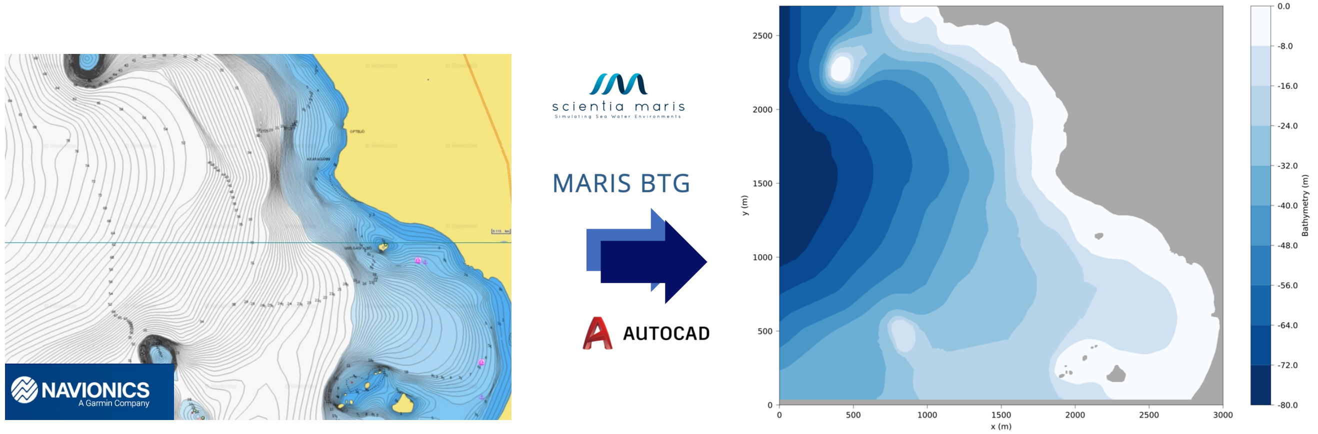
Case Study: Application of the Proposed Methodology

Study Area

- Coastal zone of the archaeological site of Archontiki in Psara Island, in Greece.
- Mainly exposed to waves generating from the NNW, NW, WNW, W, SSW and S directions
- Protection by the island of Antipsara from the SW and WSW directions.



Wave data

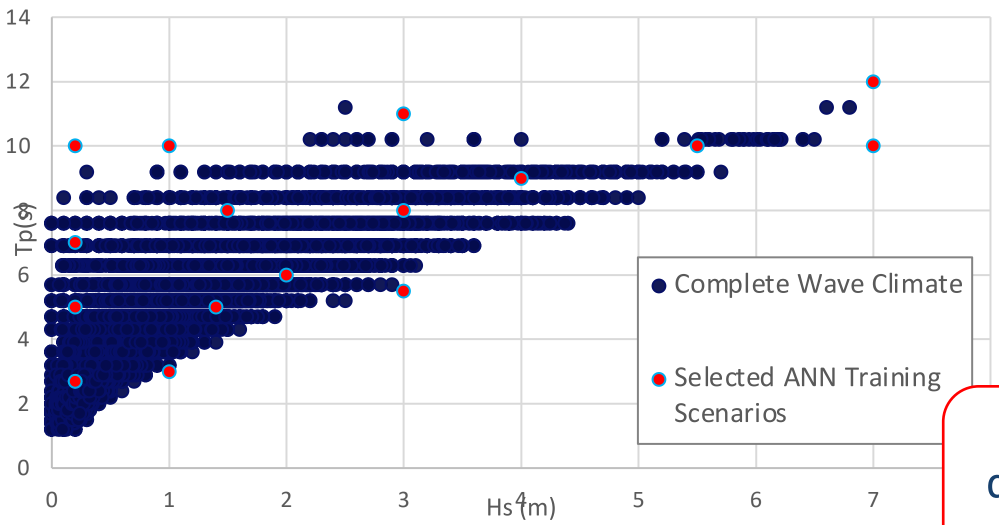


Bathymetry of the study area

ANN Development

- Selection of Training Scenarios
- Target Output Calculation
- ANN Training
- Optimal Architecture Selection

Adequate Representation of the Full Wave Climate



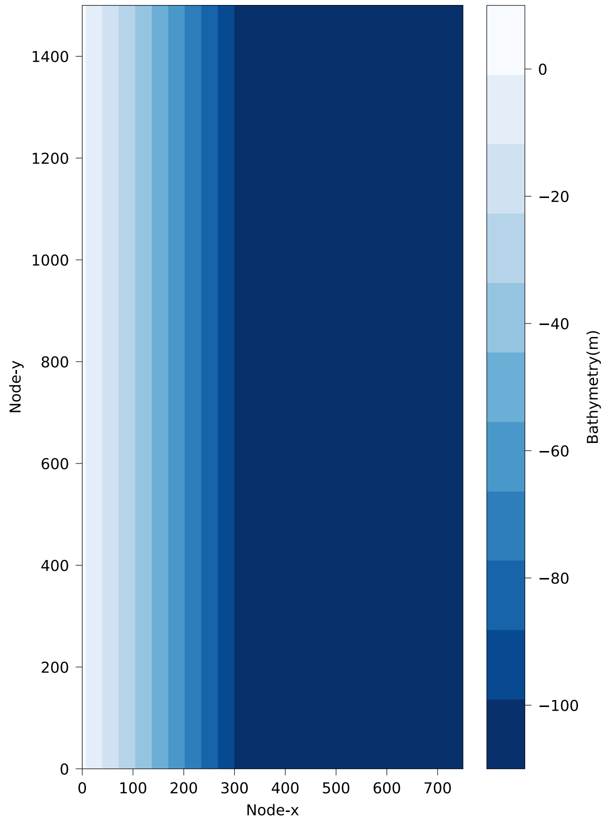
Hs, Tp pairs that follow the distribution of the wave data in the study area

Effect of the characteristic parameters on sediment transport

Incident wave scenarios where sediment transport is minimized (Hs=0, Tp=0, MWD=0, MWD=85°), and maximized respectively (MWD=45°)

ANN Development

- Selection of Training Scenarios
- Target Output Calculation
- ANN Training
- Optimal Architecture Selection



Bathymetric grid of an ideal shore with

Training Scenarios (Hs,Tp,MWD)

Wave Field

Currents

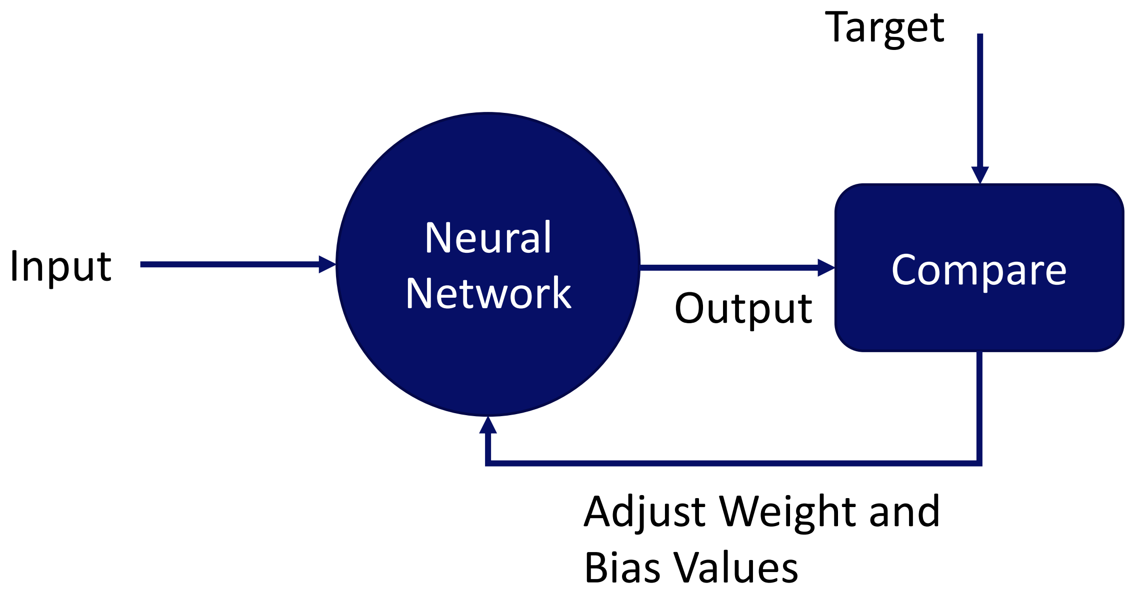
Target Outputs

Total sediment transport magnitude (Qt)

ANN Development

- Selection of Training Scenarios
- Target Output Calculation
- ANN Training
- Optimal Architecture Selection

The Network is trained using the Levenberg-Marquardt backpropagation algorithm

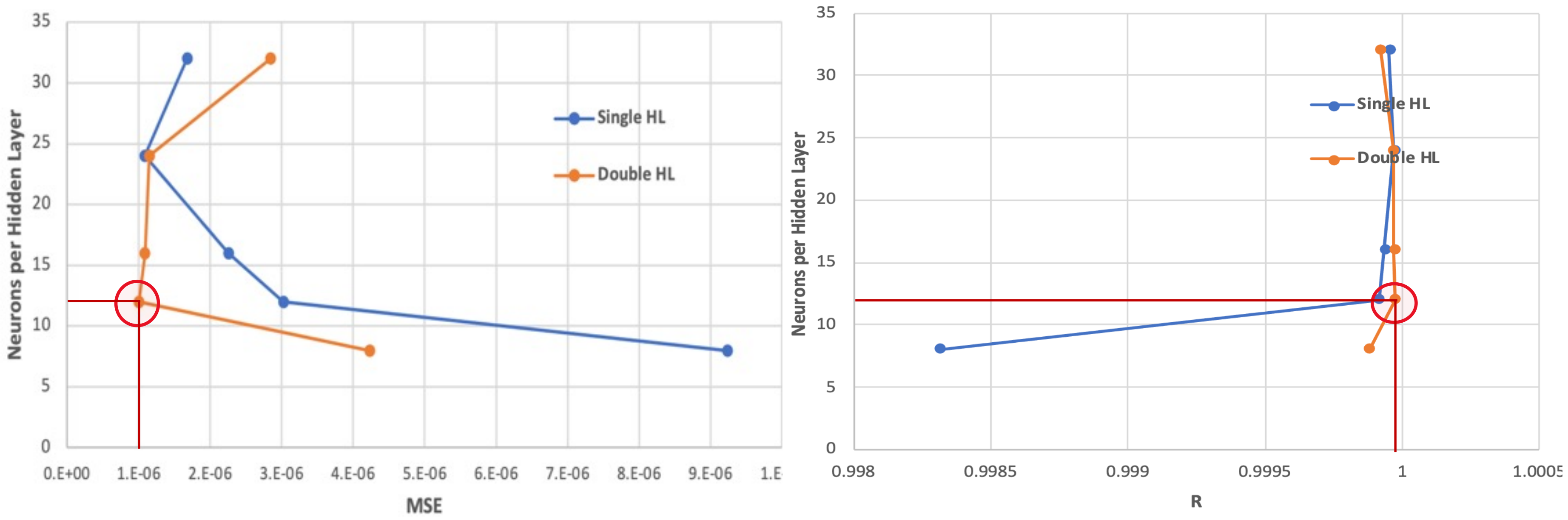


Training Process

ANN Development

- Selection of Training Scenarios
- Target Output Calculation
- ANN Training
- Optimal Architecture Selection

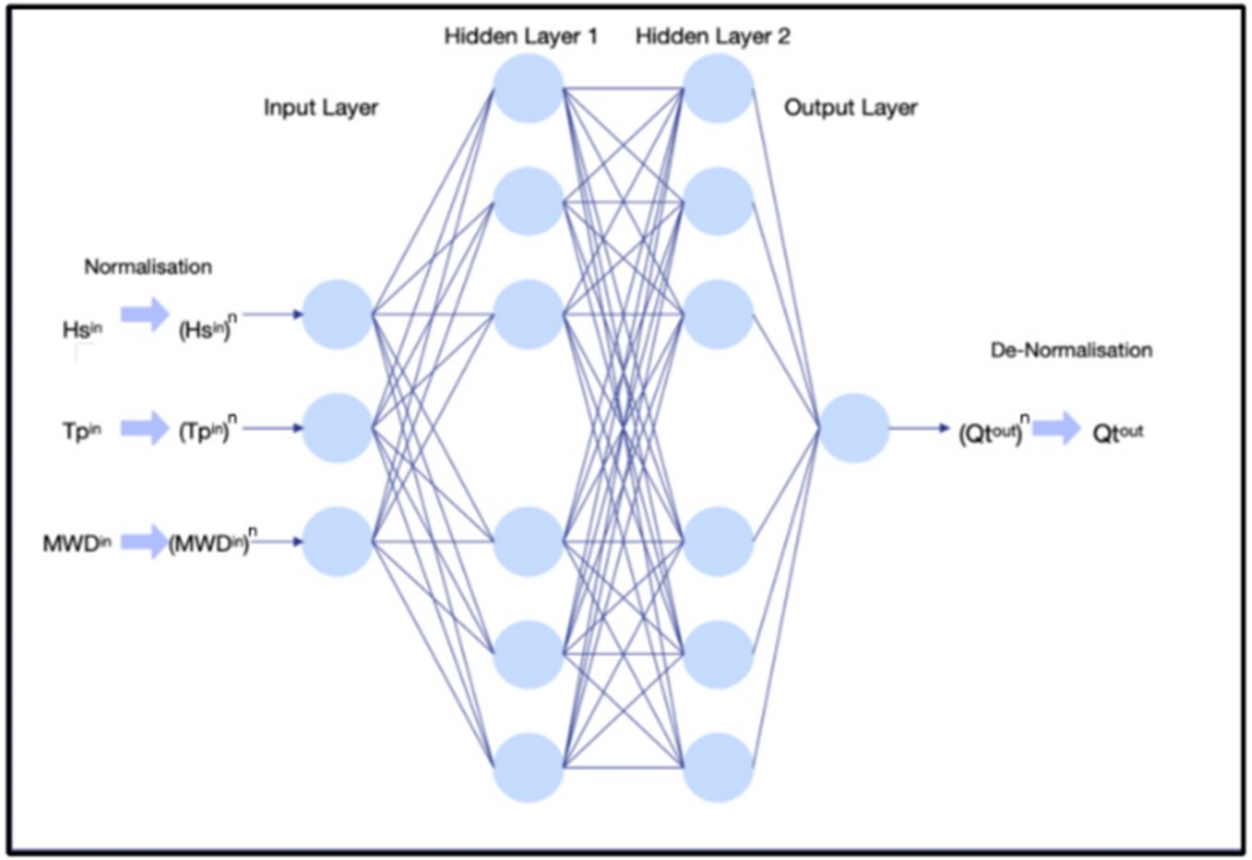
Performance metrics:



Mean square error and R value between the Target Outputs and the ANN predicted values

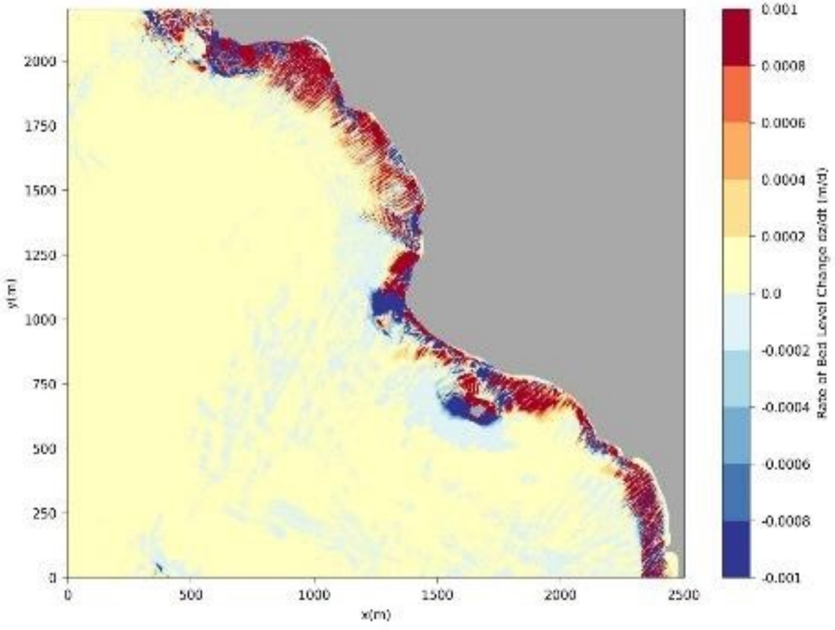
ANN Development

- Selection of Training Scenarios
- Target Output Calculation
- ANN Training
- Optimal Architecture Selection

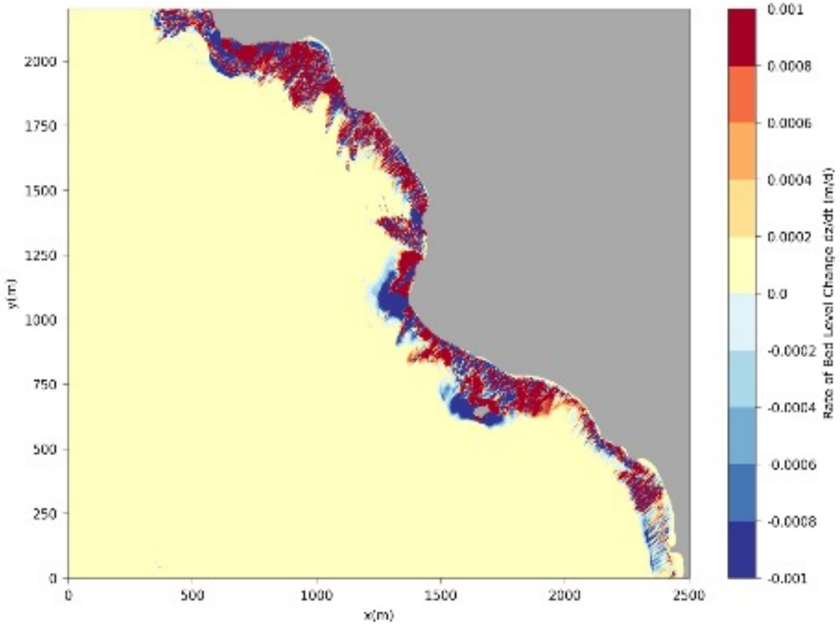


Optimal architecture: Double Layered Feedforward Network with 8 Neurons in each Layer.

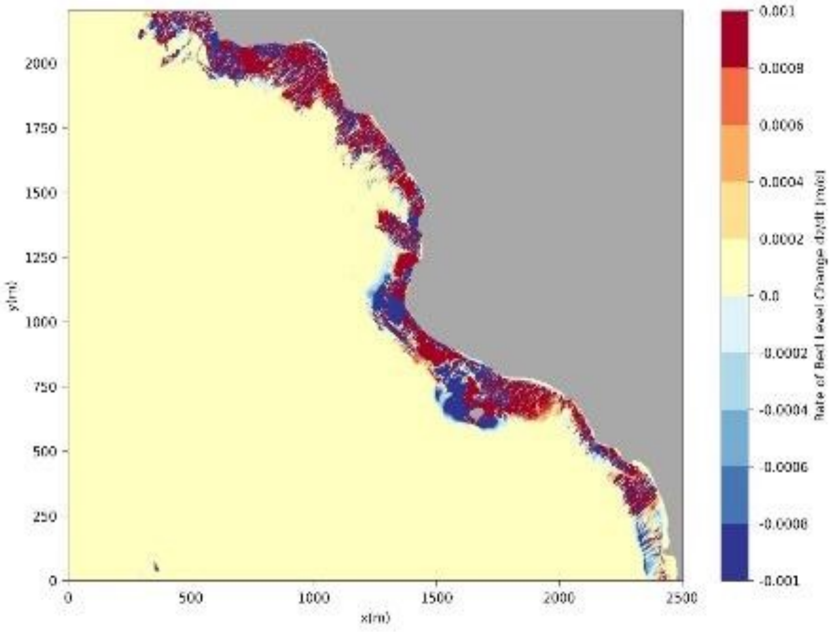
Morphological Modelling Results: Comparative Evaluation



Classical Approach
(260 required simulation scenarios)



Chondros et al. Methodology
(7 required simulation scenarios)



Proposed Methodology
(7 required simulation scenarios)

Morphological Modelling Results: Comparative Evaluation

Brier Skill Score (BSS): performance index for morphological evolution models

Scale

Excelent	**0.5< BSS < 1**
Good	0.2< BSS < 0.5
Fair	0.1 < BSS < 0.2
Poor	0.0 < BSS < 0.1
Bad	BSS < 0.0

✓

PM	**Chondros et al.(2022)**
0.595	0.562

Discussion and Conclusions

Conclusions

- ➢ Drastic reduction of the required simulation effort while simultaneously preserving the accuracy and reliability of the results.
- ➢ Further expansion on the recent approach established by Chondros et al. (2022) by incorporating the development of an Artificial Neural Network (ANN).
- ➢ No further reduction of the computational burden , but a higher accuracy while maintaining the same required number of simulations.
- ➢ A valuable tool for engineers and scientists to accelerate the simulations of sedimentation and erosion trends in coastal areas.

Future Research

- Enhance ANN training of the developed ANN by incorporating additional parameters (bottom slope, sediment grain size, and wave characteristics) to generalize the method so that it can be applied in any coastal area.

- Investigation of appropriate parameters and training methods for the ANN in order to provide a more comprehensive tool for engineers and scientists in the field of coastal engineering.

Thank you!